LS-DYNA® ALE Modeling of Blast in an Urban Environment

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Abstract

In LS-DYNA finite element analysis software, Arbitrary Lagrangian Eulerian (ALE) approach can be applied to modeling dynamic loading due to explosives. The main advantage of this method is its good accuracy as it explicitly models the explosive and the pressure wave propagation through the media. However, this approach typically requires using very fine meshes in order to accurately model problems characterized by high peak pressures as mesh refinement in the close vicinity of the explosive can be crucial for obtaining accurate results. In this work, the effects of an air blast in an urban environment are examined using a simple geometric model of a street intersection configuration typical of a city business district. Accuracy and mesh sensitivity of the results in terms of the peak pressures at certain gauge points are investigated. The modeling approach is verified by comparing the numerical results from the finite element models to experimental data found in the literature.

Introduction

A series of experiments of blast events for several generic street configurations have been previously conducted and reported in [1-2]. In addition, LS-DYNA simulations have been performed for one of those configurations, namely the dead-end configuration [3]. In the experiments, 1/50th scale models of several typical street intersections were built using steel plates. In those models, the street width was 0.3 meters (corresponds to 15 meters at full scale), and the buildings height along the street was 1 meter. The applied explosive charge was 11.13g SX2 plus approximately 1g detonator, which is equivalent to about 12-13 grams of TNT, and was detonated at 25 mm above ground, which at a full scale would correspond to a vehicle bomb of approximately 1625 kg TNT.

In the current work, we focus on two important street configurations – the dead end, and the crossroads. In each case, we provide simulation results by LS-DYNA using two finite element models with different mesh densities and validate these results by comparing to the experimental data from the literature. Plan views of the two street configurations are shown in Figure 1. Here, the top view of the models is given for the dead end (left) and the crossroads (right) along with the approximate location of gauge devices. In each case, due to symmetry of the problem, only a part of the physical domain has to be explicitly modeled in numerical simulation as schematically shown in the figure. Thus, by applying the appropriate symmetric boundary conditions, only half of the whole physical domain has to be explicitly modeled for the dead end configuration and only 1/8th for the crossroads.

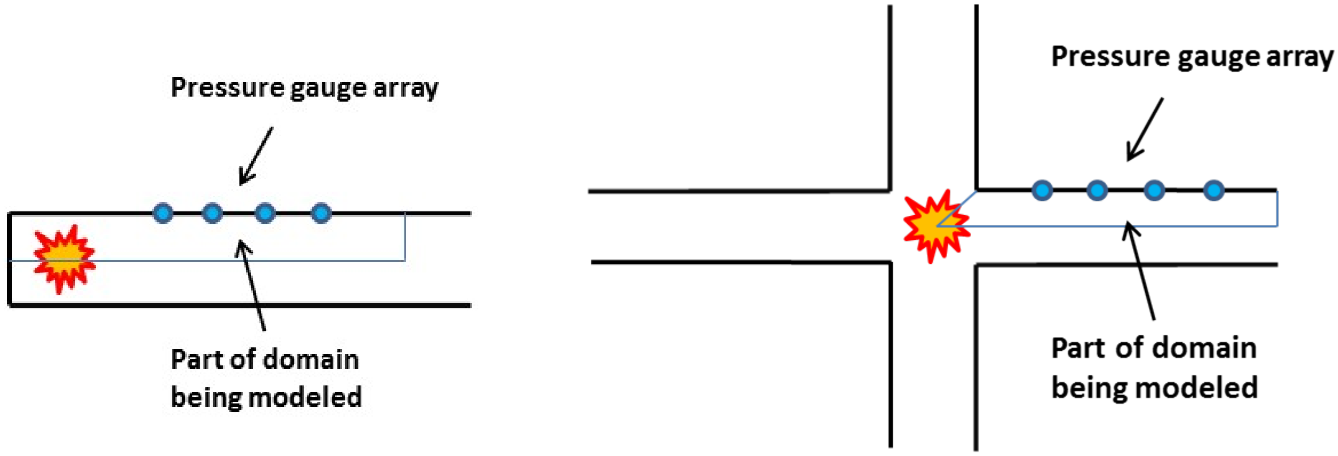


Figure 1: Schematic of the two test configurations for blast in an urban environment: Dead End (left) and Crossroads (right).

