Site specific seismic study for a power plant site at Samalkot, Godavari rift basin in Peninsular India

A. Boominathan, M.G.Vikshalakshie & RM.Subramanian
Department of Civil Engineering, Indian Institute of Technology Madras, India

SUMMARY
A site specific seismic study considering local site effect was carried for the proposed power plant site near Samalkot town located at Godavari Rift basin in Peninsular India. The deterministic seismic hazard analysis performed using three attenuation relationships identified the Vasishta – Godavari fault located at 50 km from the site with magnitude M_w of 5.0 as the controlling earthquake source. One dimensional ground response analysis was carried out by equivalent linear approach using the measured shear wave velocity profile for six input motions. The site specific spectra obtained by Ratio of Response Spectra (RRS) analysis was compared with Indian codal spectra. It is found that the spectral accelerations at the mid period range (0.1 to 0.4 s) is about 1.5 times higher than Indian Standard design spectra for rocky site or hard soil.

Keywords: Seismic hazard, Site effects, Ground response analysis, Response spectra, Peninsular India

1. INTRODUCTION

Ground motions are usually developed in one of two approaches: (1) provisions from building codes and standards and (2) site-specific analyses. The former is based on developed hazard maps and provides zone factors that reflect to an extent the local site conditions, however do not consider local site variations. The latter involves, performing both seismic hazard analysis and ground response analysis to evaluate site specific ground motion parameters that captures the effects of local soil conditions on the seismic response. The observed damage patterns and statistical analysis of recorded ground motions at well instrumented soil sites suggest that, the seismic design of structures must take into account the influence of local soils. Seismic hazard analysis can be carried out by probabilistic or deterministic approaches considering the seismicity and seismo-tectonics of the region. Probabilistic seismic hazard analysis provides a frame-work in which uncertainties in size, location and rate of recurrence of earthquakes can be identified, quantified, and combined in a rational manner to provide a more complete picture of the hazard but requires careful attention to source characterization and the mechanics of the probability computations. Deterministic Seismic Hazard Analysis (DSHA) analysis is simple and identifies individual faults with their estimated maximum credible earthquakes affecting a site and gives site-specific hazard estimates based on the earthquake potential of each fault (Krinitzsky 2003).

Peninsular India (PI), though traditionally considered to be more stable and less prone to seismic hazard, but the past earthquakes predominantly, Latur earthquake (30th September 1993, M_w 6.1), Jabalpur earthquake (22nd May 1997, M_w 5.8) and Bhuj earthquake (26th January 2001, M_w7.7) have influenced the need for site specific seismic study and their effects on Indian cities in PI. This paper presents the details of site specific seismic study carried out for a power plant site near Samalkot (India) situated at Godavari Rift Basin in the northern part of Peninsular India.

2. SIGNIFICANCE OF SITE-SPECIFIC ANALYSIS

The design ground motion at a particular site is influenced by the various factors such as the potential seismic sources, the seismicity of those sources, and the nature of rupture at the source, travel path effects, and the importance of the structure or facility for which the ground motion is to be used. Design ground motions can be developed based on the available codal provisions or on the basis of site specific analysis. The codes are developed with relevance to accounting for broad range of similar group of soils, hence within which the design ground motion for the site considered may fall and can be established. But design motions based on codes are highly conservative and hence require strong level of shaking than the motion obtained from ground response analysis. The site specific design ground motion takes into account the attenuation effects of the actual soil conditions present at the site and helps to obtain optimum ground motion parameters of practical relevance. Site specific ground response analysis involves sequence of steps. The characterization of site is done at first with geological, geophysical and geotechnical investigations. The site is then classified as per NEHRP recommendations with respect to shear wave velocity profile of the site for the top 30 m from the ground surface. The seismic hazard analysis is carried out by either Deterministic or probabilistic approach. In the present study Deterministic Seismic Hazard Analysis (DSHA) is carried out to determine the ground motion parameters at bed rock level. The DSHA identifies individual faults with their estimated Maximum considered earthquake (MCE) affecting a site and gives site specific hazard estimates from the earthquake potential of each fault. The ground motion parameters are predicted based on the relevant available attenuation equations, which usually correspond to a narrow range of subsurface conditions. Attenuation relations may be site specific, which means

