Numerical determination of reflected blast pressure distribution on round columns

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Abstract

Blast load parameters are reasonably easily determined for rectangular columns and can be derived from either the literature or numerous utility programs. Little compiled information is available with respect to exposed round columns. A series of numerical simulations were carried out to investigate the design pressure imparted to a round column by an explosion. The column diameter and charge weight were varied and pressure-time histories recorded at regular radial intervals along the face of the column from the closest point of first contact (front) to the extreme point at the side. A numerical model was created in AUTODYN, which simulated a blast wave diffracting around a rigid round cross section. The results indicate that as the diameter of the section increases, the peak reflected pressure at the point of first contact rapidly approaches that of a flat wall. However, the pressure varies sinusoidally between this peak at the point of first contact to a minimum equal to approximately the incident pressure at the furthest point at the side. The results support the obvious advantages when designing against blast to be realized by the use of round vs. rectangular columns, particularly when in the near field.

Keywords: AUTODYN, numerical modelling, round column, reflected pressure, pressure distribution.

1 Introduction

Fujikura *et al.* [1] have shown experimentally that the reflected over pressure experienced by a round column is substantially lower than the indicated design values. This fact and the intuitive expectation that round columns would deflect

WIT Transactions on State of the Art in Science and Engineering, Vol 60, © 2012 WIT Press
www.witpress.com, ISSN 1755-8336 (on-line)
doi:10.2495/978-1-84564-750-6/04

the blast wave indicate the need for modified design parameters. The first step in obtaining these modified parameters is determining the pressure distribution acting on a round column. In order to accomplish this, the problem was modelled numerically using the commercial software ANSYS AUTODYN. Both the size of the blast and the size of the column were varied to determine the effect of these parameters on the distribution. The model was verified against the current design values and it showed good agreement.

2 Numerical model

The problem was modelled using the commercial software ANSYS AUTODYN, an explicit analysis tool for modelling the nonlinear dynamics and interactions of solids, fluids, and gases.

The model was necessarily constructed in 3D as the cylindrical curvature of the columns could not be captured using 2D axial symmetry, while none of the blast energy dissipated in the third dimension if 2D planar symmetry were used.

The AUTODYN material library properties of air and TNT were used. Air was given an internal energy of 206.8 J, which results in the standard atmospheric pressure of 101.325 kPa.

The blast was initially modelled using 2D axisymmetry from the explosion out to 1.95 m (just before the blast wave interacts with the column) in a multi-

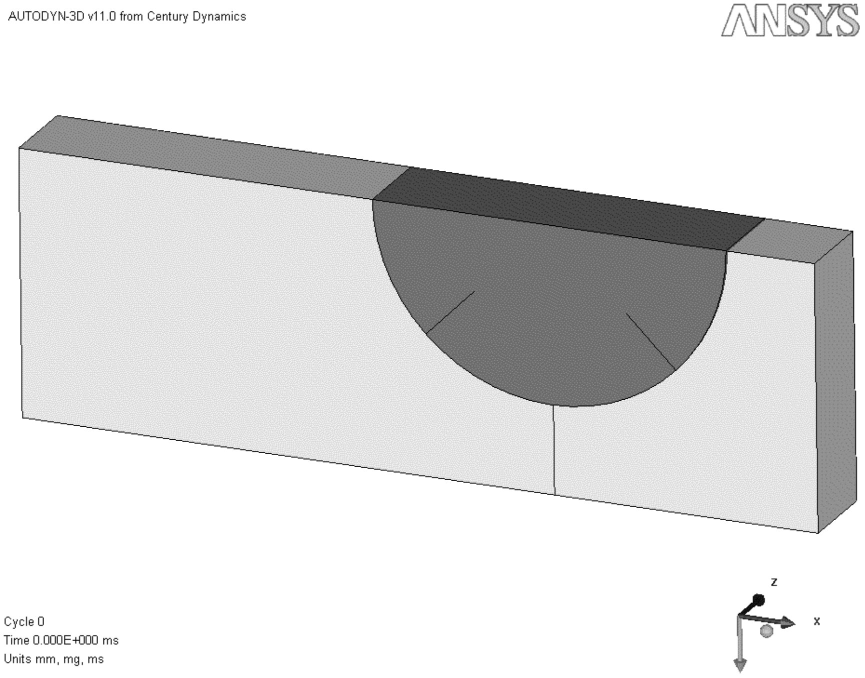

Figure 1: Euler parts and 1000 mm radius column.

material Euler wedge. Then, AUTODYN's remapping capabilities were used to set the results of the 2D model as initial conditions for the 3D model in an ideal gas Euler mesh. The remapping and the use of quarter symmetry reduced the computation time and memory requirements considerably.

