

ハノイ市における繊維質材料混合流動化処理土の埋 戻し地盤への適用に関する研究

メタデータ	言語: eng
	出版者:
	公開日: 2015-12-22
	キーワード (Ja):
	キーワード (En):
	作成者: ズゥオン, クヮン フン
	メールアドレス:
	所属:
URL	https://doi.org/10.15118/00005132

Acknowledgments

I would like to express my deepest gratitude and sincere appreciation to my supervisor, Professor Dr. Yukihiro Kohata, for his continuous support on my research, giving me the opportunity to perform this research and for his professional supervising, fruitful discussions and constructive suggestions throughout the course of this research. Thank you for your endless guidance and putting up with my frustration.

The author would like to thank Japanese Government (Monbukagakusho: MEXT) for providing scholarship on my doctor course helping me complete this research.

I also wish to thank Associate Professor Dr. Shima Kawamura and Professor Dr. Tsutomu Tsuchiya, my committee members, for their precious comments and invaluable advices helping me improve the quality of my research.

Special I am grateful to Dr. Nguyen Cong Giang for his introduction and recommendation to Muroran Institute of Technology and Professor Kohata before I applied for doctor course here.

I would like to thankfully appreciate and acknowledge the support and technical assistance of Dr. Nguyen Quang Dung (Ton Duc Thang University, Ho Chi Minh City) throughout this study. Notwithstanding his hectic work schedule, He always welcomed and positively responded to my queries.

My sincere thanks are due to Ms. Taiko Shiozaki and all the staffs of the Centre for International Relations, Muroran IT, Mr. Shinya Miyashita and Ms. Kozue Takekawa, Mr. Jinro Endo, Ms. Naoko Naito, Mr. Masahiro Takei and Ms. Hatsuki Noda for making my life in Hokkaido really comfortable and enjoyable. They always extended instant help whenever I needed. Especially thanks to Associate Professor Naoko Yamaji' teaching, my Japanese has been improved much.

The author would like to thankfully appreciate Mr. Satoshi Omura, Mr. Keita Ozaki, and all our lab members, Ms. Abiru Saori, Mr. Hiroyuki Imada, Mr. Do Tuan Anh and Mr. Hisanori Sugawara, Mr. Kenichi Yamamoto (Dorokogyo Co., Ltd.) and Mr. Makoto Kaji (Ueyama - Shinsui Co., Ltd.) as well for their cooperation in experimental works.

I am indeed indebted to my friends who assisted in life during three years of my doctor course, Mr. Phommasak Uthai, Mr. Toung Thoulasith, Mr. Snow Pipoliomess, Mr. Daniel L. Mabazza and International friends, Mr. Yuudai Miyamoto and Japanese friends, Teacher Sachiko Usami, Mr. Masahito Fukushima, Ms. Nguyen Thien Truc and Vietnamese friends here. Thanks to everyone.

Further, I also sincerely thank Dr. Do Dinh Duc and Associate Professor Dr. Vuong Ngoc Luu of the Hanoi Architectural University (HAU) for offering me recommendation letters to apply for the doctor course. I also thank to Concrete Structure Department, Civil Engineering Faculty and HAU for creating good conditions to study in Muroran IT.

Finally, I would like to express sincere thanks to my wife, Ms. Hoang Thu Trang and son, Duong Quang Huy for their unlimited patience, understanding, encouragement, and love during three years of research in Japan. Without their continuous support this work would not have been completed. Special thanks to my mother and family members in Vietnam for their support and encouragement.

Abstract

In this study, the applicability to back fill ground by Liquefied Stabilized Soil (LSS) mixed with fibered material in Hanoi city of Vietnam has been investigated. Research works including experiment and analysis have been conducted simultaneously aiming to promote the application of LSS in Vietnam in the coming time.

(1) Effect of time-dependency on strength and deformation characteristics of LSS mixed with fibered material was evaluated. A series of Consolidated–Undrained triaxial compression tests with measured pore water (CUB tests) under the various conditions at constant strain rates, constant deviator stress, and strain rates changed during monotonic loading have been carried out for LSS mixed with fibered material content of 0 and 20 kg/m³ at curing time of 28 and 56 days, respectively. Based on the test results, it was found that the effect of time-dependency is not seen in stress-strain curve independently of curing time.

