9th International Conference on
Shock & Impact Loads on Structures
Fukuoka, Japan, Nov. 16-18, 2011

BLAST DEMOLITION PLANNING TOOL USING KEY ELEMENT INDEX

Daigoro Isobe* and Takuya Katsu†

* University of Tsukuba
1-1-1 Tennodai Tsukuba-shi, Ibaraki 305-8573, Japan
e-mail: <isobe@kz.tsukuba.ac.jp> webpage: http://www.kz.tsukuba.ac.jp/~isobe/

Keywords: Blast demolition, key element index, collapse analysis, ASI-Gauss technique

Abstract. *The main objective of this study is to develop a demolition planning tool for buildings based on a parameter called the key element index, which indicates the contribution of a structural column to the vertical capacity of the structure. Two ways of selecting specific columns to demolish the whole structure are demonstrated: selecting the columns from the largest index value and from the smallest index value. The demolition results are confirmed numerically by carrying out collapse analyses using the adaptively shifted integration (ASI)-Gauss technique, and the tendencies of the demolition modes to follow the key element index values are estimated. The numerical results suggest that for a successful demolition, a group of columns with the largest key element index values should be selected when explosives are ignited in a simultaneous blast, whereas those with the smallest values should be selected when explosives are ignited sequentially, with a final blast set on a column with a large index value.*

1 INTRODUCTION

The technology used in the demolition of old or uninhabitable buildings has always been of major interest in civil engineering and remains a challenge in engineering practice. Because conventional demolition techniques that use a hydraulic concrete crusher, a concrete cutter or a nonexplosive demolition agent are lengthy and costly, demolition techniques using controlled explosives are often used to meet the heavy demand for demolition work. Although this method increases work efficiency, it also poses a high risk of damage to neighboring buildings, especially in urban areas[1]. Furthermore, blast demolition requires high levels of knowledge and experience[2,3], which are very difficult for general engineers to master. Although there are several blast demolition companies currently working in the USA and Europe, the demolition technique has been only used in a few cases in Japan, which may or may not be due to the above reasons. To help familiarize Japanese construction companies with blast demolition methods, numerical assumptions using computational analysis will be essential in ensuring the success of this technique.

To date, only a few numerical codes have shown high performance when modeling structurally discontinuous problems; e.g., the distinct element method (DEM)[4] and discontinuous deformation analysis (DDA)[5] have been successfully applied to model overall collapse phenomena[6,7,8,9]. However, there are still no adequate numerical procedures available to accurately track the blast demolition process, which includes coupled and complicated failure mechanisms of structural frame members. Therefore, we applied the adaptively shifted integration (ASI)-Gauss technique[10] to develop an analysis code for blast demolition that can explicitly express member fracture and elemental contact in

† Kubota, Co.

the demolition process. In this code, the accurate modeling of a fractured section in a member is enabled by shifting the numerical integration points in the finite elements and by reducing the sectional forces of the elements immediately after the occurrence of the fractured section. It also yields highly accurate solutions with small mesh subdivisions and requires little calculation time and a small amount of memory.

The main objective of this study, on the other hand, is to develop a demolition planning tool based on a parameter called the key element index, which indicates the contribution of a structural column to the vertical capacity of the structure. Two ways of selecting specific columns to demolish the whole structure are demonstrated: selecting the columns from the largest index value and from the smallest index value. The demolition results are confirmed numerically by carrying out collapse analyses using the numerical code mentioned above, and the tendencies of the demolition modes to follow the key element index values are estimated.

2 KEY ELEMENT INDEX

Due to variations in their span lengths and strengths, certain columns in a structure support more vertical loads than other columns and thus act as “key elements” in the structure. Several indexes have been developed to evaluate the contribution of each column to the strength of a structure, i.e., to determine the key elements, such as the redundancy index by Frangopol[11] and the sensitivity index by Itoh *et al.* [12]. These indexes are effective for identifying highly sensitive columns that support the vertical load; however, they equivalently identify those columns that only cause partial collapse and are thus not useful for demolition planning, where the major aim is the total collapse of a structure. Therefore, we propose a new index, called the key element index, for estimating the contribution of base columns to the total collapse of the structure.

