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Analysis of Concrete Wall under Blast Loading

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ABSTRACT

The terrorist attacks and threats are the growing problem all over the world that not only affect the life of human being but also affect the structure integrity and its resistance. Explosive devices, human bomb and the other bomb equipments are the major weapon choices for these attacks, significantly threatens civilians and military personnel. As we know that ceasefire and bombing activities are increasing day by day also the terrorist attacks on major buildings can cause catastrophic failure on the building's external and internal structural frames, collapsing of walls and shutting down of critical life-safety system. Because of all these threat from such extreme condition, effort has been made from the last few decades to find suitable method of structural analysis and design to resist blast load. Detail understanding is required about the blast phenomena and the propagation of waves towards the structure and also response of structure against such shock waves. This paper presents a comprehensive study of concrete wall against this dynamic loading. Concrete wall subjected to blast loading is modeled in Finite Element package Ansys and then analyzed in Autodyn with and without steel plate to study the impact of blast loading.

Keywords

Blast Load, Explosion Phenomena, Material Behaviour, ANSYS Autodyn®

1. INTRODUCTION

The terrorist attacks and threats are the growing problem all over the world that not only affect the life of human being but also affect the structure integrity and its resistance. Explosive devices, human bomb and the other bomb equipments are the major weapon choices for these attacks, significantly threatens civilians and military personnel. A comprehensive overview of the effect of explosion on structures and explanation of explosion and the mechanism of blast waves in free air is given by T.Ngo [1]. Zeynep Koccaz, Fatih Sutcu and Necdet Torunbalci [2] shed light on blast resistant building design theories, the enhancement of building security against the effects of explosives in both architectural and structural design process and the design techniques that should be carried out. A.M. Remennikov [3] showed some of the currently available analytical and numerical techniques that can be employed to effectively predict loads on structures when a terrorist weapon is detonated in urban environment. Harvoje Draganic, Vladimir Sigmund [4] describes the process of determining the blast load on structures and provides a numerical example of a fictive structure exposed to this load. The blast load was analytically determined as a pressure-time history and a numerical model of the structure was created in SAP2000. Manmohan Das Goel, Vasant A.Matsagar, Anil K. Gupta and Steffen Marburg [5] providing various blast computation equations, charts, and references in a concise form at a single place and to serve as a base for researchers and designers to understand, compare, and then compute the blast wave parameters. The Recommendations are presented to choose the best suitable technique from the available methods to compute the pressure-time function for obtaining structural response. A. Khadid et al. [6] studied the fully fixed stiffened plates under the effect of blast loads to determine the dynamic response of plates. The effect of an external explosion on the outer reinforced concret shell of a typical nuclear containment structure was studied by A.K. Pandey. [7]. The effect of spherical and hemi-spherical TNT (trinitrotoluene) in blast waves was first introduced by J.M. Dewey [8] and also determined the density throughout the flow by application of Lagrangian conservation of mass equation which used for calculating the pressure by assuming the adiabatic flow for each air element between the shock fronts.

Analysis of structure under blast loading requires a careful understanding about the blast phenomena and its impact on structural elements and response of materials against such a high strain rate loading. Analysis consists of several steps: (a) estimation of risk; (b) determination of computational load; (c) structural behaviour analysis; (d) selection of structural system; (e) evaluation of structural behaviour.

2. EXPLOSION PHENOMENA

An Explosion is defined a sudden and rapid release of energy on large scale. On the basis of nature explosion can be categorised as physical, nuclear and chemical explosion. Modelling and Analysis of explosive detonations requires a good understanding of chemistry because the chemical composition of an explosive source governs its physical properties like detonation velocity. Explosive detonations are products of complex physical and chemical processes within and in the immediate vicinity of the explosive and are accompanied by a near-instantaneous release of a huge amount of energy in the form of heat, light and sound. The chemical reactions involved in a detonation are thus oxidation and exothermic reactions because the reactants are oxidized to give a mixture of hot gaseous products. There are two major types of oxidation reactions involved in a detonation a) In the first type, there are two reactants, a fuel and an oxidizer, that react to form the products of the explosion; b) The second type of reaction, involves a single reactant where the fuel and the oxidizer are contained in the same molecule, which decomposes during the reaction and is transformed into oxidized products. It is more common in explosives.

The majority of the explosives consist of single molecules made up of Carbon (C), Hydrogen (H), Nitrogen (N) and Oxygen (O). These are called CHNO explosives and can be represented by the general formula Cc Hh Nn Oo, where n, c, h, o are the number of nitrogen, carbon, hydrogen and oxygen atoms, respectively, contained in a molecule of the explosive. During the decomposition reaction, the reactant molecule breaks down into its individual component atoms as follows:

$C_c H_h N_n O_o \rightarrow cC + h H + nN + oO$

These individual atoms then recombine to form the final products of the reaction. The order of reaction is

$2N \rightarrow N_2$

$2H + O \rightarrow H_2O$

$C + O \rightarrow CO$

$CO + O \rightarrow CO_2$

If oxygen remains after the formation of CO_2, then the explosive is called over-oxidized. Any oxygen left after the formation of CO_2 forms O_2. However most explosives, with the exception of nitro-glycerine and ammonium nitrate, do not have sufficient oxygen to convert all of the carbon to CO_2 and these are called under-oxidized explosives. For such explosives, the products of the reaction extract oxygen from the surrounding air as they expand freely. While doing so, these products mix with oxygen and may burn to form CO2. These secondary reactions are part of a process known as afterburning.

The relative amount of oxygen in an explosive is therefore an important factor in determining the nature and reactivity of the detonation products; it is quantitatively expressed as oxygen balance. The heat generated by an oxygen-deficient explosive (such as trinitrotoluene (TNT)) is less than that generated by an explosive that oxidizes completely.

3. PREDICTION OF BLAST LOADING

The study and analysis of the blast loading on the structure started in 1960's. There are three methods available for predicting blast load i.e. a) Empirical method; b) Semi-empirical Method; c) Numerical Method.

The first method i.e. empirical methods are correlated with experimental data. The accuracy of all empirical equations diminishes as the explosive event becomes increasing near field. Semi-empirical methods are based on simplified model of physical phenomena. Extensive data and case studies is important parameters on which semi-empirical method depends. Numerical methods are based on mathematical equations that describe the basic laws of physics governing a blast problem. These principles include conservation of energy, mass and momentum. Now these models are commonly called as computational fluid dynamics (CFD) models.

The key elements are the loads generated from explosive sources, how they interact with structures and how structures respond to them. Sources of explosion include gas, high explosives, nuclear and dust materials. The basic features of the blast wave and explosion phenomena are presented along with a discussion of TNT (trinitrotoluene) equivalency and laws of blast scaling.. The type of burst mainly classified as a) Air Burst; b) Surface Burst; c) High Altitude Burst; d) Underground Burst; e) Under water Burst. Here study is limited to surface and air burst. This information is then used to determine the dynamic loads on surface structures that are subjected to such blast pressures and to design them accordingly. It should be pointed out that surface structure cannot be protected from a direct hit by a nuclear bomb; it can however, be designed to resist the blast pressures when it is located at some distance from the point of burst.

The rapid and sudden release of energy forms a pressure wave in the surrounding medium, known as a shock wave as shown in (see Figure 1a). When an explosive source burst, the expansion of the hot gases produces a pressure wave in the surrounding air. This wave moves away from the centre of explosion and the inner part moves through the region that was compressed and is now heated by the leading part of the wave. The pressure waves moves with the velocity of sound, the temperature is very high about 3000-4000 degree Celsius and the pressure is nearly about 300 kilo bar of the air causing increase in velocity. The inner part of the wave starts to propagate faster and gradually overtakes the leading waves. After a small interval of time the pressure wave front becomes abrupt, thus forming a shock front (see Figure 1b). The peak overpressure is the maximum overpressure occurs at the shock front. Behind the shock front, the overpressure falls very rapidly to about half of the peak overpressure and remains almost uniform in the central region of the explosion. As the expansion continuous, the overpressure in the shock wave front decreases steadily; the pressure behind the front does not remain constant, but fall off in a regular manner. After a short time, at a certain distance from the centre of explosion, the pressures behind the shock wave front becomes lesser than that of the surrounding atmosphere and so called negative-phase or suction (see Figure 2).

