CALCULATION OF TUNNEL LININGS UNDER SEISMIC LOADS OF THE EARTHQUAKES BY GENERATED THE ARTIFICIAL ACCELERATION APPLIED IN THE HA NOI AREA

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Abstract
Dynamic analysis of the tunnel affected by earthquakes requires the input are accelerations suitable for seismic conditions in the survey area. Hanoi city is the area where many tunnels are being built, but earthquakes in the past were not recorded, so the data of supply problems is limited. It is necessary to use artificial acceleration. One of the most widely used methods of creating artificial ground acceleration is the method of directly correcting available acceleration records according to spectral matching conditions. Base on this approach, the authors built PG01 program on Matlab language to generate the artificial acceleration. In this paper, the program PG01 will be used to create artificial ground acceleration which matching the response spectrum in Ba Dinh district, Hanoi city according to National Standard of Vietnam TCVN 9386-2012 with 3 different records. Take the obtained ground acceleration as input in to practice calculations the typical tunnel structure of the project Metro line No.3 (Nhon - Hanoi Station) using Plaxis2D program.

Keywords: *Underground structure; seismic design; spectral matching; time-history analyses; wavelet.*

1. Introduction

Metro lines are an integral part of the infrastructure of modern society. They are built in the areas subject to earthquake activities and must withstand both seismic and static loading. Some tunnels in fact have experienced significant damage in recent large earthquakes. Earthquake effects on underground structures can be grouped into two categories: ground shaking, ground failure such as liquefaction, fault displacement, and slope instability. Ground shaking refers to the ground motion or acceleration. In performance-based earthquake engineering for tunnel, a large number of ground-motion time histories are needed for analyzing the dynamic response of structures. Spectral matching procedure is an approach to create a time history (acceleration), which compatibles with a target response spectrum.

In Vietnam, studies of tunnels during an earthquake were also studied by the authors. The author Do Ngoc Anh (2016) [1] used numerical simulations to survey some types of tunnel structures subjected to seismic loads of the earthquakes. The

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author Le Bao Quoc (2015) [2] used the Plaxis 2D program to calculate the tunnel structure under geological conditions in Ho Chi Minh City,...

In the world, 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. (2006) [5] has instructed to use Plaxis 2D software to analyze underground structures affected by earthquakes. The authors Kontoe et al (2008) [8] presented a case study of the Bolu highway twin tunnels, which experienced extensive damage during the 1999 Duzce earthquake in Turkey, in this study, static and dynamic plane-strain finite element (FE) analyses were undertaken to investigate the seismic tunnel response at two sections and to compare the results with the post-earthquake field observations,... But they have not paid attention and given an appropriate acceleration spectrum. Therefore, the study of stability calculations for this work is the need for further in-depth studies.

2. Theoretical foundations for generating the artificial acceleration accordance with National Standard of Vietnam TCVN 9386-2012 by using response spectral matching producer

2.1. General theory of methods of generating the artificial acceleration from existing records under response spectrum matching conditions

When designing works according to design standards, background acceleration records are suitable for each seismic region. The input acceleration is a function of time and denoted by $a(t)$, the response spectrum for the acceleration $a(t)$ is denoted as S_a; target response spectrum is denoted as: S_{aTk}; response spectrum gap: $\Delta S_a = S_{aTk} - S_a$.

