

# **EFFECT OF THE DISTANCE BETWEEN TWIN TUNNELS ON THE INTERNAL FORCES IN THEIR LININGS UNDER THE IMPACT OF EARTHQUAKES - A CASE STUDY IN HANOI**

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## **Abstract**

Calculating earthquake-resistant underground structures is becoming more and more important in general design, many civil structures in the field of constructions over the world have used different tools to calculate this problem. However, among of them, there are few publications which are interested in the influence of the distance between the two tunnels on the internal forces occurring in the tunnel linings. On the basis of using the commercial software Plaxis, the input data is the acceleration graph generated under the condition of matching the response spectrum in accordance with the conditions in Hanoi. This is done by computing with models in case of the distance between the two tunnels increases. The results show a significant influence of the distance between the two tunnels, when their distance is less than 3 times the tunnel diameter, this effect will decrease in case of the larger distance.

*Keywords:* Dynamic analysis; artificial acceleration; twin tunnels; numerical simulation; shallow tunnels.

## **1. Introduction**

The metro line is an important component of the future urban transport system. The full dynamic analysis of tunnel structures under seismic loads has also been studied by many authors. Numerical analysis techniques have been used in many documents recently. Authors have used numerical simulations to calculate some types of tunnel structures subjected to seismic loads [1-5]. Although the current metro lines mainly use the double tunnel solution, but most of the current studies have not evaluated the effect of the distance between the tunnels on the change of the internal forces in linings. Therefore, in this article, the influence of tunnel distance on the internal forces induced in the tunnel structure are investigated.

## **2. Numerical analysis model for twin tunnels subjected to earthquakes**

To further investigate the influence of the distance between the two tunnels on the internal force of the tunnel when subjected to earthquakes from the dynamic point of view and compare the variation of the tunnel's internal force with the static problem, the

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author investigates the problems with the change of distance between two tunnels (L) from 1 D to 5 D with a survey step of 0.5 D, where D is the diameter of a tunnel. Because the tunnel length is much larger than the other dimensions, it is assumed that the structure modeling is plane strain. The model is built by the Plaxis software, the boundary conditions are absorbent boundary [6], the model is shown in Figure 1.

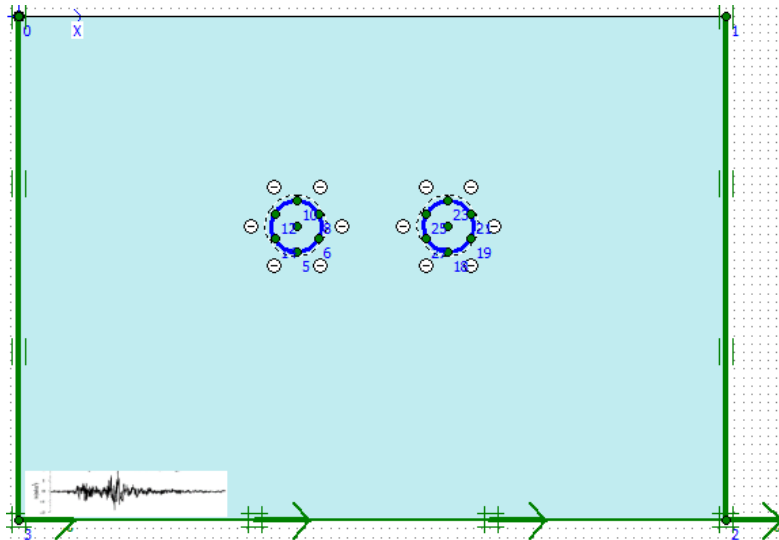


Figure 1. Numerical modeling under earthquake impact for twin tunnels.

### 2.1. Soil properties

Geology from the ground level to the bottom has a thickness of 60 m and is assumed to be homogeneous. The specific parameters of soil are given in Table 1. Ground surrounding medium the tunnel is simulated as 15-nodes triangle elements and the Hardening Soil (HS) model is adopted. The depth of underground water is 5 m from the ground surface.

