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SEISMIC RESPONSE OF AN ISOLATION METHOD FOR CUT AND COVER TUNNEL USING POLYMER MATERIAL

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ABSTRACT :

An effective seismic retrofit for a sidewall of a cut and cover tunnel has not been established yet. We develop a new method of seismic retrofit for the cut and cover tunnel. We call this “polymer isolation method.” In this method, we insert a thin wall made of polymer material in which the wall is called “isolation wall.” The effectiveness of the proposed method is demonstrated through some numerical simulations. It is found that the proposed method depends on thickness of the covered soil over the tunnel and ratio of stiffness between soil and structure. Finally, a simple chart is proposed to represent an applicability of the polymer isolation method for convenience to design seismic retrofit of a cut and cover tunnel.

KEYWORDS: cut and cover tunnel, isolation wall, polymer material

1. INTRODUCTION

For a structure that is constructed above ground level, such as bridge pier or a viaduct column, effective methods have been already developed to improve seismic performance [Kobayashi, et. al., 2001]. On the other hand, if a seismic performance of an existent tunnel is not enough for the present standard, any effective reinforcement methods for a sidewall of a cut and cover tunnel have not been established yet. Generally, the seismic behavior of cut and cover tunnel depends on deformations of soil around the tunnel. This means that we may improve the seismic performance of the tunnel by using an isolation technique between tunnel and soil. We develop a new method for seismic retrofit for the cut and cover tunnel under a concept of isolation between the tunnel and soil: thin wall made of polymer material, whose stiffness are extremely small, is inserted between the ground and sidewall of the tunnel. We call this technique “polymer isolation method” and the inserted thin wall "isolation wall." The isolation wall reduces the seismic load conducted from ground and deformations of the tunnel. We introduce the outline of the polymer isolation method, and demonstrate the effectiveness of the proposed method.

2. MODELS FOR NUMERICAL ANALYSIS

2.1. Condition of a tunnel and ground

Figure 1 shows a cross section view of the tunnel which is dealt with in this study. The condition of the ground is also shown in Figure 1. The height is about 6m and the width is about 16m for the tunnel. The model of tunnel consists of one layer and two spans. We use two dimensional and non-linear Finite Element Method (FEM) for the numerical analysis. Figure 2 shows the schematic figure of the model for the analysis. We apply solid elements to soil and polymer material, and beam elements to the tunnel. We introduce some nonlinear characteristics into soil, polymer material and tunnel. The characteristics of soil is modeled by the modified Ramberg-Osgood model, the polymer by the hyperbolic model, and the tunnel by the tri-linear model [Murono, et. al., 2006]. The shear strength of the polymer material is about only 1/100 of that of the ground. The width of the isolation wall is 800mm and the isolation wall is inserted from ground surface to bottom level of the tunnel. The horizontal roller elements are used for the vertical boundaries of the calculation area and the viscous boundary for the horizontal boundary at bottom of the area.