(2) The difference in triaxial shear property of LSS mixed with fiber material cured in laboratory and at field was investigated to be carried out a series of CUB tests for both specimens of LSS mixed with fiber material amount of 0 and 20 kg/m³ prepared by trimming LSS retrieved from a model ground by block sampling and cured in laboratory at curing time of 28 and 56 days, respectively. Based on the test results, it was found that the maximum deviator stress in $q \sim \varepsilon_a$ relations of LSS mixed with fiber material cured at field tend to be larger than that cured in laboratory, and the brittle property of LSS after the peak in $q \sim \varepsilon_a$ relations has been improved to ductile property by the addition of fiber material even in field.

(3) In-situ stiffness of backfilling ground reinforced with fiber was investigated by using of portable Falling Weight Deflectometer at curing time of 28, 56 and 84 days, respectively. The stiffness was estimated by Young's modulus $E_{P,FWD}$ calculated from $K_{P,FWD}$ -value. In parallel, in order to comparing with the tangent Young's modulus E_{tan} obtained from $q \sim \varepsilon_a$ relations, a series of CUB tests have been carried out for specimens prepared by trimming LSS retrieved by block sampling from the model ground. It is considered that the $K_{P,FWD}$ -value is able to estimate the stiffness of backfilling ground by LSS reinforced with fiber.

(4) A procedure for prediction of train-induced vibration from railway tunnels in conformity with condition of Vietnam has been established as an example for Hanoi metro line No.3. The vibration propagation from the tunnel into the ground surface was analyzed by the 2-D FEM. The numerical results in terms of vibration velocity allow estimating the vibration velocity level, and then it is applicable to the prediction of train-induced vibration. The calculated vibrations indicated to be higher than the allowable threshold, therefore appropriate measures should be taken to decrease these vibrations.

(5) Using the established procedure, mitigation of train-induced vibration as using LSS for backfill ground of cut and cover tunnel was evaluated. If the LSS can mitigate the ground vibration, it will be a new advantage, and then LSS will be promoted more to use especially in metro projects in Vietnam. Thus, it is considered that LSS has an effective potential in mitigation of the train-induced vibration.

Table of Contents

Acknowledgments	i
Abstract	ii
List of Tables	vii
List of Figures	viii
Chapter 1 Introduction	1
1.1 General background	1
1.2 Objective and scopes	3
1.3 Organization of thesis	5
Chapter 2 Overview of Liquefied Stabilized Soil (LSS) in Japan and Its Feasibilit in Vietnam	
2.1 LSS - an effective method for utilization of excavated soil in Japan	8
2.2 Current situation of excavating work in Vietnam	15
2.2.1 Road cave-ins	15
2.2.2 Inappropriate disposal of excavated soils	16
2.2.3 Mining of new material from natural resources	17
2.3 Feasibility for utilization of LSS in Vietnam	18
2.4 Summary	19
Chapter 3 Deformation and Strength Characteristics of Liquefied Stabilized So	; 1
(LSS) Evaluated by Laboratory Testing	22
3.1 Introduction	22
3.2 Time-dependency on deformation property of LSS	23
3.2.1 Test procedure	23
3.2.1.1 Test material	23
3.2.1.2 Mixing method	24
3.2.1.3 Specimen preparation	24
3.2.1.4 Test method and equipment	24
3.2.2 Test results and discussion	25
3.2.2.1 Relationship between deviator stress and axial strain	25
3.2.2.2 Deformation property	27
3.2.3 Summary	30
3.3 Strength and deformation characteristics of LSS prepared at laboratory and field	30
3.3.1 Test procedure	30

3.3.1.1 Test material and mixing method	
3.3.1.2 Specimen preparation	
3.3.1.3 Test method	
3.3.2 Test results and discussion	
3.3.2.1 Relationship between deviator stress and axial strain	
3.3.2.2 Deformation property	
3.3.3 Summary	

Chapter 4 Mechanical Properties of Liquefied Stabilized Soil (LSS) Evaluated by Field Testing Method