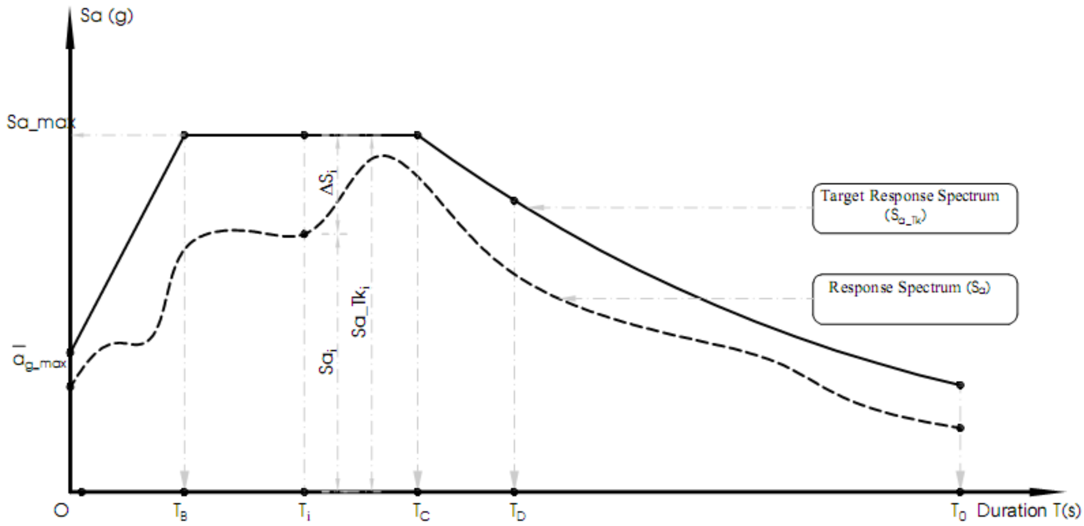

Figure 1. Respone and target spectrum of acceleration.

The problem is to find the function of representing the background acceleration over time in accordance with the rule of the input acceleration function and the response spectrum (S_a) close to the design target response spectrum (S_{aTk}).

The chosen method to solve this problem is to add a time function $\delta a(t)$ which is the sum of the basic Wavelet functions and have the response spectrum closest to the response spectrum gap ΔS_a.

The author has built the PG01 program based on Matlab language to help create acceleration matching the target response spectrum by adjusting an existing acceleration.

2.2. The target response spectrum parameters according to National Standard of Vietnam TCVN 9386-2012

In National Standard of Vietnam [4] the response spectrum $S_{aTK}(T)$ can be described as Fig. 2 and determined by following formulas:

$$0 \le T \le T_B : S_{aTK}(T) = a_g S\left[1 + \frac{T}{T_B}(\eta \cdot 2,5 - 1)\right] \tag{2.1}$$

$$T_B \le T \le T_C : S_{aTK}(T) = a_g \cdot S \cdot \eta \cdot 2,5 \tag{2.2}$$

$$T_C \le T \le T_D : S_{aTK}\left(T\right) = a_g \cdot S \cdot \eta \cdot 2,5\left[\frac{T_C}{T}\right] \tag{2.3}$$

$$T_D \le T \le 4s : S_{aTK}\left(T\right) = a_g \cdot S \cdot \eta \cdot 2,5\left[\frac{T_C.T_D}{T^2}\right] \tag{2.4}$$

where $S_{aTK}(T)$ - elastic respone spectrum; T - the duration of single freedom; a_g - acceleration design for A type of ground ($a_g = \gamma_I.a_{gR}$); T_B, T_C, T_D - the limited duration; S - the cofficient of the ground conditon; η - the cofficient relation to the damping ratio, $\eta = 1$ when $\xi = 5\%$.

Table 1. The cofficient S, T_B, T_C, T_D [4]

Ground type	S	T_B(s)	T_C(s)	T_D(s)
A	1	0,15	0,4	2
B	1,2	0,15	0,5	2
C	1,15	0,2	0,6	2
D	1,35	0,2	0,8	2
E	1,4	0,15	0,5	2

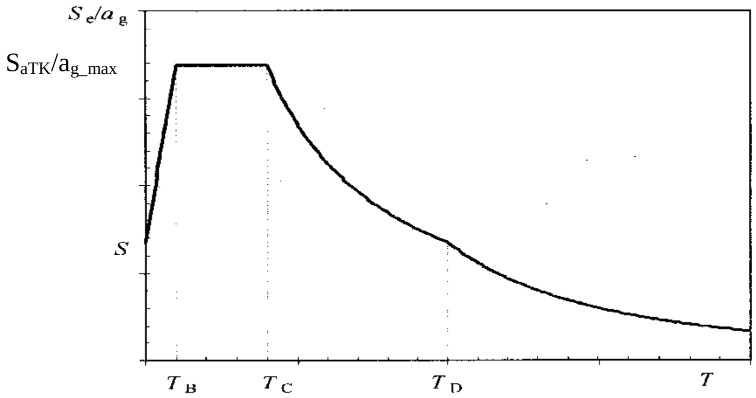

Figure 2. Response spectrum by TCVN 9386-2012 [4].

3. Numerical experiment PG01 program to create new acceleration according to response spectrum matching conditions

3.1. Input parameters for calibration by PG01

The National Standard of Vietnam TCVN 9386-2012 [4] required the minimum number of 3 artificial acceleration in the calculation. Proceeding with the scheme of artificial accelerometer based on the spectral matching condition by PG01 program in accordance with the conditions of Hanoi city.

