Mutual Effects between High Buildings and Underground Shopping Arcade during Earthquake

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SUMMARY:
It is considered that the seismic safety of underground structure will be affected by the mutual effects between underground structure and ground structure. Then, we made 3D dynamic analyses for the coupled subway - underground shopping arcade - high building system in order to evaluate the influence of earthquake behaviors of high buildings on the seismic safety of underground shopping arcade. As the results, it was confirmed that the high buildings behaved not only in the same phase but also in the reverse phase. The dynamic tensile stresses around the connecting parts between the underground shopping arcade and the high buildings were increased largely by the displacement behaviors of high buildings in the reverse phase. A seismically isolated structure, which allows opening and sliding along the contact plane, will be effective to release and reduce the dynamic tensile and shear stresses at the connecting parts.

Keywords: Mutual effect, seismic safety, 3D dynamic analysis, underground shopping arcade, high building

1. INTRODUCTION

It is generally thought that the underground is safer than the ground, because the acceleration amplitudes of earthquake motions tend to become smaller in the underground. However, it is considered that the seismic safety of underground structure may be affected by the dynamic behavior of plural ground structures during large earthquake. Taking these matters into consideration, we studied about the mutual effects between underground structure and ground surface structure. We made 3D dynamic analyses for the coupled subway-underground shopping arcade-high building system in order to evaluate the influence of earthquake behaviors of high buildings on the seismic safety of underground shopping arcade. The 3D analytical model was made on the assumption the underground shopping arcade is located just above the subway, and two high buildings are located at the both sides of the underground shopping arcade. Based on the analytical results, we considered about the relationship between the phase of displacement behavior of high buildings and the dynamic stresses around the connecting area between the underground shopping arcade and the high buildings.

2. PURPOSE OF STUDY

Various kinds of structure, such as high-rise building, highway, railway, subway, underground shopping arcade and so forth have been constructed densely in urban area. Generally, seismic design of structure has been made individually one by one, therefore mutual effects among the adjacent structures have not been considered in the seismic design thus far. The connecting parts between underground structure and ground structure may be damaged or destroyed by stress concentration and relative displacement induced by earthquake motion because of the difference of dynamic response properties. Furthermore, amplification of acceleration, lengthening of period and duration time of earthquake motion will be supposed because of the soft ground in urban area. In order to improve seismic performance of urban area, it is considered that the seismic safety evaluation should be made by taking mutual effects among the adjacent structures. From such a necessity, we studied about the influence of earthquake behavior of ground structures on the underground structures based on the results by 3D dynamic analysis.

