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The management and maintenance of second generation sand-filled synthetic sports pitches

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ABSTRACT

Synthetic sports surfaces have increased in popularity since their introduction into the United Kingdom in the early 1970's. In many sports, such as hockey and athletics, they have become the standard for play. The benefit of synthetic turf is commonly judged to be lower in maintenance requirements and operating costs, and having an increased quantity of play, when compared to natural turf. Synthetic turf has, historically, been perceived to be *'maintenance free'* and there has been little or no research into the effect that maintenance has on its performance and physical characteristics. The aim of this thesis was to develop a fundamental understanding of the mechanical wear and decline in hydraulic performance of second generation synthetic turf surfaces, its impact on technical performance characteristics, and economic costs in relation to maintenance and usage.

A questionnaire survey of 2% of the synthetic turf pitches within the United Kingdom was conducted alongside a surface performance field survey of eighteen sand-filled synthetic turf pitches that had been selected with different ages and locations. There was no correlation between surface performance and the frequency of maintenance. The surface performance exercise was revisited on purpose built homogeneous sand-filled synthetic turf pitch profiles to remove the effect of uncontrollable external factors. The concentration of contamination and the moisture content of the sand infill were found to have a significant affect on surface performance characteristics.

A survey of the effectiveness of a sample of existing maintenance equipment showed the concentration of contamination that each process removed and whether they were cost efficient. A custom-built test rig was designed to represent the loading conditions of rotating equipment and demonstrated that repeated application of the brushing processes did not significantly wear 'new' synthetic turf fibres. The effective brushing depth was found to be significantly affected by brush load and the moisture content of the sand infill.

The data from the questionnaire, field, laboratory and equipment studies was used to conduct a financial analysis of the management and maintenance of sand-filled synthetic turf sports pitches within the United Kingdom. The analysis showed that, over a projected 15 year lifespan, an STP would have a Net Present Value of £236,538 assuming an existing cost of capital of 6%. Implementation of an ineffective maintenance programme was shown to reduce the pitch lifespan by three years and resulted in the project Net present value being reduced to -£14510

This study has advanced the understanding of the role of maintenance within the provision of a synthetic sports surface. It has characterised the mechanisms involved in the loss of playing surface performance and the future financial penalties that this can cause.

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e	Coefficient of restitution
h_1	Height of ball rebound (m)
h_2	Height of ball release (m)
a	Deceleration of ball (m s^{-2})
V_1	Initial ball velocity (m s^{-2})
V_2	Ball velocity after travelling 1 metre (m s^{-2})
s	Distance between timing gates (m)
v	Velocity (m s^{-1})
g	Acceleration due to gravity (m s^{-2})
r	Effective radius of particle (m)
ρ_1	Liquid density (g cm^{-3})
ρ_2	Particle density (g cm^{-3})
η	Liquid viscosity (Pa s)
τ	Torque (Nm)
r	The position of the tip of the brush position relative to the fulcrum (m)
F	Force acting on the brush (N).
ω	Rotational speed (revolutions per minute)

1 Chapter One: Introduction

Synthetic sports surfaces (STP) have increased in popularity since their introduction into the United Kingdom in the early 1970's. In many sports, such as hockey and athletics, they have become the standard for play.

Synthetic turf is perceived to be 'maintenance free', but this is not the case. Rapid deterioration in the playability of an artificial turf pitch will occur without regular maintenance due to reduced infiltration from surface capping by contamination, irregular surface levels from displacement of the infill and increased risk of wear of the turf fibres. This will result in a reduced lifespan of the pitch and an increase in replacement costs.

The benefits of synthetic turf are generally judged in respect of lower maintenance requirements, reduced costs, and having an increased quantity of play, when compared to natural turf. Previous research has shown that the annual cost of maintaining a sand filled synthetic turf hockey pitch is £7900 p.a. compared to £7450 p.a. for a natural turf pitch. The advantages of synthetic turf surfaces are seen with an average weekly usage of 54 hours compared to 4 hours on natural turf pitches (McLeod, 2003).

In the past there was little information given to managers of facilities that included an STP, on the processes involved in the surface maintenance (Rhodes, 1997). It was regarded that synthetic turf could be less intensively maintained compared to natural turf; it was soon found that, over time, there was a loss of surface performance and that certain appropriate processes were needed to maintain the surface (Table 1.1).

It was found that the condition of the STP surface was affected by overhanging trees, buildings, atmospheric pollutants, abraded fibre particles, soil and litter (Rhodes, 1997). Brushing procedures, such as renovation, were designed to improve porosity and playing characteristics.

Table 1.1 Maintenance practices that were introduced after the installation of synthetic turf pitches

Time period		
Weekly	Quarterly	When required
Drag brush	Turf Renovation	Turf Rejuvenation
Litter collection	Turf Revitalisation	Infill replacement
Routine checks		Vegetation control
Routine repairs		Line marking
		Seam repair

At present, the information available on the maintenance of STPs is generic and does not allow managers and operators to make informed decisions on the maintenance requirements of their surface. There is no information available to the efficacy of existing techniques and whether they will damage the carpet structure through their action.

1.1 Aim of the research project

The aim of the research project is to develop a fundamental understanding of the mechanical wear and decline in hydraulic performance of second generation synthetic turf surfaces, its impact on technical performance characteristics, and economic life-cycle costs in relation to maintenance and usage.

1.2 Overview of sports provision within the United Kingdom

Within the United Kingdom (UK), participation in sport is expected to be worth in excess of £4 billion by the end of 2007. There is an increasing pool of participants which, at present, consists of 18 million Britons taking part in sport at least once a month (Mintel, 2007). There is an expectation that the 2012 London Olympics will be a further opportunity to encourage the UK population, especially younger members, to participate in sport.

The UK government recognizes how important sports participation is in the reduction of the rates of ill health, obesity and poor mental health. Between 1997 and 2007, the UK government has invested £4 billion of public money into sports provision at all levels of ability. In February 2007, Rt. Hon. Tony Blair MP, the then UK prime minister, stated: “I sometimes say to people that the best cure for anti-social behaviour in young people is sport. The best health policy for people is sport, the best way of teaching them interpersonal skills, as we call it nowadays, is sport.” This statement reinforces the belief that sport can help generate safe and sustainable communities by increasing social interaction, reducing crime and anti-social behaviour thus improving the quality of life within the built environment and creating a focus for residents, particularly the young members of the community (Mintel, 2007).

There are now government initiatives that promote sport to help to encourage healthy life styles and enable older sections of the population to maintain their independence. Overall, involvement in sports will help to reduce the burden on healthcare services due to inactivity within the UK population by an estimated £8.2 billion, annually (Mintel, 2007). In 2002, a report from the Department of Culture, Media and Sport (DCMS) stated that a 10% increase in adult activity would prevent around 6,000 premature deaths caused by physical inactivity and have economic benefits worth at least £2 billion a year. The benefits of physical activity on health are clear, well evidenced and widely accepted. 30 minutes of moderate activity five times a week can help to reduce the risk of cardiovascular diseases, some cancers, strokes and obesity (DCMS, 2002).

The UK Government is currently encouraging development of new sports facilities, protection of existing school and local authority owned playing fields, and introducing a community club development fund to enable clubs to develop their facilities as a way of increasing participation.

Within the UK there are over 55000 sports facilities registered with UK sports governing bodies (e.g. the Football Association, the Lawn Tennis Association and the Rugby Football Union). Figure 1.1illustrates the distribution of these facilities within different sports.

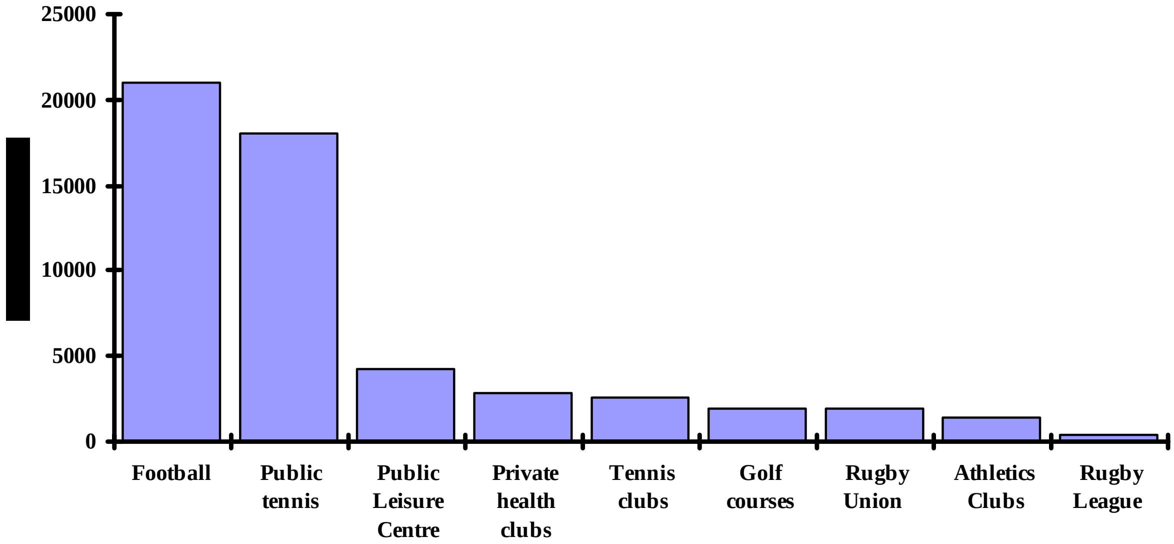


Figure 1.1 Registered sports facilities within England - 2006 (source Mintel, 2007)

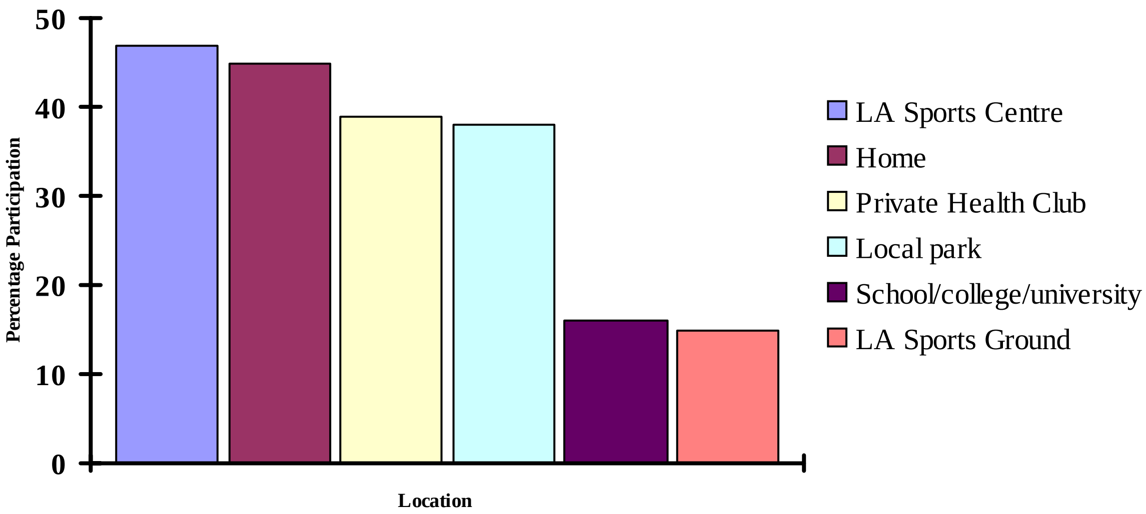


Figure 1.2 Location of sports participation. (LA = Local Authority)

(source: Mintel -Based on 1,374 Internet users aged 16+ who do any sport or exercise)

With the increase in the use of sports facilities research has found that convenience is a major influence on the choice of venue (Mintel, 2007); the two most popular locations are local authority leisure centres and in the home, with local authority parks in fourth (Figure 1.2). This results in an increased requirement for the continuous use of natural turf pitches (NTP) for a number of different activities.

In the UK, the football and rugby union seasons include the months of December to February, a period when there is little or no grass growth and rainfall exceeds evapotranspiration (Gibbs et al, 1991). The intense use of NTP's during the winter months can lead to unsatisfactory surface conditions (Adams & Gibbs, 1994). Matches during this period are more likely to be cancelled due to the effects of excessive soil moisture content. If play goes ahead then severe damage can be caused and there will be little or no recovery of the turf. An NTP has an average maximum weekly usage of approximately 3 hours (Gibbs et al, 1994) before surface quality is lost, whereas a synthetic alternative is more durable and can sustain over 50 hours of play per week (McLeod, 2003).

Due to the increased wear of NTP's, and the associated increase in maintenance costs, the installation of a synthetic turf pitch (STP) becomes a more viable alternative (Chaker, 2002). STPs have become a common addition to both private and local authority sports facilities (Davis, 1981).

Synthetic turf pitches are now being used in areas of high land value, e.g. inner cities, where open space is at a premium and there is high pitch demand and limited pitch availability. Their increased capacity for use allows for pitches to be used for other activities other than football/hockey. Within inner city areas this has the socio-economic benefit of reducing anti-social behaviour and encourages community interaction (Mintel, 2007). Independent schools, throughout the UK, have taken the lead in the provision of STPs; they need to be seen to offer high quality sports facilities within their prospectuses. A prime winter-spring sport for children within the independent school system is field hockey and STPs are the FIH recognized playing surface for the sport. Schools without such facilities may be viewed as less attractive by prospective parents, who perceive the positive benefits of competitive sport within schools (Gillies, 1995).

The installation of STPs has increased since their introduction in the early 1970s. This is a new segment to the sports industry which has developed and has, historically, been sales led. The industry has completed little or no research into the management and long term cost implications involved with the installation and use of STPs.

1.3 Background to synthetic turf sports pitches

Synthetic turf sports surfaces have been under development since the late 1950's. They were originally designed in the USA, to provide city children with increased play space and enable them to maintain a fitness level equal to their peers in more rural areas (Levy et al, 1990). In the mid 1960's, the Houston 'Astrodome' was the first major stadium to lay a synthetic turf surface (Rhodes, 1996). Synthetic turf was introduced into the UK in 1971, when a football pitch was installed at Islington, London (Roberts, 1994). Over the next decade a number of pitches were installed at high profile locations, such as Loughborough University and Queens Park Rangers Football Club (QPR FC). The original STP at QPR FC was removed after complaints from visiting clubs of uneven high bounce and risk of severe skin abrasion (Waterman, 2003). By 1990 there were over 200 synthetic turf pitches within the UK (Roberts, 1994). Anecdotal evidence from the synthetic sports turf industry indicates that there are now over 2000 STPs within the UK; there is no definitive figure because individual funding bodies do not pool information on pitch installation (Abbott, pers comm.).

The consensus among STP manufacturers is that the benefits from installing an STP are:

- Low maintenance costs
- Plays like natural grass
- All weather capability
- Increased volume of play

STPs are branded for their multi-sport capabilities, but the limitations of individual specifications are not mentioned. It is quite common for sand-filled STPs to be installed for play at county standard hockey along with the option of being also used for tennis. The playing requirements for the two sports are quite different: hockey requires a fast, even surface with little bounce, whereas tennis requires a fast, even surface that has a higher predictable ball bounce. The presence of the shock absorbing layer in the sand-filled STP is designed to dissipate the energy of the ball rebound by a damped response to contact with a relatively stiff hockey ball. The elastic nature of a tennis ball increases the energy dissipation by the ball itself, deforming on contact with the surface and this reduces the level of ball rebound, adversely affecting play (Coaplen et al, 2004).

STPs are now recognised as suitable for competitive sport by a number of sports governing bodies. In hockey, competitive leagues throughout the UK have made the use of STPs mandatory for matches under their jurisdiction (Abbott, 2002; EHA, 2006). The introduction of synthetic turf has had a significant impact on field hockey; it provides a fast, consistent playing surface that encourages the development of technical skills and reduces the likelihood of cancelled matches due to poor weather (Gillies, 1995), which has had the added benefit of attracting sponsorship (Howells, 1988).

Over the last decade, the increased media coverage of football (Figure 1.3) has increased the interest in the sector; e.g. football magazine sales increased by 191.3% between 2002 and 2006 (Mintel, 2007). There has been a 6.1% increase in the number of people over the age of 15 that have more interest in football between 2004 and 2006 (Mintel, 2006). The increasing interest in winter sports has had an effect on the strategy of winter sports provision within the UK. The higher requirement for football usage has increased the number of STPs designed for football being installed. The changing pitch specification has had an effect on the field hockey clubs that have generally been the prime user of STPs. The increase in pile length and the presence of a rubber infill, in pitches designed for football, results in different playing characteristics from the short pile water/sand based hockey pitches (FIH, 1999; FIFA, 2001). In 2003, England Hockey commissioned a report on the playability of long pile synthetic turf for hockey (England Hockey, 2003), which stated that pile lengths over 40 – 45 mm were not suitable for hockey. However, the report did state that 'long pile synthetic turf pitches were better than tarmac or poor natural grass for the introduction of the sport to young people'. This report illustrates that organisations will have to prioritise on the importance and skill level of the sports to be played on a prospective synthetic surface, selecting the wrong specification would reduce possible future revenue and limit the usefulness of the surface. At present, there are alternative surface under test that are licensed for both elite football and hockey, and may be a viable alternative to sand-filled STPs.

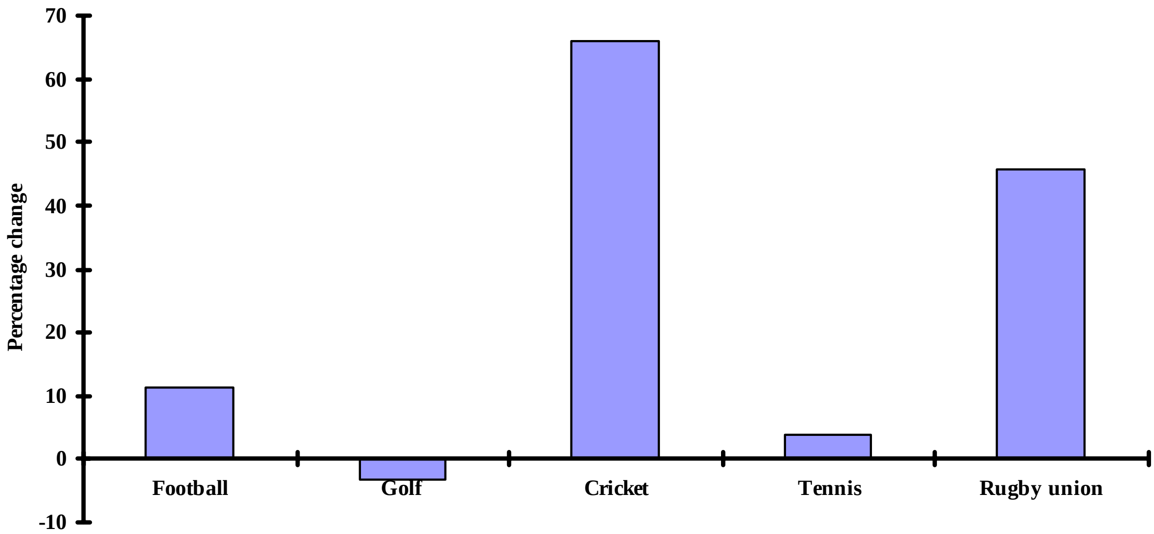


Figure 1.3 The change in televised sports between 2002 and 2006 (source: Mintel, 2007)

There was an advertising campaign for that claimed that synthetic turf is 'The Greatest Turf on Earth', 'It looks like grass…Feels like grass...Plays like grass' (Panstadia, 2002). It has been marketed as a safer alternative to natural turf, where sports-related injuries are reduced, and that it is not affected by factors such as wet weather, insects and fungi. Although products claim to reduce sports-related injuries, there are a number of studies from the United States that show a significant increase in injuries when players are using synthetic turf as reviewed by Powell & Schootman (1992). These are complemented by research from the UK indicating that use of synthetic turf increases the potential for injury from overuse. Although Dixon et al (1999) state that overuse injuries cannot be completely blamed on the ‘stiffness’ of the synthetic surface, there are data showing that the increased levels of traction are causing an increase in lower limb joint injuries (Morehouse, 1992). Recent unpublished research by FIFA (Harrison, 2006) has shown that there is no significant difference between the numbers of injuries sustained on either natural or synthetic turf. Further research by Ekstrand et al (2006) has indicated that there was no evidence of a greater risk of injury when football was played on synthetic turf compared with natural grass. Both studies were carried out at the elite level of football, played on long-pile third generation pitches only and do not reflect on injuries sustained by players at a lower playing standard of football or partaking in any other sport, and the different surface specifications that are used.

In June 2001, the Federation of International Football Associations (FIFA) officially awarded the ‘Field Turf’ pitch installed at Boston University a ‘Recommended’ status, which meant that it could host preliminary FIFA world cup matches, Olympic football tournaments and professional league games (Waterman, 2003). This decision, alongside the FIFA Quality Concept (FIFA, 2001) was designed to encourage the installation of synthetic turf football pitches in locations where it was deemed difficult to sustain a natural turf football pitch; this included stadia as well as areas of low water availability such as Africa.

In 2002, UEFA announced that five professional football clubs in Europe would be using synthetic turf pitches in the 2003/04 season. The clubs involved in the test were: Salzburg (Austria), Örebro (Sweden), Moscow (Russia), Dunfermline (Scotland) and Almelo (Netherlands). This is an ongoing project that has received mixed response and in some cases, like Dunfermline, the synthetic surface has been replaced with natural turf. Visiting teams complained that the surfaces give the home team an advantage and players complained that the surface caused skin burns (Woods, 2004).

During 2004 FIFA and UEFA harmonized the rules on STPs, which now are all based on the FIFA Quality Concept. This is designed to:

- Assure minimum levels of quality

- Improve standards, based on the ability of contractors, using quality materials and conventional methods at reasonable cost.
- Be able to compare surfaces
- Protect contractor from unreasonable demands from customers.

On 1st July 2004 there was a change to the laws of football, with FIFA stating that "matches may be played on natural or artificial surfaces if permitted by the applicable competition regulations" (FIFA, 2004).

1.4 Review of the literature

1.4.1 Selection of a synthetic turf pitch

Before deciding on the specification of the STP to be installed, a demand analysis should be carried out (Roberts, 1994). This should evaluate:

- Existing pitch demands and use.
- Type of sport/sports to be played on the pitch.
- Expected level of sport on the pitch and possible use for other sports.
- Type of use – training, representative matches, recreation.
- The demand from external bodies.

The climate in the UK, with its pattern of rainfall, can have a detrimental effect on sport played on NTP's. During the winter, a period of little or no grass growth, rainfall exceeding evapotranspiration (Gibbs et al, 1991) and intense use of NTP's leads to unsatisfactory surface conditions (Adams & Gibbs, 1994). If an NTP is used when the soil moisture content is above field capacity there is a loss of cohesion and friction between the soil particles/aggregates and mechanical stress will cause a disruption to the soil structure. The loss of surface soil structure will result in compaction and a reduction in surface water infiltration which will provide an unfavourable environment for turfgrass plant growth. Continued use of the surface, the reduced plant growth and loss of soil structure will result poor pitch playability and cancellation of games (Baker, 1991).

If it is intended for there to be an almost continuous use of pitches for a variety of activities then synthetic turf may be the answer. Although there is a high initial outlay for construction of the pitch, it does have major advantages over natural turf (Davis, 1981):

- Increased volume of play
- Flexibility
- All weather capability
- Requires a less technical management team
- The surface has a comparatively ‘low maintenance’ requirement

Table 1.2 The use of synthetic turf for different sports (adapted from Football Foundation, 2002)

	Sport					
Surface	Hockey	Football	Rugby	Short Football	Tennis	Multi sport
Water-filled	☑☑☑	☒	☒	☒	☒	☒
Sand-filled	☑☑	☑	☒	☑☑	☑☑	☑☑
Sand-dressed	☑☑☑	☑	☒	☑☑	☑	☑☑
Short pile sand/rubber infill	☑☒	☑☑☑	☑☒	☑☑☑	☒	☑
Long pile, sand/rubber infill	☒	☑☑☑	☑☑	☑☑☑	☒	☑

☒	Not recommended	☑☑	Good
☑☒	Training only	☑☑☑	Recommended
☑	Acceptable		

The design and purchase decisions on each synthetic turf specification involve compromises. The design should address playability (i.e. the surface should not fundamentally change the nature of the sports played on it) and value for money; (Milner, 1990). Capital or grant applications to funding bodies will be based on these decisions which will have been used as the basis for the initial budget and can be a major limiting factor in the construction process. Table 1.2 shows the sports that can be played on the different synthetic turf specifications.

1.4.2 The all weather suitability of synthetic turf

There are some doubts over the all weather capability of synthetic turf; during periods when temperatures are below freezing, it becomes necessary to use a de-icing agent. Historically, the de-icing agent used is kiln dried salt (sodium chloride) applied to the surface at a rate of 150-250 g m^{-2} (Rhodes, 1996); for a surface with an area of 6000 m^2 this would mean using 1-1.5 t of salt per application. Use of this quantity of salt for each frost treatment will affect the management decision on its use, not only from an environmental point of view, but also financially.

During periods of rainfall the chemical will leach, through preferential flow and run off, into the surface water drainage system and aquifers due to the high infiltration rates of an STP and the high solubility of the salt (Larson et al, 1999); for this reason, the Lawn Tennis Association, recommends that salt is not used as a de-icing agent (LTA, 2002). This movement of rain water through the STP profile is aided by the high permeability and the low cation exchange capacity (CEC) of the infill material.

1.4.3 Economic considerations for installing a synthetic turf pitch

For an organisation to invest capital in installing a synthetic turf pitch, consideration has to be given to the time between installation and re-placing or upgrading the surface (LTA, 2002). Strict proactive maintenance practices will assist in extending the life expectancy of the turf (FIH, 2001a). A prospective buyer needs to be sure that the product or system selected will function efficiently at a low cost over its lifecycle; even though at times, the initial cost may be higher than lower quality systems. Because of this, it is prudent that when competing systems are compared, it is not only the initial cost that is considered, but also what the quality of the surface after a number of years of usage. Previous research has shown that annual maintenance costs are approximately £7-8 k per annum for a sand filled field hockey pitch (McLeod, 2003) and £8-10 k per annum for a third generation pitch (Football Association, 2004; Lockyer, 2003), inclusive of labour and materials.

It is important that the overall situation is accurately assessed when costs are being evaluated, *i.e.*, that operating costs are taken fully into account, as well as the capital expenditure (Roberts, 1994). The costs involved with constructing and using a synthetic turf pitch can be divided into three sections that are shown in Figure 1.4.

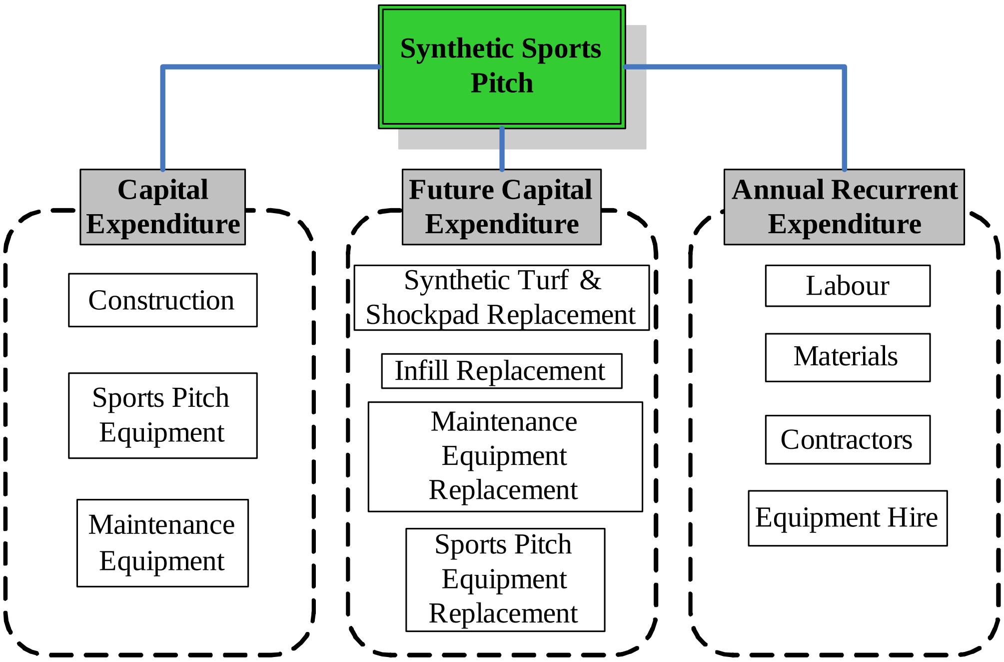


Figure 1.4 The capital and recurrent costs involved in the provision of a synthetic turf pitch

Purchasers of synthetic turf surfaces should add the concerns of cost, durability and value to those of playability. Synthetic surfaces should have a long lifespan (e.g. 15 years) and require minimum maintenance under constant use (Rhodes, 1997). The most common system selected is the sand-filled pitch; the probable reason for this is has been the best value for money out of all of the STP specifications (Abbott, 2002), and it is the most flexible of the specifications, as it is presently used to accommodate a wide range of sports. With the rising popularity of football, long pile STPs are growing in popularity and installation of these pitches is encouraged by Sport England, the Football Foundation and the Football Association (Football Foundation, 2006). Although synthetic turf cannot sustain different high level sports on the same specification of surface, the sand-filled turf surfaces provide a safe environment for basic standards of play for a number of sports.

1.4.4 Materials used in the construction synthetic turf pitches

The construction profile of an STP is dependent on the sport to be played on the surface. There are two main profiles that are used for the base below the playing surface: engineered and dynamic (Figure 1.5).

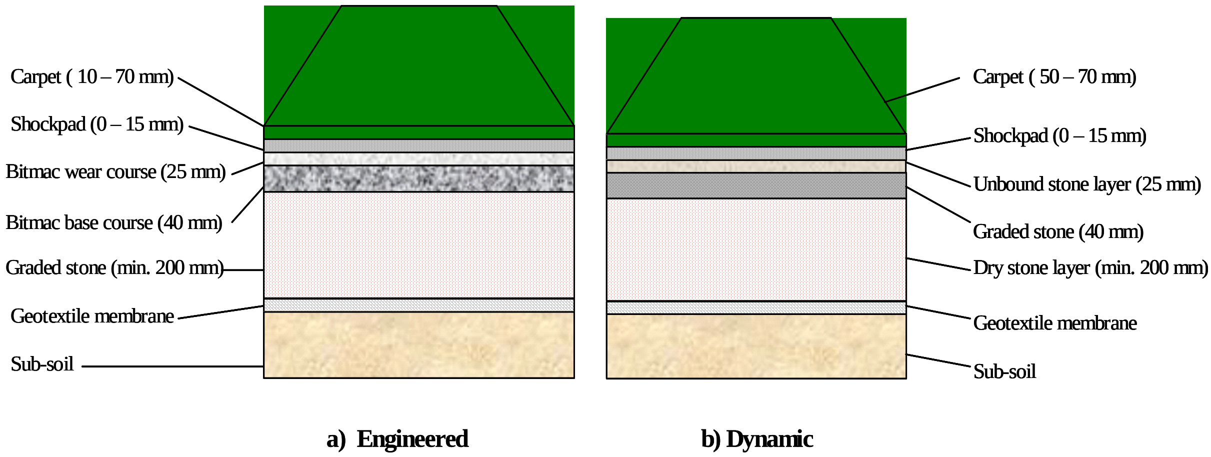


Figure 1.5 Illustration of the two main specifications for construction of a STP

The engineered and dynamic bases are similar in design, consisting of a geotextile membrane (to prevent soil contamination of the above layers) and a graded stone base. The engineered base has a bitmac wear course that is designed to provide a level base onto which a shock pad is laid. The shock pad is laid as a loose mix of rubber granules and a binding agent; a level base enables a quicker, more accurate application of the shock pad material. The engineered bases are mainly used for water based and sand filled/dressed STPs that are designed for hockey, tennis and multi-sport use. The dynamic base is mainly used for STPs that are designed for football where a longer pile carpet is used. These pitches either have a rubber infill which acts as the shock pad or have a shock pad incorporated into the carpet backing.

The construction profiles can be divided into synthetic turf carpet, shock pad, wear course and stone sub-base.

1.4.5 The structure of a synthetic turf carpet

The pile fibre of synthetic turf is selected from a broad class of semi-crystalline thermoplastic materials, such as polypropylene, polyethylene and the seldom used nylon. Each of these polymers has specific performance attributes for use in synthetic turf (Orofino, 1990). The fibres that make up the synthetic turf surface are made from an extruded monofilament ribbon or tape; these fibres are incorporated into the surface system by merging them with a carpet backing. The gauge of the fibre or ribbon varies between individual carpet specifications. The fibre size is represented by either the Denier measure which represents the weight, in grams, of a 9000 metre length of fibre or the dtex which represents the weight, in grams, of a 10000 metre length of fibre. A polypropylene fibre used for a 23 mm fibre length, sand-filled carpet will have a dtex of approximately 8800 (Tipp & Watson, 1982). The different fibre structures are shown in Figure 1.6.

Figure 1.6 Examples of different fibre densities and fibre denier within carpet systems: (a) Monofilament, (b) Fibrillated, (c) Fibrillated and monofilament and (d) Monofilament with fibrillated (adapted from UEFA, 2002)

This final product can be woven, knitted or tufted (Levy, 1990); the fibres are ‘locked’ into the carpet backing by a layer of latex (Figure 1.7). The yarn in long-pile pitches is designed to be ‘fibrillated’, so that individual fibres split into smaller fibres with wear, this allows the fibres to interlock and bind the infill.

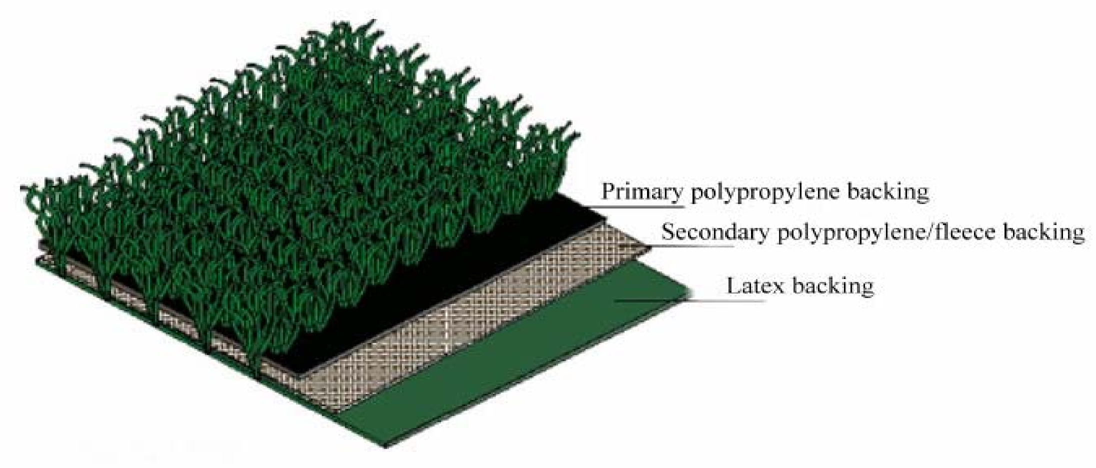


Figure 1.7 Example of the structure of a tufted synthetic carpet (source: TigerTurf, 2003)

Fibre component materials

The most common materials used are the polyolefin’s, polypropylene (PP) and polyethylene (PE); manufactured fibres in which the fibre forming substance is a synthetic polymer of at least 85% weight of ethylene, propylene or other olefin unit (Wust & Gammelgaard, 2004). The monomer for the production of PP and PE are extracted from “Cracking" refinery-derived petroleum products, such as natural gas or light oils, at high temperature producing ethylene or propylene (Figure 1.8). The production of the polymers is achieved by charging a polymerization vessel with the monomer, under pressure and at 60oC, and a catalyst. The molecular weight of the polymer can be controlled by varying the catalyst concentration, polymerization temperature or the monomer pressure. The resultant polymer powder is dechloronated to remove the catalyst which, if left in the powder during further processing, would degrade the polymer. The polyolefin fibre is produced by an extrusion process that melts the colourless polymer powder along with any additives, such as pigments, ultra-violet (UV) stabilisers and rheological modifiers.

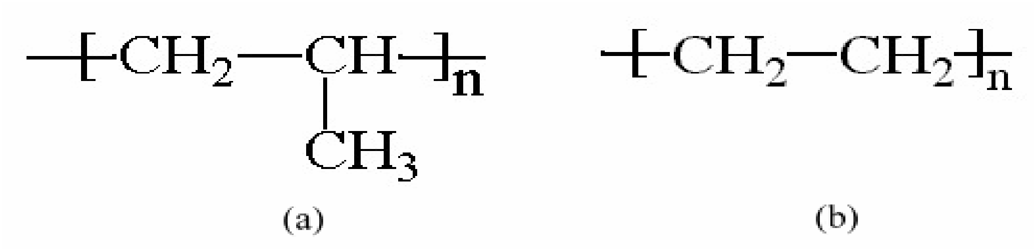


Figure 1.8 Chemical composition of the monomer units for (a) polyethylene and (b) polypropylene, where n= number of repeating units.

The process pumps the molten polymer through a slit or tubular die to form a polyolefin ribbon. The die defines the size and shape of the fibre which can be drawn out up to six times its original length (Wust & Gammelgaard, 2004). At this point of the process the tape can be used for the longer pile football carpets or fibrillated to form monofilaments to be used for sand-filled/dressed hockey pitches.

The semi-crystalline nature of the polyolefin group of polymers reduces chemical reaction by non-oxidising acids, alkalis and most aqueous solutions but the presence of UV can cause oxidization of the polymers at room temperature. In the case of STPs, the turf fibre will be affected by sunlight-induced (UV) degradation that, over time, will accelerate polymeric degradation (Tipp & Watson, 1982). The degradation, caused by radiation at wavelengths between 290-400 nm (Maier & Calafut, 1998), will be seen as discolouration, surface cracking, fibre hardening or loss of physical properties (Brydson, 1982). To reduce the effect of UV, a stabiliser is used (Wust & Gammelgaard, 2004); these are additives that bind to the polymer structure, therefore reducing release into the environment, and are compounds derived from benzophenone, benotriazole, amyl ester and formamides (Maier & Calafut, 1998). To reduce the effect of UV radiation post-installation, the synthetic turf can be regularly brushed to keep the fibres upright; reducing the surface area of the fibre exposed to UV (Rhodes, 1996).

The low glass transition point (T_g) of Polyolefin's (PP = -18^{o}C, PE = -118^{o}C) and high melting point (T_m) (PP = 155-162^{o}C, PE = 124-131^{o}C) reduces the effect of the variation in seasonal temperatures on the fibre structure. The T_g is the temperature below which the physical properties of amorphous zones within the polymer vary in a manner similar to those of a crystalline phase (glassy) and above which amorphous materials behave like liquids (rubbery state). At temperatures below the T_g the polymer molecules have little relative mobility. Above the T_g, the secondary, non-covalent bonds between the polymer chains become weak and the polymer becomes rubbery and capable of elastic or plastic deformation without fracture (Brydson, 1982).

Although the polymers used for the production of synthetic turf are combined with additives to reduce the affect of environmental exposure (Ram, 1997), there will be a gradual degradation of polymer structure through mechanical damage (pitch use) and environmental exposure. The primary cause of degradation of the fibre polymers is two-body abrasive wear through a dynamic load being applied to the sand/fibre surface (Lancaster (1969). Exposure long-term exposure to ultra-violet radiation causes photo-oxidation within the polymer molecules. This formation of free radicals leads to molecular scissions which results in a reduction of the physical and mechanical properties of the polymer (Yakimets et al, 2004). The effect on the fibre will be seen as in a loss of tensile strength, elongation and will increase fibre brittleness (Tipp & Watson, 1982).

Sub-surface shock absorbent layer (shockpad)

A shockpad is designed to provide comfort and cushioning properties for the player, and to interact with the ball to produce the required playing characteristics (Anderson, 2005). The shockpad can be a separate layer to the carpet (closed cell) or attached to the carpet (open cell) and is made from a variety of recycled rubber compounds (Breland, 1990). Variations in the shock pad design will alter the ball roll and bounce characteristics, as well as influence player/surface interactions (Levy, 1990). The design must have a high mechanical strength that resists the loss of properties due to wear and weather (Breland, 1990). The shockpad must be able to deform under stress and then return to its normal state for an even surface. The most common type used is the cast in-situ shockpad, which is produced, on site, by mixing recycled granules (2 – 8 mm particle size) and a polyurethane binder (Charles Lawrence, 2007).

A recent introduction is a light-weight expanded polypropylene-bead based shock pad that has similar properties to the rubber shockpad. This type of shockpad has a 10 year warranty along with compliance with the relevant European environmental legislation, DIN V 18035-6 (Brock, 2006). The shockpad is light and uses a puzzle design to lock individual sections together that, at the end of their lifespan, are completely recyclable and the company literature infers that there is a financial saving to be made using this product (Brock, 2006). As this is a new product, there is no data to indicate the performance of this system over its life span or whether the financial claims are true.

1.4.6 Wear course and Sub-base

A wear course in an engineered STP consists of two layers of tar macadam. The upper wear course will comprise 90% - 100% of 6 mm crushed stone, such as Aggregate Industry's LeisureTex Plus – multi-use (Aggregate Industries, 2006). This is laid on to a lower tar macadam base that has a larger aggregate (15-20 mm) particle size.

MOT Type 1x is the material, composed of crushed limestone or granite, that is typically used for the graded stone sub-base; this differs from standard MOT Type 1 by having fines less than 75 µm reduced from 10% to less than 5% total composition (Table 1.3). MOT type 1 has historically been used to provide structural support below roads and also for buildings and is defined by the specification for highway works (Highways Agency, 2007).

Table 1.3 Comparison of percentage particle size distribution between MOT Type 1 and 1x

	Sieve Size (mm)							
	75	50	37.5	20	10	5	0.6	0.075
Type 1x	100	80-100		40-75		20-35	0-10	0-5
Type 1	100		85-100	65-100	40-70	25-45	8-22	0-10

The particle size within the wear course and sub-base will have a direct affect on the drainage properties of the surface. Water is held within the pores by capillary action (matric potential) and drainage through the material is mainly through the effect of gravity on the water (gravimetric potential). In materials with a high ratio of micropores the matric potential is greater than the gravimetric potential and drainage will be reduced. The materials used in the STP construction have a high level of macropores which enables free drainage under gravity.

Performance characteristics of a synthetic turf pitch

The materials selected for a synthetic turf pitch should allow for:

- The surface to perform, and allow users to perform on it, similarly to well-maintained natural turf pitches.
- The surface not to adversely change the fundamental nature of the sport being played.
- The surface to lend itself for practising and teaching game skills.
- The surface to suit competitive play.
- Over the long and short-term, the surface to allow safe playing conditions for players of all age and skill levels.

Individual governing bodies such as the Football Association (2004), FIFA (2001) and FIH (1999), as well as independent bodies such as The Institute of Groundsmanship (IOG, 2000), have produced performance quality standards (PQS) that ensure that STPs fulfil the above criteria.

Performance testing of synthetic turf concentrates on a number of characteristics:

a. Durability

A synthetic turf pitch needs to be durable to reduce the loss of playability caused by long-term use of the surface and still conform to the relevant PQS level; installation costs of an STP are high and it will not be cost-effective if it has a short lifespan. An important factor is the stability of the sub-base and synthetic turf specification, but durability is also affected by the quality of maintenance, intensity of usage as well as environmental and climatic conditions (Tipp & Watson, 1982). At present there are no field tests for durability, but in the laboratory (for the purpose of product licensing) turf samples are tested for wear, shock absorbency, vertical deformation, impact response, traction, joint strength and climatic resistance to conform with the standards set by differing governing bodies (FIFA, 2001). Using torque differential to imitate the linear slip applied to synthetic turf by player's footwear, the Lisport wear machine is used to quantify the long-term mechanical wear of individual products. This method does not quantify the abrasive wear that is applied by the interaction of the player's footwear, a sand infill, contamination and the turf fibres.

b. Player/surface interaction

The interaction between player and surface has a direct effect on the performance and safety of the players using the surface. Two key factors are friction and impact absorption; both are dependent on the pitch construction and its mechanical properties (Martin, 1990). As the grass fibres over time are damaged by play, maintenance, environmental and climatic conditions, it is important regularly to check the change in these factors. At present, only the FIFA 1* and 2* licensed pitches are regularly tested; annually (2*) and every three years (1*). For other specifications of surface there is currently no recommendation for the period between testing.

Player/surface interaction tests include:

Artificial Athlete Berlin (AAB). A 50 kg mass falls onto a spring of relatively low stiffness from a height of 30 mm. The equipment has two measuring devices; a load cell and a displacement cell, which measure the peak impact force and resultant displacement of the surface, allowing calculation of the force reduction of the surface and the energy restitution. The falling mass is damped by the spring to replicate the controlled loading of the surface by the human, more closely. Although this device is used to test surfaces for their compliance to specifications and PQS, there are concerns about the signal processing not identifying the true signal from background noise (Young & Fleming, 2007) and the time it takes to set the equipment up in the field and its portability (Abbott, pers com).

Clegg Impact Hammer (CIH). An aluminium cylinder of a specified mass is dropped on to the test surface, and an accelerometer mounted within the cylinder is logged to record peak deceleration on impact (Clegg, 1976; note: some devices will log acceleration with time, over the whole contact period). The inclusion of a guide tube for the weight improves the repeatability of the test. Previous research has shown that the results from the test can be influenced by the drop height, missile shape and the mass of the falling missile (Nigg, 1990); because of this it is not regarded as an acceptable method for surface testing. In a later study by Young and Fleming (2007), a significant correlation between a 2.25 kg CIH and the AAB, indicated that the CIH could be used as a more portable, cheaper surrogate for the AAB in surface classification, although it is less informative and loads the soil over a shorter period of time. With reference to this study, where a 0.5 kg hammer is used, the observation of Dixon *et al.*, (2008) that using a 0.5 kg hammer dropped from 0.55 m was a 73% reduction in potential energy c.f. a 2.25 kg hammer dropped from 0.45 m. Baker *et al.*, (2001) determined that a 0.5 kg CIH dropped from 0.55 m and a 2.25 kg dropped from 0.45 m were more strongly correlated with cricket ball bounce on natural turf cricket pitches.

Rotational Resistance. This measurement is derived by applying a torque on a weighted test foot from a stationary position, with the maximum resistance to rotational movement measured. The contacting area is covered with a material specific to the type of sports surface being tested (i.e. studs or dimples) Previous studies have shown that the rotational resistance is influenced by factors such as surface material, normal force, speed of movement and contact area (van Gheluwe *et al.*, 1983; Valiant, 1987 & 1990).

c. Ball/surface interaction

PQS are very specific about the acceptable levels of ball/surface interaction, as it directly affects the movement of the ball. The surface is tested for vertical ball rebound, ball roll, ball deceleration and ball deviation. The importance of each factor depends on the sport being played on a surface. For instance, the level of vertical ball rebound will be different between hockey and football; for safety reasons a hockey ball should not rebound more than 400 mm (and with a variation in ball bounce limited to +/- 20% of the mean) when dropped from a height of 1500 mm (FIH, 1999), whereas this low level of bounce would impede play in football. Keeping a balance between playability and the safety/comfort of the players is a difficult task, as the needs of different standards of player vary. STPs are designed to deform under load and return energy to the player (Baroud et al, 1999); but a surface that deforms too easily may reduce ball roll, prevent ball bounce and result in the surface being too compliant. The resultant high energy expenditure by the player can increase injury risk through fatigue (Rogers & Waddington, 1990).

The tests that are quoted by the sport governing bodies to be used to test ball/surface interaction are:

Ball Rebound. A ball is released from a known height and the height of its rebound from the surface is measured. There are two existing methods for measuring this distance: optical measurement by way of viewing the ball rebound height against a vertical scale or by the use of acoustic recording apparatus. Both methods require either expensive equipment or more than one operator.

Ball Roll. A ball is rolled down a ramp and the distance it rolls determined. The ball is allowed to roll until it comes to rest and the distance travelled is recorded. This method has been shown to have disadvantages when used in the field; this is due to the distance of the ball roll (Kolitzus, 2003). The roll of the ball can be affected by wind speed, localised changes in levels within PQS, irregular infill levels and the multi-directional nature of the synthetic turf.

1.4.7 Maintenance of synthetic turf pitches

There is a lack of peer-reviewed, published information available concerning optimal maintenance practices for the different surface systems, or the effect that maintenance has on the carpet. Published maintenance regimes tend to be generic in nature and few allowances are made for the differing carpet specifications and geographical location of the facility (FIH, 2001a; FIFA, 2001).

The main goal of maintaining a synthetic turf pitch is to maintain the surface playability by:

- Removal of grass, litter, leaves, twigs, chewing gum and contaminant soil
- Cleaning from pollution (dust, finer contaminant particles)
- Removal of weeds, algae and moss
- Provision of a uniform infill
- Conditioning the pile of the carpet

In the early 1990's there was a belief within the sports turf industry that STPs, compared to NTP's, require little or no maintenance (Russell, 1992) ; experience has now shown that for a synthetic pitch to retain playability that pro-active maintenance is required. A lack of maintenance will result in the build up of abraded fibre fragments, contaminants from air emissions and various other impurities (SMG, 2003a), which include organic material and worn fibres. These contaminants migrate to the lower pile through the course of play and rainfall; this reduces the porosity of the infill and the infiltration rate of water into the surface is reduced (Rhodes, 1997).

An irregular depth of infill reduces the fibre support and causes the pile to collapse; this will have a negative effect on the surface playability. Areas of high traffic, such as goalmouths and penalty areas, will show sign of wear (Figure 1.9) and these areas cannot easily be replaced. Wear on an STP is spatially variable and the areas of most wear will vary depending on the sports played on the surface (Football Association 2004b). Relaying areas of wear or damage, on a mature surface, will introduce materials that differ from the original specification, in particular pile height, density, colour and polymer structure. The patches can cause a variation in traction on the pitch which can result in lower leg injuries or uneven levels can cause a hockey ball to deflect towards a player's body (Ekstrand, 1982).

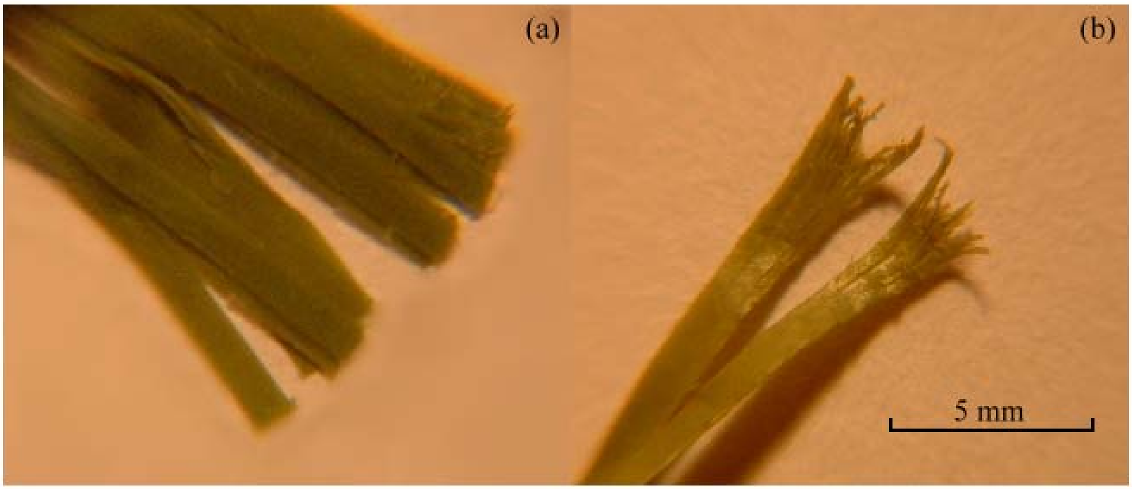


Figure 1.9 Polypropylene fibres in (a) new condition and (b) exhibiting fibrillated wear after 7 years of use.

Proactive maintenance systems are provided by specialist contract maintenance and installation companies, which claim that they will assist in ‘maximising’ the economic return of the facility (Hession, pers.comm). Figures provided by the contractors imply that a proactive maintenance regime can increase the life expectancy of the turf by over 100% (Replay Maintenance, 2007); there is no evidence presented to substantiate these claims and the information seems to be aimed at generating sales of the various maintenance systems available. There is no doubt that there is a requirement for regular maintenance of the STP, but the claims made by individual maintenance companies are, at present, unproven, and there is a need for further research to substantiate the claims.

The subject of maintenance of synthetic turf playing surfaces is not reviewed in any detail by any of sports governing bodies. In a 112 page document UEFA covered pitch maintenance in five pages, whereas 20 pages are given to the testing and examination of materials for performance quality standards (UEFA, 2003). Since 2004 FIFA and UEFA have harmonised their approach to STP provision and the maintenance of STPs for football has now been upgraded in a new document (FIFA, 2006) Along with FIFA, some of sports governing bodies do provide maintenance recommendations (FIH, 2001a; Football Association, 2004b), but once again they are generalised (Table 1.4). None of the recommendations provided by the governing bodies are derived from scientific research into the effect that these procedures have on the wear and playability of the STP.

Table 1.4 Recommendations made by two governing bodies for the procedures used to maintain synthetic turf pitches (☑= recommended, ☒= not recommended)

	International Hockey Federation	Union of European Football Associaltions
Routine checks	☑	☑
Litter collection	☑	☑
Leaf collection	☑	☑
Drag brush	☑	☑
Power brush	☑	☑
Infill repalcement	☑	☑
Vegetation control	☑	☑
Line marking	☑	☒
Repair tears & seams	☑	☒
Treatment for algae/moss	☑	☒
Carpet repalcement	☑	☒
Snow removal	☒	☑

1.4.8 Maintenance Procedures

The existing, commercially available, procedures for maintaining all generations of STP throughout their life span are:

Drag brushing

This is a process that redistributes the infill from areas of high concentration to low, restoring the surface levels. It also agitates the surface, which aids in the prevention of the formation of an impermeable surface layer, which will impair drainage (LTA, 2002). These layers are formed by low density contaminant particles and fibre fragments that float to the carpet surface when the infill is saturated. The process keeps the fibre upright and reduces the area of fibre exposed to ultraviolet light.

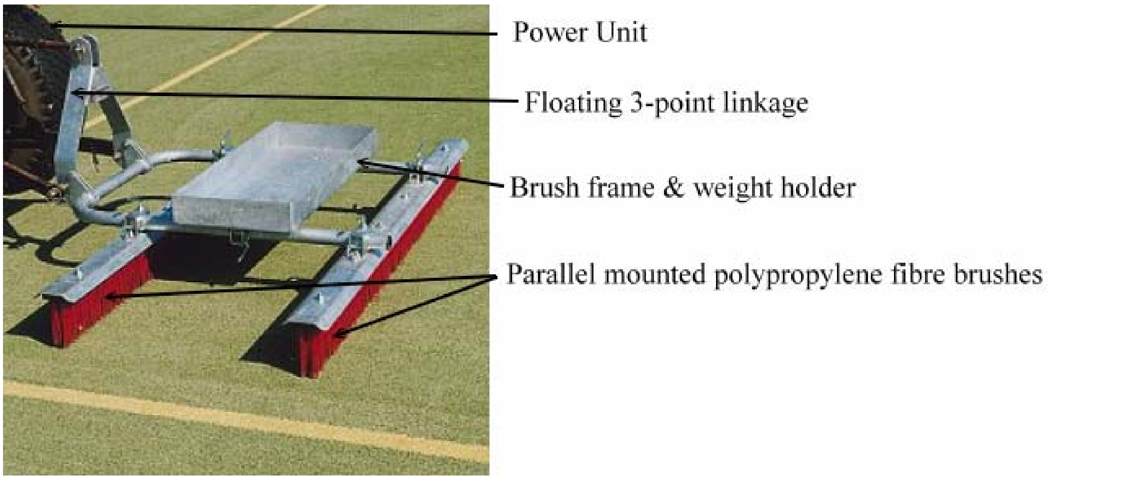


Figure 1.10 an example of a drag brush in use on a sand-filled synthetic turf pitch (source Astro Tech, 2007)

A drag brush consists of a polypropylene brush (Figure 1.10), which is attached to a compact tractor or utility vehicle; all vehicles should be fitted with low ground pressure tyres to prevent excessive compaction of the infill. There are a number of designs for the drag brush (Sisis, 2003; Technical Surfaces, 2002), which include different formations of brush layout, and each brush, if used correctly, should satisfactorily accomplish the task for which it is designed. The brushes are manufactured from a polypropylene that has a lower molecular weight than the synthetic turf and will therefore have a higher rate of wear than the carpet fibres. There is no research indicating the effect of the brushes on synthetic pitches and especially on older, more worn synthetic turf, whose fibres are more brittle and therefore more susceptible to wear.

If drag brushes are mounted on a three point linkage then uneven areas, such as hollows that conform to PQS, of the pitch are likely to be missed, due to the rigid attachment to the power unit. Where there is no float mode on the tractor unit's three point linkage, the problem can be negated by mounting the brushes on a single hitch pin; allowing the brush to float with the variations of the surface.

Surface renovation

The objective of this process is to clean the top 2-5 mm of the fibre/infill matrix, using contra-rotating brushes (Figure 1.11) that remove the infill to a maximum depth of 5 mm; it is then drawn over 5 mm sieves to remove the larger particulate contamination. The brush is transverse and rotates in the opposite direction to the forward movement of the vehicle. The infill is then re-deposited onto the surface and redressed with a drag mat/brush. Contractors state that if the process is carried out every two to three months, it will aid in extending the life span of the infill and carpet, by removing the larger abrasive particles from the surface. At present there is no research to confirm this.

There is an indication that there is no significant relationship between regular surface renovation and improved drainage (McLeod, 2003), although the sample of test subjects in this study was low (1% of total pitch population); the results obtained give reason for a more detailed evaluation of the procedure.

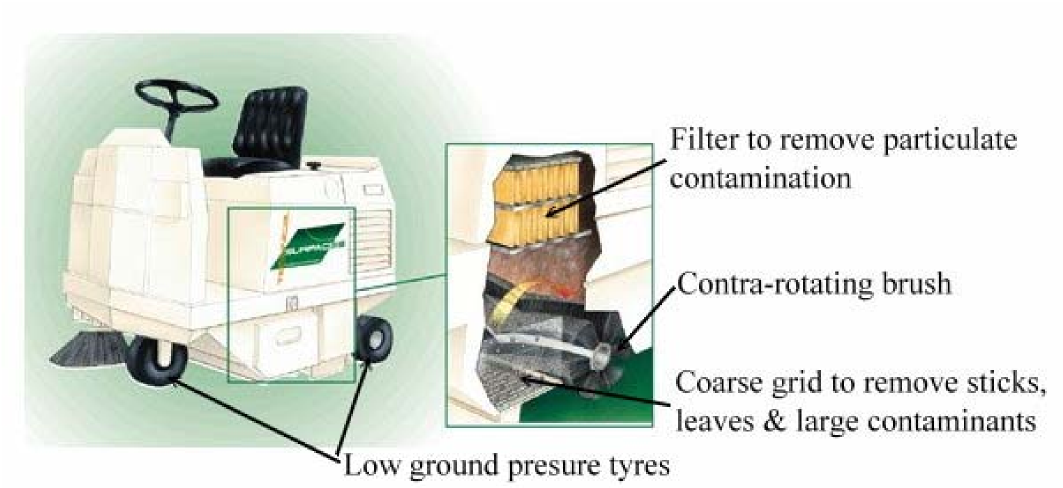


Figure 1.11 An example of a Dulevo contra-rotating brush (source: Technical Surfaces, 2007)

The available machinery is all of similar design (Figure. 1.11), using brushes to loosen the surface and only really removing the larger particles of contamination (SMG, 2001; CCM, 2002). As with the drag-brush, the brushes are manufactured from polypropylene which has a lower hardness than the carpet fibres. All specifications of this equipment rely on the air speed from the brush to move finer particles to the filters. If the infill is damp, the cohesion between the fine particles of contaminant and the larger sand particles will cause the contamination to be returned to the playing surface.

Rejuvenation

This procedure involves directing a jet of compressed air or water into the pile, which removes approximately 10 - 20 mm of the infill from the carpet. The infill is then replaced with fresh material. Specialist contractors carry out this procedure once or twice during the life of a carpet. This will incur a cost, inclusive of labour and materials, of £15-30k. On heavily used, well maintained, sand filled STPs, this procedure may be expected to be carried out after approximately eight years (Replay Maintenance, 2007). To prevent reduced infiltration performance, replacement sands must be hydraulically compatible with the remaining original material. This discrepancy between materials may be due to poor management of the process or financial reasons i.e. use of the cheapest of the sands available.

This is a specialist procedure and the availability of machinery is very limited, the two principal machines, the Beaver 2000M and the Beaver 2000 (Figure 1.12), are patented by Charles Lawrence plc and are only used by themselves or their sub-contractors. Although the specialised nature of the machinery raises the barriers of entry to any company considering an alternative design (Porter, 1980), there is equipment now being used that utilises compressed air or water as a medium to remove both the infill and the contamination (Sweepfast, 2007). There is a limited market and therefore it is difficult for incumbent companies to achieve economy of scale with the product. This lack of competition is likely to keep machinery and maintenance prices at high levels

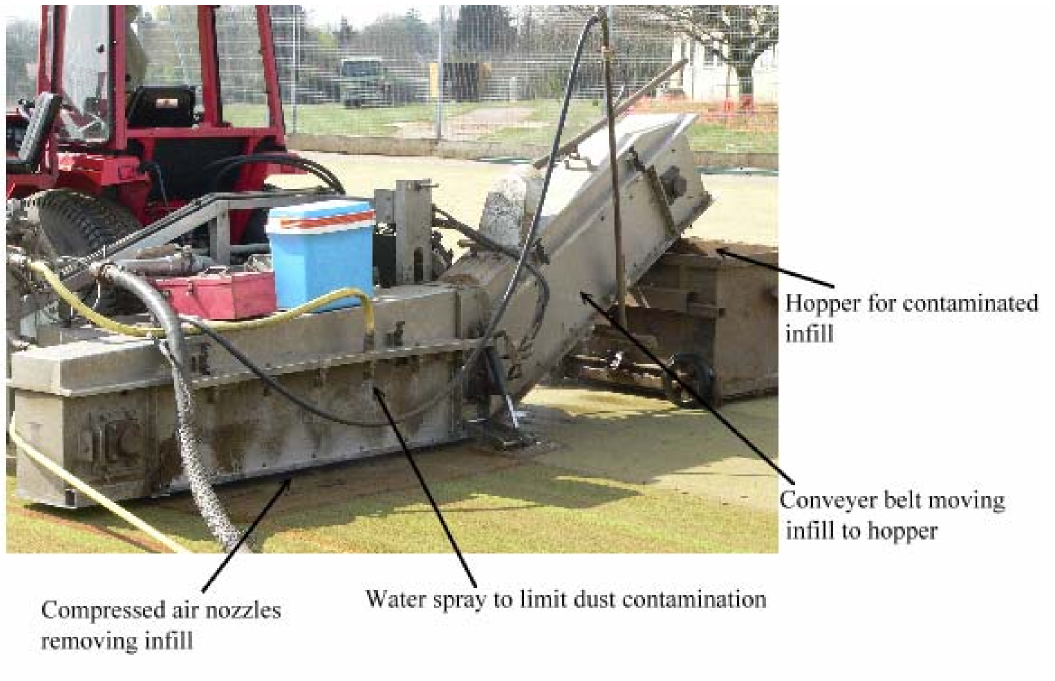


Figure 1.12 Removal of a sand infill using compressed air (source: Technical Surfaces, 2007)

Problems have been encountered when removing the sand/rubber infill from the longer pile length carpets (3G); these pitches need to be regularly raked with metal or plastic tines to prevent the fibre from matting together and compacting (Ferguson, pers.comm). In 2003, Charles Lawrence plc unveiled the Beaver 2000 Multi (SAPCA, 2003), which removes the infill from all the different types of surface, and is designed to remove infill from any specified depth. After treatment the pile is intended to be left in an upright position ready for fresh infill application.

Revitalisation

The term ‘Revitalisation’ has been trademarked to one individual maintenance company and is also known as ‘Revive’ and ‘Revival’. This process is relatively new to synthetic turf maintenance. It falls between rejuvenation and renovation, as infill to a depth of 8 mm is removed, filtered and returned to the surface where it is brushed back into the pile (Figure 1.13). This operation removes and filters large quantities of the sand infill and can be very time consuming; it can take up to 5 days to complete. Although this prevents use of the STP for up to 5 days, the cost is less than that of infill replacement. At present, maintenance companies can have up to two machines operating at the same time to finish the operation in two to three days. Each machine has an initial cost of £24k (Gunn, pers.comm) and the revitalisation process costs approximately £4k per pitch (inclusive of fresh infill to top up levels). This process is restricted by rainfall; the equipment cannot remove the infill if it is wet.

Figure 1.13 Example of equipment used for revitalisation (source: SMG, 2006a)

Pesticide application

As the life of a synthetic turf progresses, loss of porosity due to contamination can cause a number of biological problems, mainly moss and algae, which in turn cause a loss of player traction and surface playability. Water based hockey pitches mainly suffer from algae growth, as they have a lower permeability to water. For water-based hockey pitches, algae can be prevented by using regular chemical applications with an algicide, such as Bayer Dimanin Spezial (active ingredient: didecyl-dimethyl-ammonium chloride); the application of the chemical is through a dosing plant added to the irrigation system. For sand-filled pitches moss is the main problem and any occurrence can be treated using a moss killer, such as Scott's Enforcer (active ingredients are dichlorophen and sodium hydroxide); the dichlorophen within this product will be degraded by phototransformation within eight days of application (Zertal et al, 2004) if there has been no rain. Dichlorophen is classified as a list 1 organohalogen under the EC groundwater Directive (2004) and should be prevented from entering the groundwater. Before using any chemical treatment on a synthetic surface, the manufacturer of the carpet should be contacted to check any possible chemical reaction with the fibres or backing. Any treatment with pesticides should be performed by staff qualified with the NPTC PA1, PA2 and PA6a certificates of competence in the safe use of pesticides (NPTC, 2006)

Infestation of an STP surface by moss or algae is caused by the reduction of infill porosity by contaminant particles. Removal of these particles, by mechanical brushing and filtration of the infill, will increase porosity and decrease the moisture content of the infill. This will remove the optimal growth conditions for algae or moss (Rhodes, 1996) and, in turn, will reduce the need for pesticide application.

General maintenance

Throughout the year, there is the need to remove larger debris, such as leaves, from the surface and its surround. During the autumn, pedestrian vacuum equipment (Figure. 1.14) can be used to collect the large volumes of leaves that collect on the surfaces, which the other more specialised sweepers are not designed to collect. Construction of STPs close to deciduous woods and the frequent planning permission requirements for the provision of extra tree planting increases the levels of organic material contaminating the surface.

Figure 1.14 A pedestrian leaf sweeper (source: CCM, 2002)

Equipment design

Even though new machines are being developed and put into production, the range of STPs that they are expected to work on widens because of the advances being made in the production of STPs. This may well be one of the reasons for the present limited availability and variety of machinery. A limited market for the sale of the powered equipment will discourage manufacturers from future development; this has resulted in the maintenance companies designing or adapting existing equipment for their own purposes (CCM, 2002).

At present, the majority of equipment used to maintain synthetic turf surfaces has been adapted from conventional road sweepers (CCM, 2002). They do not have suction required to work on the open texture of a synthetic turf and their small wheels may add to compaction of the surface. Equipment design has improved (Redexim, 2007; SMG, 2001), but the main limiting factor for the effectiveness of the equipment is the surface conditions; if the infill is damp then the efficacy of all maintenance practices is seriously affected.

The one problem that affects all types of synthetic turf surface is the reduction of infill porosity by smaller particles of contamination. Future designs need to address this problem so that the more regularly used machines are able to remove, if not all, a high percentage of these particles. This would help to reduce the need for expensive rejuvenation procedures and help prolong the life span of the carpet pile.

1.5 Direction of research and contribution of the study to knowledge

1.5.1 Overview

The popularity of synthetic turf sports pitches has increased with a number of the governing bodies within the sports sector and the literature review shows that there are gaps in the knowledge and understanding of the maintenance and management of synthetic turf surfaces. The predominant specification of STP within the UK is second generation sand-filled pitches that have a post installation age range of 0-20 years. The third generation rubber/sand infill specification is a relatively new design and the oldest pitches are less than 10 years old.

As previously mentioned, the main benefits for the installation of an STP are extended hours of play, use for multi-sport and an increase in revenue streams. From these factors, the experimental approach to the study is based on the relationship between the requirement and efficacy of maintenance and the factors that have an effect on this output (Equation 1.1).

Equation 1.1 The factors affecting the efficacy of maintenance

$$Effect\ of\ \ maintenance = \int (age, location, maintenance\ levels, usage, sport, specification)$$

The research project will use second generation sand-filled STP’s, an established specification, as the base for experimental and field work. Use of STP’s of this specification will provide a larger usable sample base.

1.5.2 Project aim

Therefore, as stated above, the aim of this study is:

To develop a fundamental understanding of the mechanical wear and decline in hydraulic performance of second generation synthetic turf surfaces, its impact on technical performance characteristics, and economic life-cycle costs in relation to maintenance and usage.

1.5.3 Objectives

To achieve the aim of the project the following objectives were set:

1. To determine a relationship between wear, maintenance and performance characteristics of the synthetic turf surface over time.
2. To identify, characterise and quantify the mechanisms causing the degradation of synthetic turf surfaces and infill materials through usage.
3. To develop and implement measurement methods and techniques for assessing the effectiveness of existing maintenance equipment on synthetic turf and infill material.

4. To determine a relationship between wear, maintenance programme and economic costs of synthetic turf surfaces over a typical surface lifespan.

5. To devise a technique for the quantification of wear in synthetic turf fibres

6. To provide scientific based guidelines for managers to make informed decisions on the management and maintenance of synthetic turf pitches.

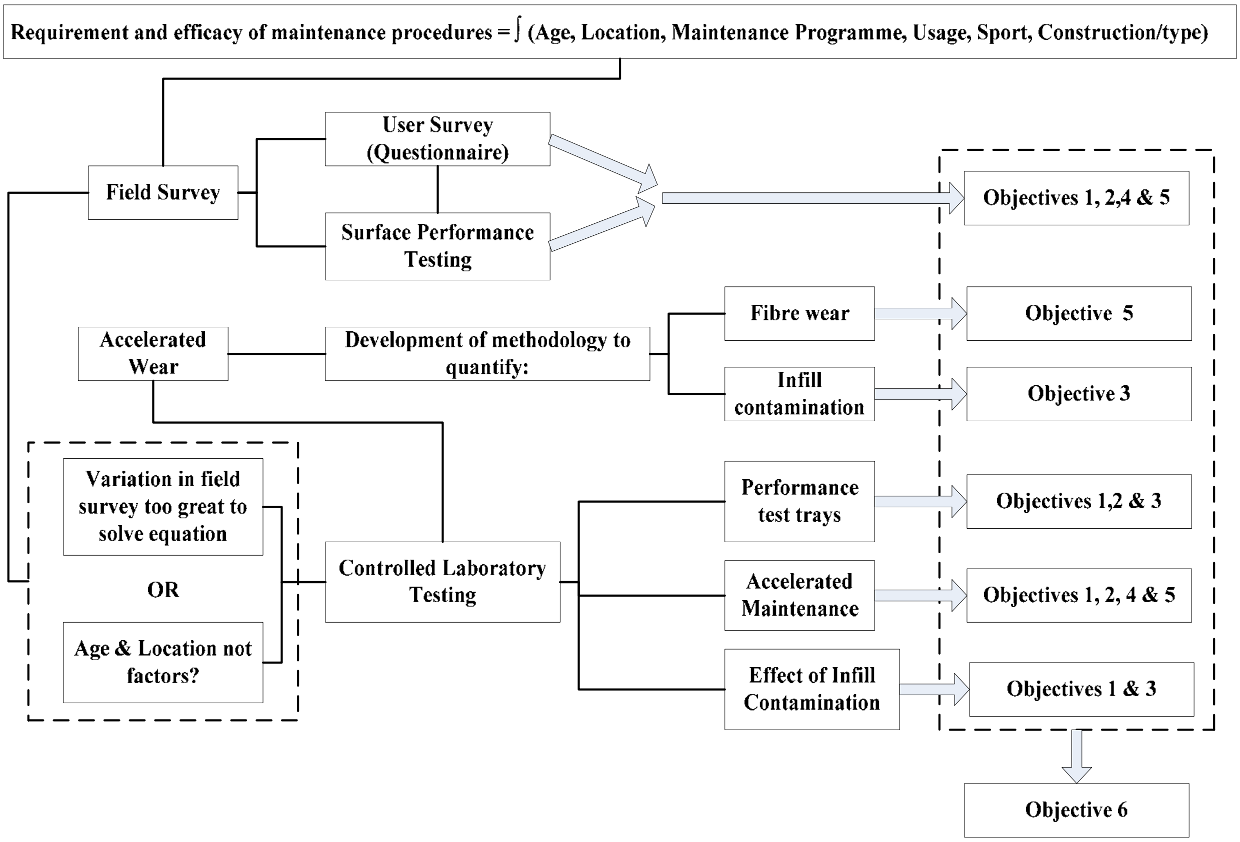


Figure 1.15 Summary of the research approach in this study

1.5.4 Research approach

To achieve the objectives of the research, the research methodology was structured into five main investigations based on the research approach shown in Figure 1.15. These investigations were:

1. A Field Survey

To quantify the combined effect of age, location, maintenance levels, usage and sport, the performance characteristics of STPs randomly selected from the database of an STP contract maintenance company will be measured and their relationship investigated. As part of the field survey, a questionnaire was used to obtain information on the management and maintenance of individual STPs. An increased knowledge of the effect that age and environmental factors have on the playability of a surface will benefit future research projects investigating reduced surface performance. The survey and site investigations illustrated complexities in the factors affecting field performance caused by variation in construction, management and environmental variables. Therefore laboratory experiments were required to determine the effect of isolated variables in controlled conditions.

2. Accelerated Wear and Maintenance

At present, within the sports industry, the measurement of the resistance to wear of synthetic turf sports surfaces is carried out pre-installation. Normal testing of the integrity of the carpet system is carried out by measuring the tensile properties of individual fibres, the effect of ultra violet light and aging. Furthermore, fibre is subjected to simulated wear by metal blades, abrasive wheels and the reproduced action of football studs (FIFA, 2005; BS EN 15306:2007). Such approaches to testing do not characterize the wear mechanism of the whole system of polymer carpet fibres and infill materials in the field environment. The quantification of wear in fibres extracted from an existing pitches and comparison against known levels of fibre wear will enable strategic planning into the future of the pitch.

There are different methods of brushing and filtering the synthetic turf/infill system. Sports governing bodies do provide generic maintenance recommendations (FIFA, 2001; FIH, 2001a; Football Association, 2004b) and information is provided by existing STP maintenance companies. Although some measurement of existing maintenance equipment in the field will be conducted, there is a need to replicate the brushing action in controlled laboratory conditions to allow the quantification of the effect that brushing has on the fibre polymer structure. This will investigate whether the maintenance procedures can have a detrimental effect on the surface and if existing maintenance recommendations are exceeding maximum levels in the controlled studies.

3. Quantification of infill contamination

A lack of maintenance will result in the build up of abraded fragments from foot traffic, contaminants from air emissions and various other impurities, which include organic material and worn turf fibres. These contaminants migrate to the lower pile through the course of play and rainfall; this reduces the porosity of the infill and the infiltration rate of water into the surface is reduced (Rhodes, 1997). In recent years many facilities have introduced proactive maintenance systems that utilise regular brushing and filtering of the sand infill. There has been no quantification of the concentrations of contamination present within the infill/ carpet system and how these levels affect the surface infiltration rate. Low infiltration rates cause loss of surface playability, through growth of moss/algae and flooding, and this causes a loss of revenue through loss of play. An ability to quantify the contamination levels of an existing pitch and the levels at which contamination will start to affect play would be beneficial to the design and implementation of maintenance protocols and the evaluation of machinery effectiveness.

4. Surface Performance Testing on Homogeneous Pitch Construction

As identified in Investigation 1, variability in field survey data was significant, it is necessary to conduct controlled experiments in the laboratory. Surface performance testing is to be carried out on replicated, controlled test STPs to give an indication of the effect that pitch age has on playability. Replicated engineered base test surfaces will be constructed and identical performance testing will be performed on surfaces where individual factors or factor-interactions, such as level of contamination, are changed. Quantifying the effect that individual surface conditions have on performance testing will enable explanation of variation between test surfaces.

5. Financial management of synthetic turf pitches

Financial information about 2nd generation sand-filled STPs is to be obtained from the field survey questionnaire. This will provide information on the cost and revenue streams involved in running a facility, which are not clearly stated in the literature. These data will be collated and used in a financial model that will provide information on future recurrent and capital costs. This model will provide information, which presently is unavailable, to managers of STPs. It will enable them to make more informed decisions on STP installation and surface management.

1.6 Thesis structure

The investigations outlined above are presented in different chapters throughout the thesis as follows:

Chapter 2 describes the materials and methods used throughout the research and the validation of any new methodology that has been developed in the project.

Chapter 3 reports the results from the field survey and the accompanying questionnaire survey. This determined the need for further controlled laboratory experimentation.

Chapter 4 presents the laboratory based studies that were conducted as a result of the findings of Chapter 3.

Chapter 5 details the design of a mechanical test rig that was designed to accelerate the wear due to contra-rotating brushing on samples of second generation synthetic turf.

Chapter 6 presents the financial model for the management of an STP which is based on the collated data from the questionnaire, which is also presented in this chapter.

Chapter 7 is an overall discussion of the data and findings of the research and how these can be used to produce guidelines for the management and maintenance of sand filled synthetic turf pitches. An evaluation of the data and the analysis throughout the thesis outlines the boundaries for the guidelines and makes recommendations for further research.

Chapter 8 is the specific conclusions of this study.

2 Chapter Two: Methods and site locations

A range of methods were used to quantify the performance characteristics, efficacy of existing maintenance equipment and the mode of wear of STPs.

2.1 Selection of synthetic turf pitch test sites for use within the research project.

In literature review it was shown that there are gaps in the knowledge and understanding of the maintenance and management of synthetic turf surfaces.

To understand these gaps, a sample of STPs was audited for:

I. Detailed information to obtain an overall representation of the maintenance practices and financial management being presently used. This information was obtained using a postal questionnaire.

II. The measurement and quantification of the combined effect of age, location, maintenance levels, usage and sport, on the STP performance characteristics.

2.1.1 The criteria for test pitch selection

As previously mentioned in Chapter 1, the relationship between the requirement and efficacy of maintenance and the factors that affect this output is shown in Equation 1.1

Equation 1.1 The factors affecting the efficacy of maintenance

$$Effect\ of\ \ maintenance = \int (age, location, maintenance\ levels, usage, sport, specification)$$

From this relationship, the initial criteria used to select the test pitches were:

1. Maintenance levels (Low and High) – This would indicate the reasons for the different levels of maintenance and provide information to compare to surface performance testing to quantify any effect on surface quality.

2. Age (0-5 yrs, 6-10 yrs, 11-20 yrs) – The data would indicate whether there is any variation of maintenance between pitches of different ages.

3. Location (Urban, Rural) – Anecdotal evidence from contract maintenance companies indicated that these locations require different maintenance

programs. This indicated whether the higher levels of airborne contaminants increased the concentration of contamination within the sand infill.

4. Owner/Manager (School, Local Authority, Private Club) – The information would show if there was any variation of the management of the STPs and whether there is a difference in the levels of use.

To make results statistically significant, three replicates of each criterion would be required.

The initial selection matrix is shown in Table 2.1. To fulfil all the selection criteria, 108 pitches would have been required for testing. From a logistical point of view, a programme of selection and testing of this number (108) of pitches, over a 12 month period, was not viable within the financial and time constraints of the project.

Table 2.1 Initial criteria selected for test pitch survey. (LA = Local Authority)

		Urban			Rural		
Maintenance Level	Age Band (yrs)	School	Local Authority	Private	School	Local Authority	Private
Low	0-5	3	3	3	3	3	3
	6-10	3	3	3	3	3	3
	11-20	3	3	3	3	3	3
High	0-5	3	3	3	3	3	3
	6-10	3	3	3	3	3	3
	11-20	3	3	3	3	3	3
					Total	108 Pitches	

To reduce the number of test pitches, the criteria used for selection were subdivided, by location, into urban and rural groups and then further divided into age groups based on time since installation (0-6 years, 7-12 years and 13-20 years). Three pitches were selected at random for each location-age group combination; resulting in a total test sample of 18 pitches (Table 2.2).