For Hanoi city area, the results of the Geophysical Research Institute are presented in [3], which can be used the input ground acceleration as the record of ground acceleration in some areas where the characteristics of earthquake source structure and similar conditions, including:

- Record Dien Bien earthquake in 19/02/2001, M_S = 5,3; R_{hyp} = 12 km, Dien Bien station, R_{rup} = 19 km, PGA = 88,4 cm/s^2.

- Record 321 Campano Lucano earthquake (Italy) in 16/01/1981, M_S = 5,0; R_{hyp} = 15 km at Lioni - Macello station (Italy), R_{rup} = 8km. PGA = 63,6 cm/ s^2.

- Record ca064 Lang Cang earthquake (China) in 27/11/1988; M_S = 6,3; R_{hyp} = 12 km. Station: YNBB0003 (China), R_{rup} = 13 km. PGA= 105 cm/s^2.

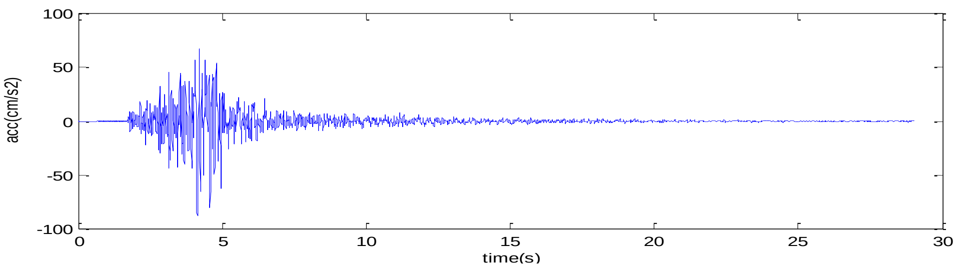

Figure 3. Ground motion record Dien Bien earthquake in 19/02/2001.

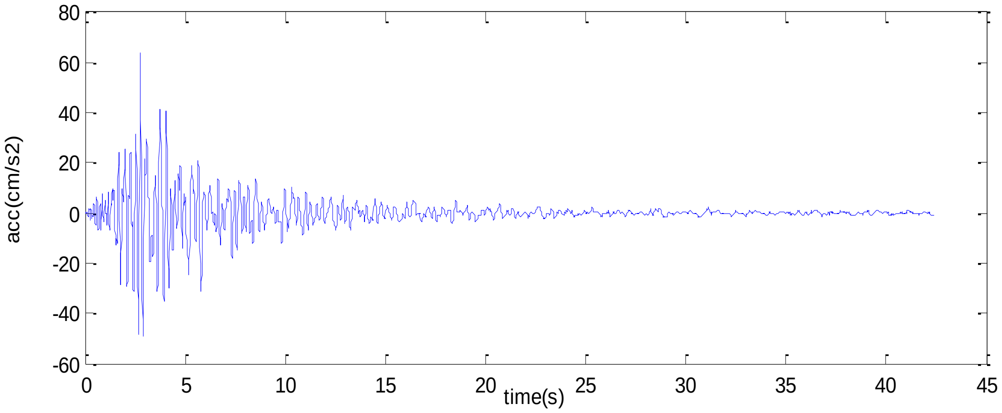

Figure 4. Ground motion record of Campano Lucano earthquake in 16/01/1981.

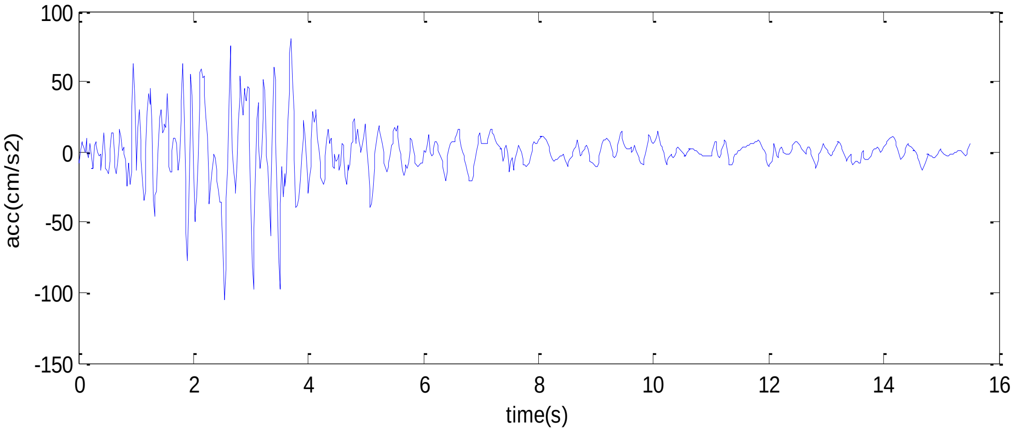

Figure 5. Ground motion record ca064 of Lang Cang earthquake in 27/11/1998.

