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Blast Resistance Analysis of Door Panel

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***Abstract:*— During earlier days, not much importance was given to the blast resistance design of doors in blast resistant design of structures. Later on, due to large numbers of deaths because of failure of doors, high priority was given to the blast resistant design of doors. In earlier cases, doors were traditionally designed using huge solid materials to resist the blast load. The use of traditional design results in increased material quantity and cost of construction. Recent technological advancement lead to use of engineered materials wherein use of reserved material strength was made to resist blast loading. The blast load is the load with high energy and higher frequency, thus need special attention for analysis and design of structural components. The present study deals with the different doors configurations wherein effect of stiffness, natural frequency and mass of the door is investigated. Finite Element (FE) analysis is carried out to study the dynamic response of door under a given blast loading using ABAQUS®. In the present investigation, tempered AISI 1045 steel is used as door material. Modal analysis is carried out to obtain modal frequency of different door configurations considered in the present investigation wherein mass of all the doors are kept almost constant. Herein, blast loading from 5 kg TNT at a standoff distance of 1 m is applied to the door to understand their dynamic response. The peak displacement of door at different locations has been computed to understand their failure pattern. From the results, it is observed that displacement is significantly reduced just by changing the geometry of door with other parameters being same.**

***Index Terms* :-- CONWEP Blast, AISI 1045, Quasi-static stress-strain curve, Dynamic Analysis, Design of door.**

I. INTRODUCTION

In recent years, analysis of structures and its components under explosive loading has received considerable attention due to various blast events all over the world [1]. The explosive loading results in large deformation of structures including its components. In such situations, the utmost requirements are that the structure should be safe and operative, especially in case of the industrial installations like thermal power plants, nuclear plants and refineries etc. [1]. Earlier not much importance was given to the blast resistant door structure. The deaths are noticed due to the failure of doors and then higher priority was given for the design of blast resistant door. High intensity explosions may lead to severe damage or full collapse of the door. To avoid such calamitous predestine it is of prime importance to examine the dynamic response of the door.

Xinzhing and Jianjing [2] carried out analytical investigation on dynamic finite element analysis (FEA) and simulation for a series of blast resist door using ANSYS and SAP. Koh *et al*. [3] investigated the dynamic analysis of shell structures with application to blast resistant door. Hsieh *et al*. [4] carried out investigation on the blast resistance of a stiffened door structure. Aitavade *et al*. [5] carried out investigation on finite element analysis of blast resistant doors. Chen and Hao [6] carried out numerical investigation on numerical study of a multi-arch double layered blast resistance door panel. Lowak *et al*. [7] carried out research on testing and analytical evaluation of doors. Meng *et al*. [8] carried out investigation on composite blast resistant door structure with hierarchical stiffeners.

Many researchers carried out experimental study on blast resistance analysis of door and presented varying results. It is to be noted that experimental blast analysis is costlier, difficult to carry out due to its non-availability particularly in academic institution in India. However, due to advancement in computational technology, numerical simulation using finite element modelling is gaining momentum. Further, more parameters can be studied before the actual field test using numerical simulation. Hence, herein numerical simulation is carried out to obtain dynamic response of door under blast loading. The present investigation focusses on the study of (a) different configurations of the doors, and (b) comparison of displacement at various locations under given blast loading.

II. DOOR CONFIGURATIONS AND NUMERICAL MODELLING

1) *Material properties*

In the present investigation, AISI 1045 steel is used to develop the door. Quasi-static AISI 1045 engineering stress-strain curve is converted to true stress-strain curve for the dynamic analysis of door [9]. The characteristic of plasticity in ductile metals is defined by its yield point and post yield hardening. It is to be noted that for most of the ductile metals, yield point range will be 0.05% to 0.1% of the yield modulus. Further, strains in compression and tension are the same only if considered in the limit as $\Delta l \rightarrow dl \rightarrow 0$

