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Geotechnics for Catastrophic Flooding Events

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Geotechnics for Catastrophic Flooding Events – Iai (Ed)
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Preface

This book is prepared for sharing knowledge and improving understanding of the geotechnical engineering issues associated with catastrophic flooding events. The book will discuss hurricane, rainstorm and storm surge induced riverine and coastal flooding events, such as the 2004 Sumatra earthquake in Indonesia, the 2005 Hurricane Katrina disaster in New Orleans, USA, Typhoon Morakot, which devastated parts of Taiwan in 2009 and the 2011 earthquake and tsunami disaster in Eastern Japan.

Combined failure mechanism, multiple hazards, and rare event with significant consequence exemplified by Fukushima accident and lessons learned are just a few examples characterizing this book. The book also includes contributions to a workshop on liquefaction experiment and analysis projects (LEAP) and a workshop for developing guidelines and recommendations for local governments to mitigate the risk of coastal and river flooding disasters.

The book is compiled at the Fourth International Conference on Geotechnical Engineering for Disaster Mitigation and Rehabilitation (4th GEDMAR), held on 16–18 September, 2014, Kyoto, Japan. The 4th GEDMAR provided a forum for members of ISSMGE and built on the tradition of previous successful GEDMAR conferences held in Singapore, Nanjin/China, and Semarang/Indonesia since 2005.

The editor hopes that the book will further advance the geotechnics for catastrophic flooding events. In compiling the manuscripts, the assistance by Ms. Chihiro Tsurui, Kyoto University and Ms. Waka Yuyama, FLIP Consortium, are gratefully acknowledged.

Susumu Iai
Editor

Table of contents

Preface

Keynote Lectures

Workshop on liquefaction experiment and analysis project (LEAP)

Workshop on guidelines and recommendations for local governments to mitigate flooding disasters

Panel Discussions "How to meet catastrophic flooding events?"

General Papers
- Theme 1. Materials and modeling
- Theme 2. Natural hazards
- Theme 3. Disaster mitigation and rehabilitation

Author index

Keynote Lectures

Combined failure mechanism of breakwaters and buildings subject to Tsunami during 2011 East Japan earthquake
S. Iai

Performance-based assessment of liquefaction hazards
S.L. Kramer, Y.-M. Huang & M.W. Greenfield

Progresses on disaster mitigation and rehabilitation technologies for embankment dam in China
H.L. Liu

Development of seismic risk microzonation maps of Jakarta city
M. Irsyam, D. Hutabarat, M. Asrurifak, I. Imran, S. Widiyantoro, Hendriyawan, I. Sadisun, B. Hutapea, T. Afriansyah, H. Pindratno, A. Firmanti, M. Ridwan, S.W. Haridjono & R. Pandhu

Use of biogeotechnologies for disaster mitigation
J. Chu, V. Ivanov, J. He & M. Naeimi

Damage to river levees by the 2011 Off the Pacific Coast Tohoku earthquake and prediction of liquefaction in levees
M. Okamura & S. Hayashi

Geoenvironmental issues for the recovery from the 2011 East Japan earthquake and tsunami
T. Katsumi, T. Inui, A. Takai, K. Endo, H. Sakanakura, H. Imanishi, M. Kazama, M. Nakashima, M. Okawara, Y. Otsuka, H. Sakamoto, H. Suzuki & T. Yasutaka

Fukushima Accident: What happened and lessons learned
S. Muto

Workshop on liquefaction experiment and analysis project (LEAP)

Liquefaction Experiment and Analysis Projects (LEAP) through a generalized scaling relationship
S. Iai

Proposed outline for LEAP verification and validation processes
B.L. Kutter, M.T. Manzari, M. Zeghal, Y.G. Zhou & R.J. Armstrong

LEAP projects: Concept and challenges
M.T. Manzari, B.L. Kutter, M. Zeghal, S. Iai, T. Tobita, S.P.G. Madabhushi, S.K. Haigh, L. Mejia, D.A. Gutierrez, R.J. Armstrong, M.K. Sharp, Y.M. Chen & Y.G. Zhou

