Analytical Study On Scaling Of RC Beams Under Close-In Blast Loading

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***Abstract*— Damage effects analysis and assessment of buildings under blast loading is an important problem concerned by the area of explosion accident analysis, blast-resistant design, anti-terrorist and military damage modes and damage levels of RC beams are studied under different blast loads. The results show that the max deformation is obtained at the centre of the beam and reduced to the edges. From the analysis it is noted the equivalent stress acting on the beam is very less. The max equivalent stress weapon design. The damage character of RC beam under close-in blast loading is investigated through analytical study. The acting on the beam at the centre. In the analysis the maximum principal stress is obtained at the bottom centre and at the top on the edges**

Keywords— Blast load, Reinforced concrete beam, Damage modes, Damage evaluation

I. Introduction

Military assault, terrorist attack and accidental explosion may cause serious damage to buildings and other infrastructures. Important structures, such as government buildings and big bridges are undergoing great risk of attack. In fact, some researches indicated that terrorist attack and accidental explosion have recently increased worldwide . For those reason, Damage effects analysis and assessment of buildings under blast loading is very important which concerned by the area of explosion accident analysis, blast-resistant design, and anti-terrorist and military weapon design.

The current analysis methods for RC beams under blast loading consist of numerical studies. Many experimental studies are not feasible because the preparations and measurements in full-scale development field experiments are complex and expensive. In the field of explosion, the factor of safety should also be under consideration. Experiments at reduced scales can identify the critical effects, improve the engineering design, and validate the physics-based models that can be used to predict the structural dynamic response at all scales. However, few studies have been conducted to estimate the damage levels and validate the scaling law of RC beams subjected to blast loadings. In the current study, static and dynamic analyses are conducted for blast load of 0.36kg mass of TNT.

II. Design of RC beams and blast loading

The dimensions of RC beam is 1100 mm 100 mm 100 mm. The tensile, compressive and hoop reinforcement bar used in the tests are all U6-HPB235. The distribution of reinforcing bars in the RC beams is shown in Fig.1 . Uniaxial compressive strength of concrete is contrived to be 40 MPa.

III. Finite element modelling

Finite element (FE) modeling of RC concrete beams was developed using the commercial software ANSYS Workbench 18. The beam is modelled using a three-dimensional solid part and was meshed with 20-node three-dimensional solid elements of SOLID186. A fixed–fixed ends condition was introduced such that the rotation and translations were restricted at the supports.

The beam section used for this study is 1100x100x100

The material properties of steel and concrete used for the RC concrete beam are shown in Table 1 and Table 2. The concrete beam was modelled in ANSYS Workbench 18, its cross-sectional details are shown in Fig. 1

Table 1 Material properties of Steel

Material property Steel 4340	Value
Density	7.83g/cm3
Bulk modulus	1.59*10^8 kPa
Shear Modulus	7.7*10^7 kPa
Yield Stress	3.5*10^5 kPa

Table 2 Material properties of concrete

Material property Concrete 35MPa	Value
Density	2.75g/cm3
Bulk modulus	3.527*10^7 kPa
Shear Strength (fs/fc)	0.18
Tensile strength (ft/fc)	0.10
Compressive strength	35 MPa
Shear Modulus	1.67*10^7 kPa

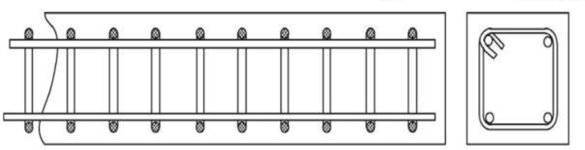

Fig 1 Distribution of reinforcing bars in RC beams.

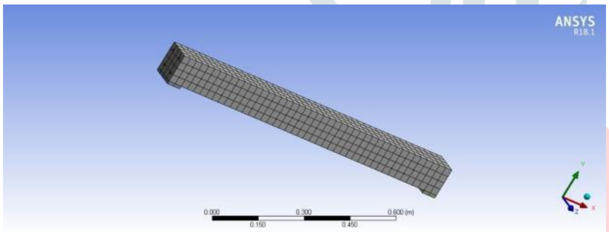

Fig 2 Meshing in RC beams.