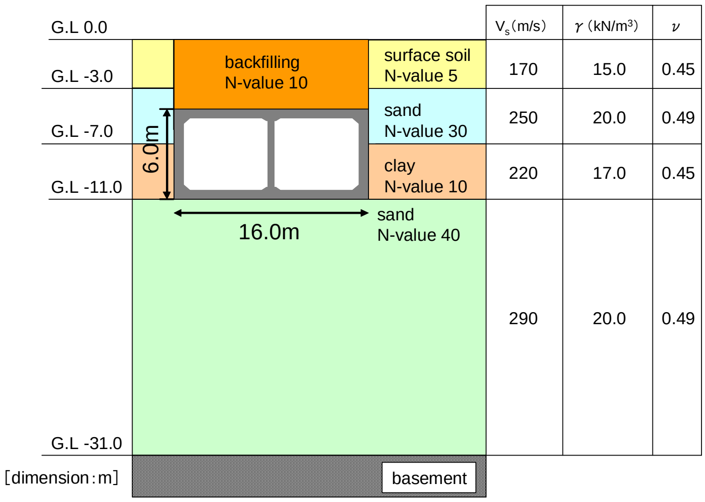


Figure 1 The condition of the ground and tunnel

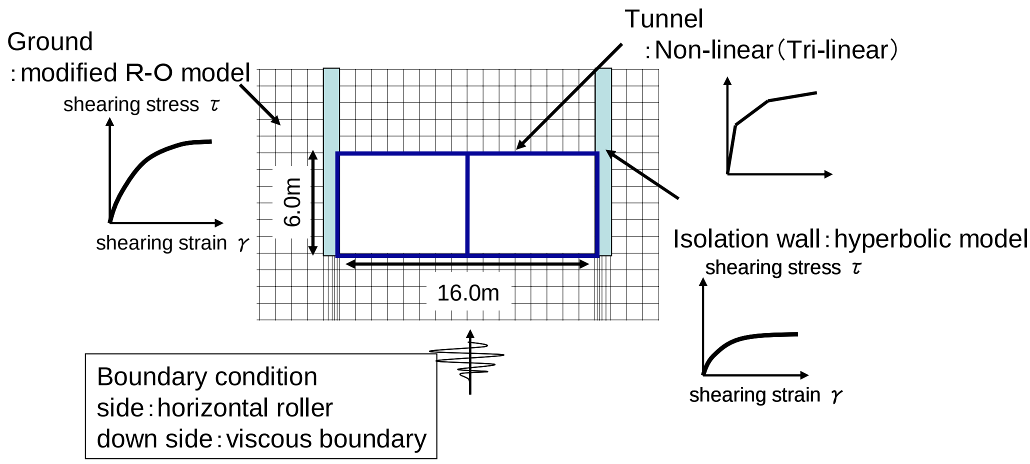


Figure 2 A model for numerical analysis

2.2. Input Seismic Motion

For the numerical analysis, we use the time history as shown in Figure 3, which is one of the seismic motions for the seismic design code for the Japanese railway structures [Railway Technical Research Institute, 1999].

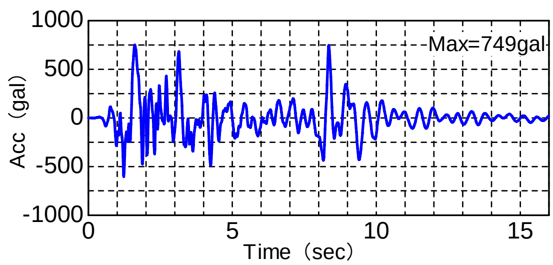


Figure 3 Input seismic wave

For the time integration in the analysis, Newmark's β method is applied (β=1/4) and the time increment of 1/1000 seconds is used. The time duration of the analysis is 16 seconds. The damping constants for soil and structure are considered as Rayleigh damping, whose value is 5%.

2.3. Conditions for Analysis

Table 1 lists the setting of some different conditions of the analyses. In each case, we examine with and without isolation wall. In case A, the thickness of the covered soil over the tunnel is 0m. In cases B and C, the tunnel is covered with soil of 5m. The stiffness of the structure of case C is different from other cases.

Table 1 Setting for the analysis

CASE	Covered soil	Stiffness of the structure	Without isolation	With isolation
A	Without	Rigid		
B	With			
C	With	Soft		

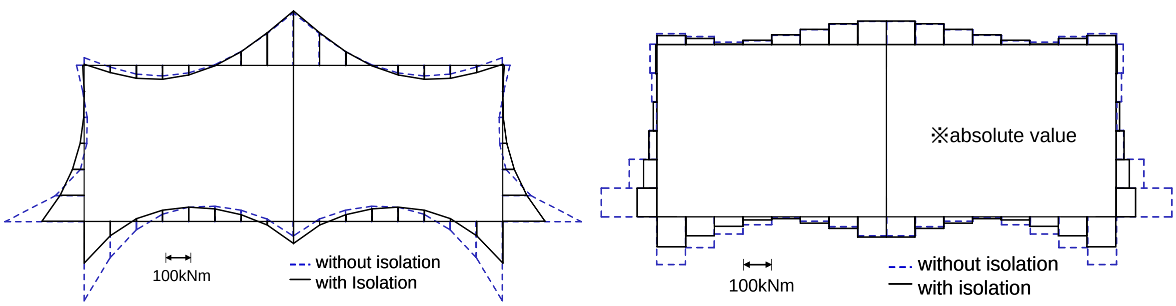
3. DISCUSSION

3.1. Initial Condition of the Section Force

The underground structure is usually stable by a balance between weight of the covered soil and/or reaction force against ground, and a soil pressure to the sidewalls. The isolation wall made of polymer material, whose stiffness is extremely small, is inserted into the outside of the tunnel. We, therefore, are apprehensive that the initial condition of the stress of ground changes by setting the isolation wall. First, to verify the safety of the tunnel, the static conditions of the section force after the isolation wall is inserted. In the analysis of the static conditions of the section forces, it is important practically to consider the progress of construction. However, we omit this, because a purpose of this study evaluates qualitatively whether the polymer isolation method works effectively or not.