40
40
40
40
41
42
42
42
42

5.1 Introduction	
5.2 Soil dynamic parameter and estimating methods	
5.3 Estimation of dynamic soil properties	
5.3.1 Estimation of shear wave velocity, vs, from SPT data	49
5.3.2 Estimation of shear wave velocity, vs, from CPT data	50
5.3.3 Estimation of damping ratio	52
5.4 Estimation of dynamic soil parameters for metro line No.3 in Hanoi city	53
5.4 Summary	58

Chapter 6 Study on Establishment Procedure for Prediction of Train-induce	
Vibration from Tunnel in Vietnam	60
6.1 Introduction	60
6.1.1 Definition of vibration level	61

6.1.2 Problem of tunnel-soil interaction	1
6.1.3 Basic of FEM on tunnel-soil interaction problem	2
6.2 Analysis procedure	4
6.2.1 Selection of material model	6
6.2.2 Simulation of moving train load	8
6.2.3 Estimation of natural frequencies of multi-layered ground7	2
6.2.3.1 Estimation of natural frequencies for metro line No.37	4
6.2.3.2 Influence of multi-layered ground and damping of soil7	6
6.3 Prediction of train-induced vibration from metro line No.37	8
6.3.1 Tunnel and ground conditions	9
6.3.2 Finite element model7	9
6.3.3 Analysis results and discussion	2
6.3.3.1 Vibration level	2
6.3.3.2 Influence of random frequency due to irregularities on vibration level8	5
6.3.3.3 Influence of train velocity on the vibration level	5
6.3.3.4 Influence of tunnel shape on the vibration level	6
6.3.3.5 Influence of sidewall thickness on the vibration level	6
6.3.3.6 Influence of weak soil layer on the propagation of vibration velocity8	7
6.4 Summary	8

7.1 Introduction	
7.2 Analysis procedures	94
7.2.1 Simulation of moving train load	94
7.2.2 Case study and tunnel, ground conditions	96
7.2.3 Characteristics of backfilling materials	
7.2.4 Numerical model in Plaxis	
7.3 Results and discussion	99
7.3.1 Vibration velocity in case 1 and case 2	99
7.3.2 Maximum vibration velocity and level in case 1 and case 2	
7.3.3 Vibration velocity in case 3 and case 4	
7.3.4 Maximum vibration velocity and level in case 3 and case 4	104
7.4 Summary	106

Chapter 8 Conclusions and Recommendations	108
8.1 Conclusions	108

8.2 Recommendations	110
Appendix A Simulation of moving train load with velocity of 80 km/h by en method	npirical 111
Appendix B Simulation of moving train load with velocity of 80 km/h by Ne numerical method	wmark 115
Appendix C Simulation of moving train load with velocity of 60 km/h by Ne numerical method	wmark 121
Appendix D Contour of displacement and acceleration for case 1 and case 2	
Appendix E Contour of displacement and acceleration for case 3 and case 4	129

List of Tables

Table 3.1 Physical Properties of NSF-CLAY	
Table 3.2 Test conditions of axial strain rate	
Table 3.3 Initial Young's modulus E ₀ (MPa)	
Table 5.1 SPT (N_{60}^*) – Shear Wave Velocity, v _s , Equation for Sand	49
Table 5.2 Recommended Age Scaling Factors (ASF) for SPT	49
Table 5.3 CPT (q_c) – Shear Wave Velocity, v_s , Equations for Soils	
Table 5.4 Recommended Age Scaling Factors (ASF) for CPT	
Table 5.5 Geological classification	
Table 5.6 Estimation of shear wave velocity, v _s with depth of soil layers for No.3 in Hanoi city	metro line 57
Table 5.7 Results of computing the shear wave velocity and damping ratio at K	m0+94058
Table 5.8 Results of computing the shear wave velocity and damping ratio at K	m6+70058
Table 6.1 Geotechnical properties of soil layers in Metro line No.3	
Table 6.2 Parameters of tunnel	
Table 7.1 Geotechnical properties of soil layers	
Table 7.2 Parameters of tunnel	
Table 7.3 Physical properties of backfilling material	