The key element index is calculated as follows. First, we perform a static pushdown analysis by equally applying incremental vertical loads at every structural joint in a modeled structure. Several columns on the upper floors may yield in this process, but the vertical loads are nevertheless continuously applied in steps until one of the base columns yields. The total vertical load (including the floor loads) applied to a column at the step when one of the base columns yields is defined as the ultimate yield strength P_G of the structure. The ultimate yield strength of the initial, undamaged structure is denoted ${}_0P_G$, and the ultimate yield strength of a structure with one base column eliminated is denoted ${}_1P_G$. The key element index KI of column m, for example, can be defined as the ratio of the ultimate yield strengths of the present and the initial step. The index can thus be written as:

$$ {}_1^0KI_m = {}_0P_G/{}_1P_G \tag{1} $$

The key element index at the nth step is then:

$$ {}_n^0KI_m = {}_0P_G/{}_nP_G \tag{2} $$

The index shown above indicates the contribution of the present column (or columns) to the strength of the initial, undamaged structure and can be used for cases in which the columns are eliminated simultaneously. However, the sensitivity of columns may change momentarily for those cases when the columns are eliminated sequentially within a certain interval. Therefore, the updated index, as

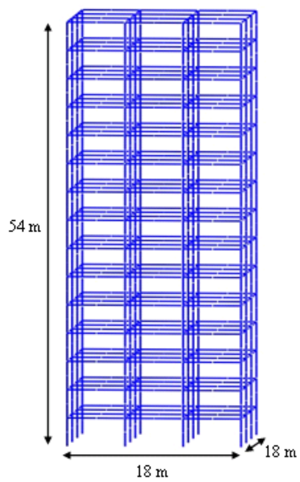


Figure 1: A 15-storey, three-span model

shown below, is used for those cases with a sequential blast.

$$ {}_{n}^{n-1}KI_m = {}_{n-1}P_G / {}_{n}P_G \tag{3} $$

In this case, the index can be defined as the ratio of the ultimate yield strengths of the present and the previous step.

As an example, the key element index values were calculated for a 15-story, three-span model, as shown in Fig. 1. Each span length is 6 m, and the height between each floor is 3.6 m. The material used for the columns and beams is SN490B steel. We selected box-type section of 430 mm × 430 mm × 13 mm × 13 mm on the 1st floor columns and H-type section of 331 mm × 825.7 mm × 18.4 mm × 13.2 mm for the beams, with the sectional sizes becoming gradually thinner in the higher stories. The floor load, in this case, is set to 400 kgf/m^2. The updated index values and the selection of columns from the largest index value at each step are shown in Fig. 2. For example, the key element index value *KI* for column No. 16 (in the upper right corner) can be calculated at the first step as:

$$ {}_{1}^{0}KI_{16} = {}_{0}P_G / {}_{1}P_G = 1.693 \tag{4} $$

and at the second step as:

$$ {}_{2}^{1}KI_{16} = {}_{1}P_G / {}_{2}P_G = 1.012 \tag{5} $$

If the index values calculated for multiple columns are the same, the column at the left and lower side is selected prior to the other columns; in this case, to direct the whole collapsing building toward the lower left side. As shown in the figure, the selected columns tend to bias to the intended demolition direction if the columns are selected from the largest index value. Furthermore, the distribution of the