A side-view schematic of the experimental set-up and pressure gauge locations used in [1-2] for the crossroads configuration is shown in Figure 2. A similar set-up was also used for the dead end configuration. There are three arrays of gauges attached to the side wall: 4 horizontal (H1 to H4), 4 vertical (V1 to V4), and 4 on a diagonal line at 45 degrees (D1 to D4), making a total of 10 gauge points since locations of gauges H1, V1, and D1 coincide.

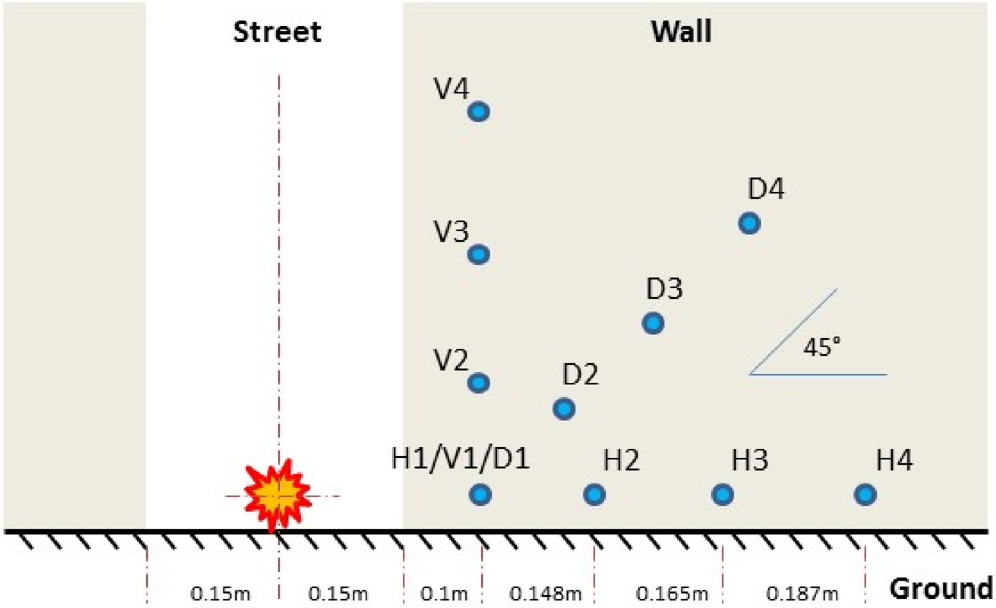


Figure 2: Schematic of experimental set-up and gauge locations.

Dead End Configuration

In order to resolve the highly localized pressure wave in the vicinity of the explosive and obtain good correlation with the test data, two finite element models with different mesh densities are employed in this study. The first model covers domain of a larger size and allows to study the response at all the gauge points shown in Figure 2. However, due to the relatively large domain size this model has limited capabilities in terms of the mesh refinement. The second model employed in this study covers a smaller domain size, which includes only one of the gauge points (H1 – the closest to the explosive) but uses the finest mesh possible in order to achieve the best resolution in the area. The two models – large and small, also identified here as Model 1 and Model 2 correspondingly, are schematically demonstrated in Figure 3, where they are shown on top of each other along with the locations of the explosive and the gauge point H1.