List of Figures

Figure 1.1 Metro rout map of Hanoi city up to 2020	2
Figure 1.2 Metro rout map of Hochiminh city up to 2020	2
Figure 1.3(a) $q \sim \epsilon_a$ relation of Vinh Phuc-Clay LSS	4
Figure 1.3(b) $q \sim \epsilon_a$ relation of NSF-Clay LSS	4
Figure 1.4 Flow chart of this dissertation	5
Figure 2.1 Flow of Liquefied soil stabilized method (Tomoharu et al., 2005)	10
Figure 2.2 Liquefied soil stabilizing method (LSS method, Miki et al., 2005)	10
Figure 2.3 Production system for foam mixed lightweight soil	11
Figure 2.4 Light-weight banking method using in-situ surface soils	11
Figure 2.5 Cement treated soil using as slope protection (Tang et al., 2001)	12
Figure 2.6 Placement of cement treated soil along slope (Tang et al., 2001)	12
Figure 2.7 Two stages construction method using lightly lime/cement treated claye soils (Hino et al., 2008)	y 12
Figure 2.8 Use of LSS for filling cavity under road surface	13
Figure 2.9a LSS used for backfill at upper part of cut and cover tunnel	13
Figure 2.9b LSS used for invert material of shield tunnel	13
Figure 2.10a Backfilling of building foundation	14
Figure 2.10b Backfilling of underwater seawall	14
Figure 2.10c Backfilling of abutment	14
Figure 2.10d Backfilling of box culvert	14
Figure 2.10e Backfilling of underground pipe	14
Figure 2.10f Filling of void under floor due to subsidence	14
Figure 2.11 Backfilling of LSS	15
Figure 2.12 Cave-ins and road collapses in Hanoi city	15
Figure 2.13 Cave-ins and road collapses in Ho Chi Minh city	15
Figure 2.14 Broken water supply pipe line in Hanoi	16
Figure 2.15 Repairing and backfilling work of the broken water supply pipe line	16
Figure 2.16 Inappropriate disposal of excavated soils from construction sites in Hanoi	17
Figure 2.17 Bank erosion due to depletion of sand in streambed	17
Figure 2.18a Sand mining near Thang Long Bridge	18
Figure 2.18b Sand mining near Can Tho Bridge	18
Figure 3.1 Aging effect on stress-strain	23
Figure 3.2 Loading rate effect on stress-strain relation	23
Figure 3.3 Schematic of CUB test apparatus	24
Figure 3.4 $q \sim \epsilon_a$ relation for all cases	25

Figure 3.5 q ϵ_a relation for case 1, 2	26
Figure 3.6 q ϵ_a relation for case 3, 4	26
Figure 3.7 q ϵ_a relation at small strain for case 1, 2	26
Figure 3.8 q ϵ_a relation at small strain for case 3, 4	26
Figure 3.9 Definition of various Young's moduli	27
Figure 3.10 $E_{tan}/E_0 \sim q/q_{max}$ relation for case 1, 2	28
Figure 3.11 $E_{tan}/E_0 \sim q/q_{max}$ relation for case 3, 4	28
Figure 3.12 E_{tan} ~log ε_a relation for case 1, 2	29
Figure 3.13 E_{tan} log ϵ_a relation for case 3, 4	29
Figure 3.14 Schematic drawing of pits	31
Figure 3.15 Case 1 of test condition	31
Figure 3.16 Case 2 of test condition	31
Figure 3.17 q~ ε_a relations at 28 days	32
Figure 3.18 q~ ε_a relations at 56 days	32
Figure 3.19 Definition of various Young's moduli	33
Figure 3.20a q _{max} ~curing days relations	33
Figure 3.20b E ₀ ~curing days relations	33
Figure 3.21 $E_{tan}/E_0 \sim q/q_{max}$ relations for case 1	34
Figure 3.22 $E_{tan}/E_0 \sim q/q_{max}$ relations for case 2	34
Figure 3.23 E_{tan} -log ϵ_a relations for case 1	35
Figure 3.24 E_{tan} log ϵ_a relations for case 2	35
Figure 3.25 $E_{eq}/E_0 \sim q/q_{max}$ relations	36
Figure 4.1 Schematic of portable FWD test apparatus	40
Figure 4.2 An example of displacement and loading stress at one measurement point	41
Figure 4.3 K _{P.FwD} -value~curing days relation	42
Figure 4.4 K _{P.FwD} -value~dry density relation	42
Figure 4.5 Figure 4.5 $E_{P,FWD}$ and $E_{tan} \sim \log \epsilon_a$ relations	43
Figure 5.1 Field and laboratory methods for determining dynamic parameters	46
Figure 5.2 Overview of possible shear strain amplitudes	47
Figure 5.3 h~ γ relation of sandy soils (PI = 0 %)	53
Figure 5.4 h~ γ relation of plastic soils (PI = 35 %)	53
Figure 5.5 Computing result of shear wave velocity from CPT data at penetration point HX02 of metro line 03	t 56
Figure 5.6 Computing result of shear wave velocity from CPT data at penetration point HX08 of metro line 03	t 56
Figure 6.1 Schematic simplified the model of train-track-tunnel problem	62

