A Study of RC Beam-Column Against Close-in Blast Loading Using 3D ALE Mapping to S-ALE Technique

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1 Introduction

Mapping technique has been developed to allow the decomposition of a calculation in several steps. The transitions are allowed 1D to 2D/3D, 2D to 2D/3D, or 3D to 3D/2D etc [1], that the data from the model's latest cycle is saved in a binary file and can be mapped into another model using the "map" command in the expression. This technique has a wide range of application since it allows to adjust mesh length or model size, as well as include Lagrangian or Eulerian Parts.

Nicolas et. al.[2] conducted a practical demonstration of the blast wave propagation by utilizing axisymmetric 2D ALE mapped to 3D ALE. It showed that computation time can be saved, and the results met a good agreement. Lapoujade et al. [3] presented an assessment of the efficacy of 2D and 3D mappings in the context of a free air burst. The evaluation specifically focuses on comparing the inclusion of pressure forms and impulse, while varying the ratio of mesh size. The study's findings that a ratio less than 15 is advised if maximum pressure is critical, while a ratio of 20 or less is indicated if impulse is vital.

In this study, a RC beam-column subjected to close-in detonation was simulated using the 3D ALE mapping to 3D S-ALE method. The S-ALE solver was used to reduce the solution time and the memory required, since there was no external mesh generation requirement. A two-stage loading on the RC beam-column that consisted of blast stage and post-blast stage in order to determine its residual capacity. A mesh sensitivity analysis is conducted to assess the various mesh sizes on the S-ALE model and the RC beam-column. The simulation results were compared to experimental blast test.

2 Methodology

A 400mm x 400mm x 3000mm RC beam-column section with header and footer 700mm x 700mm x 500mm was modeled. The cylinder strength of concrete was 32MPa, and the yield strength of rebar was 500MPa. Figure 1 depicts the RC beam-column rebar details. *MAT72R3 material model with constant stress solid element was used to model the concrete, and *MAT24 with Hughes-Liu beam element was used to model the rebar. CBIS (CONSTRAINED BEAM IN SOLID) was used to coupling concrete and rebar. *MAT72R3 strain rate effect was determined using the Comite Euro-International du Beton (CEB) data (CEB 1990)[6], and *MAT EROSION with a maximum principal strain of 0.25 was used. Figure 2 depicts the strain rate effect on the concrete compressive strain of 32MPa.

In the model, two-stage loadings on the RC beam column were analysed, including blast stage and post-blast stage. During the blast stage, the RC beam-column was laid down and placed on a rigid planer and subjected to close-in detaionation. The cylinder-shape TNT charge was placed at a Z-scale distance of 0.24m/kg$^{1/3}$ on the RC beam-column, with a lateral distance of 0.2m from the charge to the edge of footer. The RC beam-column model blast setup is shown in Figure 3.

The blast stage used two steps ALE mapping technique, which saved 3D ALE air blast final step results in a binary mapping file for the S-ALE 3D model. The air and TNT were used *MAT NULL with EOS Linear Polynomial and MAT High Explosive Burn with EOS JWL material models.The charge iginition was done at 0.1ms on a finer mesh 3D ALE half-symmetry model, then mapped to coasrer mesh 3D S-ALE model. The 3D S-ALE air model corresponding to the mesh ratio which are 10,6.7,and 4.2, as well as RC beam-column in this mesh sensitivity study, and the 3D ALE air mapping model fixed mesh size of 6mm in this study. Figure 4 illustrates the air blast pressure distribution contour, which the 3D S-ALE model with the ratio of 4.2. For the Fluid-Structure Interaction (FSI) coupling between the air and RC column, the keyword *CONSTRAINED LAGRANGIAN IN SOLID (CLIS) was employed.

The post-stage load used a full restart deck to remove S-ALE parts and applied axial force with prescribe motion control on the top of the header untill the RC beam-column failure to eveluate its residual capacity. In order to reduce computation run time, half symmetry model was considered in this study.

