

LITHOLOGICAL IDENTIFICATION OF DEVASTATED AREA BY PIDIE JAYA EARTHQUAKE THROUGH POISSON'S RATIO ANALYSIS

Marwan¹, *Asrillah¹, M. Yanis¹, Yoshinori Furumoto²

¹Department of Geophysical Engineering, Universitas Syiah Kuala, Indonesia

²Department of Civil Engineering National Institute of Technology, Nagano College, Japan

*Corresponding Author, Received: 31 Jan. 2019, Revised: 05 March 2019, Accepted: 10 April 2019

ABSTRACT: A combination of geophysical methods has been applied in the earthquake-devastated area in late December of 2016 in Pidie Jaya Regency, Aceh Province, Indonesia. The methods are refraction seismic and Multichannel Analysis Surface Wave (MASW). This research aims to identify the types of near-surface lithologies through Poisson's ratio analysis. These velocity values were acquired through measurements in three sites among the devastated areas. The measurement of VP and VS values deploys the PASI 16S Seismograph with 24 channels. The geometry of seismic refraction lines was designed by placing 2-meter long geophone intervals, and nine total shot points were inserted, while in VS data measurement, the geophone intervals were the same set as the refraction seismic with differently laid out geometry of shot points and total. Both data were processed using ZondST2D for the 2D profile of VP and SeisImager for 2D section of VS. The result of the study indicated that all of the Poisson's ratio profiles show lithology consisting of clayey sand, clay and saturated clay with a value generally ranging from 0.22 to 0.46. The clay lithology is a prominent finding of this research. These interpretations more or less match other results even though some are in different research areas. This finding was proven by the damaged area affected by the earthquake in late 2016. Thus the result can be beneficial to designing and customizing building types according to lithological characteristics then mitigating from the forthcoming threat of the earthquake.

Keywords: Lithology, MASW, Refraction Seismic, Poisson's ratio

1. INTRODUCTION

Lithological information of shallow subsurface is a valuable insight for mitigation especially in high seismic areas as lithology or medium controls the seismic wave's propagation. The behavior of waves can be described through the elastic modulus, such as Poisson's ratio, Young's, shear and bulk modulus derived from P and S wave velocity measurement. However, in a geotechnical investigation, the S wave velocity is more frequently applied than P wave velocity as it has a better indicator for lithology's characterization, where S-wave propagation is dominantly governed by the structural strength of the matrix and the size and the strength of grains, rather than by the saturation level [1]. Another view [2] stated that if P-and S-wave velocities are available as two independent parameters, manual verifying of clusters is a reliable method to characterize lithological strata along with the profile. The P-wave parameter is also effectively successful to obtain the shallow structure of in geothermal system [3].

In this research, the lithological identification based on the Poisson's ratio will be mainly pointed out. The Poisson's ratio is a comparison between the compressional wave (V_p) and shear wave velocity (V_s), where V_p travels faster than V_s and shear wave decreases when traveling through a filled-fluid-media. Poisson's ratio of 0.25 and $V_p \approx 1.7 V_s$ is for compacted lithology. The existing fluid in sedimentary lithology reduces the elastic modulus, Poisson's ratio, and V_p/V_s ratio. According to Kearey [4], higher than 2.0 V_p/V_s ratios indicate an unconsolidated sandy lithology and less than 2.0 ratio is described as a compacted sandstone or gas-filled uncompacted sand.

The Poisson's ratio has been used for saturated lithology that enforces shear modulus and porosity as parameters. The result shows porosity will decrease when Poisson's ratio is increased [5]. In another case, the comparison of Poisson's ratio and P-wave velocity will gain precision of lithological classified prediction. The Poisson's ratio is one of the crucial elastic moduli and is frequently used to delineate types of lithology [6]. The Poisson's ratio (σ) plays an important role in the shallow

investigation, especially for geotechnical prospecting [7].

Based on previous research of determining lithology, this current study was conducted in a new prone area of the earthquake, which was previously unpredicted, in Pidie Jaya Regency of Aceh Province, Indonesia. The Mw 6.5 earthquake and the 10-15 km depth of hypocentre in Pidie Jaya, Aceh on 6 December 2016 indicates that the hypocentre is about 30 km to the north of the Great Sumatran fault (GSF). This typical shallow earthquake was generated by a local strike-slip fault.

