Using LS-DYNA MM-ALE capabilities to help design a wall mitigating accidental blast effects

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Abstract

A solution had to be found in order to protect buildings neighboring an industrial site from the blast effects of possible accidental explosions on the site. One of the main issues was that the point of detonation would occur relatively close to the endangered buildings.

A possible answer was to build a blast-mitigating wall between the buildings and possible blasts. The MM-ALE features of LS-DYNA provided a way to evaluate the effects of the wall on the pressure waves around the building. As the amount of explosive was rather small when compared to the distances involved, the new 2D to 3D and 3D to 3D re-mapping methods came in handy to avoid the use of an impractically large numerical model.

After a first series of computation showed that the proposed solution was indeed promising, a series of simulation runs enabled the design of a wall tall enough to achieve the desired mitigation effect on the pressure waves experienced by the building's walls and roof.

Motivation

On a storage and treatment facility for hydrocarbons, the blast effects from accidental explosions could endanger neighboring buildings. The facility itself was large and neighbored by many other buildings but an earlier risk assessment study had determined that only a few, closer to the facility and less sturdy than the others were in real jeopardy. The earlier study had also determined the TNT equivalent levels for the possible accidental situations and concluded that the maximum possible equivalent was only a few kilograms.

The most dangerous situation were created by transportation of the explosive materials in or out of the facility as the trains run almost immediately on the border of the facility and accidental explosions at this location will thus create the largest loads on the neighboring buildings.

A potential solution to the problem was the building of blast-mitigation wall, located at the edge of the facility and shielding the neighbors from the full force of the blast. The validity of this idea had to be tested first as the potential effect of the presence of such a wall on the blast propagation were not initially accepted by all.

Scope of the study

The study was organized in three phases. A first phase attempted to determine the feasibility of a wall-based solution to mitigate the effects of an accidental blast occurring in a freight car on the closest buildings. A second phase was meant to determine the necessary height the wall had to be to efficiently protect the buildings. Finally, a third phase dealt with the structure of the wall itself which had to withstand the effects of the blast.

Numerical solution

The initial problem was to guarantee that the proposed wall would be efficient to protect the vulnerable buildings from explosions occurring anywhere on the facility. It soon became apparent that the only risk to each individual building was from explosions occurring close to it. In order to evaluate the protection a wall would afford to the buildings, it was necessary to use the MM-ALE capabilities of LS-DYNA as the analytical formulas (implemented through the *LOAD_BLAST and *LOAD_BLAST_ENHANCED keywords) are unable to take masking structures into account. The main issue with this was a difference in scale between the explosive itself (a few kilograms of TNT in a sphere shape) and the complete domain which had to be on the order of 10 meters on a side to incorporate the explosion center, wall and areas of interest on the buildings.

The recent possibility to perform 2D MM-ALE simulations in LS-DYNA and to map the results of one ALE run to another enabled to overcome this difficulty. Whereas a single MM-ALE grid, with a mesh density sufficient to correctly represent the initial pressure wave formation around the explosive and covering all areas of interest would have counted billions of elements, a 2D mesh of the initial propagation of the blast around the explosive (actually a mesh of the complete area where the blast kept a 2D geometry) was about sixty thousand elements.

The results of this first 2D simulation run are then mapped onto a 3D mesh. This mapping wasn't directly performed onto the final mesh taking all areas of interest into account as this final had to be about 20 times coarser than the initial mesh to remain at a manageable level in terms of model size (i.e. in the million element area). The information loss during a direct mapping where element sizes differ so much results in significant decrease of the pressure peaks measured in the ALE elements. This, in turn, would obviously have led to a risk of under-estimating the loads and risks to the buildings at risk. Because of this, the mapping was first performed to a 3D mesh with elements about four times larger than the 2D ones used in the first run and limited in size. Results from this second mesh were later mapped to the final (full) mesh of the complete case. This two-step strategy, using mappings between meshes where sizes differ by a factor of four or five alleviates the risk of altering the pressure signal during the mapping.

The buildings and wall could have been meshed as lagrangian structures coupled to the fluids through the use of the *CONSTRAINED_LAGRANGE_IN_SOLID keyword but, given the simple geometries to be studied, they were modeled as boundary conditions imposed directly on the eulerian mesh. This has two major advantages : the quality of the coupling between fluid and structure doesn't have to be checked and the model operates at a much larger timestep, reducing computation costs very significantly.