LEAP: Selected data for class C calibrations and class A validations
M. Zeghal, M.T. Manzari, B.L. Kutter & T. Abdoun

Benchmark centrifuge tests and analyses of liquefaction-induced lateral spreading during earthquake
T. Tobita, M.T. Manzari, O. Ozutsumi, K. Ueda, R. Uzuska & S. Iai

Workshop on guidelines and recommendations for local governments to mitigate flooding disasters

Preparing 'Guidelines and Recommendations' for disaster mitigation – what is the lesson from recent flood and tsunami
K. Ichii

Geotechnical lesson and application on earth bank for tsunami disaster prevention
K. Tokida

On the failure mechanisms of different levee designs under extreme rainfall event – case studies in Southern Taiwan
W.-C. Huang, R.-K. Chen & M.-C. Weng

Impact of the recent earthquake and tsunami on Chilean port
F. Caselli, M. Beale & M. Reyes

Numerical analysis of Darcy/Navier-Stokes coupled flows and seepage-induced erosion of soils
K. Fujisawa

Effect of incidence angle of current and consolidation pressure on the hydraulic resistance capacity of clayey soil
Y.S. Kim, S.H. Jeong, T.M. Do, C. Lee & K.O. Kang

Evaluation of liquefaction susceptibility of soils using Dynamic Weight Sounding test
S. Sawada

Earthquake and tsunami damage estimation for port-BCP
Y. Akakura, K. Ono & K. Ichii

Reliability on the stability of long continuous earth-structures
T. Hara, M. Nonoyama, Y. Otake & Y. Honjo

Panel Discussions “How to meet catastrophic flooding events?”

Prelude to Panel Discussion: How to meet catastrophic events
W.D.L. Finn

Prelude to Panel Discussion: How to meet catastrophic events
M.J. Pender

Contribution to Panel Discussion: How to meet catastrophic events
H. Ohta

Laboratory test on lateral spreading of plastic sand in zero effective state
Y.M. Chen, C.X. Xu & G. Zhou

The development of non-contact displacement test method and its application in shaking table test
S. Chen, G.X. Chen, L.-Y. Wang, H.-M. Gao & D.-D. Jin

Engineering properties of varved clays from the Junikowski Stream Valley in Poland
A. Florkiewicz, M. Flieger-Szymańska, K. Machowiak & D. Wanatowski

Experimental study on static and dynamic characteristics for silty clay of dam foundation
L. Gao, Q.Y. Zhou & X.J. Yu

Practical assessment on seismic damage to an airport runway based on 2-D and 3-D non-linear FEM analyses with special reference to crack occurrence
Y. Hata, K. Ichii & A. Nozu

Experimental study on static and dynamic properties of asphalt concrete core material
B. Huang, W. Zhang & B.-J. Zhang

Seismic response of geosynthetic reinforced earth embankment on different soil deposit
W.Y. Hung & C.J. Lee

Laterally loaded behavior of mono-pile in sandy ground
C.J. Lee, Y.T. Lin, W.Y. Hung, C.H. Tsai &Y.C. Tu

Three-phase coupled analysis of shaking table test of unsaturated embankment on inclined ground
T. Matsumaru & R. Uzuoka

Seismic response of unsaturated embankment reinforced with soil nails
Y. Nakai, R. Uzuoka & T. Matsumaru

Subsidence of breakwater on sandy ground due to earthquake motion
Y. Ohya, E. Kohama, A. Nozu, T. Sugano & N. Yoshida

Evaluation of topographic slope based $V_{S,30}$ estimation for Indonesia
W.A. Prakoso, D. Damoerin, I.N. Sukanta & E. Santoso

Dynamic penetration test with measurement of the pull-out resistance
S. Sawada

Geotechnical study for inpit dump on low-wall part in coal mining South Kalimantan
S.T.M.T. Sujatono

continued on next page

Ultra-soft soil improvement via vacuum preloading in combination with electroosmotic consolidation
Z.H. Sun & M.J. Gao