By identifying the types of the lithology of the devastated area, future mitigation in planning and customizing a friendly building can be done. According to Keat [8], the geological view of the research area, Meurah Dua Subdistrict of Pidie Jaya Regency as shown by the red box, are completely composed of superficial deposits symbolized by Qh or specifically termed as coastal and fluvial deposits and noted in Holocene age (Quarter period) as seen in Figure 1.

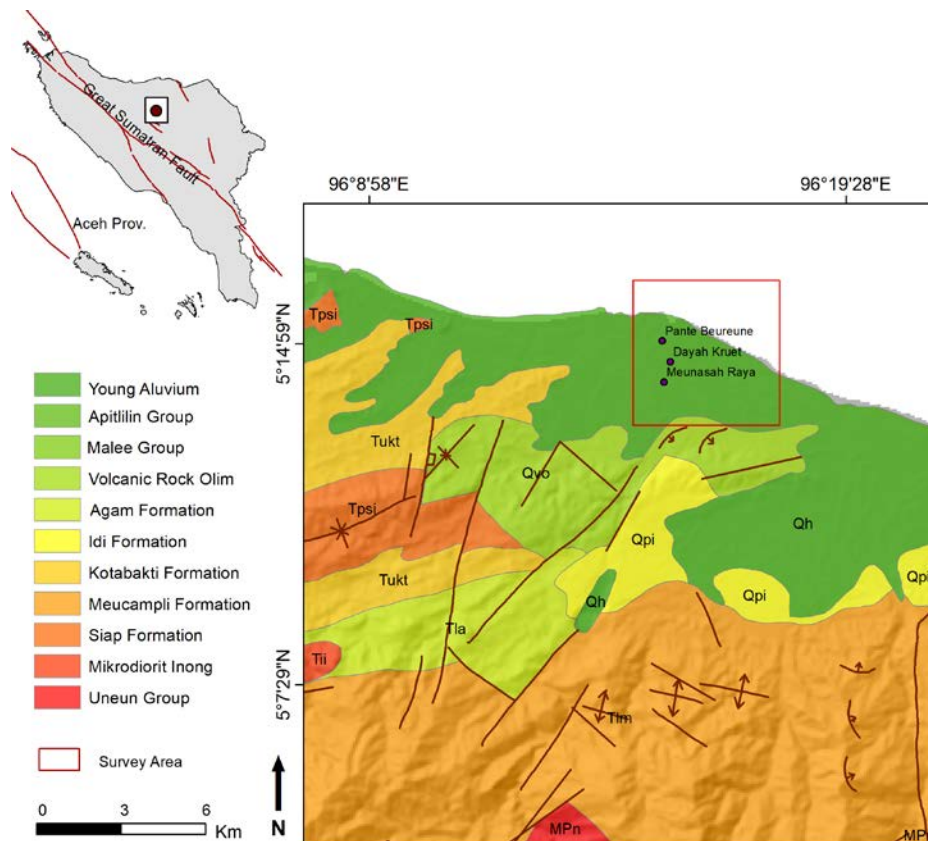


Fig. 1. Geological map of the study area which explains the existence of the Sumatran fault. The map is also overlaid with the geological structure for more comprehensive interpretation.

The study area is adjacent to olim volcanic (Qvo) consisting of andesitic breccia and tuffaceous sandstones in the Southern part from which the existing lithology have possibly been sediment. The sedimentary lithology (Qh) is a low dip deposition. The types of deposition consist of sand, silt, clay, and organic material. The alluvial deposit (Qh) in our study area is young sediment in the geological period (Quarter period), and it is considered less consolidated, loose, and soft. The loose sediment will increase the intensity of the earthquake, and it may amplify the intensity of ground shaking of the earthquake [9]. On the other hand, our study area is near to the coastal zone which means the composition of the sediment

mostly consist of sand to clayey sand. These sand layers will increase the possibility of liquefaction when the earthquake occurs, and the information of liquefaction susceptibility location is important for future planning in coastal areas prone to big earthquakes [10].

Another feature of the geological setting of the research area is the existence of unknown faults as the source of the 2016 earthquake. This research aims to unveil the lithology of the defective area caused by the Pidie Jaya earthquake by quantifying Poisson's ratio to which P and S-wave velocity were provided. The combined MASW and seismic refraction to engineering issues can constrain the lithological prediction [11]. Furthermore, the

application of S-wave velocity structure to 15m in depth is important in the engineering and environmental case.

