A SEISMIC ANALYSIS OF SEGMENTAL TUNNEL LINING USING ARTIFICIAL ACCELERATION

Vu Ngoc Anh[1,*], Cao Chu Quang[1]

[1]*Le Quy Don Technical University*

Abstract

This paper aims to generate a set of artificial accelerations by using PG02 program, based on Yamamoto's regression equations and response spectrum of Vietnamese National Standard TCVN 9386-2012 condition. Taking the obtained ground motion as input data to calculate the tunnel structure of the project Metro line No.3 (Nhon - Hanoi Railway Station) by program Plaxis2D. The connections among the tunnel segments are replaced by semi-rigid joint under Jassen's assumption. The results show that the peak ground acceleration value can be considered as one of the important factors affecting on the internal force of tunnel besides a number of other acceleration factors (peak ground velocity, root mean square acceleration, intesity of Arias, time duration of strong motion).

Keywords: Seismic analysis; segmental lining; artificial acceleration; semi-rigid.

1. Introduction

The metro line is an important component of the future urban transport system. The underground sections of these lines are often constructed using TBM. Although underground structures have many advantages compared to above structures when subjected to seismic waves, in fact, there have been many failures of tunnel in the world when they are affected by earthquakes.

The full dynamic analysis of tunnel structures under seismic loads has also been studied by many authors. The recently common trend is to use numerical analysis techniques. Brinkgreve R.B.J. and Broere W. [3], Kontoe et al. [6], Hassash [10], St. John [8], Anh DoNgoc [2]... have used numerical simulations to calculate some types of tunnel structures subjected to seismic loads. The above studies have shown the behavior of the tunnel when subjected to earthquakes but did not pay attention and give an appropriate acceleration spectrum.

This study focuses on using the artificial accelerations, which compatiable with Vietnamese National Standard TCVN 9386-2012, to calculate the tunnel structrure at Hanoi, a case in Ba Dinh district. These input accelerations are randomly generated by

PG02, a program based on the Yamamoto's regression equations [8] and response spectrum matching condition.

2. Numerical analysis for segmental tunnel

2.1. Objects of research and assumptions

The object selected for the survey is the underground section of the project "Urban Railway (Metro) No.3, Nhon - Hanoi Railway Station" (from station S9 to S12, Figure 1), located at Ba Dinh district. Because the tunnel length is much larger than the other dimensions, it is assumed that the structure modeling is plane deformation problem.

Figure 1. Plan of Metro line No.3 in Hanoi City.

2.2. Soil properties

Geology from the ground level to bottom has a thickness of 60m, including 6 geological layers (denoted from L1 to L6). The specific parameters of each layer are given in Table 1. Ground surrounding medium the tunnel is simulated as 15-nodes triangle elements and the Hardening Soil (HS) model is selected. The depth of groundwater is 5m from the ground surface.

Table 1. Table of parameters of soil layers

Row	Parameters	Denote	Layers					
			1	2	3	4	5	6
1	Layer thickness (m)		2.5	15	3.5	15.0	11.0	13.0
2	Model materials		HS	HS	HS	HS	HS	HS
3	Saturated density (kN/m^3)	γ_{sat}	18	17.8	19.4	20.0	21.0	23.0
4	Natural density (kN/m^3)	γ_{unsat}	17	16.8	19.4	20.0	21.0	23.0
5	Oed-stiffness modulus (kN/m^2)	E^{ref}_{oed}	5,100	3,600	16,200	25,200	48,800	131,000
6	Secant stiffness modulus (kN/m^2)	E^{ref}_{50}	5,100	3,600	16,200	25,200	48,800	131,000

Row	Parameters	Denote	Layers					
			1	**2**	**3**	**4**	**5**	**6**
7	Load- unloading Modulus (kN/m^2)	E^{ref}_{ur}	1.53E+04	1.08E+04	4.85E+04	7.55E+04	1.46E+05	3.94E+05
8	Poisson's coefficient	ν	0.3	0.35	0.30	0.30	0.30	0.28
9	Cohesion force (kN/m^2)	c	55	30	0.1	0.1	0.1	0.1
10	Internal friction angle (º)	φ	20	12	31	37	39	45
11	Interactive coefficient	R_{inter}	0.8	0.8	0.7	0.7	0.7	0.7

