Modelling of residual capacity of slabs damaged by combined impact and blast loading

†*P. Del Linz[1], S.C. Fan[1], and C. K. Lee[2]

[1] School of Civil and Environmental Engineering, Nanyang Technological University, Nanyang Avenue, 639798 Singapore.
[2]School of Engineering and Information Technology, University of New South Wales Canberra, Northcott Drive, Campbell, ACT, Australia, 2600
†*Presenting and corresponding author: paolo@ntu.edu.sg

Abstract

Several tests were performed loading 200 mm thick concrete slabs on the ground with combined shrapnel impact and blast pressure waves. Cylindrical TNT charges 8.9 kg in weight at 2.1 m stand-off were used to generate the blast loads and propel steel ball bearings to generate the impact loads. The damaged slabs were then tested quasi statically in 3 point bending to measure their residual capacity. In this research, the Ls-Dyna finite element analysis (FEA) software was employed to simulate both the dynamic and the quasi static parts of the experiment, with the aim of reproducing the recorded residual capacities. Solid elements were used for all the structural components of the model and appropriate failure conditions were employed to represent the dynamic damage. Additionally, a slip condition was included between the concrete and the steel reinforcement. Results showed that the peak residual capacity could be adequately represented using theses FEA models.

Keywords: Impact, Blast, Concrete, FEA

Introduction

The resistance of military and civilian structures to blast threats is of increasing importance to designers. Whilst concrete elements are well suited to resisting blast pressure loads, they exhibit significant more susceptibility to shrapnel impact loading [1, 2]. Some experimental programs have been performed to estimate the effect of combined blast and fragment loading on concrete slabs. These included subjecting concrete elements to bare and cased charges to compare the relative levels of damage [1], using steel fragments to inflict impact damage on slabs which were then quasi statically tested [3, 4] and producing models to simulate dynamic damage levels [2, 5]. Experiments were performed loading slabs on the ground using steel ball bearings placed on the underside of cylindrical charges. The damaged slabs were then quasi statically tested to measure their residual capacity. The aim of this research was to utilize the data collected in these experiments to produce finite element models which could simulate both the dynamic loading phase and the quasi static tests. These will then be able to be used to design more efficient structures to resist this type of threats.

Method

Experimental program

The concrete samples used in the experimental program consisted of slabs 200 mm thick and 1.6 m × 0.8 m in planar dimensions. The slabs considered for further analysis were all reinforced using 12 no. 6 mm diameter reinforcement bars in the longitudinal direction and 9 bars of the same diameter in the transverse direction. The reinforcement mesh was placed both on top and on the bottom surfaces. The concrete grades varied between 32 and 45 MPa cube strength. TNT cylindrical charges between 8.85 and 8.92 kg in weight were used to load the samples at a stand-off of 2.1 m. 8 mm diameter ball bearings were placed underneath the charges to produce the impact loading. For the quasi static tests the samples were placed on supports providing a 1.4 m clear span and were loaded using a flanged beam. Both undamaged and damaged slabs were tested to produce estimates of the original and residual capacities. Central deflection and total load data were recorded.

Full FEA model

The finite element model of the system was produce using LS-Dyna. 3D elements were used for all the model components, except for the ground which was modelled using 2D shell elements. The material properties recorded for the test components were used during modelling. The concrete part employed the CSCM material model available in the LS-Dyna software [6]. The automatic parameter generation option was used, as only the cube capacity of the samples material was known. The steel ball bearings were modelled using a Johnson Cook material model, as the rate sensitivity of the material was deemed to be relevant to the models given the high speed of the loading. The parameters for this were obtained from Shrot and Baker [7]. The reinforcement bars were modelled using a plastic kinematic material model [8]. A slip condition was also simulated between the reinforcement bars and the concrete. A tie break contact was employed for this, using parameters obtained from Bao et al. [9].

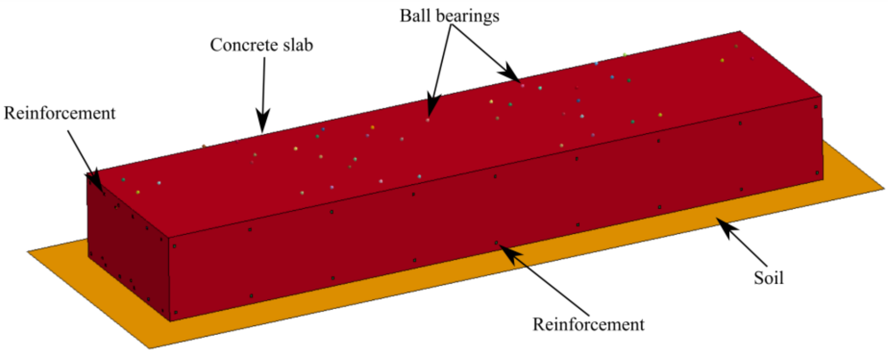

Figure 1: FEA model including the ball bearing parts.

The fragment loading was simulated by modelling the ball bearings and assigning to them an initial velocity using the experimentally recorded speeds. The blast pressures were then simulated using the LOAD_BLAST command in LS-Dyna, which simulated a varying pressure applied on the surface of the slab. The model including the ball bearings is shown Figure 1.
After this, the boundary conditions were changed, eliminating the ground and introducing the steel supports. The loading rigid parts were introduced and the slab was loaded at a speed of 0.133 m/s. The reaction forces were measured in the model to compare with the experimental results.