In this research, in obtaining the P and S wave velocity, we use both the refraction seismic and Multichannel Analysis of Surface Wave (MASW) in the three areas of devastation by the Pidie Jaya

earthquake (figure 2.) The MASW method provides the fundamental mode to be separated visually from other modes, such as higher mode and body waves. The V_p/V_s ratios are widely used as a lithological prospecting of soil amplification and classification, aquifers and oil and gas reservoirs [12] and [13].

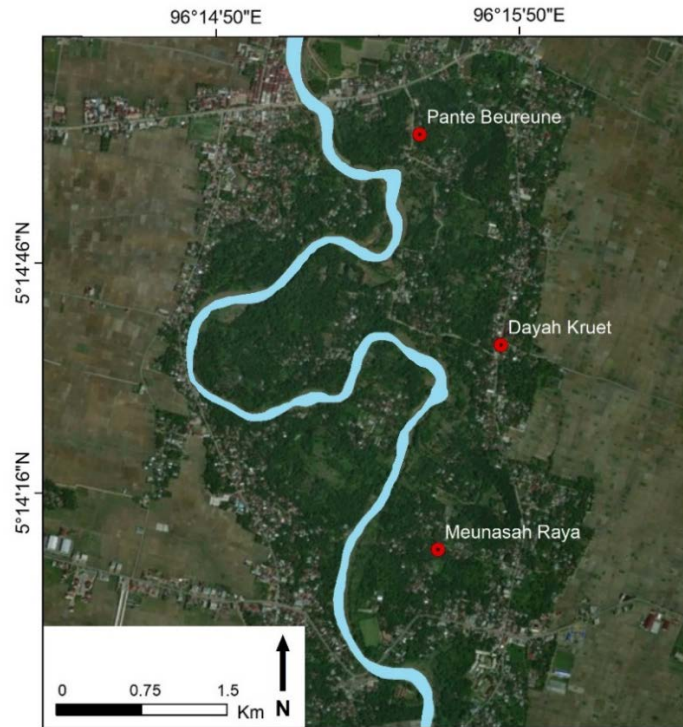


Fig. 2. The study area of Poisson's ratio analysis. Red circles mark the refraction seismic and MASW profiles. The locations of the surveys are dominated in the residential area.

2. DATA AND METHODS

Data were acquired by deploying 1 set of PASI 16S Seismograph with 24 channels. Both refractions seismic and MASW lines were set for each point so that each point has two seismic lines for either P or S-wave travel time measurement recorded from a 5-kg Sledgehammer as the seismic source. This is intended to obtain the P and S-wave velocity from which Poisson's ratio (σ) is finally obtained. The V_p/V_s ratio or Poisson's ratio analysis is a useful function of some physical parameters such as clay content, saturated water, porous strata, crack intensity and porosity [14].

Technically, seismic lines for acquiring seismic refraction data were laid out by placing 2m spacings of each geophone or channel, with nine total shot point spread along the seismic line, where the two shot points with a 23m distance were set as the left and right offset. The remaining were fired at the left end shot, in between geophone 4 and 5, geophone 8 and 9, geophone 12 and 13, geophone 16 and 17, geophone 20 and 21 and at the right end shot.

For MASW data measurement, the spacing between geophones was similarly set with refraction seismic data measurement, but the geometry of shot points and its total was differently laid out. Where the total 25 shot points were fired, with 23 placed in between geophones and 2 of the remaining were shot as the left and right offset at a 5 m distance.

3. RESULT AND DISCUSSION

The V_p data were processed by ZontST2D in the demo version, while V_s data has been inverted by SeisImager for 2D. Both data were extracted for calculating the Poisson's ratio value. Figure 3 shows an example of 1D V_p , V_s and Poisson's ratio data in the location of Meunasah Raya. Based on 1D data, the V_s value relatively increased with the corresponding of depth. However, in the depth of 3-5 m, the V_s data is reduced. The V_p data also increase in the depth of 6 - 12 m. While Poisson

Ratio data only increases at a depth of 3 meters. Furthermore, all of the data response showed a similar pattern that can be indicated as good data quality.