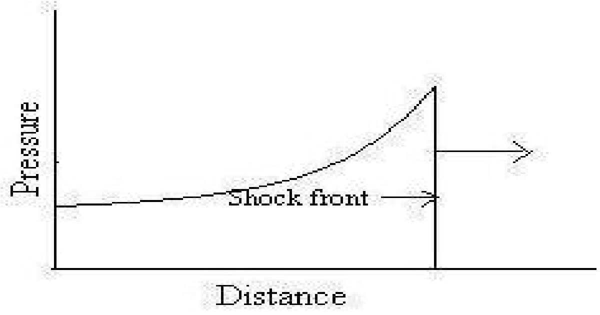


Fig. 1a: Shock wave-front

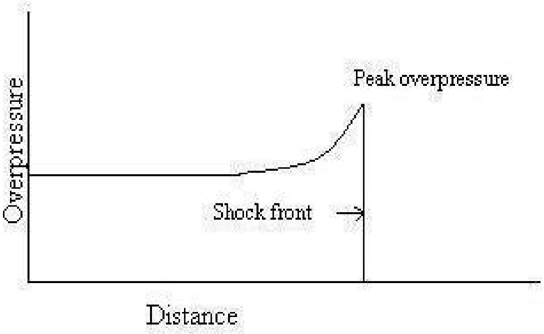


Fig. 1b: Abrupt shock wave-front

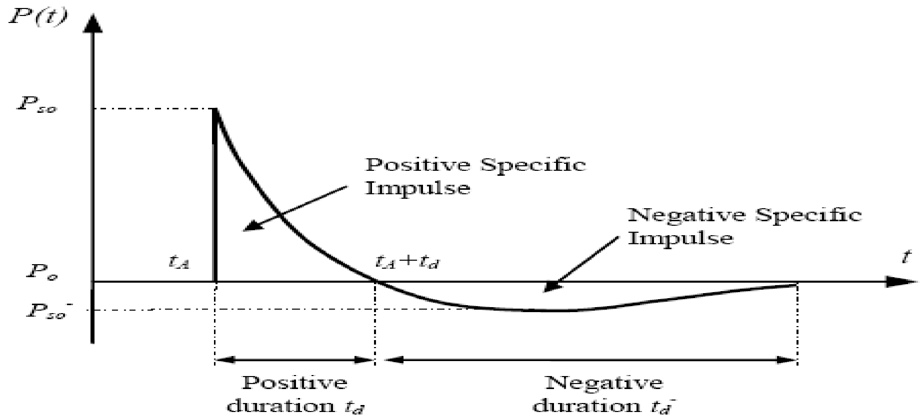


Fig 2: The variation of overpressure with distance at a given time from center of explosion

4. BEHAVIOUR OF MATERIAL AT HIGH STRAIN RATE

Loads due to blast or explosion typically produce very high strain rates in the range of 10^{2}-10^{4} s^{-1}. This high strain rate loading would changes the dynamic mechanical properties of target structures and, accordingly, the expected damage mechanisms for various structural parts and elements. For RCC structures subjected to blast effects the strength of steel reinforcing bars and concrete can increase significantly due to strain rate effects. It can be seen that ordinary static strain rate is located in the range: 10^{-5} to 10^{-6} s^{-1}, while blast pressures normally yield loads associated with strain rates in the range:10^{2} to 10^{4} s^{-1} (see Figure 3). The mechanical properties of concrete under high strain rate loading conditions can be quite different from that under static loading. But the dynamic stiffness does not vary from the static stiffness; the stresses which are sustained for a short period of time under dynamic loading conditions may gain values that are exceptionally higher than the static compressive strength. Strength magnification factors as high as 6 in tension and 4 in compression for strain rates in the range: 10^{3}-10^{-3}/sec have been reported (Grote et al., 2001).

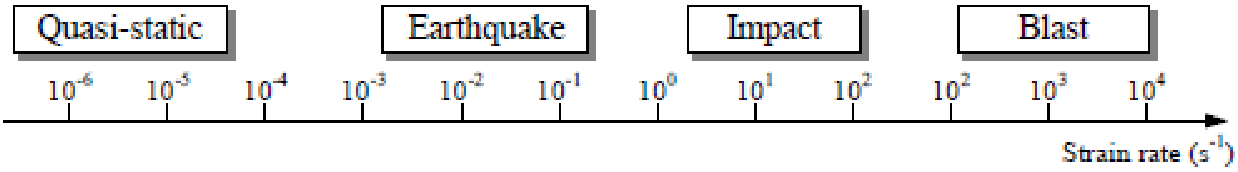


Fig 3: Strain rate associated with different types of loading

5. BLAST SIMULATION USING ANSYS AUTODYN

ANSYS Autodyn® is a versatile explicit analysis software tool for modelling the nonlinear dynamics of gases, solid, fluid and their interactions. The product has been developed to provide advanced capacities within a robust, easy-to-use tool. Less effort is required for simulation projects, less time and lower labour costs than with the other explicit softwares. It saves time and effort in problem setup and analysis by options to define contact, by interfaces coupling and by minimizing requirements of inputs using safe logical defaults.

M30 concrete wall with different shapes with and without steel plates is analysed in ANSYS-Autodyn to study the behaviour of concrete in such a high strain loading. The properties of concrete used are tabulated in Table 1.

Table 1. Properties of concrete

Properties	Value	Unit
Density	2400	Kg/m^3
Young Modulus	30000	Mpa
Poisson’s ratio	0.18	

5.1 Single concrete wall (with or without steel plate cladding)

The concrete wall is modelled in Explicit Dynamics module of ANSYS with the plan dimensions as 5m × 3m in V and W directions, respectively with thickness of 0.2 (see Figure 4a).The same concrete wall with steel plate having thickness 0.005 m (see Figure 4b). The analysis is done by using a charge weight of 100 kg TNT at a height of 1m above ground surface with a stand-off distance of 3m.

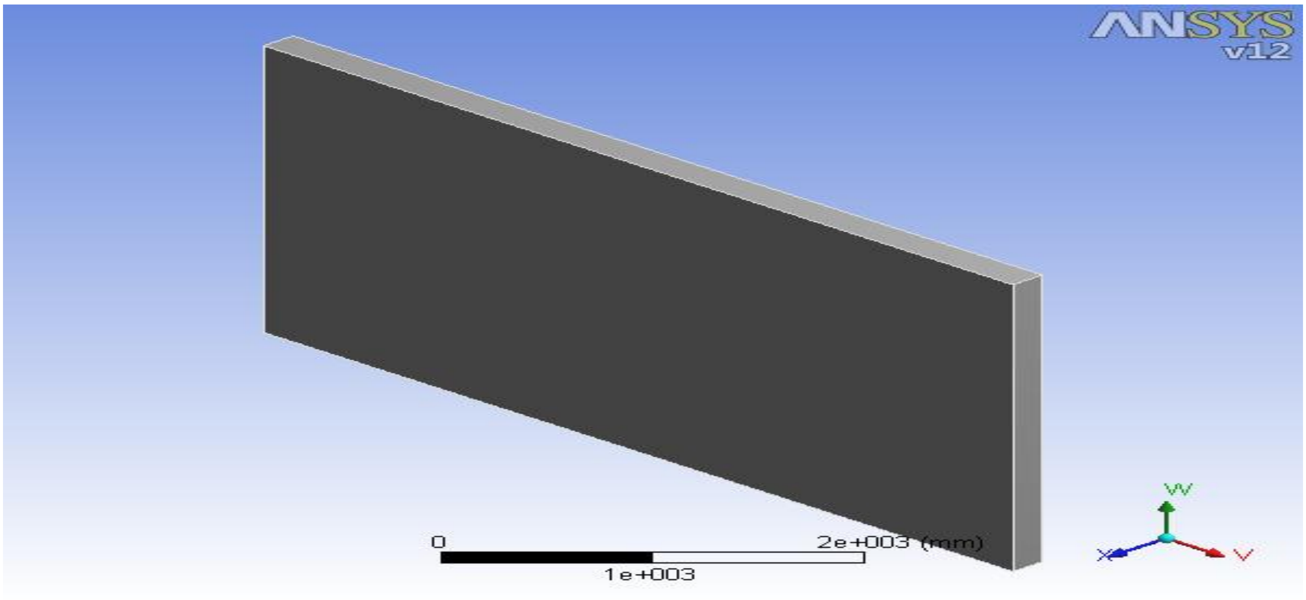
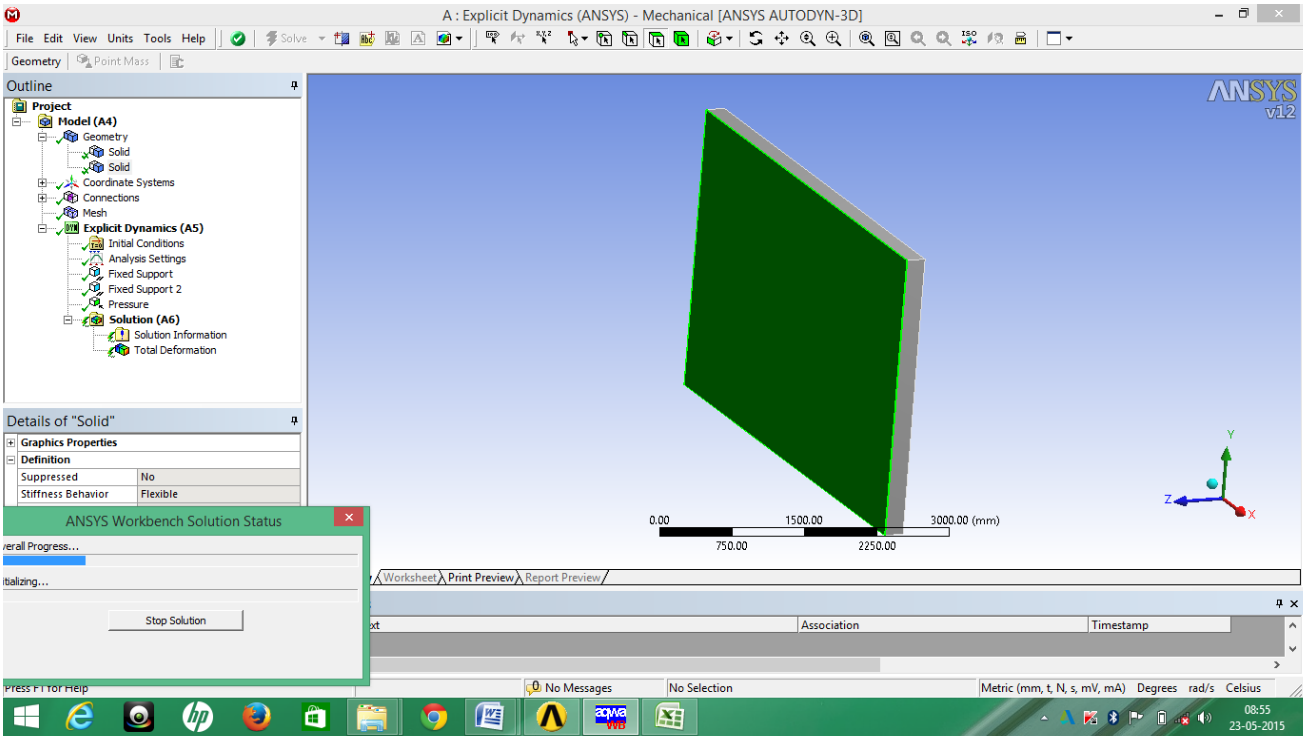


Fig 4a: Geometry of single concrete wall without steel plate cladding



Suppressed: No
Stiffness Behavior: Flexible

verall Progress...

itializing...

