CoA/M/ASAE-4

ASAE Memo No. 4

ST. NO. R31876
U.D.C.
AUTH.

ADVANCED SCHOOL OF AUTOMOBILE ENGINEERING
CRANFIELD

COLLEGE OF AERONAUTICS
LIBRARY

A PROPOSED INTEGRAL LAND ROVER STRUCTURE

by

G. H. Tidbury

R31876

ASAE Memo. No. 4

CoA Memo No. 95

March, 1966

Advanced School of Automobile Engineering

A Proposed Integral Land Rover Structure

- by -

G.H. Tidbury, B.Sc., D.I.C., A.M.I.Mech.E., A.F.R.Ae.S.

COLLEGE OF AERONAUTICS LIBRARY

SUMMARY

This note summarises the methods available for the analysis of vehicle structures and points out the advantages of each method. Reasons are given for the choice of the matrix force method in the analysis of a proposed integral Land Rover structure. Some results of the analysis are given and the design of the structure described.

2. Introduction

Integral vehicle structures have been developed largely on a trial and error basis and although some attempts at load analysis were made as early as 1939, it has not been the practice of designers to carry out such calculations up to the present. Several design organisations in the vehicle industry are now investigating the possibility of performing structural calculations, either for stiffness or strength purposes, in order to save the time normally spent on trial and error modifications after a prototype vehicle has been built.

Cooke, Ref. 1 has proposed a very simple idealisation of a car body that will give an indication of torsional stiffness. Similar methods have been in use for some time in Europe as mentioned in Ref. 2 where further references have been given. There is little doubt that, used comparatively, these simple calculations can assist in the early design of a car body. A more elaborate extension of these techniques still assuming hand calculation, has been suggested by Pawlowski, Ref. 3 and his idealisation is probably as detailed as it is advisable to go without the use of computers, indeed it would probably be economical to mechanise his solution to avoid computational errors. The methods so far mentioned evade the problem of solving the redundant structure by allocating loads in proportion to the stiffness of each member. This type of simplification is not necessary when digital computers are used.

Any method of solution of redundant structures may be mechanised for a computer and these broadly fall into two groups; (a) force methods (b) displacement methods. Force methods reduce the number of equations to be solved to the number of redundants in the structure and are generally thought to be suitable for small computers. Displacement methods can be highly mechanised and are currently performed on very large computers. Ref. 2 compares the methods in detail and sets out the reasons for using the force method for the Land Rover structure. It is interesting to note that Japanese workers Ref. 4 and 5 have also proposed the use of these methods for vehicle structures. The structural idealisation of a combination of shear panels, end load carrying bars and shallow beams with negligible shear stiffness developed for this report is identical to that used in Ref. 4. Both Kirioka, Ref. 4, and Crawford, Ref. 6 have shown good agreement between analyses using this idealisation and tests on actual vehicle structures.

The Land Rover structure has been analysed in considerably greater detail than either of the above and has brought out limitations in the method as well as suggesting future improvements to it.

3. The Integral Land Rover Structure

The structure proposed is shown in outline in Fig. 1 with constructional details in Fig. 2. A vestigial chassis is retained by using two parallel longitudinals to carry the spring hangers, engine supports, etc. Fairly substantial cross members are used to distribute the load from these longitudinals to the side frames of the vehicle. These side frames clearly constitute a very deep beam which would easily carry the bending load if the shear force could be transmitted across the large side door opening. In normal pressed steel car design the sill members are generally thought to carry most of the bending but it is known that some is carried by the roof cantrail. On the structure the sills are not designed to carry a large proportion of the main moment. The wheel arches are included in the load carrying structure as the effect of these was ignored in Refs. 4 and 6. It will be noted that a vertical windscreen is used in the design, this is the worst case for transmitting loads into the roof and a practical design with sloping screen pillar would almost certainly be more efficient. The shock absorber attachment points and bump stops are assumed to be at the same point on the structure. The load transmitted is generally higher at this point that at the spring hangers because the spring is compressed to the full bump position well before the assumed 3g load has been achieved.

The main design problem in any integral vehicle is that of transferring the suspension loads from the narrow chassis to the side frame. At the front a large panelled box is included at each end of the scuttle to perform this function, but in practice the rear panel of this box would be cut away to provide a footwell for the passenger and access to the pedal controls for the driver. It is assumed that there would be no difficulty in providing sufficient shear stiffness in the footwell surround to match the panel stiffness assumed.

At this stage of design it is assumed that all members are supported against buckling, but it is obvious from the calculated loads that this will not be true. Extra members will be designed before testing and rivetted on during the test programme as buckling occurs. In this way no unnecessary weight will be added to the structure and some confirmation of the predicted buckling will be obtained. The floor structure assumes that both the longitudinals and the cross members are continuous in bending but not in torsion and the joints between the two have been designed to achieve this. Sample joints have been manufactured and tested to ensure that they fulfilled their theoretical load carrying ability.

The results of the bending calculation indicates that a sufficiently strong structure will be obtainable with little increase in weight over the present non-load carrying body thus saving the weight of the present chassis frame, approximately 370 lb, or 58% of the original structure weight or 6.5% of the vehicle gross weight. The calculations indicate very large deflections and this is to some extent confirmed by joint tests that have been completed. The full scale model will be built first as calculated and subsequently modified both theoretically and practically until sufficient strength and stiffness have been obtained to finally design a bodywork for an actual vehicle. This may seem a departure from the expressed aim of design by calculation but it is also necessary to determine the suitability of the idealisation especially with regard to stiffness and to avoid over-design at this stage.