2) Door designs

A door is a moving structure used to block off, and allow access to, an entrance to or within an enclosed space, such as a building or vehicle. Doors normally consist of a panel that swings on hinges on the edge, but there are also doors that slide or spin inside of a space. Typically, doors have an interior side that faces the inside of a space and an exterior side that faces the outside of that space. The door is used to control the physical atmosphere within a space by enclosing the air drafts, so that interiors may be more effectively heated or cooled. Doors are significant in preventing the spread of fire. They also act as a barrier to noise. Many doors are equipped with locking mechanisms to allow entrance to certain people and keep out others. Doors can be hinged so that the axis of rotation is not in the plane of the door to reduce the space required on the side to which the door opens. This requires a mechanism so that the axis of rotation is on the side other than that in which the door opens. Most doors are hinged along one side to allow the door to pivot away from the doorway in one direction, but not the other. The axis of rotation is usually vertical. In some cases, such as hinged garage doors, the axis may be horizontal, above the door opening.

For the present analysis of blast resistant door panel, five different door configurations are used. The door size of 3.2 m × 1.4 m with varying different configurations is used. Fig. 2 shows cross-sections of different door configurations considered in the present investigation.

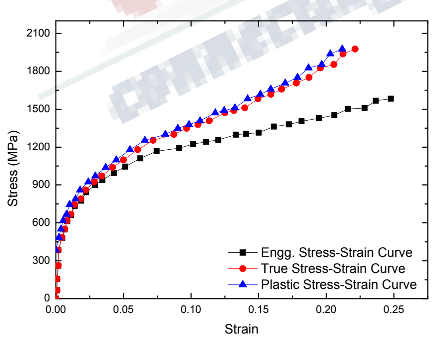

Fig. 1: Quasi-static stress–strain curve of AISI 1045 [9].

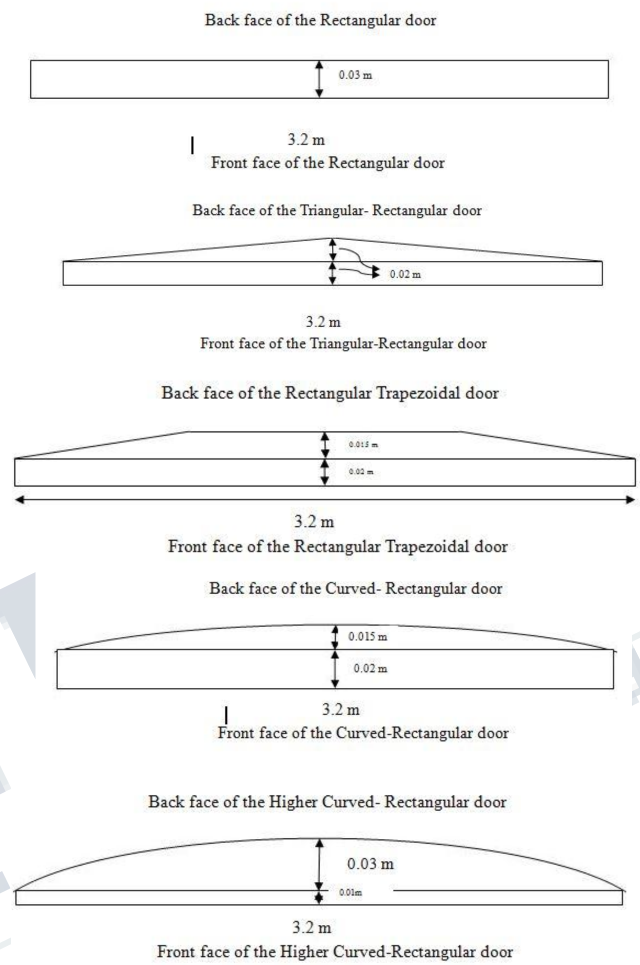

Fig. 2: Cross-sections of different doors.

3) Finite Element Modelling

The door with different configurations, as shown above, with a size 3.2 m × 1.4 m and varying thickness are used. Linear perturbation analysis is carried out to obtain fundamental natural frequencies and dynamic response of door. Dynamic explicit analysis is carried out in ABAQUS® to obtain the dynamic response of the door [1].

