Session 1

Seismic Analysis of the Cross Section of Shield Tunnels Lying between Soft Alluvial and Hard Diluvial Stratum Utilizing the Seismic Deformation Method

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1. Introduction

Currently, the design guidelines(1) utilize the seismic deformation method for the aseismic design of shield tunnels in the transverse direction. The case of the cross section of the tunnel lying across an interface between soft alluvial and hard diluvial stratum is usually encountered, and an equivalent shear modulus can be applied. However, if the shear vibration of the two layers are quite different, the equivalent model may not give accurate response. The purpose of this research is to develop a new two-dimensional finite element elastic model that can effectively take account of such case.

2. Analytical Model of Tunnel-Ground System & Analysis Method

The tunnel-ground system illustrated in Fig.1 is divided into a number of nodes along the tunnel lining which consists of two-nodes curved beam elements. The interaction effect between the tunnel lining and the surrounding ground is represented by two-nodes coupled-type spring elements. Seismic forces are the product of the ground displacements and the interaction spring stiffnesses applied to the system through the end of the interaction springs, and the ground shear stresses applied directly on the tunnel nodes. Based on the theory of mode superposition and the utilization of Fourier expansion and Bessel functions, the input seismic forces can be formulated for each mode of vibration. The response (system displacements) to each mode of vibration is determined, from which the forces in the tunnel elements can be calculated. The total forces in any section are equal to the summation of those of all modes of vibration.

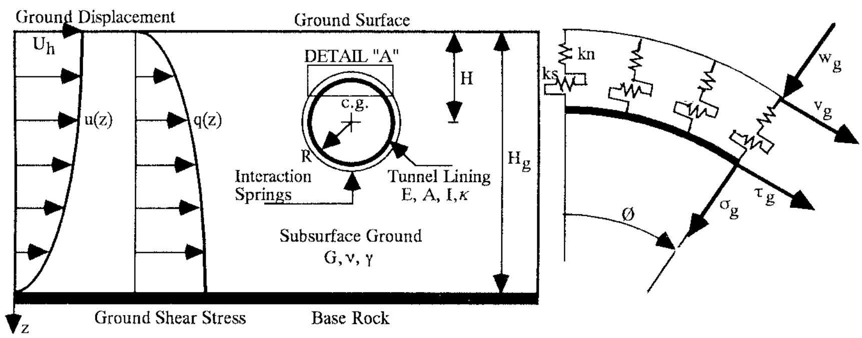

Fig.1 Tunnel-Ground system and seismic forces

3. Interaction Spring Constants

The interaction springs constants K_n and K_n' are expressed in Fourier series as follows(1) :

$$K_n = C_n \cdot (2G/R) \quad , \quad K_n' = C_n' \cdot (2G/R) \qquad \cdots\cdots\cdots \text{(1a)}$$

$$C_0 = 1 \quad , \quad C_1 = 2 \quad \text{and} \quad C_{(n\geq 2)} = [2n + 1 - 2\nu(n+1)] \,/\, (3-4\nu) \qquad \cdots\cdots\cdots \text{(1b)}$$

$$C_0' = 0 \quad , \quad C_1' = 0 \quad \text{and} \quad C_{(n\geq 2)}' = [n + 2 - 2\nu(n+1)] \,/\, (3-4\nu) \qquad \cdots\cdots\cdots \text{(1c)}$$

4. Numerical Analysis

The tunnel shown in Fig.2 is analyzed by the proposed method. Various rigidity ratio are considered as shown in Table1. The equivalent shear modulus and the maximum horizontal ground displacement are determined as follows(1),(2) :

$$Gs_{eq} = \gamma_{eq} V_{eq}^2 / 9.8 \ \text{(tf-m units)} \quad , \quad U_h = 1/\pi^2 \cdot T_s \cdot S_V \qquad \cdots\cdots\cdots \text{(2a)}$$

$$\gamma_{eq} = \sum \gamma_i H_i / H_g \quad , \quad V_{eq} = 5 H_g / T_s \quad , \quad T_s = 5 \sum H_i / Vs_i \qquad \cdots\cdots\cdots \text{(2b)}$$

where T_S is the fundamental period of vibration of the subsurface ground and S_V is a design velocity response spectrum at the design base rock. Its maximum value is 0.25 m/s for *Level 1* earthquakes for T_S is more than or equal one second. The results are shown in Figs.3 to 5.