The 2D blast was modelled as a multi-material Euler wedge divided into 1950 elements and filled with air. The radius of the central TNT sphere was calculated using the predetermined TNT mass and a density of 1657 kg/m^3.

The 3D model consisted of an Euler part surrounding a cylindrical Lagrange fill part. Fill parts are used to define the interaction boundaries in rigid coupling. The Euler gird was the same in all the models and only the column fill parts were varied. The dimensions of the Euler part were dictated by the range of the blasts (2000 mm), the largest column section (radius = 1000 mm), and the influence of the approximate outflow boundary condition (≈ 500 mm). Therefore the dimensions of the Euler part were x = 4500 mm, y = 1500 mm, and z = 500 mm. The Euler parts and a 1000 mm radius Lagrange fill part are shown in fig. 1.

The area of interest in the Euler part, where the blast interacted with the column, consisted of 10 mm cubic elements. Beyond the area of interest, AUTODYN's mesh grading capabilities were used to increase the element sizes geometrically by the maximum recommended rate of 1.2 in all three directions.

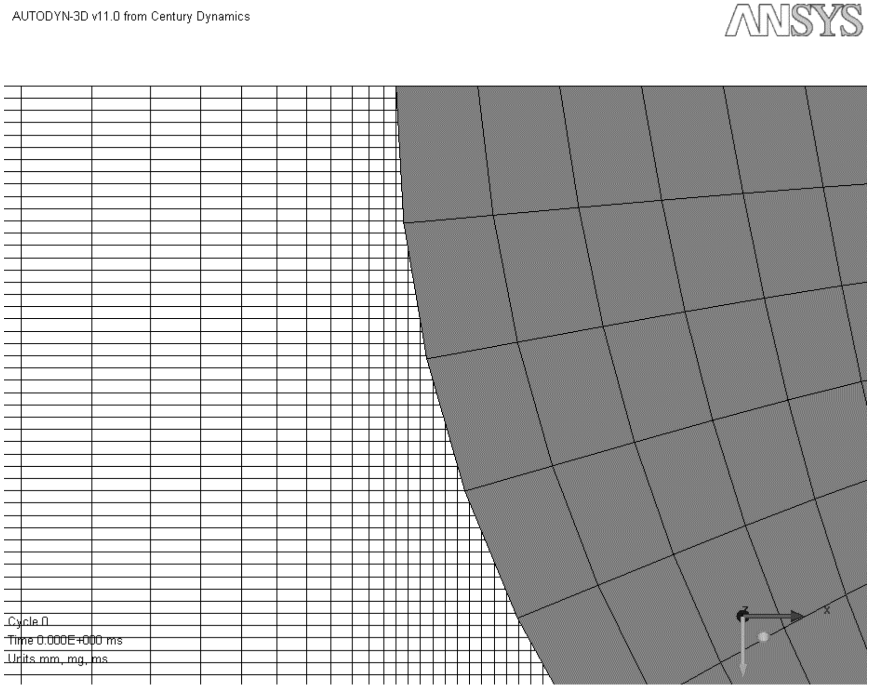

Figure 2: Grid detail at the interface between the 1000 mm radius column and the Euler part.

The column radii to be studied were chosen to be divisible by 10 mm to minimize the merging of Euler cells, which AUTODYN does automatically once a certain proportion of a cell is covered. AUTODYN also approximates circles using polygons, therefore, the number of elements in the cylindrical fill parts needed to be chosen carefully because they determined the precision of the circle. However, the restriction that the side of a Lagrange element must be larger than the smallest Euler element had to be adhered to too.

