Influence of Poisson's ratio of isolation material on seismic isolation effect for a shield-driven tunnel in the transversal direction

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1. Introduction

Tunnels are widely used in the fields of water supply, sewage, public transportation and telecommunication, and they constitute a major part of infrastructures. These underground structures follow the displacement of the surrounding ground at the time of earthquake and do not cause self-excited vibration, so it is generally said that it is not easily affected by earthquakes. However, in a place where ground condition changes sharply, such as the boundary between soft and hard ground, where ground displacement suddenly changes, large ground srain is transmitted to the tunnel and a large sectional force is generated in the tunnel.

In order to evaluate appropriately the behavior of a tunnel during an earthquake, the interaction between ground and tunnel should be treated appropriately. Therefore, the axisymmetric finite element model which proposed by Suzuki1) is used to analyze the seismic response of a seismically isolated tunnel in this paper.

The seismic isolation developed for underground structures is a structure that can sharply reduce the effect of earthquakes by forming a soft layer around the outer periphery of an underground structure to insulate the underground structure from deformation of its peripheral ground. Therefore, the isolation material need a certain degree of compressibility to absorb the ground deformation. In this case, it is very important to study the influence of Poisson's ratio of isolation layer on seismic isolation effect.

2. Simulation model and parameters

In order to study the influence of Poisson's ratio on seismic isolation effect, seismic response analyses are conducted on cases where seismic isolation layers with different values of Poisson's ratio are applied to a shield-driven tunnel burried in irregularly bounded surface soil deposits and results of these analyses are compared in this paper. A shield-driven tunnel with outer diameter of 5.1 m made of reinforced concrete segments with a thickness of 25cm constructed in the place where ground conditions change sharply shown in Fig. 1 is analyzed. Because the outer diameter of the shield machine was 5.2m, the thickness of the isolation layer was set at 10cm that equals the thickness of the tail void. The irregular surface deposit consists of hard ground with shear wave velocity Vs=400m/s and soft ground with Vs=100m/s. The seismic isolation layer was decided to apply over 80 m so as to cross the ground boundary (Fig. 2). The irregular ground and tunnel were modeled by axisymmetric FEM model (Analysis code: EASIT)[2].

The input earthquake motion for Level 2 earthquake motion were chosen from among standard waves used for seismic design of road bridges. Waves obtained by performing amplitude compension of EW component at JR Takatori Station were used as Type II earthquake motion for category II ground, which is a motion originated from a near-fault earthquake (Fig. 7). The one-dimensional seismic response analysis of the surface ground was performed by the substitute structure approach: considering these input earthquake motions to be waves observed at the outcrop of free rock, reducing the amplitude by 50%, and inputting the resulting waves from the top of the bedrock layer. The strain dependency of the ground used for the analysis was obtain from a mean strain dependency evaluation equation for typical ground.

Ground acceleration at the time when the maximum value of the total of the shear strain of ground from the bedrock to the surface is obtained by one-dimensional seismic response analysis of the surface deposit based on multiple reflection theory. Based on the ground response seismic intensity method which gives the ground inertial force (mass × acceleration) to each node of the analytical model, the seismic response of the tunnel by applying external force was analyzed.

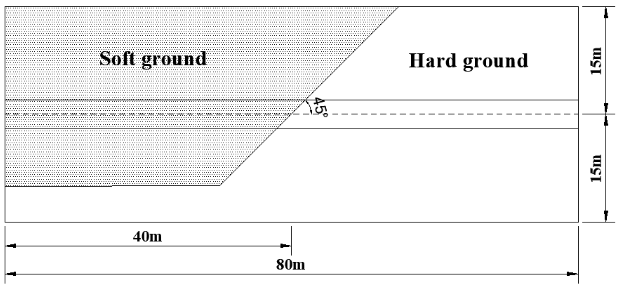

Fig. 1 Schematic diagram of a tunnel for numerical simulation

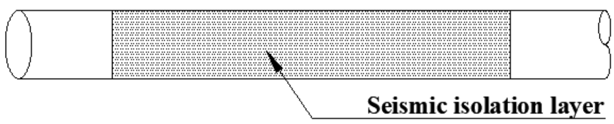

Fig. 2 Tunnel seismic isolation layer

3. Poisson's ratio affecting the isolation layer effect

Key word: shield tunnel, isolation layer, Poisson's ratio, transversal seismic response
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Assuming that Possion's ratio of the isolation material may be affecting the seismic isolation effect, since a seismic isolation layer is deformed greatly when the tunnel body is deformed in the tunnel transversal direction. The Possion's ratio of isolation material ranges from 0.1 to 0.48. The shear modulus ratio of an isolation material to a ground is 1/100.