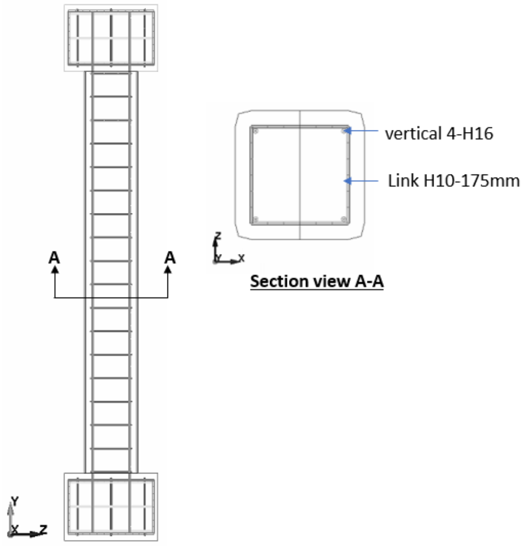


Figure 1: RC beam-column rebar details

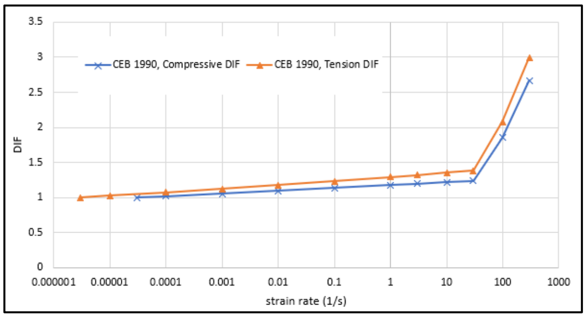


Figure 2: Strain rate effect on the concrete compressive strength of 32MPa

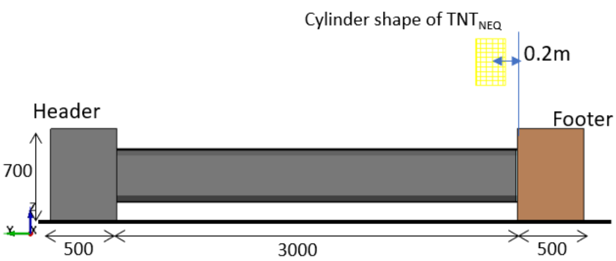


Figure 3: RC Beam-Column blast model setup

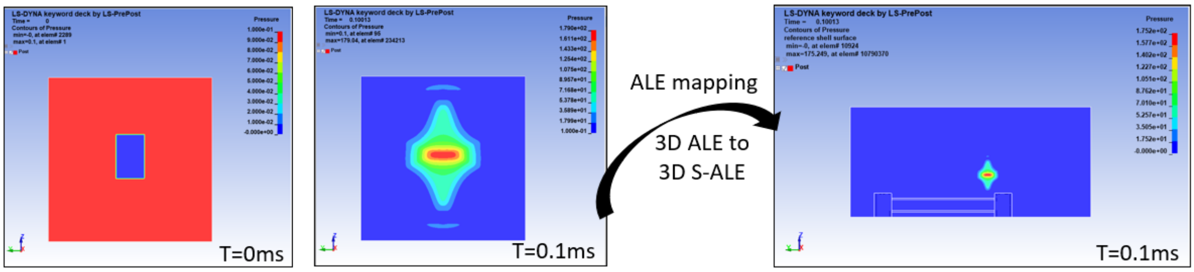


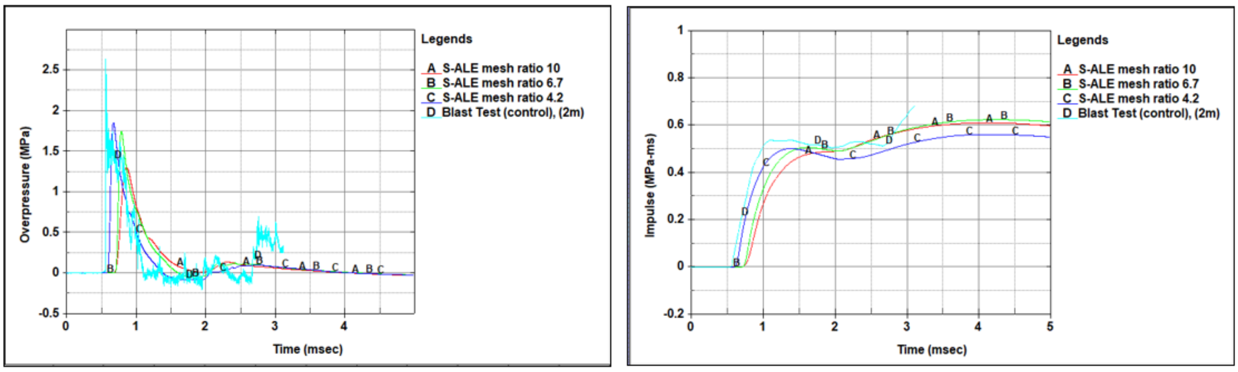
Figure 4: 3D ALE mapping to 3D S-ALE model blast pressure distribution contour