Using the PG01 program in accordance with the type C with conditions of Ba Dinh district, the input parameters are:

- Maximum ground acceleration a_{gmax} = 0,0976g;

- Period parameters: T_B = 0,2(s); T_C = 0,6(s); T_D = 2(s).

3.2. Results of acceleration modified by PG01 program

Performing adjusting of each input ground acceleration band according to the response spectrum matching conditions by PG01 program with the input parameters as defined above, are obtained 3 new acceleration diagrams respectively. The response spectrum is close to the required response spectrum. These acceleration diagrams are denoted as BaDinh_01C, BaDinh_02C and BaDinh_03C and presented in Figures 6 to 11, summarizing the results of pre- and post-calibration acceleration are shown in Table 2.

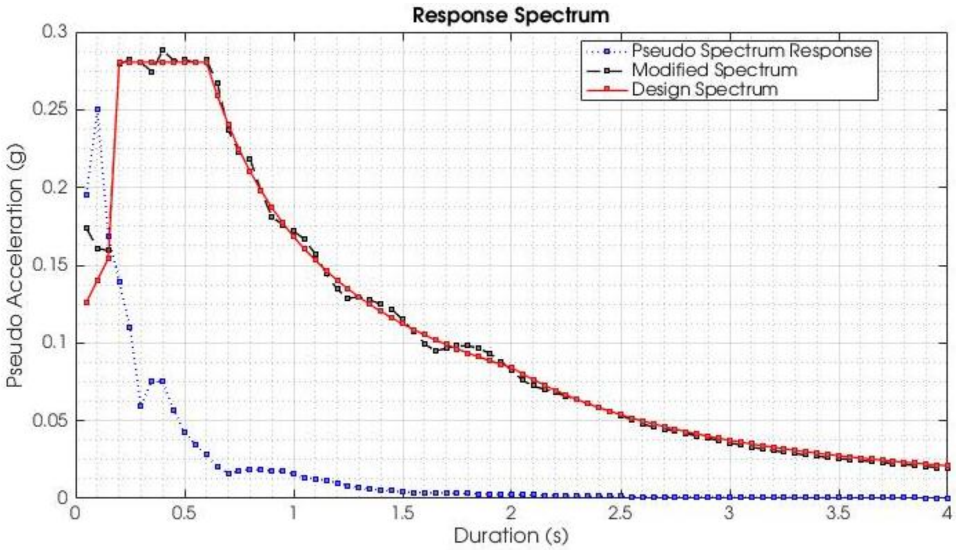

Figure 6. Results adjusting response spectrum for Dien Bien acceleration using PG01 program (BaDinh_01C).

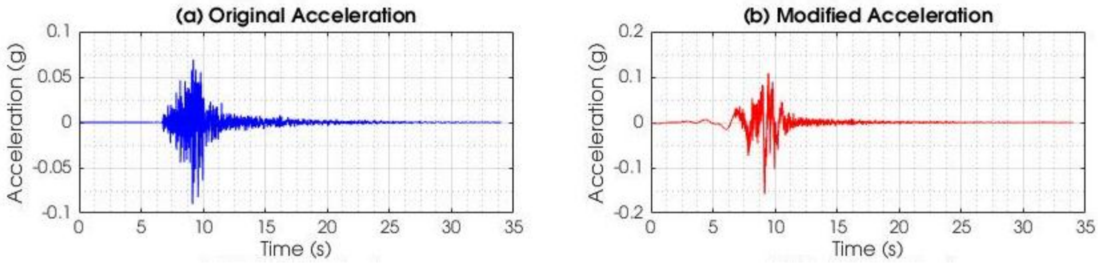

Figure 7. Original and modified acceleration with Dien Bien earthquake (BaDinh_01C).