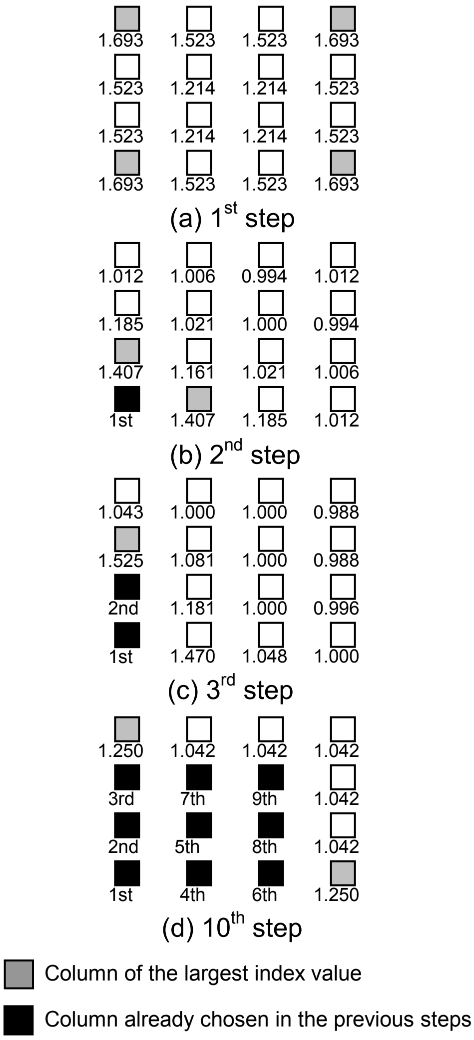


Figure 2: Updated index values and the selection of columns from among those with the largest values

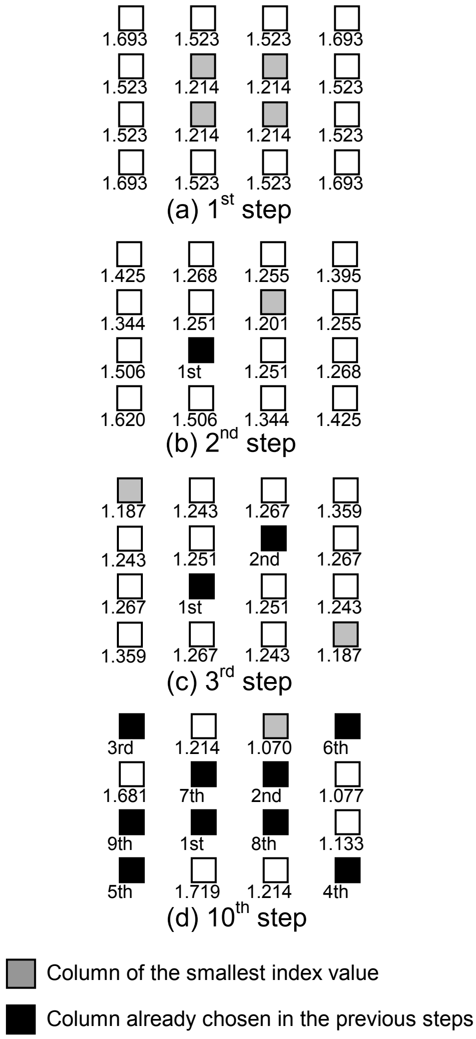


Figure 3: Updated index values and the selection of columns from among those with the smallest values

selected columns differs, as shown in Fig. 3, when the columns are selected from the smallest index value. The selected columns tend to distribute the load, stabilizing the structure and preventing instantaneous collapse.

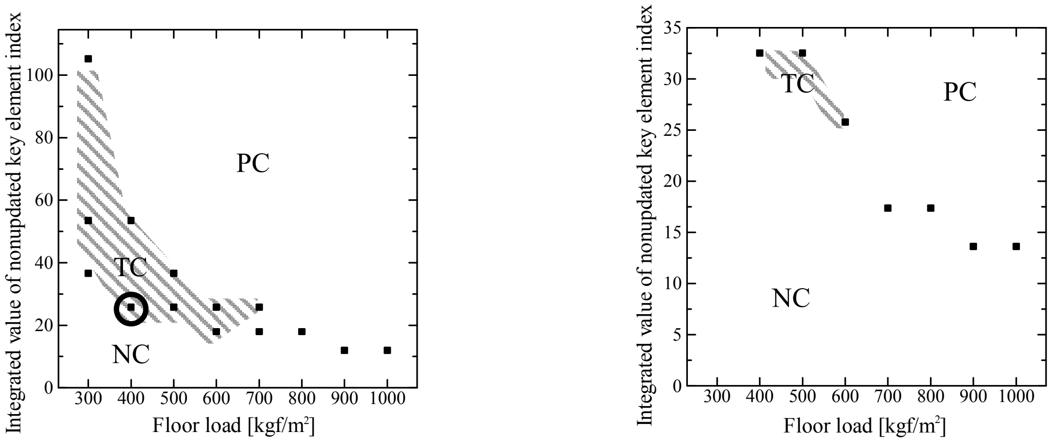
3 BLAST DEMOLITION PLANNING USING THE INTEGRATED KEY ELEMENT INDEX VALUES

Several blast demolition analyses were performed using selected columns, as described in the previous section. We summed the key element index values of the selected columns and plotted the collapse modes for each case. Each procedure was performed on models with different floor loads. Figure 4 shows the distribution of the integrated values of the key element index and the collapse modes of the structure for a simultaneous blast, where nonupdated index values are used. TC in the figures indicates total collapse, PC indicates partial collapse, and NC indicates no collapse. The integrated value indicated by the black circle in Fig. 4(a), for example, is calculated as follows:

$$ {}_1^0KI_1 + {}_2^0KI_5 + {}_3^0KI_9 + {}_4^0KI_2 + {}_5^0KI_6 + {}_6^0KI_3 = 1.693+2.382+3.633+4.284+5.979+7.863 $$

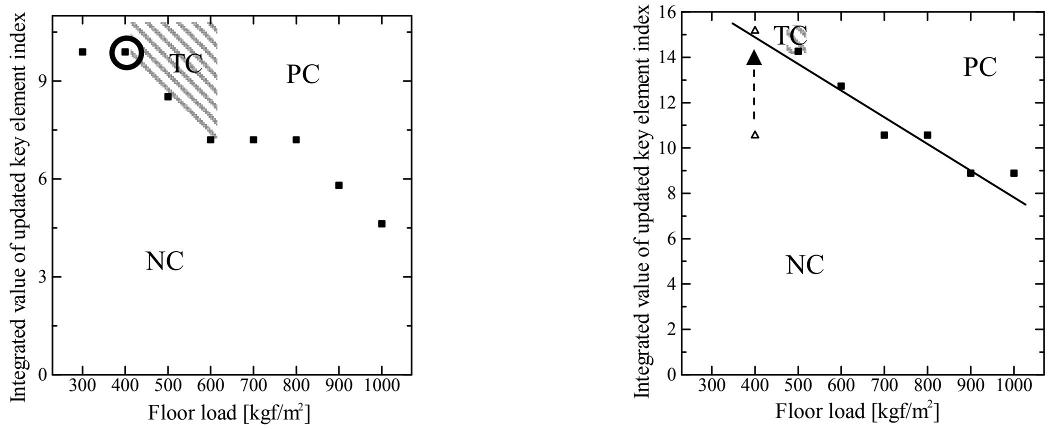
$$ = 25.834 \qquad (6) $$

Here, again, note that the lower right subscript in the key element index indicates the column number, the upper left subscript indicates the step number under consideration in the calculation of the ultimate yield strength ratio, and the lower left subscript indicates the present step number. As shown in the figures, there are certain requirements for the integrated values of the key element index to ensure that the structure is partially or totally demolished. The region of total collapse is large when the



(a) Selecting columns from the largest index value (b) Selecting columns from the smallest index value

Figure 4: Key element index values and collapse behavior of the model (simultaneous blast, nonupdated index value)



(a) Selecting columns from the largest index value (b) Selecting columns from the smallest index value

Figure 5: Key element index values and collapse behavior of the model (sequential blast, updated index value)

columns with the largest index values are successively selected (see Fig. 4(a)), whereas the region is very small when the columns with the smallest index values are selected (see Fig. 4(b)). To accomplish total collapse, neither the integrated index values nor the floor load should be too large because larger values tend to make the structure relatively stable in the collapse process.

Figure 5 shows the distribution of the integrated values of the key element index and the collapse modes of the structure for sequential blast, where updated index values are used. The integrated value indicated by the black circle in Fig. 5(a), for example, is calculated as follows:

$$ {}_1^0KI_1 + {}_2^1KI_5 + {}_3^2KI_9 + {}_4^3KI_2 + {}_5^4KI_6 + {}_6^5KI_3 + {}_7^6KI_{10} = 1.693+1.407+1.525+1.179+1.396+1.315+1.377 $$

$$ = 9.892 \qquad (7) $$

The same tendencies as observed in Fig. 4 can be seen here in the distribution of the index values and the collapse modes. However, the region of total collapse becomes much smaller than in simultaneous blasting because the structure tends to become relatively stable during each blast interval.

