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COMPARATIVE ANALYTICAL STUDY OF REINFORCED CONCRETE WALL SUBJECTED TO BLAST LOADING PATTERN

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ABSTRACT

To construct a numerical model of reinforced concrete structures in nonlinear dynamic formulation against blast loads or accidental loads needs a lot of assumptions and approximations, to simplify the simulation process. There are two main elements, that are important to be simplified; material properties and structural elements. Any information added to the modelling process consumes more analysis time, which requires more computational capabilities and all of that translated into more cost. Unified Facilities Criteria (UFC) is considered one of the most important references to design structures, to resist the effects of accidental explosions. A reinforced concrete wall, subjected to pressure-time relationship, such as blast load was analysed and designed by UFC, then modelled using the advanced finite element software program; LS-DYNA to simplify the analysis and design processes of these structures. Dynamic response Results were evaluated, for the maximum displacement time history. Result values were extremely, in close agreement between UFC and LS-DYNA. Also, reinforcement ratio was compared between and found to be the same. The results of this study can be used, for design and evaluation studies.

KEYWORDS: Accidental Load, Ls-Dyna, Dynamic Response, Finite Element & UFC

INTRODUCTION

Catastrophic extreme lateral loads, such as blast have drawn attention of many designers today. Blast resistance becomes an important characteristic for many structures. Various dictionary definitions, for explosions are found such as: Bursting noisily, a sudden loud and violent release of energy, undergoing a rapid chemical or nuclear reactions, resulting in a high temperature, loud noise, violence and expansion of gas. However, a scientific definition of explosions can be stated from Strehlow and Baker (Strehlow and Baker, 1976): “In general, explosions occur in the atmosphere, if energy is released in very small time and in a small volume, so as to generate pressure waves of finite amplitude travelling far away from the source. This energy, stored in the system in different forms; these include nuclear, chemical, and pressure energy. However, the release energy is not considered to be explosive, unless it is rapid and concentrated enough to produce a pressure wave, that anyone can hear. Eventhough, many explosions damage their areas around it; it is not a condition that external damage be produced by the explosion only. The necessity is that, the explosion is capable of being heard by anyone.” This definition refers to explosions in the air. There are three types of explosions: physical, nuclear or chemical explosions. The most commonly used explosives are condensed. They could be solids or liquids. When an explosion occurs, the explosive violently decomposes, which produces heat and gas. If the explosive is in contact with a solid material, the expansion of gas will generate shock pressures. However, if this expansion happens in a non-solid medium, such as air, what it will generate is called blast waves (Mays and Smith, 1995). To construct a numerical model of reinforced concrete structures, in nonlinear dynamic against blast loads or accidental loads needs a lot of assumptions and approximations, to simplify the simulation process. There are two main elements, that are important to be simplified; material properties and structure full details. Any information added to the modeling process consumes more analysis time, which requires more computational capabilities and all of that translated into more cost. Lucconi et al. (2003) had confirmed two important notes, when using computer blast resistance assessment of the response of the structures. The first one is the need for the validation of experiments. A Lot of researches had been done to structural elements and materials, which were subjected to blast hazards, however the full-scale model results came from actual accidental explosions or terrorist attacks. The second one is the required computational time and the corresponding cost, which makes it impractical to perform a realistic blast analysis of structure, with all its details. Assumptions and simplifications have to be assumed, in order to perform any analysis. They relate to the material specifications of structures, which should be treated as a homogenous material, with approximately average properties. Luccioni, et al. (2004) confirmed that, for numerical simulation of the building, collapsed in Argentina was made using AUTODYN, the finite element software. The building suffered from structural collapse, due to attack of terrorists using a 400 kg TNT bomb. The building was a reinforced concrete structure. Lucconi et al. (2003) used a homogenize elastoplastic material to model reinforced concrete structures, as to be similar to concrete materials models, but with more tensile strength to take the tension strength of reinforcement into consideration. The results were found to be close, for actual and simulated damages. The authors concluded that, using simplifying assumptions for the structures and materials are suitable to be used in finite element analysis and successfully had performed a complete collapse analysis. Phuvoravan & Sotelino (2005), studied an accurate new nonlinear finite element model, to analyze concrete slab, that is simple and easy to be used efficiently, with ability to capture each reinforcement bar. The authors concluded that, there were two techniques, that can be used to model a reinforced concrete slab, by discrete modeling or layered modeling, for the reinforcement. Discrete modeling of the reinforcements is more realistic than the layered, in representation; however, it is also more expensive for the computational costs. Also, the models are more complicated and time consuming, to be constructed in this way. Layered modeling is simple, but only can represent high strength reinforced concrete materials. Barmejo et al. (2011) used LS-DYNA program, to simulate the structural concrete elements such as columns, slabs and beams in a similar method, to feel the real difference of results; concrete shell elements were used together with steel beam elements. For the concrete modeling, they had been using the EC2 material model (*MAT_172). This model can include steel bars, as a fraction of steel into it, which was used to model transverse steel bars, while beams were used for the longitudinal bars. The reinforcement steel bars material model was simulated by the piecewise linear plasticity material model (*MAT_024). Corresponding column, beam and slab elements were also constructed, using the continuum element models with the CSCM material model (*MAT_159), with beam element reinforcement. Comparison for a quasi static bending and dynamic response was performed among them, in order to calibrate shell with beam structural elements. The shell with beam models were then used to evaluate the response of building of a frame type, subjected to blast. It was concluded that, the shell with a beam model was accurate enough, in providing the basis for the realistic simulation of the response of building with full scale.