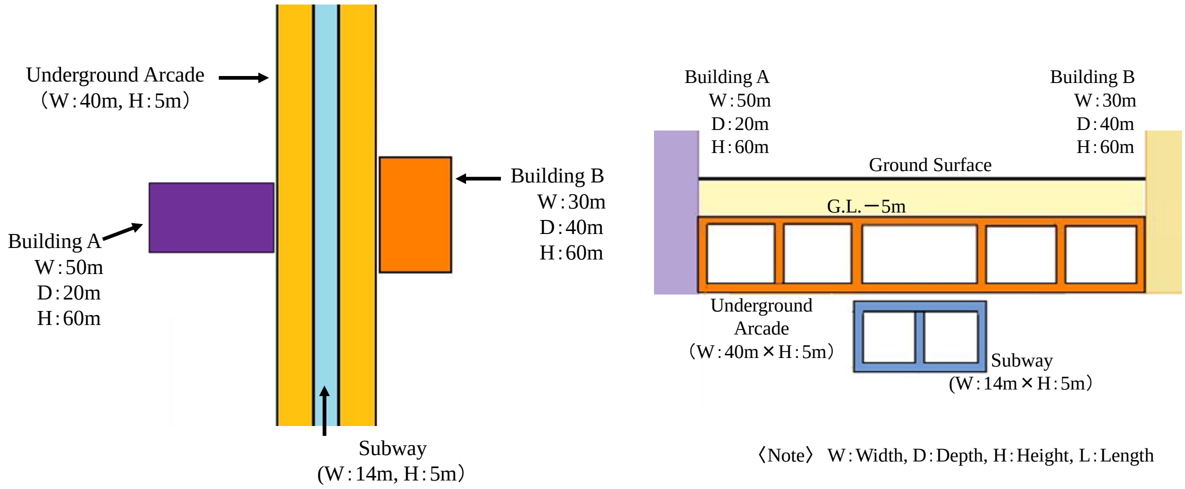
3. THREE DIMENSIONAL DYNAMIC ANALYSIS

3.1. Outline

We made 3D dynamic analysis in order to evaluate the mutual effects between underground structures and ground surface structures during large earthquake. Influence of displacement behaviors of high buildings on the seismic safety of underground shopping arcade was studied by using 3D FEM model for a coupled subway-underground shopping arcade-high building system. The analytical model was made on the assumption the underground shopping arcade is located just above the subway, and two high buildings are located at the both sides of underground shopping arcade. The height and width of subway are set to be 5m and 14m, respectively. The height and width of underground shopping arcade are 5m and 40m, respectively. And, the ground height and underground depth of high buildings are 60m and 15m, respectively. As for the analysis program, DIANA was used.

3.2. Dynamic Analysis Model

The shapes and the locations of subway, underground shopping arcade and two high buildings are set as shown in Fig. 3.1, and the measurements of them are shown in Table 3.1.



(1) Plane (2) Cross section

Figure 3.1. Fundamental concept for rational confirmation method for seismic safety

Table 3.1. Measurements of High Buildings and Underground Structures

Structure	Width	Height		Depth
		Ground	Underground	
High building A	50m	60m	15m	20m
High building B	30m	60m	15m	40m
Underground shopping arcade	40m	5m		200m
Subway	14m	5m		200m

The underground shopping arcade is located 5m below the surface (G.L.-5m). The ground height of two high buildings, which are located at the both sides of underground shopping arcade, are assumed to be 60m, and the buildings are assumed to be twelve stories. The first-mode natural period of the buildings is assumed to be 1.2 second by tanking the empirical relationship between height and natural period of existing buildings into consideration.

3D FEM model for coupled subway-underground shopping arcade-high building system is shown in Fig. 3.2. And the central cross section of the model is shown Fig. 3.3. The model was made by using solid elements. The buildings were modelled as the structures composed of pillars and beam. As for the foundation ground, four layered horizontal ground was assumed. The bottom boundary of model is set to be rigid boundary, and the lateral boundary is set to be viscous boundary.

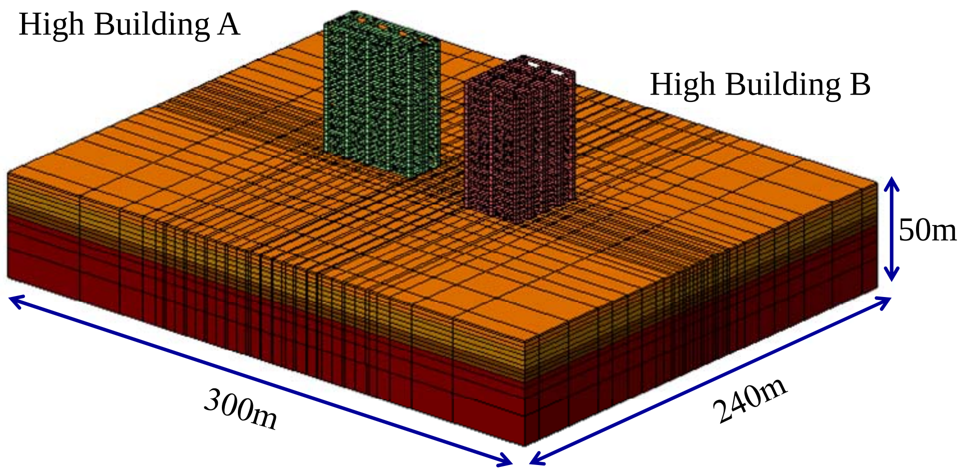


Figure 3.2. FEM model for subway-underground shopping arcade-high building system

