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Application of Crosshole Seismic technique and MASW at Heavy Engineering Site, near Mahabalipuram, Tamilnadu

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ABSTRACT

Seismic velocities (Vp and Vs) of the subsurface play a vital role in designing the engineering parameters for major civil engineering structures. A case history is presented from the charnockite province in east coast of India near Mahabalipuram, Tamilnadu. As a part of the feasibility study Crosshole seismic and Multi Channel Analysis of Surface waves (MASW) surveys were conducted near a heavy engineering construction site. Vp and Vs are determined up to 55 m depth with an interval of 1.5 m. Dynamic elastic constants, average shear wave velocity, predominant frequency and amplification of the area were calculated. Velocity data reveals that soil cover composition varies with depth, namely, highly weathered, moderately weathered and fresh Charnockite occur successively from top to bottom in the subsurface. Dynamic elastic constants, average shear wave velocity, predominant frequency, and amplification are estimated.

Key words: Vp and Vs, crosshole seismics, MASW and Charnockites

INTRODUCTION

Estimation of elastic moduli and seismic velocities in hard rock terrain is essential to analyze the foundation vibrations, earthquake resistance and geotechnical problems at heavy civil engineering structure sites. Usually, these constants are calculated with the help of engineering methods (Cone Penetration test, Soil Penetration test etc.), geophysical methods (Seismic downhole, Seismic uphole, Seismic Refraction, Crosshole Seismics, etc.) and laboratory methods (ultrasonic Pulse Transmission). Compared to engineering and laboratory methods, the geophysical techniques have been proved to be more reliable, non-destructive and cost- effective (Hassani et al., 1997; Turesson, 2006).Laboratory methods have certain limitations (core samples are free from the overburden stress, and core samples are too small as compared to relative rock heterogeneity) to determine the seismic velocities and elastic moduli of rock mass (Swain, 1962). The cross-hole seismic technique provides good results compared to laboratory methods in certain cases (Young, 1961). Estimation of seismic velocities using Crosshole method yielded best results at heavy engineering structure sites (Dobecki, 1979). This technique/ method also provide attenuation properties of the rock mass, which play a key role in determining the quality of the rock (Balakrishna et al., 1981). In view of the above, Crosshole seismic technique was employed at Mahabalipuram, Tamilnadu (Figure 1) to estimate the in situ seismic velocities and elastic moduli of the Charnockite basement and estimating the weathering profile of the subsurface. This study was carried out in one set of boreholes, which includes one-shot hole (BH-S) and two receiver holes (BH-R1 & BH-R2). The P & S wave velocities are calculated up to 55 m depth with an interval of 1.5 m. The laboratory estimated density values are used to calculate the elastic moduli (Rao et al., 2006). The MASW test (Park et al., 1999; Miller et al., 1999 Seshunarayan et al., 2008; Seshunarayan et al., 2008; Satish Kumar et al., 2010) was also conducted to know the shear wave velocities of top layers at places where cross-hole technique was not possible to conduct due to the presence of borehole casing. In this paper, P&S wave velocities, Dynamic elastic constants, average shear wave velocity, predominant frequency, and amplification of the area were calculated.

GEOLOGICAL SETTING

The study area is located in Eastern Dharwar Craton and consists of Tonalite-Trondhjemite-Granodiorite (TTG) gneisses, Charnockites, schist belts and younger granites (Rogers, 1986). The present study area is characterized by Charnockite rocks containing quartz, feldspar, hypersthenes, garnet, and mica (Holland, 1990). The Charnockite rock samples collected from the excavated portions indicates, they are inter- layered and contain garnet, biotite, muscovite, pyrites and phlogopite mica. Three different shades of Charnockites are seen in this area such as blue, gray and black, and they are particularly medium grained (Elango et al., 2004).The Charnockite rocks exposed in the area are fresh with slight weathering. Although altered materials are also seen mostly along the fractures, it is mainly due to weathering and leaching (Figure 1).