OBJECTIVES OF THE STUDY

The objective of this paper is to use a simplified finite element model, based on shell element formulation of two ways reinforced concrete wall fixed from all edges, using the advanced finite element software program LS-DYNA.

METHODS

The method was done by constructing a finite element model of LS-DYNA software, to simulate two-way reinforced concrete wall, which was designed before, according to the requirements and recommendations of UFC. The validation process has been done on the maximum displacement time history, which were the most important parameter for the design of the structure. The advanced general purpose finite element modelling software program LS-DYNA, which developed by Livermore Software Technology Corporation (LSTC). LS-DYNA version 9.71-R4.2 is a transient dynamic finite element program with an advanced solver which mainly based on explicit time integration methodology (LSTC, 2006). LS-DYNA's advanced pre and post-processor LS-PrePost used to post processor the results generate fringe plots and response diagrams (LSTC, 2011). The reinforced concrete wall was designed to resist pressure-time load relationship of 35 psi (0.25 Mpa) as shown in Figure 1. The design steps and results of the wall by UFC were described briefly in example 4a-1 (UFC 3-340-02, 2008). LS-DYNA was used in this paper for the finite element modelling.

Units, Dimensions and Geometry

Millimeter for length, second for time, ton of mass, newton of force and MPa for stress, are the measurement scales used. Wall thickness was 12in. (300mm), where the height was 12ft. (3650mm) and the width was 180in. (4570mm) as shown in Figure 1.

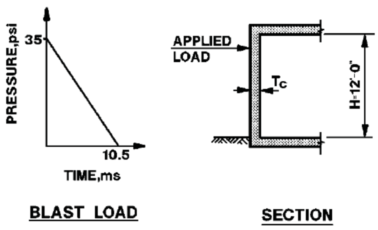


Figure 1: Geometry and Load Configuration of the Wall

Parts

Parts are defined in this model under *PART cards. It represents the reinforced concrete wall. Part card in LS-DYNA input deck includes material identification and section identification which are defined in *MAT and *SECTION sections respectively in the input file. *MAT card contains the material properties information and *SECTION card contains element property information.

Elements

An element used in this FEM was shell element and included in *SECTION_SHELL card. Length and width of each element were divided into 50x50 mesh of not more than10 mm max for each direction as shown in figure 2.

