

BEHAVIOR OF SEGMENTAL TUNNEL LININGS UNDER THE IMPACT OF EARTHQUAKES: A CASE STUDY FROM THE TUNNEL OF HANOI METRO SYSTEM

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ABSTRACT: The current metro systems have become an important part of the public transport system in major cities around the world. With the development of construction technology as well as technical requirements, the segmental tunnel lining has become the main lining used protective for tunnels. The main effect of segmental tunnel lining when it is used for tunnels that is ability strengthened stability of tunnels under the impact of earthquakes. This paper presents methods for calculating to effects of earthquakes on tunnels lining in two cases: tunnel continuous lining and segmental tunnel lining by identifying internal forces present on tunnels lining and the deformation of tunnels lining. Based on results obtained, analysis the effect of the joints for segmental tunnel lining under seismic loads and the effect of the rotation stiffness of joints to the segmental tunnel lining when have got the impact of earthquakes to the tunnel. This paper used parameters of the tunnel in Hanoi metro system as a case study.

Keywords: segmental tunnel lining, earthquake, joint, lining deformation.

1. INTRODUCTION

The metro tunnel system is considered to be the primary solution for satisfying traffic needs. However, when design and construction of tunnels in the metro system the impact of earthquakes to tunnels this needs to be resolved. At present, the segmental tunnel lining is used extensively for tunnels in the metro system. This is lining that could minimize the impact of an earthquake to a tunnel. There are many methods of calculating for tunnels lining under the impact of the earthquake. With the tunnel continuous lining, calculation methods for the tunnel lining continuous of Wang [1], Pezien & Wu [2] were built and given. With the segmental tunnel lining, calculation methods for the tunnel lining able to be divided into two groups of methods: Indirect methods and direct methods. Indirect methods-the tunnel segmental lining as be an equivalent the tunnel lining continuously. These methods of calculating in this group can be taken to be methods [3]: method of Wood (1975), method of Liu and Hou (1991), method of Lee and Ge (2001) Direct method groups include Takano (2000), Lee et al. (2002), Bloom (2002), Naggar and Hinchberger [2008]). Indirect methods have the advantage of being simple, easy to calculate, giving fast results, but there are disadvantages such as: do not accurately reflect the effect of joints in the tunnel lining, don't update change for parameters of joints in the lining as the position of joints, the rotation stiffness of joints... In this study, to calculate of the case for the tunnel in Hanoi system metro, use Wang's analysis method and Penzien's analysis method to calculate the tunnel continuous

lining under the impact of the earthquake, followed by the use numerical methods: using Abaqus software to build the tunnel model with the tunnel continuous lining, calculating internal forces in lining under the influence of earthquakes; used HRM method - using Matlab software to calculate for tunnel lining under the impact of earthquakes in two cases, tunnel continuous lining and segmental tunnel lining. Then, perform the calculation of the impact of the earthquake on the segmental tunnel lining when changing properties of rotational stiffness of joints, based on the results obtained, compared and given comment about the effect of rotation stiffness joints in the segmental tunnel lining under the impact of earthquakes.

2. CHARACTERISTICS OF TUNNEL IN HANOI METRO AND PARAMETERS OF EARTHQUAKE IN CENTRE HANOI

The tunnel in Hanoi metro system is located at depth $H = 20\text{m}$, diameter $D = 6.3\text{ m}$ [4], cross section of tunnel is round, the parameters of the tunnel lining: Young's modulus $E = 35500\text{ MPa}$; Poisson's ratio $\nu = 0.15$; tunnel lining thickness $t = 0.3\text{ m}$ [5]. Hanoi is located in an area affected by two faults: Red River and Lai Chau - Dien Bien - Son La. Parameters of largest earthquake that can occur in Hanoi: maximum magnitude of $M_w = 6.5$ Richter, the distance from epicenter of the earthquake to center of Hanoi of about 20 to 50 km, the peak acceleration of $a_{\text{max}} = 0.2g$ [4].