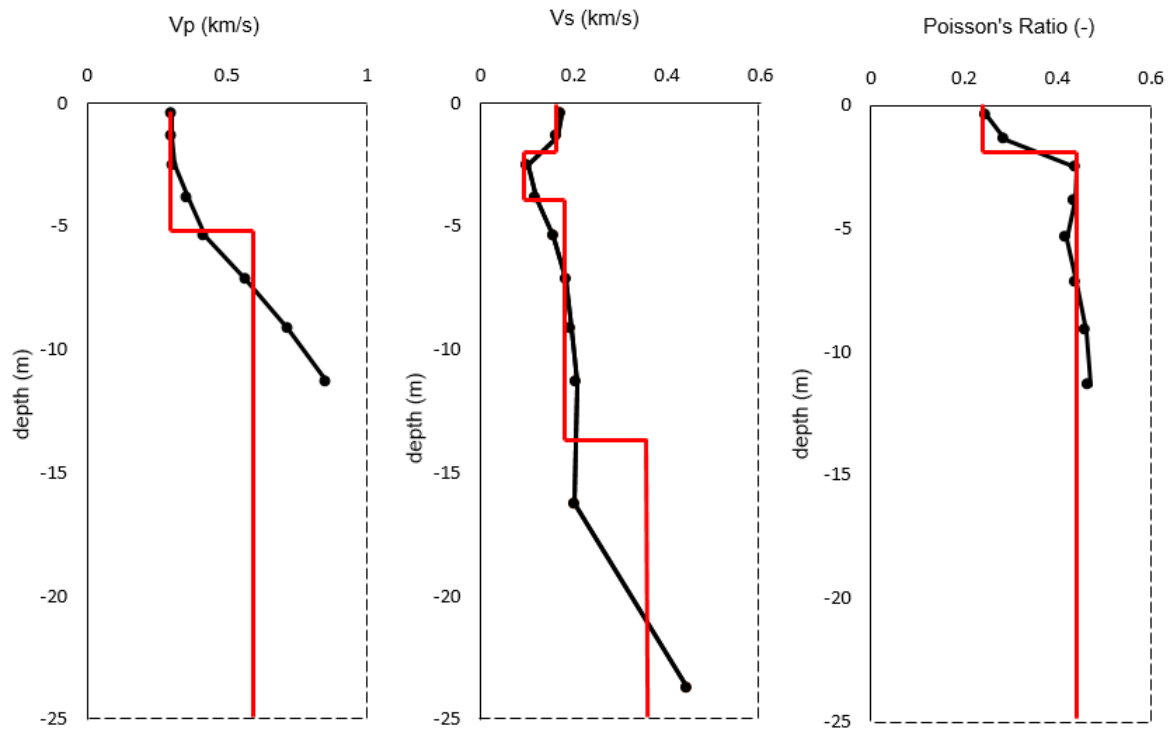


Fig. 3. Comparison of 1D data V_p , V_s and Poisson's Ratio in the location of Meunasah Raya.

The Poisson's ratio is calculated from the extraction of V_s and V_p data, and the data are plotted using Generic Mapping Tools (GMT). Poisson's

ratio profiles of every site measurement were obtained to provide the basic analysis of probable lithological variation beneath the surface. Figure 4 is a 2D profile of Poisson Ratio in Meunasah Raya.