Figure 6.2 So tu	chematic diagram of prediction procedure for train-induced vibration from innel	65
Figure 6.3 M	Iohr-Coulomb model parameters in Plaxis	67
Figure 6.4 C	am-Clay model parameters in Plaxis	67
Figure 6.5 S	Schematic of single wheel load on track and diagram of its function according to Bernoulli-Euler	69
Figure 6.6 G	eometric profile of train wheel loads	70
Figure 6.7 C	haracteristic of the dynamic load applied to the tunnel	72
Figure 6.8 In	nput excitation	73
Figure 6.9 Pr	rocedure for estimation of natural frequency in Plaxis	74
Figure 6.10 I	Estimation of natural frequency of ground at Km0+940	75
Figure 6.11 I	Estimation of natural frequency of ground at Km6+700	76
Figure 6.12 l	Influence of multi-layered ground on natural frequency	77
Figure 6.13 l	Influence of damping of soil on natural frequency	78
Figure 6.14	Tunnel shape and ground profile at Km0+940	80
Figure 6.15	Tunnel shape and ground profile at Km6+700	80
Figure 6.16 l	Finite element model with symmetrical loading at Km0+940	81
Figure 6.17 I	Finite element mesh	81
Figure 6.18 (Graph of total vibration velocity with time at B with $v=80$ km/h, $f_{ir}=63$ Hz in the case of symmetrical and nonsymmetrical loading	82
Figure 6.19	Graph of vertical and horizontal vibration velocities with time at B of Km0+940 with $v = 80$ km/h, $f_{ir} = 63$ Hz	83
Figure 6.20	Graph of total vibration velocities with time at B, E, H of Km0+940 with $v = 80$ km/h, $f_{ir} = 63$ Hz	83
Figure 6.21	Relationship between vibration level and elapsed time of loading at B, E, H of Km0+940 with $v = 80$ km/h, $f_{ir} = 63$ Hz	84
Figure 6.22	Relationship between distance and maximum vibration velocity and level at Km0+940 with $v = 80$ km/h	84
Figure 6.23	Relationship between distance and maximum vibration velocity and level at Km6+700, $v = 80$ km/h	84
Figure 6.24	Relationship between maximum vibration level and velocity and random frequency at B of Km0+940 with $v = 80$ Km/h	85
Figure 6.25 H	Relationship between maximum vibration level and velocity and train velocity at B of Km0+940, L_{ir} = 30 cm	85
Figure 6.26	Relationship between distance and maximum vibration level and velocity at Km6+700 with $v = 80$ Km/h, $L_{ir} = 30$ cm in case of the circle and rectangle tunnel shape	86
Figure 6.27	Relationship between distance and maximum vibration level and velocity at Km0+940 with $v=80$ Km/h, $L_{ir}=30$ cm in the case of different tunnel thicknesses.	86