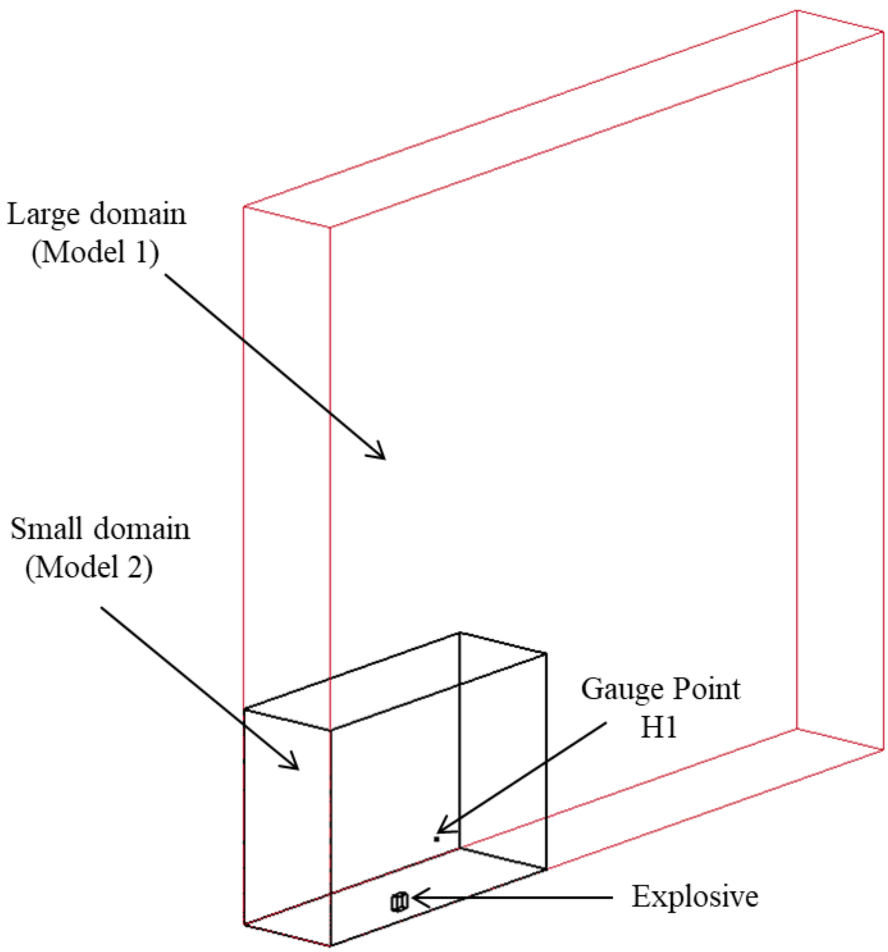


Figure 3: Two finite element model domains for the Dead End configuration.

The large domain length (in x-direction) is 1.15 m, the width (y-direction) is 0.3 m, and the height (z-direction) is 1 m. The small domain length is 0.45 m, width 0.3 m, and the height is 0.3 m. Both models have variable mesh density so that they have the highest node density near the location of the explosive. Model 1 has the smallest element size of 1.25 mm, and Model 2 – twice smaller at 0.625 mm. The total mesh size is 4.08 million elements for Model 1 and 6.6 million elements for Model 2.

LS-DYNA simulation results obtained from the two finite element models are demonstrated in the figures below. First, Figure 4 shows pressure contour plots at four moments of time obtained for the large domain from Model 1. These results give a good qualitative idea about blast pressure propagation through the whole domain as well as general behavior including wave interactions with the rigid walls, which result in dramatic pressure concentrations as well as tunneling effects.

