Proceedings of International Structural Engineering and Construction, 8(1), 2021
Interdisciplinary Civil and Construction Engineering Projects
Edited by El Baradei, S., Abodonya, A., Singh, A., and Yazdani, S.

ISSN: 2644-108X
www.doi.org/10.14455/ISEC.2021.8(1).CON-04

STUDY ON SAFETY OF PULLING DOWN COLUMNS IN BUILDING DEMOLITION

HIROKI TAKAHASHI, SEIJI TAKANASHI, and TOMOHITO HORI

Construction Safety Research Group, National Institute of Occupational Safety and Health, Kiyose, Japan

When walls and columns are demolished during the demolition of buildings in Japan, the lower parts of the walls and columns are cut, after which they are pulled down. This method is called the fall-down method. However, the amount of cutting required is unknown. If a worker cuts the columns too deeply, the walls and columns will collapse and may crush the worker. In this study, the fall-down test of columns was carried out to assess the safety of cutting the lower part of columns. The parameters of the test included the pattern of cutting the lower part of columns and the material properties of the model. In addition, the position of the neutral axis was examined by numerical analysis. The results showed that the cutting pattern involving leaving the main reinforcement at the front of the fall-down and cutting the concrete near the neutral axis is safe at demolition sites. In contrast, the cutting pattern with one row of main reinforcement at the front was unsafe and could potentially lead to premature collapse. Columns at demolition sites should not be cut by this latter cutting pattern. The test and the analysis in this study reproduce the demolition site, and the results of these be widely applied in the actual demolition site.

Keywords: Fatal accident, Demolition work, Wall, Column, Cutting, Fall-down, Reinforced concrete.

1 INTRODUCTION

When walls and columns are demolished during the demolition of buildings in Japan, the lower parts of these walls and columns are cut. Subsequently, the walls and columns are pulled down. This method is called the fall-down method. When the walls and columns are cut too deeply during cutting work, they can collapse and can crush the worker. When the lower parts of walls and columns are cut, there is thus a recommended cutting pattern (Study Group on Demolition Methods 2017). This pattern involves cutting of the concrete at the front (referring to the direction towards which the structure is planned to fall), while cutting of the main reinforcement at the back; meanwhile, the main reinforcement at the front is left in place, as shown in Figure 1. (Hereafter, the front of the structure towards which the structure will fall is referred to as the "front," while the back of it is referred to as the "rear.") However, many of the safety issues associated with this column cutting have not been addressed.

Safety on construction site have been published by Japan Construction Occupational Safety and Health Association (2012), Assadzadeha *et al.* (2019), and Arashpour *et al.* (2021), but they do not discuss the extent to which walls and columns should be cut.

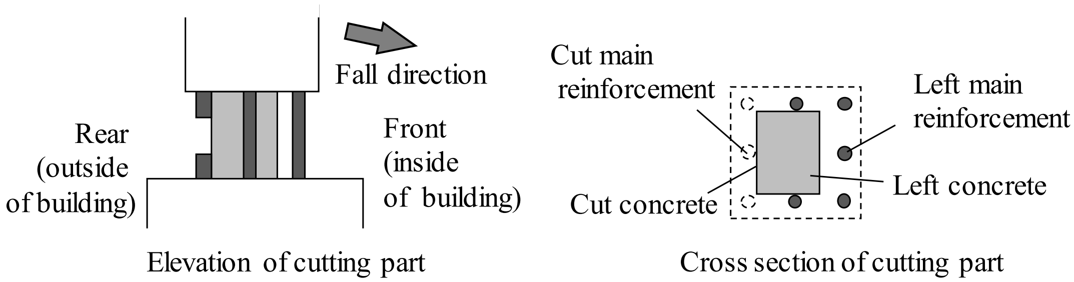


Figure 1. Recommended cutting pattern.

Against this background, the authors carried out fall-down tests of columns with cutting of their lower part in a previous study. The results showed that all models were independent without falling because the dead load has a small effect on the falling down of columns. However, the safety of the recommended cutting pattern is unknown. The test was carried out on one pattern of the material property of the column in the previous study.