The door is modelled using deformable extruded solid feature available in ABAQUS®. The door is made with high ductile material tempered AISI 1045 with material properties are derived from tempered AISI 1045 engineering stress-strain curve [9]. The AISI 1045 has yield strength of 385 MPa, modulus of elasticity as 206 GPa, and Poisson's ratio of 0.29. Herein, plastic properties or post yielding points defined through plastic curve as shown in Fig. 1. The door has one edge pinned boundary condition and other three edges displacement boundary condition i.e. ($U_1 \neq 0$, $U_2 = 0$, $U_3 \neq 0$, $U_{r1} = 0$, $U_{r2} \neq 0$, $U_{r3} = 0$). The modal analysis is

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performed to check the variations in the natural frequencies of different doors. The doors are discretized with C3D8R continuum elements available in ABAQUS® element library. Further, in order to study the effect of variation of mesh, the mesh size is varied in different seed i.e. 0.09, 0.06, 0.03, 0.015 and 0.01 (Fig. 3). Finally, the converged mesh is used for all further analysis i.e. size of 0.01. The blast load is applied on the front face of the door using CONWEP function as follows:

$$P(t) = P_r \cos^2\theta + P_i(1+\cos^2\theta - 2\cos\theta) \quad (1)$$

This function considers the enhancement of pressure due to reflection of waves. The pressure, P(t) on the face is determined based on the input amount of TNT, the stand-off distance, and angle of incidence,θ. The final pressure is computed using above equation.
The source of the blast is at a standoff distance of 1 m vertically exactly at the center of the doors. The property of the blast load is specified using the incident wave interaction property and the CONWEP charge property at the model level and the incident wave interaction at the step level. 5 kg TNT blast at a distance of 1m is applied to all the doors [1].

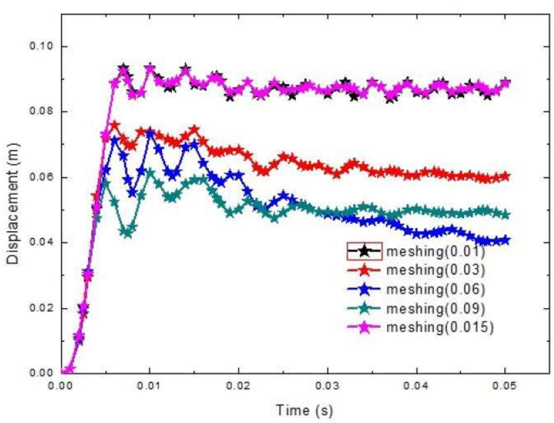

Fig. 3: Mesh convergence of the door panel.

4) Validation of Finite Element Scheme

To compare the exactness of present finite element analysis approach, the results reported by Boyd has been used [10]. Boyd investigated a simply supported plate under blast. Plate with a dimension of 1.2 m × 1.2 m and thickness of 0.005 m is modelled as per Boyd [10]. The plates are modeled in ABAQUS®/Explicit using shell elements. The material properties are defined as provided by Boyd [10]. Simply supported boundary conditions are used. 0.25 kg of Pentolite is used in the analysis which is equivalent 0.283 kg of TNT. Hence, 0.283 kg TNT CONWEP air-blast is applied on both the plates [1, 11-12]. Finally, the maximum displacement with respect to time at centre of the plate observed as 33 mm. Fig. 4 shows the results of validation and it can be observed from this figure that results are in close agreement with the Boyd results. The reason of discrepancy may be attributed to the fact of conversion of Pentolite to equivalent TNT.