Results

The initial simulated configurations were meant to assess the effect of a wall on blast propagation and were simply intended to provide an idea of the gains associated with the wall's presence at various points on the first affected wall of a building affected by the blast. The wall used in these initial numerical tests was 7 meter high.

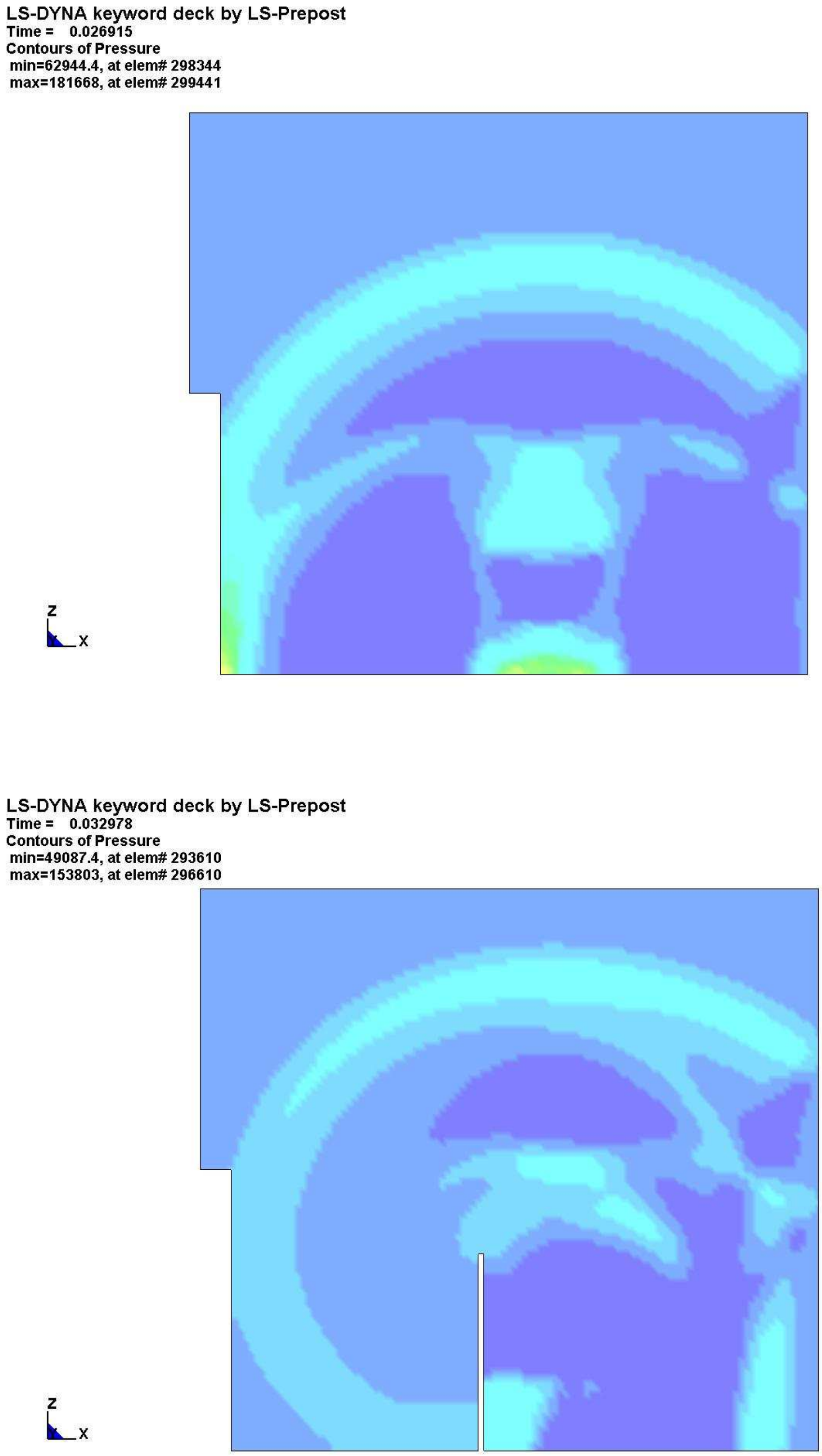
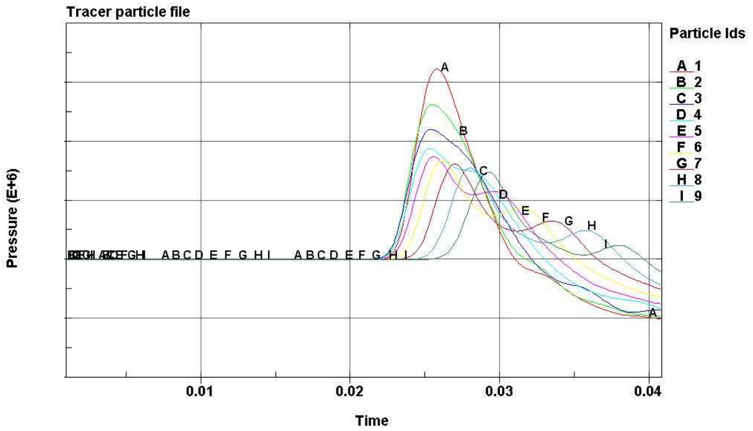


