Blast Mitigation Effects on Facade System with Projections Utilizing Fluid-Structure-Fluid Interaction

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Abstract. Various studies have been conducted on facade system exposed to blast loading have been explored in various studies. Studies conducted are limited to interaction between the fluid and solid domain neglecting the coupling effects of both domains. The impact upon interacting with a free standing will cause the structure to displace its position in the direction of the impact which will decrease the impact upon the structure. At the same time, the impact induced behind the structure will further reduce the effect of impact. This impact generated will marginally counteract the reduction of pressure on the structure. The displacement of the structure as well as shock-wave generated play a major role in reduction of impact on stationary structure. The effects of stress propagation within the structure have been ignored.

1. Introduction
This research paper focuses on reflection of impact wave on the structure leading to formation of Triple point and further exploring the effect of FSI in Blast Wave Mitigation.

![Figure 1. Schematic of a free standing plate subjected to blast wave.](image.png)

2. Impact wave and an immobilized structure
The potential dangers of exposure to explosives can be minimized by carrying out theoretical and numerical simulation. Majority of the research work carried out in past utilize a simplified approach. A numerical model has been created in this work to simulate the effect of an impact wave interacting with an immobilized structure. The effect of stress wave proliferation within in the structure is ignored.
3. Simulation environment
The initial conditions for the flow fields (\(p_0, T_0, u_0\)) both sides of the plate are prescribed as the ambient conditions, which are given by

\[ p_0 = 101.3 \text{ kPa}, \quad T_0 = 298 \text{ K}, \quad u_0 = 0 \text{ m/s} \]

Initial velocity of the plate, (\(u_0 = 0 \text{ m/s}\)).

Uniform Blast Wave, \(p(t) = p_u\)

Where, \(p_u\) is a constant overpressure of the blast wave.

Ignoring last negative phase of the Impact Wave,

Exponentially Decaying Blast Wave, \(p(t) = p_u e^{-\frac{t}{\tau}}\)

4. Numerical model validation

4.1. Immobilized Plate
In case of an immobilized plate exposed to exponentially decaying blast wave for simulation of the flow fields, the ratio of Impulsive force transmitted to incident Impulsive force is

\[
\frac{I_p}{I_i} = \gamma_R \left( \frac{C_R f_R}{\gamma_R} \right) \frac{(\beta_2)}{(\beta_1 + 1)} \frac{p_0}{(1 - \beta_3)}
\]

where,

\[
C_R = 2^{\frac{2+4+s}{7-s}} \frac{p_0}{\rho_0} \quad f_R = \left( \frac{6s^3}{p_0} + 7 \right) \quad \gamma_R = \lim_{\rho p h = 0} \frac{I_p}{I_i} = 42 \frac{p_3}{p_3} \ln \left( 1 + \frac{p_3}{p_3} \right)
\]

Here, \(p_u\) is peak overpressure of incident blast wave,

\(\beta_s\) = non-dimensional parameter describing FSI and is inversely proportional to the plate thickness \(h_p\).

\(\rho_0\) = density behind the incident shock front, and

\(U_{As}\) = incident blast wave propagation speed.

The results obtained for six sizes of plate thickness and of different blast intensities as shown in figure agree well with the results obtained by Kambouchev et al. With the decrease in plate thickness, impulse ratio decreases whereas for thin plates it becomes very small which suggests the suitability of thin plates for Blast Wave Mitigation.

4.2. Plate moving at a constant velocity

![Figure 2. Ratio of Impulse for different blast parameters.](image)

For, low plate velocity \(\frac{P_0}{P_i} = 10/\text{s}\)
In this case, the shock wave generated behind the plate is induced due to the moving plate in addition to the Blast Wave which can be given by:

\[ u_p = a_0 \left( \frac{2/T_e}{p_e} \right)^{1/2} \]

Where, \( p_e \) = overpressure in the back of the shock front, \( u_p \) = velocity of the plate.

5. Results and discussion
The numerical simulation for Impact wave between an immobilized plate and a blast wave considering FSI is discussed. Considering the proportion of the reflected impact wave overpressure to the episode impact wave overpressure leads to constraining instances of plates of infinitesimal mass and infinite mass. For air which ranges from 2 to 8.

\[ C = \frac{p_r}{p_e} = \frac{(3\gamma - 1)p_e/p_0 + 4\gamma}{(\gamma - 1)p_e/p_0 + 2\gamma} \]

Figure 3. Ratio of Impulse for different blast parameters for different velocities.

Figure (a)

Figure (b)
Figure 4. Reflection coefficients for different plate thickness.

