ENHANCEMENT OF HESCO-BASTION WALL MODELS TO BETTER PREDICT MAGNITUDES OF RESPONSE UNDER FAR-FIELD LOADING CONDITIONS

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Abstract

At the previous ISIEMS conference (2015), a UK-German initiative to generate validated models of Hesco-Bastion wall systems exposed to far-field loading was presented. Although the work produced models which very convincingly recreated the tipping and sliding modes of response, transient diagnostics revealed that the rates of deformation and the thresholds of wall instability were not faithfully predicted. During a subsequent series of wall trials in Germany (extending into 2017), the "in situ" condition of the wall's fill material was investigated prior to blast testing and the extracted soil properties compared to those measured under laboratory conditions. This exercise revealed that the lower portion of the wall fill was considerably more saturated than had previously been assumed. When soil properties commensurate with this state were integrated into the simulations, a more faithful threshold for tipping was predicted. In addition to enhancements made to the modelling process and the aspiration to generate a quicker-running simulation technique, this paper describes the field measurement techniques used to assess the "in situ" water content together with the philosophy behind the resulting adjustments to the model geometry and material properties. The paper also describes the testing and blast response of other wall types and the improvements made to the general diagnostic process with respect to obtaining more comprehensive high quality model validation data and generally improving design and fabrication of field camp protection systems.

Keywords: Camp Protection, Gabions, Numerical Simulation; Shock Tube

INTRODUCTION

Recent VBIED attacks against the infrastructure of civil and military forces in Afghanistan demonstrate the growing need for suitable measures to mitigate explosive effects. Typically the first line of physical defence for infrastructure is a heavy protective wall, such as those constructed from soil-filled Hesco-Bastion gabion units. Knowledge concerning the performance of these walls against the effect of VBIED attack is essential both for designing a perimeter and for the implementing short term measures against new, evolving threats. The individual design and performance of perimeter walls is often driven by local conditions and the number of possible wall variants is almost unlimited. As a consequence, a modelling technique, capable of accurately reproducing the response of gabions under blast-loading conditions is highly desirable. For this reason, the Wehrtechnische Dienststelle 52WTD 52 in Germany and the Defence Science and Technology Laboratory (Dstl) in the UK have

undertaken a joint research programme, which combines well characterised testing with high fidelity Finite Element simulations. Up to the present, testing and numerical evaluation has focussed on far-field blast loading scenarios as documented in Table 1. In the previous ISIEMS conference (2015), WTD 52 and Dstl presented the preliminary findings. This following section now describes the results, analysis and improved understanding gained from undertaking further experiments.

TEST SERIES 2015, 2016, 2017; EXPERIMENTAL SET-UP

The basic test setup was described in the ISIEMS 2015 paper [1], the LBS (Large Blast Simulator) at WTD 52 being used to provide a simulated far-field blast function. The LBS generates a blast wave via the sudden release of compressed air, from an array of pressurized bottles located at the closed end of a tunnel (Figure 1). The walls, constructed outside the tunnel on a 1.5 to 1.9 degree slope, consisted of a number of gabion segments with a total length of 10 m. Both Hesco-Bastion and Defencell gabion types were scrutinised, examples of which are shown in Figure 2. With reference to Table 1, the entire scope of parameters investigated includes:

- Wall types (Hesco Bastion, Defencell, Stone filled Gabions, Substitute of Hesco Bastion)
- Shape of wall (Tall H x W: 2.7 m x 1.2 m, Pyramidal H x W: 3 m x 3 m)
- Filling material (sand, gravel, stone)
- Moisture content of sand
- Foundation (concrete, sand, gravel)
- LBS Loading (high intensity, low intensity)