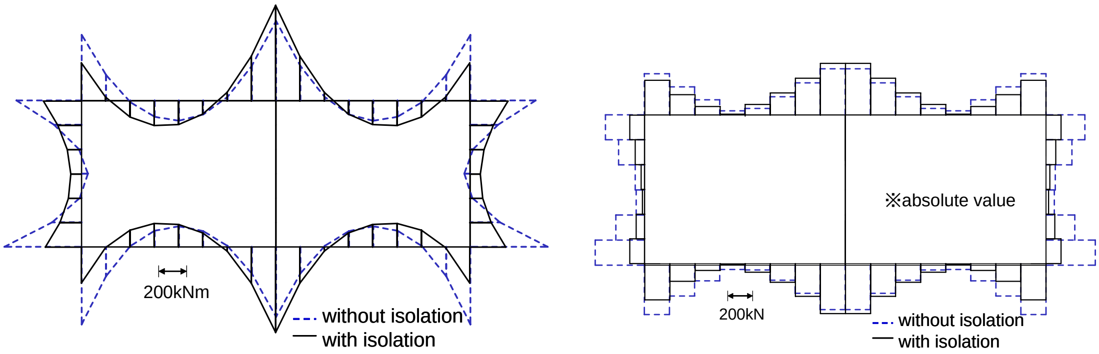
We analyze the static condition of section forces including the isolation wall. Figures 4 and 5 show section forces of the static condition for case A and B, respectively. The dashed lines denote the section forces without isolation wall, and the solid lines show the section forces with isolation wall. The results of case C are omitted because they are similar to the results of case B. From the comparison between dashed and solid lines, it is observed that the section forces are changed by inserting the isolation wall for all cases. In case A, though the section forces around the lower corner of the sidewall are reduced by the isolation wall, those around the center of lower slab are slightly increased. In case B, the section forces of sidewalls are uniformly distributed and reduced by the isolation walls, though, those around center of upper and lower slabs are increased. This comes from the covered soil over the tunnel and the distribution of the section force for upper and lower slabs are very similar.

To apply the proposed method to an existent tunnel, it is very important to check and verify whether the capacity of the shear forces is enough for the upper and lower slabs.



(a) Bending moment (b) Shear force

Figure 4 Section forces of static condition (Case A)



(a) Bending moment (b) Shear force

Figure 5 Section forces of static condition (Case B)

3.2. Effectiveness of the Polymer Isolation Method

Figure 6 shows the distribution of maximum shear forces during the earthquake ground motion for case A and B. The dashed lines show the section forces without isolation wall, and the solid lines with isolation wall. The shear forces are reduced and show less irregularity for sidewall by inserting the isolation wall. This results correspond to the distribution of the shear force for static condition.

This means that the maximum section forces during an earthquake ground motion depends on the section forces of static condition. Thus, to evaluate the effectiveness of the polymer isolation method, we introduce a kind of normalization of parameters as

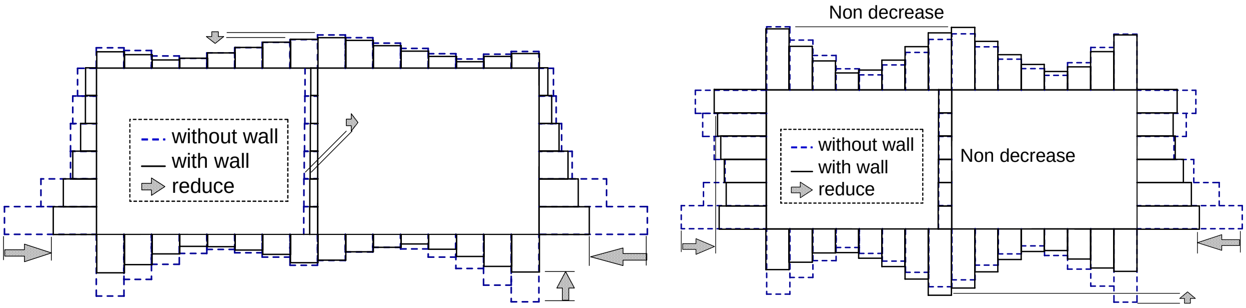
$$\alpha = \frac{(Q_{\max})_{with\_isolation} - (Q_{\mathrm{int}})_{with\_isolation}}{(Q_{\max})_{without\_isolation} - (Q_{\mathrm{int}})_{without\_isolation}}, \tag{1}$$

that is, α denotes the ratio of maximum section forces with and without the isolation wall during an earthquake ground motion. From the definition of α, we can say that the proposed method works effectively to reduce the seismic load, when $\alpha < 1$. Figure 7 shows the values of the index α for various conditions and members such as the sidewall, upper and lower slabs, and pillar.