Press F1 for Help

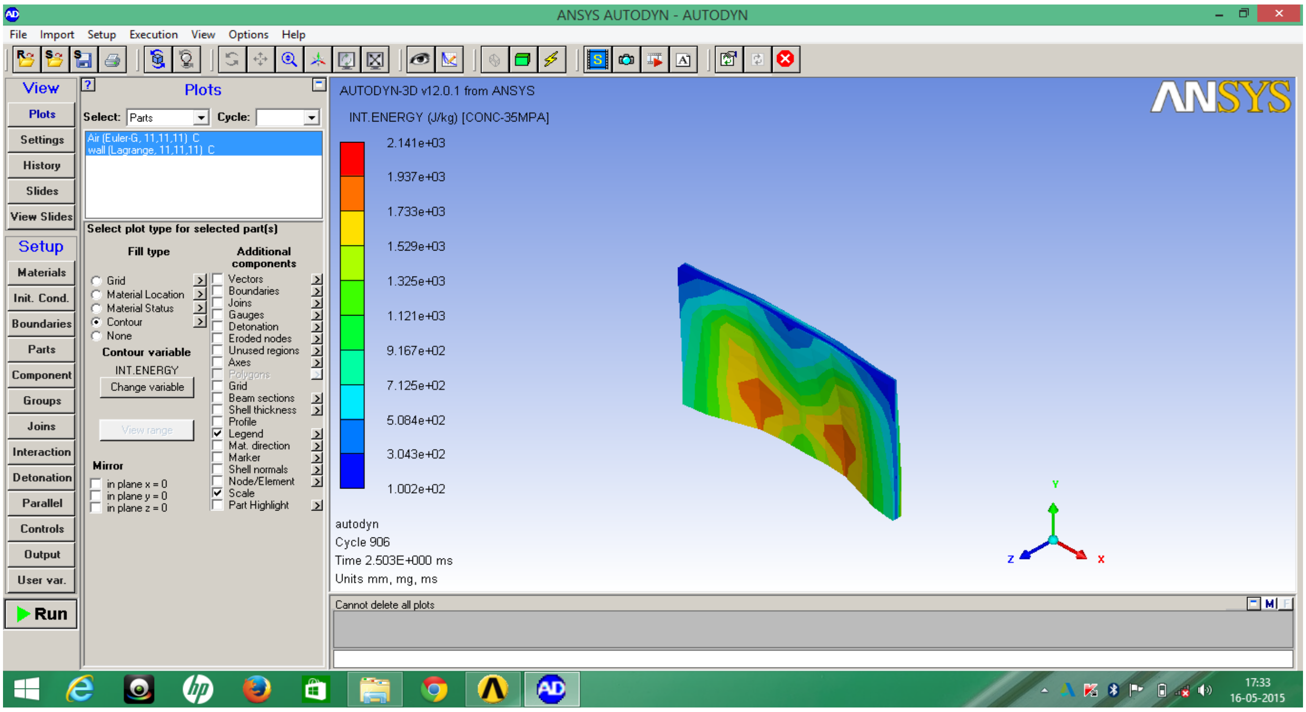
Fig 4b: Geometry of single concrete wall with steel plate cladding

The concrete wall is firstly analysed for a pressure of 50 Mpa in FE Modeller and then transferred to Autodyn for blast scenario. Gauge point is defined at the centre of wall. Analysis output is showed in terms of pressure contours (see Figure 5a and 5b) and pressure time history (see Figure 6a and 6b).

5.2 Case 2: L shape concrete wall with or without steel plate cladding

L-shape concrete wall is modelled in geometry module of Ansys Explicit Dynamic. Concrete wall is modelled with and without 5 mm thick plate (see Figure 7). Concrete wall is modelled as a solid part and gauge points is defined at the centre of these 2 solid parts. Detonation point is define at a coordinate of -3000, 1000, -3000 in X,Y and Z directions i.e. at an angel of 45 degree and at a height of 1m from joint. Pressure contour and time history plot at defined gauge point.

Analysis output is showed in terms of pressure contours of L-shape wall (see Figure 8) and Pressure-Time history (see Figure 9).



ANSYS AUTODYN - AUTODYN

Select: Parts

Air (Euler-G, 11,11,11) C
wall (Lagrange, 11,11,11) C

Fill type: ● Contour

Contour variable: INT.ENERGY

☑ Legend
☑ Scale

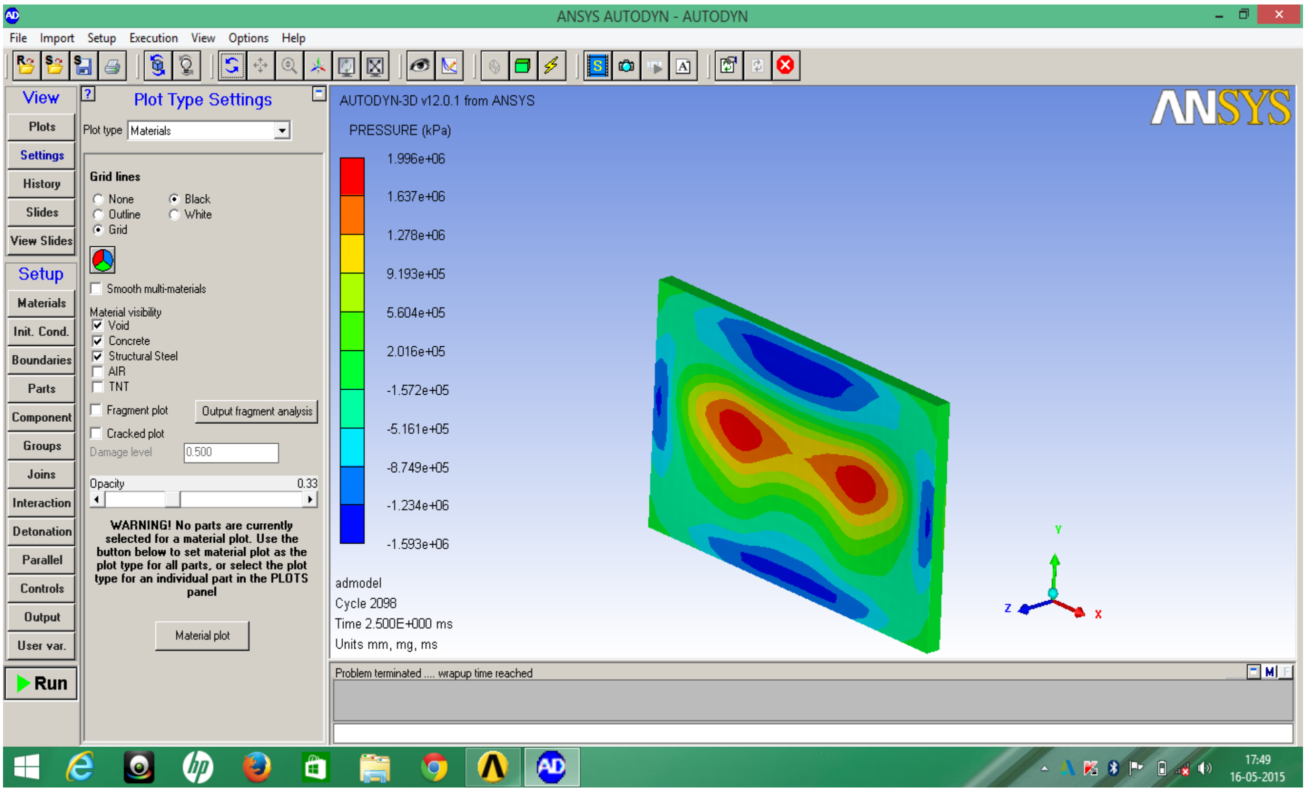
AUTODYN-3D v12.0.1 from ANSYS

INT.ENERGY (J/kg) [CONC-35MPA]

autodyn
Cycle 906
Time 2.503E+000 ms
Units mm, mg, ms

Cannot delete all plots

Fig 5a: Pressure contour of wall without steel cladding



ANSYS AUTODYN - AUTODYN

Plot Type Settings

Plot type: Materials

Grid lines: ● Grid, ● Black

☐ Smooth multi-materials

Material visibility
☑ Void
☑ Concrete
☑ Structural Steel
☐ AIR
☐ TNT

☐ Fragment plot
☐ Cracked plot
Damage level 0.500
Opacity 0.33

WARNING! No parts are currently selected for a material plot. Use the button below to set material plot as the plot type for all parts, or select the plot type for an individual part in the PLOTS panel