Table 1. Parameters of soil

Row	Parameters	Denote	Value
1	Model materials	-	HS
2	Saturated density (kN/m <sup>3</sup> )	$\gamma_{\text{sat}}$	18
3	Natural density (kN/m <sup>3</sup> )	$\gamma_{\text{unsat}}$	17
4	Oed-stiffness modulus(kN/m <sup>2</sup> )	$E_{\text{oed}}^{\text{ref}}$	5,100
5	Secant stiffness modulus (kN/m <sup>2</sup> )	$E_{50}^{\text{ref}}$	5,100
6	Load-unloading Modulus (kN/m <sup>2</sup> )	$E_{\text{ur}}^{\text{ref}}$	1.53E+04

Row	Parameters	Denote	Value
7	Poisson's coefficient	$\nu$	0.3
8	Cohesion force (kN/m <sup>2</sup> )	$c$	55
9	Internal friction angle (°)	$\varphi$	20
10	Interactive coefficient	$R_{inter}$	0.8

## 2.2. Properties of segmental tunnel linings

The tunnel is placed at the depth of 25 m from the ground surface. Model of segmental tunnel structure material is assumed to be homogeneous and satisfy the linear elastic model, cross-section features of tunnel linings are shown in Table 2.

Table 2. Parameters for the tunnel structure

No.	Parameters	Symbol	Values	Units
1	Tunnel diameter (inner/outer)	$D_{in}/D_{out}$	5.7/6.3	m
2	Modulus of elasticity of concrete lining	$E_b$	2.5E+7	kPa
3	Poisson's coefficient of concrete lining	$\nu$	0.15	
4	Thickness of lining	$t$	0.30	m
5	Width of the tunnel lining	$b$	1.0	m

Model of twin tunnels with 2-dimension plane strain model in Plaxis software can be shown in Figure 2.

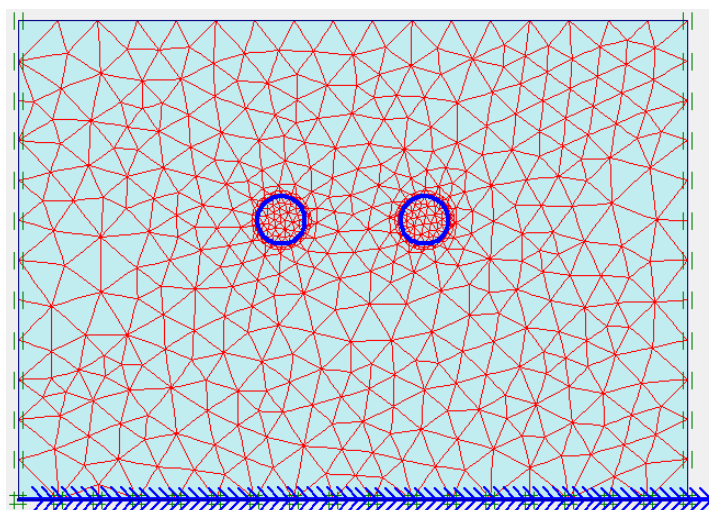


Figure 2. The mesh of 2D plane strain model in Plaxis software.

### 2.3. Input acceleration

An artificial acceleration installed on the bed rock which is randomly and generated by PG02 program [7] based on Yamamoto method [8], corrected for matching response spectrum condition with target response spectrum determined according to TCVN 9386-2012 [9]. The input parameters for generating artificial acceleration diagrams are determined base on the conditions in Ba Dinh district, Hanoi city as follows:

- Soil layer: Type A;
- The average shear wave velocity,  $v_s = 800$  m/s;
- Reference peak acceleration,  $a_{gR} = 0.0976$  g;
- The fault is the Red River - Song Chay earthquake zone including: seismic magnitude  $M_w = 6.5$ ; focal depth  $R_{hyp} = 17$  km; distance from the survey point to the epicenter  $R_{rup} = 50$  km.