Figure 1: Initial results without (top) or with (bottom) wall



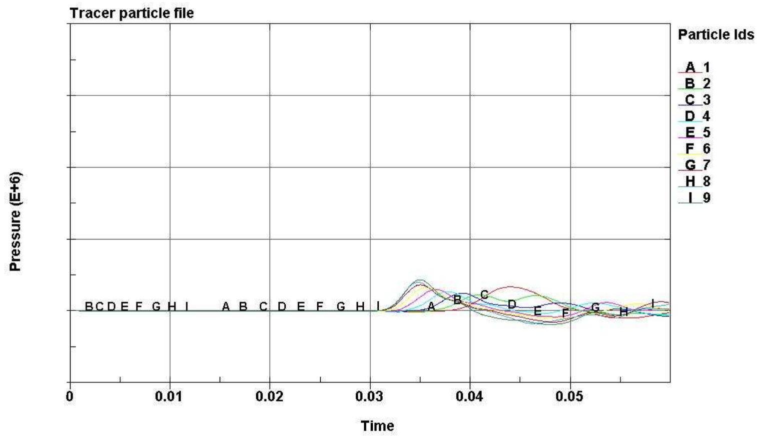


Figure 2: Initial results without (top) or with (bottom) wall

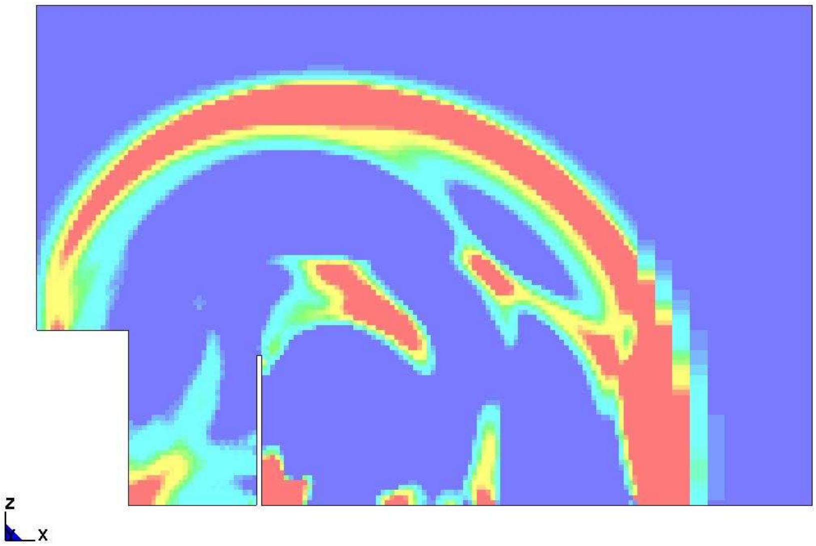
These first simulations do show a very strong effect of the wall on the pressure levels: the peak pressure, measured at the foot of the building wall, in front of the detonation point decreases by a factor of about eight. These results were good enough to call for further work on the design of the wall.

The most important factor in the wall performance as a blast-wave mitigation device was obviously his height. The higher the wall, the better it would shield the buildings from the blast. The effect is particularly important on the roof of the buildings closer to the hazardous facility.

Two buildings were particularly critical and their exact configurations had to be both tested as one was higher than the other but located slightly farther from the potential detonation points.

For each of the two buildings, walls ranging in height from 4 to 8 meters were simulated. The initial risk study had set peak pressures that were not to be exceeded for the building's integrity to be preserved. These pressure levels were the targets that were set for the protective effect of the wall to provide.