2.3. Properties of segmental tunnel lining

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

Table 2. Table of parameters for the tunnel structure

Row	Parameters	Denoted	Values	Units
1	Tunnel diameter (inner/outer)	D_{in}/D_{out}	5.7/6.3	m
2	Modulus of elasticity of tunnel concrete	E_b	2.5E+7	kN/m^2
3	Poisson's coefficient for concrete	ν	0.15	
4	Thickness of lining	t	0.30	m
5	Height of the connection	l_t	0.185	m
6	Width of the tunnel ring	b	1.0	m

The paper uses Janssen's assumptions [5] to model connection among segments of tunnel lining (Figure 2). There, C_r is elastic jointing anti-bending hardness; k_r is the elastic link hardness in the radius direction; k_t is the elastic link hardness in the tangentially direction.
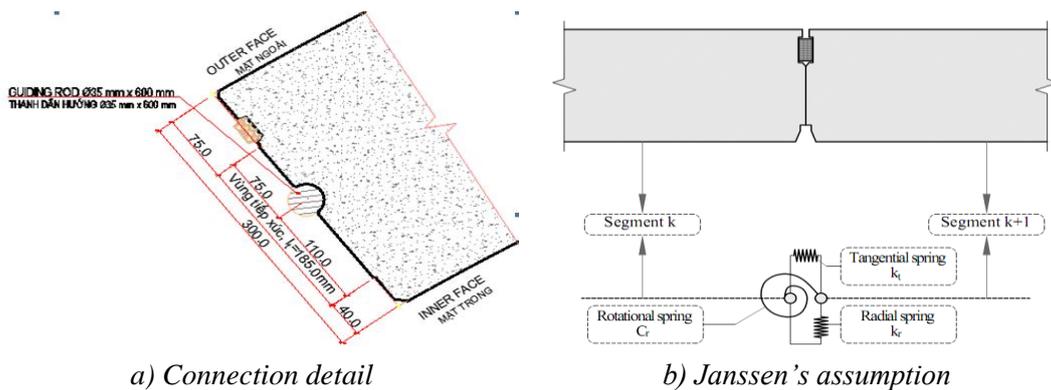

a) Connection detail   *b) Janssen's assumption*
Figure 2. Connection detail and Janssen's assumption

The values for k_r and k_t are often chosen with high values, when using Plaxis 2D, these links are usually ignored in calculation. The main parameter of the Janssen joint [5],

C_r, is determined by formula (1):

$$C_r = \frac{b \cdot l_t^2 \cdot E_c}{12} = \frac{1 \cdot 0,185^2 \cdot 2,5 \cdot 10^7}{12} = 71,302 \, (kNm/rad) \tag{1}$$

where l_t is the height of the connection (m); E_c is the elastic module of concrete (kN/m^2); b is the width of the tunnel ring (m).

The semi-rigid joints are modelled in Plaxis as a 'Hinges and rataion springs', in there, the spring stiffness is C_r value (Figure 3, Min.Moment = $-M_{yield}$ = -150 kNm; Max.Moment = M_{yield} = 150 kNm [5]).
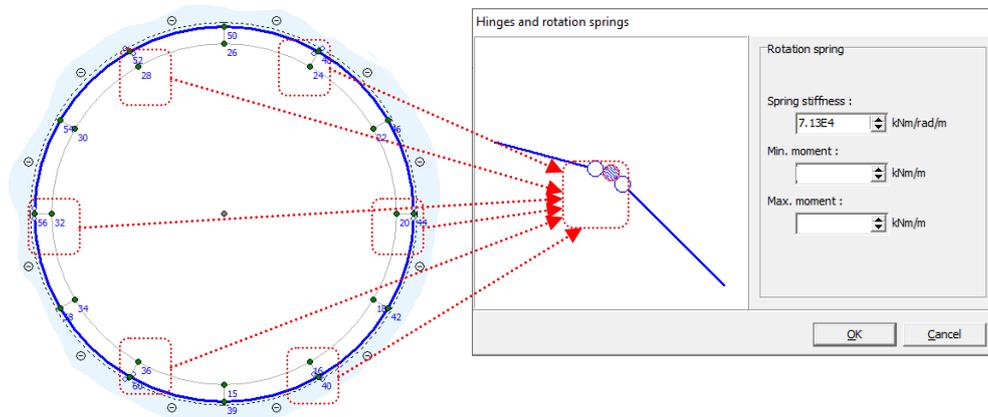
Figure 3. Semi-rigid joint is modeled in the Plaxis 2D software