Program PG02 is used with the above input data to generate the artificial acceleration diagram randomly. In this study, the diagram *badinh01-03a* is selected [7]. The acceleration diagram is shown in figures 3 and 4.

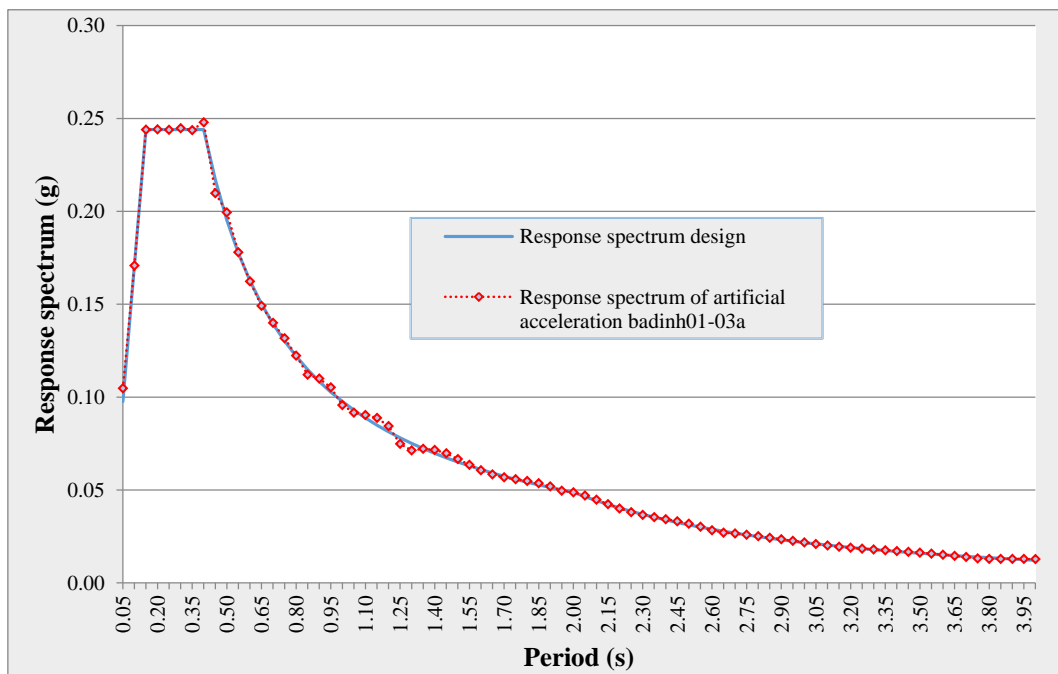


Figure 3. Response spectrum of acceleration badinh01-03a.

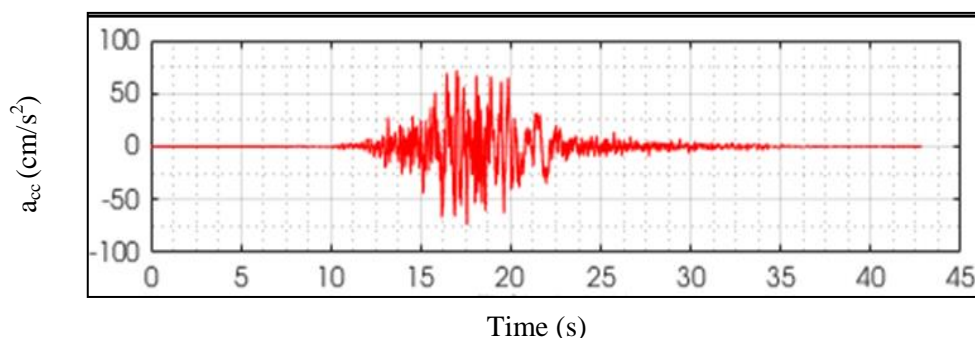


Figure 4. Acceleration bd01-03a.