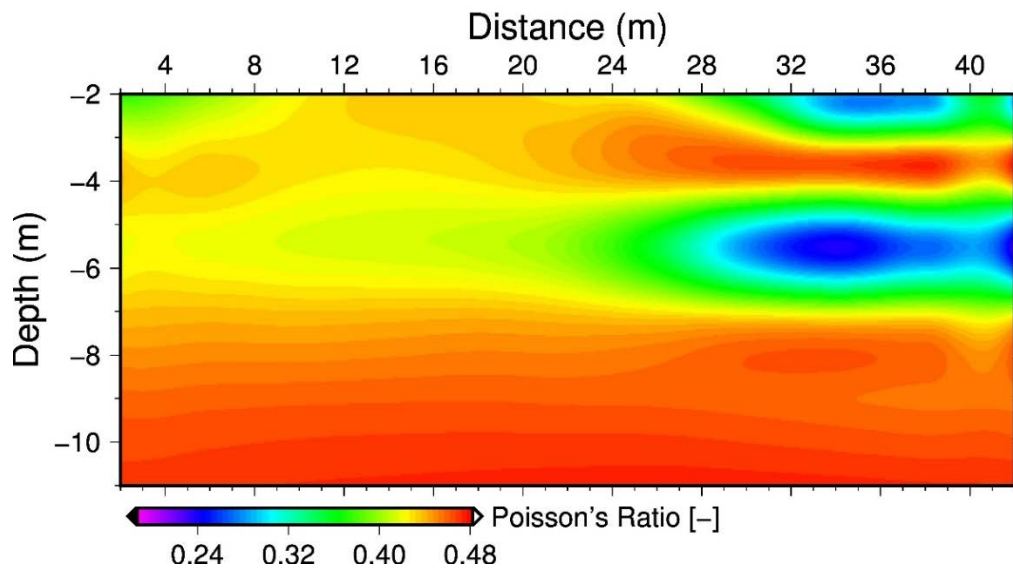


Fig. 4. Poisson's ratio section derived from 2D inversion of V_p and V_s data in Meunasah Raya.

According to the Poisson's ratio profile of the first site, as shown in Figure 4, the value

dominantly starts from 0.38 to 0.45, whereas the value from 0.22 to 0.38 is a marginal ratio. The first

range of Poisson's ratio infers that the lithological type is expected as clay. This stratum existed from 2 to 7m of depth in average. However, an insignificantly clayey sand lithology overlaying dominant strata was predicted from the second range of Poisson's ratio, and at 0.45-0.46 which is the thickest part of lithology and estimated as saturated clay and existed around 7-10 meter in depth.

Poisson's ratio in Pante Beureune that is oriented to South-West and North-East, the sorts of lithology are not systematically layered like in the first site. The clayey sand with a 0.22-0.38 of Poisson' ratio is flanked by the clay is marked by red color. This clay lithology has an interval Poisson's ratio of 0.39-0.45. The same lithology of this profile is similar to the first profile which is predicted a saturated clay (pink color) seated at around 7-10 meter depth.

A similar lithology pattern is also pointed out for the second site. Figure 5 shows a 2D profile of

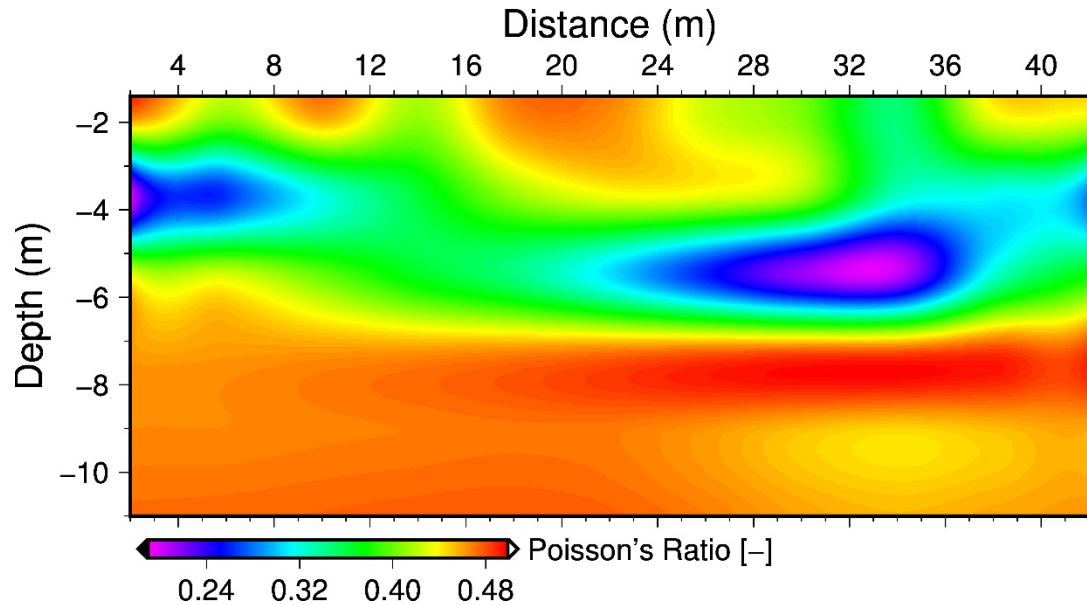


Fig. 5. Poisson's ratio section derived from 2D inversion of V_p and V_s data in Pante Beureune. The material of clay is shown by high of value ranging from 0.39-0.45.