Centrifugal model tests on collapse of coastal levee due to tsunami overflow
H. Takahashi, Y. Morikawa, N. Mori & T. Yasuda

Measurement of the earth pressure in centrifuge tests – focusing on the variation due to the settlement
M. Takamachi, K. Ichii, K. Kitade, H.T. Chen, C.J. Lee, W.Y. Hung, N. Orai & T. Matsuno

Towards understanding flow liquefaction by computation
D. Wanatowski, D.A. Shuttle & M.G. Jefferies

Centrifuge model tests on seismic response of tailings dam
X. Wang, Y. Zhou, C.F. Lee & S. Lv

Fractal properties of filter membrane for silt clogging evaluation on PVD improved soft clays
J. Wang, Z.L. Dong & H.H. Mo

Bedrock elevation measurement using ambient vibrations and ultra-sonic pulse test
S.P.R. Wardani, M. Irsyam, W. Partono & S. Maarif

Experimental study on dynamic shear modulus of saturated silty soil
X.J. Yu, Y. Bai, L. Gao & Z. Ren

Study on cyclic shear behavior of frozen soil-structure interface
L. Zhao, P. Yang & G. Wang

Test study on fluid characteristics of post liquefied Nanjing fine sand
E.Q. Zhou, Z. H. Wang, C. Lv & G.X. Chen

The compression of sand caused by multidirectional earthquake loading
G.Y. Gao, H.Q. Zhang & Q.S. Chen

Study on stability of rock slope based on Ant Colony Clustering Algorithm
W. Gao

The effect of liquefaction on the damages of factories in the Great East Japan Earthquake Disaster and on the damage estimate by the Nankai trough earthquake
K. Kitade, K. Ichii, H. Kinoshita, S. Kuga, D. Yoneura & K. Yamada

Model shake table test and numerical analysis on dynamic property of quay wall with coarse-grained rock waste
E. Kohama, S. Setoguchi, K. Kusunoki & T. Sugano

A study on seismic resistance evaluation methods with the consideration of the effect of rainfall
N. Orai & K. Ichii

River water fluctuations induced river embankment stability
R.A.A. Soemitro & D.D. Warnana

Combined effect of earthquake and tsunami on failure of a pile supported building
T. Tobita

InSAR time series analysis in deformation monitoring of Hanyuan resettlement zone, Southwest China
R. Xiao, X.F. He & G.Q. Shi

Nondestructive examination for the equality of the specimens for liquefaction test
K.Yamada, M. Takamachi & K. Ichii

Liquefaction potential of natural deposit during and after an earthquake by effective stress analysis
N. Yoshida, R. Uzuoka & H. Ishikawa

Analysis of anchor failure of prestressed single anchorage in coal mine
X. Chu

Automatic damage detection system for road surface by using image analysis
S. Ishii, O. Kurihara, T. Ito, K. Ichii & T. Tamaki

A system for flatness evaluation of road surfaces using photographs taken from a car moving at a high speed
T. Ito, K. Yamada, K. Ichii, T. Tamaki & M. Kadota

Ground health monitoring of a slope of constructed fill using the surface wave method
M. Kawano, K. Kitade, Y. Murakami, M. Takamachi, T. Ito & K. Ichii

Study on design method of drain pipe recovering stability of road embankment
S. Kitaguchi, K. Tokida & S. Kamide

Preliminary study on evaluation of failure range of residential fill slope due to the past large-scale earthquake
S. Komai, Y. Hata & K. Tokida

Preliminary study on effects of extended core structure on seepage and dynamic characteristics of earth dam
Y.H. Lee, K. Tokida, Y. Hata, J. Kawaguchi & M. Uotani

The monitoring and early warning method for USAF of offshore wind turbines
H.-J. Li, H.-J. Liu, G.-G. Xi & M.-B. Ma

Development of tensile strength test for soil
Y. Murakami, M. Kawano & K. Ichii

Seismic stability for slopes reinforced with multi-row anchors
T.K. Nian, K. Liu, G.Q. Chen & L. Song