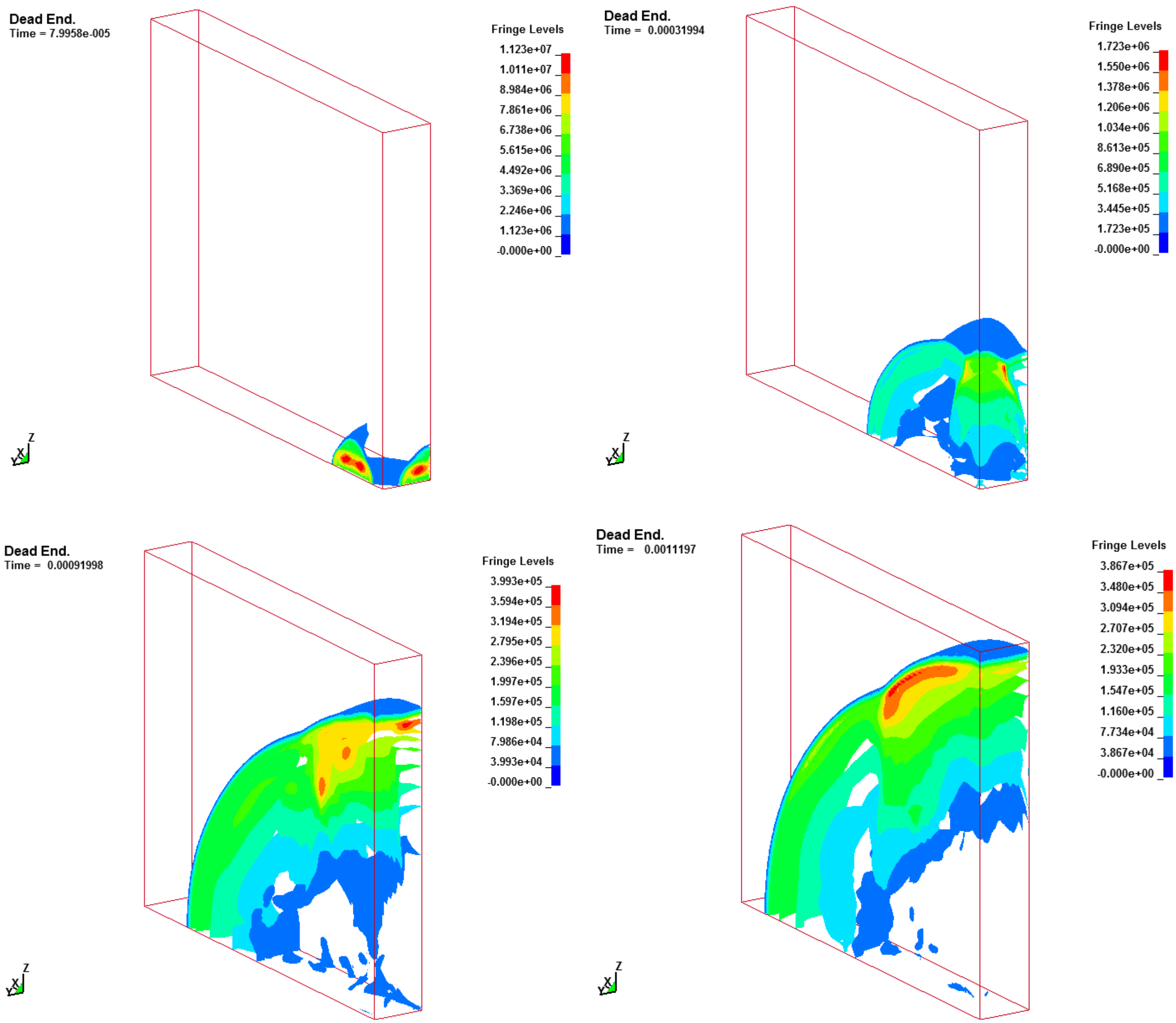


Figure 4: Pressure contour plots, Dead End configuration, Model 1 (large domain).

Pressure histories observed at point H1 are demonstrated in Figure 5 for the simulations using Model 1 (left) and Model 2 (right). It can be seen that the peak pressure at H1 is considerably higher for Model 2 than for Model1. This can be explained by the sharp, highly localized front of the shock wave as well as the gauge point H1 being too close to the explosive. In this case, finite element simulation results tend to be highly mesh-dependent and provide higher peak for the finer mesh size. A summary of the results for all the gauge points is given in Table 1. Here, experimental and current simulation data for peak pressure is presented. Simulations for Models 1 and 2 correspond to the large and small domain solutions. Experimental results are from reference [1].

