EFFECT OF BLAST LOAD ON SINGLE-LAYER BARREL VAULTS SPACE STRUCTURES

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Abstract

Depending upon their shape and also the materials used for their construction, structures exhibit various behaviors in the event of explosion. With performance analysis of these structures in such drastic circumstances, we are better able to select construction materials that can show a stronger reaction against explosion. In the present investigation, we initially outline an introduction on the characteristics and types of explosives and the various principles that elaborate on them. We then subsequently evaluate space frame structures and single layer barrel vaults and its behavior in the face of explosion using ABAQUS software, in which various key factors such as displacement, maximum stress, kinetic energy and the most critical structural model can be estimated. In this study, three cases of single-layer space frame barrel vaults with elevations of 3.33m, 4m and 6.67m are modeled. Methods of modeling space structures using ABAQUS software are other topics investigated in this thesis. The type of mainstay is assumed as joint with a symmetrical loading of 6500N. It is worth mentioning that ABAQUS 6.13-1 modeling software using finite element method is used to analyze data and explosive charge is applied to determine time series. Using charts and analysis, we can note that in this type of barrel vaults, structures soften as elevation increases, and thus ductility enhances. The most appropriate model is 6.67 m in elevation and its most critical position with an elevation of 3.33m in inside explosion mood and the middle of the first arc of a structure is obtained.

Keywords: *Explosive Loading, Single Barrel Vaults, Space Structures*

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1. INTRODUCTION

Explosion may occur by humans or as a result of a tragic event and can have wide-ranging consequences, emanating from a single gunshot to the explosion of nuclear weaponry. Explosions can facilitate engineering activities especially in road engineering, or be used for destructive purposes at times of war.

The past decade has seen an escalation of terrorist activities around the world, and Iran is no exception in this regard. Provinces such as Tehran and Fars have sustained great human and economic casualties as a consequence of such attacks.

In this research, three models, all with different elevations, are analyzed using ABAQUS software. The performance evaluation of structures under impact loading and the numerical results are presented. The result of the dynamic analysis that can be achieved is that when the height of the structure is closer to the span of the higher structural, flexibility and shifted nodes decreases after the explosion. The parameters of the kinetic energy, stress and strain are examined.

2. The Purpose of this Research

Since space frame structures are commonly used for public facilities and industrial applications, like gymnasiums, community halls, aircraft hangars, cultural and art exhibition centers, all kinds of transportation terminals or in greater projects like bridge construction, this study aims to investigate the “explosion effect” on such structures, and its impact on barrel vault space frame structures is evaluated. In an explosion, explosive potential energy is instantly released (in a matter of micro seconds) and the released energy is converted into two separate forms, thermal radiation and shock waves (both in the air and ground).

2.1 Definition of Space Structure

The three-dimensional structure which basically behaves so that its overall behavior cannot be estimated by some two-dimensional independent sets, is called space structure.

2.2 Definition of Explosion

A sudden blast of energy, which can be instigated by combustible gases, a nuclear explosion or different types of bombs.

2.3 Definition of TNT

TNT unit is usually used as reference to determine the strength of the explosion. When the explosive material is of a type other than TNT, the equivalent TNT is determined using the coefficients presented in the table below.

C.F: TNT factor (the amount of TNT in proportion to the amount of explosive)
Equation(1):
w: weight of explosive material
TNT: weight of explosive material equal to the amount of TNT.

Table -1: TNT factor for exclusive materials

C.F	Special energy (Kj/Kg)	Explosive material	C.F	Special energy (Kj/Kg)	Explosive material
	TNT	4250	1.0		
1.25	GDN	7232	1.6	Ethylene glycol dinitrate	5650
1.148	Pyroxylin	4746	1.05	B) 0.6RDX+0 TNT(	5190
1.185	dynamites	5876	1.30	RDX	5360
1.256	PETN	6690	1.48	HMX	5650
1.25	DNT	3164	0.70	Semtex	5660

Explosion is an instantaneous occurrence which releases dynamic and transient forces and has a low impact time (from a few milliseconds to several seconds). When an explosion occurs, the energy is suddenly released and divided into two parts, namely heat Radiation and wave emissions in land, whereby the latter is considered in this research study. Waves that are released into the air are the main cause for structural damage. These waves travel faster than the speed of sound and collide with the structure.