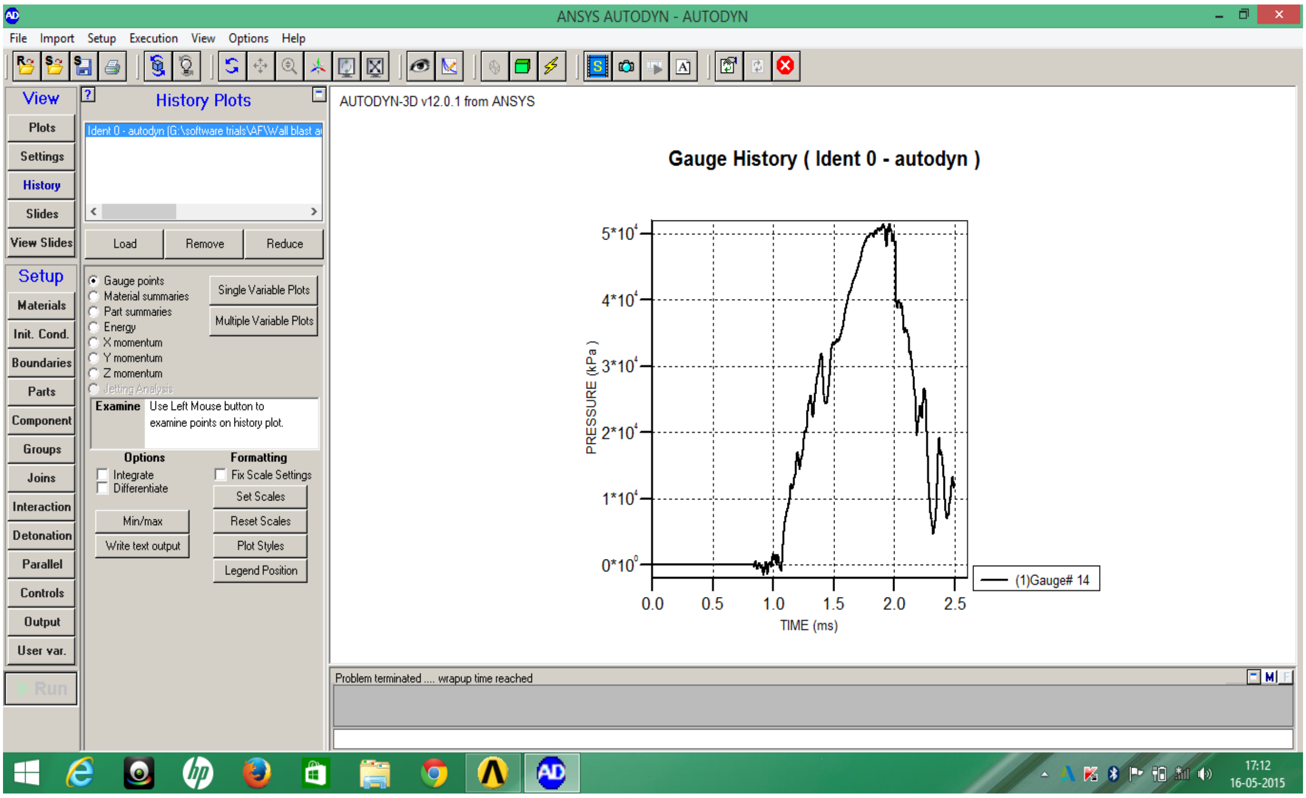
AUTODYN-3D v12.0.1 from ANSYS

PRESSURE (kPa)

admodel
Cycle 2098
Time 2.500E+000 ms
Units mm, mg, ms

Problem terminated .... wrapup time reached

Fig 5b: Pressure contour of wall with steel plate cladding



Ident 0 - autodyn (G:\software trials\AF\Wall blast a

● Gauge points
○ Material summaries
○ Part summaries
○ Energy
○ X momentum
○ Y momentum
○ Z momentum
○ Jetting Analysis

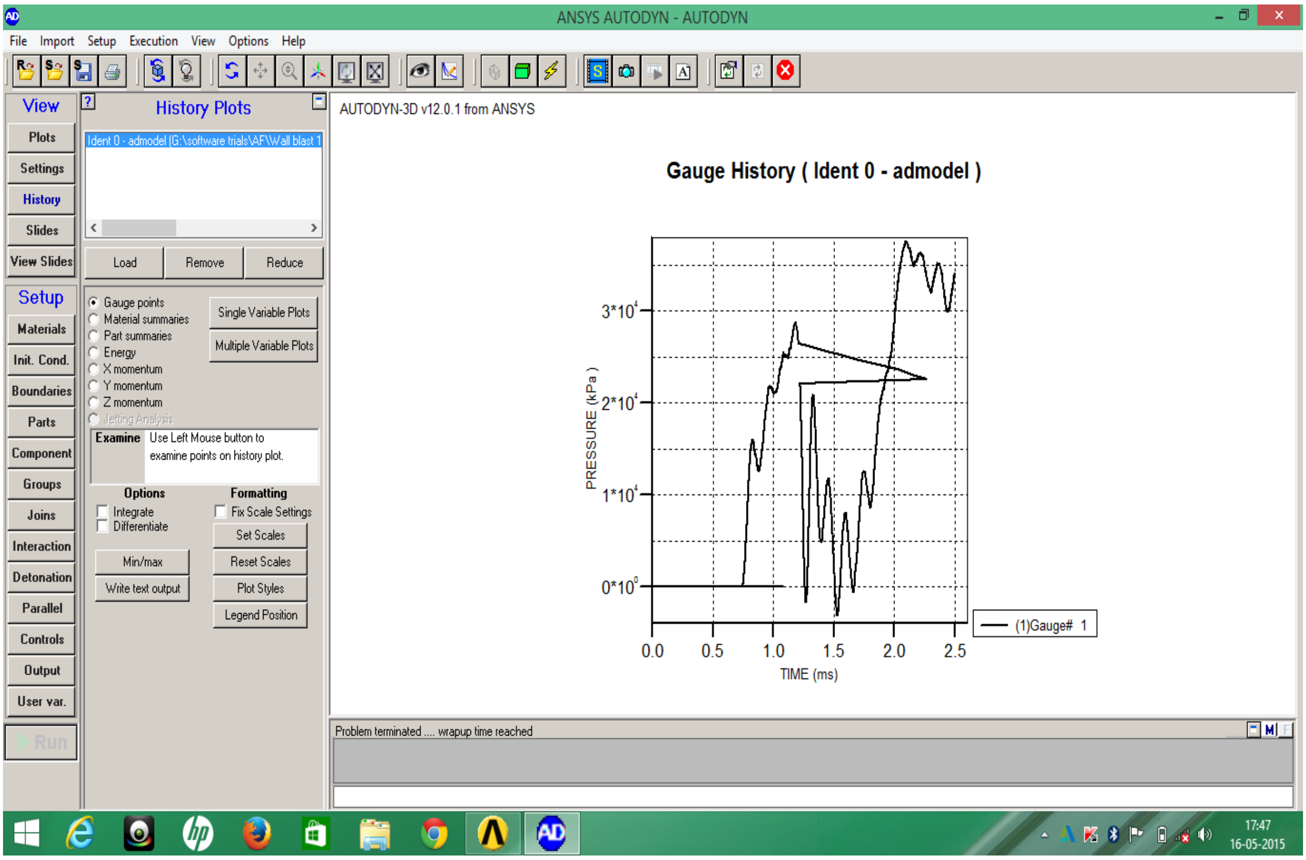
Examine Use Left Mouse button to examine points on history plot.

☐ Integrate
☐ Differentiate
☐ Fix Scale Settings

AUTODYN-3D v12.0.1 from ANSYS

Problem terminated .... wrapup time reached

Fig 6a: Pressure time history of wall without steel plate cladding



Ident 0 - admodel (G:\software trials\AF\Wall blast 1

● Gauge points
○ Material summaries
○ Part summaries
○ Energy
○ X momentum
○ Y momentum
○ Z momentum
○ Jetting Analysis

Examine Use Left Mouse button to examine points on history plot.