Table 1 Parameters of Layers Soil in Hanoi Centre [4]

| Number of soil layers | Elastic module, E , MPa | Poisson's ratio, μ | Thickness of layer (h), m | Measured SPT blow count, N | Density of the soil, ρ , g/cm ³ |
|-----------------------|---------------------------|------------------------|---------------------------|----------------------------|---|
| 1 | 9.25 | 0.41 | 4.6 | 2 | 1.75 |
| 2 | 7.68 | 0.38 | 1.1 | 1 | 1.76 |
| 3 | 15.3 | 0.35 | 11.8 | 3 | 1.81 |
| 4 | 35.02 | 0.33 | 12.5 | 7 | 1.78 |
| 5 | 53.9 | 0.32 | 11.0 | 10 | 1.83 |
| 6 | 65 | 0.3 | 7.0 | 12 | 1.86 |

3. THE INFLUENCE OF JOINTS AND ROTATION STIFFNESS JOINT

3.1 Influence of Segmental Joints

At present, the segmental lining is widely used for tunnels in the metro system, especially tunnels in the metro system were built in areas affected by earthquakes. The reason of the segmental lining has been used for a tunnel in a metro system that is the segmental lining is more resistant to the effects of earthquakes due to its deformability than the lining continuous. Use to equivalent method, is consider the segmental lining of the tunnel as the continuous lining but under the influence of the joints in the lining, the rigidity of the segmental lining has been reduced significantly compared to the corresponding the tunnel lining continuously with a reduced rigidity by applying a reduction factor [3,6]:

$$\eta = \frac{(EI)_{eq}}{EI} \quad (1)$$

Where $(EI)_{eq}$ is the bending stiffness of the segmental lining and EI is the bending stiffness of the continuous lining.

Equivalent methods for the tunnel segmental lining are considered to be easy to use. However, they have disadvantages: according to these methods, the internal forces produced in the joints is not different with the internal forces in other locations. Second, there is no change in the rotation stiffness of the joint in a ring - this is not true in practice. For above reasons, the method of direct presence of joints in the lining of the tunnel is recommended be used. Another group of calculation methods for fractional tunnel lining, which is the group of direct computation methods. In this group of methods, the joints were shown directly in the tunnel segment lining and are simulated by the three main properties of the joint: the rotational stiffness, the axial stiffness and the radial stiffness.

3.2 Influence of Rotation Stiffness at Joint

In the tunnel segmental lining, segmental joints are considered elastic beams and it has the stiffness characteristics that are affected by rotational stiffness K_{RO} , axial (normal) stiffness K_A and radial (shear) stiffness K_R . The K_{RO} value is the bending moment-per-unit length required to develop a unit rotation angle along the joints of the tunnel assembled segments. According to studies by the authors, the effects of K_A and K_R can be ignored when calculating the effect of joints in the tunnel segmental lining.

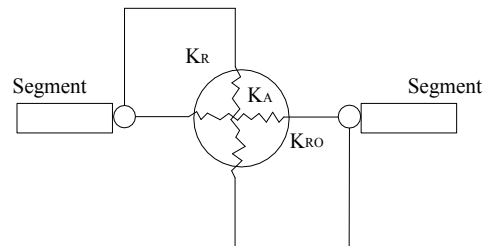


Fig. 1 Types of the stiffness of joints [3]

In 2001s, Lee et al [7] given the rotational stiffness ratio: $\lambda = K_{RO} / E_l I_l$ (2)

This is the ratio representing the relationship between the reduction factor of the bending rigidity (η) and the joint stiffness, this ratio showed the relative joint stiffness of the lining segment bending stiffness. A calculation length, l , of 1 m is usually taken to present a typical unit lining segment length, get value from 0.25 to 1.5 - Naggat et al. (2008) [3, 6, 8].

In this paper, nonlinear behavior was adopted to simulate the segmental joint behavior. The rotational stiffness values during the analysis process that were continuously updated. According to Jensen's formula [3, 6], the rotation stiffness of the joint K_{RO} is determined in stages during work of the joint:

Closed of joint

$$K_{RO} = \frac{Wt_j^2 E_s}{12} \quad (3)$$

Opened joint

$$K_{RO} = \frac{9Wt_j E_s M \left(\frac{2M}{Nt_j} - 1\right)^2}{8N} \quad (4)$$

Where M – Bending moment present in the joint, kNm/m. K_{RO} – rotation stiffness, kN.m/rad. θ - rotation of joint, degree. N - normal forces, kN. W - width of the longitudinal joint (segment width), m. E_s - Young's modulus of the lining, kN/m². t_j - height of the contact in the longitudinal joint, m.