In this study, fall-down tests of columns were carried out with cutting of the lower part to determine the safety of the recommended cutting pattern. The test was carried out on two patterns of the material property of the column. The final goal of this study was to establish safe management methods during wall and column demolition.

2 OVERVIEW OF THE TEST

2.1 Model of the Test

The tests were carried out reproduce the fall-down method on demolition site. The tests were carried out at the National Institute of Occupational Safety and Health in Tokyo. One of the models for the test is shown in Figure 2. The models were full-scale reinforced concrete columns. From Figure 2, the cross section of each column was 24 cm in length and width, and the column itself was 1.2 m high. The height at which the column was cut was 30 cm from the bottom.

The names of the eight models are shown in Table 1. The parameters varied in the tests are the cutting pattern of the lower part of the column and the material properties of the model. The cross sections of the lower part of the column are shown in Figure 3. Figure 3 also shows the neutral axis of the lower section by numerical analysis, as described in section 2.2. A total of four cutting patterns were evaluated. From Figure 3, cutting pattern 1 is the standard model in the test. The concrete at the front and the main reinforcement at the back were cut, while the main reinforcement at the front was left in place. Cutting pattern 2 involves cutting at the position of the main reinforcement the same as in cutting pattern 1. The amount of cutting of the concrete is greater than that of cutting pattern 1. In cutting pattern 3, the amount of cutting of concrete is the same as in cutting pattern 1. The main reinforcement is cut in two rows at the rear. Cutting pattern4 is used as a model to examine the safety of cutting pattern 1. The amount of concrete for this is the same as in cutting pattern 1. The main reinforcement is cut in one row at the front.

The material properties of the model are shown in Table 2. There are two types of material property used. The strength of material property II is greater than that of material property I, as shown in Table 2. The strengths of the concrete and the steel bar, as shown in Table 2, are the results of tests by the Standards (Japanese Industrial Standards Committee 2010, Japanese Industrial Standards Committee 2012).

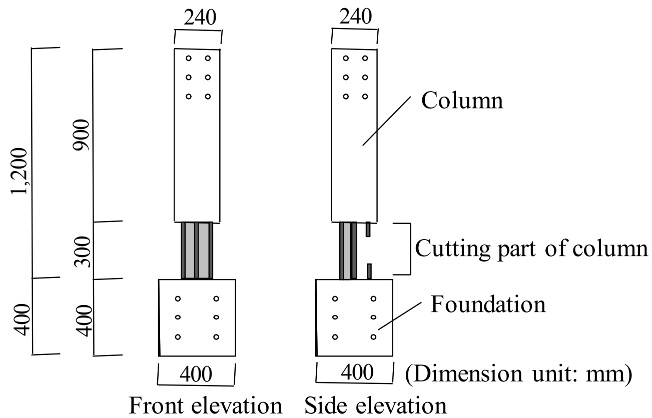
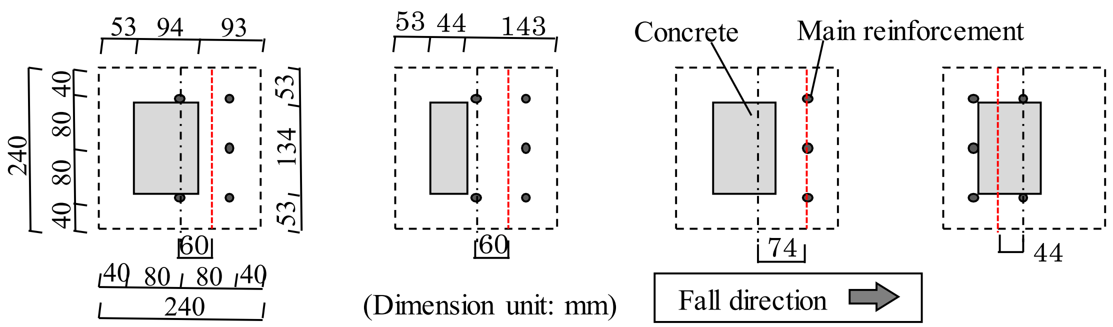


Figure 2. Models of the test.