### 3. Results

The maximum values of internal forces (bending moment, shear force and normal force in linings) are shown in Table 3 (x is distance between two tunnels,  $\Delta$  (%) is the difference by percentage).

The results of internal forces in the table 3 allow to obtain the relationship between the maximum values of bending moment, shear forces and the normal forces with the distance between the two tunnels. The results are shown in figures 5, 6, and 7. Through the calculation results, it can be seen that, when subjected to earthquakes, the maximum internal force (bending moment and shear) appearing in the two tunnels (left and right) has a difference, this can explained by the asymmetry of the applied load. However, it can be seen from Table 3 that the difference is not large (about 5%) and can be ignored in the calculation and design process.

Table 3. Maximum values of internal forces

x	$M_{max}$ (kNm/m)			$Q_{max}$ (kN/m)			$N_{max}$ (kN/m)		
	Left tunnel	Right tunnel	$\Delta$ (%)	Left unnel	Right tunnel	$\Delta$ (%)	Left tunnel	Right tunnel	$\Delta$ (%)
1.0 D	251.58	244.95	2.64	164.41	168.8	2.67	-1040	-1050	0.96
1.5 D	235.18	226.6	3.65	152.99	158.63	3.69	-1030	-1030	0.00
2.0 D	227.16	217.38	4.31	147.15	153.38	4.23	-1020	-1030	0.98
2.5 D	221.86	212.91	4.03	144.15	149.62	3.79	-1020	-1020	0.00
3.0 D	218.64	210.36	3.79	142.43	147.45	3.52	-1020	-1020	0.00
3.5 D	216.83	208.78	3.71	141.4	146.22	3.41	-1020	-1020	0.00
4.0 D	216.35	207.59	4.05	140.59	146.04	3.88	-1020	-1020	0.00
4.5 D	216.79	206.12	4.92	139.47	146.08	4.74	-1020	-1020	0.00
5.0 D	217.16	205.03	5.59	138.82	146.39	5.45	-1020	-1020	0.00

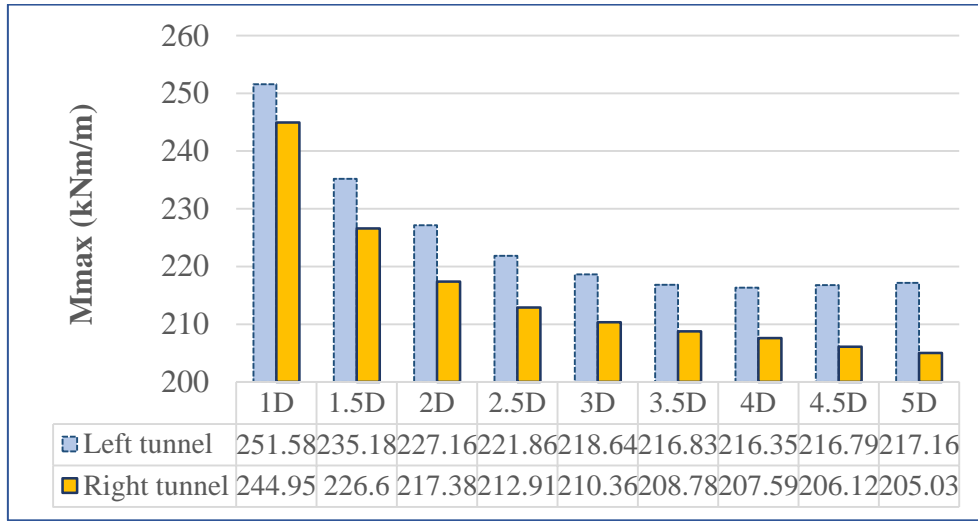


Figure 5. The relationship between the maximum bending moment and the distance of twin tunnels.