4. CALCULATION METHODS

4.1 Wang's Method

Wang [1, 3, 5, 9] has been probably the first person to propose calculation method for a tunnel under the influence of earthquakes. In 1993, Wang has given calculations of internal forces on the tunnel lining, which were influenced by the earthquake. With his method, Wang has formulated tunneling formulas in two cases: full slip at the soil-tunnel lining and no-slip at the soil – lining tunnels.

4.2 Penzien's Method

Penzien and others authors [2, 3, 5, 9] have come up with a method of calculating the internal force that appeared on the tunnel lining under the impact of earthquakes in 1998 and improved this calculation method in 2000 s. In Penzien's method, there are also two cases: full slip at the soil-tunnel lining and no-slip at the soil – lining tunnel's.

4.3 2D Numerical Method

The 2D numerical model was used in this paper. This study used the Abaqus Simular software. The model of a tunnel with tunnel lining continuous was building [5, 9]. The tunnel has got parameters as in section 2.1 wrote. Note, in the model generated by this 2D numerical model, two spatial regions were created. Zone 1 has got the tunnel and the soil environment surrounding the tunnel. Zone 2 is an area, where is built to cause: that model so has not wave reflection phenomenon when the model is affected by earthquakes, all elements in zone 2 are elements of an infinite element. In this method, hasn't effect of gravity and underground water. In process working of model, has 3 phases: the first phase - the setup of the model, assignment of the plane strain boundary conditions, the second phase - build of the tunnel lining with parameters of soil layer, assigning the tunnel lining with layers soil by link conditions, set boundary conditions such as: the

pressure in the boundary of model, assign the acceleration shifts of the earthquake to the mode, the third phase - Results obtained of the model. The model used data of El Centro earthquake [8, 9] (with parameters of the El Centro earthquake almost identical to parameters of the strongest earthquake that can occur in the Hanoi).

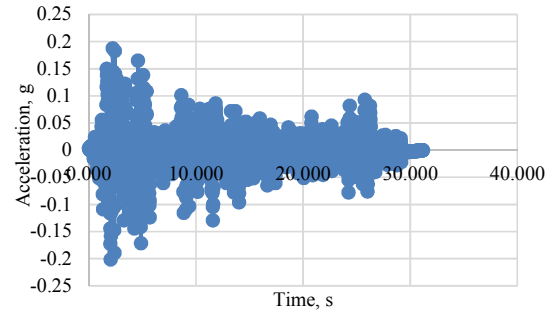


Fig. 2 Data from El Centro earthquake [5, 9]

4.4 HRM Method

Hyperstatic reaction method (HRM method) is a numerical method. This is the method used to calculate the reaction of the tunnel lining under the influence of the load. In this method, the interaction between the lining and the soil surrounding the tunnel is reflected through independent "Winkler" type springs.

In the method HRM [3, 5, 9, 10], the tunnel lining is split into a finite number of linear sub-domains-elements. Those elements are connected with the external environment and different elements through stiffnesses these are distributed over the nodes. Mono-dimensional elements that are able to develop bending moments, axial forces and shear forces. The beam element "i" is defined by two limit nodes, with the distance between two nodes being the length of the element. Main parameters of the element include the inertia modulus J and area A of the transversal section, the elastic modulus E of the constituent material. The tunnel lining with the surrounding soil environment in the following ways: through the normal and tangential springs connected to the nodes of the tunnel lining and through applied active loads. The undefined parameters of the element and of the tunnel lining are the displacement of the nodes of the element. Once the nodes of the element have been identified, the stresses inside each element and therefore also along the entire tunnel lining length.

According to Huebner and others authors in 2001[4], the local stiffness matrix Z_i of the corresponding "i" element was created by placing the effects of the inner forces of the "i" element equal the effects by the force at a node of the element, evaluated according to the local reference

system.

The equation represents the displacement at the nodes of the element with the internal force at the node and the rotational angles at the nodes of the element "i":

$$Z_i \cdot S_i = G_i + R_i \quad (5)$$

Where S_i is the vector displacements in nodes h, j of the element "i", G_i is the external nodal forces of the element "i", R_i is the nodal forces applied by the neighboring elements.