With the reflection of waves on the surface structure, pressure increases. Moreover some air waves infiltrate into the structure through doors, windows and openings and thus affect the structure's members. During this process, the refraction of waves also occurs in the corners of the structure, which can increase or decrease the pressure of the wave. This process continues until all accessible areas of the structure are influenced by wave pressure.

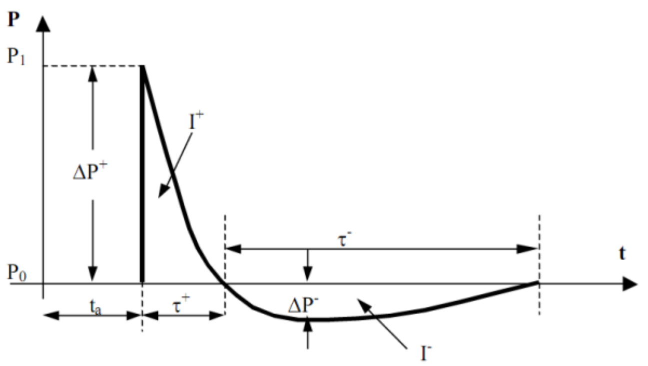


Chart -1:the chart of pressure wave and time of blast in the Air

3. RESEARCH OBJECTIVES AND APPROACH

The first studies that were conducted on explosion effect in the thirteenth century, such as that on pressure emanating from explosion, were aimed at providing adequate resistance in guns and canons and the estimation of initial velocity, and that various studies have been carried out on this topic over the centuries using different methods. The early years of the twentieth century, and in particular during the time of both world wars, saw an incredibly increasing amount of investigation on explosion effect.

In 1919, Hopkinson presented scale rule for simple explosions. It lacked mathematical principles yet was founded upon experimental experience. Hopkinson asserted that if two buildings, with similar shapes and constructions materials used, are made in different sizes and then exploded, the amount of explosives needed to create the same destructive effect has a direct proportion to the cube of the building's dimensions. Guernsey introduced such rule in 1926. Horace Lamb [3], mathematician and professor of mathematics at the University of Manchester, conducted extensive research on hydrodynamic and wave propagation phenomena.

Cranky [4] discovered changes in pressure, velocity and that density of the gas passes through the excitation wavelength, and published his conclusions in a paper in 1870. His research played a significant role in explosion analysis. Cranky, like Hopkinson, was also one of the few scientists who held great expertise in both physics and engineering.

Taylor [5] was another scientist whose study was on the dynamics of the explosive blast wave had a huge role in the development of research center of Great Britain's Defense Ministry between 1936 and 1950. His early papers were on wave propagation and dissipation of the explosion censed by conventional weapons. But in his later studies, he was concentrated on the behavior of the explosion of the first atomic explosion in New Mexico in 1946.

4. PROBLEM

To investigate the behavior of barrel vault structures when an outer explosion occurs, three models with elevations of 3.33m, 4m, 6.67 m are used in the vicinity of structure, in which all connections are assumed rigid. This structure includes three levels and three different explosives (research conducted on blast).

5. MATERIAL AND METHODOLOGY

Considering the fact that our structure should be subject to explosive loading, vault structures log in to the plastic drum structure is inevitable. Because of this, to simulate the behavior of steel, both elastic and plastic Chart -1 are considered and information given to the software. The elastic properties of materials used in the analysis are as follows:

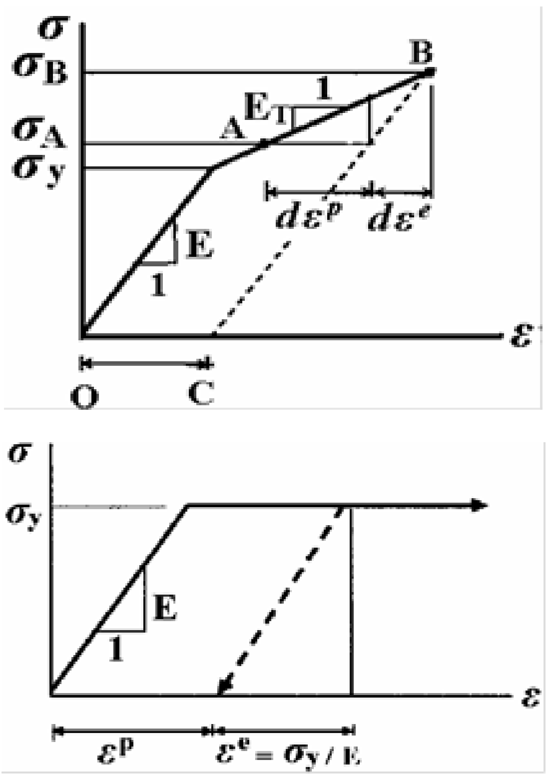


Chart -2: material stress- strain diagram

E (elasticity module): 206*109 (N/m2)

ν (poisons ration): 0.3

(Weight of volume): 7850 (kg/m3) ρ

Fy(material's yield stress): 300 * 106 (N/m2)

Plastic materials are presented in the following table.

Table -2: Values of stress and strain of steel

Actual stress (mpa)	Plastic strain(dimensionless)
300	0.0
350	0.01
400	0.35

5.1 Sections Characters

Members of the considered models are as follows;
mm Two pipes , one with an inside diameter of 177.8 m and a wall thickness of 4 mm, and another with a 177.8 mm inside diameter and thickness of 5.6 mm, are shown in Fig -1.

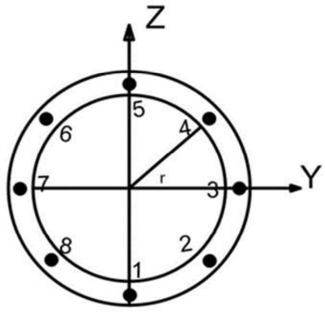


Fig -1: finite element and integral parts of Gaussian

In modelling method, the amount of pressure on each point of the structure is obtained based on distance from the centre of the explosion and explosive:
Equation (2):

$$\frac{P_{max}}{P_{\circ}} = \frac{808\left[1+\left(\frac{Z}{4.5}\right)^2\right]}{\sqrt{1+\left(\frac{Z}{0.048}\right)^2}\sqrt{1+\left(\frac{Z}{0.32}\right)^2}\sqrt{1+\left(\frac{Z}{1.35}\right)^2}} \qquad (2)$$

This formula is chosen since it can be used for all z values while in other equations the value of z is limited. The formula is an experimental correlation to calculate the static pressure caused by the explosion on the structure that is based on the distance parameter, z (scaled distance) is expressed in equation (2).

This parameter is calculated based on the weight of explosives:

Equation (3):

$$Z = \frac{R}{\sqrt[3]{W}} \qquad (3)$$

R: the distance from the centre in meters
W: the weight of explosive in proportion to TNT amount in kilograms.

Blast waves reflect once striking a rigid barrier. With a conservative assumption, reflect pressure (pr) can be calculated based on shock waves' vertical impact with the structure. Now as the maximum pressure, it is multiplied by each node's surface based on reference and the applied force on each node must be introduced and defined to the software.

Equation 4:

$$P_r = 2P_{so}\left[\frac{7P_o + 4P_{so}}{7P_o + P_{so}}\right] \quad (4)$$

P_{so} : Base pressure or the maximum explosion pressure

P_o : Environmental pressure

5.2 The Initial Design and Construct Validation of the Modeling

To study the behavior of single-layer barrel vault space structures with an elevation of 4m, we need to assess whether or not our work corroborates reports concluded by Abedi et al. Once assured of the accuracy of the modeling for explosive loading, with the application of three different weights , 20kg, 50kg and 100kg ,and three different distances , 4m, 2m and in the middle of the first arc of the structure, dynamic analysis is done using ABAQUS / CAE V.6.13-1. Other modeling characters are as follows.

4.3 Anchor and Load Conditions 3

For all nodes in the longitudinal direction, all anchors are assumed as joints. The drum types are symmetrical and the applied force on each node is 6500N. The applied loading is a combination of dead load and live load, whereby it is assumed that (LL) / (DL) =1.

