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Parametric Study of Blast Loads on Masonry Wallusing Hydrocodes

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Abstract: *The recent rise of terrorist attacks has reinforced the need for mitigation of damage caused by blast loading on unreinforced masonry walls. The failure of masonry walls has been widely witnessed even in low magnitude blasts. The failure of masonry often leads to flyingdebris resulting in loss of life and disabilities/injury to many people. The primary goal of the techniques is to prevent the loss of life while simultaneously preserving the integrity of the structure. This paper presents theparametric study of blast loads on confined masonry dry-stacked masonry walls by using numerical techniques. It seeks to present the state of the art analytical hydrocodes such as ANSYS-AUTODYN. The results have been obtained for the charge weight parameter of the explosivewith the blast analysis. Some parametric studies of field interestwere also carried out for understanding the behaviour of masonry walls against blast loads andderiving some useful conclusions. The numerical simulation technique can provide a theoretical referencefor the design of walls and may help in reducing the requirement of extensive testing. The most significant parameter for assessing the severity of damage in structures under blast loads is the scaleddistance. It has been demonstrated that the use of confined dry-stacked masonry walls offers great potential walls to resist low or moderate blast loads and contain flying debris.*

Keywords: *Hydrocodes, Autodyn, Masonry, Blast loads.*

1. Introduction:

Recent rise in terrorist activities around the globe have attracted attention of engineers and scientists towards the vulnerability of buildings and infrastructure to blast loads. The consequent effects of these loads may range from minor damage to structural collapse accompanied by huge loss of life. The masonry, which is the oldest and the most widely used building material [1–3] either in masonry buildings or in the form of infill walls in reinforced concrete (RC) framed buildings, suffers most damage. Even if there is no complete damage or structural collapse, the flying debris may cause significant loss of lives or injuries. As a result, efforts were made by several investigators to examine feasible methods for strengthening masonry walls in order to enhance their resistance to blast loads. Although several techniques have been tried but one of the most popular methods of retrofitting unreinforced masonry (URM) walls is the application of fiber reinforced polymers (FRP) to its surface. As the blast causes a pressure to be exerted on the surface of a wall, the flexural resistance of the wall needs to be enhanced. The applications of externally affixed FRP materials have been shown to improve the out-of-plane bending resistance of walls.

Many investigators have used externally applied FRP strips for the retrofitting of URM walls against lateral static loads and found these to be effective in increasing the load carrying capacity. Dennis et al. [4] conducted blast experiments on one-quarter scale concrete masonry unit (CMU) walls. Finite-element model was developed for the simulation of these experiments. Myers et al. [5] tested full-scale infill masonry walls retrofitted using different layouts of GFRP rods and GFRP strips against blast loads. The test results demonstrated the effectiveness of FRP retrofitting of masonry walls to resist blast loads. Authors highlighted the need to improve wall-to-frame connections and the shear capacity of wall. Some guidelines were also provided for the retrofitting of masonry walls with FRP laminates. Buchan and Chen [6] reviewed the experimental and numerical studies in strengthening concrete and masonry structures using FRP composites for blast protection and emphasized the need for further research.

Wu et al. [7] analyzed two- and six-story masonry infill RC frames against blast induced ground excitations using Autodyn3D. A two-story masonry structure was also considered. The existing material damage model was extended for simulating masonry. The two-story masonry structure was found to suffer more damage as compared to the two-story masonry infill RC frame whereas the six-story RC frame with infill masonry wall experienced the least damage. It was shown that the displacement-based criteria such as ductility ratio and interstory drift cannot be directly used for assessing the structural performance of masonry structures under blast ground motions. The same research team further extended the blast analysis of masonry structures using LS-DYNA software for establishing the relationship between the scaled distance and the damage of infill masonry walls [7]. The numerical results were compared with the provisions of different codes [8-9].

Chen et al. [10] tested half-scale masonry infill walls retrofitted with CFRP strips, steel wire mesh and laminated steel bars against blast loads. LS-DYNA was used for the numerical simulation of the blast tests. FE modeling of masonry involved the modeling of bricks and mortar separately. The URM retrofitted with steel mesh performed the best among the three retrofitting measures in blast loading resistance. Rafsanjani et al. [11] presented a constitutive material model for masonry and implemented it in ABAQUS software for the low velocity impact analysis of masonry walls. The results were validated with field test data.

Irshidat et al. [12] studied the performance of nano-particle reinforced polymeric materials for the strengthening of masonry structures when exposed to blast loads. One-quarter scale model of infill masonry walls were tested against blast load. The polyhedral oligomeric silsesquioxane reinforced polyurea was found to significantly enhance the performance of infill masonry walls against blast loads. The numerical models were developed employing ANSYS-AUTODYN for the simulation of the test results. Analytical models were also developed.