Figure 1: LBS Shock tube systems with typical gas bottle arrangement

Figure 2: Example wall: Double stacked, MIL 8 Hesco Bastion wall unit used in test series 2015 / 2016
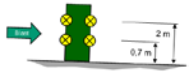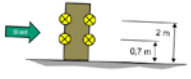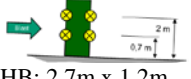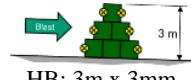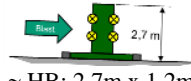
Test No	Wall Type	Filling	Found.	Load.	p_{refl}, I_{refl}
2015 – 01	Hesco Bastion (HB) H x W: 2.7m x 1.2m	Sand	Con-crete	High	200 kPa; 1100 kPa-ms
2015 – 02		Sand		High	
2015 – 03		Sand		Low	125 kPa; 900 kPa-ms
2015 – 04		Sand		Low	
2015 – 05	DEFENCELL (DC)	Sand		Low	
2015 – 06		Sand		Low	
2015 – 07		Sand		High	200 kPa; 1100 kPa-ms
2015 – 08		Sand		High	
2015 – 09	HB: 2.7m x 1.2m	Sand		Low	125 kPa; 900 kPa-ms
2016 – 01		Gravel		Low	
2016 – 02		Gravel		Low	
2016 – 03		Gravel		Low	
2016 – 04		Sand		Low	
2016 – 05		Sand		Low	
2016 – 06		Gravel		High	200 kPa; 1100 kPa-ms
2016 – 07		Gravel		High	
2017 – 01	HB: 3m x 3mm	Gravel		High	
2017 – 02		Gravel		High	
2017 – 03	Gabions: 3m x 3m	Stones		High	
2017 – 04		Stones		High	
2017 – 05	≈ HB: 2.7m x 1.2m (HB Substitute)	Sand	Sand	Low	125 kPa; 900 kPa-ms
2017 – 06		Sand		Very low	
2017 – 07		Sand		Very low	
2017 – 08		Sand		Low	125 kPa; 900 kPa-ms
2017 – 09	≈ HB: 2.7m x 1.2m	Sand	Gravel	Low	
2017 – 10		Sand		Low	

Table 1: List of all tests

EVALUATION OF PRESSURE LOADING

The 2015 test series was conducted with pressure gauges located along the longitudinal symmetry plane of the LBS tunnel at the front and rear side of the wall. The testing was

supported with detailed numerical simulations of the blast propagation in the tunnel and resulting pressure distribution across the surfaces of the wall. Out of plane gauges (Figure 3) were used during the subsequent test series, which helped to extend the scope for validating the blast and structural response modelling.
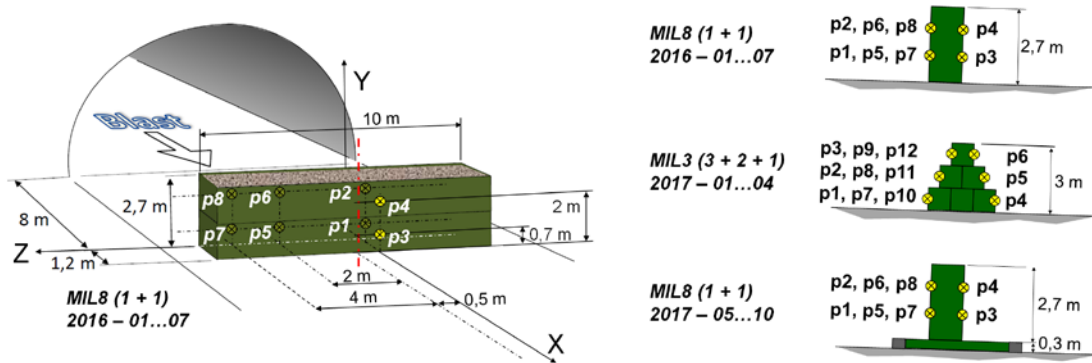