Model of segmental tunnel structure and the 2-dimension plane strain model (with 6 segments) in Plaxis software can be shown in Figure 4.
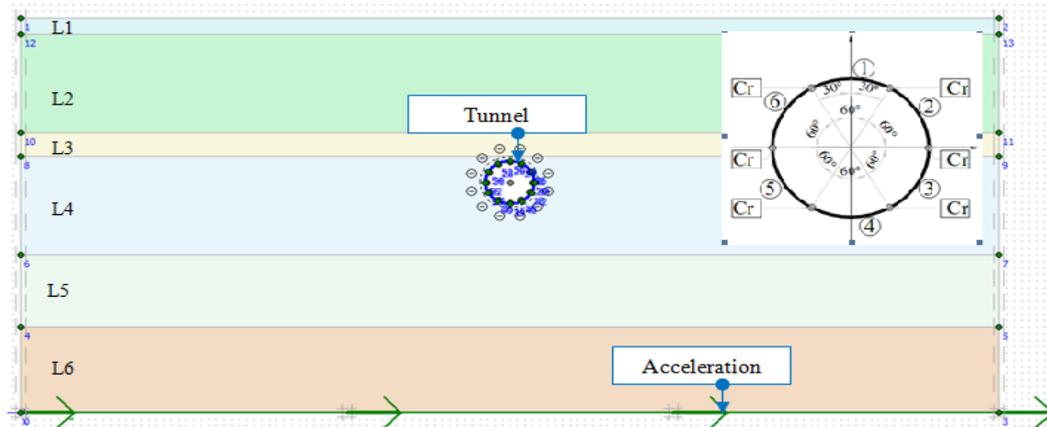
Figure 4. 2D plane strain model in Plaxis software

3. Earthquake time history

Earthquake time history input are artificial accelerations, which is generated by PG02, a program was written on Matlab. This program is a random simulation method

based on Yamamoto's regression equation, randomly generating artificial acceleration with a same target spectrum.

The target spectrum is determined by Vietnamese National Standard TCVN 9386-2012 with Ba Dinh district: the peak reference acceleration: $a_{gR} = 0.0976g$; the important coefficient: $\gamma_I = 1.0$; site classification: A class.

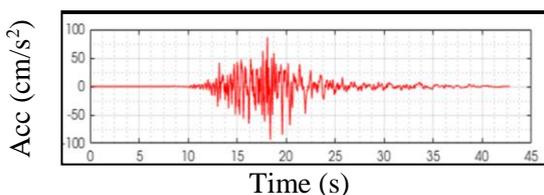Using PG02 to generate 18 accelerations (denoted from bd01_01a to bd01_18a) as shown in Figure 5 to Figure 22.
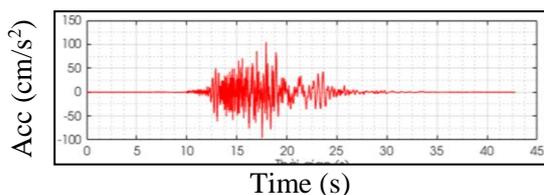

