Utilising Digital Image Correlation for the Characterisation of Ground Shock from Buried Charges

Ross Waddoups

Sam Clarke, Richard Curry, Andy Tyas,

Tommy Lodge, Joshua Mullins, Joseph Cordell

University of Sheffield

Blastech

[dstl] The Science Inside

Context – Unexploded Ordnance

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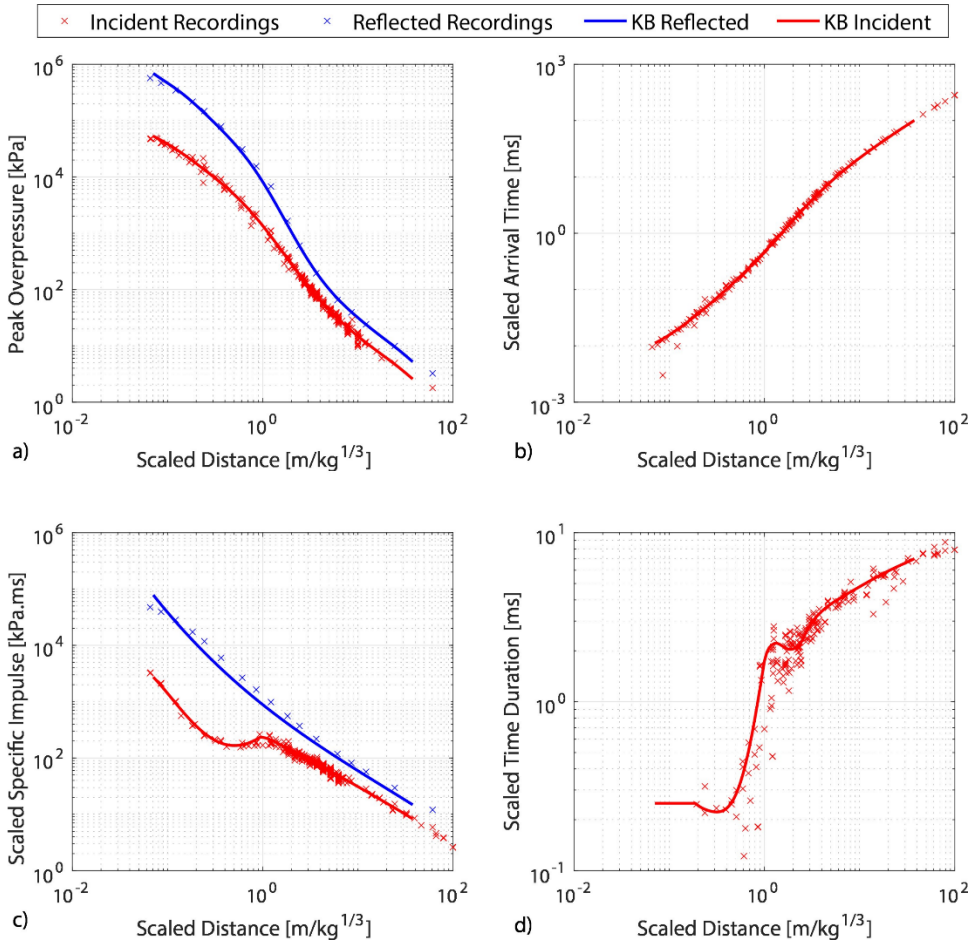
Norfolk Police, from https://www.bbc.co.uk/news/uk-england-norfolk-64604115

Predictive Methodologies

- Kingery & Bulmash (1984) – Free Air
- Lampson (1946) – Ground shock from large scale (3.6kg to 1800kg) testing
- Drake & Little (1983) / ConWep (TM5-855-1, 1986) - Ground shock predictions currently in use
  - Modifications proposed by Drake et al. (1989), Laine & Larsen (2007) and others



Reproduced from Farrimond et al. (2023)

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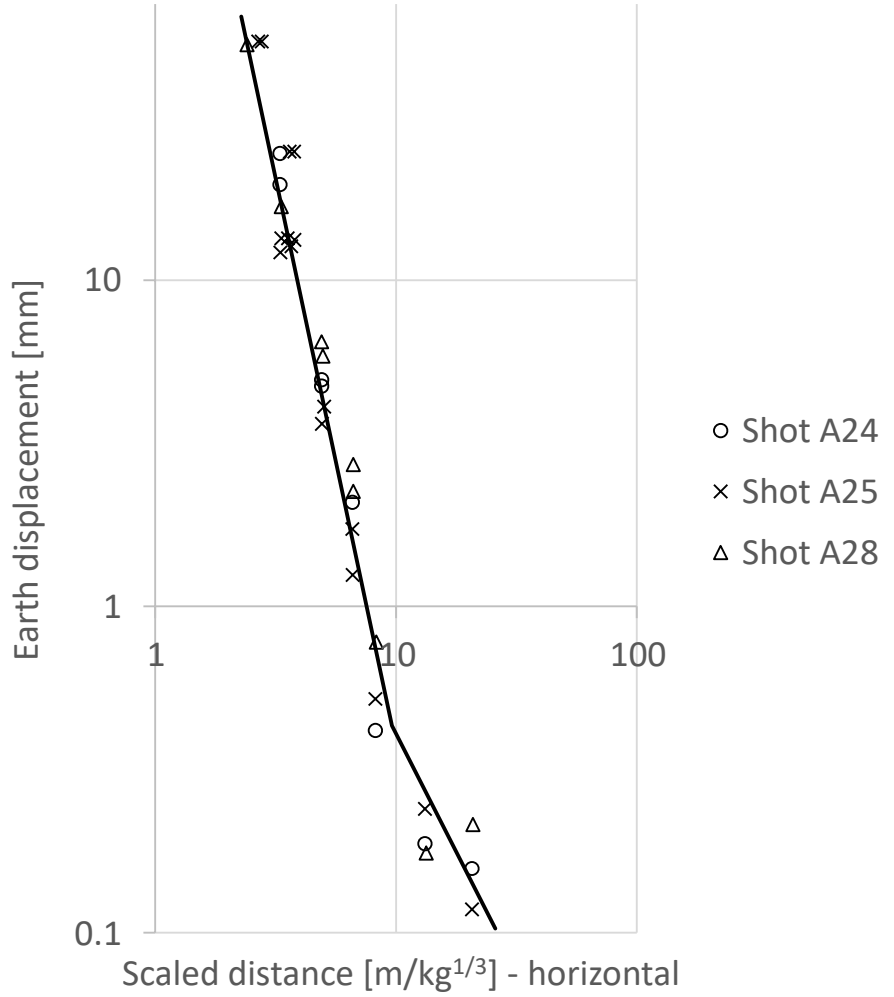

Adapted from Lampson (1946)

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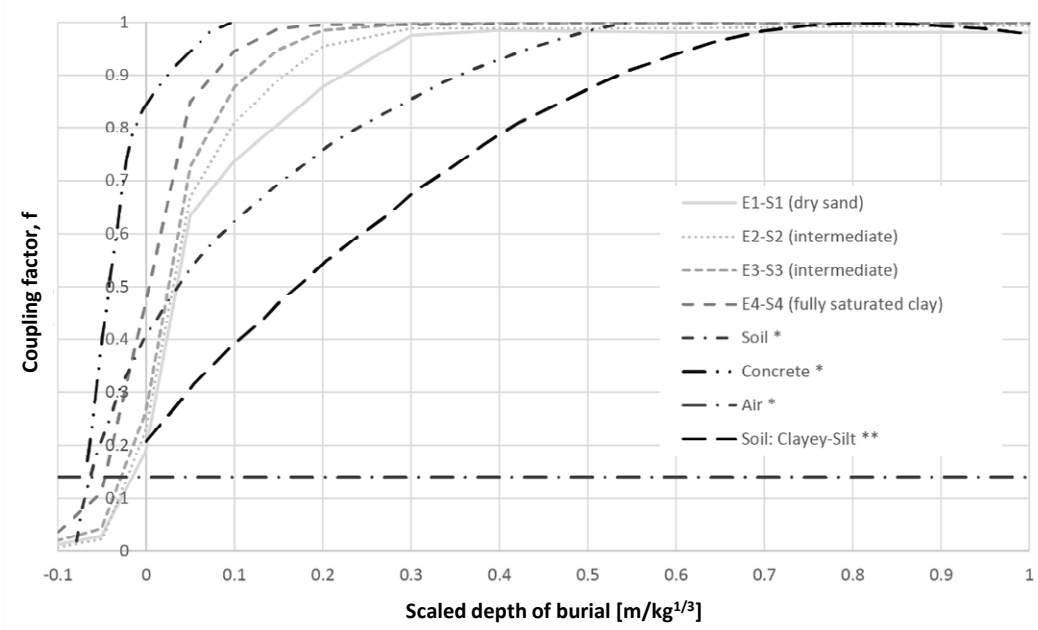
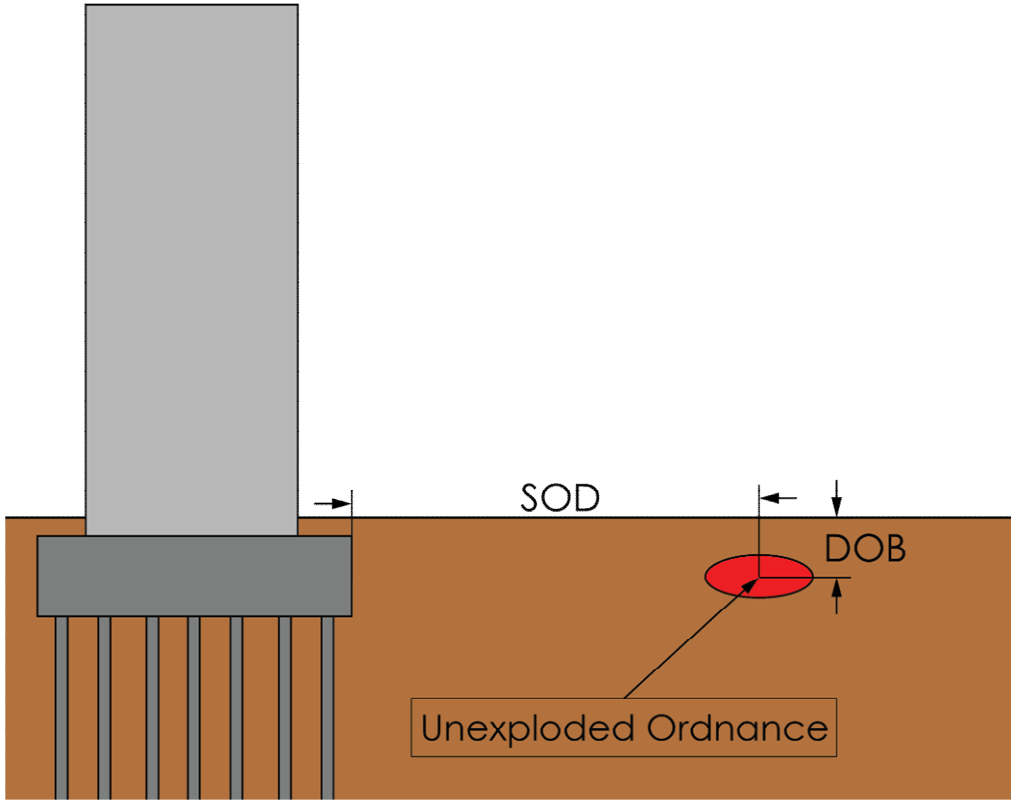