Figure 3: Pressure gauges used during latest testing

As shown in Figure 4, comparison of the pressure time histories recorded in tests involving the same wall shape and bottle configuration demonstrates the highly reproducible performance of the LBS. The pulses were used as a basis for generated piecewise descriptions of the loading for input into the numerical simulation of the wall system.
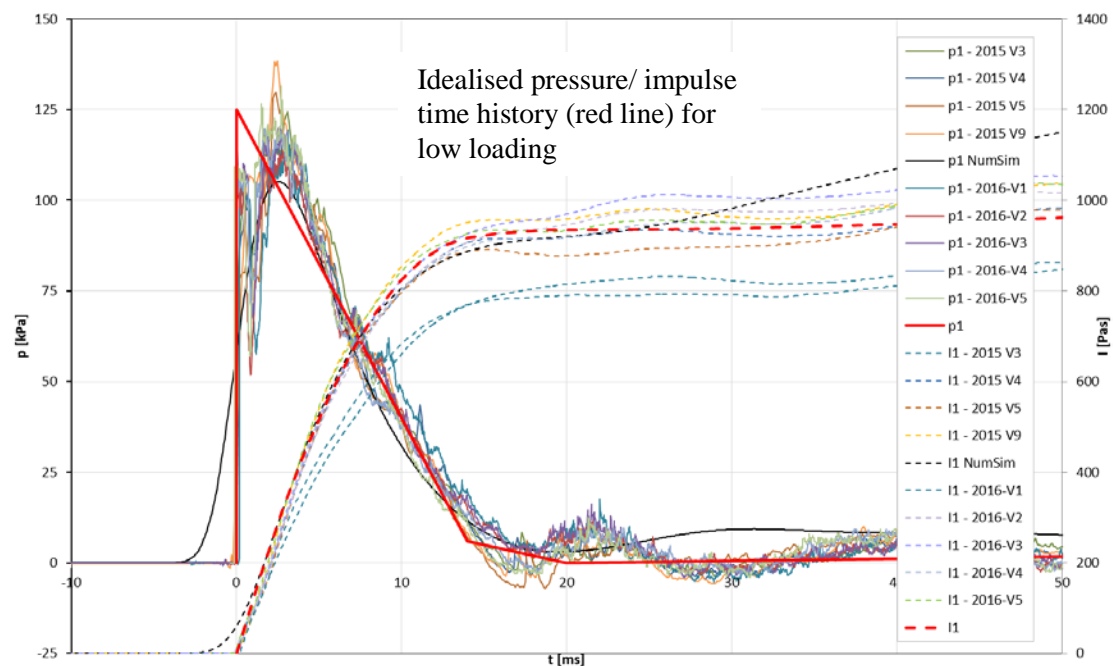

Figure 4: Reproducible pressure pulses generate by the LBS with an idealised piecewise description used for numerical simulation