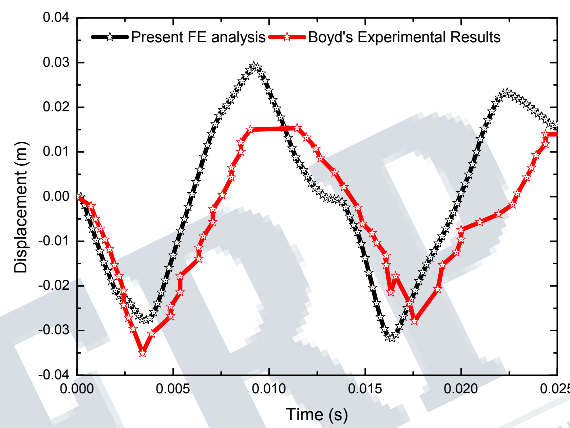

Fig. 4: Validation of present FE analysis.

5) Results and Discussions

A total of five different door configurations are considered in the present investigation. For comparison purpose, the door with rectangular configuration is considered as the base door and all the results are expressed in comparison with the base door. Herein, all the doors are subjected to a blast load of 5 kg TNT at a standoff distance of 1 m.

The displacement time history is obtained at various locations of the door. Fig. 5 shows the location of observation points considered in the present investigation. It is to be noted that displacements at all the locations are of particular interest due to the change in geometry of the door. The displacement response obtained in all the locations of the door in-order to compute the largest deflection for the different geometry of door considered in the present investigation. As the door thickness is not uniform throughout the section, hence, displacement-time history is computed at various locations of the door. Moreover, thickness is not uniform in all the doors, may lead to the chance of getting higher displacement at other locations of the door. As it is not easy to compute the deformation of the door from the deformed plot only, it is desirable to view the deflection response of the all the locations.

For obtaining the fundamental frequency linear perturbation is used by applying appropriate boundary conditions and without any loads. The undeformed shape is the shape of the different doors in the base state. This makes it easy to see the motion relative to the base state. The natural

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frequency of the different door configurations is reported Table I. It can be observed from this table that first fundamental frequency is increasing for all doors configurations in comparison with the base door. i.e. rectangular door. Further, stiffness is increased in all other doors as compared to the rectangular door.

Table I: First fundamental frequency of the doors considered in the present investigation.

Door configurations	Frequency (Hz)
Rectangular door	85.947
Triangular-Rectangular door	85.704
Trapezoidal-Rectangular door	88.830
Curved-Rectangular door	88.435
Higher curved-Rectangular door	90.69

Fig. 6a to Fig. 6e shows displacement-time history of different doors considered in the present investigation. Herein, U_2 displacement (i.e. vertical displacement) at the edges of the door is restricted. Thus, displacements observed in the analysis at the locations 3, 5, 7, and 9 are zero. However, edges are not fixed, hence lateral displacement are observed along both the directions. Since, these lateral displacements are insignificant as compared to U_2, hence can be neglected. From the displacement responses of different doors, it is observed that the maximum displacement occurs at centre point of the door.

It is observed that, in all doors configuration, displacement at center of the door is decreasing as compared to the rectangular door (considered as base door). The reason for such behavior is attributed to increased stiffness of the doors. The stiffness increases without significant change in the mass of the door when different geometric configurations are used.

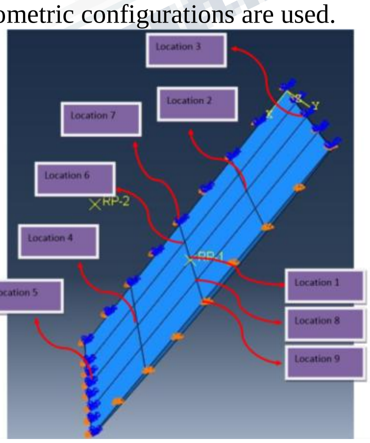

Fig. 5: Displacement response locations of the door.