A simple device for trapping small-scaled debris flows
K. Ozasa, K. Kumagai, H. Takahashi, M. Imashiro & H. Ohta

Comparative experiments on influence of EKG and iron electrodes on electro-osmotic effects
Y. Shen, Y.D. Li, W.J. Huang, H.D. Xu & P.F. Hu

Study on hardly-permeable earth bank against tsunami flood
J. Shimakawa, K. Tokida, Y. Hata & R. Tanimoto

Numerical modeling of DJM column reinforced dyke performances under dredging
M.W. Wang, K.Y. Zhao, H. Jiang, L.B. Zhang & X.F. Li

continued on next page

A treatment solution to differential settlement in existing highway on soft ground
Y.D. Wu, C.C. Zeng, J. Liu & H.L. Liu

Collapse episodes and remedial works for an earth dam during construction of cut-off walls
X.Y. Xie, L.W. Zheng & H.B. Cao

Research on slope stability treatment by using PCC pile based on Yanglintang project
Y. Zhuang, Y.M. Lu & H.L. Liu

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Bedrock elevation measurement using ambient vibrations and ultra-sonic pulse test

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ABSTRACT: One of the important steps in site specific analysis is finding the elevation of bedrock. Seismic waves in terms of acceleration time histories will be propagated from bedrock elevation to the earth surface. Invasive and non invasive are two methods commonly used for estimating the elevation of bedrock. Invasive methods required drilling into the ground. Non-invasive methods for estimating of bedrock elevation can be performed using ambient vibrations. Ambient vibrations are short period vibrations (0.02 to 50 Hz) result from environment activities such as traffic, wind interaction with vegetation, factory activities etc. A single feedback seismometer can be performed for measuring ambient vibration waves. A simple method by placing seismometer on the earth is required for ambient vibrations measurement.

This study presents result of bedrock measurements in south area of Semarang City, Indonesia using a single feedback seismometer. The Horizontal-to-Vertical Spectral Ratio (HVSR) analysis method from Nakamura (1989) was performed for estimating the depth of bedrock elevation. Bedrock elevation map was performed based on 196 locations of ambient vibration measurement. Drillings for finding rock sample for rock elevation less than 30 meter were also performed. To get the information of shear wave velocities of rock sample Ultrasonic Pulse Test of rock tests were performed.

Keywords: bedrock, ambient vibrations, HVSR, Ultrasonic Pulse Tests.

1 INTRODUCTION

Semarang is the capital city of Central Java Province and lies at the Northern part of Central Java Province. Semarang has an area of ±374 square kilometers. The city spans for 22 km long and 22 km wide and elongated in both North-South and East-West directions. Based on the geological formations, the northern part of Semarang (Light blue in Figure 1) lies on the alluvial sediments. They composed of soft clay, silt and sand and their thickness can reach more than 100 m (Thanden et al. 1996). The central part of Semarang lies on the Damar formation and composed by tuff sandstone conglomerate (orange in Figure 1). The other formation, a transition formation, is found in the southern part of Semarang and lies on Kaligetas and Kaligesik formations and composed of volcanic breccias, clay-stone, basalt and hornblende-augite-andesite (brown, red and pink in Figure 1). Based on the geology map and geology information there

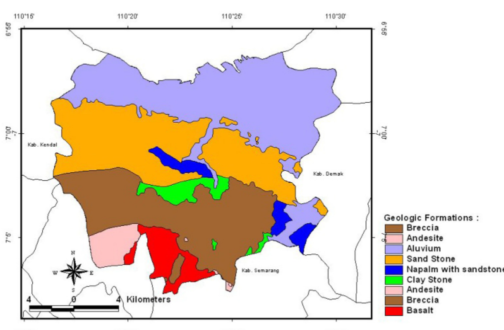

Figure 1. Geology map of Semarang city.

are no complete information concern with bedrock elevation in the city of Semarang. Whereas the overlying soil sediments are clearly important for the amplification prediction and for site response analysis.

The Semarang city can be divided in two major land-slopes, coastal plain area in the Northern part with max 5% slope and hilly part in the center and Southern part with max 33% slope.