A fixed–fixed ends condition was introduced so that the rotation and translations were restricted at the supports. Beam was modelled using a three-dimensional solid part and was meshed with 20-node three-dimensional solid elements of SOLID186. Different mesh size configurations were examined to simulate the accurate results, and the element size adopted was 25 mm (Fig. 2). From this particular analysis total deformation, equivalent stress, maximum principle stress is obtained. Blast load analysis was conducted for both loaded and unloaded condition. The responses of the beams are recorded and compared to analyze the improvement in the response of concrete beam against blast load.

IV. One Dimensional Analysis of Wedge in Autodyne

The blast in the air can be modelled using ID analysis of AUTODYN with a multi-material Euler solver. In AUTODYN, one-dimensional simulation was performed using a 2D axis symmetric solver in the shape of a wedge. The software itself automatically defined the angle of the wedge. The wedge's inner radius and outer radius were calculated based on the amount of TNT used for the blast analysis [14]. The length of the wedge should be greater than the distance of the beam from the point of detonation. The stand-off distance of the beam from the centre of the charge was taken to be 0.5 m, and hence, the length of the wedge was fixed at 0.6 m. The wedge was modelled and meshed using a one-degree quadrilateral element. Air and TNT are the materials used to fill the wedge, and they are directly available from the AUTODYN material library. The explosive was modelled using the John Wilkins Lee Equation of State, and the air was modelled as an ideal gas. The material properties of air and TNT are shown in Tables 3 and 4. A detonator was placed at the vertex of the wedge (0, 0, 0) to start the blast. The amount of TNT used for the blast loading depends upon the weight of TNT that can be carried. In the study, 0.36kg of TNT can be carried in a suitcase, and a radius of charge calculated as 40 mm was used for the blast charge. A schematic diagram of the wedge modelled in AUTODYN is shown in Fig. 3. A schematic representation of the pressure wave propagation in a wedge is shown in Fig. 4.

The one-dimensional wedge model was analysed until the wave reached the end of the wedge, and hence, the negative pressure in the ideal blast pressure curve was ignored in the analysis. The output of the one-dimensional analysis was re-mapped into the three-dimensional air domain. The wedge contains multiple materials, such as air and TNT. When the output was re-mapped into a single-material 3D Euler domain, the TNT also mixed to the air was defined in the 3D domain. The beam is defined as a Lagrangian meshed element, and the air is defined as an Euler element; hence, the coupling between the beam and air is achieved by defining them to be ''fully coupled,'' making the Lagrangian mesh interact dynamically with the Eulerian mesh.

Table 3 Material properties of air

Properties	Value
Reference density	0.001225 g/cm3
Gamma	1.4
Reference temperature	288.200012 K
Specific heat	717.599976 J/kg K
Internal energy	2.068x10^5 kJ/kg

Table 4 Material properties of TNT

Properties	Value
Reference density	1.63 g/cm3
Parameter A	3.7377x10^8 kPa
Parameter B 3	3.7471x10^6 kPa
Parameter R1	4.15
Parameter R2	0.9
Parameter W	0.35
C–J detonation velocity	6.93 x10^3 m/s
C–J energy/unit volume	6x10^6 kJ/m3
C–J pressure	2.1x10^7 kPa

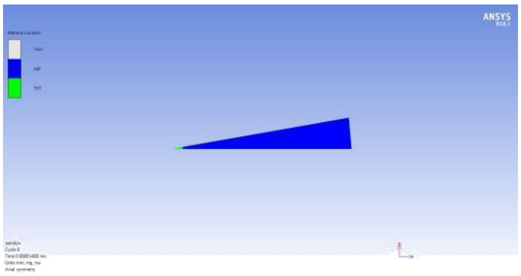

Fig. 3 One-dimensional wedge modelled in AUTODYN

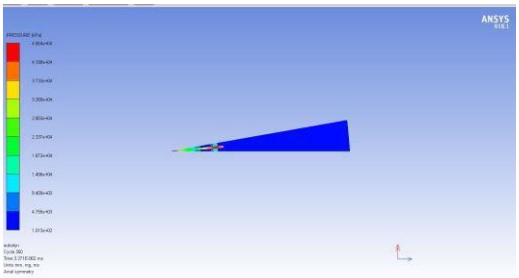

Fig. 4 Blast wave propagation in the one-dimensional wedge

V. BLAST ANALYSIS OF BEAM

A discrete model of concrete beams was developed using 20 nodded 3D solid elements. The beam was analyzed for loaded and unloaded conditions for the 0.36kg TNT blasting. The beams are fixed at ends and the beam itself is restricted to velocity along its axial direction such that the beam does not move in the axial direction. A flow-out boundary condition was given around the air domain to let the blast energy flowout without reflecting when it reaches its end boundaries. In loaded beams, the supports provide the safe load capacity of beam.