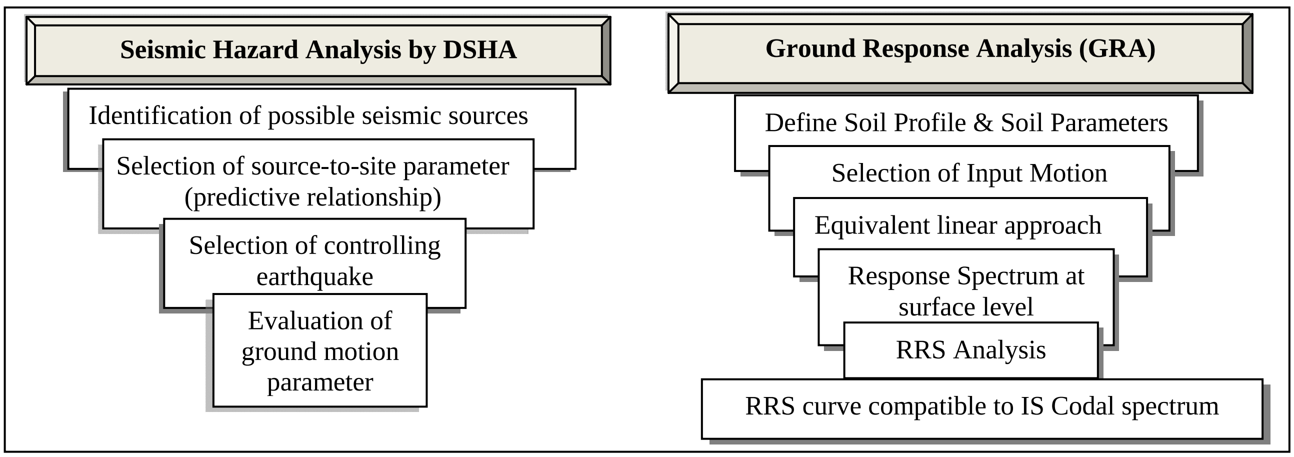


Figure 1. Steps involved in DSHA (Kramer 1996) and Ground Response Analysis

for a particular soil conditions such as rock, soft soil, deep stiff soil, shallow stiff soil, etc (Ansal, 2004). Then the ground response analysis is performed using equivalent linear approach on the site of interest with different suitable base input motions and required design ground motion parameters like PGA, acceleration time history, predominant period, design response spectra compatible to codal provisions are obtained. The steps involved in DSHA and Ground Response Analysis is presented in Fig. 1.

3. SITE DESCRIPTION & CHARACTERIZATION

The site is located near Samalkot area of East Godavari district of about 150 km south-west of Vishakhapatnam, Andhra Pradesh. Its geographical coordinates are 17° 2' 28" N, 82° 8' 18.07" E situated at Godavari Rift Basin in the northern part of Peninsular India. Historical records does not indicate occurrence of any significant earthquakes in the Godavari valley region in the past two hundred years, only a few minor events were reported (Gupta et al., 1970). However Samalkot and its neighbourhood has experienced the effects of two moderate level earthquakes: Ongole earthquake of March 27, 1967 (m_b 5.4) and Bhadrachalam earthquake of April 13, 1969 (m_b = 5.3). The site comes under the category of Zone III as per Indian seismic code (IS: 1893 Part-I 2002) which is broadly associated with seismic intensity VII on MMI scale corresponds to horizontal ground acceleration range of 18-240 cm / sec^2 or an average of acceleration 67 cm / sec^2 in any direction.

Site characterization is the initial phase of the site-specific ground response analysis, which involves acquiring, processing, and interpretation of qualitative and quantitative information of the site, such as geological, geotechnical, seismic and seismotectonic details, to evaluate the hazard based on level of site response. One of the major problems in geotechnical engineering is the risk of encountering unexpected geological conditions such as sudden variation in the soil profile, rock strata, failure plane and faults in the rock, etc. Failure to anticipate such conditions generally is due to inadequate geological understanding of the site and may lead to issues concerning design and performance of critical and important structures. Hence it is very important that rigorous geological and geophysical analyses accompany extensive geotechnical investigation to understand the behavior of the site to seismic loads (Boominathan, 2004).

3.1. Geology

Geologically, the region comprises two major tectonic domains viz. the Dharwar Craton and the Bastar Craton separated by Godavari Rift Basin which represents a polycyclic structural trend in NNW- SSE direction to N -S. The Godavari valley is a Mesozoic rift with a length of ~800 km. The eastern margin of the Godavari rift is bound by NNW-SSE trending basin margin fault. Two DSS profiles across the valley reveal the presence of two sedimentary basins, separated by a basement ridge. It has also indicated the presence of 2.8 km thick lower Gondwana sediments within the graben. The prominent geological/tectonic features identified in and around Samalkot region in Andhra Pradesh are the Addanki - Nujivdu fault, the Bapatla Ridge, the Kolleru lake fault, the Godavari valley fault etc (IMD). Major faults in the area indicate neotectonic signature. They are WNW–ESE trending Kinnerasani - Godavari Fault with its splays and the Godavari Valley Fault. The faults associated with the Godavari Graben namely, the Kaddam Fault and the Gundlakamma Fault near Ongole on the coast trending NW-SE is regarded to be moderately active in PI (GSI 2000).