4. Stress Analysis

The matrix force method requires the following steps in the analysis:-

1. Determination of the order of redundancy or indeterminacy of the structure.

2. Separation of a 'basic system' that will support the external loads from the actual structure.

3. Selection of a number of self-equilibrating redundant systems, one system being required for each indeterminacy.

4. Preparation of the b_o and b_1 matrices corresponding to the internal loads caused by unit external loads in the case of the b_o system and unit redundancy loads for the b_1 system.

5. Preparation of the unassembled flexibility matrix for the complete structure.

6. Determination of the loading cases and preparation of the R matrix of external loads on the structure.

7. Preparation of the programme for carrying out the matrix manipulations in the computer to calculate the load in each member and the relative deflections of the load points.

Of the above steps No. 1 was given incorrectly in Ref. 2 and should have read 48 redundancies. This number must be assessed separately for each structure analysed. Although methods have been developed in the United States for automatic determination of the number of indeterminancies Ref. 7 and 8 they demand the use of large computers. While this step has to be performed by the analyst it will remain a source of error but with sufficient check loads in the programme the errors can be traced. It is certainly time consuming and in spite of the simple rules given in Ref. 2 skill is required. An argument in favour of this procedure is that it helps the anlyst in the understanding of how the structure behaves.

COLLEGE OF AERONAUTICS LIBRARY

Step 2 is usually a simple one and part of the value of the present analysis is to show that the choice of a basic system which will not, in the event, carry the majority of the load is justified. If it is always possible to choose a vestigial chassis as the 'basic system' for a vehicle the analysis of other vehicle structures will be simplified.

Step No. 3 depends entirely on the skill of the analyst and together with Step No. 4 is the longest part of the analysis. 48 separate structural systems have to be analysed and the load in each element due to an internal load allocated the correct place in the 284 row matrix. It would be possible to largely mechanise this procedure on the computer but a separate programme would be required for each structure to be analysed. In the analysis performed so far these steps were carried out by hand and the time taken for doing them once is probably less than the time that would have been required to write the necessary programmes. However, the whole process required three separate checks and subsequent corrections and it would probably have been quicker to concentrate on using the computer at an early stage. Two theses (ref. 9 and 10) have been completed at the A.S.A.E. where these steps have been performed by Autocode programmes operating on the minimum of input data. The structures concerned were both very simple, one being a space frame and the other a ladder frame, but the methods will, it is hoped, be extended to more complicated structures as used for the Land Rover.

Step No. 5 comprises 364 small arithmetical computations that were done on a desk calculator. These could have been programmed for the computer quite simply and again this procedure would be adopted in future work. Due to modifications to the flexibility of components as a practical design was evolved these calculations have been carried out several times as checks were required in each case.

The loading conditions were determined to conform with the worst expected load distributions on the vehicle. The six load cases are shown in Figs. 3a and b. In each case the estimated structure weight was added and the nett down load at each load point calculated. Although the 3g factored load corresponds to a dynamic load it is assumed that it is applied statically and that the distribution of the support load is fixed in each case.

Step 7 is the only true computer operation and even with the double partitioning required it is straight forward. Most of the matrix manipulations are of a standard form and very little programme development was required. In order to be able to use the computer in reasonably short sessions the total 5 hour programme was split into two parts, reading the intermediate information out in binary form which takes up little time. An attempt was made to make up the partitioned b_i matrices in the computer by reading in small data matrices and adding them to a large zero matrix held in the store. The human error involved in doing this correctly meant that the complete b_1 matrices had to be read out from the computer and checked against the originals. Unfortunately, owing to the non-recurrent form of the structure these corrected matrices will only be of use for this particular vehicle.

5. Results of the Analysis

Only sample results are given in this report, of these the bending moments in the main floor members are the most important and are given in Fig. 4. The checking device used was to calculate both bending moments in the beams and end loads in members normal to the beams so that the equilibrium condition of some joints could be found from different sources, an example of this is shown in Fig. 5. An additional advantage of this method was that the bending moments were obtained as computer read outs instead of requiring further calculation from the end load values.

The attempts to design the structure so that the main bending load would be carried by the vehicle side panels was not entirely successful and the floor beams were therefore designed to be fairly substantial. One of these beams and a cross bearer are shown in Figs. 6a and 6b. As has been stated the local bending stiffness across the joint will be made sufficient to carry the expected bending load although the predicted displacement is likely to be high. Certain structural properties have not been included in the idealisation, probably the most important is the torsional stiffness of the cross bearers which become closed sections when the floor is attached. Also the idealisation of a panel and a beam when adjacent is as shown in Fig. 7, i.e. the effects on the bending stiffness of the beam of the very deep web attached is ignored. It has been shown by Marsden, Ref. 1 that for a simple structure this idealisation will give approximately correct stresses but the displacements will be greater than the actual structure. Marsden suggested an improved idealisation which made some allowance for the stiffening effect of the panel on the beam and obtained the same theoretical stress distribution but the calculated displacements were less than those for the actual structure. It may well be that for a more complicated structure it is more important to include the stiffening effect of the panel on the beam and this could be established when the model has been tested.

The most remarkable result of the analysis is the fact that the bending moment in the floor beam is not shared by the inner wall of the rear wheel arch. It appears that the sudden change in stiffness at the ends of the arch makes the two beams work against each other instead of sharing the load (see Fig. 8). This result, although satisfying equilibrium and compatibility conditions for the structure as idealised, is a little surprising and the results of the analysis in this area will be carefully checked on the model.