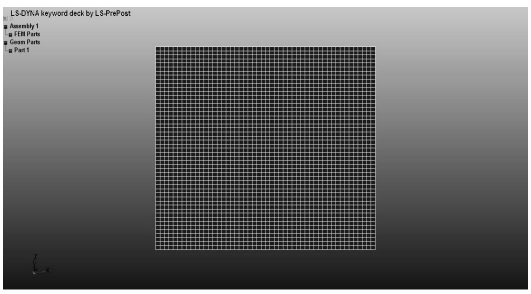


Figure 2: Finite Element Model of the Wall

Material Models Definition

The material model used was *PLASTIC_KINEMATIC. The required parameters in the material cards are: mass density, Young's modulus, Poisson's ratio and material yield stress. Table 1 summarizes LS-DYNA's input parameters used for the simulations.

Table 1: Parameters Assigned to the Default Model

Parameter	Value	Unit
Mass Density	2.1E-9	Ton/mm3
Young's Modulus	2.0E+4	MPa
Poisson's ratio	0.2	-
Yield Stress	0.275E+2	MPa

Hourglass Control Definition

Hourglass control must be incorporated in the code under *HOURGLASS card to avoid the zero energy modes. The default algorithm was used.

Boundary Condition Definition

The wall is fixed from all sides. *BOUNDARY_SPC cards, Translational parameters DOFX, DOFY, DOFZ, DOFRX, DOFRY and DOFRZ in the code was assigned with 1 to restrain the movement and rotation at boundaries.

Blast Load Definition

In the FEM the *LOAD_SEGMENT_SET option was used to apply pressure loads to the wall due to explosion. Where a segment set corresponding to the face of the wall on which the pressure will be applied is created. In *LOAD_SEGMENT_SET, the parameter LCID in the defining load curve was defined as shown in figure 3 to determine the pressure for the segment. Ordinate represents the load while, abscissa represent the time.

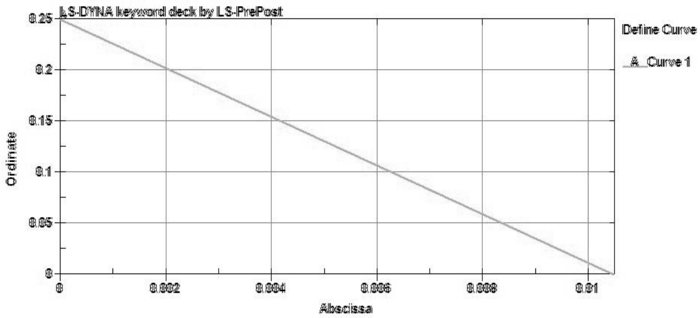
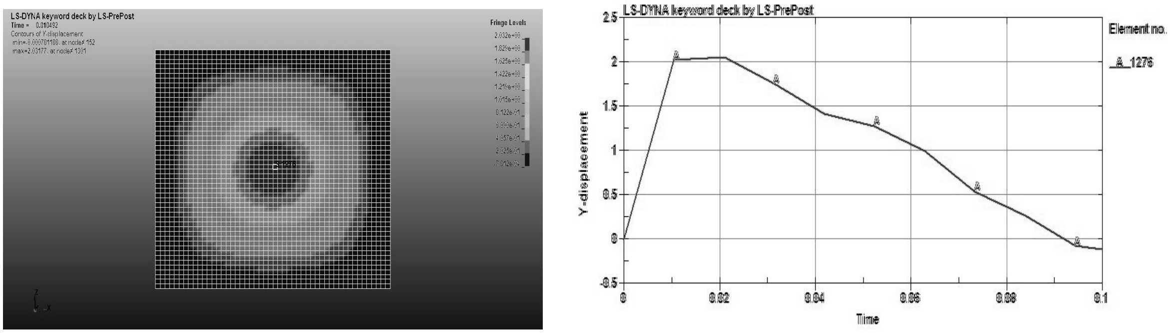