Table 1. Name of model.

Model	Mterial property	Cutting pattern
I-1	I	1
I-2	I	2
I-3	I	3
I-4	I	4
II-1	II	1
II-2	II	2
II-3	II	3
II-4	II	4



(a) Cutting pattern 1 (b) Cutting pattern 2 (c) Cutting pattern 3 (d) Cutting pattern 4

Figure 3. Cutting patterns of the lower part of the column.

Table 2. Material properties of the model.

(a) Material property I.

Concrete (column)

Compressive strenght (N/mm^2)	Slump (cm)
29.5	18

Steel bar

Diameter (mm)	Yield point (N/mm^2)	Tensile strength (N/mm^2)
12.7	373	512

(b) Material property II.

Concrete (column)

Compressive strenght (N/mm^2)	Slump (cm)
52.3	18

Steel bar

Diameter (mm)	Yield point (N/mm^2)	Tensile strength (N/mm^2)
12.7	367	560

2.2 Calculation of Neutral Axis

The neutral axis of the cross section of the cut part was calculated by numerical analysis. The calculation method was as follows. The cross section of the cut part was divided into minute elements as shown in Figure 4. The strain ε_n due to axial force was given. The minute curvature

$\Delta\varphi$ was increased. The strain $\varepsilon_m(y)$ corresponding to $\Delta\varphi+\varphi$ was given. The stress $\sigma(y)$ corresponding to $\varepsilon_n+\varepsilon_m(y)$ was calculated by the relationship between stress and strain with reference to the results shown in Table 2. The neutral axis was iteratively calculated using the distribution of the stress $\sigma(y)$.

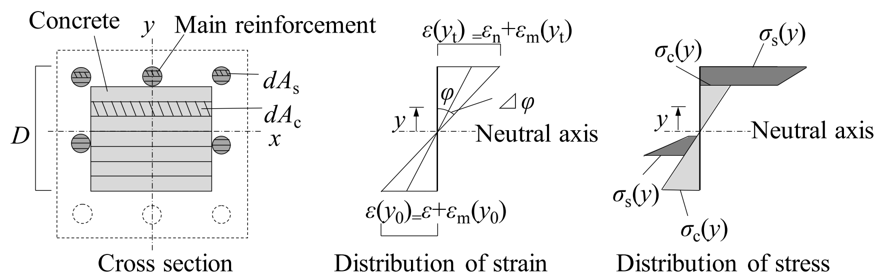


Figure 4. Cutting pattern of the lower part of the column.

2.3 Set-up of the Test

The set-up of the test and the model is shown in Figure 5. The model was fixed on the floor, as also shown in Figure 5, and a steel column was placed on top of the model because of raise the height of the model. The height of model and steel column were 2.9 m. The model was pull down by an electric hoist. The load and displacement while pulling down the model were measured. The load and the displacements were measured at the tension point of the column as shown in Figure 5.

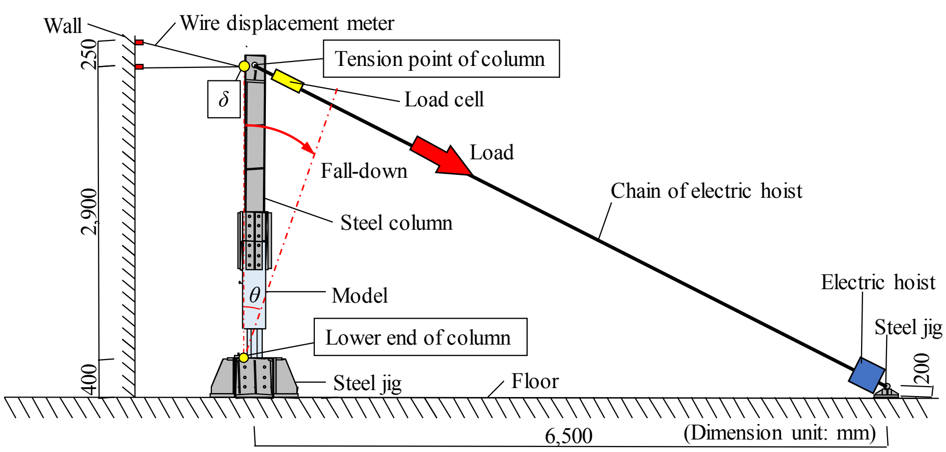


Figure 5. Set-up of the test.