6. Conclusions

The method of analysis used would be justifiable for an organisation designing occasional special vehicles if a technical staff of at least two people could be employed full time for about 3 months on each project and having the occasional use of a small computer. It is inevitable that the need for greater speed in analysis will lead to greater use of the computer and the need for larger computers. The logic of this has been shown by Argyris, Ref. 12 where very large and complicated aircraft structures can be analysed and optimised in a matter of days using the largest available computer in Europe. In order to achieve this scale of automation a new computer language has been written. Argyris, although pioneering the force method as used here for economy of computer space, has used displacement methods for his later work. Allwood and Norville, Ref. 13 have used a basically similar displacement method to analyse a sheet metal car underbody with considerable success. Again time saving was possible as many sub-routines were already available from aircraft work in the particular computer organisation. These displacement methods using triangular or rectangular elements seem well suited to pressed sheet metal structures but the force method with its basic advantage of less equations to solve still has an appeal for fabricated structures where the idealisation is fairly simple and the understanding of the load paths in the structure is likely to be greater as the analysis is less automatic. Work will be continued to improve the parts of the analysis that are at present time consuming and liable to error while retaining the ability to use a small computer and the structural 'feel' that goes with the force method.

References

1. Cooke, C.J. — 'Torsional Stiffness Analysis of Car Bodies'. Inst. of Mech. Eng. Automobile Division Paper, 1965.

2. Tidbury, G.H. — 'Stress Analysis of Vehicle Structures', A.S.A.E. Memo No. 3, July 1964.

3. Pawlowski, J. — 'Nadwozia Samochodowe'. Wydawnictwa Komunikacje i Laczonosci 1964 (in Polish).

4. Kirioka, K. — 'An Analysis of Body Structures' S.A.E. Report No. 979A, 1965.

5. Kawai, H., and Koganei, Y. — 'Experimental Analysis of Automobile Bodies'. Mitsubishi Technical Review.
Part 1, Vol. 2, No. 1, 1965.
Part 2, Vol. 2, No. 3, 1965.

6. Crawford, R.G. 'Analysis of an Integral Van Body in Bending' A.S.A.E. Thesis, 1965.

7. Denke, P.H. 'A General Digital Computer Analysis of Statically Indeterminate Structures'. N.A.S.A. TN. D-1666, 1962.

8. Robinson, J., and Regl, R.R. 'An Automated Matrix Analysis for General Plane Frames' ('The Rank Technique'). Journal of the American Helicopter Society October, 1963.

9. Sharp, R.S. 'The Analysis and Design of Space Frames'. A.S.A.E. Thesis, 1965.

10. Marshall, P.H. 'The Torsional Stiffness of Ladder Frames' A.S.A.E. Thesis, 1965.

11. Marsden, F.D. 'Analysis of a Structure with a large cut-out by the Matrix Force Method'. A.S.A.E. Thesis, 1964.

12. Argyris, J.H. 'The Computer Shapes the Theory' Lecture to the Royal Aeronautical Society 18th May, 1965. To be published in the R.Ae.S. Journal.

13. Allwood, R.J., and Norville, C.C. 'The Analysis by Computer of a Motor Car Underbody Structure'. Inst. of Mech. Eng. Automobile Division Paper. March, 1966.