Figure 5. Acceleration bd01_01a

Figure 6. Acceleration bd01_02a
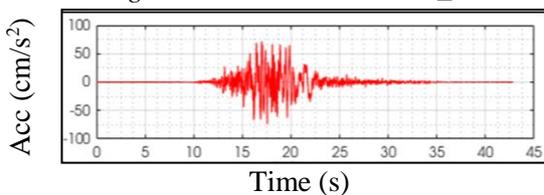
Figure 7. Acceleration bd01_03a
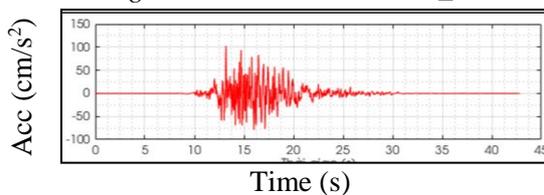
Figure 8. Acceleration bd01_04a
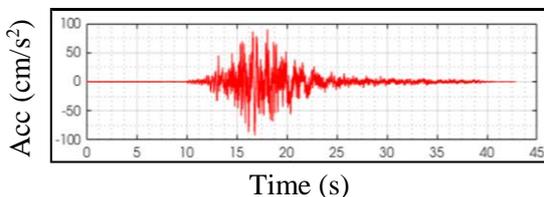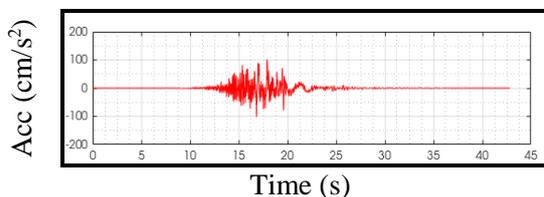

Figure 9. Acceleration bd01_05a

Figure 10. Acceleration bd01_06a

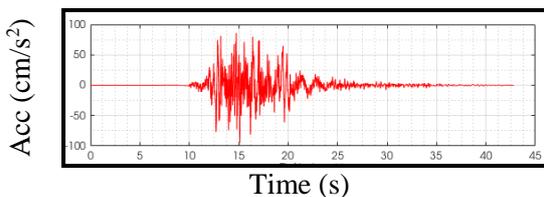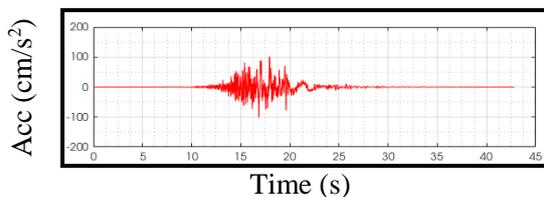*Figure 11. Acceleration bd01_07a*
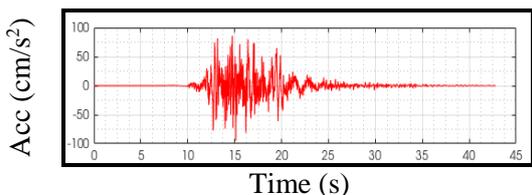

Figure 12. Acceleration bd01_08a

Figure 13. Acceleration bd01_09a

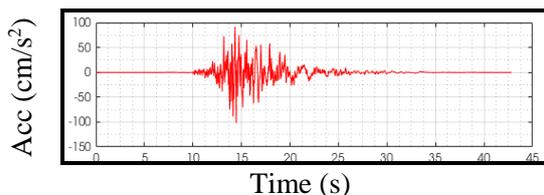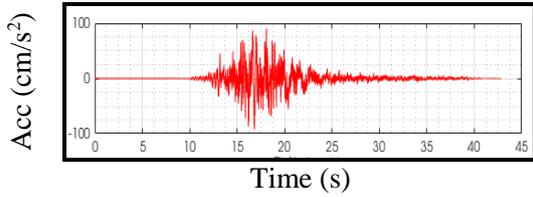*Figure 14. Acceleration bd01_10a*
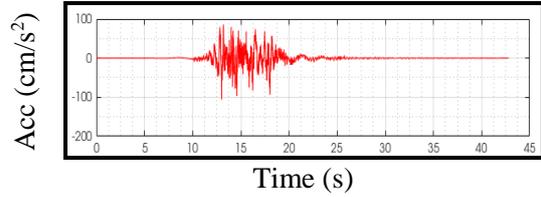
Figure 15. Acceleration bd01_11a