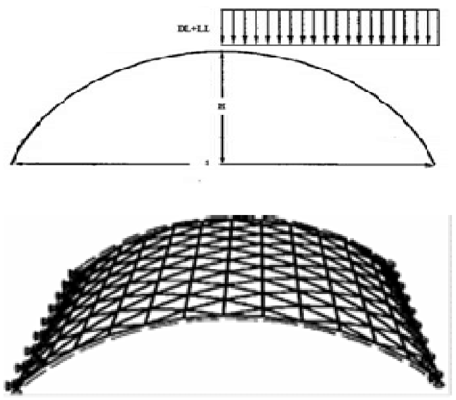


Fig -2: General view of single-layer barrel vault

S: vault span
H: height
The three evaluated models are different in the ratio of H/S, from 3.33m, 4m and 6.67 meters.

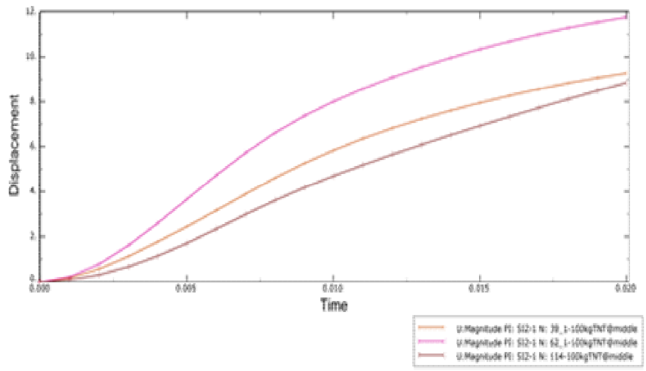
6. RESULTS AND TABLES

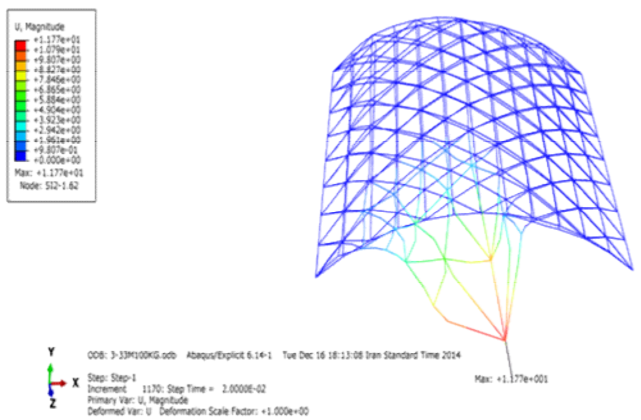
In this section, the structure's behaviour under blast loading is examined. For this purpose, finite element's analysis of dynamic structures is used. To analyse models, ABAQUS definite dynamic analyser (dynamic explicit) is used. Such application is appropriate when the purpose is to analyse dynamic models in a fraction period of time.

Definite dynamic analyser is preferred because of its distinct capability of calculation in extremely rapid fashion, and its convergence ability during a shorter span period. Also, this application is easier to perform for great deformations and its meticulousity in non-linear analysis. While analysing behaviour of all models, time intervals of 0.02 seconds is defined. The parameters to be examined are displacement, stress, strain and kinetic energy.

In this part, the displacement contour for three consecutive nodes on three models with elevations of 3.33m, 4m and 6.67m are provided, and the time series of structure elements at various distances of the explosion, 2m, 4m and middle of first arc of the structure, will be evaluated and explained. For example, some of the contours and curves of the critical weight (100 kg TNT) are shown in the following figures.

In figure (2), three consecutive nodes are shown longitudinally and the node with maximum displacement in the model, which is node no 62 with displacement of 11.77m, through this comparison are used. Imaging two nodes located in the further distance of maximum node, a decrease in displacement is observed.





7. CONCLUSIONS

In this research study, three different elevations of 3.33m, 4m, and 6.67 meters with different charging intervals of 4m and 2m and the middle of the first arc were evaluated. The most critical condition was observed at 3.33 m elevation with distance from the middle of the structure's first arc, which had the most displacement, 11.77

ACKNOWLEDGEMENT

The authors can acknowledge any person/authorities in this section. This is not mandatory.

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