Equivalent Static Blast Load Analysis of Structure

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Abstract- The performance of structures under blast loading conditions is attracting significant attention from researchers and engineers to ensure the safety of structures against terrorist attacks and accidental explosions. Time history analysis is considered a conventional method of blast load analysis. However, it is proposed by some researchers that in the early design stages, a simplified analysis approach can be adopted by considering the blast load as an equivalent static load. For the detailed analysis, a time history analysis can be performed. The present study compares the blast load response of a building obtained by an equivalent static blast load approach with that obtained by a dynamic analysis approach. A 3-storey reinforced concrete (RC) building designed for seismic load is being considered for the investigation. To simulate different blast loading conditions, charge weights 1000 kg and 500 kg of TNT and standoff distances 5m, 10m, 15m, 30m, and 60m are considered. The response regarding base shear, maximum top storey displacement, and inter-story drift is compared. The results show that as the standoff distance increases and charge weight reduces, responses obtained by an equivalent static analysis approach are close to those obtained by dynamic analysis.

Keywords– Equivalent static blast Load, structural response, RC building, SAP 2000

1. INTRODUCTION

In the recent past, the frequency of terrorist attacks on buildings has increased worldwide, resulting in increased attention to designing all public buildings for blast loading.

Blast load analysis is conventionally performed by simulating the pressure–time variation using code recommendations [1]–[3] or empirical equations developed by several researchers [4]. The response of the building is then examined by performing a nonlinear time history analysis of the three-dimensional model of the building. The effect of airblast-induced air pressure on buildings is widely investigated in the available literature [5]–[10]. In recent years, surface-blast-induced ground vibration and air pressure's effect on buildings has also been investigated [11]–[15].

Some studies are done to simplify the blast load analysis of buildings. Newmark, [16] and Yasseri [17] presented an approach for conducting a preliminary blast-resistant structure design. With the help of the preliminary structure design, member sizes, and reinforcement detailing of the building can be obtained. This design procedure gives better values of the structure's fundamental period and ductility factor. After that, nonlinear time history analysis can be performed for detailed analysis and design. Walker [18] highlighted the significance of the equivalent static blast load method in studying structure performance at an early project phase and derived blast load response spectra. These response spectra give a quantitative estimate of blast load on structure.

With the abovementioned studies, the present paper investigates the applicability of the equivalent static analysis for free air blast conditions. The results obtained by equivalent static analysis are compared with dynamic analysis of the 3D building frame. For this purpose, a three-storey building, seismically designed for earthquake zone V as per IS 1893-2002 [19], is investigated for free air blast loading. Different magnitudes of charge weight (Q) and standoff distance (R) are considered to study the structure's response under a wide range of blast loading. Dynamic and equivalent static analyses are performed on the building using the SAP 2000 software package. The responses from both analyses are compared regarding the peak top storey displacement, the inter-story drift, and the base shear.

2. THEORY

2.1 Dynamic Blast Loading

Figure 1 shows a typical blast wave profile. As the explosion occurs, the blast wave travels and reaches the target point after time T_a, causing a sudden increase in pressure. The peak pressure is known as peak static overpressure (p_{so}). After that, there is an exponential decay in pressure, and after time t_d, the pressure reaches ambient pressure; this phase is called the positive pressure phase. This phase is then followed by a negative pressure phase in which the pressure becomes less than ambient pressure. For dynamic analysis of structures, the blast pressure is most commonly represented by a loading-time history that is applied to the structure to conduct time history analysis.

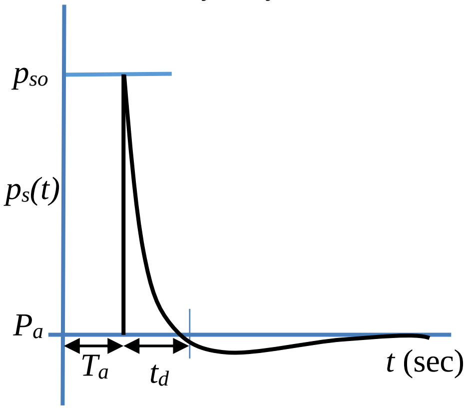

Figure 1: Nature of Air Pressure Time History

For simplification, the negative pressure phase of the blast wave can be neglected as the pressure magnitude in this phase is much less compared to peak static overpressure. The blast wave profile is obtained by Friedlander's equation (Equation 1) [4].

$$p_s(t) = P_a + p_{so}\left(1 - \frac{t - T_a}{t_d}\right) e^{-b\frac{t - T_a}{t_d}} \quad (1)$$

Here

$p_s\,(t)$: pressure at the target point at time t after an explosion occurs.