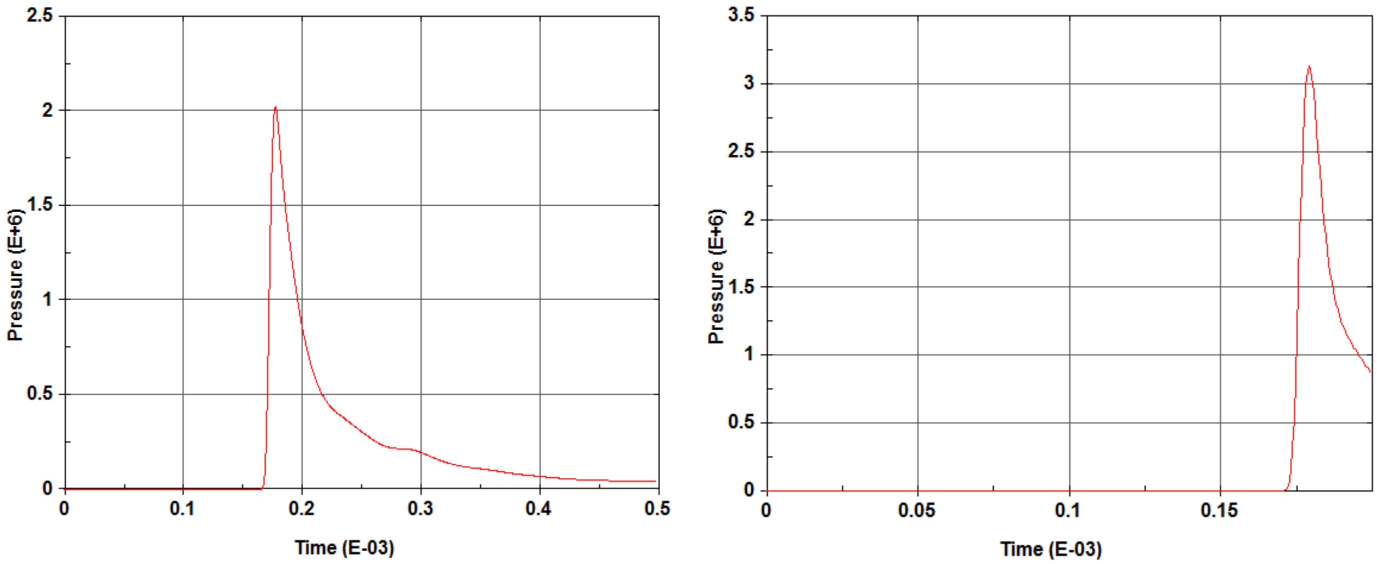


Figure 5: Pressure histories at point H1 from Model 1 (left) and Model 2 (right).

Table 1: Experimental and current simulation data for peak pressure at all gauge points.

Gauge set	Location number	Peak pressure (kPa)		
		Model 1 Large domain 4 million elements	Model 2 Small domain 6.6 million elements	Experiment
Horizontal (H)	1	**2026**	**3142**	**3210**
	2	606	-	1352
	3	325	-	570
	4	200	-	363
Vertical (V)	1	**2026**	**3142**	**3476**
	2	830	-	1672
	3	471	-	679
	4	270	-	760
Diagonal (D)	1	**2026**	**3142**	**2612**
	2	648	-	1297
	3	354	-	468
	4	218	-	398

Regarding comparisons to the experiment, it has to be noted that a high level of variability was observed in the test data in [1]. For example, experimental values measured for the peak pressure by three different gauges H1, V1, and D1 (see Table 1, Experiment, bold) vary considerably although the three gauges were placed in the same physical location. The average of the three experimental values (3210, 3476, and 2612) for point H1/V1/D1 is 3099 kPa. This compares very well with the value of 3142 kPa obtained from the more accurate Model 2 with a deviation between the simulation and the experiment of only about 1.4%.

Crossroads Configuration

Similarly to the case of Dead End configuration described in the previous section, two different finite element models (Model 1 and Model 2) with varying mesh densities are employed in this study. Model 1 is a large scale but not very fine mesh model, which is used to model a larger domain that includes all the gauge points, while a finer mesh but smaller domain size model (Model 2) is applied to obtain more accurate values at gauge point H1, which is the closest to the explosive.