As an example, Figure 5 shows 10 sectors on the front side and two sectors on the rear side of the wall where these piecewise loadings could be applied for a HB 2.7m x 1.2 m wall type. Curves were generated for both low intensity and high intensity loadings.
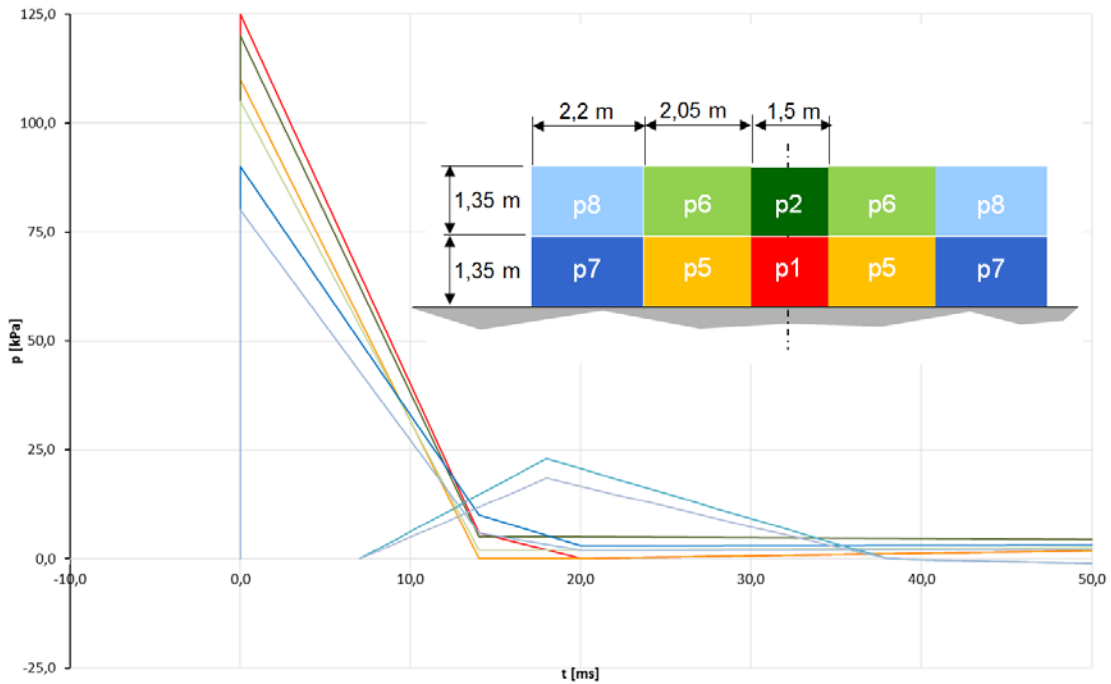
Figure 5: Piecewise scenario (input for numerical simulation)

EVALUATION OF WATER CONTENT (SAND FILLING)

A closer look at the test results of the 2015 series showed that, even for apparently similar loading and setup conditions, the behaviour of the walls varied considerably. It was also observed that numerical modelling generally over-predicted the tipping load of the wall and under-predicted the rate of tipping once the process had commenced. A team from the UoS (University of Sheffield) visited the WTD 52 site during the 2016 test campaign and used a Delta-T ML3 ThetaProbe to evaluate the water content at various grid points across the span and through the depth of the wall. With reference to Figure 6a, this work revealed that a soil layer, extending about 100 mm up from the base of the wall, was in fact completely saturated possessing a water content of up to 15%, Figure 6b. The presence of this layer would considerably reduce the wall's shear strength and the extent of the saturation would be dependent on the weather conditions and hence prone to considerable variability. The presence and influence of the layer has now been incorporated into a revised modelling approach as discussed below.
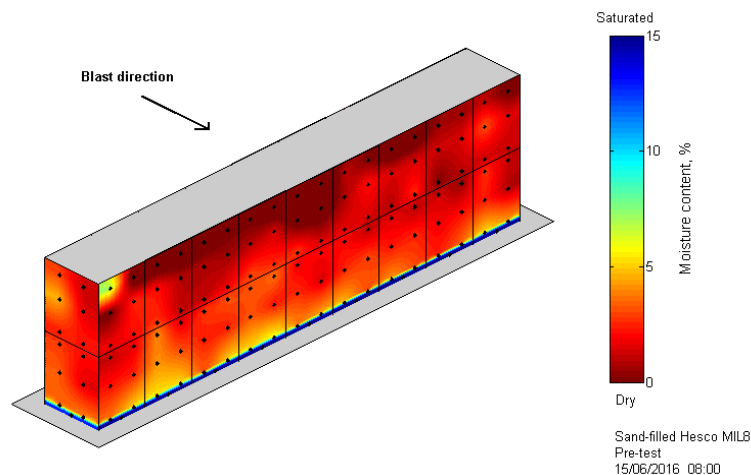