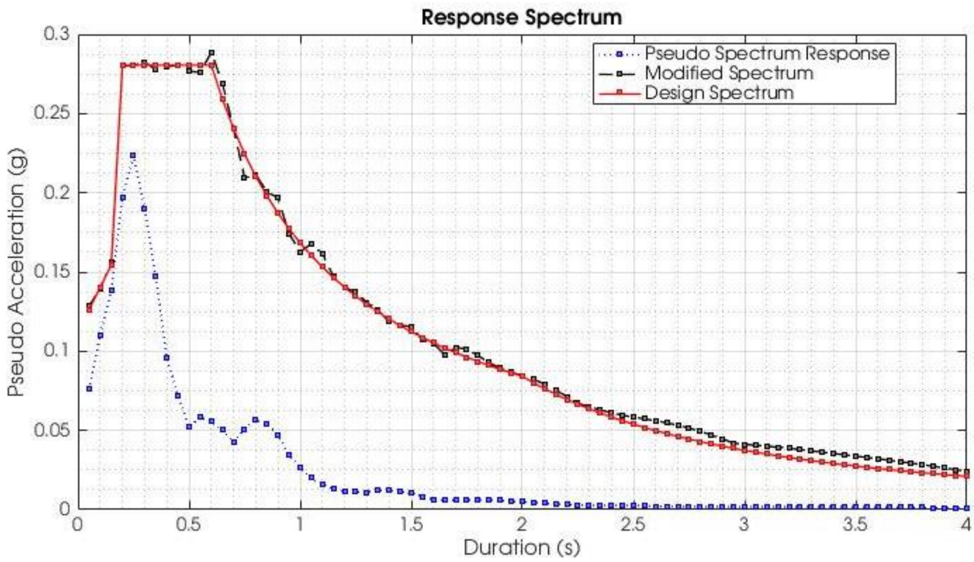

Figure 8. Results adjusting response spectrum for Campano Lucano acceleration using PG01 program (BaDinh_02C).

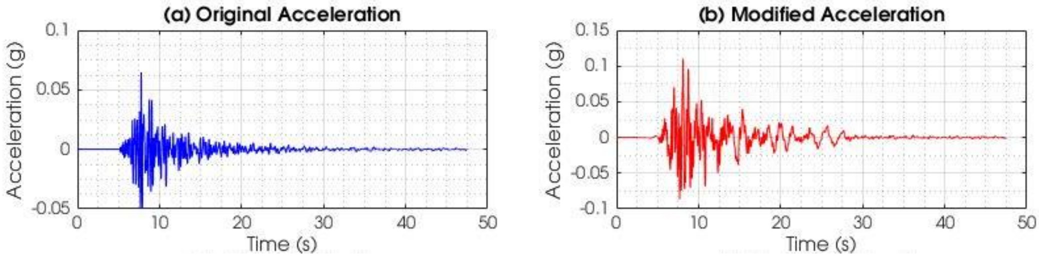

Figure 9. Original and modified acceleration with Campano Lucano earthquake (BaDinh_02C).

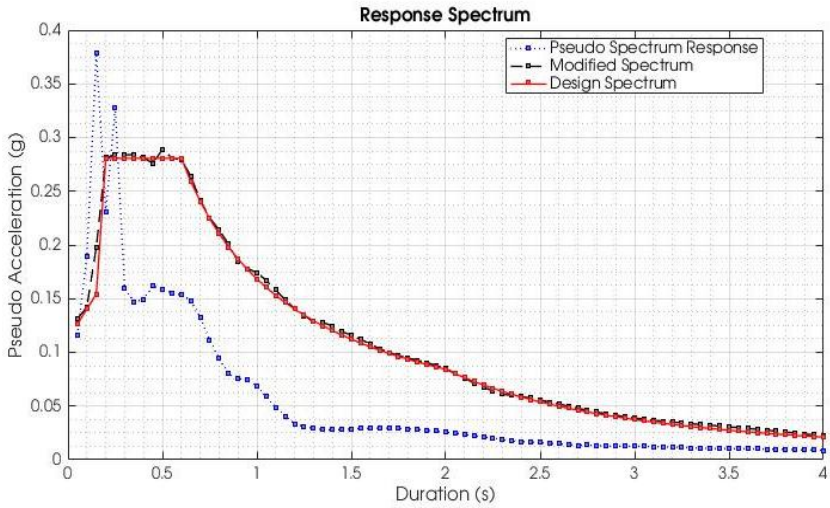

Figure 10. Results adjusting response spectrum for Lang Cang acceleration using PG01 program (BaDinh_03C).