After **Lampson (1946), *Drake et al. (1989), Laine & Larsen (2007)

Test Setup



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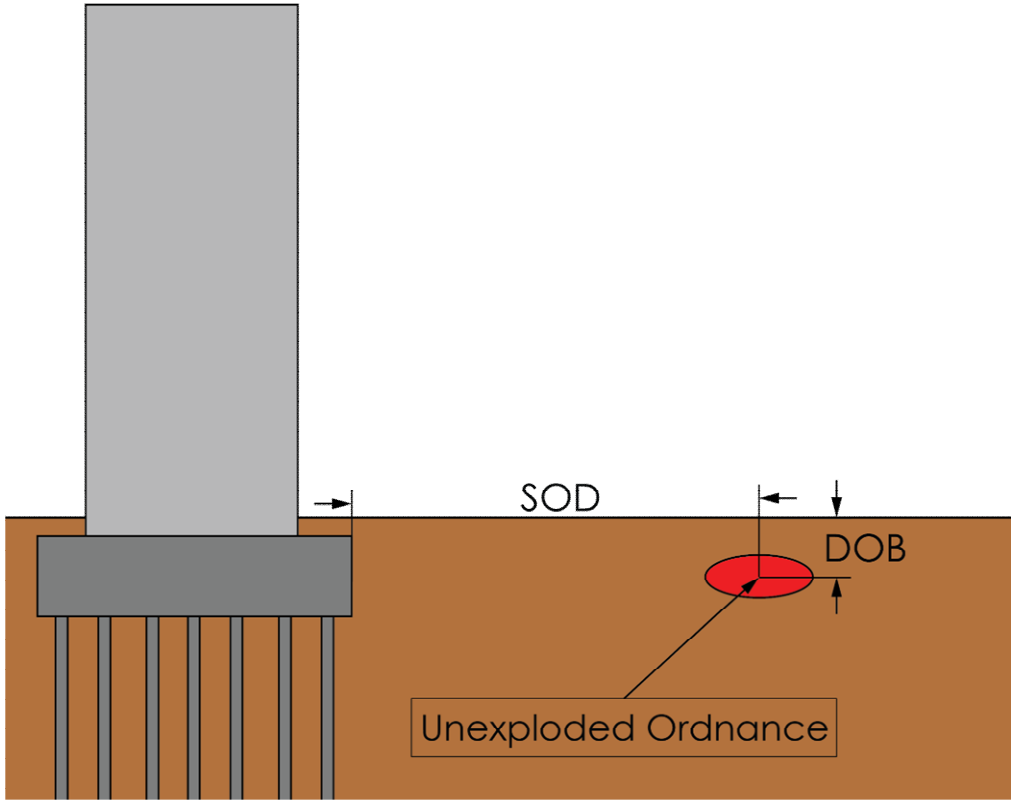
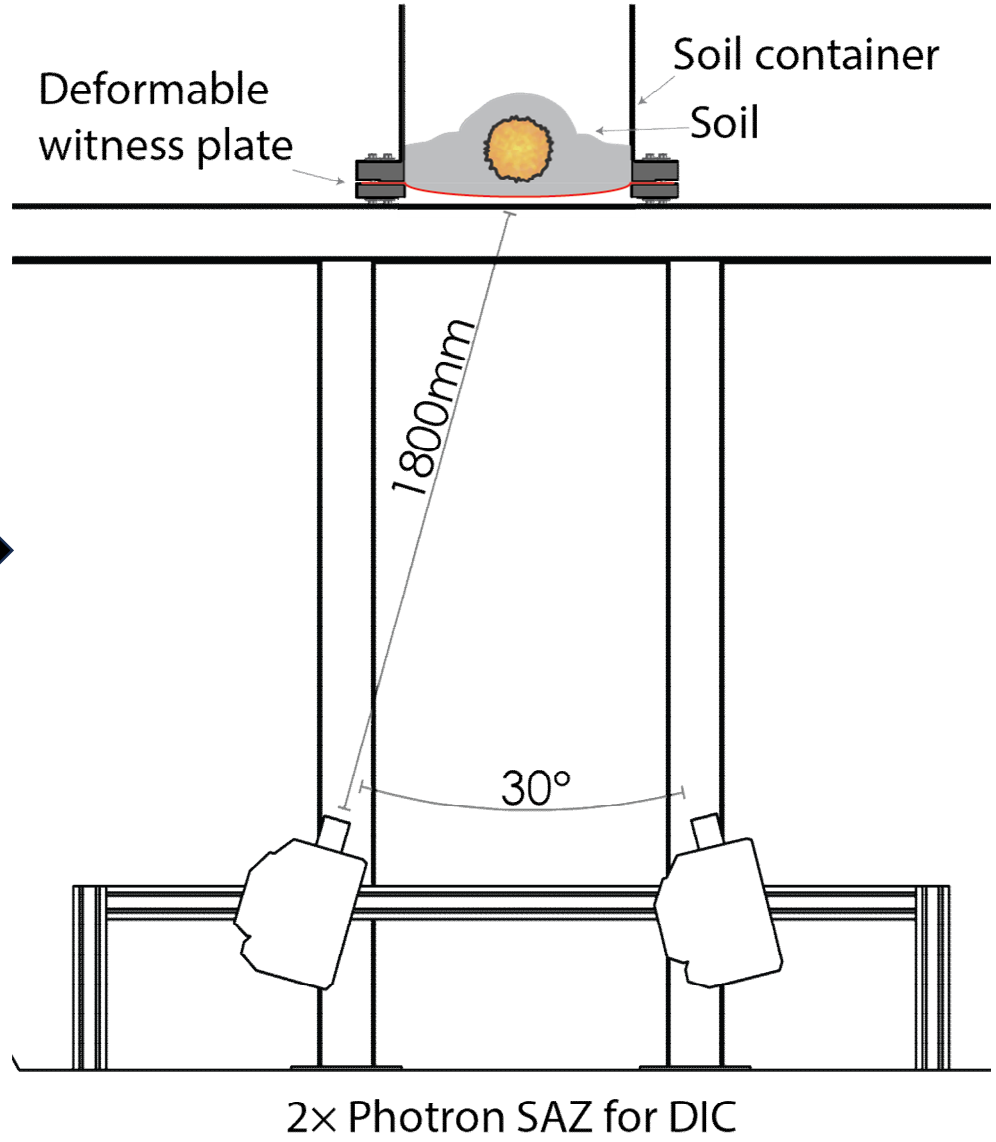
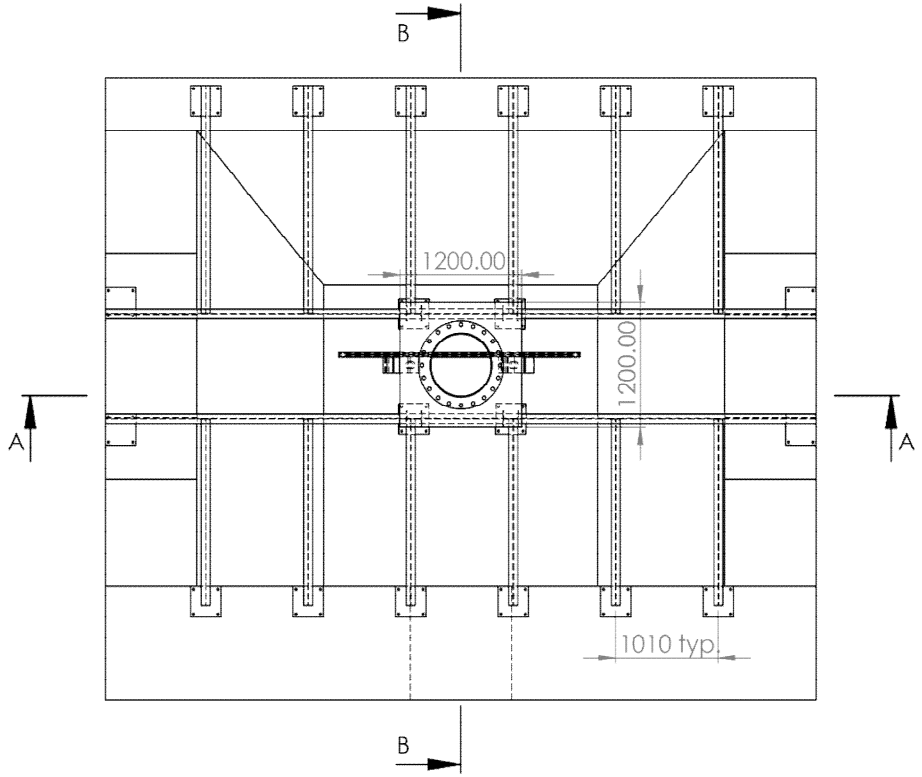
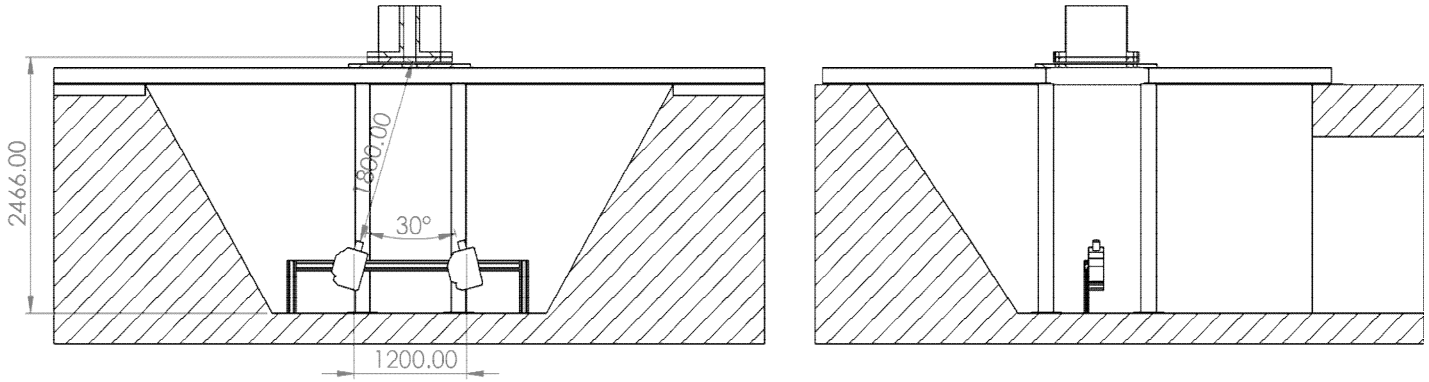