It is evident from Fig. 4 and Fig. 5 that there are several specific areas of integrated index values that allow for successful demolition, especially when the columns are selected from the largest key element index values. However, the sequential blast of columns from the largest index values causes the whole structure to gradually collapse in sequence, which may, in practical terms, cut the explosive trigger wires and/or make the whole demolition procedure quite unstable. Therefore, the selection of columns with the largest index values may only be used in demolition by simultaneous blasting. In contrast, the selection of columns with the smallest index values may be used to keep the structure stable until the last moment in a demolition by sequential blasting. The structure may be completely

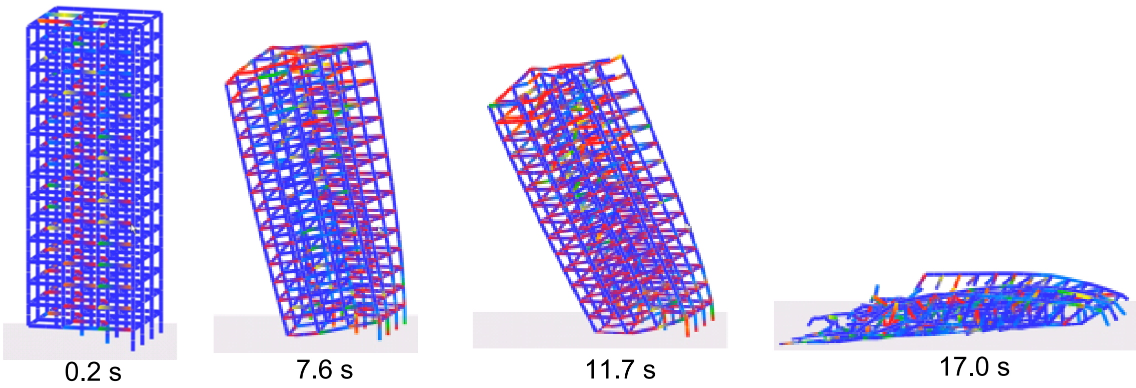


Figure 6: Demolition mode for the simultaneous blast case
(six columns selected from the largest nonupdated index value)

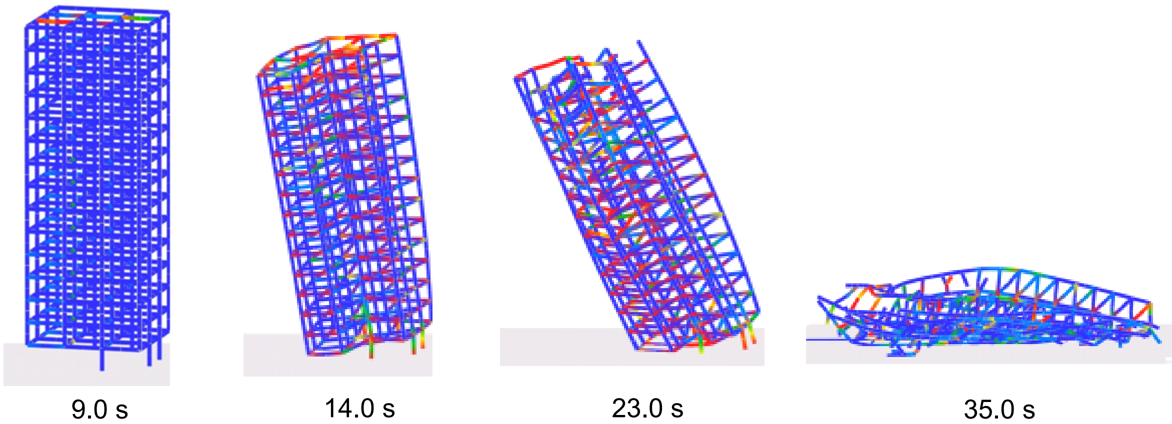


Figure 7: Demolition mode for the sequential blast case
(nine columns selected from the smallest updated index values and three columns from the large ones selected for the final blast)

demolished by a final blast on a column (or columns) with a large index value, essentially traversing the solid line in Fig. 5(b) in one step.