Results and discussion

The quasi static analysis method was firstly tested for a non-damaged slab case. The peak capacity and general behavior of the slab were captured by the FEA model, which however showed an increased initial stiffness and premature failure of the reinforcement bars.
After the quasi static modelling technique had been tested, the 3D model was loaded dynamically. The observed damage was superficial and similar in extent to that seen during the experiments, as shown in Figure 2. The quasi static results are shown in the same image. Again the peak residual capacity was captured by the simulation as well as the more gradual failure. However, the initial stiffness and displacement at failure were different than seen in the experiments.

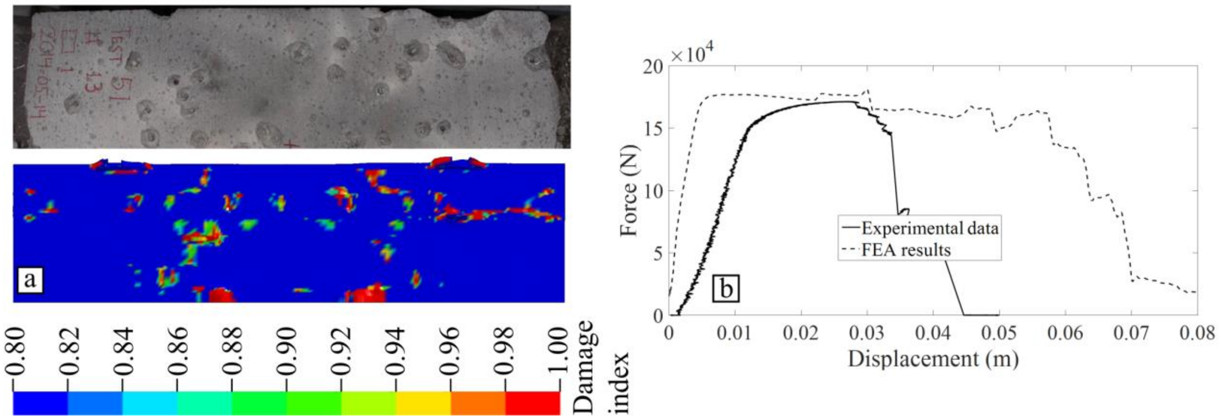

Figure 2: (a) Dynamic damage on a typical slab. The FEA results show a similar damaged area to the experimental pictures. (b) Quasi-static force-displacement results.

Conclusions

Three dimensional FEA models were created to simulate the combined impact and blast pressure loading on concrete slabs resting on the ground. The damaged concrete slabs were then used in further analyses to measure their residual capacity through quasi-static three point bending tests. The dynamic and quasi static results were compared with experimental results, including the capacity of an undamaged slab. The FEA model could capture the peak quasi-static capacity of the elements, though other aspects, such as the initial slab stiffness and exact failure deflection proved more challenging. Further work is being performed to improve these aspects. It is hoped that the procedure developed could be used for the design of structural elements subject to combined dynamic loadings, as the peak residual capacity will represent a key design parameter.

Acknowledgments

This research was supported by a research grant provided by the Defence Science & Technology Agency (DSTA), Singapore, under the Protective Technology Research Centre, Nanyang Technological University, Singapore. Any opinions, findings and conclusions expressed in this presentation are those of the writers and do not necessarily reflect the view of DSTA, Singapore.

References

[1] H. Hader (1983), Effects of Bare and Cased Explosives Charges on Reinforced Concrete Walls, Defense Technical Information Center, AD P0011747.

[2] U. Nyström and K. Gylltoft (2009) Numerical studies of the combined effects of blast and fragment loading, *International Journal of Impact Engineering* **36**, 995-1005.

[3] R. Forsén and M. Nordström (1992), Damage to reinforced concrete slabs due to the combination of blast and fragment loading, FOA, B 20101-2.6.

[4] M. Nordström, R. Forsén, and P. S. Bulson (1994), Damage to reinforced concrete slabs due to fragment loading with different fragment velocities, fragment areal densities and sizes of fragments, in *Structures under Shock and Impact III*, PS Bulson ed, Computational Mechanics Publications, Ashurst, pp. 131-138.

[5] J. Leppänen (2005) Experiments and numerical analyses of blast and fragment impacts on concrete, *International Journal of Impact Engineering* **31**, 843-860.

[6] Y. D. Murray (2007), Users manual for LS-DYNA concrete material model 159, Volpe National Transportation Systems Centre and Federal Highway Administration, FHWA-HRT-05-062.

[7] A. Shrot and M. Bäker (2012) Determination of Johnson–Cook parameters from machining simulations, *Computational Materials Science* **52**, 298-304.

[8] J. O. Hallquist, *LS-DYNA keyword user's manual, V. 970*, 2007.

[9] Y. H. Bao, H. S. Lew, and S. K. Kunnath (2012) Modeling of Reinforced Concrete Assemblies under Column-Removal Scenario, *Journal of Structural Engineering* **140**, 04013026.