VI. RESULT AND DISCUSSIONS

Total Deformation

In static analysis the max deformation is obtained at the centre of the beam and reduced to the edges. The max obtained value at the centre is 0.0058395m and the minimum value of deformation is 0m at the edges represented as red and blue and respectively. It is shown in Fig.5.

Equivalent Stress

Equivalent stress provides any three dimensional stress states to be given as a single positive stress value. From the analysis it is noted the equivalent stress acting on the beam is very less. The max equivalent stress acting on the beam at the centre and the value is 1.7093e8 Pa. The minimum value is 2.22335e6Pa. It is represented in Fig 6.

Maximum Principle Stress

Maximum principle stress postulates that the growth of the crack will occur in a direction perpendicular to the maximum principal stress. In the analysis the maximum principal stress is obtained at the bottom centre and at the top on the edges as represented in Fig. 7.

Fig. 8, Fig.9, Fig.10 respectively represents the response of air, concrete and steel during explicit dynamics action. Total energy of air remains constant throughout where as concrete and steel have linear variations with respect to time.

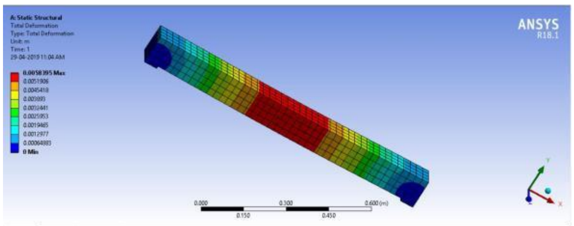

Fig. 5 Total Deformation on the Beam

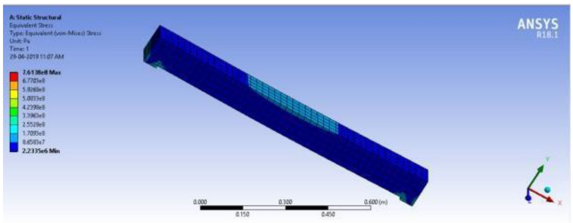

Fig. 6 Equivalent stress

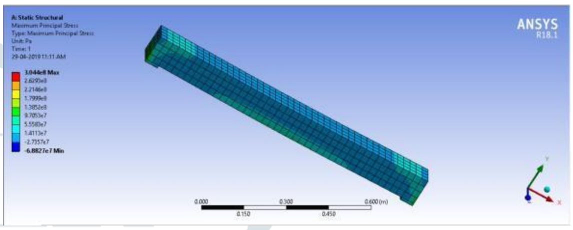

Fig. 7 Maximum principle stress

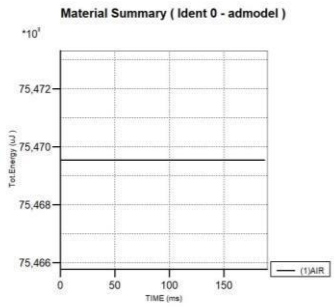

Fig. 8. Air explicit dynamics graph

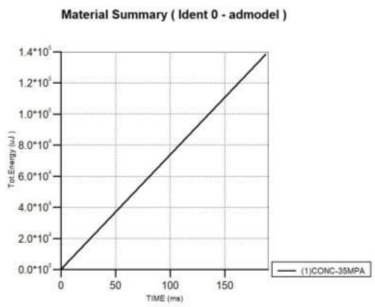

Fig. 9 Concrete explicit dynamics graph

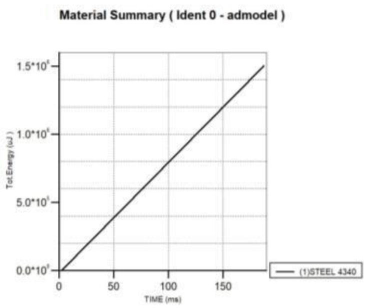

Fig. 10 Steel explicit dynamics graph

ACKNOWLEDGMENT

The authors are thankful to Mar Baselios College of Engineering and Technology, Kuttikanam for helping to conduct this research

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