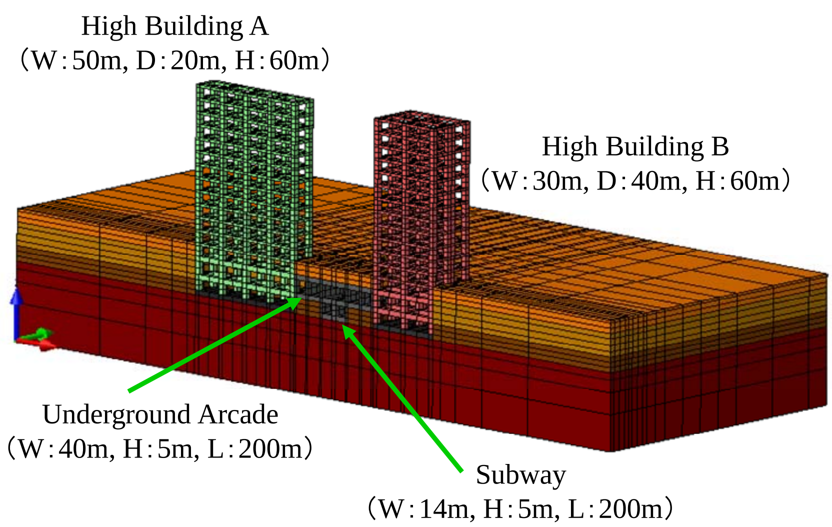


Figure 3.3. Cross section at the centre of the model

The dynamic property values of subway, underground shopping arcade and high buildings are shown in Table 3.2. The dynamic property values of foundation ground are shown in Table 3.3.
The subway and the underground shopping arcade are supposed as the reinforced concrete structures. The value of dynamic shear modulus of high buildings was set as the natural frequency became 1.2 second based on the eigenvalue analysis. The values of damping factor were assumed to be 3% or 5% by taking non-linear effects against dynamic shear strain into account. Shear wave velocity of first

layer of foundation ground was assumed to be 400m/s, because the form of foundation is supposed to be a spread foundation.

Table 3.2. Dynamic Property Values of Structures

Item	High building		Underground arcade
	A	B	Subway
Dynamic shear modulus (N/mm^2)	6700	6700	9000
Density (g/cm^3)	2.3	2.3	2.3
Poisson`s ratio	0.2	0.2	0.2
Damping factor (%)	3	3	3

Table 3.3. Dynamic Property Values of Foundation Ground

Layer No.	Thickness (m)	Shear wave Velocity (m/s)	Density (g/cm^3)	Poisson's ratio	Damping Factor (%)
1	5	400	2.1	0.40	5
2	9	500	2.2	0.35	5
3	6	600	2.3	0.35	5
4	30	700	2.5	0.25	3

3.3. Input Earthquake Motion

Input earthquake motion is shown in Fig. 3.4, which is suggested by Japan Society of Civil Engineer. The maximum amplitude of the motion is 749.6 gal. The motion was input from the bottom boundary in the transversal direction of underground shopping arcade.

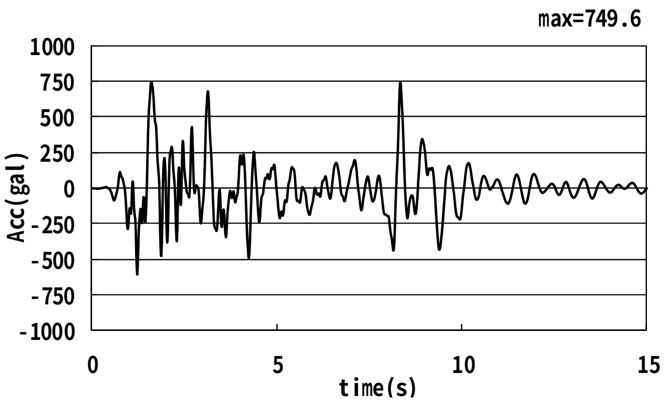


Figure 3.4. Input earthquake motion

3.4. Results of Analysis

3.4.1. Displacement behaviours of high buildings

The displacement behaviour of high buildings at the time when the distance between Building A and Building B became shortest is shown in Fig. 3.5. Similarly, the displacement behaviour when the distance became longest is shown in Fig. 3.6. According to Fig. 3.5 and Fig. 3.6, it is clear that two high buildings behave not only in the same phase but also in the reverse phase, or out of phase.

