The war against surprise

As improvised explosive devices evolve, **Professor Daniel Rittel,** of Technion – Israel Institute of Technology, details how scaled down armoured vehicles subjected to large blasts can be utilised…

Structural and survivability design of armoured vehicles involves costly and time consuming experiments in which a full-scale structure is subjected to blast loading. The recent evolution of the threats to armoured vehicles includes very large-scale explosions that are operated from a very short range (eg. buried charges or side attacks).

A recent study has addressed the applicability of available scaling concepts to these specific cases by combining a series of experiments with advanced numerical simulations.

The outcome of this work is that the vehicle geometry, stand-off distance and charge can all be combined into one scaling model to yield accurate results for the full-scale prototype (excluding fracture). This study has also shed new light on the relationship between the maximal dynamic and residual plastic structural responses, allowing a safer protective design for the crew of the vehicle. This study addresses both flush buried charges and air blasts. These new results open new opportunities for a significant cut down of the development costs and time, while allowing for the design of optimal and safer structures.

The character of the threats faced by armoured vehicles has evolved over the recent years, from conventional armour piercing rounds (eg. shaped charges, kinetic ammunition) to buried or side charges that are detonated remotely when the vehicle is passing. The damage inflicted by these improvised charges can be severe as the crew is often caught by surprise in a seemingly quiet neighborhood, as opposed to the traditional battlefield. This new situation has prompted the need for an improved design of armoured vehicles with the main characteristic of the threat being that the charges are often very large and are detonated from a rather small stand-off distance, with very dramatic consequences.

Conventional design requires, among other things, that full-scale experiments be carried out in the proving ground, with a vehicle that is usually instrumented with various devices aimed at measuring accelerations that are imparted to the crew, the latter being lethal above a certain documented level. The instrumentation ranges from conventional strain gauges and accelerometers to high-speed cameras, and may also involve dummy mock-ups used in the automotive industry for crash investigation. This stage is, of course, accompanied by extensive numerical simulations carried out on very large computers capable of handling a huge quantity of data. It comes out that the development stage is both quite expensive and time consuming, and a situation occurs in which a constant race is run between the designers on one side and the ever renewing threats on the other side.

> *'…it is clear that scaling concepts can be successfully employed to characterise the full-scale structural response of an armour plate by means of scaled down miniature models, with a significant reduction of the duration and costs of the design stage.'*

This state of affairs has prompted the need for an investigation of the possibility to scale down the problem, in other words to use miniature models and reduced charges to faithfully mimic the structural response of the full-scale prototype. Here one should mention that scaling concepts have been available in the scientific literature for decades, but they address the case of remote explosions as opposed to the small stand-off distances in question here. The problem was examined through a co-operative research between the Israel Institute of Technology (Technion, Faculty of Mechanical Engineering, Professor D Rittel), Lt-Col. (res). *Dr A Neuberger* (Tank Directorate, Israel Defense Forces) and *Dr S Peles* (Senior Research Engineer, Israel Military Industry). The study comprised analytical, experimental and numerical work, and its main results and implications are summarised as follows.

Two different scaled down similar test rigs were built in order to experimentally assess the applicability of scale down modelling of the studied problem. The generic circular target plate was supported by two thick armour steel plates with circular holes that were tightened together with bolts and clamps. The thick plate that faces the charge has a hole with inclined side walls to prevent reflection of the blast wave to the tested plate in fig. 1.

In a typical experiment, the permanent deflection of the plate is measured using a comb-like device, whose teeth get bent by the deflecting plate. A spherical TNT charge is exploded over the plate, with the maximum deflection being measured

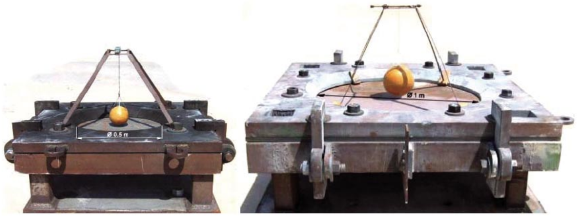

Fig. 1

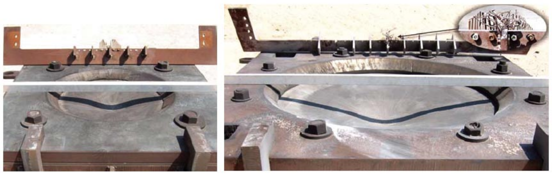

Fig. 2

by the comb-like device, while the residual deflection is measured upon completion of the test, as outlined by the shadow of the metallic ruler in Fig. 2.

The main outcome of this systematic campaign of experiments and numerical calculations was the validation and verification of the scaling concepts for short range, open air explosions that are characteristic of side charges. The same concepts can also be successfully applied to flush buried spherical charges in dry sand. For this, the charge is buried in the sand box underneath the plate.

Here, too, the investigation successfully showed that the buried charge problem can indeed be scaled. Moreover, a very practical result for the designer is that one can 'translate' a flush buried situation into an 'open air' equivalent one, which significantly simplifies the required computer time and resources. At this stage, it is clear that scaling concepts can be successfully employed to characterise the full-scale structural response of an armour plate by means of scaled down miniature models, with a significant reduction of the duration and costs of the design stage.

Another crucial issue is that of the transient peak deflection of the plate in relation to the measured permanent one. In other words, can we infer what was the maximum deflection of the plate during the process when all that is measured after the field explosion is the permanent deflection of the plate? The importance of this point is obvious because it can make the difference between a lethal and a benign explosion. This point was also addressed in this work and a series of results was produced that tie the peak to permanent plate deflections, as a function of the stand-off distance and plate dimensions, using again the scaling concepts developed in the first part.

Quantitative results were obtained that tie the transient and the residual deflection to the size of the charge and the dimensions of the plate. These results can be applied to the characterisation of the actual charge if a record of the deflections is available, but they can also be used to estimate the margins of safety for a particular design in terms of stand-off distance and weight of the charge.

To summarise, the war against surprise never ends. The sophistication and efficiency of improvised explosive devices improves constantly, together with their conditions of operation that create ever varying situations. On the other side, the constant concern for the crew of combat vehicles requires quick and adaptive armour solutions without compromising safety. The development of new armour solutions is quite complex and time consuming, and the study presented here is a first step towards a significant reduction of both the costs and time of the development phase. This collaborative study between academic and defence partners has refined our understanding of structural reaction to large explosions, with emphasis on scaling down the experimental set-up while preserving the accuracy of the predictions, in terms of plate deflection (fracture being excluded). In addition, accurate results were derived that tie the 'post-mortem' measured deflection to the transient peak deflection, which is a very dangerous phase to the crew, although being usually quite difficult to predict accurately.

These results are easily implemented into design procedures based on numerical simulations, and the experimental validation phase relies on miniature models that are readily assembled and tested. From here, the full structural behaviour can be faithfully predicted, while minimising the use of empirical 'rules of thumb' and cutting down dramatically the number of full-scale experiments to be carried out. Basically, the experimentation phase is largely transferred from the proving ground to the computer model, allowing a rapid reaction to new threats. In other words, you 'scale down' the problem experimentally and 'scale it up' numerically. Such progress brings us one step closer to the 'virtual experimentation phase' that is the ultimate dream of many engineers and scientists.

Future research will certainly focus on the reaction of the full structure, rather than the generic plate mentioned here, as a guideline for more practical aspects of vehicle design. Additional effort will be likely to tackle dynamic failure and fracture issues that were not included here. To wrap up this research into one sentence, one may say that the assessment of the blast performance of the current and future platforms is under better control.

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