Table 2.2 Final criteria selected for test pitch survey

	Location	
Age Band (yrs)	Urban	Rural
0-6	3	3
7-12	3	3
13-20	3	3
	Total 18 pitches	

2.1.2 Identification of synthetic turf pitches to be used in the performance survey

Initially 76 second generation sand filled synthetic turf pitches were selected, from the database of a UK synthetic turf maintenance company. The initial selection was based on the pitch specifications of: a sand infill, an initial pile depth of 23 mm, infill specification and the presence of a shockpad. In most cases, information on other carpet characteristics such as fibre denier, pile density and brand were not known to either the maintenance company or the pitch managers.

On selection, each of the managers of the 18 prospective test pitches was contacted by letter inviting them to take part in the performance and questionnaire survey. From the initial selection there was a positive response of over 90% from the managers. When there was no response, further random selection of pitches was undertaken and the process was repeated. To fulfil the selection of the 18 test pitches the selection cycle was repeated 4 times. The location of the final 18 test pitches is shown in Figure 2.1.

It should be noted at this stage that using the database of a synthetic turf maintenance company limits the research to surfaces that are maintained. This was the only database available to work with, however, as there was not central database held by a coordinating body such as Sport England. The results of the research must be viewed with this in mind.

Figure 2.1 Final location of synthetic turf pitches

2.2 Management questionnaire survey of sand-filled synthetic turf pitch managers within the United Kingdom

2.2.1 Introduction

To be able to provide data for other investigations within the research project, it was important to be able to obtain relevant information on the management and maintenance of STPs. The role of the survey was to elicit information for the objectives which were:

1. To define the sample age and use. This will confirm the age group into which individual STPs fit and whether they are used for multi-sport purposes.

2. To define the reasons for installing an STP. Using this information will illustrate the key drivers behind the selection of an STP over an NTP. It will indicate whether STPs are regarded as low/no maintenance or if there are other factors involved in the selection other factors

3. To assess the difference in maintenance techniques currently used. The provision of maintenance information will allow the range of equipment used and the frequency of maintenance procedures. This will indicate whether there is a proactive maintenance programme being used.
4. To determine the costs involved in managing an STP. The information provided will be used in a financial model that will be used to illustrate the future costs involved in managing an STP over a 15 year period.
5. To statistically analyse data for use within other project investigations. The range of data supplied will be used in statistical analysis of any correlation between factors such as age, maintenance programme and measured performance characteristics.

2.2.2 Methodology

The population to be investigated was all facilities that have a second generation sand-filled synthetic turf pitch (approx. 2000 within the UK) as part of their sports surface provision.

In order to collate the information required for the project, it was necessary to select a strategy that would enable the most effective data collection. The barrier in accessing complete records of all STPs within the UK was that no definitive list exists. This had a direct effect on the sampling strategy; it was decided to use a non-probabilistic, convenience sampling method (Baines & Chansarkar, 2002). Since the type of data required for analysis was quantitative, a fixed sub-strategy was selected; this involved setting a strict specification before the data collection stage (Robson, 2002). The fixed design research strategy has historically been broken down into two different strategies, experimental and non-experimental. In this case a non-experimental strategy was chosen, as there is a collection of data, but unlike the experimental strategy, there is no attempt to change the situation, circumstances or experience of the participants. The design process for the collection of relevant data is shown in Figure 2.2.

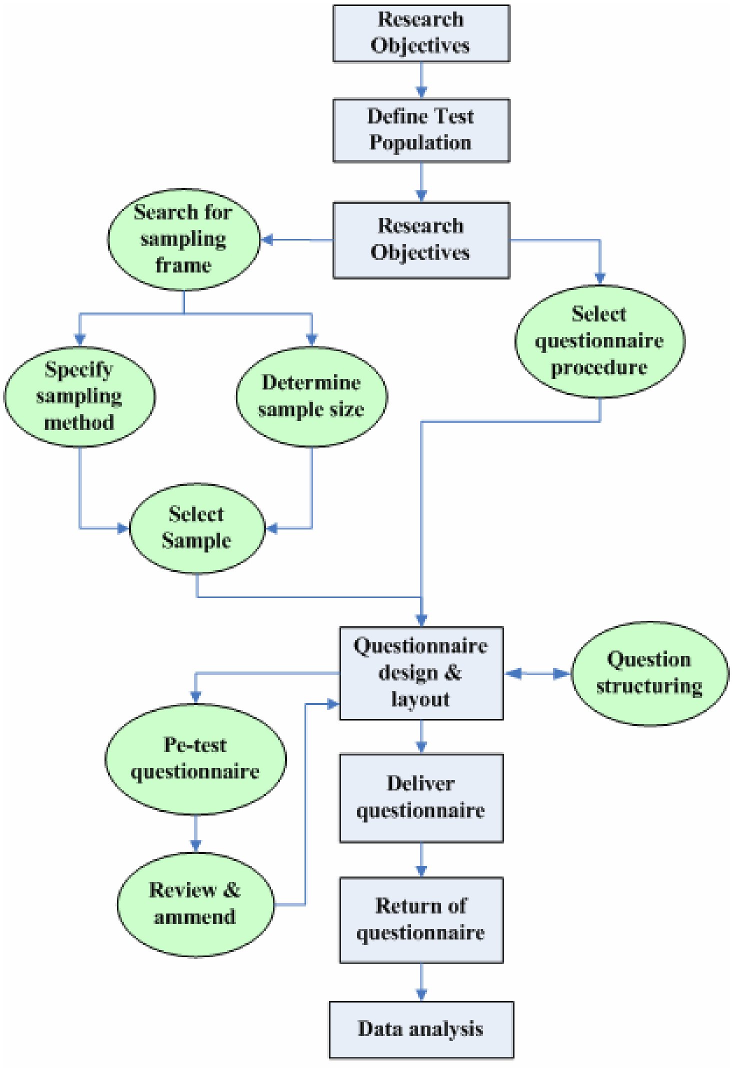


Figure 2.2 Design process for the postal questionnaire (adapted from Baines & Chansarkar, 2002)

2.2.3 Data collection method

The most feasible data collection method, that provided the necessary structure to obtain the relevant information from the targeted respondents, was a questionnaire. As part of the consideration made in design, both the advantages and disadvantages of a questionnaire-based survey were taken into account. Although data gained from the respondents would be affected by their characteristics (e.g. memory, experience), there would be a high level of data standardisation and the questionnaire provided a relatively straightforward and simplistic approach to data collation (Robson, 2002). An additional benefit was that this approach allowed for the fact that the low target population and that the targeted recipients often lacked the time needed for personal interviews with the author (Bailey, 1995).

2.2.4 Sampling frame

The defined population, from which the sample for the questionnaire was drawn, was adequate, up to date and relevant for the purposes of the survey. The documentation was sent out to individual respondents at each of the facilities within the sample, The Facility Managers.

The facilities used for the sample were the same sites selected for surface performance testing, with additional random sites selected from published listings found on the internet, independent schools directory, local authority listings and the database of a synthetic turf maintenance company. This method of selection ensured that the target sample was random and not reduced to facilities known to the author.

2.2.5 Designing the questionnaire

The basis of the questionnaire was to gather as much information as possible on the financial and maintenance practices of each facility. To construct the questionnaire a flow chart of the information, which would be required to fulfil the project objectives, was produced (Figure 2.3).

After initial discussions with a statistician from Cranfield University, it was decided that the questionnaire should not take any longer than thirty minutes for a respondent to complete; this was in order to maximise rates of return. A minimum number of 35 questionnaires needed be returned (approx 2% of the population) to ensure the statistical significance of the results. The questionnaire was designed for self-completion, but with the option of contacting the respondent, if necessary, for supplementary information.

As the questionnaire was postal, its appearance was vital. It had to appear easy to fill in, with plenty of space for the answers, again this was in order to maximise rates of return. It was important for the questionnaire to be concise and for it not to contain ambiguous or multiple-sectioned questions, as these types of questions increase the likelihood of non-response.

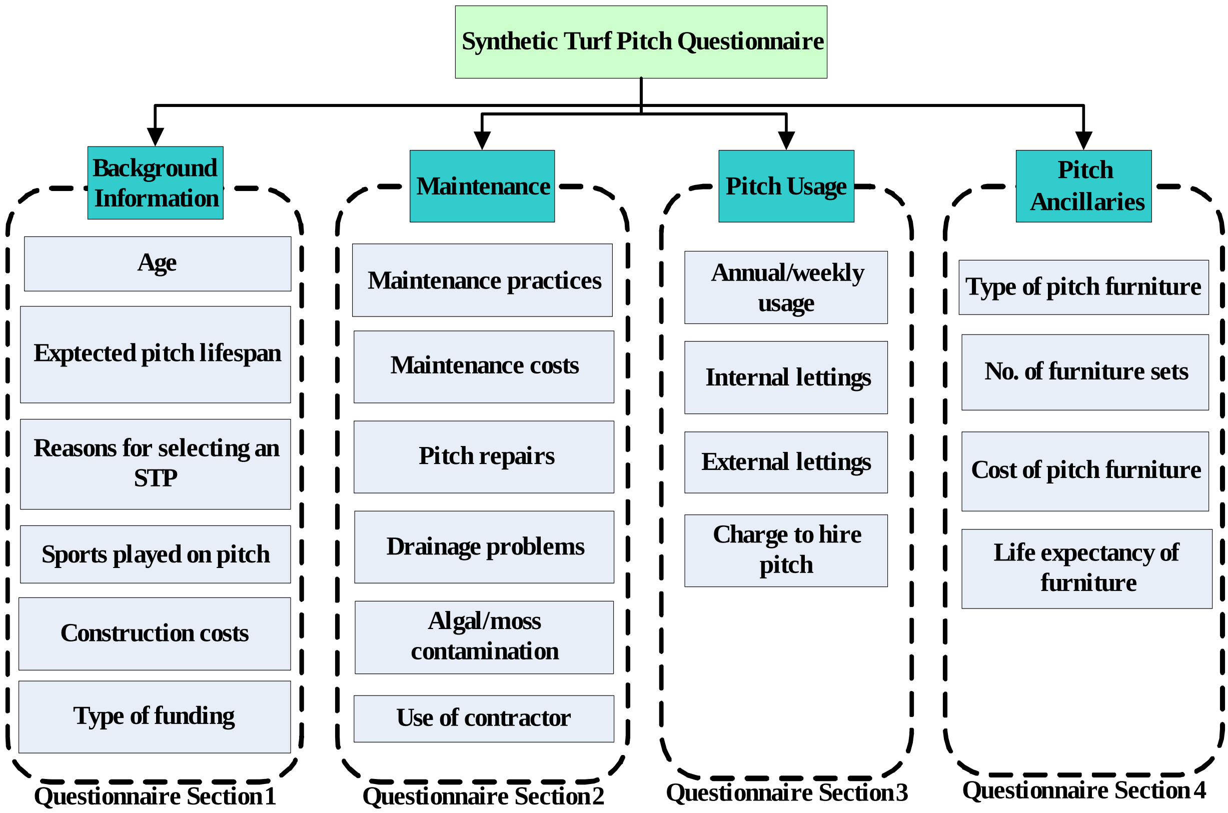


Figure 2.3 Flowchart of the data included in the questionnaire survey.

To encourage accurate information on certain financial matters, a closed question was used to allow the respondent to select one single category that contained a range of costs (Figure 2.4). This reduced the requirement for exact figures and increasing the likelihood of this information being divulged. Consideration was also given to the possibility that the respondent may not have access to the exact costing of the installation, but would have enough knowledge to relate it to a cost banding.

What was the cost of the pitch construction?	£'000	<250	250 - 300	300 - 350	350 - 400
		400 - 450	450 - 500	500 - 550	600 - 650
		650 - 700	700 - 750	>750	

Figure 2.4 An example of a closed question used in the questionnaire to obtain financial information.

To enable the calculation of the income and expenditure involved in the running of an STP, it was important to ascertain what costs were involved with the maintenance of the pitch and whether there was an expectation for the generation of an external revenue stream. The degree of internal usage and the availability of floodlighting for play in the winter months would affect any revenue stream generated from use of the pitch.

Section 1 of the questionnaire was devised to gather basic information about the pitch, such as:

- The age of the STP.
- The range of sport played on the pitch.
- Initial construction costs and the type of funding used.
- Perceived life expectancy of the turf.
- Factors that influenced the facility manager's choice of an STP. These were measured using a uni-dimensional scaling method, a Likert Scale (Likert, 1932), where respondents are given a choice of reply on a five point scale that allows data to be presented as a single or a summated score (Figure 2.5). Point 3 on the scale represents neither low nor high priority.

Is increased hours of play a factor that influenced your choice of pitch specification?

Low Priority	→			High Priority
1	2	3	4	5

Figure 2.5 An example of a five point Likert Scale used in the questionnaire

The second section of the questionnaire was designed to review:

- The background information on the maintenance of STP that the respondents had been provided with on completion of the installation.
- Whether managers had adhered to recommended maintenances practices.
- The type and frequency of maintenance practices used.
- The time allotted to weekly maintenance.
- The use of contractors
- The costs involved in the maintenance of the individual STPs.

- Whether surfaces or infill had been replaced
- The repair of failed seams or damage caused by tearing of the carpet.
- The use of chemicals on moss/algal contamination of the surface.

Part of this information is linked to qualitative questioning on maintenance information provided at the point of sale.

The third section was used to assess the frequency of play on the pitch and how the play is divided between internal and external usage. This information included the charge for hiring the pitch, which aids in the calculation of any revenue earned by the external lettings and to apportion a charge to internal use. Although internal usage has no direct charge, it does have an effect on the wear of the pitch and equipment as well as affecting the required maintenance levels.

The final section dealt with the number, cost and life expectancy of the pitch ‘furniture’, the various posts and equipment required for the individual sports played on the pitch. This equipment is expensive and with high usage pitches, there is an increase in the wear to the nets and posts.

2.2.6 Issuing the questionnaire

Once the questionnaire had been compiled, an initial pilot survey of five STP managers was performed. The aim of this exercise was to receive feedback on the wording, structure, question order, flow, timing and respondent interest of the questionnaire. As a result of the pilot study, a number of minor changes were implemented to the wording and layout of the document. The final task before issuing the questionnaire was to ensure that there were no typographical errors and that the layout was professional with the appropriate spacing and clarity of presentation (Robson, 2002).

The final questionnaire (Appendix B) was sent out with a personalised covering letter, explaining the reasons for the information requested, and a first class stamped addressed return envelope (Diamantopoulus and Schlegelmilch, 1996). It was also stated that all financial information would be kept confidential and the facility’s identity would not be disclosed within this study in order to encourage a higher rate of return of the document.

2.2.7 Data analysis

The data was entered into the statistics software package, SPSS (Statistical Package for the Social Sciences) standard version 13.0 for Windows. This software is specifically designed for the analysis of survey research data of all types, Marketing and Sales Analysis. Within the questionnaire an allowance was made for any missing data by the provision of coding for three different possible reasons: question not applicable, information not known and no information available. There is no satisfactory method for dealing with missing data (Huisman, 2000) but the coding enables effective analysis of the data.

After completion of the statistical analysis, it was envisaged that a pattern of the maintenance procedures and their costs would emerge. The data was to be used to construct a financial model of the revenue and expenditure streams that are involved with the management on a sand-filled STP.

2.3 Synthetic turf pitch surface performance testing

2.3.1 Selection of test areas for performance testing

The performance testing of the individual pitches was used to address Objective 2. The tests were carried out on what were perceived to be the high and low wear areas of the test pitches (Figure 2.6). Each pitch was divided into test areas and the performance tests were carried out at random points within those areas.

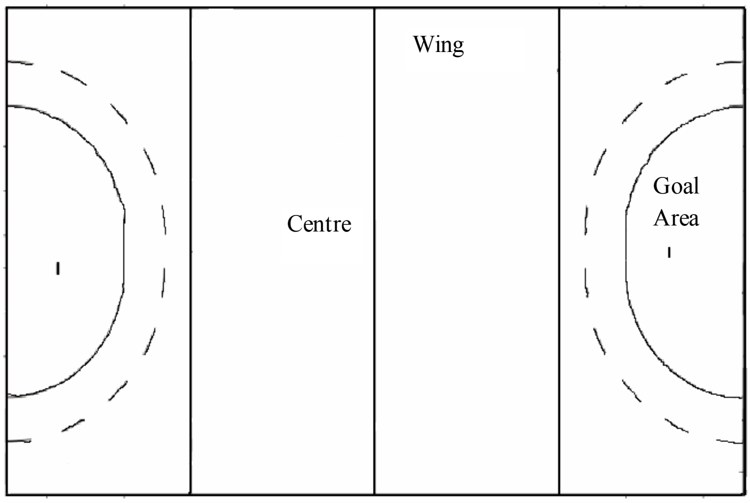


Figure 2.6 Test areas reflecting perceived high wear (goal area), medium wear (centre) and low wear (wing)

2.3.2 Governing Body Standards (PQS) used for comparison

A synthetic field hockey pitch has to conform to performance standards set by the Federation de Internationale Hockey (FIH) that have been defined in the FIH manual Synthetic Hockey Pitches – Outdoor: Handbook of Performance Requirement (1999) as:

- **Global** – Pitches for playing (and qualifying for) global FIH competitions
- **Standard** – Pitches for other (inter)national competitions
- **Starter** – Pitches (mostly multipurpose) for national level

The performance standards define upper and lower limits of properties such as ball roll, ball rebound, rotational resistance, infiltration and impact behaviour. As a pitch ages, it is exposed to wear factors such as user foot and equipment traffic, exposure to air pollution, contamination through dust and soil deposition, and exposure to ultra-violet radiation.

Using these standards as a benchmark, the results from the selected test surfaces were used to test the hypothesis that although initially uniform in performance, synthetic turf pitches become more spatially variable with time due to differential wear. Each of the performance tests was performed on the three different wear areas (Figure 2.6) for each of the selected test pitches.

The tests used to test the hypothesis are outlined below.

2.3.3 Ball rebound

Theory

This test measures the degree of bounce of a ball that can be expected during play. A ball falling onto a compacted surface, which will deform less under load than a loose material, will conserve mechanical energy and will exhibit an elastic response to the surface. The energetic coefficient of restitution (COR) is defined as the square root of the ratio of the work done by the normal contact force during restitution, to the work done by the normal contact force during compression. The effect that the surface compaction has on the ball is expressed in Equation 2.2.

Equation 2.2 Calculation for the coefficient of restitution

$$e = \sqrt{\frac{h_1}{h_2}}$$

In this case, e = coefficient of restitution, h_1 = height of ball rebound (m) and h_2 = height of ball release (m).

On contact with the surface, both the ball and the surface deform and energy is dissipated by the deforming of the material. The COR represents the part of the initial kinetic energy of normal relative motion that is dissipated during the ball/surface contact period. The relative magnitude of the separate parts of the total energy dissipation depends on the relative normal compliance of the contact regions and the loading/unloading hysteresis of the material of each surface (Coaplen et al, 2004).

The COR is a measure of the total energy that is recovered during the collision between the ball and the surface. e.g. a COR of 0 indicates that all of the initial kinetic energy of normal relative motion is dissipated on contact with the surface.

Details of this method

A hockey ball was dropped vertically, without spin or extra impulse, on to the playing surface from a height of 1.5 m. The rebound height was measured from the surface to the underside of the ball. A minimum of three replicates were carried out for each test area on the pitch. For field tests, the FIH stipulate a maximum standard deviation of ±20% from the mean is an acceptable result. The test would normally be performed using a graduated vertical straight edge and a video camera/the naked eye (FIH, 1999); a test that is more accurate with two operators.

To enable an accurate, single user measurement, new equipment was designed and constructed (Figure 2.7). The designs for this equipment are shown in Appendix C. On release, the hockey ball falls under gravity and on collision with the pitch surface an infra-red (IR) beam is broken and the IR sensors mounted on the side of the tube are activated. On rebound the ball breaks individual IR beams which are indicated on the control unit by the illumination of light emitting diodes (LED). The height of each LED is calibrated to a known measured ball height; this allows accurate measurement of the position of the ball's lower edge.

The accuracy of the equipment was validated using a hockey ball, of known dimensions, placed on a series of vertical tubes of known height. The test apparatus was lowered over the ball and as each LED illuminated the distance from the base of the equipment to the test bench surface was measured. The comparison of the measurements indicated that the equipment was accurate to be relevant within the parameters of the FIH guidelines.

The test was performed at three points within the individual test areas and the results expressed as the mean of the replicates.

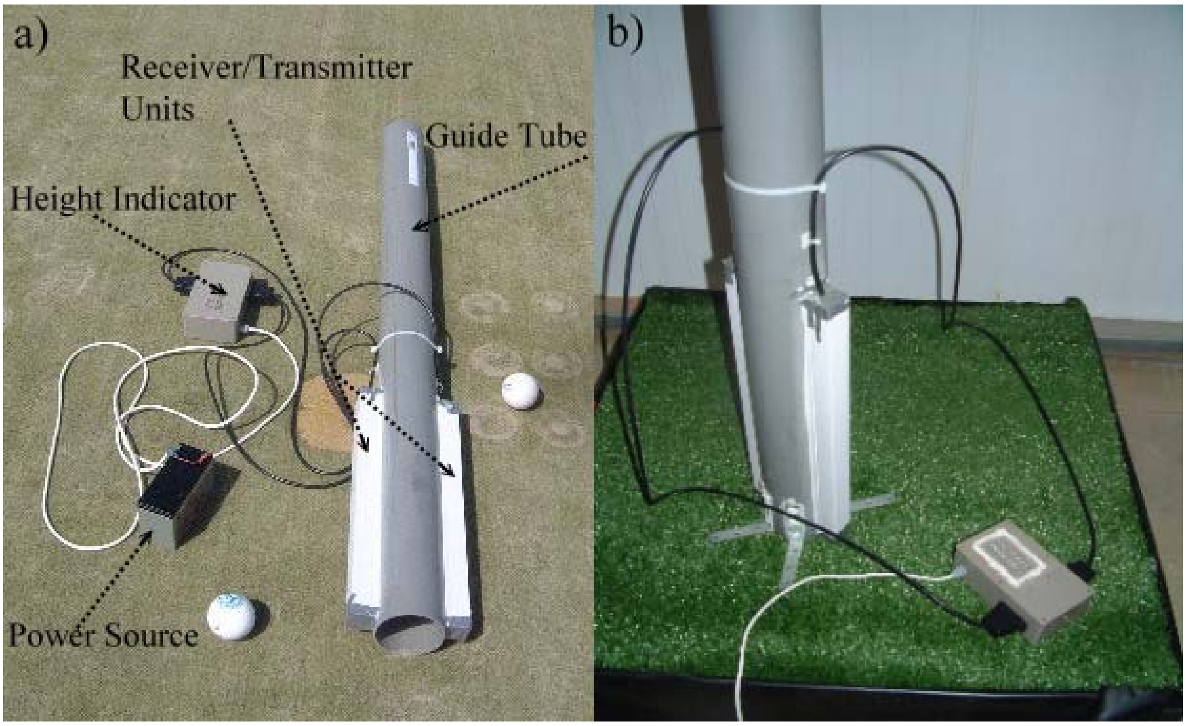


Figure 2.7 Device used to measure ball rebound a) constituent parts and b) in use on a trial plot

2.3.4 Surface Hardness

Theory

There are two surface properties that can effect player/surface and ball/surface contact; they are surface hardness and Surface stiffness. Dixon et al (1999) defines these properties as:

a) Surface hardness is a measure of the yield stress of a material and is related to plastic(or permanent) strain or deformation; and

b) Surface stiffness is a measure of the recoverable deformation under the application of a known load and is primarily related to the Young's Modulus and a dampening, and is a geometric factor related to the volume of the material carrying the load.

The surface of STPs that are used for sports such as field hockey and football are termed 'point elastic'; this is where the surface only deforms at the location of the force application (Dixon et al, 1999; Nigg & Yeadon, 1987)

Details of this method

A Clegg Impact Soil Tester (CIST; Clegg, 1976), using a 0.5 kg missile and a drop height of 55 cm, was used to assess the surface hardness (impact attenuation) of the test surfaces (Canaway, 1985). Impact attenuation, as measured by an accelerometer mounted on the missile, was used to indicate surface hardness and is reported as Gmax, expressed in gravities. The standard FIH test for impact attenuation is the Berlin Artificial Athlete (AAB) which measures the peak impact force and force reduction (Young & Fleming, 2006);. Although the AAB is the accepted method for measuring surface the peak impact, there were financial, time and availability restrictions which prevented the use of this equipment. The CIST (Figure 2.8) was used in this study as test of comparative hardness between the test pitches; research has shown that there is a correlation with the AAB over a range of pitch specifications (Young & Fleming, 2007). The CIST has the added benefit of being highly portable, a usable characteristic when there are restrictions on the time available to test pitches.

Figure 2.8 A Clegg Soil Impact Tester on a sand-filled synthetic sports pitch

The test was performed at three points, 300 mm apart, within the individual test areas and the results expressed as the mean of the replicates.

2.3.5 Horizontal ball roll and deceleration

Theory

The movement of a hockey ball across a synthetic turf surface can be equated to a solid sphere rolling on a deformable horizontal surface. After the ball has attained the angular velocity required to prevent slippage between ball and surface, the ball is in uniform motion. When the turf surface deforms the contact point of the ball becomes a contact area which forms a frictional force acting in the opposite direction to the direction of motion. This frictional force reduces the angular acceleration of the ball and will stop the ball (Hierrezuelo & Carnero, 1995).

Details of this method - Ball roll

A hockey ball was released from a height of 1 m (± 5 mm) down a standard 45^{o} ramp (BS7044: Section 2.1, 1989) and the distance rolled from the end of the slope was measured in metres using a tape measure (Figure 2.9). Any deviation of the ball greater than 3^{o} from plane of the slope was rejected and the test repeated. The ramp was moved after every third ball roll to prevent 'channelling' on the pitch surface. The ball was rolled 10 times in each direction to allow for wind, slope, pile bias and wear (FIH, 1999) and the average distance was used to represent horizontal ball roll of the test location.

During testing it was important to allow for the effect of the wind on test conditions. If the ball was found to deviate from its path due to wind then the testing was halted. Similarly, debris on the surface, e.g. small stones, were removed from the surface to prevent them influencing the ball roll.

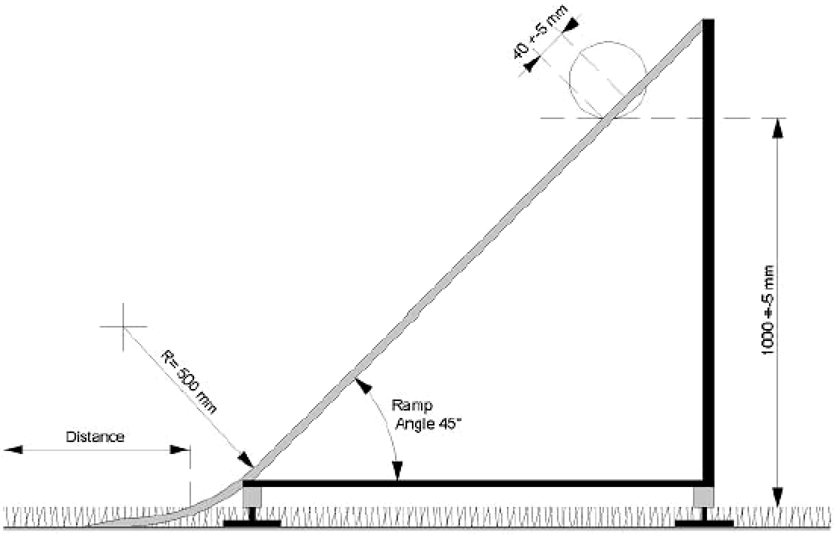


Figure 2.9 Standard design of ramp for measurement of the distance of Ball roll (source: BS7044: Section 2.1, 1989)

Details of this method - Deceleration

In the horizontal ball roll experiment; infra-red timing gates (Figure 2.10) were used to determine the deceleration of the ball over a 1 m distance, starting at the bottom of the slope. The design specification for the timing gates is shown in Appendix D. Note that in a study by Verhelst et al (2007), the ball was observed to decelerate on immediate contact with the surface from the slope due to the retardation effect of ball spin.

When released the ball's inertia becomes relevant to the test. The rolling speed is then calculated from the relationship that potential energy at the top of the ramp and the kinetic energy at the end of the test are equal. With knowledge of the initial velocity it is possible to calculate the reduction in velocity (deceleration) between the two timing gates.

The initial velocity was determined at Gate 1 (between two beams 200 mm apart) and the final velocity at Gate 2, a distance of 1 m from Gate 1, again using timing gates at 200 mm apart. The deceleration was calculated using Equation 2.3, such that *a* is positive for deceleration in this case.

Equation 2.3 determination of the average deceleration over a known distance

$$a = \left(\frac{v_1^{\,2} - v_2^{\,2}}{2s} \right)$$

Where V_1 = velocity at Gate 1 [m s^{-1}]; V_2 = velocity at Gate 2 [m s^{-1}]; s = distance between gates [m]; a = average deceleration [m s^{-2}]

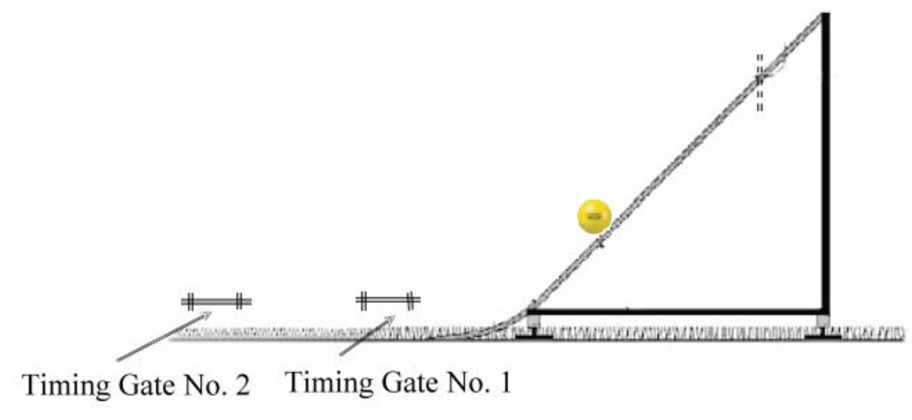


Figure 2.10 Ramp and timing gates to measure ball roll and velocity change

2.3.6 Rotational resistance

Theory

Rotational resistance, sometimes referred to as traction, may be defined as the coefficient of friction between a specified sports shoe sole and the surface. It is expressed as the pulling force required initiating (static) or sustaining (sliding) motion divided by the vertically applied force (Orofino, 1990). As a player's footwear initially contacts the surface there is slip between the two surfaces before traction occurs; this lessens the chance of injury by allowing the footwear to rotate or slide forwards and reducing the strain on the lower limb joints; Van Gheluwe et al (2003) showed that varying the number of studs/dimples and contact area of a sports shoe displayed significant differences in the coefficient of friction of the shoe.

There are other methods available to test the frictional resistance of the playing surface, the Le Roux Pendulum and the sliding distance test foot, this method was selected for its ease of transport and use across the wide range of test surfaces as wells as the financial limitations within the project itself.

Details of this method

The apparatus used was adapted from the studded disc illustrated in BS7044: Section 2.2 (1990). The soles from a pair Mizuno Objectivo Astro football boots, with a dimple depth 8 mm and even dimple distribution (4 mm spacing), were attached to a 150 mm diameter steel disc (Figure 2.11). A normal load of 456 N was applied and the peak rotational resistance against the initiation on motion was measured using a torque wrench. The results were expressed to the nearest Newton metres (Nm).

The test was performed at three points, 500 mm apart, within the individual test areas and the results expressed as the mean of the replicates.

A consideration in the methodology is that, due to the manufacturing process, the fibres of the carpet will not all have the same orientation. The use of a rotational device removes this effect of the multidirectional fibres.

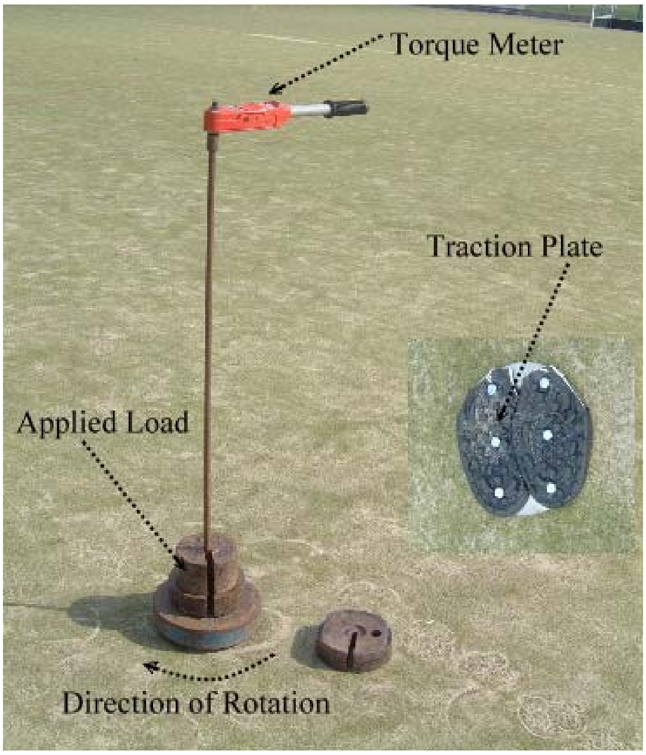


Figure 2.11 An example of the rotational traction plate equipment

2.3.7 Synthetic carpet pile height

Although pile height measurement is not part of the PQS, a reduction in fibre length is likely to be an indicator of pile wear. This is the most basic method of measuring wear of the synthetic turf fibres. The main consideration is where the measurements are 'from and to'. The length of the fibre was measured from the base of the pile to the tip of the fibre. The standard method used to measure height of natural turf is using a rising plate (BS 7370: Part 3, 1991). In this project a smaller version, a tyre tread gauge (Figure 2.12), which penetrated to the carpet backing whilst resting on the carpet surface to give an accurate reading, was used. Either method for measuring pile height will not allow for the curling over of the fibre ends in poorly maintained and older synthetic turf. This measurement will reflects more on the infill depth rather than the pile height.

Figure 2.12 Tyre tread gauge used to measure carpet pile height

Outline method

The measure on the gauge was fully depressed and then pushed through the infill until it came in to contact with the carpet backing. The body of the gauge was then lowered onto the surface of the carpet fibres. The reading taken from the gauge was recorded as the height of the carpet pile in millimetres (+/- 0.5 mm).

2.4 Data analysis used within the project

The data for the different parameters measured during the field and laboratory testing were analysed using GenStat Eighth Edition v8.1 for Windows (software). The separation of the means of treatments was by the least significant difference (LSD) of the means at p = 0.05 (5% significance). The management questionnaire data were analysed using SPSS standard version 13.0 for Windows, statistics software specifically designed for the social sciences. Where questions had not been answered by survey respondents, discrete missing values were inputted and coded to show if the answer was not applicable, not known, or illegible (Miller *et al.* 2002).

For all analyses, descriptive and frequency tests were conducted to summarise the data. Correlation analysis was carried out to examine the relationship between two variables, for example frequency of power brushing and the presence of moss/algae, and Analysis of Variance (ANOVA) was used to determine whether any statistically significant relationships existed among the variables.

The Least Significant Difference test determines if the difference found between two treatments is due to the treatment or if the difference is simply due to random error. It is the standard error of the difference of two means, multiplied by the 't' probability statistic. For each set of data, the least significant difference value is calculated at a chosen level of significance. If the difference between two treatment means is greater than this value, then it is said to be 'significantly different' i.e. not due to random chance.

For dataset, a letter(s) is placed by each treatment mean to show its relationship to every other treatment mean. If two means have identical letters, they are not significantly different. The level of significance used was 0.05 and the LSD is denoted $LSD_{0.05}$ throughout.

2.4.1 *Example of data analysis*

An example of the raw data obtained from the field site survey is shown in Table 2.3. The data was analysed using ANOVA in GenStat Eighth Edition v8.1 for Windows. Table 2.4 shows the statistical output for the analysis of the ball roll data in Table 2.3. There is no significant difference between the three test areas within the pitch ($p>0.05$) and this is shown in Table 2.5 by all group means having the same superscript, indication that they cannot be separated by the LSD (5%).

Table 2.3 An example of raw data from the field site survey

Pitch No.	Location	Age (yrs)	Test Location	Ball Roll (m)
3	R	1	G	9.35
3	R	1	G	9.57
3	R	1	G	9.09
3	R	1	G	9.37
3	R	1	G	9.32
3	R	1	G	9.76
3	R	1	G	10.14
3	R	1	G	9.92
3	R	1	G	10.66
3	R	1	G	10.99
3	R	1	W	9
3	R	1	W	9.69
3	R	1	W	9.21
3	R	1	W	9.61
3	R	1	W	9.25
3	R	1	W	9.13
3	R	1	W	9.38
3	R	1	W	10.14
3	R	1	W	9.51
3	R	1	W	9.51
3	R	1	C	9.88
3	R	1	C	9.43
3	R	1	C	9.42
3	R	1	C	9.66
3	R	1	C	9.92
3	R	1	C	9.69
3	R	1	C	10.18
3	R	1	C	10.04
3	R	1	C	9.74
3	R	1	C	9.31

Table 2.4 Output from ANOVA for the ball roll data shown in Table 2.3. ESE is the estimated standard error, SED is the standard error of the difference of two means, LSD is the least significant difference of two means

Analysis of variance	Variate: Ball Roll (m)				
Source of variation	Degrees of freedom (d.f.)	Sums of squares (s.s.)	Mean sums of squares (m.s.)	Variance ratio (v.r.)	F statistic for the v.r.
Test Location	2	0.7621	0.3811	1.99	0.156
Residual	27	5.1588	0.1911		
Total	29	5.9209			
Means			Test Location		
Grand mean 9.662		Centre	Goal	Wing	
		9.727	9.817	9.443	
	ESE	SED	LSD		
Replicates (reps).	10	10	10		
Degrees of freedom (d.f.)	27	27	27		
Value	0.1382	0.1955	0.4011		

Table 2.5 Variation of mean horizontal ball roll distance as a function of the test area of pitch. Means with identical superscripts cannot be separated by the LSD (5%). Note that where the F statistic for the ANOVA is greater than 0.05, as in this case, where p = 0.156, it is not usual to consider differences in means.

	Test Area		
	Centre	Goal	Wing
Ball Roll (m)	9.727^{a}	9.817^{a}	9.443^{a}

2.5 Quantification of infill contamination

In recent years, many STP managers have introduced pro-active maintenance systems that utilise regular brushing and filtering of the sand infill. To date, there has been no methodology for the quantification of the concentrations of contamination present within the infill/ carpet system. A method was developed to aid in the completion of Objectives 1, 2 and 3.

2.5.1 Theory

A typical particle density for the silica sand particles used as infill materials is 2.65 g cm^{-3} (Deer, 1992); the density of the fibre fragment is dependent on the material used (polypropylene, 0.905 g cm^{-3}; polyethylene, 0.948 g cm^{-3}). The method is based on Stokes' Law (Stokes, 1856) which relates the sedimentation velocity of a particle of a given size through a liquid to its size and density, and the viscosity of the liquid. This means that the sedimentation of particles moving with non-rotational flow through a viscous fluid is representative of the viscous frictional force on any streamlined object moving through a fluid. In the absence of turbulence, viscous friction is always opposite to velocity and proportional to the product of speed, viscosity and linear dimension; the proportionality constant depends on shape and particle size (
Equation **2.4**). In this case the contaminated infill will consist of: sand 2000 - 63 µm, silt 2 µm – 63 µm and clay <2 µm, in various quantities.

Equation 2.4 Explanation of Stokes' Law of particle sedimentation

$$v = \frac{2}{9} g r^2 \frac{(\rho_1 - \rho_2)}{\eta}$$

where: v = velocity, g = acceleration due to gravity, r = effective radius of particle, ρ_1 = liquid density, ρ_2 = particle density, and η = liquid viscosity.
When the infill particles are suspended in solution along with silt, clay and organic material, there is a formation of layers as the particles settle at different velocities.

2.5.2 Details of this method

An infill sample, 50 ml in volume, was suspended in 100 ml of a 1:10 dilution of a solution of Calgon (50 g sodium hexametaphosphate (Fisher Scientific, Loughborough) and 7 g anhydrous sodium carbonate (Fisher Scientific, Loughborough) in 1 litre of distilled water). This mixture was mechanically stirred for 15 minutes at room temperature to deflocculate aggregates within the sample and release soil particles and fibre fragments into solution. The suspension was decanted into a 500 mm long, 22 mm diameter acetate tube that was sealed at one end (Figure 2.14) and distilled water was added to fill the tube to 50 mm from the top. Finally, 2 ml of a non-ionic surfactant, Lauramine oxide (Camlab Ltd, Over), was added to reduce surface tension, before the mixture was then agitated and allowed to settle overnight at a constant temperature of 20°C.

The columns in Figure 2.14 show distinct layers, typical of settling patterns for synthetic turf of this type. The first layer comprises the sand infill material; the second layer organic matter, soil and turf-fibre fragments. The height of each layer was measured and the results expressed as a percentage contamination of the sample on a volume basis.

To quantify whether the separation tubes were an accurate representation of the level of contamination, they were calibrated using a range of 'standard' contaminated infill samples (on a weight basis) using Garside 2EW sand infill and a sandy loam. Full details of the calibration of this technique are shown in McLeod & James (2007) see Appendix A. Figure 2.13 shows the calibration curve for the separation tubes; the results show a significant correlation between the test samples and the measured contamination quantified by the method ($r = 0.954$, $p<0.01$).

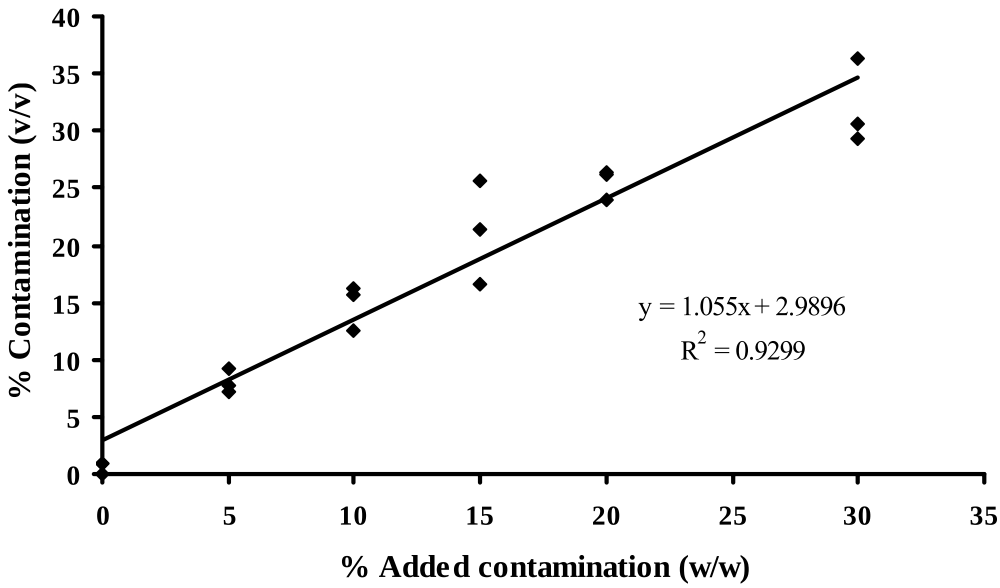


Figure 2.13 Calibration curve for the sedimentation method.

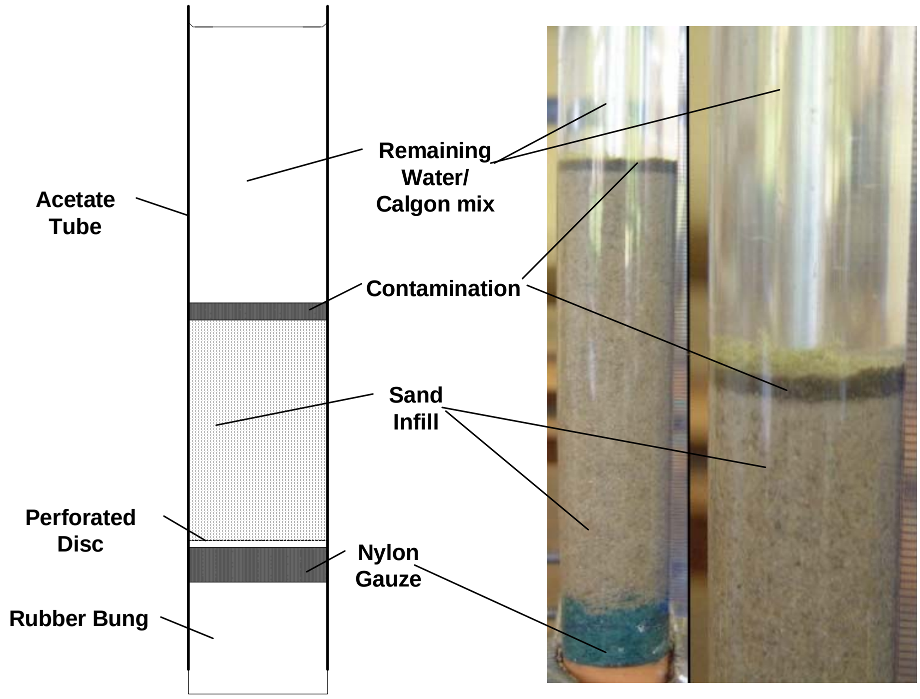


Figure 2.14 Design of the sedimentation tubes used to quantify the level of contamination present within sand infill.

The methodology was used to test the hypothesis that second-generation sand-filled pitches located in rural will be less contaminated than those in urban areas. Replicate samples of infill were removed from the wing, goal area and centre spot of each pitch

2.6 Sample collection of sand infill from test sites

To collect the sand samples to be used in the quantification of the concentration of contamination within the infill required a portable vacuum unit.

2.6.1 Details of this method

A Black & Decker 12V, 25W *Dustbuster* portable vacuum cleaner was adapted to run off a 12 V, 7 Ah rechargeable batteries. The vacuum unit had n airflow rate of 1100 l min^{-1}. Using a template (200 mm x 100 mm) the sand was loosened using a long tined comb; the sand infill was then removed from the carpet pile using the 'Dustbuster' (Figure 2.15).

Figure 2.15 Black & Decker Dustbuster (a) and the template (b) used to remove sand infill samples

It was found that wet infill was difficult to remove due to the cohesion between the sand particles.

2.7 Determination of the infiltration rate of sand-filled synthetic turf

The drainage properties of STPs are governed by criteria set by the relevant governing bodies; for the minimum standard, pitches have to drain at a rate of 50 mm h^{-1} (FIH, 1999). Prior to this study, there was no experimental methodology to quantify the effect that contamination has on the infiltration rate of a synthetic carpet/infill system and thus it was developed in this project.

2.7.1 Theory

The ability for water to move into an unsaturated soil is called infiltration which is quantified as the cumulative amount of water that has passed through a soil surface. Of particular interest is the rate at which the water enters the soil over a particular period of time. This is a key indicator of pitch hydraulic performance and how it will respond to rainfall of a particular intensity. The infiltration rate is affected by the pore size and within a sand-filled synthetic turf system, an increase in the concentration of a contaminant within the infill results in a reduction of surface permeability due to an increase in the proportion of smaller particles which decreases the void ratio (Naeini &

Baziar, 2003) and increases matric potential, reducing gravitational flow and surface infiltration

2.7.2 Details of this method

A method to quantify the effect of contamination on infill infiltration was developed using the falling head permeameter apparatus for the determination of saturated hydraulic conductivity of soils (Figure 2.16).

The turf samples used were:

a) sand-filled - polypropylene fibre pile, 23 mm in length, with a sand infill of 30 kg m^{-2},

b) water based – polypropylene, 14 mm in length, and

c) polyethylene fibre pile, 50 mm in length, with a sand/rubber infill at the rate of 23 kg m^{-2} sand and 6 kg m^{-2} rubber.

The sand was used as a stabiliser for the carpet and was agitated to the base of the carpet pile before the addition of the rubber infill. The contamination was added to the sand element of the infill.

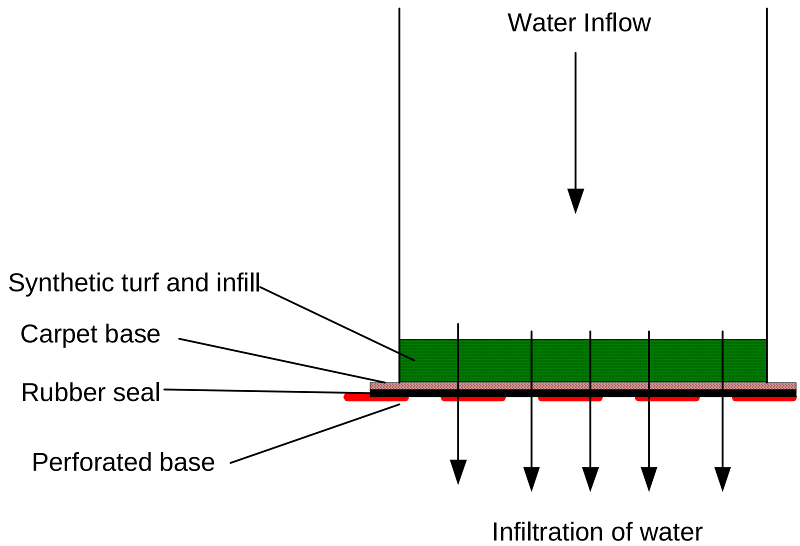


Figure 2.16 Falling Head Permeameter apparatus used to measure the infiltration rate of a carpet/infill sample.

The experimental parameters used were:

1. the presence of absence of a drainage hole in the backing of the carpet sample,
2. different infill specifications (Garside 2EW, No.21 and 16/30)
3. different rates of infill contamination (0, 5, 10, 15 & 20% w/w),
4. compaction of the infill sample, and
5. different carpet specifications (sand-filled, water-based and sand/rubber infill).

The carpet samples were 100 mm diameter circles; the fibres at the edges of the sample were removed to allow the cylinder to seal on the carpet base. The edges of the carpet base were sealed with a rubber ring and silicon grease.

An infill sample was added to the carpet sample, brushed into the pile, and tamped lightly to ensure an even distribution within the carpet pile. The cylinder was filled with water, to a head of 100 mm, and then sealed. After removing any air bubbles, water was passed through the sample to saturate the infill. Results were expressed as an infiltration rate with units of millimetres per hour.

The final test to quantify the effect of contamination on the infiltration rates of the sand infill was to apply different rates of compaction applied using dynamic force. A 3 kg load was released from two different heights and at two different frequencies. The infill material was dry when the dynamic force was applied to prevent variations of the moisture content having a differential effect on the compaction of the infill (Bodman & Constantin, 1965). The application of the dynamic load on the infill was designed to induce particle re-arrangement and a reduction in the pore size and distribution. The infill used was Garside 2EW.

All of the data were analysed using the analysis of variance (ANOVA) and correlation functions of GenStat v8.1

2.8 Quantification of wear of synthetic turf fibres

At present, pre-installation wear testing of synthetic turf carpet is carried out by measuring the tensile properties of individual fibres, the effect of ultra violet light and aging. Furthermore, fibre is subjected to simulated wear by metal blades, abrasive wheels and the reproduced action of football studs (FIFA, 2005; BS EN 15306:2007). These tests do not characterize the wear mechanism of the whole system of polymer carpet fibres and infill materials in the field environment. Other recognized methods of testing, the Charpy Impact Test and the Izod Impact Test quantify the energy required to produce a fracture on a polymer surface; the test specifications prevent the tests being used for the polymer fibres that are used for synthetic turf (Hertzberg, 1983).

The usual method for wear quantification is by mass loss measurements, which is suitable when the worn material components are detached from the main sample. Due to the low mass of the worn turf fibre components there is a loss of resolution when weighing, even on a high precision balance, which makes this method less effective for use with synthetic sports turf. In addition, this method provides no information on the distribution of wear over the component and will not show the level of wear in areas of fibre structural failure (Gahlin & Jacobsen, 1998)

2.8.1 Theory

The most common form of wear within the synthetic turf system is through abrasion, which is defined as the displacement of material from surfaces in relative motion caused by the presence of hard protuberances, or by the presence of hard particles either between the surfaces or embedded in them (Lancaster, 1969). Local shear forces caused by surface friction can lead to the surface peeling and fibre fracture (Figure 2.18).

Inherent in synthetic fibres there are randomly located microstructures, such as voids, that under applied load can start to crack and cause an interaction between defects and cause failure.

Figure 2.17 Ductile failure of a polypropylene synthetic turf fibre

During the production of synthetic turf fibre, melted polypropylene or polyethylene is pumped through a slit or tubular die to form a polyolefin ribbon. This process leaves linear features on the virgin fibres which, under wear, degrade and become less prominent. The degradation process enables the quantification of wear of the synthetic turf fibres.

2.8.2 Details of this method

Sample fibres are removed from the test pitch; sputter coated with a gold/palladium (80/20) mix and then imaged using an FEI XL30 SFEG scanning electron microscope (SEM; FEI Europe, Eindhoven). The SEM method was designed to ensure consistent resolution, magnification (x200) and luminous flux density among the replicates of each treatment. The output images were on a 256-point grey scale, 712 x 484 pixels in tagged image file format (Figure 2.18).

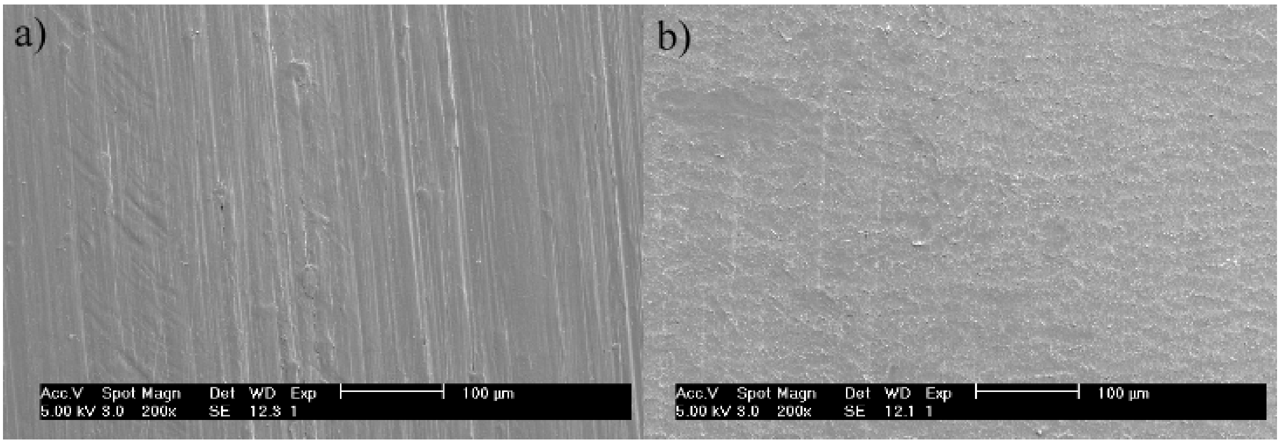


Figure 2.18 The effect of sand abrasion on a polypropylene synthetic turf fibre. a) = Day 0 and b) = Day 28.

The resultant images were analysed for the quantification of ‘linearity’ using Leica Erdas Imagine v8.7 image analysis software. The analysis algorithm measures horizontal and vertical continuity in each image. The resultant of each component was determined as an angle, and a frequency distribution of pixels within 2º classes, between 0 and 90º determined. Images with a high linearity were characterized by a distinct peak at an angle between 2º and 4º. Images with less linearity were characterized by a more uniform distribution of pixels between 0 and 90º To quantify this characterization, the ratio of the maximum frequency to the total number of pixels within the distribution was determined, referred to as the peak ratio (PR). It was hypothesized that PR would decrease with increasing wear period. A full validation of the quantification method is described in McLeod et al. (2006) see Appendix A.

2.8.3 Validation of this method

To quantify the effect of wear on synthetic turf fibres, a new method was designed to analyse fibre samples for the loss of linearity of the extrusion lines within the fibre structure using scanning electron microscope imaging and analysis using Erdas Imagine v8.7. The linearity of the images of the fibre was expressed as the Peak Ratio (PR), a measure of the number of pixels that are located in linear features within each image. The method was used to test the hypothesis that the Peak Ratio of a fibre would decrease with increasing abrasion by infill particles over time.

The images taken from polypropylene and polyethylene synthetic turf fibres that had been abraded with two different sand specifications, Garside 2EW and sharp sand, over a controlled period of time are shown in Figure 2.19. At day 0 there was visible linearity to the surface structure of the fibre. By day 7 there is a significant loss of linearity and the fibre surface was seen to be pitted and by day 21 there are no visible linear features within the image. The loss of surface structure was due to the tangential force, a result of indentation and friction during agitation, exerted onto the fibre surface and these forces resulted in ductile erosion at the points of contact with the sand particles.

For all of the treatments, PR reduced significantly after 7 days of wear, compared to the control ($p<0.001$, Table 2.6). The 2EW sand behaved as hypothesised with a significant decrease in PR until 21 days (Figure 2.20). Infill No 21 did not follow a consistent pattern, with an anomalously low PR value at day 7 and no significant difference between days 14 – 28. The sharp sand followed a similar pattern to the 2EW except for an outlier at 21 days.

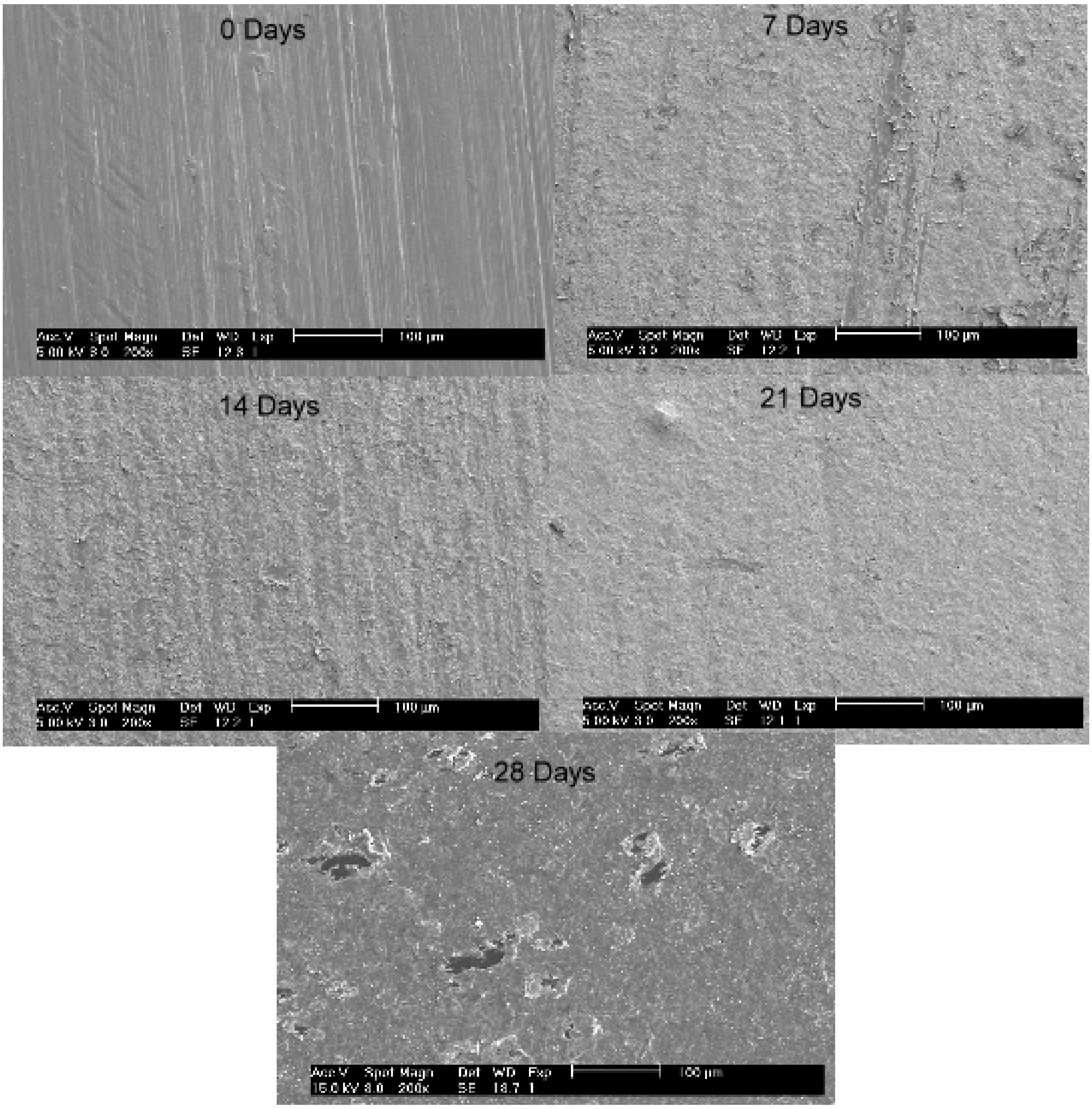


Figure 2.19 A time series of the surface of polypropylene synthetic turf fibres when abraded with sharp sand over a 28 day period

Table 2.6 Mean peak patio for the accelerated wear experiment. Means with identical superscripts cannot be separated by the LSD of 0.1 at p=0.05

		Mean peak ratio			
		Wear period, days			
Treatment		*7*	*14*	*21*	*28*
Control	8.76[e]				
2EW		3.28[a]	3.00[b]	2.89[c,d]	2.82[d]
No 21		2.87[d]	2.98[b,c]	2.93[b,c]	2.93[b,c]
Sharp		3.19[a]	2.98[b,c]	3.25[a]	2.88[c,d]

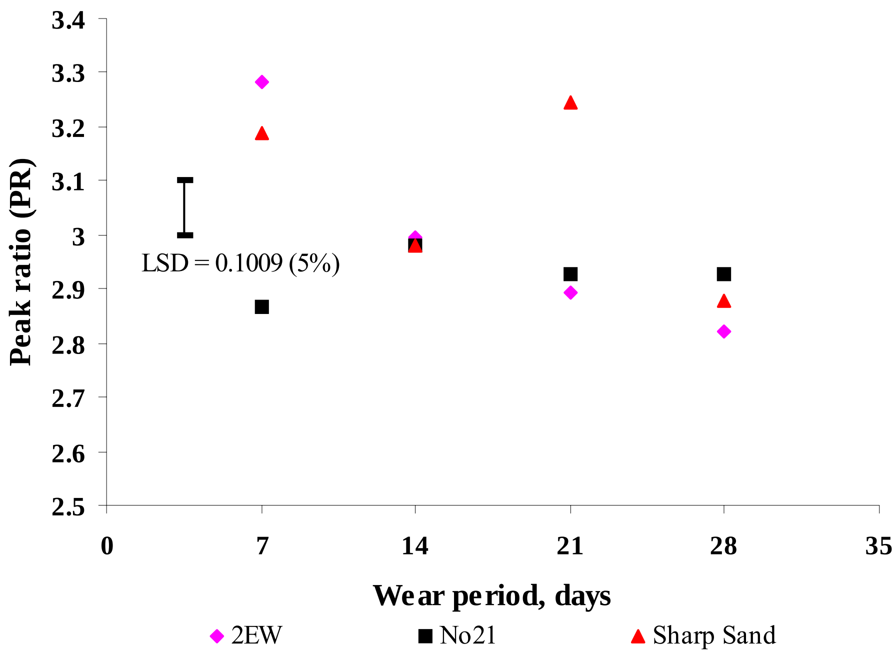


Figure 2.20 The mean peak ratio for each sand treatment over the wear period. Error bars represent the LSD (5%) of 0.1009.

To confirm the results from the original accelerated wear experiment, it was repeated using fibres extracted from new samples, polypropylene and polyethylene, of tufted synthetic turf. The fibre samples were agitated with sharp sand or 2EW up to a period of 28 days. Once again it was demonstrated that, as hypothesized, the PR value is reduced with an increase in wear (Figure 2.21). There was a significant reduction in wear after day 7 and there was a continued downward trend up to 28 days, although not at significant levels.

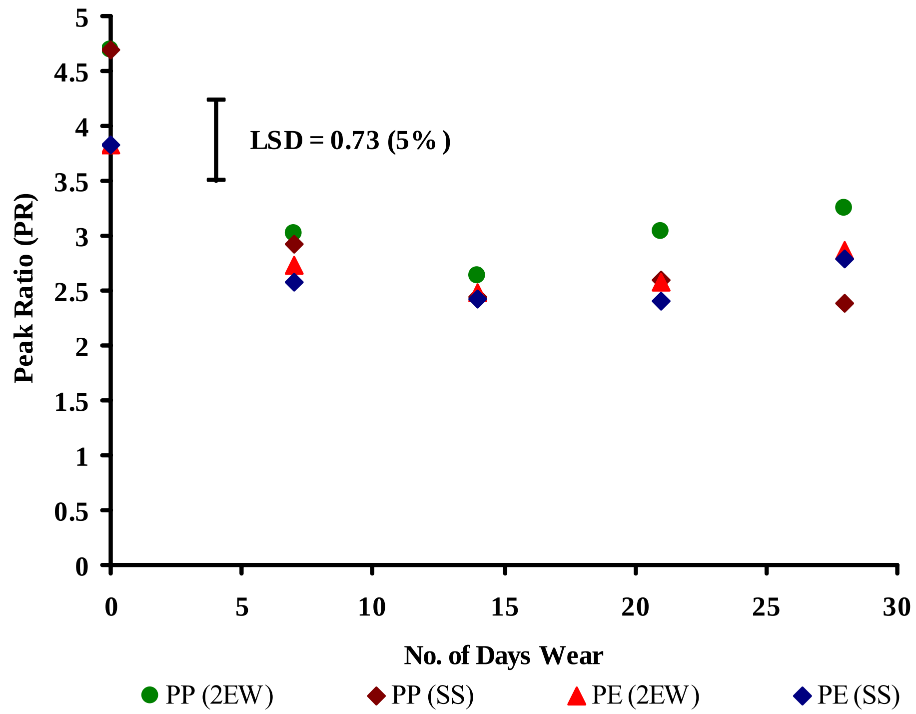


Figure 2.21 Repeat of the accelerated wear experiment with two different fibre and infill types.

In this method the effect of abrasion on the peak ratio index of ‘linearity’ was immediate and it measured the abrasion of the linear extrusion features on the fibre surface. It did not reflect the severe ‘pitting’ of the surface, which was not linear and more irregular.

This method was performed to quantify the effect of wear on synthetic turf fibres. Although the initial experimentation investigated the effect of the sand infill on fibre wear, this method can be used to quantify the effect that processes, such as maintenance and player surface interaction, have on the carpet fibre structure. The method was used to quantify the effect that individual maintenance equipment has on fibre structure. Carpet samples were exposed to wear using a test rig that was designed to reproduce the action of existing power brushing equipment (see Chapter 5).

2.8.4 Summary of the quantification of wear of synthetic turf

The quantification of synthetic turf fibre wear was based on a method that analysed fibre samples for the loss of linearity of the extrusion lines within its structure. The results were expressed as a Peak Ratio (PR) which was a measure of the linearity of the fibre structure. The method was used to test the hypothesis that the Peak Ratio of a fibre would decrease with increasing abrasion by infill particles over time.

There was a significant reduction in the fibre linearity after 7 days abrasion by the sand infill ($p<0.015$) and by Day 21 all linearity had been lost. Images from a scanning electron microscope showed that, by day 28, the surface of the fibre was beginning to degrade and fibre mass had been lost.

2.9 Performance testing on homogeneous sand-filled synthetic turf construction profiles

The results obtained from the field testing showed spatial variability within individual pitches and across pitches of a similar age and location. This does not allow pitches to be compared to quantify the effect of individual parameter changes such as the number of hours of usage, age and number of hours of maintenance. To address this problem, three replicate test samples comprising of three steel trays containing the generic profile of a second generation sand-filled synthetic turf pitch were constructed (Figure 2.22). Full design specifications are shown in Appendix E.

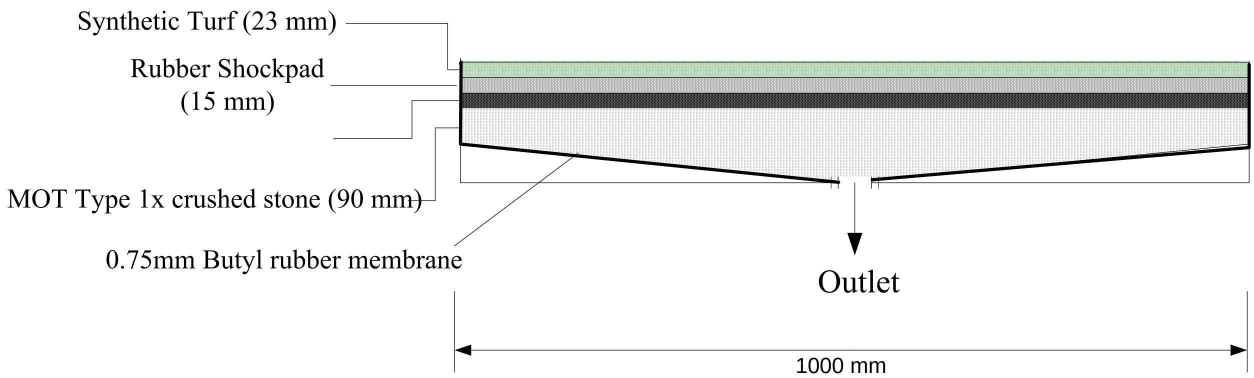


Figure 2.22 Construction profiles of the sand-filled synthetic turf test trays

2.9.1 Details of the method

Each tray was tested using the performance testing used in the field survey (Section 2.3). The use of the trays allowed for control of individual turf conditions. e.g. depth of infill, level of contamination, moisture content and fibre orientation. The test surfaces were also used to test the effect that the concentration of contamination within infill has on the infiltration rate of the surface. In the case of ball deceleration a length of synthetic turf (identical to the test surfaces) was laid on to a level workshop floor and tested as per the methodology.

2.9.2 Determination of the infiltration rate of the sand-filled synthetic turf test surfaces

The standard test for infiltration on STPs is the use of a double ring infiltrometer as described in BS EN 12616:2003 (Figure 2.23). This method is designed for on-site measurement of infiltration rates and measures the combined permeability of the infill, carpet and the base layers. It is used for testing all types of synthetic surfaces having an infiltration rate greater than 50 mm h^{-1}.

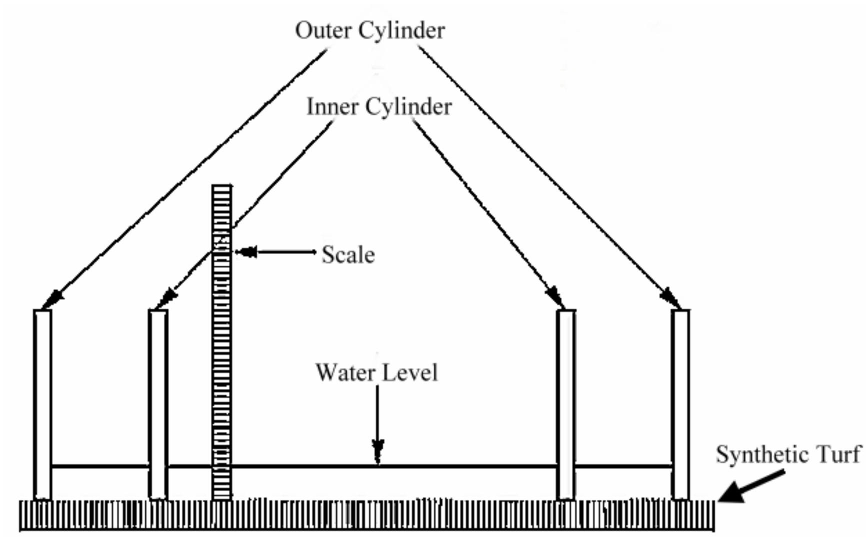


Figure 2.23 The double ring infiltrometer as specified in BS EN 12616:2003

Details of this method

Before the rings were placed onto the surface, the area to be tested was saturated with water and allowed to drain for 20 minutes. The concentric rings were pushed into the surface of the synthetic turf and weighed down with a 20 kg weight to help form a seal.

The inner and outer rings were filled to a known depth of water. Over a set period of time, the depth of water lost was measured. The results were expressed as an infiltration rate with units of mm h^{-1}.

This method was also used to measure the effect of compaction on the infiltration rate of the surface. After the 20 minute saturation period, a 20 kg weight was dropped 20 times from a height of 300 mm. The rings were then placed onto the surface and the method is as above.

2.9.3 Outcomes for the thesis

The aim of Objective No. 5 was:

To devise a technique for the quantification of wear in synthetic turf fibres.

This has been successfully addressed by the use of the quantification of surface linearity within the synthetic turf fibre. This method has shown the degradation that occurs when the fibres are exposed to sand abrasion and was used to test the effect that maintenance equipment has on fibres in Chapter 5. Although this method has been used successfully in the laboratory, the limitation of the technique is the requirement of 'virgin' fibre for comparative use.

This method of wear was also used to address Objective No. 2 which aimed;

To identify, characterise and quantify the mechanisms causing the wear of synthetic turf surfaces and infill materials through play and maintenance.

The imaging method (Peak Ratio) has also addressed Objective No. 2 by determining the main mode of wear of synthetic turf, the sand infill. All movement on a sand-filled synthetic turf pitch causes an interaction between the sand infill and the fibre samples exerting a low frequency abrasion of the fibre surface.

3 Chapter Three: Results of the field survey and the associated questionnaire

The methodology, treatments and sampling procedures for the different sections are detailed in Chapter 2. The data for the different parameters measured during the field testing were analysed using GenStat Eighth Edition v8.1 for Windows (software). The separation of the means of treatments was by LSD of the means at p = 0.05. The management questionnaire data was analysed using SPSS standard version 13.0 for Windows, statistics software specifically designed for the social sciences.

3.1 Management questionnaire

The use of the questionnaire allowed an in-depth examination of the management and maintenance of the targeted sample which represented 2-3% of the STP population within the UK. This figure is based on anecdotal evidence from STP maintenance companies; there is no definitive list of the number of sand-filled STPs within the UK. The response rate to the questionnaire was high (59%), in general, response rates average in the region of 10% (Robson, 2002).

The analysis of the respondent questionnaires included an allowance for questions that were not completed and less than 10% of all of the questions were classed as having information that was not known or not available.

The questionnaire contained some subjective data as each individual respondent has their own view on maintaining STPs; this meant that the data was subject to a certain amount of variability. A way to reduce the variability would be to increase the sample size; this would mean a national survey of all STPs, which would not have been possible within the financial and time limitations of the research and is not possible as there is not a definitive, central database of STP facilities.

3.1.1 Questionnaire Section 1: Background information of the surveyed sites.

Age distribution of the target sample of pitches

Of the 44 returned questionnaires, only three of the pitches were over 15 years old (Figure 3.1). The distribution of the pitch ages has a positive skew (0.788) indicated the increase in the popularity of installing STPs over the last 10-15 years

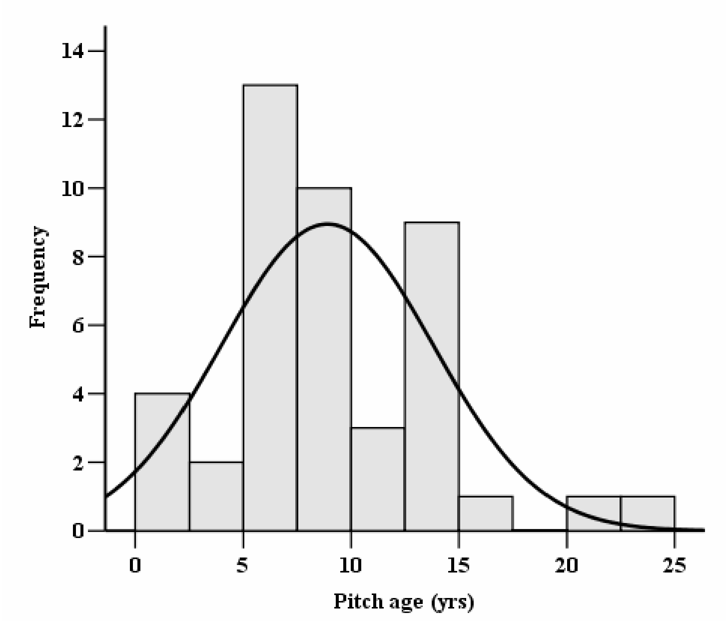


Figure 3.1 Age distribution of the completed and returned questionnaires

Sports played on synthetic turf pitches

Figure 3.2 shows the different sports played on the respondents' STPs. The results demonstrate the multi-sport use of STPs with 86% of respondents indicating use of the surface for two or more sports. The predominant sports played on the surveyed STPs are hockey and tennis; this reflects the early recognition by the International Hockey Federation (FIH) and the International Tennis Federation (ITF) for STP use at all levels of their respective sport. The questionnaire results show that 50% of all of the surfaces were used for football, but the main specification for this sport is the 3G long pile, sand/rubber infill pitches. The questionnaire results do not reflect any increase in the installation and use of the 3G specification and whether football will become the more prevalent sport played on STPs. This due to the fact that the basis of this research project is primarily sand-filled second generation pitches.

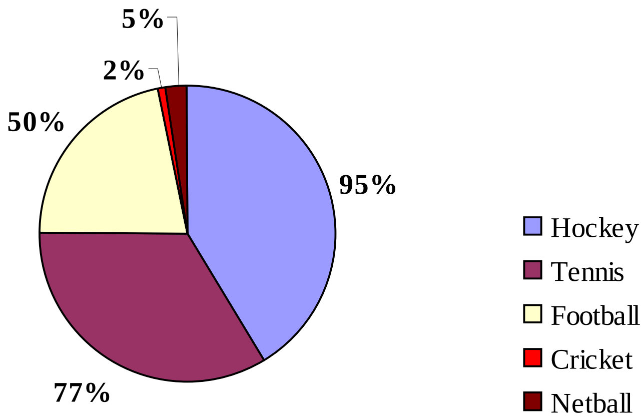


Figure 3.2 The percentage of sports played on 2G synthetic turf pitches within the test sample. (The numbers refer to the percentage of pitches on which the sport is played)

Cost of the construction of sand-filled synthetic turf pitches

There is a wide distribution of costs for the construction of sand-filled STPs (Figure 3.3). There is no significant correlation between the age of the pitch and the construction costs (r = 0.561). The median cost band is £350-400k but there are pitches that have cost over £550k. All of the STPs within the questionnaire were a single pitch construction and the wide variation in costs and age represented not only the increasing cost of materials, but the different design specifications that exist between STPs.

Figure 3.4 shows the full costs of the sample STP test sites with their costs adjusted to 2006 levels. This was carried out using the historical retail price index (RPI) figures from the National Statistics Office (NSO, 2007). The results show that there has been a general downward trend in the construction costs of STP facilities. This is due to the increased competition between construction contractors and more available grant money. Any increase in the cost of materials will have been absorbed by the contractors to ensure competitive pricing; i.e. the main composite materials of the synthetic turf carpet are polypropylene and polyethylene which are both derived from crude oil. Any fluctuation within this price will affect the fabrication costs of the STP carpet.

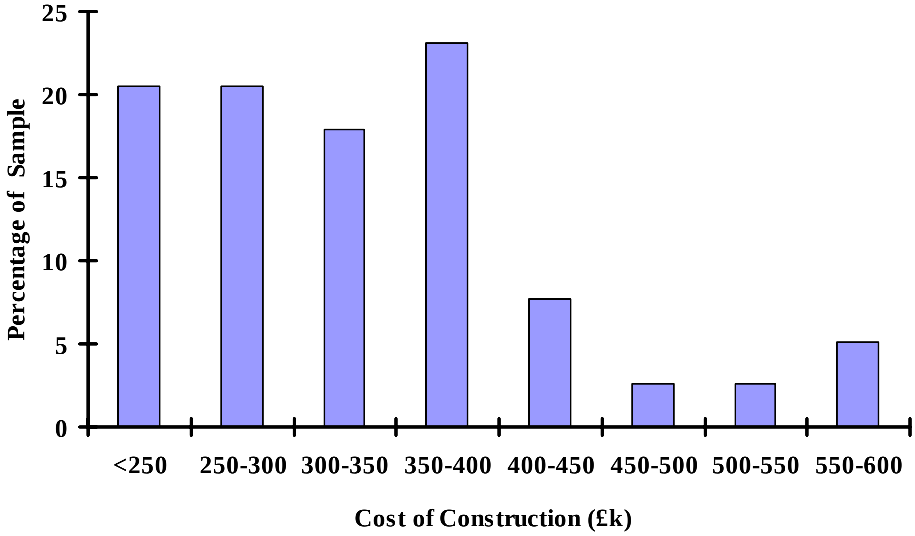


Figure 3.3 Construction costs of the synthetic turf pitches within the survey.

