STUDY OF TUNNEL BEHAVIOUR LOCATED IN DIFFERENT SOIL CONDITION UNDER TRANSVERSAL SEISMIC LOAD

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1. INTRODUCTION

Aside from being assumed to withstand earthquakes for a long time, there are many cases in recent years which show that tunnel, as an underground structure, can be damaged by earthquakes. The 2016 Kumamoto Earthquake triggered numerous damages to the Tawarayama Tunnel in Kumamoto Prefecture, Japan. There, Zhang et al. (2018)[1)] observed an interesting phenomenon that the ring of the tunnel crack appeared to have a special geological condition in which dense Andesite and crushed Andesite in tilt alternately. The schematic condition is shown in **Fig. 1**. This soil condition may lead to transverse fracture and dislocation at the interface between the soft and hard rock.

Zhang et al. (2018)[1)] stated that longitudinal analysis should be considered when designing. However, analysis in transversal direction related with internal force of the tunnel cross-section needs to be conducted as the first step, to analyze the effect of different soil conditions to the cross-section of the tunnel structure under seismic load. Therefore, numerical analysis for several cases were conducted. The cases were based on the ratio/combination of hard and soft soil.

The main purpose of this study is to understand the tunnel structure behaviour in different soil condition under transversal seismic load.

2. ANALYSIS

2.1 Numerical Model

Two-dimensional FEM analysis was conducted using DBLEAVES[2)]. The type of tunnel used in the analysis is a mountainous tunnel with a two-lane road (medium section) with lining thickness of 30 cm for arch and sidewall and 40 cm for invert, referring to the Standard Specifications for Tunneling-2006: Mountain Tunnels[3)]. The lining itself is concrete without any reinforcement.

To simplify the analysis, soil used is sandy soil with the assumption of N-SPT 30 for hard soil and N-SPT 15 for soft soil. Soil parameters are depicted in **Table 1**. Mechanical behavior of soil is modeled as elastic model.

The study focused on the final construction condition of the tunnel. The numerical model of the tunnel structure and soil along as its boundary is shown in the **Fig. 2.** Equal displacement boundary sets side boundaries in the same elevation to have identic displacement. The layer number 1-6 in **Fig. 2** indicates the soil layer. 7 cases were analysed according to hard and soft soil combination ratio, as stated in **Table 2.**

In the dynamic analysis, simple seismic wave, sinusoidal wave is used due to analysis simplification. The seismic wave is applied in transversal direction of the tunnel, along with its horizontal cross section. The wave has an acceleration amplitude of 300 gal and 25 secs duration (2501 step) (**Fig. 3**). The time interval of calculation was 0.001 second and the time integration was based on the Newmark-β method ($\beta = 1/4$, $\gamma = 1/2$).

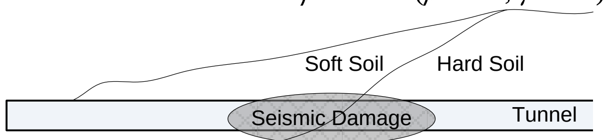

Fig. 1 Schematic of Seismic Damage in Soft and Hard Soil Interface (from Shen, et al., 2014)

