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Numerical Simulation of Progressive Collapse for a Reinforced Concrete Building

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***Abstract*—**Though nonlinear dynamic analysis using a specialized hydro-code such as AUTODYN is accurate and useful tool for progressive collapse assessment of a multi-story building subjected to blast load, it takes too much time to be applied to a practical simulation of progressive collapse of a tall building. In this paper, blast analysis of a RC frame structure using a simplified model with Reinforcement Contact technique provided in Ansys Workbench was introduced and investigated on its accuracy. Even though the simplified model has a fraction of elements of the detailed model, the simplified model with this modeling technique shows similar structural behavior under the blast load to the detailed model. The proposed modeling method can be effectively applied to blast loading progressive collapse analysis of a RC frame structure.

***Keywords*—**Autodyn, Blast Load, Progressive Collapse, Reinforcement Contact.

I. INTRODUCTION

DUE to the development in computing technology, analysis of the progressive collapse has become easier with hydro-code programs that can operate both fluid and structural analysis based on FEM (Finite Element Method). The latest researches with this dynamic analysis method for progressive collapses, however, mainly focus on analyzing local structure members rather than that of whole building structures [1]-[4]. Even though there are some researches analyzing whole building structures, most of them analyze primarily low-rise building structures. The root reason is that FEM requires significantly more time when elements are divided into smaller parts for more accurate analysis result of an entire building structure, especially reinforced concrete buildings which require modeling of concrete as well as reinforcements. Besides, higher performance of the analyzing machine is necessary for more complicated cases.

This paper shows a special analysis method for reducing elements of analysis object with relatively accurate result. In this paper, the hydro-code programs: Ansys Autodyn [5] and Ansys Workbench [6] are used to analyze the progressive collapse of reinforced concrete structures. Especially, Reinforcement Contact function included in Ansys Workbench is used as a key function for reducing the quantity of elements.

II. REINFORCEMENT CONTACT FUNCTION

Nystrôm and Gyltoft [7] offer the fullest account of Autodyn's suitability to operate blast analysis in their study. They drew optimized results which are similar with practical test values through proper material property inputs of concrete and steel. The general modeling method in Autodyn, however, requires that nodes of volume elements must be located on the same physical position with nodes of truss elements to behave as one body. It means that element size of concrete must be adjusted to fit the covering depth of steel bars to show similar failure behavior of real structures. In order that element size of concrete fits the covering depth, it is necessary to increase the quantity of elements. This increase affects the time required for analysis and has some difficulties to be applied in blast analysis of large structures such as tall buildings.

To increase efficiency of analysis, Reinforcement Contact function in Ansys Workbench is used. In this type of interaction, we can set up line body reinforcements in solid volumes without sharing of node between volume elements and beam elements. This method has an advantage to make any shape and size of solid element unit freely. The reinforcing beam nodes will be constrained to stay at the same initial parametric location within the volume element they reside during element deformation.

To verify suitability of Reinforcement Contact function, a comparison work is conducted between a detailed model which requires sharing of nodes and a simplified model using Reinforcement Contact function. The analysis model is a 1-bay frame model which includes four of 4000 mm high columns and four 6000 mm span beams shown as Fig. 1.

The concrete properties used the RHT concrete model [5] whose compressive strength is 35 MPa and the failure mode of the concrete model was selected as the tensile failure to get similar behavior with a real concrete structure. 10-percents value of the concrete compressive strength was used as the tensile failure strength. The steel material properties used the Piecewise Linear Johnson-Cook [5] model whose yield strength is 550 MPa. The Piecewise Linear Johnson-Cook model is based on Johnson-Cook model to describe a large deformation due to blast loads. These cited properties are modified material models from Autodyn material library by Nystrôm and Gyltoft [7].

The cross-sections of both column and beam have squares 500 mm on each side. The diameter of main reinforcement is 29 mm and the steel ratio is 2.0%. The spacing of tie hoops is 250 mm and the covering depth of reinforcement is 48 mm. The distance between the frame and the explosive is 5m apart and the amount of TNT is 100kg.

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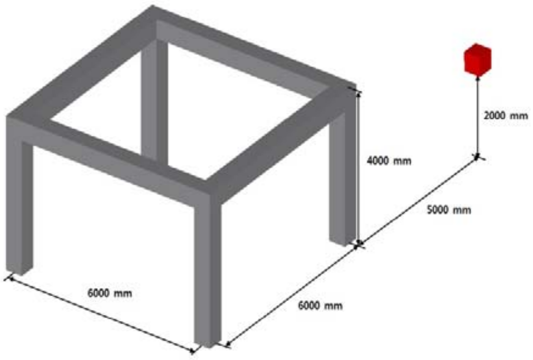


Fig. 1 Single story reinforced concrete frame model for blast analysis

The detailed model has an 8-node hexahedron Lagrange element. In order to consider the covering depth of concrete, it is determined that the element size is 31.25 mm. Whereas the simplified model which used Reinforcement Contact function has 250 mm size elements to fit cross-section of column. The number of solid elements of the detailed model and simplified model are 36,864 and 576, respectively.