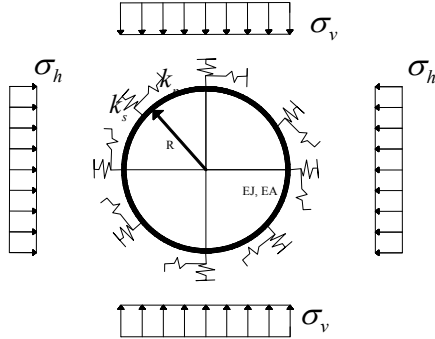


Fig. 3 Calculation scheme of tunnel lining with the HRM method. σ_v -vertical load in the model tunnel – surrounding ground; σ_h -horizontal load in the model tunnel – surrounding ground; k_n -normal stiffness of the interaction springs; k_s -tangential stiffness of the interaction springs; R -tunnel radius; EJ and EA -bending and normal stiffness of the tunnel lining [3, 5, 9, 10]

With the appearance of normal node springs and tangential node springs along the structure of tunnel, these are reasons cause stiffness changes in the structural elements in the corresponding directions. By the modification of the corresponding for elements along the diagonal of the local stiffness matrix of each element and next, modification of structure matrix in the global stiffness could be received:

$$\begin{aligned} K_{3i-2,3i-2}^* &= K_{3i-2,3i-2} + k_{n,i} \cdot \cos^2\left(\frac{\alpha_{i+1} + \alpha_i}{2} - \frac{\pi}{2}\right) + k_{s,i} \cdot \sin^2\left(\frac{\alpha_{i+1} + \alpha_i}{2} - \frac{\pi}{2}\right) \\ K_{3i-1,3i-1}^* &= K_{3i-1,3i-1} + k_{n,i} \cdot \cos^2\left(\frac{\alpha_{i+1} + \alpha_i}{2} - \frac{\pi}{2}\right) + k_{s,i} \cdot \sin^2\left(\frac{\alpha_{i+1} + \alpha_i}{2} - \frac{\pi}{2}\right) \\ K_{3i-1,3i-2}^* &= K_{3i-1,3i-2} + (k_{n,i} - k_{s,i}) \cdot \cos\left(\frac{\alpha_{i+1} + \alpha_i}{2} - \frac{\pi}{2}\right) \cdot \sin\left(\frac{\alpha_{i+1} + \alpha_i}{2} - \frac{\pi}{2}\right) \\ K_{3i-2,3i-1}^* &= K_{3i-2,3i-1} + (k_{n,i} - k_{s,i}) \cdot \cos\left(\frac{\alpha_{i+1} + \alpha_i}{2} - \frac{\pi}{2}\right) \cdot \sin\left(\frac{\alpha_{i+1} + \alpha_i}{2} - \frac{\pi}{2}\right) \end{aligned} \quad (6)$$

Where "i" is number of the node, $k_{n,i}$ is the stiffness of the normal interaction spring connected in node "i", $k_{s,i}$ is the stiffness of the tangential interaction spring connected in node "i", α_i and α_{i+1} is the angle between the local with the global reference systems for element "i" and for element "i + 1", degree. K is the matrix of the global Cartesian reference system of the segmental lining tunnel.

The relationship between the displacement vector S_i at the nodes and the local stiffness matrix of the nodes along with the stress on the nodes T_i of the element "i" is expressed by the equation:

$$T_i = S_i \cdot Z_i \quad (7)$$

Oreste has given the equation showing the relationship between the deformation of the structure and the reaction pressure, which is a nonlinear relationship [2, 3, 8].

$$p = p_{lim} \left(1 - \frac{p_{lim}}{p_{lim} + \eta_0 \delta}\right) \quad (8)$$

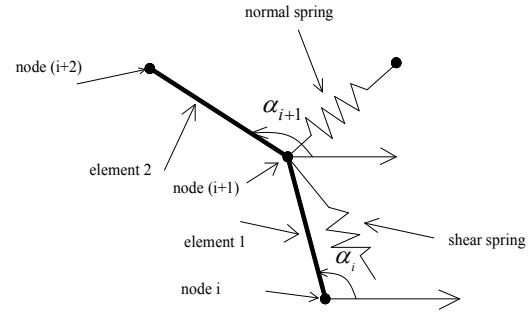


Fig. 4 Details of the ground support interaction through the Winkler springs connected to the support nodes [3, 10]

Where p is reaction pressure, p_{lim} is the maximum reaction pressure of the ground, η_0 is the initial stiffness of the ground that surrounding the tunnel lining, δ is a deformation of the structure. According to Do [3], the initial normal ground stiffness that around the tunnel can be determined by the following formula [3]:

$$\eta_{n,0} = \beta \frac{1}{1 + \nu} \cdot \frac{E}{R} \quad (9)$$

$$\eta_s = \frac{1}{3} \eta_n \quad (10)$$

Where E is Young's modulus of the ground, kN/m^2 . ν is Poisson's ratio of the ground, R is the tunneling radius, m . β is a dimensionless factor, η_s is the tangential stiffness of ground.