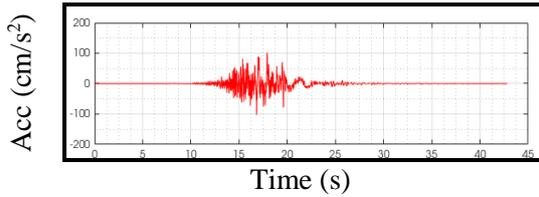*Figure 16. Acceleration bd01_12a*

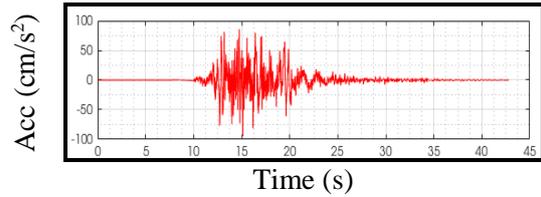*Figure 17. Acceleration bd01_13a*
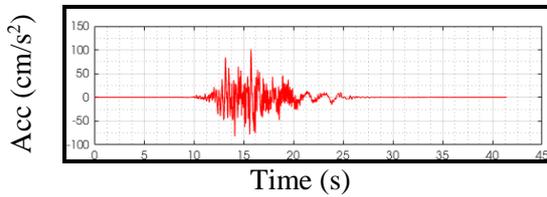

Figure 18. Acceleration bd01_14a

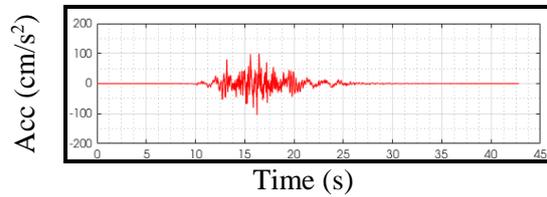*Figure 19. Acceleration bd01_15a*

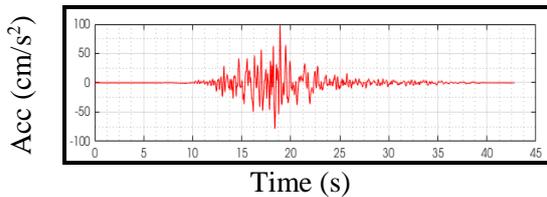*Figure 20. Acceleration bd01_16a*

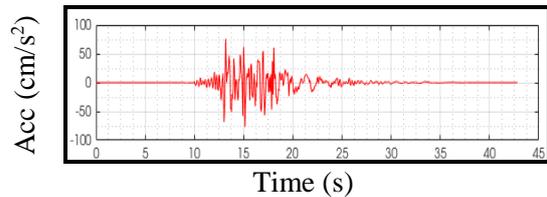

Figure 21. Acceleration bd01_17a

Figure 22. Acceleration bd01_18a

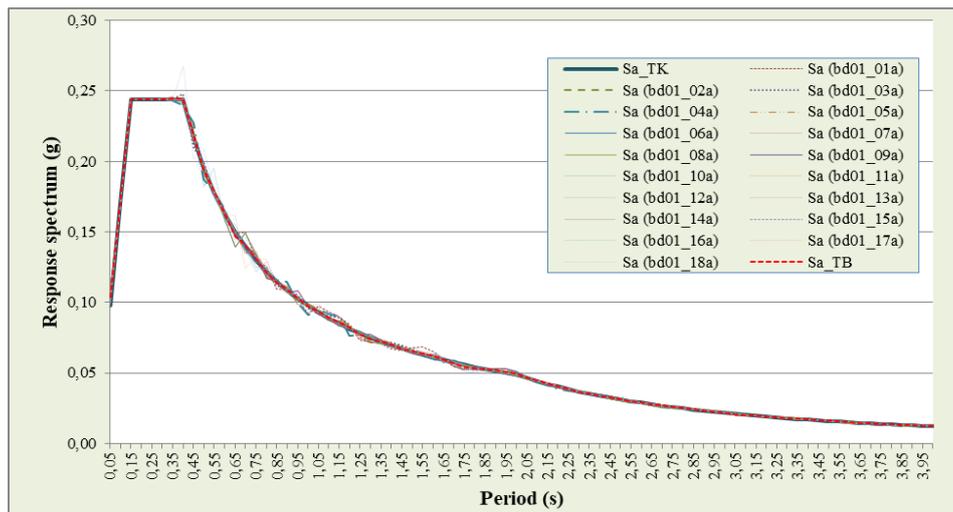The responses of 18 accelerations are shown in Figure 23.