3.2 Geophysical and Geotechnical Investigation

Geophysical/Geotechnical investigations involves conducting field/lab tests on the soil/rock to obtain information on their physical properties for a site to design earthworks and foundations for proposed structures and for repair of distress to earthworks and structures caused by subsurface conditions. In the present study, boreholes were drilled to a depth of about 20 m at various locations and undisturbed samples were collected at every 1.5 m depth. Seismic cross hole tests were carried out to a depth of 20 m and seismic refraction test was carried out to depth of 40 m to ascertain the shear wave velocity profile. The worst shear velocity profiles obtained from the both seismic surveys are averaged and utilized in the ground response analyses.

The subsurface strata at the site predominately comprises of clayey sand with gravels up to a depth of about 10m below EGL. Bore log reveals transition from clayey sand to sandy clay and vice versa throughout depth. This clayey sand formation is underlain by sandy clay with occasional presence of gravels, with an average thickness of 6.5 m to 8.0 m. This sandy clay is found to be pre-consolidated and very hard formation with “N” values ranging from 45 to 85. This formation is in turn underlain by clayey sand up to the termination depth of the boreholes of about 20 m. Seismic tests reveals the variation of shear wave velocity in the range of 310 m/s to 530 m/s for a depth of about 26 m from EGL after which it exceeds 900 m/s. The averaged shear velocity profile upto a depth of 30 m obtained from both seismic tests: cross holes and seismic refraction carried out at the site is shown in Fig. 2.

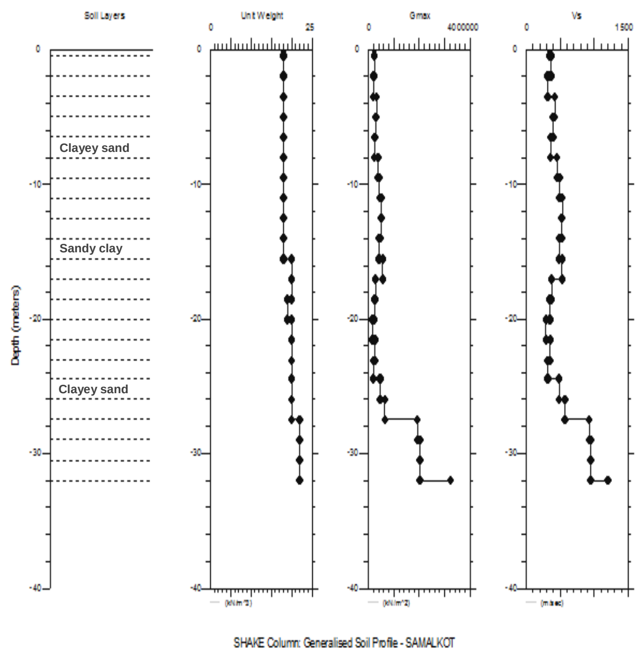


Figure 2. Soil profile used in the present study

3.3 Site Classification

Site classification can be carried out by different schemes: based on average shear wave velocity in the upper 30 m, V_{s-30}, surface geology and geotechnical data are available to represent the generic response of the site to seismic excitations (Kramer & Stewart, 2004). The V_{s-30} scheme (Borcherdt, 1994) is the most widely used site classification procedure in modern practice. Hence, in the present study the site classification is carried out based on $(V_s)_{30}$ approach. The average shear wave velocity for the upper 30 m is determined by using the equation (3.1) (Lew, 2001).

$$(V_s)_{30} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{v_{si}}} \tag{3.1}$$

Where, d_i = Thickness of Layer in m; V_{si} = Shear wave velocity in Layer i in (m/s)
The site is categorized as C class site (Very dense soil and soft rock site) as per NEHRP (BSSC, 2001) classification based on the calculated mean shear wave velocity with in upper 30 m, $(V_s)_{30}$

4. IDENTIFICATION AND CHARACTERIZATION OF EARTHQUAKE SOURCES

4.1 Regional Seismicity and Seismotectonics

The site specific seismic study involves collection of seismicity and seismotectonics details covering 300 km radius as per the Regulatory Guide 1.165 (1997) for carrying out seismic hazard analysis to arrive the controlling earthquake and peak ground acceleration (PGA). The seismicity and activity of the south Indian plate are based on the neo-tectonic activities of the region.

Seismotectonic details, which include geology, rock type, fault orientation, lineaments and shear zones with lengths and earthquake events, are well defined and documented in the Seismotectonic Atlas of India and its environs (SEISAT, 2000) were used in the present study. In the analysis, about Four SEISAT sheets (No: 29, 30, 34, 35) were geo-referenced to cover the seismic sources within 300 km radius using ArcGIS 9.3. Historical and instrumentally recorded data on earthquakes catalogue for the period from 1800 to 2009 A.D. have been obtained from various earthquake sources such as NEIC, India Meteorological Department (IMD), Geological Survey of India (GSI), Gauri Bidanur Array (GBA) and also from published literature (Chandra 1977, Rao and Rao 1984). IMD states that the earthquakes of slight to moderate intensity have been experienced in the past.