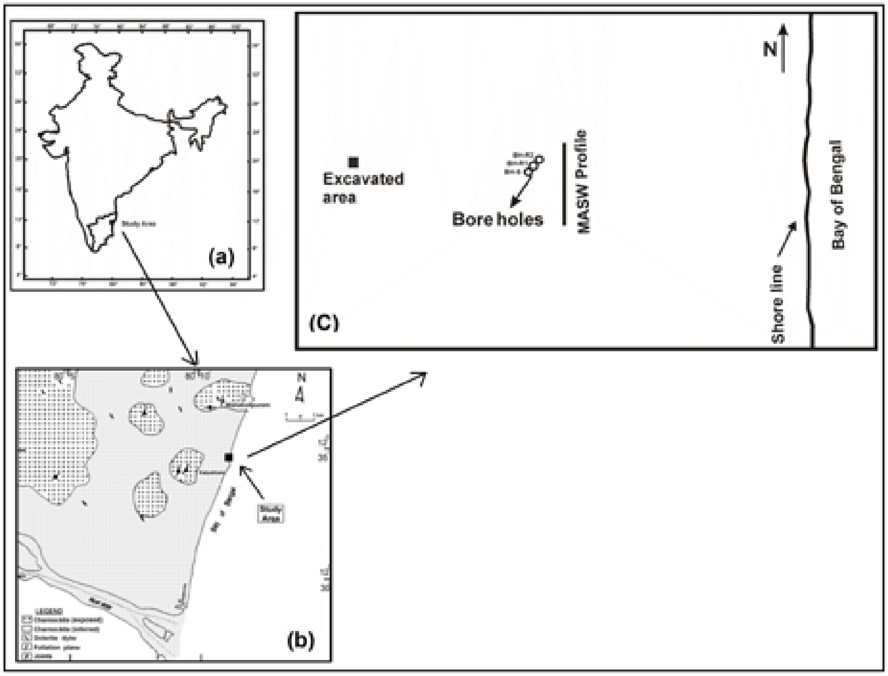

Figure 1. shows (a) Location of the study area, b) Regional Geological map of the study area (after Rao et al., 2006), c) Location of three borehole, MASW profile, and excavated area.

The lithological information obtained from the drill logs named BH-S, BH-R1 and BH-R2 correspond to alluvium, moderately weathered Charnockite and fresh Charnockite occurs successively from top to bottom (Figure 4).

METHODOLOGY

Cross- hole seismic survey was conducted across three boreholes BH-S, BH-R1 & BH-R2. Each borehole has an inner diameter of three inches and three meters of horizontal separation between two holes. Due to collapsing nature of the upper sandy alluvium layer, these boreholes have been iron cased up to the depth of 16.5 m. Explosives with "seismic" detonator have been lowered in to TBH-S borehole and detonated for generation of elastic waves. Shooting was conducted from the depth of 55.5 m to 16.5 m with an interval of 1.5 m in BH-S. 10 Hz three component geophones for generation of P, SV, and SH waves are used as receivers in other two boreholes (BH-R1 & BH-R2). Seismic data have been acquired using a 24 channel engineering Seismograph (Strata View, manufactured by Geometrics Inc, USA). In this survey, seismic energy is generated at the desired depth of one borehole and the time for that energy to travel to another borehole through the subsurface layer is measured at the same depth level. From the borehole spacing and travel time, the velocity of the seismic wave (P & S) is computed (Woods, 1978; Woods, 1994; Seshunarayana et al., 2001; Seshunarayana et al., 2005; Crice, 2002; ASTM, 2000). Inline geometry technique has been adopted to eliminate the errors caused by the inherent delay associated with the electrical detonator, (Butler et al., 1981). Moving the source and the receivers to different depths, the travel time of the wave between the source and receivers are recorded (Seshunarayana et al., 2001). To calculate the elastic properties, laboratory mean density value of 2.722 gm/cc is taken as reference (Rao et al., 2006). Elastic constants are calculated from the velocity data of Crosshole seismic survey using standard relations (Timoshenko and Goodier, 1970; Sharma 1986, Crice, 2002).