Plate thicknesses (0.0005, 0.005, 0.05, 0.5, 5.00, and 50.00 mm) have been considered with the incident impulse (I) for low blast intensity of 10.85, with resistance in the back of the plate, is shown in figure 5. An initial Impact wave with 2 MPa Overpressure and decaying time 0.5 ms have been numerically simulated. For infinitesimally light plates, blast waves lead to very high receding velocities which implies the effect of FSI on relatively light plates. Simulations of immobilized plate having thickness 2.50 mm have been subjected to various instances of impulse leading to varied decay time constants.

6. Conclusion
A numerical model of the FSI between an impact wave and an unattached plate has been produced. Considering the blast wave reflection adjoining the structure, for uniform and exponential blast wave, an acceptable validation of numerical and analytical model is achieved. The role of FSI in exponentially decaying blast wave, is limited between two cases. As the intensity of the blast wave increases, the reflection co-efficient asymptotically reached towards unity limited to certain value and thereon reaching a plateau. The reason attributed to this behavior increasing resistance of back of the plate. As the intensity increases, the blast wave impregnates the structure and interacts with the back of the plate leading to higher shock wave in the back of the plate. At the certain thickness and receding velocity conditions, the shock wave generated at the back of the plate is comparable to the shock wave generate in front of the plate leading to diminishing effect of the FSI. Simulations have also led to conclusion the relationship between ratio of impulse and incident blast intensity. For a particular case, any change in ratio of impulse can significantly affect the incident blast wave.

Figure 5. Ratio of impulse for different plate thickness.
7. References

[1] Neuberger, S. Peles and D. Rittel, Scaling the response of circular plates subjected to large and close-range spherical explosions. Part I: Air-blast loading, International Journal of Impact Engineering, Vol. 34, pp. 859-873, 2007.

[2] Vaziri and J. W. Hutchinson, Metal sandwich plates subject to intense air shocks, International Journal of Solids and Structures, Vol. 44, pp. 2021-2035, 2007.

[3] Bram Van Leer, Flux-vector splitting for the Euler equations, Lecture Notes in Physics, Vol. 170, pp. 507-512, 1982.

[4] Y. Tham, Numerical simulation on the interaction of blast waves with a series of aluminum cylinders at near-field, International Journal of Impact Engineering, Vol. 36, pp. 122-131, 2009.

[5] Redekop, Dynamic response of a toroidal shell panel to blast loading, Computers & Structures, Vol. 51, pp. 235-239, 1994.

[6] Espinosa, S. Lee and N. Moldovan, A novel fluid structure interaction experiment to investigate deformation of structural elements subjected to impulsive loading, Experimental Mechanics, Vol. 46, pp. 805-824, 2006.

[7] N. Kambouchev, L. Noels and R. Radovitzky, Numerical simulation of the fluid-structure interaction between air blast waves and free-standing plates, Computers and Structures, Vol. 85, pp. 923-931, 2007.

[8] N. Kambouchev, R. Radovitzky and L. Noels, Fluid-structure interaction effects in the dynamic response of free-standing plates to uniform shock loading, Journal of Applied Mechanics, Vol. 74, No. 5, pp. 1042-1045, 2007.

[9] N. S. Rudrapatna, R. Vaziri and M. D. Olson, Deformation and failure of blast-loaded square plates, International Journal of Impact Engineering, Vol. 22, No. 4, pp. 449-467, 1999.

[10] O. Igra, G. Hu, J. Falcovitz and W. Heilig, Blast wave reflection from wedges, Journal of Fluids Engineering, Vol. 125, No. 3, pp. 510-519, 2003.

[11] Colella, R. E. Ferguson, H. M. Glaz and A. L. Kuhl, Mach reflection from HE driven blast wave, Proceeding of 10th ICDERES, Berkeley, California, Aug. 4-9 1985, AIAA Inc., New York, pp. 388-421, 1986.

[12] W. McCoy and C. T. Sun, Fluid-structure interaction analysis of a thick-section composite cylinder subjected to underwater blast loading, Composite Structures, vol. 37, No. 1, pp. 45-55, 1997.

[13] X.Q. Zhou and H. Hao, Prediction of airblast loads on structures behind a protective barrier, International Journal of Impact Engineering, Vol. 35, pp. 363-375, 2008.

[14] Su, W. Peng, Z. Zhang, G. Gogos, R. Skaggs and B. Cheeseman, Numerical simulation of a novel blast wave mitigation device, International Journal of Impact Engineering, Vol. 35, No. 5, pp. 336-346, 2008.

[15] Z. Xue and J. W. Hutchinson, A comparative study of impulse-resistant metal sandwich plates, International Journal of Impact Engineering, Vol. 30, pp. 1283-1305, 2004.