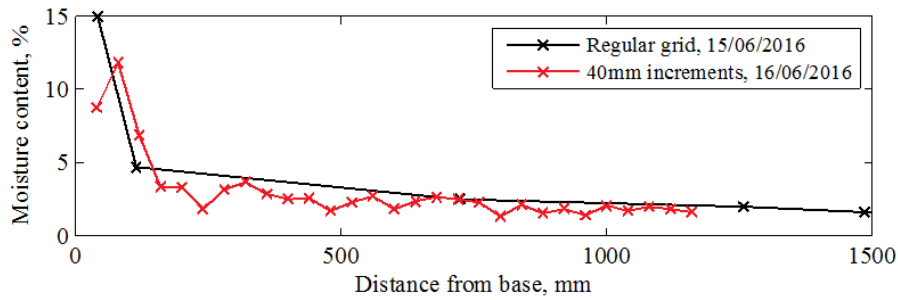
Figure 6a: Water content contours within the wall

Figure 6b: Variation of water content with wall depth

EVALUATION OF WALL SHAPE (PRIOR/POST TEST)

In the test series of 2015 and 2016, a comparison of the wall shape pre and post testing was using a combination of photogrammetry and manual measuring techniques (Figure 7) with an assumed accuracy of ± 1 cm.
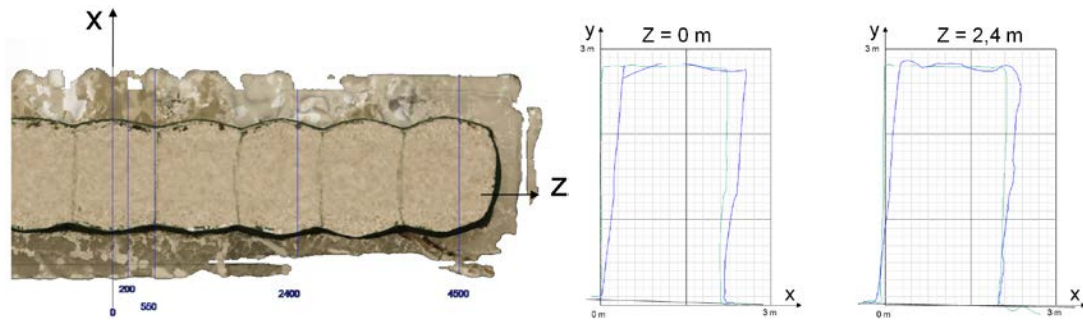

Figure 7: Cross-section pre / post test (Test 2016 – 01)

As an enhancement, the determination of the exact shape of the wall in the tests conducted during 2017 was undertaken using a laser scanner with a calculated accuracy of ± 1 mm, Figure 8.

Pre and Post test
cross-section

Figure 8: Laserscan with FARO® Laser Scanner Focus3D (Test 2017 – 07)

EVALUATION OF DYNAMIC RESPONSE

For measuring the dynamic displacement of the wall, 15 point markers were mounted to its rear side face as indicated in Figure 9. The markers could be seen and tracked by two high-speed cameras, positioned to provide different viewing angles (left and right), but with otherwise identical settings. The initial marker positions and additional calibration points were determined using the 3D laser scanning process mentioned above.