For both buildings, the simulations show that only the 8 meter high wall is able to reduce the blast effect to a level that can be thought of as non dangerous to the buildings.



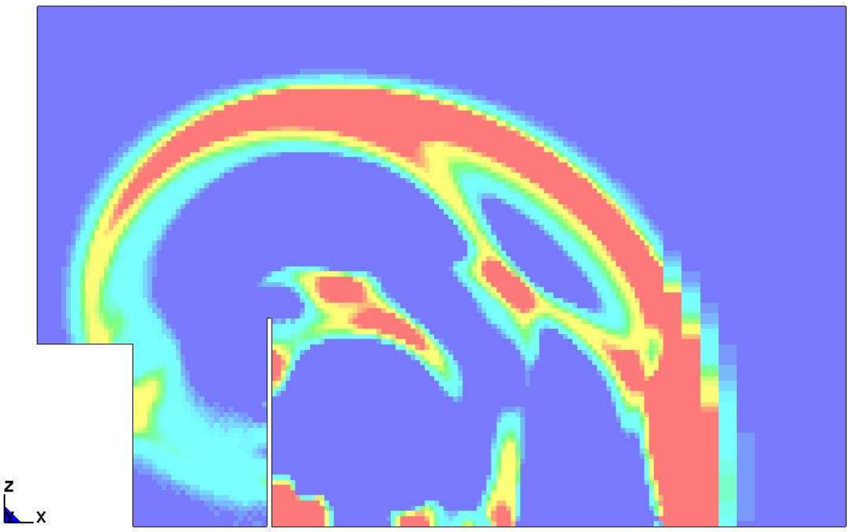


Figure 3: Pressures around front and top of building 2 for 4 (top) and 8 (bottom) meter high walls

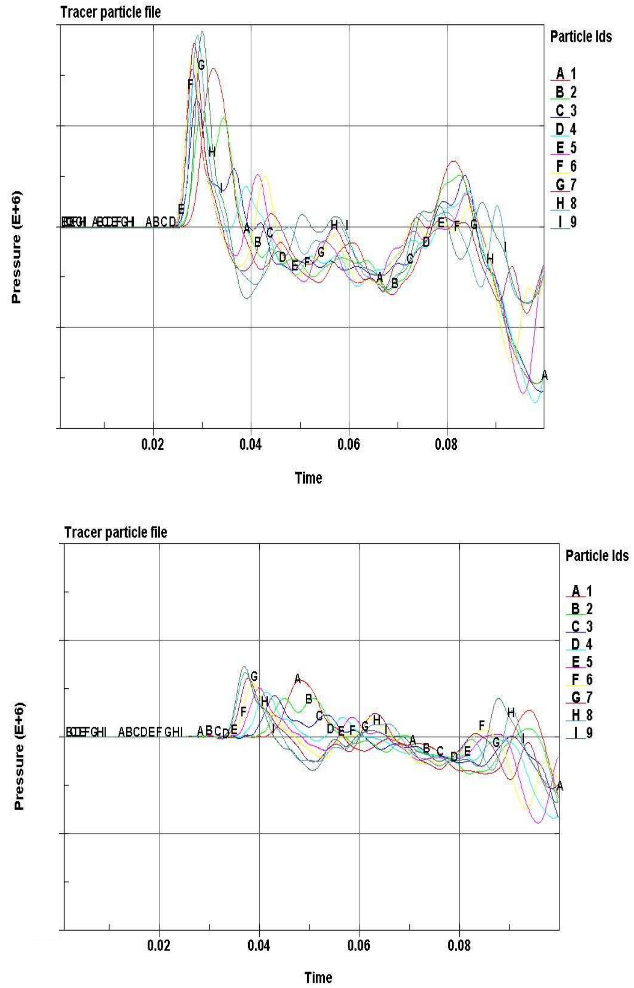


Figure 4: Pressure loads on the front wall of 1st building for 4 (top) and 8 (bottom) meter high wall

For instance, the two curves in figure 4 show that going from a wall 4 m high to one 8 m high reduces the peak pressure experienced by the front wall of one of the two buildings by a factor of slightly less than 3.

Conclusion

This study has shown that the use of the recently developed 2D ALE and re-mapping technologies enable the use of the MM-ALE method in LS-DYNA to manage even large scale computations by using a series of progressively larger grids. In addition to the usual precautions associated with the use of the MM-ALE method, care also has to be taken during the re-mapping phase as excessive differences between the mesh sizes will blunt out the signals to be studied.