Figure 6.29 Graph of vertical vibration velocity with time at bottom (X=7, Y=-16.4 m) and top (X=7 m, Y=-4.79 m) of layer 1 with ν =80 km/h, f_{ν} =63 Hz	Figure 6.28 Graph of horizontal vibration velocity with time at bottom (X=7, Y=-16.4 and top (X=7 m, Y=-4.79 m) of layer 1 with v=80 km/h, <i>f_{ir}</i> =63 Hz	· m) 87
Figure 6.30 Change of vibration level with depth at X=7 m with v =80 km/h, L_{ir} =30 cm	Figure 6.29 Graph of vertical vibration velocity with time at bottom (X=7, Y=-16.4 m) top (X=7 m, Y=-4.79 m) of layer 1 with $v=80$ km/h, $f_{ir}=63$ Hz	and 87
Figure 7.1 Schematic simplified vibration model of train94Figure 7.2 Characteristic of dynamic load applied to the tunnel96Figure 7.3 Tunnel shape and ground profile97Figure 7.4 View of modelling in Plaxis99Figure 7.5 Finite element generation in Plaxis99Figure 7.6 Graph of velocity at A in case 1 and case 2, respectively with $v = 60$ km/h100Figure 7.7 Graph of velocity at B in case 1 and case 2, respectively with $v = 60$ km/h101Figure 7.8 Graph of velocity at E in case 1 and case 2, respectively with $v = 60$ km/h101Figure 7.9 Graph of velocity at H in case 1 and case 2, respectively with $v = 60$ km/h101Figure 7.10 Contour of velocity at 1.5 sec of loading in case 1102Figure 7.12 Relationship between distance and maximum vibration velocity and level in case 1 and case 2, respectively with $v = 60$ km/h103Figure 7.14 Graph of velocity at A in case 3 and case 4, respectively with $v = 60$ km/h103Figure 7.13 Graph of velocity at B in case 3 and case 4, respectively with $v = 60$ km/h103Figure 7.16 Graph of velocity at E in case 3 and case 4, respectively with $v = 60$ km/h103Figure 7.16 Graph of velocity at H in case 3 and case 4, respectively with $v = 60$ km/h104Figure 7.16 Graph of velocity at 1.5 sec of loading in case 3105Figure 7.17 Contour of velocity at 1.5 sec of loading in case 3105Figure 7.18 Contour of velocity at 1.5 sec of loading in case 3105Figure 7.19 Relationship between distance and maximum vibration velocity and level in case 3 and case 4, respectively with $v = 60$ km/h103 </td <td>Figure 6.30 Change of vibration level with depth at X=7 m with $v=80$ km/h, $L_{ir}=30$ cm</td> <td>188</td>	Figure 6.30 Change of vibration level with depth at X=7 m with $v=80$ km/h, $L_{ir}=30$ cm	188
Figure 7.2 Characteristic of dynamic load applied to the tunnel	Figure 7.1 Schematic simplified vibration model of train	
Figure 7.3 Tunnel shape and ground profile97Figure 7.4 View of modelling in Plaxis99Figure 7.5 Finite element generation in Plaxis99Figure 7.6 Graph of velocity at A in case 1 and case 2, respectively with $v = 60$ km/h100Figure 7.7 Graph of velocity at B in case 1 and case 2, respectively with $v = 60$ km/h100Figure 7.8 Graph of velocity at E in case 1 and case 2, respectively with $v = 60$ km/h101Figure 7.9 Graph of velocity at H in case 1 and case 2, respectively with $v = 60$ km/h101Figure 7.10 Contour of velocity at 1.5 sec of loading in case 1102Figure 7.11 Contour of velocity at 1.5 sec of loading in case 2102Figure 7.12 Relationship between distance and maximum vibration velocity and level in case 1 and case 2, respectively with $v = 60$ km/h103Figure 7.13 Graph of velocity at A in case 3 and case 4, respectively with $v = 60$ km/h103Figure 7.15 Graph of velocity at E in case 3 and case 4, respectively with $v = 60$ km/h104Figure 7.16 Graph of velocity at H in case 3 and case 4, respectively with $v = 60$ km/h104Figure 7.16 Graph of velocity at H in case 3 and case 4, respectively with $v = 60$ km/h104Figure 7.16 Graph of velocity at 1.5 sec of loading in case 3105Figure 7.17 Contour of velocity at 1.5 sec of loading in case 4105Figure 7.18 Contour of velocity at 1.5 sec of loading in case 4105Figure 7.19 Relationship between distance and maximum vibration velocity and level in case 3 and case 4, respectively with $v = 60$ km/h105Figure 7.19 Relationship between distance and maximum vibration velocity	Figure 7.2 Characteristic of dynamic load applied to the tunnel	