3 RESULTS OF THE TEST

3.1 Relationship Between Moment and Rotation Angle

From the measurement results, the rotation angle of the column and the moment of the lower part of the column were calculated. The relationship between the moment M and the rotation angle θ while pulling down the model is shown in Figure 6. The results of the test are shown in Table 3. M_u is the max. moment and θ_u is the rotation angle corresponding to M_u in Table 3. The destruction state of the model is shown in Figure 7.

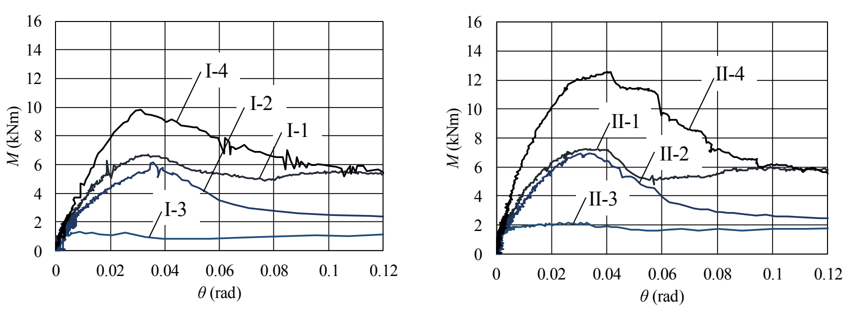
From Figure 6 and Table 3, M_u of I-1 was greater than that of I-2 because the cross section of concrete of I-1 was wider than that of I-2. However, the difference between them was small. The concrete of I-1 and I-2 is behind the neutral axis, as shown in Figure 3(a), (b). Therefore, the tensile force acted on the concrete of I-1 and I-2. The strength of the concrete was very low. Therefore, the difference between M_u of I-1 and I-2 was small. From Figure 7, when I-1 and I-2 were destroyed, buckling occurred. With cutting patterns 1 and 2 leaving the main reinforcement at the front, buckling was shown to occur. It is appropriate to cut concrete near the neutral axis like in I-1 to reduce the work amount of work involved in such cutting.

From Figure 6 and Table 3, M_u of I-3 was the smallest. In this case, the neutral axis was on the main reinforcement in the front. When I-3 was destroyed, bending failure occurred at the main reinforcement at the front, as shown in Figure 3(c). This was the cause of M_u of I-3 being the smallest. Cutting pattern 3 involving a row of the main reinforcement being left at the front may lead to collapse due to the tension of the wire rope at the top of the column in the demolition site.

From Figure 6 and Table 3, M_u of I-2 was greater than that of I-1 because of the compressive strength of the concrete beyond the neutral axis. I-4 was almost the same as I-1 in that the direction of falling was rotated 180°. When I-1 falls down inside a building, destruction occurs by buckling of the main reinforcement at the front. When I-1 starts to fall down outside a building, it is more difficult for the building to fall down than when I-1 falls down inside the building. I-1 is thus suitable for preventing public disasters.

3.2 Effect of Material Strength on Column Strength

From Figure 6 and Table 3, M_u of II-1 was greater than that of I-1, and M_u of II-2 was greater than that of I-2. This is because the strength of concrete of II-1 and II-2 was greater than that of I-1and I-2. However, the difference in strength between them was small because they were destroyed by buckling of the main reinforcement at the front.