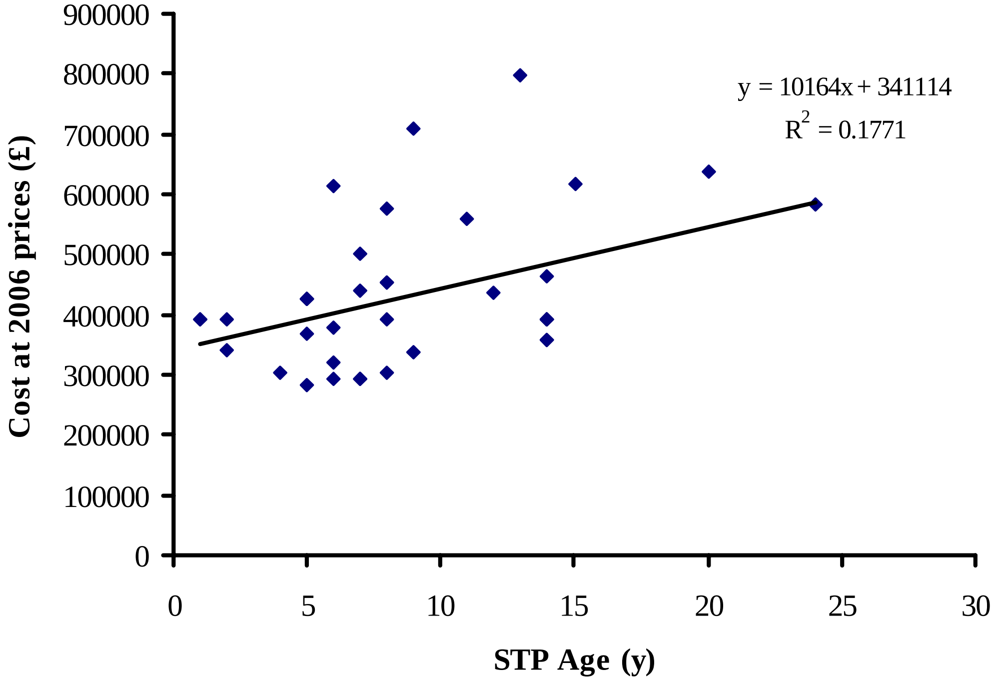


Figure 3.4 Cost of pitches within the test sample that have been index-linked to compare all the costs at 2006 rates.

Reasons for selecting synthetic turf pitches as a sports surface

Respondents were asked what factors influenced their choice of STPs over any other surface specification; Figure 3.5 shows the distribution of the responses.

The factors that were regarded by the Facilities Managers as the highest priorities were: increase standards of play, increased hours of play, the all weather capability and provision of a higher quality and performance of the synthetic turf. The results indicate that these factors outweigh the high initial expenditure and the problems that can arise when applying for planning permission to install a pitch.

Unexpectedly the ‘low maintenance’ of the synthetic turf pitch has little bearing on the selection of an STP. STPs were originally marketed with as ‘low maintenance’ which was regarded as a major selling point. The reason for this low result may actually be due to the fact that the manpower that will be used to maintain the STP is already employed to maintain the existing natural turf pitches.

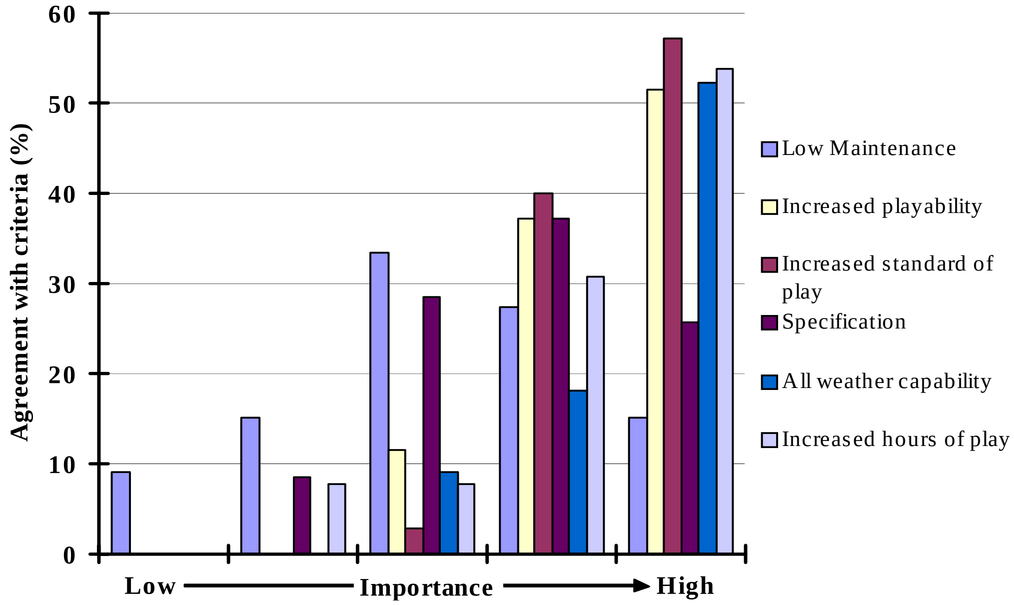


Figure 3.5 Factors important to managers in the selection of synthetic turf pitches

3.1.2 Questionnaire Section 2: Information on the maintenance synthetic turf pitches

Analysed data for the maintenance from the STPs is shown in Table 3.1. Overall, 87% of the respondents had been provided with a maintenance document on final takeover of the STP and 80% said that they had been made aware of the required levels of maintenance. Comments made by the remaining respondents indicated that no, or very little, information had been provided for the maintenance of the STP.

There was little information returned about the budgetary arrangements for individual STPs, 41% of respondents gave information, but relative to the whole questionnaire sample, 36% of respondents indicated that there was an expectation to generate revenue from the facility and 4.5% indicated no revenue expectation. When questioned about the annual expenditure for maintenance of the STP, less than 30% of respondents were willing to give an answer. Of all respondents 22% indicated annual budgets of less than £6000 per annum and for 9% this figure was below £3000 per annum. Statistical analysis determined that there was no statistical difference between the budgets set for the management of STPs in a private or local authority/state school situation (p = 0.119; Figure 3.6). However, the local authorities/state schools do have a higher operating budget and this is explained by their use of specialist contractors. Although independent schools do use contractors, the local authorities/state schools use them for more maintenance operations per annum. i.e. On average, for power brushing independent schools use contractors 4 times per annum and local authorities 9 times per annum. This indicated that the independent schools already have the labour resources to carry out maintenance operations and are regarded as a sunk cost (Figure 3.6).

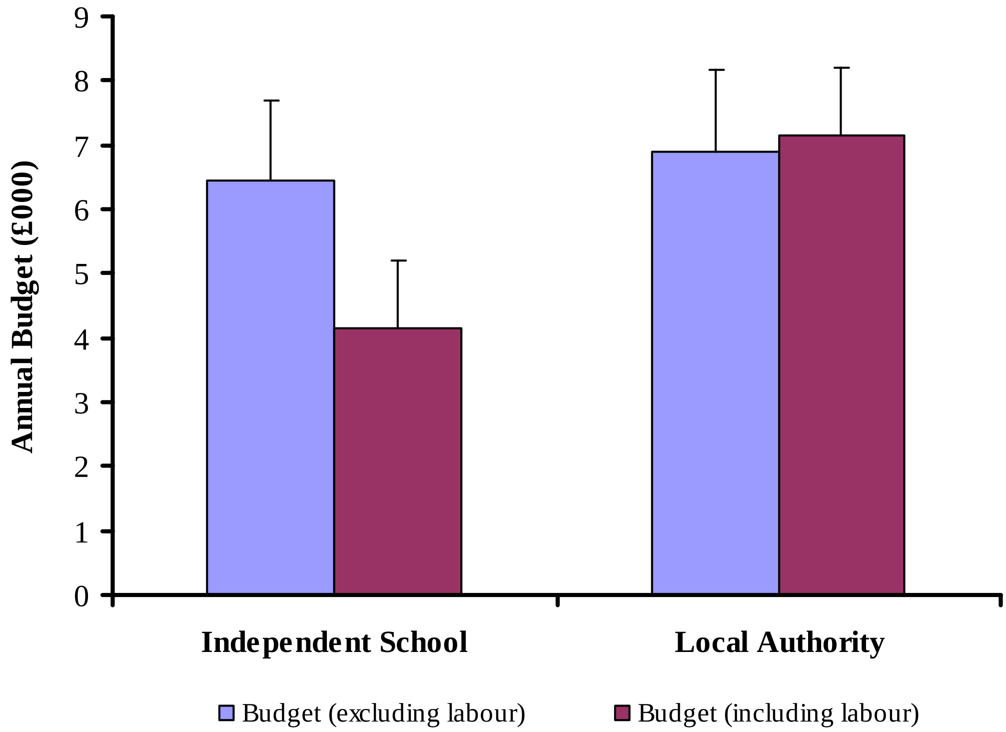


Figure 3.6 Comparison between the annual budgets of Local Authority and independent school based synthetic turf pitches. ANOVA determined that the treatments and interactions were not significant (p > 0.05)

Of those respondents provided with a maintenance document, 77% have adhered to the recommendations. 66% of respondents agreed that they had been made aware of future costs involved with the installation of STPs, such as infill or carpet replacement; this is contrary to anecdotal evidence that indicates that very little information is provided by STP manufacturers.

The most frequent operation performed on an STP is drag brushing (Table 3.2). Drag brushing is used to redress the level of the infill and so the use of this procedure should correlate with the volume of usage. It is an operation that does not require expensive specialist equipment and is easily performed by existing staff, but it was seen that there was a significant decrease in the procedure with increased pitch usage ($r = -0.7597$, $p<0.01$). This suggests that the sample STPs are being maintained to generic maintenance programmes rather than programmes that are responsive to the number of hours that a pitch is used. 48% of respondents used specialist maintenance contractors to power brush the STP surface (Table 3.2); the mean annual charge for this service was £2300 per annum.

Where a facility has purchased a power brush there the frequency of use is almost double that of where contractors are used With this increase in power brushing there is no significant reduction in drag brushing ($r = -0.256$, $p>0.05$); this indicates that drag brushing is either regarded as an important part of maintaining STPs, or that it was the simplest task to perform, or a combination of the two.

The difference between the power brushing data in Table 3.1 and was caused by respondents answering one question of the power brushing section and not completing the sub-questions.

Within the questionnaire, there was no emphasis placed on damage to the STP surface due to age. Over all there was a significant rise in STP damage from the age of 7 years upwards (Figure 3.7). Factors involved in the damage of the STP surface may have been failing seams, vandalism and wear due to carpet age. It was likely that respondents will have classed seam failure as any of the three possible answers. Through discussions with the

STP managers the most common carpet tear was a failed seam that had been further damaged by the STP users.

Table 3.1 Results from Section 2: Maintenance practices

		%		
		Yes	**No**	
No. of operator hours used for annual maintenance				324
Do you drag brush?		88	13	
Do you power brush?		69	31	
Is the power brushing	In-house	63		
(% of positive responses)	Contractor	37		
Has Sand Infill been replaced?		25	75	
How long after construction? (yrs)				7.6
Has the carpet been replaced?		7	93	
How long after construction? (yrs)				9.7
Has there been damage to the carpet?		58	42	
	Wear	54	46	
	Tear	35	65	
	other	20	80	
Have you had the infill levels adjusted?		12	88	
Do you have drainage problems?		22	78	
Does the STP suffer from algae/moss?		49	51	
Do you use chemicals to remove moss?		86	14	

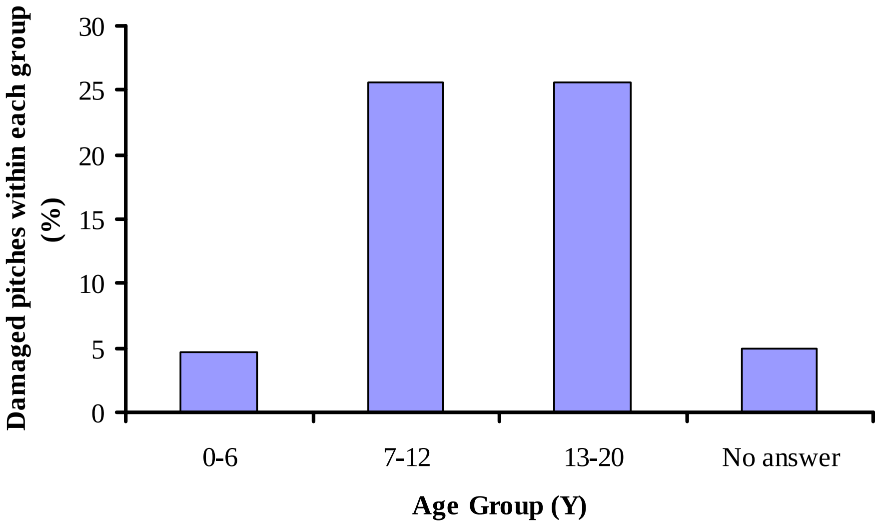


Figure 3.7 Relationship between pitch age and damage as a percentage of the whole pitch sample

Table 3.2 Annual frequency of brushing operating procedures performed on synthetic turf pitches

Operation		n	Range	Mean	Std. Error
Dragbrush		35	0 - 250	84.68	1.301
Power brush	In house	5	1 - 30	10.2	5.276
	Contractor	21	1 - 26	5.52	1.296

Only 7.3% of respondents have pitches that have had the synthetic turf replaced and 25% have had the sand infill replaced. The average time for turf infill replacement was 7.56 years and for turf replacement 9.67 years. There is a significant relationship between the age of the surface and the replacement of the sand infill ($r = 0.830$, $p<0.01$) and indicates that, although the STPs are regularly maintained, there is a build up of contamination, which reduces the porosity of the infill, as the age of the pitch increases. This was supported by the section of the questionnaire that asked about the presence of moss, algae and any drainage problems.

From the survey 22% of the STPs were reported to have drainage problems and 19% both drainage problems along with moss or algal growth. Overall 48% of the sample had incidents of moss or algal growth. This indicated that there are other causes to the incidence of moss/algae as well as poor drainage.

Table 3.3 Correlation between surface conditions and the age of the sample of synthetic turf pitches. Asterisks represent significant correlation ($p < 0.05$)

	Drainage problems	Algae/Moss	Chemical use
Algae/Moss	0.426**		
Chemical use	0.062	0.548**	
Age	0.454**	0.146	0.092

** Correlation is significant at the 0.01 level (2-tailed).

Table 3.3 indicates that there is a significant relationship between age and drainage problems and the presence of moss and the use of mossicide/algaecides. The data indicates that the use of chemicals is a reaction to the infestation of a pitch by moss/algae and not part of a proactive maintenance programme. This is a financially and an environmentally prudent use of chemicals.

Table 3.4 Correlation between surface conditions and brushing procedures used synthetic turf pitches.

	Drainage problems	algae/moss	Chemical use
Dragbrush	-0.158	-0.076	-0.125
Power brush	-0.030	-0.017	0.029

**Correlation is significant at the 0.01 level (2-tailed).

Table 3.4 indicates that there is no correlation between the brushing processes used on the STPs ($p>0.05$) and drainage or moss problems. The results do not reflect whether there are any other problems with the drainage system such as blocked silt traps or the need to rod the drainage pipes. As the main design characteristic to remove surface water from an STP is an overall slope of no more than a 1% incline, any uneven surface levels may cause ponding of surface water.

3.1.3 On site discussions with synthetic turf pitch managers

During the process of the field survey, the author had a number of discussions with the STP managers about the maintenance practices that they used and why they used them. On the whole, the majority of managers had been made aware of the maintenance requirements of their STP, but not all used the suggested programme. They were seen to be generic and uninformative. Instead they were using processes gained from a transferral of knowledge from colleagues and specialist maintenance companies. Apart from basic maintenance, the use of specialist contractors was found to be common and was seen as a cost effective method of providing the more complex maintenance procedures.

3.1.4 Questionnaire Section 3: Synthetic turf pitch usage

The wide range of STP usage within the survey is shown in Table 3.5. There is a weak correlation between the number hours of pitch use and location of the STP - Local Authority Sports Centre or Independent School ($r = 0.306$, $p = 0.05$).

Table 3.5 Annual pitch use and hourly charge for a synthetic turf pitch

	Range	Mean	S.E.
No. hours annual pitch use	450 - 4200	2061	4.75
Charge for pitch use (£)	20 - 70	41.36	0.70

There is a significant correlation between high levels of pitch use and increased levels of external lettings ($r = 0.716$, $p<0.01$) indicating the requirement for some pitches to provide a revenue stream to pay for the running of the facility and possibly to recover all costs including construction. This is not reflected in the cost of hiring individual STPs; there is no correlation between the number of hours the pitch is in use and the cost of hiring the pitch ($r = 0.28$, $p>0.05$). The variation in pitch charges indicates that STP managers either set an arbitrary level to the charges to cover the running costs or in response to local competition, which forces an STP manager to reduce hire charges. It may also be the result of a variation in the percentage of the total costs that are required to be recovered using the revenue stream achieved from the STP.

Table 3.6 Pitch usage for synthetic turf pitches within the different field survey areas

Location	Range	Mean	S.E.
Rural	22 - 60	49.88	1.38
Urban	38 - 80	37.29	1.38

Pitches located in rural locations are likely to be owned by independent schools where usage is lower. The management questionnaire documented that pitches located in urban locations were used on average 50 hours per week compared to 37 hours per week for rural pitches (Table 3.6).

3.1.5 Questionnaire Section 4: Furniture used on synthetic turf pitches

The numbers of the individual types of pitch furniture used within the test population reflects the different sports played on the sample surfaces (Table 3.7). The range of the STP managers' perceived life expectancy of each of the different types of pitch furniture was very broad and may indicate that some of the values are a "guestimate" on the part of the STP manager and a true idea of life expectancy is not known or that the pitch furniture is more poorly treated on some sites compared to others. From the experience gained by the author from managing STPs, the mean values obtained from the questionnaire are determined to be a reasonable estimate of the life expectancy of the pitch furniture.

Table 3.7 The pitch furniture used on the sample synthetic turf pitches and its perceived life expectancy.

	No. of post sets			Expected replacement year		
	Range	Mean	S.E.	Range	Mean	S.E.
Standard football	1 - 2	1	0.161	3 - 25	10	0.911
5-a-side football	1 - 3	2	0.150	2 - 20	8	0.486
Hockey	1 - 6	3	0.206	2 - 15	8	0.335
Tennis	3 - 12	10	0.347	4 - 23	10	0.429

3.1.6 Summary of the results

Overall, the questionnaire survey successfully provided a comprehensive review of the management and maintenance of STPs within the sample population. The data obtained from the questionnaire was integral in the construction of a financial model for the management and maintenance of STPs (Chapter 6).

There was a variation in the frequency of individual maintenance operations, but there was no correlation between individual procedures and the presence of moss/algae or drainage problems with the surface; this reflected the variation in the frequency and type of maintenance process used, and the volume of usage of the individual STP.

There was a significant relationship between the age of a surface and the presence of drainage problems ($p<0.01$), indicating that maintenance procedures do not remove all contamination from a surface and that there is a cumulative build up over time. Therefore, removal of contamination is not a completely optimised process, because a proportion of the contamination remains within the infill. There is an opportunity to optimise maintenance programmes because there is no relationship between the maintenance, its duration and drainage.

The results from the questionnaire do show that there is variation in the procedures that managers use in their programmes for maintaining STPs. There was no significant correlation between the number of hours that a pitch is in use and the frequency of each of the brushing procedures (drag brush: $p>0.05$; power brush: $p >0.05$). This does not support the hypothesis that an increasing volume of play on an STP will cause movement of the sand infill and surface levels will be affected and that this will require management intervention to increase the frequency of maintenance.

The reason for no increase in the frequency of the maintenance procedures may be due to the fact that the playability of the STP has not been affected or perceived to have been affected by an increase in usage. If there is no feedback on the performance of the STP from the users then it is not possible to optimise the maintenance programme and surface playability. Discussions with the pitch managers revealed the lack of maintenance programmes designed for individual pitches. There are generic programmes provided by governing bodies (i.e. FIH, FA or FIFA) and the general opinion of managers was that they provided insufficient information on the reasons behind the need to maintain a STP. These discussions also revealed that the performance characteristics of the STPs were rarely measured; there was a reliance on user feedback rather than a proactive system to regularly check the surface against the correct performance quality standards.

There was a low response to information requested on the allocated finance for maintenance available to individual STP managers; this was because that this information was classed as either sensitive, or was unknown. It is possible that existing labour and equipment is used to maintain the STPs and that there has been no budget allocation for future capital and non-capital expenditure. If the full capital cost of the STP has been grant funded, and there is only an expectation to cover annual costs, there is the possibility that any change in pitch performance may be tolerated as long as revenue is not being reduced.

Poorly funded or maintained STPs may be the result of insufficient resources available to the managers. Less than 9% of respondents indicated an operating budget under £3000 per annum could be too low to maintain a surface satisfactorily.

The results have not quantified the effect that maintenance has on a STP; for example, without a survey of playability related to expenditure, this cannot be confirmed. Therefore, an investigation of the performance and optimisation parameters for the contamination removal process is required.

3.2 Field survey

The questionnaire survey has indicated the different maintenance programmes that are used on the different STPs within the survey. It did not show the effect that the programmes have on the playability of the STPs and whether there was any deterioration of the surface through age and wear. From this, the field survey was used to address Objective No. 1 and test the hypothesis that the performance characteristics of a synthetic turf pitch are significantly affected by age and wear. There were 18 test pitches within the survey grouped into replicates of age and location.

3.2.1 Ball roll

The ball roll properties of a pitch indicate the overall speed and consistency of speed between pitches and between locations within pitches. Although ball roll speed was significantly affected by pitch age, location and test areas within a pitch ($p < 0.001$;Figure 3.8), a consistent reduction or increase in ball roll with age was not apparent. There was spatial variation across all of the test sites. This is possibly due to a difference in pitch construction methods, pitch specification, carpet wear and variation in the maintenance programmes. Other factors, such as infill moisture content, may have an effect on the results. It was noticed during testing that damp infill would adhere to the hockey ball and, if not regularly cleaned, would affect the ball roll characteristics.

With the exception of the wing area in the urban group, a statistically insignificant trend is apparent showing a slight increase in the distance of horizontal ball roll; increasing during the 7-12 years post installation and then a reducing during 13-20 years. This trend may have been due to the noisy background of the data or to possible changes in the materials used for the fabrication of the synthetic carpets.

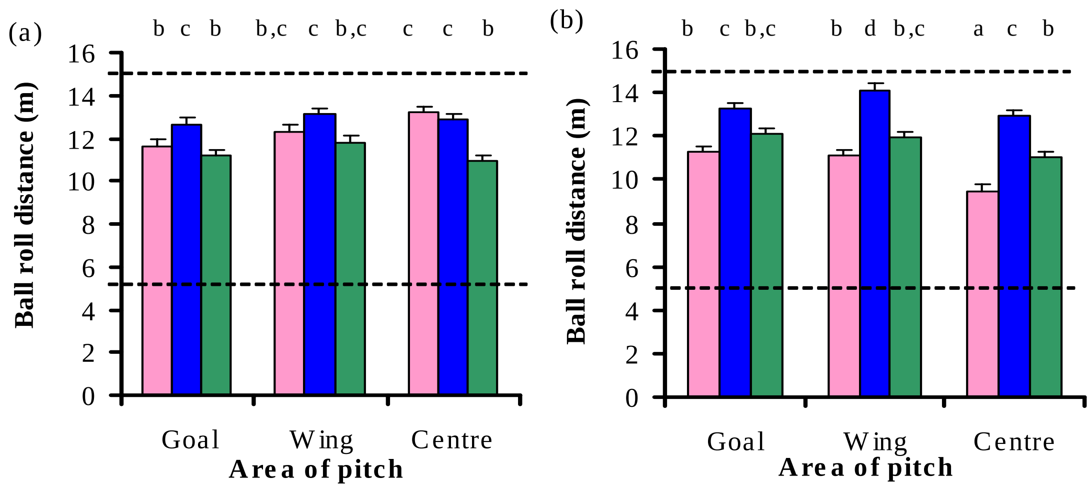


Figure 3.8 Variation of mean horizontal ball roll distance as a function of area of pitch and age group ☐ 0-6 years; ☐ 7-12 years; ☐ 13-20, for (a) urban and (b) rural facilities. Dashed lines represent the limits for the FIH 'Standard' performance level. Whiskers represent the standard error of the mean (0.29 m). Means with identical superscripts cannot be separated by the LSD (5%).

3.2.2 Surface hardness

There was significant variation in mean surface hardness (Gmax) due to the pitch age groups ($p < 0.05$) and pitch location ($p < 0.01$; Figure 3.9). Although there was a significant difference between the 7-12 year age group and the other two groups, there was no increase in pitch hardness between pitches at year zero and those at year 20. The hardness of the 7-12 year age group may be the result of technological advancement, in in-fill materials, building specification and materials or the spatial variation between pitches. There was no significant correlation between surface hardness and ball rebound height ($r = 0.383$, $p < 0.001$).

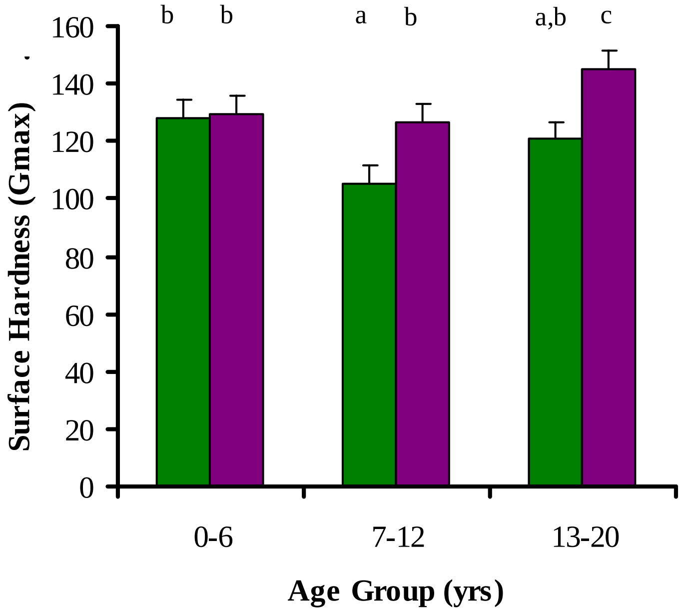


Figure 3.9 Variation of mean deceleration (Gmax) of a 0.5 kg Clegg Hammer dropped from a height of 0.55 m as a function of pitch location and age group ■ Rural; ■ Urban. Whiskers represent the standard error of the mean (6.29 G). Means with identical superscripts cannot be separated by the LSD (5%).

3.2.3 Vertical ball rebound

Ball rebound tests indicated that there was a significant variation in ball rebound height due to pitch age and pitch location ($p < 0.001$; Figure 3.10). The ball rebound height increased with pitch age on urban pitches but decreased with age on rural pitches. This effect may be due to higher levels of use of pitches located in an urban area; the majority of which are operated by local authorities who maximise the pitch usage and have restricted maintenance budgets.

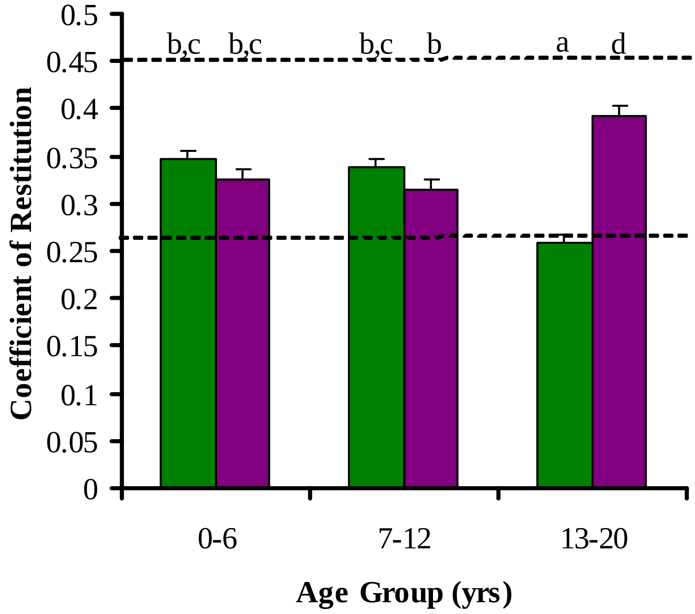


Figure 3.10 Variation of mean ball rebound (expressed as the Coefficient of Restitution) as a function of pitch location and age group ■ rural; ■ urban. Dashed lines represent the limits for the FIH 'Standard' performance level. Whiskers represent the standard error of the mean (0.01004). Means **with identical superscripts cannot be separated by the LSD (5%).**

3.2.4 Rotational resistance

Rotational resistance was significantly lower at the rural sites than the urban sites in the 0-6 year age group ($p < 0.001$; Figure 3.11). The overall mean value for rotational resistance for all of the test pitches (28 Nm) was similar to the original recommendations (30 Nm) for association football on synthetic surfaces (Winterbottom, 1985). Observations in the field illustrated the significant effect that surface repairs may have on rotational resistance. In some areas of repair, the rotational resistance was increased up to 30% of the surrounding areas; in the goal area of one test surface (Rural, 13-20 years) the peak rotational resistance was 34 Nm on a repaired section, a 2 m^2 section in the centre of the goal area, compared with a mean of 26 Nm for the rest of the measurements of the pitch. A player may not be able to adjust to an 8 Nm increase in rotational resistance over a short distance and this may cause lower leg joint injuries as the shoe becomes ‘locked’ into the turf (Morehouse, 1992).

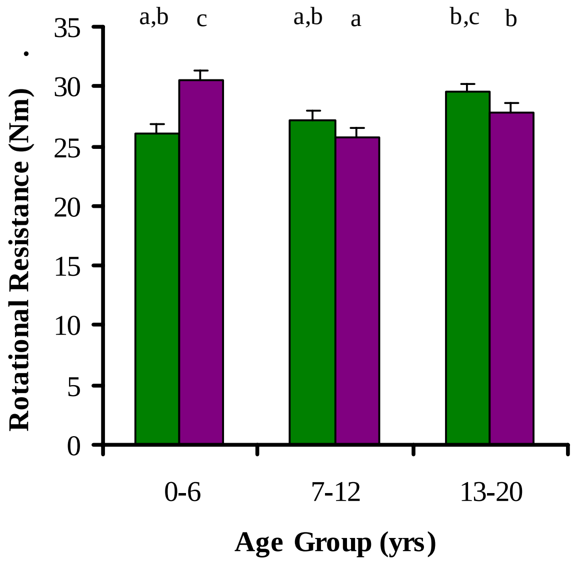


Figure 3.11 Variation of rotational resistance as a function of pitch location and age group ■ Rural; ■ Urban. Whiskers represent the standard error of the mean (0.729 Nm). Means with identical superscripts cannot be separated by the LSD (5%).Ball deceleration

3.2.5 Ball deceleration

Within the study there were areas within individual pitches that exhibited a significant increase/reduction in ball deceleration (Figure 3.12). Although not always statistically significant, all age and location groups, with the exception of the rural 7-12 year age group showed increasing deceleration in line with the perceived reduced wear areas of the pitch. The 7-12 year age group in rural locations indicated a reduction in the deceleration which did not correlate with the areas of perceived increased wear. This may be the result of the pitches being used for 7-a-side football and therefore the wing areas will be the location of the goalmouths. This is likely to have increased the wear in areas of perceived low wear. Other factors that would affect the surface performance are different meteorological or maintenance conditions. These results highlight the spatial variation not only between test sites within the same age groups but also within individual pitches themselves.

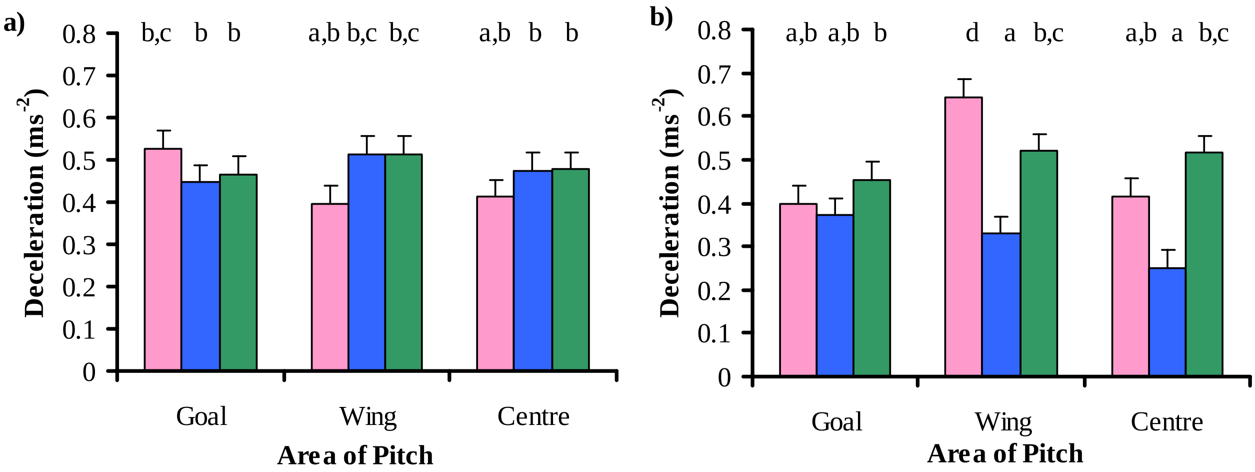


Figure 3.12 Variation of mean ball deceleration as a function of area of pitch and age group 0-6 years; 7-12 years; 13-20, for (a) urban and (b) rural facilities. Whiskers represent the standard error of the mean (0.041 ms^{-2}). Means with identical superscripts cannot be separated by the LSD (5%).

3.2.6 Quantification of the concentration of contamination of sand infill samples collected during the field survey

As part of the field survey, samples of infill were removed from the goal, centre and wing areas of individual test pitches. This process was only possible when the sand infill was dry and this allowed 61% of the test pitches to be sampled.

Table 3.8 Summary of the concentrations of contamination removed during the field survey.

		Range	Mean	S.E.
Rural	Age (y)	1 - 14	8.80	0.787
	Contamination (% v/v)	1.9 - 9.1	5.11	0.446
Urban	Age (y)	3 - 13	9.00	1.056
	Contamination (% v/v)	2.4 - 7.2	5.00	0.486

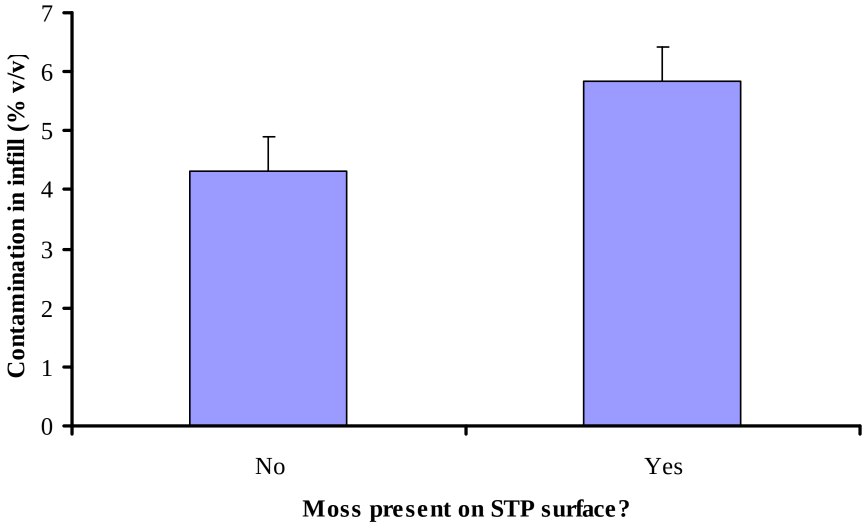


Figure 3.13 The relationship between the concentration of contamination and the presence of moss within the synthetic turf pitch test population. Whiskers represent the standard error of the mean. ANOVA determined that the treatments and interactions were not significant (p>0.05)

The concentration of contamination of each sample was quantified using the separation tube method. The results from the field survey samples are shown in Table 3.8. Anecdotal evidence from specialist maintenance companies (Gunn, pers. comm.) had indicated that STPs in an urban location were more likely to require more maintenance than those situated in a rural location. There was no correlation between the pitch location and the concentration of contamination within the infill (Rural: r = 0.022, p = 0.909; Urban: r = 0.257, p = 0.354) indicating that this is possibly a perceived increase in maintenance. Although the results have shown that there is more likelihood of the presence of moss/algae at higher concentrations of contamination, the difference is not significantly different (p = 0.064; Figure 3.13).

These data obtained are an aggregation of the concentration of contamination over the whole profile – it was not possible to stratify the sample to determine change in concentration with depth. Anecdotal evidence (Abbott. per comm.; also Figure 3.14a) indicates that the contamination within a synthetic turf system is within the top 10 mm of the infill. In pitches that have not been maintained at all over a period of years, however, the contamination is seen throughout the depth of the sand infill (Figure 3.14b).

Trials were carried out on removing the infill at known depths but this was found not to be possible because the motility of the sand infill was such that the profile could not be preserved, without destruction of the field site. The presence of the carpet fibre, with its multi-directional orientation, also hindered the process.

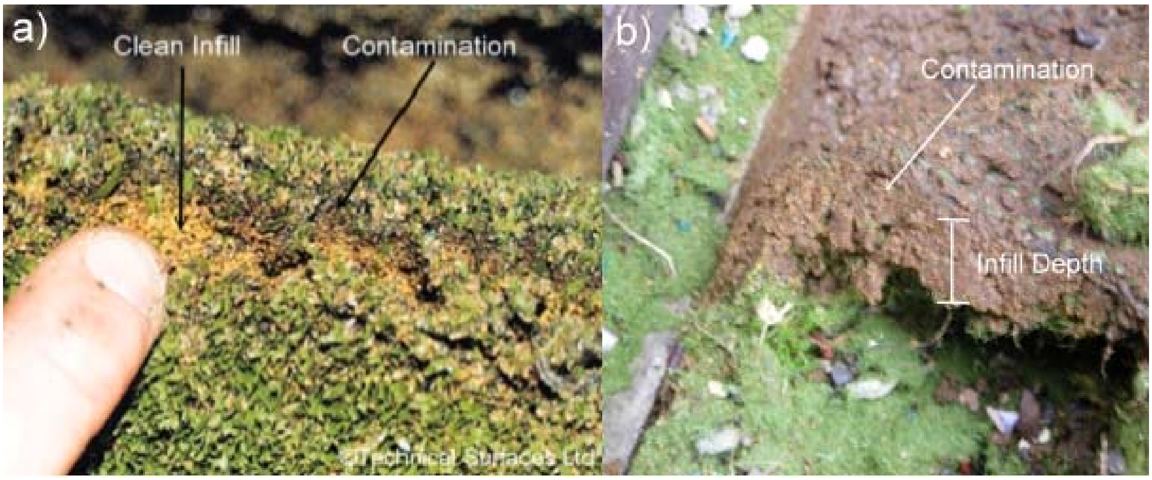


Figure 3.14 Location of contamination within the sand infill of a synthetic turf system; a) in a maintained pitch the contamination is in the top 50% of the profile, and b) in a pitch with no maintenance over a 7 year period, contamination of the infill occurs through the whole profile (inverted in this figure).

For forward comparison with later studies of infill contamination in Chapter 4, the results above could be seen as a range from 5 to 9% contamination over the whole profile, or this could be concentrated in the top 50% of the infill, in which case the comparable contamination would be 10 to 18% contamination assuming linear *pro-rata* behaviour. Whether or not this is the case depends on whether it is the infiltration rate or the moisture retention data being compared (see Chapter 4). This issue should be noted however.

3.2.7 Interaction between the measured surface performance characteristics and the questionnaire survey data.

The data from the management questionnaire and the field survey were used to quantify any relationship between maintenance and surface playability. Table 3.9 indicates that there are a number of weak correlations between the data, i.e. age and surface hardness ($r = 0.3644$, $p<0.05$) which indicated that as a pitch ages, the presence of contamination within the infill causes the loss of inter-particle contact between the sand grains reduces pore volume and increases the packing of the material.

There was correlation between pitch contamination and surface hardness ($r = -0.4025$, $p<0.05$), indicating a reduction in surface hardness with increasing concentrations of contamination. This is opposite to the effect of age on surface hardness and may be the result of the finer contaminant particles acting, not only as a filling in between the sand particles, but also as a lubricant (Naeini & Baziar, 2003). This will effect the reaction to the sand on contact with a falling mass; the infill will deform and be displaced under load reducing and the contact time increased, reducing the peak deceleration on the falling mass (Carré et al, 2005).

There was a significant correlation between age and ball deceleration and a negative correlation between age and the number of hours of pitch use, i.e. pile height reduces with an increase in pitch usage. The reduction of pile height with pitch use and the increase in deceleration are likely to be related; a reduction in pile height will result in loose sand on the pitch surface causing an increase in the friction between the ball and the sand particles. The reduction in pile height with pitch usage is an indication of the wear of the carpet fibres and this was seen to have a significant effect on the rotational resistance of the surface, but did not have any significant effect on any of the other performance characteristics.

Table 3.9 Summary of the interaction of surface performance characteristics

	Ball Roll (m)	Rebound (e)	Traction (Nm)	Hardness (G_{max})	Deceleration (m s^{-2})	Contamination (% w/w)	Pile length (mm)	Pitch use (h $week^{-1}$)
Age (y)	0.075	-0.134	0.122	0.364*	0.508*	0.123	-0.422*	0.238
Ball Roll (m)		0.123	-0.149	0.154	-0.108	0.372*	0.045	0.393*
Rebound (e)			-0.196	0.377*	-0.018	-0.153	-0.136	-0.186
Traction (Nm)				-0.095	0.074	-0.149	-0.552**	-0.256
Hardness (G_{max})					0.181	-0.403*	-0.161	-0.078
Deceleration (m s^{-2})						-0.243	-0.285	-0.089
Contamination (% w/w)							-0.091	0.684**
Pile length (mm)								0.238
Pitch use (h $week^{-1}$)								

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table 3.10 indicates the relationship between the two main maintenance procedures, drag brushing and power brushing, and the performance characteristics of the STPs within the field survey. There was a weak negative correlation between drag brushing and ball roll which indicates that, during the action of redressing the sand levels, the process is increasing the friction between the ball and the surface by moving loose sand to the pitch surface.

The strongest relationship was the negative correlation between the number of hours of pitch use and the drag brushing frequency, this may indicate a lack of resources to be able to brush the surface or possibly a lack of information on the reasons behind the process. It has already been shown, in Section 3.1.4, that local authority pitches have a higher rate of use than independent schools, 50 hours per week and 37 hours per week respectively. Local authorities are also use contractors over twice as much as independent schools which indicates that the contractors brush up to once per month reducing the frequency of drag brushing. This is confirmed by 63% of the local authority respondents did not drag brush the STP surface.

Table 3.10 Summary of the interaction of surface performance characteristics and the surface maintenance procedures

	Age (y)	Ball Roll (m)	Rebound (e)	Traction (Nm)	Hardness (G_{max})	Deceleration ($m\ s^{-2}$)	Contamination (% w/w)	Pile length (mm)	Pitch use ($h\ week^{-1}$)
Drag Brush	-0.306	-0.379*	-0.197	0.342	-0.291	-0.164	-0.333	0.251	-0.760**
Power Brush	-0.185	0.247	-0.214	-0.108	-0.307	-0.367*	0.262	0.477*	0.229

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

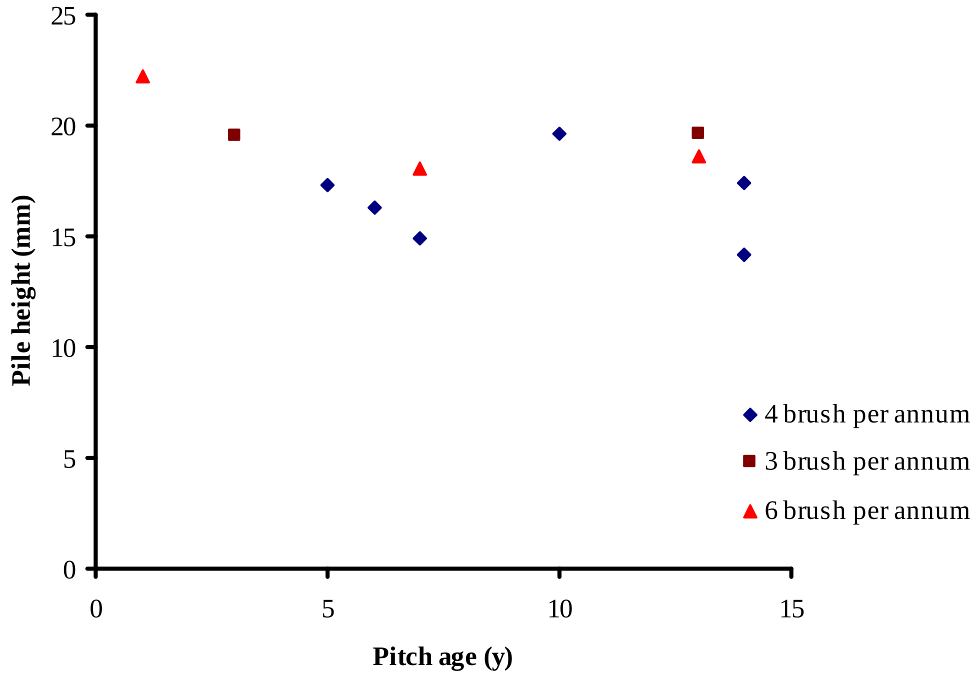


Figure 3.15 The relationship between the annual power brushing frequency and the synthetic turf pile length.

The weak correlation between power brushing and pile height is shown in Figure 3.15. The power brush has a grooming effect on the fibres within the pile and reduces the collapse of the fibre ends over time. Power brushing three times per annum is shown to have the most consistent effect on pile height.

There was weak correlation between the surface performance characteristics of the test STPs and the maintenance programmes that were used. The poor correlation may have been caused by the time at which the pitches were tested.meteorological conditions and the timing of the maintenance procedures will have affected the performance of the surfaces.

3.2.8 Evaluation of field survey data and implications for further research

As discussed in Chapter 2, the population from which the pitches selected for the field survey were taken was a database of an STP maintenance company. This meant that each pitch tested was maintained to some degree and that non-maintained pitches were not represented. This skewed population was the result of there being no information, from funding bodies or construction organisations, available on STPs that have been constructed in the UK.

During the period of the field testing there was no control on external factors such as when the pitch was last maintained, the moisture content of the infill, the exact surface specification and the standard of construction of the STP. Due to the geographical spread of the pitches around the United Kingdom and the limited time period allowed by STP managers to carry out surface performance testing, this variation in conditions was unavoidable.

These factors resulted in ‘noise’ in the data which resulted in weak correlations between the surface performance characteristics and the management programme. A contributing factor to the background noise was the differing meteorological and surface conditions during the testing period.

Although the literature review has shown the historical reasons for maintenance, the data from the field survey did not allow any conclusions to be drawn on the relationship between the management programme and the performance of an STP. To quantify the effect that factors such as contamination, infill moisture content, fibre orientation and depth of infill have on the performance characteristics of a STP these factors must be isolated and controlled. This would allow the quantification of the effect that each of the individual factors have on the performance on an STP. For this reason, controlled laboratory experiments were conducted and are detailed in Chapters 4 and 5.

3.2.9 Summary of field survey results

The field survey has highlighted that there is spatial variation not only between pitches, but also between areas on individual pitches. This is important because it illustrates that spatial variability could affect playability and even safety across a pitch. It is not possible to determine from these data, however, whether this spatial variation is a function of maintenance – or some other background factor, such as construction or environmental variables.

The aim of the field survey was to address Objective No. 2 and test the hypothesis that the performance characteristics of a synthetic turf pitch are significantly affected by age and wear. This was done by the measurement of performance characteristics over a range of STPs of different age and location. The wear of the pitch was characterised by the significant reduction of the carpet pile height with increased pitch use. The reduction in pile height had a weak correlation with the process of power brushing suggesting that pile height is longer where power brushing takes place because of the grooming action of the process on the fibre ends. The reduction in pile height is a function of cumulative pitch usage but also cumulative exposure to ultra-violet radiation which was not isolated in this survey.

There was a significant negative correlation between surface hardness and the concentration of contamination within the infill which was likely to have been caused by the finer contaminant particles reducing the inter-particle contact of the sand particles and increasing infill deformation under load.

The data did not show any correlation between the concentration of contamination within the sand infill and either of the maintenance processes, but did indicate that there was an increased chance of drainage problems as the pitch aged. This may have been due to a build up of contamination within the sand infill or poor maintenance of the drainage system itself. Although there was significant correlation between incidences of algae/moss, when there was poor drainage, there was no relationship between the age of the pitch and algae/moss infestation. This would indicate that it is the presence of the poor drainage that provides optimum growth conditions for the moss/algae and the increased drainage problems with age if the pitch drainage system has been maintained; the poor drainage is likely to be caused by a build up of contaminants within the sand infill. Of the field survey sites 22% indicated drainage problems (of which 19% also had moss or algal growth), but 48% had incidences of moss growth. This suggested that where there is poor surface infiltration rate, that are being caused by a build up of contaminants within the infill, this will result in the infill moisture content remaining at levels which promote moss or algal growth.

The occurrence of moss and algae on 48% of the test STPs, which are all maintained to varying levels, indicated the need to quantify the efficacy of the existing maintenance equipment and processes. This would indicate whether the build up of contaminants is due to ineffective maintenance or whether there may be other reasons for it.

3.3 Quantifying the efficacy of maintenance equipment used commercially

Using the sedimentation method, detailed in Chapter 2.6, three different types of maintenance equipment were tested for their efficacy at removing contamination from the sand infill of STPs within the field survey and were used to address Objective No.3. Each equipment type is typically used for a specific cleaning task: renovation, revitalisation and rejuvenation. It was not possible to measure the infiltration rates in conjunction with individual maintenance process due to commercial sensitivity over the use of the double ring infiltrometer system of measurement.

3.3.1 Renovation (Power Brush)

The process of renovation removes and filters sand infill to a depth of approximately 5 mm. The renovation equipment tested was a Dulevo SH75 that is designed to remove the top 2 – 5 mm of infill (with a rotary brush), filter out the contaminant materials and then return the sand to the pitch surface. In this case the material was filtered through a coarse grid (10 mm) and through finer filters but there are other techniques that do not use a filtering system. Despite the use of a filtration system, there was no significant reduction in the concentration of contamination ($p>0.05$) by the treatment (Figure 3.16;

Table 3.11) and a determinable, significant reduction in contamination by this method was not measured. Therefore the most likely benefit of this method is to increase the porosity of the infill surface by loosening the sand particles.

Although the equipment is designed to clean to a depth of 5 mm, the field testing showed a range of 2-3 mm. The effective working depth is affected by the moisture content of the sand infill; the presence of moisture providing cohesion between the infill particles. This emphasises the need for renovation to be carried out in dry infill conditions to allow maximum effectiveness.

Analysis of variance determined that there was no significant treatment effect between the mean contamination before and after the brushing process ($p = 0.351$); likewise, there was no difference between pitches ($p = 0.055$). Moisture contents were 25-45% of saturation (see Section 4.1.3); whether or not this is sufficient to compromise the cleaning process due to adhesion between the contaminants and the sand infill, preventing separation in the filtration process, is not apparent. It could be that contaminants remain adhered to sand particles and are then passed back onto the surface along with the 'filtered' sand infill or it is simply that sand is not removed when wet. This hypothesis is revisited in Section 5.5 where experiments measuring sand removal in the wear test rig showed significantly reduced sand removal in wet infill (9% moisture) *c.f.* dry infill (0.9%).

The renovation (power-brush) method only removed a mean of 0.4% contamination from Pitch G and 0.9% from Pitch H; furthermore this was only from the top 2-3 mm (*ca.* 15-23% of the infill depth). From this analysis, it appears that the renovation (power-brush) method does little to reduce infill contamination – however there are other benefits from redressing sand levels and grooming fibres to a more vertical orientation (not measured in this experiment).

Table 3.11 Percentage of contamination within the sand infill pre and post renovation (power brushing) on two test pitches G and H (p > 0.05).

				Pre-treatment			Post Treatment		
Surface	Pile Length (mm)	Measured Working Depth (mm)	Moisture content (% w/w)	Range	Mean	S.E.	Range	Mean	S.E.
G	15	2	8.08	3-6.6	4.8	0.776	3.8-5.2	4.4	0.477
H	16.5	3	5.49	6-7.7	6.6	0.519	4.7-6.2	5.7	0.537

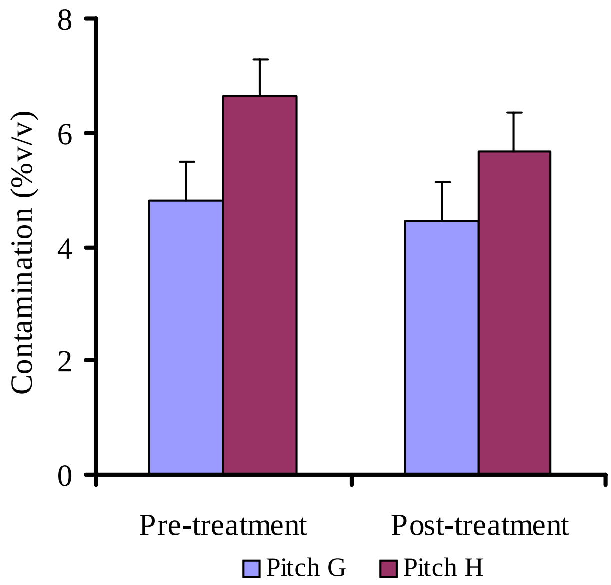


Figure 3.16 Concentration of contamination (% v/v) within the sand infill pre and post renovation on two test pitches (G & H). Whiskers represent standard error of mean (2.191 % v/v). ANOVA determined that the effect of treatment and pitches was not significant (p > 0.05 for both).

Revitalisation

The specified working depth for the revitalisation process, which removes and filters sand infill, is 8 – 10 mm; in field tests of this equipment, the measured working depth was 7 - 8 mm, *i.e.* the maximum field working depth was the minimum specified. In this case the equipment used was an SMG Sportchamp. Samples and infill depth measurements were taken at three points on each test site, goalmouth, wing and centre but there was no significant difference in contamination among these areas ($p = 0.076$).

On pitch E, contamination was reduced by 1.5% w/w and on pitch F, by 1.7% w/w however, this reduction was not significant ($p = 0.315$;

Table 3.12). Field observations determined that the majority of material removed was plastic fibre, not other forms of contamination. This fraction has the lowest mass and its selective removal would not result in a significant difference in this analysis. Whether or not the removal of the plastic fraction has a significant effect on performance parameters such as infiltration rate was not determined in this study and is a recommendation for further work.

Because significant volumes of infill are removed and returned, porosity is expected to increase immediately following treatment and before re-compaction – this could result in an increase in infiltration rate immediately post-treatment, even if contamination has not been reduced.

Because the revitalisation process described relies on separation of the sand infill particles and the contamination in the airflow between the brush and the receiving tanks, like the renovation process, revitalisation should be carried out in dry infill conditions to encourage maximum effectiveness.

There was a small, but not significant reduction in contamination in the treated depth. Using a maximum depth of 8 mm, this was only in the top 41-44% of the profile depth. This indicated that any contamination in the bottom 56-59% of the profile was untreated. Regular use of this method is liable to cause layering within the infill; beyond the maximum depth of the brush penetration a contamination 'pan' could accumulate. This may be able to reduce infiltration rates even though the surface is being maintained.

Table 3.12 Percentage of contamination within the sand infill pre and post revitalisation performed on two test pitches E and F (p = 0.315)

			Pre-treatment			Post Treatment		
Surface	Pile Length (mm)	Measured Working Depth (mm)	Range	Mean	S.E.	Range	Mean	S.E.
E	19.5	8	5.7-7.7	6.6	0.578	4.2-6.1	5.1	0.563
F	18	7	6.8-10.3	8.7	0.778	5.6-8.4	7.0	0.687

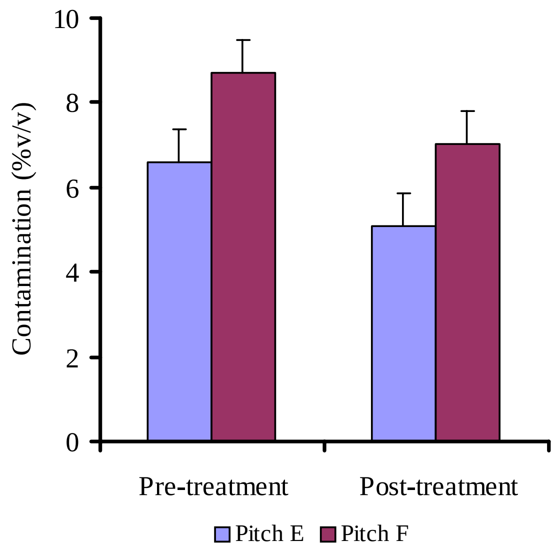


Figure 3.17 Concentration of contamination (% v/v) within the sand infill pre and post revitalisation performed on two test pitches (E & F). Whiskers represent standard error of mean (0.776 % v/v). ANOVA determined that the effect of treatment and pitches was not significant (p > 0.05 for both).

3.3.2 Rejuvenation

The specified working depth for sand removal in the process of rejuvenation is a maximum of 20 mm. The removed material is then replaced with fresh sand. Rejuvenation is a process performed using either compressed air or compressed water; the maximum effective working depth of each process was shown to be 15-16 mm and 6-9 mm respectively in the comparative field tests. One example of each process was tested (Table 3.13). On longer pile carpets (17 – 20 mm) the use of compressed air was significantly more effective ($p<0.05$) than the use of compressed water.

Compressed air method

Both test surfaces had pile lengths close to the maximum specified operating depth. The method significantly reduced contamination from 4.9 to 0.9% on Pitch A (i.e. 81% of the original contamination was removed) and from 9.1 to 1.6% on Pitch B (83% removal) ($p<0.05$). What is of particular interest is that this was removed from 94-100% of the total profile depth, respectively. Note that any contamination remaining within the infill after replenishment was either in the fresh sand infill and/or within the small amount of remaining original infill. Although the working depth of this equipment is quoted as up to 20 mm, on site measurements showed it to work to a maximum depth of 16 mm.

The removed sand was disposed of on natural turf pitches and replaced with fresh infill. This results in the direct transfer of plastic into the soil environment, which could be in contravention of waste-to-land application regulations.

The benefit of this method is that it does not rely on dynamic filtering and return of the infill; however, this process can cost up to £30 000 due to lack of supply of this equipment/service and because of the cost of replacement infill.

Table 3.13 Percentage of contamination within the sand infill pre and post rejuvenation using both processes; Compressed air (A & B) and Compressed water (C& D).

				Pre-treatment			Post Treatment		
Treatment	Surface	Pile Length (mm)	Measured Working Depth (mm)	Range	Mean	S.E.	Range	Mean	S.E.
Compressed Air	A	19	16	4.4-5.7	4.9	0.473	0.8-0.9	0.9	0.108
	B	17	15	7.8-10.4	9.1	0.661	0.9-2.0	1.6	0.420
Compressed Water	C	11	9	16.4-20.6	18.3	0.839	0.8-3.3	1.9	0.647
	D	20	6	9.8-11	10.4	0.444	6.9-9.8	8.6	0.700

Compressed water

There is no specified working depth for the compressed water technique. The infill is removed by upward movement of water and flotation. Unlike the compressed air method, this method did not directly collect material that has been removed from the carpet in one pass. The material was collected a short period of time later using a contra-rotating brush to move the material into heaps ready to be removed from the surface by a front bucket loader.

On short pile carpets (11 mm) the process removed infill to a depth of 9 mm (100% of total depth). This resulted in a significant reduction ($p<0.05$) of contamination from 18.3% to 1.9% (90% removal). On this carpet, performance was comparable to the compressed air technique, however pile length was nearly half of that in the tests above. On a longer, 20 mm pile carpet, this method only reduced contamination from 10.4% to 8.6% (17% removal). Furthermore, effective working depth was only 6 mm, *i.e.* 33% of the total sand infill depth. It follows that pressurised water techniques are not suitable for 20 mm (and longer) pile carpets.

This method of infill removal introduces water to the infill which could act as a carrier for the less dense particles of contamination and as it drains through the profile of the synthetic turf, could move the particles further into the infill.

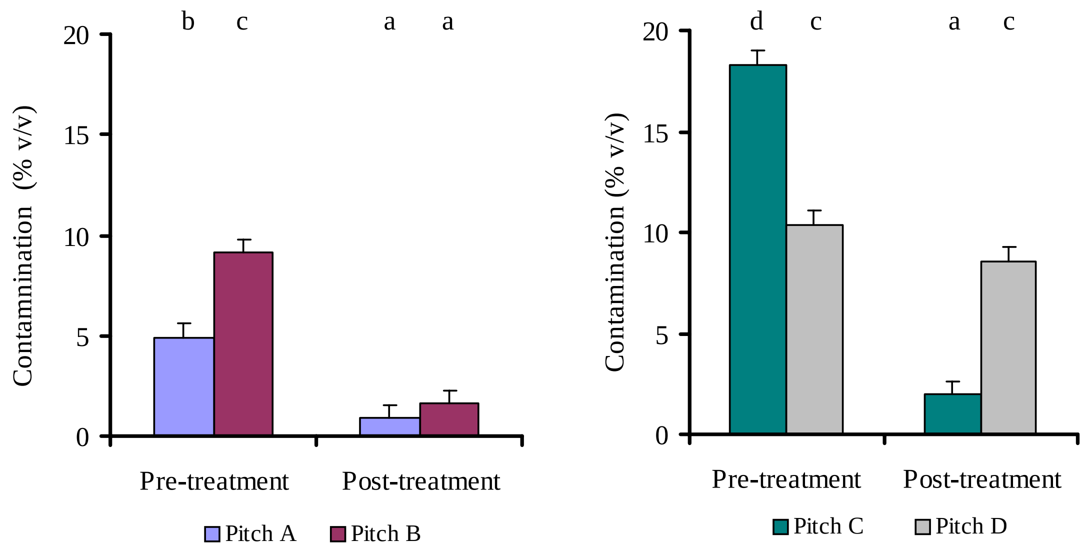


Figure 3.18 A comparison of two methods of rejuvenation: compressed air (pitches A & B; Pile height 19 mm & 17 mm) and compressed water (pitches C & D; Pile height 11 mm & 20 mm). Whiskers represent the standard error of mean (0.689 % v/v). Means with identical superscripts cannot be separated by the LSD (5%). Summary of the existing maintenance equipment

The quantification of the efficacy of existing maintenance equipment has determined a significant difference between the three main types of rotary brushing. The results show that the most effective method for contamination removal is rejuvenation using compressed air (**Table 3.14**). Regular renovation (power brushing) will probably increase surface porosity but does not remove the contaminants within the 2 – 3 mm of the infill profile where the brushing is active. Working depth with the revitalisation technique is greater (7-8 mm) but it does not reduce contamination significantly and it main action appears to be loosening of the sand material and increasing its porosity, as per the renovation (power-brushing) process.

The three different methods have been shown to have different working depths but the cost difference between each method is significant and reflects the working depth, but not necessarily the contamination removal performance (especially with revitalisation), of each method (Figure 3.19).

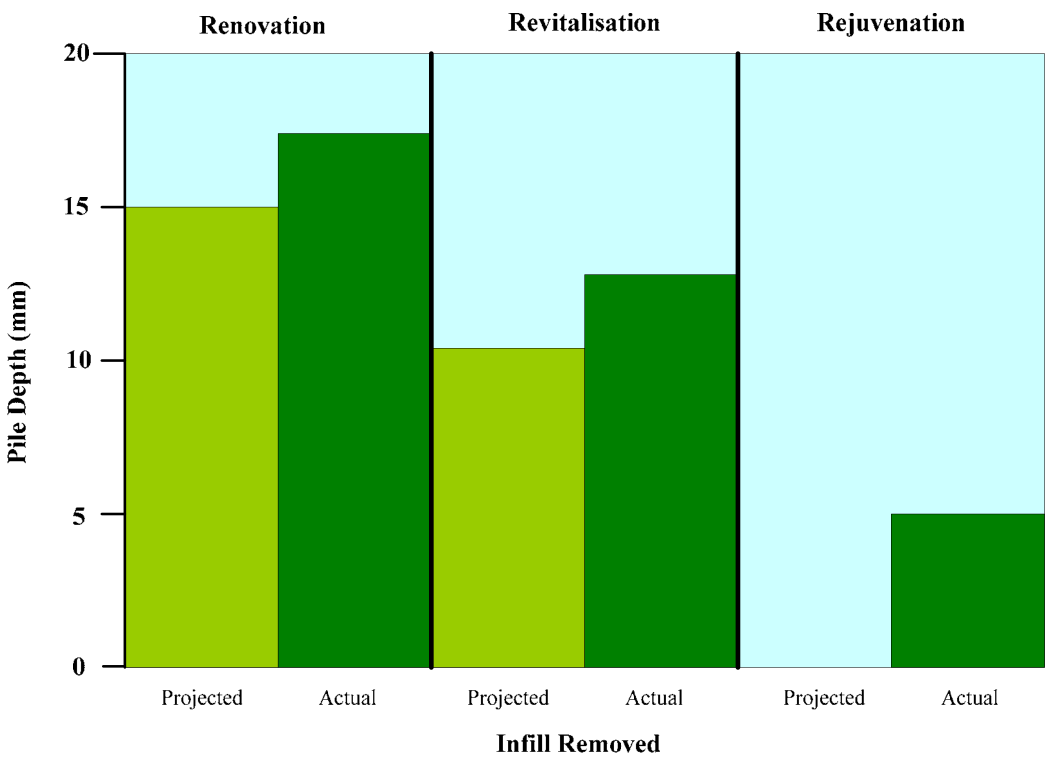


Figure 3.19 Working depth (blue) for each synthetic turf maintenance processes.

The method of renovation which did not significantly reduce contamination takes between two and three hours to complete at a cost of approximately £300. Revitalisation did not significantly reduce contamination either and takes one to two days to complete, depending on the moisture levels within the infill and can cost up to £3000. Compressed air rejuvenation, the most effective method, removes up to 83% of contamination, can take 5 – 7 days to complete and can cost up to £30,000 inclusive of replacement infill (Figure 3.20).

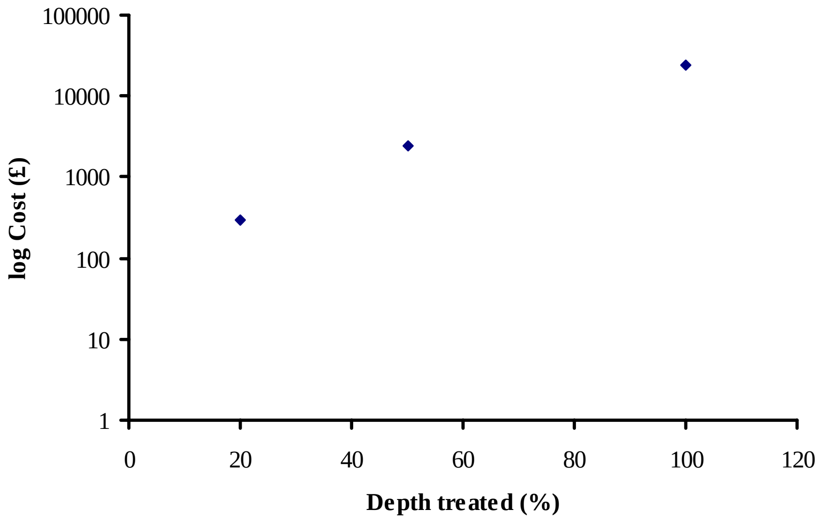


Figure 3.20 The logarithmically increasing cost of synthetic turf maintenance as a function of the depth of infill treated (not necessarily cleaned).

The use of each method should be a balance between their cost and effectiveness. Regular rotary brushing to a depth of 2 - 3 mm will not necessarily reduce contamination significantly but could result in other benefits from infill redistribution and increase in porosity. This may also happen with revitalisation, which brushes to a greater depth. As a pitch ages, each of these methods will become more effective as the pile height is reduced through wear and a greater proportion of the infill is brushed, however contamination will continue to accumulate. For removal of contamination, compressed air rejuvenation is the only effective technique tested for 20 mm carpets.

The testing of the three different methods indicated the efficacy of each method but gave no indication of the possible wear that is caused by each. This was addressed in Chapter 5 where the conditions of each method that utilises a rotary brush were reproduced and used to quantify the wear of the synthetic turf fibre by each method

Furthermore, the analysis quantifies the extent to which contamination has been removed from the infill within the pitch. It does not account for where the removed contamination ends up – this could be redistributed within the pitch or its drainage system or it could be redistributed within the local environment. Further studies should consider this point.

Table 3.14 Summary of the results from the testing of the efficacy of the existing synthetic turf pitch maintenance equipment. (Infill depth is assumed as pile height; -2 mm)

					Concentration of contamination (% v/v)			
Maintenance Process	Pitch	Average Pile Height (mm)	Infill Depth (mm)	Infill depth treated (mm)	Treatment		Overall contamination removal (%)	Total reduction in contamination (%)
					Pre	Post		
Rejuvenation	A	19	17	16	4.9	0.9	4	82
	B	17	15	15	9.1	1.6	7.5	82
	C	11	9	9	18.3	1.9	16.4	90
	D	20	18	6	10.4	8.6	1.8	17
Revitalisation	E	19.5	17.5	8	6.6	5.1	1.5	23
	F	18	16	7	8.7	7	1.7	20
Renovation	G	15	13	2	4.8	4.4	0.4	8
	H	16.5	14.5	3	6.6	5.7	0.9	14

3.3.3 Evaluation of field survey of maintenance equipment and implications for further research

As discussed above, the gradient of contamination concentration though the profile, is not known. To quantify the exact position that contamination is present within the infill, a process needs to be designed to enable the removal of the sand infill from a known depth without damaging the carpet or contaminating the sand below. To account for this in this study, a range of field contamination values is considered. This range accounts for the two cases illustrated in Figure 3.14, either the contamination is distributed throughout the whole profile, in which case field contamination ranges from 5-9%, or contamination only occurs in the top 25% of the profile and field contamination (for comparison with later investigations) is 10-18%.

3.4 Quantification of the wear of fibre samples removed from the field survey test sites

Using the method for quantifying wear of synthetic turf fibres, detailed in Chapter 2.7, fibre samples taken the field survey test sites, imaged with a scanning electron microscope and analysed using Erdas Imagine v8.7 image analysis software for linear surface characteristics. From this, the wear data was used to address Objectives No. 2, 3 & 5, and test the hypothesis that the wear of the synthetic turf fibres on an STP is significantly affected by age.

Overall, it was possible to remove replicate fibre samples from 10 of the survey test sites; permission was not granted on the remaining eight STPs. An example of the imaged fibres are shown in Figure 3.21

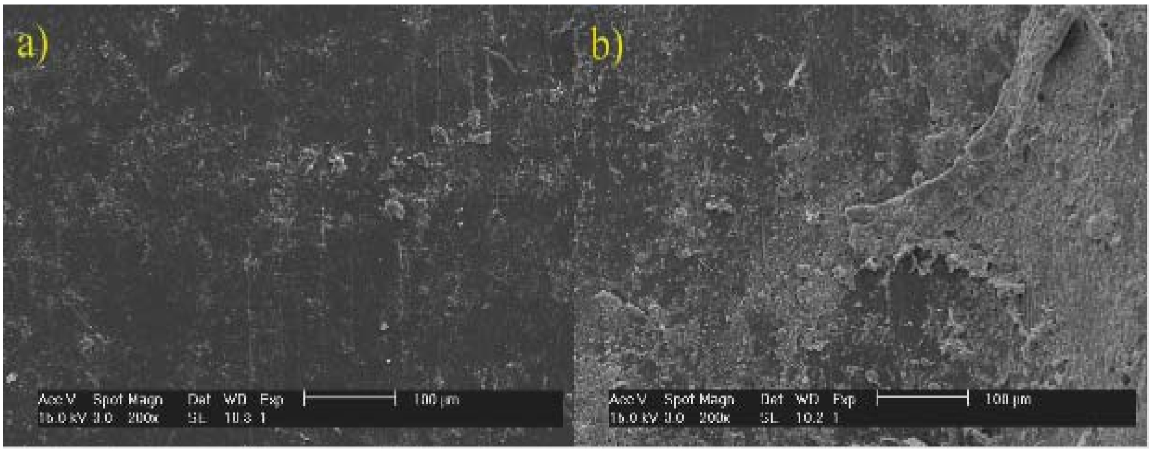


Figure 3.21 Scanning electron microscope images of two field survey test site synthetic turf fibres. a) a pitch 1 year old and b) a pitch 14 years old.

The results from the fibre analysis showed no significant relationship between age and wear ($p>0.05$; Figure 3.22) and no relationship with any of the surface performance or questionnaire survey results ($p>0.05$).

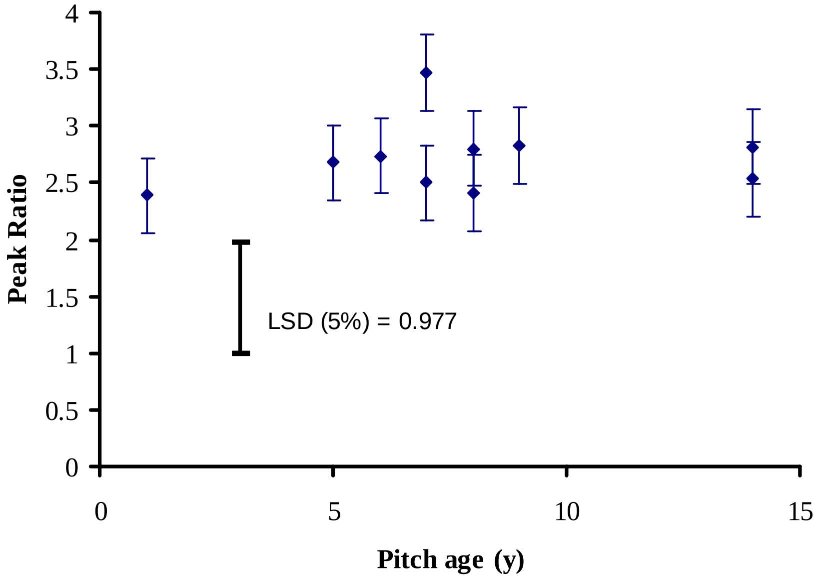


Figure 3.22 The relationship between fibre wear (represented as the mean Peak Ratio) and pitch age.

The results did not confirm the hypothesis that the wear of the synthetic turf fibres on an STP is significantly affected by age. The results showed a wide variation in the Peak Ratio value (2.40 – 3.6) which was comparable to the Peak Ratio values found in the validation of the method.

It was not possible to get control samples of the original synthetic fibre for each surface tested and therefore a comparison with the samples was not possible. Each of the pitches, although being second generation sand-filled STPs, did not originate from the same turf manufacturer. The variation in source materials will have affected the final results.

The sample of pitches tested was low and not representative of the STP population within the UK; further testing of a larger population would further test the original hypothesis and give a more accurate outcome.

3.5 Summary of field and questionnaire survey

3.5.1 The questionnaire survey

When STP managers were asked for the main reasons for selecting a synthetic surface, an unexpected result was the low ranking of ‘low maintenance’. It may have indicated a shift away from the original marketing of STPs where they were a major selling point was their ‘No Maintenance’ label or that the products were never sold on this point, but is contrary to anecdotal reports (Rhodes, 1997). Managers of STPs are more aware that these surfaces do need maintenance and that this can commonly be achieved using current labour resources. The factors that were regarded by the Facilities Managers as the highest priorities were: increase standards of play, increased hours of play, the all weather capability and provision of a higher quality and performance of the synthetic turf and indicated that these characteristics the relatively high construction costs

There was a variation in individual maintenance programmes and there was no significant correlation between individual procedures and the presence of moss/algae or drainage problems with the surface. There was a significant correlation between drainage problems and the incidence of moss on the STP surface as well as a significant correlation between the pitch age and drainage problems. This suggested that there is a build-up of finer contaminant material over time, reducing surface infiltration rates and providing good growth conditions for moss.

Within the test population, there was a discernable reduction in installation costs which reflects the increased availability for grant funding and the competition between construction companies. The installation cost of the actual playing surface was included in the overall facility cost which included items such as fencing, floodlighting and tarmac run off areas. Although the age distribution of the sample was between 0 and 24 years, the sample was positively skewed and most pitches were under 15 years old. This may have highlighted the growing popularity of STPs, that grant funding for their installation has become more freely available or that the normal lifespan for an STP is fifteen years and the older pitches have been resurfaced.

The questionnaire survey results gave an in-depth view of the maintenance and management programmes that are currently in use within the sample population. The survey did not give any information on:

1. how the maintenance programmes affected the playability of the STPs, or
2. whether or not the maintenance processes actually had a positive effect on the STP surface.

3.5.2 The field survey

The field survey was designed to test these two questions but the results were limited by significant background variation due to a number of different field factors. There was a significant reduction in the pile height with age which, in turn, did have a significant effect on ball deceleration which increased as pitches aged. This was due to the increase friction between the ball and the sand infill particles.

There was an increase in surface hardness with age and in ball rebound with this increase in surface hardness. With the ball rebound, as the falling ball contacts the surface the force exerted on the sand particles moves them away from the point of contact and there is increased contact (Figure 3.23). The flat head of the falling mass of the Clegg Impact Hammer has a larger surface area and compresses the sand particles and reduces the surface deformation (Dixon et al, 1999). Surface hardness was seen to be reduced as the concentration of contamination was increased. This was because the finer contaminant particles reduced the contact area between sand particles in the infill (Naeini & Baziar, 2003). This reduction in friction reduces the bulk strength of the infill, resulting in increased plastic deformation, increased missile/surface contact time and thus reducing deceleration of the Clegg Hammer and therefore surface hardness. Although the field survey showed that the concentration of contamination has a significant effect on some aspects of surface playability, it did not indicate the minimum concentration of contamination that was required for these effects to take place; this is explored further in a controlled environment (Chapter 4). Nor did it differentiate a gradient of contamination through the profile – thus a range of 5-9% or 20-36% will be considered in laboratory studies.

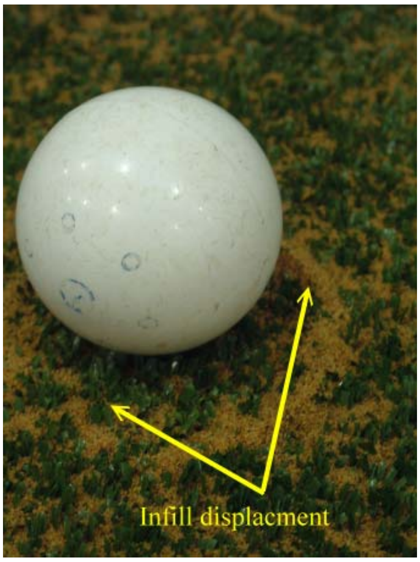


Figure 3.23 Infill displacement after contact of a falling hockey ball

There was a significant increase in rotational resistance with an increase in pile depth; the dimples on the sole of the test apparatus were able to penetrate further in to the infill/pile which increased the surface contact area and the friction acting upon the surface.

Analysis of the interaction between the performance characteristics and the maintenance programmes from the questionnaire survey revealed two weak correlations:

1. Drag brushing reduced ball roll and,

2. Power brushing increased ball deceleration.

Both of these relationships were because of the more uniform distribution and fibre uprightness, increasing ball/surface friction.

Image analysis of synthetic turf fibres removed from field survey test sites did not indicate any significant relationship between the age of the STP and fibre wear. This was a small sample of the overall UK population of STPs and further testing is required for a more comprehensive analysis of the relationship.

3.5.3 Existing maintenance equipment

The quantification of the efficacy of the existing maintenance equipment has successfully addressed Objective No. 3 by using the sedimentation method to indicate the benefits and limitations of the three main maintenance procedures

The outcomes of the quantification of the three methods of infill cleaning were:

1. Renovation and Revitalisation methods did not significantly reduce contamination. This was thought to be due to the separation / filtration process.

2. Renovation only brushes the top 2-3 mm. Revitalisation brushed 7-8 mm. This is compared to specified working depths of 5 and 8-10 mm respectively.

3. Compressed air rejuvenation removed 81-84% of contamination present over 94-100% of the total infill depth infill to a maximum depth of 20 mm.

4. The use of compressed water for the rejuvenation process on longer pile synthetic carpets (20 mm pile length) was ineffective and only removed a maximum of 17% of the total contamination.

The use of the different maintenance equipment may have a significant effect on the playability of the STP surface. The field survey indicated that increased concentrations of contamination affected pitch hardness and ball roll; the use of the incorrect equipment will not remove contamination from the surface and result in reduced playing performance.