2× Photron SAZ for DIC

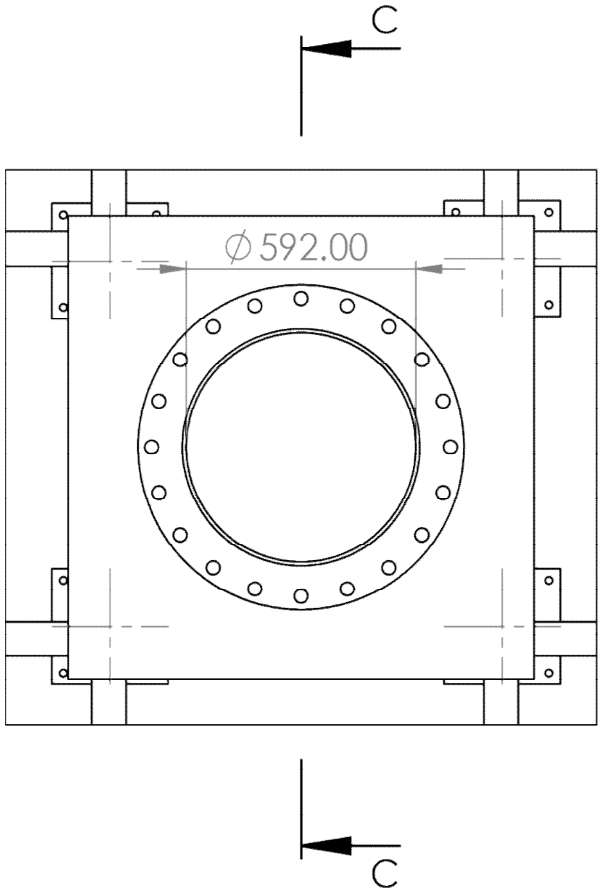
Test Setup

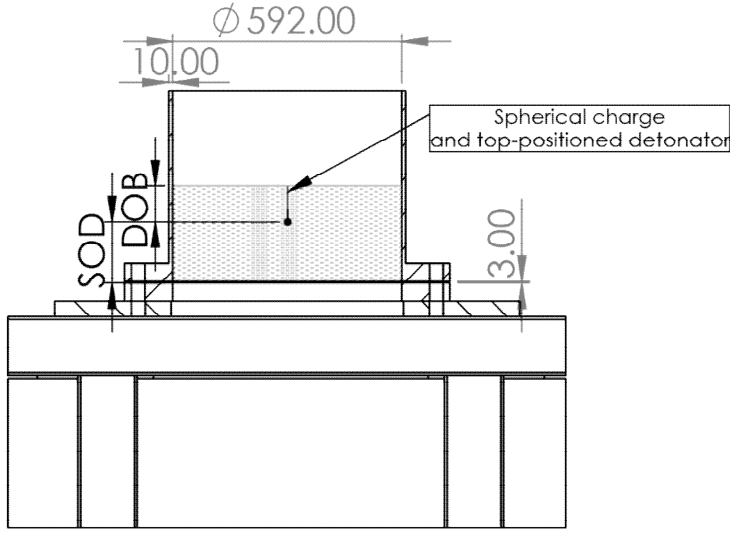




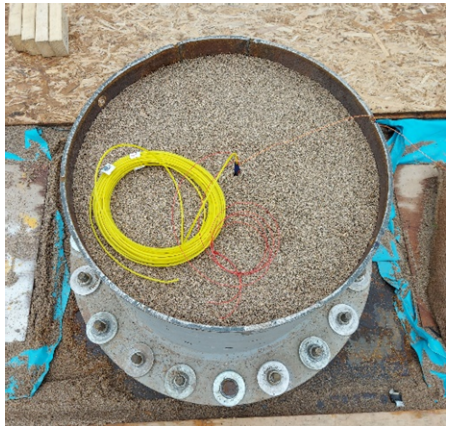
Test Setup

- 9 shots
- 2 charge masses
- Varied Stand-Off Distance (SOD)
- Constant scaled Depth of Burial (DOB) – $Z=0.434 m/kg^{1/3}$





SECTION C-C



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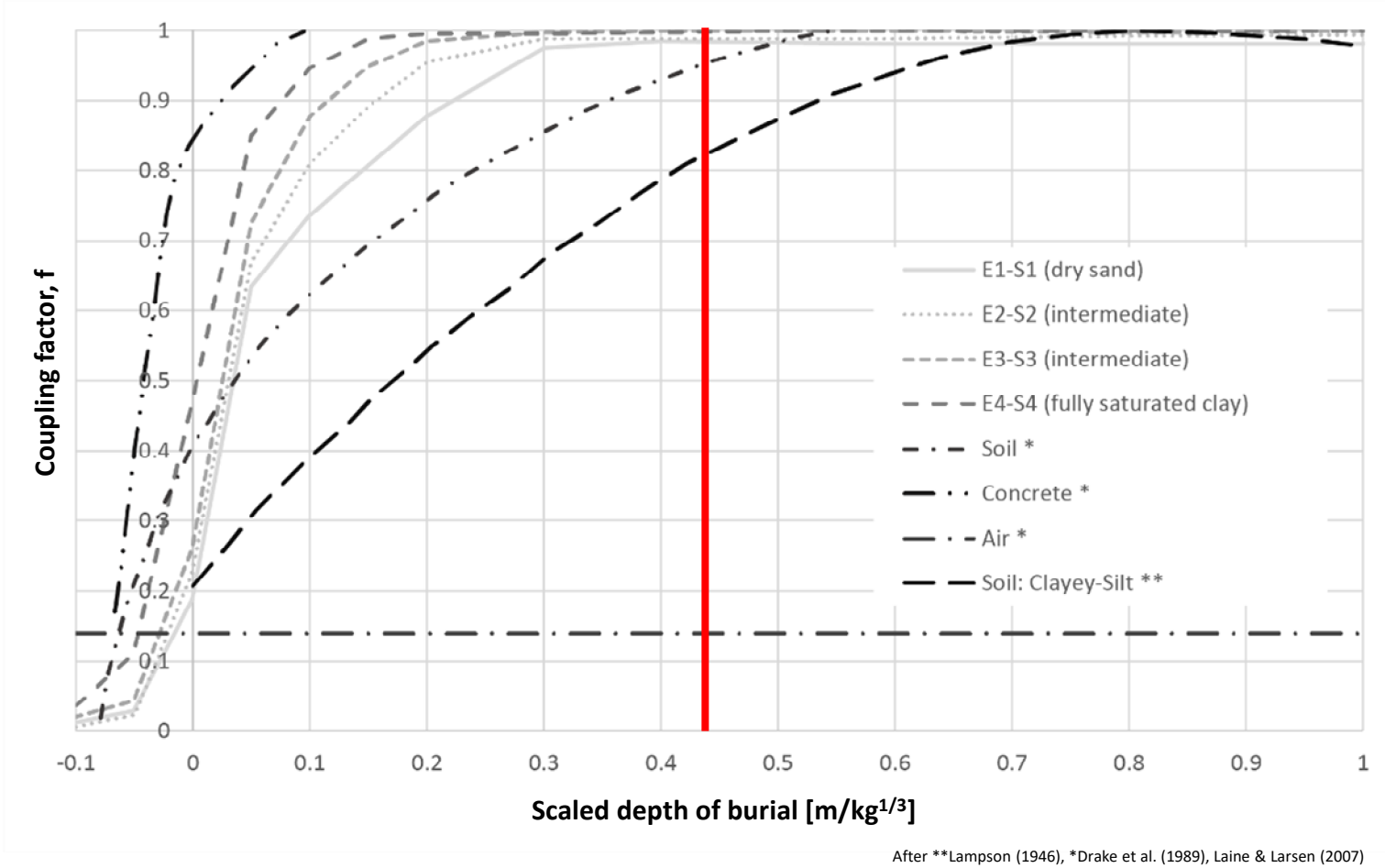
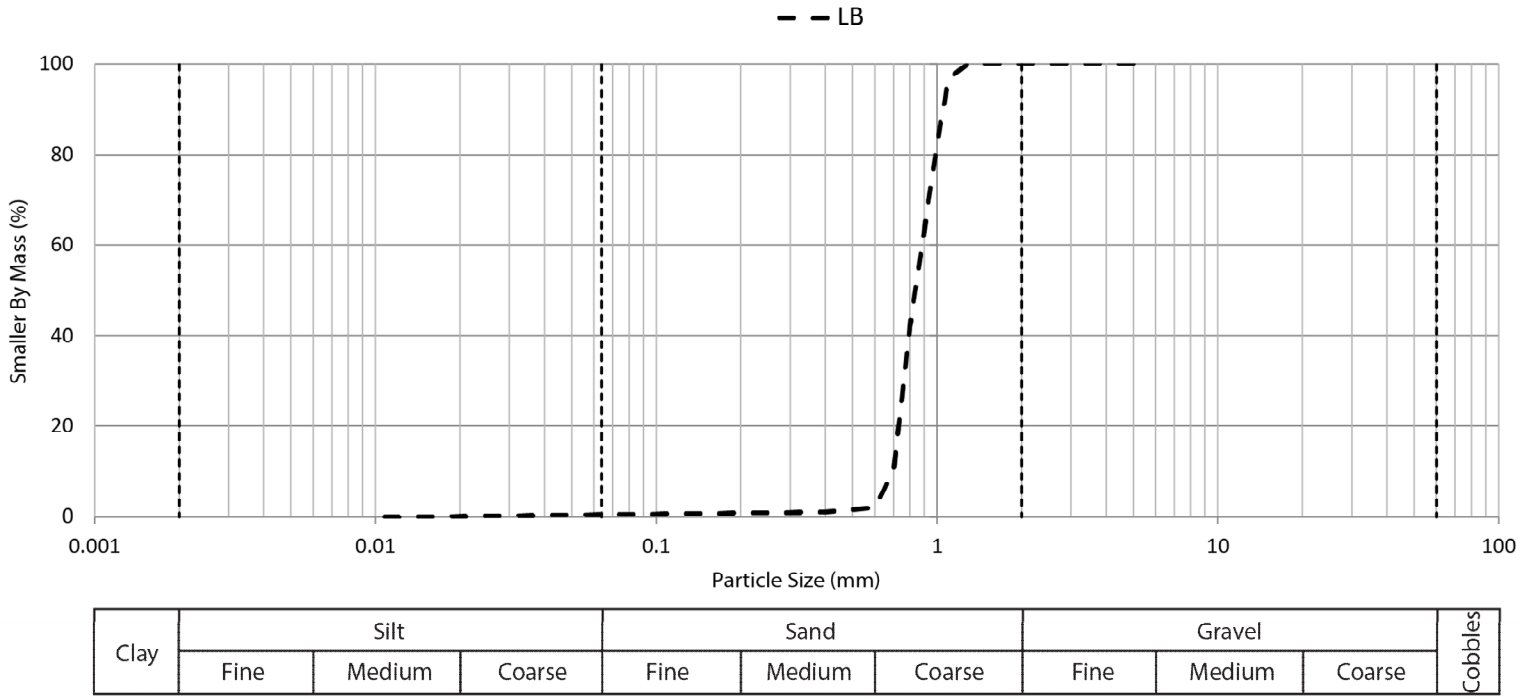


After **Lampson (1946), *Drake et al. (1989), Laine & Larsen (2007)

Soil Conditions

- Uniform sand
- Bulk density – 1.65g/cm^3 ±0.01g/cm^3
- Moisture content – 5% ±0.2%