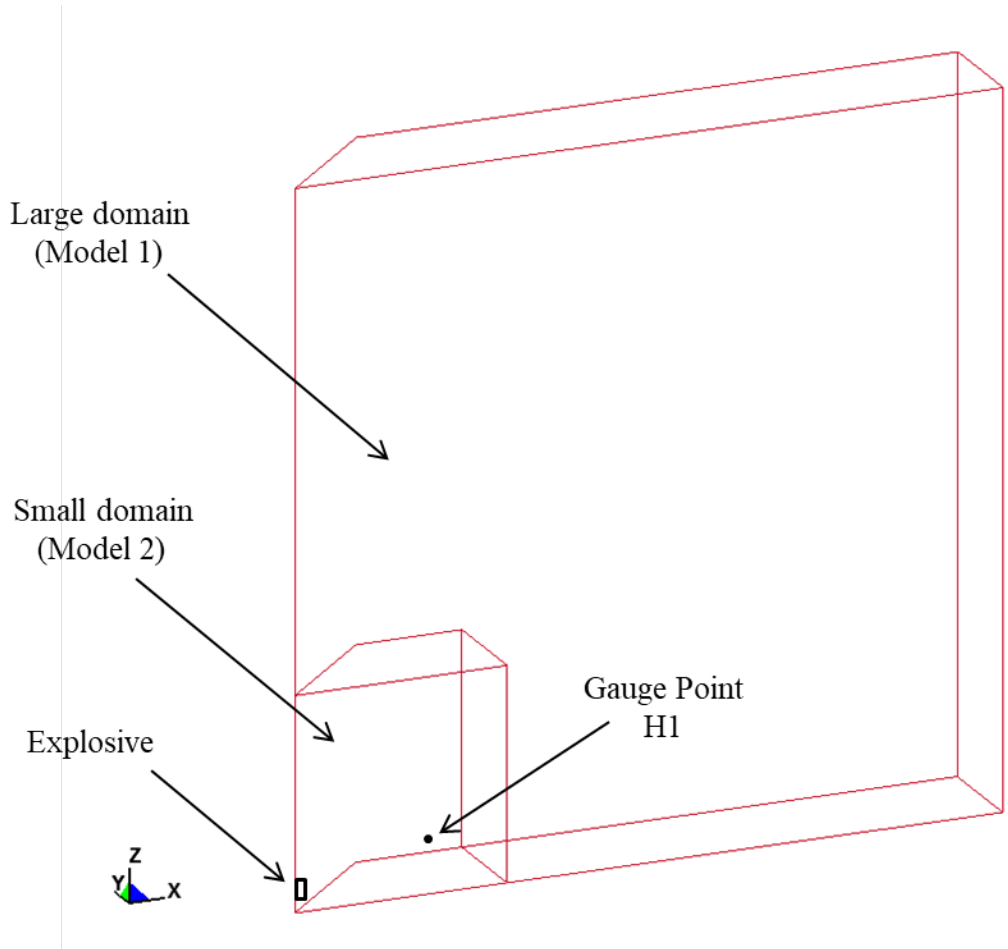
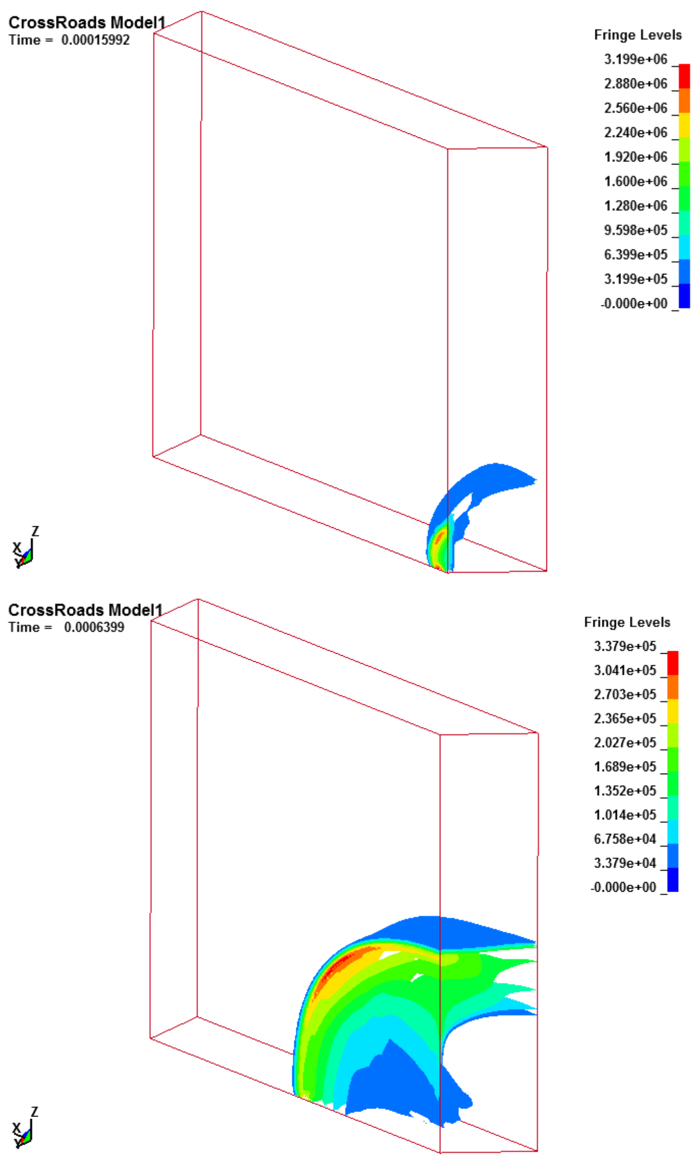


Figure 6: Two finite element model domains for the Crossroads configuration.

The two models are demonstrated in Figure 6. Here, the two domains are shown on top of each other along with the locations of the explosive and the H1 gauge point. The large domain's length (in x-direction) is 1 m, the width (y-direction) is 0.15 m, and the height (z-direction) is 1 m. The small domain's length is 0.3 m, width 0.15 m, and the height is 0.3 m. In terms of discretization, Model 1 has a total of 1,020,000 solid elements and Model 2 has 5,020,000 elements. In each case, the element size varies over the domain, with the finest mesh found near the explosive. The smallest element size is 2.5mm for Model 1 and 0.75mm for Model 2. In order to make computations more efficient, the approach takes advantage of the symmetry of the crossroads configuration by modeling only 1/8th part of the physical model. This is achieved by applying symmetric boundary conditions to the two sides adjacent to the explosive.