Although the questionnaire survey indicated the type of brushing methods that were used on the sample population of STPs, there was no quantitative data requested on their efficacy in removing contamination within the sand infill.

3.5.4 Outcomes and implications for further work within the thesis

The field survey has indicated the difficulty in comparing the playing performance characteristics of different pitches. To quantify the effect that maintenance has on the performance characteristics of a surface it is necessary to reduce field variation. A controlled laboratory experiment was designed to re-assess many of the performance parameters identified in this chapter but with reduced environmental and systematic variation (see Chapter 4).

The survey of equipment performance did not indicate whether the actual process of brushing the surface caused any synthetic turf carpet fibre wear through abrasion by the infill. This was tested using a purpose built rig that was designed to apply the same loading conditions as the existing equipment and to quantify its effect. The construction, methodology and results from the test rig are shown in Chapter 5. Neither did this analysis consider the final fate of the removed contamination – this should be considered in future work.

Results from the equipment survey, along with data from the questionnaire survey, were used to address the effect that the maintenance programme has on the financial management of a STP in Chapter 6.

Reviewing the objectives, the aim of Objective No. 1 was:

To determine a relationship between wear, maintenance and performance characteristics of the synthetic turf surface over time

Although the results from the field survey showed wide variation, there was weak correlation between the different maintenance processes and some of the playing characteristics. The STPs were seen to wear by age, illustrated by the reduction in pile length.

The aim of objective No. 3 was:

To develop and implement measurement methods and techniques for assessing the effectiveness of existing maintenance equipment on synthetic turf and infill material.

The quantification of field infill contamination using the sedimentation method allowed quantification of the efficacy of existing maintenance equipment and has therefore been successfully addressed.

4 Chapter Four: Results from laboratory based experimentation

Chapter 3 illustrated that the results derived from the field survey highlighted the need for trial testing under controlled conditions. These experiments were used to quantify the effect that a range of surfaces (2G & 3G) and infill (Garside 2EW, No. 21 & 16/30) specifications, under controlled conditions, have on the performance and structural quality of the synthetic turf surface. The results obtained from this section were used to explain the variability within the field survey data.

The methodology, treatments and sampling procedures for the different sections is shown in Chapter 2. The data for the different parameters measured during the laboratory testing were analysed using GenStat Eighth Edition v8.1 for Windows (software). The separation of the means of treatments was by the LSD of the means at p = 0.05.

The laboratory testing was divided into three sections:

1. The individual effect that fibre orientation, infill levels, infill moisture content and concentration of contamination within the infill have on the performance characteristics of a sand-filled STP surface.
2. The effect that the concentration of contamination within the sand infill has on the infiltration rate of the surface.
3. The effect of wear on the synthetic turf fibres.

4.1 Surface performance testing on homogeneous pitch construction

4.1.1 Mass per unit area of sand infill

a. Surface Hardness (as determined by the peak deceleration of a falling mass)

The quantification of the effect that the concentration (mass per unit area) of sand infill had on surface hardness was used to test the hypothesis that an increase in the mass per unit area of infill causes an increase in hardness because the sand is deformed less easily than the turf fibre. There was a significant correlation between the mass of sand infill per unit area and measured surface hardness (r = 0.9495, p = 0.01) indicating that the increase in the mass of sand infill per unit area reduces the energy adsorption properties of the rubber shockpad.

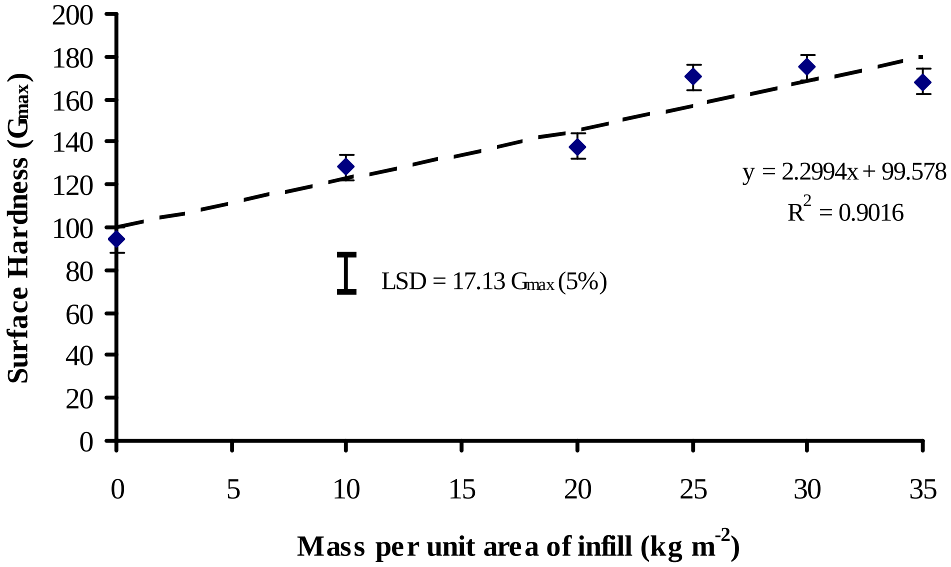


Figure 4.1 The effect of the mass per unit area of the sand infill on the surface hardness (Gmax) of a synthetic turf surface. Whiskers represent the standard error of the mean (5.97 Gmax). Dashed line represents the linear relationship between surface hardness and the mass per unit area of infill.

When a ball falls and makes contact with the constructed profile with no infill, the shockpad exhibits a point elastic response causing the solid ball to rebound (Figure 4.1). The increasing level of sand infill had a dampening effect and the height of ball rebound was reduced. The range of hardnesses between 0 and 35 kg m^{-2} of infill was similar to that observed in the field (ca. 100 – 140 g; Section 3.2.2).

Contrary to the surface hardness results the ball rebound was significantly decreased with an increase in the rate of infill (Figure 4.2). The interaction between surface hardness and ball rebound has highlighted the difference in surface contact that between the ball and the falling missile of the Clegg Impact Soil Tester (CIST) as discussed by Carré & Haake (2004). Carré et al (2004) found that the falling missile within the CIST is prone to irregular contact with the surface due to collision with the tube during freefall. The shape of the falling missile was also found to be significant; a spherical shape, having a reduced contact surface, displayed increased displacement and reduced the maximum force exerted on the object (Carré et al, 2004).

The results from the test surface showed a surface hardness of 162 g at the manufacturer's infill rate of 30 kg m^{-2}. This is equivalent to the top reading taken on the field survey. The reduced surface hardness within the field sample was due to the shorter pile length on the test synthetic turf pitches. This increased the effect of the shock pad and reduced peak deceleration.

b. Ball Rebound

The rate of sand infill was used to test the hypothesis that the increase in hardness of a surface caused by the increase in infill concentration results in an increased ball rebound height because of less energy loss.

The effect of the mass of infill per unit area was seen to be a two part interaction (Figure 4.2):

a. Between 0 & 10 kg m^{-2} there was no significant effect on the ball rebound
b. An increase in the infill level over 10 kg m^{-2} showed that there was a significant negative linear correlation with the coefficient of restitution for the ball rebound ($r = -0.992$, $p<0.05$).

These results indicate that the mass of infill per unit area has an effect on the point elasticity that is exhibited by the rubber shockpad. The contrasting results of ball rebound and surface hardness indicate that without infill, the shockpad/carpet deforms on contact with the ball and ball rebound is exhibited. There is little difference in the energy state of each falling mass, the hockey ball and the CIST missile, 2.35 J and 2.7 J respectively.

The sand infill acts as a damper to the shockpad and on contact with the ball energy is dissipated through the movement of the sand infill, non recoverable deformation of the surface and the height of ball rebound is reduced. As the falling ball contacts the surface the force exerted on the sand particles moves them away from the point of contact and there is increased contact The flat head of the falling mass of the Clegg Impact Soil Tester has a larger surface area and compresses the sand particles and reduces the surface deformation (Dixon et al, 1999).This reduction in friction reduces the bulk strength of the infill, resulting in increased plastic deformation, increased missile/surface contact time and thus reducing deceleration of the Clegg Hammer and therefore surface hardness.

When compared to the results from the ball rebound it was found that there was a significant negative correlation (r = -0.8648, $p<0.05$) indicating that there was a reduction in ball rebound as the surface hardness increased (Table 4.1). Therefore the hypothesis that an increase in the hardness of a synthetic turf surface results in a greater ball rebound height because of less energy absorption was rejected.

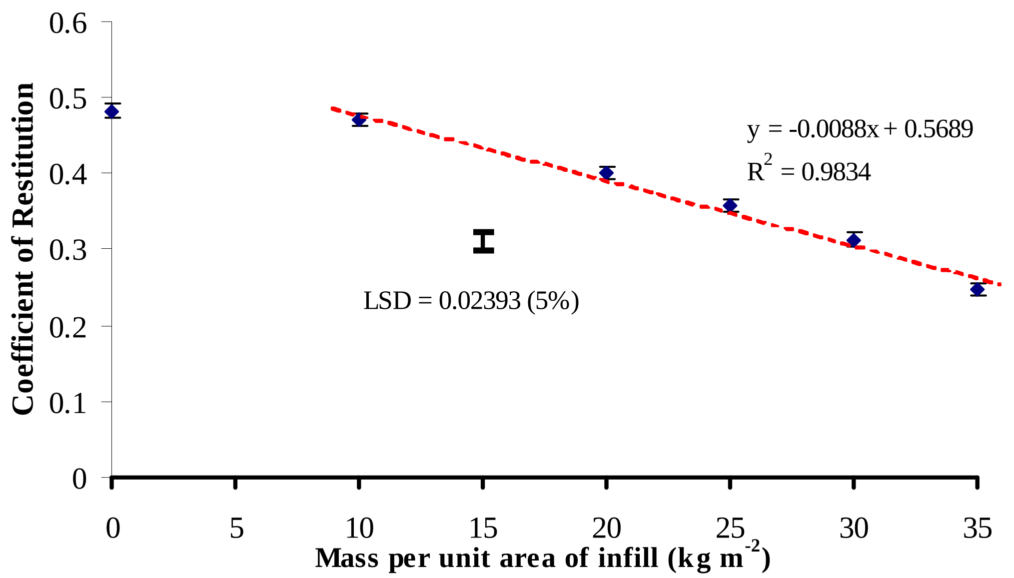


Figure 4.2 The effect of the mass per unit area of the sand infill on ball rebound (as determined by the coefficient of restitution) of a synthetic turf surface. Whiskers represent the standard error of the mean (0.00842). Red dashed line represents the linear relationship between ball rebound and the mass per unit area of infill above a mass per unit area of 10 kg m^{-2}.

Table 4.1 The relationship between surface hardness, ball rebound and mass of infill per unit area expressed as a Pearson correlation coefficient.

	Surface Hardness (Gmax)	Mass of infill per unit area (kg m^{-2})	Ball Rebound (e)
Surface Hardness (Gmax)		0.9495**	-0.8648*
Mass of infill per unit area (kg m^{-2})	0.9495**		-0.9612**
Ball Rebound (e)	-0.8648*	-0.9612**	

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

c. Rotational Resistance

The quantification of the effect that the mass per unit area of sand infill had on rotational resistance was used to test the hypothesis that an increase in the sand infill will increase traction due to increased friction between the sand particles and the player footwear. There was a significant negative correlation ($r = -0.894$, $p<0.05$) indicating that there was a reduction in rotational resistance as the rate of sand in fill increased (Figure 4.3).

An increase in the mass per unit area of sand infill reduced the applied force needed to overcome the friction between the surface and the base of the equipment. With no infill, the area of the dimples, on the apparatus base, in contact with the fibre was increased as they penetrated the carpet pile. This increased the static friction of the contact surfaces and a greater torque was required to rotate the apparatus. The increase in the rate of infill reduces the contact surface of the dimples and introduced loose packed semi-rounded particles into the contact area. When rotational force is applied shear bands form between the sand particles reducing the friction at the surface/shoe interface (Shi & Horii, 1989). The results indicated that over a rate of 25 kg m^{-2} of sand infill, the rotational resistance is significantly reduced and may cause surface user injury (Heidt et al, 1996).

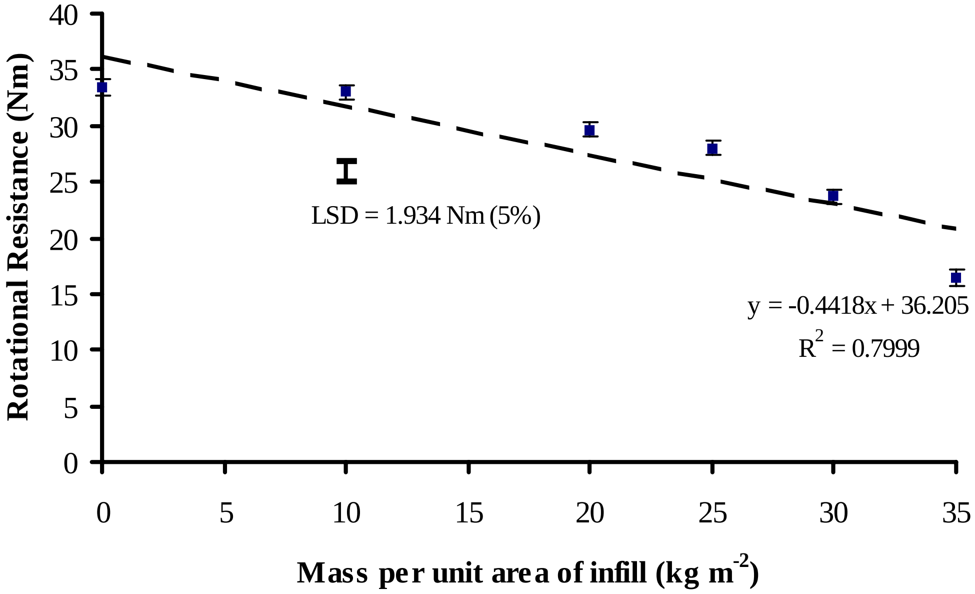


Figure 4.3 The effect of the mass per unit area of the sand infill on the rotational resistance of a synthetic turf surface. Whiskers represent the standard error of the mean (0.674 Nm). Dashed line represents the linear relationship between rotational resistance and the mass per unit area of infill.

d. Ball deceleration

The deceleration of a hockey ball in contact with the playing surface was quantified to test the hypothesis that an increase in the mass per unit area of sand infill will increase the deceleration of the hockey ball due to the increased friction between the sand particles and the ball. The results indicated an increase in the deceleration of the ball (Figure 4.4) as the deformable synthetic turf fibres are incorporated into the sand infill. The increased mass of infill per unit area reduced the height of pile above the infill and resulted increase ball infill contact causing an increase in the friction between the ball and the sand particles.

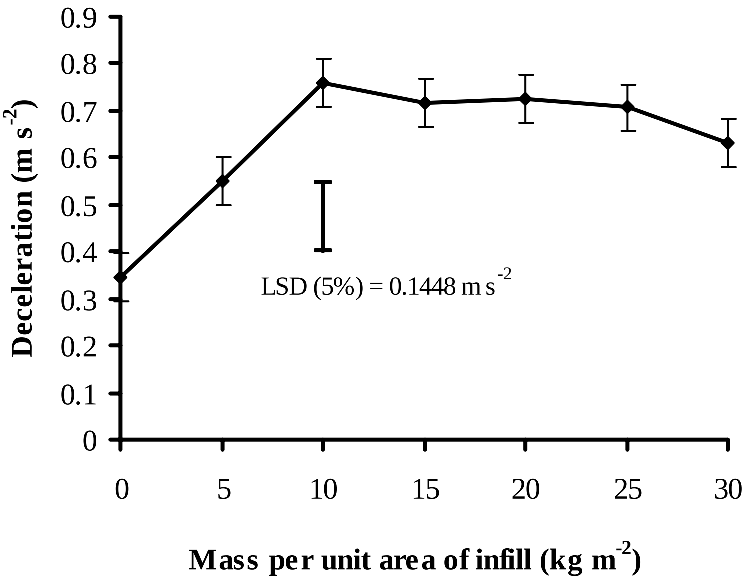


Figure 4.4 The effect of the mass per unit area of the sand infill on the ball roll deceleration on a synthetic turf surface. Whiskers represent the standard error of the mean (0.0507 m s^{-2}).

4.1.2 Concentration of contamination within the sand infill

The quantification of the effect of the concentration of contamination (COCn) was performed to test its effect on the performance characteristics of the trial STP surfaces. The tests were performed when the infill was in a dry condition (0.5% gravimetric moisture content) and one hour after saturating the surface with water (16 - 18% gravimetric moisture content, depending on the COCn) to characterise the interaction between the COCn, moisture content and surface performance. Three concentrations are considered 0, 10 and 20% by mass; these represent the range of concentrations found in the field, including a possible surface concentration in the top 50% of the infill.

a. Surface hardness

The quantification of the effect that the COCn had on the surface hardness of a synthetic turf surface was used to test the hypothesis that an increase in the COCn causes a decrease in hardness because the infill compacts more easily as its particle size distribution widens.

The effect of contamination on surface hardness was the reverse of what was seen with the increase in the mass of infill per unit area. The hypothesis is confirmed as the negative correlation ($r = -0.740$, $p<0.01$; Figure 4.5) indicated that, under the load of the missile, on contact with the surface the infill is compacting and reducing the surface hardness. This is a result of the finer contaminant particles acting, not only as a filling in between the sand particles, but also as a lubricant (Naeini & Baziar, 2003). This will effect the reaction to the sand on contact with a falling mass; the infill will deform and be displaced under load reducing and the contact time increased, thus reducing the peak deceleration on the falling mass (Carré et al, 2005).

The results for an increase in COCn on the test surfaces are similar to the field survey results. There is higher correlation on the test surfaces showing that the controlled laboratory conditions, after removing external factors, such as meteorological conditions, have confirmed the field results.

Figure 4.5 indicated that there was a significant difference between the surface hardness in a dry and wet state ($p<0.01$). The surface hardness measured when the infill was wet did not show any consistent pattern; there was no significant difference between 0% and 20% contamination whereas 10% contamination showed a significant increase in surface hardness. The inconsistency in surface hardness may have been due to uneven wetting of the infill or inconsistent mixing of the contamination with the infill before application to the carpet. In a wet state the surface hardness is significantly reduced by the water, either by lowering the interparticle friction and the infill deforming under load, therefore increasing missile/surface contact time and reducing deceleration or the water dissipating and not returning the energy of the impact.

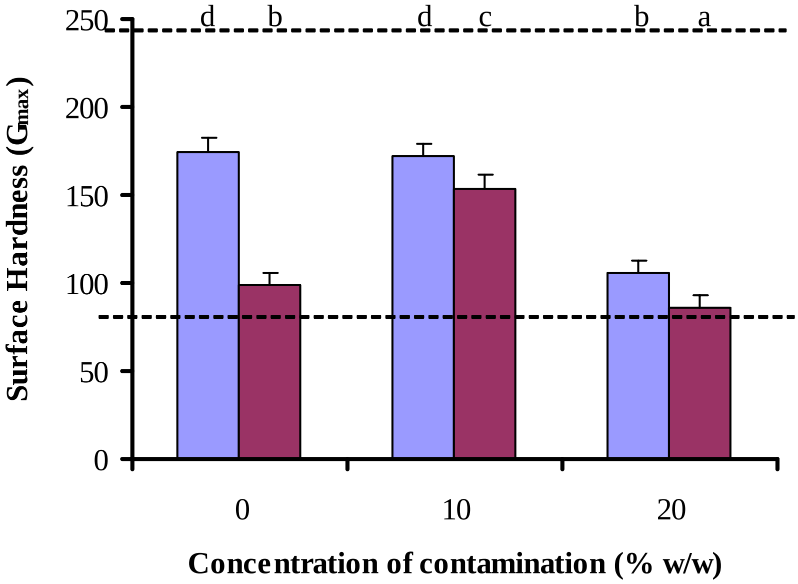


Figure 4.5 Variation of surface hardness as a function of concentration of contamination and moisture content ■ Dry; ■ Wet. Whiskers represent the standard error of the mean (7.23 G). Means with identical superscripts cannot be separated by the LSD (5%). Dashed lines represent the lower and upper values for surface hardness from the field survey.

b. Ball Rebound

Overall, when the infill was dry, there was no significant correlation between the COCn and the height of ball rebound ($p>0.05$). There was a significant difference between the height of rebound at 0% and 10% contamination (Figure 4.6), but there was no significant increase in the height of ball rebound over 10% contamination. When the infill had been wetted there was a significant reduction in ball rebound when compared to dry conditions ($p<0.01$, Figure 4.7), but, overall there was no significant relationship between the COCn and the presence of water and their combined affect on ball rebound ($p>0.05$).

The presence of a COCn of 10% and above significantly increased ball rebound; this indicated that contrary to the effect that ball surface contact had with normal infill, the finer contamination is reducing the inter-particle gaps and increasing the friction between infill particles. This increases the stiffness of the surface and increases the height of ball rebound.

In a saturated state the excess pore water pressure reduces the cohesion between the infill particles, which are easily moved by the contact of the ball with the surface; this deformation of the infill resulted in reduced ball rebound. A similar effect was found by Young (2006) when investigating the effect of water on ball rebound on water-based synthetic field hockey pitches. It was shown that ball rebound was significantly reduced as the volume of water present within the infill increased, resulting in a greater energy loss on contact of the ball with the surface.

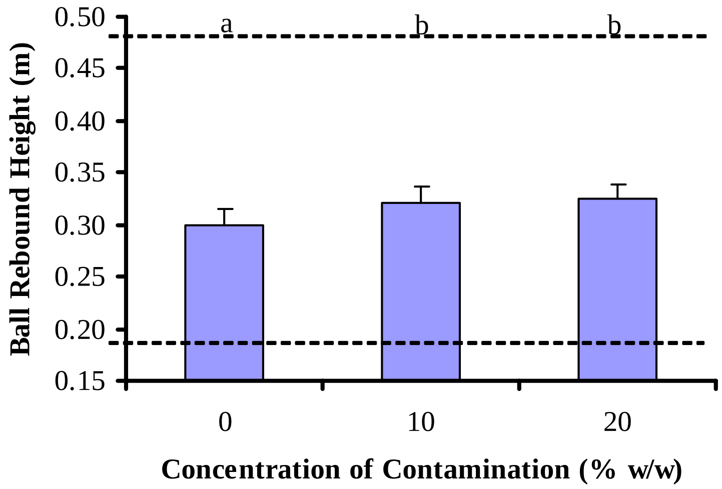


Figure 4.6 The effect of the concentration of contamination on ball rebound (as determined by the coefficient of restitution) of a dry synthetic turf surface. Whiskers represent the standard error of the mean (0.01879). Means with identical superscripts cannot be separated by the LSD (5%). Dashed lines represent the lower and upper values for the coefficient of restitution from the field survey.

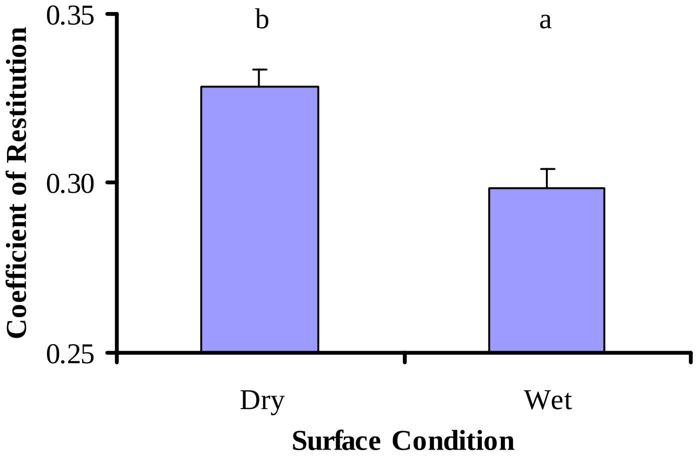


Figure 4.7 The effect of water within the sand infill on ball rebound (as determined by the coefficient of restitution) of a synthetic turf surface. Whiskers represent the standard error of the mean (0.0054). Means with identical superscripts cannot be separated by the LSD (5%). Dashed lines represent the lower and upper values for the coefficient of restitution from the field survey.

c. Rotational resistance

The quantification of the effect that the COCn had on rotational resistance was used to test the hypothesis that an increase in the COCn will increase traction due to increased friction and adhesion between the soil particles, caused by increased inter-particle contact, and footwear which are derived from different parent materials. When the infill was dry there was no significant correlation between the COCn and rotational resistance ($r = 0.267$, $p>0.05$) whereas there was a positive correlation under wet conditions ($r = 0.603$, $p<0.01$). The increased rotational resistance was due to the increased water content, allowing capillary rise and meniscus formation which increased the forces binding the soil particles together (Soni & Salokhe, 2006). This increased the applied force required for the equipment to move over the surface. Overall, there was no significant relationship between the COCn and the presence of water and their combined effect on rotational resistance ($p>0.05$; Figure 4.8).

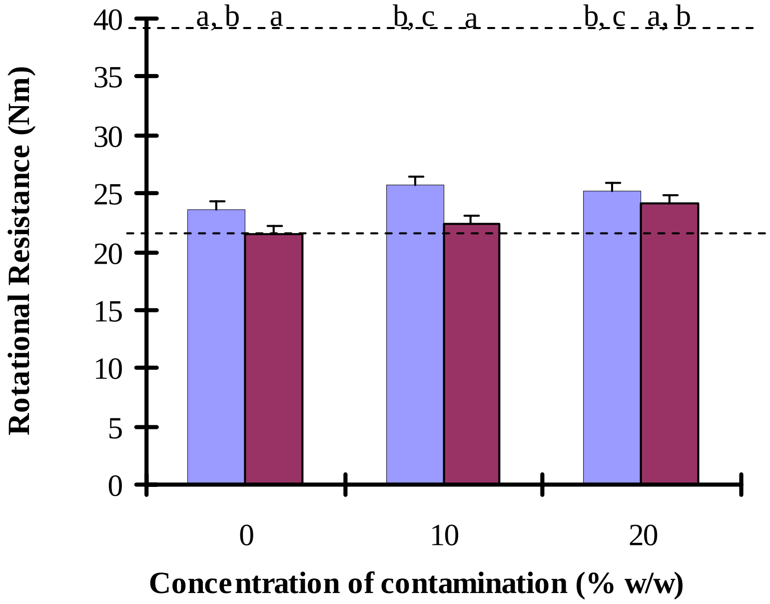


Figure 4.8 Variation of rotational resistance as a function of concentration of contamination and moisture content ■ Dry; ■ Wet. Whiskers represent the standard error of the mean (0.694 Nm). Means with identical superscripts cannot be separated by the LSD (5%). Dashed lines represent the lower and upper values for rotational resistance from the field survey.

d. Deceleration of a test hockey ball.

The quantification of the effect of the concentration of the sand infill on deceleration showed that there is a significant relationship between the two factors ($r = 0.815$, $p<0.01$; Figure 4.9). The increasing concentration of contamination significantly increased the deceleration of the ball across the surface. This was caused by the increased inter-particle friction reducing the slip of particles at the contact point of the ball with the surface, and therefore increased friction between the ball and surface. This reduced slip increased rolling resistance and deceleration of the ball.

When in contact with the STP surface, the forward motion of the hockey ball is reduced by force locking, the friction caused by the interaction of the ball and playing surface. The base of the equipment used to measure rotational resistance has a dimpled sole and as the dimples penetrate into the turf surface; the forces acting on the dimples are both force and form locking. Form locking is the frictional and shear forces within the carpet infill profile acting against the applied rotational force.

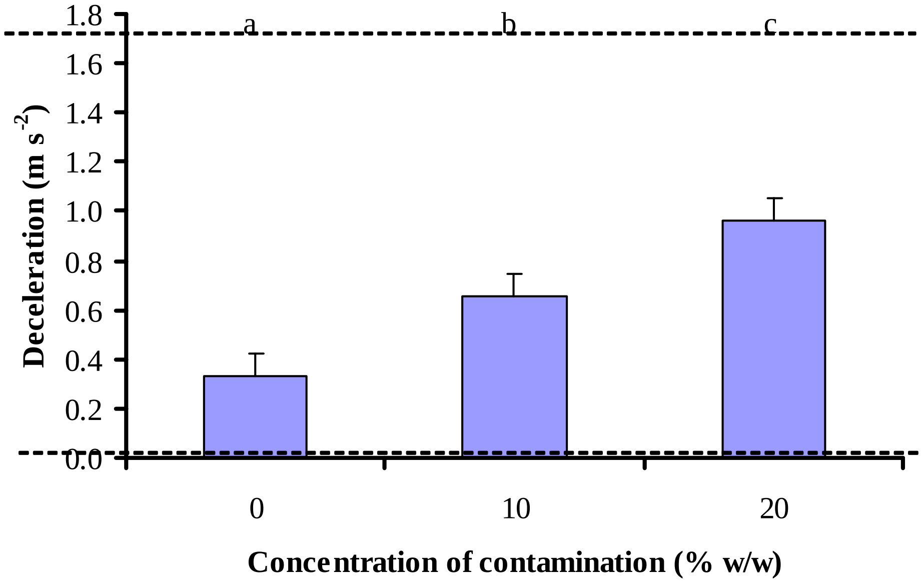


Figure 4.9 Variation of ball deceleration as a function of the concentration of contamination within a synthetic turf surface. Whiskers represent the standard error of the mean (0.0917 m s^{-2}). Means with identical superscripts cannot be separated by the LSD (5%). Dashed lines represent the lower and upper values for ball deceleration from the field survey.

4.1.3 Effect of contamination on the rate of drying of the sand infill

The effect that the COCn within the sand infill was used to test the hypothesis that increased COCn within the infill reduces pore size and therefore reduces the change in moisture content per unit time through the process of evaporation.

Once saturated and then allowed to drain for 60 minutes, the mean gravimetric moisture content of the sample infills ranged from 15.38% (0% contamination) to 19.04% (20% contamination). All COCn showed a significant negative correlation with time which shows that the infill dries out over time at all levels of concentration ($r = -9727$, $p<0.01$). There was no significant difference between 0% and 5% contamination of the period of the experiment, but up to days five and six there was significantly higher moisture content within the 10% and 20% COCn (Figure 4.10).

The broadening of the particle size distribution, by the increased COCn, increased the matric water potential within the infill and therefore reduced infiltration. This was seen to have an effect on the drying of the STP surface (Figure 4.10). The loss of water from the system was seen to occur in three different phases. At all COCn there was a reduction in infill moisture content from Day 0-1, principally through drainage. Then depending on the pore distribution within the infill: days 2-4/7 evaporation from macropores and day 4/7 evaporation from the micropores. These results were obtained under controlled conditions; when installed, the STP surfaces would be exposed to varying meteorological conditions. It is likely that during the winter months, there will be little evaporation from the micropores and so the surface will remain damp. On pitches that have areas of low light, due to shade from trees or buildings, and limited air movement across the surface, the conditions are beneficial to establishment of moss or algae on the surface. This reduces playability and may be viewed as a health and safety risk.

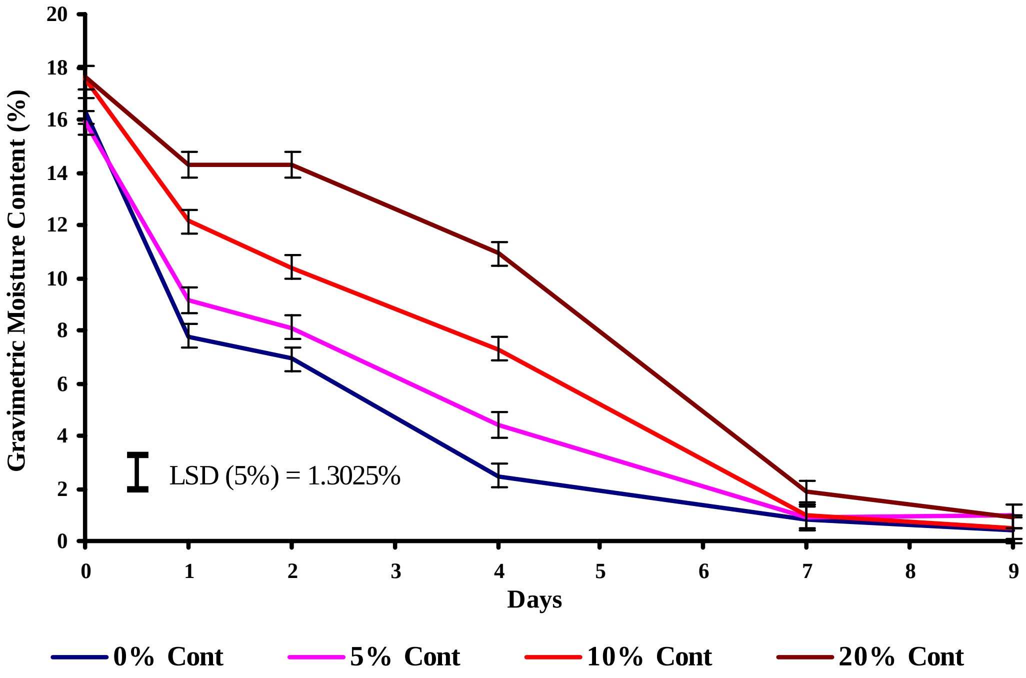


Figure 4.10 The effect of the concentration of contamination within an infill on the period of time to dry at an air temperature of 20°C. Whiskers represent the standard error of the mean (0.4581%)

4.1.4 Orientation of carpet fibres

The deceleration of a hockey ball when passing over the carpet surface was used to test the hypothesis that the orientation of the individual carpet fibres increases ball/surface friction, therefore, reducing the velocity of a hockey ball rolling on the surface.

There is a significant difference between each orientation used ($p<0.01$) and, in this case, the hypothesis can be supported (Figure 4.12). The process of brushing an STP realigns the fibres in the direction of the brushing action. During the action of play the fibres will become multi-directional and testing has shown that this significantly affects the deceleration of a ball across the surface. Fibres orientated with the fibre tip towards the rolling ball significantly increased the deceleration by fibre stiffness and increasing resistance against the rolling ball. Fibres orientated away from the direction of ball roll significantly reduced the deceleration by the displacement of the fibres during ball roll (Figure 4.11). In a normal state the carpet under test will have fibres that are multi-directional that will affect the performance testing. Regular brushing in different directions will prevent the carpet forming a 'nap', and will reduce the effect that the fibre orientation has on ball roll.

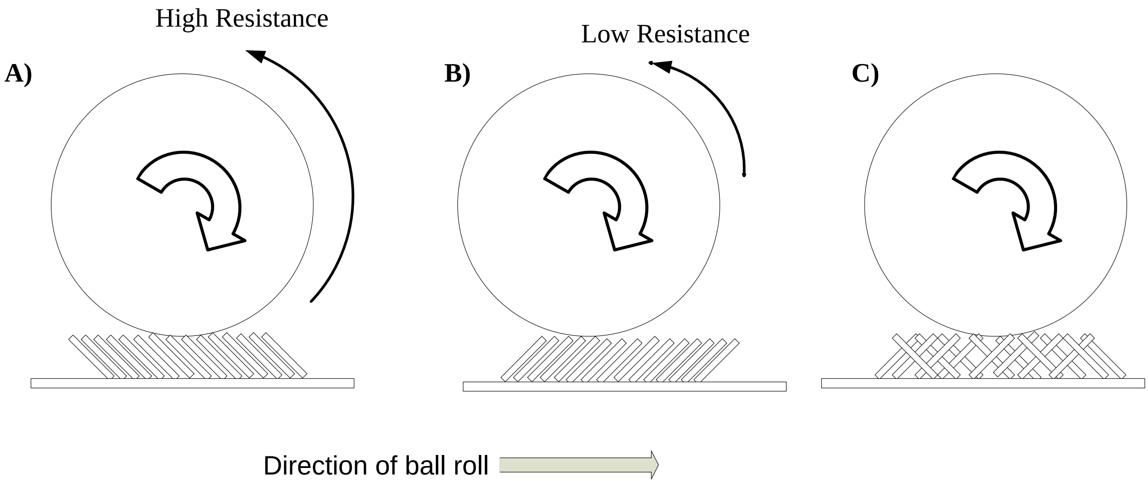


Figure 4.11 Interaction between a field hockey ball and synthetic turf fibres that are orientated A) against , B) away from and C) multi-directional to the ball roll.

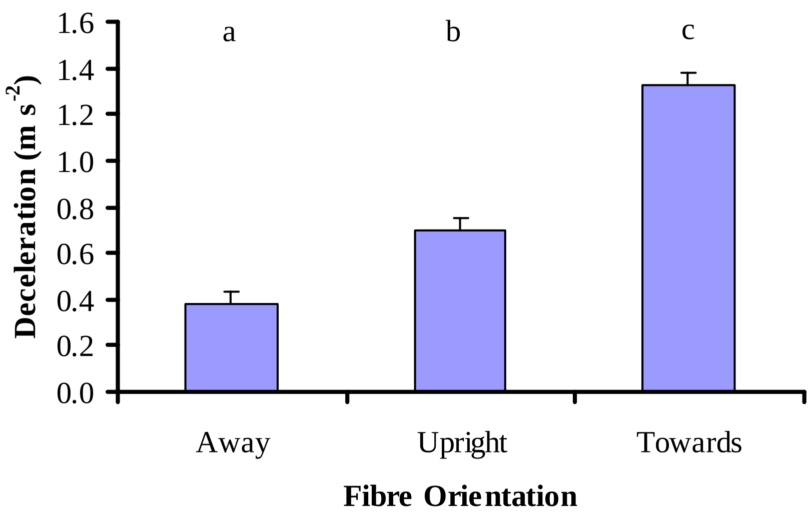


Figure 4.12 The effect of fibre orientation on ball roll deceleration on a synthetic turf surface. Whiskers represent the standard error of the mean (0.0524 m s^{-2}). Means with identical superscripts cannot be separated by the LSD (5%)

4.1.5 Evaluation of laboratory performance data and implications for further work

The laboratory investigations were used to isolate the external factors that affected the measurement of the performance data in the field survey.

The data obtained from the laboratory investigations were found to be within the minimum and maximum values for each of the performance tests in the field survey. There was less variation within the data and this made it possible to quantify any relationships that were exhibited between surface conditions and performance characteristics on the assumption that the scaled plots were representative of the field construction –as indicated by the comparable hardness in Sections 3.2.2 and 4.1.1.

The laboratory experimentation allowed testing on homogeneous replicates; it controlled factors such as maintenance, meteorological variations and surface conditions such as infill moisture content and construction variables. The experimentation could be extended by varying infill, carpet and shockpad materials in future studies but time did not permit such investigations in this research.

4.1.6 Summary of the surface performance testing of the laboratory test surfaces

The test STP surfaces have been used to carry out performance testing under controlled laboratory conditions. External factors, such as meteorological conditions, that in the field survey caused inconsistency during testing, were removed. The surface performance data were then used to investigate the possible interaction of different surface conditions seen in the field survey (see Chapter 3.2)

The aim of the laboratory performance testing was to address objective No. 1 and to test the hypothesis that the performance characteristics of a synthetic turf pitch are affected by infill contamination and moisture content.

The mass of infill per unit area was found to have a significant effect on surface hardness ($p<0.01$). At 15 – 20 kg m^{-2} of infill there was a significant increase as the inter-particle friction of the infill reduced the deflection of the carpet fibre and shock pad. The addition of contamination to the infill resulted in a significant reduction in surface hardness ($p<0.01$)

caused by the finer contaminant particles acting, not only as a filling in between the sand particles, but also as a lubricant (Naeini & Baziar, 2003). This will affect the reaction to the sand on contact with a falling mass; the infill will deform and be displaced under the reducing load and the contact time increased, reducing the peak deceleration on the falling mass (Carré et al, 2005).

There was a significant reduction of ball rebound with an increase in the mass of infill per unit area ($p<0.01$). As the falling ball contacts the surface, the force exerted on the sand particles moves them away from the point of contact and there is increased contact reducing the deceleration of the ball and reducing the rebound height (Figure 4.13). The addition of 10% contamination had the opposite effect and there was a significant increase in ball rebound ($p<0.01$) caused by the increase of inter-particle friction at the point of contact of the ball. This reduces surface deformation and increases ball rebound. The presence of moisture within the infill reduced ball rebound as the water acted as a lubricant reducing the inter-particle friction, and absorbing impact energy by permanent deformation, thus reducing energy return to the ball and the resultant rebound.

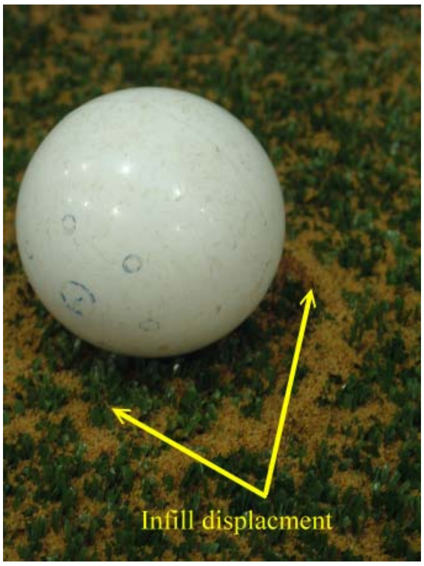


Figure 4.13 Infill displacement after contact of a falling hockey ball

There was a significant decrease in rotational resistance with an increase in mass of infill per unit area ($p<0.01$); the increased infill reduced the contact area between the dimples on the base of the apparatus and the carpet fibre. The increased mass of infill reduced the penetration depth of the dimples and lowered the friction between the two surfaces. Increased concentrations of contamination increased rotational resistance at 10% (w/w), but had no significant effect at higher concentrations.

Fibre orientation was found to have a significant affect on ball deceleration ($p<0.01$). Fibres facing towards the direction of ball roll were found to exert greater resistance through the stiffness of the fibre. When orientated away from the direction of ball roll, the fibres deformed and this reduced the friction between the surfaces. Deceleration increased with an increase in contamination within the infill; the increased number of particles increased the ball contact surface and the friction between the two surfaces.

The analysis of the data in this section has shown that an ineffective maintenance programme, which does not redress infill levels or reduce the build up of contamination within the infill, will result in the loss of surface playability. A surface will become faster and harder with a reduction in rotational resistance that may result in player injury. An STP manager will need to balance the maintenance of the infill, using a range of brushing methods, to ensure adequate player traction and ball bounce.

If the build up of contamination is not addressed, the widening particle size distribution of the infill could reduce surface infiltration rates, which has a significant effect on surface performance characteristics. The effect of contamination on the infiltration rates of an STP surface is addressed in the next section.

The laboratory results have shown that the control of factors such as concentrations of infill and contamination, and fibre orientation can change the performance of a synthetic turf pitch. The results have highlighted that it is not possible to recreate the conditions found in field testing, in the laboratory. The complex interaction between physical surface conditions, the pitch management programme, site location and meteorological conditions significantly vary between individual pitches; this prevents an effective experimental design to recreate all of the factors.

The performance characteristics of the carpet may be affected by a ‘capping’ layer, composed of synthetic fibres that have folded over, that reduces the contact of the player/ball and the sand infill. This layer will bind in the infill and prevent particle movement under load. This will result in increased surface hardness, ball roll deceleration and ball bounce and reduced rotational resistance.

4.2 Quantification of synthetic sports turf surface infiltration

Analysis of the test pitches experiment determined, in controlled conditions, that carpet infiltration rates were adversely affected by both the quantity of the infill and the contamination of that infill. The infiltration rate is a key parameter in the surface performance function and the infill contamination is a direct function of maintenance factors.

To investigate this relationship further, a series of laboratory experiments were designed, using an adapted permeameter described in Chapter 2.6.2. These experiments investigated the effect of factors such as the drainage hole, different infill specifications and different types of carpet.

4.2.1 The interaction between the drainage holes within a synthetic turf carpet and the concentration of contamination in the infill

The carpet backing is designed to be permeable; analysis showed that the drainage hole has a significant effect on the infiltration rate of the carpet/infill system (Figure 4.14). There was a significant negative correlation between the increase in contamination and the reduction in infiltration for both the ‘hole’ ($r = -0.973$ $p<0.01$) and the ‘no hole’ ($r = -0.723$, $p<0.01$) samples. The infiltration testing of carpet alone indicated that the presence of a drainage hole, as part of the carpet design, has a significant effect on the rate of infiltration through the infill/carpet system (Figure 4.14). This was significantly reduced by the introduction of contamination to the infill. A COCn of above 10% (w/w) will reduce the infiltration rate to the FIH minimum standard of 50 mm h^{-1}. This is caused by the reduction in pore size by the introduction of the finer particulate material. The results showed the effect that the contamination has on one part of a synthetic turf profile. In the conductivity chamber the carpet sample was positioned on perforated gauze and then a perforated cast iron base. Although rigorously checked for leaks the flow of water through the profile may have been inconsistent due to edge effects where the cylinder contacted the turf sample. Within a constructed STP profile, the synthetic turf is laid on top of a layered system that includes a rubber shock pad, tar macadam and engineered stone; all of which have an individual effect on the infiltration rate of the system.

Any spatial variation of infiltration within the STP profile will cause problems such as increased algal and moss growth, due to the increased moisture content of the infill (Figure 4.15).

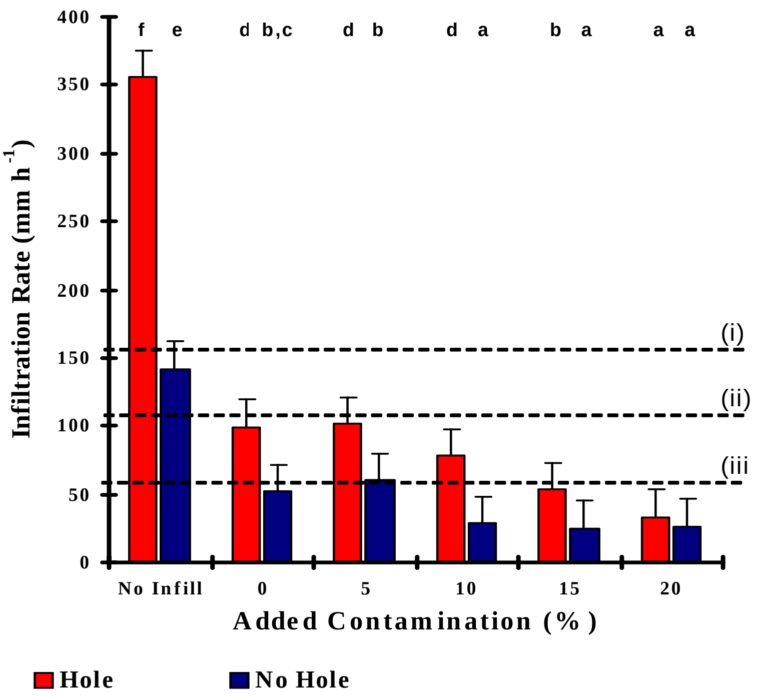


Figure 4.14 Comparison of infiltration rates with and without a drainage hole as a function of contamination and infill (Garside 2EW). Dashed lines represent the limits for the FIH performance Standards (i) Global, (ii) Standard, (iii) Basic. Means with identical superscripts cannot be separated by the LSD (0.05) of 19.58 mm h^{-1} (represented by the whiskers).

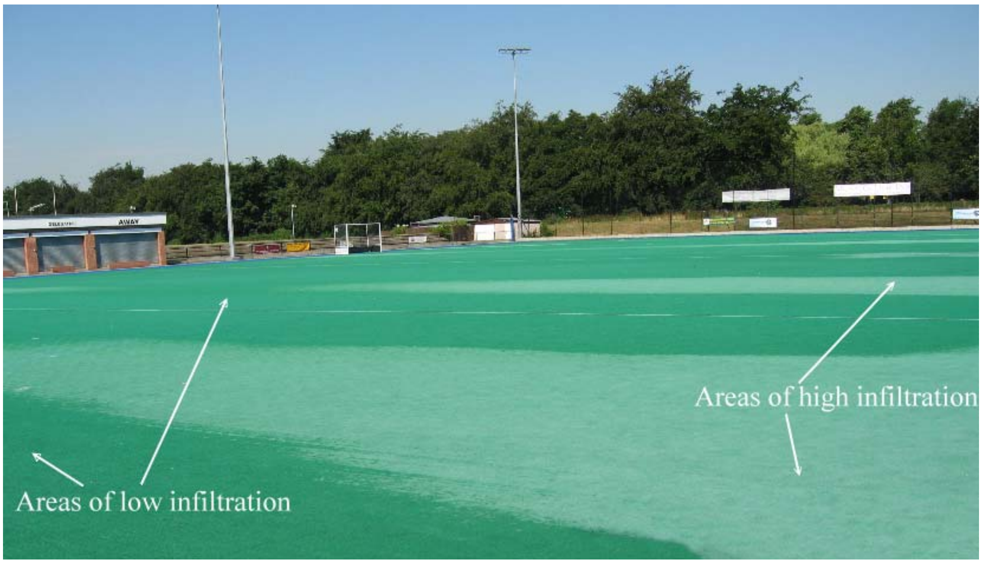


Figure 4.15 An example of uneven drainage, on a water based field hockey pitch (Severn, pers com)

4.2.2 The effect of infill specification on the infiltration rate of synthetic turf

Again a range of 0 -20% contamination was added, as per the recommendation from the field study. The addition of 5% contamination significantly reduced the infiltration rate of all three sand infills (Figure 4.18). At a 5% concentration of contamination the infiltration rates for all of the infill types were above the FIH basic performance quality standard of 50 mm h^{-1} (FIH, 1999). At over 10% contamination, both 2EW, the most commonly used of infill material and No.21 approached the ‘basic’ standard. 16/30 remains above the ‘basic’ rate until a concentration of 20% contamination. The results of the experiment indicate that if the level of contamination increased to above 10% then infiltration rates will be significantly reduced due to the reduction in the void ratio of the infill by the increased number of fines within the infill (Figure 4.17). Garside16/30 is less affected by the addition of contamination as it initially contained a larger particle size and had a narrower particle size distribution (Figure 4.16)

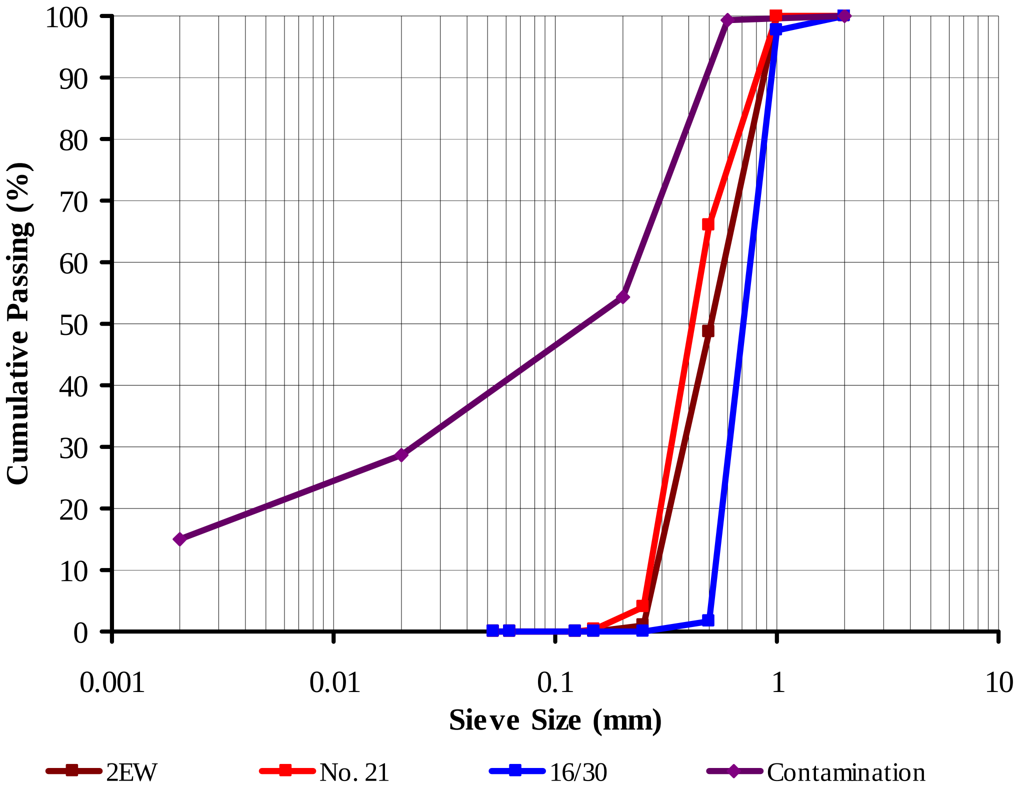


Figure 4.16 Gradation curve of the three sand infills and the sandy loam contamination used in the infiltration experimentation

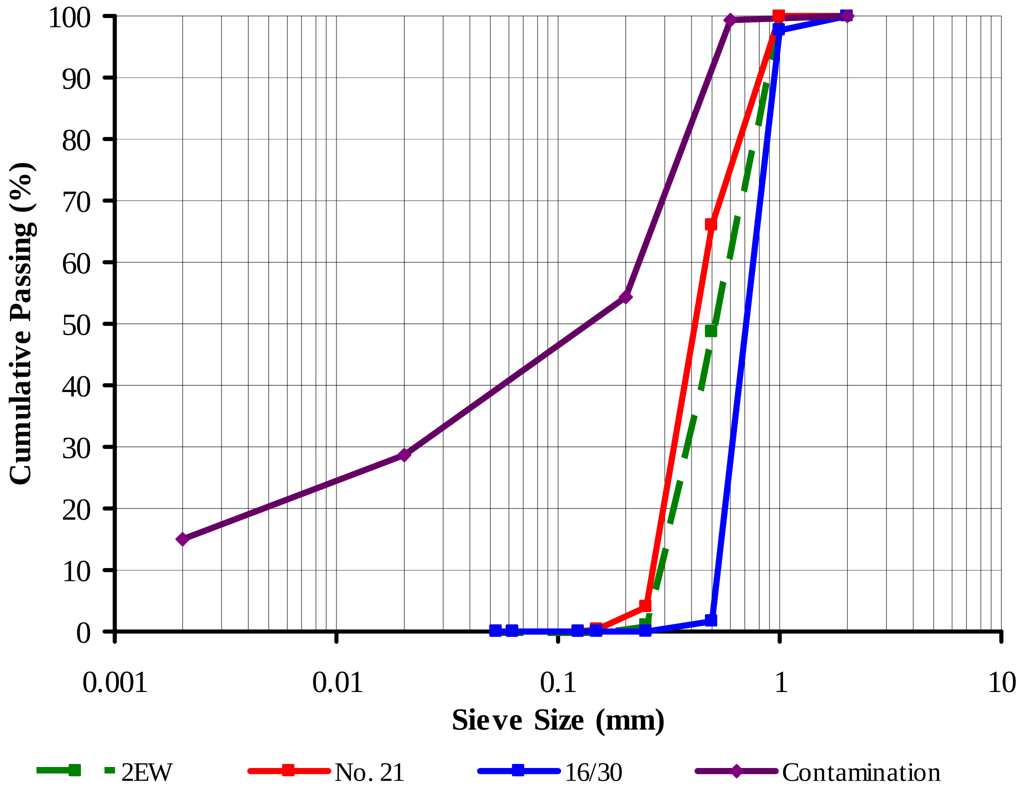


Figure 4.17 Gradation curve showing the change in particle size distribution with the increase of loamy sand contamination in Garside 2EW sand infill

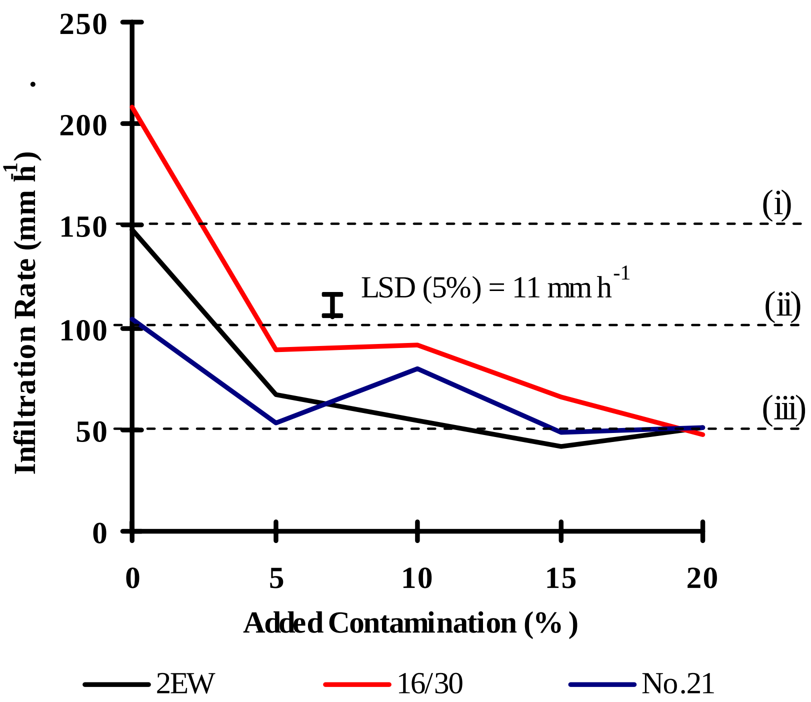


Figure 4.18 The effect of contamination on three commonly sand infills used in STP's. Dashed lines represent the limits for the FIH performance Standards (i) Global, (ii) Standard, (iii) Basic

4.2.3 The effect of compaction on infiltration rate

This was used to test the hypothesis that an increase in the concentration of contamination will, under a repeated dynamic load, increase infill compaction through deformation of the infill and reduce infiltration rates. The results indicated that compaction actually has less of an effect on infiltration rate than contamination (Figure 4.19) and therefore the hypothesis could be rejected.

The results from the effect of compaction on infiltration rates showed that, although there was an overall reduction of infiltration rates, there were inconsistencies in the effect it had on the different sand specifications. There was seen as an increase in infiltration rather than a continued reduction. The results are counterintuitive and could be the effect of the compaction process. This method will need to be explored at a later date. For this reason, the hypothesis cannot be rejected as there are doubts to the validity of the results.

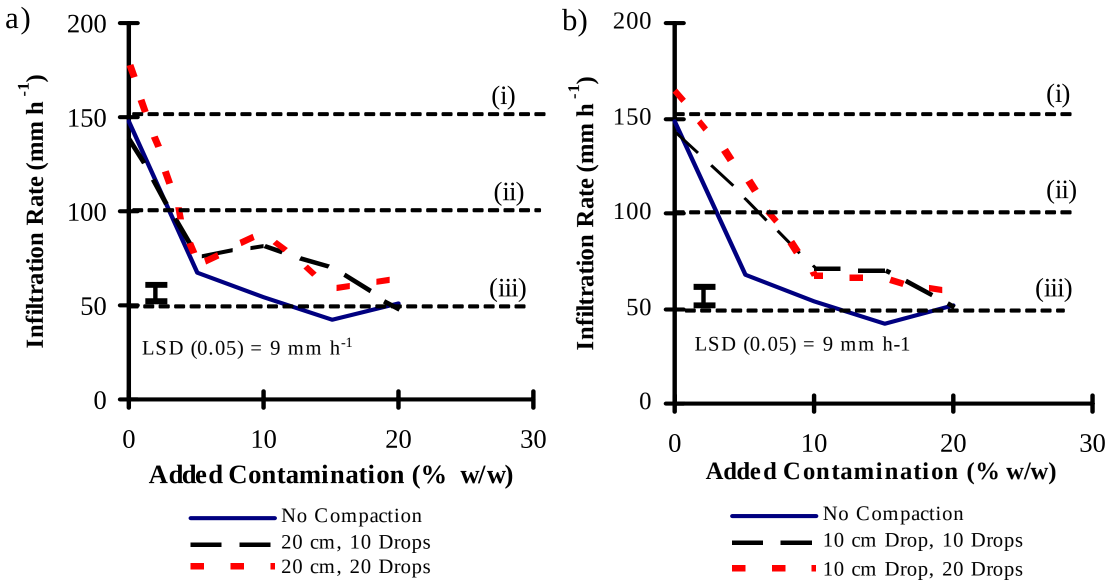


Figure 4.19 The effect of contamination on three commonly sand infills used in STP's. Dashed lines represent the limits for the FIH performance Standards (i) Global, (ii) Standard, (iii) Basic

4.2.4 The effect of contamination on infiltration rates in a third generation sand/rubber infill synthetic turf

The results were similar to the 2G sand-filled samples (Figure 4.20). As the concentration of contamination increased to 10%, the infiltration rate was reduced to the FIFA minimum standard. The 5% concentration of contamination had a less significant effect on infiltration rates of a 3G carpet than on a 2G carpet. This was caused by the differences in carpet specification shown in Table 4.2; the 3G carpet weave is less dense and has a mixed sand/rubber infill with larger granules and pores that allow higher rates of infiltration. The carpet samples were tested in their 'virgin' state, as the fibres defibrillate and start to wear and the fibres bend and lay flat the infiltration rate should be reduced further.

Table 4.2 Difference in carpet specification between the second and third generation synthetic turf carpets used for infiltration testing

Carpet Specification	Pile density (stitches metre^{-1})	Pile Height (mm)	Mass per unit area of infill (kg m^{-2}) Sand	Rubber
Second Generation (2G)	220	24	30	-
Third Generation (3G)	110	45	17	6

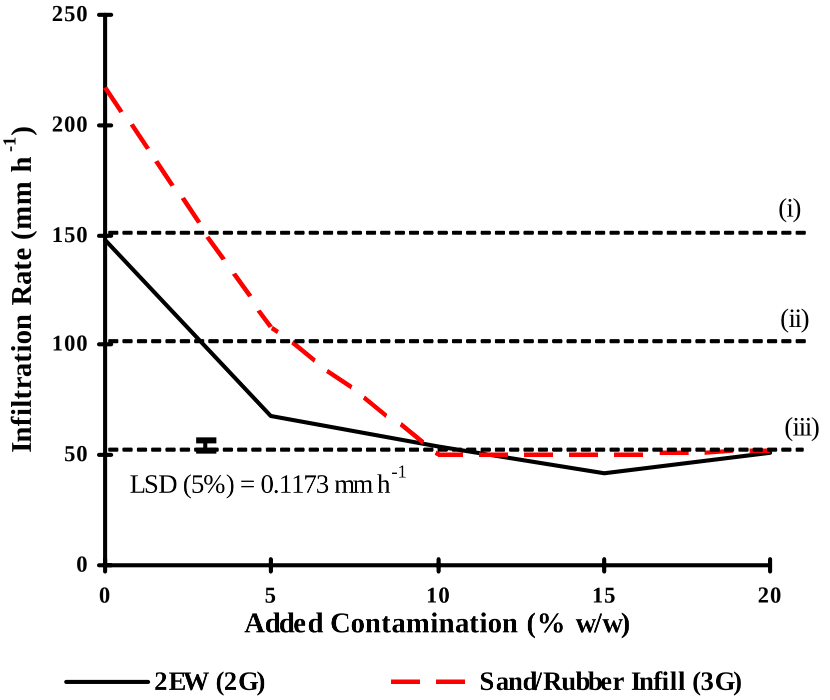


Figure 4.20 The effect of contamination of the infill rate of second generation sand infill (30 kg m^{-2}; 24 mm pile)and third generation long pile carpets (17 kg m^{-2} sand & 6 kg m^{-2} rubber; 45 mm pile) Dashed lines represent the limits for the FIH performance Standards (i) Global, (ii) Standard, (iii) Basic

4.2.5 *The effect of contamination on the infiltration rates of a short pile water based synthetic turf*

Although the dense pile of a short-pile carpet is designed to hold water in the densely packed fibres, it has a significantly greater infiltration rate ($p<0.001$) than the carpets with infill (Figure 4.21). Unlike other carpet specifications, the carpet backing for water-based carpets is impermeable and all movement of water is through the drainage holes; this prevents flooding of the surface due to the high volume of water used, approximately 140,000 litres, for each field hockey match. The high volume of water is used to provide a consistent coverage of water across the surface. Pressure caused by the head of water above the playing surface ensures infiltration into the carpet pile but excess water drains out to prevent flooding of the surface. The addition of contamination at a rate of 10 g m^{-2} significantly reduced infiltration rates. The lack of an infill and high infiltration rate meant that the contaminant was moved through the carpet pile to the drainage holes. Under the carpet layer there is a layer of shockpad that would have prevented any further movement of the contaminant particles blocking the drainage holes and reducing infiltration rates and water movement into the shockpad (Figure 4.22), see page 4.34.

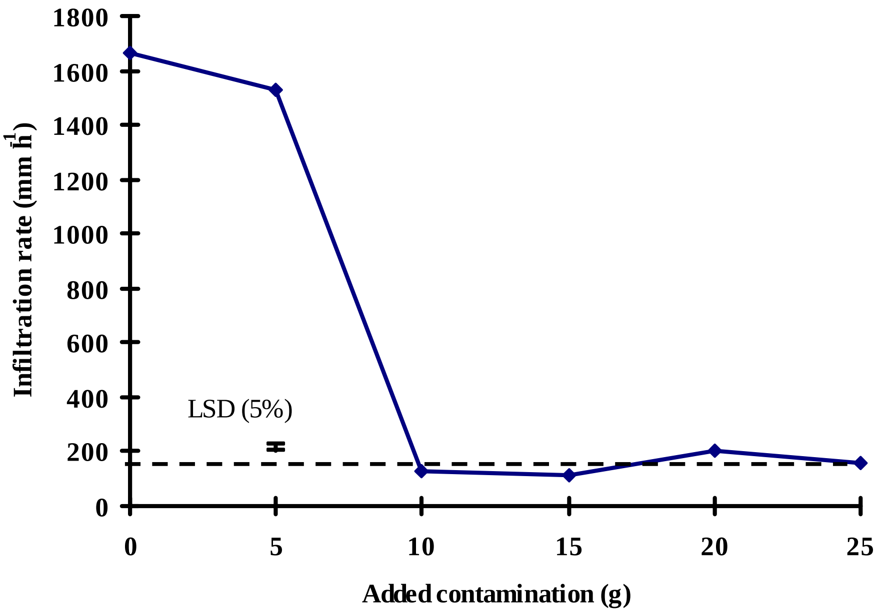


Figure 4.21 The effect of contamination of the infill rate of short pile water based hockey turf. Dashed lines represent the Global limit (150 mm h^{-1}) for the FIH performance Standards

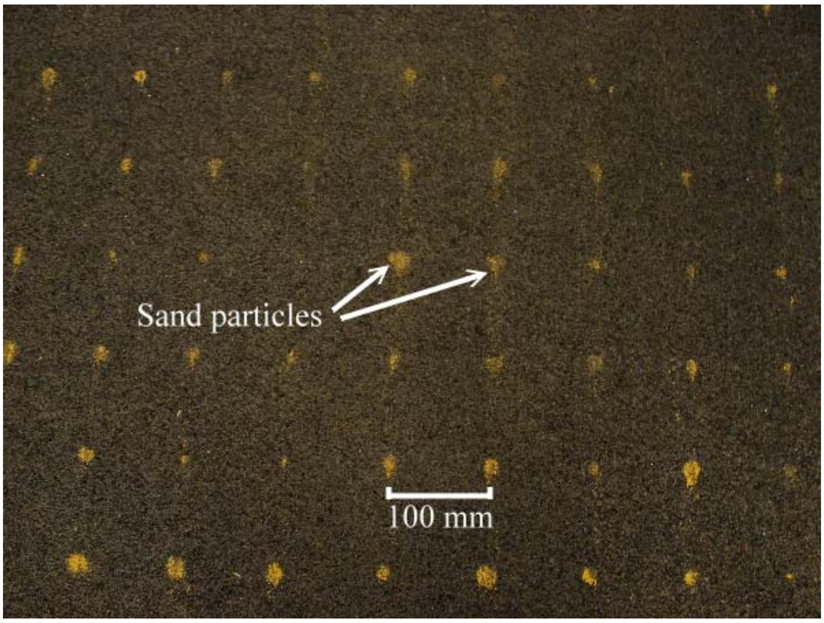


Figure 4.22 Sand particles that have been washed through the drainage holes of a second generation sand-filled carpet on a shock pad layer.

4.2.6 The effect of contamination on the infiltration rate of a purpose built synthetic turf construction profile.

The infiltration testing was performed using the homogeneous sand-filled synthetic turf construction profiles describe in Chapter 2.8. The experimentation was designed to compare the results from the carpet/infill only testing to infiltration testing performed on a complete STP construction profile.

The addition of 5% contamination significantly reduced the infiltration rate in both loose and compacted infill ($p<0.01$; Figure 4.23). The performance of the compacted infill was reduced to below the FIH global standard at a level of 10% contamination and at the 20% level (worst-case field scenario) was reduced below the basic standard. At this level of contamination the loose infill still performed above the FIH basic standard.

The effect of compaction on the constructed profile differed significantly from the carpet/infill only testing using the conductivity cells described above. The reason for this is the presence of the shock pad, in the constructed profile that deformed and absorbed energy from the applied dynamic load. In previous infiltration testing, the carpet sample was laid onto a rigid porous cast iron base.

This is a result of the finer contaminant particles acting, not only as a filling in between the sand particles, but also as a lubricant (Naeini & Baziar, 2003). This will effect the reaction to the sand on contact with a falling mass; the infill will deform and be displaced under load and the contact time increased. The deformation will reduce spore space within the infill and reduce the infiltration rate.

When compared to the results from the conductivity method of measuring the infiltration rate of synthetic turf carpet and infill only, the infiltration rates of the compacted surface confirm the original hypothesis that an increase in the concentration of contamination will, under a repeated dynamic load, increase infill compaction through deformation of the infill and reduce infiltration rates. This highlights the concerns that experimental error with the apparatus operation limited the relevance of the results.

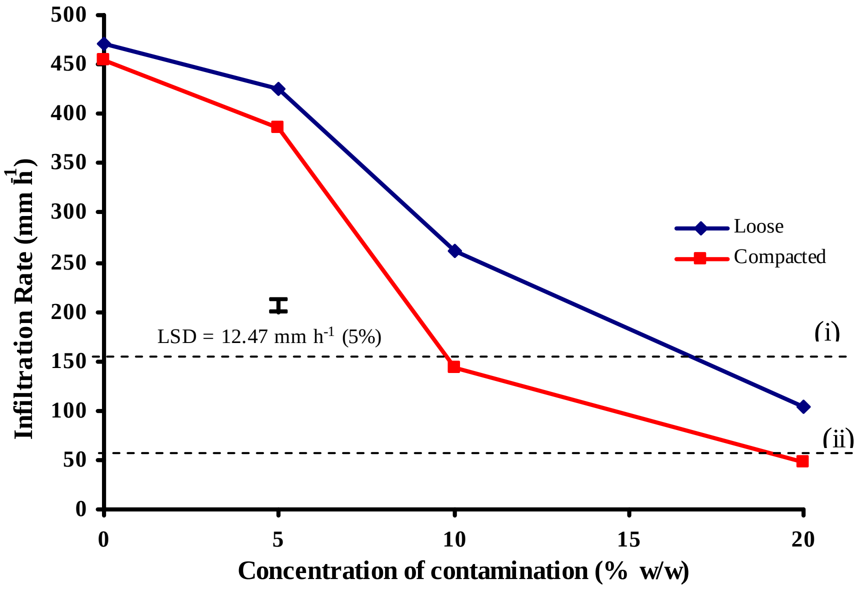


Figure 4.23 The effect of contamination of the infill rate of a second generation sand infill construction profile. Dashed lines represent the limits for the FIH performance Standards (i) Global, (ii) Basic.

4.2.7 Evaluation of infiltration data and implications for further work

The experiment was designed to quantify the effect that factors such as infill type (particle size and material specification), concentration of contamination and carpet specification had on the infiltration rates of synthetic turf. The method did not include a full construction profile and only measured the effect on the carpet/infill matrix; it did not measure the additional cumulative effect on infiltration rates of the shock pad and engineered base. There was a difference between the measured infiltration rate of identical turf samples, in the conductivity chamber (5.4 m d^{-1}), and on a constructed surface using a double ring infiltrometer (10.2 m d^{-1}). It was not possible to compare the two measurements because the field method, using the double ring infiltrometer has an intrinsic problem of how to seal the rings into the synthetic turf surface, thus sideways leaking above the surface interface occurs. The double ring infiltrometer was designed for field measurement of the infiltration rate of soils where the ring could be inserted into the soil surface to form a physical barrier to above-surface sideways movement of water.

The conductivity method used existing apparatus that was used for measuring hydraulic conductivity in natural soils. To include more layers from the synthetic turf pitch design the apparatus would need to be redesigned to accommodate deeper specimens and increasing diameter would reduce edge effects.

4.2.8 Summary of the quantification of infiltration rates of synthetic sports turf

The measurement of the infiltration rates of synthetic turf was used to quantify how they are affected by contamination and compaction. In the previous chapter, examples of existing maintenance equipment were tested for their efficacy in removing contamination from the sand infill of second generation STPs. The infiltration results of this chapter were used to determine the concentrations of contamination that reduce surface infiltration rates and consequently surface performance within the range of 'worst-case' scenarios measured in the field.

There was a significant interaction between the presence of a drainage hole in the carpet backing and the COCn. The infiltration rate of the semi-permeable carpet backing was significantly reduced ($p<0.01$) with the addition of infill only, from 140 mm h^{-1} to 50 mm h^{-1} and it was reduced further, to 20 mm h^{-1}, by the addition of contamination ($p<0.01$). The addition of a drainage hole, to the carpet backing, significantly increased the infiltration rate ($p<0.01$) from 50 mm h^{-1} to 100 mm h^{-1}. A further addition of 10% (w/w) of contamination reduced the infiltration rate to 70 mm h^{-1} and this was further reduced to 40 mm h^{-1} when the concentration of contamination was increased to 15% (w/w). The addition of 10 – 15% (w/w) of contamination reduced the infiltration rate to below the FIH basic standard of 50 mm h^{-1}. This is the upper range of measured field conditions in the survey of maintained facilities in Chapter 3, but is comparable to a scenario where contamination is concentrated in the top 50% of the infill.

The addition of 5% contamination significantly reduced the infiltration rate of all three sand infills tested; this was the minimum contamination measured in the field survey of maintained pitches in Chapter 3. At 5% concentration of contamination the infiltration rates for all of the infill types were above the FIH basic performance quality standard of 50 mm h^{-1} (FIH, 1999). The results of the experiment indicate that if the level of contamination increased to above 10% then infiltration rates will be significantly reduced due to the reduction in the void ratio of the infill by the increased number of fines within the infill. Garside 16/30 was less affected by the addition of contamination as it initially contained a larger particle size and had a narrower particle size distribution

Although a sand-filled second generation carpet was used as the main basis for this research, other carpet specifications, such as a third generation long pile, sand/rubber filled carpet and a water-based carpet, were also tested. The 3G carpet specification has a longer and less dense pile than the 2G carpet and, although 10% COCn significantly reduced the infiltration rate to the FIFA minimum of 50 mm h^{-1}, a 5% COCn had less of an effect than on the 2G specification. Although a water-based pitch has a shorter, denser pile than the other carpet specifications and is designed to hold water in the packed fibre, the FIH infiltration rate for this carpet is 150 mm h^{-1}. Rates of infiltration were significantly reduced by the addition of contamination ($p<0.01$) to the lower FIH standard of 50 mm h^{-1}.

The conductivity method was used to test the hypothesis that an increase in the concentration of contamination will, under a repeated dynamic load, increase infill compaction through deformation of the infill and reduce infiltration rates. The results from the effect of compaction on infiltration rates showed that, although there was an overall reduction of infiltration rates, there were inconsistencies in the effect it had on the different sand specifications. An increase in infiltration rather than a continued reduction was observed. The results were counterintuitive and could be the effect of the compaction process, within a confined cell.

To follow this up, the compaction was repeated on the three replicate homogeneous sand-filled synthetic turf construction profiles, described in Chapter 2.8. This was a further development on the conductivity cell method as it considers the complete system, including the sub-base. The addition of a 5% COCn significantly reduced the infiltration rate in both loose, from 500 mm h^{-1} to 416 mm h^{-1}, and compacted infill from 460 mm h^{-1} to 375 mm h^{-1} ($p<0.01$). This confirms the observations above regarding the minimum field value of 5%. The performance of the compacted infill was reduced to below the FIH global standard of 150 mm h^{-1} at a level of 10% contamination and at the 20% level was reduced below the basic standard of 50 mm h^{-1}. At this level of contamination the loose infill still had an infiltration rate higher than the FIH basic standard. The difference in results was due to possible experimental error within the compaction process of the conductivity method samples.

4.3 Summary of the laboratory based experimentation

The laboratory experimentation developed upon the results of the data from the field and questionnaire surveys. The results from the previous chapter could not be used to prove or disprove the hypothesis that the performance characteristics of a synthetic turf pitch are significantly affected by age and wear and therefore did not completely address objective 2. This objective can only be fully addressed once the effect of maintenance equipment has on wear of the fibre has been quantified.

4.3.1 The interaction between infill rates, contamination and surface performance parameters

The surface performance testing on the homogeneous sand-filled synthetic turf profiles was used to revisit the results from the field survey (Chapter 3.2) which were adversely affected by uncontrollable external factors, such as pitch age and surface conditions.

The field survey indicated that the concentration of contamination within the infill of an STP had an effect on surface playability. Analysis of the data showed that the mass of infill per unit area significantly reduced ball rebound ($p<0.01$) and rotational resistance ($p<0.01$), and significantly increased surface hardness ($p<0.01$) and ball deceleration ($p<0.01$). When wet, an increased concentration of contamination (10% w/w) significantly reduced ball rebound, surface hardness and rotational resistance. A proactive maintenance programme can be used to reduce the build up of contamination within the infill and prevent the loss of performance.

The relationship between the field and laboratory experiments is critical in terms of understanding the effect of contamination. For infiltration rate, the minimum field value of 5% is significant (see below). For other parameters 10% is a critical value. In the filed experiments maximum contamination was in this range – but if a concentration effect (in the top 50% of the infill profile) does exist then field contamination is significantly affecting the performance of the pitches in this study. It is important to note that the field investigation was carried out on maintained surfaces – it is possible that unmaintained surfaces could be affected to a greater extent.

There was an increase in surface hardness with increased mass of infill per unit area, and an associated reduction in ball rebound. As the falling ball contacts the surface the force exerted on the sand particles moves them away from the point of contact, absorbing energy that is not returned to the ball and increasing contact time. The flat head of the falling mass of the Clegg Impact Soil Tester has a larger contact area and compresses the sand particles normally and there is less translation of infill (Dixon et al, 1999). Surface hardness reduced as the concentration of contamination increased. This was because the finer contaminant particles reduced the contact area between sand particles in the infill (Naeini & Baziar, 2003). This reduction in friction reduces the bulk strength of the infill, resulting in increased plastic deformation, increased missile/surface contact time and thus reducing deceleration of the Clegg Hammer and therefore the measure of surface hardness. The reduction in ball rebound as the surface hardness increased is as outlined above.

Infiltration and subsequent drainage does not account for all water loss during the pitch drying phase. Like soils STPs retain water after drainage and further reduction in moisture content is a result of evaporation. To investigate whether the rate at which drying of the surface by this mechanism is a function of infill contamination, the loss of water through evaporation was determined by increasing the concentration of contamination in the infill of the test surfaces. Increased contamination resulted in significantly ($p<0.01$) increased moisture content immediately following saturation, until day 7 where there was no significant difference between the samples. During the winter months when evaporation is at its lowest, higher concentrations of contamination within the infill will provide the required conditions for the growth of moss or algae

4.3.2 The effect of surface type, infill and contamination variables on infiltration rates

The outcomes of the in-depth laboratory studies were that the sand used as the turf infill had a significant effect on the surface infiltration rate. Garside 16/30 (which had the largest pores) had the highest infiltration rate of 210 mm h^{-1} and Garside No.21 the lowest at 105 mm h^{-1} showing that the particle size and distribution have a significant effect on the infiltration rates of the surface. The selection of infill material is affected not only by infiltration performance, but also material cost; 1 t of 2EW costs £36 and 16/30 costs £73, at current prices (Robins, pers comm.).

When 5% (w/w) of contamination was added, the infiltration rates of all three infills were significantly reduced ($p<0.01$) and an addition of 10% contamination reduced the infiltration rates of No.21 and 2EW to the FIH basic standard of 50 mm h^{-1}. 16/30 was reduced to this infiltration rate by a concentration of contamination of 15 – 20 %. This effect on infiltration rate will increase the moisture content of an infill, resulting in reduced ball rebound, rotational resistance and surface hardness and slower drying as demonstrated above. The moisture within the infill acts as a lubricant between the infill particles and absorbs impact energy by permanent deformation.

The exercise included the investigation of the effect of contamination on both 3G long pile, sand/rubber infill carpets and dense pile, water-based carpets. The 3G sample had significantly reduced rates of infiltration at 5% concentration of contamination which were further reduced to below the FIFA basic standard of 50 mm h^{-1} by a 10% concentration.