Site response is an important part of geotechnical earthquake engineering studies. Amplification of seismic waves propagating up through a soil column depends on the depth of bedrock or the thickness of sediment layer. Investigation of bedrock elevation is an important part for developing seismic microzonation. Geology map of Semarang city (Figure 1) has no complete information about the elevation of bedrock elevation. The cost of deep boring down to the bedrock at all sites of the Semarang city is unrealistic approach. Due to this lack of bedrock elevation and unrealistic approach for deep boring for the whole city, introducing alternative cheaper method for predicting bedrock elevation is important. H/V (Horizontal to Vertical Spectral Ratio) analysis of ambient vibrations is a cheaper approach for predicting bedrock elevation.

This paper presents a geological map of bedrock elevation of Semarang city by performing site investigations using single station feedback seismometer. Extensive ambient noise measurements were performed in the whole sites of Semarang city and the H/V technique (Nakamura, 1989) for predicting bedrock elevation was conducted.

In order to better understand the use of feedback seismometer and H/V technique for estimating bedrock elevation, drilling investigations were performed. The purposed of these drilling investigations are to compare the elevation of bedrock calculated using ambient vibrations with real geological layers on site from drilling investigations. Laboratory geotechnical tests were conducted for all rock samples. The purpose of geotechnical test is to get the information of shear wave velocities (Vs) of all rock samples.

2 BACKGROUND THEORY

Estimating sediment thickness and the geometry of the bedrock is one of the important steps for site specific analysis in calculating surface hazard spectra. Estimating sediment thickness can be performed by using single station seismometer and H/V technique (Claudet et al. 2009, Johansson et al. 2008). The H/V method uses a single station broad-band three component seismometer to record ambient vibrations (North-South/NS, East-West/EW and Vertical/V). The horizontal-to-vertical (H/V) technique for ambient vibrations is a non-invasive technique that can be used to rapidly estimate the depth to bedrock. The H/V technique was first proposed by Nogoshi and Igarashi (1971) and then widespread by Nakamura (1989). The H/V technique consists of estimating the ratio between the Fourier amplitude spectra of the horizontal and the vertical components of ambient vibrations. The ratio of the averaged horizontal-to-vertical frequency spectrum is used to determine the fundamental site resonance frequency, which can be interpreted using regression equations to estimate sediment thickness or depth to bedrock.

The H/V method is a "passive" method that uses three-component measurements of ambient vibrations (vibrations induced by wind, ocean waves, anthropogenic activity, etc.) to determine and evaluate a site's fundamental seismic resonance frequency. Kramer (1996) described that soil response to the strong ground motion can be approximated by the transfer function of layered and damped soil on elastic rock. If Vs is the shear wave velocity of soil layer and H is the thickness of soil layer, the fundamental frequency of the soil (fo) can be predicted using Equation (1). Based on Equation (1) if Vs and fo can be defined, the depth or the thickness of soil layer can be easily calculated.

$$fo = \frac{Vs}{4H} \quad (1)$$

Nakamura (1989) showed that the fundamental resonance frequency of a site can be determined from the ratio of the horizontal Fourier amplitude spectra and the vertical Fourier amplitude spectra of ambient vibrations. If SNS and SEW are the horizontal Fourier amplitude spectra and SV is the vertical Fourier amplitude spectra of the ambient vibrations, Delgado et al. (2000) proposed a simple formulae for estimating the H/V spectral ratio as (Equation 2):

$$H/V = \sqrt{\frac{SNS^2 + SEW^2}{2SV^2}} \quad (2)$$

where SNS = North-South amplitude Fourier spectra; SEW = East-West amplitude Fourier spectra; SV = vertical amplitude Fourier spectra

Several equations can be used to establish the thickness of sediment layer. The equation which is used in this study was performed by Ibs-von Seht and Wohlenberg (1999) and Parolai et al. (2002). They developed an empirical power law equation for predicting the thickness of sediment layer (Equation 3):

$$Z = a(fo)^b \quad (3)$$

where "a" and "b" are two fitting parameters determined from non-linear regressions of resonance frequencies and borings in Germany. The value of a (in meter) and b are given in Table 1. The advantage of this equation is that there is no Vs value required for calculating sediment thickness.