In this study, full-scale confined dry stacked masonry walls were modelled in AUTODYN against the blast loads of dynamite explosive. The blast pressures records have been obtained from numerical results of analysis. The numerical models were then used for studying the influence of various parameters of interest.

2. Test Setup

The experiments involved the testing of the performance of confined dry-stacked masonry walls subjected to blast loads. RC confining frame was prepared after masonry wall was constructed on site after putting the RC frame in position. The details of the program are given in the figure-01.

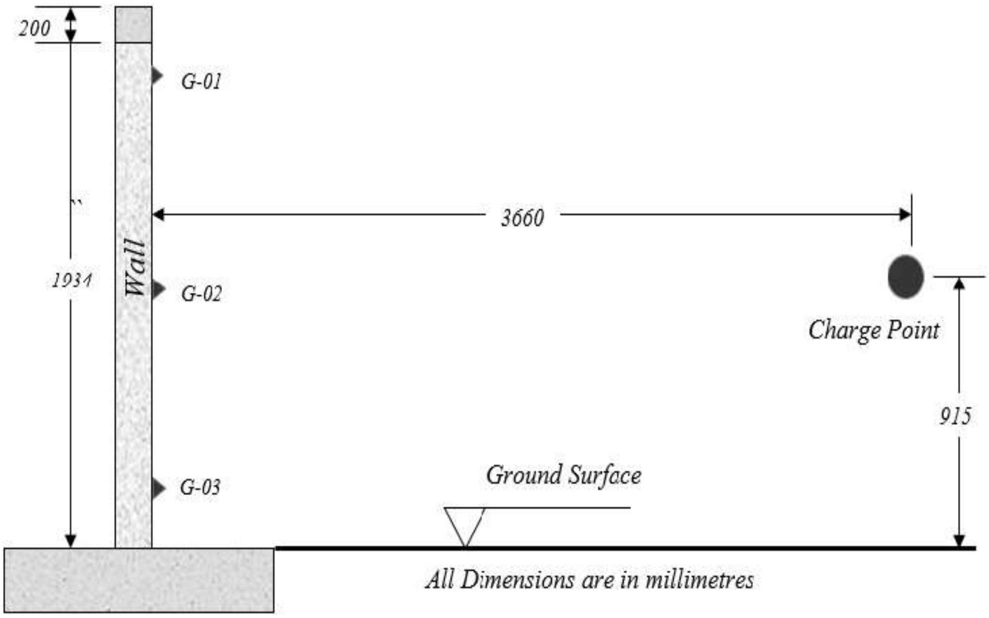


Figure-01Test-setup detail with dimensions

3. Finite element modelling

In order to investigate the influence of blast waves on confined dry-stacked masonry walls, the simulation conducted in this study have to be extended to cover more parameters. The focus in this section is to develop a cost and memory efficient numerical model that can reasonably represent the behaviour and failure mechanisms of infill masonry walls against blast generated waves. FE models were developed and then was extended to study more parameters. The readymade computer package ANSYS-AUTODYN [13] was employed in this study to model and analyse the infill masonry walls against blast loads.

3.1. Model parts

The FE model consists of the infill wall specimen and the air volume occupied by and surrounding the wall. Half of the specimen and the air volume were modelled accounting for the model symmetry. The wall specimen is composed of 3 different Lagrangian parts, viz. RC footing, RC frame and dry-stacked masonry wall. The all three parts were modelled as 8-node hexahedral solid elements. The element size of all Lagrangian parts range from 40 to 50 mm.
Figure-02 illustrates the FE mesh for the different parts of the model. In the model, unbreakable bonded face connection was assumed between the frame and the footing. However, stress-criteria breakable bonded face connections were assumed between the infill wall and the frame. The air was modelled as an Euler, ideal gas part. A 3D cuboid-shaped air domain was created. The air domain had dimensions of (R + 0.4) x 2.0 x 1.80 m, where R is the standoff distance. A cell size of 20 mm was used for the air volume. The model detail with cells are as shown in the figure.