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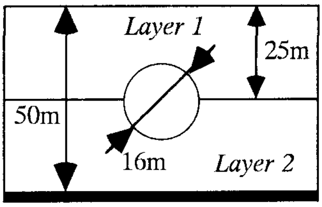

Fig.2 Case Analyzed

Table 1 Equivalent rigidity & ground displacement for various rigidity ratios

Gs_2/Gs_1	1.0	1.5	2.0	2.5	3.0	3.5	4.0
Geq	2351	2850	3227	3529	3780	3994	4180
U_h	0.0528	0.0479	0.045	0.0431	0.0416	0.0405	0.0396
$\gamma=1.6t/m^3$ $\nu=0.45$ $Vs_1=120m/s$ $Gs_1=2351tf/m^2$ t=0.8m							

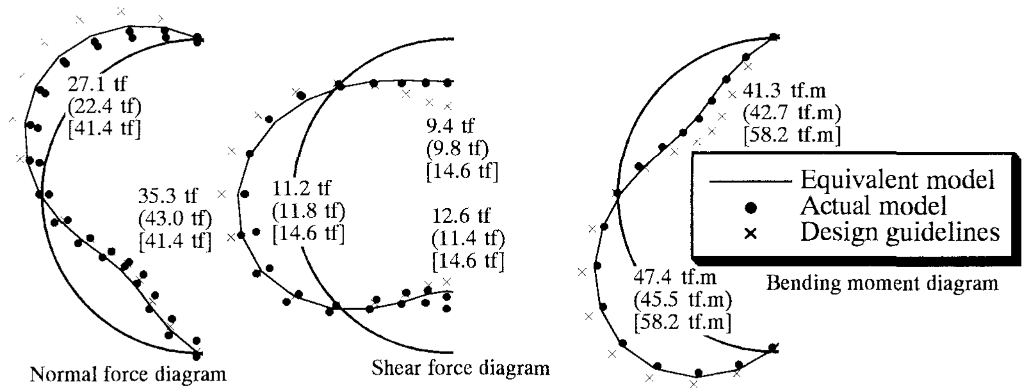

Fig.3 Response of the tunnel to rigidity ratio of 2.0

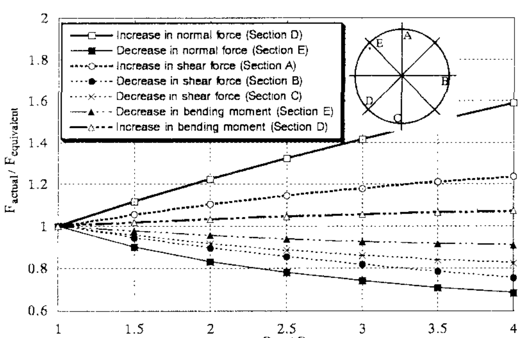

Fig.4 Response of the tunnel to various rigidity ratios

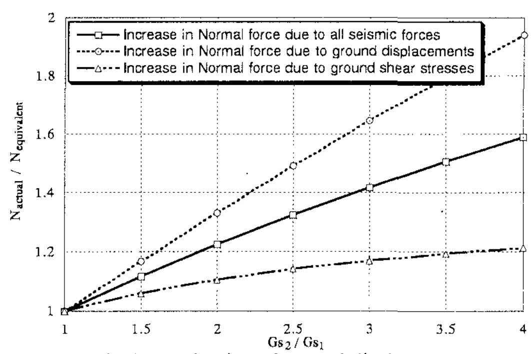

Fig.5 Contribution of ground displacements & shear stresses on normal force response

The results of the actual model show different response than that of the equivalent model. The maximum normal force in the upper half of the tunnel (section E) decrease while that of the lower half (section D) highly increase. The increase in the normal force is almost linearly related to the increase in rigidity ratio of the two layers. On the contrary, the maximum bending moment in the upper half of the tunnel (section E) slightly increase while that of the lower half (section D) decrease. The shear forces in section A increase while those in sections B and C decrease. The design guidelines is conservative for the bending moment and shear force, while it underestimates the normal force. The ground shear stresses have a little influence on the increase of the tunnel forces. This is because the external forces due to ground shear stresses are applied directly to the tunnel nodes, and not to the interaction springs. On the other hand, the influence of the ground displacements is mainly dependent on the rigidity ratio of the two layers.

References

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