Table 1. H/V resonance Frequency Fitting Parameters.

a	b	Reference
96	−1.388	Ibs-von Seht and Wohlenberg (1999)
108	−1.551	Parolai et al. (2002)

3 METHODS AND RESULTS

3.1 *Ambient vibrations measurements*

Extensive ambient noise measurements, 196 locations, were performed in the city of Semarang during August to November 2012. The ambient noise vibrations were recorded using feedback seismometer. The type of seismometer used in this study is 100 Hz sampling rates three-component Feedback Short Period Seismometer model DS-4A. The signal has been recorded with 2 Hz velocity sensors for minimum 15 minutes.

Figure 2 shows setting up of equipments for ambient vibrations measurements. The seismometer is connected to computer laptop via digital portable data logger and GPS. The locations for which 196 ambient noise were recorded are shown in Figure 3. These locations were distributed randomly inside the study area (165 locations) and outside the study area (31 locations).

The H/V technique (Nakamura, 1989) in estimating the ratio between the Fourier amplitude spectra of the horizontal and the vertical components of ambient noise vibrations were calculated using Geopsy software. H/V ratios were calculated for the frequency range 0.2 Hz until 20 Hz. The average H/V curves were systematically analyzed and the application of the reliability criteria of peaked H/V curve frequencies was carried out using SESAME guidelines (SESAME, 2004). At the end, the H/V peak frequencies can then be used for estimating sediment thickness. Two simple empirically non-linear regression equations determined by Ibs-von Seht and Wohlenberg (1999) and Parolai et al. (2002) are used for predicting sediment thickness.

Based on the H/V peak frequencies calculation of all datas can be divided into four spatial distribution intervals: 0.5–2 Hz, 2–5 Hz, 5–10 Hz and 10–20 Hz. Figure 4 shows the spatial distribution of H/V peak frequencies. Data with peak frequency between 0.5–2 Hz are clearly located on the North and North-East area of Semarang (red area in Figure 4). Data with peak frequency between 2–5 Hz (green area in Figure 4) are located within three separated locations, middle, Southern and South-East part of the city. Data with peak frequency between 5–10 Hz (blue area in Figure 4) are located in the middle part and southern part. Data with peak frequency between 10–18 Hz (dark green in Figure 4) are scattered in small area in the City.

Using the value of peak frequency (fo), value of ‘a’ and ‘b’ from Table 1, the depth of bedrock can be estimated directly. Figure 5 shows the relation between the

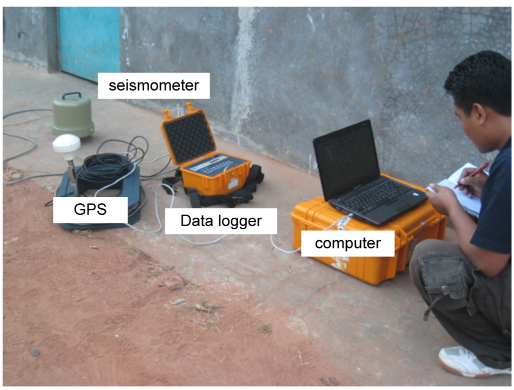

Figure 2. Feed-back seismometer connected to laptop via portable data logger for H/V ambient noise surveys.

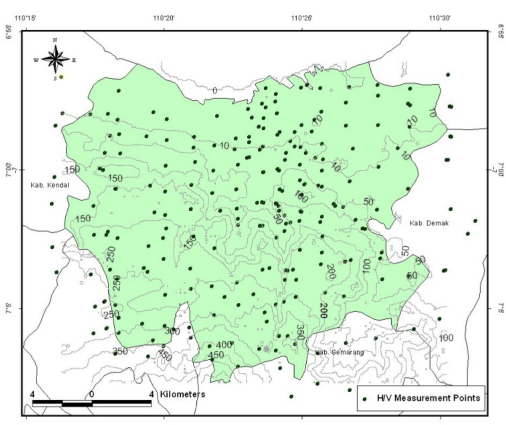

Figure 3. Ambient noise test locations.