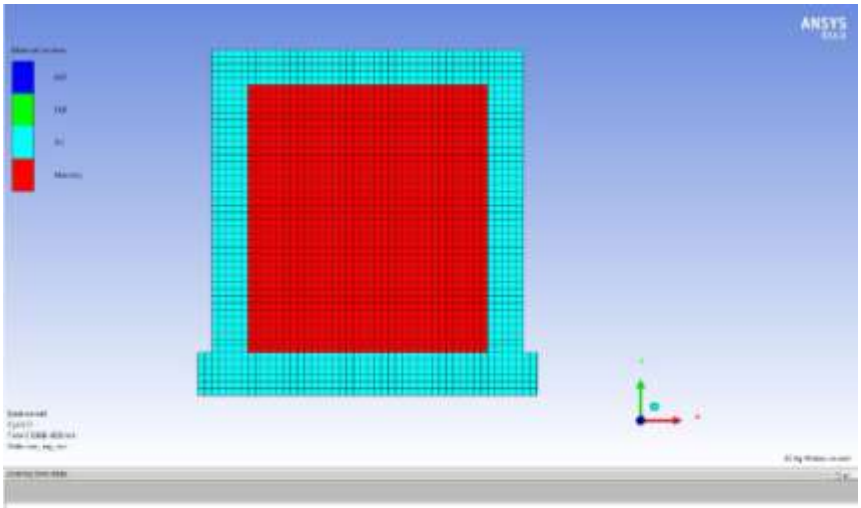


Figure-02 Model with meshing of elements

3.2. BLAST ANALYSIS IN AUTODYN

The blast load analysis of the dry-stacked masonry wall in Autodyn was performed in two phases. The first phase which is a 1D analysis simulates the time expansion in early stage of the explosive materials in one-dimension (1D) using radial symmetry. This expansion continues until a reflecting or bouncing surface is faced by waves. The second phase process, interaction of the generated blast pressure waves and the masonry wall are studied. In this step, the output of the 1D (one dimensional) analysis is then transferred to the 3D domain which is created independently. In this study, the blast is considered as air blast as the Wabox explosive is place at 0.92 m above the ground. Therefore, in this analysis only the forces generated from theair blast waves are considered and ground shocks ignored due to its negligible effects. The 1D blast analysis were carried outfor four different scaled distances covering different charge weight blast tests.

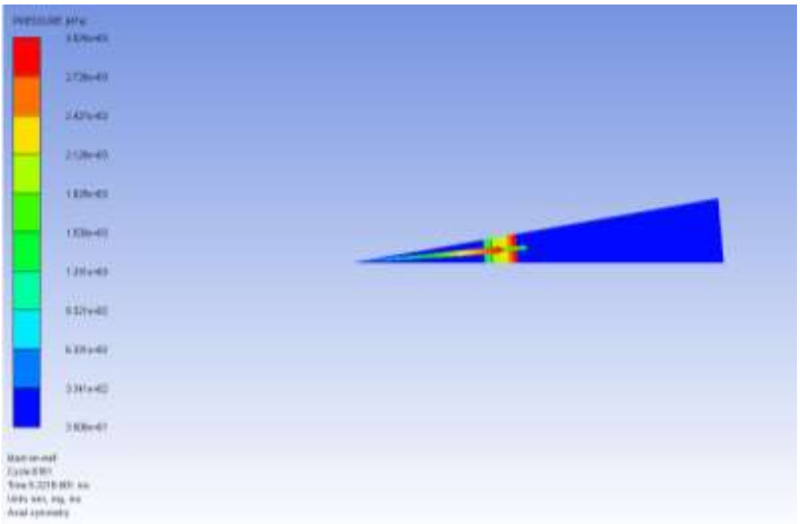


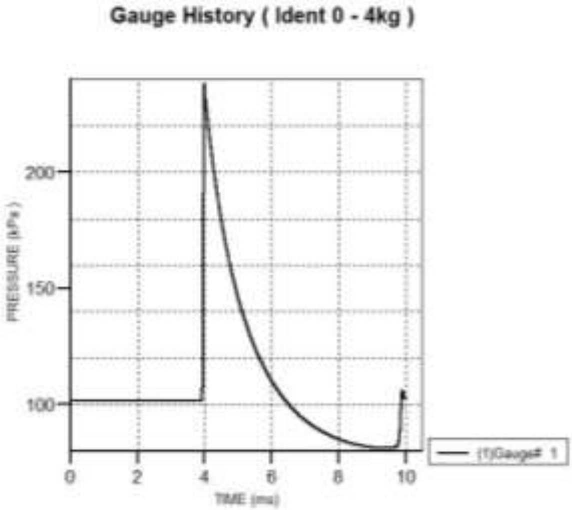
Figure-03Pressure contours in 1D wedge filled with WA Box and air