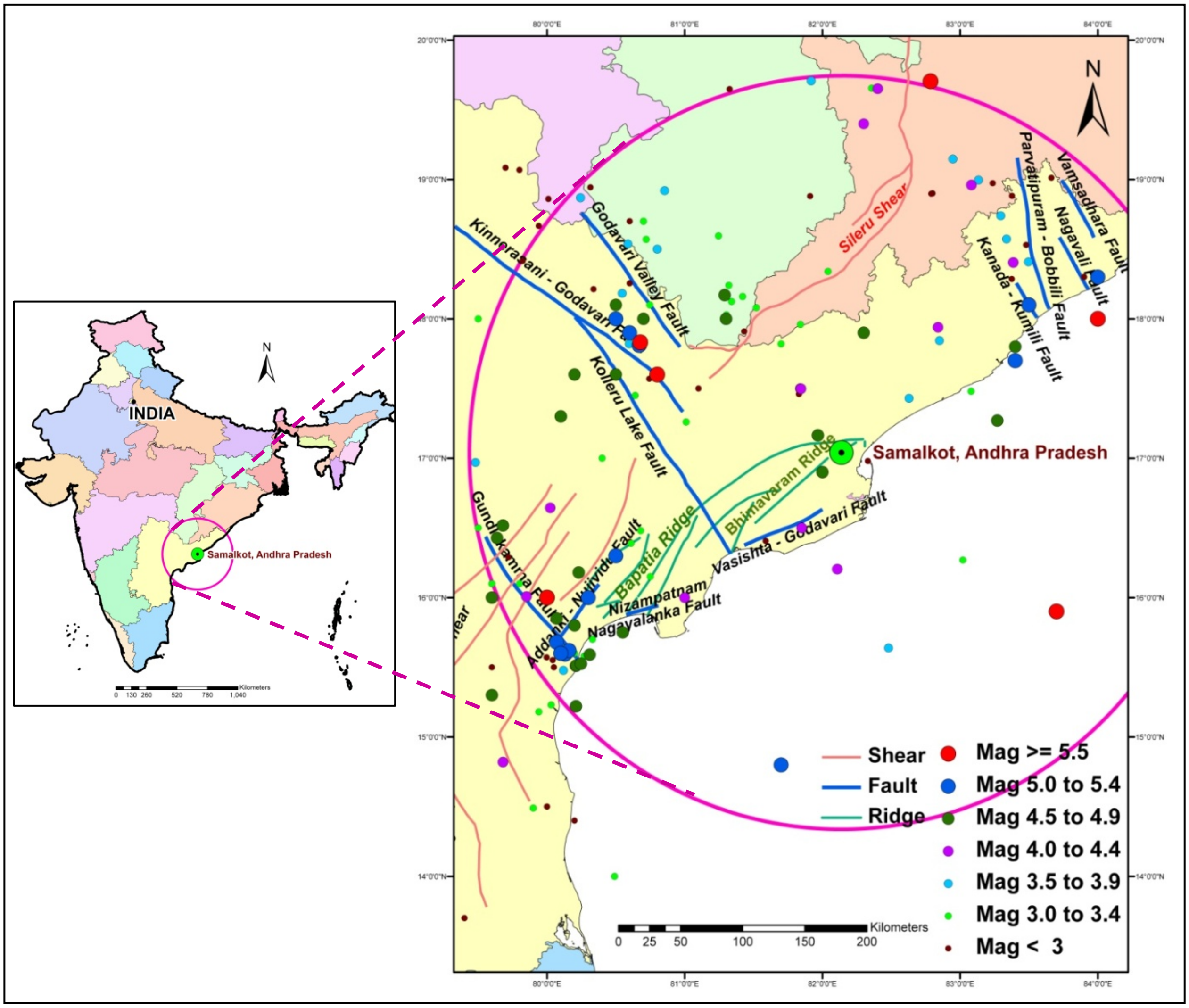


Figure 3. Seismotectonics and Seismicity of the site

These sources were compiled and seismic source map was prepared based on SEISAT using GIS (Fig. 3). The developed map consists of around 11 major faults with length ranging from 50 to 115 km and the epicenter distance varies from 50 to 215 km from the site. The map also shows ridges which are close to the site. The mere presence of fault however does not indicate the likelihood of future earthquakes. Hence it is required to identify the capable faults which are capable of generating strong ground motion. This information is utilized while assigning the maximum magnitude for each fault source by considering the observed seismicity around the particular fault source. The maximum magnitude for a particular seismic source was taken as the largest observed past magnitude plus 0.5 (Kijko and Graham 1998; Sokolov et al 2001). The earthquake details were mapped onto the faults based on the location and depth of the earthquake and the length of the fault, thus the faults capable of producing strong motion were identified.

4.2 Controlling Earthquake

The earthquake that is expected to produce the strongest level of shaking is the controlling earthquake, generally expressed in terms of a ground motion parameter at the site. The selection is made by comparing the levels of shaking produced by earthquakes assumed to occur at the distances. The controlling earthquake is described in terms of its size (usually expressed as magnitude) and distance from the site (Kramer, 1996).