4 BLAST DEMOLITION ANALYSIS OF A FRAMED STRUCTURE USING THE OBTAINED PLAN

Two analyses using the plans of blast demolition obtained in the previous section were performed on the model shown in Fig. 1. Each analysis took 50 to 90 minutes on a personal computer (CPU: 2.0 GHz Xeon, 8GB RAM). Figure 6 shows the demolition mode for the simultaneous blast case, in which the eliminated columns were selected from among those with the largest nonupdated index values. Six columns altogether were selected, in this case, and the integrated value of the key element index was 25.834 as calculated in Eq. (6). Figure 7 shows the demolition mode for the sequential blast case, in which the columns were selected for elimination from among those with the smallest updated index values. To achieve a total collapse, the columns with the large index values at the final step were selected for the final blast. In this case, nine columns from among those with the smallest index values (with the integrated value of 10.552) were sequentially eliminated over an interval of one second, and then, three columns with the large index values (with the integrated value of 4.614) were simultaneously eliminated at the final blast. Please note that the integrated index value of the initial nine columns does not traverse the solid line in Fig. 5(b), however, the total value including the final three columns, which is 15.166, slightly traverse the line. Although the timings of the collapse initiation and the collapse modes slightly differ in each case, both display a successful demolition pattern, with the structure totally demolished to ground level and towards the intended direction.

5 CONCLUSIONS

The key element index and its integrated values, as demonstrated in this paper, may be used to quantitatively verify which columns should be eliminated to best achieve a total collapse. The numerical results suggest that for a successful demolition, a group of columns with the largest key element index values should be selected when explosives are ignited in a simultaneous blast, whereas those with the smallest values should be selected when explosives are ignited sequentially, with a final blast set on a column with a large index value. However, further investigation should be undertaken to enable the precise planning of blast intervals and locations required to allow the whole structure to collapse in its own wake, which is very important to lower the risk of damage to neighboring buildings.

REFERENCES

[1] G.T. Williams, Explosive demolition of tall buildings in inner city areas, *Municipal Engineer,* 7(4), (1990), 163-173.

[2] E. Yarimer, Demolition by Controlled Explosion as a Dynamical Process, *Structures under Shock and Impact*, (1989), 411-416.

[3] M. Kinoshita, A. Hasegawa, S. Matsuoka and K. Nakagawa, An experimental study on explosive demolition methods of reinforced concrete building, *Proc. of the Japan Society of Civil Engineers,* 403(VI-10), (1989), 173-182.

[4] P.A. Cundall, A Computer Model for simulating Progressive, Large-scale Movement in Blocky Rock System, *Proceedings of the International Symposium on Rock Mechanics* II-8, (1971), 129-136.

[5] G.H. Shi and R.E. Goodman, Discontinuous Deformation Analysis, *Proc. of 25th U.S. Symposium on Rock Mechanics*, (1984), 269-277.

[6] N. Tosaka, Y. Kasai and T. Honma, Computer Simulation for Felling Patterns of Building, *Demolition Methods and Practice*, (1988), 395-403.

[7] M.Y. Ma, P. Barbeau and D. Penumadu, Evaluation of active thrust on retaining walls using DDA, *Journal of Computing in Civil Engineering*, 1, (1995), 820-827.

[8] M. Itoh, N. Yoshida, N. Utagawa and I. Kondo, Simulation of Blast Demolition of Reinforced Concrete Buildings, *Proc. of the Third World Congress on Computational Mechanics*, Chiba, Japan, (1994), 1152-1153.

[9] I. Kondo, N. Utagawa, M. Ito and N. Yoshida, Numerical Method to Simulate Collapse Behavior in Blasting Demolition of Space Framed Structure, *Proc. of the 13th Symposium on Computer Technology of Information, Systems and Applications*, (1990), 49-54, in Japanese.

[10] K.M. Lynn and D. Isobe, Finite Element Code for Impact Collapse Problems of Framed Structures, *International Journal for Numerical Methods in Engineering*, 69(12), (2007), 2538-2563.

[11] D.M. Frangopol and J.P. Curley, Effects of Damage and Redundancy on Structural Reliability, *Journal of Structural Engineering, ASCE*, 113(7), (1987), 1533-1549.

[12] T. Ito, K. Ohi and Z. Li, A Sensitivity Analysis related to Redundancy of Framed Structures Subjected to Vertical Loads, *Journal of Structural and Construction Engineering, AIJ*, 593, (2005), 145-151, in Japanese.