The shear wave (S-wave) velocity section was obtained by modeling the Multichannel Analysis of Surface Waves (MASW) data (Park et al., 1999; Miller et al., 1999). Rayleigh wave data (rich in ground-roll) has been recorded using an engineering Seismograph (Strata View, manufactured by Geometrics Inc, USA) and 24 low-frequency vertical geophones with a natural frequency of 4.5 Hz, placed at 1 m interval. Acoustic energy was generated using a 10-kg sledgehammer hit on a metal plate. The 5 m near offset was chosen depending upon the site condition (Xu and Butt, 2006). The acquired surface wave data was processed using the Standard procedures by the Surfseis software. Each set of Rayleigh wave data (shot gather) was transformed from time domain to frequency domain to generate dispersion curves (frequency vs. phase velocity), which have been further transformed into S-wave velocity-depth profile through an inversion process. Each set of velocity-depth profiles was arranged in sequential

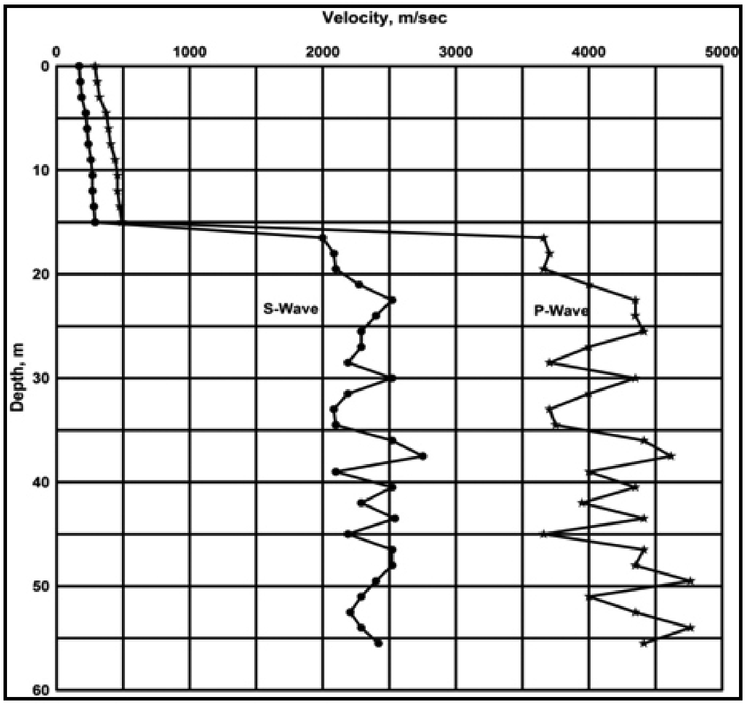

Figure 2. Shows the plot of calculated P & S wave velocities of the subsurface concerning depth. (m/s: meter/second).

order from the first shot station to form a 2-D shear wave velocity field. The depth-velocity results of the MASW are commonly found to be in good agreement with the borehole velocity measurements (Xia et al., 2002). Probing depth of the MASW investigation, in this study is 15 m, which is dependent on the energy source parameters (e.g., frequency) and the mechanical properties of subsurface materials. P- wave velocity of 15 m column was obtained by the standard relation of Vp and Vs.

Shear wave velocity is known to be an important parameter to access the dynamic properties of the site. The National Earthquake Hazard Reduction Program (NEHRP) provision (BSSC, 1994) and new 1997 uniform building code classify the sites depending on the average shear wave velocity of the site (example: Velocity column up to 30 m) (Dobry et al., 2000; Kanli et al., 2006). The classification of sites based on harmonic mean shear wave velocity is given by Federal Emergency Management Agency, (FEMA, 1997).This classification is applicable in determining the seismic coefficients for earthquake resistant structure design. Average shear wave velocity of the site using MASW test was calculated as fallows.

$$Vs^{Average} = \sum_{i=1}^{n} di \;/\; \sum_{i=1}^{n} di/Vsi$$

Where,
i is a layer between 1 to n
di is a thickness of a layer
Vsi is an S-wave velocity in m/s of a layer

The average shear wave velocity up to top 30 m of the area computed using MASW and crosshole data is 410 m/s.