To compare the detailed model with node sharing and the simplified model which uses Reinforced Contact function, several factors were measured at the gauges located in the center of the nearest column from the explosive.

Fig. 2 shows displacement at the center of columns from three different models: a plain concrete model, the detailed model, and the simplified model in Reinforcement Contact function. In plain concrete model, the displacement value is steadily increased. Whereas the values of the detailed and the simplified models start decreasing at 7 ms and increasing back at about 15 ms and declining again at approximately 65 ms. In comparison of the greatest displacements in the two models, the value of the detailed model is 11 mm, and that of the Reinforced Contact model is 18 mm. The simplified model shows an increase of about 60% from the detailed model. Considering the fact that the quantity of elements in the detailed model is 64 times that of elements in the simplified model and the fact that the shapes of two graphs are similar to each other in broad outlines, it is enough to say that these two graphs show approximately similar results.

The damage contour of the detailed model and the Reinforcement Contact model are given in Fig. 3 and Fig. 4. The red part is where high stresses are concentrated. Stress concentrated parts in the two models are similar to each other.

Consequently, Reinforcement Contact model graph is approximately similar with the detailed model. It means that Reinforcement Contact function is enough to be used in analyses of larger structures.

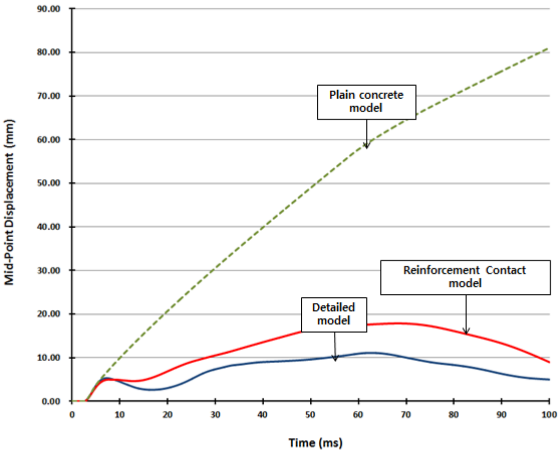


Fig. 2 Lateral displacements at the center of the column

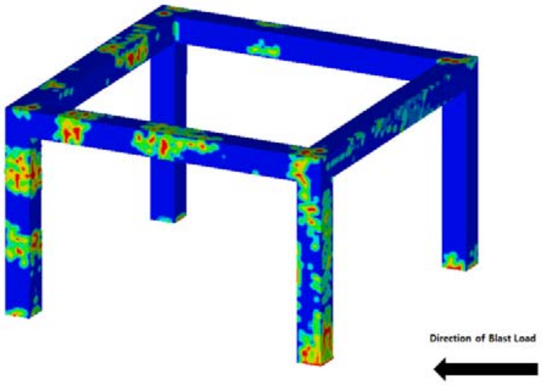


Fig. 3 Damage contour of the detailed model

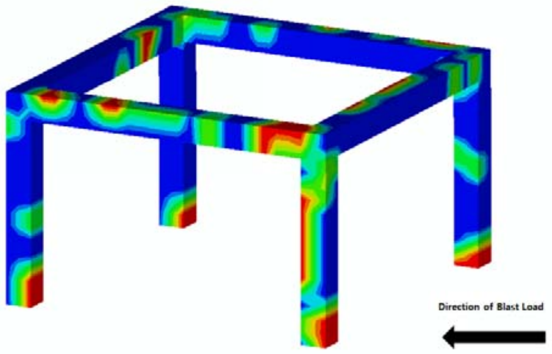


Fig. 4 Damage contour of the simplified model

III. APPLICATIONS

As this paper mentioned before, Reinforcement Contact function is demonstrated as an effective method for the progressive collapse analysis. In this chapter, results from blast analysis using reinforcement contact function will be compared. The main purpose of the progressive collapse analysis is assessing resistance performance of structure members or building structure against abnormal loads.

When supported by columns, girders are usually subjected to negative moment. When columns are removed by abnormal loads, however, girders around the removed column are subjected to positive moment and then the progressive collapse is initiated. Therefore, in most of progressive collapse resistance design guide lines, they suggest increasing progressive collapse resistance by reinforcing girders around columns. In this paper, steel reinforcement patterns and spacing of stirrups are altered to increase resistance and then the progressive collapse analyses are operated. After this analysis, whether the changes of conditions are well reflected in results will be checked.

The basic condition of the analysis model is as in the following. This model is a reference model cited from DoD (department of defense) guideline [8]. The weight of TNT is applied as 1000 kg to make proper loads which are enough to assess feasibility of the progressive collapse as shown at Fig. 5.