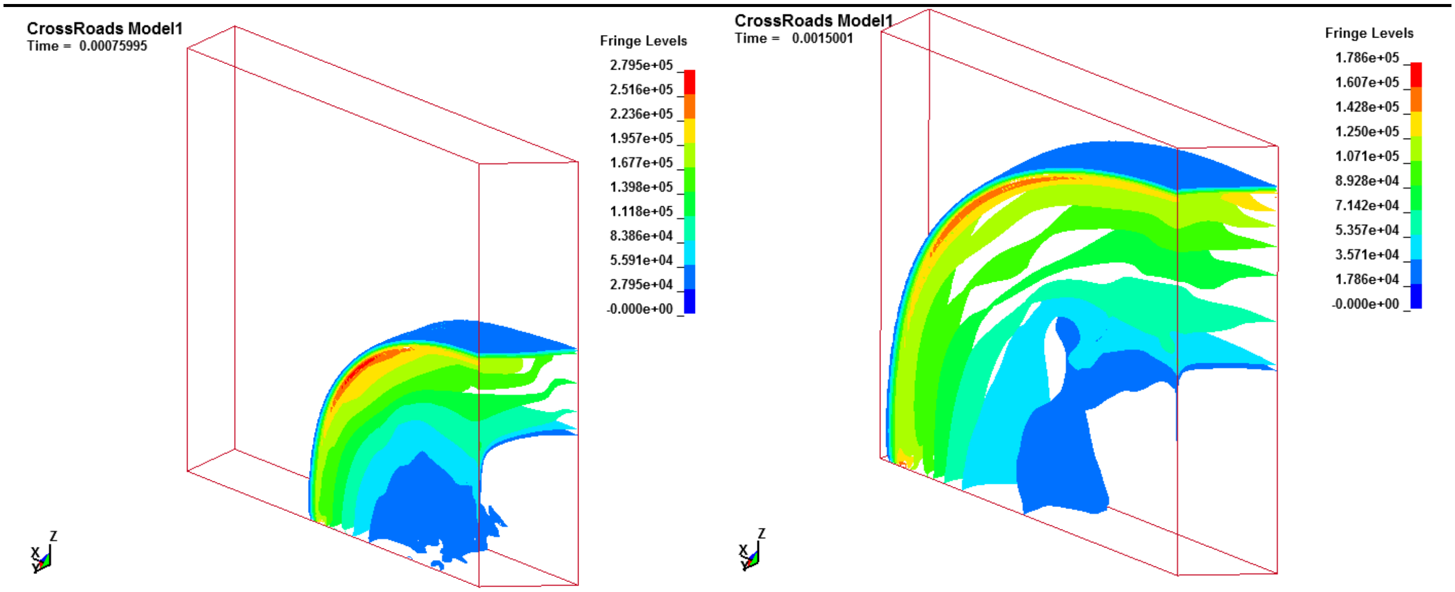


Figure 7: Pressure contour plots, Crossroads configuration, Model 1 (large domain).

Simulation results using Model 1 are graphically illustrated in Figure 7, where pressure contour plots are shown at four moments of time: shortly after the explosion, in the middle of the simulated time duration, and at the end, when the blast wave is about to reach the far end of the modeled domain. The plots correspond to 0.16, 0.64, 0.76, and 1.5 milliseconds after the explosion. High pressure areas can be seen at the rigid wall where the gauge points are located. Pressure history plots for point H1 are shown in Figure 8. Similarly to the case of the Dead End configuration, the peak pressure at H1 is considerably higher for Model 2 than for Model1. This is due to the highly localized pressure wave, which results in severe mesh-dependency of the finite element solution.