Amplification and Predominant Frequency

Local amplification of the ground is often controlled by the soft surface layer which leads to trapping of seismic energy due to the impedance contrast between the soft surface soils and the underlying bedrock. The soil properties and thicknesses of surface layers play a key role in influencing the ground motion. The amplification depends on the resonance between the frequency content of the earthquake waves and the natural period(s) of the ground layers. The predominant frequency and amplification are proportional to the layer thickness and impedance contrast, respectively. Shima (1978) found that the analytically calculated amplification factor is linearly related to the ratio of shear wave velocity of the surface layer to that of bedrock. The period of vibration corresponding to the fundamental frequency is called characteristic site period. The value indicates a period of vibration at which the most significant amplification would occur. Borcherdt, et al., (1991) proposed relation between the average shear wave velocity of surficial layers and the relative amplification as given in equation.

$$AHSA = 700/V_S{}^{30}$$

AHSA is the average horizontal spectral amplification, VS^{30} is the average shear wave velocity (m/s) over a depth of 30m.

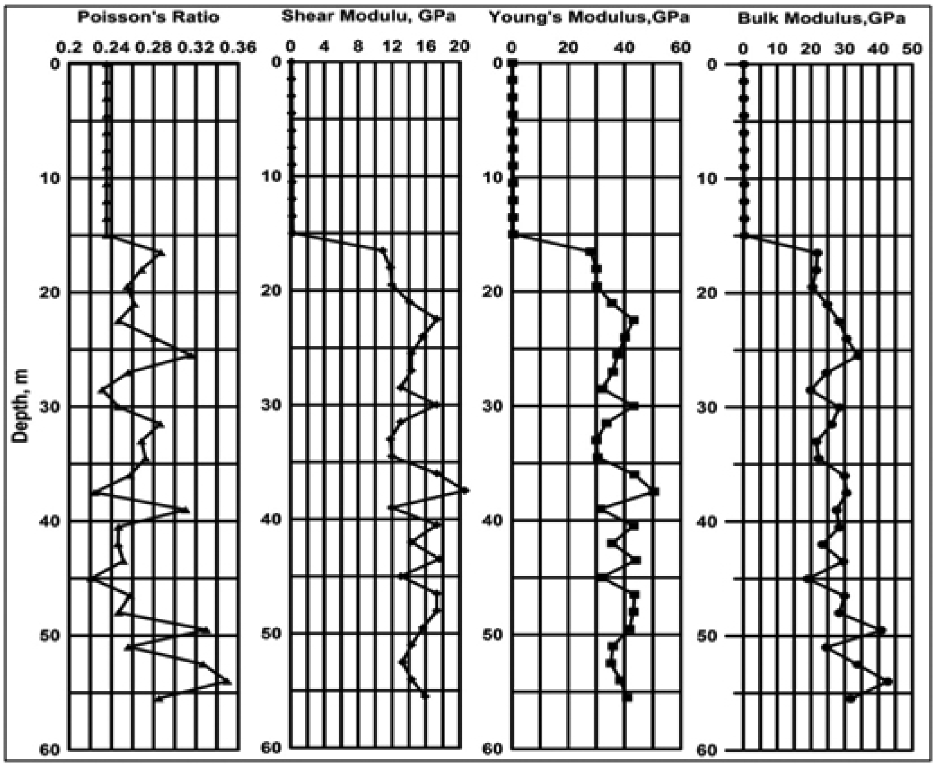

Figure 3. Shows the plot of calculated elastic moduli ((GPa: Giga Pascal)).

The calculated horizontal spectral amplification of the site is 1.7.

The fundamental site period (Ts) corresponds to the first mode of vibration of the soil deposit. It is one of the parameters for seismic microzonation. It is governed by the thickness and the shear wave velocity of the soil layer and is calculated by using the expression given by Kramer (1996). The period of vibration corresponding to the fundamental frequency is called the characteristic site period. We have estimated the frequencies at which the seismic waves are expected to resonate in the soil column of 30 m depth.