Testing Summary

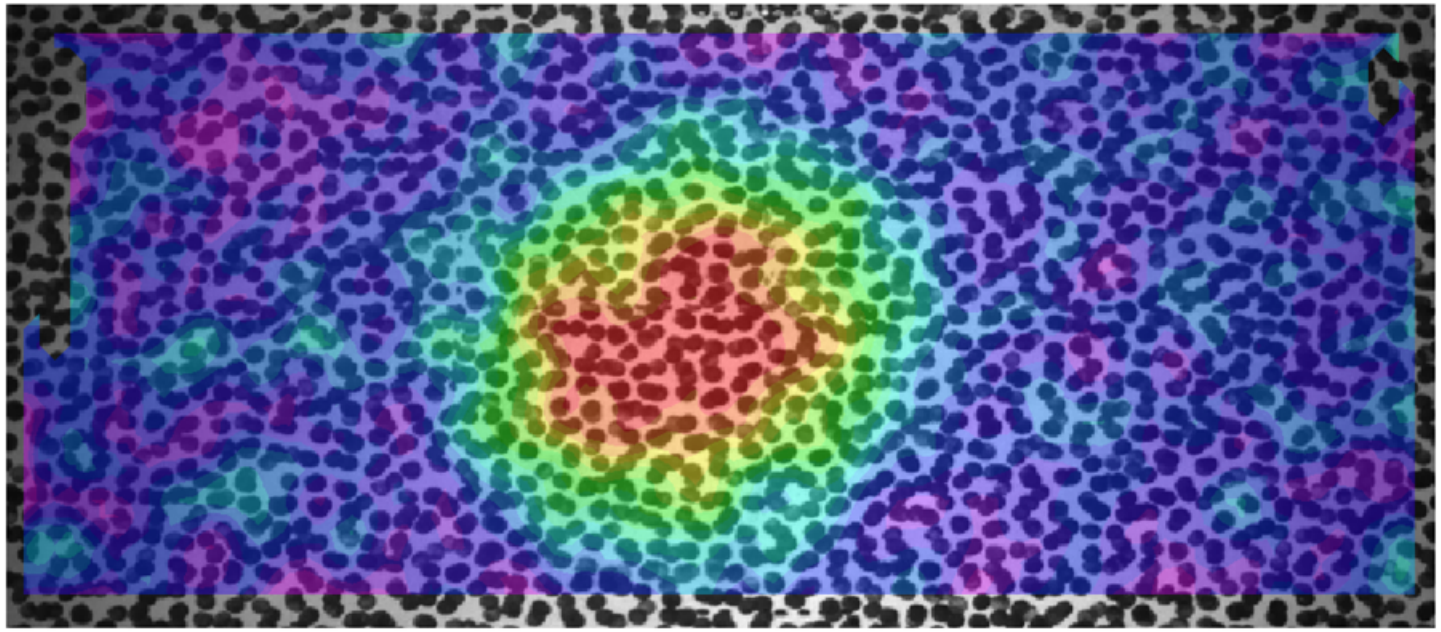
Shot ID	SOD (mm)	Charge Size (g)
A, B, C	50	10
D	100	10
E, F	250	10
G	350	10
H	500	10
I	171	50

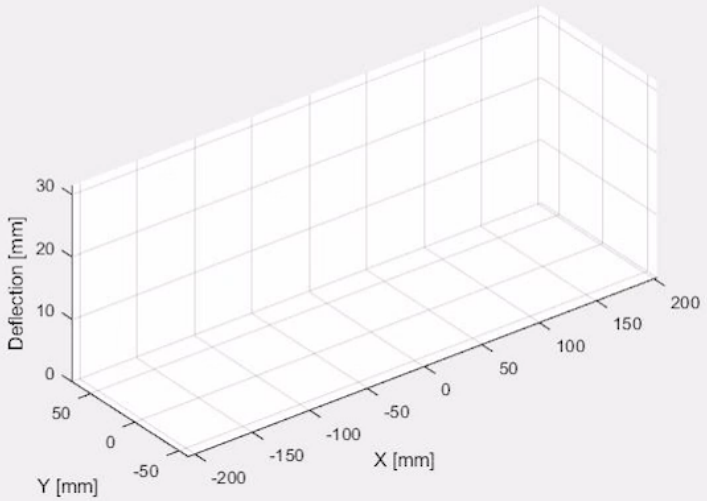
Increasing SOD

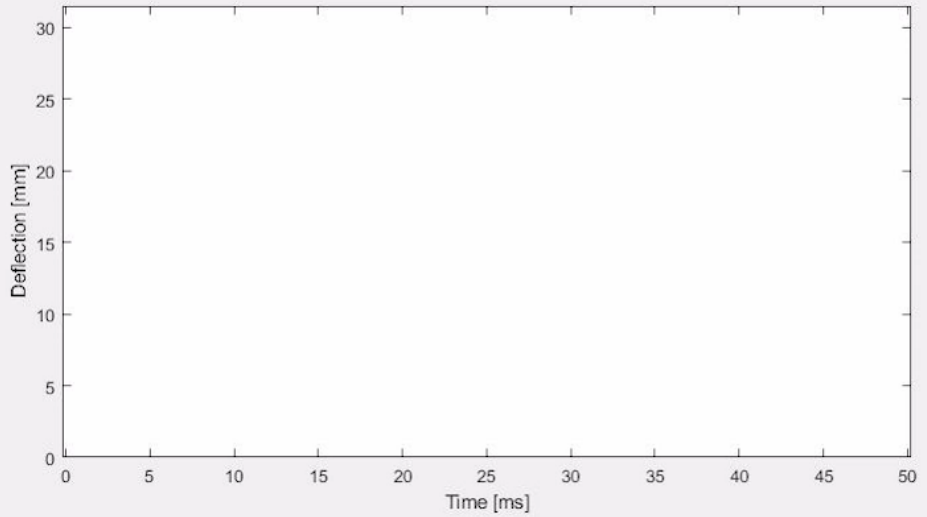
Same scaled SOD as D) 100mm / 10g

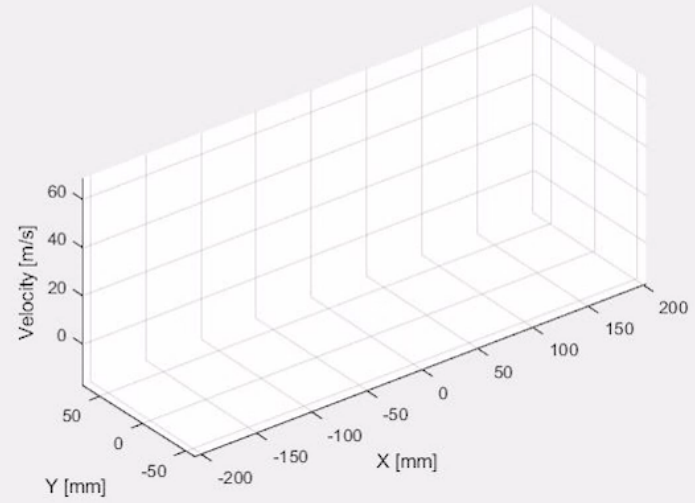
Digital Image Correlation (DIC)

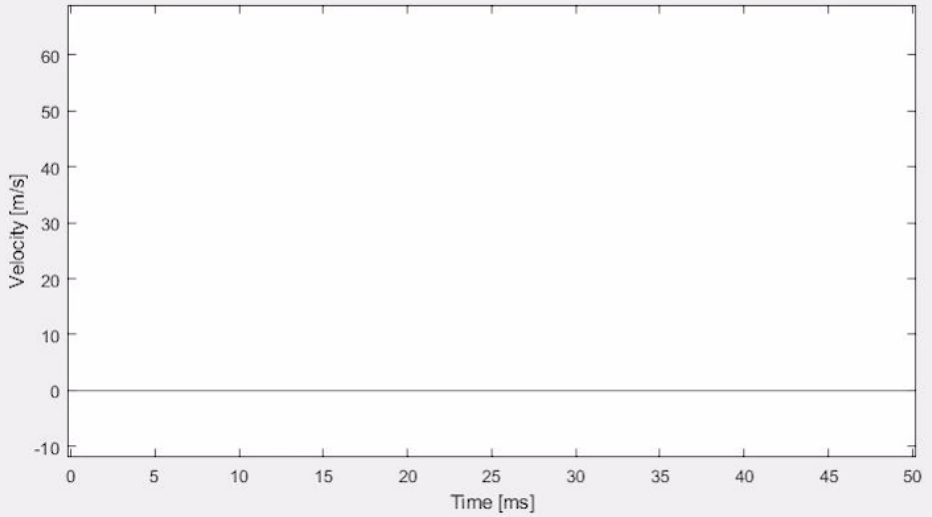
- Capture area of 380mm x 160mm
- 640 x 280 pixels
- ~3500 data points per frame per test
- 100k FPS




Deflection [mm]
30
20
10
0
50
0
-50
Y [mm]
-200
-150
-100
-50
0
50
100
150
200
X [mm]


Deflection [mm]
30
25
20
15
10
5
0
0
5
10
15
20
25
30
35
40
45
50
Time [ms]


Velocity [m/s]
60
40
20
0
50
0
-50
Y [mm]
-200
-150
-100
-50
0
50
100
150
200
X [mm]


Velocity [m/s]
60
50
40
30
20
10
0
-10
0
5
10
15
20
25
30
35
40
45
50
Time [ms]

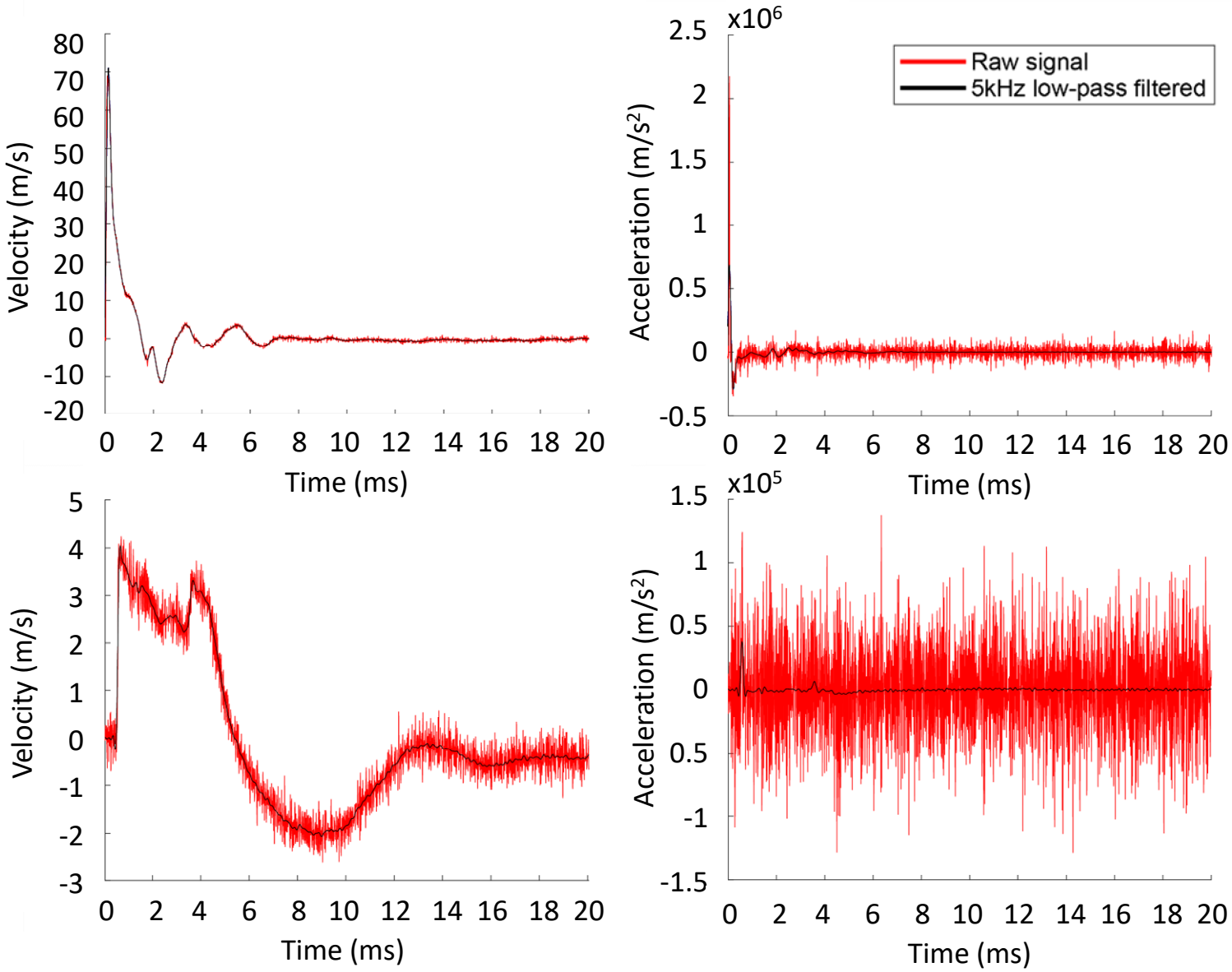
Signal Noise

Test C:

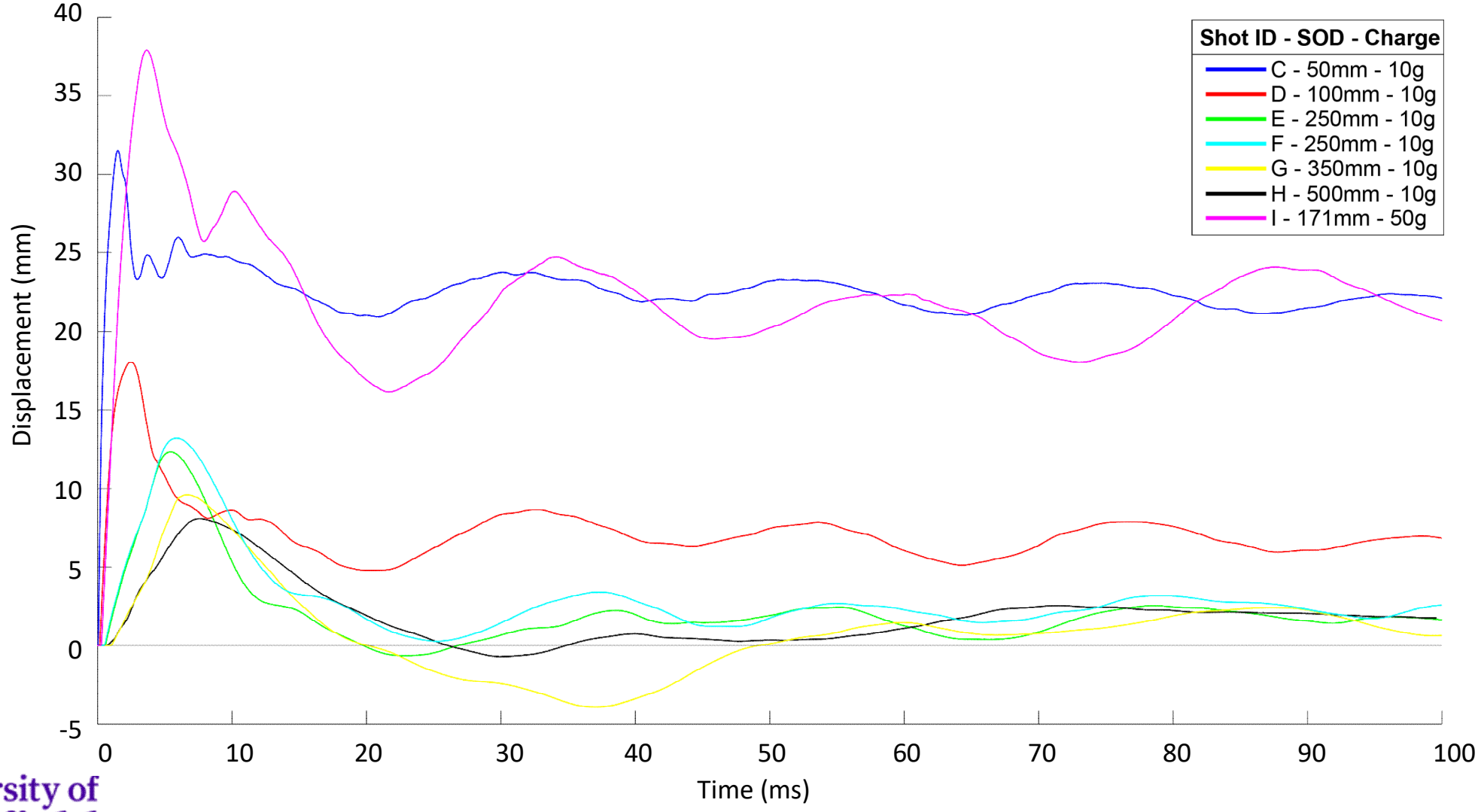
50mm SOD
10g PE10

Test E:

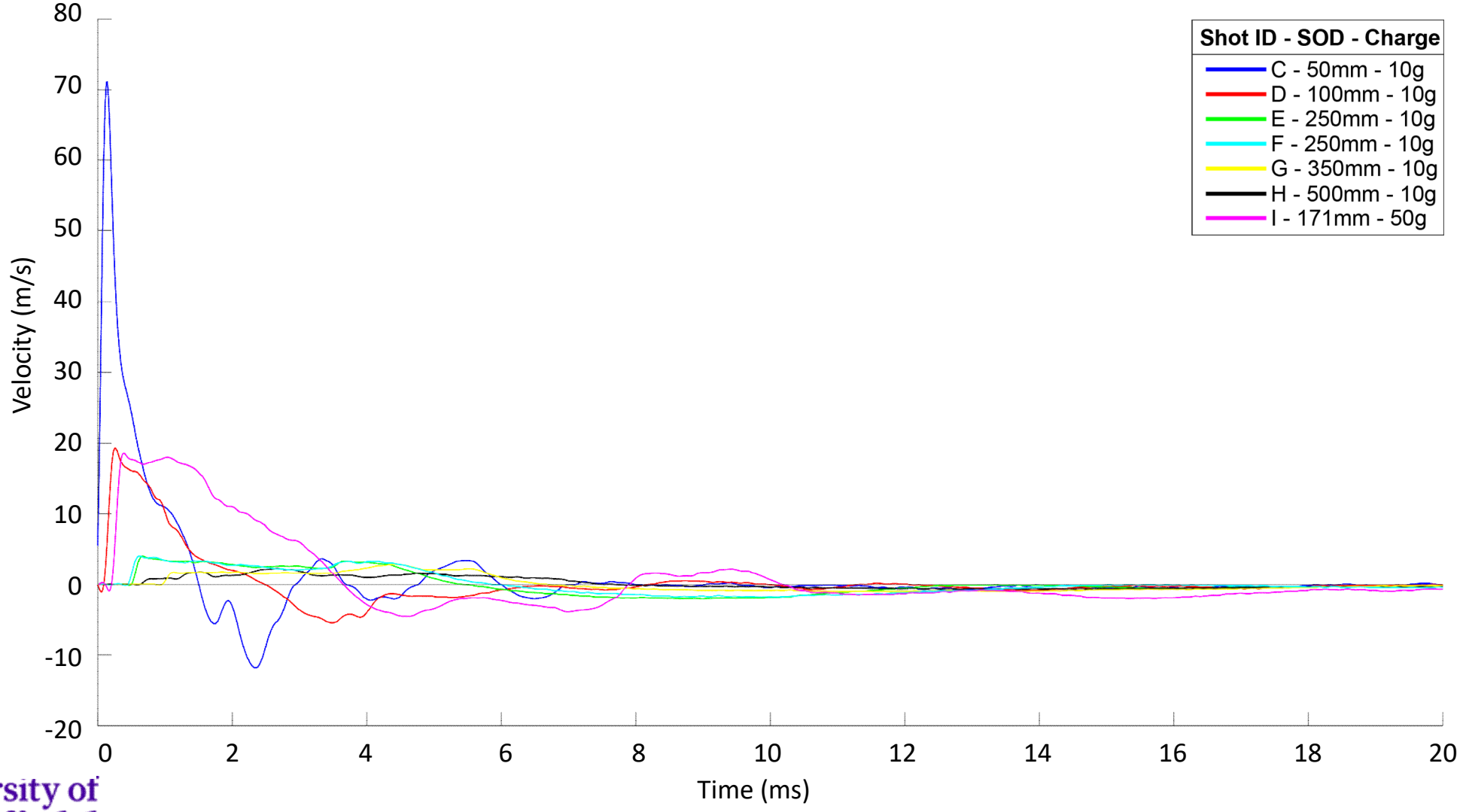
250mm SOD
10g PE10



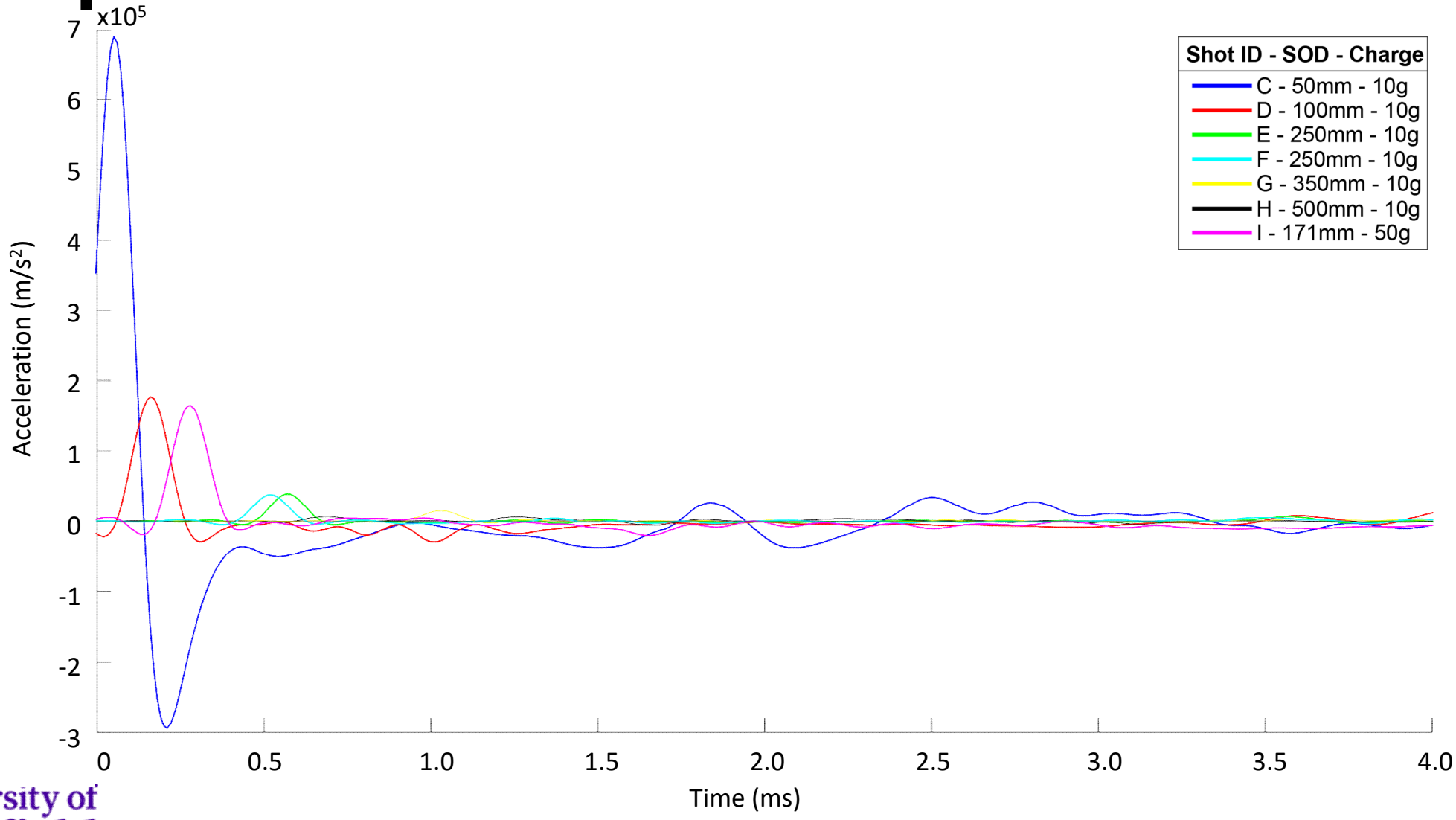
Midpoint transient deflection



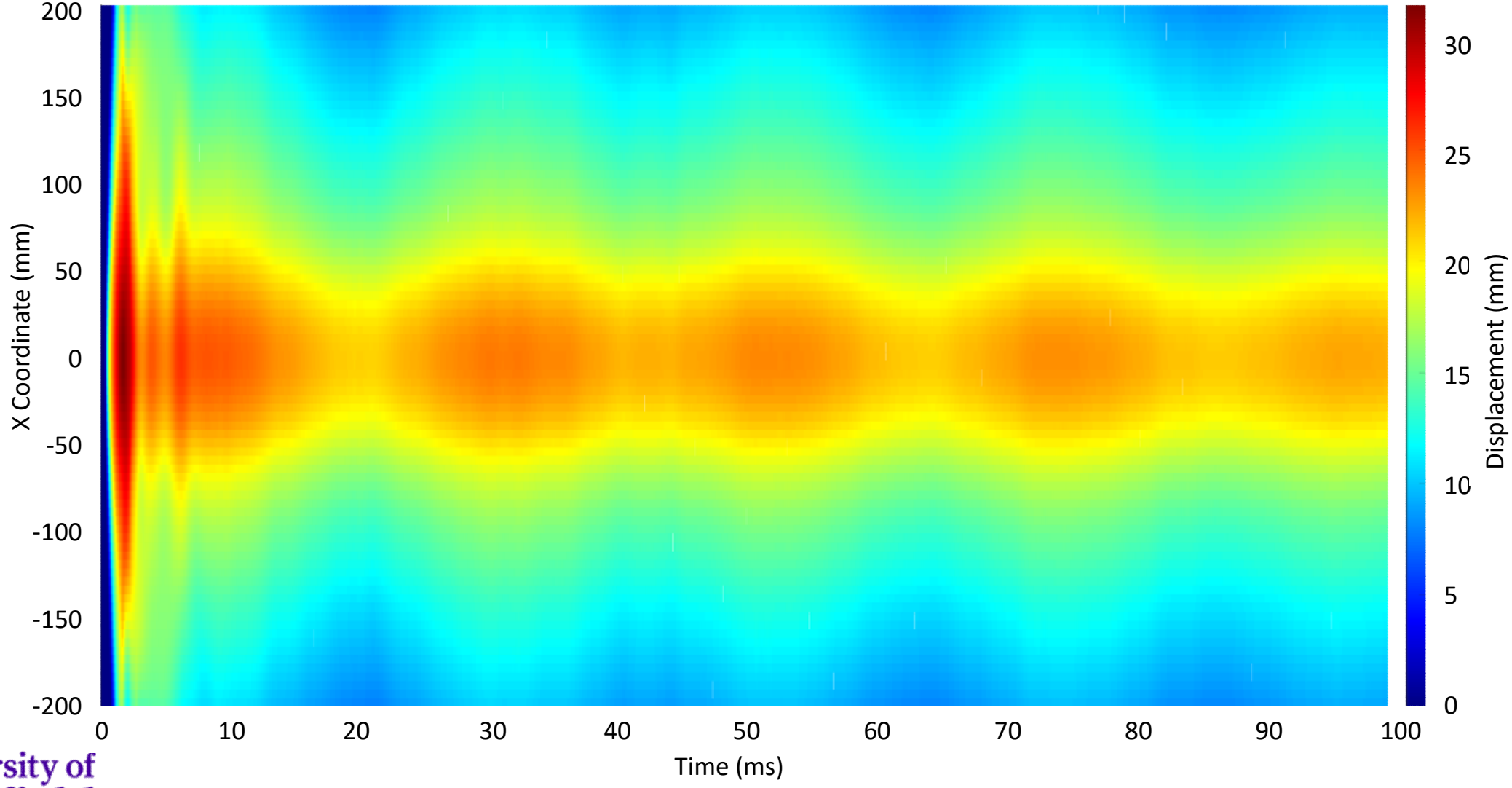
Midpoint velocity



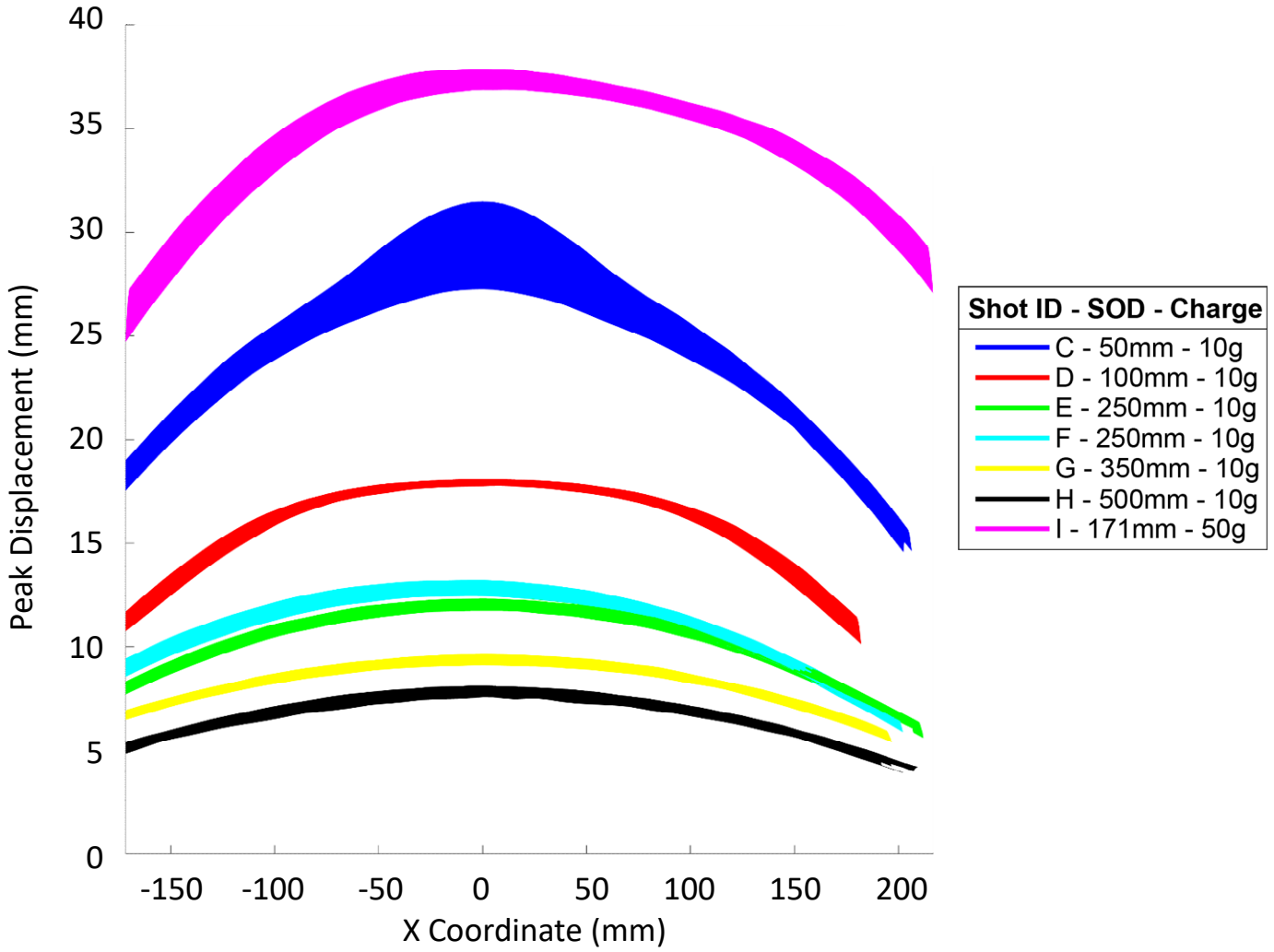
Midpoint acceleration



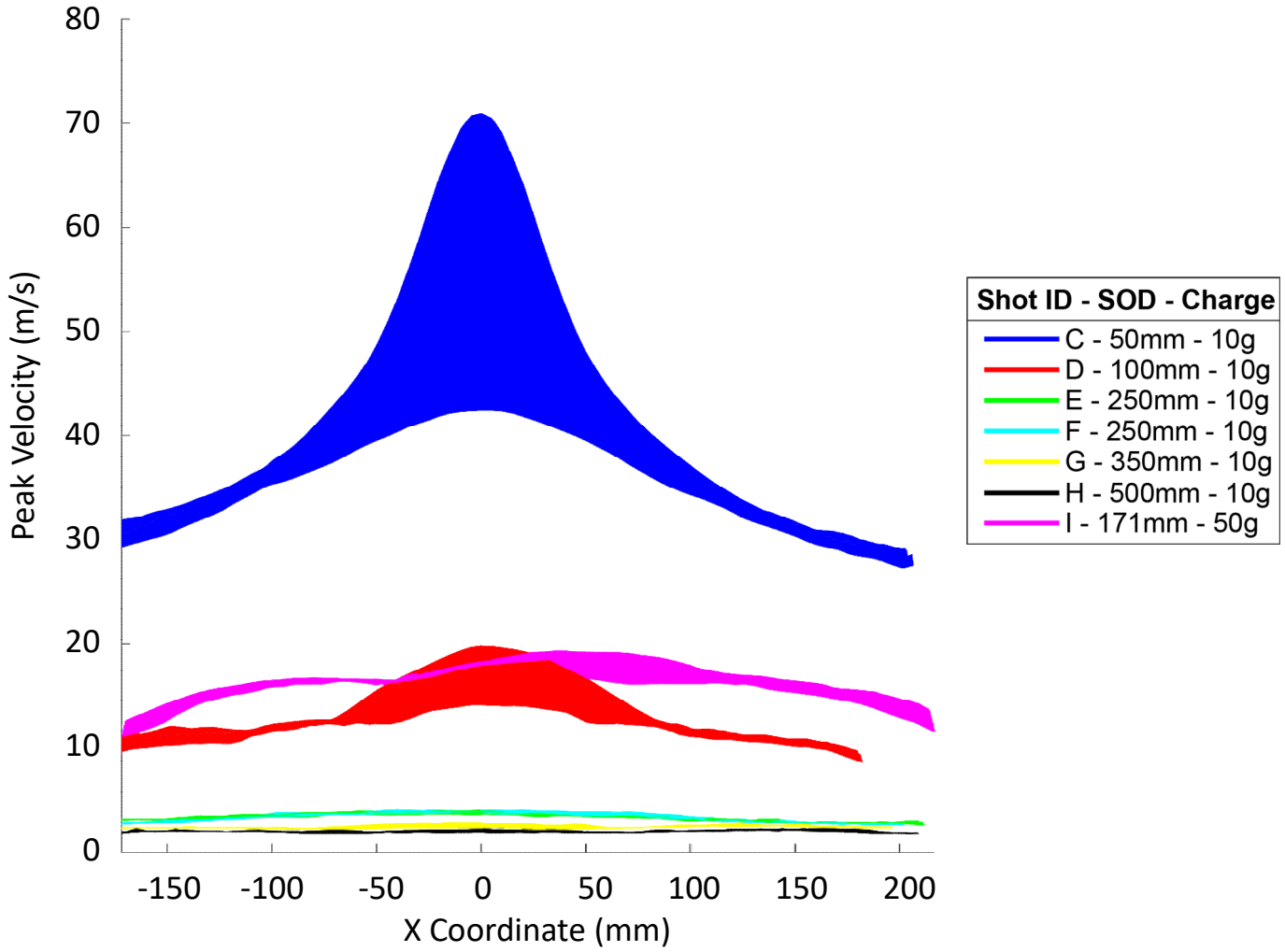
Deflection vs time



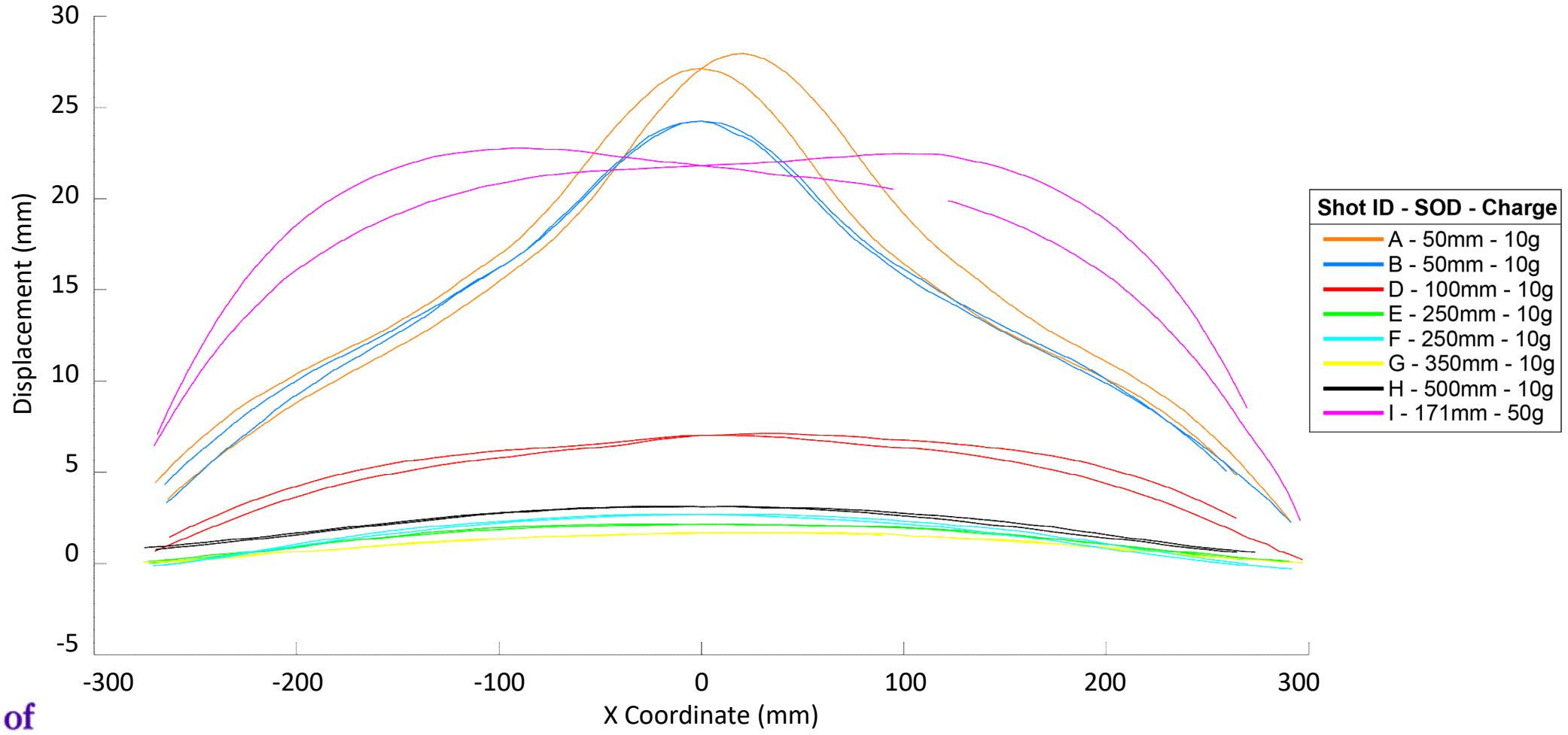
Peak Deflection



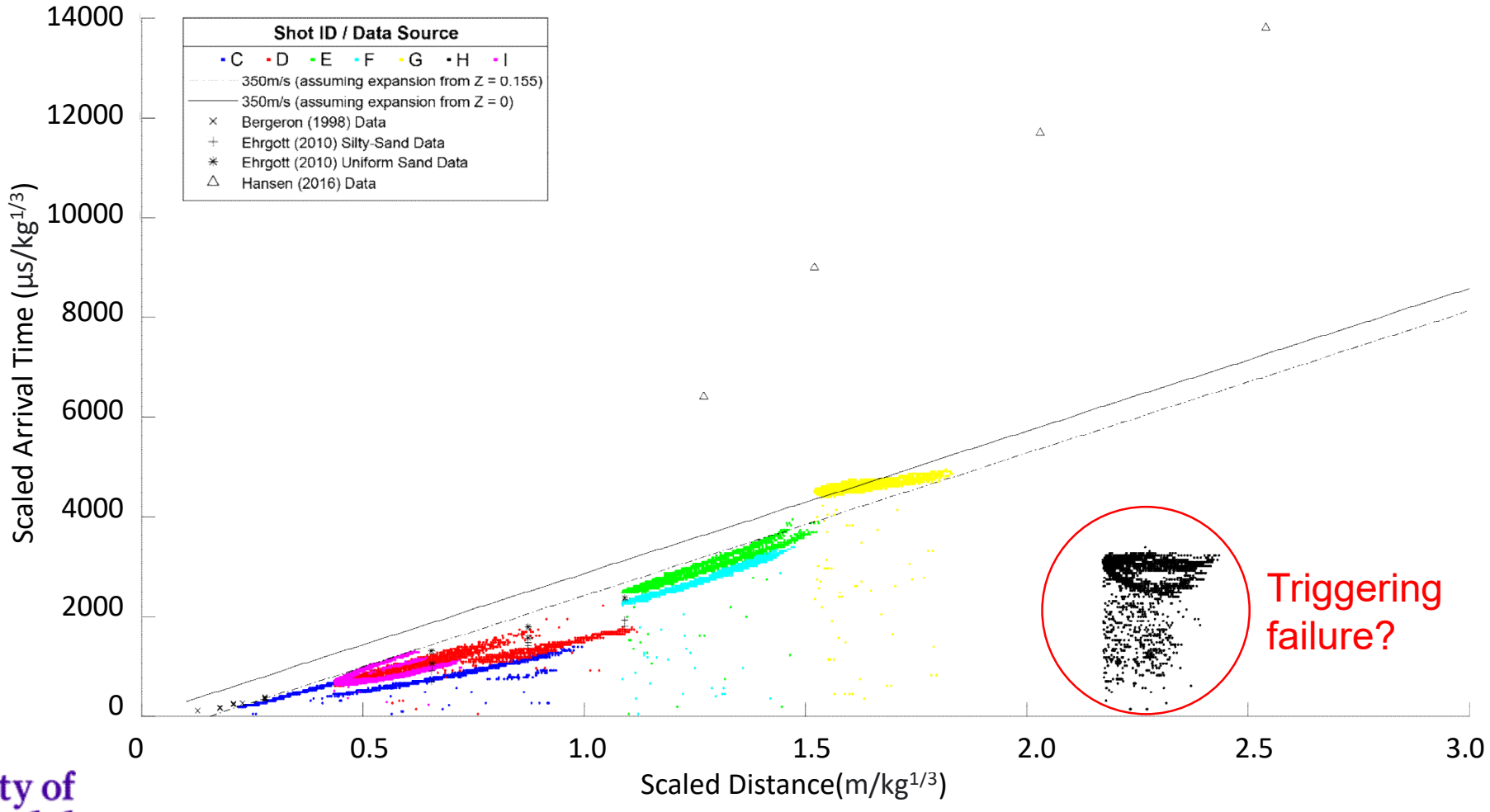
Peak Velocity



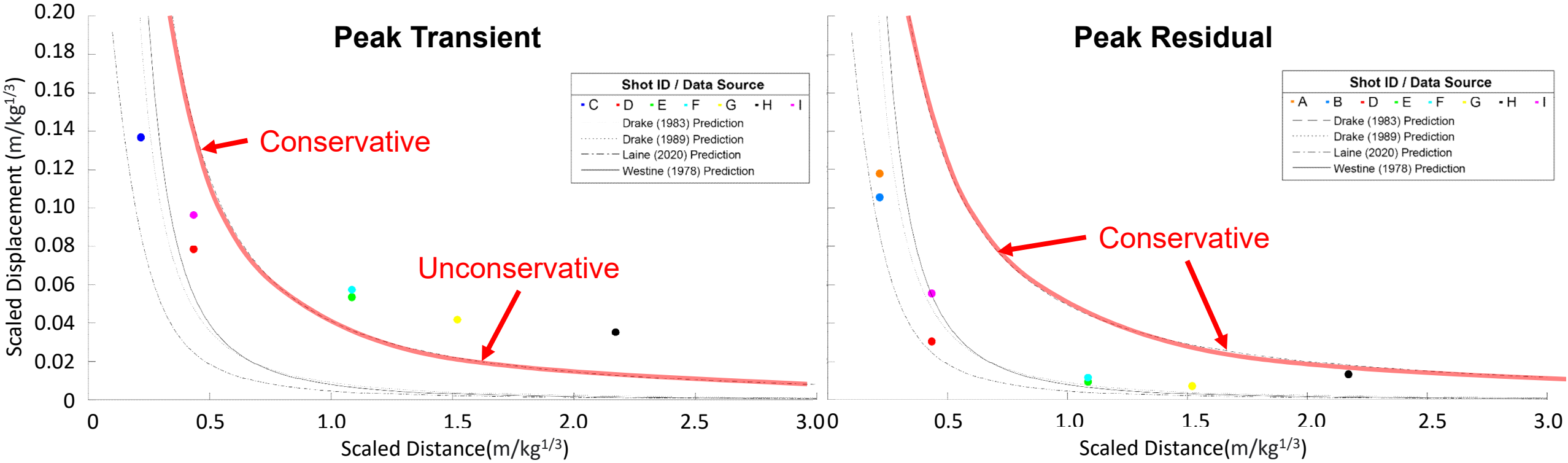
Residual deflection



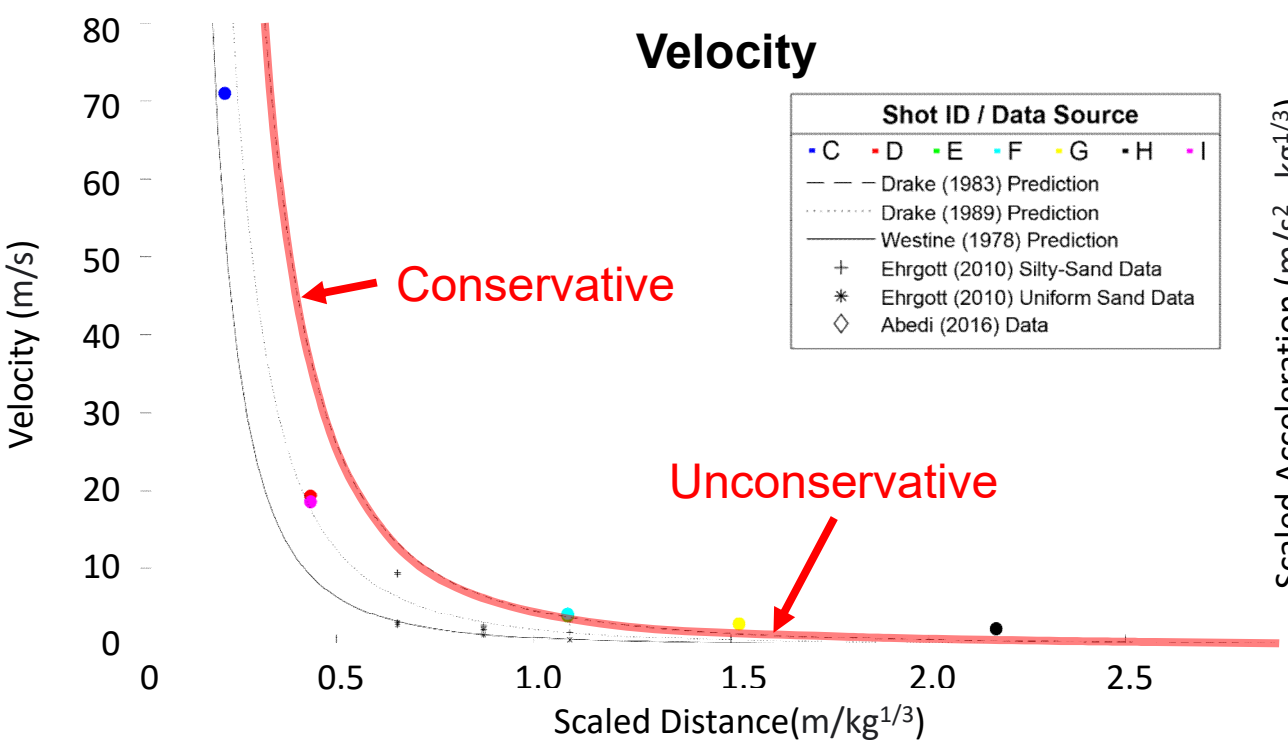
Soil wave speed

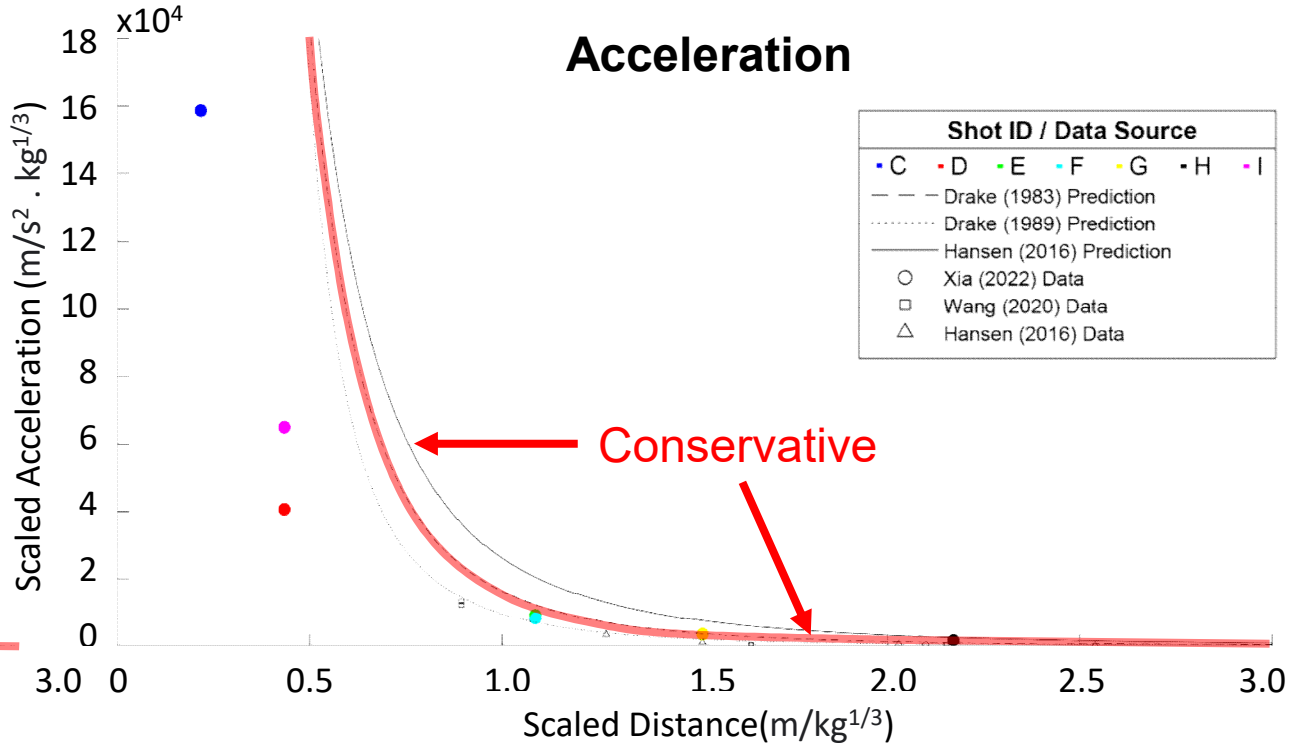


Prediction accuracy - displacement



Prediction accuracy – velocity / acceleration



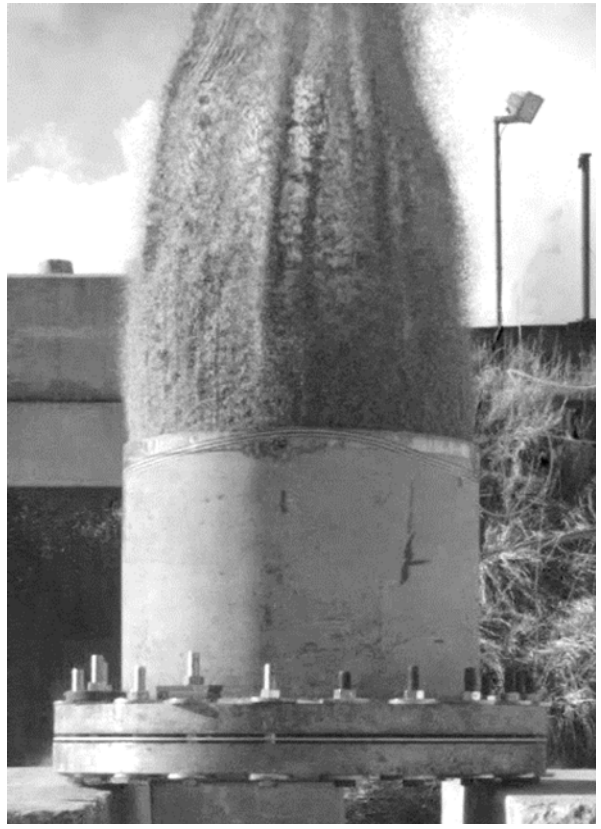


Conclusions

- New DIC technique developed for the quantification of ground shock loading
- Large datasets attainable from relatively few tests
- Data shows predictions are mostly conservative by current standard practice (Drake & Little (1983) curves / ConWep)
- Numerical modelling is ongoing, with promising signs of agreement with experimental results

References

- Abedi, A. S., Hataf, N., & Ghahramani, A. (2016). Analytical solution of the dynamic response of buried pipelines under blast wave. *International Journal of Rock Mechanics and Mining Sciences*, *88*, 301–306. https://doi.org/10.1016/j.ijrmms.2016.07.014