4. RESULTS OF AUTODYN

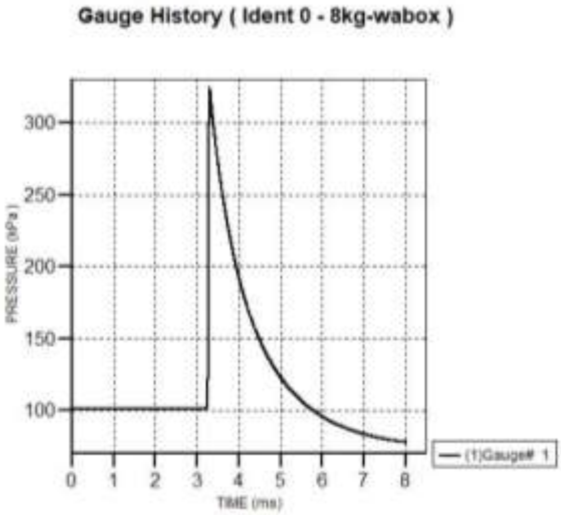
The results obtained from Autodyn analysis was in shape of pressure-time history from 1D analysis. The results are obtained from four blast load analysis of various charge weight. The results obtained from Autodyn during 1D analysis were also calibrated with empirical model develop by Kingery-Bulmash [16]. The Kingery-Bulmash equations have also been automated in the computer program CONWEP. Summary of numerical results of all test specimens in terms of peak incident overpressure, arrival time and failure modes were compiled and documented.

4.1. RESULTS OF 1D ANALYSIS

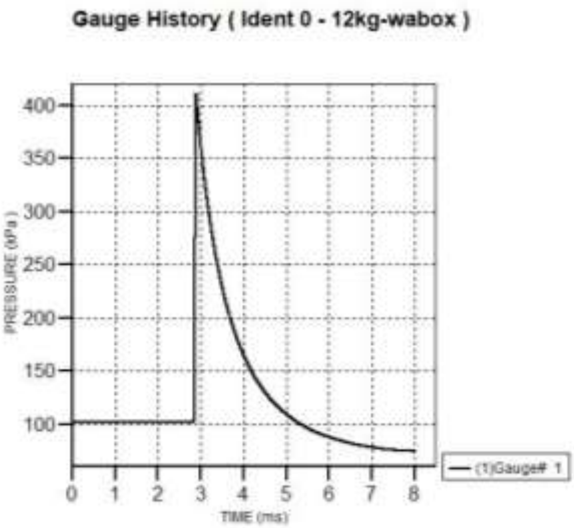
The Results of 1D wedge model analysis for various charge weight of explosive and standard standoff distance are shown in Figure in term of pressure-time history. These graph are obtained from Autodyn through it readymade plotting graph package. The summary of all pressure time history parameters are listed in Table 1 shows the summary of results in terms of arrival time of the blast and the peak incident overpressure from Autodyn analysis. Also, it shows that as the scaled distance decreased, the blast arrival time decreased, and the incident overpressure increased.



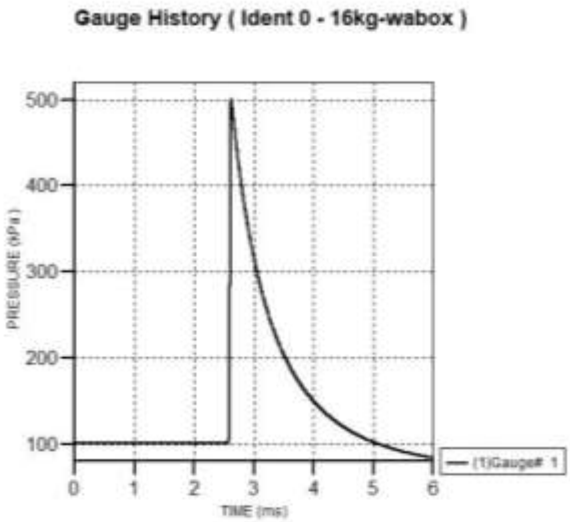
(a)



(b)



(c)



(d)

Figure-04Pressure-time history curve for various charge detonations (a) 4 kg explosive (b) 8 kg explosive (c) 12 kg explosive (c) 16 kg explosive

Table1Results of 1D wedge model analysis for different scaled distances.

