DYNAMIC TIME HISTORY ANALYSIS OF BLAST RESISTANT DOOR USING BLAST LOAD MODELED AS IMPACT LOAD

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ABSTRACT

A blast resistant single door was designed to withstand a 0.91 bar blast pressure and 44 ms blast duration. The analysis was done using Dynamic Time History Analysis using Blast Load modeled as Impact Load for given duration. The material properties used have been modified to accommodate dynamic effects. The analysis was done using dynamic finite element method (fem) for time of the blast duration, and the maximum/minimum internal forces and displacement were taken from the time history output, in order to know the behavior under blast load and estimate the safety margin of the door. Results obtained from this research indicated that the maximum z-displacement is 1.709 mm, while in the term of serviceability, the permitted is 25 mm. The maximum reaction force is 73,960 N, while the maximum anchor capacity is 82,069 N. On blast condition, the maximum frame stress is 71.71 MPa, the maximum hinge shear stress is 45.28 MPa. While on rebound condition, the maximum frame stress is 172.11 MPa, the maximum hinge shear stress is 29.46 MPa. The maximum door edge rotation is 0.44 degree, which is not exceed the permitted boundary (1.2 degree).

Keywords: Dynamic time history, blast resistant door, single door, finite element method.

1 INTRODUCTION

1.1 Background

Technical hazards are different from natural hazards. Blast load due to gas explosion, chemical explosion and terrorist attack; or impact load due to transportation or fragments accidental are included in the technical hazards category.

Explosion inside a LNG structure could directly threaten the lives of people inside and outside of the structure, and also damage the structure and cause further loss of lives and properties. Preventive measures should therefore be implemented not only to significantly reduce the possibility of terrorist attacks, but also to protect the existing structure from collapsing under internal blast loading. Such internal blast loading should also be properly taken into consideration in the design of a new structure.

Design considerations (loading types) for blast resistant structure are both static and dynamic loads. Static load includes no inertia effect, not a time dependent response, and acts on the structure for a long period of time while dynamic load includes wind load, earthquake load, and blasting load.

In terms of blasting load, load type is no-cyclic load or impulse load, strong time dependencies, typical duration in milliseconds, magnitude inversely proportional to mass, and has a high frequency.

1.2 Objective and Scope

The aim of this research is to conduct preliminary investigation and numerical analysis (dynamic finite element method) of the blast resistant single door, in order to know the behavior under blast load and estimate the safety margin of the door. The height of the door is 2,239 m, while the width is 1,039 m. Door material is steel, door post is steel frame, and columns are concrete columns.

The type of loading is blasting load, the blast pressure is 0.91 bar (89.27 kPa) with 44 ms duration for blast pressure and 132 ms duration total time with rebound pressure. The door was designed as a part of LNG Plant Structure (Madutujuh, 2011).Dynamic Elastic Finite Element Method was carried out with the 900-nodes Finite Element Method software ADINA (ADINA, 2009).

2 BASIC THEORY

2.1 Blast Basic

Air blast is the foremost damage mechanism. Air blast phenomena occur within milliseconds and the local effects of the blast are often over before the building structure can globally react to the effects of the blast. Also, initial peak pressure intensity (referred to as overpressure) may be several orders of magnitude but decays exponentially with distance from the source and time and eventually becomes negative. In many cases, the effects of the negative phase are ignored because it usually has little effect on the maximum response (Javed, 2009). The reflection of the blast wave occurs after striking with the structure. The structure moves after receiving the blast impact, and its magnitude depends on the impulsive force. Within the elastic range, no permanent deformation occurs owing to inadequate pressure or scarce duration. The structure transforms into plastic range with the excessive pressure load. The structure may fail with the displacement in the plastic range.

The structural response against blast is associated with stress. A comprehensive application of shock wave phenomenon is required during traveling of blast waves through the transmitting medium. If the explosion initiates from extremely great scaled distance e.g. a small charge weight or a large scaled distance from a structure, then global deformation will result in the structure. It shows that all the structural elements offer some resistance to the shock wave. It is of utmost importance that the expected loading and the resisting elements to absorb shock wave should be incorporated in the dynamic analysis and design for proper visualization of structural response (Javed, 2009).