COLLEGE OF AERONAUTICS
LIBRARY

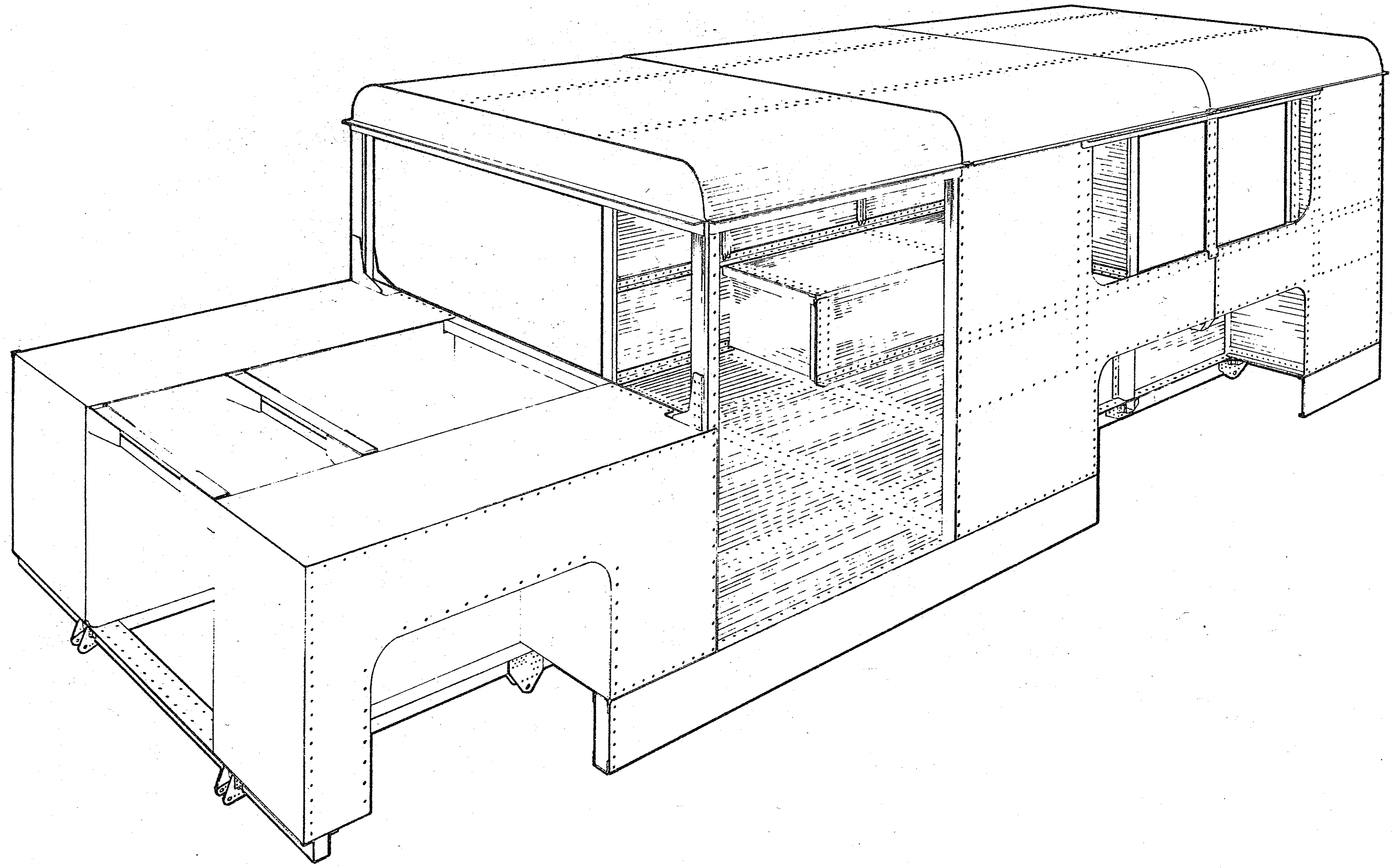
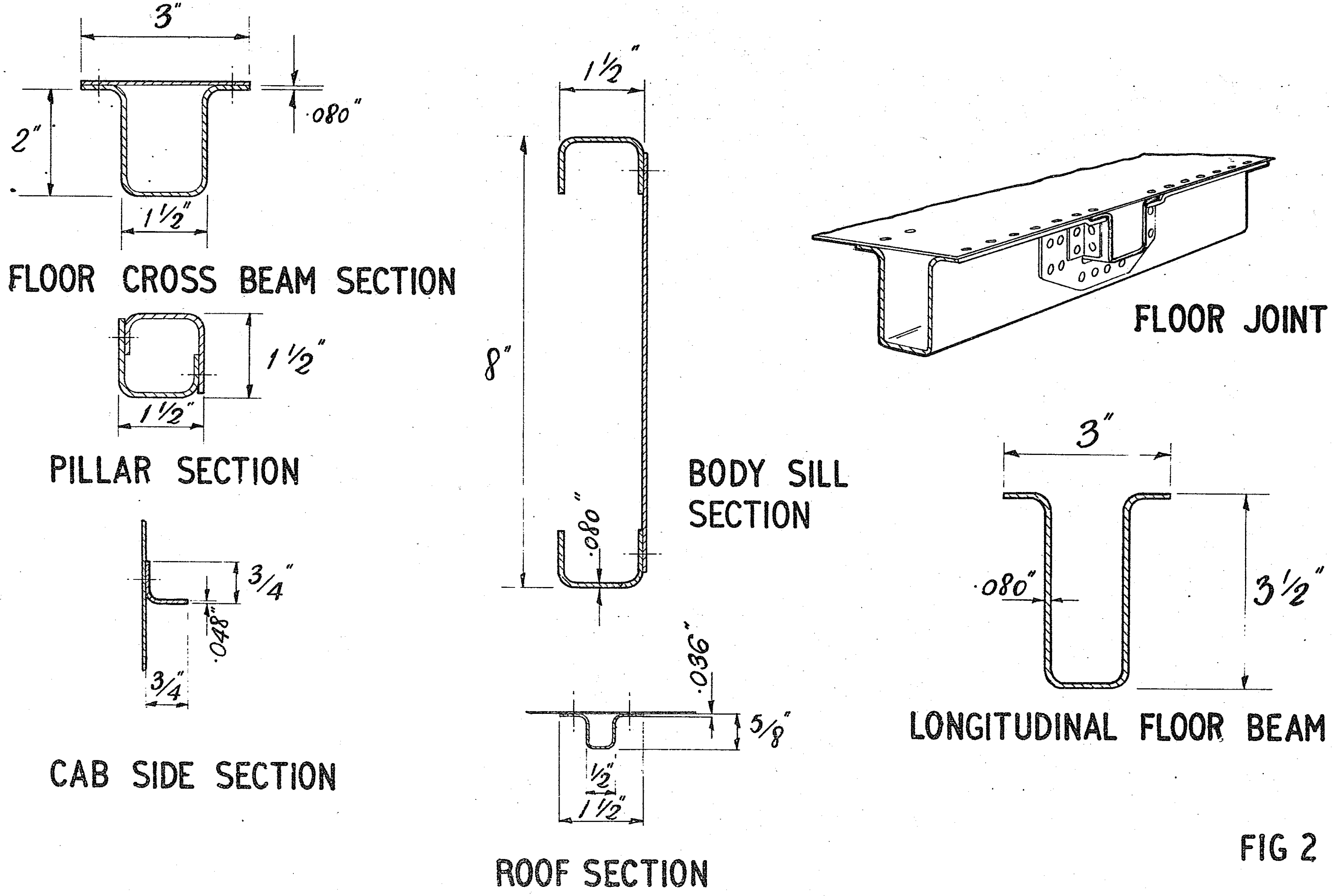