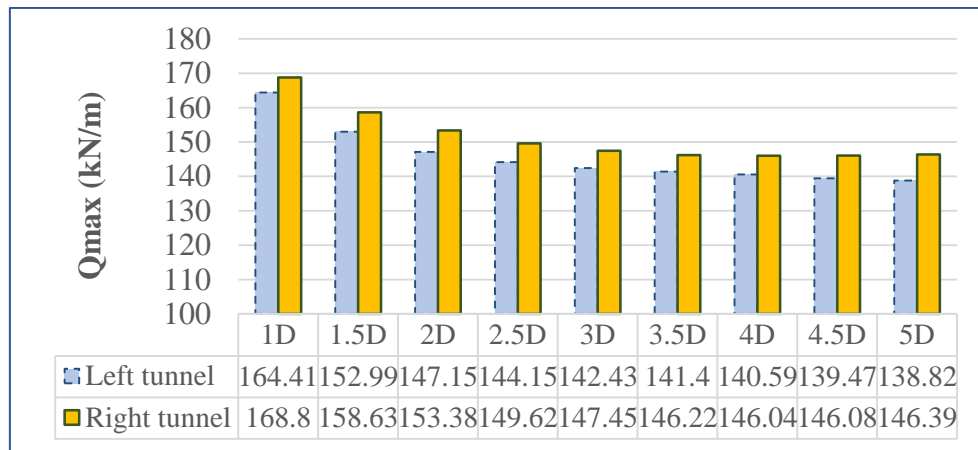


Figure 6. The relationship between the maximum values of shear force and the distance of twin tunnels.

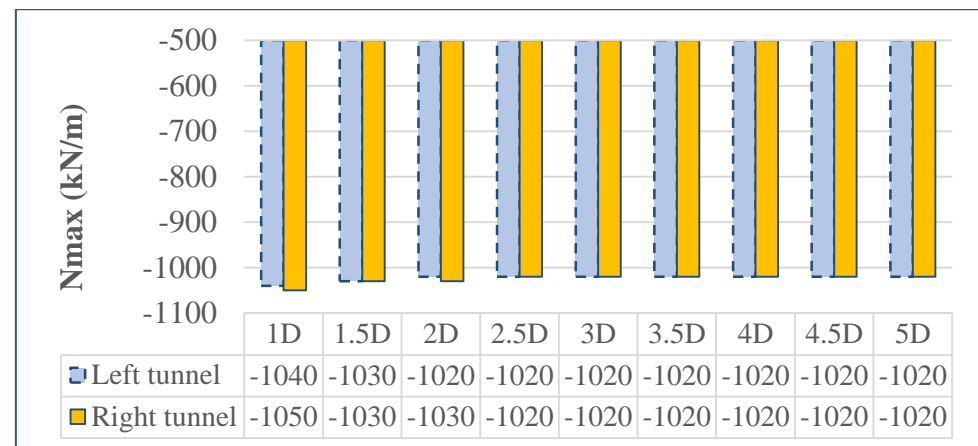


Figure 7. The relationship between the maximum normal force and the distance of twin tunnels.

To evaluate the results of internal forces, the calculation method of underground works subjected to earthquakes by the quasi-static method (ISGD) and by the dynamic method (full dynamic), the following parameters have been selected: The inputs are specifically soil model parameters, the tunnel parameters and the calculated model size which are the same for the two methods. Calculation results for the right tunnel obtained from the two methods are shown in Table 4 and figures 8, 9, and 10.