Fig. 3 shows that the tunnel axis strain decrease, the smaller the Possion's ratio of the materials becomes, and the effect of the axial strain reduction is considerable when the Possion's ratio becomes 0.3. When the Poisson's ratio of an isolation material is 0.3, axis strain of the tunnel was reduced to 1/3 at the maximum value generation position of the strain, and a large axial strain reduction was achieved.

When the Poisson's ratio is less than 0.3, the reduction of the axial strain of the tunnel is very small with the decrease of the Poisson's ratio. Because when the Poisson's ratio is less than 0.3, the reduction of isolation layer spring stiffness is very small.

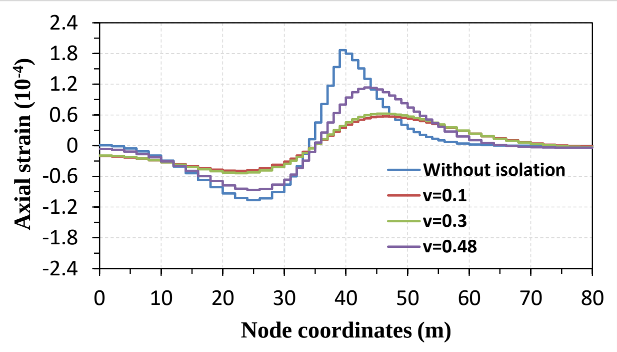

Fig. 3 Poisson's ratio of the isolation material on seismic isolation effect

4. The mechanism of Poisson's ratio affecting the seismic isolation effect

The interaction between the ground and the tunnel with seismic isolation layer which is modelled by spring. The spring stiffness can be calculated by the formula (1) proposed by Matsubara[2].

$$K = \frac{8\pi \cdot G(3-4v)(1-v)}{(3-4v)^2 \ln(R/r) - \left[(R/r)^2 - 1\right] / \left[(R/r)^2 + 1\right]} \quad (1)$$

Where:

K: spring constant of the unit length isolation layer in the tunnel transversal direction

G: shear modulus of the seismic isolation layer

L: length of the seismic isolation layer

v: Possion's ratio of the seismic isolation layer

R: 1/2 of the external diameter of the seismic isolation layer

r: 1/2 of the external diameter of the tunnel

The stiffness of the isolation layer spring of unit length isolation layer changes with the Poisson's ratio as shown in Fig.4. When Poisson's ratio is less than 0.3, the spring stiffness decreases very little. Therefore, when the Poisson's ratio is less than 0.3, the reduction of the axial strain of the tunnel is very small with the decrease of the Poisson's ratio.

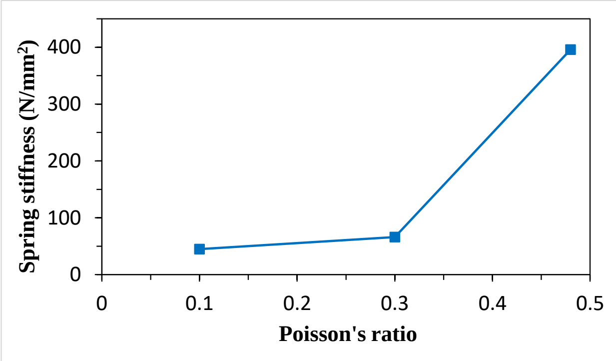

Fig. 4 Effect of Poisson's ratio on the spring stiffness of unit length isolation layer

5. Summary

In this paper, through numerical analyses of seismically isolated shield-driven tunnel in the transversal direction, the influence of Poisson's ratio of the isolation material on seismic isolation effect was studied. Conclusions obtained in this study are as follows:

(1) It was shown that the isolation layer reduces the bending deformation along the tunnel longitudinal direction by absorbing the ground deformation.

(2) The lower the Poisson's ratio of the isolation material is, the higher the seismic isolation effect can be obtained. There is a threshold, however, when the Poisson's ratio of the isolation layer is lower than the threshold, the isolation effect of seismic isolation does not increase. Under the conditions described in this paper, the threshold value of the Poisson's ratio was 0.3.

(3) Due to the fact that Poisson's ratio of isolation material constituting the outer periphery of a tunnel affects the apparent spring stiffness in the transversal direction, the seismic isolation effect depends on Poisson's ratio of isolation material even with the same Young`s modulus.

References

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