FIG. 1



FLOOR CROSS BEAM SECTION

PILLAR SECTION

CAB SIDE SECTION

BODY SILL SECTION

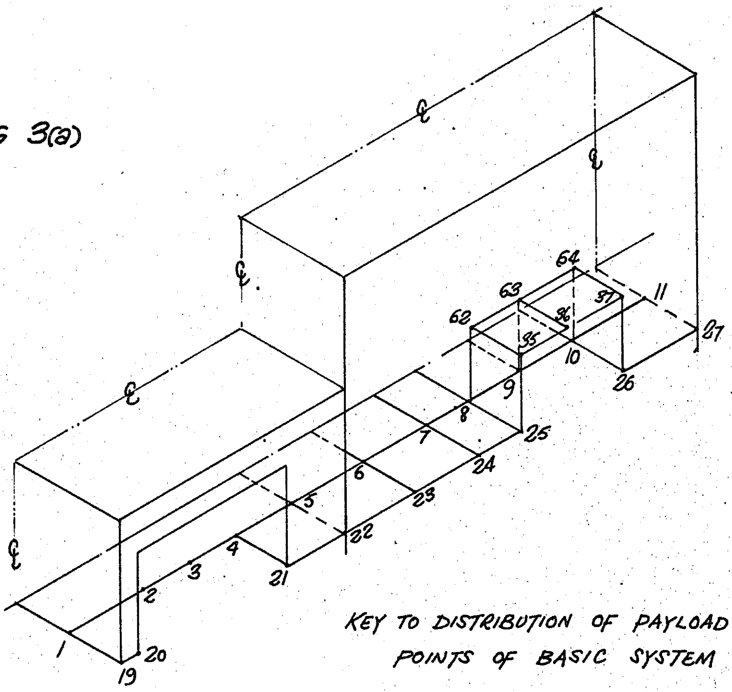
ROOF SECTION

FLOOR JOINT

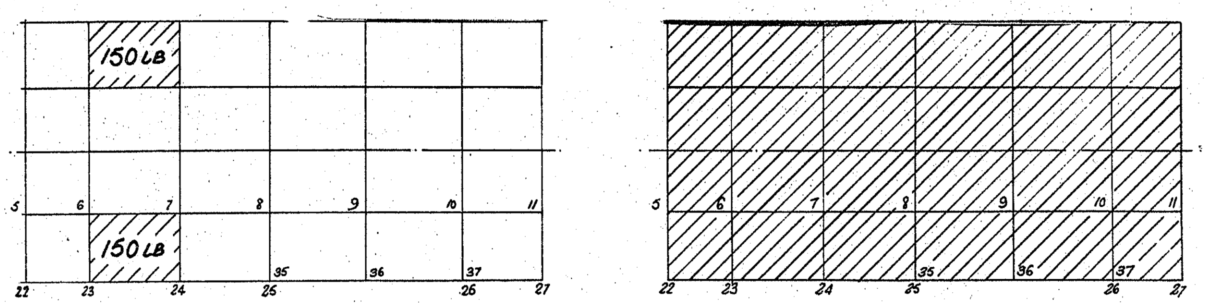
LONGITUDINAL FLOOR BEAM

FIG 2

FIG 3(a)

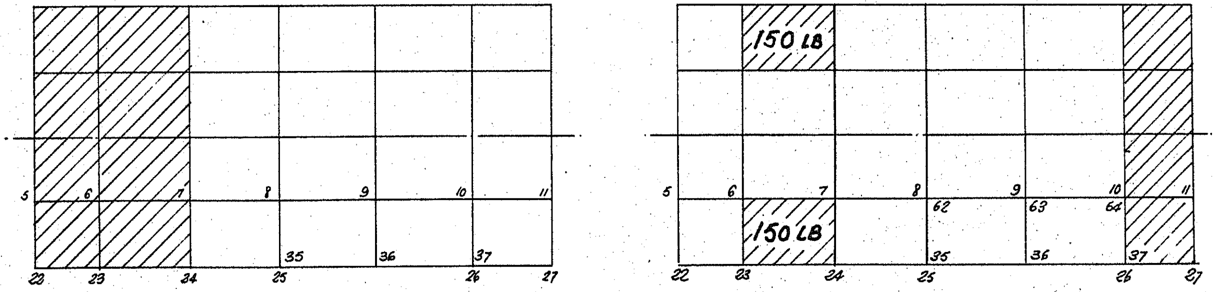


KEY TO DISTRIBUTION OF PAYLOAD ON POINTS OF BASIC SYSTEM



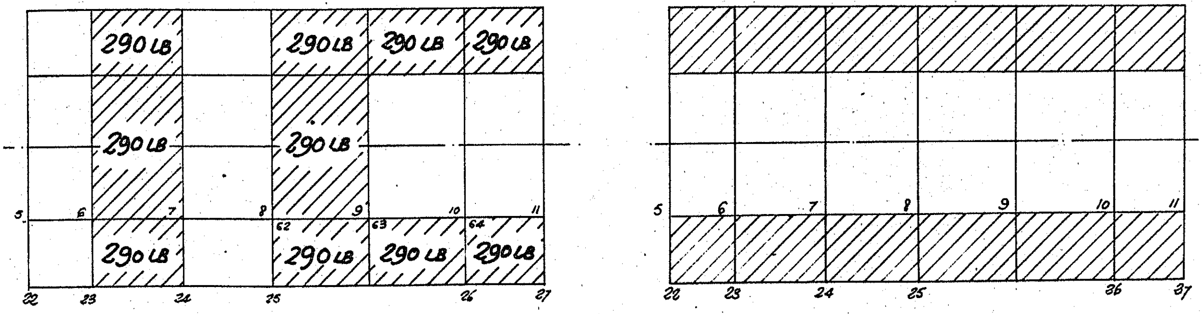
CASE 1 Driver & Passenger

CASE 4 Uniformly distributed load aft 5-22



CASE 2 Load distributed between 5-22 & 7-24

CASE 5 Driver, Passenger + 2489 lb aft 64-37



CASE 3 10 People & 1289 lbs of luggage.