Table 4. The maximum values of internal forces (in the right tunnel)

Distance between two tunnels	ISGD			Full dynamic		
	$N_{max}$ (kN/m)	$Q_{max}$ (kN/m)	$M_{max}$ (kNm/m)	$N_{max}$ (kN/m)	$Q_{max}$ (kN/m)	$M_{max}$ (kNm/m)
1D	-1050	168.68	253.12	-1040	168.8	244.95
1.5D	-1030	158.36	236	-1030	158.63	226.6
2D	-1030	153.6	228.01	-1020	153.38	217.38
2.5D	-1020	150.51	223.17	-1020	149.62	212.91
3D	-1020	149.08	220.78	-1020	147.45	210.36
3.5D	-1020	148.24	219.41	-1020	146.22	208.78
4D	-1020	147.75	218.64	-1020	146.04	207.59
4.5D	-1020	147.56	218.3	-1020	146.08	206.12
5D	-1020	147.5	209.24	-1020	146.39	205.03

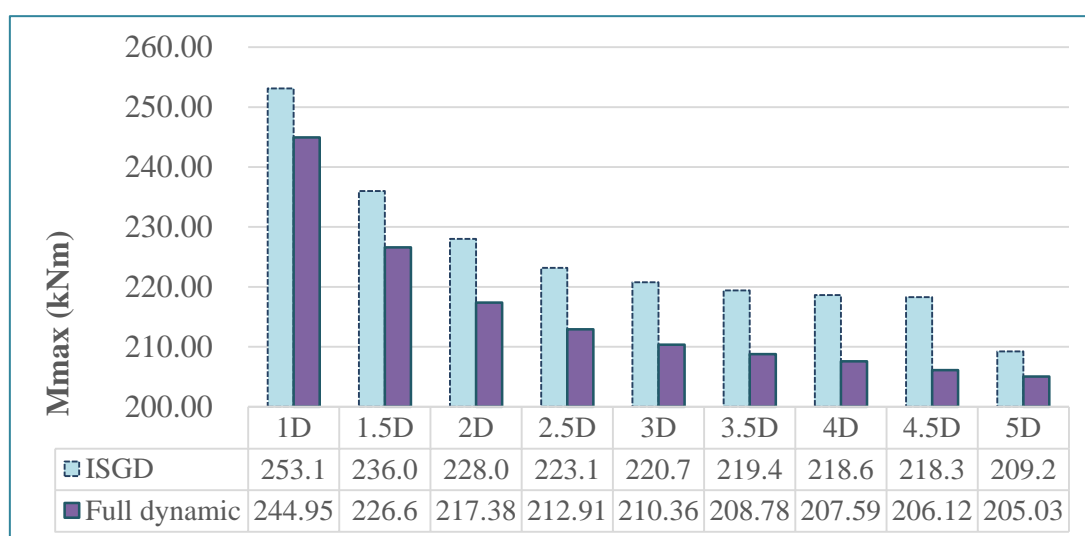


Figure 8. Comparison of the maximum bending moments in the tunnel structure (right tunnel) with other distance of twin tunnels.