It is possible to determine the value of the maximum reaction pressure of the ground, based on the values of ground properties such as cohesion c , the friction angle of ground ϕ and considering the effect of confining pressure.

$$p_{n,lim} = \frac{2 \cdot c \cdot \cos \phi}{1 - \sin \phi} + \frac{1 + \sin \phi}{1 - \sin \phi} \cdot \Delta \sigma_{conf} \quad (11)$$

$$\text{With } \Delta \delta_{conf} = \frac{\sigma_h + \sigma_v}{2} \cdot \frac{\nu_s}{1 - \nu_s} \quad (12)$$

The same way, maximum shear reaction pressure

was determined the value by the formula:

$$p_{s,lim} = \frac{\sigma_h + \sigma_v}{2} \cdot tg\phi \quad (13)$$

Where σ_v and σ_h are the vertical and horizontal loads effect to tunnel lining, respectively.

Define the lateral earth pressure coefficient K_0 ,

$$\sigma_h = K_0 \sigma_v \quad (14)$$

In the new HRM method proposed by Do (2014) [6], the change of rotational spring stiffness of joints in the tunnel lining segmental through the fixity factor. In this method, consider the joint as a lengthless rotational spring is widely used in the semi-rigid analysis of structure.

“Fixity factor” is defined to reflect the relative stiffness of the beam and the rotational springs [3, 6]:

$$r_j = \frac{1}{1 + \frac{3E_s J_s}{K_{RO} L_i}} \quad (15)$$

The connection element “i” in a structure that had elastic stiffness matrix with two semi-rigid end-connections and with rotational stiffness modulus K_{RO1} and K_{RO2} , the stiffness matrix of the element “i” was represented by a semi-rigid correction matrix:

$$K_i^{SR} = Z_i \cdot C_i \quad (16)$$

Where K_i^{SR} is semi-rigid correction matrix of the connection element “i” in structure; Z_i is the stiffness matrix of the member considered to have rigid ends and C_i is the correction matrix.

$$C_i = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{4r_2 - 2r_1 + r_1 r_2}{4 - r_1 r_2} & \frac{-2L_1 r_1 (1 - r_2)}{4 - r_1 r_2} & 0 & 0 & 0 \\ 0 & \frac{6(r_1 - r_2)}{L_i (4 - r_1 r_2)} & \frac{3r_1 (2 - r_2)}{4 - r_1 r_2} & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{4r_1 - 2r_2 + r_1 r_2}{4 - r_1 r_2} & \frac{2L_2 r_2 (1 - r_1)}{4 - r_1 r_2} \\ 0 & 0 & 0 & 0 & \frac{6(r_1 - r_2)}{L_i (4 - r_1 r_2)} & \frac{3r_2 (2 - r_1)}{4 - r_1 r_2} \end{bmatrix} \quad (17)$$

Where L_i is the length of the element “i”

When has effect of earthquake (seismic load) to tunnel, the seismic load diagram on the tunnel lining in the HRM method that has properties as the static load diagram on the tunnel lining but the horizontal loads components are in opposite direction, the external loads have the impact to tunnel lining are rotated counter - clockwise 45° degrees. In the HRM method, in this case, the external loads acting

on the tunnel lining can be different from the theory that Naggar has given since 1998 [8]. At this point, the external loads that act on the tunnel lining are determined by the coefficients a, b coefficient and shear stress (see figure 5).