The Peak ground acceleration (PGA) is an important input parameter to measure the maximum value of earthquake acceleration on the ground and also known as the design basis earthquake ground motion.
In the present study PGA at bedrock level has been evaluated using the attenuation relationship proposed by Iyengar and Raghukanth (2004) and Abrahamson and Litehiser (1989). The site lies in-between the western-central and the southern region of Peninsular India as shown in Fig. 4. and hence PGA was estimated using attenuation relationship proposed for southern and Western-Central Region of Peninsular India by Iyengar and Raghukanth (2004). The variation of PGA with Hypocentral distance using three attenuation relationships for M_w 5.0 is shown in Fig. 5. It can be easily noticed from Fig. 5. that the PGA

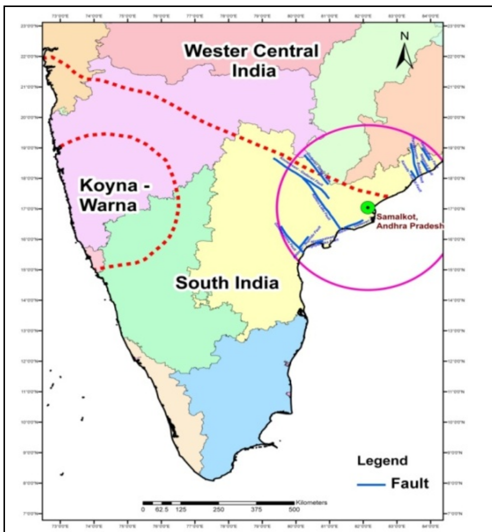


Figure 4. Three sub-regions of Peninsular India (R.N.Iyengar and S.T.G.Raghukanth, 2004) along with the study area fault details.

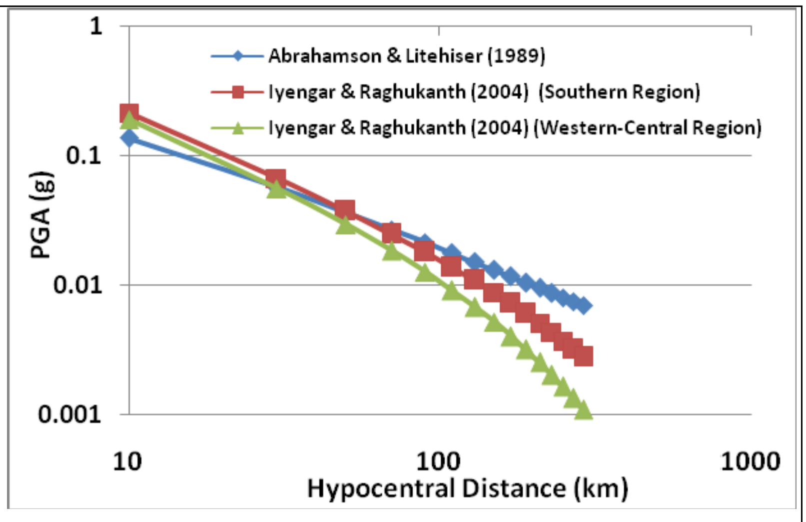


Figure 5. PGA Values versus Hypocentral distance using three Attenuation Relations for M_w 5.0

obtained from Iyengar and Raghukanth (2004) attenuation relationship for southern region of Peninsular India is higher than the PGA obtained from the other attenuation relationships upto a distance of about 80 km from the site and above that Abrahamson and Litehiser (1989) predicts higher values.

The calculated PGA value for the identified major faults varies from 0.001g to 0.036g. It is found that the Vasishta – Godavari fault located at the epicentral distance of about 50 km from the site with magnitude

M_w of 5 causes the maximum PGA of 0.036 g and hence it is identified as the controlling earthquake source. The obtained maximum PGA is used as an input acceleration for the ground response analysis.

5. SITE-SPECIFIC GROUND RESPONSE ANALYSIS

One dimensional ground response analysis is carried out to capture the local site effects on ground motion amplification. Equivalent linear analyses are more efficient than non linear analyses when the input motion can be characterized with acceptable accuracy (Kramer, 1996). Hence in the present study equivalent linear approach is adopted to perform one dimensional ground response analysis using the software SHAKE2000. The site specific ground response analysis is carried out for the design magnitude of 5.0 with PGA of 0.036 g.

5.1 Input Motion

The site specific ground response analysis involves the determination of input acceleration time history characterized by amplitude, frequency and duration content. The maximum PGA of 0.036g is obtained at the bedrock from the DSHA. The acceleration time history at the bed rock is obtained from the recorded ground motion data considering similar magnitude, distance and frequency content of the controlling earthquake. In this case Drama, Greece Earthquake accelerogram (1985; M_w = 5.2; recorded at 47 Km from the source) is used. The time history for Drama, Greece earthquake scaled to 0.036g shown in Fig. 6. is used to carried out ground response anlysis. The Fourier spectrum for the input motion is plotted in Fig. 7. and it shows the predominant frequency of 3.5 Hz.