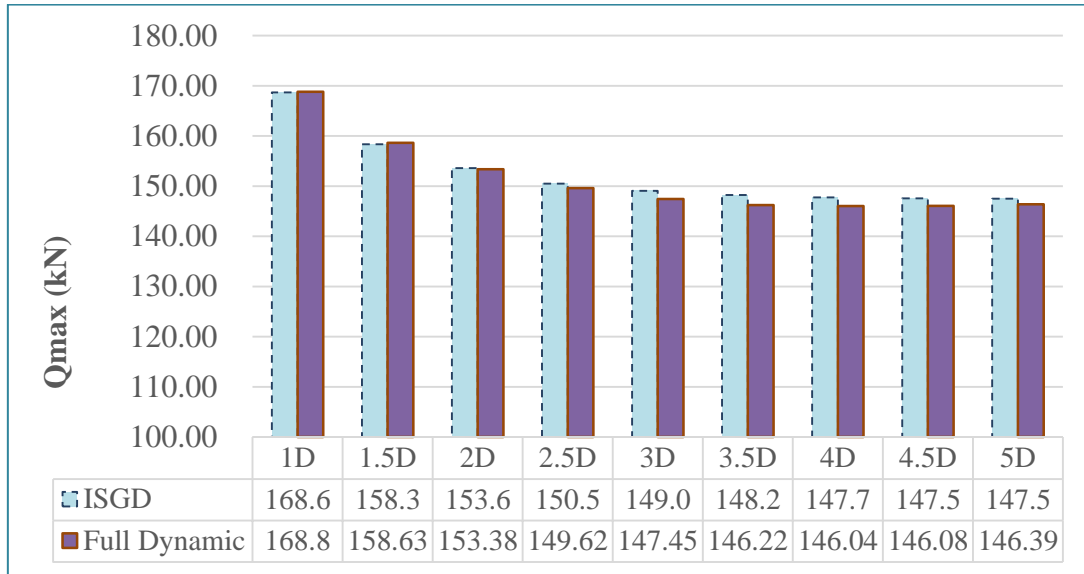


Figure 9. Comparison of the maximum shear forces in the tunnel structure (right tunnel) with other distance of twin tunnels.

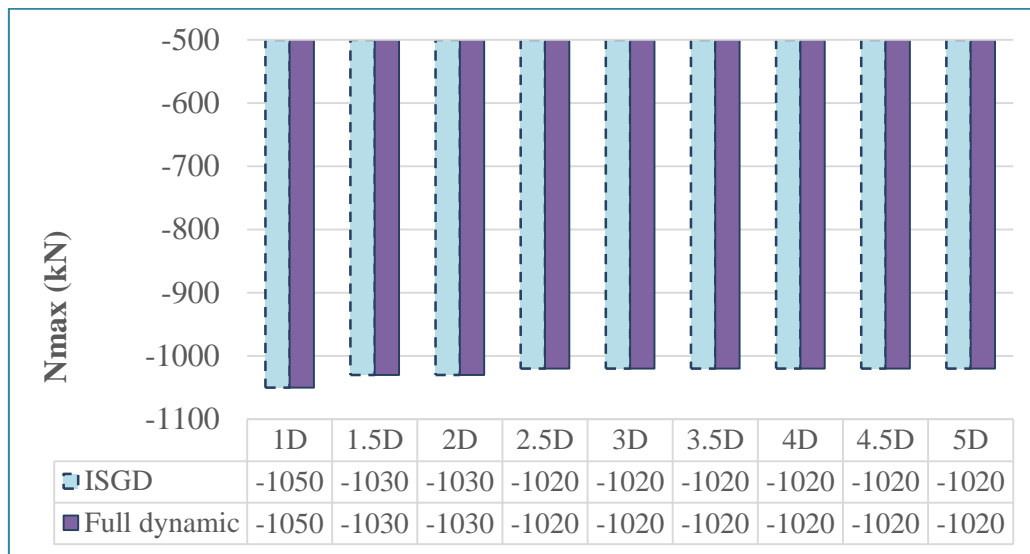


Figure 10. Comparison of the maximum normal force in the tunnel structure (right tunnel) and the distance of twin tunnels.

It can be shown from the charts 8, 9, 10 that, when the environment is homogeneous, the internal forces appearing in the tunnel lining calculated by the two methods of ISGD and the full dynamic are not significantly different. In particular, the ISGD method gives bigger internal forces (in the range of 5 - 10% for bending moment). Therefore, in practice, this method can be used to calculate and preliminary design the structure of tunnel.

## 4. Conclusion

Based on the obtained results in this study, some conclusions can be drawn as follows:

When increasing the distance between the two tunnels, the internal forces in the tunnel linings will decrease. Especially, when the distance between the two tunnels increases from 1D to 3D, the internal forces in the tunnel lining will decrease significantly. Specifically, the maximum bending moment value  $M_{\max}$  in the tunnel lining decreases by 13.1%, the maximum shear force  $Q_{\max}$  is reduced 11.4%; In other case, if the distance between the two tunnels increases from 3D to 5D, the maximum bending moment  $M_{\max}$  and the maximum shear force  $Q_{\max}$  in the tunnel lining decrease at the same time insignificantly, 2.5% and 0.72%, respectively. In other words, when the distance between the two tunnels is greater than 3D, the interaction influence between the two tunnels is insignificant.