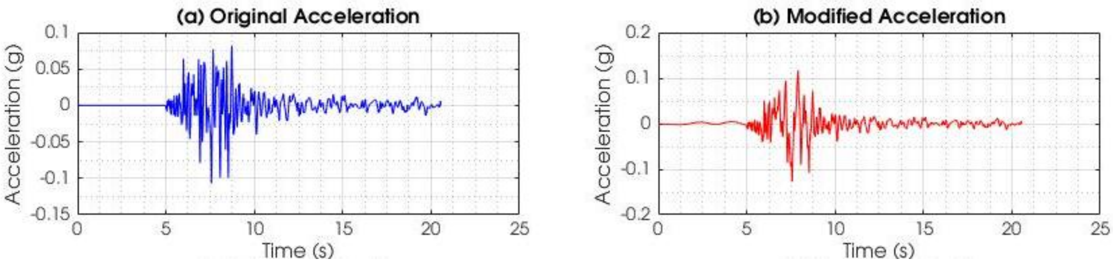

Figure 11. Original and modified acceleration with Lang Cang earthquake (BaDinh_03C).

Comment: From figures 6, 8 and 10, we can see that the modified results for the three original acceleration according to the response spectrum matching conditions by the PG01 program all response spectrum lines close to the response spectrum according to the National Standard of Vietnam TCVN 9386-2012 [4].

Table 2. The cofficient S, T_B, T_C, T_D [4]

Row	Raw Acceleration (input)	M_S	R_{hyp} (km)	R_{rup} (km)	Artificial Acceleration (output)	
					Peak (cm/s^2)	Denote as
1	Record Dien Bien earthquake in 19/02/2001	5,3	12	19	146	BaDinh_01C
2	Record 321 Campano Lucano earthquake	5,0	15	8	110	BaDinh_02C
3	Record ca064 Lang Cang earthquake	6,3	12	13	151	BaDinh_03C

4. Numerical example

In order to calculate the underground works impacted by earthquakes, in the research using the structural analysis program by Plaxis software. Which widely is applied in the world to analyze the problems of underground works subject under dynamic loads in general and earthquakes. Plaxis software was built basing on the Finite Element Method (FEM) and has many advantages to investigate the soil-structure interaction problems. The model for a single in the soil can be related in [1].

4.1. Modelling in Plaxis

Using 03 accelerations created from PG01 program to calculate the typical linings structure of the project in the Urban Railway (Metro) project No.3, Nhon-Hanoi Station, the underground section of the route between S9 and S10 is located at center of Ba Dinh district (plan as in Figure 12).

In fact, the length of tunnel is larger much more than the other dimensions. Hence, it is assumed that the structure performs as the plane strain problem. In the types of waves that form and propagate in soft ground due to the oscillation of the original bed rock layer, only the impact of shear waves on underground structures is considered.

In the calculation, the following assumptions should be applied:

- Structural and ground surrounding in terms of plane strain case;

- The boundary conditions of the circumference of the surveyed area, the left and right sides, are described as the non-reflective wave absorption band;

- The effects of earthquakes only consider the shear waves transmitted from the bedrock and have the propagation direction perpendicular to the horizontal ground and are modeled by the acceleration of forced displacement at the bedrock;

- Materials of structure working in the elastic phase;

- The ground is as elastic-plastic medium, the mechanical properties of the foundation vary by layer but within a layer are considered constant;

- Transposition and deformation at any point of the structure-environment system is small, so it does not consider the geometric nonlinear problem.

Figure 12. Plan of Metro line number 3 in Hanoi City.

The model of the structure material is assumed to be homogeneous and satisfies the linear elastic model, the hypothetical characteristics as shown in Table 3 below:

Table 3. Table of parameters of tunnel structure

Row	Parameters	Values	Units
1	Tunnel diameter (inner/outer)	6.0/6.6	m
2	Modulus of elasticity of tunnel concrete	3.5E+7	kPa
3	Poisson's coefficient for concrete	0.2	
4	The coefficient considers the interaction of the tunnel structure and ground surrounding, R_{int}	0.7	

The geological conditions of the construction site in Ba Dinh district in the project number 3 lines can be seen in Table 4. The rock layer above the bedrock consists of 6 different soil layers, the specific parameters of each layers are given in Table 4.