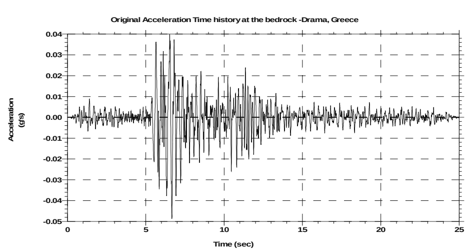


Figure 6. Input acceleration time history of Drama, Greece Earthquake accelerogram

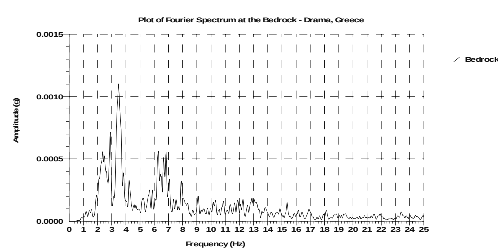


Figure 7. Fourier spectra of the input motion of Drama, Greece Earthquake accelerogram (1985)

6. GROUND MOTION PARAMETERS

6.1 Surface Acceleration Time History, PGA and Fourier Spectra

The results of site specific ground response analysis performed for the site is presented in Fig. 8. to Fig. 10. The surface acceleration time history presented in Fig. 8. shows that the maximum peak ground acceleration (PGA) of 0.085 g. The variation of PGA with depth is shown in Fig. 9. The Fourier spectrum for the surface motion for site is shown in Fig. 10. It is observed from the figure that the predominant frequency is not altered by the local site conditions due to presence of stiff soil and rocky layers.

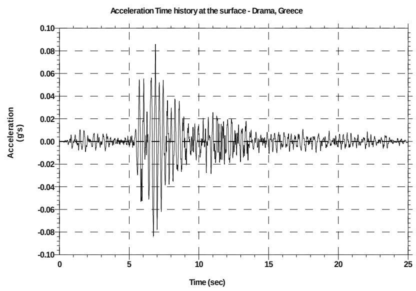


Figure 8. Acceleration time history obtained at the surface Drama, Greece Earthquake accelerogram (1985)

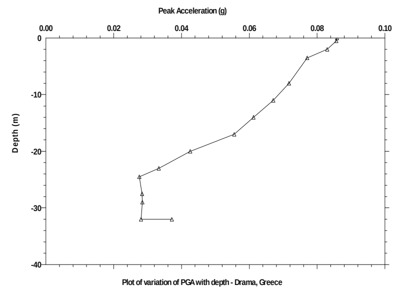


Figure 9. Variation of PGA with depth for Drama, Greece Earthquake accelerogram (1985)

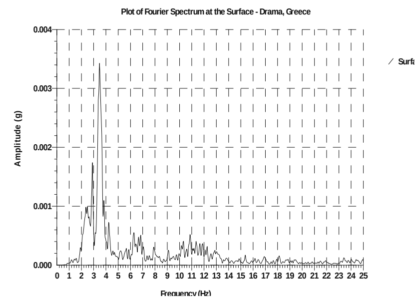


Figure 10. Fourier spectra of the surface motion obtained from the ground response Analysis

6.2 Spectral Acceleration

The spectral acceleration versus the period of structure obtained from the surface time history of acceleration for 5%, 10%, 15% and 20% damping are presented in Fig. 11. For the typical damping of 5%, the peak spectral acceleration of about 0.42 g occurs at a structural period of 0.3 s which represents a typical 3 storey building.

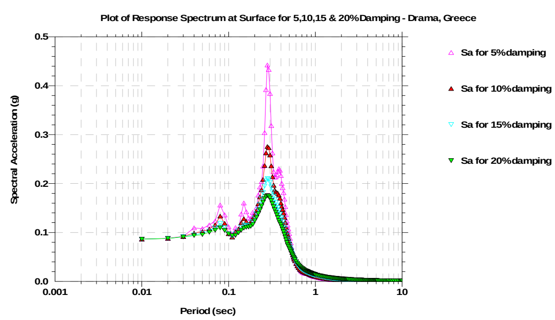
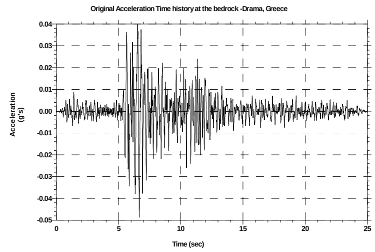


Figure 11. Spectral acceleration response of the surface motion

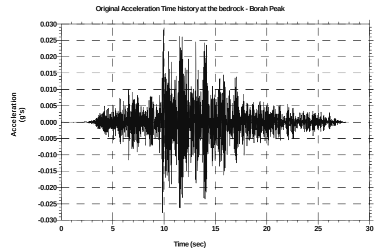
6.3 Site Specific Response Spectra

The Ratio of Response Spectral (RRS) analysis was carried out using SHAKE2000. RRS analysis involves obtaining the spectral acceleration for the surface and the base motion, then dividing the surface spectrum by the base spectrum for each period (Dobry et al., 2000; Martirosyan et al., 2002). In the present case the the Ratio of the Response Spectra (RRS) curves were obtained from the ground response analysis carried out for the six different ground motions (Fig. 12.) taking into account the effect of near field and far field earthquakes which focal depth in the range of 10 - 15 km.