From the comparison between cases A and B, it is noted that there is less effectiveness for larger thickness of the covered soil over the tunnel. On the other hand, it is suggested from the comparison between cases B and C that contrast of the stiffness between soil and the tunnel must play an important role in the polymer isolation method.

Key issues to evaluate effectiveness of the polymer isolation method are obtained as follows:

1) ratio of stiffness between ground and the structure, and
2) behavior of the covered soil during an earthquake ground motion



Case A Case B

Figure 6 Maximum shear forces

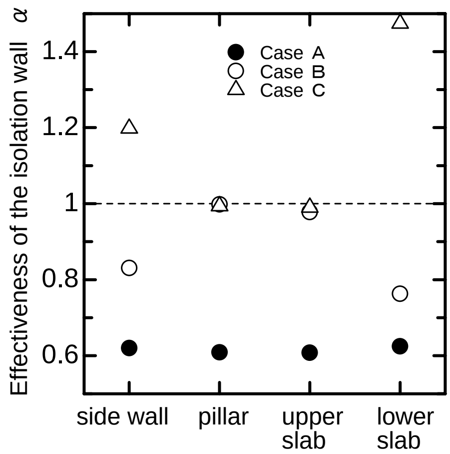


Figure 7 Effectiveness of the polymer isolation method

3.3. Different Types of Deformations

We will consider a state, when ground and the structure deformed to X direction, which is shown in Figure 8. The distribution of stress in X direction is shown in Figure 9. In this figure, compression stress is colored with warm color and tensile stress is 0 N/mm^2 as shown on blue. Figure 10 shows schematically a concept to represent the different types of the deformations of the ground during an earthquake ground motion.

From Figure 9, it is observed that the compressional stress of ground is very low around the outside of the upper-left corner of the tunnel for cases A and B, and is high around the upper-right corner. This means that the seismic load is conducted from ground to the right side of tunnel. On the other hand, the compression stress is high around left side and low around right side for case C. In this case, the ground supports the structural deformation. These two different types of the deformations come from the difference of the ratio of stiffness between soil and the tunnel.

From the above discussion, we may estimate qualitatively whether the polymer isolation method works effectively or not, using the distribution of the compression stress without the isolation wall. Furthermore, it is suggested that the ratio of stiffness can be used as a simple index to estimate the effectiveness of the polymer isolation method.

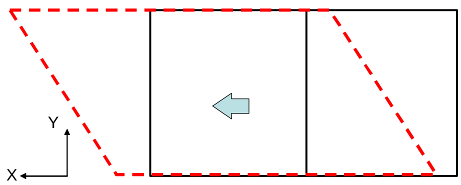
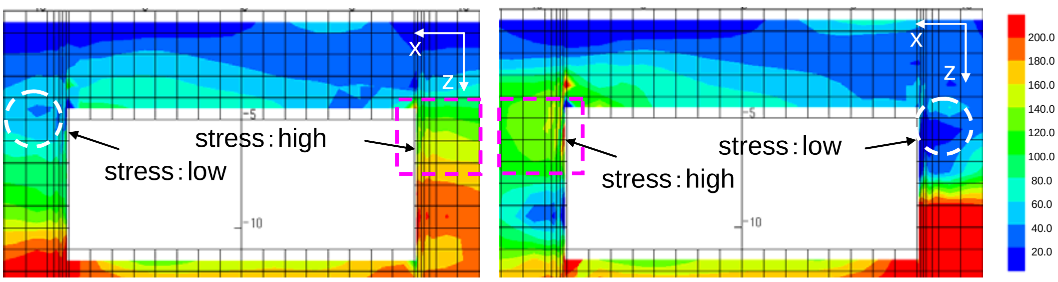


Figure 8 Structure deformed to X direction



Case B Case C

Figure 9 Compression stress of the ground

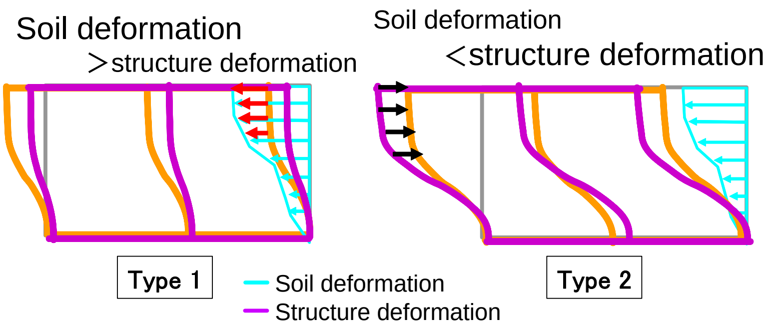


Figure 10 Different types of the deformations and their stress distribution

4. CHART TO REPRESENT APPLICABILITY OF THE POLYMER ISOLATION METHOD

To design the seismic retrofit of an existent tunnel, we have to choose and decide an appropriate method from the various possibility. For this purpose, a simple index to represent the effectiveness of the polymer isolation method must be convenient for designers. From the previous sections, it is observed that ratio of stiffness between ground and structure, and thickness of the covered soil over the tunnel are key issues.