As for the maximum value of normal force  $N_{\max}$  in the tunnel lining, the tunnel distance has an insignificant influence, especially when the distance between two tunnels is greater than 2D.

Furthermore, the comparison results of two calculation methods (ISGD and full dynamic) show that the values of internal forces received by ISGD method will be larger than those of full dynamic method. However, this difference is not large.

## References

- [1] Youssef M. A. Hashash, Jeffrey J. Hook, Birger Schmidt, John I-Chiang Yao, "Seismic design and analysis of underground structures" *Tunnelling and Underground Space Technology*, 16, 2001, 247-293. DOI: 10.1016/S0886-7798(01)00051-7
- [2] St. John, C. M., Zahrah, "A seismic design of underground structures," *Tunneling Underground Space Technol.*, 2(2), 165-197, 1987. DOI: 10.1016/0886-7798(87)90011-3
- [3] Kontoe, S., Zdravkovic, L., Potts, D. M. and Menkiti, C. O., "Case study on seismic tunnel response," *Canadian Geotechnical Journal*, 45, 1743-1764, 2008. DOI: 10.1139/T08-087
- [4] Anh. DoNgoc, "Numerical Analyses of segmental tunnel lining under static and dynamic loads," PhD thesis, 2014.
- [5] Lê Bảo Quốc, "Tính toán công trình ngầm đô thị chịu động đất," Luận án tiến sĩ kỹ thuật, Học viện Kỹ thuật quân sự, Hà Nội, 2015.
- [6] Brinkgreve R. B. J. and Broere W., *Plaxis manual version 8*, Delft University of technology & Plaxis b.v., The Netherlands, 2006.

- [7] Vu, N. A., & Cao, C. Q., "Calculation of tunnel linings under seismic loads of the earthquakes by generated the artificial acceleration applied in the Ha Noi area," *Journal of Science and Technique - Section on Special Construction Engineering*, 3(01), 2020. DOI: 10.56651/lqdtu.jst.v3.n01.75.sce
- [8] Yamamoto, "Stochannstic model for earthquake ground motion using Wavelet packets," PhD thesis, Stanford University, 2011.
- [9] Tiêu chuẩn Quốc gia TCVN 9386:2012 - Thiết kế công trình chịu động đất.

## ẢNH HƯỞNG CỦA KHOẢNG CÁCH GIỮA HAI NHÁNH CỦA HÀM ĐÔI ĐẾN NỘI LỰC XUẤT HIỆN TRONG KẾT CẤU HÀM KHI CHỊU TÁC DỤNG CỦA ĐỘNG ĐẤT

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**Tóm tắt:** Tính toán công trình ngầm chịu động đất đang ngày càng trở thành vấn đề quan trọng trong công tác thiết kế nói chung, nhiều công trình trên thế giới đã sử dụng các công cụ khác nhau để tính toán kết cấu dạng này. Tuy nhiên, trong số đó, còn có ít công bố quan tâm đến việc ảnh hưởng của khoảng cách giữa hai đường hầm đến nội lực xuất hiện trong vỏ hầm. Trên cơ sở sử dụng phần mềm thương phẩm Plaxis, số liệu đầu vào là giản đồ gia tốc được phát sinh theo điều kiện khớp phổ phản ứng phù hợp với điều kiện tại Hà Nội, nhóm tác giả đã khảo sát, tính toán ảnh hưởng này bằng cách tính toán với các mô hình có khoảng cách giữa hai đường hầm tăng dần. Kết quả cho thấy ảnh hưởng đáng kể khi khoảng cách đường hầm nhỏ hơn 3 lần đường kính và ảnh hưởng ít hơn khi khoảng cách này tăng lên.

**Từ khóa:** Phân tích động lực học; giản đồ gia tốc nhân tạo; đường hầm đôi; mô phỏng số; đường hầm đặt nông.

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