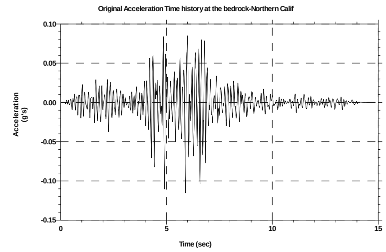
The RRS curves obtained from the ground response analysis is shown in Fig. 13. It can be found from the figure that the higher RSS values occur in the period range of 0.1 to 0.5s. The mean and the median values of RRS curves are multiplied with the base spectrum to arrive the site specific spectra. The base spectrum in this case considered is the IS: 1893 (Part 4):2005 design response spectra for Type 1 soil. The site specific spectra arrived from the RRS analysis considering the response spectra specified in IS: 1893 (Part 4):2005, i.e., site specific spectra compatible to IS design spectra is shown in Fig. 14. The IS design spectra for Rocky site or hard soil is also shown in Fig. 14.It can be seen from the figure that the Site specific response spectra at short periods (less than 0.1 s and relatively long period greater than 0.4 s) is practically similar but at the mid period range (0.1 to 0.4 s) is about 1.5 times higher than IS design spectra for Rocky site or hard soil.



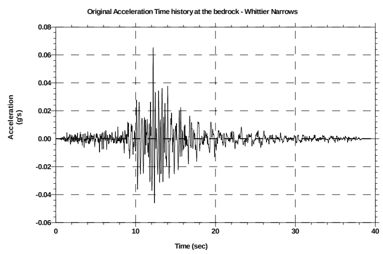
a) Drama, Greece Earthquake accelerogram (1985; M_w = 5.2; 47Km)



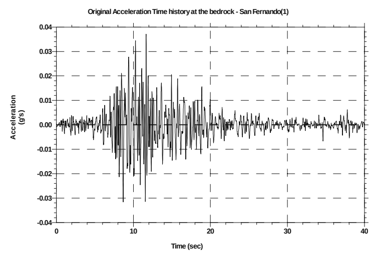
b) Borah Peak Earthquake accelerogram (1983; M_w = 5.1; 50 Km)



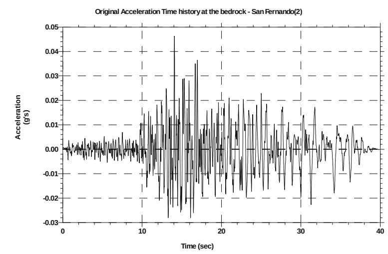
c) Northern Calif Earthquake accelerogram (1975; M_w = 5.2; 30 Km)



d) Whitter Narrow Earthquake accelerogram (1987; M_w = 6; 86 Km)



e) San Fernando Earthquake accelerogram1 (1971; M_w = 6.6; 187 km)



f) San Fernando Earthquake accelerogram 2 (1971; M_w = 6.6; 261km)

Figure 12. Input acceleration time history

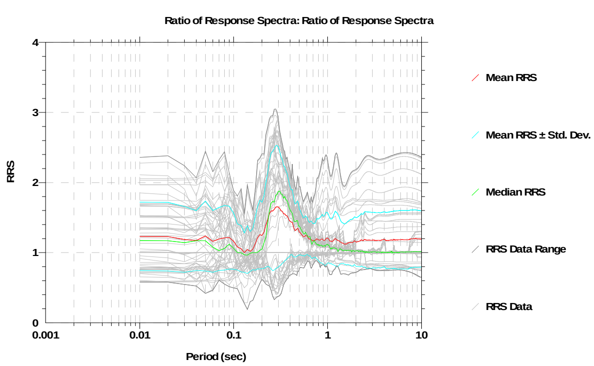


Figure. 13 Mean RRS spectra obtained from the six acceleration time histories

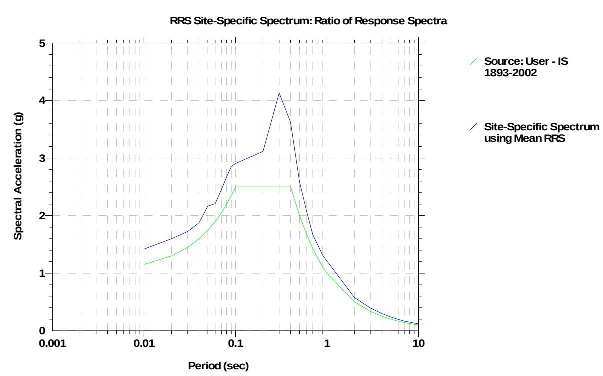


Figure. 14 RRS curve compatible to IS 1893 (Part 4) - 2005

7. CONCLUSIONS

The site specific seismic hazard analysis carried out for the proposed power plant site near Samalkot considering the seismicity and seismotectonics within 300 km radius reveals that the Vasishta – Godavari fault located at a distance of about 50 km away from the site with Moment magnitude M_w 5 causes the highest PGA of 0.036 g and is considered as the main seismogenic source for the site considered. The attenuation relationship proposed by Iyengar and Raghukanth (2004) for southern region of Peninsular