The representative nodal points for output of time histories are shown in Fig. 3.7, and the maximum displacement at the points are shown in Table 3.4. Displacement time histories at the top of the buildings and the connecting parts between underground shopping arcade and high building are shown in Fig. 3.8 and Fig. 3.9. The maximum displacement at the top of Building A (point 5) and Building B (point 10) was 37.1cm and 38.7cm, respectively. The maximum displacement at the connecting part of Building A (point 1) and Building B (point 6) was 3.45cm and 3.48cm, respectively.

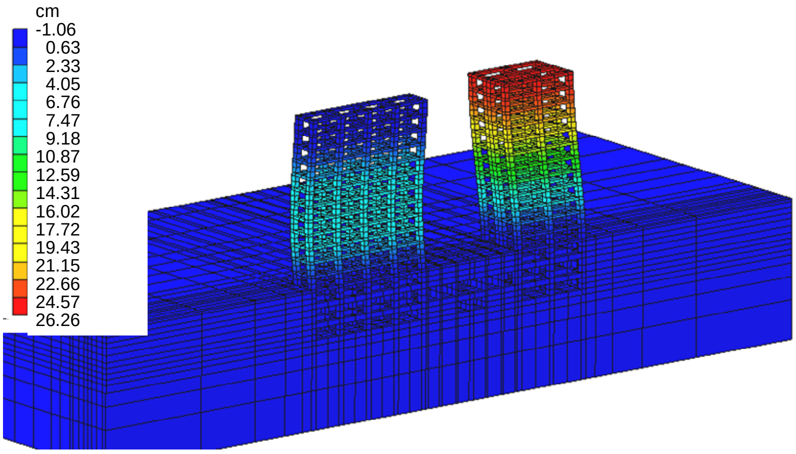


Figure 3.5. Displacement behaviour of high buildings when the distance between the Building A and the Building B became shortest

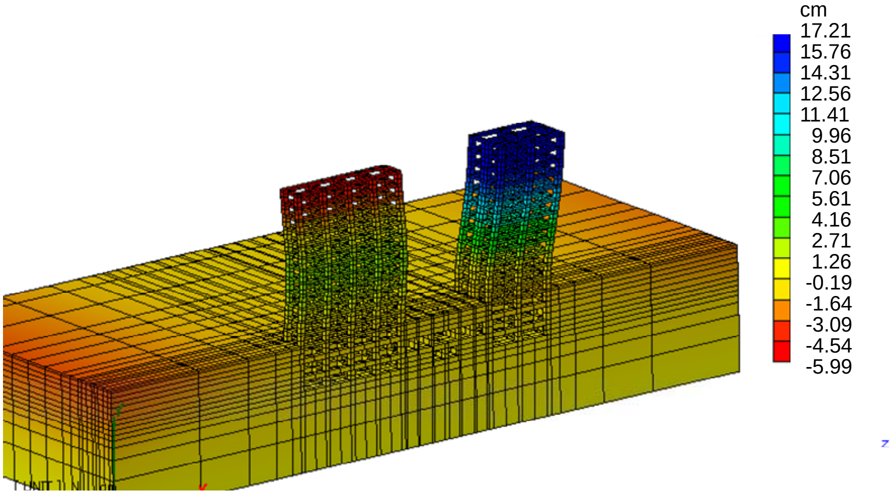
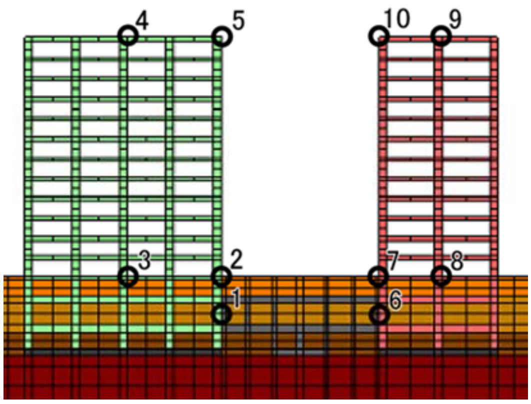