The predominant frequencies at which the seismic waves are expected to resonate in the soil column of 30 m depth are computed by using the frequency-shear wave velocity relationships (Kandpal et al., 2009; Trupti et al., 2013). To estimate the frequencies at which the seismic waves are expected to resonate in the soil column of 30 m depth, the simple relationship between the shear wave velocity (β) of the sediment column (30 m), is

$$f = \beta/4H$$

Where, β is the average shear wave velocity,

H is the thickness of the sediments.

The estimated predominant frequency of the area is 3.42 Hz.

RESULTS

The velocity model prepared based on the field studies is shown in Figure 2. P-wave and corresponding S-wave velocities of the formation are calculated by using interval times of the two receivers and distance between the boreholes. The calculated P- wave velocity (Vp) is in the range of 3660 m/s to 4750 m/s, and the S wave velocities (Vs) vary in the range of 2000m/s to 2600m/s. The calculated elastic constants such as σ =0.16-0.29, E =28.02GPa-42.8GPa, G =10.89GPa-18.4GPa and k =20.28GPa-24.81GPa of the Charnockites are shown in Figure 3. Vp and Vs velocity in alluvium, are estimated. From the surface and bore hole studies it is inferred that the alluvial soils are upto depth of about 16 m and moderately weathered Charnockite are up to about 20 m depth. Beyond 20 m depth it is fresh Charnockite rock (Figure 2) from MASW data (Figure 4). It is interpreted from Figure 2. Moderately weathered Charnockite is characterized by 2000 to 3600 m/sec P-wave velocities and fresh charnockite range between ~3660 -4750 m/sec. The thickness of this layer is 1.5m. Fresh Charnockite present from 21 m to 55.5 m depth has Vp and Vs velocities of ~4000 m/sec to 4750 m/sec and ~2270 m/sec to 2600 m/sec, respectively. Minor fractures or deviations in the borehole are characterized by low velocities (both Vp & Vs) within the higher velocities as shown in Figure 2. A 50-m-long (N-S oriented) shear wave velocity section of the study area is shown in Figure 5. It is inferred from this section, that the soil cover and weathering cap of varying consolidation are characterized by S-wave velocities of approximately ~160-240 m/s, and ~240-350 m/s, respectively. The soil cover and highly