Figure 10 shows an instant of time, seen from the right camera view alongside displacement time histories recorded at the position of the coloured markers. The Tema Motion software was used to generate these outputs
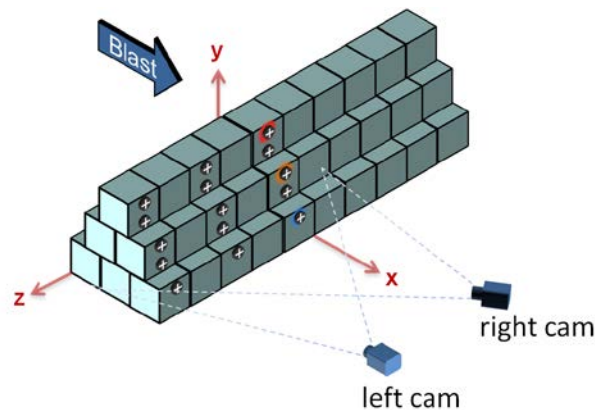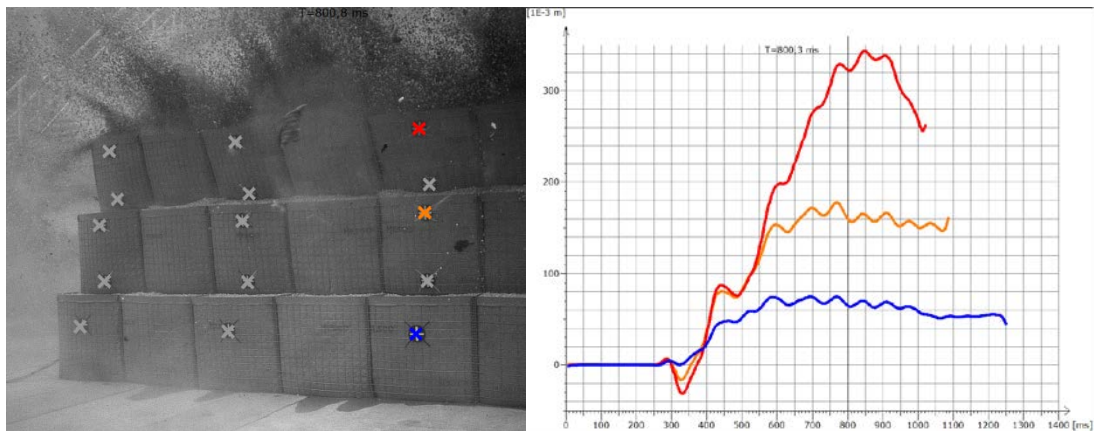
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Figure 9: Set-up for 3D motion analysis

Figure 10: Right-hand camera view at a particular instant in time during a wall test (left), displacement time history graphs (right). The black vertical line indicates the point at which the image was captured

ADDITIONAL LESSONS LEARNED CONCERNING WALL DESIGN AND CONSTRUCTION

The main purpose of the experiments was to create a comprehensive database of high quality data for the validation of numerical models. Nevertheless the work precipitated considerable additional information with respect to the practical aspects of wall construction and design. This included:

- Importance of the quality / strength of the gabion system: In the test series of 2017 a cheap substitute for the Hesco Bastion was evaluated. Although this system looked like the

original product at first glance, the strength of the steel mesh and welded joints was in fact much lower. Moreover the textile was not securely fixed to the mat at the bottom of the gabion units. These inferior features resulted in poor wall stability when loaded with blast.

- In an attempt to address the problem associated with high levels of saturation at the base of the wall, the latter six 2017 tests were conducted with the wall being positioned on a gravel foundation. The intention was to improve drainage conditions and hence enhance stability but testing revealed a higher tendency for wall collapse compared to the earlier tests conducted on a concrete foundation. It is believed that the penetration of the gabion units into the foundation prior to testing resulted in this behaviour. Such response emphasises the importance of a properly prepared foundation.

ENHANCEMENTS TO MODELLING APPROACH

Previously, models of the Hesco wall systems were generated using the LS-DYNA finite element software [2]. As can be seen in Figure 11, these simulations accurately predicted the modes of response but, as discussed above, the rates of deformation and threshold of tipping were significantly underestimated. Considering the findings of the UoS with regard to the saturation of the fill material, the original simulations were adapted to include a separate layer of material in the high water content region at the base of the wall, Figure 12.
UoS also adapted the original laboratory-derived material properties, to be more appropriate for modelling the "in situ" conditions. This effectively entailed generating higher fidelity strength and compaction representation of the unsaturated material in line with the experiments originally undertaken by EMI (Ernst Mach Institute). In terms of the saturated layer the:

- Bulk modulus was set to one more pertinent to water
- Bulk density was increased to account for a greater proportion of water-filled voids
- Shear strength was set to a lower but stable value within the Mohr-Coulomb formulation
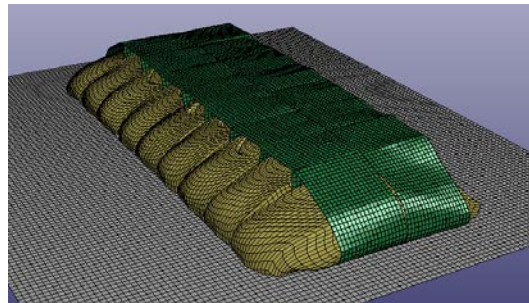