It was decided that all the cylindrical fill parts were to approximate Pi to two decimal places. Thus, the area of a polygon in terms of the number of its sides was equated to Pi to two decimal places multiplied by the radius squared. The number of sides was then solved. The number of sides used for all the columns was 56, which was obtained by having 15 cells across the radius in a type 2 cylindrical Lagrange part. This also gives a polygon side length of 11.2 mm which is larger than the minimum Euler element size of 10 mm. The interface between the 1000 mm radius column and the Euler grid is shown in fig. 2.

The default reflection boundary was applied to all planes of symmetry, and the approximate out flow boundary was applied to all surfaces where the blast is free to expand.

3 Investigation

The problem investigated was the variation of the reflected pressure (Pr) on the surface of a round column. The two variables that affect this distribution are the size of the column and the size of the blast. Therefore, in order to obtain a clear picture of the solution both the size of the column and the amount of explosive were varied to cover a practical range. The 100 mm radius lower bound for the column size was determined based on the fineness of the Euler grid in the model. While the 1000 mm radius upper bound was chosen as a practical limit. Thus, the column radii investigated were: 100 mm, 250 mm, 500 mm, 750 mm and 1000 mm with the two limiting cases of an unobstructed blast and a flat rigid wall.

For each of these seven cases, the blast was varied between a Z value of 0.8 $\mathrm{m/kg}^{-1/3}$ to 2.4 $\mathrm{m/kg}^{-1/3}$ in 0.4 $\mathrm{m/kg}^{-1/3}$ increments resulting in 35 total runs. Z is the scaled distance and is given by the formula in eqn (1) below.

$$Z = \frac{R}{\sqrt[3]{W}}. \tag{1}$$

where R is the range and W is the weight of TNT.

To capture pressure measurements on the surface of the columns, nine gauges were placed radially at 11.25 degree increments around the circumference from the point closest to the blast to the point where the radius is perpendicular to the original point.

4 Verification

The model was verified against the design charts in TM 5-855 [2]. The values verified were the two limiting cases of the side-on pressure of an unobstructed blast and the pressure reflected off of an infinite flat rigid obstacle. The chart and model values are shown in table 1 below. The results showed very good agreement. The average per cent difference of the values was 12% for the side-on pressure and 21% for the reflected pressure.

5 Results and discussion

The surface plot in fig. 3 shows the variation of reflected pressure with respect to the radius of the column and the radial location around the circumference for a given Z value.

Table 1: Verification of model pressure values from model and charts.

	Chart		**Model**	
Z ($m/kg^{-1/3}$)	**P_{so} (MPa)**	**P_r (MPa)**	**P_{so} (MPa)**	**P_r (MPa)**
0.8	1.75	10.0	1.5	8.9
1.2	0.7	3.5	0.67	2.9
1.6	0.4	1.5	0.37	1.15
2.0	0.2	0.6	0.21	0.44
2.4	0.15	0.3	0.197	0.38

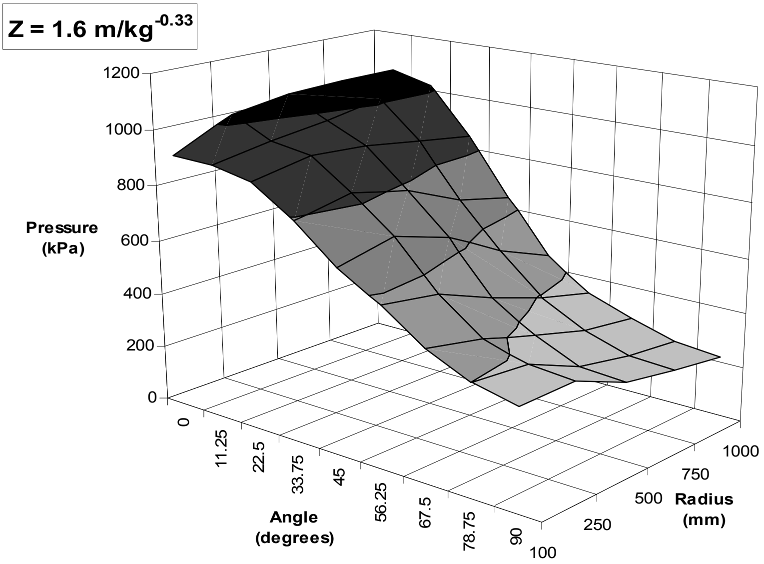

Figure 3: Surface plot of variation of pressure with respect to radius and angle for a given Z.