Case	*Charge Weight, W (kg) (WA Box)*	*Equivalent charge weight, W_e (kg)*	*Standoff distance, R (m)*	*Scaled distance, $z = R / \sqrt[3]{W_e}$ ($m/kg^{1/3}$)*	*Arrival time, t_a (ms)*	*Peak incident overpressure (kPa)*
1	*4*	*4.4*	*3.66*	*2.23*	*3.97*	*240*
2	*8*	*8.8*	*3.66*	*1.77*	*3.25*	*325*
3	*12*	*13.2*	*3.66*	*1.55*	*2.85*	*425*
4	*16*	*17.6*	*3.66*	*1.41*	*2.50*	*500*

5. CALIBRATION FOR PEAK INCIDENT OVERPRESSURE

Summary of results in term of arrival time obtained from Autodynand Kingery-Bulmash empirical model are listed in Table 2. The arrival obtained from Autodynand Kingery-Bulmash shows good correlation with slight variation which can be ignored for such type of large deformation or strain phenomenon.

Table 2Summary of Results of Arrival time for wall specimen

Case	*Scaled distance,* $z = R / \sqrt[3]{W_e}$ *(m/kg$^{1/3}$)*	*Numerical Peak Incident overpressure (ms)*	*Kingery-Bulmash Peak Incident overpressure (ms)*
1	*2.23*	*3.97*	*3.41*
2	*1.77*	*3.25*	*2.79*
3	*1.55*	*2.85*	*2.48*
4	*1.41*	*2.50*	*2.28*

The summary of incident peak overpressure for different scaled distances obtained from Autodyn and Kingery-Bulmash model is also plotted in Figure-07 for better judgment.

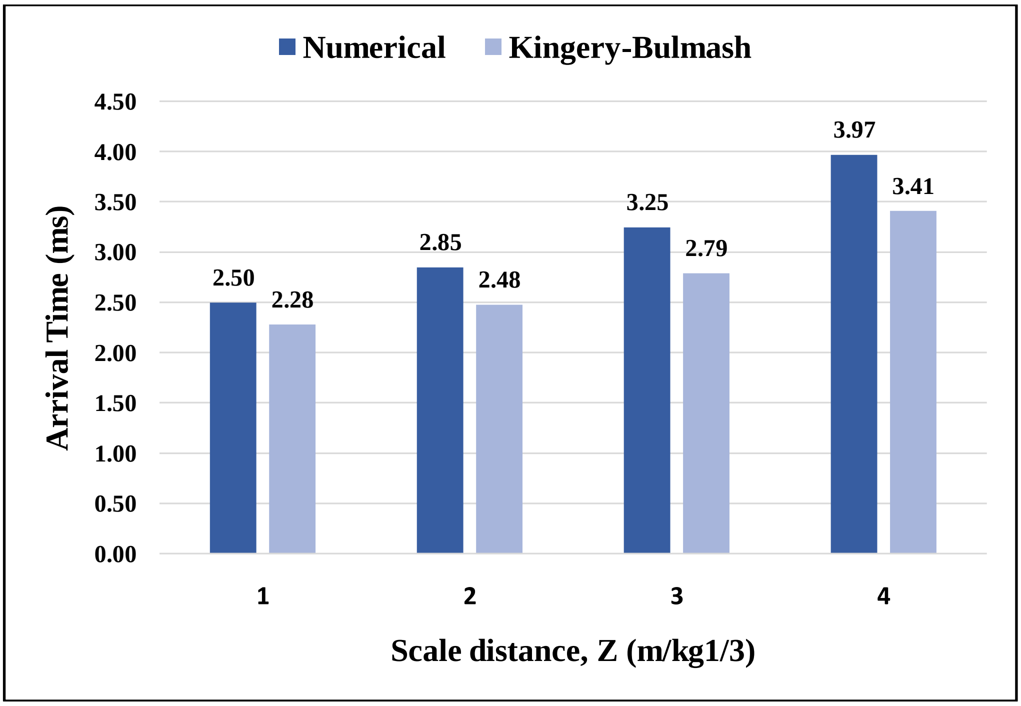


Figure-05A comparison of Arrival time for different scaled distances.

In general, the arrival time of blast and peak incident obtained from the Autodyn are close to the Kingery-Bulmash values. Thus the Autodyn results can be relied on for deriving conclusions based on the parametric studies.

6. Conclusion

It has been concluded from this parametric study that damage level of the wall has been increased with increased charge weight which further reduces the scale-distance. Also, with increasing the charge weight the incident overpressure has been increased while the time of arrival has been decreased. It supported the initial presumption that, with the increase of weight of explosive materials, pressures are increasing but the sensitivity on the mesh size and scattering of the results are greater for smaller scaled distances. The pressure values for larger scaled distances were less sensitive to air mesh size.

Finally, it is concluded from this parametric study that in all cases, results indicate that AUTODYN is a suitable tool for blast wave investigations and performance of structures against blast loads.

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