Figure 23. Response spectrum of artificial accelerations are generated by PG02

4. Results

The maximum envelope of inner force (bending moment, shear force and normal force) are shown in Table 3. In this table, PGA, PGV, a_{RMS}, IA, t_{5-95} respectively are peak ground acceleration, peak ground velocity, root mean square acceleration, intensity of Arias, time duration of strong motion.

Table 3. Table of max inner forces results

Artificial acceleration	Parameters of acceleration					Max. inner forces		
	PGA (cm/s^2)	PGV cm/s)	a_{RMS} (cm/s^2)	IA (cm/s)	t_{5-95} (s)	Bending moment (kNm)	Shear force (kN)	Normal force (kN)
bd01-01a	93.73	6.21	25.63	10.800	9.28	138.96	105.08	765.54
bd01-02a	104.57	6.62	25.71	12.500	10.62	135.19	102.67	764.91
bd01-03a	73.69	6.89	27.99	9.450	6.78	138.98	105.61	765.54
bd01-04a	102.86	6.41	30.84	12.700	7.51	138.82	103.92	766.73
bd01-05a	92.15	8.05	27.74	10.600	7.73	140.02	106.45	766.91
bd01-06a	102.64	7.87	30.29	9.900	6.09	138.41	104.80	769.77
bd01-07a	94.65	7.53	29.15	11.700	7.72	138.50	105.12	768.06
bd01-08a	102.01	5.61	27.58	9.500	7.02	134.25	101.53	763.17
bd01-09a	105.74	7.93	32.82	10.900	5.70	142.04	105.70	769.45
bd01-10a	101.60	6.03	27.95	9.900	7.13	135.30	102.99	765.32
bd01-11a	104.24	6.49	26.95	9.900	7.67	136.07	103.28	767.08
bd01-12a	98.04	6.31	24.89	8.900	8.06	137.16	103.67	764.33
bd01-13a	76.83	6.86	28.99	12.200	8.16	140.42	106.26	764.62
bd01-14a	93.59	7.54	28.95	11.000	7.36	140.31	106.08	765.56
bd01-15a	88.56	8.31	28.85	9.500	6.43	136.96	103.17	768.53
bd01-16a	101.51	7.24	29.54	14.400	9.28	138.60	103.55	769.30
bd01-17a	99.88	8.18	30.89	10.200	5.98	142.33	107.34	769.57
bd01-18a	76.57	7.84	25.85	8.600	7.25	136.40	102.27	764.63
Mean	**95.16**	**7.11**	**28.37**	**10.70**	**7.54**	**138.26**	**104.42**	**766.61**

Statistical characteristics of max inner forces results are determined and presented in Table 4. Notice the ratio between standard deviation (σ) and mean (μ), the acceleration has negliable influence on normal force. Histogram of max. bending moment and max. shear forces are shown in Figure 23 and Figure 24 respectively.