CASE 6 Full payload outside main longitudinal member.

FIG 3(b) DISTRIBUTION OF PAYLOAD ON POINTS OF BASIC SYSTEM

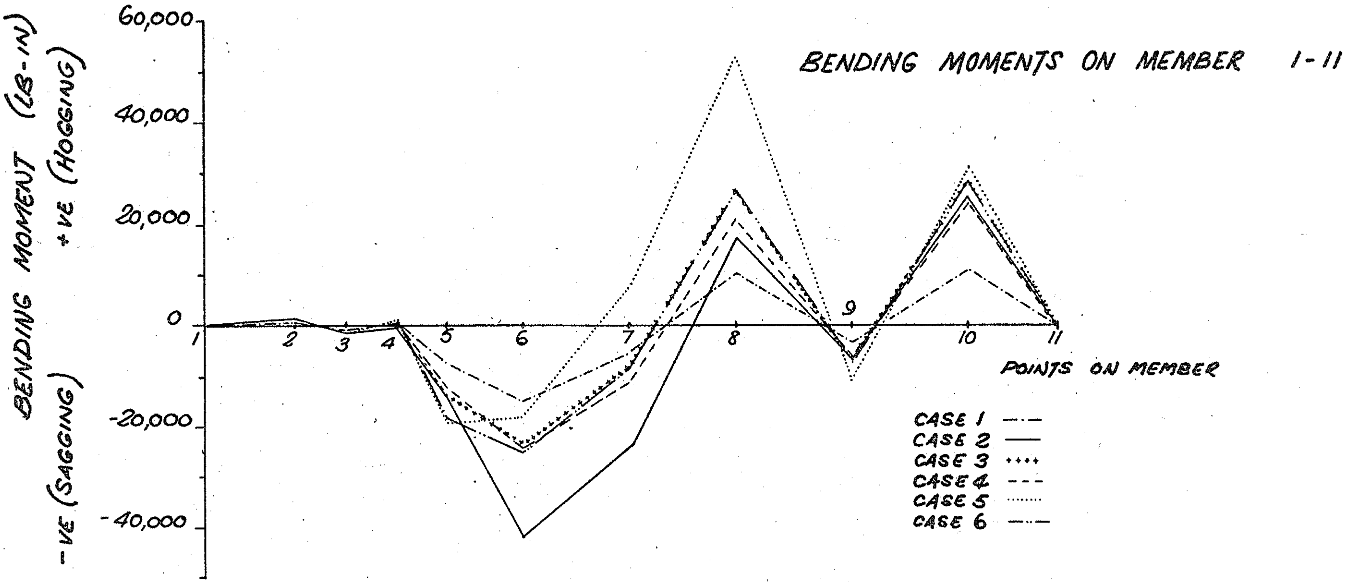


FIG 4

EQUILIBRIUM & CROSS CHECKS FROM COMPUTOR RESULTS FOR WINDSCREEN DOOR PILLAR.