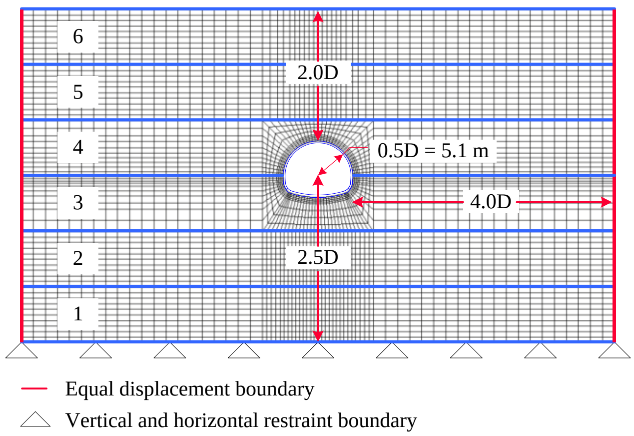

Fig. 2 Analysis mesh

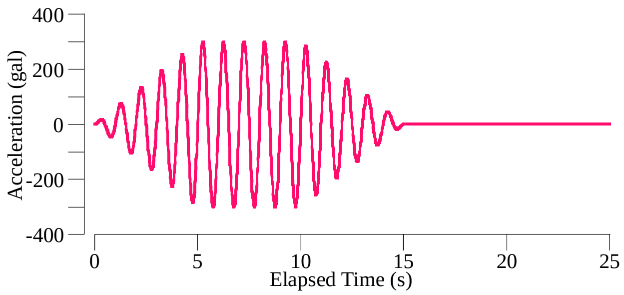

Fig. 3 Seismic Wave

Table 1 Soil Parameter

N-SPT		30	15
Young's modulus	[kPa]	84000	42000
Poisson ratio	-	0.294	0.324
Density	[g/cm³]	1.806	1.728
K0	-	0.417	0.479

Table 2 Analysis Case

Case No.	1	2	3	4	5	6	7
Hard layer	-	1	1-2	1-3	1-4	1-5	1-6
Soft layer	1-6	2-6	3-6	4-6	5-6	6	-

2.2 Result and Analysis

In the analysis results, step 575 (5.75 secs) is chosen to discuss the internal force of the tunnel because in this step, middle crown of tunnel has the biggest

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displacement in x direction. For soft soil dominant, Case 1-3, as shown in **Fig. 4a**, the bending moment of tunnel is similar. This is also applied in hard soil dominant, Case 5-7 (**Fig. 4b**). This means that there is not much difference observed in tunnel behaviour when soft soil is dominant or hard soil dominant for the surrounding ground. **Fig. 4c** and **Fig. 5** compares Case 1, Case 4 and Case 7. In the invert (270°), Case 1 shows the biggest bending moment, while Case 4 and Case 7 have similar bending moment. On the other hand, the arch part of tunnel in Case 4 has the similar tendency as Case 1. However, in the spring-line (0°) area, Case 4 shifts from being similar to Case 1 in the arch part then becomes similar to Case 7 in lower part. In overall part of tunnel, Case 1 gives the biggest bending moment to tunnel in the corner of the sidewall and invert. Furthermore, if only the arch part is considered, tunnel shoulder has the critical condition due to Case 4.

The displacement of the tunnel is also important to understand tunnel behaviour, especially during earthquake. It is better to have uniform displacement in all the tunnel parts. Referring to **Fig. 6**, in the crown (Node 4004); Case 7 has the biggest displacement in x-direction during the seismic period. Case 1 and Case 4 has similar displacement, since the crown is located in the soft soil condition for both cases. **Fig. 7** shows the displacement difference between top and bottom part of the tunnel. Case 4 gives the biggest difference. Case 1 and Case 7 have similar displacement difference between top and bottom part.

3. CONCLUSION

In this study, the largest bending moment in lining is still dominated by soft soil condition, Case 1-3. Even though the ratio of soil condition is different, the behaviour of tunnel in soft soil dominant or hard soil dominant is similar to each other. This means that transversal seismic wave in interface soil condition is not the main reason for the biggest bending moment in tunnel lining. However, displacement difference will be more dangerous if the soil has bigger bearing capacity difference. For future study, analysis of tunnels located in different soil condition needs to be conduct again, but with different seismic wave direction: vertical and longitudinal, to see which of the two directions gives the largest bending moment to the tunnel structure. Three-dimensional analysis is strongly recommended.