The parameter b is constant and equal to 1.25, parameter a depends on the tunnel radius R and can be defined using the following expression:

$$a = -0.7 \ln(R) + 0.885 \quad (18)$$

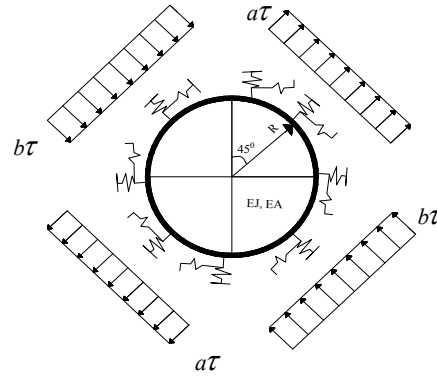


Fig. 5 External forces applied to the earthquake tunnel in the HRM method [3]

The maximum shear reaction pressure of ground can be defined by the formula:

$$p_{s,lim} = \frac{(b - a)\tau}{2} tg\phi \quad (19)$$

Where ϕ is the internal friction angle of the soil, a and b are parameters these defined in formula (18)

The confining pressure was calculated by the formula:

$$\Delta\sigma_{conf} = \frac{(b - a)\tau}{2} \frac{v_s}{1 - v_s} \quad (20)$$

Where v_s is Poisson's ratio of the soil, τ is the in-plane shear stress, $\tau = \gamma_c G$. G is the the shear modulus of the soil, kN/m². γ_c is the shear strain of soil, %.

5. RESULTS AND DISCUSSIONS

The results of calculations for the tunnel case of the Hanoi metro system according to the methods were presented in Table 2. On the basis of these results, a comparison of the internal forces in the tunnel lining under the impact of the largest earthquake, which may occur in the center of Hanoi. These results are obtained when using different methods for calculating with the case of tunnel continuous lining and the case of the segmental tunnel lining.

The results of calculating the internal forces in

lining tunnels under the influence of the Wang's method, Penzien & Wu method, 2D numerical method- using Abaqus software are presented in Figures 6 to 11. Using the HRM method to obtain the results of internal force calculations for the tunnel lining in two cases: the tunnel lining continuous and the segmental tunnel lining of Hanoi

metro system under the impact of the largest earthquake can occur in the centre of Hanoi, these results are shown in figure 12, 13, 14. In the results of tunnel lining calculations by HRM method, the displacement of tunnel lining was presented in two cases: the case of the tunnel lining continuous and the case of the segmental tunnel lining.

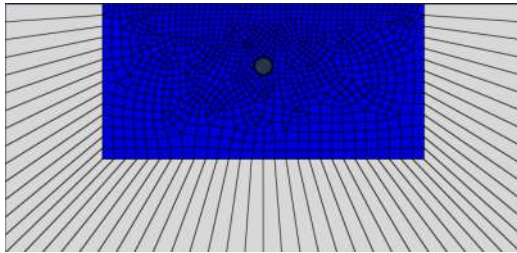


Fig. 6 Tunnel model under consideration [5, 9]

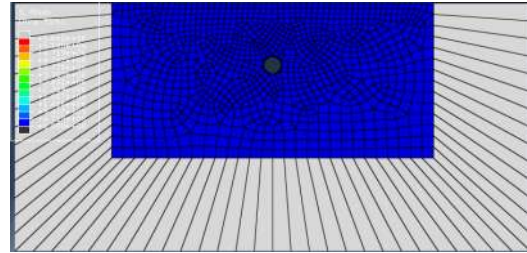


Fig. 7 Result calculation by 2D numerical method

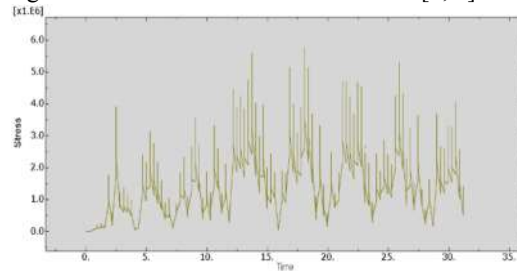


Fig. 8 State stress on the tunnel

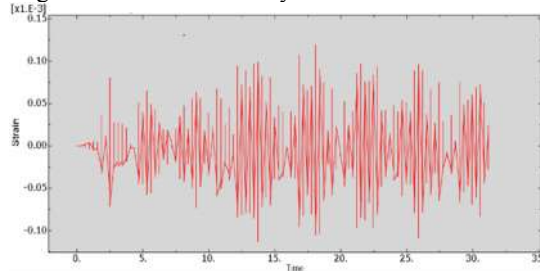


Fig. 9 Strain of the tunnel lining

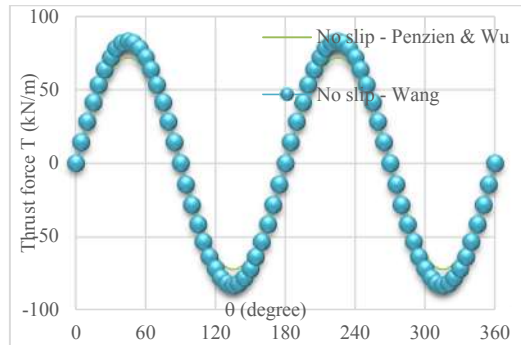


Fig. 10 Thrust force T (kN/m) [5]