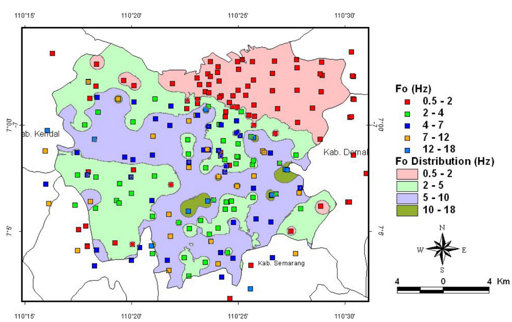

Figure 4. Distribution of peak frequencies (fo).

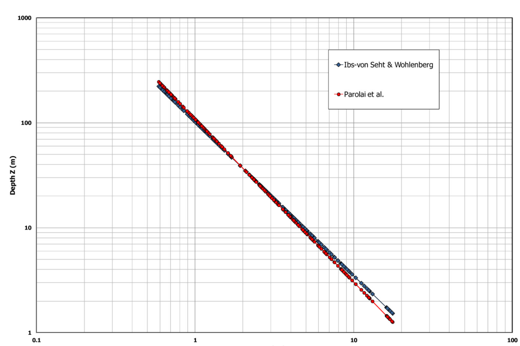

Figure 5. Relation of sediment thickness (z) and peak frequency (fo) developed from 196 data.

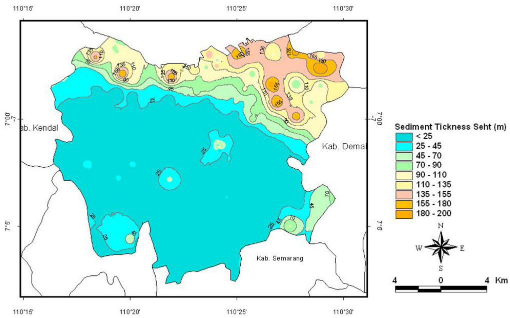

Figure 6. Sediment thickness spatial distributions based on Ibs-von Seht and Wohlenberg method.

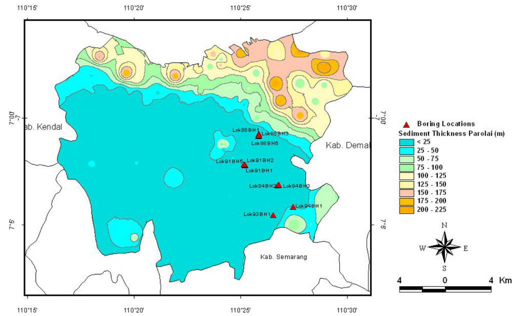

Figure 8. Drilling locations.

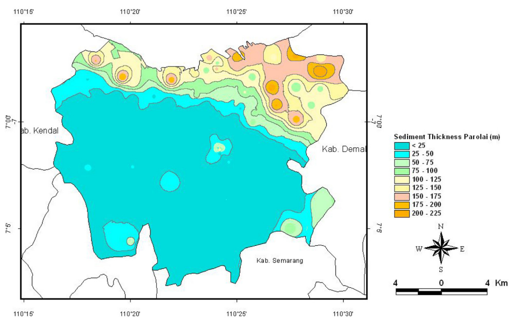

Figure 7. Sediment thickness spatial distributions based on Parolai et al. method.

Figure 9. Ultrasonic Pulse Test and example output Using Sonic Viewer SX.

thickness of sediment layer "z" and peak frequency "fo" developed from 196 data. Figure 5 shows the comparison of two graphical models developed using Ibs-von Seht and Wohlenberg (1999) and Parolai et al. (2002) approaches. As it can be seen in Figure 5, both graphs have no significant differences. For fo less than 2 Hz, Ibs-von Seht and Wohlenberg method gives the value of z less than Parolai et al. method. However for fo greater than 2 Hz, Parolai et al. method gives the value of z less than Ibs-von Seht and Wohlenberg method.