Table 4. Table of parameters of soil layers

Row	PARAMETERS	DENOTE	LAYERS					
			1	2	3	4	5	6
1	Layer thickness (m)		2,5	15	2,8	15,2	10,6	13,9
2	Model materials	Model	MC	MC	MC	MC	MC	MC
3	Natural density (g/cm^3)	γ	1,5	1,68	1,94	20	21	23
4	Poisson's coefficient	ν	0,3	0,4	0,32	0,3	0,3	0,28

Row	PARAMETERS	DENOTE	LAYERS					
			1	2	3	4	5	6
5	Modulus of elasticity of materials (kN/m^2)	E_{ref}	4000	2700	4800	1,17E+04	4,18E+04	7,12E+04
6	Cohesion force (kN/m^2)	C	5	10	25,1	20	25	40
7	Internal friction angle (°)	φ	20	6	16	25	30	40
8	Interactive coefficient	R_{inter}	1	1	1	1	1	1
9	Plasticity index of the soil	PI	4,6	34	10.9	34	20	34
10	Parameter K_0 when solving according to MC	K_0(Cal)	0,674	0,648	0,646	0,733	0,718	0,733

Based on structural data and engineering geological conditions, in the research are used Plaxis 8.2 software and standard boundary conditions for earthquake. Ground surrounding medium the tunnel is simulated as element 15-button triangle elements. The result of model in Plaxis 8.2 can be shown in Figure 13.

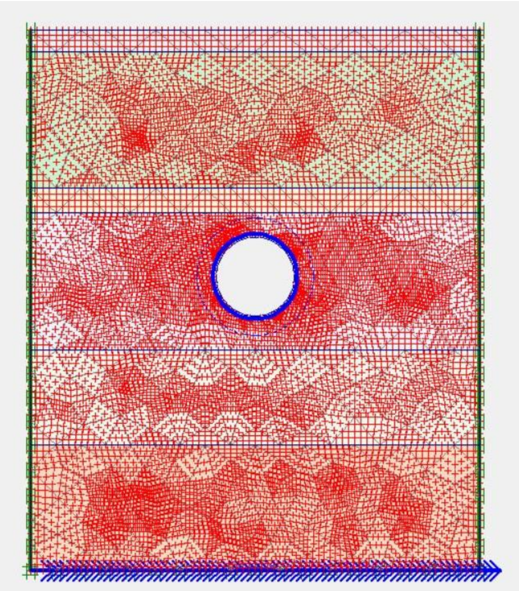

Figure 13. Element mesh of the model in Plaxis.

The basic acceleration to analysis consists of 3 artificial ground accelerations from BaDinh_01C, BaDinh_02C, BaDinh_03C, which received from above calculation.

4.2. Analysis results

By the dynamic analysis with the calculation steps in case of 3 artificial accelerations of BaDinh_01C, BaDinh_02C, BaDinh_03C can be received the results peak of bending moments, normal forces and shear forces as in figures 15-17. In particular, the points on the tunnel lining are conventional as shown in Figure 14 below.

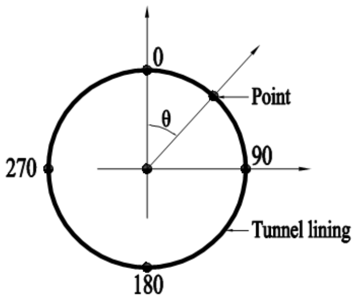

Figure 14. Conventional numbering points on the tunnel lining.

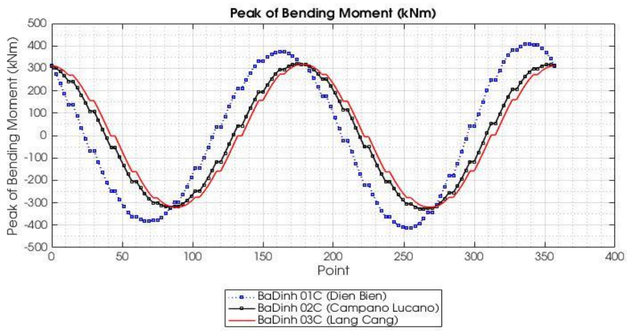

Figure 15. Survey results peak of bending moment for 3 load cases BaDinh_01C, BaDinh_02C, BaDinh_03C.

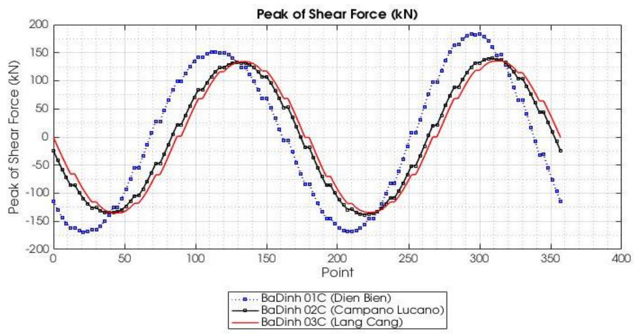

Figure 16. Survey results peak of shear force for 3 cases of load: BaDinh_01C, BaDinh_02C, BaDinh_03C.