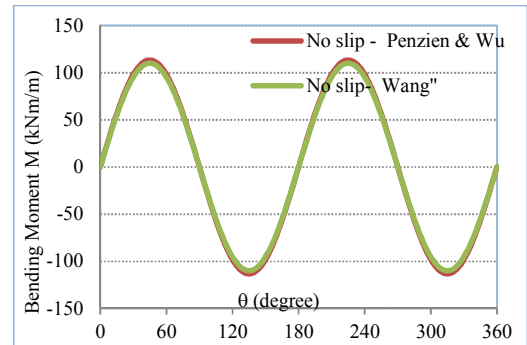


Fig. 11 Bending Moment M (kNm/m) [5]

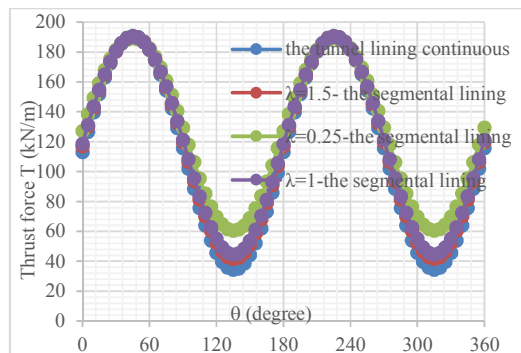


Fig. 12 Thrust force T (kN/m) in HRM method

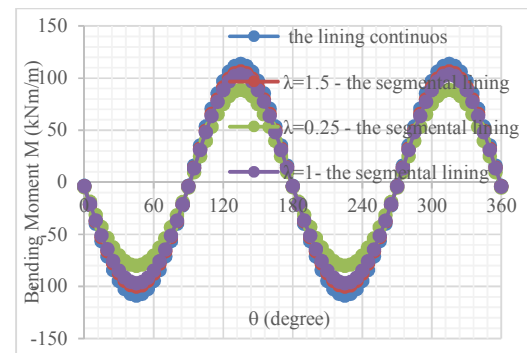


Fig. 13 Bending Moment M (kNm/m) in HRM method

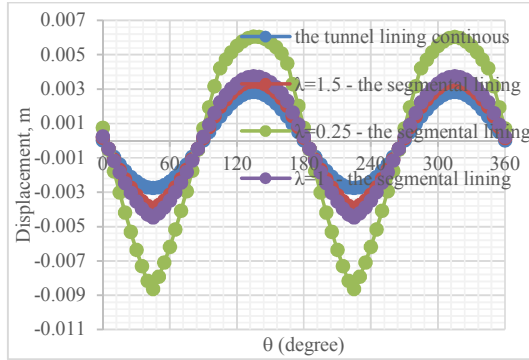


Fig. 14 Displacement (m) in HRM method

Compare the results obtained by the above calculation methods (the results are shown in Fig. 12 - 14). Special attention is given to two cases of continuous tunnel lining and the case of tunnel segmental lining. Select the internal force values (moment, thrust force and stress) in the tunnel lining under the influence of the earthquake received using the Penzien's method as the reference values.

Table 2 Analysis Results of Different Calculation Methods

| The internal forces in lining tunnel | Wang's method | Penzien & Wung's method (reference case) | 2D numerical method | HRM method | | | |
|---|---------------|--|---------------------|--------------------------------|-----------------------------|-------------|----------------|
| | | | | The tunnel lining continuously | The segmental tunnel lining | | |
| | | | | | $\lambda=1.5$ | $\lambda=1$ | $\lambda=0.25$ |
| M (kN.m/m) | 110.03 | 113.34 | - | 113.67 | 106.64 | 103.88 | 88.89 |
| % difference with the reference case - M | 3.01 | - | - | 0.29 | 5.91 | 8.35 | 21.57 |
| T (kN/m) | 82.95 | 71.96 | - | 190.84 | 190.33 | 190.13 | 189.12 |
| % difference with the reference case -T | 13.25 | - | - | 165.26 | 164.49 | 164.21 | 162.82 |
| σ (MPa) | 5.626 | 5.757 | 5.721 | 6.11 | 5.76 | 5.63 | 4.89 |
| % difference with the reference case - σ | 2.275 | - | 0.625 | 6.18 | 0.172 | 2.185 | 12.989 |