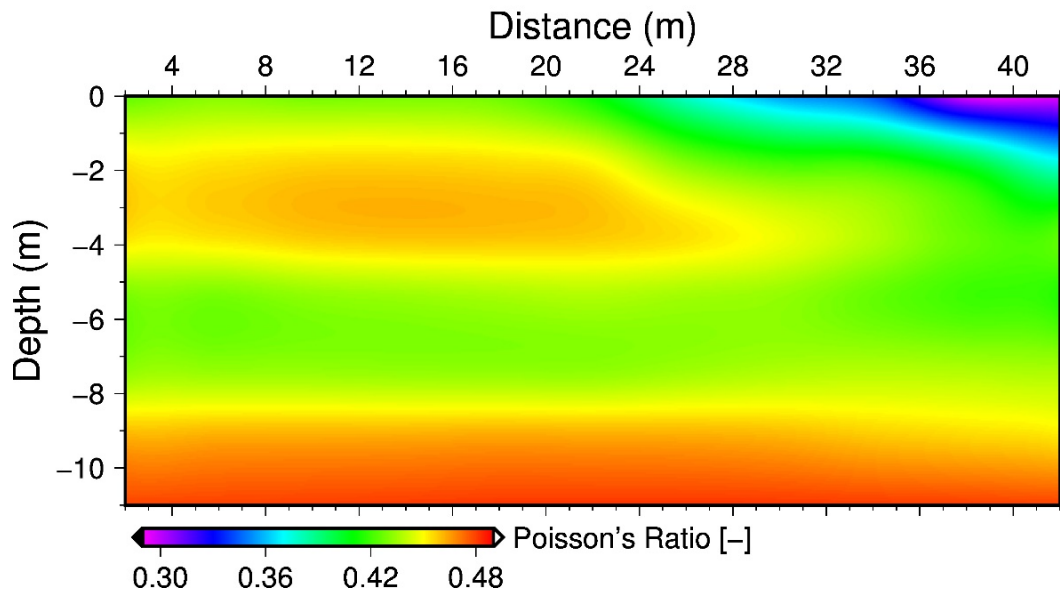


Fig. 6. Poisson's ratio section derived from 2D inversion of V_p and V_s data in Dayah Kruet.

The Poisson's ratio values of the third site namely Dayah Kruet is shown in Figure 6. The

profile shows that they are dominantly in the range of 0.44-0.46. These values can be simply

interpreted as being from clay to saturated clay where clay as a dominant lithology overlay the saturated clay, this value also correspond to Bowles [14] in his research which classifies 0.40-0.50 as saturated clay and 0.20-0.30 as clayey sand. Based on USGS [15], a Poisson's ratio of 0.36 as claystone was obtained from core measurement in the laboratory of Tyonek Formation, Alaska USA.

All Poisson's ratio profiles can correlate that the lithology of the study area consists of clayey sand, clay, and saturated clay. The clay lithology is a prominent finding of this research; the others are also clay however it was mixed with sand and saturated water. These interpretations are more or less similar to other results even though they come from different research areas. For example, Gómez & Castagna [16] explain that a high Poisson's ratio or V_p/V_s ratio indicates a layer containing clay and vice versa. This clay content strata as a near-surface soil will tend to be a failure of engineering foundation structure, such as upwelling and shrinking because soils are polarized when containing clay mineral.

4. CONCLUSION

Generally, this applied method expressed that identifying lithology by using the Poisson's ratio parameter is effectively helpful, although this identification was not complemented with a measurement of the sample in the laboratory as similar research has been done and proved that a lithological determination showed a successful result of in situ tests.

The result of the study specifically demonstrated that all the Poisson's ratio profiles elaborate lithology consisting of clayey sand, clay and saturated clay which the value generally ranges from 0.22 to 0.46. The clay lithology is a prominent finding of this research; the others are also clay however it was mixed with sand and saturated water. These interpretations more or less match other results even though they are in a different research area. This finding was proved by the damaged area affected by the earthquake in late 2016. The clayey sand and clay strata are prone to be a devastating structure when experiencing a shallow quake. Thus the result is very useful for designing and customizing building types based on lithological characteristics to facilitate future earthquake mitigation.