An explosion is a very rapid release of stored energy as radially expanding shockwaves are converted into thermal radiation, audible wave, air pressure, and ground shock, where air blast is the principal damaged mechanism. Air pressure will change rapidly during the blasting as follows: Ambient Pressure, Initial Peak Pressure (at Blast Source), Incident Overpressure (Near building), Reflected Overpressure (Multiplier effect on building surface), and Suction Pressure (after shock) (Madutujuh, 2011).

Incident Overpressure or Initial Peak Pressure may be several orders of magnitude higher than ambient atmospheric (normal) pressure. The pressure decays exponentially with distance from the source and time and eventually becomes negative (outward rushing pressure or suction pressure).

Usually the negative pressure is neglected in the design, except for special cases that may need consideration for suction pressure, such as roof element. So the blast load history will be defined as triangular load, with peak at t = 0 and decays to zero at t = duration.

higher than ambient atmospheric pressure. The overpressure radiates from the point of detonation

Avoid building with L or U shape that can trap the shockwave and create very high local pressure because of reflected waves.

2.2 Blast Load

After the positive blast pressure, a negative pressure will be applied on the door leaf (Xinzheng, 2002). On the other hand, the door leaf will rebound because of the impact between the door leaf and the doorframe. Both of these forces will be resisted by the door hinge and door latches. These forces are important parameter for both of the hinge and latches.

In the USSR code for blast resistant structure, the rebound factor is 0.7, while the rebound factor in United States of America code is 0.5 (Xinzheng, 2002. In this research, the USA approach is used (Figure 1).

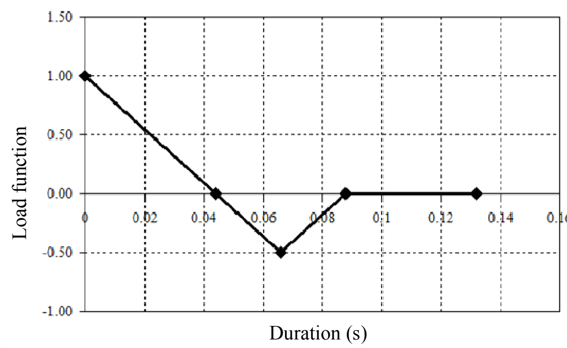

Figure 1. Blast load model

In this research, the contact between the door leaf and the doorframe, and the contact between the door hinges and the door bearings, can be simulated using an idealization, which are a spring element modeled at the each door's edges, except at the bottom edge. The idealization model for spring element can be seen in Figure 2.

Numerous research works exist for scaled blast parameters for conventional explosions (Javed, 2009). Tomlinson (1971) & Newmark (1961) provide shock front characteristics for incident and perpendicularly reflected waves for spherical pentolite charges exploded in free air. Kingery (1966) provides data for incident waves for surface bursts of TNT which are usually regarded as the standard waves for this scenario. Details for both air and surface bursts of TNT are discussed by Baker (1973) & Strehlow (1976). A comparative study of the calculations of blast wave properties has been carried out by Newmark (1972).

Blast pressure can be calculated using the following Formula 1 and Formula 2, where P_{so} is dynamic peak overpressure (bar), W is the equivalent charge weight measured of the explosive TNT (in kilograms), Z is scaled distance or the distant area of an overpressure associated to the proximity factor, and R is distance from the blast (Javed, 2009).

$$P_{50} = \frac{1772}{Z^3} - \frac{114}{Z^2} + \frac{108}{Z} \text{ (unit kN/m}^2\text{)} \quad (1)$$

$$Z = \frac{R}{W^{1/3}} \quad (2)$$

Blast load model (triangular shape) used in finite element analysis is as follows Figure 1, which is Trinangular shape $F(t)$ versus Time function (time). Blast pressure is 0.91 bar or 89.27 kPa, while Rebound pressure is 44.64 kPa.

2.3 Modeling of Material and Element

The constitutive relationship of elastic-isotropic is selected for steel material. The elastic material model was chosen for purposes of design. The value of elastic modulus for steel plate (E) is 269,667.09 MPa, poisson's ratio (v) is 0.29, and density is 7.701E^{-5} N/mm^3.