Figure 7.4 View of modelling in Plaxis99Figure 7.5 Finite element generation in Plaxis99Figure 7.6 Graph of velocity at A in case 1 and case 2, respectively with $v = 60$ km/h100Figure 7.7 Graph of velocity at B in case 1 and case 2, respectively with $v = 60$ km/h100Figure 7.8 Graph of velocity at E in case 1 and case 2, respectively with $v = 60$ km/h101Figure 7.9 Graph of velocity at H in case 1 and case 2, respectively with $v = 60$ km/h101Figure 7.10 Contour of velocity at 1.5 sec of loading in case 1102Figure 7.12 Relationship between distance and maximum vibration velocity and level in case 1 and case 2, respectively with $v = 60$ km/h102Figure 7.13 Graph of velocity at B in case 3 and case 4, respectively with $v = 60$ km/h103Figure 7.15 Graph of velocity at E in case 3 and case 4, respectively with $v = 60$ km/h103Figure 7.16 Graph of velocity at E in case 3 and case 4, respectively with $v = 60$ km/h104Figure 7.17 Contour of velocity at E in case 3 and case 4, respectively with $v = 60$ km/h104Figure 7.18 Graph of velocity at H in case 3 and case 4, respectively with $v = 60$ km/h104Figure 7.17 Contour of velocity at 1.5 sec of loading in case 3105Figure 7.18 Contour of velocity at 1.5 sec of loading in case 4105Figure 7.19 Relationship between distance and maximum vibration velocity and level in case 3 and case 4, respectively with $v = 60$ km/h104Figure 7.19 Relationship between distance and maximum vibration velocity and level in case 3 and case 4, respectively with $v = 60$ km/h105Figure 7.19 Relationship between dista	Figure 7.3 Tunnel shape and ground profile	
Figure 7.5 Finite element generation in Plaxis99 Figure 7.6 Graph of velocity at A in case 1 and case 2, respectively with $v = 60$ km/h100 Figure 7.7 Graph of velocity at B in case 1 and case 2, respectively with $v = 60$ km/h101 Figure 7.8 Graph of velocity at E in case 1 and case 2, respectively with $v = 60$ km/h101 Figure 7.9 Graph of velocity at H in case 1 and case 2, respectively with $v = 60$ km/h101 Figure 7.10 Contour of velocity at 1.5 sec of loading in case 1102 Figure 7.11 Contour of velocity at 1.5 sec of loading in case 2102 Figure 7.12 Relationship between distance and maximum vibration velocity and level in case 1 and case 2, respectively with $v = 60$ km/h102 Figure 7.13 Graph of velocity at A in case 3 and case 4, respectively with $v = 60$ km/h103 Figure 7.16 Graph of velocity at E in case 3 and case 4, respectively with $v = 60$ km/h103 Figure 7.16 Graph of velocity at H in case 3 and case 4, respectively with $v = 60$ km/h103 Figure 7.16 Graph of velocity at H in case 3 and case 4, respectively with $v = 60$ km/h104 Figure 7.16 Graph of velocity at H in case 3 and case 4, respectively with $v = 60$ km/h104 Figure 7.17 Contour of velocity at 1.5 sec of loading in case 3	Figure 7.4 View of modelling in Plaxis	
Figure 7.6 Graph of velocity at A in case 1 and case 2, respectively with $v = 60$ km/h100 Figure 7.7 Graph of velocity at B in case 1 and case 2, respectively with $v = 60$ km/h101 Figure 7.8 Graph of velocity at E in case 1 and case 2, respectively with $v = 60$ km/h101 Figure 7.9 Graph of velocity at H in case 1 and case 2, respectively with $v = 60$ km/h101 Figure 7.10 Contour of velocity at 1.5 sec of loading in case 1	Figure 7.5 Finite element generation in Plaxis	
Figure 7.7 Graph of velocity at B in case 1 and case 2, respectively with $v = 60$ km/h100 Figure 7.8 Graph of velocity at E in case 1 and case 2, respectively with $v = 60$ km/h101 Figure 7.9 Graph of velocity at H in case 1 and case 2, respectively with $v = 60$ km/h101 Figure 7.10 Contour of velocity at 1.5 sec of loading in case 1	Figure 7.6 Graph of velocity at A in case 1 and case 2, respectively with $v = 60$ km/h	100