REFERENCES

- [1] Jack K. O., Cynthia A. G., Henry R. S., Lynn A.Y., and Larry L.D., Lithological, geotechnical properties analysis and geophysical log interpretation of U.S Geological Survey Drill Holes 1C-79, 2C-80, CW 81-2, and CE 82-1, Tyonek Formation, Upper Cook Inlet Region, Alaska. US Geological Survey Bulletin, 1988.
- [2] Jacek S., Klaus B., and Trond R., Lithology classification from seismic tomography: Additional constraints for the surface wave, Journal of African Earth Sciences, Vol 58, Issue 3, 2010.
- [3] Marwan A., Asrillah., T Rian, F., Seismic Refraction Tomography (SRT) Study to Characterize Potential Resource of Ie Jue's Geothermal Field of Seulawah Agam Volcano, Aceh Besar-Indonesia, Electronic Journal of Geotechnical Engineering, 2015.
- [4] Philip K., Michael B., and Ian H., An introduction to geophysical exploration, Blackwell Publishing Company, 2002.
- [5] Koefoed O., Oosterveld M. M. & Alonso I. J. G., A laboratory investigation into the elastic properties of limestone, Geophys. Prosp, Vol. 11, Issue 3, 1963.
- [6] Klaus B., Schulze A., Ryberg T., Stephan V. S., and Weber M. H., Classification of lithology from seismic tomography; a case study of the Messum igneous complex, Nimbria. Journal of Geophysical Research. Vol. 108, Issue B3, 2003.
- [7] Julian I., Choon P., Richard D. M., and Jianghai X., Mapping Poisson's ratio of unconsolidated materials from a joint analysis of surface-wave and refraction events. Kansas Geological Survey, SAGEEP, 2000.
- [8] Keats W., Cameron N. R., Djunuddin A., Ghazali S. A., Harahap H., Kartawa W., Ngabito H., Rock N. M. S., Thompson, S. J., and Whandoyo R., Geological Map of Lhokseumawe sheet, Sumatra, scale 1:250.000, 1981.
- [9] Ibnu R., Khaizal J., Eldina F., Syafrizal., Fauzi A., and Yoshinori F., Estimation of Site Amplifications from Shear-Wave Velocity at Pyroclastic Deposits and Basins in Aceh Tengah and Bener Meriah District, Aceh Province, Indonesia. International Journal of Disaster Management, Vol. 1, No 1, 2017.
- [10] Adrin T., Khori S., & Eko S., Cone Penetration Test (CPT)-Based Liquefaction Susceptibility of Banda Aceh City, Jurnal Riset Geologi dan Pertambangan, Vol. 25(2): 99 – 110, 2015
- [11] Beatriz B., Anna G., Albert M., Bellmunt F., Figueras S., Vilà M., and Pi, R., Combination of Geophysical Techniques to characterize sediments, Near Surface Geoscience:

- Conference and Exhibition. EAGE, 2016.
- [12] Dongjun F., Charlotte S. and Kurt J., Rock-property and seismic-attribute analysis of a chert reservoir in Devonian Thirty-one Formation, *Geophysics*, Vol. 71, No. 5, 2006.
- [13] Carvalho J., Dias R., Pinto C., Leote J. and Mendes V. L., SPT seismic hazard seismic refraction soil classification and geotechnical data applied to the soil micro-zoning of western Algarve, Portugal, *European Journal of Environmental and Engineering Geophysics*, Vol.5, pp.3-14, 2009.
- [14] Joseph E. B., *Foundation Analysis and Design*, Fifth Edition, McGraw-Hill, Washington D.C, 1997
- [15] United States Geological Survey (USGS)-Bulletin, Lithological, geotechnical properties analysis, and geophysical log interpretation of USGS survey drill holes, Tyonek Formation. Alaska, USA, 1835.
- [16] Frank H. G., and Jhon P. C., *Lithology and fluid seismic determination for the Acae area, Puerto Colón Oil Field, Colombia*, Vol. 3, No.1, pp.35-44, 2005.

Copyright © Int. J. of GEOMATE. All rights reserved, including the making of copies unless permission is obtained from the copyright proprietors.