☐ Integrate
☐ Differentiate
☐ Fix Scale Settings

AUTODYN-3D v12.0.1 from ANSYS

Problem terminated .... wrapup time reached

Fig 6b: Pressure time history of wall with steel plate cladding

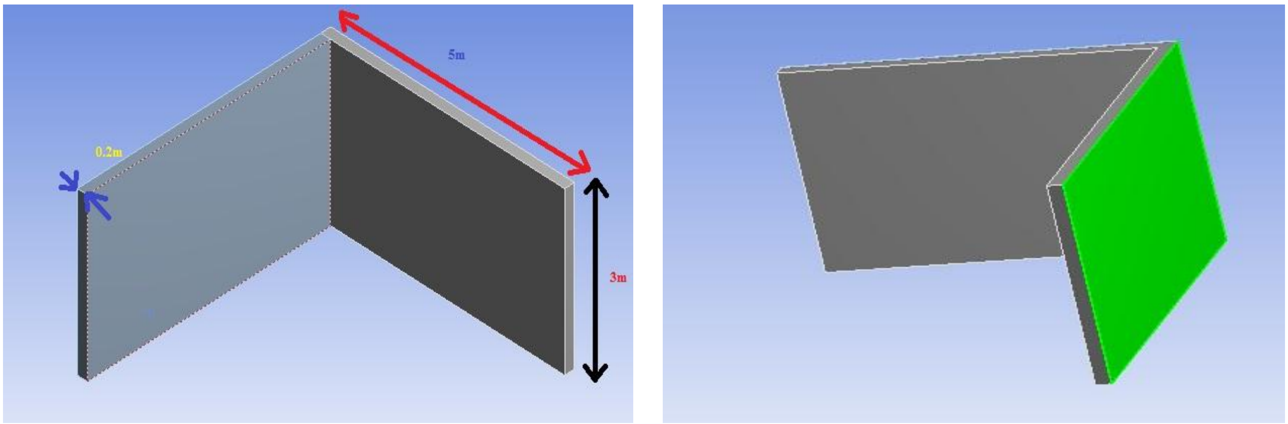
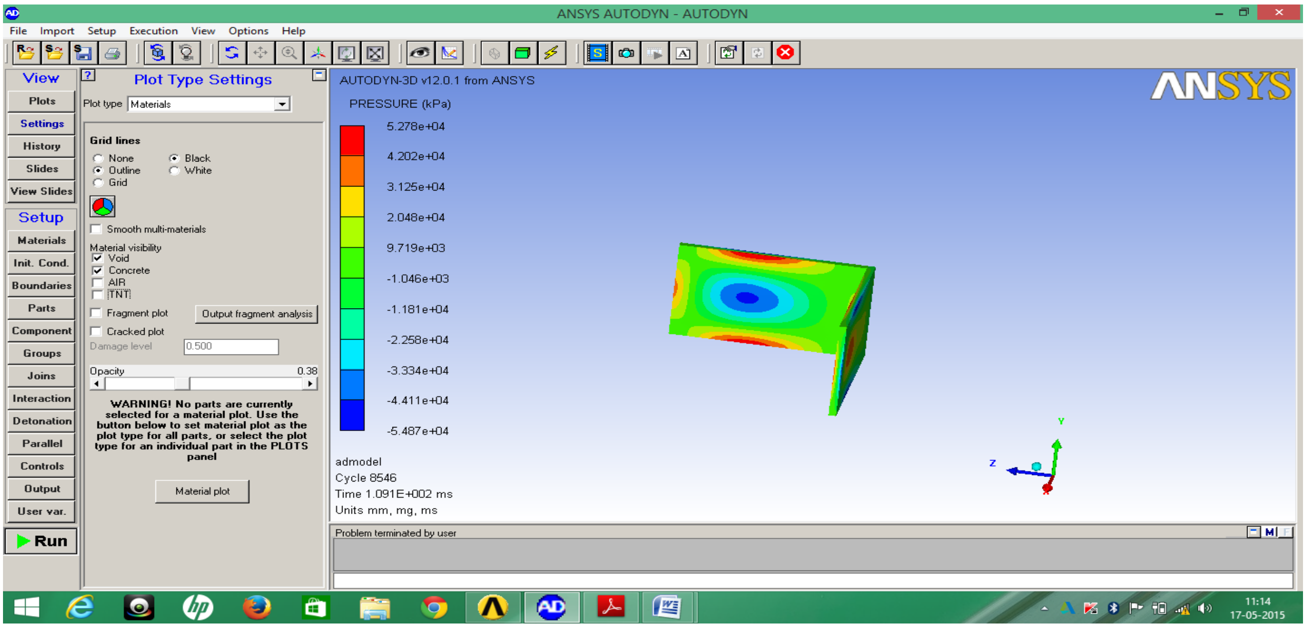


Fig 7: Geometry of L-shape concrete wall without and with steel plate cladding



Plot Type Settings

Plot type: Materials

Grid lines
○ None
● Outline
○ Grid
● Black
○ White

☐ Smooth multi-materials

Material visibility
☑ Void
☑ Concrete
☐ AIR
☐ TNT

☐ Fragment plot
☐ Cracked plot
Damage level 0.500
Opacity 0.38

WARNING! No parts are currently selected for a material plot. Use the button below to set material plot as the plot type for all parts, or select the plot type for an individual part in the PLOTS panel

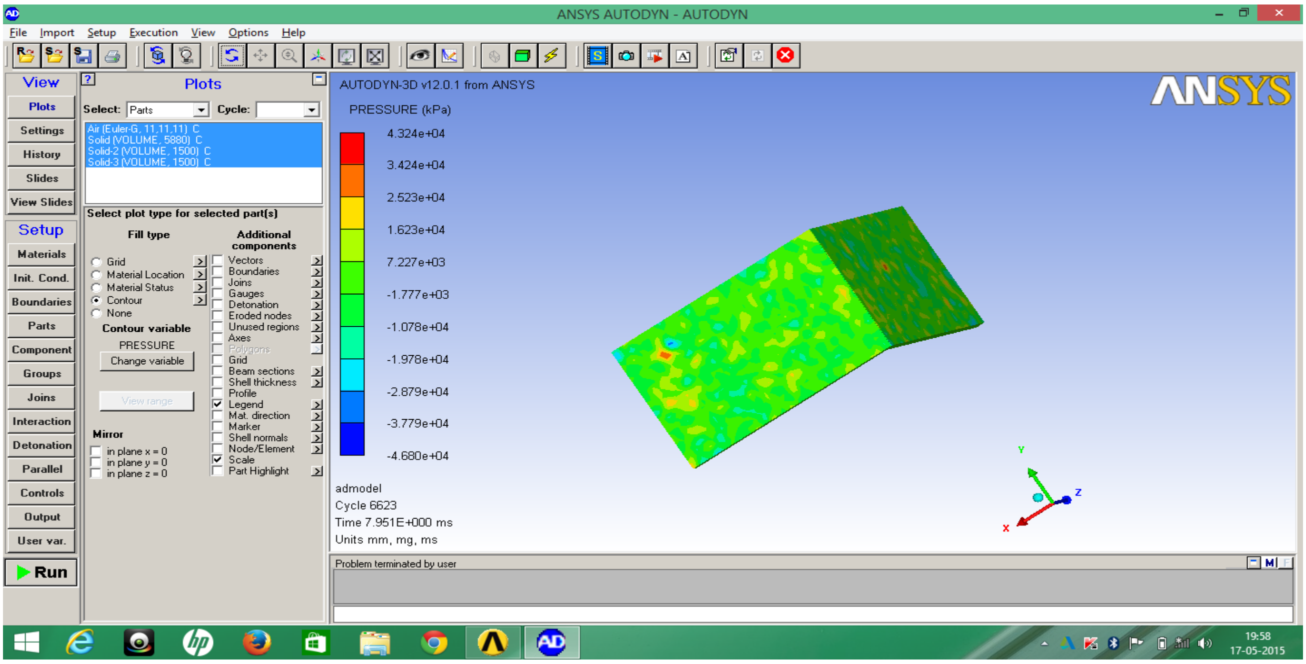
AUTODYN-3D v12.0.1 from ANSYS

PRESSURE (kPa)
5.278e+04
4.202e+04
3.125e+04
2.048e+04
9.719e+03
-1.046e+03
-1.181e+04
-2.258e+04
-3.334e+04
-4.411e+04
-5.487e+04

admodel
Cycle 8546
Time 1.091E+002 ms
Units mm, mg, ms

Problem terminated by user

Fig 8a: Pressure contour of wall without steel plate cladding



Plots

Select: Parts Cycle:

Air (Euler-G, 11,11,11) C
Solid (VOLUME, 5880) C
Solid-2 (VOLUME, 1500) C
Solid-3 (VOLUME, 1500) C

Select plot type for selected part(s)

Fill type
○ Grid
○ Material Location
○ Material Status
● Contour
○ None

Contour variable
PRESSURE

Mirror
☐ in plane x = 0
☐ in plane y = 0
☐ in plane z = 0

Additional components
☐ Vectors
☐ Boundaries
☐ Joins
☐ Gauges
☐ Detonation
☐ Eroded nodes
☐ Unused regions
☐ Axes
☐ Polygons
☐ Grid
☐ Beam sections
☐ Shell thickness
☐ Profile
☑ Legend
☐ Mat. direction
☐ Marker
☐ Shell normals
☐ Node/Element
☑ Scale
☐ Part Highlight