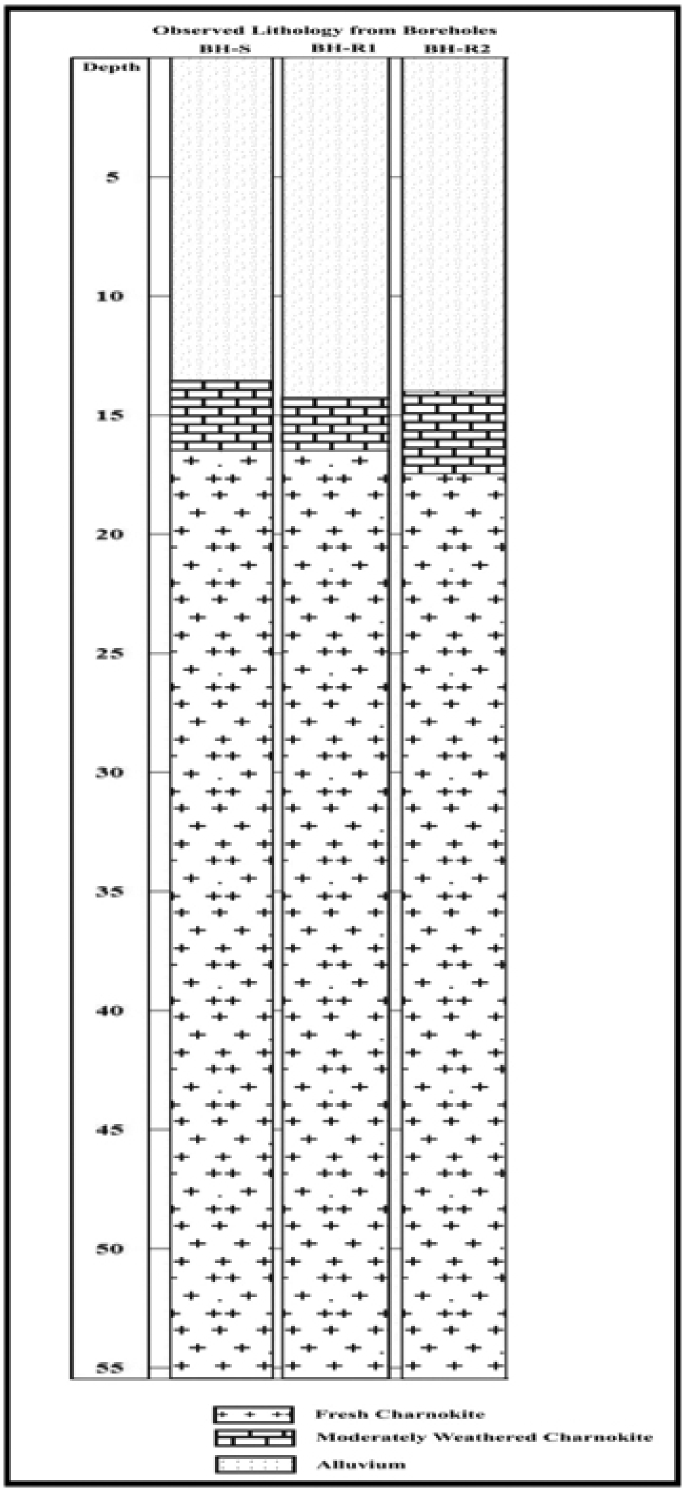

Figure 4. shows the observed lithology from core log data and Interpreted lithology from MASW and Crosshole survey. (BH-S: Source Borehole, BH-R1: Receiver Borehole one, BH-R2: Receiver Borehole two).

weathered Charnockite occur successively from top to bottom. The thickness of soil cover varies from surface to 7 m depth, and the highly weathered cap is present from 7 m to 15 m. The average shear wave velocity of site up to 30 m is 410 m/sec, whereas amplification and predominant frequency of the area are 1.7 and 3.42 Hz, respectively.

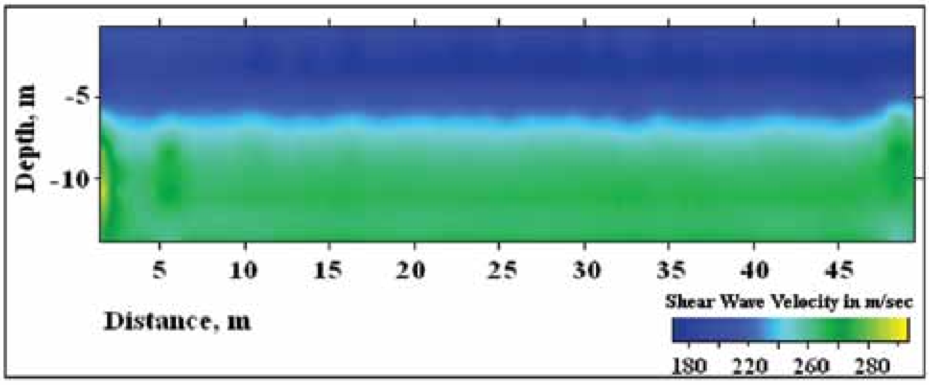

Figure 5. Shows the Shear wave velocity field consists of two velocity layers. It is interpreted that the soil cover and weathering cap of varying consolidation are characterized by an S-wave velocity of ~160-240 m/s, and ~240-350 m/s, respectively.

CONCLUSION

It is observed from Crosshole seismic and MASW studies that the present study area occupied by alluvium up to the depth of 15 m is underlain by a weathered and hard Charnockitic rocks. Dynamic elastic constants, average shear wave velocity, predominant frequency, and amplification are estimated through field studies.

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Compliance with Ethical Standards

The authors declare that they have no conflict of interest and adhere to copyright norms.