The high initial infiltration rates of a water-based specification, 1640 mm h^{-1}, were reduced to 40 mm h^{-1}, by the addition of the equivalent of 1.27 kg m^{-2} of contamination (as this carpet system does not have an infill, the results are expressed as a quantity rather than a percentage of infill).

The interaction between infill contamination and compaction was investigated using the test surfaces as the adapted conductivity cell method was shown not to be suitable. The infiltration rate of the surfaces was reduced to below the FIH global standard by a 15%

concentration of contamination. On compaction of the surface, the infiltration rate was significantly reduced by the reduced pore size and fell below the FIH basic standard at 15 – 20% concentration of contamination.

4.3.3 Outcomes and implications for further work within this thesis

The surface and infill conditions that affect the performance of a synthetic turf surface have been identified. The results highlight two issues for the ideal maintenance of synthetic turf:

1. The importance of the mass of infill per unit area of synthetic turf
2. The significant effect of contamination on surface performance.

Practioners should be making regular checks on infill depth (assuming that this is a surrogate of mass of infill per unit area). Routine brushing methods should aim to reduce contamination through the depth of infill, which has been shown to increase over time.

The results from this Chapter, along with the findings of Chapter 3 were used to construct the scenario analysis for Chapter 6, the financial management of sand-filled synthetic sports pitches.

5 Chapter Five: Quantification of the effect of maintenance equipment on synthetic turf wear

5.1 Introduction

The development of maintenance equipment for synthetic turf pitches (STP) has, historically, been based on the adaptation of processes and equipment from the natural turf industry. This process of development has not included any research into the effect that the individual processes have on the structure of the synthetic turf; it has been on the basis that if it works on natural turf then it will on synthetic turf. Results from the existing equipment survey in Chapter 3 showed the efficacy on the equipment at removing contamination from the infill but did not quantify the effect that the equipment had on the structure of the synthetic turf fibre or whether moisture within the infill reduced the efficacy of infill removal.

A test rig was designed and fabricated to quantify the physical effect that the existing maintenance equipment had on synthetic turf. Testing the efficacy of the brushing processes under controlled conditions aided in the production of maintenance guidelines for second generation synthetic turf pitches. Full engineering and electrical drawings of the test rig are shown in Appendix F.

5.2 Test rig design

The initial design of the test rig is shown in Figure 5.1. To design the test rig, the following equipment characteristics were required:

a. The mode of action of the equipment upon the STP,

b. Brush dimensions (overall brush size and bristle dimensions),

c. Rotational brush speed,

d. Forward velocity of the brush in use,

e. The load exerted by the machine on the contact area of the brush; and

f. The applied force that is required to act upon the brush to exceed the frictional properties of the STP surface.

The test rig was based on a linear transmission guide moving a tray, containing a sample of synthetic turf, through a horizontal plane at a designated rate of translation. The tray was to be mounted on linear bearings and was to be moved through the required plane by a variable speed three phase electric motor.

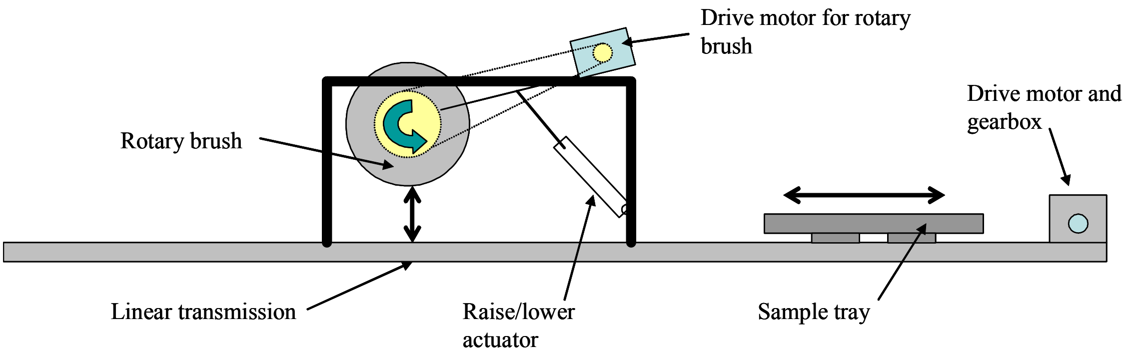


Figure 5.1 The original basic design for the maintenance test rig

The carpet samples that were used within this experiment were TigerTurf MP24, a 24 mm pile length polypropylene synthetic turf. The infill used was Garside 2EW (Garside, Leighton Buzzard, UK) applied at a rate of 30 kg m^{-2}.

5.2.1 Characterisation of the existing maintenance equipment

Prior to the design and fabrication of the test rig, the action of individual processes was reviewed and the forces applied by the relevant equipment were measured. There are two main processes used for the maintenance of synthetic turf: drag brushing and rotary brushing (Revitalisation and Renovation). Power brushing (rotary brush) is designed to penetrate the infill/carpet system to relieve compaction and remove contamination whereas; drag brushing redresses loose surface infill and realigns the turf fibre orientation.

The measurements taken during the course of characterising, both the action and the design, of the equipment used were used as a basis for the design of the test rig. There is a wide range of equipment used to maintain STPs and there was some reluctance from sectors of the synthetic turf industry to allow the characterisation of the equipment to be performed, but access was granted to a standard model SMG SportChamp (Vöhringen, Germany; Figure 5.2). The drag brush used was a double straight 1.85 m wide brush, previously provided with an STP build by Charles Lawrence plc (Newark, UK; Figure 5.3). These two pieces of equipment represented the perceived low and high levels of wear exerted on to the synthetic turf fibre by maintenance operations.

Figure 5.2 The SMG SportChamp that was used for the characterisation of the maintenance equipment

The results from the initial equipment characterisation are shown in Table 5.1 and indicated that the action of the rotary brush exerts a load approximately three times that of the drag brush (Table 5.1). This upper limit, along with the greater forward velocity, was used as the basis for the test rig design.

The measurement of the rotational speed of the rotary brush was performed using a mechanical direct contact torque meter (Smiths, London).

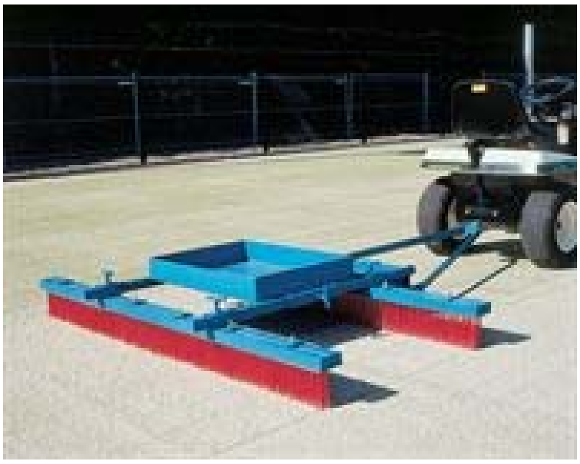


Figure 5.3 Double straight Dragbrush used for the maintenance of synthetic turf pitches

Table 5.1 Initial measures from the maintenance equipment characterisation

Measure	Drag Brush	Rotary Brush
Total brush length (mm)	1850	1200
Maximum forward velocity (m s^{-1})	6	9
Maximum rotational speed (rpm)	-	370
Rotational speed in contact with surface (rpm)	-	170
Bristle Length (mm)	150	140
Bristle diameter (mm)	1.9	2.3
Load per 100 mm of brush (g)	2430	7100

5.2.2 Calculation of the force required to move the brush over the synthetic turf surface

The design of the rotary brush of the SMG SportChamp did not allow the measurement of the torque, generated by the brush, using a torque wrench or any other conventional method of measurement. Test equipment was designed to measure the applied force required to apply the optimum shear stress between the brush and the sample of sand-filled synthetic turf (Figure 5.4). The output from this experiment was used to calculate the power output required for an electric motor to duplicate the rotational velocity of the SMG machine.

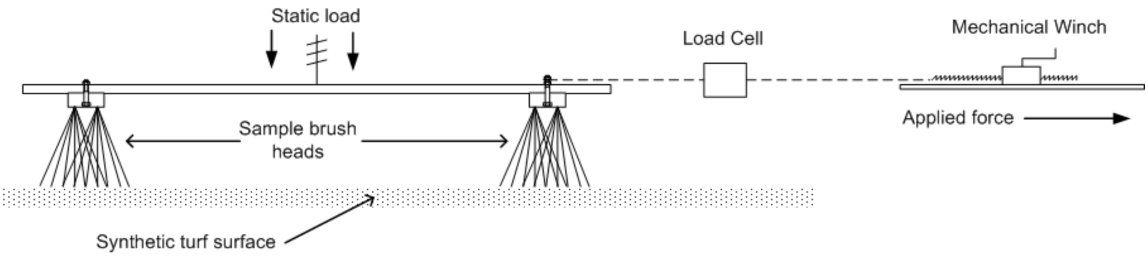


Figure 5.4 Apparatus used to measure the peak applied force to move the brushes under static load

Materials and Methods

The test surface was a 23 mm pile, polypropylene monofilament synthetic turf carpet with Garside 2EW sand infill at the rate of 30 kg m^{-2}. The test brush was composed of 2 mm diameter, 150 mm in length polypropylene bristles mounted in a softwood base. The two brushes were mounted either end of a 1000 mm x 350 mm, 3 mm steel plate that was connected to a Zbeam 100 kg load cell (Zbeam, London, UK). This was in turn connected to a manual mechanical winch that was used to apply horizontal force to the brushes. The output of the load cell was captured, via a data logger, on a laptop computer running DaisyLab version 8 data capture software (Figure 5.5). The design of the apparatus used for this experiment differed from the normal design of a power brush; it consisted on two contact brushes rather than one. This design was used to give stability to the apparatus when applying a normal load. The calculations for shear force allowed for the increased contact area.

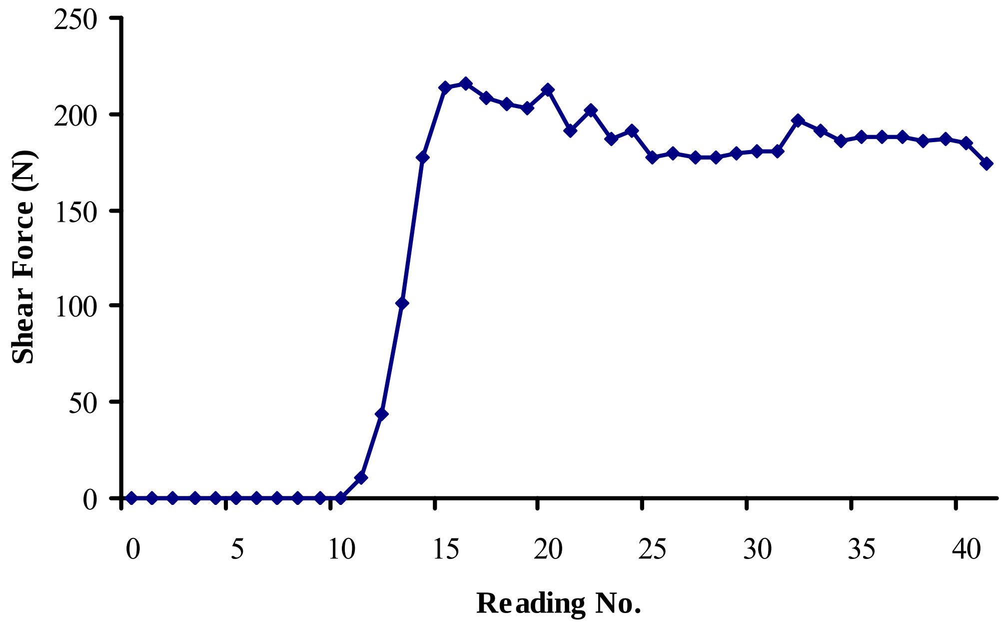


Figure 5.5 An example of the peak shear force output for the polypropylene brush under 65.2 kg applied load

The applied force was measured in kilograms and logged at 2 hertz. Normal load was applied to the brushes at 10 kg increments (3 replicates of each) and the mean peak applied force was recorded.

Results and discussion

The design of the apparatus used in this experiment differed from the rotary brush by the addition of an extra length of brush to give the apparatus stability under load (Figure 5.4). The results represented a greater area of bristle surface contact (2 x 300 mm wide brushes) and an example of the shear stress required to move the brushes over the surface under applied load are shown in Figure 5.6. From the results, the peak shear stress required to move the 700 mm length of brushes across the STP surface was 211.49N and the torque required to turn the brush when in contact with the surface was calculated using.

Equation 5.1 Calculation of torque

$$\tau = r\ F$$

Where τ = Torque, r = the position of the tip of the brush position relative to the fulcrum (m), and F = Force acting on the brush (N).

For this case, where there are two 350 mm wide brushes in contact with the surface, r = 150 mm and F was determined as 211.49 N, therefore the torque required to turn the brush was 31.7 N m. For the case of the test rig, the 300 mm wide brush required a torque of 13.60 N m

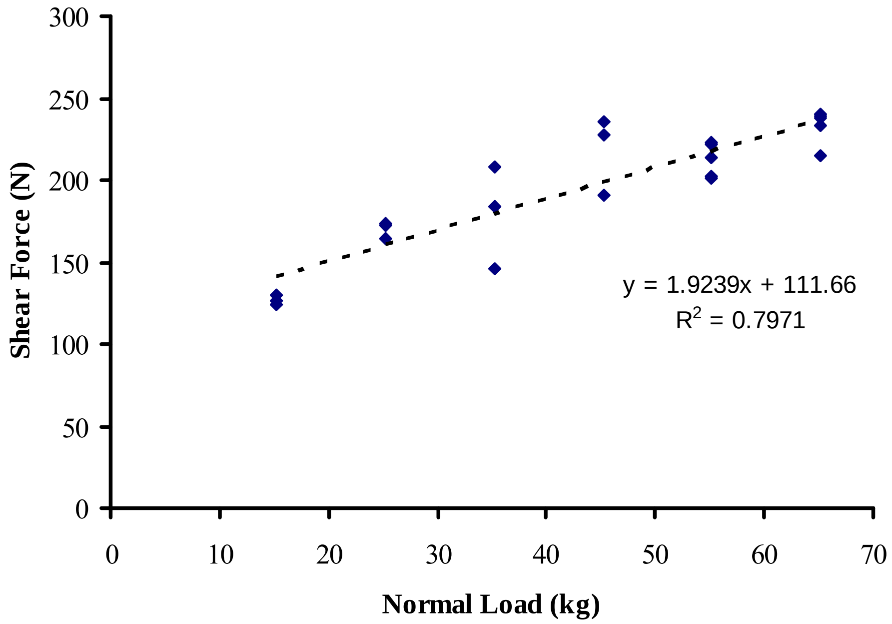


Figure 5.6 The shear stress required to move the brushes under increasing normal load. Dotted line represents the normal load exerted on the brush of an SMG SportChamp.

To calculate the power output of an electric motor to drive the brush Equation 5.2 was used.

Equation 5.2 Power output as a factor of torque and rotational speed

$$Power = \frac{2\pi\ \omega\ \tau}{60}$$

Where ω = rotational speed (rpm) and τ = torque (N m).

From this calculation it was determined that it would require an electric motor with a nominal output of 513 W to drive the rotary brush. A 20% allowance was made for possible inefficiencies within the motor and drive train, increasing the nominal output to 615 W. For selection of the relevant electric motor the nominal output was increased to 1 kW (1.3 hp).

5.2.3 Materials for use in the fabrication of the test rig

Test rig framework and linear transmission

For ease of fabrication and versatility the material used for the frame of the test rig was the 80 mm x 80 mm, Hepco (Tiverton, UK) Aluminium Machine Construction System (MCS).

The linear transmission used was a Hepco DLS4 with two carriages to carry the test tray. The weight of the tray including the test carpet and infill was calculated to be 12 kg and the load applied onto the tray from the brushing unit another 25 kg. The total load was 37 kg (363 N) which was within the specified maximum of 35 kN.

Drive unit for the rotary brush

The drive unit selected to drive the rotary brush on the test rig was a Clarke (Whyteleafe, UK) 1.5 hp, single phase, 4 pole motor with a rotation speed of 1500 rpm. The drive speed to the brush was reduced to 360 rpm, by using a belt drive pulley ratio of 1:4.2. As with the actual maintenance equipment the design rotated the brush in the opposite direction of the moving carpet sample.

The load exerted on the test surface by the rotary brush unit was tested using a Salter spring balance (1 x 250 N) and was measured at 132 N (13.66 kg). This was almost double the loading of the brush for revitalisation. This was reduced to 98 N (10 kg) by changing the pivot point on the brush drive arms. For the test rig to be used for rotary brushes designed to have a shallower depth of penetration, for renovation, the applied load on the brush was reduced to 69 N.

Raise/lower mechanism for the rotary brush unit was a compressed air actuator – SMC (Anaheim, USA) CP95 ISO/VDMA single rod, air cylinder with a stroke of 200 mm and a bore of 50 mm. The maximum load capacity of the cylinder was 7.5 kN operating under a compressed air feed of up to 10 psi. The brush unit was raised under pressure and lowered by releasing the compressed air. To prevent unwanted vibration, a restricting valve was located on the air output port to slow lowering speed of the brush unit (Figure 5.7).

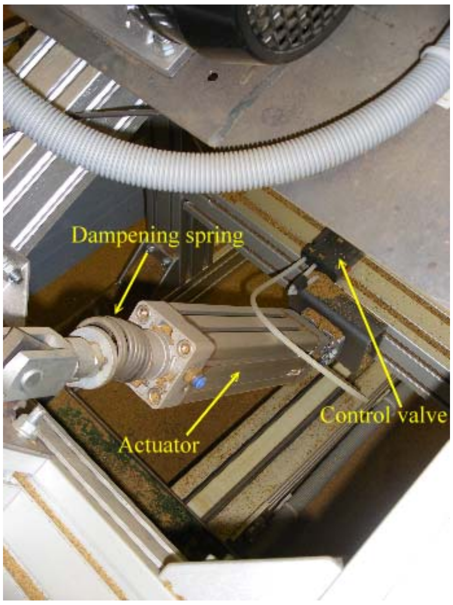


Figure 5.7 Brush unit raise/lower system

Drive unit and controller for the linear transmission

The selection of the drive unit was based on the requirement to accelerate the tray up to a maximum velocity of 2.5 m s^{-1} (9 km h^{-1}) and the weight of the tray. To enable this acceleration it was calculated that there would be 13 N m of torque generated at the pulley of the linear transmission. To ensure that the drive unit could react to the application of the rotary brush a Baldor (Fort Smith, USA) brushless AV servo motor was specified. To control the servo motor, a Baldor Flex+ Drive^{II} was used (Figure 5.8); this unit was used to define the tray acceleration, period of known velocity, deceleration, return of the tray to a 'home' position and the number of cycles for the tray to complete. Using an external output the controller initiated the raise/lower cycle of the rotary brush. The software used to in conjunction with the controller was Baldor Workbench version 5 which incorporated the Mint® programming language. The algorithm used is shown in Appendix F. The Workbench software enabled the capture of data, from the test rig, such as torque demand on the drive, acceleration profile and tray position. An example of the data capture output is shown in Figure 5.10; the negative values indicate the return stroke of the cycle which was defined at a velocity of 1000 mm s^{-1}.

Figure 5.8 Baldor Flex+ Drive^{II} located in the control box of the test rig

Confirmation of tray forward velocity and rotary brush speed

The rotary brush speed and the tray velocity were recorded by an independent external logging system. The tray velocity was measured by timing the transit of the tray between two micro switches mounted at fixed points on the track. The distance between the two micro switches was 700 mm and this represented the top of the speed profile for the tray. Once passed the second micro switch, the tray decelerates to a stop and then returned to a home sensor at a fixed velocity of 500 mm s^{-1}.

The rotary brush speed was measured using a Hall Effect gear tooth sensor (Honeywell, Canada) to sense 14 equally spaced steel screws embedded in the plastic hub of the conditioning brush (Figure 5.9). The brush speed, when in contact with the test surface, was measured by counting the number of pulses generated during sample transit between the two track fixed points. The average tray velocity and brush speed were computed by the logger for each test pass. The data was labelled with time, date and pass number and then stored.

Figure 5.9 Hall Effect gear tooth sensor (Honeywell, Canada)

Emergency stop strategy

An emergency stop strategy was incorporated in to the design of the test rig. Positioned at each end of the linear transmission were micro switches that would isolate the electrical feed to the system if the tray over ran. There were also emergency switches on the front of the test rig as well as on the control box.

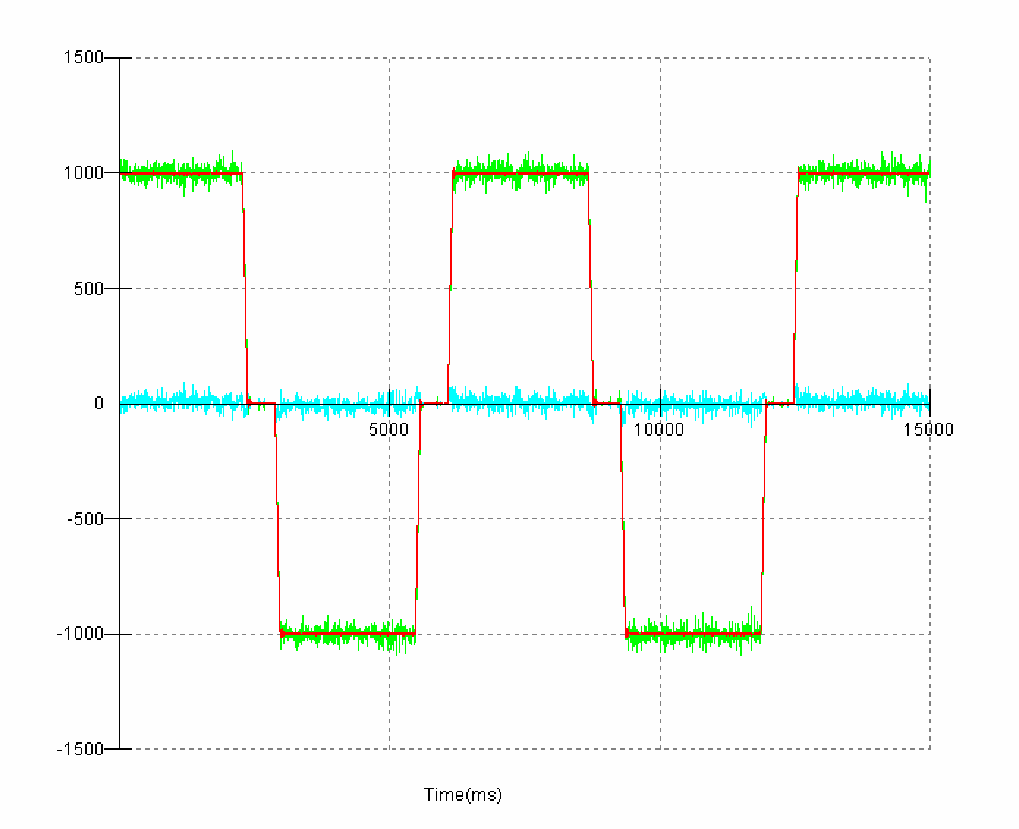


Figure 5.10 An example of the data capture from the Workbench software. The target velocity of the sample was 1000 mm s^{-1}. The red line represents measured velocity (smoothed); the green line, actual measured velocity and the blue line is torque demand on the motor.

5.3 Experimental design

The aim of the test rig design was to quantify the effect that maintenance has on the wear characteristics of synthetic turf and the efficacy of the action of brushing under controlled conditions. The conditions tested by the experimental design were:

a. The effect of infill and brushing on the wear of the synthetic turf.

b. The effect of the brush depth setting on infill removal.

c. The effect of moisture within the infill on brushing.

5.4 Quantification of the effect of brushing on the wear of synthetic turf fibres.

The field questionnaire indicated that the average frequency of power brushing was 6 – 10 times per annum. Using 15 years as the average lifespan of an STP, there would be up to 150 power brush applications on a pitch. The test rig was used to apply the power brushing procedure for up to 500 cycles, which equated to a frequency of 33 applications for each year of the STP lifespan. The brush was set at a depth of 10 mm below the carpet surface; this reflects the depth used during actual maintenance. After every 25 cycles of the test rig, fibres were taken from the carpet and the hypothesis that the abrasive contact between the synthetic turf fibre and the sand infill, when under load from the brush action, increased fibre wear was tested using the method devised by McLeod & James (2006). It was hypothesised that an increase in the mass of infill per unit area of synthetic carpet would reduce brush contact to the fibre that is above the infill surface resulting in fibrillation of the fibre tips.

5.4.1 Results

The initial exercise was to apply the brush to un-filled turf and quantify the effect of the bristle on fibre contact only. Although there was a reduction in the Peak Ratio (PR) between 0 and 60 applications of the brush, it was not significant (Figure 5.11). With no infill present to hold the fibres upright, there was little resistance by the fibre on contact with the bristles; resulting in the fibre deflecting out of the bristle path. After 500 applications there was a significant reduction ($p<0.05$) in the PR value showing that the brushing process only caused minor wear to the fibre.

The exercise was then repeated, this time including a Garside 2EW sand infill applied at a rate of 30 kg m^{-2}. The exercise was repeated to a maximum brush application of 500. After every 10 brush applications the sand infill was topped up to ensure bristle/fibre/sand contact. The results showed no significant reduction in PR ($p>0.05$) between 0 and 500 brush applications (Figure 5.12). Similar to the exercise that did not include sand infill, there was an initial reduction in PR but the variation in the data was high and so any significant change to the PR was masked by the background ‘noise’. Figure 5.13 indicates that there is a reduction in the linearity of the surface of the test fibres and that there was little abrasive wear caused by the displacement of fibre material from the surfaces in relative motion caused by the presence of the sand infill (Lancaster, 1969). There was no evidence of shear forces, caused by surface friction, fracturing the surface. There was pitting on the surface caused by the ductile properties of the fibre material (Figure 5.13).

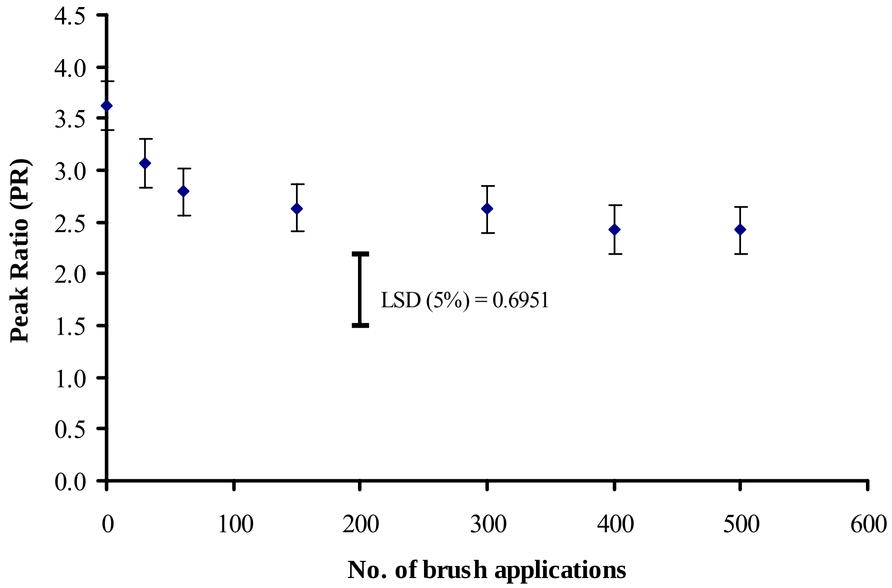


Figure 5.11 The wear of synthetic turf fibres caused by repeat applications of the rotary brush without infill and an applied load of 98 N. Whiskers represent the standard error of mean (0.2292)

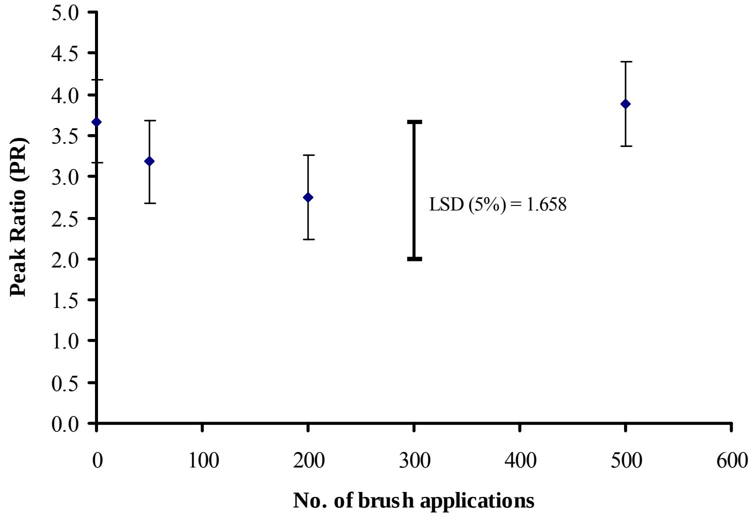


Figure 5.12 The wear of synthetic turf fibres caused by repeat applications of the rotary brush, with infill and an applied load of 98 N. Whiskers represent the standard error of mean (0.509)

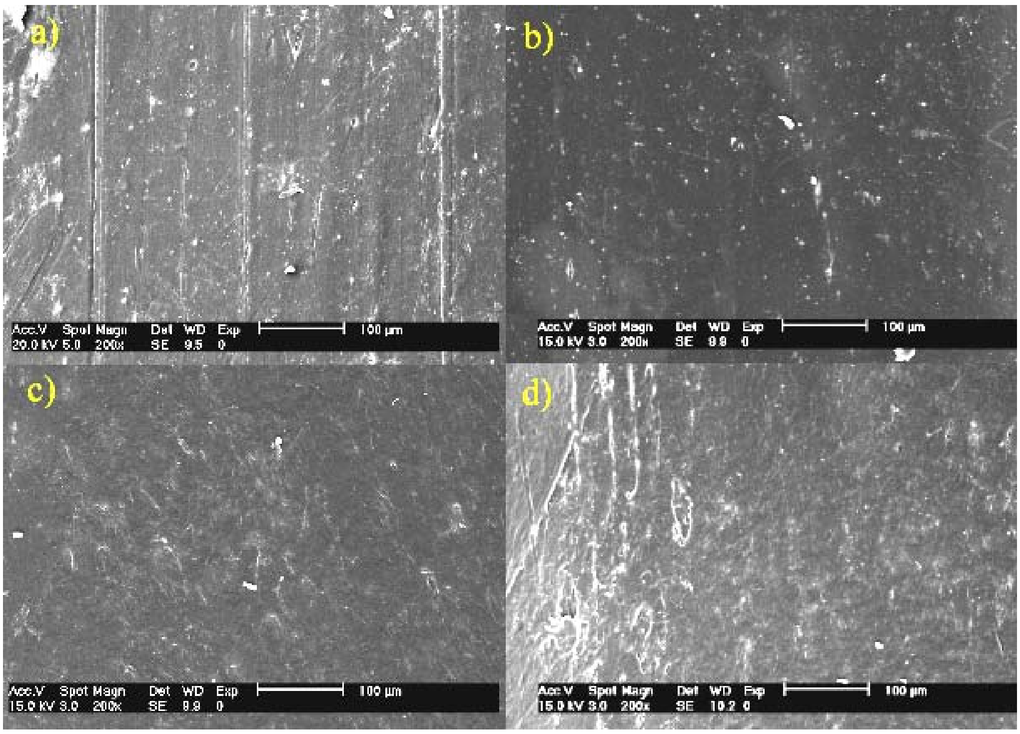


Figure 5.13 Time series of sand-filled synthetic turf and the number of brush applications; a) = 0, b) = 50, c) = 200 and d) = 500 brush applications

The above method considers the effect on the surface of the fibre. Optical methods were used to investigate the effect of the brushing on the fibre tip (Figure 5.14 and Figure 5.15). The images illustrate both the effect of increased brush passes (Figure 5.14) and the effect of sand infill (Figure 5.15) which both act to damage the fibre tips by splitting the tape. The fibre used in this experiment is a tape that is designed to fibrillate. The brushing with infill does 'fray' the fibre tip, causing it to split.

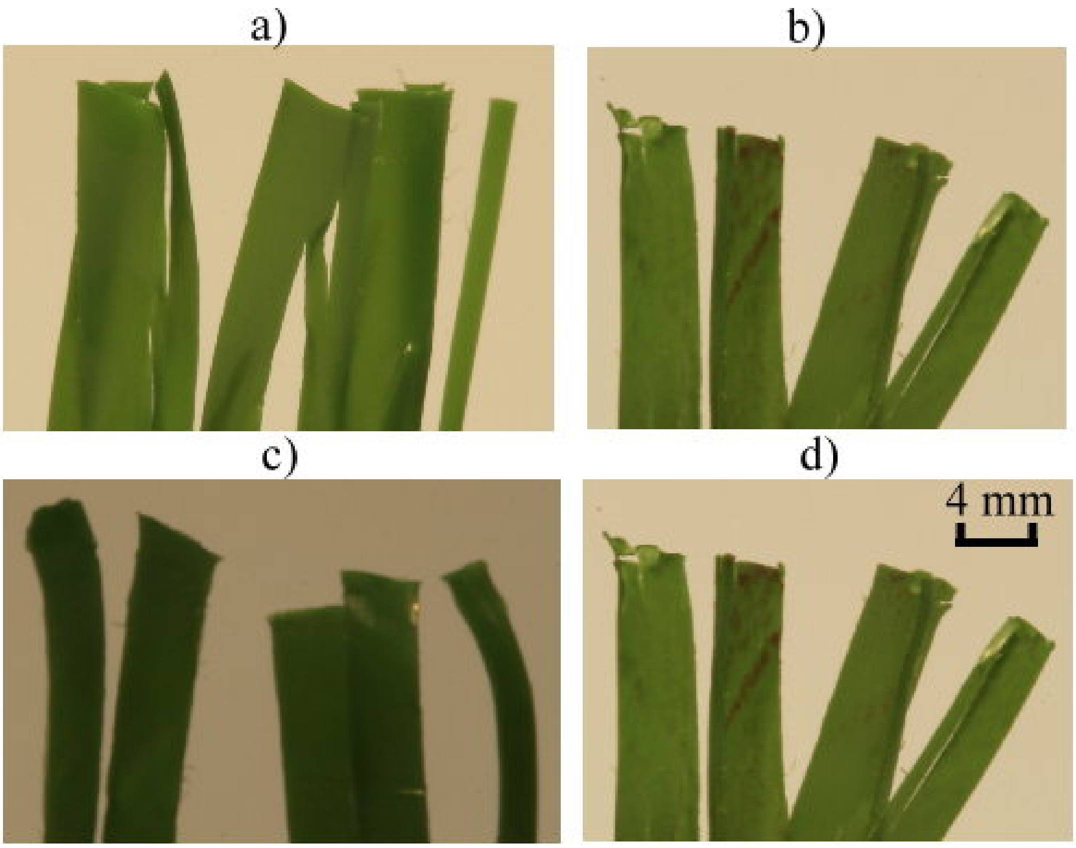


Figure 5.14 The effect of repeated brushing on a polypropylene fibre with sand infill a) virgin fibre, b) after 500 passes, c) after 60 passes and d) after 150 passes. (10 mm working depth, 98N brush load).

Figure 5.14b shows the damage after 500 passes, which is equivalent to 33 passes per year over a 15 year pitch lifecycle. This is at a frequency 11 times typical practice. Figure 5.14d shows the damage is present after 150 passes (10 passes per year over a 15 year pitch lifecycle) but it is not evident at typical brushing frequencies of 4 passes a year (60 passes over 15 years; Figure 5.14c). Figure 5.15 illustrates the important effect that the infill has in the wear of the fibre under brushing loads. Without the abrasive sand material, even after 500 passes, the wear is significantly reduced *c.f.* when sand infill is present.

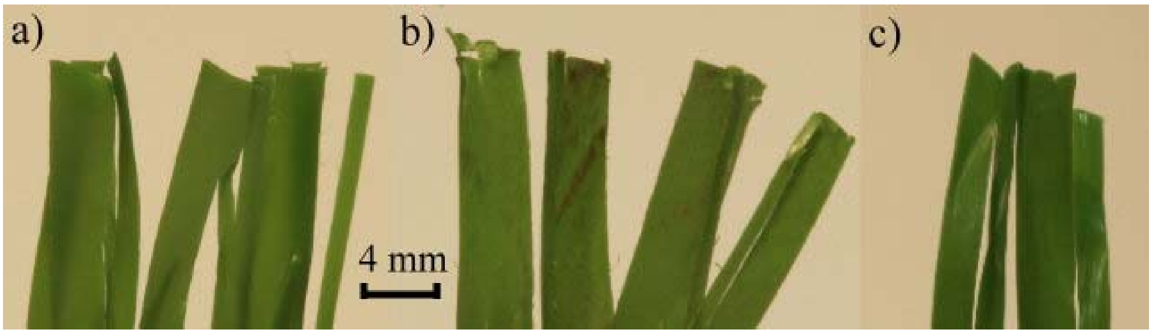


Figure 5.15 The effect of repeated brushing on a polypropylene fibre a) virgin fibre, b) after 500 passes with sand infill c) after 500 passes without sand infill. (10 mm working depth, 98N brush load).

5.5 Quantification of the effect of operational parameters on infill removal

5.5.1 Method outline

The test rig was used to reproduce the removal of the sand infill by the rotary action of the brush. The depth of infill removed was measured for the following conditions:

a. Working depth

The expected operating depth for existing maintenance processes is 5 mm for renovation and 10 mm for revitalisation. The brush depth was set using a fixed datum set below the test rig tray and rotary brush. From this datum the brush was set to the required working depth below the surface of the turf sample. The operating depth of the brush was set on the test rig using a rigid adjuster bar which prevented the brush mounting arms from depressing below the set depth. This design did not prevent any upward movement when the brush was in contact with the synthetic turf surface. These conditions were replicated three times.

b. Brush normal load

Characterisation of existing maintenance equipment calculated the normal load applied to the synthetic turf was 68 N for renovation and 98 N for revitalisation over an equivalent brush width. The normal load applied by the brush was adjusted by the addition of weights to the rear end of the rotary brush arms to counter balance the rotary brush head. These conditions were replicated three times.

c. *Infill moisture content*

The laboratory testing in Chapter 4 showed that an increase in the concentration of finer contaminants within the sand infill reduced surface infiltration and reduced the rate of evaporation of moisture from the surface (Figure 4.10). Further experimentation showed that surface hardness was reduced by moisture in the infill (Figure 4.5). To quantify the effect that moisture had on the removal of infill, distilled water was added to saturate the test surfaces. The samples were then left for 60 minutes to drain; gravimetric moisture content was then determined and then used in the wear simulator.

The depth of the height of the fibres above the infill was measured using a Sealey electronic vernier calliper (Bury St. Edmunds, UK) with an accuracy of +/- 0.02 mm. In this case, each turf sample was exposed to 5 cycles of the test rig to quantify the efficacy of repeated brushing to remove the infill.

It was not possible to measure wear using a mass balance approach because infill was removed from the sample by brushing and thus the change in infill mass was much greater than fibre mass and would require complete removal of the infill from the sample, which was not achievable, without further damaging fibres.

d. *Forward velocity*

Existing maintenance equipment have a maximum forward velocity of up to 2.5 m s^{-1} but there is no peer reviewed data on the effect of the forward velocity on infill removal. The forward velocity of the test sample was set at 0.5, 1.0 and 2.0 m s^{-1} using the MINT software, but was also checked independently using a data logger measuring the time taken for the tray to pass two fixed points on the test rig.

5.5.2 Results

Effect of working depth and brush normal load

The test rig was set up to reproduce the contra-rotating brush action of renovation (operating depth = 5mm & 10 mm; normal load 69 N) and revitalisation (operating depth = 10 mm & 20 mm; normal load 98 N). Figure 5.16 shows that as a general rule, there were significant differences between brush loads but not between working depths at the same brush load. Furthermore, there was an increase in infill removed with increasing number of passes but that the increment in removal reduced with each pass, whether a second pass is beneficial requires an analysis of the economic cost of doing so versus the marginal benefit.

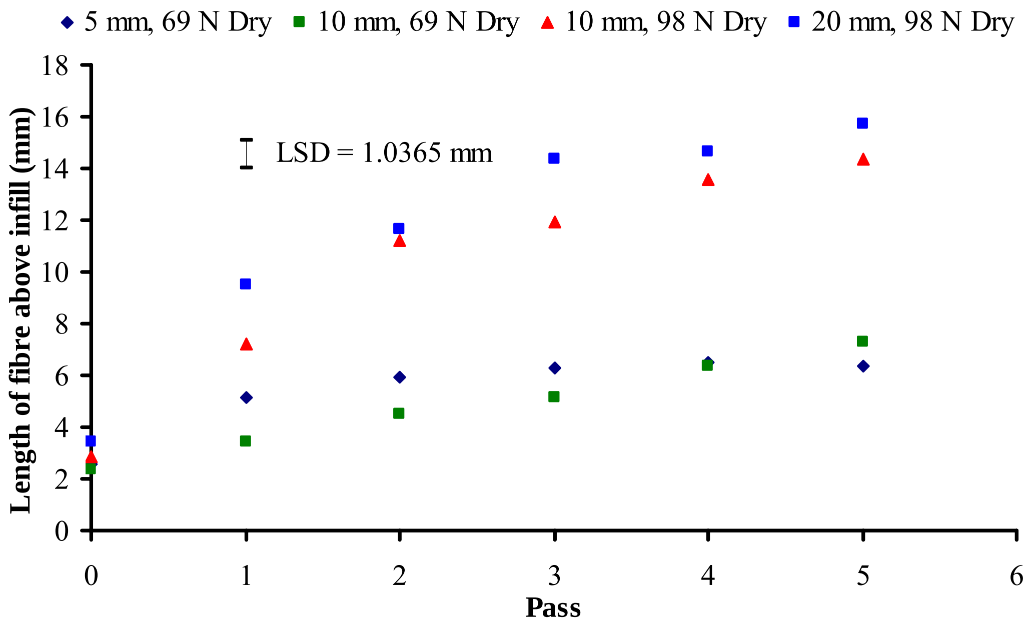


Figure 5.16 Length of fibre remaining above the dry infill for 1 – 5 passes of the rotary brush at a combination of working depths and brush loads.

This raises the question as to whether when the operating height stop on the rig is lowered the operational working depth of the brush is actually increased. The height stop fixes the maximum working depth but the brush is free to float and thus vertical reaction forces can act to reduce working depth.

If working depth increased, at the same brush load, then this should result in an increased load on either the tray or the rotating brush drive systems. The torque of the translational motor moving the tray was logged but the specification was such that no extra load on the system could be determined at the point of contact between the tray and the brush. Brush rotation speed was logged and there was a significant reduction of the brush rotational speed on contact with the synthetic turf surface ($p < 0.01$; Figure 5.17). The bars in Figure 5.17 illustrate the absolute difference in mean brush speed under load and the line represents the relative difference.

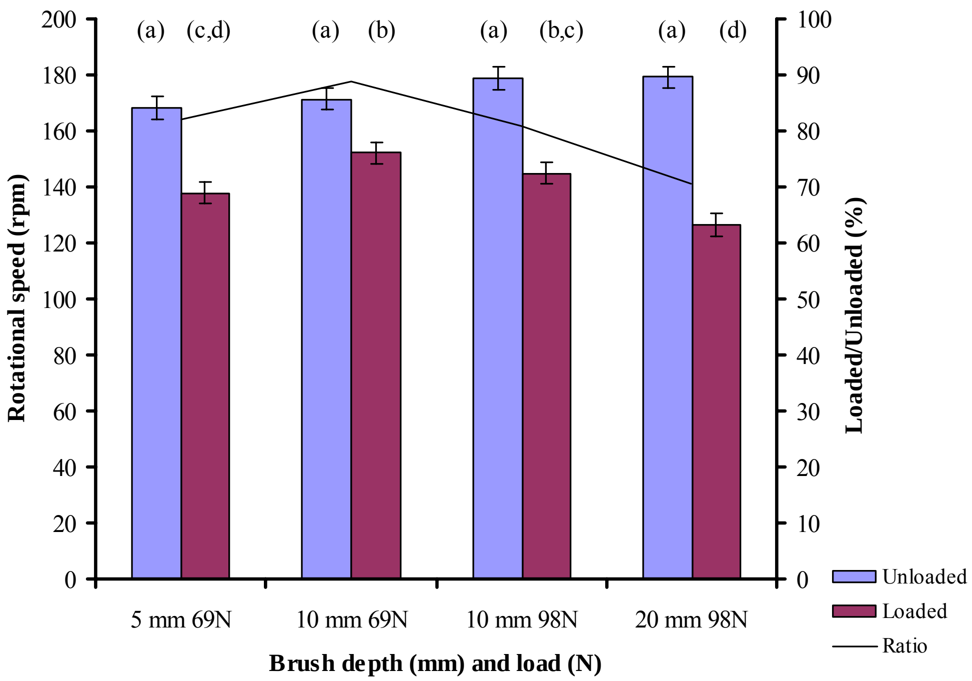


Figure 5.17 The effect on mean rotational velocity and working depth by contact with the synthetic turf surface. Whiskers represent the standard error of the mean (3.96 rpm). Subscripts represent group means separated by the LSD (5%).

For the 69 N brush load, there was actually less of a decrease in brush speed at the greater working depth, which is not expected because increased working depth should result in increased contact area between the brush and the carpet/infill matrix – resulting in increased load. Therefore either the brush fibre strength acts to raise the brush above the working depth stop on the rig by resisting the load on the brush or the increased working depth from 5 mm to 10 mm does not result in an increase in brushing load or effect by deforming the bristles and changing the angle of contact of the bristle tip with the surface (Holopainen & Salonen, 2004), or sufficient torque back-up in the brush drive for example.

The pattern observed at the 98 N load is as expected and the increase with load at the same nominal working depth of 10 mm also follows the pattern of increased load on the brush resulting in reduced brush speed. However this does not result in an increase in the amount of infill removed. The evidence from this investigation suggests that to increase depth of infill removal requires an increase in load on the brush, as well as a nominal drop in the working depth. Operators should be aware that it is important not to increase the load on the transport wheels of the machine as this could result in adverse compaction of the sand infill.

Effect of infill moisture content

The wetted infill moisture content was 9% ± 0.5% w/w. The increased moisture content of the infill had a significant effect on all combinations of brush depth and load ($p<0.01$; Figure 5.18). The magnitude of this reduction was greatest for the 98 N brush load.

The moisture increased the cohesion within the infill matrix due to surface tension and this reduced the ease with which infill could be removed for the same brush working depth and load treatments.

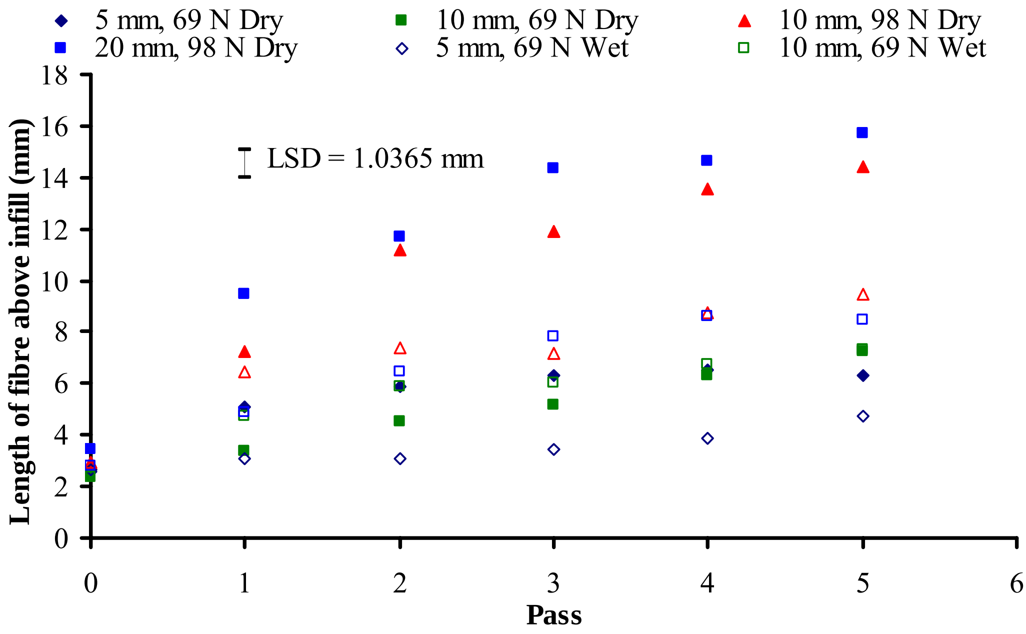


Figure 5.18 Length of fibre remaining above the dry infill (solid symbols) and wet infill (hollow symbols) for 1 – 5 passes of the rotary brush at a combination of working depths and brush loads.

5.5.3 Effect of forward speed on the removal of infill

To test the effect of forward velocity on the removal of dry sand infill, the brush working depth was set at 10 mm and the forward velocity of the sample increased from 500 mm s^{-1} to 2000 m s^{-1}. There was no significant difference between 500 mm s^{-1} and 1000 mm s^{-1} ($p>0.01$). There was a significant reduction in the infill removed when the velocity was increased to 2000 mm s^{-1} ($p<0.01$; Figure 5.19). As the rotation speed increased the bristle started to deform closer to the centre of rotation, reducing the contact with the infill, therefore reducing the friction between the two surfaces (Holopainen & Salonen, 2004).

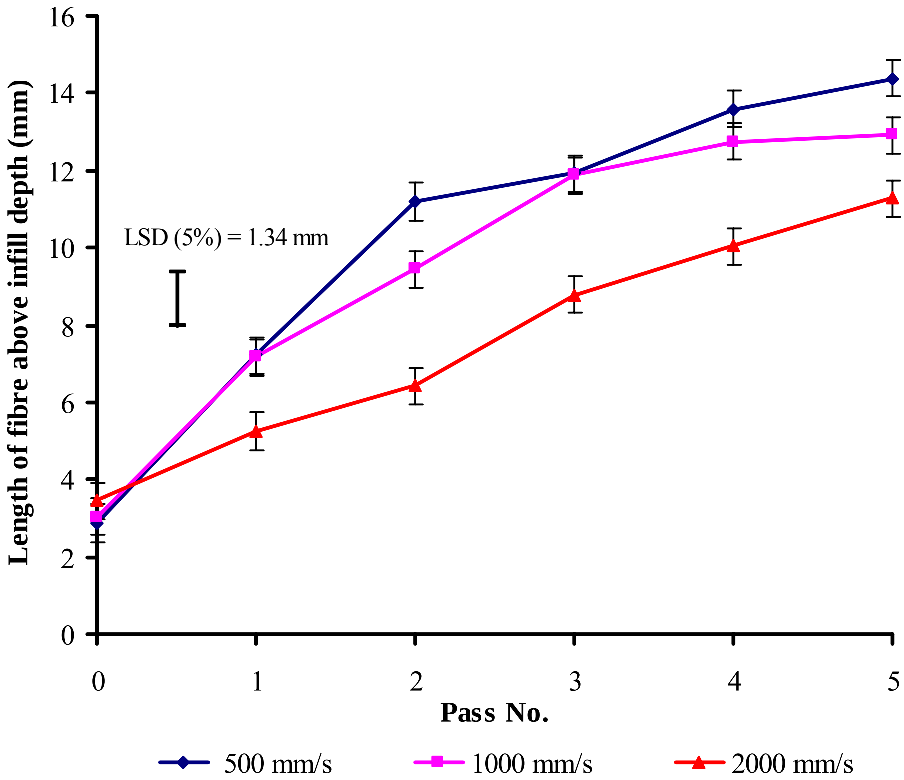


Figure 5.19 The effect of tray speed on the depth of dry infill removed from the synthetic turf carpet. Brush working depth was 10 mm and brush load 98N. Whiskers represent the standard error of the mean (0.477 mm)

5.5.4 Evaluation of fibre wear and infill removal data and implications for further research

How representative of the field condition, the laboratory experiment is, is not clear. The main reason for this is the carpet samples used on the test rig. The samples were new carpet that had not had exposure to wear, UV light or any meteorological conditions. Although the infill was 'tamped' into the carpet, it did not have the levels of compaction that would have been expected in the field. The results, therefore, represent the effect that maintenance would have on a 'new build' surface and not an ageing surface where perhaps conditions are more conducive to wear and are harder to treat; during the period of testing it was not possible to source samples of worn carpet.

The results did not show the effect that the folding of the fibre ends had on the penetration of the fibre/infill matrix. When a carpet fibre is not supported by the sand infill, regular dynamic loading through play causes the fibre tips to lose structure and fold over (Figure 5.20). The fibrillated fibre ends become matted and form a layer over the sand infill. This effect will reduce the efficacy of any brushing procedure that is designed to penetrate the surface of the pitch. This would reduce the working depth of the process and the infill removed and cleaned. If samples of 'capped' carpet had been available during the test period, the depth of brush penetration would have been significantly reduced when compared to that of the new carpet. To investigate the true effect of a 'capped' surface, further brushing trials should be run using worn samples.

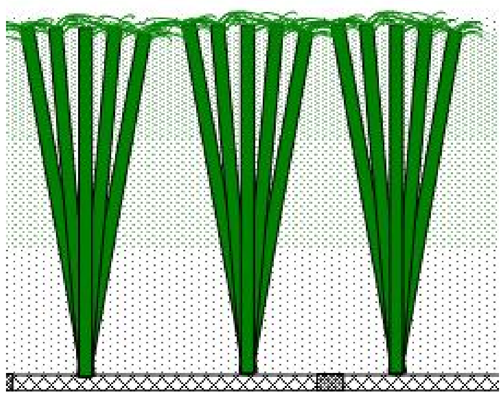


Figure 5.20 Fibrillated fibre ends 'capping' a synthetic turf surface.

Although the maintenance rig was designed to reproduce the action of maintenance equipment under laboratory conditions, there was some variation in the fixed depth of penetration by the brush on the samples. The rig design should be adapted to remove any 'floating' by the brush head.

5.6 Discussion and conclusions

The test rig was designed to characterise the effect that rotary brushing under differing normal loads and operating brush depths had on the wear of synthetic turf fibres and the efficacy of removing the sand infill. The following discussion is limited by the observations in the evaluation above.

5.6.1 The effect of contra-rotating brushes on fibre wear

The Peak Ratio method of quantifying wear of a synthetic turf fibre did not determine any significant wear effect on the face of the fibre from repeated passes of the brush. The results did show that the interaction between the sand infill and the fibre under load produced new surface characteristics such as 'pitting' of the fibre surface. The method quantifies the change in linear features of the fibre surface, but it could be developed to measure the degree of surface pitting.

Optical microscopy determined that there was wear of the fibre tip by repeated brushing when sand infill was present. The effect was observed at 150 and 500 passes (2x and 11x typical brushing frequencies, respectively; it was not observed at 60 passes (equivalent to 4 passes/annum and more typical of high commercial brushing frequencies). Neither was it observed in the absence of sand infill.

The fibre used in the carpets tested is designed to fibrillate in this way but it must contribute to fibre wear if brushing frequency is excessive – it is possible to over-brush a surface but it is unlikely to be economical to do so. This analytical method could be used on modern mono-filament fibres to investigate whether this effect is significant in new 3G surfaces.

5.6.2 The effect of operational parameters on infill removal

The effectiveness of the brush in terms of infill removal was determined to be a function of brush vertical load, rather than brush working depth, as it was controlled in this experiment. For brush systems where the brush is free to rise in operation, then the requirement for increased vertical brush load needs to be considered. Furthermore, the first pass of the brush removed the largest quantity of infill; whether or not a second pass is of benefit will depend on the economic cost of doing so, versus the marginal benefit.

The effectiveness of the brush after a single pass was reduced when forward speed was increased form 1 m s^{-1} to 2 m s^{-1}, thus an optimum (both technical and economic) operating forward speed of 1 m s^{-1} was determined. Current commercial operating equipment is capable of 2.5 m s^{-1} and the equipment can be pushed to this limit to improve cost effectiveness of contract operations – this is not advised.

5.7 Outcomes and implications

The results from the test rig showed that the conditions under which the maintenance process is operating have a significant effect on the removal of the sand infill. The main objective of each of the individual maintenance processes is to remove and filter the sand infill, and return it to the playing surface. The presence of moisture reduces the infill removal by approximately 60%; further passes of the equipment will remove infill to a greater depth, but this will increase the time that the STP is out of use and the cost of the maintenance process. These factors would need to be balanced against the benefit of the maintenance process before deciding on further action.

The results from the test rig and Chapters 3 & 4 were used to address the effect that the maintenance programme has on the financial management of an STP.

The results from the test rig were also used to address some of the research objectives for this study.

Objective 1 was

To determine a relationship between wear, maintenance and performance characteristics of the synthetic turf surface over time.

The Peak Ratio method showed that regular Revitalisation and Renovation of the STP does not cause significant wear to the turf fibre faces but optical analysis did show damage to the fibre tip at a simulated wear of 10 passes per annum. This damage was not observed at four passes per annum; neither was it observed at 33 passes per annum in the absence of sand infill.

Objective 3 was

To develop and implement measurement methods and techniques for assessing the effectiveness of existing maintenance equipment on synthetic turf and infill material.

The results have shown that brush vertical load and the presence of moisture within the infill have a significant effect on the efficiency of the maintenance processes. Operating forward speed should be limited to 1 m s^{-1}.

Objective 4 was

To determine a relationship between wear, maintenance programme and economic life-cycle costs of synthetic turf surfaces over time.

The efficiency data from this exercise were used as part of the scenario analysis in the management of sand-filled synthetic turf surfaces.

Objective 6 was

To provide scientific based guidelines for managers to allow informed decisions on the management and maintenance of synthetic turf pitches.

The data from this chapter along with the data from the preceding chapters was used as the basis of the guidelines for the maintenance of STPs.

6 Chapter Six: The financial management of sand-filled synthetic turf sports pitches

6.1 Introduction

This chapter addresses Objective No. 4, which is: *To determine a relationship between wear, maintenance program and economic life-cycle costs of synthetic turf surfaces over time*. This chapter also aims to use this relationship to build and run a sand-filled synthetic turf sports pitch (STP) which is economically sustainable in the long run. The provision of an STP requires capital investment from the sports provider and can be a drawn out process. It is, therefore, important that any information, that may improve the efficiency of such a project, is made available to the purchaser. A prospective buyer needs to know the expected expenditure for the selected system over its lifecycle to enable effective budgeting for future non-capital and capital expenditure.

Often the only information available is commercial literature which is designed to attract prospective customers towards the desired product. There is a variety of independent information available on STPs, most of which is available from sports governing body websites (e.g. FIH, FA & FIFA). This information mainly covers the planning and selection process, performance quality standards and advice on the grant application process. There is little or no independent information on the financial cost involved with STP provision and how these costs are affected by factors such as maintenance and pitch use.

The literature review indicated that there are gaps in the knowledge and understanding of the management of synthetic turf surfaces. A financial model was constructed to achieve, Objective No. 4 and to provide financial information for existing and potential managers of STPs.

The input information for the financial model was derived from the field questionnaire survey. Any other financial information that was required was taken from commercial sources at the same time as the survey.

6.2 Stakeholder analysis of individuals and companies involved in the construction of a sand-filled synthetic turf pitch

To be able to address Objective No. 4 it was important to identify the key stakeholders within the process of construction, maintenance and provision of an STP. This allowed the financial analysis to be in a format that was relevant and understandable to the key stakeholders.

Using the process of stakeholder mapping (Mendelow, 1991), the stakeholders within a project were identified by the author, considering the interests that they represent, the amount of power that they possess and whether they represent inhibiting or supporting factors for the project.

To help demonstrate the importance of the relationships with these stakeholders a power/influence matrix was designed, based upon the Author's opinion. The matrix was used to classify the stakeholders in relation to the power or influence that they are able to exert on the organisation and the extent that they are likely to show interest in a STP project. The following individuals/companies were identified as potential stakeholders of a STP (Figure 6.1):

a) Operators of STPs – senior, management level, employees who are involved in key financial and strategic decision making processes.

b) Funding bodies – organisations, such as The Football Foundation and The Football Association, who provide grant aid to sports clubs for the provision of sports surfaces.

c) Installation contractors – this includes all contractors and sub-contractors who are involved in the design and build of an STP.

d) STP users – all members of the club/organisation who are to use the STP.

e) Specialist maintenance contractors – companies who provide specialist services extra to the normal maintenance on STPs.

f) Local residents – this is the part of the community that will be affected by the initial build and ongoing use of the STP.

g) Local authority – the STP build will require planning permission from this body.

h) Company/club employees – once constructed there will be a requirement for routine maintenance, which is often performed by existing staff.

i) Natural turf traditionalists – there are areas of the sports turf industry that are against the use of synthetic turf in any form.

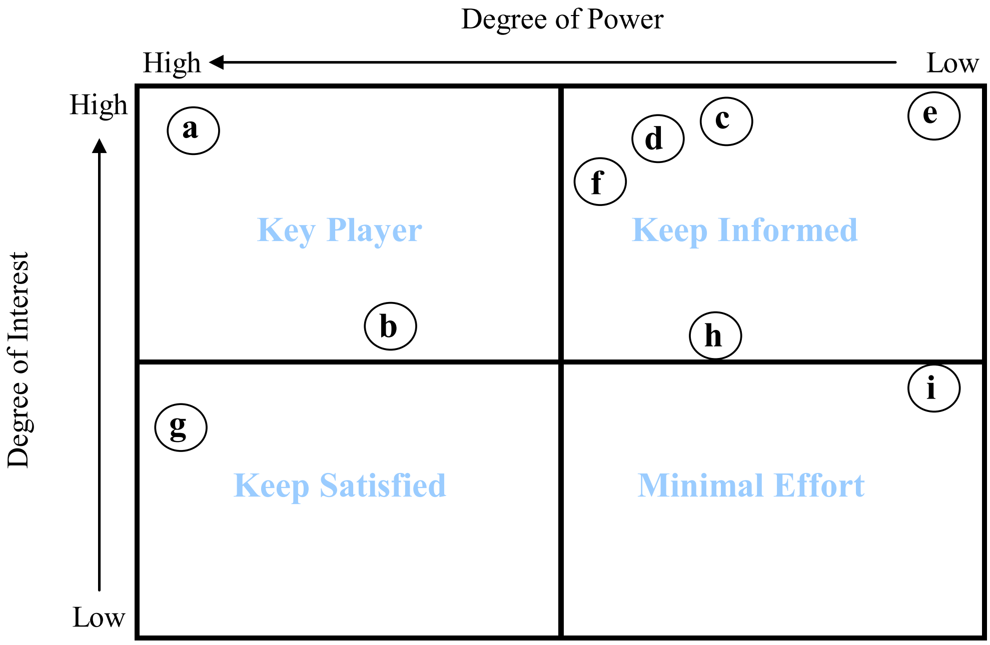


Figure 6.1 Stakeholder mapping of the interested parties, as identified by the author, involved with the build, maintenance and use of a synthetic turf sports pitch. Letters represent: a) STP operators, b) Funding bodies, c) Installation contractors, d) STP users, e) Specialist maintenance contractors, f) Local residents, g) Local authority, h) employees and i) Natural turf traditionalists.

The Key Players were seen to be STP operators and sport governing bodies as they are the only organisations that are able to directly affect the progression of the project. Due to competition within the market, the installation contractors have a high interest but cannot directly affect the project.

6.3 Development of the financial model for the management of synthetic turf sports pitches.

6.3.1 Identification of the costs involved with the management of a synthetic sports pitch

The main revenue streams and costs involved in managing an STP were identified from the literature review, commercial information, the questionnaire survey (Chapter 3.1) and previous research (McLeod, 2003). Figure 6.2 indicates the cost areas and the three sections that they sub-divided into: Initial capital, future capital and non-capital expenditure.

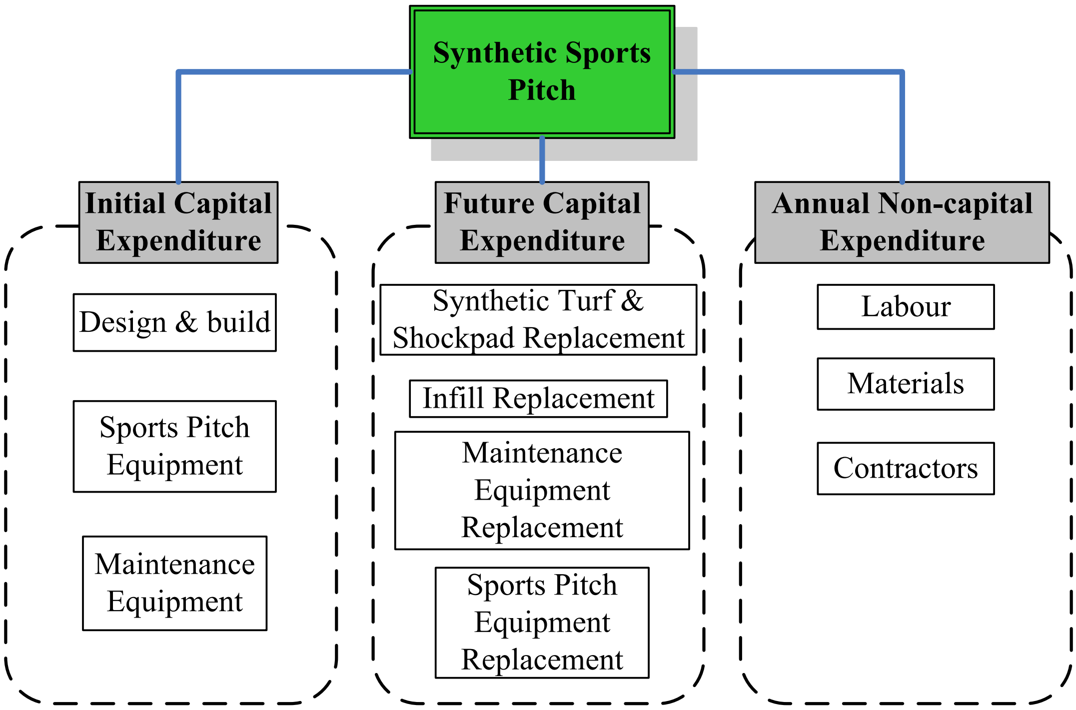


Figure 6.2 The capital and recurrent costs involved in the provision of a synthetic turf pitch

The costs used in the financial model have been taken from the questionnaire survey and are used as an illustrative example of probable costs involved. Recognising the variability of the costs involved in individual STP projects, the model has been designed to allow users to replace these standard costs with their own costs.

The costs identified by the questionnaire survey were:

Design and Build

The full capital cost of the construction of the STP facility was taken as the median of the most common cost band which was £350k – 400k; 23.1% of the STPs were within this band. The median of this band is £375k and the expenditure was allocated to Year 0.

Revenue

The value for revenue included used in the financial model was derived from the total number of hours the STP was used multiplied by the average charge per hour of use (Table 6.1). The total number of hours included external lettings (which is a direct revenue stream into the facility) and the numbers of hours of internal use (which tends to generate no direct payment but which do represent the savings of hiring external facilities).

Table 6.1 Mean usage and revenue stream from the field questionnaire survey of sand-filled synthetic turf pitches

	Range	Mean
Annual pitch use (h)	450 - 4200	2061
Charge for pitch use (£ h^{-1})	20 - 70	41.36
Annual income (£)	30110 - 180660	85260

In-house labour

In most situations, existing labour is being used for routine maintenance of STP facilities. Although this could be considered as a sunk cost, it has been included as part of the financial model calculation to illustrate the actual annual labour costs involved with an STP project (Table 6.2).

Table 6.2 Mean numbers of maintenance hours and operator cost of a sand-filled synthetic turf pitch

	Hours	£
Annual no. of operating hours	260	
Cost per operator hour		9.60
Total annual in-house labour cost		2496

Use of contractors

There are specific maintenance tasks that in most cases are performed by external contractors, unless there is capital available to purchase expensive single-use equipment (11% of respondents had purchased equipment for this task). The mean annual contractor cost used in the model was £2300.

Cost of maintenance equipment

This covers the drag brush that is used for routine basic maintenance. 89% of respondents had purchased a drag brush with a mean cost of £1171. There was no allowance within the financial model for any equipment maintenance costs or hire of replacement equipment when required and the assumption was made that the prime tractor unit for the brush was already on site being used for other tasks.

Replacement of synthetic carpet and sand infill

Within the lifespan of a STP there are two processes that may be viewed as capital expenditure: 1) replacement of the sand infill and 2) replacement of the carpet and infill. The mean replacement period for the sand infill was 7 – 8 years at a mean cost of £23000. This process takes 5 – 7 days to complete and allowance should be made for lost revenue during the pitch closure.

Only 7% of the field questionnaire survey had replaced the carpet and infill at a mean replacement period of 8 years at a cost of £130,000. The remaining responses collected from the survey showed that the mean expected lifespan of a STP was 15 years. Therefore within the financial model the replacement has been classed as an end of lifespan event at year 15.

Cost of pitch furniture

There is an initial outlay for pitch furniture (posts and nets) and then a proactive replacement programme of the furniture over the life of an STP. The full costs and perceived life expectancy for the pitch furniture are shown in Table 6.3. The costs used were from an existing maintenance company (Sportsequip, 2007) and do not include any local negotiations on price discounts. A bi-annual allowance of £280 was included in the financial model to allow for the replacement of nets on each piece of pitch furniture used on the STP.

Table 6.3 Pitch furniture cost and replacement for a sand-filled synthetic turf pitch (source: Sportsequip, 2007)

	No. of post sets		Expected replacement year		Cost (£)		
	Range	Mean	Range	Mean	Per set	Total	+ VAT + delivery *
Standard football	1 - 2	1	3 - 25	10	2665	2665	3351
5-a-side football	1 - 3	2	2 - 20	8	880	1760	2213
Hockey	1 - 6	3	2 - 15	8	1358	4073	5120
Tennis	3 - 12	10	4 - 23	10	535	5350	6726
						Total	17410

* VAT = 17.5% & Delivery 7% of total order

Hours of use

This is the basis of the revenue stream for the STP. For all respondents to the field questionnaire, an hourly rate was being charged for external lettings. Within the financial model the mean charge for external letting was also apportioned to internal use of the STP. This allowed for the savings in rental charges for external STPs that the operation would have in the absence of their own STP. This information is shown in Table 6.4.

Table 6.4 Mean hours of use and hourly rental charge of a sand-filled synthetic turf pitch

	Range	Mean	S.E.
No. hours annual pitch use	450 - 4200	910.16	4.66
Charge for pitch use (£)	20 - 70	41.36	0.70

Provision for floodlights

The normal STP design has provision for floodlighting to allow pitch use outside daylight hours. The questionnaire provided data about the presence of floodlights and whether there were any limitations to use under planning regulations. The number of daylight hours were calculated between September and May were calculated for Bedford, England (52.1N, 0.05W). From the questionnaire, the mean time of floodlight switch off was used (21.30 hrs) plus an allowance of one hour (30 minutes before dusk and 30 minutes after 21.30 hrs) was allowed for security and switching off of lights. Full calculation of the floodlight times is shown in Appendix G. The annual cost allocated for use in the model was £3798.

6.3.2 Identification of the method used for the analysis within the financial model

The stakeholder mapping identified that the Key Players (Figure 6.1) involved in the construction, maintenance and provision of an STP were the Operators and Funding Bodies.

The basis of Objective No. 4 is to provide information on the costs involved in the management of an STP. Therefore, the financial analysis was required to be in a format that illustrated the cash flows over a set period of time expressed in monetary value. Using the most commonly used financial evaluation models with which the key players are most likely to familiar with. Therefore the financial analysis could be provided in one of four possible formats:

1. Weighted Average Cost of Capital (WACC) – This is a measure of the STP project’s cost in relation to the organisation’s cost of capital, which can be used to see if it will create any added value for the organisation by a return on the invested capital that is above their cost of that capital.
2. Internal Rate of Return (IRR) – This measures the true interest yield expected from the project expressed as a percentage. IRR computes a break-even rate of return; if the IRR exceeds the organisation’s cost of capital then the STP will generate a positive net cash flow stream.
3. Discounted Cash Flow (DCF) – This is an expression in today’s money value of an anticipated cash flow of future years. The DCF method converts future earnings to today's money. In this way the value of an STP project as a whole is determined.

4. Net Present Value (NPV) –The NPV is a product of a DCF calculation. The NPV is an amount that expresses how much value, to the organisation, the STP project will result in. If the result is positive then the project will add value; if negative it will subtract value.

The first two methods of financial analysis of the expected return of a project do not illustrate the year-on-year costs that may be expected across the STP lifespan. As mentioned above, the DCF method can illustrate cashflow at any point of the STP lifespan. This, combined with the NPV, has the advantage of being a widely used and understood method, which is likely to appeal to the Key Players. DCF/NPV calculations do not account for uncertainty or intangibles within the project but, in this case, it is not being used as a strategic tool, but instead as a means of illustrating all future operating costs to the relevant decision makers. The inputs and outputs of the NPV model used are illustrated in Figure 6.3.

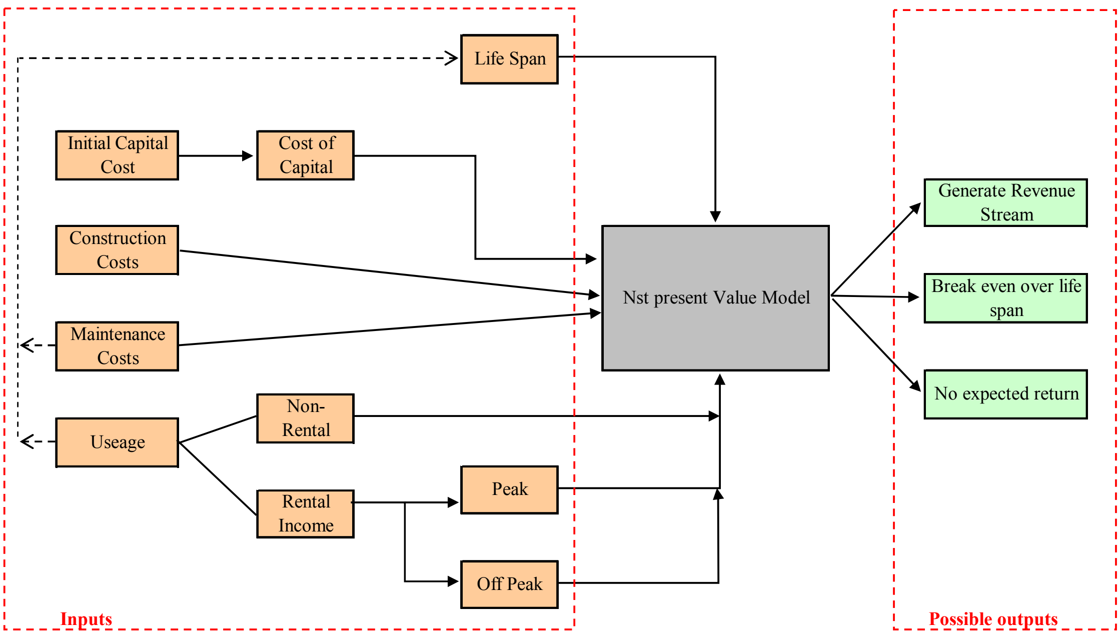


Figure 6.3 An illustration of the inputs and outputs of the financial model for the management of synthetic sports turf pitches

6.3.3 Approach and assumptions used for the financial model

During the development of the financial model, the option to replace the synthetic turf carpet at the 15 year point was identified as the largest financial variable, excluding construction. To ensure that the financial model was developed to include as many potential users/stakeholders as possible, it was decided that two financial models would be run; one including and one excluding the synthetic turf carpet replacement.

In order to simplify the financial model a number of assumptions were made; this simplified model was then more generic in nature and therefore easier to apply to differing situations. The assumptions made were:

a. The cost of capital is assumed to be at a level of either 6% or 10%. Each company/facility provider will have differing costs of capital. A cost of capital of 6% was selected to represent the public sector; this was set by central government in The Green Book. (HM Treasury, 1997). A level of 10% was arbitrarily allocated as the second cost of capital to give a commercial comparison.

b. The effects of Taxation have been ignored for this NPV calculation. When calculating for a specific project, relevant levels of Corporation Tax and Capital Allowances will need to be taken into consideration.

c. It is assumed that the labour costs for the STP are extra to existing costs and therefore will illustrate the 'worst case' scenario.

d. Capital and revenue expenditure are as defined in current account convention (UKGAP).

e. NPV calculations were calculated over a 15 year life of a pitch; this was based on the questionnaire respondents' mean expected lifespan of an STP. Within the model, the lifespan of an STP is deemed to have expired when the synthetic turf carpet is replaced.

f. Intangibles - No values were attached to intangibles such as: location, associated facilities (bar, changing etc), surface specification, the ability to use the surface in most types of weather and any prestige gained by offering these facilities.

g. Shockpad replacement – The life expectancy of the shockpad of a synthetic turf system is 25 years, nearly double the time period of the financial model. When using the model for a resurfaced facility, at year 15 (year 30 for the shockpad), the NPV calculation should include shockpad replacement which, for a full sized sand-filled STP (6000 m^2) is approximately £42000 (Carl Whelan, pers com).

6.3.4 Further analysis of the outputs from the net present value calculations

Sensitivity Analysis

Sensitivity analysis (SA) is commonly referred to as "what if…" analysis (Myddelton, 2000); it facilitates the investigation of how results may change if the original inputs or underlying assumptions change. Inputs for NPV calculations are predominantly based on estimates, and as such are not completely accurate. SA is carried out in order to identify which of the inputs into the NPV calculation, when changed, will have the most impact on the NPV, thus identifying the areas of least flexibility. When the SA was performed for a specific factor the assumption of *ceteris paribus* (all other things are equal) was made in order to facilitate comparisons.

Internal rate of return

Although IRR was not selected as the main tool, it was deemed to be of use in further analysing the outputs from the NPV calculation. The results from carrying out the IRR calculation indicated whether the financial model could be adapted to the particular circumstances of any of the Key Players (i.e. demonstrating the effects of differing costs of capital).

Break even analysis

Break even analysis (BEA) is a calculation used to identify the point at which revenue equals expenditure. It is also used to identify a point in time where a given project will begin to realise a profit for an organisation. Using the NPV outputs to carry out BEA indicated to stakeholders the financial timescales involved in a STP project. Furthermore, the BEA illustrated the impact of any changes made to the NPV inputs on the financial returns of the project. The breakeven point for each calculation was made using Equation 6.1.

Equation 6.1 Formula used to calculate the breakeven analysis for the synthetic turf pitch

$$BEP = \frac{R1}{\left(\frac{R1 - R2}{V2 - V1}\right)} + V1$$

Where BEP = Break even point, R1 = the result of the initial NPV calculation, R2 = results from the second NPV calculation, V1 = the first variable input into the NPV and V2 = the second variable input into the NPV.

Scenario analysis

The NPV calculation was used to show the future costs of managing a STP, by utilising the questionnaire survey data. Using the same form of analysis two scenarios were analysed; these were characterised as “poor” and “effective” maintenance programmes.

For the purpose of scenario analysis, poor maintenance was defined as the completion of basic tasks such as drag brushing and litter collection only. There was no allowance made for infill cleaning and was classed as a purely reactive maintenance programme. Effective maintenance was defined as a programme that was structured to regularly redress the surface infill and made allowance for infill cleaning. This programme also allowed for extra operator time in order to regularly collect litter and leaf matter from the surface. The processes used for each maintenance programme are shown in Table 6.5.

Table 6.5 Processes involved in the poor and effective maintenance programmes for the scenario analysis

	Maintenance Scenario	
	Poor	Effective
Annual no. of operative hours used for maintenance	106	416
Annual drag brush frequency	52	104
Annual power brush frequency	0	3
Revitalisation frequency	0	Every 3rd year

Costs used for scenario analysis

Basic information on costs for factors such as construction, labour rates, floodlights and initial pitch furniture were taken from the questionnaire survey.

To run the scenarios the following basic assumptions were made:

1. The cost of construction was £375,000.
2. Each pitch would be used for 2061 hours per year (40 hours per week).
3. In Chapter No. 3.2.7, it was determined that there is a direct correlation between pitch use and concentration of contamination within the infill. On this basis, it was assumed that both pitches, if not maintained, would become contaminated at the same rate.
4. Further experimentation (Chapter 4) has shown that there is a reduction in surface playability with the increase of contamination within the sand infill. Using this information, it was assumed that the poor maintenance scenario would show a significant reduction in playability over a short period of time (3 – 5 years).

5. It was indicated in Chapter 6 that the rotary brush action of the Revitalisation process did not cause significant wear to the synthetic turf surface and so in the effective maintenance scenario it can be used as a regular process.
6. Each drag brushing process would take 60 minutes to complete.
7. There was basic maintenance with each scenario. This included litter clearance and goal movement.
8. The cost of labour was £9.60 per hour.
9. Floodlight costs would be £3798 per annum.
10. Initial pitch furniture costs would be £17410.
11. Both surfaces would be rejuvenated when there was a significant reduction in the infiltration rate of the surface.