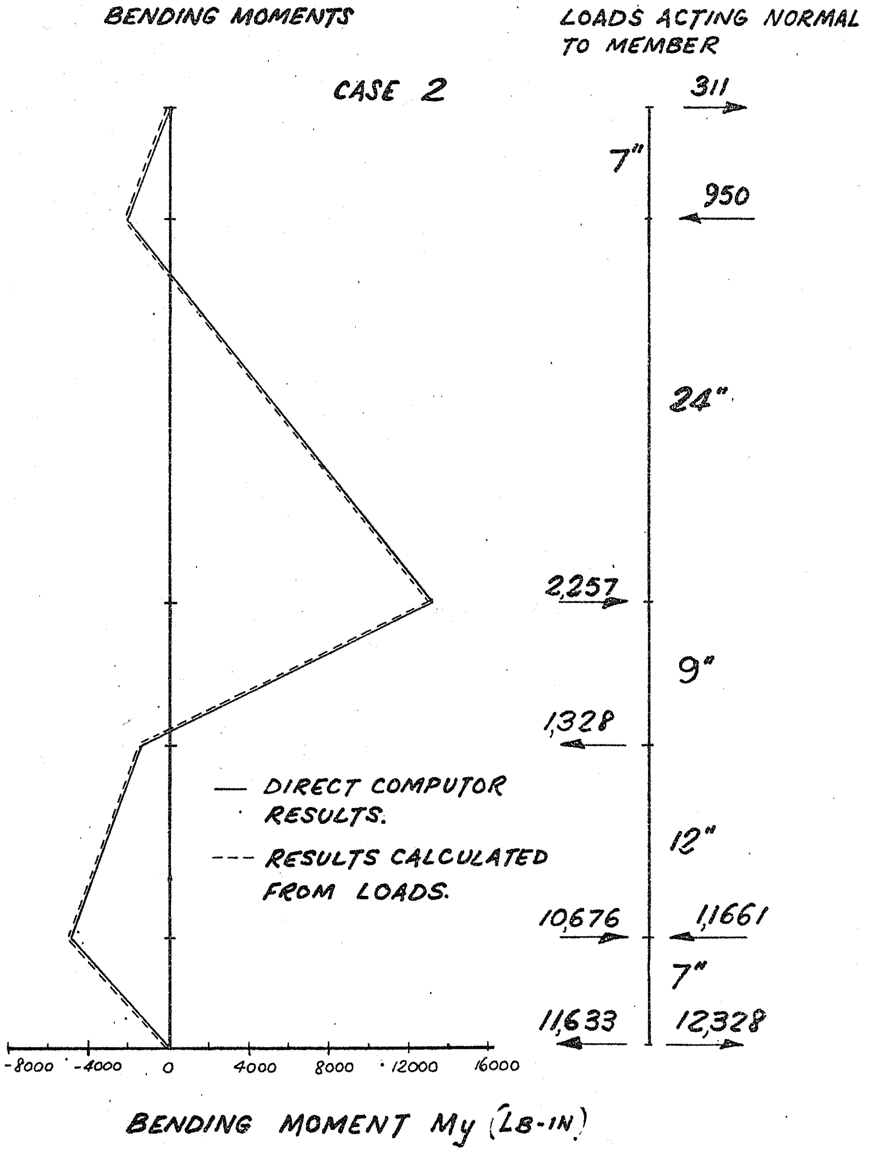


FIG. 5.