REFERENCES

American Society of Testing and Materials (ASTM)., 2000. Standard test methods for Crosshole seismic testing, Designated 4428/D4428M-84 report.

Balakrishna, S., Ramana,Y.V., Varadarajan, G., Seshunarayana, T., Subrahamanyam, K., and Prabhakara Prasad, P., 1981. Propagation velocity of rocks of Panchpatmani region by laboratory and field geophysical methods, un published NGRI Tech.Report.No.81-184 and 185.

Borcherdt, R.D., Wentworth, C.M., Glassmoyer, G., Fumal, T., Mork, P and Gibbs, J., 1991. On the Observation, Characterization, and Predictive GIS Mapping of Ground Response in the San Francisco Bay Region, California, Proc 4th International Conference on Seismic Zonation, Stanford, California, v.3, pp: 545-552.

Building Seismic Safety Council (BSSC), 1994. NEHRP Recommended provisions for the development of seismic regulations for new buildings, part I: Provisions, developed for the Federal Emergency Management Agency, Washington D.C.

Butler, D.K., Joseph, R. and Curro, J.R., 1981. Crosshole seismic testing-procedures and pitfalls, v.46, no.1, pp: 23-29.

Crice Doug., 2002. Borehole shear wave surveys for engineering site investigations, open document of Geostuff, pp: 1-14, available in http://www.geostuff.com/shearwave2.pdf.

Dobecki, T.L., 1979. Measurement of in-situ dynamic properties in relation to geological conditions: in reviews in engineering geology, Geological Society of America, v.4, pp: 201ff.

Dobry, R., Borchedt, R.D., Crouse, C.B., Idriss, I.M., Joyner, W.B., Martin, G.R., Power, M.S., Rinne and Seed, R.B., 2000. New site coefficients and site classification system used in recent building seismic code provisions, Earthquake Spectra, v.16, no.1, pp: 41-67.

Elango, L., Sanjeevi, S., Nagendra, R., and Selvan, T.A., 2004. A report on geological mapping of PFBR project site at Mahabalipuram, Tamilnadu. un published report of Anna University, Chennai.

Federal Emergency Management Agency (FEMA)., 1997. Multi Hazard Identification and Assessment. FEMA. Washington, D.C.

Hassani, F.P., Guevremont, P., Momayezl, M., Sadril, A., Saleh, K., 1997. Application of nondestructive evaluation techniques on concrete dams, Int. J. Rock Mech. & Min. Sci. v. 34, no.3-4, pp: 125.

Holland, T.H., 1900. The Charnokite series, a group of Achaean hypersthene rocks in peninsular India, Mem.Geol.Surv. India, v. 28, pp: 182-249.

Kandpal G.C., John, B., Joshi, K.C., 2009. Geotechnical Studies in relation to Seismic Microzonation of Union Territory of Chandigarh. J.Ind.Geophys.Union, v.13, no.2, pp: 75-83.

Kanli, A.I., Tildy, P., Pronay, Z., Pinar, A., and Hemann, L., 2006. V_S^{30} mapping and soil classification for site effect evaluation in Dinar region, SW Turkey, Geophysics J.Int, v.165, pp: 223-235.

Kramer, S.L., 1996. Geotechnical earthquake engineering. Prentice Hall Publishers, Englewood Cliffs, New Jersey.

Miller, R.D., Xia, J., Park, C.B., and Ivanov, J., 1999. Multichannel analysis of surface waves to map bedrock, The Leading Edge, v.18, pp: 1392–1396.

Park, C.B., Miller, R.D., and Xia, J., 1999. Multi-channel analysis of surface waves, Geophysics, v.64, pp: 800-808.

Rao, M.V.M.S., Prasanna Lakshmi, K.J., Sarma, L.P., and Chary, K.B., 2006. Elastic properties of granulite facies rocks of Mahabalipuram, Tamil Nadu, India, J. Earth Syst. Sci., v.115, no.6, pp: 673-683.

Rogers, J.J.W., 1986. Dharwar Craton and assembly of Peninsular India. Jour.Geol. v.94, pp: 129-143.