- Drake, J. L., & Little, C. D. (1983). *Ground Shock From Penetrating Conventional Weapons*.
- Drake, J. L., Smith, E. B., & Blouin, S. E. (1989). Enhancements of the Prediction of Ground Shock From Penetrating Weapons. *Proceedings of the Fourth International Symposium on the Interaction of Non-Nuclear Munitions with Structures (Volume 2)*, 7–12.
- Ehrgott, J. Q. (2010). *Tactical Wheeled Vehicle Survivability: Results of Experiments to Quantify Aboveground Impulse Final report*.
- Farrimond, D. G., Woolford, S., Tyas, A., Rigby, S. E., Clarke, S. D., Barr, A., Whittaker, M., & Pope, D. J. (2023). Far-field positive phase blast parameter characterisation of RDX and PETN based explosives. *International Journal of Protective Structures*. https://doi.org/10.1177/20414196221149752
- Hansen, C. B. (2016). *Buried Explosive-Induced Blast Characterization By Geotechnical Centrifuge Modeling*.
- Kingery, C. N., & Bulmash, G. (1984). *Airblast parameters from TNT spherical air burst and hemispherical surface burst*. Technical Report ARBRL-TR-02555, U.S. Army Armament and Development Center Ballistic Research Laboratory.
- Laine, L., & Pramm Larsen, O. (2007). Numerical Study of How the Ground Shock Coupling Factor is Influenced by Soil Properties. *78th Shock & Vibration Symposium*.
- Laine, L., Larsen, O. P., & Leppänen, J. (2020). Proposal for modifying the empirical equations of soil displacement for ground shock from buried explosions. *WIT Transactions on The Built Environment, Vol 198*, *198*, 3–13. https://doi.org/10.2495/SUSI200011
- Lampson, C. W. (1946). *Final report on effects of underground explosions*.
- US Army Engineers Waterways Experimental Station. (1986). TM5-855-1 Fundamentals of protective design for conventional weapons. *US Army, Navy and Air Force, US Government Printing Office, Washington DC*.
- Wang, X., Li, Y., Zhou, H., Dai, H., & Jayasinghe, L. B. (2020). Accurate measurement of ground shock with cellular solid. *International Journal of Impact Engineering*, *145*. https://doi.org/10.1016/j.ijimpeng.2020.103675
- Westine, P. S. (1978). Ground Shock From the Detonation of Buried Explosives. *Journal of Terramechanica*, *15*(2), 69–79.
- Xia, C., Chen, L., Xu, R., Cao, M., Chen, D., & Fang, Q. (2022). Experimental and Numerical Studies on Ground Shock Generated by Large Equivalent Surface Explosions. *Applied Sciences (Switzerland)*, *12*(16). https://doi.org/10.3390/app12167987



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