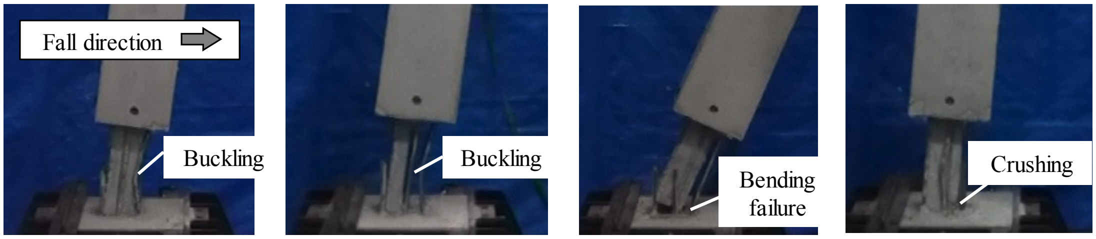
(a) Material property I (b) Material property II

Table 3. Results of test.

Model	M_u (kNm)	θ_u (rad)
I-1	6.68	0.034
I-2	6.14	0.036
I-3	1.32	0.009
I-4	9.82	0.031
II-1	7.22	0.033
II-2	6.96	0.033
II-3	2.13	0.023
II-4	12.55	0.040

Figure 6. Relationship between moment and rotation angle.

From Table 3, M_u of II-3 was the second smallest. This model may collapse like I-3 due to the tension of the wire rope at the top of the column. From Figure 6 and Table 3, M_u of II-4 was greater than that of I-4 because the compressive strength of the concrete of II-4 was strong. Cutting pattern 4, involving leaving the concrete beyond the neutral axis, was affected by the compressive strength of the concrete. However, in cutting pattern 1, involving leaving the main reinforcement at the front, buckling occurred. Therefore, in cutting pattern 1, the fall-down strength of the column was affected by the diameter and quantity of the main reinforcement at the front, but was not affected by the strength of the main reinforcement at the front.



(a) I-1 (b) I-2 (c) I-3 (d) I-4

Figure 7. Destruction state of model.

4 CONCLUSION

In this study, the safety of the cutting method was examined by performing fall-down tests of columns in which the lower part was cut. This test is a good reproduction of the demolition site. This is a new test method. A summary of the obtained findings is as follows.

1. With cutting pattern 1, involving leaving the main reinforcement at the front, buckling occurs. Therefore, in cutting pattern 1, the fall-down strength of the column is affected by the diameter and quantity of the main reinforcement at the front, but is not affected by the strength of the main reinforcement at the front.
2. When a column with cutting pattern 1 falls down outside a building, it is harder for the building to fall down than when the column falls down inside the building. Cutting pattern 1 is thus suitable for public disaster prevention.
3. With the cutting pattern involving leaving the main reinforcement at the front, it is appropriate to cut concrete near the neutral axis like cutting pattern 1 to reduce the amount of work involved in demolishing buildings.
4. The cutting pattern with one row of main reinforcement at the front had low strength. This cutting pattern may lead to collapse due to the tension of the wire rope at the top of the column in demolition sites.

References

Arashpour, A., Ngo, T., and Li, H., *Scene Understanding in Construction and Buildings Using Image Processing Methods: A Comprehensive Review and a Case Study*, Journal of Building Engineering, Elsevier, 33 (2021) 101672.

Assadzadeha, A., Arashpoura, M., Rashidib, A., Bab-Hadiasharc, A., and Fayezid. S., *A Review of Data-Driven Accident Prevention Systems:Integrating Real-Time Safety Management in the Civil Infrastructure Context*, 36th International Symposium on Automation and Robotics in Construction, ISARC 2019, Al-Hussein, M. (ed.), 289-296, Banff, Canada, 2019.

Japan Construction Occupational Safety and Health Association, *Recommendation on Demolition Work of Reinforced Concrete Building*, Japan Construction Occupational Safety and Health Association, Tokyo, 2012.

Japanese Industrial Standards Committee JIS G3112, *Steel Bars for Concrete Reinforcement*, Japanese Industrial Standards Committee, Tokyo, 2010,

Japanese Industrial Standards Committee, JIS A1107, *Compression Strength Test Method of Concrete*, Japanese Industrial Standards Committee, Tokyo, 2012.

Study Group on Demolition Method, *New Demolition Method and Estimating*, Economic Research Association, Tokyo, 2017.