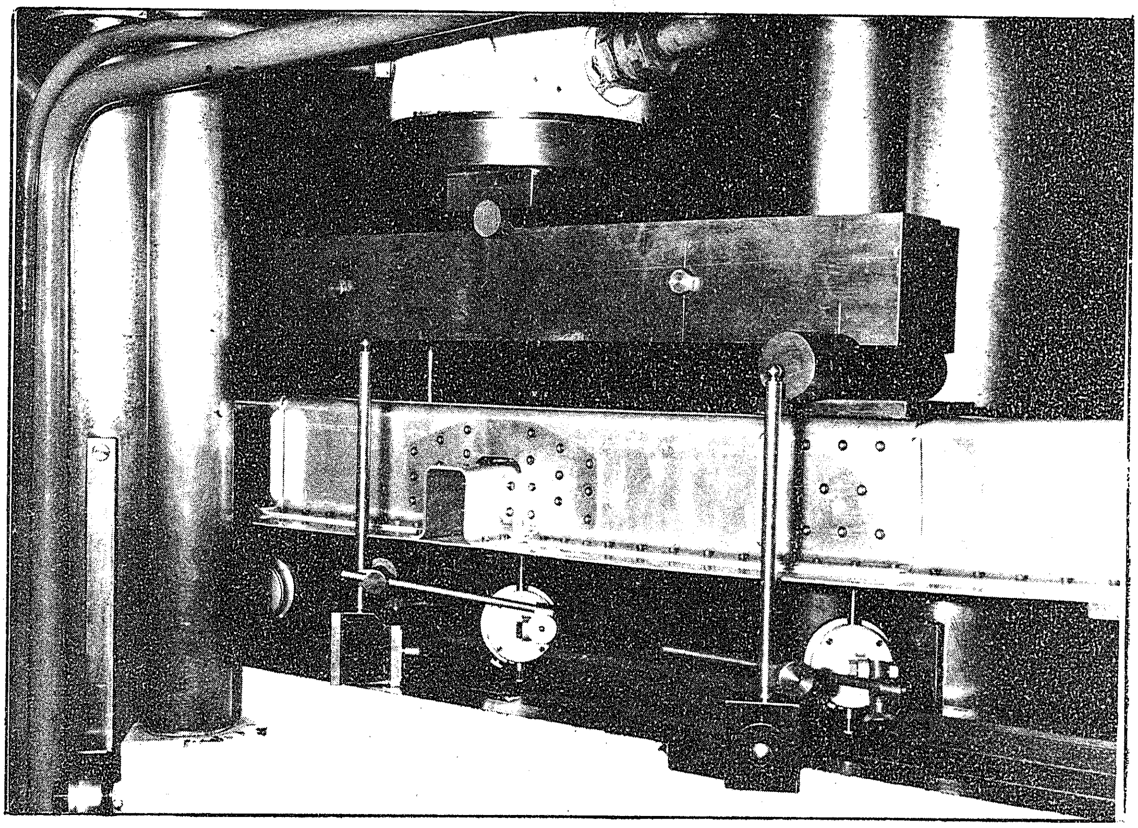


FIG. 6(A) FLOOR BEAM JOINT BENDING TEST

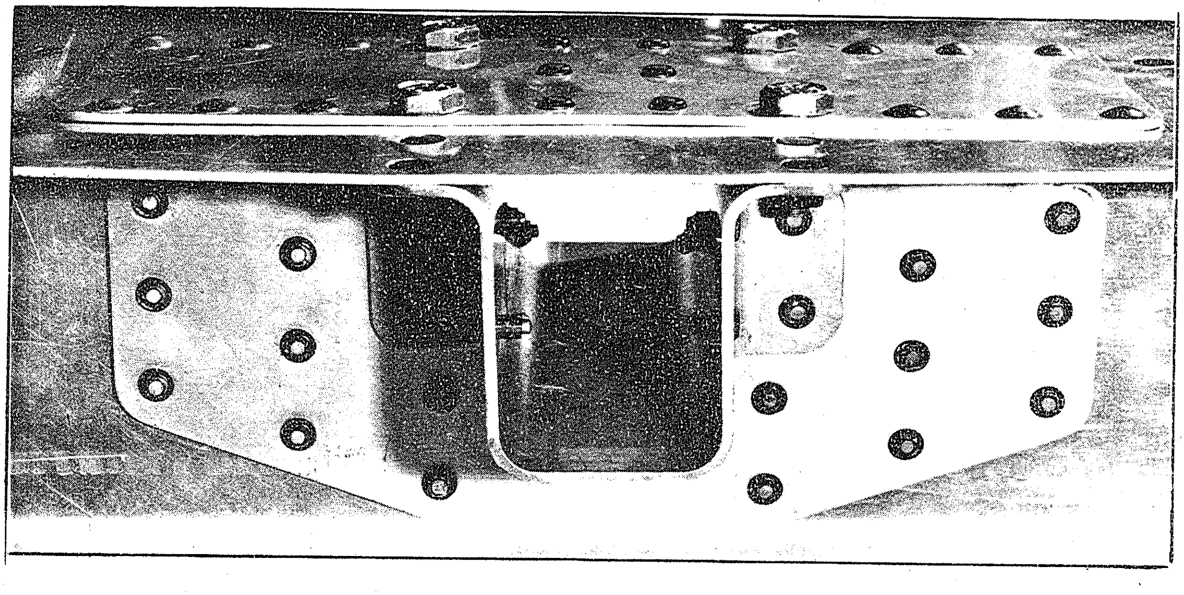
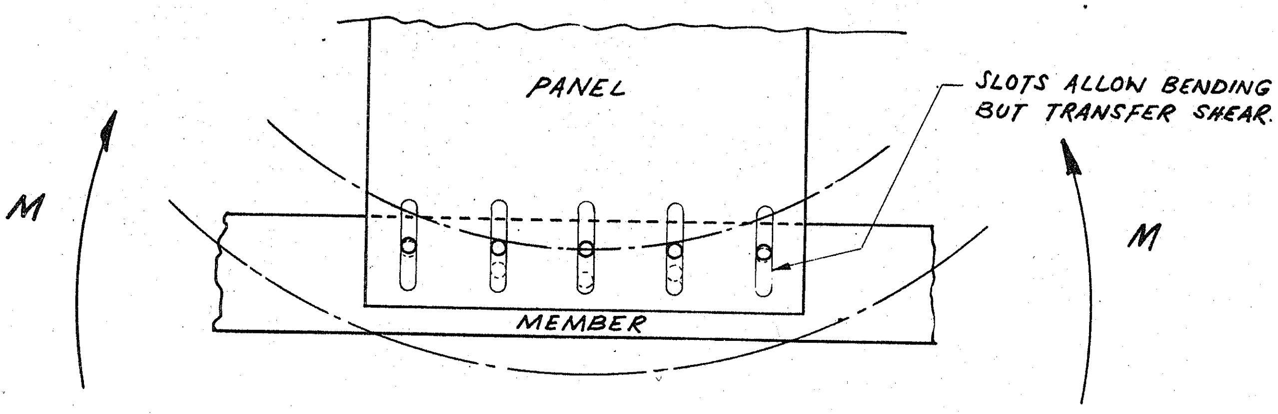


FIG. 6(B) FLOOR BEAM AND CROSS BEARER JOINT

BENDING OF MEMBERS ATTACHED TO SHEAR PANELS



THEORETICAL ASSUMPTIONS:-

1. MEMBER BENDS WITHOUT DEFORMING PANEL.
2. END LOAD IN MEMBER CAN BE TRANSFERRED TO SHEAR IN PANEL.

FIG. 7.

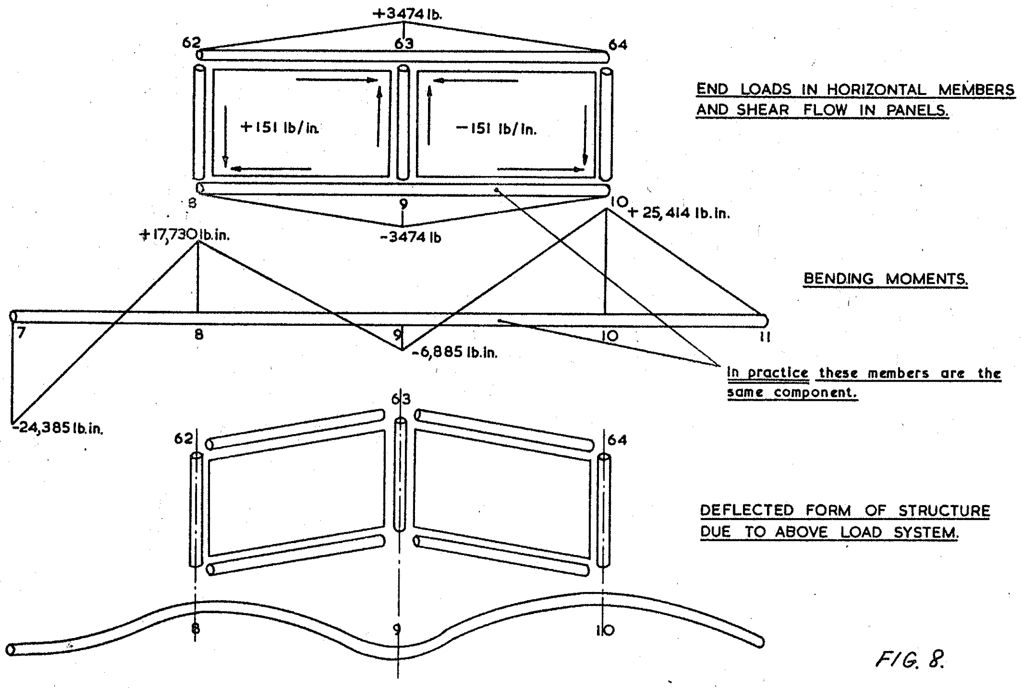


FIG. 8.