6.4 Results

6.4.1 Overview of the maintenance data in the net present value calculation

The basic NPV calculations were carried out using data obtained from the questionnaire survey (Section 7.3.1). The maintenance programme that the costs were based on is shown in Table 6.6.

Table 6.6 Processes within the maintenance program derived from the questionnaire survey that were used for the original Net Present Value calculations.

Process	
Annual no. of operative hours used for maintenance	324
Annual drag brush frequency	104
Annual power brush frequency	5
Rejuvenation	after 7 years

6.4.2 Financial model for synthetic turf project including carpet replacement

Net present value calculation

The NPV for the STP including carpet replacement was £236,538 and £133,282 for the 6% and 10% discount rates respectively (Table 6.7). In terms of standard usage for NPV calculations, the positive result from applying the model to this STP project, for both discount rates, gave an indication that the project should be accepted.

Analysis of the cash flows revealed the following; for years 1-6 there was an average annual expenditure of £9334; at year 7 it increased to £32194, reflecting the rejuvenation of the STP surface; years 8-14 it remained at £11984 and in the final year the replacement of the STP surface saw expenditure increase to £139194. The cash flow showed a static income of £85260 per annum, reflecting that predicted pitch usage was attained each year. The highest outflow of cash, as anticipated, was £393610 in year 0, which covered capital expenditure for construction, pitch furniture and basic maintenance equipment.

Table 6.7 Net present value analysis of the questionnaire data including synthetic carpet replacement

	Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15
Income																
External Lettings		85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260
Variable & Fixed Costs																
Labour costs		(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)
Contractor		(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)
Chemical Treatment		(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)
Cost of Floodights		(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)
Replace Sand Infill								(23,000)								
Repair Damage										(1,000)						
Carpet Replacement																(130,000)
Capital Expenditure																
Construction	(375,000)															
Pitch Furniture	(17,410)		(280)		(280)		(280)		(280)		(280)		(280)		(280)	
Maintenance Equipment	(1,200)															
Replace 5-a-side Football Goals									(2,213)							
Replace Standard Football Posts											(3,351)					
Replace Hockey Posts									(5,120)							
Replace Tennis Posts											(6,726)					
Net Cash Flows	(393,610)	76,066	75,786	76,066	75,786	76,066	75,786	53,066	68,453	75,066	65,709	76,066	75,786	76,066	75,786	(53,934)
Discount Factor @ 10%	1.000	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value @ 10%	(393,610)	69,144	62,599	57,126	51,762	47,237	42,743	27,223	31,968	31,828	25,364	26,623	24,176	22,059	19,932	(12,890)
Net Present Value @ 10%	**133,282**															
Discount Factor @ 6%	1.000	0.943	0.890	0.840	0.792	0.747	0.705	0.665	0.627	0.592	0.558	0.527	0.497	0.469	0.442	0.417
Present Value @ 6%	(393,610)	71,760	67,449	63,866	60,030	56,841	53,426	35,292	42,948	44,431	36,692	40,071	37,663	35,663	33,520	(22,505)
Net Present Value @ 6%	**263,538**															

Break even point

After applying the discount factor, the present values were analysed to calculate the point at which the project was expected to break even. It is shown in Figure 6.4 that for a discount rate of 6% the STP break even point would be expected at the end of year 6 and for 10% at the end of year 8. These lengths of pay back period would be considered as long term by an investor and stakeholders need to be made aware that this project is not going to pay for itself in the short term, if indeed at all.

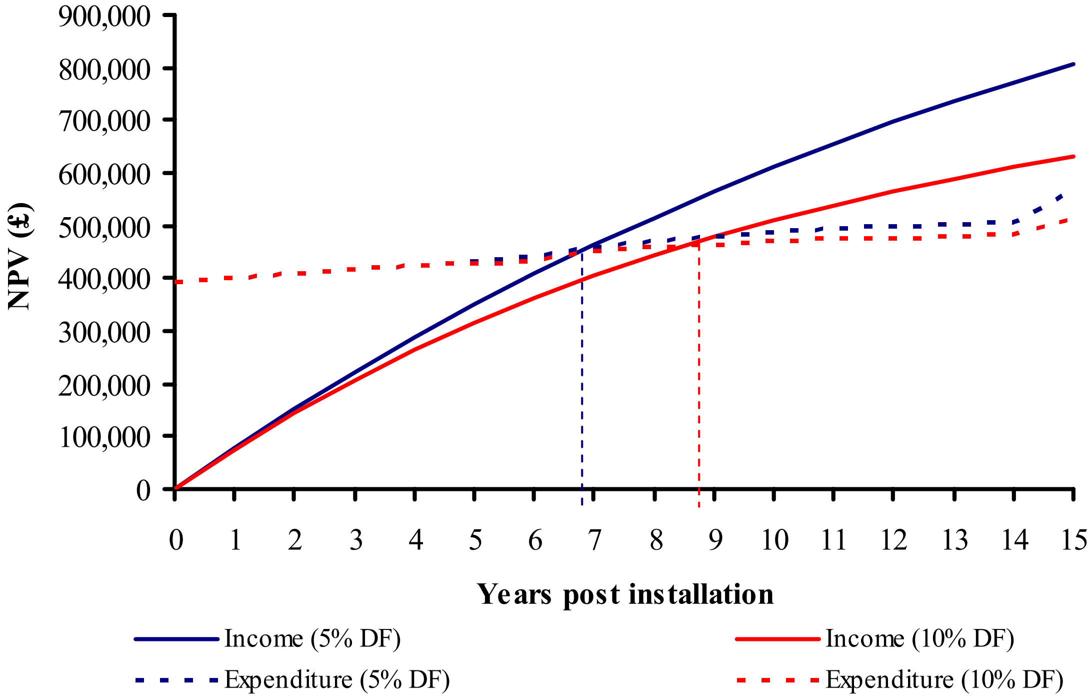


Figure 6.4 Breakeven analysis of net income of a sand-filled synthetic turf sports pitch, including surface replacement, over a 15 year lifespan. Red and blue dashed lines represent the breakeven point,

Sensitivity analysis

Four inputs of the NPV were tested for their sensitivity; revenue, construction costs, labour costs and contractor costs (Table 6.8). Of these the most sensitive to change was revenue, with only a 32% and 21% decrease (for 6% and 10% discount rates respectively) in revenue resulting in a zero NPV. Both the labour and contractor costs demonstrated themselves to be relatively insensitive to change, with similar results of an increase in costs of around 1085% and 700% (for 6% and 10% discount rates respectively) required for either input before the NPV would move to zero. The analysis of sensitivity on the construction costs showed that they would need to increase by 70% and 36% (for 6% and 10% discount rates respectively) in order for the NPV to equal zero.

Table 6.8 Sensitivity analysis of a sand-filled synthetic pitch, including carpet replacement at the end of its 15 year lifespan. Where a = the primary NPV input and b = the secondary NPV input. (↓ = reduction in factor to breakeven; ↑ = increase in factor to reach breakeven; BEP = Break Even Point))

			NPV					
		Value	**6%**	**10%**		**BEP**	**% Change**	
Revenue	**a**	£40,000	(£176,038)	(£210,920)	**6%**	£58,125	31.83%	↓
	b	£85,260	£263,538	£133,282	**10%**	£67,734	20.56%	↓
			NPV					
		Value	**6%**	**10%**		**BEP**	**% Change**	
Construction	**a**	£375,000	£263,538	£133,282	**6%**	£638,538	70.28%	↑
	b	£700,000	(£61,462)	(£191,718)	**10%**	£508,282	35.54%	↑
			NPV					
		Value	**6%**	**10%**		**BEP**	**% Change**	
Labour	**a**	£2,496	£263,538	£133,282	**6%**	£29,631	1087.12%	↑
	b	£40,000	(£100,710)	(£151,935)	**10%**	£20,022	702.15%	↑
			NPV					
		Value	**6%**	**10%**		**BEP**	**% Change**	
Contractor	**a**	£2,500	£263,538	£133,282	**6%**	£29,635	1085.38%	↑
	b	£40,000	(£100,671)	(£151,905)	**10%**	£20,026	701.03%	↑

This analysis indicated that the impact of labour and contractor costs increasing would be minimal. The SA showed that, using a 6% discount rate, these two factors could increase by approximately £27000 per annum before having a critical impact on the STP project. Using a 10% discount rate that amount would be approximately £17500.

Conversely the SA showed that revenue only needed to decrease by approximately £27000 per annum (using a discount rate of 6%), which equated to a reduction of about 12 hours per week. Using a discount rate of 10% this was further reduced to approximately an eight hour reduction per week. In either case the reduction in revenue would cause the STP project to become unprofitable.

Construction costs could increase by approximately £263500 (using a discount rate of 6%), or £133000 (using a discount rate of 10%).

This sensitivity analysis highlighted to a potential stakeholder that relatively small changes in the construction, labour and maintenance costs would have little impact on the financial viability of the project. The area of cash flow that had the greatest impact is the revenue generated by the STP.

Internal rate of return

The IRR for the STP project, excluding the carpet replacement, was calculated to be 16% (Figure 6.5). This indicated that the STP project will yield a return of 16% to an investor.

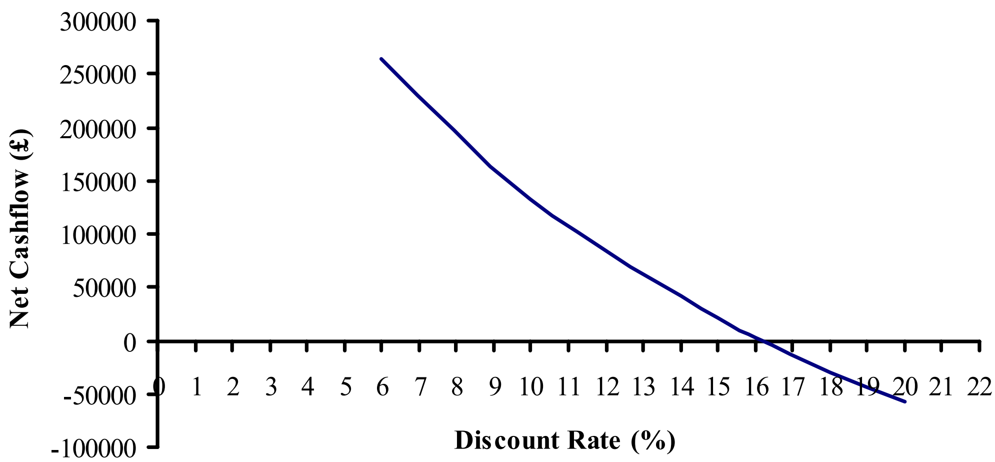


Figure 6.5 The Internal Rate of Return for the STP project including the replacement of the synthetic turf carpet at year 15.

6.4.3 Financial model for synthetic turf project excluding carpet replacement

Net present value calculation

The result of running the NPV for the STP including carpet replacement was £307,610 and £158,303 for the 6% and 10% discount rates respectively (Table 6.9). In terms of standard usage for NPV calculations, the positive result from applying the model to this STP project, for both discount rates, gave an indication that the project should be accepted.

Analysis of the cash flows revealed the following; for years 1-6 there was an average annual expenditure of £9334; at year 7 it increased to £32194, reflecting the rejuvenation of the STP surface; years 8-13 it remained at £10631, in year 14 it increased to £32474 again reflecting the rejuvenation of the STP surface and in the final year it reduced to £9194 reflecting the lack of carpet replacement.. The cash flow showed a static income of £85260 per annum, reflecting that predicted pitch usage was attained each year. The highest outflow of cash, as anticipated, was £393610 in year 0, which covered capital expenditure for construction, pitch furniture and basic maintenance equipment.

Table 6.9 Net present value analysis of the questionnaire data excluding synthetic carpet replacement

	Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15
Income																
External Lettings		85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260
Variable & Fixed Costs																
Labour costs		(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)	(2,496)
Contractor		(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)	(2,500)
Chemical Treatment		(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)
Cost of Floodlights		(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)
Replace Sand Infill								(23,000)							(23,000)	
Repair Damage										(1,000)						
Carpet Replacement																
Capital Expenditure																
Construction	(375,000)															
Pitch Furniture	(17,410)		(280)		(280)		(280)		(280)		(280)		(280)		(280)	
Maintenance Equipment	(1,200)															
Replace 5-a-side Football Goals									(2,213)							
Replace Standard Football Posts											(3,351)					
Replace Hockey Posts									(5,120)							
Replace Tennis Posts											(6,726)					
Net Cash Flows	(393,610)	76,066	75,786	76,066	75,786	76,066	75,786	53,066	68,453	75,066	65,709	76,066	75,786	76,066	52,786	76,066
Discount Factor @ 10%	1.000	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value @ 10%	(393,610)	69,144	62,599	57,126	51,762	47,237	42,743	27,223	31,968	31,828	25,364	26,623	24,176	22,059	13,883	18,180
Net Present Value @ 10%	**158,303**															
Discount Factor @ 6%	1.000	0.943	0.890	0.840	0.792	0.747	0.705	0.665	0.627	0.592	0.558	0.527	0.497	0.469	0.442	0.417
Present Value @ 6%	(393,610)	71,760	67,449	63,866	60,030	56,841	53,426	35,292	42,948	44,431	36,692	40,071	37,663	35,663	23,347	31,740
Net Present Value @ 6%	**307,610**															

Break even point

After applying the discount factor, the present values were analysed to calculate the point at which the project was expected to break even. It is shown in Figure 6.6 that for a discount rate of 6% the STP break even point would be expected at the beginning of year 8 and for 10% at the end of year 8. These lengths of pay back period would be considered as long term by an investor and stakeholders need to be made aware that this project is not going to pay for itself in the short term, if indeed at all.

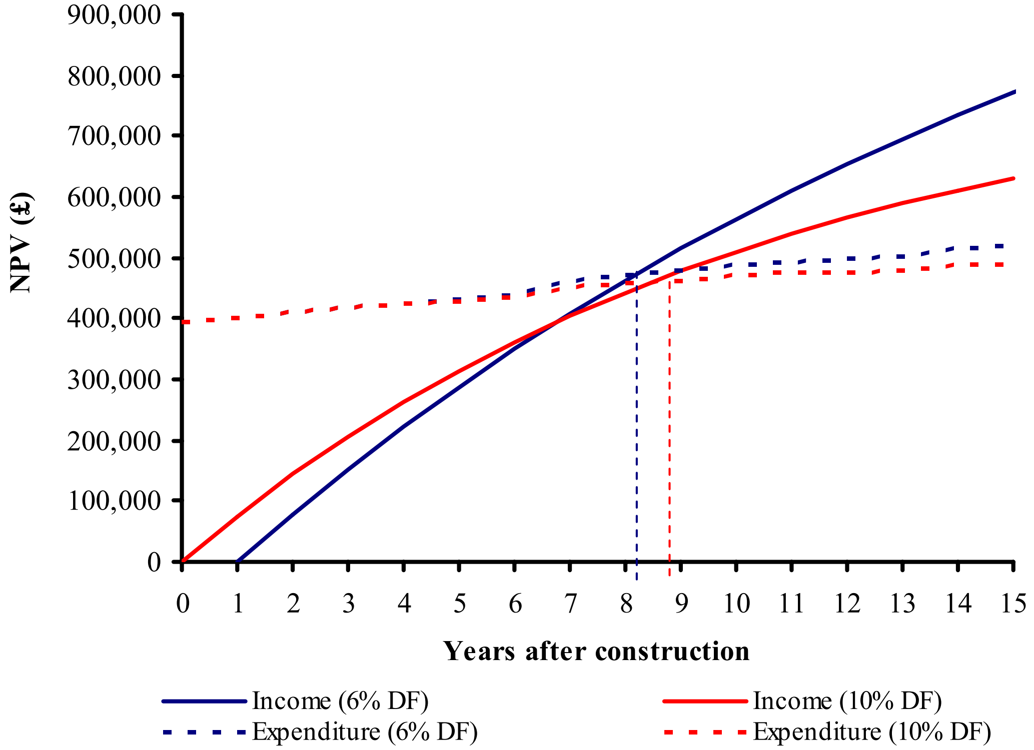


Figure 6.6 Breakeven analysis of a sand-filled synthetic turf sports pitch, not including surface replacement, over a 15 year lifespan. Red and blue dashed lines represent the breakeven point,

Sensitivity analysis

Four inputs of the NPV were tested for their sensitivity; revenue, construction costs, labour costs and contractor costs (Table 6.10). Of these the most sensitive to change is revenue, with only a 37% and 24% decrease (for 6% and 10% discount rates respectively) in revenue resulting in a zero NPV. Both the labour and contractor costs demonstrated themselves to be relatively insensitive to change, with similar results of around 1265% and 830% (for 6% and 10% discount rates respectively) increase in costs required for either input before the NPV would move to zero. The analysis of sensitivity on the construction costs showed that they would need to increase by 82% and 42% (for 6% and 10% discount rates respectively) in order for the NPV to equal zero.

Table 6.10. Sensitivity analysis of a sand-filled synthetic pitch, not including carpet replacement, at the end of its 15 year lifespan. Where a = the primary NPV input and b = the secondary NPV input (↓ = reduction in factor to breakeven; ↑ = increase in factor to reach breakeven)

			NPV					
		Value	**6%**	**10%**		**BEP**	**% Change**	
Revenue	**a**	£40,000	(£131,967)	(£185,899)	**6%**	£53,588	37.15%	↓
	b	£85,260	£307,610	£158,303	**10%**	£64,444	24.41%	↓
			NPV					
		Value	**6%**	**10%**		**BEP**	**% Change**	
Construction	**a**	£375,000	£307,610	£158,303	**6%**	£682,610	82.03%	↑
	b	£700,000	(£17,390)	(£166,697)	**10%**	£533,303	42.21%	↑
			NPV					
		Value	**6%**	**10%**		**BEP**	**% Change**	
Labour	**a**	£2,496	£307,610	£158,303	**6%**	£34,168	1268.92%	↑
	b	£40,000	(£56,639)	(£126,914)	**10%**	£23,312	833.96%	↑
			NPV					
		Value	**6%**	**10%**		**BEP**	**% Change**	
Contractor	**a**	£2,500	£307,610	£158,303	**6%**	£34,172	1266.89%	↑
	b	£40,000	(£56,600)	(£126,884)	**10%**	£23,316	832.63%	↑

This analysis indicated the impact of labour and contractor costs increasing would be minimal. The SA showed that, using a 6% discount rate, these two factors could increase by approximately £31500 per annum before having a critical impact on the STP project. Using a 10% discount rate that amount would be approximately £21000.

Conversely the analysis showed that revenue only needed to decrease by approximately £31500 (using a discount rate of 6%), which equated to a reduction of about 15 hours per week. Using a discount rate of 10% this was further reduced to approximately a ten hour reduction per week. Construction costs could increase by approximately £308000 (using a discount rate of 6%), or £158000 (using a discount rate of 10%).

This sensitivity analysis highlighted to a potential stakeholder that relatively small changes in the construction, labour and maintenance costs would have little impact on the financial viability of the project. The area of cash flow that had the greatest impact was the revenue generated by the STP.

Internal rate of return

The IRR for the STP project, excluding the carpet replacement, was calculated to be below 17% (Figure 6.7). This indicated that the STP project would yield a return of 17% to an investor.

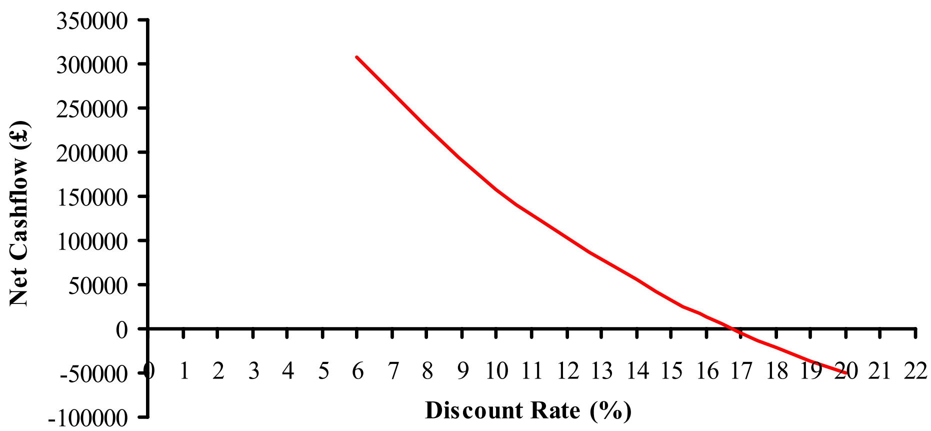


Figure 6.7 The Internal Rate of Return for the STP project including the replacement of the synthetic turf carpet at year 15

6.4.4 Scenario analysis

Use of a poor maintenance programme

The inputs to the NPV that were varied to reflect the impact of a poor maintenance programme were:

- Labour costs; these were reduced to £1020 per annum to represent a minimum utilisation of labour resources, two hours per week, on the basic maintenance aspect of the programme. This would result in limited litter collection and limited movement of pitch furniture.
- Contractor costs; these were taken out to represent a limited availability of financial resources or a lack of knowledge on the maintenance requirements of an STP.
- Chemical costs; these were removed as the application of chemicals to remove problems of moss/algae are normally pert of an effective proactive maintenance programme.
- Replace sand infill; as a result in poor basic maintenance this process, which will result in an uncontrolled build-up of contamination within the infill, was moved from year seven back to year five.
- Repair damage; this was moved from year nine back to year six as minor damage or seam failure may not have been assessed due to the limited maintenance time.
- Carpet replacement; to reflect the decrease in maintenance, this was reduced from year 15 back to year 11.

The playability of the STP will be reduced as poor surface infiltration rates result in the loss of surface use due to poor surface conditions. It was assumed that the loss in playability would result in the loss of external lettings moving to other facilities, and therefore there would be a reduction in revenue. In year four, revenue was reduced to 80% (of the base £85260 per annum), in year five it was at 60%, in year six it increased to 80%, in year nine it reduced to 60%, year 10 it was 40% and year 11 20%. The increase in revenue in year six was the result of surface rejuvenation and it was assumed that the increased playability would encourage some of the previous external lettings to return. usage for NPV calculations, the negative result from applying the model to this STP project, for both discount rates, gave an indication that the project should be rejected.

Without the implementation of an effective maintenance programme the STP project cannot be considered as a commercial concern and would not even generate enough revenue to cover the initial capital and future non-capital costs. Apart from the project not being financially viable, any gains to be had by the organisation from elevated status by having a STP facility will be negated by the negative impact on reputation by providing an underperforming surface.

Table 6.11 Net present value analysis of the a synthetic turf sports pitch that uses a poor maintenance programme

	Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11
Income												
External Lettings		85,260	85,260	85,260	68,208	51,156	68,208	68,208	68,208	51,156	34,104	17,052
Variable & Fixed Costs												
Labour costs		(1,020)	(1,020)	(1,020)	(1,020)	(1,020)	(1,020)	(1,020)	(1,020)	(1,020)	(1,020)	(1,020)
Contractor												
Chemical Treatment												
Cost of Floodights		(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)
Replace Sand Infill						(23,000)						
Repair Damage							(1,000)					
Carpet Replacement												(130,000)
Capital Expenditure												
Construction	(375,000)											
Pitch Furniture	(17,410)		(280)		(280)		(280)		(280)		(280)	
Maintenance Equipment	(1,200)											
Replace 5-a-side Football Goals									(2,213)			
Replace Standard Football Posts											(3,351)	
Replace Hockey Posts									(5,120)			
Replace Tennis Posts											(6,726)	
Net Cash Flows	(393,610)	80,442	80,162	80,442	63,110	23,338	62,110	63,390	55,777	46,338	18,929	(117,766)
Discount Factor @ 10%	1.000	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350
Present Value @ 10%	(393,610)	73,122	66,214	60,412	43,104	14,493	35,030	32,519	26,048	19,647	7,307	(41,218)
Net Present Value @ 10%	**(56,933)**											
Discount Factor @ 6%	1.000	0.943	0.890	0.840	0.792	0.747	0.705	0.665	0.627	0.592	0.558	0.527
Present Value @ 6%	(393,610)	75,889	71,344	67,541	49,989	17,440	43,785	42,158	34,995	27,427	10,570	(62,038)
Net Present Value @ 6%	**(14,510)**											

The impact of these changes on the financial model was that the NPV fell to -£14510 and -£56933, for 6% and 10% discount rates respectively (Table 6.11). In terms of standard

Effective maintenance programme

The inputs that were varied to reflect the impact of an effective poor maintenance were as follows:

- Revenue; remains static across the 15 years; this reflects little or no loss in performance, which would be associated with a well maintained STP.
- Labour costs; the increased usage of labour resources, eight hours per week, allowed increased levels of regular basic maintenance, and the costs were increased to £3994 per annum.
- Contractor costs; the contractors were used for specialist tasks that reduced the concentration of contamination within the STP infill, which maintained surface infiltration rates. The costs were reduced to £900 per annum (3 x power brushing) and every third year the cost was £3900 (Revitalisation).
- Replace sand infill cost; this cost was removed to reflect the action of the maintenance programme keeping the concentration of contamination below 10% v/v, and therefore maintaining surface infiltration rates.

The resulting NPV increased by £8387 and £6401 (for 6% and 10% discount rates respectively) to £271925 and £139683 is shown in Table 6.12 . This demonstrated the amount of value that could be added to the project, a 3% and 5% increase (for 6% and 10% discount rates respectively), by having an effective maintenance programme.

By using an effective maintenance programme, the STP facility would be able to operate as a commercial project that would generate a profit to the operators and provide a quality surface for the users that conforms to the relevant governing body's performance standards.

Table 6.12 Net present value analysis of the a synthetic turf sports pitch that uses an effective maintenance programme

	Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8	Y9	Y10	Y11	Y12	Y13	Y14	Y15
External Lettings		85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260	85,260
Labour costs		(3,994)	(3,994)	(3,994)	(3,994)	(3,994)	(3,994)	(3,994)	(3,994)	(3,994)	(3,994)	(3,994)	(3,994)	(3,994)	(3,994)	(3,994)
Contractor		(900)	(900)	(3,900)	(900)	(900)	(3,900)	(900)	(900)	(3,900)	(900)	(900)	(3,900)	(900)	(900)	(900)
Chemical Treatment		(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)	(400)
Cost of Floodights		(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)	(3,798)
Replace Sand Infill																
Repair Damage										(1,000)						
Carpet Replacement																(130,000)
Construction	(375,000)															
Pitch Furniture	(17,410)		(280)		(280)		(280)		(280)		(280)		(280)		(280)	
Maintenance Equipment	(1,200)															
Replace 5-a-side Football Goals									(2,213)							
Replace Standard Football Posts											(3,351)					
Replace Hockey Posts									(5,120)							
Replace Tennis Posts											(6,726)					
Net Cash Flows	(393,610)	76,168	75,888	73,168	75,888	76,168	72,888	76,168	68,555	72,168	65,811	76,168	72,888	76,168	75,888	(53,832)
Discount Factor @ 10%	1.000	0.909	0.826	0.751	0.683	0.621	0.564	0.513	0.467	0.424	0.386	0.350	0.319	0.290	0.263	0.239
Present Value @ 10%	(393,610)	69,237	62,683	54,949	51,832	47,300	41,109	39,074	32,015	30,599	25,403	26,659	23,251	22,089	19,959	(12,866)
Net Present Value @ 10%	**139,683**															
Discount Factor @ 6%	1.000	0.943	0.890	0.840	0.792	0.747	0.705	0.665	0.627	0.592	0.558	0.527	0.497	0.469	0.442	0.417
Present Value @ 6%	(393,610)	71,857	67,540	61,433	60,110	56,917	51,383	50,656	43,012	42,716	36,749	40,124	36,223	35,711	33,565	(22,462)
Net Present Value @ 6%	**271,925**															

6.5 Summary and outcomes of using the financial analysis

6.5.1 Summary of the financial analysis

The stakeholder analysis identified the Key Players involved in the design and management of a STP: the senior management of the facility operators and the sports funding bodies. The choice and design of the financial model was focused on the commercial aspects of the project, due to the identification of these key players.

The net present value method of illustrating the capital and non-capital cash flows involved in the provision of a sand-filled STP was selected as it was considered to have the advantage of being a widely used and understood method, which was likely to appeal to the Key Players

Although the Key Players involved in an STP project were the senior management of the facility operators, not all are driven by financial considerations alone, with the overall objective of installing a STP being used to increase the value of services provided by the operator. This is certainly the case with STP provision within the independent school sector; provision of STP facilities delivers a degree of 'added value' to the overall sports provision. The presence of an STP can be one of the contributing factors to the selection of the school by prospective parents (Crick, pers com)

Data obtained from the questionnaire survey showed that a STP facility can generate positive cash flows and over its lifespan generate a positive NPV. Although affected by the discount rate, the IRR calculation indicated that an organisation could have a cost of capital up to 17% before it resulted in a negative NPV.

Sensitivity analysis showed that revenue was the most sensitive of inputs into the project and decisions made on the project needed to consider the impact on revenue above all other considerations. The lack of an effective maintenance programme will have an impact on potential revenue, as customer groups will be unlikely to be prepared to pay for a STP with sub-standard surface performance, especially with the increase in choice of facilities available. As the number of STP facilities has increased, the choice of sites within the same geographical area will increase the competition to attract external lettings. This competition may have the effect of driving down the hourly rental charge of the STP and therefore affect rental income. This competition would be directly affected by the playability of a surface; poor playability due to a limited maintenance programme would have an influential affect on prospective STP users.

The use of specialist contractors was common throughout the respondents of the questionnaire survey and the maintenance processes that they perform on STPs have an impact on the surface playability and lifespan of the facility. Although their services are an extra cost to the basic ‘in-house’ maintenance procedures, the financial model showed that the effect on future cash flows can be significant.

The provision of floodlights was present within the NPV analysis and is a requirement for any facility that intended to use the surface for external lettings as, during the October to March period, a large percentage of the STP use is under lights. The lack of floodlights would have a direct impact on revenue from external lettings; this emphasises the need to check with local planners about the impact of floodlights before deciding on the construction of an STP.

Scenario analysis has shown that the maintenance programme affects the viability of a STP project and its lifecycle costs. It has a negative result not only on the NPV of the STP project, but also on the intangible costs, which are not taken into consideration within the financial model (e.g. damage to the facility’s reputation and the need for re-advertising the STP after surface rejuvenation). These would be further “costs” to the organisation and would need to be offset by the revenue generated by the STP.

6.5.2 Outcomes of the use of the financial model

The financial model successfully integrated information from the field survey, the questionnaire survey, the laboratory based experimentation, and the outcomes of the test rig experimentation on the effect of maintenance on wear of the synthetic turf fibres. It has clearly shown their effect on the financial outcome of a STP project and provided information on the projected year on year expenditure.

The output of the financial model represents a summary of expected cash flows, over the lifespan of a STP, for one combination of inputs to the model. If the inputs are varied then the expected cash flows will be affected. It is worthwhile highlighting that the inputs into this financial model were all estimates, and as such the outputs are only as accurate as the inputs, which is why sensitivity analysis was carried out.

The model clearly demonstrated that if wear is not taken seriously or if the investment in an effective maintenance programme was not taken into consideration from the outset, then the costs, whether tangible or intangible, are not going to be balanced out by any gains. Whilst looking at cash flows in isolation may identify cheaper options within reduced maintenance programmes, this does not take into consideration the time value of money nor the impact on the organisation as a whole.

The financial model presented in this chapter represents the expected cash flows for a sand-filled synthetic turf sports pitch. It can easily be adapted for use for third generation, long pile, sand/rubber infill carpets, but input factors such as construction costs and maintenance would have to be changed.

The aim of Objective No. 4 was:

To determine a relationship between wear, maintenance program and economic life-cycle costs of synthetic turf surfaces over time.

By creating the financial model, it has been possible to provide an illustration of capital and non capital expenditure over the lifespan of a sand-filled STP, based on information obtained from existing STP facility managers. By utilising the outputs from the financial model it has been possible to identify the relationship between the maintenance program and the economic life-cycle of the STP. These findings have been incorporated into the guidelines that are shown in Chapter 8.

7 Chapter Seven: Overall discussion

7.1 Summary of the findings of the experimental and financial analyses

The aim of this study was to develop a fundamental understanding of the mechanical wear and decline in hydraulic performance of second generation synthetic turf surfaces, its impact on technical performance characteristics, and economic life-cycle costs in relation to maintenance and usage. The literature review identified that there is a lack of validated research available to the sports turf industry on which to base maintenance management decisions.

7.1.1 An outline model of synthetic turf fibre – infill interaction

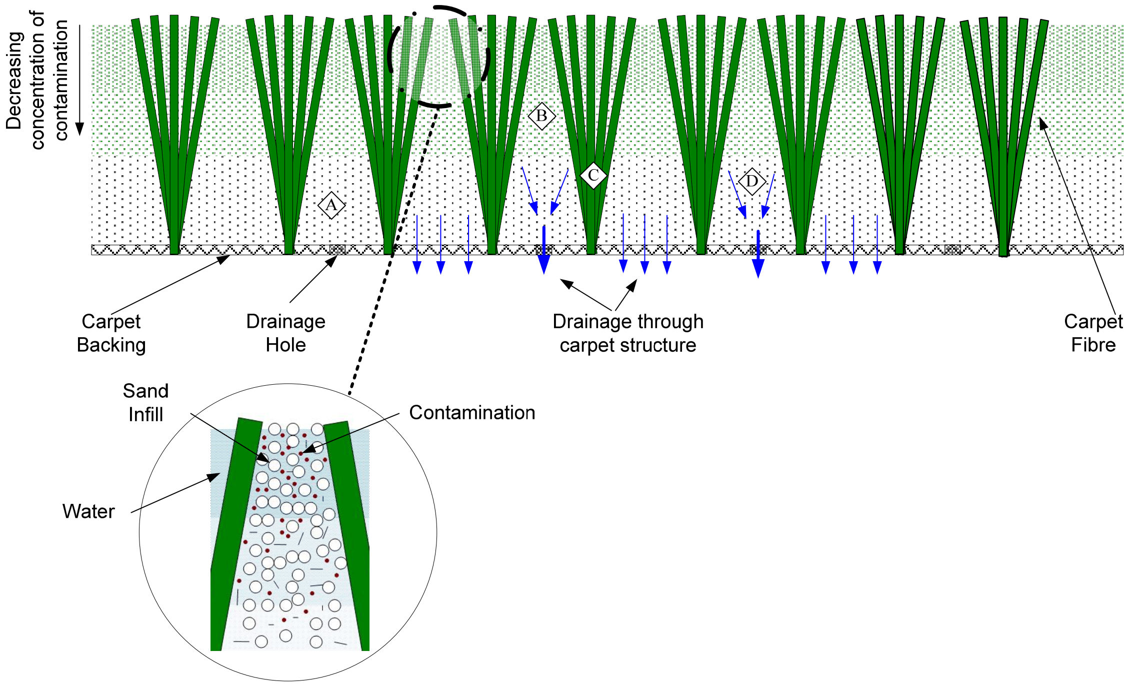


Figure 7.1 The key features within a synthetic turf system: A. sand infill, B. contamination, C. fibre specification, and D. infill moisture content.

Four key features within the synthetic turf system have been shown to affect the performance of a synthetic turf pitch (Figure 7.1), namely (A) the sand infill, (B) contamination of the infill by finer particles, (C) the synthetic fibre, and (D) the moisture content of the infill.

The effectiveness of maintenance can be quantified by an analysis of the extent to which the above factors are affected by a particular maintenance technique. A surface is contaminated by player use and the environment. The relationship between the key features is outlined in Figure 7.2.

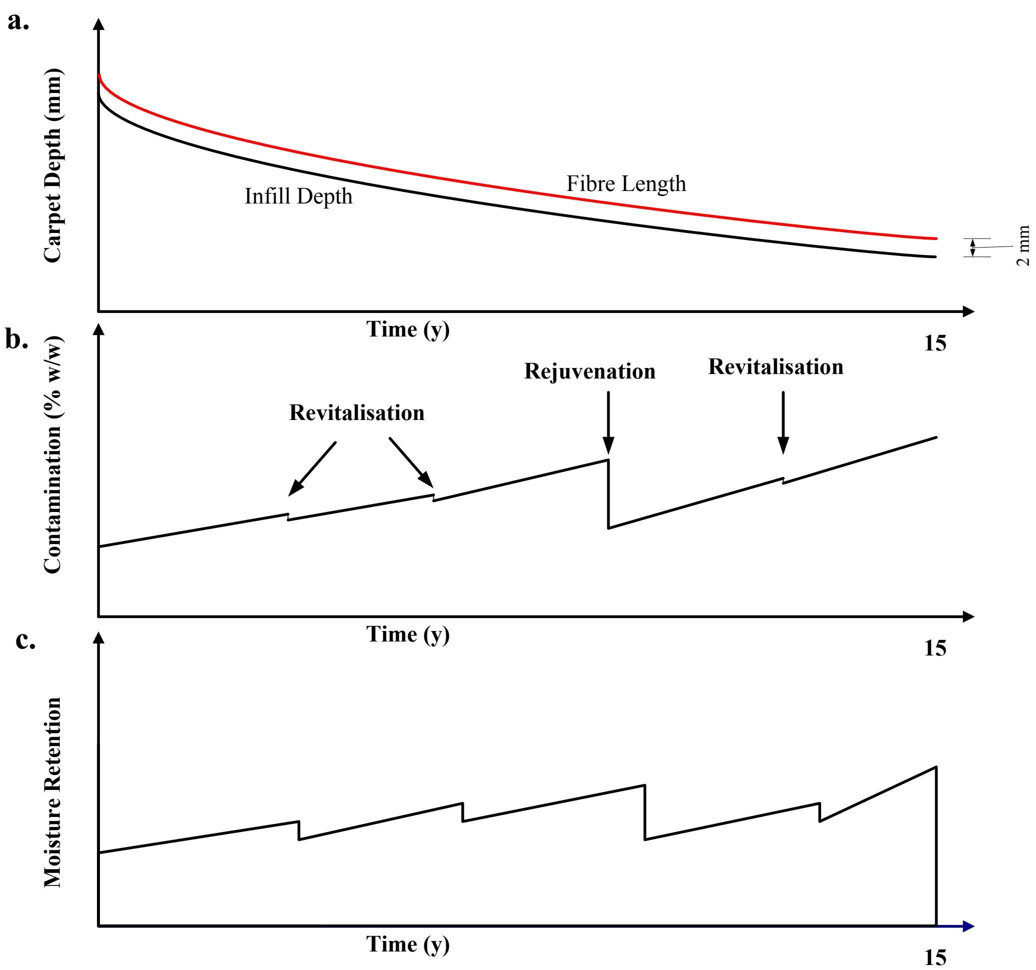


Figure 7.2 Schematic of the relationship between time, maintenance and surface conditions as a function of a. depth of infill which decreases with pile wear over time, b. concentration of contamination which tends to increase but is affected by maintenance, note that reduction due to revitalisation is small and in experiments in this study, non significant and c. moisture retention, a quasi-inverse of infiltration rate which increases as porosity is reduced and contamination increases. The effect of revitalisation is thought to be more significant in this case.

The sand infill is thought to behave as a filter for any water moving through the system under gravity. The pore size of the infill is reduced by the contaminants being filtered from the water; the reduced pore size reduces the flow of water through the system. Furthermore retention is increased due to increased matric potential. It was found that contamination reduced infill porosity and at a concentration of 10 – 15% (w/w), the contamination reduced surface infiltration rates from 150 mm h^{-1} to under 50 mm h^{-1}, the minimum standard for field hockey. Increasing concentrations of contamination and increased moisture content within the infill significantly affected the performance characteristics of an STP, reducing surface hardness, ball bounce and increasing deceleration of ball roll. The contamination broadens the particle size distribution within the infill which results in increased packing of the infill and increased inter-particle contact that, in turn, increases friction between the particles.

The presence of moisture within the infill/contamination mixture may have one of two effects: 1. moisture held under matric potential stabilises the infill particles due to cohesion/adhesion or 2. with increased moisture content the excess pore water pressure reduces the adhesion between the infill particles, which are easily moved by the contact of the ball with the surface; this deformation of the infill resulted in reduced ball rebound and surface hardness.

The field survey showed that the pile length, and therefore the infill depth, is reduced with age and, in turn showed that the concentration of contamination with in the infill also increases (Figure 7.2 a and b).

During the life of a synthetic turf pitch, the fibres lose structure and become fibrillated (Figure 7.3). The main cause of wear is a combination of two factors: exposure to ultra-violet (UV) radiation (not examined in this study) and the mechanical stresses of surface use. The effects of polymer exposure to UV radiation are well documented (Yakimets, 2004), and cause surface cracking followed by a degradation of the mechanical behaviour of the fibre. In younger pitches, the polymer fibres are more resilient and resistant to a high number of hours of use but, over time, their wear resistance is reduced by the photo-oxidation caused by the UV.

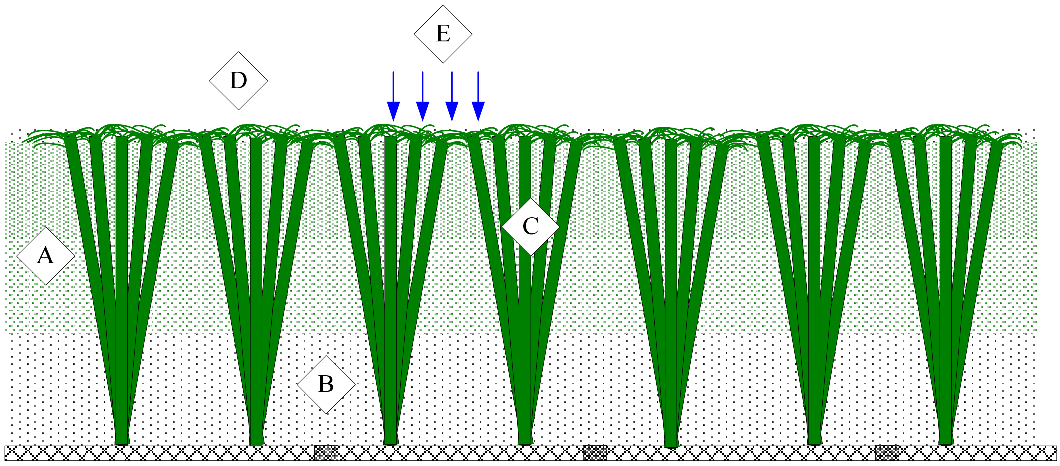


Figure 7.3 The effect of fibrillation on the synthetic turf fibre and its key components - A. contamination, B. sand infill, C. fibre specification, D. 'capping layer of fibrillated fibre and E. penetration of surface water.

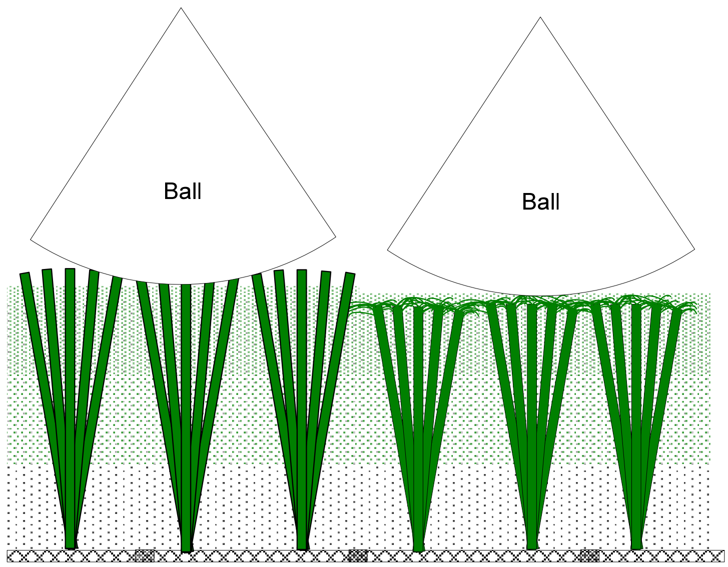


Figure 7.4 The difference in area of ball to surface contact between a new synthetic surface and a worn surface with fibrillated fibres.

The fibrillated fibre has little or no rigidity and folds over forming a 'capping' layer over the pitch surface; this 'locks' the infill, and any contamination, into the carpet structure. This has a significant effect on the performance of the surface by reducing ball/infill contact and limiting the deformation of the surface under load. This will result in increased ball rebound and surface hardness, and reduced ball roll deceleration *i.e.* longer ball roll distances, rotational resistance and surface porosity (Figure 7.4). The layer of fibre reduces evaporation of moisture from the infill and therefore, once drainage has resulted from gravimetric potential, the infill will have a limited rate of drying. This effect was observed in the field in Chapter 3 but not re-created in the laboratory in Chapter 4.

Without a 'capping' layer, a concentration of contamination above 10% (w/w) in laboratory experiments had a significant effect on the moisture loss characteristics of the STP; higher concentrations of contamination increase the micropores within the sand and increase water retention within the infill matrix. Surface infiltration was significantly reduced, which ultimately will result in standing surface water. A long-term result of this can be infestation by moss or algae; the presence of 'capping' in conjunction with the contamination within the infill will cause an enhanced deterioration of the surface conditions.

7.1.2 The operational context for maintenance across surveyed facilities

This may be viewed as a health and safety risk and may well result in the loss of surface use and revenue. If the synthetic turf pitch is installed as a commercial venture, the loss of revenue through poor maintenance practices will have an impact on the profitability of the project as discussed in Chapter 6. Poor surface quality could result in a loss of business to competing synthetic turf pitches within the area; business that may be difficult to regain once remedial maintenance has been performed.

To reduce the build up of contamination and prevent loss of playability, maintenance programmes are used. Proactive maintenance programmes are often provided by specialist contract maintenance and installation companies, which claim that they will assist in 'maximising' the economic return of the facility (Hession, pers.comm). A management and maintenance questionnaire, completed by the facility managers of 44 STPs (referred from a maintenance company database) showed that there was a wide variation in the processes used within individual maintenance programmes (Chapter 3). Further analysis showed that 77% of the managers used the maintenance documents supplied by the construction companies even though they generally regarded the programmes as generic and provided very little information on why the processes should be used.

The literature review showed there is a lack of peer-reviewed, evidence-based published information available concerning the benefits of using optimal maintenance practices for the different surface systems, or the effect that maintenance has on the synthetic turf system. Published maintenance programmes have, in the past, been similar in nature and few allowances are made for the differing carpet specifications and geographical location of the facility (FIH, 2001a; FIFA, 2001). This is because STP systems are so varied in their materials, their manufacture and their construction. Furthermore, the specific requirements of manufacturers' warranties may require or prevent certain maintenance processes or techniques.

7.1.3 Review of the effectiveness of current maintenance techniques

The four principal commercially available processes for the maintenance of a STP are drag brushing, Renovation (power brushing), Revitalisation and Rejuvenation. Each process is designed to treat a different depth within the infill profile – and costs increase logarithmically with depth. The process of brushing an STP realigns the fibres in the direction of the brushing action. During the action of play the fibres will become randomly orientated and this research shows that this significantly affects the deceleration of a ball across the surface. The maximum ball roll deceleration was 1.4 m s^{-2} (when the ball was rolling in the opposite direction to fibre brushing), but was 0.38 m s^{-2} when the ball was rolling in the same direction as fibre brushing; when the fibre was vertical deceleration was 0.7 m s^{-2}. Regular brushing of a surface in different directions will prevent a 'nap' forming (where all of the raised fibres are orientated in the same direction) on the surface that will adversely affect ball roll.

The brushing processes can be split into two groups; passive and active (powered) brushing. Drag brushing is passive as the bristles rest on the pitch surface under the load applied by the frame; the brush is then dragged in a forward motion. The other processes are active; the brush is contra-rotating, and in conjunction with forward motion increases the forces applied on the pitch surface and removes infill to a set depth. This group also contains rejuvenation which uses either compressed air or water to blow the infill out of the carpet pile.

The brushing processes exert stresses on the fibres which can damage the ends of the fibre over time with abrasion between the brush, the infill and fibres. A maximum powered brushing frequency was determined to be four passes with a rotary brush per year. The damage caused by a passive brush working at a shallow depth (drag-brushing) is less and therefore the brushing frequency can be higher.

Maintenance processes such as drag brushing and power brushing reduce the exposure of the fibres to UV radiation by grooming them into an upright position and reducing the surface area in direct sunlight. It should be noted that the samples used in this study were all less than 24 months old and had not been stored outside. The brushing frequency outlined above could differ in fibres exposed to UV over a number of years. A recommendation for further research is to repeat this testing programme with UV aged samples.

Drag brushing is a basic process that is used to redress the sand infill levels and does not have an infill cleaning function. Regular drag brushing of an STP surface ensures even levels of sand infill and reduces the bending over of the fibre tips; this increases ball deceleration which results in a more playable and more consistent surface. The frequency of the treatment should increase when the surface has a high number of hours of use; increased play displaces the sand infill at a greater rate and therefore needs to be redressed more often.

Renovation uses a rotary brush and has a specified working depth of 5 mm; in the field performance test, it was 2–3 mm. The technique removed up to 14% of the total contamination within the infill. Contamination will accumulate below this depth as the rest of the infill will not be affected by the brushing action (Figure 7.5). Some specifications of rotary brush do not filter the infill that has been disturbed and the action of the process is to restore porosity to the affected depth of infill. This will only be effective until the infill compacts and loses porosity once again. This process was also found to have a grooming effect, arranging fibres vertically; the field survey indicated that three treatments per year was the most common practice.

Revitalisation also uses a rotary brushing action but is designed to work more deeply at 10 mm; in the field performance test working depth was 7-8 mm. The infill is filtered and returned to the surface and the levels topped up with fresh material. This process removes up to 23% of the total contamination within the infill but, as with renovation, the remaining infill is not disturbed and contamination will build up over time (Figure 7.5). This process tends to be used for reactive maintenance rather than part of a proactive programme.

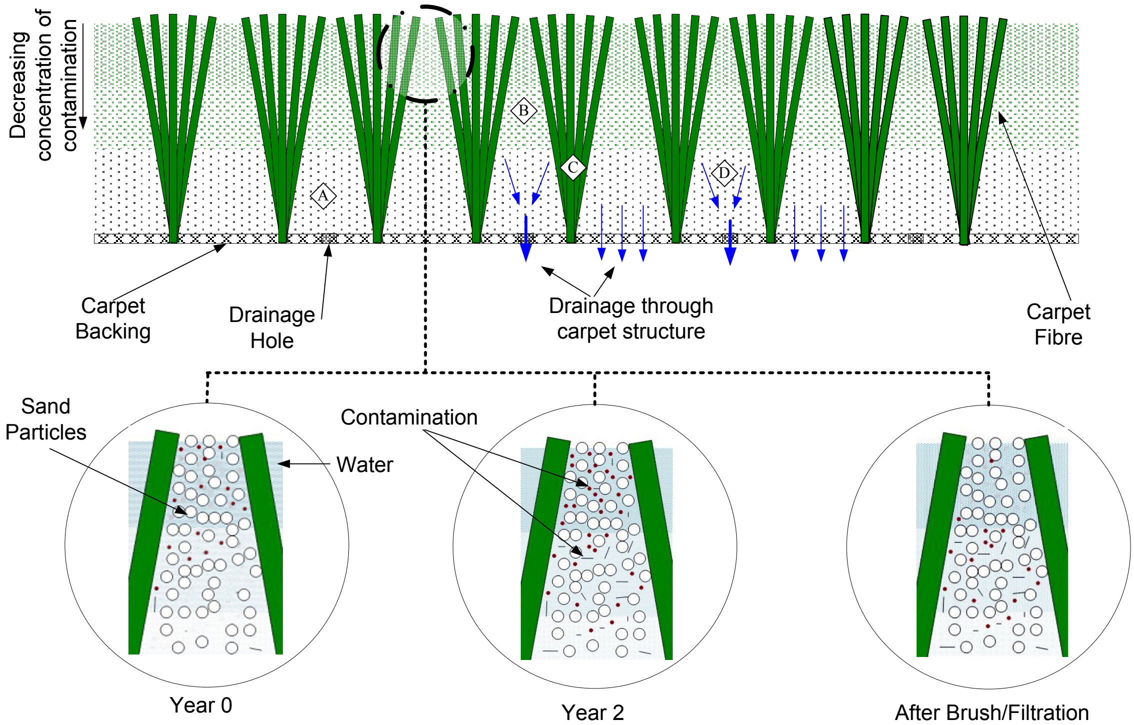


Figure 7.5 The effect of brushing and filtering the infill of a sand-filled synthetic turf sports pitch over time.

Rejuvenation removes the sand infill by the application of compressed air or water and has an expected maximum working depth of 20 mm; which the field survey showed to be 94-100% accurate for the compressed air process and 6 – 9 mm for the compressed water process – which was an issue of concern in a 20 mm carpet. The compressed-air process removed up to 90% of the contamination within the whole infill, by replacing the infill with new material. Rejuvenation can be the most effective of the processes for restoring infiltration rates to an STP surface, it is, however, the most expensive and time consuming, with a cost of up to £30,000, and can take up to one week to complete. These factors are the reason that this process is only used by managers when surface infiltration has been reduced to an extreme and surface use is restricted during periods of precipitation.

The effective working depth of renovation and revitalisation was found to be, on average, reduced by 60% with an infill moisture content of 10% (w/w); this was due to the adhesive forces of the water, within the infill structure. This shows that there are limited time periods when, under optimum surface conditions, any of the powered rotary brush applications can be used efficiently. The effective working depth is also affected by the presence of a 'capping' layer which is a product of a loss of fibre structure. The fibrillated fibres fold over and form a layer of fibre material over the infill. The fibre/bristle contact is increased during the brushing process and the friction caused by this contact deforms the bristles and changes the angle of contact of the bristle tip; this reduces the penetration of the brush and reduces the efficacy of the process.

The results suggest that a maintenance programme should utilise all three methods of brushing to maintain porosity and control the build of contamination at all depths of the infill.

7.1.4 The effect of maintenance on surface performance

Over time, the regular treatment of an STP with these individual processes, with the exception of rejuvenation, results in a cumulative build up of contamination within the infill below, and even within, their operating depth. Laboratory experiments determined that a rise in the concentration of contamination to 10 -15% (w/w), will result in a reduction in infiltration rate to the FIH basic standard of 50 mm h^{-1} and surface performance will be lost due to the high moisture content of the surface.

Field infill contamination was found to be 5 – 9 % by mass in maintained surfaces. This was in bulked samples of infill from the whole profile. Taking a hypothetical concentration of the contamination into the top 50% of the profile, then this range doubles to 10-18% for comparison with laboratory experiments.

The results showed that, over the life span of a synthetic surface, maintenance changes the surface performance (Figure 7.6). There is an interaction between the sand infill, the concentration of contamination and the infill moisture content that can be controlled, in the short-term, by surface maintenance as described in Figure 7.1 also. The cumulative build-up of contamination will increase the moisture holding capacity of the infill, which has been shown to reduce surface hardness and ball rebound significantly. This, added to the loss of infill depth through wear, means that a pitch could have a significant loss of performance over time if not maintained to control / reduce contamination.

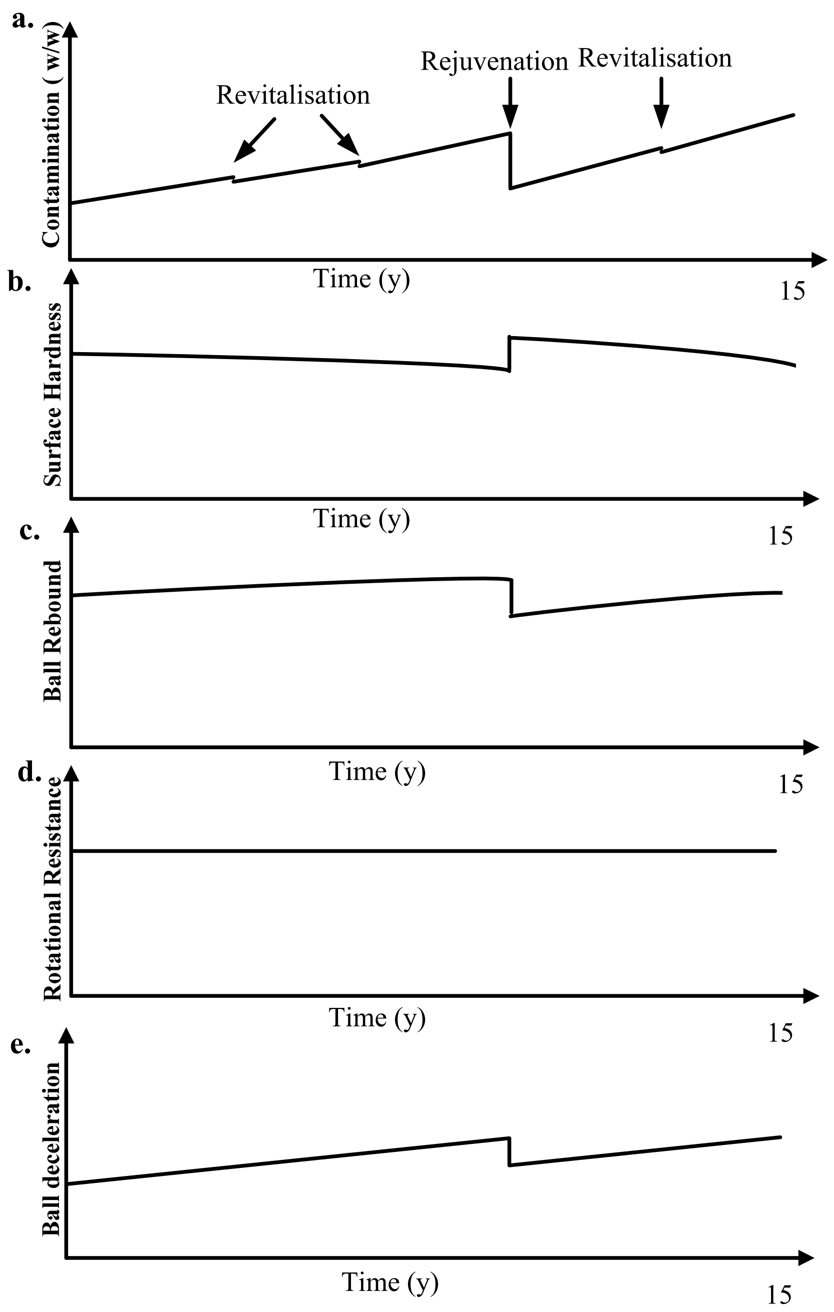


Figure 7.6 Schematic of the effect that maintenance has over time as a function of the performance of a synthetic turf surface: (a) contamination increases over time, unless rejuvenation takes place; (b) hardness is the inverse of contamination; (c) ball rebound decreases as hardness increases; (d) rotational resistance is unaffected by contamination (but increases if infill depth relative to pile height decreases); (e) ball deceleration increases as contamination increases (i.e. a positive outcome from contamination).

7.1.5 Financial modelling of STP facility operation and maintenance

The effect that the loss of surface performance due to an ineffective maintenance programme has on the revenue generated by an STP was analysed using a Net Present Value financial model. This showed that revenue was the most sensitive of all of the financial factors tested. A reduction of 12 hours of use per week, through loss of users because of poor surface performance, will result in the STP running at a financial loss. Integration of a proactive maintenance programme in to the management of an STP was shown to be commercially viable with an increase in the overall profit made from the STP and an extended surface lifespan. Figures provided by the contractors imply that a proactive maintenance regime can increase the life expectancy of the turf by over 100% (Replay Maintenance, 2007); prior to this research, there was no evidence presented to substantiate these claims. This research did not set out to prove or disprove this claim and it is not possible to determine a 100% lifecycle increase due to the benefits of maintenance with these data.

Scenario analysis was used to model the effect of insufficient maintenance on revenue loss, based on a relationship between lack of maintenance and the resultant loss of infiltration/drainage with consequences for surface performance. There are both direct and indirect tangible benefits for maintaining STPs identified from using this approach.

A stakeholder analysis determined the 'key players' in the purchasing decision making process, to be the facility manager and the funding body. It is important that both parties are aware that the lifespan of a pitch can be reduced from 15 to 12 years, at least, with insufficient maintenance and there is a direct benefit from optimized maintenance. The most experienced party, in terms of project history, will be the funding body and they should be in a position to leverage a sustainable maintenance plan and equipment provision as part of the funding agreement.

7.2 Application of the research findings to the maintenance of sand-filled synthetic turf pitches

The final objective of the research project (No. 6) is the provision of guidelines for the maintenance of second generation sand-filled synthetic sports pitches.

The objective of the guidelines is to provide the managers of synthetic turf pitches (STP) with information that will allow them to make informed decisions on when to maintain and which maintenance processes to include in an effective proactive programme.

The following section is an outline of the text to be supplied to the Institute of Groundsmanship (IOG), the commercial sponsor of this project, for joint publication of guidelines for the management and maintenance of second generation sand-filled synthetic turf pitches. As such, it includes summaries of results that repeat those above, but are used to provide an evidence base and justification for the guidelines developed. The final guideline document will include images and will be presented in an appropriate, accessible corporate format.

7.2.1 Draft Cranfield University - Institute of Groundsmanship guidelines for the management and maintenance of second generation sand-filled synthetic turf pitches

Note: The types of maintenance procedure are controlled within the warranty for many surfaces. You should consult your supplier *re* any specific exclusions or limitations regarding maintenance techniques and programmes and your warranty.

A synthetic turf pitch is selected for its high capacity for use, multi-sport capability and its use during most weather conditions. The initial high capital cost is off-set by the capacity of the surface to generate a revenue stream from external lettings. These benefits can be reduced if the surface loses playing performance through the lack of an effective maintenance programme. Research at Cranfield University has shown that the main contributing factors to the loss of surface performance are:

a. Contamination within the sand infill

An increase in the amount of contamination within the sand infill (from plastic fibre fragments, soil *etc.*) reduces the surface infiltration rate which has a significant negative affect on surface performance. At a concentration of 10 – 15%, surface infiltration is reduced below the FIH basic standard of 50 mm h^{-1} and surface evaporation is reduced, providing optimum growth conditions for moss or algae. In a survey of 2G (short pile, sand-filled) STP sites across England, contamination levels were found to be 1.9% - 9.1% w/w. A method for determining the contamination of the infill at your site can be downloaded from the Cranfield University website. In addition to some maintenance techniques, the build up of contamination can be reduced by preventative measures such as:

- At the design stage, limit the number of deciduous trees close to the pitch to reduce leaf fall and other tree-based contaminants,
- Controlled routing of foot traffic over clean hard standing to reduce contamination being carried on to the surface on footwear
- provide footwear brushes and entrance mats
- Provide litter bins that are emptied frequently
- Provide information boards outlining both acceptable and unacceptable behaviour

b. Wear of the synthetic carpet

Fibre wear is seen as a reduction in the length of the turf fibre, which reduces the depth of infill within the carpet and has a significant effect on surface performance characteristics such as: surface hardness, ball rebound, ball roll and rotational resistance. Although it is not possible to prevent the wear of synthetic turf fibre, caused by the interaction of the fibre and the infill under load, it is possible to reduce wear rates by effective maintenance and the use of a pitch management system that rotates the use of pitch areas for 5-a-side football and hockey.

c. Orientation of the synthetic turf fibres

Synthetic turf pitches that are brushed in one direction only may form a 'nap' on the synthetic turf which will significantly affect ball roll; the deceleration of the ball will vary depending on the direction of play. Fibres orientated with the fibre tip towards the rolling ball significantly increased the deceleration by fibre stiffness and increasing resistance against the rolling ball (this is desirable as it reduces ball roll distances). Fibres orientated away from the direction of ball roll significantly reduced the deceleration by the displacement of the fibres during ball roll. Although brushing is an essential part of a maintenance programme, varying the direction of the procedure will reduce the effect that fibre orientation has on surface performance and the formation of naps.

d. Fibre shape

The amount that the fibre is displaced during contact with the ball will affect ball deceleration. There are different structure of the fibres used in synthetic turf, the principal difference being between monofilament fibre and fibrillated tape, which will each have a different affect on the surface performance. The fibrillated tape structure will change over time as the fibres wear and breakdown in to smaller filaments; the surface performance will change as the stiffness of the fibres is reduced but the area of ball to fibre contact is increased.

Synthetic turf maintenance programme

A proactive maintenance programme will reduce the build up of contamination within the infill and provide a consistent level of surface performance in both time (month to month) and space (across the pitch). This is achieved by the use of a combination of four different maintenance processes:

1. Drag brushing: is a basic process that is used to redress the sand infill levels and does not have an infill cleaning function. Regular drag brushing of a STP surface ensures even levels of sand infill and reduces the bending over of the fibre tips; this increases the ball deceleration which results in a consistent playing surface. The frequency of the treatment increases when the surface has a high number of hours of

use; increased play displaces the sand infill at a greater rate and therefore needs to be redressed more often. The equipment required to carry out the drag brushing process is readily available from most sports turf equipment manufacturers and will cost approximately £1000 depending on the brush design and manufacturer. If there is no existing tractor unit for the brush then this will need to be taken into consideration. The process of drag brushing on a standard size hockey pitch should take approximately 60 – 70 minutes to complete.

2. Renovation uses a rotary brush and has an expected maximum working depth of 5 mm, which the field performance test showed to be 2–3 mm; it removes up to 14% of the total contamination within the infill. Contamination will accumulate below this depth as the rest of the infill will not be affected by the brushing action. Some specifications of rotary brush do not filter the infill that has been disturbed and the action of the process is to restore porosity to the affected depth of infill. This will only be effective until the infill compacts and loses porosity once again. This process was found to have a grooming effect, arranging fibres vertically; the field survey indicated that three treatments per year were optimal.

   This process is normally carried out by a specialist maintenance contractor, but provision of the equipment for in-house use will cost up to £15,000 and will take approximately 2 – 3 hours to complete. A specialist contractor will charge approximately £300 to perform this task.

3. Revitalisation also uses a contra-rotating brush action but has a typical working depth of 7-8 mm. The infill is filtered and returned to the surface and the levels topped up with fresh material. This process removes up to 23% of the total contamination within the infill but the remaining depth of infill is not disturbed and contamination will build up over time reducing the infiltration rate of the sand/fibre matrix. As with renovation, this process is normally carried out by a specialist maintenance contractor, but provision of the equipment for in-house use will cost up to £30000 and will take approximately 2 – 3 days to complete using one machine only. A contractor will use two or three machines and finish the task in one day and typically costs around £3000.

4. Rejuvenation removes the sand infill by the application of compressed air or water and has a typical working depth of up to 16 mm. The compressed air process is effective on both short (12 mm) and long pile (23 mm) carpet types and removed up to 90% of the contamination from the whole infill by replacing the infill with new material in a study at Cranfield. The compressed water process is effective on short pile 2G carpets, removing over 90% of the contamination from the whole infill by replacing the infill with new material; it is less effective on longer pile carpets, removing less than 20% of the contamination from the whole infill in the same study. When using pressurised water, particularly on longer (>15 mm) pile carpets, it is essential to ensure that contamination is not mobilised downwards through the profile or laterally across the pitch (including into drainage) due to the water transport.

   Rejuvenation is the most effective of the processes for reducing contamination and restoring infiltration rates in an STP surface, it is, however, the most expensive and time consuming with a cost of up to £30000 for a single treatment and can take up to one week to complete. These factors are the reason that this process is typically only used by managers when surface infiltration has been reduced to an unacceptable level and surface use is restricted during periods of precipitation.

It is important that the renovation and revitalisation processes are carried out when the surfaces are dry, i.e. the moisture content of the infill is as low as possible. An infill moisture content of 10% reduces the effective working depth of the processes by up to 60%. This reduces the depth of infill treated and the amount of contamination removed, therefore limiting the desired effect of the process. The filtering process of the equipment is also affected by the moisture content as finer contaminant particles will adhere to the larger sand particles and will not be separated by the filters.

Brushing frequency

Typically, pitches managed by local authorities and state schools have a significantly higher number of hours of pitch use compared to independent schools and private clubs. Research has also shown that an increase in the number of hours of pitch use significantly increases the concentration of contamination within the infill. As previously mentioned, the increased contamination will affect the surface performance of the STP.

Only rejuvenation removes all of the contamination from the infill, renovation and revitalisation have a marginal effect on contamination and you could still end up with a contaminated layer impeding drainage below the working depth of these machines. These techniques do help to groom the fibre, break up surface capped infill and increase porosity and infiltration rate if used regularly (but no more than 4 passes per year).

The frequency of the individual processes is controlled by the budget of each individual facility but to reduce the rate of the build-up of contamination and to regularly redress the infill levels there is a requirement for the implementation of a proactive maintenance programme. Based on the information from a questionnaire survey of regularly maintained STP sites, the following is a programme of maintenance that has been implemented in practice:

1. Drag brushing – 2 times per week
2. Renovation (power brushing) – 4 times per year
3. Revitalisation – 1 time every 2 – 3 years
4. Rejuvenation – only when there is a loss of the surface infiltration rates of the STP and there has been a loss of surface performance.

Research has shown that the processes used during maintenance do not cause any significant wear to the synthetic turf surface provided that the number of passes does not exceed that above, but it is important that the surface is regularly checked for tears and seam failure as the brushing action may cause further damage by exerting strain on the damaged carpet. Also *you must* consult your warranty documents and any advice on maintenance provided by your supplier to ensure these techniques are compatible with your surface.

7.3 Evaluation of research methodology, results and analysis

Initial decisions on the project structure confined the research to second generation sand-filled synthetic turf pitches only. This specification of STP has been used in the UK since the 1980's and the population of prospective test surfaces is greater than that of the younger carpet specifications at the time of writing this thesis.

Two factors not considered were:

1. 3G long pile surfaces designed for football. – These surfaces have only been in use for the last 8 – 10 years and the variations in the design specifications would have made a comparative study difficult to complete. To include these surfaces would have required a repeat of the questionnaire, field and laboratory studies and the financial analysis.

   The fibre materials are similar so the fibre/equipment interaction is thought to be similar. However, there is less sand and less infill relative to the fibre length which will increase the deformation of the fibre. Also a greater depth of infill, obstructed by a greater length of fibre will become contaminated and have to be treated. The effect of rubber on contaminant accumulation rates also needs to be quantified.

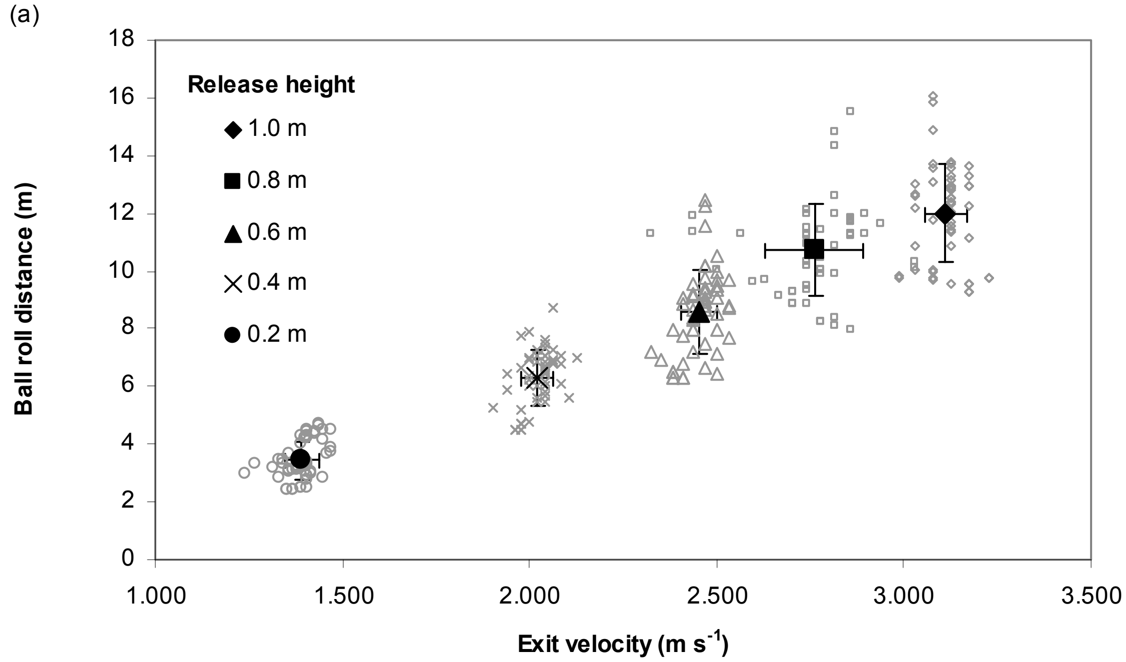
2. Aged surfaces in laboratory experiments – These surfaces were not included as there was difficulty procuring samples, which would not include a control sample, for use. This could be addressed by using carpet from a site where the surface is being replaced or samples where aging has been accelerated, using exposure to UV radiation, which is known to increase fibre brittleness, so wear rates could be increased under controlled conditions.

The methods used for performance testing were based on British and European standards which are the basis for performance testing throughout the synthetic turf industry. The research did, however, show that not all of the tests were appropriate for the characteristics that they were designed to measure.

The method that was seen to be ineffective was the measurement of ball roll over the synthetic turf surface. It was found that the greater the distance of ball roll, the more external factors such as localised surface levels, fibre orientation, infill moisture content and meteorological conditions caused a higher variation within the data. A study of how ball roll distance varies with release height (i.e. initial potential energy) from the ramp is revealing (Figure 7.7a). Even in controlled conditions in the laboratory, with a brushed surface, it is evident that the variation in ball roll distance (and exit speed from the ramp) increases as the release height increases. An inspection of the coefficient of variation, however, shows this increase to be proportional to the increase in drop height for the ball roll distance and that the variation in exit speed decreases relative to the mean exit speed as release height increases (Figure 7.7b). In controlled laboratory experiments at a 1.0 m release height the coefficient of variation was ca. 5%; in the field this increased to an extent to which the test was not correlated with ball deceleration over a shorter distance due to field variability. In the 1 m test, mean initial velocity was 3.1 m s^{-1}; in real play, ball roll speed will be 14 times this, and on the assumption that ball will travel further (not that it is travelling more quickly) there will be an increase in variation of ball roll distance.

The lack of a central database of synthetic pitches within the United Kingdom meant that the test pitches were selected from the database of a national maintenance company; this skewed the data as all of the pitches were maintained to some degree, however, it is representative of maintained pitches. There were no test pitches available that had no maintenance carried out on them. A recommendation for future research would be to test pitches that have been free of maintenance for a number of years. Also there is a justified need for a coordinated database of sports surface facilities.

The field study highlighted the effects of manufacturing, environmental and construction variation that exists even within synthetic turf pitch systems. This resulted in data that reflected field variability but was too 'noisy' to isolate maintenance treatment effects.



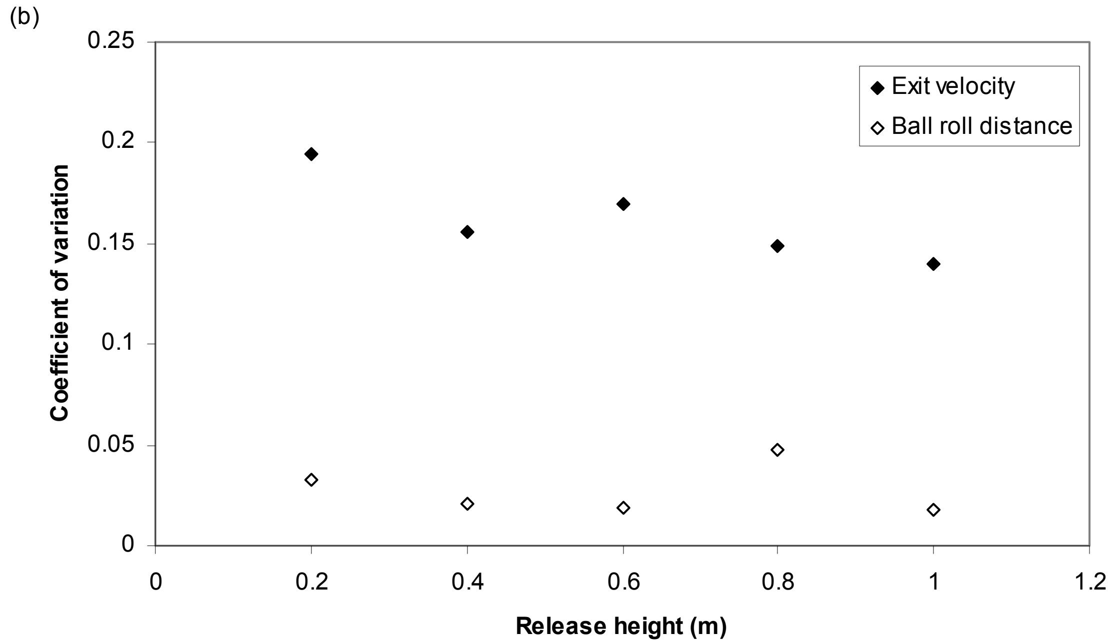


Figure 7.7 (a) The relationship between measured ball roll and the initial velocity on exit from the ramp as a function of ball release height on the 1 m high ramp in BS7044. (b) The coefficient of variation for exit velocity and ball roll distance in the same experiment.

This could be due to a reduced range of maintenance intensity as described above, but it is more likely to be a function of the large variability from pitch to pitch and to an extent from day to day which is a challenge to studies of this type, particularly on older pitches where construction specifications *etc*. are harder to source.

7.4 Recommendations for further study

1. The sedimentation method was designed for use with infill extracted from sand-filled synthetic turf pitches. With the increasing numbers of sand/rubber infill pitches, the method requires adapting to suit the different infill specification. The method can then be designed to be available as a field test that is accessible to all managers of synthetic turf pitches.

2. The effect of contamination on performance of a playing surface should be extended to include third generation long pile, sand/rubber infill pitches.

3. The field performance survey should be extended to synthetic pitches that have been free of maintenance to compare the data with the research results.

4. Further development of the Peak Ratio method to measure synthetic turf fibre wear should be extended to include the surface pitting seen within this study.

5. It was not possible to preserve infill profiles when quantifying infill contamination. Future work should develop a non-destructive sampling method to stratify the infill profile and investigate the variation in contamination with depth. This is important for machinery design and evaluation as it is related to working depths of machines.

6. At present, the method used to remove the sand infill from a synthetic turf pitch requires the sand to have low moisture content. New research is required to develop a method of removal that can be used when the infill has high moisture content. This will enable the use of the sedimentation method at any time of the year.

7. The accelerated wear testing of synthetic turf fibres needs to be repeated using UV exposed samples to quantify any difference in the wear process.

8. The test rig should be further developed to include finer control on the brush depth to prevent any floating of the rotary brush over the turf sample surface. This will indicate the depth at which the bristles of the brush are deflected away from the surface and tip/surface contact lost.

9. The test rig should also be adapted to quantify the wear of the turf caused by player interaction, perhaps in a similar way to the Lisport device.

7.5 Publications from this study

The following conference papers were published during this research project:

McLeod, A., James, I., Blackburn, K. and Wood, W. (2006) A Novel Quantitative Method for the Determination of Wear in an Installed Synthetic Turf System. *The Engineering of Sport 6 Volume 1: Developments for Sports.* Eds, Moritz, E.F. and Haake, S. International Sports Engineering Association, Munich. P217-222.

McLeod, A.J. and James, I.T. (2007) An evaluation of surface performance for second generation sand-filled synthetic hockey pitches in the United Kingdom. *The 2nd International ISHS Conference on Turfgrass Science & Management of Sports Fields. Beijing*

McLeod, A.J. and James, I.T. (2007) The effect of particulate contamination on the infiltration rates of synthetic turf surfaces. *Science, Technology and Research into Sport Surfaces (STARSS). Loughborough*

The following journal papers are to be submitted:

1. McLeod, A.J., James, I.T. and Neame, C. The development of a financial model to analyse the outputs of an effective management and maintenance programme for second generation sand-filled synthetic pitches
2. McLeod, A.J. and James, I.T. Guidelines for the management and maintenance of second generation sand-filled synthetic pitches
3. McLeod, A.J., James, I.T. and Brighton, J.L. A novel method of quantifying the effect of existing maintenance equipment on the wear processes of synthetic turf fibres.
4. McLeod, A.J. and James, I.T. A survey of the management and maintenance practices of second generation sand-filled synthetic pitches within the United Kingdom.

The target journals will include sports/facilities management, sports engineering and mechanical engineering. In addition, a journal version of the guidelines will be produced with colleagues at Cranfield University and the Institute of Groundsmanship.