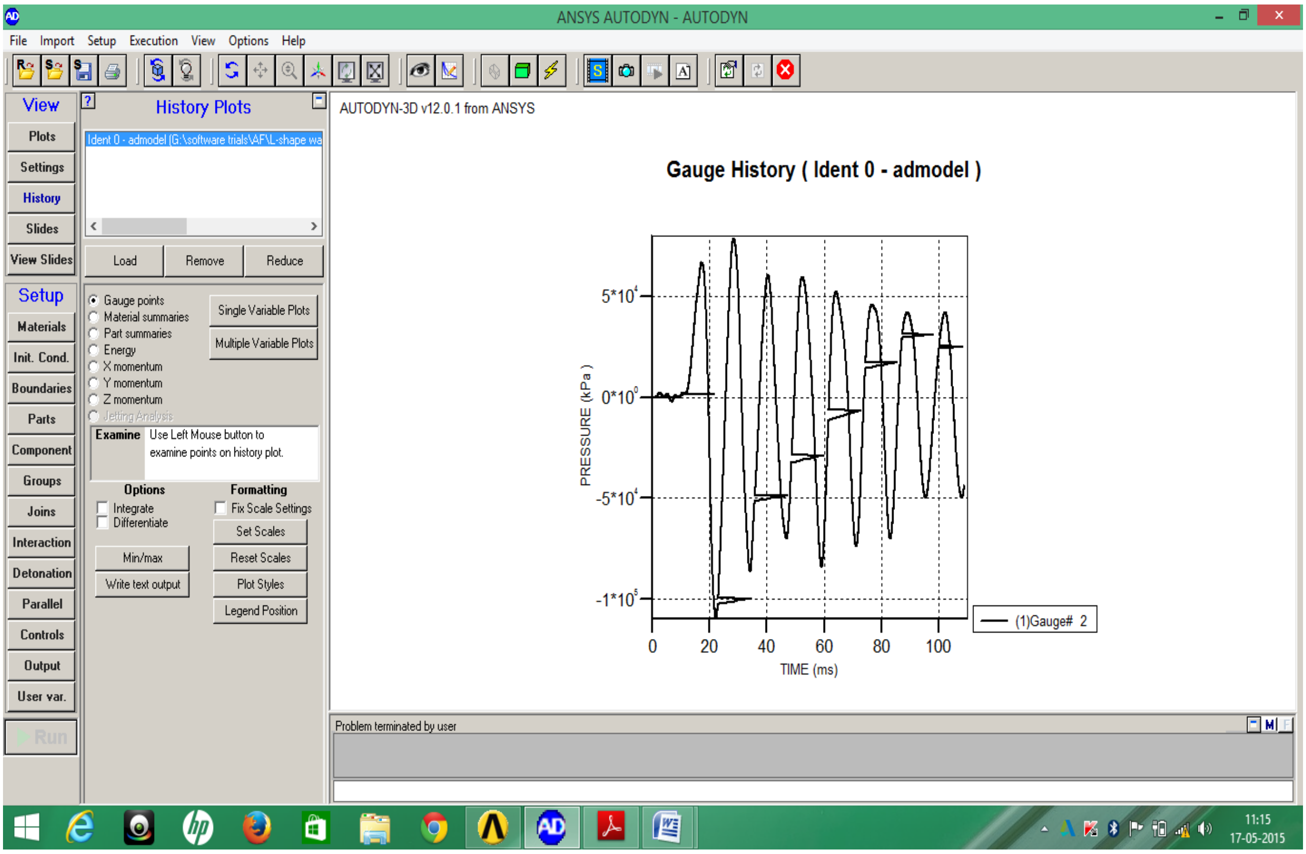
AUTODYN-3D v12.0.1 from ANSYS

PRESSURE (kPa)
4.324e+04
3.424e+04
2.523e+04
1.623e+04
7.227e+03
-1.777e+03
-1.078e+04
-1.978e+04
-2.879e+04
-3.779e+04
-4.680e+04

admodel
Cycle 6623
Time 7.951E+000 ms
Units mm, mg, ms

Problem terminated by user

Fig 8b: Pressure contour of wall with steel plate cladding



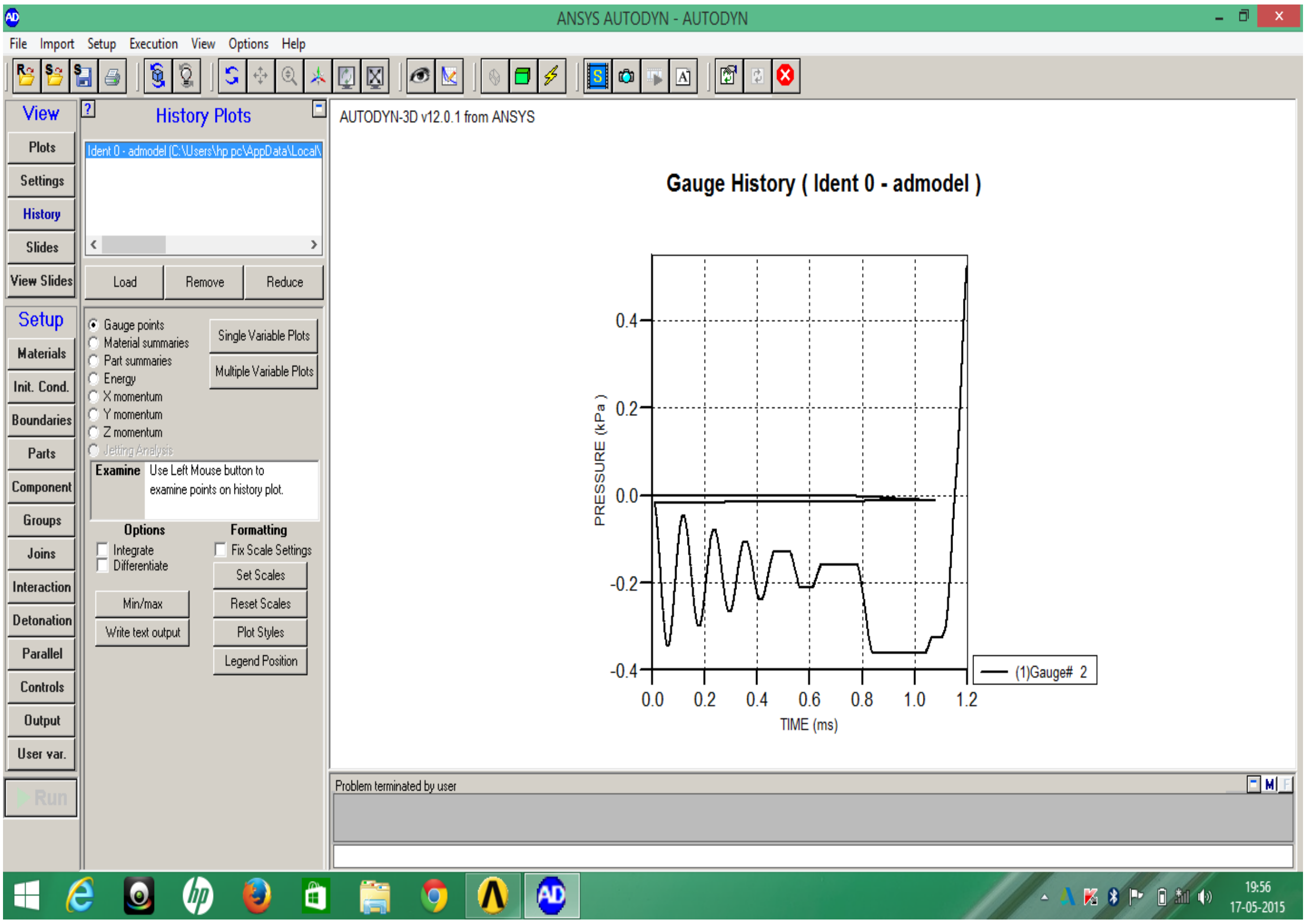
Ident 0 - admodel (G:\software trials\AF\L-shape wa

Examine Use Left Mouse button to examine points on history plot.

AUTODYN-3D v12.0.1 from ANSYS

Problem terminated by user

Fig 9a: Pressure-Time history without steel plate cladding



Ident 0 - admodel (C:\Users\hp pc\AppData\Local\

Examine Use Left Mouse button to examine points on history plot.

AUTODYN-3D v12.0.1 from ANSYS

Problem terminated by user

Fig 9b: Pressure-Time history with steel plate cladding

5.3 Case 3: U-shape wall without and with steel plate cladding

Another shape of concrete wall is used to study the behaviour of blast pressure on wall without steel plate and with steel plate. The geometry of C-shape (in plan) concrete wall along with dimensions is shown (see Figure 10). The detonation point is same as used in case 2 and gauge point are defined at the centre of middle wall. End conditions are fixed and steel plate is bonded with concrete at the outer side which is exposed to explosion source. The pressure contour and pressure time history plots for this case is showed below (see Figure 11 and Figure 12).