Table 4. Table of results

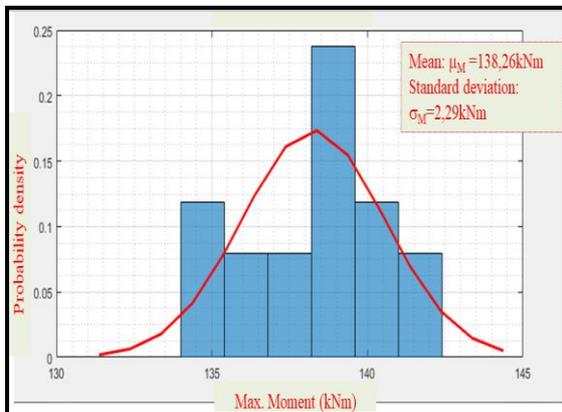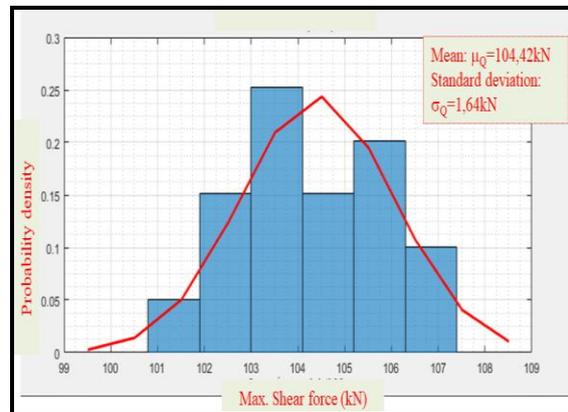| Row	Random variable	Unit	Mean (μ)	Standard deviation (σ)	μ/σ (%)	The range of random variable	
						($\mu-2\sigma$)	($\mu+2\sigma$)
1	Max. bending moment	kNm	138.26	2.29	1.66%	133.68	142.84
2	Max. shear force	kN	104.42	1.64	1.57%	101.14	107.70
3	Max. normal force	kN	766.61	2.07	0.27%	762.47	770.75

Figure 24. Histogram of max. bending moment

Figure 25. Histogram of max. shear forces

5. Conclusion

By above researches can be received some conclusions such as:

- Acceleration data set created by the PG02 program (18 accelerations) in accordance with Vietnamese National Standard TCVN 9386-2012 and suitable for seismic conditions of Ba Dinh district. These accelerations can be used to analyze the dynamics of earthquake-resistant underground structures.

- Although the peak of bd01_03a, bd01_13a, bd01_18a accelerations are smaller than the rest, though, the internal forces results of the 3 cases are not significantly different from results of others. Therefore, the peak ground acceleration value can be considered as one of the important factors affecting the internal force of the tunnel besides some other acceleration factors (PGV, a_{RMS}, t_{5-95}...). The effects of these factors on the behaviour of tunnel lining need to be investigated in more detail.

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PHÂN TÍCH KẾT CẤU VỎ HẦM DẠNG LẮP GHÉP CHỊU TÁC DỤNG CỦA ĐỘNG ĐẤT VỚI GIA TỐC NHÂN TẠO

Tóm tắt: *Bài báo này nhằm mục đích xây dựng bộ gia tốc nhân tạo phù hợp với điều kiện thành phố Hà Nội bằng cách sử dụng chương trình PG02, chương trình được xây dựng dựa trên hệ phương trình hồi quy của Yamamoto và phổ phản ứng mục tiêu theo Tiêu chuẩn TCVN 9386-2012. Sử dụng bộ số liệu giản đồ gia tốc đã xây dựng để tính toán kết cấu hầm của dự án Tuyến metro số 3 (Nhổn - Ga Hà Nội) chịu tác dụng của động đất bằng chương trình Plaxis2D. Các mối nối giữa các phân tố vỏ hầm được mô hình hóa theo giả thiết của Jassen. Kết quả cho thấy, giá trị gia tốc đỉnh chỉ là một trong những yếu tố ảnh hưởng đến nội lực của đường hầm bên cạnh một số yếu tố gia tốc khác (như: vận tốc đỉnh, gia tốc hiệu dụng, cường độ Arias, thời gian duy trì dao động mạnh).*

Từ khóa: *Tính toán công trình chịu động đất; vỏ hầm lắp ghép; giản đồ gia tốc nền nhân tạo; liên kết nửa cứng.*

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