3 Results and Discussions

To study blast wave propagation mesh sensitivity after the mapping. Figure 5 shows that the comparison of various mesh ratio with blast test result, (a)the incident pressure and (b)incident impulse time history measured at 2m from TNT charge after an appropriate time offset. Table 1 presents the comparison peak incident pressure and peak incident impulse relative error percentage at 2m from TNT charge, the comparison baseline is blast test control. The impulse simulation result shows a good accuracy (<10%) with ratio 6.7 and 4.2. However, the pressure simulation result only 30% accurate with mesh ratio 4.2. Decreasing the 3D ALE mapping model mesh size may help to increase the pressure accuracy.

Figure 6 shows the RC beam-column damage comparison between simulation and blast test result against close-in detonation. The occurrence of localized spalling on the surface of the beam-column near the footer was observed after the blast test. The simulation results demonstrate a well correlation with the blast test.

The static experiment compression test of the RC beam-column before blast damage showed an axial force capacity of 5883kN, as a baseline. Table 2 shows the RC beam-column residual capacity remaining percentage after blast damage. The result showed that the RC beam-column axial force capacity was dropped at least 80%. From the simulation results, it had a good correlation with the experimental test results.



(a) (b)

Figure 5: Comparison of various mesh sizes with blast test result, (a)the incident pressure and (b)incident impulse time history at 2m from TNT charge.

Mesh ratio	|Peak overpressure error %|	|Peak incident impulse error %|

10	50.7%	13.4%
6.7	34.0%	5.9%
4.2	29.9%	6.9%

Table 1: Comparison of peak incident pressure and impulse relative error percentage at 2m from TNT charge

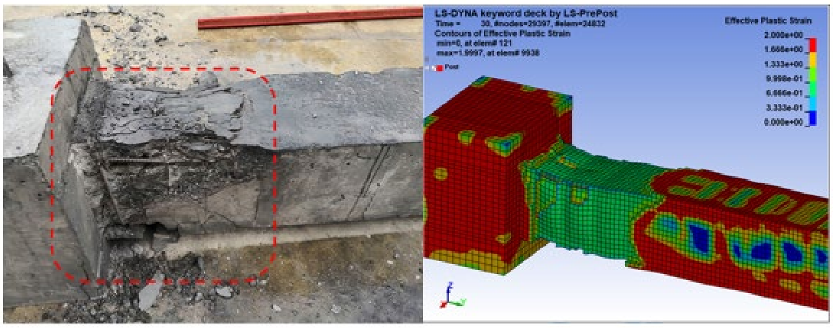


Figure 6: RC beam-column damage comparison against close-in detonation (mesh ratio 4.2)

Descriptions (A)	Residual capacity remaining percentage (A/Fs) %
S-ALE mesh ratio 10, residual capacity	19.6%
S-ALE mesh ratio 6.7, residual capacity	19.2%
S-ALE mesh ratio 4.2, residual capacity	18.3%
Experimental test result, residual capacity	18.6%

RC beam-column static compression test, axial force capacity, Fs = 5883 kN (static experiment)

Table 2: Comparison of RC beam-column residual capacity at post-blast stage

4 Summary

This research presents the development of a reinforced concrete (RC) beam-column model subjected to close-in detonation using 3D ALE mapping to the 3D S-ALE method. Furthermore, a investigation on different mesh ratios was undertaken to assess the accuracy of blast pressure and impulse compare with blast experimental test. The impulse exhibited a satisfactory level of accuracy, measuring below 10%, for mesh ratios of 4.2 and 6.7. However, the accuracy of pressure measurements was found to be only 30%.

The simulation model also performed a post-blast analysis to evaluate the residual capacity of the RC beam-column. The presence of localized spalling was seen on the surface of the beam-column in close proximity to the footer. Furthermore, the residual capacity of the beam-column was determined to be around 20% of its original capacity. The simulation findings shown a good correlation with the experimental blast test.

5 References

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