8 Chapter Eight: Conclusions

The aim of the research project was to develop a fundamental understanding of the mechanical wear and decline in hydraulic performance of second generation synthetic turf surfaces and its impact on technical performance characteristics, and economic life-cycle costs in relation to maintenance and usage. To achieve this aim there were seven objectives (Chapter 1.5). The following conclusions were aligned to these objectives:

1. In a survey of 44 second generation synthetic turf pitch sites across England, maintenance programmes varied significantly from irregular drag brushing to regular use of drag and power brushing methods. The variation in programmes used was because a) the programmes were based on limited information supplied by a variety of sources and b) managers appeared to be adjusting maintenance programmes according to the available maintenance budget which ranged from an average of £4000 per annum for a private facility and £6500 per annum for a public facility

2. A field survey showed variation in surface performance, but there was no correlation with the type or frequency of maintenance. Therefore either maintenance does not affect the surface performance or other uncontrollable factors, such as construction, maintenance programme, contamination within the sand infill or meteorological conditions were masking the correlation.

3. Using the sedimentation method, the concentration of contamination within the infill of the sites on the field survey varied from 1.9% to 9.1%. The variation was due to pitches differing in a) the number of hours of use, b) maintenance programme, c) pitch age and d) facility design. It was not possible to determine whether this bulk contamination varied in distribution with depth due to the sampling technique.

4. Laboratory experimentation showed that maintenance of the synthetic turf is required to optimise the effects of: i) the mass of infill per unit area of synthetic turf – increased levels of infill reduced surface hardness and ball rebound, and decreased ball deceleration and rotational resistance, and ii) reduce the concentration of contamination within the infill – increased contamination significantly increased ball rebound and ball deceleration, and increased surface hardness and rotational resistance.

5. The imaging method (Peak Ratio) enabled the quantification of synthetic turf fibre wear in laboratory accelerated wear tests. The range of Peak Ratios for the field survey sites was 2 – 4.8 and there was no significant correlation with the questionnaire output data for pitch age, use or maintenance programme. The field sample images showed that there is a need for further development of this method to include the quantification of surface pitting along with the existing measurement of linearity.

6. Measurement of the effectiveness of existing maintenance equipment in the field showed that a) renovation (power brushing) worked to a depth of 2-3 mm but did not significantly reduce contamination, b) revitalisation worked to a depth of 7-8 mm and did not significantly reduce contamination either. This is not to say that these processes are ineffective – they have a role in grooming fibres and loosening compacted or capped infill – but they did not reduce contamination significantly in this experiment.

7. Compressed air rejuvenation removed 81-83% w/w of the total contamination from the infill from 95-100% of the infill depth. This technique was effective at reducing contamination but this was achieved using material replacement and operational costs were significant.

8. Compressed water rejuvenation was found to be inefficient on longer pile carpets (20 mm) working in only the top third of the profile and removing 17% of

contamination present (in the whole profile), but was effective on shorter pile carpets (11 mm) removing 90% of contamination from the whole profile depth.

9. Simulated maintenance equipment operation showed that the depth of infill removed was significantly affected by the normal load of the rotary brush, the brush depth and the moisture content of the sand infill.

10. The scanning electron microscope method (Peak Ratio) showed that repeated maintenance treatments do not increase the wear of the face of new fibres within a synthetic turf pitch, but optical imaging of the fibre tips showed that contra-rotating brush action should not be used for more than 4 passes per annum (in samples of new synthetic turf) or fibrillation is increased. This conclusion was not tested for UV aged samples.

11. The ball roll method described in BS 7044 was found to be reflective of field variation and thus ineffective in isolating single factors affecting pitch performance. The greater the distance of ball roll the more the ball was affected by external factors such as pile orientation, infill moisture content, concentration of contamination and meteorological conditions.

12. A Net Present Value financial model showed that a synthetic turf facility is financially viable over a 15 year lifespan. Including replacement of the carpet at the end of the lifespan the NPV for the project was £236,538 for a 6% discount factor and £133,282 for a 10% discount factor; the projects would break even at the end of years six and eight respectively. The NPV's were increased if the replacement of carpet was not included as a future cost, but ineffective maintenance was shown to be a significant factor in the financial viability of a facility which resulted in a reduced lifespan, 12 years instead of 15 years, causing the NPV's to fall to -£14,510 and -£56,933 for 6% and 10% discount values respectively.

13. It was possible to improve the current maintenance guidelines for sand-filled synthetic turf pitches by showing the actual effect of infill levels and contamination

on surface performance, the efficacy of existing maintenance equipment and the optimum conditions for its use, and the financial effect that ineffective maintenance will have.

9 Chapter Nine: References

Abbott, M. Artificial Intelligence. (2002) *SAPCA Guidance Leaflet: No.3* [available online] http://www.sapca.org.uk/downloads/leaflets/TGL3.pdf [accessed 24/07/2006]

Adams, W.A. & Gibbs, R.J (1994). Natural Turf for Sport and Amenity: Science and Practice. CAB International

Aggregate Industries (2006) Material Specification: LeisureTex Plus (Multi-use). *Technical Department*, Aggregate Industries.

Ashford, N. (2004) Compliance Costs: The Neglected Issue. *European Agency for Safety and Health at Work Magazine.* Issue 1. [available online] http://www.agency.osha.eu.int/publications/magazine/1/en/index_14.htm [accessed 05/05/2007]

Avery, B.W. and Bascomb, C.L. (1982) Soil Survey Laboratory Methods. Soil Survey Technical Monograph No 6

Baker, S.W. (1991) Temporal variation of selected mechanical properties of natural turf football pitches. *Journal of Turfgrass Science*, Vol. 67, 983-992

Baker, S.W., Hammond, L.K.; Stewart, K.F. (2001) Technical note: Influence of Clegg hammer weight on the relationship between surface hardness and ball rebound for cricket. *Journal of Turfgrass Science,* Vol. 77, 71-74

Baroud, G., Nigg, B.M. and Stefanyshyn, D. (1999) Energy storage and return in sports surfaces. *Sports Engineering*, Vol. 2, p173-180

Bodman, G.B. and Constantin, G.K. (1965) Influence of Particle Size Distribution in Soil Compaction. Hilgardia, Vol. 36, No. 15. p 567-591

British Standards Institute (1990) Artificial sports surfaces – Part 1: Classification and general introduction. *BS7044-1* [available online] http://www.bsonlinetechindex.co.uk [accessed 12/03/2007]

BS7044 (1990). BS 7044-2.3:1990: Artificial sports surfaces methods of test: methods for determination of durability. British Standards Institution, London, UK

BS EN 15306:2007 (E) Surfaces for Outdoor Sports Areas – Exposure of Synthetic Turf to Simulated Wear. European Committee for Standardization, Brussels, Belgium.

Brady, N.C. and Weil, R.R. (2002) The Nature and Properties of Soils. 13th Ed. Prentice Hall, New Jersey.

Brock (2006) Brock Synthetic Bases: leading the Field. Brock, USA

Brydson, J.A. (1982) Plastic Materials. 4th Ed. Butterworths, London

Carré, M.J. and Haake, S.J. (2004) An examination of the Clegg impact hammer test with regard to the playing performance of synthetic sports surfaces. *Journal of Sports Engineering*. vol. 7, p 121-129

Carré, M.J., Dodd, D., Senior, T. and Haake, S.J. (2004) A system for predicting the impact between a ball and a sports surface. *The Engineering of Sport 5*. vol. 2, p45-51. ISEA

CCM (2002) Turfman Astroturf Cleaner [available online] http://www.chapelcleaning.co.uk [accessed 25/02/2007]

Chaker, A. (2002) Fake Grass Is Always Greener, Cheaper, but it's Harder Too. *Wall Street Journal*, Jul. p.24

Charles Lawrence plc (2007) Recycling [available online] http://www.clgplc.co.uk/rec_rub.asf [accessed 05/05/2007]

Clegg, B. (1976). An impact testing device for in situ base course evaluation. Australian Road Research Bureau Proceedings, Vol. 8 1-6.

Coaplen, J., Stronge, W.J. and Ravani, B. (2004) Work equivalent composite coefficient of restitution. *International Journal of Impact Engineering*, Vol. 30, Issue 6, p. 581-591

Davis, W.B. (1981), Natural versus Artificial Turf; an Economical Alternative. *California Turfgrass Culture*, vol. 31, Number 2.

DCMS (2002) Game Plan: a strategy for delivering Government's sport and physical activity objectives. DCMS/Strategy Unit Report

Deer, W.A., Howie,R.A. &. Zussman, J. (1992) An introduction to the rock-forming minerals. Longman Scientific & Technical, Harlow, UK

Desso (2003) DD Grassmaster. [available online] http://www.dessodlw.com [accessed 06/02/2007]

DIN 18035-6 (2004) Sportsgrounds; Synthetic Surface Areas [available online] http://www.din.de [accessed 06/05/2007]

Dixon, S.J., Batt, M.E. and Collop, A.C. (1999). Artificial playing surfaces: A review of medical, engineering and biomechanical aspects. *International Journal of Sports Medicine* 20, p. 209-218.

Dixon, S.J., James, I.T., Blackburn, K., Pettican, N., Low, D. (2008). Influence of footwear and soil density on loading within the shoe and soil surface during running. *Proceedings of the Institution of Mechanical Engineers*, Vol. 222, Part P: Journal of Sports Engineering and Technology. (in press). DOI: 10.1243/17543371JSET16.

European Community Groundwater Directive (80/68/EEC).

Ekstrand, J., Timpka, T. & Hagglund, M. (2006) Risk of Injury in elite football played on artificial turf versus natural grass: a prospective two-cohort study. *British Journal of Sports Medicine*, 40, p975-980

Ekstrand, J. (1982) Soccer Injuries and their Prevention. *University Medical Dissertations* No. 130, Linkoeping, Sweden

Environment Agency (1998) The Groundwater Regulations [available online] http://www.environment-agency.gov.uk/business/444217/444663/955191/?version=1&lang=_e [accessed 06/05/2007]

EHA (2006) Hockey Pitches – Basic Information [available online] http://www.englandhockey.co.uk/core_files/fileDownload(718).pdf (accessed 05/11/2007)

FIFA (2001) FIFA Guide to Artificial Surfaces. *FIFA Marketing AG*,Switzerland

FIFA (2005) FIFA Quality concept: Handbook of test methods and requirements for artificial football turf. FIFA Marketing & TV AG, Switzerland

FIFA (2006) FIFA Quality Concept for Football Turf: Maintenance of a Football Turf Field. *FIFA Marketing AG*,Switzerland

Football Association (2004a) Guide to Artificial Grass Pitches for Community Use: Part 1 Performance Standards for Surfaces and Pitches Used Outdoors. *Football Association Publication*, London

Football Association (2004b) Guide to Artificial Grass Pitches for Community Use: Part 2 Their Design, Specification and Construction. *Football Association Publication*, London

FIH (2001) Synthetic Hockey Turf Pitches: Guidelines for Care and Maintenance. FIH Lausanne, Switzerland

FIH (2001a) Handbook for the Care and Maintenance of Synthetic Turf Hockey Pitches - Outdoors 1st Ed. FIH, Lausanne, Switzerland

FIH (1999) Synthetic Hockey Pitches – Outdoor: Handbook of Performance Requirements. International Hockey Federation, Brussels

Football Foundation (2002) Synthetic Turf Pitches: Data Sheet 6 [available online] http://www.footballfoundation.org.uk/htmlformats/SyntheticTurfPitchesDataSheet.asp [accessed 23/02/2007]

Football Foundation (2006) Annual Review 2005/06. London

Gahlin, R. & Jacobsen, S. (1998) A novel method to map and quantify wear on a micro-scale. *Wear*. 222, 93-102

Gibbs, R.J., Adams, W.A. & Baker, S.W. (1991) Making the most of natural turf pitches. Final Results of a case studies approach: II Playing Quality. Natural Turf Pitch Prototypes Advisory Panel Report No. 7, *Sports Council Publication*

Gillies, E. (1995) Good Grounding, *Leisure Management*, Jan

Harrison, E (2006) FIFA Quality Concept: Medical. *2nd SPORTSURF Workshop*, Cranfield, UK.

Heidt, R.S., Dormer, S.G., Cawley, P.W., Scranton, P.E., Losse, G. and Howard, M. (1996) Differences in friction and torsional resistance in althletic shoe-turf interfaces. *The American Journal of Sports Medicine*, Vol. 24, No. 6, p834-842.

Herbert, J. (1989) Going Plastic at the Roots. *Hockey Digest*. April

Hertzberg, R.W. (1983) Deformation and Fracture Mechanics of Engineering Materials. John Wiley & Sons, New York, 826 pp

Hession, T (pers.com) Managing Director, Replay Maintenance Ltd

Highways Agency (2007) Specification for Highway Works. [available online]

http://www.standardsforhighways.co.uk/mchw/index.htm (accessed 30/09/2007)

HSE (1986) Control of Pesticides Act [available online] http://www.defra.gov.uk [accessed 02/05/2007]

Institute of Groundsmanship (2000) Guidelines for Performance Quality Standards Part One: Sports Surfaces Natural and Non Turf. *I.O.G. Publication*

Kolitzus, H. (2003). Covering the overlooked standards: measuring the technical characteristics of synthetic fields over time and the long-term maintenance issues. *Stadia Sports Turf Summit*, Amsterdam. Broadcast Publishing LTD.

Lancaster, J.K. (1969) Abrasive wear of polymers. *Wea*r, Vol. 14, p223-239

Larson, S.j>, Capel, P.D. & Majewski, M.S. (1999) Pesticides in Surface Waters: Distibution, Trands, and Governing Factors. Ann Arbor Press, Inc. Michigan

Levy, M., Skovron, M.L. & Agel, J. (1990) Living with Artificial Grass. *The American Journal of Sports Medicine*, Vol.18, No.4, pp406-412

LTA (2002) Data A6: Artificial Grass [available online] http://www.lta.org.uk/facilities/datasheets/A6.pdf [accessed 26/02/2007]

Lockyer, J. (2003) An investigation into the sustainability of sand/rubber filled artificial football pitches. MSc Thesis, *Cranfield University*

Maier, C and Calafut, T. (1998) Polypropylene: The Definitive User's Guide and Databook. William Andrew Publishing.

Mendelow, A. (1981). *Proceedings of 2nd International Conference on Information Systems*, Cambridge, MA

McLeod, A.J. (2003) An Assessment of the Benefits of Artificial Turf Over Natural Turf Playing Surfaces Within the Independent School Environment. MSc Thesis, *Cranfield University*.

McLeod, A., James, I., Blackburn, K. and Wood, W. (2006) A Novel Quantitative Method for the Determination of Wear in an Installed Synthetic Turf System. The Engineering of

Sport 6 Volume 1: Developments for Sports. Eds, Moritz, E.F. and Haake, S. International Sports Engineering Association, Munich. p217-222.

McLeod, A.J. and James, I.T. (2007) The effect of particulate contamination on the infiltration rates of synthetic turf surfaces. Science, Technology and Research into Sport Surfaces (STARSS). Loughborough

Milner, E.M. (1990) Selecting a Synthetic Turf Surface. Natural and Artificial Playing Fields: Characteristics and Safety Features *ASTM* STP 1073. pp183-187

Mintel (2007) Sport Participation – UK – May 2007 *Mintel Report*

Morehouse, C.A., (1992) ‘Turfgrass’, *Turfgrass-Agronomy Monograph* 32 ASA-CSSA-SSSA, 677S Seghoe Rd., Madison, WI53711.

Naeini, S.A. and Baziar, M.H. (2003) Effect of fines content on steady-state strength of mixed and layered samples of a sand. *Soil Dynamics and Earthquake Engineering*. Vol 24 p 181-187

Nigg, B.M. and Yeadon, M.R. (1987) Biomechanical aspects of playing surfaces. Journal of Sports Sciences, Vol. 5, p117-145

NPFA, (2000). ‘Sports Provision’ Cost Guide 2000. *NPFA Publication*

NPTC (2006) Certificate of Competence in the Safe Use of Pesticides. NPTC, Warwickshire

Orofino, T.A. and Leffingwell, J.W. (1990) Selection of Materials for Artificial Turf Surfaces. Natural and Artificial Playing Fields: Characteristics and Safety Features. *ASTM* STP1073 Philadelphia, pp. 166-175

Panstadia International (2002) The Greatest Turf on Earth, *Panstadia International.* May

Porter, M.E. (1980) Competitive Strategy: Techniques for Analyzing Industries and Competitors. Free Press, New York

Porter, M. (1991) America's Green Strategy. *Scientific American*, April, pp 96

Porter, M.E. & van der Linde, C. (1995) Toward a New Conception of the Environment-Competitiveness Relationship. *Journal of Economic Perspectives*, 9(4):97:118

Ram, A. (1997) Fundamentals of Polymer Engineering. Springer-Verlag

Redexim (2007) [available online] www.redexim.co.uk [accessed 11/05/2007]

Replay Maintenance (2007) Why Maintain? [available online] http://www.replaymaintenance.co.uk [accessed 08/08/2007]

Rhodes, D.I. (1996) The Maintenance of Artificial Sandfilled Turf Used for Sport. Sports Surface Management, Bolton

Rhodes, D.I. (1997) Carpet Care. *Panstadia International Quarterly Report*. Vol. 4 No.1

Roberts, J.R. (1994). Artificial turf Pitches for Hockey. *Sports Council publication*

Rogers III, J.N. and Waddington, D.V. (1990) Portable Apparatus for Assessing Impact Characteristics of Athletic Field Surfaces. Natural and Artificial Playing Fields: Characteristics and Safety Features. *ASTM* 1073. American Society for Testing and Materials, Philadelphia. p 96-110

Rugman, A.M. & Verbeke, A (1998) Corporate Strategy and International Environmental Policy. *Journal of International Business Studies*, 29(4), pp 819-833

Russel, M. (1992) Cutting down the costs of sport with the help of synthetic grass. *Technical Textiles International*. July/August. p12-15

SAPCA (2003) First Outing for New Charles Lawrence Maintenance Machine [available online] http://www.sapca.org.uk/storyRJHDQO3J04.asp [accessed 11/03/2003]

Scott's (2004) 'Enforcer' Safety Data Sheet, *The Scott's Company Ltd*, Ipswich

Shi, Z. and Horii, H. (1989) Microslip model of strain localisation in and deformation. *Mechanics of Materials 8*, p.89-102

Sisis (2003) Rakes, Brushes and Combinations. [available online] Http://www.sisis.com/mach/ine10.html [accessed 25/02/2007]

SMG (2001) Maintenance and Cleaning of Sports grounds [available online] http://www.smg-gmbh.de/booklet-english.pdf [accessed 25/02/2007]

SMGa (2003) Turf Top [available online] http://www.smg-gmbh.de/sp_turftop.pdf [accessed 25/02/2007]

Sports Venue Technology (2003) Ecorr Rubber Infill [available online] http://www.sportsvenue-technology.com/contractors/surfaces/rubber/index.html [accessed 17/04/2007]

Sports Venue Technology (2003a) Greenfield’s United FT Football Turf [available online]

http://www.sportsvenue-technology.com/contractors/surfaces/greenfields/index.html [accessed 17/04/2007]

Stokes, G.G. (1856) Stokes Law. Trans. Cambridge Philos. Soc., 9 ~1856

Sweepfast (2007) Surface Refurbishment [available online] http://www.sweepfast.com/refurbishment.htm [accessed 08/08/2007]

Sweet, E. (2002) Artificial turf has come a long way [available online] http://www.djc.com/news/co/11136434.html [accessed on 12/05/2007]

Technical Surfaces (2002) Synthetic Sports Turf Maintenance [available online] Http://www.technicalsurfaces.co.uk [accessed 12/05/2007]

Tipp, G. and Watson, V. (1982). Polymeric Surfaces for Sports and Recreation.

Applied Science Publishers, London, UK.

UEFA (2002) Artificial Turf in UEFA Competitions [available online] http://www.uefa.com/newsfiles/38018.pdf [accessed 12/05/2007]

Veerbrink, B. (2003) Commercial Decisions-Year Round Performance versus Natural Preferences. *Stadia Sports Turf Summit*, Broadcast Publishing LTD.

Verhelst, R., Verleysen, P., Degrieck, J., Rambour, S., Schouckens, G. (2007). Development of a setup for the Study of Ball Roll Behaviour in Soccer on Artificial Turf. In Fleming, P.; Young, C.; Dixon, S.; James, I.T.; Carré, M.; Walker, C. (Eds). *Proceedings of the Science Technology and Research into Sports Surfaces (STARSS 2007).* September 2007, Loughborough UK. ISBN 978-1-897911-30-3

Waterman, S. (2003), Magic Carpet. Panstadia International Quarterly Report: Vol. 9 No.3

Woods, H. (2004) Plastic could be footballs flexible friend. *The Sunday Herald*. Feb 2.

Wust, C.J. & Gammelgaard, E.G. (2004) Olefin Fibres. Encyclopedia of polymer Science and Technology. Pp1-28. John Wiley & Sons.

Yakimets, I., Dawei, L. and Le Guigon, M (2004)Effect of photo-oxidation cracks on behaviour of thick polypropylene samples. *Polymer Degradation and Stability*, Vol. 86, 59-67

Young, C. and Fleming, P.R. (2006) A review of mechanical impact testing devices for sports surfaces. Science, Technology and Research into Sport Surfaces (STARSS). Loughborough

Zertal, A., Jacquet, M., Lavédrine, B. and Sehili, T. (2004) Photodegradation of chlorinated pesticides dispersed on sand. Chemosphere, vol. 58, 10. p1431-1437.

10 Chapter 10: Appendices

Appendix A: Data from the field performance survey

Pitch No. 1

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
R	6	G	9.77	0.272	31	156	0.533	6.6	16			
R	6	G	9.45	0.292	30	156	0.733	6.6	15			
R	6	G	8.98	0.272	27	160	0.702	6.6	14			
R	6	G	9.34		26		0.702	6.6				
R	6	G	9.89		26		0.488	6.6				
R	6	G	9.37				0.803	6.6				
R	6	G	10.2				0.510	6.6				
R	6	G	9.8				0.467	6.6				
R	6	G	10.01				0.488	6.6				
R	6	G	10.13				0.467	6.6				
R	6	W	9.13	0.192	26	108	1.688	6.5	15			
R	6	W	10.05	0.192	22	161	1.360	6.5	16			
R	6	W	10.09	0.192	24	151	1.082	6.5	16.5			
R	6	W	10.14		23		1.251	6.5				
R	6	W	10.62		24		1.466	6.5				
R	6	W	9.44				1.330	6.5				
R	6	W	9.87				0.374	6.5				
R	6	W	10.09				0.624	6.5				
R	6	W	9.61				0.488	6.5				
R	6	W	9.99				0.488	6.5				
R	6	C	9.78	0.232	24	152	0.702	6.6	16			
R	6	C	10.84	0.232	24	157	0.510	6.6	16.5			
R	6	C	10.43	0.232	27	157	0.533	6.6	16.5			
R	6	C	9.82		28		0.597	6.6				
R	6	C	10.26		24		0.488	6.6				
R	6	C	11.21				0.374	6.6				
R	6	C	11.15				0.391	6.6				
R	6	C	10.52				0.526	6.6				
R	6	C	10.82				0.488	6.6				
R	6	C	10.91				0.733	6.6				

Pitch No. 2

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
R	5	G	13.4	0.212	30	133	0.558	4.99	16	52	4	25
R	5	G	14.83	0.212	26	133	0.448	4.99	18	52	4	25
R	5	G	15.51	0.212	25	134	0.427	4.99	16.5	52	4	25
R	5	G	13.64		28		0.558	4.99		52	4	25
R	5	G	13.43		26		0.584	4.99		52	4	25
R	5	G	13.42				0.448	4.99		52	4	25
R	5	G	13.97				0.584	4.99		52	4	25
R	5	G	14.97				0.142	4.99		52	4	25
R	5	G	14.13				0.305	4.99		52	4	25
R	5	G	14.76				0.291	4.99		52	4	25
R	5	W	8.81	0.172	28	96	0.838	4.99	17.5	52	4	25
R	5	W	8.37	0.172	22	108	0.533	4.99	18.5	52	4	25
R	5	W	8.97	0.172	25	101	0.391	4.99	17.5	52	4	25
R	5	W	9.32		27		0.533	4.99		52	4	25
R	5	W	9.18		26		0.558	4.99		52	4	25
R	5	W	9.23				0.801	4.99		52	4	25
R	5	W	9.18				0.558	4.99		52	4	25
R	5	W	9.38				0.558	4.99		52	4	25
R	5	W	9.13				0.682	4.99		52	4	25
R	5	W	8.75				0.652	4.99		52	4	25
R	5	C	12.54	0.192	28	117	0.558	4.99	17.5	52	4	25
R	5	C	13.54	0.212	26	118	0.558	4.99	17.5	52	4	25
R	5	C	12.94	0.192	25	123	0.448	4.99	17	52	4	25
R	5	C	13.2		28		0.714	4.99		52	4	25
R	5	C	13.49		26		0.427	4.99		52	4	25
R	5	C	13.62				0.305	4.99		52	4	25
R	5	C	13.47				0.558	4.99		52	4	25
R	5	C	13.03				0.584	4.99		52	4	25
R	5	C	13.26				0.305	4.99		52	4	25
R	5	C	10.48				0.714	4.99		52	4	25

Pitch No. 3

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
R	1	G	9.35	0.132	28	90	0.136	2.1	22	104	6	22
R	1	G	9.57	0.152	25	94	-0.142	2.1	22.5	104	6	22
R	1	G	9.09	0.152	27	156	0.533	2.1	22	104	6	22
R	1	G	9.37		28		0.408	2.1		104	6	22
R	1	G	9.32		28		0.266	2.1		104	6	22
R	1	G	9.76				0.427	2.1		104	6	22
R	1	G	10.14				0.000	2.1		104	6	22
R	1	G	9.92				0.408	2.1		104	6	22
R	1	G	10.66				-0.278	2.1		104	6	22
R	1	G	10.99				0.000	2.1		104	6	22
R	1	W	9	0.092	30	131	0.255	1.9	22	104	6	22
R	1	W	9.69	0.112	26	141	0.266	1.9	22	104	6	22
R	1	W	9.21	0.112	25	142	0.391	1.9	22	104	6	22
R	1	W	9.61		27		0.266	1.9		104	6	22
R	1	W	9.25		24		0.374	1.9		104	6	22
R	1	W	9.13				0.266	1.9		104	6	22
R	1	W	9.38				0.624	1.9		104	6	22
R	1	W	10.14				-0.136	1.9		104	6	22
R	1	W	9.51				0.652	1.9		104	6	22
R	1	W	9.51				0.130	1.9		104	6	22
R	1	C	9.88	0.112	30	139	0.149	1.9	22	104	6	22
R	1	C	9.43	0.112	24	165	0.427	1.9	22.5	104	6	22
R	1	C	9.42	0.132	25	166	0.558	1.9	22.5	104	6	22
R	1	C	9.66		23		-0.142	1.9		104	6	22
R	1	C	9.92		23		0.124	1.9		104	6	22
R	1	C	9.69				0.408	1.9		104	6	22
R	1	C	10.18				-0.391	1.9		104	6	22
R	1	C	10.04				0.278	1.9		104	6	22
R	1	C	9.74				0.408	1.9		104	6	22
R	1	C	9.31				0.136	1.9		104	6	22

Pitch No. 4

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
	8		12.9	0.132	34	85	0.408	7.2	19	52	0	
	8		4.08	0.152	29	87	0.408	7.2	18.5	52	0	
	8		3.96	0.152	30	88	0.278	7.2	18.5	52	0	
	8		3.81		30		0.533	7.2		52	0	
	8		3.65		29		0.427	7.2		52	0	
	8		4.29				0.533	7.2		52	0	
	8		3.65				0.408	7.2		52	0	
	8		2.92				-0.645	7.2		52	0	
	8		4.16				0.427	7.2		52	0	
	8		3.05				0.584	7.2		52	0	
	8		2.71	0.152	31	84	0.278	7.2	18	52	0	
	8		3.41	0.152	31	82	0.408	7.2	19	52	0	
	8		4.11	0.152	30	87	0.266	7.2	18.5	52	0	
	8		3.51		30		0.714	7.2		52	0	
	8		4.41		29		0.427	7.2		52	0	
	8		3.55				0.408	7.2		52	0	
	8		3.12				0.558	7.2		52	0	
	8		4.51				0.584	7.2		52	0	
	8		4.79				0.427	7.2		52	0	
	8		13.8				0.427	7.2		52	0	
	8		0.83	0.132	30	78	0.533	7.2	19	52	0	
	8		2.74	0.132	25	82	0.448	7.2	18	52	0	
	8		3.45	0.132	23	87	0.427	7.2	18.5	52	0	
	8		3.43		25		0.142	7.2		52	0	
	8		2.31		27		0.278	7.2		52	0	
	8		1.99				0.533	7.2		52	0	
	8		1.79				0.533	7.2		52	0	
	8		2.79				0.558	7.2		52	0	
	8		3.09				0.408	7.2		52	0	
	8		3.32				0.142	7.2		52	0	

Pitch No. 5

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
R	7	G	11.51	0.232	34	132	0.558	3.9	15.5	52	4	35
R	7	G	12.09	0.232	33	153	0.427	3.9	15.5	52	4	35
R	7	G	11.51	0.352	32	232	0.291	3.9	14	52	4	35
R	7	G	11.23		34		0.427	3.9		52	4	35
R	7	G	12.79		33		0.469	3.9		52	4	35
R	7	G	12.35				0.612	3.9		52	4	35
R	7	G	12.81				0.305	3.9		52	4	35
R	7	G	12.32				0.427	3.9		52	4	35
R	7	G	13.76				0.320	3.9		52	4	35
R	7	G	13.16				0.156	3.9		52	4	35
R	7	W	12.07	0.192	28	115	0.427	4.2	15.5	52	4	35
R	7	W	11.97	0.212	27	187	0.427	4.2	15.5	52	4	35
R	7	W	12.19	0.232	28	174	0.584	4.2	14.5	52	4	35
R	7	W	12.66		26		0.427	4.2		52	4	35
R	7	W	12.17		29		0.558	4.2		52	4	35
R	7	W	13.83				0.469	4.2		52	4	35
R	7	W	13.23				0.584	4.2		52	4	35
R	7	W	13.81				0.305	4.2		52	4	35
R	7	W	12.59				0.748	4.2		52	4	35
R	7	W	13.23				0.448	4.2		52	4	35
R	7	C	13.94	0.232	27	140	-0.149	4	14.5	52	4	35
R	7	C	13.23	0.252	27	145	0.448	4	14.5	52	4	35
R	7	C	12.99	0.252	25	143	0.612	4	14.5	52	4	35
R	7	C	13.78		26		-0.149	4		52	4	35
R	7	C	13.9		26		0.448	4		52	4	35
R	7	C	12.79				0.612	4		52	4	35
R	7	C	13.71				0.000	4		52	4	35
R	7	C	14.07				0.000	4		52	4	35
R	7	C	14.11				0.448	4		52	4	35
R	7	C	12.92				0.149	4		52	4	35

Pitch No. 6

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
R	7	G	11.39	0.132	22	118	0.408	9.1	18	52	6	60
R	7	G	11.65	0.132	26	157	0.533	9.1	18	52	6	60
R	7	G	11.86	0.152	21	95	0.408	9.1	16.5	52	6	60
R	7	G	12.19		21		0.000	9.1		52	6	60
R	7	G	11.9		27		0.682	9.1		52	6	60
R	7	G	11.61				0.533	9.1		52	6	60
R	7	G	11.8				0.130	9.1		52	6	60
R	7	G	12.24				0.130	9.1		52	6	60
R	7	G	12.64				0.533	9.1		52	6	60
R	7	G	12.17				0.408	9.1		52	6	60
R	7	W	11.61	0.132	25	76	0.136	9.1	17.5	52	6	60
R	7	W	12.52	0.152	24	82	0.000	9.1	17.5	52	6	60
R	7	W	11.45	0.152	27	81	0.408	9.1	19	52	6	60
R	7	W	11.99		30		0.136	9.1		52	6	60
R	7	W	12.13		27		0.000	9.1		52	6	60
R	7	W	12.57				0.000	9.1		52	6	60
R	7	W	11.82				0.000	9.1		52	6	60
R	7	W	11.59				0.000	9.1		52	6	60
R	7	W	12.03				-0.136	9.1		52	6	60
R	7	W	12.44				-0.149	9.1		52	6	60
R	7	C	12.64	0.132	30	86	0.136	9.1	18.5	52	6	60
R	7	C	12.41	0.132	25	91	0.427	9.1	18.5	52	6	60
R	7	C	13.56	0.132	24	91	0.278	9.1	19	52	6	60
R	7	C	13.36		26		0.427	9.1		52	6	60
R	7	C	12.88		28		0.000	9.1		52	6	60
R	7	C	13.71				0.000	9.1		52	6	60
R	7	C	13.41				-0.136	9.1		52	6	60
R	7	C	13.39				-0.142	9.1		52	6	60
R	7	C	12.89				0.142	9.1		52	6	60
R	7	C	13.98				0.000	9.1		52	6	60

Pitch No. 7

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
R	14	G	10.78	0.092	32	95	0.533	4.1	16	52	4	55
R	14	G	10.47	0.092	27	156	0.391	4.1	16	52	4	55
R	14	G	10.81	0.092	26	163	0.533	4.1	16.5	52	4	55
R	14	G	11.34		26		0.000	4.1		52	4	55
R	14	G	11.12		32		0.391	4.1		52	4	55
R	14	G	10.67				0.533	4.1		52	4	55
R	14	G	10.57				0.533	4.1		52	4	55
R	14	G	10.33				0.510	4.1		52	4	55
R	14	G	10.75				0.510	4.1		52	4	55
R	14	G	10.71				0.597	4.1		52	4	55
R	14	W	13.62	0.092	30	201	0.408	4.4	17	52	4	55
R	14	W	13.1	0.072	28	223	0.510	4.4	20	52	4	55
R	14	W	13.43	0.072	28	235	0.266	4.4	18	52	4	55
R	14	W	12.51		28		0.510	4.4		52	4	55
R	14	W	12.95		27		0.408	4.4		52	4	55
R	14	W	13.61				0.408	4.4		52	4	55
R	14	W	13.12				0.558	4.4		52	4	55
R	14	W	13.76				0.408	4.4		52	4	55
R	14	W	13.57				0.427	4.4		52	4	55
R	14	W	13.72				0.000	4.4		52	4	55
R	14	C	10.01	0.092	27	86	0.652	4.1	18	52	4	55
R	14	C	9.98	0.092	24	154	0.652	4.1	17.5	52	4	55
R	14	C	10.05	0.112	24	152	0.510	4.1	18	52	4	55
R	14	C	10.05		26		0.652	4.1		52	4	55
R	14	C	10.32		30		0.510	4.1		52	4	55
R	14	C	10.53				0.391	4.1		52	4	55
R	14	C	10.83				0.624	4.1		52	4	55
R	14	C	9.84				0.624	4.1		52	4	55
R	14	C	10.27				0.255	4.1		52	4	55
R	14	C	10.59				0.652	4.1		52	4	55

Pitch No. 8

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
R	14	G	12.57	0.052	28	121	0.427	8.08	14.5	52	4	42
R	14	G	12.01	0.052	34	190	0.558	8.08	14	52	4	42
R	14	G	12.44	0.052	30	135	0.448	8.08	14	52	4	42
R	14	G	13.37		32		0.320	8.08		52	4	42
R	14	G	12.37		32		0.584	8.08		52	4	42
R	14	G	12.74				0.291	8.08		52	4	42
R	14	G	12.93				0.408	8.08		52	4	42
R	14	G	13.44				0.305	8.08		52	4	42
R	14	G	12.51				0.427	8.08		52	4	42
R	14	G	12.34				0.448	8.08		52	4	42
R	14	W	7.56	0.052	31	95	0.702	8.08	14.5	52	4	42
R	14	W	8.06	0.052	33	99	0.624	8.08	14	52	4	42
R	14	W	7.49	0.052	34	108	0.624	8.08	14.5	52	4	42
R	14	W	8.32		32		0.733	8.08		52	4	42
R	14	W	8.21		32		0.733	8.08		52	4	42
R	14	W	8.1				0.766	8.08		52	4	42
R	14	W	8.08				0.488	8.08		52	4	42
R	14	W	8.02				0.682	8.08		52	4	42
R	14	W	8.26				0.533	8.08		52	4	42
R	14	W	7.98				0.733	8.08		52	4	42
R	14	C	11.63	0.052	34	104	0.427	8.08	14	52	4	42
R	14	C	11.49	0.052	30	121	0.408	8.08	14.5	52	4	42
R	14	C	12.91	0.052	28	210	0.552	8.08	14	52	4	42
R	14	C	12.83		32		0.558	8.08		52	4	42
R	14	C	12.39		28		0.558	8.08		52	4	42
R	14	C	12.71				0.427	8.08		52	4	42
R	14	C	12.86				0.427	8.08		52	4	42
R	14	C	12.12				0.427	8.08		52	4	42
R	14	C	12.96				0.427	8.08		52	4	42
R	14	C	12.4				0.408	8.08		52	4	42

Pitch No. 9

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
R	13	G	13.3	0.212	28	125	0.558	2.8	18	104	6	22
R	13	G	12.52	0.212	28	206	0.278	2.8	19	104	6	22
R	13	G	12.05	0.232	28	131	0.533	2.8	19	104	6	22
R	13	G	13.26		31		0.291	2.8		104	6	22
R	13	G	12.51		28		0.558	2.8		104	6	22
R	13	G	11.58				0.533	2.8		104	6	22
R	13	G	14.05				0.149	2.8		104	6	22
R	13	G	11.82				0.714	2.8		104	6	22
R	13	G	12.67				0.838	2.8		104	6	22
R	13	G	14.02				0.448	2.8		104	6	22
R	13	W	11.66	0.152	29	127	0.408	2.8	19	104	6	22
R	13	W	12.72	0.152	28	130	-0.142	2.8	18	104	6	22
R	13	W	10.85	0.152	27	139	0.533	2.8	18.5	104	6	22
R	13	W	12.06		28		0.558	2.8		104	6	22
R	13	W	11.43		25		0.510	2.8		104	6	22
R	13	W	11.14				0.533	2.8		104	6	22
R	13	W	11.95				0.714	2.8		104	6	22
R	13	W	11.83				0.714	2.8		104	6	22
R	13	W	11.64				0.408	2.8		104	6	22
R	13	W	11.31				0.838	2.8		104	6	22
R	13	C	13.27	0.152	29	119	0.558	2.8	18.5	104	6	22
R	13	C	13.13	0.172	26	189	0.291	2.8	18.5	104	6	22
R	13	C	12.54	0.172	28	173	0.427	2.8	19	104	6	22
R	13	C	13.66		26		0.448	2.8		104	6	22
R	13	C	13.31		26		0.714	2.8		104	6	22
R	13	C	13.17				0.558	2.8		104	6	22
R	13	C	12.91				0.652	2.8		104	6	22
R	13	C	12.97				0.682	2.8		104	6	22
R	13	C	12.33				0.558	2.8		104	6	22
R	13	C	13.61				0.408	2.8		104	6	22

Pitch No. 10

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
U	3	G	12.76	0.152	26	84	0.801	2.4	19.5	52	3	38
U	3	G	12.91	0.152	25	106	0.427	2.4	20	52	3	38
U	3	G	12.89	0.152	27	160	0.682	2.4	18	52	3	38
U	3	G	13.04		24		0.558	2.4		52	3	38
U	3	G	13.29		26		0.682	2.4		52	3	38
U	3	G	13.4				0.584	2.4		52	3	38
U	3	G	14.04				0.584	2.4		52	3	38
U	3	G	13.87				0.714	2.4		52	3	38
U	3	G	12.28				0.682	2.4		52	3	38
U	3	G	13.84				0.584	2.4		52	3	38
U	3	W	10.89	0.132	24	91	0.584	2.9	20	52	3	38
U	3	W	11.94	0.152	25	158	0.000	2.9	20	52	3	38
U	3	W	10.71	0.152	24	94	0.427	2.9	20	52	3	38
U	3	W	10.03		27		0.558	2.9		52	3	38
U	3	W	12.25		23		-0.149	2.9		52	3	38
U	3	W	10.91				0.584	2.9		52	3	38
U	3	W	11.32				0.558	2.9		52	3	38
U	3	W	11.45				0.000	2.9		52	3	38
U	3	W	11.66				0.427	2.9		52	3	38
U	3	W	12.05				0.427	2.9		52	3	38
U	3	C	13.67	0.132	23	109	0.149	2.5	19.5	52	3	38
U	3	C	12.9	0.152	27	122	0.278	2.5	19	52	3	38
U	3	C	13.53	0.172	27	185	0.558	2.5	19.5	52	3	38
U	3	C	12.8		26		0.427	2.5		52	3	38
U	3	C	12.88		28		0.558	2.5		52	3	38
U	3	C	12.59				0.558	2.5		52	3	38
U	3	C	11.72				0.558	2.5		52	3	38
U	3	C	14.31				-0.142	2.5		52	3	38
U	3	C	14.03				0.558	2.5		52	3	38
U	3	C	13				0.558	2.5		52	3	38

Pitch No. 11

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
U	6	G	9.42	0.172	24	154	0.597	6.15	15.5	52	4	45
U	6	G	10.12	0.192	26	101	0.510	6.15	15	52	4	45
U	6	G	10.33	0.192	28	100	0.533	6.15	15	52	4	45
U	6	G	10.37		27		0.682	6.15		52	4	45
U	6	G	10.35		25		0.408	6.15		52	4	45
U	6	G	10.29				0.533	6.15		52	4	45
U	6	G	10.05				0.408	6.15		52	4	45
U	6	G	10.12				0.558	6.15		52	4	45
U	6	G	10.41				0.533	6.15		52	4	45
U	6	G	10.6				0.149	6.15		52	4	45
U	6	W	16.89	0.132	28	189	0.584	7.2	14.5	52	4	45
U	6	W	16.1	0.152	27	115	0.584	7.2	16	52	4	45
U	6	W	16.88	0.132	31	125	0.469	7.2	19	52	4	45
U	6	W	16.72		29		0.305	7.2		52	4	45
U	6	W	19.39		28		0.000	7.2		52	4	45
U	6	W	18.95				-0.164	7.2		52	4	45
U	6	W	17.13				0.448	7.2		52	4	45
U	6	W	17.02				0.448	7.2		52	4	45
U	6	W	18.08				0.305	7.2		52	4	45
U	6	W	17.15				0.305	7.2		52	4	45
U	6	C	10.46	0.172	25	94	0.488	6.2	16	52	4	45
U	6	C	10.98	0.172	27	113	0.408	6.2	17	52	4	45
U	6	C	11.33	0.172	27	111	0.682	6.2	19	52	4	45
U	6	C	10.9		28		0.682	6.2		52	4	45
U	6	C	11.45		32		0.682	6.2		52	4	45
U	6	C	11.95				0.408	6.2		52	4	45
U	6	C	11.72				0.558	6.2		52	4	45
U	6	C	12.35				0.408	6.2		52	4	45
U	6	C	12.28				0.136	6.2		52	4	45
U	6	C	12.28				0.682	6.2		52	4	45

Pitch No. 12

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
U	4	G	11.2	0.192	28	170	0.142		19.5			
U	4	G	11.31	0.192	32	184	0.427		20			
U	4	G	10.45	0.192	31	198	0.714		20			
U	4	G	11.11		34		0.448					
U	4	G	11.91		36		0.448					
U	4	G	11.49				0.612					
U	4	G	11.09				0.584					
U	4	G	11.66				0.448					
U	4	G	11.92				0.612					
U	4	G	12.64				0.156					
U	4	W	10.09	0.132	38	134	0.682		15			
U	4	W	10.62	0.152	38	163	0.558		16			
U	4	W	10.93	0.132	39	148	0.682		16.5			
U	4	W	10.71		35		0.714					
U	4	W	11.3		32		0.149					
U	4	W	11.25				0.714					
U	4	W	11.15				0.142					
U	4	W	10.29				0.558					
U	4	W	10.55				0.558					
U	4	W	11.12				0.427					
U	4	C	11.16	0.172	32	144	0.448		19			
U	4	C	12.28	0.172	34	150	0.448		18			
U	4	C	12.35	0.152	30	228	0.156		20			
U	4	C	11.93		30		0.469					
U	4	C	12.83		36		0.164					
U	4	C	12.37				0.427					
U	4	C	12.87				0.320					
U	4	C	12.05				-0.043					
U	4	C	12.08				0.469					
U	4	C	12.82				0.305					

Pitch No. 13

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
U	10	G	14.7	0.172	23	219	0.408	6.4	20	0	8	68
U	10	G	15.97	0.192	23	159	0.408	6.4	19.5	0	8	68
U	10	G	15.97	0.172	24	161	0.427	6.4	22	0	8	68
U	10	G	16.25		21		0.427	6.4		0	8	68
U	10	G	15.32		24		0.291	6.4		0	8	68
U	10	G	16.41				0.448	6.4		0	8	68
U	10	G	14.02				0.266	6.4		0	8	68
U	10	G	15.48				0.448	6.4		0	8	68
U	10	G	15.47				0.278	6.4		0	8	68
U	10	G	16.38				0.291	6.4		0	8	68
U	10	W	13.99	0.112	21	152	0.408	6.4	22	0	8	68
U	10	W	14.17	0.132	24	94	0.408	6.4	19.5	0	8	68
U	10	W	15.05	0.132	26	153	0.558	6.4	21	0	8	68
U	10	W	14.42		22		0.558	6.4		0	8	68
U	10	W	15.04		22		0.533	6.4		0	8	68
U	10	W	15.55				0.291	6.4		0	8	68
U	10	W	14.36				0.136	6.4		0	8	68
U	10	W	13.91				0.427	6.4		0	8	68
U	10	W	13.91				0.682	6.4		0	8	68
U	10	W	15.15				0.408	6.4		0	8	68
U	10	C	15.83	0.112	26	115	0.533	6.4	20	0	8	68
U	10	C	14.91	0.132	25	120	0.408	6.4	21.5	0	8	68
U	10	C	16.04	0.112	24	118	0.278	6.4	20	0	8	68
U	10	C	15.1		23		0.427	6.4		0	8	68
U	10	C	14.84		26		0.408	6.4		0	8	68
U	10	C	15.47				0.652	6.4		0	8	68
U	10	C	16.55				0.448	6.4		0	8	68
U	10	C	16.72				0.427	6.4		0	8	68
U	10	C	17.28				0.552	6.4		0	8	68
U	10	C	16.7				0.149	6.4		0	8	68

Pitch No. 14

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
U	10	G	10.59	0.172	35	113	0.624		18.5	0	26	80
U	10	G	10.89	0.172	26	115	0.488		18	0	26	80
U	10	G	11.02	0.192	34	122	0.510		18	0	26	80
U	10	G	12.36		30		0.510			0	26	80
U	10	G	11.9		30		0.510			0	26	80
U	10	G	11.67				0.391			0	26	80
U	10	G	11.4				0.510			0	26	80
U	10	G	11.8				0.533			0	26	80
U	10	G	12.05				0.510			0	26	80
U	10	G	12.16				0.408			0	26	80
U	10	W	13.12	0.112	28	86	0.682		20	0	26	80
U	10	W	12.42	0.112	28	95	0.548		20.5	0	26	80
U	10	W	13.11	0.112	28	154	0.533		19.5	0	26	80
U	10	W	12.44		26		0.702		?	0	26	80
U	10	W	11.9		26		0.510			0	26	80
U	10	W	13				0.533			0	26	80
U	10	W	12.92				0.533			0	26	80
U	10	W	13.03				0.408			0	26	80
U	10	W	12.5				0.533			0	26	80
U	10	W	12.93				0.533			0	26	80
U	10	C	12.11	0.152	26	114	0.803		19	0	26	80
U	10	C	13.96	0.172	26	119	0.558		20	0	26	80
U	10	C	13.8	0.172	24	117	0.558		18.5	0	26	80
U	10	C	12.99		25		0.624			0	26	80
U	10	C	12.69		28		0.374			0	26	80
U	10	C	13.58				0.488			0	26	80
U	10	C	12.98				0.682			0	26	80
U	10	C	13.48				0.408			0	26	80
U	10	C	12.86				0.558			0	26	80
U	10	C	13.6				0.533			0	26	80

Pitch No. 15

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
U	10	G	12.96	0.152	33	138	0.652		18.5	12	4	45
U	10	G	13.19	0.152	28	85	0.408		19	12	4	45
U	10	G	12.03	0.152	27	148	0.374		20	12	4	45
U	10	G	12.43		22		0.408			12	4	45
U	10	G	12.38		24		0.652			12	4	45
U	10	G	12.41				0.408			12	4	45
U	10	G	13.01				0.408			12	4	45
U	10	G	12.6				0.408			12	4	45
U	10	G	11.02				0.597			12	4	45
U	10	G	13.12				0.374			12	4	45
U	10	W	11.07	0.132	24	93	0.510		21	12	4	45
U	10	W	10.87	0.132	26	104	0.652		21.5	12	4	45
U	10	W	11.39	0.132	27	101	0.408		21	12	4	45
U	10	W	12.18		24		0.558			12	4	45
U	10	W	11.73		24		0.448			12	4	45
U	10	W	11.75				0.652			12	4	45
U	10	W	11.32				0.533			12	4	45
U	10	W	11.46				0.533			12	4	45
U	10	W	11.18				0.510			12	4	45
U	10	W	11.77				0.682			12	4	45
U	10	C	12.88	0.192	35	151	0.374		20.5	12	4	45
U	10	C	12.63	0.192	34	165	0.510		18	12	4	45
U	10	C	13.02	0.192	31	165	0.510		17	12	4	45
U	10	C	12.32		30		0.391			12	4	45
U	10	C	13.7		32		0.533			12	4	45
U	10	C	14.28				0.391			12	4	45
U	10	C	12.99				0.488			12	4	45
U	10	C	12.49				0.448			12	4	45
U	10	C	13.89				0.255			12	4	45
U	10	C	13.76				0.488			12	4	45

Pitch No. 16

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
U	13	G	10.37	0.272	26	168	0.558	3	15.5	0	2	45
U	13	G	11	0.272	25	241	0.278	3	15.5	0	2	45
U	13	G	11.6	0.272	24	248	0.558	3	18	0	2	45
U	13	G	11.29		22		0.584	3		0	2	45
U	13	G	11.03		22		0.448	3		0	2	45
U	13	G	10.86				0.584	3		0	2	45
U	13	G	11.69				0.427	3		0	2	45
U	13	G	11.87				0.584	3		0	2	45
U	13	G	11.69				0.584	3		0	2	45
U	13	G	11.67				0.448	3		0	2	45
U	13	W	11.29	0.192	22	133	0.584	3	17	0	2	45
U	13	W	11.6	0.192	26	196	0.448	3	16.5	0	2	45
U	13	W	12.46	0.212	26	193	0.584	3	15.5	0	2	45
U	13	W	11.81		24		0.291	3		0	2	45
U	13	W	12.06		23		0.682	3		0	2	45
U	13	W	12.81				0.427	3		0	2	45
U	13	W	11.94				0.558	3		0	2	45
U	13	W	12.43				0.558	3		0	2	45
U	13	W	12.87				0.584	3		0	2	45
U	13	W	12.54				0.584	3		0	2	45
U	13	C	11.19	0.232	24	220	0.558	3	16	0	2	45
U	13	C	10.81	0.232	24	223	0.000	3	17	0	2	45
U	13	C	10.81	0.232	27	231	0.130	3	15.5	0	2	45
U	13	C	11.51		25		0.533	3		0	2	45
U	13	C	11.39		26		0.558	3		0	2	45
U	13	C	11.93				0.000	3		0	2	45
U	13	C	10.99				0.408	3		0	2	45
U	13	C	10.97				0.558	3		0	2	45
U	13	C	12.29				0.558	3		0	2	45
U	13	C	11.97				0.558	3		0	2	45

Pitch No. 17

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
U	13	G	12.16	0.152	26	155	0.533	6.5	19.5	52	3	38
U	13	G	12.02	0.152	25	97	0.558	6.5	19.5	52	3	38
U	13	G	12.17	0.152	26	168	0.714	6.5	20	52	3	38
U	13	G	12.6		24		0.584	6.5		52	3	38
U	13	G	12.46		23		0.427	6.5		52	3	38
U	13	G	12.31				0.149	6.5		52	3	38
U	13	G	13.45				0.584	6.5		52	3	38
U	13	G	12.55				0.427	6.5		52	3	38
U	13	G	12.41				0.291	6.5		52	3	38
U	13	G	12.03				0.533	6.5		52	3	38
U	13	W	9.56	0.152	25	103	0.801	6.5	19	52	3	38
U	13	W	11.01	0.152	24	166	0.266	6.5	19.5	52	3	38
U	13	W	11.36	0.152	26	108	0.558	6.5	20	52	3	38
U	13	W	10.7		22		0.408	6.5		52	3	38
U	13	W	11.6		24		0.000	6.5		52	3	38
U	13	W	10.2				0.682	6.5		52	3	38
U	13	W	10.6				0.838	6.5		52	3	38
U	13	W	10.43				0.558	6.5		52	3	38
U	13	W	10.79				0.878	6.5		52	3	38
U	13	W	11.09				0.878	6.5		52	3	38
U	13	C	13.62	0.132	24	107	0.427	6.5	19	52	3	38
U	13	C	14.03	0.112	24	161	0.469	6.5	19.5	52	3	38
U	13	C	14.22	0.132	23	175	0.584	6.5	20	52	3	38
U	13	C	13.54		26		0.612	6.5		52	3	38
U	13	C	15.04		24		0.305	6.5		52	3	38
U	13	C	14.56				0.558	6.5		52	3	38
U	13	C	12.83				0.448	6.5		52	3	38
U	13	C	14.32				0.305	6.5		52	3	38
U	13	C	13.54				0.427	6.5		52	3	38
U	13	C	15.39				0.427	6.5		52	3	38

Pitch No.18

Location	Age (yrs)	Test Location	Ball Roll (m)	Ball Rebound (m)	Traction (Nm)	Hardness (G)	Deceleration (ms^{-2})	Contamination (%)	Pile Length (mm)	Drag Brush frequency (Annual)	Power Brush Frequency (Annual)	No of Hours Use
U	14	G	9.52	0.312	28	135	0.427		14.5	104	4	40
U	14	G	10.5	0.332	34	149	0.448		14	104	4	40
U	14	G	10.43	0.332	30	152	0.558		14	104	4	40
U	14	G	10.11		32		0.142			104	4	40
U	14	G	9.71		32		0.278			104	4	40
U	14	G	9.95				0.278			104	4	40
U	14	G	9.61				0.408			104	4	40
U	14	G	9.77				0.278			104	4	40
U	14	G	9.31				0.682			104	4	40
U	14	G	9.58				0.652			104	4	40
U	14	W	8.49	0.352	31	119	1.231		14.5	104	4	40
U	14	W	9.62	0.352	33	131	0.124		14	104	4	40
U	14	W	9.64	0.352	34	137	0.801		14.5	104	4	40
U	14	W	9.61		32		0.000			104	4	40
U	14	W	10.54		32		0.278			104	4	40
U	14	W	10.19				0.558			104	4	40
U	14	W	10.33				0.408			104	4	40
U	14	W	9.62				0.278			104	4	40
U	14	W	10.32				0.584			104	4	40
U	14	W	10.72				0.000			104	4	40
U	14	C	9.54	0.332	34	131	0.838		14	104	4	40
U	14	C	9.79	0.332	30	142	0.878		14.5	104	4	40
U	14	C	9.29	0.332	28	142	0.714		14	104	4	40
U	14	C	10		32		0.469			104	4	40
U	14	C	10.04		28		0.291			104	4	40
U	14	C	9.83				0.558			104	4	40
U	14	C	10.1				0.558			104	4	40
U	14	C	9.93				0.878			104	4	40
U	14	C	10.44				0.584			104	4	40
U	14	C	10.53				0.149			104	4	40

Appendix B: Peer reviewed publications

McLeod, A., James, I., Blackburn, K. and Wood, W. (2006) A Novel Quantitative Method for the Determination of Wear in an Installed Synthetic Turf System. *The Engineering of Sport 6 Volume 1: Developments for Sports.* Eds, Moritz, E.F. and Haake, S. International Sports Engineering Association, Munich. P217-222. ISBN 0-387-31773-2

McLeod, A.J. and James, I.T. (2007) An evaluation of surface performance for second generation sand-filled synthetic hockey pitches in the United Kingdom. *The 2nd International ISHS Conference on Turfgrass Science & Management of Sports Fields. Beijing. ISBN 978-90-66051-08-9*

McLeod, A.J. and James, I.T. (2007) The effect of particulate contamination on the infiltration rates of synthetic turf surfaces. *Science, Technology and Research into Sport Surfaces (STARSS). Loughborough. ISBN 978-1-897911-30-3*

A novel quantitative method for the determination of wear in an installed synthetic turf system

Andy McLeod, Iain James, Kim Blackburn and Gavin Wood

Abstract. This study focuses on the initial development of an image analysis methodology for quantifying the wear and degradation of synthetic sports turf, post installation, where the carpet/infill system is subjected to systemic abrasion and wear from play and maintenance. The pilot study images the surface of polypropylene fibres, which have been agitated with differing sand infill types, with a scanning electron microscope. The resultant images were analysed to determine the degradation of the extrusion features evident in virgin fibre, and it was found that there was significant, quantifiable wear of the turf fibres after seven days with all test sands. The image data for fibres between 7 and 28 days was dependent upon sand type. Further development of the technique is required for determining the next stage of wear – characterized by pitting of the fibre surface by the sand.

1 Introduction

The use of a quantitative model of fibre wear within a synthetic sports turf system will enable identification of the main causes of wear and, by a change of materials and management techniques, will allow significant advances in the financial sustainability of synthetic turf surfaces.

At present, within the sports industry, the measurement of the resistance to wear of synthetic turf sports surfaces is carried out pre-installation. Normal testing of the integrity of the carpet system is carried out by measuring the tensile properties of individual fibres, the effect of ultra violet light and aging. Further fibre is subjected to simulated wear by metal blades, abrasive wheels and the reproduced action of football studs (FIFA, 2005; BS7044, 1990). These methodologies were designed for testing the compliance of a product with the relevant specifications for installation and performance; such approaches to testing do not characterize the wear mechanism of the whole system of polymer carpet fibres and infill materials in the field environment

The usual method for wear quantification is by mass loss measurements, which is suitable when the worn material components are detached from the main sample. Due to the low mass of the worn turf fibre components there is a loss of resolution when weighing, even on a high precision balance, which makes this method less effective for use with synthetic sports turf. In addition, this method provides no information on the distribution of wear over the component and will not show the level of wear in areas of fibre structural failure (Gahlin & Jacobsen, 1998).

This paper will show the results of a pilot study for a field assessment method, in development, which aims to objectively quantify the 'degree of wear' of fibre samples and identify the processes causing the wear of the fibre, using surface image analysis techniques. The aim of this experiment was to quantify the effect of sand infill abrasion on has on the fibres of an artificial turf surface

2 Materials and Methods

2.1 Test Materials

The fibres used were from a stock roll of 4mm wide, extruded monofilament polypropylene used in the manufacture of synthetic sportsturf. Fibres were cut by scalpel to a length of 23 mm.

The infill materials comprised two rounded sands commonly used in sand filled (2nd generation) synthetic turf surfaces in the UK, with the trade names ‘No 21’ and ‘2EW’; in addition a sharp sand was used as a contrast.

2.2 Test Method

50g of each sand was placed with three of the 23 mm long fibres specimens into a 250 ml polypropylene screw capped bottles. The bottles were placed on an over-and-under shaker and rotated through their long axis at 28 rpm. Treatment periods were 7, 14, 21 and 28 days, with an untreated control. Each treatment combination of sand and period was replicated five times. On removal from the shaker the fibre samples were washed gently with distilled water to remove sand particles and allowed to air dry.

2.2 Fibre imaging technique

Initial investigations of images recorded with high power optical microscopy, using transmitted and reflected light, determined that such techniques were not appropriate for quantification of the degree of wear.

Subsequently, the fibres were imaged using an FEI XL30 SFEG scanning electron microscope (SEM) to investigate the pattern of abrasion and how this contributed to surface deformation and ultimately plastic and brittle failure of the turf fibres. Before the fibres were viewed using the SEM they were sputter coated with a gold/palladium (80/20) mix, to increase the conductivity of the sample. The SEM method ensured consistent resolution, magnification (x200) and luminous flux density among the replicates of each treatment. Images were captured from each replicate. Output images were 256 grey scale, 712 x 484 pixel in tagged image file format.

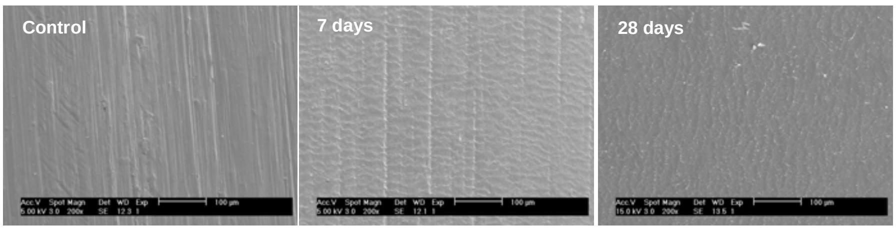


Fig. 1. SEM images of the control and after 7 and 28 days of continuous agitation with the 2EW sand

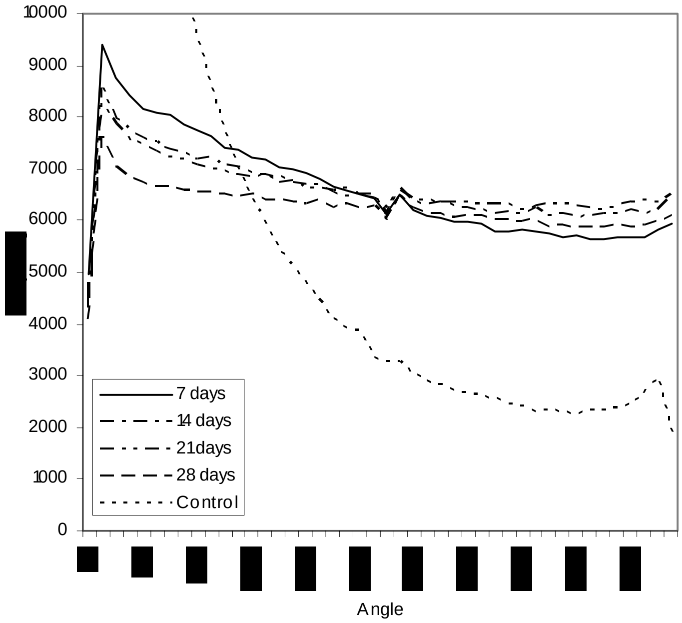


Fig. 2. Frequency distribution of image processing output: frequency of orientation in each 2º angle class within a 7 x 7 window for the mean of the five 2EW sand images. Maximum frequency decreases with increasing wear period; maximum frequency for the control is 11922

2.3 Image analysis

Initial visual inspection of the images determined that the linear patterns on the virgin fibre, resulting from the extrusion process were degraded into random pattern orientations with increased wear period (Fig.1). In extremis this resulted in punctured fibres with point defects that were related to fibrillation in SEM images of field samples of synthetic turf of 5 years age.

To determine objectively whether this pattern of degradation was related to sand type and wear period, a filtering process was used to quantify 'linearity' in each image using the Leica Erdas Imagine v8.7 image analysis software.

The filter comprised two 7 x 7 matrices that measured horizontal and vertical continuity in each image. The resultant of each component was determined as an angle, and a frequency distribution of pixels within 2º classes, between 0 and 90º determined. Images with a high linearity were characterized by a distinct peak at an angle between 2 and 4º (the specific angle is an artefact of fibre alignment on the SEM, it is the peak that is significant, see Fig. 2). Images with less linearity were characterized by a more uniform distribution of pixels between 0 and 90º (see Fig. 2). To quantify this characterization, the ratio of the maximum frequency to the total number of pixels within the distribution was determined, referred to as the peak ratio (PR). It was hypothesized that PR would decrease with increasing wear period.

3 Results

Table 1. Mean peak ratio of linearity in SEM images of synthetic turf fibres subjected to wear by three sands for four wear periods

	Mean peak ratio				
		Wear period, days			
Treatment		*7*	*14*	*21*	*28*
Control	8.76^{e}				
2EW		3.28^{a}	3.00^{b}	$2.89^{c,d}$	2.82^{d}
No 21		2.87^{d}	$2.98^{b,c}$	$2.93^{b,c}$	$2.93^{b,c}$
Sharp		3.19^{a}	$2.98^{b,c}$	3.25^{a}	$2.88^{c,d}$

Means with identical superscripts cannot be separated by the LSD of 0.1 at p=0.05

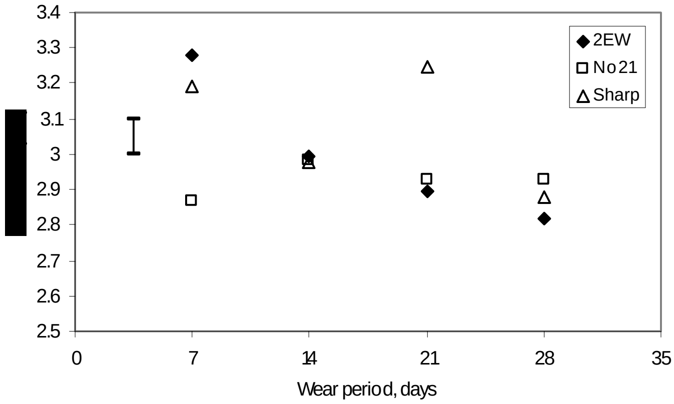


Fig. 3. Mean peak ratio for each sand – wear period. Error bar represents the LSD at p=0.05

For all treatments, PR reduced significantly after 7 days of wear, compared to the control ($p<0.001$). The 2EW sand behaved as hypothesised with a significant decrease in PR until 21 days (Table 1). No 21 did not follow a consistent pattern, with an anomalously low PR value at day 7 and no significant difference between days 14 – 28 (Fig. 3). The sharp sand followed a similar pattern to the 2EW except for an outlier at 21 days.

4 Discussion

The results of this trial illustrate the potential of the SEM image analysis methodology for the quantification of wear of synthetic turf in field samples of different ages. A clear effect of abrasion by sand infill material has been shown and quantified.

For application in field samples, however, more development is required. In this experiment the effect of abrasion on this PR index of 'linearity' was immediate. The PR value measured the abrasion of the linear extrusion features on the fibre surface, it did not reflect the severe 'pitting' of the surface at 28 days, which is not linear and more irregular – further image processing techniques are being investigated to identify these features as they are believed to be critical in creating point defects in the fibre.

Further work will also include a quantification of wear and an investigation of wear mechanisms in the field for fibre collected from field sites of different usage and maintenance. The final objective is to characterize and quantify the effect of maintenance equipment on turf fibre and surface performance.

5 Conclusion

A directional filter image processing technique was successfully applied to scanning electron microscope image of synthetic turf fibres following increasing periods of wear with different sands used in the infill of sand filled synthetic turf surfaces.
Significant wear of the turf fibres was identified after seven days with all three sands. Over a 7 to 28 day period, further wear was identified with the 2EW and sharp sands; this effect was not observed with the No 21 sand.

Further development of the technique is required for determining the next stage of wear – characterized by pitting of the fibre surface by the sand.

Acknowledgements

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References

Adachi, K., Hutchings, I.M. (2005) Sensitivity of wear rates in the micro-scale abrasion test to test conditions and material hardness. Wear. 258, 318-321

BS7044 (1990). BS 7044-2.3:1990: Artificial sports surfaces methods of test: methods for determination of durability. British Standards Institution, London, UK

FIFA (2005) FIFA Quality concept: Handbook of test methods and requirements for artificial football turf. FIFA Marketing & TV AG, Switzerland.

Gahlin, R. & Jacobsen, S. (1998) A novel method to map and quantify wear on a micro-scale. Wear. 222, 93-102

Hertzberg, R.W. (1983) *Deformation and Fracture Mechanics of Engineering Materials*. John Wiley & Sons, New York, 826 pp

An evaluation of surface performance for second generation sand-filled synthetic hockey pitches in the United Kingdom

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Abstract

This paper details the results from an audit carried out on the surface performance characteristics of 18 'second generation' sand-filled field hockey pitches of different ages (0-6, 7-12 and 13-20 years) and locations (urban and rural). Measurements of ball roll, ball deceleration, ball rebound, rotational resistance and surface hardness were taken in three locations of different usage (goal area, centre and wing) on each pitch. Results showed that although the test pitches conform to Federation de Internationale Hockey (FIH) performance standards, there was significant spatial variation between the test pitches. Furthermore, the survey did not support the hypothesis that the level of performance of a pitch reduces with age or pitch location. It was noted that because the parameters of the FIH 'Basic' and 'Standard' standards are so wide, the performance characteristics of a pitch can change significantly and still conform to the appropriate standard. This study provides an essential reference for the state and wear of synthetic turf pitches of this type in the UK and is part of a wider programme of research developing recommendations for the maintenance of synthetic turf surfaces.

INTRODUCTION

Synthetic turf sports surfaces have been under development since the late 1950's. Their installation has had a significant impact on field hockey; in particular, providing a fast, consistent playing surface that encourages the development of technical skills and a fast flowing, less interrupted game. A synthetic hockey pitch has to conform to performance standards set by the Federation de Internationale Hockey (FIH) at a basic, standard or global level of play (FIH, 1999). The performance standards define upper and lower limits of properties such as ball roll, ball rebound, rotational resistance, infiltration and impact behaviour. As a pitch ages, it is exposed to wear factors such as user foot and equipment traffic, exposure to air pollution, contamination through dust and soil deposition, and exposure to ultra-violet radiation. It is hypothesized that although initially uniform in performance, pitches become more spatially variable with time due to differential wear.

This paper is part of a larger project researching the effect that maintenance has on the playability and durability of sand-filled synthetic sports surfaces. This paper attempts to document the spatial variability of specific performance characteristics of sand-filled hockey pitches categorised in terms of age and location. The results will indicate the viability of a programme of pitch testing that will enable managers to maintain pitches to comply with the relevant performance standards.

MATERIALS AND METHODS

Pitch selection

Initially 76 second generation synthetic turf pitches were selected, from the database of a UK synthetic turf maintenance company. The initial selection was based on the pitch specifications of: a sand infill, an initial pile depth of 23 mm, infill specification and the presence of a shockpad were used. In most cases, information on other carpet characteristics such as fibre denier, pile density and brand were not known to either the maintenance company or the pitch managers. The pitches were subdivided, by location, into urban and rural groups and then further divided into age groups based on time since installation (0-6 years, 7-12 years and 13-20 years). Three pitches were selected at random for each location-age group combination; resulting in a total test sample of 18 pitches.

Surface performance tests

All tests were performed in three areas of the pitch: wing, goal area and centre spot (Figure 1). The same positions were used for each surface tested.

For tests involving a hockey ball the manufacturer was Kookaburra (Corby, UK).

1. Horizontal Ball Roll The ball was released from a height of 1 m down a standard 45^o ramp (BS7044: Section 2.1, 1989) and the distance rolled was measured in metres using a tape measure. Any deviation of the ball greater than 3^o from plane of the slope was rejected and the test repeated. The ramp was moved after every third ball roll to prevent ‘channelling’ on the pitch surface; The ball was rolled 10 times in each direction to allow for wind, slope, pile bias and wear (FIH, 1999) and the average distance was used to represent horizontal ball roll of the test location.

2. Ball Deceleration In the above horizontal ball roll experiment; infra-red timing gates were used to determine the deceleration of the ball over a 1 m distance, located 0 m from the bottom of the slope. The initial velocity was determined at Gate 1 (between two beams 200 mm apart) and the final velocity at Gate 2, a distance of 1 m from Gate 1, again using timing gates at 200 mm apart. The deceleration was calculated using Equation (1), such that *a* is positive for deceleration in this case.

$$a = \left(\frac{V_1^{\ 2} - V_2^{\ 2}}{2s} \right) \qquad (1)$$

Where V_1 = velocity at Gate 1 [m s^{-1}]; V_2 = velocity at Gate 2 [m s^{-1}]; s = distance between gates [m]; a = average deceleration [m s^{-2}]

3. Ball Rebound The ball was released from a vertical height of 1.5 metres in accordance with FIH (1999) and the height of ball rebound was measured in metres. The apparatus used to measure ball rebound was developed at Cranfield University and comprised pairs of 20 mm vertically spaced infra-red emitters and phototransistors which, when passed by the ball, on rebound, determined the height of the bottom edge of the ball from the pitch surface.

4. Surface Hardness A Clegg Soil Impact Tester (CIST) (Clegg, 1976) using a 0.5 kg missile and a drop height of 55 cm was used to assess the surface hardness (impact attenuation) of the surface. (Canaway, 1985). Impact attenuation, as measured by an accelerometer mounted on the missiles, was used to indicate surface hardness and is reported as Gmax, which is the ratio of maximum negative acceleration on impact, in units of gravities, to the acceleration due to gravity. The standard FIH test for impact attenuation is the Berlin Artificial Athlete (AAB). The CIST was used in this study as it is a rapid test and is not as cumbersome as the AAB (Fleming & Young, 2006).

5. Rotational Resistance The apparatus used was adapted from the studded disc illustrated in BS7044: Section 2.2 (1990). The soles from a pair Mizuno Objectivo Astro football boots, with a dimple depth 8 mm and even dimple distribution (4 mm spacing), were attached to a 150 mm diameter steel disc. A normal load of 456 N was applied and the peak rotational resistance against the initiation on motion was measured using a torque wrench. The results were expressed in Newton metres (Nm). Van Gheluwe *et al* (2003) showed that varying the number of studs/dimples and contact area of a sports shoe resulted in significant differences in the coefficient of friction between the studded disc and the surface.

All of the data was analyzed using the analysis of variance (ANOVA) and correlation functions of Genstat v8.1

RESULTS AND DISCUSSION

The ball roll properties of a pitch indicate the overall speed and consistency of speed between pitches and between locations within pitches. Although ball roll speed was significantly affected by pitch age, location and test areas within a pitch ($p < 0.001$; see Fig. 2), a consistent, meaningful reduction or increase in ball roll with age was not apparent. There was spatial variation across all of the test sites. This is possibly due to a difference in pitch construction methods and specification as well as the wear of the pitch. With the exception of the wing area in the urban group, a statistically insignificant trend is apparent showing a slight increase in the distance of horizontal ball roll; increasing during the 7-12 years post installation and then a reducing during 13-20 years. In this study there was no significant correlation between horizontal ball roll and deceleration this is dissimilar to the findings of Baker & Canaway (1993); this difference may be due to the variation within the test pitch specifications.

Ball rebound tests indicated that there was a significant variation in ball rebound height due to pitch age and pitch location ($p < 0.001$), see Fig. 3. The ball rebound height increased with pitch age on urban pitches but decreased with age on rural pitches (Fig. 3). This effect may be due to higher levels of use of pitches located in an urban area; the majority of which are operated by local authorities who maximise the pitch usage and have restricted maintenance budgets. Pitches located in rural locations are likely to be owned by independent schools where usage is lower. A questionnaire documented that pitches located in urban locations were used on average 50 hours per week compared to 37 hours per week for rural pitches.

There was significant variation in mean surface hardness (Gmax) due to the pitch age groups ($p < 0.05$) and pitch location ($p < 0.01$), see Fig. 4. Although there was a significant difference between the 7-12 year age group and the other two groups, there was no increase in pitch hardness between pitches at year zero and those at year 20. The hardness of the 7-12 year age group may be the result of technological advancement, in in-fill materials, building specification and materials or the spatial variation between pitches. There was a significant correlation between surface hardness and ball rebound height ($r = 0.383$, $p < 0.001$).

Rotational resistance was significantly lower at the rural sites than the urban sites in the 0-6 year age group ($p < 0.001$; Figure 5). The overall mean value for rotational resistance for all of the test pitches (28 Nm) was similar to the original recommendations (30 Nm) for association football on synthetic surfaces (Winterbottom, 1985) Observations in the field illustrated the significant effect that surface repairs may have on rotational resistance. In some areas of repair, the rotational resistance was increased up to 30% above that of the surrounding areas; in the goal area of one test surface (Rural, 13-20 years) the peak rotational resistance was 34 Nm on a repaired section, a 2 m^2 section in the centre of the goal area, compared with a mean of 26 Nm for the rest of the measurements of the pitch. A player may not be able to adjust to an 8 Nm increase in rotational resistance over a short distance and this may cause lower leg joint injuries as the shoe becomes ‘locked’ into the turf (Morehouse, 1992).

It is questionable whether the performance testing actually represents the playability of a pitch. The standard tests do not reproduce the conditions of play (faster ball speeds and actual foot movements) and so really can only be used as a comparative measure between pitches, defining minimum standards for play. Under FIH guidelines, all pitches should be tested on completion of construction, but only the global standard water-based pitches which are used for elite level field hockey, are tested regularly to ensure a consistent level of performance. It is a concern that this requirement does not take into consideration that most sand-filled synthetic pitches tend to be used for training by children and the lower levels of sport. On installation, a pitch should have uniform performance characteristics but due to temporal differential wear (especially where maintenance levels are too low) the contrast in player-pitch parameters, such as traction and hardness are thought to increase the likelihood of injury. The contrast in the performance characteristics are also a barrier to the technical development of players at all standards of play. At present, there is further research being carried out that will provide more information on the effect that inconsistent traction has on player injury.

CONCLUSIONS

The initial objective of the site testing was to quantify the effect that age and location have on second generation sand-filled synthetic pitches. The results from the testing show that although the pitches conformed to FIH performance standards, there was significant spatial variation across the test sites and the hypothesis that the level of performance of a pitch reduces with age cannot be supported in this case. The spatial variability, which was observed on all ages of pitch, is likely caused by differing pitch construction, specification, levels of use and surface maintenance. As the parameters of the FIH 'Basic' and 'Standard' standards are so wide, the performance characteristics of a pitch can change significantly and still conform to the appropriate standard. The audit illustrated an inconsistency in the quality of repairs to seams and tears on pitches; often repairs were found to be 10 mm above the surrounding surface levels, which can result in a potential health and safety risk, due to inconsistent ball roll, to the players.

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Literature Cited

Baker, S.W., & Canaway, P.M., (1993) Concepts of Playing Quality: Criteria and Measurement. International Turfgrass Society Research Journal 7, Intertec Publishing Corp., Kansas

BS7044 Section 2.1 (1989) Artificial Sports Surfaces. Part 2: Methods for Determination of Ball/Surface Interaction. British Standards Institution, 8p.

BS7044 Section 2.1 (1990) Artificial Sports Surfaces. Part 2: Methods for Determination of Person/Surface Interaction. British Standards Institution, 8p

Canaway, P.M., Bell, M.J., Holmes, G. and Baker, S.W. (1990) Standards for the playing quality of natural turf for association football. Natural and Artificial Playing Fields: Characteristics and Safety Features, ASTM STP 1073, American Society for Testing of Materials, Philadelphia, pp29-47

Clegg, B. (1976) An impact testing device for in-situ base course evaluation. Australian RoadRes. Bur. Proc. 8:1-6

Fleming, P. & Young C.,(2006) Sports Surfaces Impact Assessment Tools. The Engineering of Sport 6, vol 2 pp319-324. Springer, USA

FIFA (2006) FIFA Quality Concept: Handbook of Requirements for Football Turf. Federatio Internationale de Football Association, Zurich

FIH (1999) Synthetic Hockey Pitches – Outdoor: Handbook of Performance Requirements. International Hockey Federation, Brussels

Morehouse, C.A., ‘Turfgrass’, Turfgrass-Agronomy Monograph 32 ASA-CSSA-SSSA, 677S

Seghoe Rd., Madison, WI53711.

Van Gheluwe, B. Deporte, E & Hebbelink, M (2003) Frictional Forces and Torques of Soccer Shoes on Artificial Turf. Proceedings of the International Symposium on Biomechanical Aspects of Sports Shoes and Playing Surfaces. Calgary, Canada.

Winterbottom, W (1985). Artificial Grass Surfaces for Association Football. The Football Association/ The Sports Council. London

The effect of particulate contamination on the infiltration rates of synthetic turf surfaces

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Abstract

The high level of usage and common lack of maintenance of second generation, sand-filled synthetic turf pitches results in the accumulation of contaminants such as organic material, soil from footwear, fibre fragments and deposited air-borne particles. With time, these contaminants migrate throughout the carpet/infill matrix during the course of play and rainfall, reducing the porosity of the infill and ultimately the infiltration rate of the surface. The effect of this contamination on the infiltration rate of the infill-carpet matrix was quantified in the laboratory. A falling head permeameter was used to quantify the infiltration rate of samples of: a)'second generation', sand-filled, b) short pile water-based and c) third generation long pile synthetic turf. Sand infill was added to the sample at the rate of 30 kg m^{-2}. The infiltration rate of the carpet sample was calculated for changing factors such as infill type, rate of contamination, compaction, and presence of drainage hole and carpet specification. Results show that, although the carpet backing is permeable, there is a significant reduction in infiltration rate when no drain hole is present. There is also a significant effect on the rate of infiltration by changing the infill specification and that a combination of low levels of compaction and contamination significantly increase infiltration rates. Overall, levels of contamination above 10% (w/w) reduce the rate of infiltration to below 50 mm h^{-1}, which is below the basic level of performance quality standards.