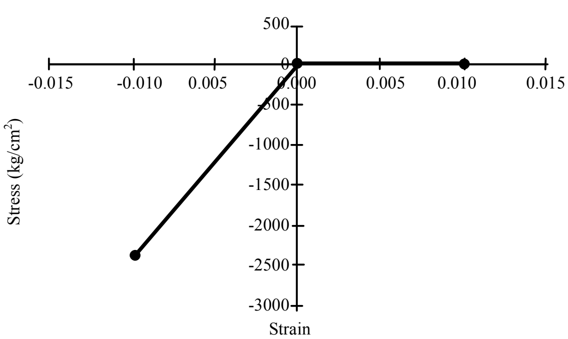

Figure 2. Nonlinear spring property

The plate element (two dimensional 3-node triangle) is used to simulate the steel plates, the beam element (hermitian beam) is used to simulate the door frame, and the nonlinear spring element is used to simulate the contact problem between door and door-frame.

Door frame made from series of C sections, which are C150x75x1.5x1.5, C100x50x6x8.5, and L60x60x6x6. For guidance, the cover plate (SS400, thickness 5.7 mm) allowable bending stress is 228.83 MPa, hinge material (ASSAB700) allowable bending stress is 293.99 MPa, hinge cylinder material (ASSAB760) allowable bending stress is 284.81 MPa, bracket angle (SS-400) allowable bending stress is 248.06 MPa, and anchor bar (ST-41, diameter 15.8 mm) allowable bending stress is 384.04 MPa.

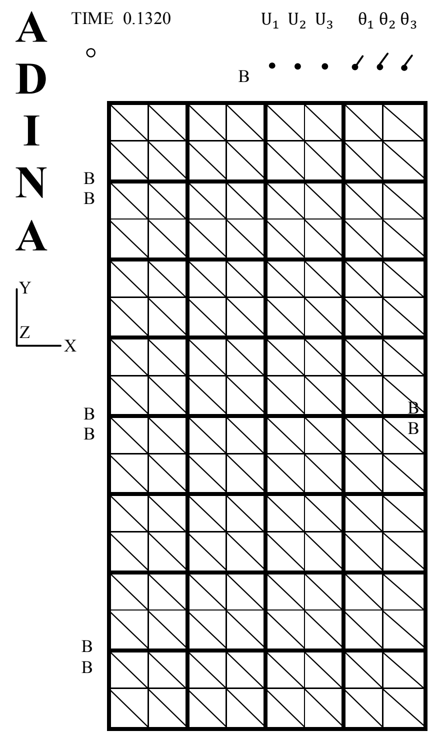

Figure 3. Finite element model of the single door using ADINA

3 METHOD

The numerical modeling used the following assumptions, which are large deformation and small strain, nonlinear dynamic analysis using direct integration time step analysis, available for iteration for equilibrium and nonlinear material.

Integration method used is Newmark method for implicit transient dynamics, with delta parameter is 0.5, alpha is 0.25, theta is 1.4, and gamma is 0.5.

The implicit method can use much larger time steps since it is unconditionally stable (ADINA, 2009). However, it involves the assembly and solution of a system of equations, and it is iterative. Therefore, the computational time per load step is relatively high. The explicit method uses much smaller time steps since it is conditionally stable, meaning that the time step for the solution has to be less than a certain critical time step, which depends on the smallest element size and the material properties. However, it involves no matrix solution and is non-iterative. Therefore, the computational time per load step is relatively low.

Dynamic Material Properties

Material strength properties should be multiplied by strength increase factor (*SIF*) and dynamic increase factor (*DIF*) as follows:

$$E_d = E \cdot SIF \cdot DIF \quad (3)$$

$$F_d = F \cdot SIF \cdot DIF \quad (4)$$

where E_d and F_d are dynamic modulus of elasticity and yield stress. SIF used in this research was taken from ASCE Appendix 5 [ASCE, 1997].

4 ANALYSIS AND RESULTS

Results obtained from analysis, namely nodal displacement and cover plate bending moment can be seen in Figure 4, Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, and Figure 11 (all of the figures are not scaled).

The maximum bending moment M_{xx} is 800,594.10 N.mm, the maximum bending moment M_{yy} is 561,622.50 N.mm, and the maximum z-displacement is 1.709 mm (at node 17). In terms of serviceability, the permitted displacement is 25 mm.