India predicts higher PGA upto a distance of about 80 km from the site than Abrahamson and Litehiser (1989) and Iyengar and Raghukanth (2004) for western – central region of Peninsular India attenuation relationships.

Based on the Ratio of Response Spectral (RRS) analysis carried out for the site considering six scaled recorded motions, the site specific spectra compatible to Indian codal design spectra is developed and it is found that the spectral accelerations at the mid period range (0.1 to 0.4 s) is about 1.5 times higher than IS design spectra for rocky site or hard soil. It is evident from the present site-specific seismic study even stiff clayey sandy sites can amplify the ground motion.

REFERENCES

Abrahamson, N. A. and Litehiser, J.J. (1989). Attenuation of- vertical peak accelerations. *Bulletin of the Seismological Society of America.* **Vol 79:** 549-580.

Ansal, A. (2004). Recent Advances in Earthquake Geotechnical Engineering and Microzonation, Kluwer Academic Publishers.

Boominathan, A. (2004). Seismic site characterization for nuclear structures and power plants. *Current Science,* **Vol 87(10):** 1388-1397.

BSSC (2001). BSSC, NEHRP recommended provisions for seismic regulations for new buildings and other structures 2000 edition, part 1: Provisions. Report no. FEMA 368, Building seismic safety council for the federal emergency management agency, Washington, D.C., USA (2001).

Chandra, U. (1977). Earthquakes of Peninsular India – A seismotectonic study. *Bulletin of the Seismological Society of America.* **Vol 67(1):** 1387-1413.

Dobry, R., Borcherdt, R.D., Crouse, C.B., Idriss, I.M., Joyner, W.B., Martin, G.R., Power, M.S., Rinne, E.E. and Seed, R.B. (2000). New site coefficients and site Classification system used in recent building seismic core provisions. *Earthquake spectra*. **Vol 16(1):** 41- 67.

Gupta, H.K., Mohan, I. and Narain, H. (1970). The Godavari earthquake sequence of April 1960. *Bulletin of the Seismological Society of America.* **Vol 69:** 601–615.

IS 1893 (Part 1):2002 Indian Standard Criteria for Earthquake Resistant Design of structures: Part 1 General Provisions and Buildings (5th Revision).

IS: 1893 (Part 4):2005 Indian Standard Criteria for Earthquake Resistant Design of structures: Part 4 Industrial Structure including Stack-Like Structures

Iyengar, R. N. and Raghukanth, S. T. G. (2004). Attenuation of strong ground motion in Peninsular India. *Seismological Research Letters.* **Vol 75(1):** 530-540.

Kijko, A. and Graham, G. (1998). Parametric-historic procedure for probabilistic seismic hazard analysis, Part I: Estimation of maximum regional magnitude Mmax. *Pure and Applied Geophysics*, **Vol 152(1):** 413-442.

Kramer, S. L. (1996). Geotechnical Earthquake Engineering, Prentice Hall, Upper Saddle River, NJ.

Kramer, S. L. and Stewart, J. P. (2004). Geotechnical Aspects of Seismic Hazards- Chaper 4, Earthquake Engineering: From Engineering Seismology to Performance-BasedEngineering, Eds. Y. Bozorgnia and V.V. Bertero, CRC Press, Boca Raton.

Krinitzsky, E. L. (2003). Deterministic versus probabilistic seismic hazard analysis for critical structures. *Engineering Geology.* **Vol 40(1):** l-7.

Lew (2001). Geotechnical design considerations, The Seismic Design Handbook, Ed. Naeim, Kluwer Academic Publishing Company.

Martirosyan, A., Dutta, U., Biswas, N., Papageorgious, A. and Combellick, R. (2002). Determination of Site Response in Anchorage, Alaska, on the Basis of Spectral Ratio Methods. *Earthquake Spectra.* **Vol 18(1):** 85-104.

Regulatory Guide 1.165 (1997). Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion, US Nuclear Regulatory Commission, Washington, USA.

SEISAT (2000). Seismotectonic Atlas of India, Geological Survey of India, New Delhi.

Sokolov, Y. V., Loh, C. H. and Wen, K. L. (2001). Empirical models for site and region dependent ground motion parameters in the Taipei Area: A unified approach. *Earthquake Spectra.* **Vol 17(2):** 313-332.