Based on the results obtained by Wang, Penzien, 2D numerical method and HRM methods when calculation for the tunnel continuous lining as well as for case using HRM method to calculation for the segmental tunnel lining under the influence of earthquake, be able to give comments: In the case of tunnel lining continuous, Penzien's method given a stress in the tunnel lining is 5.757 MPa, Wang's method given a stress value is 5,626 MPa - difference with Penzien's method is 2.275%, 2D numerical method given a stress value is 5.721 MPa - the difference with the Penzien's method is 0.625%, the HRM method given the stress value is 6.11 MPa - the difference with the stress value that Penzien's method given is 6.18%. These differences are not large. From the above results – in Table 2, it could realize too that: although there are large differences in T - thrust force in results of methods, however, due to the difference of moment values of the methods is small and this difference did not largely affect to the value of the corresponding stresses on the tunnel lining continuously under the influence of the earthquake. In the case of the segmental tunnel lining, HRM

method was used to calculate for the segmental tunnel lining under the impact of the earthquake in Hanoi. Comparing results of the internal forces and the stress value in the tunnel lining under the impact of the earthquake in two cases: case of the tunnel continuous lining and case of the segmental tunnel lining (M_{max} , T_{max} , σ_{max}) calculated by the HRM method - the calculation results by Penzien's method have been used to as the reference results. Results are compared as in Table 2. It could realize to that the presence of joints in the tunnel lining causes increase the flexibility of the tunnel lining under the impact of the earthquake and reduces the maximum bending moments on the tunnel lining, thus reducing the stress values in the tunnel lining under the impact of the earthquake. With three different values of the rotational stiffness ratio of joints in the tunnel lining, λ is 1.5; 1; 0.25 obtained results of the moment, M_{max} , thrust force T_{max} and radial displacement d_{max} of the tunnel lining. Based on these values as well as the comparison in Table 2, could be concluded that the value of the rotational stiffness of joints in the segmental tunnel lining has a great influence to the internal force values in

the segmental tunnel lining when the tunnel is affected by the earthquake. When the rotational stiffness of joints was smaller this could make for the moment value in the tunnel lining the same was smaller, the stress value in the tunnel lining was lower and the displacement of the tunnel lining was bigger ($\lambda = 1.5$ the moment is 106.64 kNm, the stress is 5.76 MPa, displacement is 3.46 mm but when $\lambda = 0.25$, the moment is 88.89 kNm, the stress is 4.89 MPa, displacement increased to $d_{\max} = 8.85$ mm).

6. CONCLUSIONS

In this paper, the typical calculation methods for tunnels under the impact of earthquakes are in two cases: the tunnel continuous lining and the segmental tunnel lining these have been submitted presented. The paper also performs calculations for the force internal in the segmental tunnel lining by HRM method when the rotational stiffness values of joints are changed. Comparison of results obtained using calculation methods in the above two cases using data of the tunnel in the Hanoi metro system and data of the earthquake that has a greatest possible magnitude that may occur in the center of Hanoi, received the following conclusions:

- The use of the segmental tunnel lining with the appearance of joints in the tunnel lining, resulting in internal forces in the tunnel lining under the impact of the earthquake these have varied considerably from the internal forces in the tunnel continuous lining. The joints in the segmental tunnel lining significantly reduce the value of moment in the tunnel lining, while significantly reducing the value of stress in the tunnel lining when the tunnel lining works under the impact of earthquakes. In this case, the displacement of the segmental tunnel lining is also much larger than the displacement of the tunnel lining when the tunnel lining is continuous;

- With the different rotational stiffness values of joints, the internal force in the segmental tunnel lining will also have different values when the tunnel is affected by earthquakes. The reason for this phenomenon, when the rotational stiffness of joints is greater, the impact of the joints to the internal force in the segmental tunnel lining smaller and vice versa. In other words, the rotational stiffness of joint is directly proportional to the internal force values that appear in the segmental tunnel lining and inversely proportional to the displacement of the segmental tunnel lining under the impact of the earthquake.

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