Introduction

Within the sports turf industry, synthetic turf surfaces have, historically, been viewed as maintenance-free. A lack of maintenance will result in the build up of abrasive fragments from foot traffic, contaminants from air emissions and various other impurities, which include organic material and worn turf fibres. These contaminants migrate to the lower pile through the course of play and rainfall; this reduces the porosity of the infill and the infiltration rate of water into the surface is reduced (Rhodes, 1997). An irregular depth of infill reduces the fibre support of the infill and causes the pile to collapse; this will have a negative effect on the surface playability. In recent years many facilities have introduced pro-active maintenance systems that utilise regular brushing and filtering of the sand infill. There has been no quantification of the concentrations of contamination present within the infill/ carpet system and how these levels affect the surface infiltration rate. Low infiltration rates cause loss of surface playability, through growth of moss/algae and flooding, and this causes a loss of revenue through loss of play. At present, the recognized method for measuring the infiltration rate of a synthetic turf sports pitch is a double ring infiltrometer which has been adapted from use on natural turf (FIH, 1999). For accurate measurement of infiltration rate this equipment is designed to be driven into the turf surface to prevent any edge effect caused by leaking water; this is not possible with synthetic turf and so errors are likely to occur.

This paper is part of a larger project researching the effect that maintenance has on second generation sand-filled synthetic turf sports pitches and will test the hypotheses: (1) an increase in the concentration of a contaminant within the infill results in a reduction of surface permeability due to an increase in the proportion of smaller particles which decreases the void ratio (Naeini & Baziar, 2003) and increases matric potential, reducing gravitational flow and surface infiltration; and, (2) pitches located in urban areas will have higher levels of contamination within the infill compared to those located in rural areas. It will then be possible to model the effect that contaminants have on the infill/carpet system and use the results to predict loss of surface permeability of pitches from site samples.

Materials and methods

The material used for contamination throughout both experiments was a sandy loam that had been graded to a particle size < 500 µm. The results were expressed as ‘added contamination’; this is due to the presence of 0.9% contamination within the original infill samples. Each infill grade used had a different particle size range: 16/30 (1.00mm - 0.50mm), No 21 (0.71mm - 0.25mm) and 2EW (0.71mm - 0.25mm). The particle size distribution of each sand type is shown in Figure 1.

Quantification of infill contamination

An infill sample, 50 ml in volume, was suspended in 100 ml of a 1:10 solution of Calgon (50 g sodium hexametaphosphate and 7 g anhydrous sodium carbonate in 1 litre of distilled water) and distilled water. This mixture was mechanically stirred for 15 minutes at room temperature to deflocculate aggregates within the sample and release soil particles and fibre fragments into solution. The suspension was decanted into a 500 mm long, 22 mm diameter acetate tube that was sealed at one end (Figure 2) and distilled water was added to fill the tube to 50 mm from the top. Finally, 2 ml of a non-ionic surfactant, Lauramine oxide, was added to reduce surface tension, before the mixture was then agitated and allowed to settle overnight at a temperature of 20^{o}C. The particles in solution were sand, silt, clay, organic material and fibre fragments. Stokes' Law relates the sedimentation velocity of a particle of a given size through a liquid to its size and density, and the viscosity of the fluid.

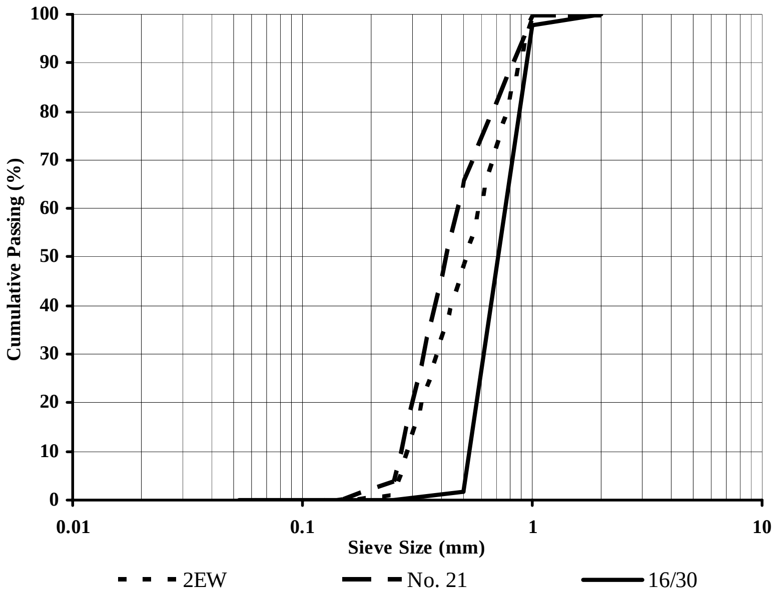


Figure 1 Gradation curves, derived from dry sieving of

Samples, of the sand infills used within this paper

A typical density for the silicate soil particles is 2.65 g cm^{-3}; the density of the fibre fragment is dependent on the material used, polypropylene = 0.905 g cm^{-3} and polyethylene = 0.948 g cm^{-3}. The sedimentation velocity of the soil particles is dependent on particle size which in this case is: sand >60 µm, silt 2 µm – 60 µm and clay <2 µm. This results in the formation of layers of different material enabling the quantification of contamination, which will be silt, clay and fibre particles.

The columns in Figure 2 show distinct layers, typical of settling patterns for synthetic turf of this type. The first layer comprises the sand infill material; the second layer organic matter, soil and turf-fibre fragments. The height of each layer was measured and the results expressed as a percentage contamination of the sample on a volume basis.

To quantify whether the separation tubes were an accurate representation of the level of contamination, they were calibrated using a range of 'standard' contaminated infill samples (on a weight basis) using Garside 2EW sand infill and a sandy loam.

The methodology was used to test the hypothesis that second-generation sand-filled pitches located in rural will be less contaminated than those in urban areas. Replicate samples of infill were removed from the wing, goal area and centre spot of each pitch.

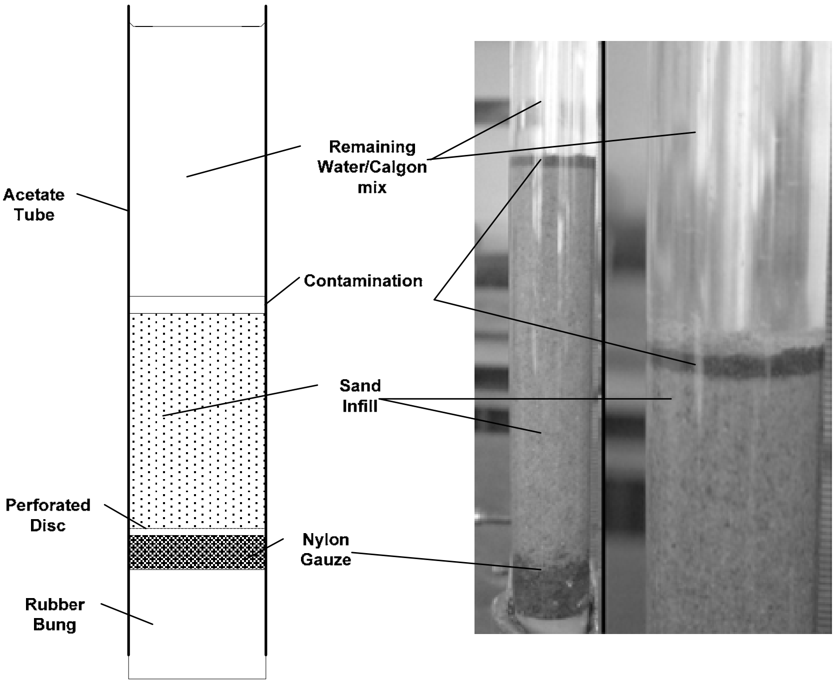


Figure 2. Design of the separation tubes used to quantify the level of contamination present within sand infill

Determination of infiltration rate

The turf sample used were a) sand-filled - polypropylene fibre pile, 23 mm in length, with an infill at the rate of 30 kg m^{-2}, b) water based – polypropylene, 14 mm in length, and c) polyethylene fibre pile, 50 mm in length, with a sand/rubber infill at the rate of 23 kg m^{-2} sand to 6 kg m^{-2} rubber. The sand was used as a stabiliser for the carpet and was agitated to the base of the carpet pile before the addition of the rubber infill. The contamination was added to the sand element of the infill.

Although use of the settlement tubes quantifies the level of contamination within a sand infill sample, the data has little significance unless the effect of contamination on the infill can be demonstrated. A method to quantify the effect of contamination on infill infiltration was developed using the falling head permeameter apparatus for the determination of saturated hydraulic conductivity of soils (Figure 3). The experimental parameters used were: the presence of absence of a drainage hole in the backing of the carpet sample, different infill specifications (Garside 2EW, No.21 and 16/30), different rates of infill contamination (0, 5, 10, 15 & 20% w/w), compaction of the infill sample and different carpet specifications (sand-filled, water-based and sand/rubber infill). The carpet samples were 100 mm diameter circles; the fibres at the edges of the sample were removed to allow the cylinder to seal on the carpet base. The edges of the carpet base were sealed with a rubber ring and silicon grease.

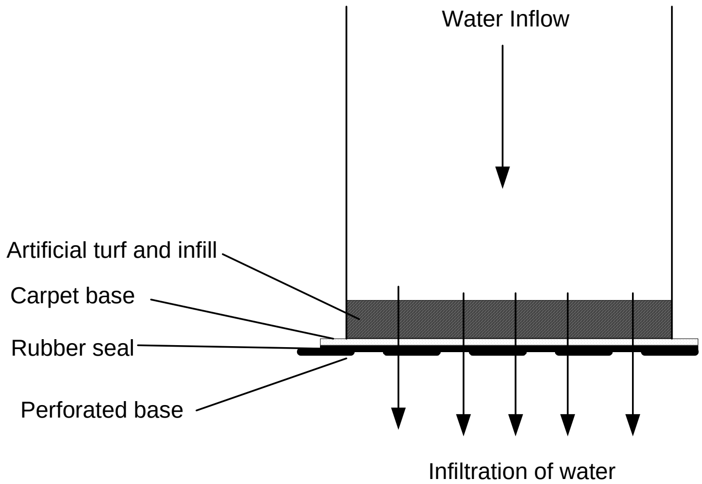


Figure 3. Falling Head Permeameter apparatus used to measure the infiltration rate of a carpet/infill sample.

An infill sample was added to the carpet sample, brushed into the pile, and tamped lightly to ensure an even distribution within the carpet pile. The cylinder was filled with water, to a head of 100 mm, and then sealed (Figure 3). After removing any air bubbles, water was passed through the sample to saturate the infill. Results were expressed as an infiltration rate with units of millimetres per hour.

The final test to quantify the effect of contamination on the infiltration rates of the sand infill was to apply different rates of compaction applied using dynamic force. A 3 kg load was released from two different heights and at two different frequencies. The infill material was dry when the dynamic force was applied to prevent variations of the moisture content having a differential effect on the compaction of the infill (Bodman & Constantin, 1965). The application of the dynamic load on the infill will induce particle re-arrangement and a reduction in the pore size and distribution. The infill used was Garside 2EW.

All of the data was analyzed using the analysis of variance (ANOVA) and correlation functions of Genstat v8.1

Results and discussion

Quantification of infill contamination in field samples

The calibration of this technique to known standards showed that there was a significant correlation (r = 0.954, p<0.01) between the settlement tube method (v/v) and the range of standard concentrations of contamination (Figure 4). There is not a perfect correlation between the samples because some of the finer silt particles stay in suspension in the

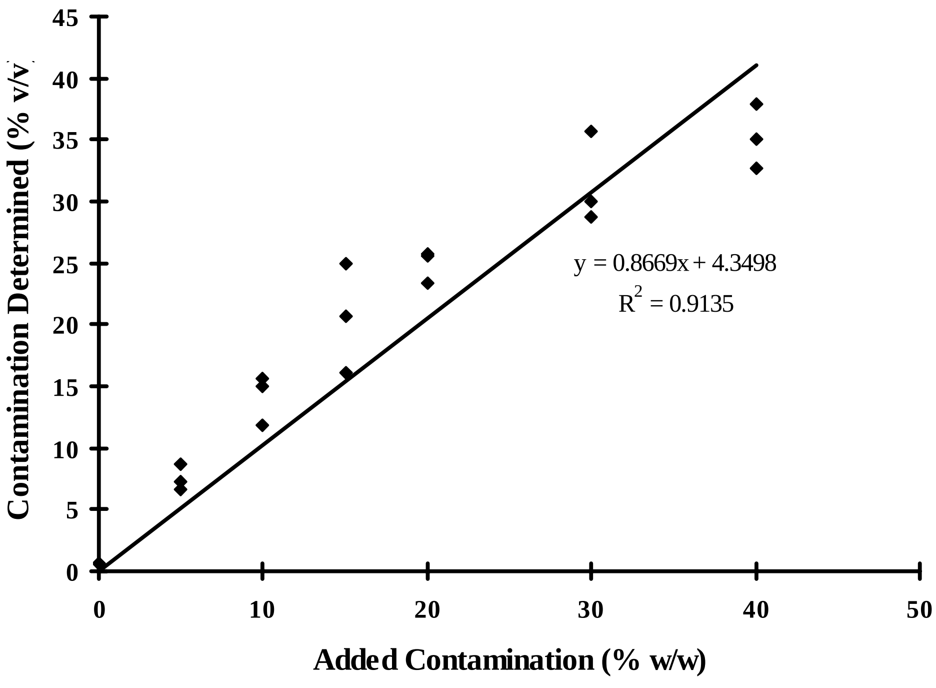


Figure 4. Calibration of sedimentation tube method

Calgon solution. Using field samples, collected from test sites located in rural and urban areas, the pitches were found to contain between 1.9% and 9.1% contamination (Table 1). One pitch, a seven year old, second generation, sand-filled turf pitch with a mean pile length of 18 mm, had a history of drainage problems in one corner, where the infill contained 20% contamination. Although the pitch was maintained, a fault in the pitch design allowed contamination to wash onto the surface from the surrounding grass banks. A relationship between location (urban or rural) and contamination values was not apparent ($p>0.05$) and there was insufficient evidence to support Hypothesis 2. This was because within the Urban and Rural classifications the test pitches had different levels of maintenance and infill specification.

Determination of infiltration rate

Presence of a drainage hole in carpet backing

Although the carpet backing was permeable, ANOVA showed that the drainage hole has a significant effect on the infiltration rate of the carpet/infill system (Figure 5). There was a significant negative correlation between the increase in contamination and the reduction in infiltration for both the 'hole' ($r = -0.973$ $p<0.01$) and the 'no hole' ($r = -0.723$, $r<0.01$) samples. The spacing of the drainage holes varies between manufacturers and, on average, is 100 mm. This spacing allows the carpet to qualify for the relevant

Table 1. The concentration of contamination within the infill of the second generation sand-filled test pitches

			Contamination (%)		Usage (h / week)	
Location	Age range	n	Mean	Range	Mean	Range
Rural	1-7	3	5	2.1-9.1	39	22-60
	8-14	3	3.8	2.8-4.5	39.7	22-55
Urban	1-7	2	4.3	2.4-6.2	41.5	38-45
	8-14	3	5.3	3.0-6.5	50.3	38-68

Federation de Internationale Hockey (FIH, 1999) infiltration and fibre retention strength standards. Any spatial variation of infiltration within the carpet will cause problems such as increased algal and moss growth, due to the increased moisture content of the infill.

Infill material

The addition of 5% contamination significantly reduced the infiltration rate of No.21 ($p<0.001$) but did not have a significant effect on 2EW and 16/30 (Figure 6);

infiltration rates were all above the basic performance quality standard of 50 mm h^{-1} (FIH, 1999). At over 10% contamination, both 2EW, the most commonly used of infill material, and No.21 approach the 'basic' standard. 16/30 remains above the 'basic' rate until a concentration of 20% contamination. The results of the experiment indicate that if the level of contamination increases to above 10% then infiltration rates will be significantly reduced.

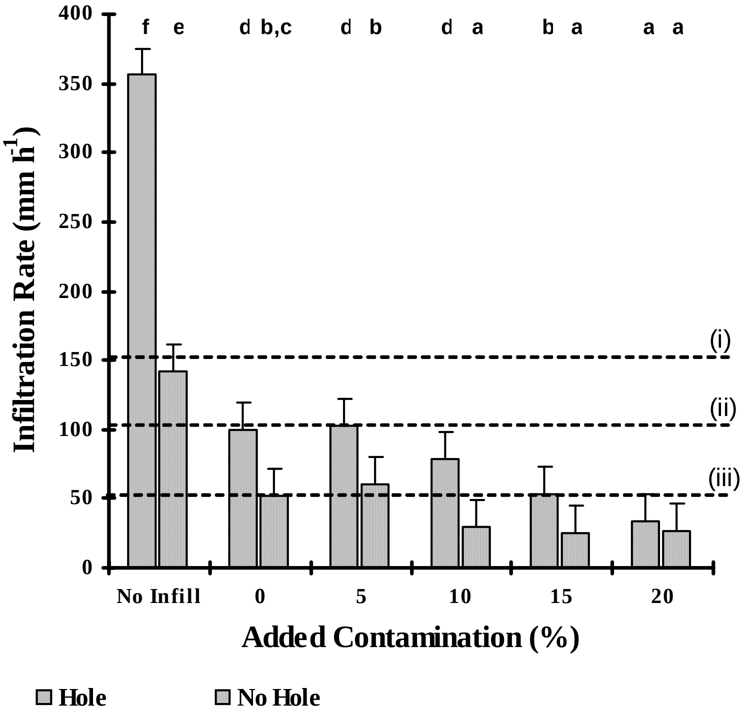


Figure 5. Comparison of infiltration rates with and without a drainage hole as a function of contamination and infill (Garside 2EW). Dashed lines represent the limits for the FIH performance Standards (i) Global, (ii) Standard, (iii) Basic. Means with identical superscripts cannot be separated by the LSD (0.05) of 19.58 mm h^{-1} (represented by the whiskers)

The effect of compaction on infiltration rate

The results indicate that compaction has less of an effect on infiltration rate than contamination (Figure 7). In an infill/carpet system that has low compaction, the fine contamination can pass through the infill and form a layer on the carpet backing which

reduces infiltration. To prevent this reduction in infiltration rate, any maintenance procedure will need to remove and filter/replace the infill to the full depth of the pile.

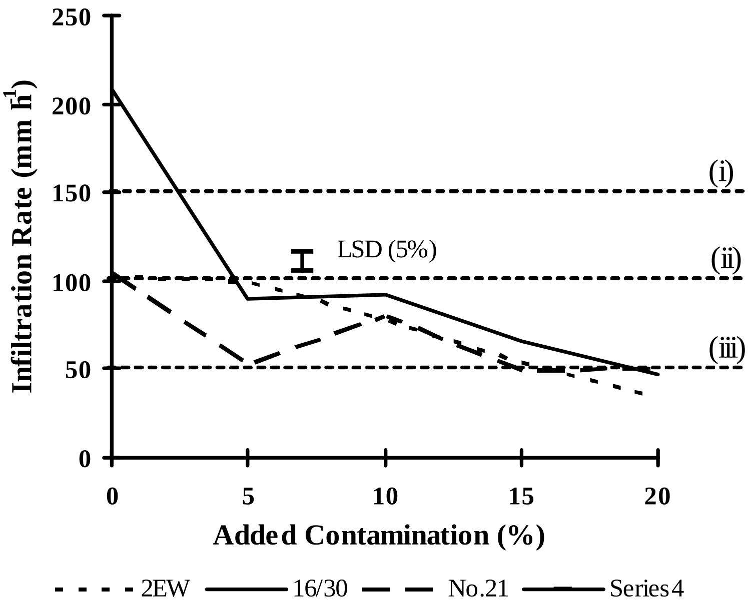


Figure 6. The effect of contamination on three commonly sand infills used in STP's. Dashed lines represent the limits for the FIH performance Standards (i) Global, (ii) Standard,(iii) Basic

Third generation sand/rubber infill synthetic turf

The results were similar to the second generation sand-filled samples (Figure 8). As contamination level reached 10%, the infiltration rate was reduced to the FIH minimum standard. Although the rate of infiltration was not reduced by an increase in contamination over 10%, it will be affected by other factors such as compaction, fibre deterioration and 'capping' of the surface by the long fibre structure. The carpet samples were tested in their 'virgin' state, as the fibres defibrillate and start to wear and the fibres bend and lay flat the infiltration rate will be further reduced.

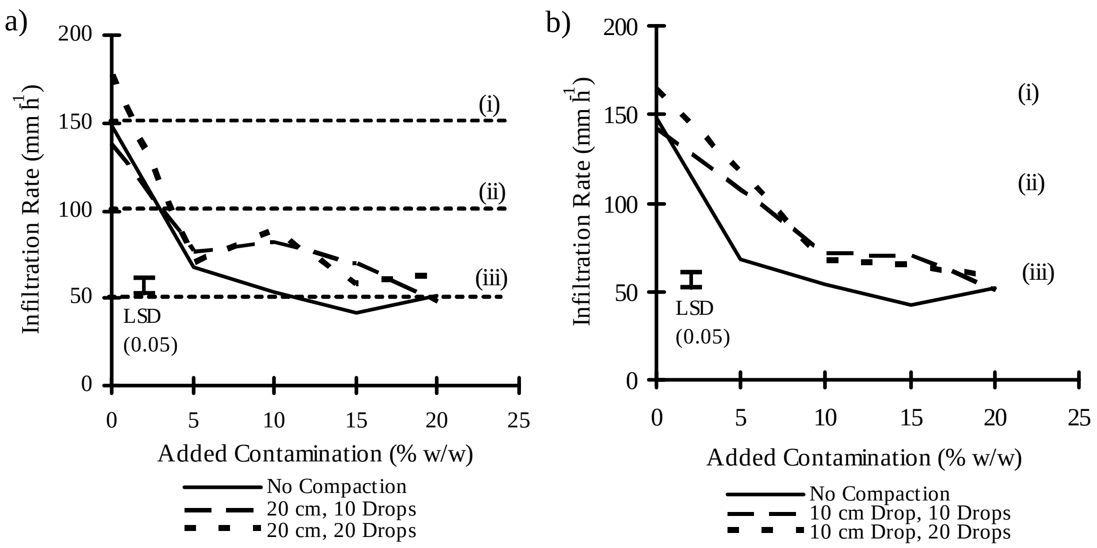


Figure 7. The effect of compaction on a contaminated sand-filled (2EW) second generation carpet sample. The results of compaction are shown in graph a) 20 drops and b) 10 drops of the 3kg weight. Dashed lines represent the limits for the FIH performance Standards (i) Global, (ii) Standard, (iii) Basic

Short pile water based synthetic turf

Although the dense pile of the carpet is designed to hold water, it has a significantly higher infiltration rate ($p<0.001$) than the carpets with infill (Figure 9). The carpet backing is impermeable and all movement of water is through the drainage holes; this prevents flooding of the surface due to the high volume of water used, approximately 36000 litres, for each field hockey match.

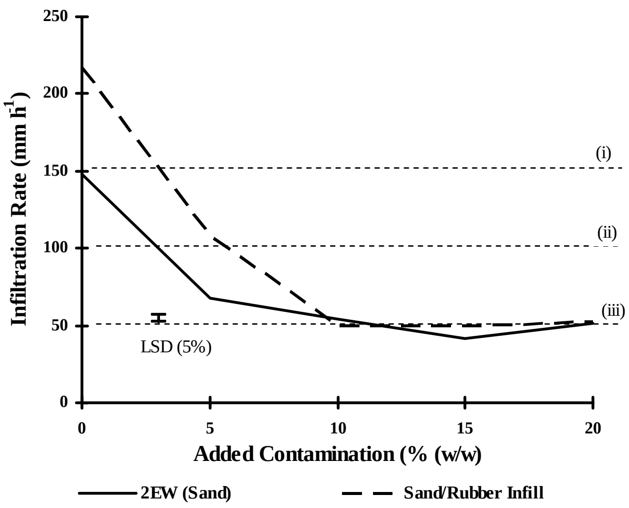


Figure 8. The effect of contamination of the infill rate of second generation sand infill and third generation long pile carpets Dashed lines represent the limits for the FIH performance Standards (i) Global,(ii) Standard, (iii) Basic

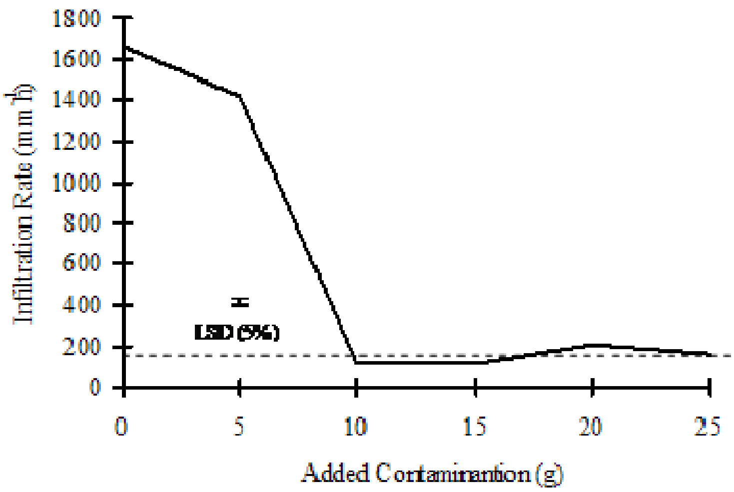


Figure 9. The effect of contamination of the infill rate of short pile water based hockey turf. Dashed lines represent the Global limit (150 mm h^{-1}) for the FIH performance Standards

Conclusions

There was a significant reduction of surface infiltration with an increase in contamination and that this effect was present in both second and third generation carpet specifications. The infiltration rates were significantly reduced at a critical concentration of 10% contamination causing a loss of playability on pitches. A new method for determining the quantification of the levels of contamination within the sand infill has been developed using sedimentation tubes. The procedure has been shown to be accurate, simple to perform and economical. Quantification of infill contamination and identification of critical values allows facility managers and maintenance companies to plan pro-active maintenance programs to prevent loss of playing quality. Hypothesis 2 that contamination was related to location (urban or rural) was not supported in this study because maintenance programmes and sand infill specification varied within and between location treatments.

References

Avery, B.W. and Bascomb, C.L. (1982) Soil Survey Laboratory Methods. Soil Survey Technical Monograph No 6

Bodman, G.B. and Constantin, G.K. (1965) Influence of Particle Size Distribution in Soil Compaction. Hilgardia, Vol. 36, No. 15. p 567-591

FIH (1999) Synthetic Hockey Pitches – Outdoor: Handbook of Performance Requirements. International Hockey Federation, Brussels

Gibbs, R.J. (2005) A practical Model of assessment of sand carpet sportsfield condition and control of surface contamination. Proceedings of the International Turfgrass Society, Llandudno, Wales. p 347-156

Naeini, S.A. and Baziar, M.H. (2003) Effect of fines content on steady-state strength of mixed and layered samples of a sand. Soil Dynamics and Earthquake Engineering. Vol 24 p 181-187

Rhodes, D.I. (1997) *Carpet Care*. Panstadia International, Vol.4 No.1 January.

Appendix C: Questionnaire survey

Research sponsored by

THE INSTITUTE OF GROUNDSMANSHIP

Name of Organisation :……………………………

Contact Name:……………………………….

All information from this questionnaire will be kept confidential

Cranfield UNIVERSITY Silsoe

Cranfield Centre for Sports Surfaces

(If accurate details for the following questions are not known, please give your best estimate)

1) What is the approximate area of the playing surface? (m^2)

2) What is the approximate age of the pitch? (years)

3a) For which sports is the pitch used?

Hockey	Football	Rugby	Tennis	Other

b) *If other, please provide details*

4a) What was the cost of the pitch construction? £'000

<250	250 - 300	300 - 350	350 - 400
400 - 450	450 - 500	500 - 550	600 - 650
650 - 700	700 - 750	>750	

b) How was the capital expenditure funded?

c) Is it expected that the facility will fund itself, either in part or full?

5) Factors that influenced your choice of surface:

	Low priority				High priority
a) Low maintenance costs	1	2	3	4	5
b) Increased standard of play	1	2	3	4	5
c) Playability of surface	1	2	3	4	5
d) Installation costs	1	2	3	4	5
e) Specification	1	2	3	4	5
f) Planning regulations	1	2	3	4	5
g) All weather capability	1	2	3	4	5
h) Increased hours of play	1	2	3	4	5

6) In total, How long do you expect the pitch to last? (yrs)

Maintenance of Artificial Turf Sports Pitch

7a) Was a maintenance document supplied by the manufacturer? **Yes** | **No**

b) Do you feel that you were made fully aware of the required maintenance levels? **Yes** | **No**

c) Have you adhered to the document? **Yes** | **No**

8) Were future costs made clear? **Yes** | **No**
(e.g. for power brushing, rejuvenation, carpet replacement)

9a) Is there a maintenance budget for the artificial turf pitch? **Yes** | **No**

b) If yes, what is the approximate anuual budget for the pitch? (£000's)

0-3	4-6	7-9	10-12	13-15

c) If no, are the costs absorbed by the overall grounds budget? **Yes** | **No**

d) If there is a budget, what is the expcted annual increase? (%)

e) If no, what is your annual expendiure on the maintenance? (£000's)

0-3	4-6	7-9	10-12	13-15

10) How many operator hours are used maintaining the pitch? (per week)

<5	6-10	11-15	16-20	21-25
26-30	>30			

11)	What is the total cost of employment per operator hour?		(£)			
12a)	Do you drag brush your pitch?			**Yes**	**No**	
b)	If yes :	What is the frequency of brushing	(per week)			
c)		Approximately, how long does each brushing take?	(minutes)			
d)		How much did the drag brush cost?				
e)		Who is the brush manufacturer?				
13a)	Do you power brush the surface?			**Yes**	**No**	
b)	If yes:	Do you or a contractor carry out the procedure?		**In-house**	**Contractor**	
c)	If in-house:	What is the annual frequency of brushing?				
d)		How much did the power brush cost?				
e)	If contractor:	What is the annual frequency of brushing?				
g)		How much are you charged annually?	(£)	**<1000**	**1001-1500**	**1501-2000**	**2001-2500**
14a)	Have you had the sand infill replaced?			**Yes**	**No**	
b)	If yes:	How long after construction?	(years)			
c)		How much did it cost?	(£000's)	**<5** / **26-30**	**5-10** / **31-35**	**11-15** / **>35**	**16-20**
15a)	Have you had the carpet replaced?			**Yes**	**No**	
b)	If yes:	How long after construction?	(years)			
c)		How much did it cost?	(£000's)	**<25** / **126-150**	**25-50** / **>150**	**51-75**	**76-100**
16a)	Have you had to have damage to the carpet repaired?			**Yes**	**No**	
b)	If yes:	Was it due to:		**Wear**	**Tear**	**Other**
c)	If other:	What was the damage?				
d)	What was the cost of the repair?					
17a)	Has there been a re-adjustment of surface levels?			**Yes**	**No**	
b)	If yes:	How much did it cost?				
18)	Does the pitch have drainage problems?			**Yes**	**No**	
19a)	Does the pitch have algae/moss problems?			**Yes**	**No**	
b)	If yes:	Do you treat the pitch with a fungicide/mossicide?		**Yes**	**No**	
c)	If yes:	How much does the treatment cost?	(per annum)			

Usage of Artificial Turf Sports Pitch

20a) How many hours is the pitch used for? (weekly) [ ]

b) Of these hours, how many are paid lettings? (weekly) [ ]

c) Of these hours (Q. 20 a), how many are in-house? (no charge) (weekly) [ ]

d) Please detail any other usage (weekly) [ ]

21) What is the cost of hiring the facility? (per hour) [ ]

Sports Equipment

22) How many sets of the following equipment do you have for the surface, what was their purchase cost and life expectancy?

	Number	Cost (£)	Life (yrs)
a) Standard football posts			
b) Short football posts			
c) Hockey posts			
d) Tennis posts/nets			
e) Other, please detail.			

23) Please include any other information you feel is relevant

[ ]

24) If you ave a preferred time of the year that I can make a site visit, please can you circle the relevent months below.

May **June** **July** **August** **September**

Contact information

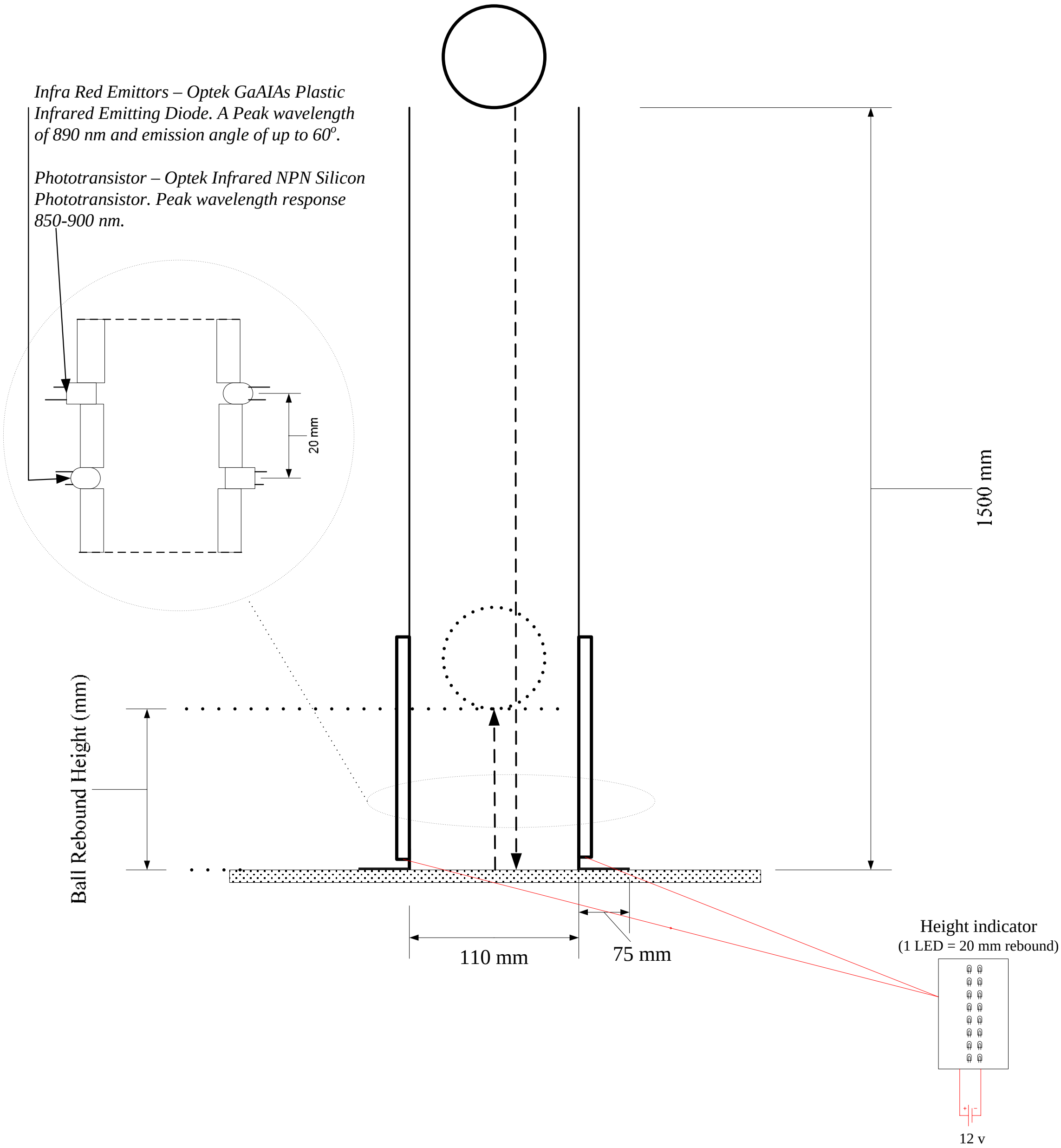
Ifyou have any questions about the questionnaire, I can be contacted by telephone or e-mail.

Telephone ***01525 863091 (o)***
07833 593220 (m)

e-mail ***a.j.mcleod.s01@cranfield.ac.uk***

Cranfield Univerity
Barton Road
Silsoe
Bedfordshire
MK45 4DT

Appendix D: Schematics of the equipment to measure ball rebound



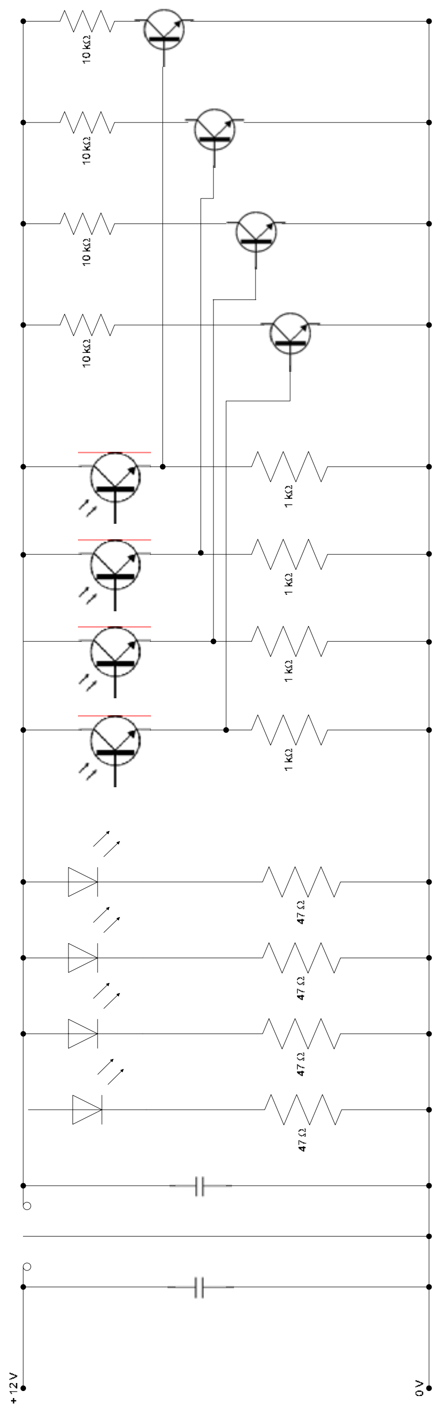
Apparatus description and mode of action

As the ball drops and breaks the beam of the lowest emitter the circuit for the rest of the emitters/phototransistors is switched on. The phototransistors in the system are saturated with infrared light, and produce a voltage proportional to the light received until the output reaches a maximum. As a ball passes through the beam the voltage becomes negative and this action causes the in-line quadruple s-r switch to move from a negative to a positive charge; this powers a super bright red light emitting diode on the front of the control box. For each of the phototransistors there is a matching switch. The height of the ball rebound height can then be translated from the height of the phototransistor ‘switched off’.

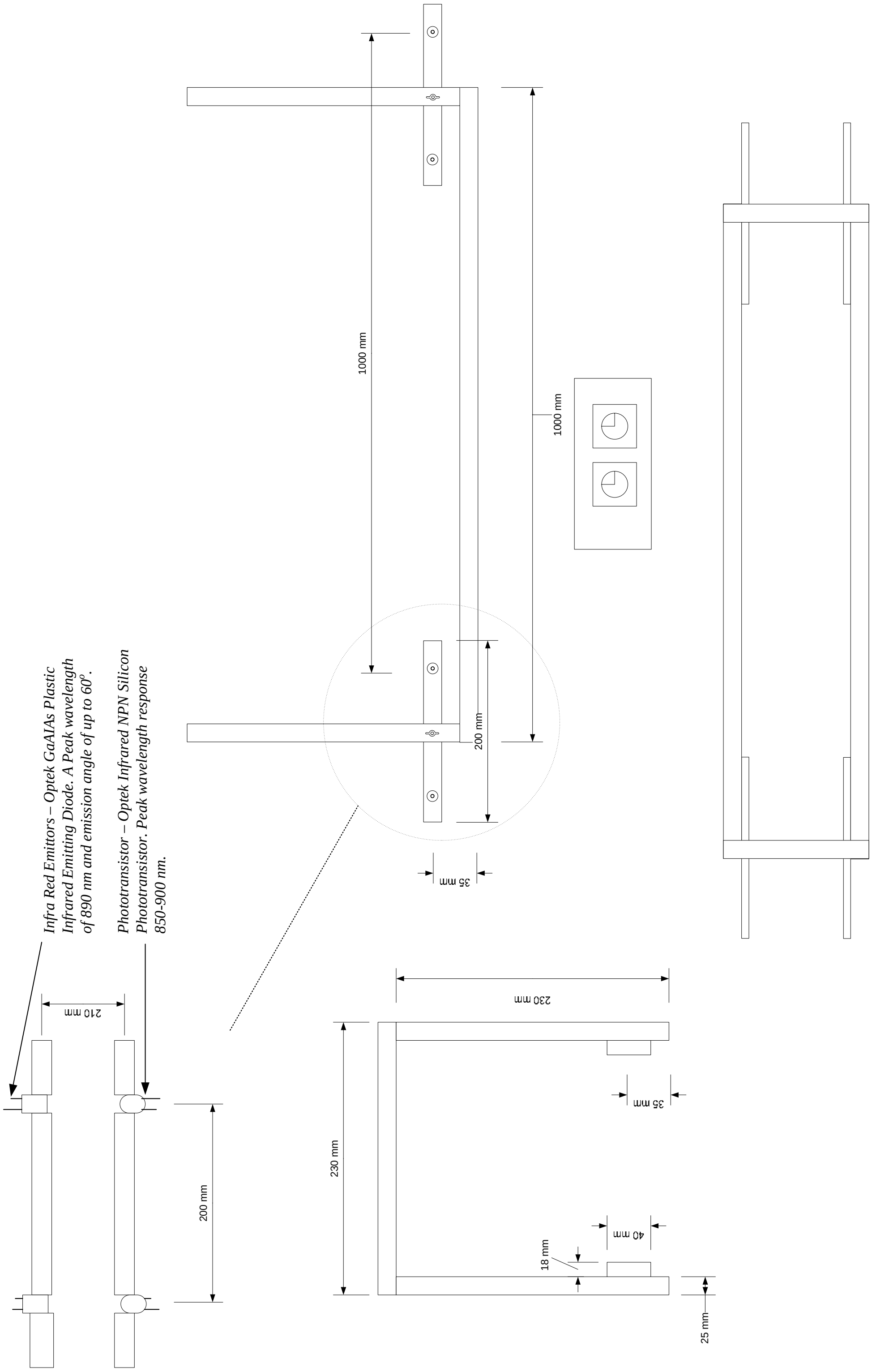
16 matched pairs of infra-red transmitters and phototransistors are located 20 mm apart and linked to quadruple s-r latch chips are mounted which, when activated power the LEDs on the height indicator and keep the light on until the indicator is reset to 0 V. By passing the ball through the sensors it was calculated that the ball breaks the infra red beam 7 mm from the ball edge.

Circuit diagram for the ball rebound measure

(Circuit for 4 of the 16 height indicators. This circuit is repeated 4 times)



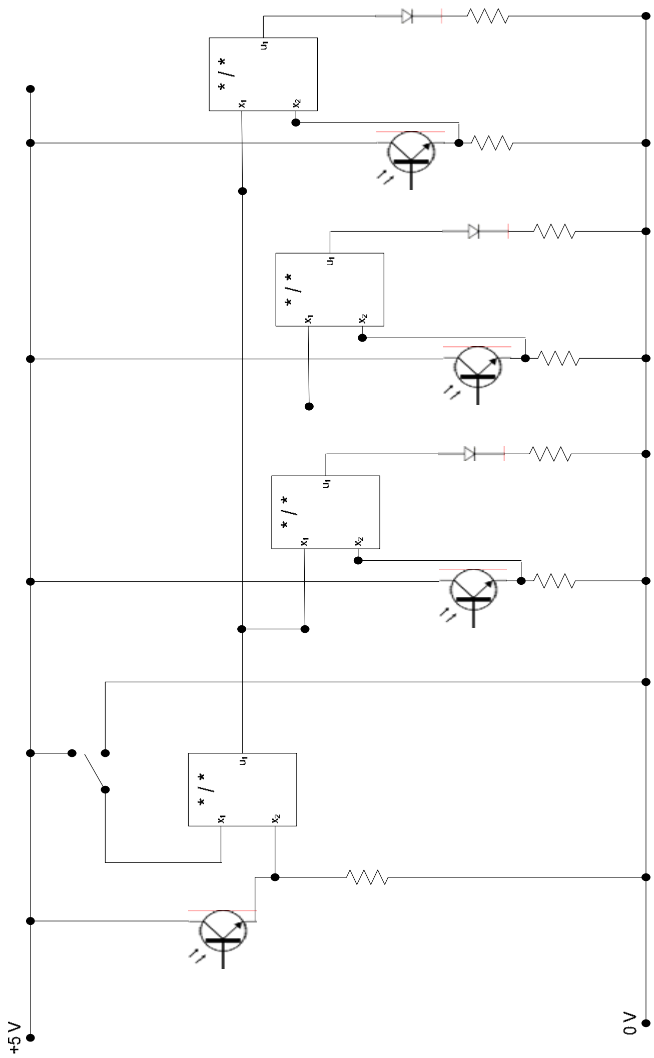
Appendix E: Timing gates for the measurement of ball deceleration



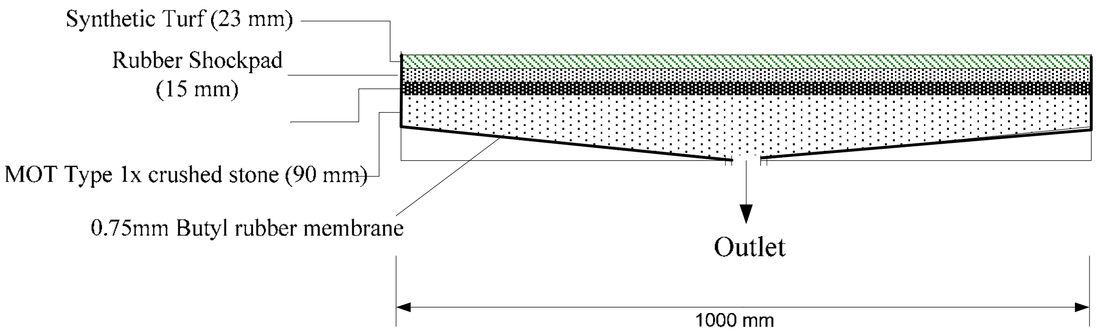
Apparatus description and mode of action

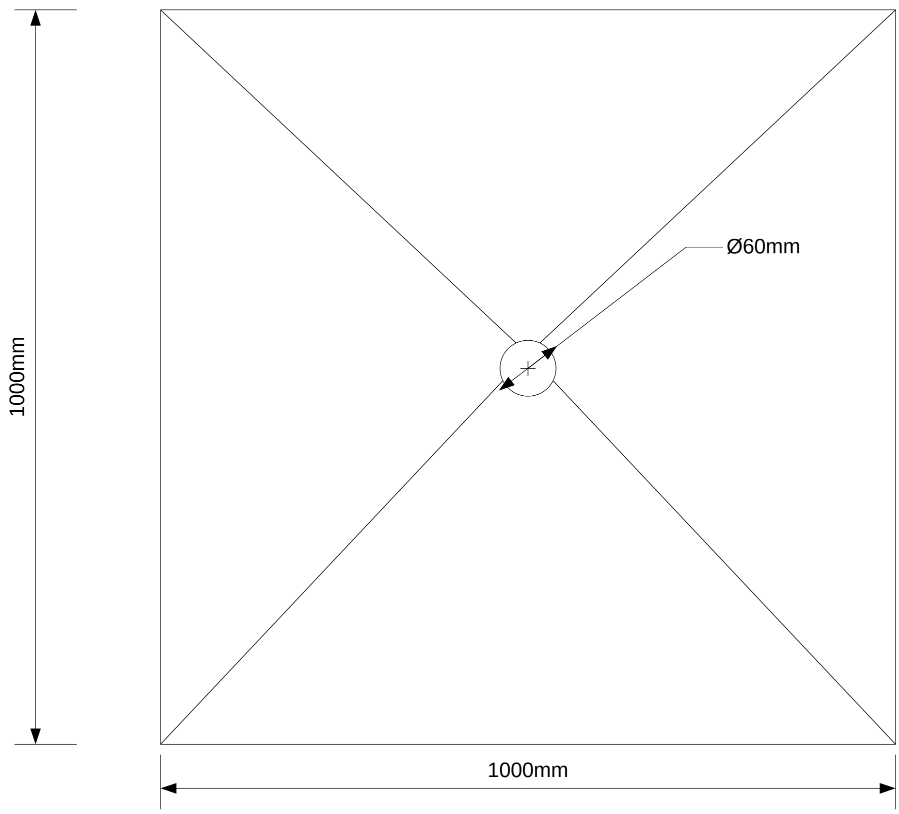
As the passes and breaks the beam of the first IR emitter the circuit for the first timer is activated; after 200 mm the next emitter/phototransistor circuit is broken and the timer is switched off. The same happens for the two pairs of emitter/phototransistors located 1000 mm away, but this time for a second timer. The difference between the two registered times is used to calculate the deceleration for the ball over a 1000 mm distance.

Circuit diagram for the timing gates



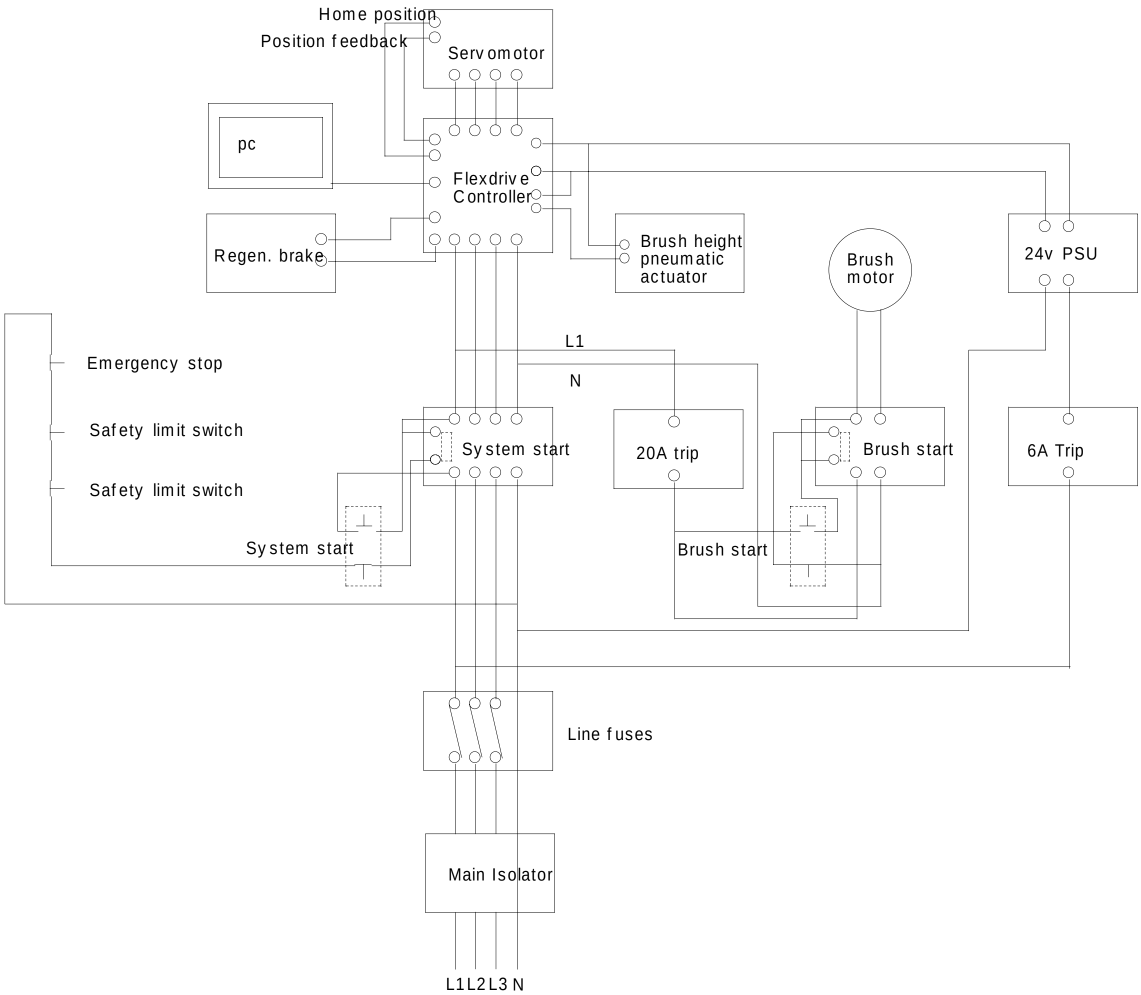
10.1 Appendix F: Design of sand-filled synthetic turf test surfaces



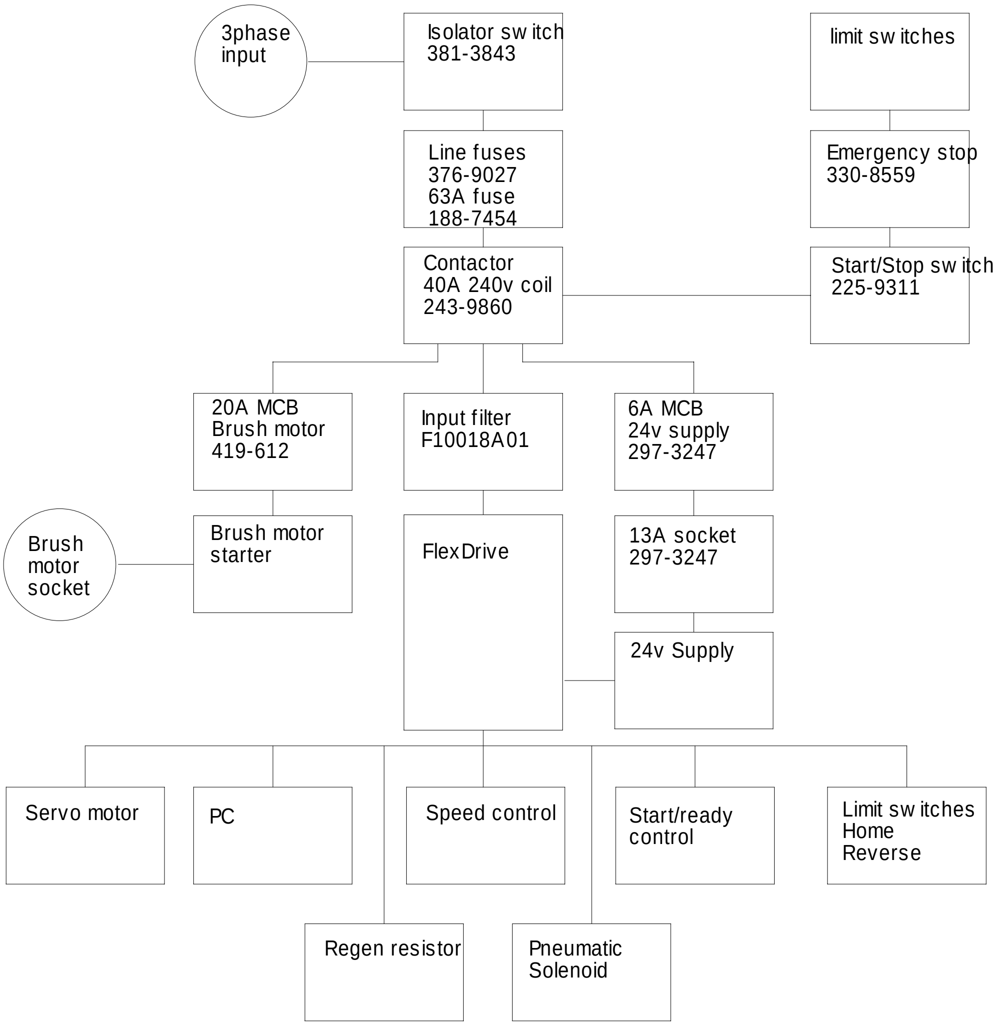


Appendix G: Design drawings of the accelerated wear test rig

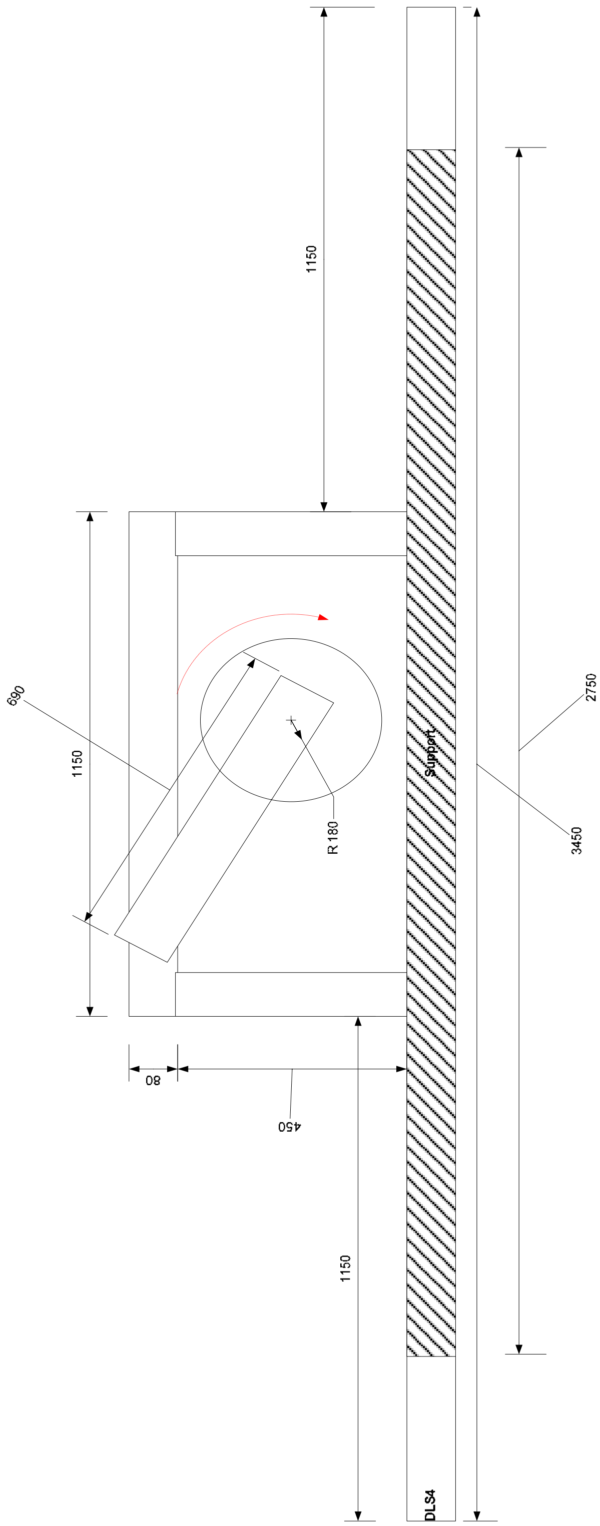
Schematic wiring diagram of the test rig.

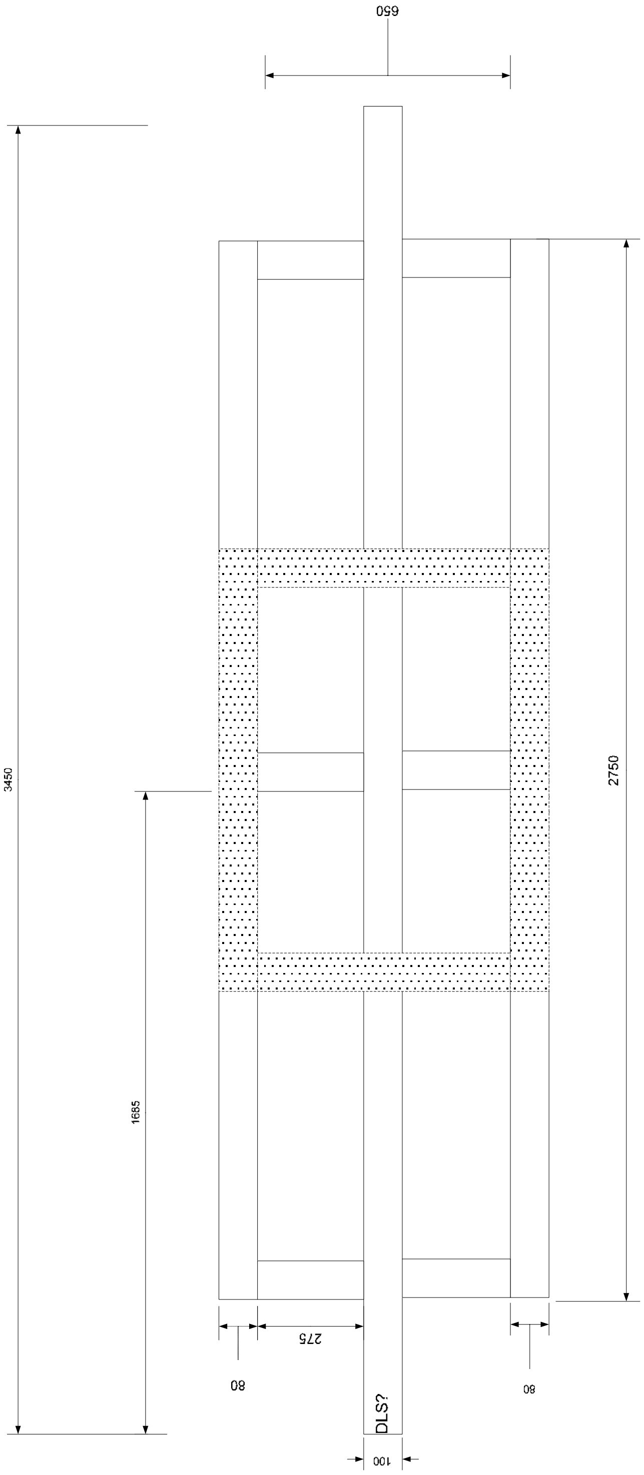


General layout of the test rig electrical system

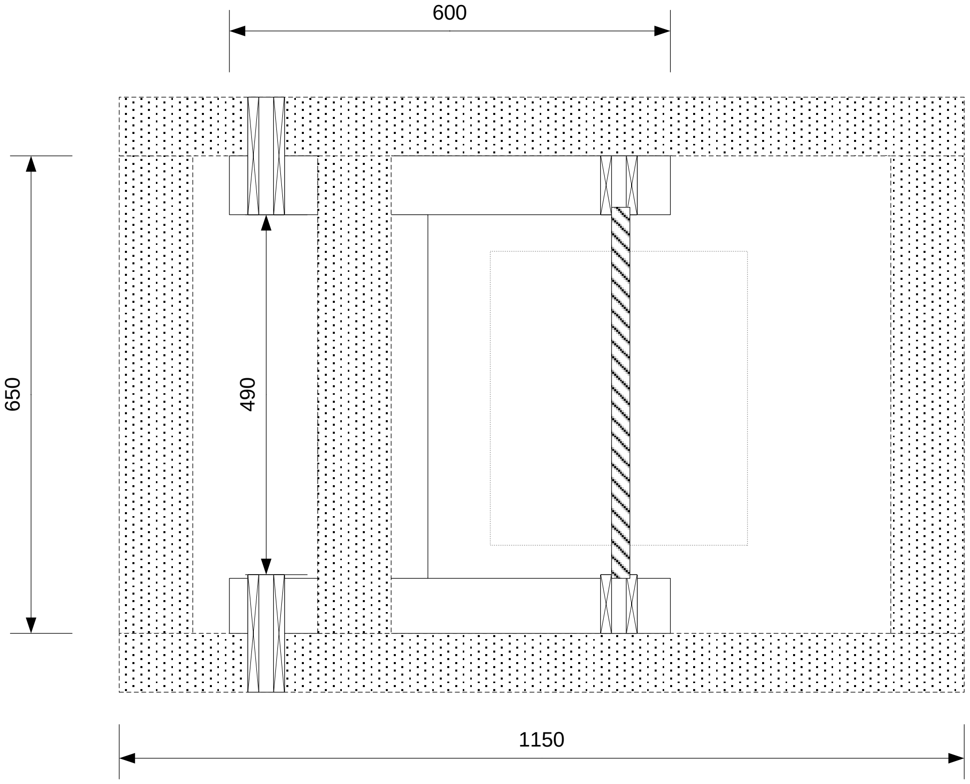


Basic design of the test rig

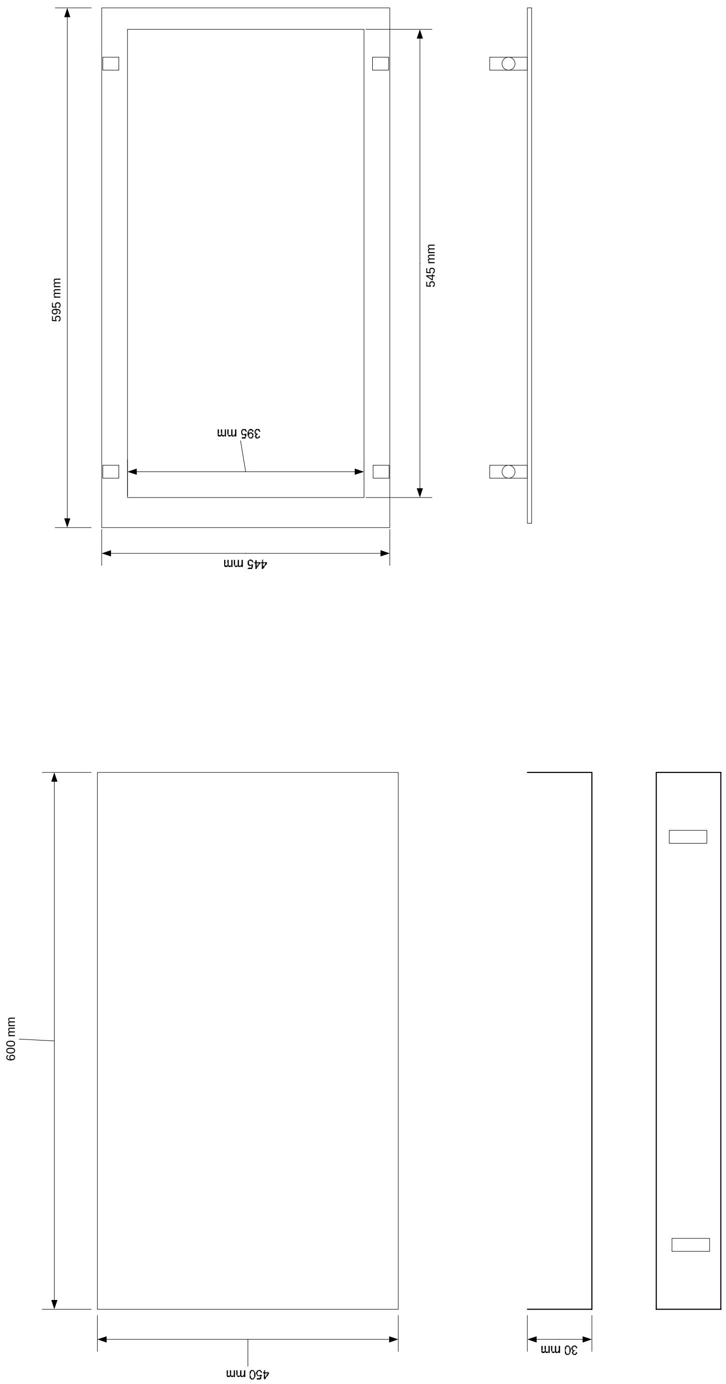



650
3450
2750
1685
275
80
80
DLS?
100

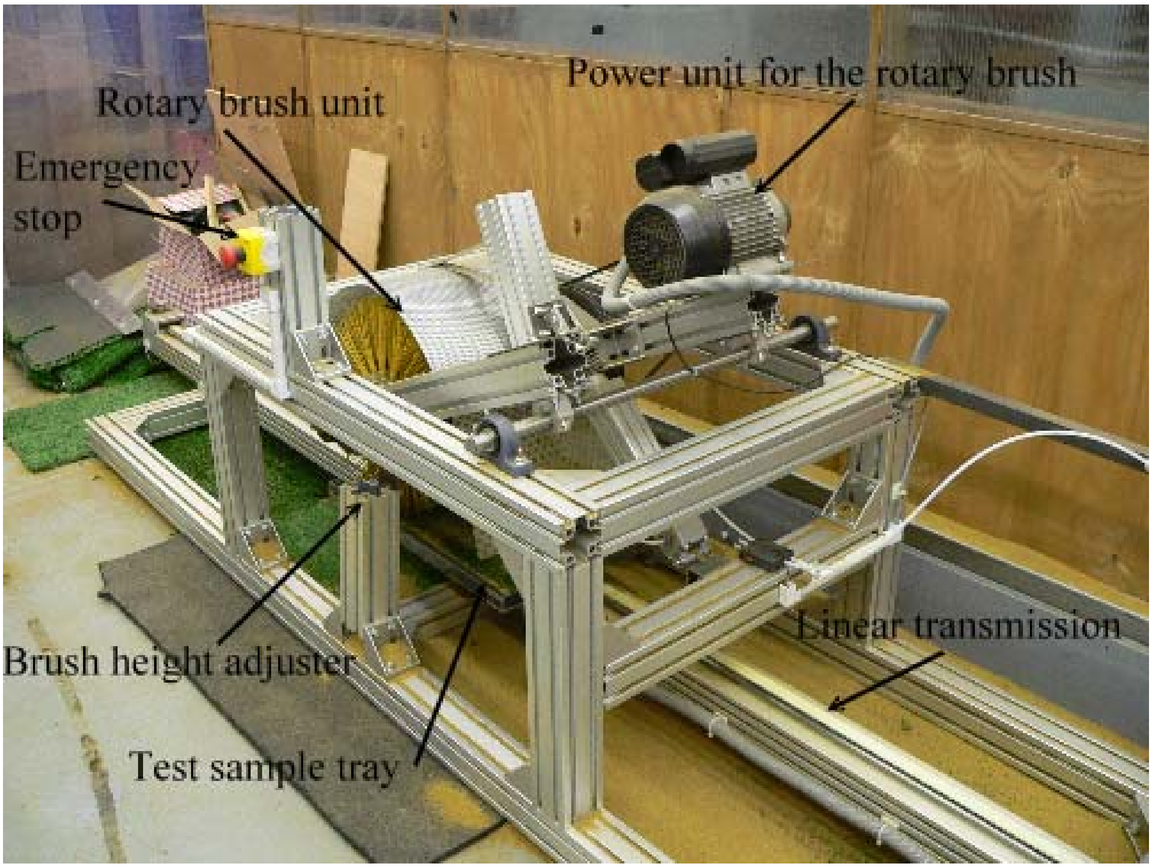
Brush head and pivot arms



Turf sample tray



Final design of the test rig



Algorithm for the MINT software for the Flex + II control system

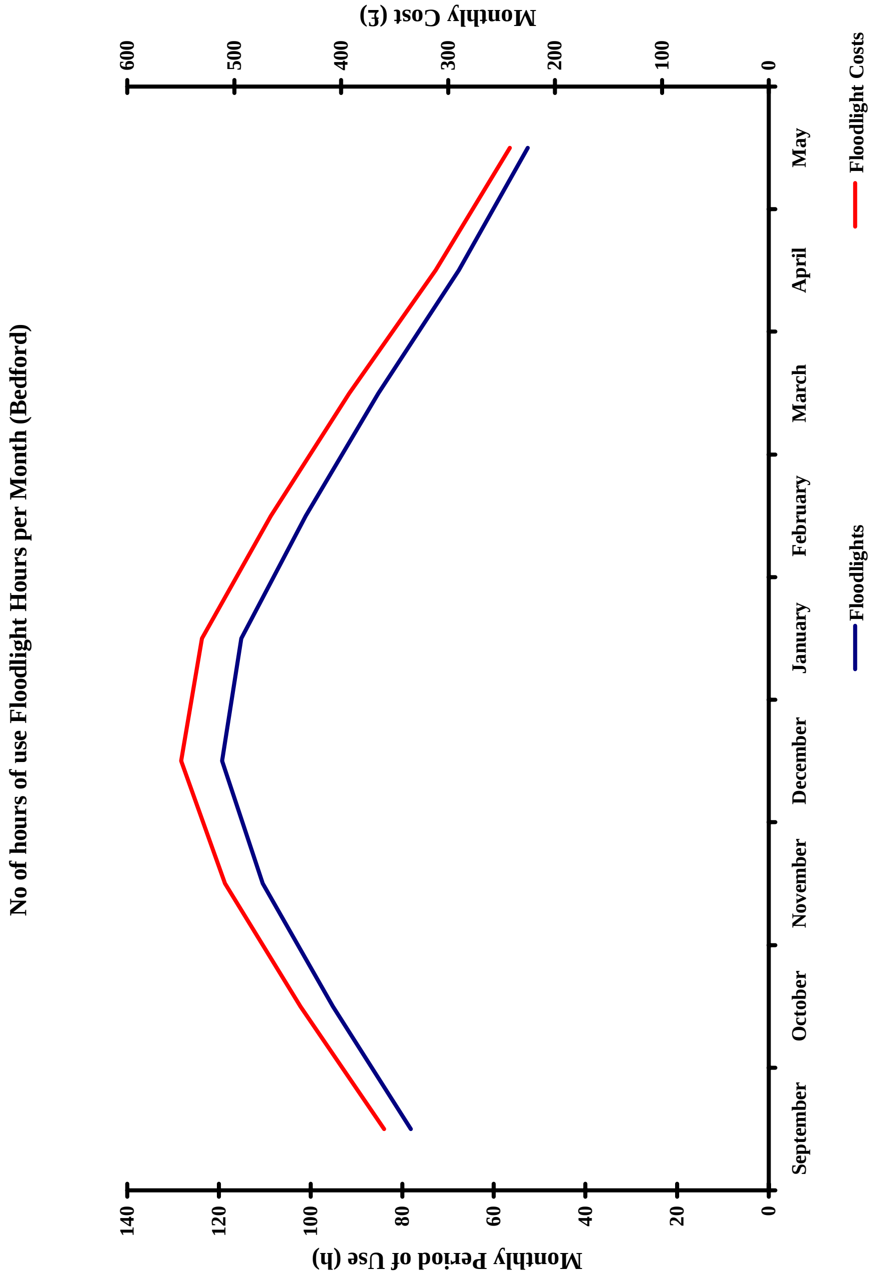
```
  'lower brush
  RELAY = _OFF
  Wait 500
  'move forward
  SPEED(0) = setspeed
  MOVEA(0) = 2600
  GO(0)
  Pause IDLE(0)
    'raise brush
  RELAY = _ON
  Wait 500
   'move back
  SPEED(0) = 1000
  MOVEA(0) = 0
  GO(0)
  Pause IDLE(0)
Next
Print "Test complete."
'lower brush & disable motor
RELAY = _OFF
DRIVEENABLE = _OFF
End
Startup
' Thursday, May 10, 2007
Define ALL = 0
Define SELECTED = 0
Define SERVOS = 0
Define DINBANKS = 0, 1, 2
Define DOUTBANKS = 0, 1, 2
Define ADCS = 0
```

```
Define ENCODERS = 0
Define AUXENCODERS = 0
' Abort any motion currently in progress
ABORT:Wait = 10
' Define loop times
LOOPTIME = 1000
' Define config modes for all axes
CONFIG[SELECTED] = _cfSERVO
' Initialize the axes
CANCELALL
DRIVEENABLE[SELECTED] = 0;
' Digital input configuration
INPUTMODE[DINBANKS] = 0, 0, 0 ' 0x0, 0x0, 0x0
INPUTACTIVELEVEL[DINBANKS] = 011111111, 01111111111, 01111111111 ' 0xff,
0x3ff, 0x3ff
INPUTPOSTRIGGER[DINBANKS] = 0, 0, 0 ' 0x0, 0x0, 0x0
INPUTNEGTRIGGER[DINBANKS] = 0, 0, 0 ' 0x0, 0x0, 0x0
' Analog input configuration
ADCMODE[ADCS] = 0
' Digital output configuration
GLOBALERROROUTPUT = -1
OUTPUTACTIVELEVEL[DOUTBANKS] = 0111, 011111, 01111111111 ' 0x7, 0x1f,
0x3ff
' Axis scaling
SCALEFACTOR[SELECTED] = 16384 * 3 / 200
' Axis Error parameters
ERRORINPUTMODE[SELECTED] = _emCRASH_STOP_DISABLE
ABORTMODE[SELECTED] = _emCRASH_STOP_DISABLE
LIMITMODE[SELECTED] = _emCRASH_STOP_DISABLE
SOFTLIMITMODE[SELECTED] = _emIGNORE
STOPINPUTMODE[SELECTED] = 3
SOFTLIMITFORWARD[SELECTED] = 2610
```

```
SOFTLIMITREVERSE[SELECTED] = -10
FOLERRORMODE[SERVOS] = _emCRASH_STOP_DISABLE
FOLERRORFATAL[SERVOS] = 4.07
' Axis Digital input events
ERRORINPUT[SELECTED] = -1
HOMEINPUT[SELECTED] = 0
STOPINPUT[SELECTED] = 1
LIMITFORWARDINPUT[SELECTED] = -1
LIMITREVERSEINPUT[SELECTED] = -1
RESETINPUT[SELECTED] = -1
' Axis Drive Output Enables
DRIVEENABLEOUTPUT[SELECTED] = -1
' Axis Tuning Parameters
KDERIV[SERVOS] = 0.00
KINT[SERVOS] = 0.00
KINTLIMIT[SERVOS] = 100.00
KINTMODE[SERVOS] = 0
KPROP[SERVOS] = 2.00
KVEL[SERVOS] = 0.00
KVELFF[SERVOS] = 1.88
KACCEL[SERVOS] = 0.00
' Axis Parameters
SPEED[SELECTED] = 4000
ACCEL[SELECTED] = 11000
DECEL[SELECTED] = 11000
ERRORDECEL[SELECTED] = 50000
SRAMP[SELECTED] = 0.00
MOVEBUFFERSIZE[SELECTED] = 2
HOMEBACKOFF[SELECTED] = 10.00
HOMESPEED[SELECTED] = 100
IDLEPOS[SERVOS] = 4.07
```

```
IDLEVEL[SERVOS] = 20.35
' Encoder configuration
ENCODERSCALE[ENCODERS] = 1.00
ENCODERWRAP[ENCODERS] = 0.00
ENCODERMODE[ENCODERS] = 0
' Aux Encoder configuration
AUXENCODERSCALE[AUXENCODERS] = 1.00
AUXENCODERWRAP[AUXENCODERS] = 0.00
AUXENCODERMODE[AUXENCODERS] = 0
End Startup
```

Appendix H: Calculation of floodlight usage for a synthetic turf pitch



<u>Technical Specification used for calculation of floodlight costs</u>

Abacus Lighting	
Floodlights	3 x Challenger 1 per mast
Masts	8 x 15 m
Lighting	Phillips 2kW
	Initial 481 Lux
	Maintained 370 Lux

Power usage for pitch per hour = 3 x 8 x 2 kW = **48 kWh**

Unit energy cost (kWh) taken from the DTI energy statistics for the 2nd quarter of 2006 and is the mean cost to all commercial consumers (including the climate change levy -0.43 p/kWh)

6.42 p/kWh *Accessed on 20/11/2007*

Using the average cost may affect the lower usage facilities therefore the figure used is the average mean cost to all commercial of a very small commercial user (<278MWh per annum)

8.16 kWh

Cost per hour of floodlight usage for the above specification

Power Use (kWh)	Cost of Energy (p/kWh)	Hourly cost (p)	**Hourly Cost (£)**
48	8.16	391.68	**3.92**

<u>Annual cost of floodlighting</u>

Cost per hour (£)	Annual Usage (h)	**Annual Cost (£)**	VAT (17.5%)	**Gross Annual Cost (£)**
3.92	1683	**6597**	1155	**7752**

The rate of VAT used is 17.5%, the satndard rate for electricity used for business purposes only.
A lower rate of VAT (5%) is used for a usage of <33 kWh per day. This rate is also available for charitable institutions, but for this calculation the high rate has been used.

This figure is for a pitch that is used for 1683 hrs for these months and only played on under floodlights.

Questionnaire Results

From the questionnaire the average use per week is 40 hrs
The period covered is 45 weeks = 1800 hours of use
The hours of floodlight use vary with the differing number of daylight hours.
To simplify the calculation a correction factor is uded to calculate an average level of lighting over the period
The correction factor is **0.49**

Cost per hour (£)	Annual Usage (h)	**Annual Cost (£)**	VAT (17.5%)	**Gross Annual Cost (£)**	**Correction Factor (£)**
3.92	1683	**6597**	1155	**7752**	**3798**