The maximum hinge shear force is 73,960.0 N while the hinge shear capacity is 104,199.3 N. The maximum reaction force is 73,960.0 N while the maximum anchor capacity (double anchors) is 82,068.9 N.

On blast condition, the maximum frame stress is 71.71 MPa, the maximum hinge shear stress is 45.28 MPa. While on rebound condition, the maximum frame stress is 172.11 MPa, the maximum hinge shear stress is 29.46 MPa.

The maximum door edge rotation is 0.44 degree, which does not exceed the permitted boundary (1.2 degree).

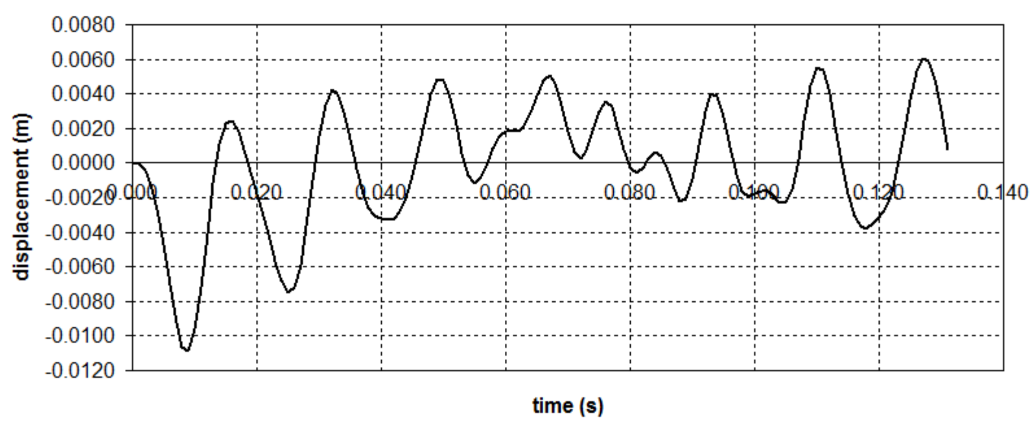

Figure 4. Displacement Vs Time curve at node 17