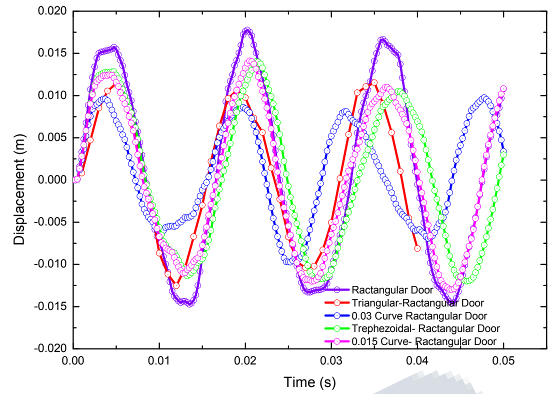

Fig. 6a. Displacement response at center of the door or location 1.

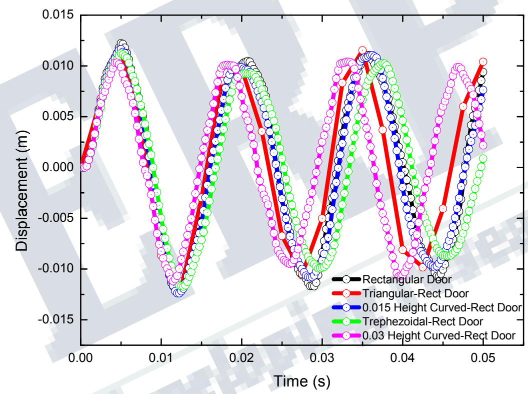

Fig. 6b. Displacement response at location 2 of the door.

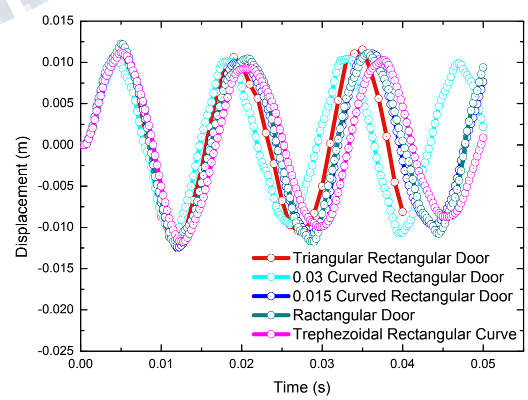

Fig. 6c. Displacement response at location 4 of the door.

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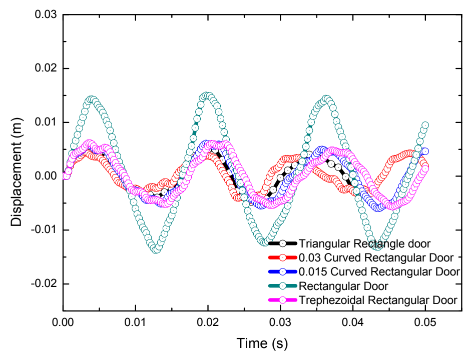

Fig. 6d. Displacement response at location 6 of the door.

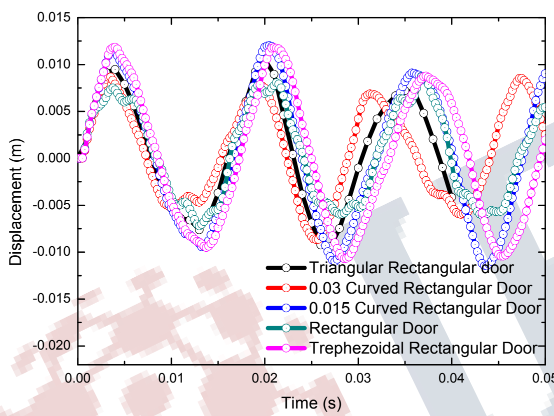

Fig. 6e. Displacement response at location 8 of the door.

III. CONCLUSIONS

The present study deals with blast resistance analysis of door panel considering different configurations of the door. From the analysis following conclusions are drawn:

1. As compared to the rectangular door, natural frequency is increased in all other door configurations by keeping almost same mass for different configurations of the door considered in the present investigation.
2. The higher curved door possessed highest natural frequency among all the door configurations.
3. Even though the cross section of different doors gets reduced at different locations of the door the maximum displacement is observed at the center.
4. For higher curved door, displacement response reduces in all the locations of the door as compared to other configurations.

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