Figure 11: Original modelling accurately predicted mode of response

For reasons of computational efficiency the process of verifying these implementations was initially undertaken using a single, double stacked Hesco unit or ("test bed", Figure 12), before the approach was transitioned to represent the full wall. The test bed was also used to develop more robust methods of contacting the wall components during the phases of response as unrealistic penetrations had sometimes occurred in the original approach. This was particularly important when modelling some of the more complex construction types shown in Table 1. The frictional parameters at the interfaces between the components remained unaltered. Figure 13 shows the difference in response between the original (homogenous) model and the new (separate base-layer) approach for a high intensity LBS loading of the type idealised in Figure 4.
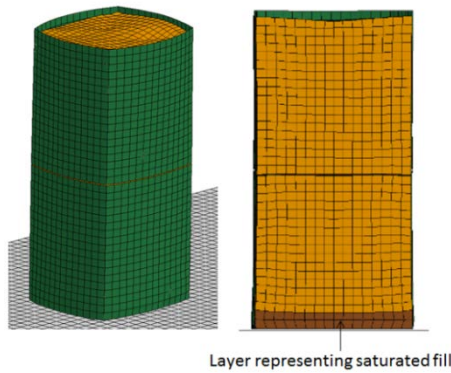
Layer representing saturated fill

Figure 12: Hesco "Test bed" used to efficiently enhance the simulation technique

The transient X and Y coordinates of Point 1 (upper unit) and Point 2 (lower unit) for the original and new method are respectfully compared in Figure 14a and Figure 14b. As can be observed, the explicit representation of the saturated layer within the model greatly lowers the tipping threshold of the Hesco system. This is more consistent with the observations made in the tests.
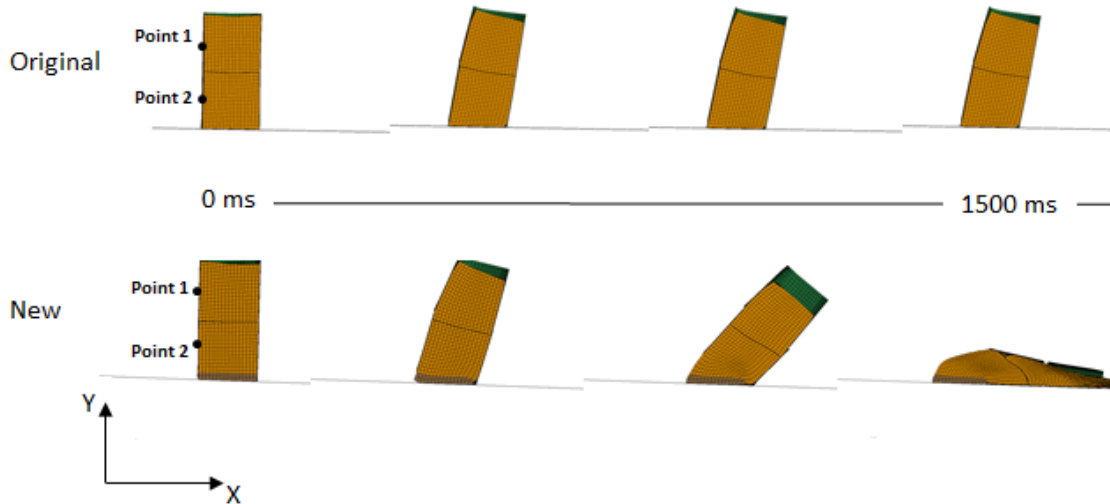