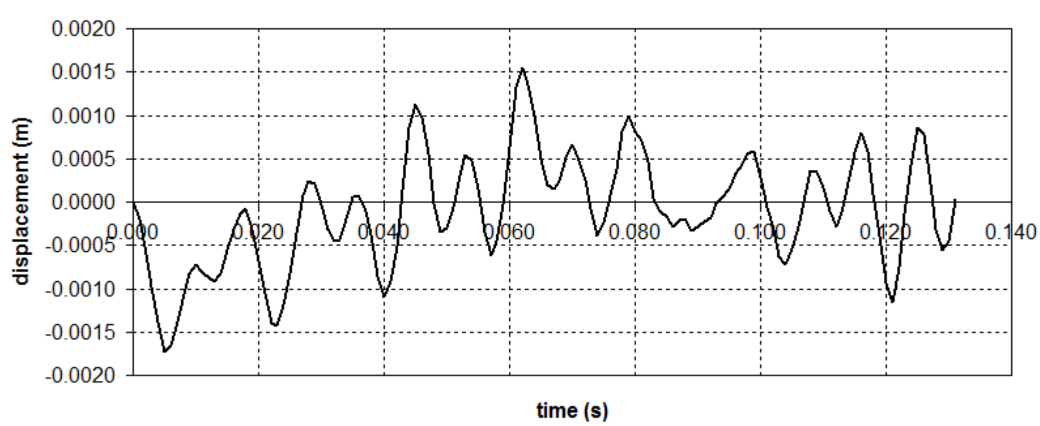

Figure 5. Displacement Vs Time curve at node 100

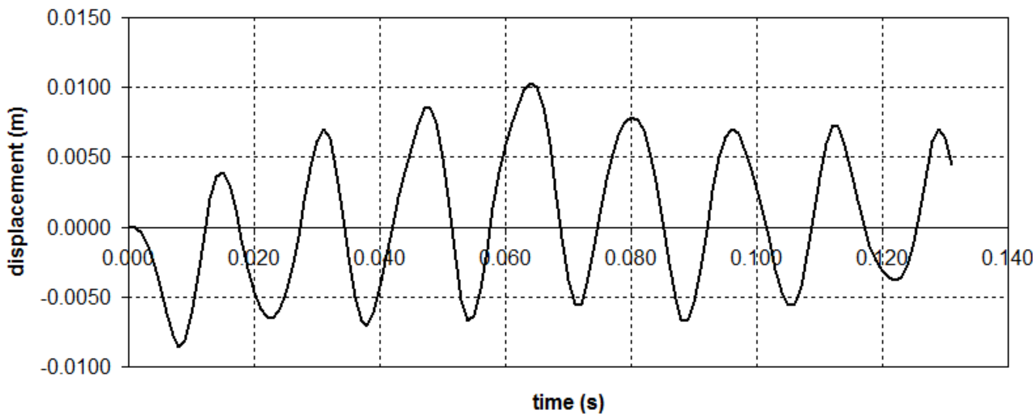

Figure 6. Displacement Vs Time curve at node 153

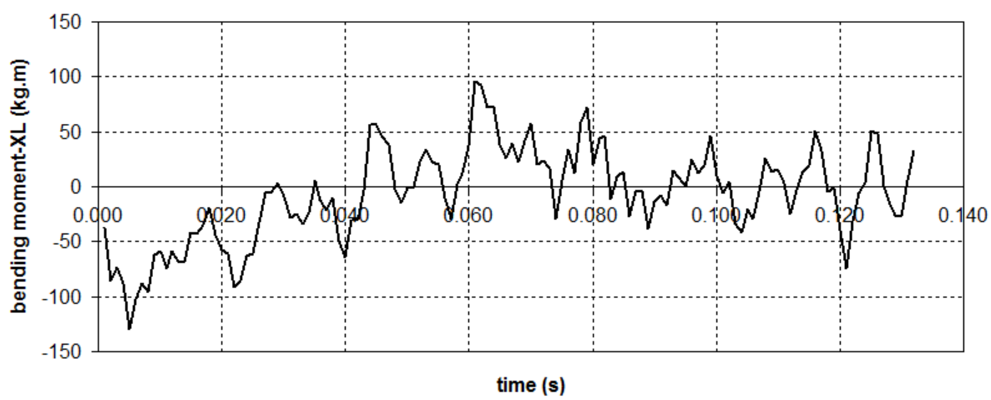

Figure 7. Cover plate: bending moment-XL Vs Time curve at element 179

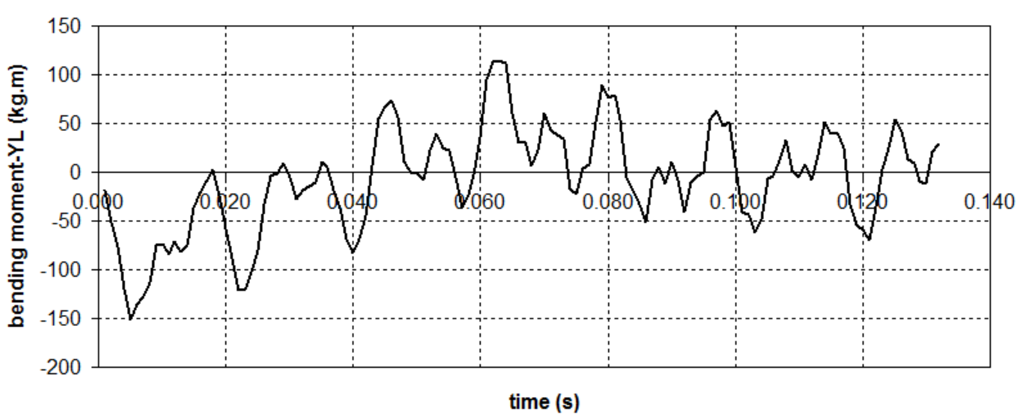

Figure 8. Cover plate: bending moment-YL Vs Time curve at element 154

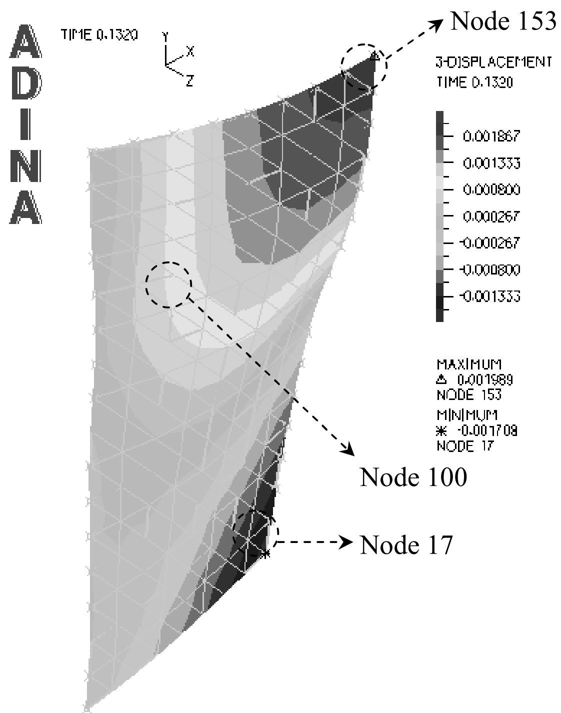

Figure 9. Displacement contour at time 132 ms

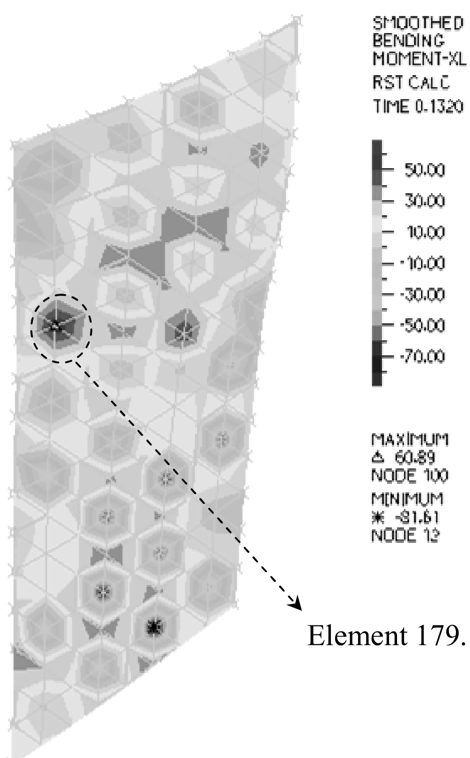

Figure 10. Cover plate: bending moment-XL at time 132 ms