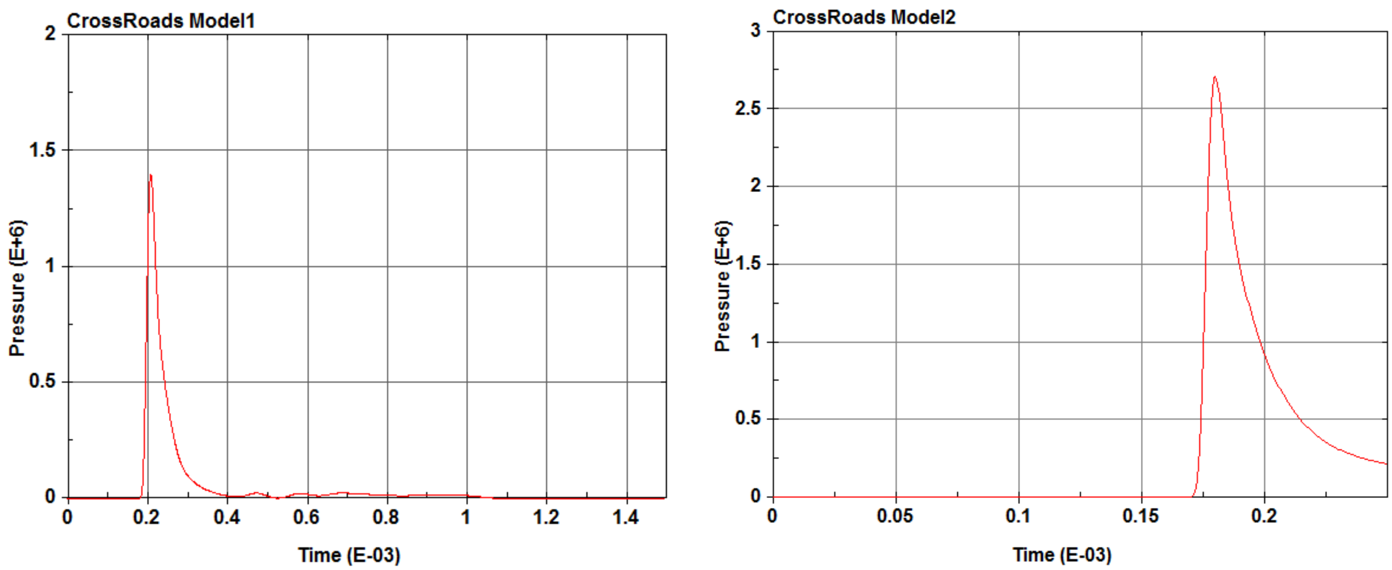


Figure 8: Pressure histories at point H1 from Model 1 (left) and Model 2 (right).

Table 2: Experimental and current simulation data for peak pressure at all gauge points.

Gauge set	Location number	Peak pressure (kPa)		
		Model 1 Large domain 1 million elements	Model 2 Small domain 5 million elements	Experiment
Horizontal (H)	1	**1405**	**2714**	**2281**
	2	483	-	728
	3	225	-	312
	4	135	-	224
Vertical (V)	1	**1405**	**2714**	**2432**
	2	1099	-	1272
	3	398	-	472
	4	217	-	252
Diagonal (D)	1	**1405**	**2714**	**3613**
	2	650	-	921
	3	352	-	402
	4	227	-	238

A summary of the results for all the gauge points is given in Table 2, which presents both experimental and current simulation data for the observed peak pressure values. Simulations using Models 1 and 2 correspond to large and small domain sizes respectively. Experimental results are from reference [1].

When comparing experimental and simulation data from Table 2, it is important to remember that a high level of variability was observed in the test data in [1]. For example, experimental values measured for the peak pressure by three different gauges H1, V1, and D1 (Table 2, Experiment, bold) vary considerably although the three gauges were placed in the same physical location and each of them represents an average of several firings. Furthermore, experimental values shown in Table 2 and taken from Ref. [1] are somewhat different from the the values observed in Ref. [2] for a similar experiment. The average of the three experimental values from Table 2 (2281, 2432, and 3613 kPa) for the point H1/V1/D1 is 2775 kPa. This compares very well with the value of 2714 kPa obtained from the current simulations using Model 2 with a deviation between the simulation and the experiment of only about 2.2%.

Conclusions

In conclusion, it can be noted that finite element simulations using LS-DYNA can give very accurate solutions (with deviation from the experiment of just a few percent) even when modeling blast events characterized by sharp shock waves and highly localized pressure profiles. However, the solutions tend to be severely mesh-dependent and require considerable effort (and computational expense) in applying models with appropriate mesh sizes in order to obtain good quantitative agreement with experimental data. While solutions obtained using less accurate models may not achieve the desired quantitative accuracy, they still may be useful for general qualitative description of blast wave propagation phenomena important for urban environments, such as pressure concentrations, wave reflections, tunneling effects, and others.

Acknowledgment

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References

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