The result of sediment thickness distribution is presented in two contour maps. The first map (Figure 6) shows the contour of sediment thickness based on Ibs-von Seht and Wohlenberg (1999) approach. The second map (Figure 7) shows the contour of sediment thickness based on Parolai et al. (2002) approach. Both maps give almost the same information about the spatial distribution of sediment thickness layer. The depth of bedrock elevation gradually increases from south to north part of the city. The deepest elevation of bedrock lays on the north-east part of the city.

Area with sediment thickness less than 50 meter (blue and light blue area in Figure 6 and Figure 7) are clearly located on the south and middle part of the city. Area with sediment thickness between 50 meter and 100 meter (soft green and green area in Figure 6 and Figure 7) are located in the middle part of the study area. It can be seen in Figure 6 and Figure 7 that the majority of the north part of the city area (yellow to orange area) has minimum 100 meter sediment thickness.

3.2 *Ultrasonic pulse test*

In order to better understand the use of feedback seismometer and H/V technique for estimating bedrock elevation, drilling investigations were performed during October 2012 until July 2013. Ten drilling locations with minimum 30 meters depth were performed. All the boreholes crossed the sediment layer and reached the geological bedrock within minimum 30 meter dept. Figure 8 shows ten drilling locations in the study area.

To get the real physical characteristics of all rock samples, laboratory geotechnical tests were conducted for all rock samples using ultrasonic pulse test (Sonic Viewer Type SX). The purpose of geotechnical test is to get the information of shear wave velocities (Vs) of all rock samples. Ultrasonic pulse test (Figure 9) was used for conducting the shear wave velocities of rock samples. Based on SNI 03-1276-2012, bedrock (SB) is a soft-rock with Vs greater than 760 m/s and less than 1500 m/s.

Table 2 shows the conclusion result of ultrasonic pulse test. As can be seen in Table 2 all rock samples have shear wave velocity Vs greater than 760 m/s.

Table 2. Bedrock elevation and Shear Wave Velocity Tests Result.

No	Location	Date	Bedrock Elevation (m)	Rock Types	VS (m/s)
1	Lok84BH2	Oct-12	−8	Breccia	2457
2	Lok84BH3	Oct-12	−5	Breccia	3461
3	Lok88BH1	Mar-13	−17	Sandstone	2265
4	Lok88BH3	Apr-13	−27	Sandstone	1947
5	Lok88BH6	Apr-13	−26	Sandstone	1848
6	Lok91BH1	Apr-13	−23	Sandstone	1631
7	Lok91BH2	Apr-13	−21.5	Sandstone	2554
8	Lok91BH5	Apr-13	−22	Sandstone	2150
9	Lok93BH1	Jul-13	−11	Sandstone	2012
10	Lok94BH1	Jul-13	−5	Claystone	2895

Figure 10. Sample sand stone from Lok93BH1 with minimum depth −15 meter.

Figure 11. Sample clay stone from Lok94BH1 with minimum depth −5 meter.

Based on the information get from Table 2 the elevation of bedrock are less than 30 meter. Figure 10 to Figure 12 show three examples of rock sample from drilling investigations.

Figure 12. Sample sand stone from Lok88BH3 with minimum depth −26 meter.

4 CONCLUSIONS

The use of ambient vibrations recorded by single station feedback seismometer can be an alternative method for investigating bedrock elevation. The ambient vibrations data produce peak resonance frequency which gives a good correlation with the geology map of Semarang. The depth of bedrock elevations were interpreted using two different regression equations and give a good estimates for predicting bedrock elevations. The detail analysis of ambient vibrations data and H/V method outlines two major areas of sediment thickness or bedrock elevations. The South and middle part of Semarang have bedrock elevation less than 50 meter. The North part of the City, the alluvial sediments area, has bedrock elevation more than 50 meter. The deepest elevation of bedrock lies on the North-East part of the City. The depth of bedrock elevation of this area is more than 200 meter.

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