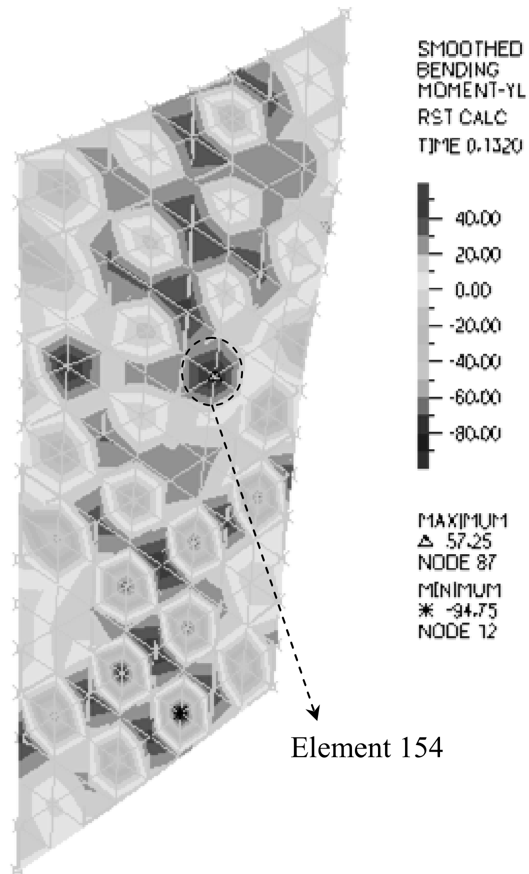

Figure 11. Cover plate: bending moment-YL at time 132 ms

5 CONCLUSIONS

Analysis was done using dynamic finite element method (fem) for time of the blast duration, and the maximum/minimum internal forces and displacement were taken from the time history output, in order to know the behavior under blast load and estimate the safety margin of displacement of the door, hinges, and anchors.

The maximum z-displacement is 1.709 mm (occur at node 17). In terms of serviceability, the permitted displacement is 25 mm.

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