Evaluation Performance of a Reinforced Concrete Column Subjected to Explosion Using Incremental Explosive Analysis

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ABSTRACT

To protect citizens and infrastructures in a modern society, the safe design of structures against accidental explosion is a particular importance. In this study, the aim is to evaluate the performance of a reinforced concrete column using incremental explosive analysis (IEA), which is inspired by the method of incremental dynamic analysis. In order to achieve this goal, the concrete moment frame is designed for dead, live, and earthquake loads based on Iranian national regulations codes in Etabs software. Then, an exterior designed column related to the RC moment frame is analyzed under different ground blast intensity (hemispherical explosions at the ground level) at stand of distance 3, 5, 7, 10, 12, 15, 17 and 20 meter. Eulerian-Lagrangian coupling method has been used to obtain the dynamic response of the structure against rapid explosion load in Autodyn. After completing the analysis and obtaining the structural response, the IEA Curves is drawn as a structural response in terms of the explosion intensity. Fragility curves also is obtained to determine the probability of exceeding each limit states. The results show that the probability of exceeding the limit state Ls-1 for intensity measure $\frac{1}{Z}$ equals to 1 approximately equals to 80%, for the Ls-2 is about 60% and for the Ls-3 is 40%. Finally, the pressure-impulse diagram on a logarithmic scale is obtained as the combination of pressures and impulses which produce the column response in the three considered limit states. The results show that fragility curves and pressure-impulse diagrams along with IEA curves provide useful information to design.

KEYWORDS

Incremental explosion analysis, Incremental dynamic analysis, Performance, Fragility curve, IEA diagrams, P-I diagram

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1. Introduction

Today, with the increasing number of terrorist incidents around the world, and considering the explosive uncertainties such as the amount of charge, the distance of the explosion from the structure and the type of explosive, the design of the members of the structure for a particular explosion does not seem to be conservative. Therefore, the purpose of this study is to evaluate the performance of a reinforced concrete column (R.C Column) against different blast intensities using Incremental Explosive Analysis (IEA) [1]. In order to achieve this goal, the concrete moment frame is designed for dead, live, and earthquake loads based on Iranian national regulations codes in Etabs software. Then, an exterior designed column related to the RC moment frame is analyzed under different ground blast intensity (hemispherical explosions at the ground level) at stand of distance 3, 5, 7, 10, 12, 15, 17 and 20 meter. Eulerian-Lagrangian coupling method has been used to obtain the dynamic response of the structure against rapid explosion load in Autodyn 3D. After completing the analysis and obtaining the structural response, the IEA Curve is drawn as a structural response in terms of the explosion intensity. Fragility curves also is obtained to determine the probability of exceeding each limit states

2. IEA Analysis

Incremental explosive analysis method inspired by Incremental dynamic analysis [2] method, used in order to determine the level of structural performance, estimate the full range of the structure response accurately (from elastic to yield and then nonlinear phase and finally general instability of the structure) by performing a series of nonlinear dynamic analysisfor different explosion intensities. To use this method numerically, the following steps should be considered: 1. Numerical modeling and validation, 2. Selection of two appropriate parameters for intensity measure (IM) and damage measure (DM), 3. Drawing and summarizing IEA curves based on performing a series of nonlinear dynamic analysis for different explosion intensities, 4. Drawing fragility curves. In this study, the inverse of the scaled distance is considered as an intensity measure and a maximum support rotation as a demand parameter based on ASCE code [3].

3. Numerical Modeling

3.1 Model parts

The designed column for this study has dimensions of 300*300 mm and a height of 3 meters. The Eulerian-Lagrangian method was used to obtain the column response to explosion in Autodyn 3D. Concrete was modeled using Lagrange processor, while reinforcement modeled using Beam sub grid. The air around the column and the explosive were modeled using Euler sub grid. A mesh size of 10mm was selected for the model. To reduce computation time, for different stand-off distances, the explosion is first performed in one dimension, then it is transferred to three dimensions using mapping technology. Also, in order to experience the column deformation behavior similar to reality, a contact algorithm based on body interaction (The bond of concrete and reinforcement without a slip) has been considered.