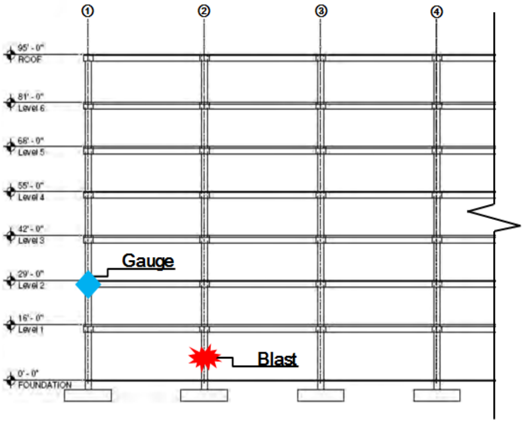


Fig. 5 Multi-story reinforced concrete building subjected to blast

To verify effect of steel reinforcement patterns and spacing of stirrups, progressive collapse analyses are operated with conditions for reinforcement patterns shown as Table I. First, reinforcements are cut off to reflect normal reinforcement patterns. Second, in order to effectively resist positive moments developed when the column is removed, reinforcements are continuously placed without cut-off. In addition, stirrup spacing is applied as 5 inch and 10 inch at each above reinforcement patterns.

Fig. 6 shows the vertical velocity at the gauge points located at the corner column on second story. The curve for models (a), (b), and (c) show rapidly increasing velocity which means progressive collapse is developing. However, the progressive collapses are initiated at the time of 1s, 2s, and 3s, respectively. The continuously placed bottom bars of model (b) and the closely spaced stirrups of model (c) delayed the initiation of the progressive collapse but it was not enough to resist the collapse. Model (d) shows small velocity change around 2.5second and nearly zero velocity after 5second, which means some damage developed but they are not serious enough to cause the progressive collapse.

Fig. 7 shows the failure mode of each analysis model 10 seconds after blast. All the models except model (d) which has continuously placed top and bottom reinforcement and 5 inch spaced stirrups show total collapse triggered by blast. The continuously placed bottom bars and closely spaced stirrups of model (d) contribute to resist the positive moment and the increased shear force developed after removal of the column which is directly subjected to the blast load.

Consequently, we can confirm that well reinforced girders can prevent the progressive collapse which may develop after removal of a column. In addition, it shows that Reinforcement Contact function reflects these design conditions effectively.

TABLE I
ANALYSIS MODELS FOR MULTI-STORY BUILDING

Model	Reinforcement pattern	Stirrup spacing
(a)	Cut-off	10 inch
(b)	Continuous	10 inch
(c)	Cut-off	5 inch
(d)	Continuous	5 inch

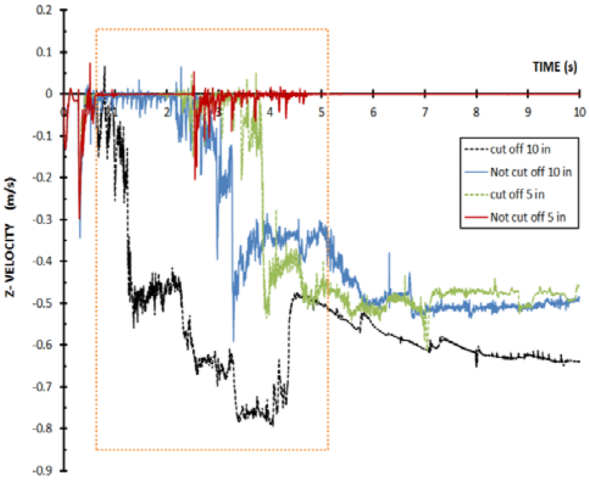
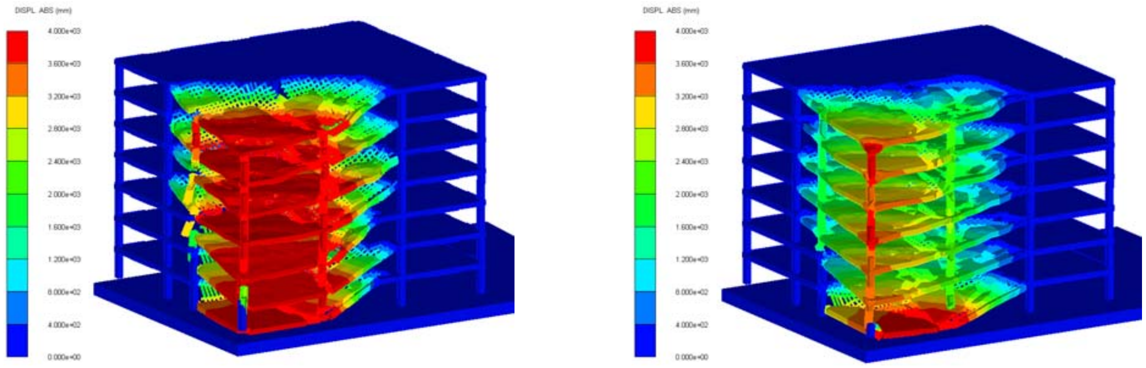