Figure 7.8 Graph of velocity at E in case 1 and case 2, respectively with $v = 60$ km/h101 Figure 7.9 Graph of velocity at H in case 1 and case 2, respectively with $v = 60$ km/h101 Figure 7.10 Contour of velocity at 1.5 sec of loading in case 1	Figure 7.7 Graph of velocity at B in case 1 and case 2, respectively with $v = 60 \text{ km/h}$.	100
Figure 7.9 Graph of velocity at H in case 1 and case 2, respectively with $v = 60$ km/h101 Figure 7.10 Contour of velocity at 1.5 sec of loading in case 1	Figure 7.8 Graph of velocity at E in case 1 and case 2, respectively with $v = 60$ km/h	101
Figure 7.10 Contour of velocity at 1.5 sec of loading in case 1	Figure 7.9 Graph of velocity at H in case 1 and case 2, respectively with $v = 60$ km/h	101
Figure 7.11 Contour of velocity at 1.5 sec of loading in case 2	Figure 7.10 Contour of velocity at 1.5 sec of loading in case 1	
Figure 7.12 Relationship between distance and maximum vibration velocity and level in case 1 and case 2, respectively with $v = 60$ km/h102 Figure 7.13 Graph of velocity at A in case 3 and case 4, respectively with $v = 60$ km/h103 Figure 7.14 Graph of velocity at B in case 3 and case 4, respectively with $v = 60$ km/h104 Figure 7.15 Graph of velocity at E in case 3 and case 4, respectively with $v = 60$ km/h104 Figure 7.16 Graph of velocity at H in case 3 and case 4, respectively with $v = 60$ km/h104 Figure 7.17 Contour of velocity at 1.5 sec of loading in case 3	Figure 7.11 Contour of velocity at 1.5 sec of loading in case 2	102
Figure 7.13 Graph of velocity at A in case 3 and case 4, respectively with $v = 60$ km/h103 Figure 7.14 Graph of velocity at B in case 3 and case 4, respectively with $v = 60$ km/h103 Figure 7.15 Graph of velocity at E in case 3 and case 4, respectively with $v = 60$ km/h104 Figure 7.16 Graph of velocity at H in case 3 and case 4, respectively with $v = 60$ km/h104 Figure 7.17 Contour of velocity at 1.5 sec of loading in case 3	Figure 7.12 Relationship between distance and maximum vibration velocity and let in case 1 and case 2, respectively with $v = 60 \text{ km/h}$	evel 102
Figure 7.14 Graph of velocity at B in case 3 and case 4, respectively with $v = 60$ km/h 103 Figure 7.15 Graph of velocity at E in case 3 and case 4, respectively with $v = 60$ km/h 104 Figure 7.16 Graph of velocity at H in case 3 and case 4, respectively with $v = 60$ km/h 104 Figure 7.17 Contour of velocity at 1.5 sec of loading in case 3	Figure 7.13 Graph of velocity at A in case 3 and case 4, respectively with $v = 60$ km/h	
Figure 7.15 Graph of velocity at E in case 3 and case 4, respectively with $v = 60$ km/h104 Figure 7.16 Graph of velocity at H in case 3 and case 4, respectively with $v = 60$ km/h104 Figure 7.17 Contour of velocity at 1.5 sec of loading in case 3	Figure 7.14 Graph of velocity at B in case 3 and case 4, respectively with $v = 60$ km/h	103
Figure 7.16 Graph of velocity at H in case 3 and case 4, respectively with $v = 60$ km/h104 Figure 7.17 Contour of velocity at 1.5 sec of loading in case 3	Figure 7.15 Graph of velocity at E in case 3 and case 4, respectively with $v = 60$ km/h	104
Figure 7.17 Contour of velocity at 1.5 sec of loading in case 3	Figure 7.16 Graph of velocity at H in case 3 and case 4, respectively with $v = 60$ km/h	104
Figure 7.18 Contour of velocity at 1.5 sec of loading in case 4	Figure 7.17 Contour of velocity at 1.5 sec of loading in case 3	105
Figure 7.19 Relationship between distance and maximum vibration velocity and level in case 3 and case 4, respectively with $y = 60$ km/h	Figure 7.18 Contour of velocity at 1.5 sec of loading in case 4	105
In case 5 and case 4, respectively with $V = 00$ km/m	Figure 7.19 Relationship between distance and maximum vibration velocity and let in case 3 and case 4, respectively with $v = 60$ km/h	evel 103