3.2 Constitutive material models

In Autodyn hydrocode, by solving three equations of conservation of mass, momentum and energy, the structural response subjected to the impact of the explosion is obtained. Five variables are needed to solve these equations. Since the number of existing equations (three conservation equations) is less than the number of unknowns, two more equations are needed to solve the problem. The fourth equation is the material equation of state (EOS), which shows the behavior of matter (gas or solid) in an explosion simulation. The fifth equation is the known one of the variables [4]. In this study the Jones-Walkins-Lee (JWL) equation of state and ideal gas EOS have been used for explosion and air. The JWL equation can accurately describe the state of explosion products in many explosives. The JWL EOS is used for describing the pressure, volume, and energy of explosives used in many hydro codes [5]. To investigate the effect of air compression and its temperature increase under the explosion, Ideal gas EOS for Eulerian air domain needs to be defined [6]. In addition, designing structures to withstand the effects of explosion requires knowledge and understanding of the dynamic properties of materials. In this study, the Johnson-Cook strength model has been selected to investigate the dynamic stresses in reinforcements. The Johnson-cook equation expresses the hydrostatic stress in material as a function of strain rate and temperature [7]. To obtain an accurate prediction of concrete response under blast loads, a proper strength model which reflects the characteristics of the concrete material behavior at a high strain rate is needed. Therefore, The RHT material model is adopted. RHT model uses three limited-surface namely, an elastic-limit surface, a failure surface, and the remaining strength surface to describe the behavior of concrete under high-pressures, high strain-rates and complex stress conditions [8].

4. Result and Discussion

By keeping the different stand of distance constant and increasing the weight of explosion with increase parameter Δ and performing nonlinear dynamic analysis for each blast intensity the displacement in the middle of the column is obtained. Then Equation 1 is used to calculate the support rotation of column.

$$\theta = \tan^{-1}(y / \tfrac{L}{2}) \quad (1)$$

After obtaining the support rotation for each blast intensities, the IEA diagram is drawn as Figure 1.

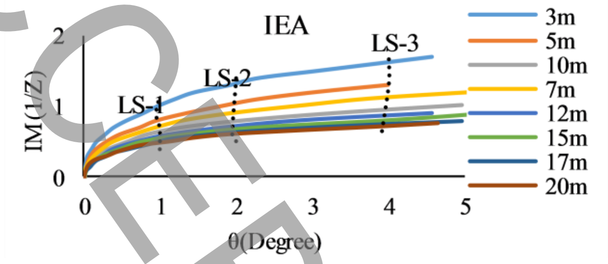

Figure 1: IEA Curves

IEA diagrams are also summarized in 16%, 50% and 84% percentiles. These percentiles are based on the normal distribution of the values obtained. Figure 2 shows a summary of the IEA curve for the 16th, 50th and 84th percentiles along with the three limit states considered. In addition to the IEA curve and the results obtained from its summarization, for designing or evaluating the performance of structures against explosions, the fragility curve can be drawn. After initial analysis and access to IEA data, fragility curves can be extracted. From fragility curves, it is possible to predict the percentage of probability of exceeding each limit states (Figure 3).

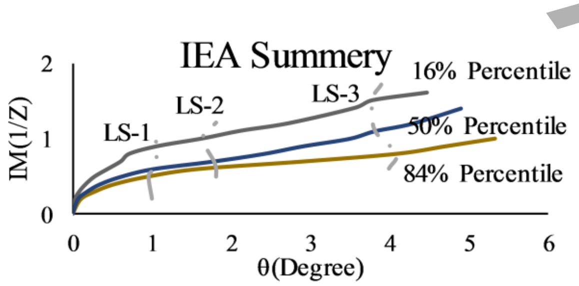

Figure 2: IEA Summary

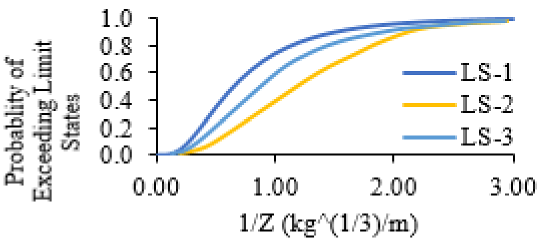

Figure 3: Fragility Curve

5. Conclusions

In this study, the results of IEA curves for different explosions (0.02 to 3400 kg at stand-of distances of 3 to 20 meters) have been obtained and summarized. By using IEA diagrams, the minimum protection distance of the structure or structural elements against different explosion weight can be calculated. After drawing the fragility curves obtained from the IEA data, the results show that the probability of exceeding the limit state Ls-1 for intensity measure $1/Z$ equals to 1 approximately equals to 80%, for the Ls-2 is about 60% and for the Ls-3 is 40%. Finally, the pressure-impulse diagram on a logarithmic scale is obtained as a combination of pressures and impulses that produce the column response in the three considered limit states. The results show that fragility curves and pressure-impulse diagrams along with IEA curves provide useful information to design. However, the use of the Eulerian-Lagrangian coupling method is more complex and its calculations require special hardware but it gives a better understanding of structural behavior (interaction of fluid (explosion) and structure).

6. References

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