Figure 13: Comparison of evolving wall deformation for original and new models
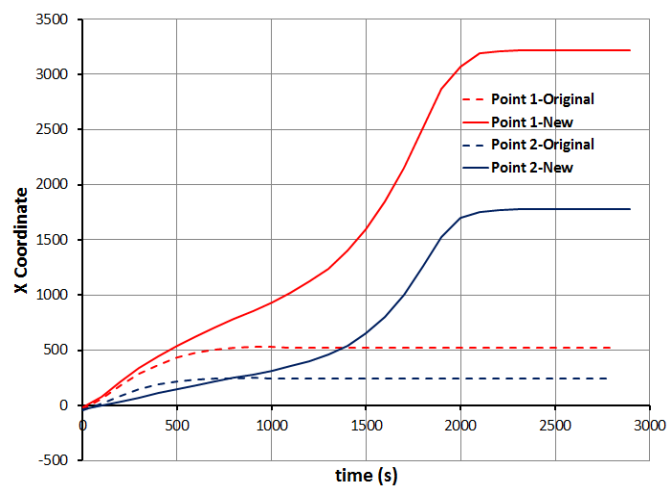

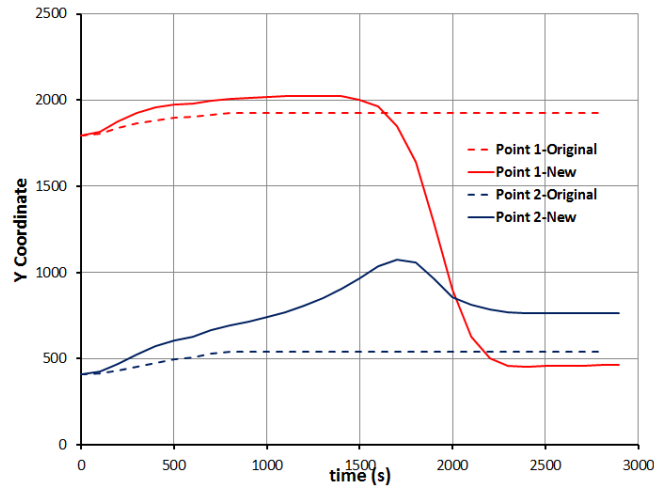Figure 14a: Transient X-coordinates (mm) for Hesco system

Figure 14b: Transient Y-coordinates (mm) for Hesco system

FUTURE MODELLING DIRECTION

Experiments and supporting numerical simulations have shown that wall behaviour under far-field explosive loading is highly sensitive to the constituent soil parameters and it is now planned to further enhance the modelling techniques to simulate wall response under near-field loading conditions. It is recognised that, within the near-field regime, different spatial integration schemes such as SPH (Smooth Particle Hydrodynamics) methods will have to be employed to cope with the much higher rates of deformation and ejection of the fill material. Broadening the analytical scope will increase understanding with regard to the design and evaluation of camp protection and the higher fidelity techniques can be used to develop simplified modelling approaches capable of dealing with the statistical variability and imponderability associated with typical scenarios. This will involve:

- Quantifying the influential factors associated with the response modes of walls, considering differing configurations and loading types.
- Execution and evaluation of scaled and unscaled tests to derive semi-empirical models for the description of damage on the wall and resulting hazards.
- Derivation of modelling approaches for far-field and near-field loading cases, which are suitable to be implemented within a fast running software evaluation tool.

CONCLUSIONS

This work has significantly expanded the dataset and understanding concerning the response of gabion wall systems under far-field explosive attack. Diagnostic enhancements have been successfully implemented to provide more comprehensive model characterisation and validation and the importance of wall (and foundation) construction quality has been emphasised. Enhancements to the existing modelling approach by improving component contact algorithms and explicitly accounting for different soil conditions have respectfully provided a method which is more robust for modelling different wall geometries and more accurate at predicting the threshold for structural collapse. This can be used as a basis for developing quicker running analytical techniques going forward.

REFERENCES

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2. http://www.lstc.com/download/manuals