Figure 3.6. Displacement behaviour of high buildings when the distance between the Building B and the Building B became longest



<Note>

5 : Right edge of top of Building A

10 : Left edge of top of Building B

1 : Connecting part between underground arcade and Building A

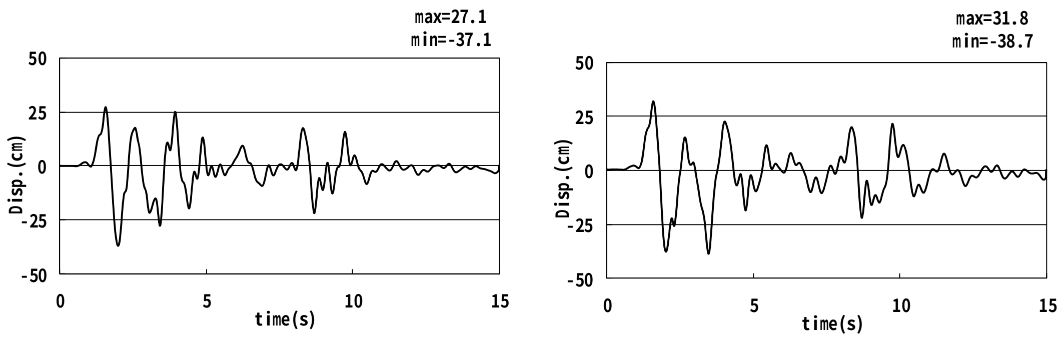
6 : Connecting part between underground arcade and Building B

Figure 3.7. Representative points for output of time histories

Table 3.4. Maximum Displacement at the Representative Points

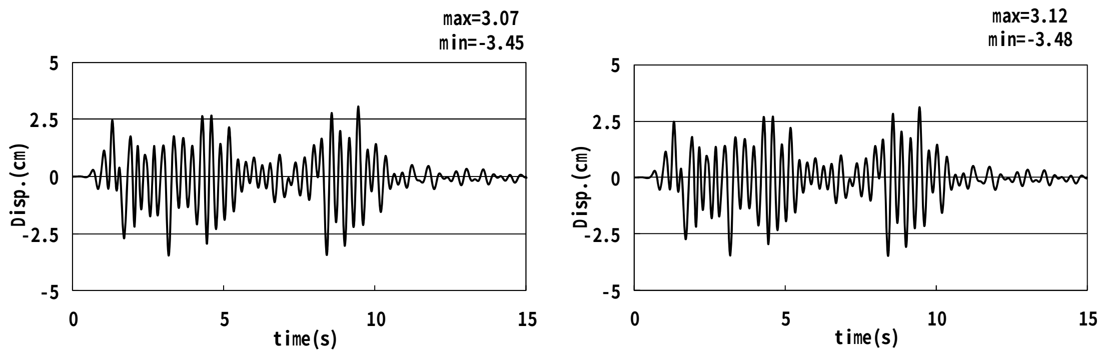
Point No.	Maximum Displacement (cm)	Minimum Displacement (cm)
1	3.07	-3.45
2	3.39	-4.75
3	3.38	-4.97
4	27.0	-37.0
5	27.1	-37.1
6	3.12	-3.48
7	3.98	-4.33
8	4.01	-4.50
9	31.7	-38.6
10	31.8	-38.7

〈Note〉 ＋: to the right direction, －: to the left direction



(1) At the right edge of top of Building A (point 5) (2) At the left edge of top of Building B (point 10)

Figure 3.8. Displacement time histories at the top of high buildings



(1) At the left side underground arcade (point 1) (2) At the right side of underground arcade (point 6)