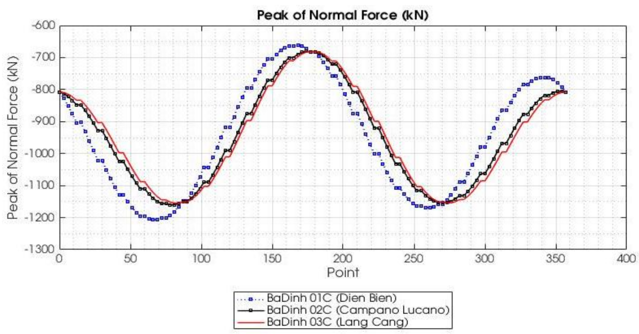

Figure 17. Survey results peak of normal force for 3 cases of load: BaDinh_01C, BaDinh_02C, BaDinh_03C.

From the diagram of internal force peak (bending moment, normal force and shear force), the maximum internal force components can be listed as shown in Table 5.

Table 5. Summary of survey results of maximum internal force components

TT	**The maximum values of internal forces**	**BaDinh_01C** (a_{gmax}=146cm/s^2)	**BaDinh_02C** (a_{gmax}=110cm/s^2)	**BaDinh_03C** (a_{gmax}=151cm/s^2)	**Unit**
1	Maximum bending momment	409,99	319,99	317,13	kNm
2	Maximum shear force	183,43	140,14	135,67	kN
3	Maximum normal force	1206,50	1159,98	1154,81	kN

5. Conclusion and discussion

By above researches can be recieved some conclusion such as:

- Although the acceleration of BaDinh_02C and BaDinh_03C has a relatively high peak values, the internal forces results of the two cases of BaDinh_02C and BaDinh_03C are not significantly different;

- Although the acceleration of base BaDinh_01C and BaDinh_03C has a negligible peak values, the internal force results of case 1 are significantly bigger than case 3, respectively 22,65% for bending moment; 26,04% for shear force and 4,28% for normal force.

And therefore, it can be seen that the peak acceleration values are not the only factor that affect on the internal strength of the structure but also must pay special attention to the distribution of energy according to different frequencies.

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TÍNH TOÁN KẾT CẤU CÔNG TRÌNH NGẦM CHỊU TẢI TRỌNG ĐỘNG ĐẤT TRÊN CƠ SỞ TẠO GIA TỐC NỀN NHÂN TẠO ÁP DỤNG TÍNH TOÁN TẠI KHU VỰC THÀNH PHỐ HÀ NỘI

Tóm tắt: *Bài toán phân tích động lực học công trình ngầm chịu tác dụng của động đất đòi hỏi cần có đầu vào là giản đồ gia tốc nền phù hợp với điều kiện địa chấn tại khu vực khảo sát. Thành phố Hà Nội là khu vực đang tiến hành xây dựng nhiều công trình ngầm đô thị chưa ghi nhận các trận động đất lớn nên số liệu cung cho các bài toán còn hạn chế, do đó cần phải sử dụng các giản đồ gia tốc nhân tạo. Một trong những phương pháp tạo giản đồ gia tốc nền nhân tạo được áp dụng rộng rãi trên thế giới là phương pháp hiệu chỉnh trực tiếp các bản ghi gia tốc nền có sẵn theo điều kiện khớp phổ phản ứng. Dựa trên cách tiếp cận này, nhóm tác giả đã xây dựng chương trình PG01 trên nền ngôn ngữ Matlab nhằm tự động phát gia tốc nền nhân tạo. Trong bài báo này, nhóm tác giả sẽ sử dụng chương trình PG01 để tạo gia tốc nền nhân tạo khớp với phổ phản ứng điều kiện nền phù hợp tại quận Ba Đình, thành phố Hà Nội theo tiêu chuẩn TCVN 9386-2012 với 3 số liệu đầu vào là 3 bản ghi khác nhau. Sử dụng các gia tốc nền thu được, thực hành tính toán cho dạng kết cấu điển hình của công trình tuyến Metro đoạn Nhổn - Ga Hà Nội, với địa chất điển hình tại vị trí quận Ba Đình bằng chương trình Plaxis2D.*

Từ khóa: Kết cấu công trình ngầm; thiết kế kháng chấn; khớp phổ phản ứng; phân tích động theo thời gian; hàm wavelet.

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