P_a: ambient pressure.

T_a: time of arrival of pressure wave.

t_d: positive pressure phase.

b: parameter describing the decay of the curve, which can be computed by equation 2 [4].

$$b = 5.2777\, Z^{-1.1975} \quad (2)$$

Here, Z is the scaled distance, which can be computed by

$$Z = \left(\frac{R}{Q}\right)^{\frac{1}{3}}$$

Pressure waves thus obtained are applied to the beam-column joints on the surface of the building exposed to the blast load. To calculate blast load at each joint, the value of p_{so} and t_d are obtained using charts of DoD 2008 [1] for different standoff distances and angles of incidences.

2.2 Equivalent Static Blast Loading

The equivalent static load on the structure given by Newmark [16] is used for static analysis. It is a function of the ductility factor and fundamental period of the structure, duration of blast pulse, and peak incident pressure and is represented in equation 3.

$$\frac{p_{so}}{q} = \frac{T}{\pi\, t_d}\cdot\sqrt{2\mu - 1} + \frac{1 - 1/(2\mu)}{1 + 2T/(\pi\, t_d)} \quad (3)$$

Where q is equivalent static blast pressure, T is the fundamental period of the structure, t_d= positive phase duration of the blast, and μ= ductility factor of the structure.

Static load at each joint on the exposed surface of the building is calculated for corresponding dynamic load, knowing p_{so} and t_d of dynamic blast load. The structure's ductility is obtained by performing a pushover analysis of the building frame.

3. NUMERICAL STUDY

A 3-storey building is considered for investigation (Figure 2). Plan Dimensions are 16m x 16m, and all storey heights are 3m. The grade of concrete and steel reinforcement bars are M30 and Fe 500, respectively. The building is designed for gravity and earthquake load for zone V following IS 1893, 2002 [19]. Dimensions and reinforcement of structural components provided are as follows:

Beam Size 300 mm x 450 mm; column Size 450 mm x 450 mm; slab thickness 150 mm; column reinforcement 1.9%; Beam reinforcement 1% at the top and 0.7% at the bottom. The first three time periods of the building are 0.34s, 0.11s, and 0.06s, respectively. With the help of pushover analysis of the building, ductility factor 2.5 is obtained.

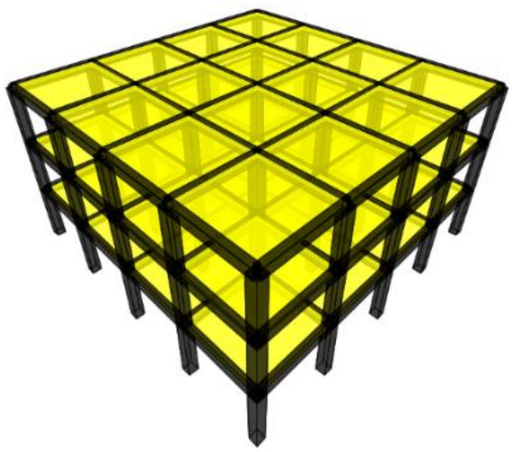

Figure 2: 3-D view of the building

The charge weight (Q) is assumed to be 500kg and 1000 kg of TNT acting at distances (R) 5 m, 10 m, 15 m, 30 m, 40 m, and 60 m, and the structural response to explosive loads at different standoff distances is simulated in the analysis. The position of the free air blast is shown in Figure 2; vertically, it is placed at mid-height of the building. Both dynamic and static analyses are carried out using SAP 2000 software.

4. RESULTS AND DISCUSSIONS

The three response quantities of interest are evaluated by dynamic blast load analysis and equivalent static blast load analysis for the seismically designed three-storey building frame shown in Figure 2 for different blast loading scenarios by varying charge weight and standoff distance. The charge weight is vertically placed at the mid-height of the building. Results obtained by both the analyses are compared.