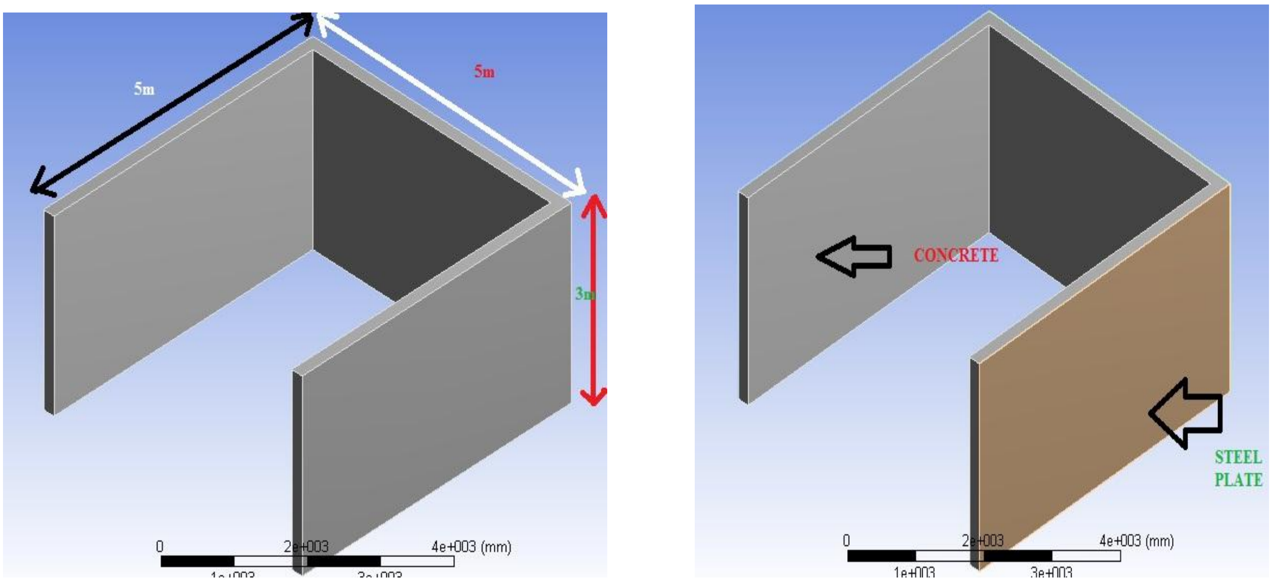
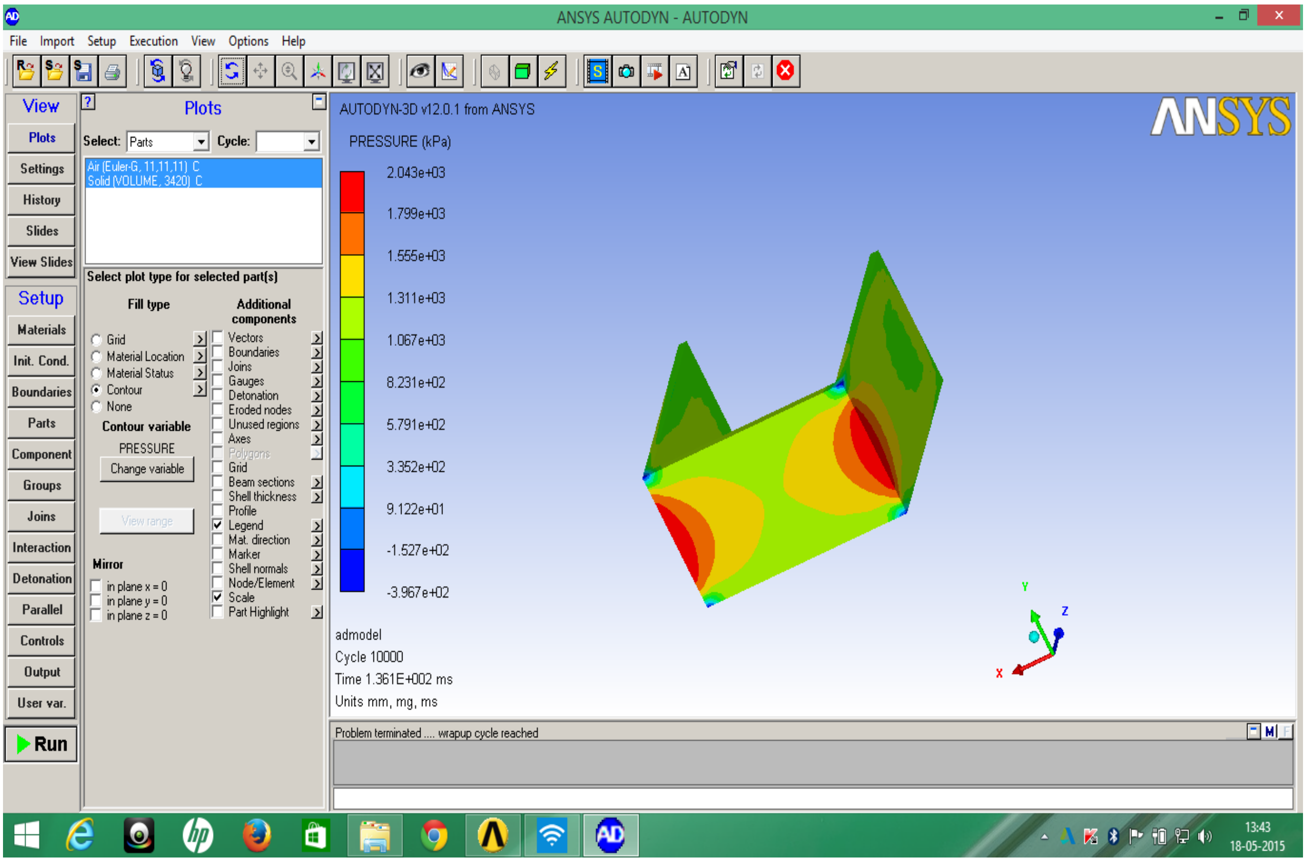


Fig 10: Geometry of wall without and with steel plate cladding



Select: Parts

Air (Euler-G, 11,11,11) C
Solid (VOLUME, 3420) C

● Contour

Contour variable: PRESSURE

☑ Legend
☑ Scale

AUTODYN-3D v12.0.1 from ANSYS

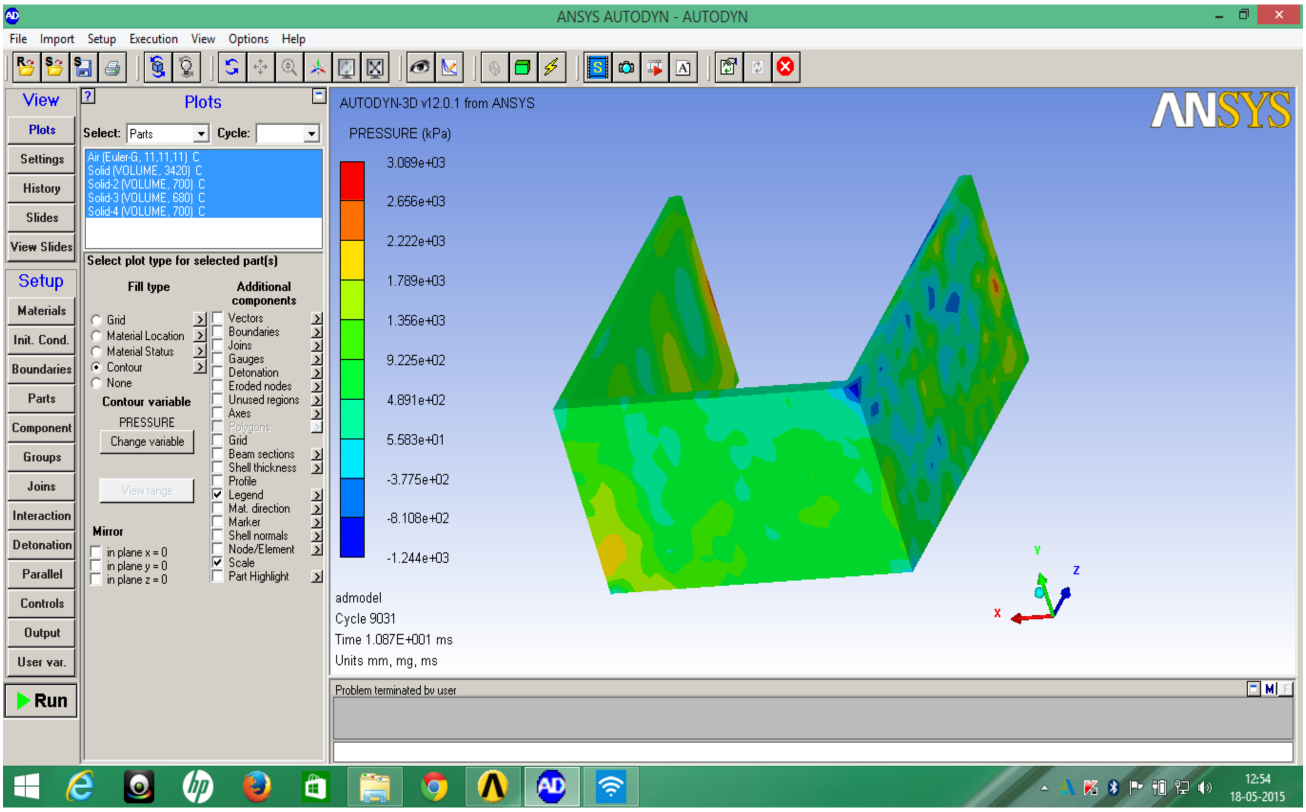
PRESSURE (kPa)

2.043e+03
1.799e+03
1.555e+03
1.311e+03
1.067e+03
8.231e+02
5.791e+02
3.352e+02
9.122e+01
-1.527e+02
-3.967e+02

admodel
Cycle 10000
Time 1.361E+002 ms
Units mm, mg, ms

Problem terminated .... wrapup cycle reached

Fig 11a: Pressure contour of wall without steel plate cladding



Air (Euler-G, 11,11,11) C
Solid (VOLUME, 3420) C
Solid-2 (VOLUME, 700) C
Solid-3 (VOLUME, 680) C
Solid-4 (VOLUME, 700) C