Figure 3.9. Displacement time histories at the connecting parts between underground arcade and high buildings

3.4.2. Dynamic stress around underground shopping arcade

The distribution of maximum principal stress around the underground shopping arcade during earthquake is shown in Fig. 3.10. The representative elements for output of maximum stress values are shown in Fig. 3.11. The maximum values of principal stress at the representative elements are summarized in Table 3.5. The maximum tensile stress at the underground shopping arcade was 4.90N/mm^2 (Location S1). It can be understood that the principal stresses during earthquake increase at the connecting parts between high building and underground shopping arcade by the influences of displacement behaviour of high buildings located at the both sides of underground shopping arcade. When two high building behave out of phase each other, it is considered that the tensile stress at the underground shopping arcade will increase considerably.

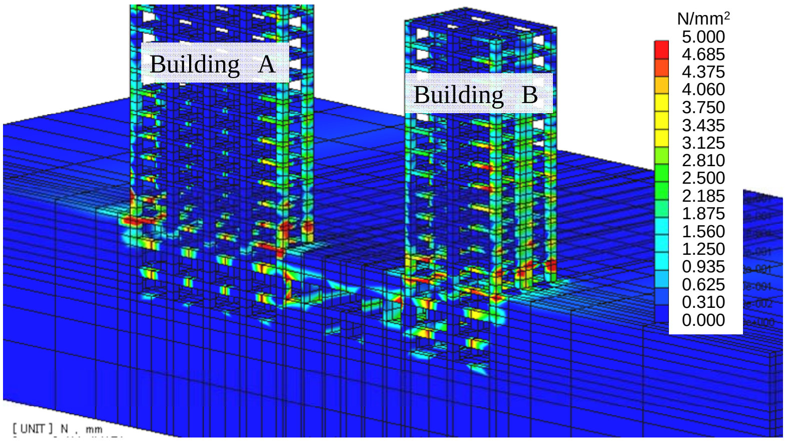


Figure 3.10. Distribution of maximum principal stresses during earthquake

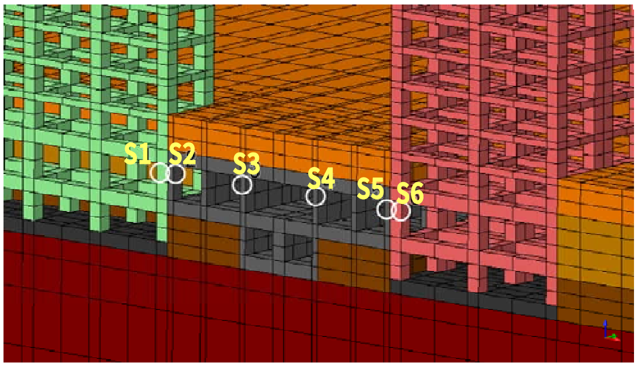


Figure 3.11. Representative elements for output of dynamic stresses

Table 3.5. Maximum Principal Stresses at Representative Elements

Location	Maximum Principal Stress (N/mm^2)
S1	-0.53
S2	4.01
S3	-0.47
S4	0.54
S5	4.90
S6	3.55

〈Note〉 ＋：tension, －：compression

4. CONCLUSIONS

We made 3-D dynamic analysis for the coupled subway-underground shopping arcade-high building system in order to evaluate the influence of earthquake behaviors of high buildings on the seismic safety of underground shopping arcade. The 3-D analytical model was made on the assumption the underground shopping arcade is located just above the subway, and two high buildings are located at the both sides of underground shopping arcade.

As the results, we could confirm that two high buildings behave not only in the same phase but also in the reverse phase. Fig. 4.1 shows the schematic concept about the influence of high building on underground shopping arcade when two buildings behave in the same phase. In this case, or in the case of same phase, it is considered that the influence will be little, because the relative displacement between the both sides of underground shopping arcade induced by the earthquake behaviors of high buildings will be little.