The effect of the radius and radial location on the reflected pressure can be isolated.

Examining the variation of pressure with respect to radius at the point of first contact shows that the pressure reaches its maximum value rapidly as the radius is increased. It should be noted that if the radius axis started at zero, then the pressure value would be the side on pressure. The maximum pressure reached was approximately 90% of the reflected pressure of a rigid wall.

The cross sections of the plot at an angle of 0° for all the Z values studied are shown in fig. 4. The plots are a ratio of the reflected pressure and side on pressure for clarity, as the reflected pressure range would otherwise be too large to discern the plots for larger Z values. This plot shows that the trend of the initially rapidly increasing reflected pressure and the ceiling that is reached occurs for all the Z values studied. Also, that the asymptote is reached at a radius of about 250 mm in all cases.

The pressure variation with respect to radius at the edge of the column was found to be approximately equal to the side-on pressure at that location. It tended to be lower for larger diameters because the pressure wave had to travel the longer distance around the circumference whereas the free wave travelled in a straight line.

Similarly to the plot above, the ratio of the reflected pressure to the side on pressure is shown in fig. 5. Again the plots show that the reflected pressure remains approximately equal to the side on pressure at that location for all the Z values studied.

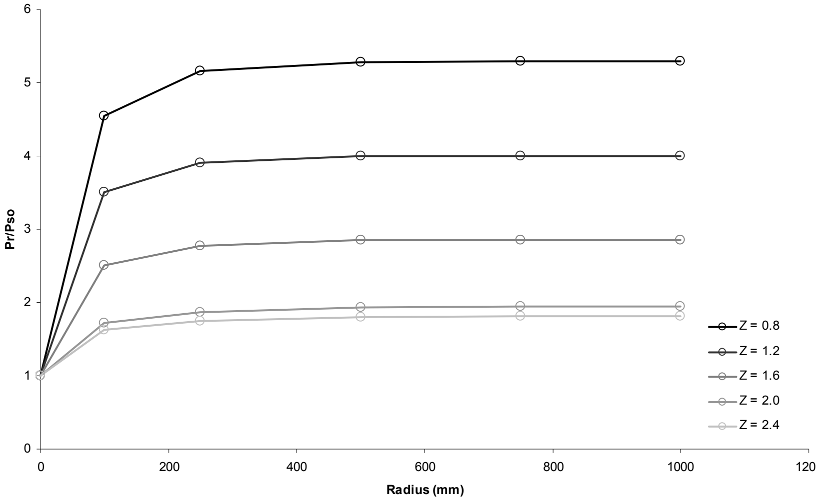

Figure 4: Variation of the ratio of reflected pressure to the side-on pressure with respect to the radius.

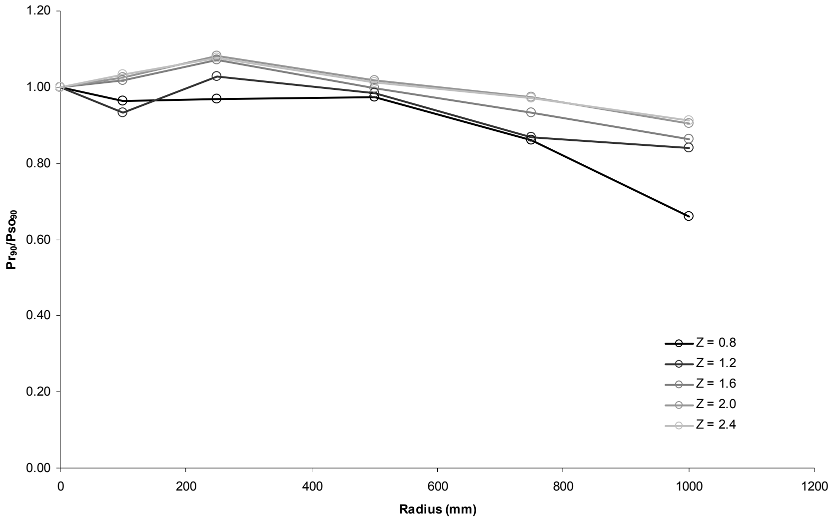

Figure 5: Variation of reflected pressure over the side-on pressure with respect to the radius at the side of the column.