For various values of stiffness and thickness of covered soil, the index α is calculated under the same conditions as Figures 1, 2, 3. In this calculation, beam elements of the tunnel are elastic and the thickness of the isolation wall is 450mm. The stiffness of the structure is defined from the displacement by a horizontal unit force as shown in Figure 11. From this calculation, a chart is proposed to show effectiveness of the polymer isolation method using the two parameters: ratio of stiffness and thickness of covered soil. First, we introduce an index β to represent the thickness of the covered soil over the tunnel as

$$\beta = 1.0 + H_2 / H_1 . \tag{2}$$

The parameters H_1 and H_2 are defined as shown in Figure 12. If thickness of the covered soil is 0m such as case A, β is 1.0. The values of ratio of stiffness and β are used as 1/10 to 1/1000 and 1.0 to 1.5, respectively.

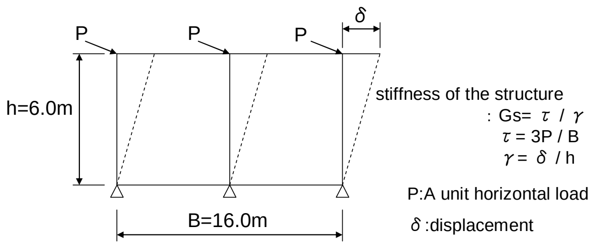


Figure 11 Schematic figure to define the stiffness of the structure

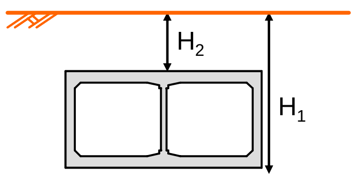


Figure 12 Parameters to define the index β

In Figure 13, the values of stiffness ratio and β used for the calculations are shown by open circles and the distribution of values of α is drawn by contour lines by using an interpolation technique. From this figure, it is observed that the qualitative properties of α mentioned in the previous section are confirmed. The upper-left corner of the chart of Figure 13, that is, large stiffness of structure and shallowly buried tunnel, corresponds to the Type 1 of Figure 10. On the other hand, the lower-right corner of the chart corresponds to the Type 2.

Thus, we can use this chart to estimate the effectiveness of the polymer isolation method: not effective for α > 1.2, unclear for 0.8 < α < 1.2, and effective for α < 0.8. This means that only two information such as the ratio of stiffness and thickness of the covered soil are needed to evaluate effectiveness of the method.

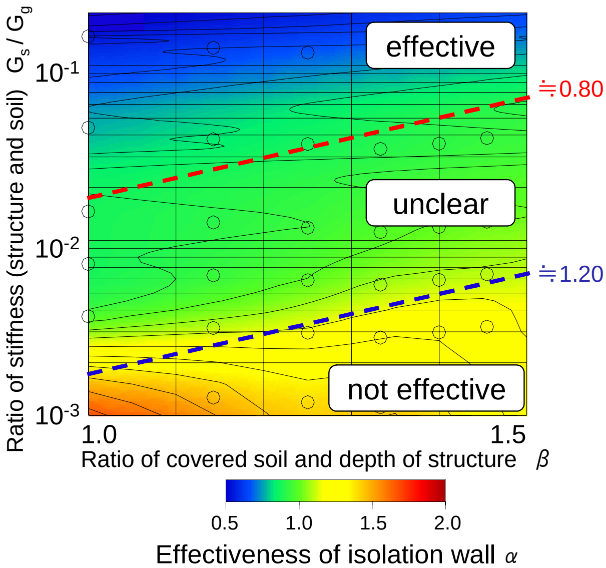


Figure 13 Chart of index α to design the seismic retrofit

5. CONCLUSION

The conclusions of this study are shown as follows:

1) When we employ the polymer isolation wall, we should verify the safety of the structure in the static condition.
2) Effectiveness of the polymer isolation method depends on thickness of the covered soil over the tunnel, and ratio of stiffness between soil and the structure.
3) A simple chart is proposed to represent an applicability of the polymer isolation method.

6. REFERENCES

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