Figure 3: Load Curve Definition

RESULTS

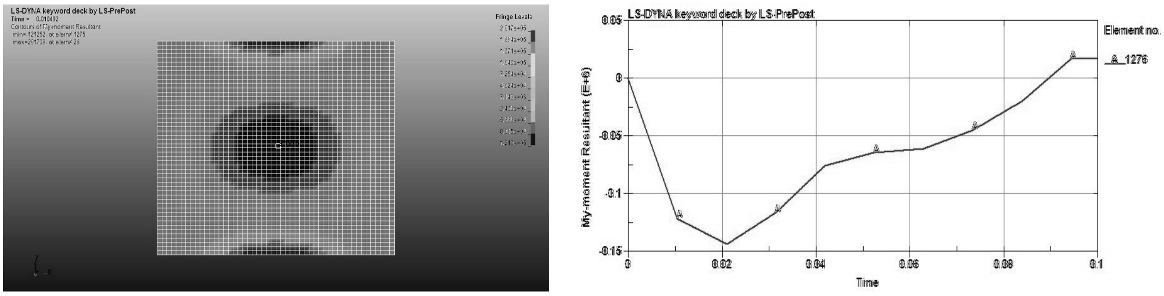
The results from the model of LS-DYNA are compared with the results of the UFC. The main criterion parameter on which the credibility of the FEM is tested is the close agreement of the maximum displacement and reinforcement design requirements. The displacement in the middle of the wall in the finite element model was illustrated in figure 4. The maximum displacement value in FEM was 2.032 mm while the maximum equivalent elastic deflection calculated by UFC was 2.489 mm with a difference of 22%.



(a) Wall Displacement Contour **(b) Wall Displacement Time History**

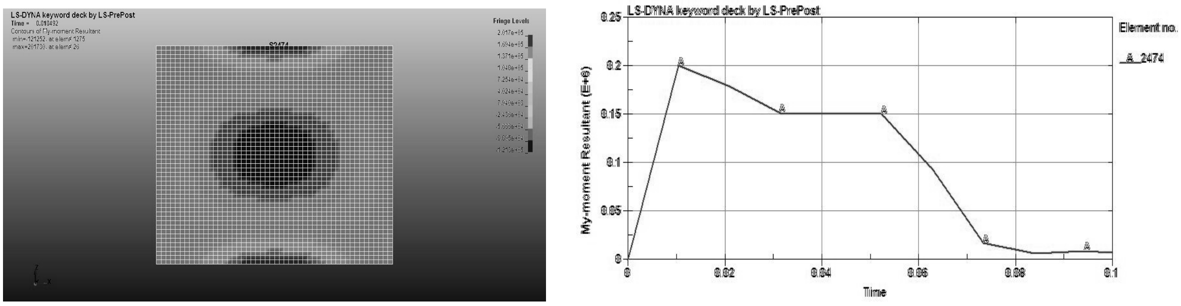
Figure 4: Wall Displacement

Therefore, in this study a small value for error (22%) is reached as FEM gives smaller values. When a structure is subjected to blast load which is a case of loading with an extremely short duration and a magnitude larger than any other load that will ever be applied to the structure in its design life, then the maximum displacement considers the most critical parameter for the structure's survival. The reinforcement ratio was designed according to moment stresses. The moment, stress on the wall in the finite element model was illustrated in figure 5 for Negative moment and figure 6 for positive moment. The maximum applied negative moment value was 1.44e+05 N-mm while the maximum applied positive moment was 2.01e+05 N-mm. Reinforcement bars 12mm diameter each 200mm each side of the wall was adequate enough to resist the previous values of bending moment which is the same reinforcement ratio used in the UFC.



(a) Bending Moment Contour **(b) Negative Bending Moment Time History**

Figure 5: Negative Bending Moment of the Wall



(a) Bending Moment Contour **(b) Positive Bending Moment Time History**

Figure 6: Positive Bending Moment of the Wall

CONCLUSIONS

This study showed that the finite element model based on shell formulation for the reinforced concrete wall can simulate the deflection results from a blast load with a close agreement value to the UFC.

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