Between these two radial extremes, the pressure increases initially as the radius increases, but then starts to decrease as the radius continues to increase. This is because as the radius increases, the pressure wave must travel further to reach the radial location on the circumference, thus dissipating more energy. This is also more pronounced the further around the circumference the location of interest is.

The variation of pressure with respect to angle can be approximated using the sinusoidal curve fit represented by eqn (2). The result of this fit is shown in fig. 6.

$$P_{rc} = P_{so} + \left(P_r - P_{so}\right)\left(\frac{\cos 2\phi}{2} + \frac{1}{2}\right). \tag{2}$$

This formula was used to find the sinusoidal curve fit for all the column size and Z combinations. The fit showed very good agreement with the numerical results. However, it did over estimate the pressure for the larger columns. Again, this is attributed to the increased distance the wave travels and that the equation does not take distance into account.

Thus, one could obtain the reflected and side on pressure for a given blast from the standard sources, and then use a sinusoidal fit to approximate the pressure distribution around a circular column.

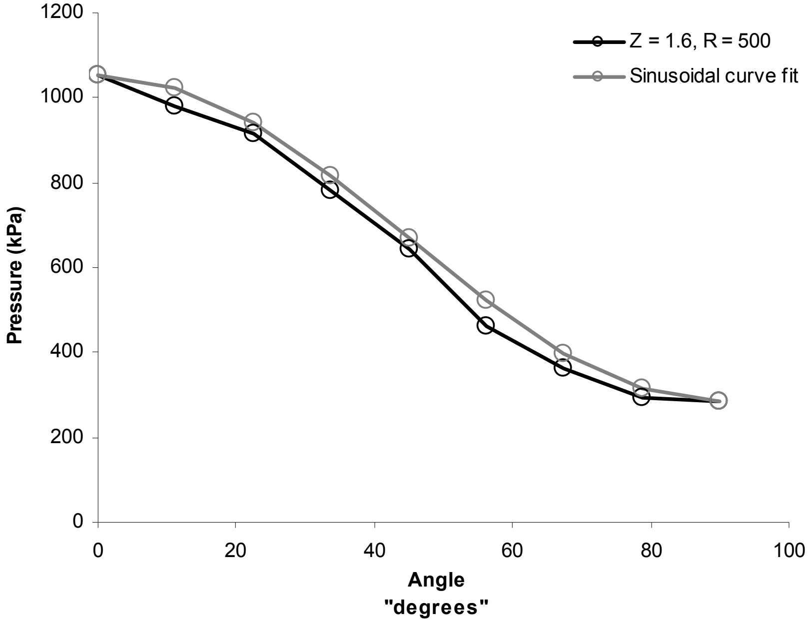

Figure 6: Variation of reflected pressure with radial location with sinusoidal curve fit.

6 Future work

The established sinusoidal fit can be used to find an average or equivalent pressure value to be used in design. A similar investigation needs to be conducted for determining the distribution of impulse around a circular column and finding an equivalent value that can be used in design. Perhaps most importantly, the determined equivalent pressure and impulse values need to be verified experimentally.

7 Conclusion

A numerical model was constructed in AUTODYN to investigate the pressure distribution around a circular column. The model was verified and showed good agreement with established values. It was found that as the column radius increased the maximum reflected pressure at the point closest to the blast approached a maximum of approximately 0.9 of the design value quickly. It was also found that the pressure varied sinusoidally from this maximum to a minimum at the side of the column approximately equal to the incident pressure. A sinusoidal function was used to fit the distribution around the column with good results and this curve fit can be used to find an equivalent design value.

References

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