Fig. 6 Time history of vertical velocity at the gauge point

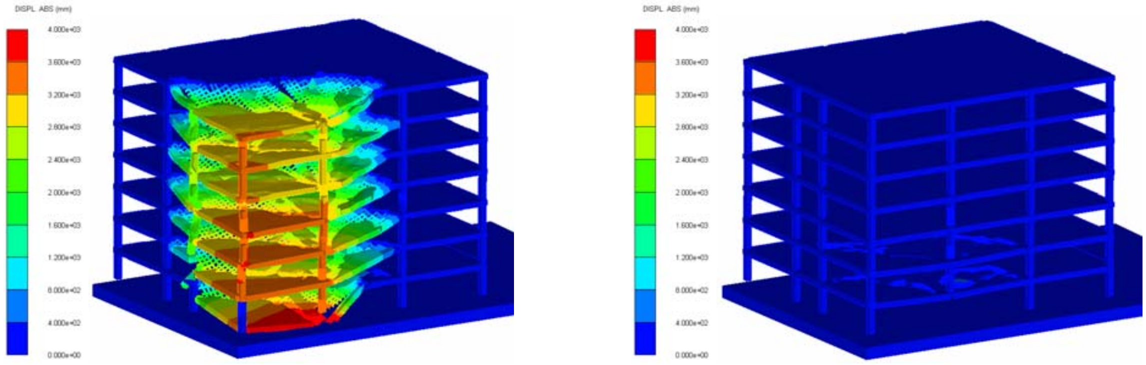
IV. CONCLUSIONS

In this paper, Reinforcement Contact function provided by ANSYS WORKBENCH is used to propose a modeling method for reducing elements when the analysis of the progressive collapse of tall buildings due to blast loads is operated. Since the reinforcement bars are arranged regardless of nodes, the quantity of elements is significantly reduced. Time required for analysis is also abbreviated. Owing to non-sharing of nodes, however, Reinforcement Contact function can cause difference from normal models. Therefore, suitability of Reinforcement Contact function is demonstrated in comparison to the detailed model using node-sharing between concrete and steel bars. And then, efficiency for the progressive collapse analysis of Reinforcement Contact function is verified through match-up with a real event of the progressive collapse. Comparison simulations regarding analysis conditions are also conducted. Conclusions through these analyses are as follows. (1) Strain and displacement measured at the center of the column



Model (a) Cut-off, 10” spacing

Model (b) Continuous, 10” spacing



Model (c) Cut-off, 5” spacing

Model (d) Continuous, 5” spacing

Fig. 7. Vertical displacement of the analysis models at 10s after blast

show that Reinforcement Contact model behaves in similar way with the detailed model when a blast load is applied. (2)

Various analyses regarding analysis conditions conducted with Reinforcement Contact function shows that the resistance performance against the progressive collapse improves when the girders around columns are more reinforced.

If Reinforcement Contact function proposed in this paper is applied, relatively small quantity of elements can draw enough results that are similar to the ones from the detailed model. Reinforcement Contact function will be an efficient method for the progressive collapse analysis of large size building structures such as high-rise buildings.

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REFERENCES

[1] Y. Shi, H. Hao and Z. Li, “Numerical derivation of pressure-impulse diagrams for prediction of RC column damage to blast loads, *International Journal of Impact Engineering*,” vol. 35, pp. 1213-1227, 2008.

[2] X. Bao and B. Li, “Residual strength of blast damaged reinforced concrete columns,” *International Journal of Impact Engineering*, vol. 37, pp. 295-308, 2010.

[3] A. Mutalib and H. Hao, “Development of P-I diagrams for FRP strengthed RC columns,” *International Journal of Impact Engineering*, vol. 38, pp. 290-304, 2011.

[4] K. Wu, B. Li and K. Tsai, “Residual axial compression capacity of localized blast-damaged RC columns,” *International Journal of Impact Engineering*, vol. 38, pp. 29-40, 2011.

[5] Ansys, *Autodyn Theory Manual*, Century dynamics, 2005.

[6] Ansys, *ANSYS Workbench User’s Guide*, Ansys Inc., 2009.

[7] U. Nyström and K. Gylltoft, “numerical studies of the combined effects of blast and fragment loading,” *International Journal of Impact Engineering*, vol. 36, pp. 995-1005, 2009.

[8] Department of Defense, *Design of Buildings to Resist Progressive Collapse*, US Department of Defense, 2010.