Reference

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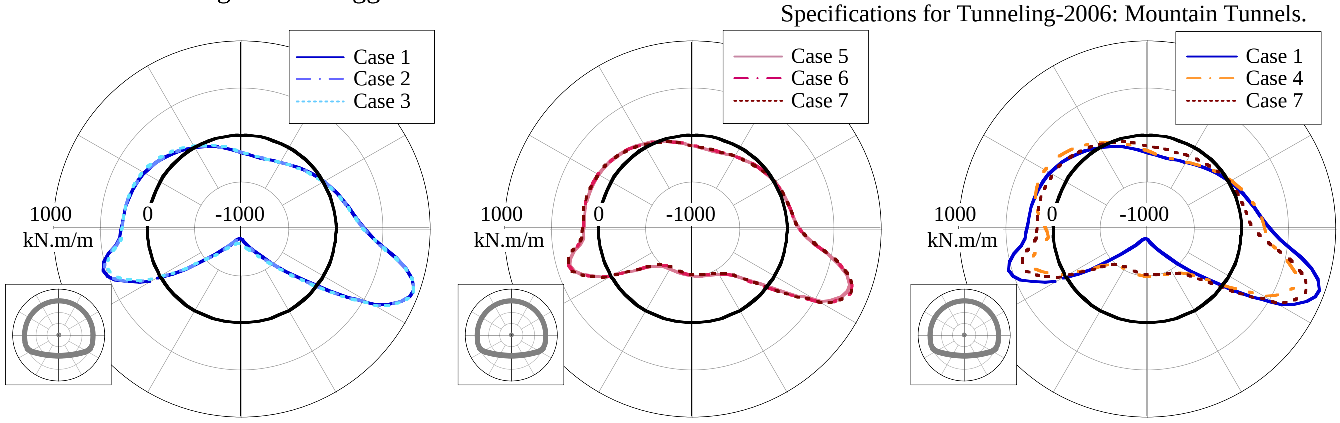

a) Case 1-3 b) Case 5-7 c) Case 1,4,7

Fig. 4 Bending Moment of Tunnel Lining in Step 575 (5.75 secs)

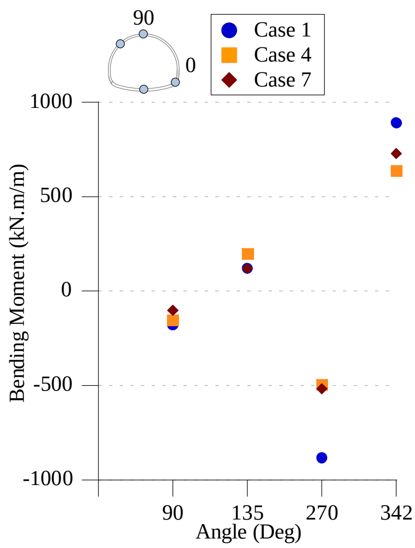

Fig. 5 Bending Moment of Case 1, 4 and 7

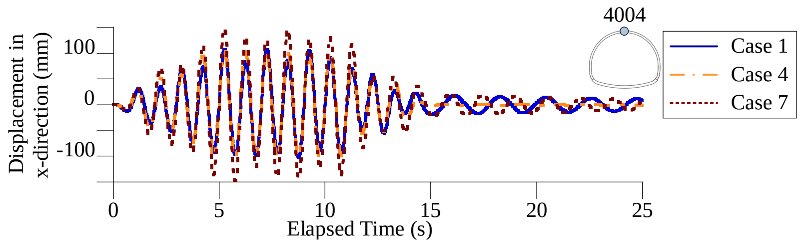

Fig. 6 Displacement History of Node 4004 in X-direction

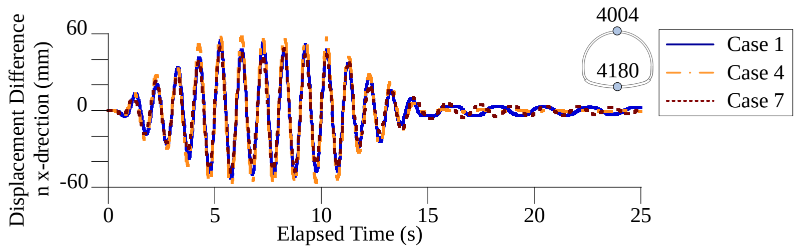

Fig. 7 Displacement Difference of Node 4004 and Node 4180 in X-direction