The schematic concepts about the influences when two buildings behave in the reverse phase are shown in Fig. 4.2 (in the mode of getting close) and Fig. 4.3 (in the mode of going apart). In these cases, it is considered that the underground shopping arcade will be affected significantly by the displacement behavior of high buildings during large earthquakes. It is considered that the dynamic compressive stresses around the underground shopping arcade will increase when the high buildings behave in the mode of getting close, and that the dynamic tensile stresses around the connecting parts between underground shopping arcade and high buildings will be increased considerable when the high buildings behave in the mode of going apart.

A seismically isolated structure, which allows opening and sliding along the contact plane, will be effective to release and reduce the dynamic tensile and shear stresses at the connecting parts between the underground shopping arcade and the high buildings.

In order to mitigate earthquake disaster in urban area, it is necessary to consider the mutual effects between the underground structures and the ground structures during large earthquake.

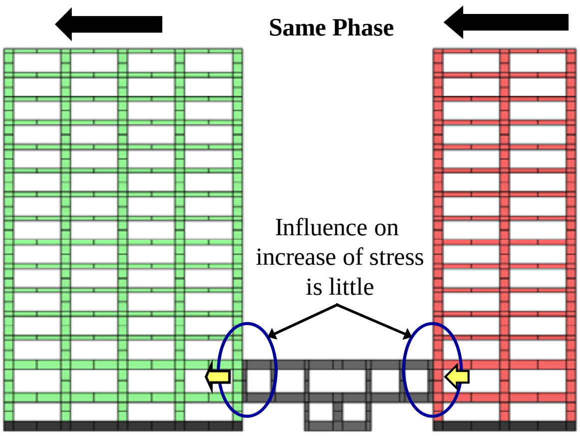


Figure 4.1. Influence of earthquake behaviours of high buildings on underground shopping arcade when two buildings behave in the same phase

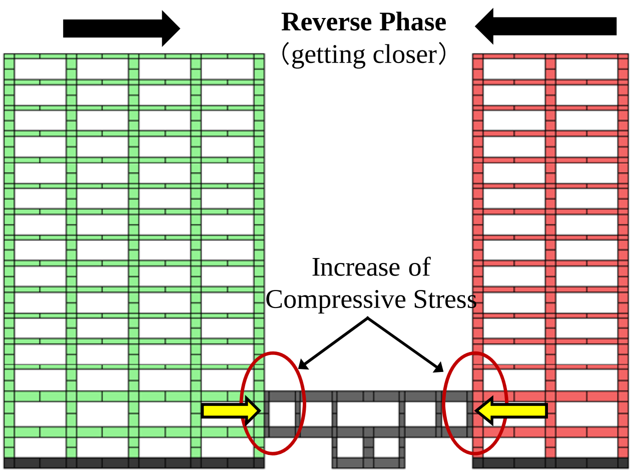


Figure 4.2. Influence of earthquake behaviours of high buildings on underground shopping arcade when two buildings behave in the reverse phase (in the mode of getting close)

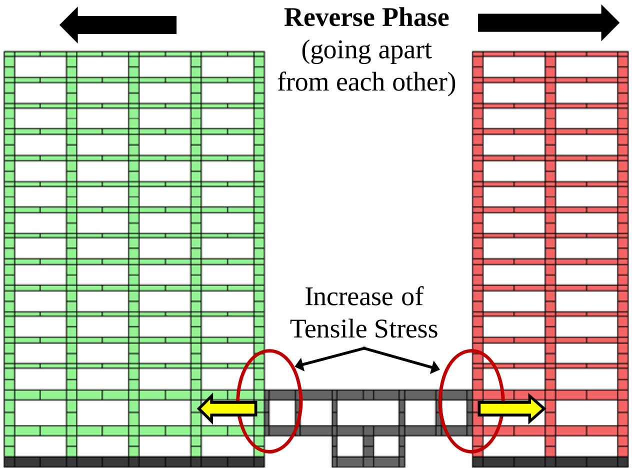


Figure 4.3. Influence of earthquake behaviours of high buildings on underground shopping arcade when two buildings behave in the reverse phase (in the mode of going apart)

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