Contour variable: PRESSURE

AUTODYN-3D v12.0.1 from ANSYS

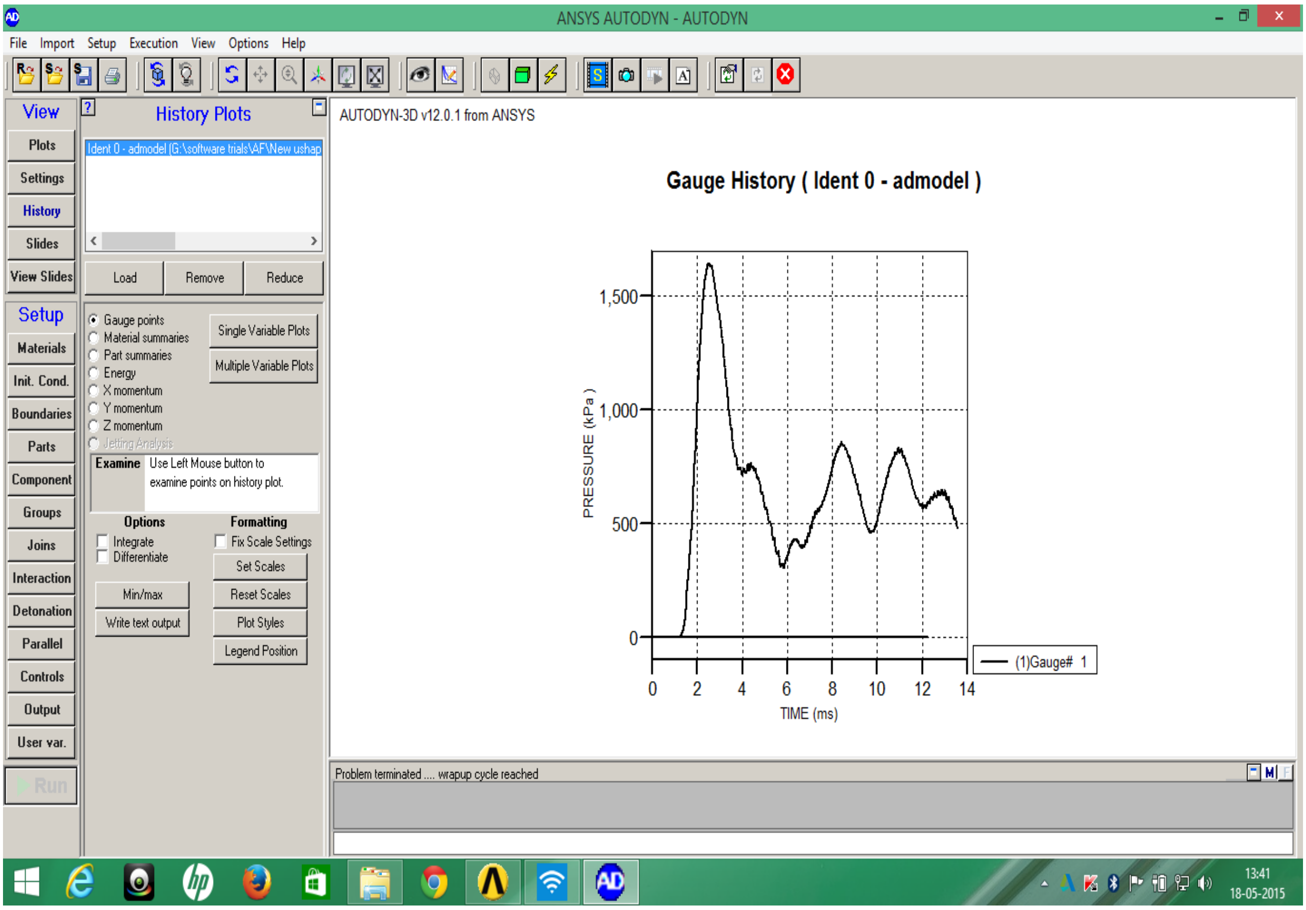
PRESSURE (kPa)

3.089e+03
2.656e+03
2.222e+03
1.789e+03
1.356e+03
9.225e+02
4.891e+02
5.583e+01
-3.775e+02
-8.108e+02
-1.244e+03

admodel
Cycle 9031
Time 1.087E+001 ms
Units mm, mg, ms

Problem terminated by user

Fig 11b: Pressure contour of wall with steel plate cladding



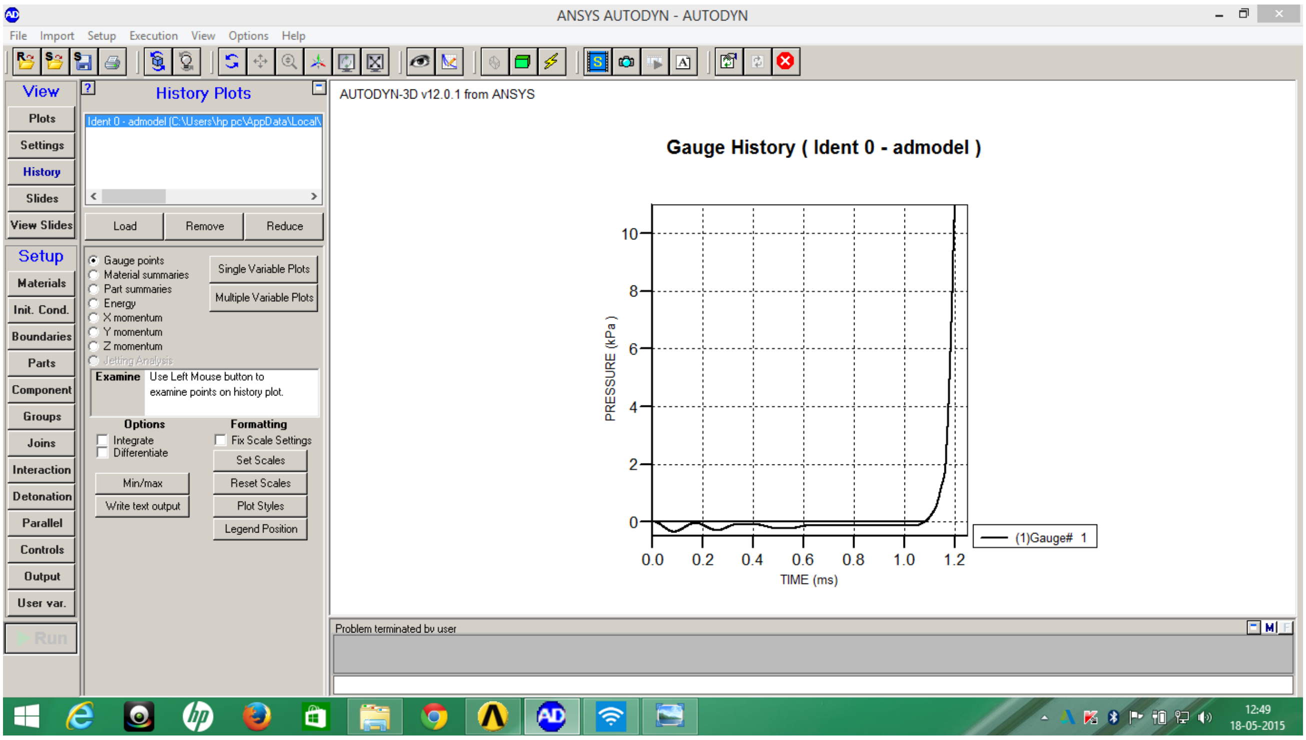
Ident 0 - admodel (G:\software trials\AF\New ushap

Examine: Use Left Mouse button to examine points on history plot.

AUTODYN-3D v12.0.1 from ANSYS

Problem terminated .... wrapup cycle reached

Fig 12a: Pressure-Time history plot without steel plate cladding



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● Gauge points

Examine: Use Left Mouse button to examine points on history plot.

AUTODYN-3D v12.0.1 from ANSYS

Problem terminated by user

Fig 12b: Pressure-Time history plot with steel plate cladding

6. CONCLUSION

It is observed from literature survey that for the estimation of blast load or pressure the empirical approach (Kinney and Graham's) proves to be ideal as blast phenomenon is complex in nature. Complexity arises due to unpredictability of charge weight and standoff distance, the behavior of material under different loading conditions and post blast triggering events. Ansys Autodyn is an efficient and user friendly tool for simulating explosives and impact loading linking it with workbench environment. The blast simulation was carried out using JWL as equation of state for explosive materials. The concrete walls of different shapes with or without steel plates cladding are analyzed in Autodyn to obtain pressure contours and pressure time history plots to study the behavior and effect of using steel. Autodyn Simulation gave good estimate of pressure time history of observed positive and negative phase. Pressure contour and time history plots signify that using a steel plate reduces the effect of blast pressure on the concrete wall thus reducing the damage due to pressure created by the 100 kg TNT with standoff distance and height of 3 m and 1 m. Similar observation goes for other plan shapes. The pressure time history plots shows that in case of L- shape wall without steel plate blast pressure fluctuates throughout the cycle but in case wall with steel plate pressure is initially negative but after completion of certain cycle the value changes to positive itself. This is due to the bonded steel plate. Also it is found that pressure is reduced by large amount due to steel plate. In case of U-shape concrete wall, pressure time history plots clearly shows the impact and pressure on concrete wall is reduced by large amount by using a 5mm thick plate. It has been observed that in case of steel plate with concrete wall initially pressure is negative but after some cycles and time the pressure becomes positive but less then pressure on concrete wall without steel plate.

7. REFERENCES

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