Satish Kumar, K., Senthil Kumar, P., Prabhakara Prasad, P., Srinivas, K.N.S.S.S. Mysaiah.D and Seshunarayana, T., 2010. Proceedings of ASCE, GeoFlorida, 2010. Advances in Analysis,Modeling &Design, edited by dante Fratta, pp: 140.

Seshunarayana, T., Prabhakara Prasad, P., Prasad Rao, S.V.V., Subrahamanyam, K., and Varadarajan, G., 2001. Crosshole velocity measurement to assess the nature of rock mass on which to erect a heavy Buddha statute in Hyderabad. Geol. Soc. India, v.58, pp: 65-68.

Seshunarayana, T., Prabhakara Prasad, P., Satish Kumar, K., and Kiran Kumar Reddy., 2005. Crosshole seismic survey near Mamallapuram, Tamilnadu, un published report of NGRI, Hyderabad, T.R.No.NGRI-2005-EXP-497. 13.

Seshunarayana, T., Satish Kumar, K., Deenanadh, S., Rama Mohan Rao, Y., and Senthil Kumar, P., 2008. Subsurface imaging of dykes in Hyderabad granite terrain using multichannel analysis of surface waves, in: Indian Dykes, edited by R.K.Srivastava, Ch. Sivaji and N.V.Chalapathi Rao, Narosa Publishing House, New Delhi, 8 pages.

Seshunarayana, T., Sentil Kumar, P., Sampath Rao, V., Mysaiah, D., Satish Kumar, K., and Pavan Kishore, P., 2008. Multichannel Analysis of Surface Waves Reveals Shear Zones and Fractures in a Shallow Granite Basement: Wailapally Watershed Near Hyderabad. Journel of Geol. Soc. India v.71, pp: 261-265.

Sharma P.V., 1986. Geophysical Methods in Geology, Elsevier Science Publishers, 2nd edition, pp: 442.

Shima, E., 1978. Seismic Microzoning Map of Tokyo, Proc. 2nd International Conference on Microzonation, v.1, pp: 433-443.

Swain, R.J., 1962. Recent techniques for determination of "in-situ" elastic properties and measurement of motion amplification in layered media.Geophysics, v.27, no.2, pp: 237-241.

Timoshenko S.P., and Goodier J.N., 1970. In Theory of Elasticity, McGraw-Hill, New York, 3rd edition.

Trupti, S., Goverdhan, K., Srinivas, K.N.S.S.S., Prabhakar Prasad, P., and Seshunarayana, T., 2013. Site classification of Pondicherry using shear-wave velocity and horizontal-to-vertical spectral ratio, Natural Hazards, v.69, pp: 953-964. DOI:10.1007/s11069-013-0746-3.

Turesson, A., 2006. A comparison of methods for the analysis of Compressional, shear, and surface wave seismic data, and determinant of shear modulus. Journal of Applied Geophysics, v.61, no.2, pp: 83-91.

Woods, R.D., 1978. Measurement of Dynamic Soil Properties, State of the Art Report: Proceedings of the ASCE Geotechnical Engineering Division Specialty Conference, Earthquake Engineering and Soil Dynamics, Pasadena, CA, v.1, pp: 91-178.

Woods, R.D., 1994. Borehole Methods in Shallow Seismic Exploration: Geophysical Characterization of Sites, Volume prepared by ISSMFE, Technical Committee # 10, XIII ICSMFE, New Delhi, India, Richard Woods, Editor, pp: 91-100.

Xia, J., Miller, R.D., Park, C.B., and Tian, G., 2002. Determining Q of near-surface materials from Rayleigh waves, J. Applied Geophysics, v.51, pp: 121-129.

Xu, C., and Butt, S.D., 2006. Evaluation of MASW techniques to image steeply dipping cavities in laterally inhomogeneous terrain, J. Applied Geophysics, v.59, pp: 106-116.

Young, D.D., 1961. In-situ measurements of elastic properties: University of California Lawrence Radiation Laboratory Report UCR L-6477.

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