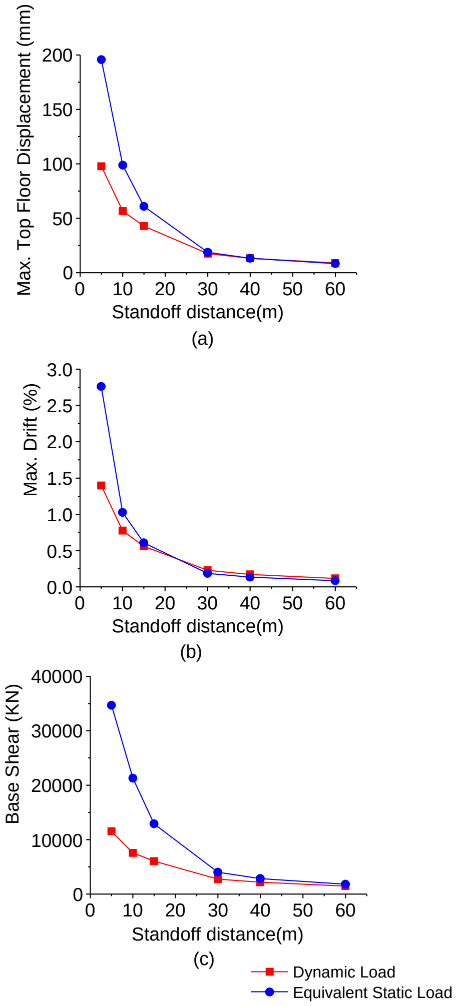

Figure 3: Response of building due to 1000 kg of TNT

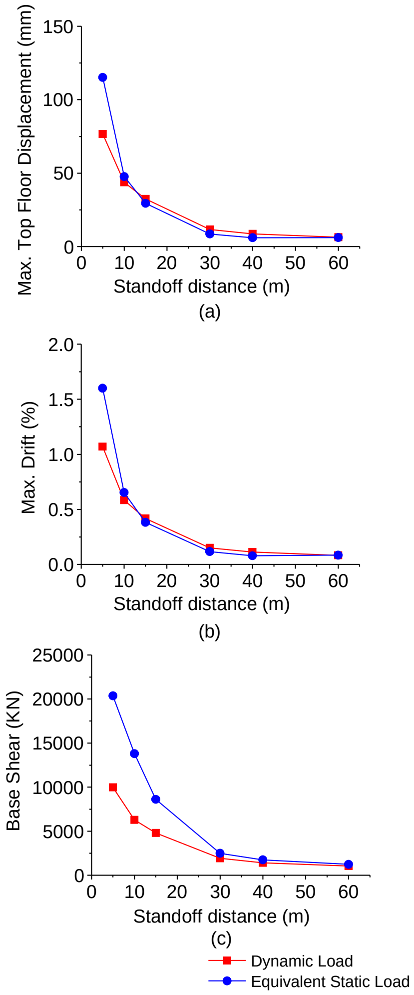

Figure 4: Response of building due to 500 kg of TNT

The effects of standoff distance on the response quantities of interest are shown in Figures 3 and 4 for charge weights of 1000 kg of TNT and 500 kg of TNT, respectively. It is seen from the figures that the responses due to equivalent static blast load sharply fall with standoff distance (R) in the close vicinity of the structure (within 5m to 30m distance). After that, the responses continue to decrease with standoff distance very mildly. Due to the dynamic blast load, responses are reduced with standoff distance.

Figure 3 shows the response of the building due to the explosion of 1000 kg of TNT. Small standoff distance responses due to equivalent static blast load are much higher than those due to dynamic blast load. At the 5m standoff distance, responses due to equivalent static blast load are nearly two times those due to dynamic blast load. As the standoff distance increases, the difference between the responses due to the two loads decreases. After the standoff distance of 30 m, responses due to the two loads are nearly the same.

Figure 4 shows the response of the building due to 500 kg of TNT. This figure also shows that responses to equivalent static load are higher than dynamic load. It can be noted by comparing figures 3 and 4 that due to 500 kg of TNT, the difference between the responses due to static and dynamic load is less than that due to 1000 kg of TNT. In the case of a blast due to 500 kg of TNT, the responses due to the static and dynamic loads are nearly the same after a standoff distance of 15m.

5. CONCLUSIONS

The effectiveness of equivalent static analysis for blast load is investigated. For this purpose, a three-storey building is subjected to free air blast at standoff distances 5m, 10m, 15m, 30m, 40m, and 60m. Charge weights considered for analysis are 1000 kg and 500 kg of TNT. Dynamic and equivalent static analyses are performed, and responses are obtained. Response parameters considered are base shear, maximum top displacement, and maximum inter-story drift percentage. The results of the numerical study lead to the following conclusions:

1. Responses obtained by equivalent static analysis are higher than those obtained by dynamic analysis.
2. The difference in response of the building obtained from the static and dynamic analysis increases with an increase in charge weight.
3. As the standoff distance increases and charge weight reduces, responses obtained by equivalent static analysis are close to those by dynamic analysis.

It can be surmised from the above conclusions that equivalent static analysis can be used for preliminary blast load analysis of structures for larger standoff distances and lesser charge weights. It can save computational time and effort. However, for higher charge weights with smaller standoff distances, dynamic analysis needs to be performed for a correct estimate of the blast load response of the structure.

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