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Geological and Surface Geophysical Studies of Lineaments along Coastal Corridor from Kakinada to Balasore, India

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Abstract— *The present study focuses on integrated geological and geophysical studies in urbanized locales of Kakinada, Visakhapatnam, Vizianagaram and Srikakulam in Andhra Pradesh, and Khurda Road, Bhubaneswar, Cuttack, Bhadrak and Balasore in Odisha. These flat areas along the coastal rivers generally consist of thick layers of soft clay and sand, wherein their susceptibility to liquefaction has devastating consequences during an earthquake. The inherent property of clay and sand amplify certain frequencies of ground motion, there by attributing to an increase in the damage due to an earthquake. To understand the local ground conditions that substantially affect the characteristics of seismic waves propagating towards the surface during earthquakes, combined study of satellite imagery and surface geological studies were done for identification of critical geological features. This led to delineation of 75 lineaments for geophysical survey, which was done at selected locations along the Kakinada to Balasore coastal corridor. The NW-SE trending lineaments viz. Kanada - Kumili fault, Parvatipuram-Bobbilli fault, Nagavali fault, Vamsadhara faults, Mahanadi, Rushikulya and Brahmoni are the major lineaments identified along the corridor for the study. The geophysical measurements were carried out using Multichannel Analysis of Surface Wave (MASW) and seismic refraction to understand the near surface characteristics of these lineament zones. Subsequently, average shear wave velocities (Vs^{30}) and stiffness were computed using the Vs and empirical relations. The results of the study (L-27, L-28, L-62 & L-64 are showing low Vs ranging from 180m/s-350m/s which indicates presence of soft soils with >20m, moderate Vs zone is 300-500m/s and high Vs zone is >600 m/s having shallow bed rock up to <10m to <5m) have an important role in seismic hazard assessment for east coast corridor and aid finding answers to puzzling questions regarding their significance in the seismic design of the engineering structures along or across the lineaments.*

Keywords— *MASW, seismic refraction, lineaments, faults, shear wave, velocity, stiffness.*

I. INTRODUCTION

The shear-wave (S-wave) velocity of near-surface materials (soil, rocks, and pavement) and its effect on seismic wave propagation are of fundamental interest in many ground water, engineering, and environmental studies (Xia et al., 1999). Several natural disasters in the coastal districts of Andhra Pradesh and Orissa states have caused havoc to the life and property of citizens and nature from time to time. These disasters include cyclones, floods, earthquakes, volcanic eruptions, drought etc. These types of floods are high stream flow that overflows the natural banks of the rivers and most of the times become calamitous. Southern Peninsular India has experienced some moderate size earthquakes during the last 50 years, eight (Anjar 1956, 6.0; Ongole 1967, 5.4; Koyna 1967, 6.3; Bhadrachalam 1969 5.7; Mt. Abu 1969, 5.3; Broach 1970, 5.4; Killari 1993, 6.1; Jabalpur 1997, 5.8) have occurred in the Indian stable continental region (SCR). These earthquakes and their effects in this coastal transect over the last few years warn us of the need to assess the hazard due to disasters and prepare for future calamities. The rise in population in cities and towns force to large settlements along the river banks making Kakinada to Balasore coastal transect highly vulnerable to earthquake disasters.

The transect passes through the major urbanized cities and towns of Andhra Pradesh namely Kakinada, Vishakhapatnam, Vizianagaram, Srikakulam etc. and Khurda Road, Bhubaneswar, Cuttack, Bhadrak and Balasore in Orissa states. The economic and social effects of these cities against earthquakes can be curtailed through a detailed study of geologically controlled lineaments, local site conditions of the seismic hazard risk for seismic prone areas. Liquefaction hazard assessment for Jabalpur city (Sundararajan and Seshunarayana, 2011) was carried out using shear-wave velocity. This technique has been applied for site characterization studies of structural lineaments along coastal Andhra Pradesh (S Trupti et al. 2012). Such a study would lead to an increase in public awareness, with a consequent upgrading of engineering properties and the reliable earthquake resistant designs for new structures for long term functioning. The role of geological and geotechnical data is becoming very important in the planning of city urban infrastructure, which can recognize, control, and prevent geological hazards (Bell et al.1987; Legget 1987; Hake 1987; Rau 1994; Van Rooy and Stiff 2001).

Hence, the present study is aimed at identification and categorization of lineaments from Kakinada to Balasore coastal transect using space imagery, Seismotectonic Atlas of India (Geological Survey of India, 2000) and Morpho-Structural Zoning Map of India followed by ground checks. Latter it includes morphostructural lineaments that depict linear zones separating regions/blocks of marked/abrupt changes in large elements of relief. Which in turn reflect geologic, geomorphic and neotectonic features in the area. These lineaments were picked from the IRS-1D (LISS-IV) data products.

II. GEOLOGY OF THE STUDY AREA

The study region encounters a series of geological formations ranging from Archean to Recent. The geology comprises a Precambrian basement over which younger rocks commencing with Jurassic, Cretaceous, Tertiary and Quaternary have given rise to varying sequences in different parts. The coastal tract of the Kakinada, Visakhapatnam, Vizianagaram, Srikakulam districts in Andhra Pradesh passes through the Eastern Ghat Mobile Belt (EGMB) of Precambrian age with intersperse estuarine rivers such as Vamsadhara, Nagavali, Champavati, Goastani, Sarada, Tandava and Varaha etc. with their narrow flood plains. The EGMB is a prominent Precambrian orogenic belt of 900 Km starts from Ongole, Andhra Pradesh and partly terminating around the E-W coarse of Brahmani river in Orissa. It constitutes the oldest metamorphic rocks, in that charnockite is the predominant member of the Eastern Ghat Complex (Ramakrishnan, M, Vaidyanadhan, R, and GSI).

The geology of the study area also comprises a Precambrian basement over which younger rocks commencing with Jurassic, Cretaceous, Tertiary and Quaternary have given rise to varying sequences in different parts. These shows considerable diversity in respect of depositional processes and environments. The active channels contain coarse-medium sand. The river systems that carried the sediments into the coastal depression are Subarnerekha, Salandi, Baitarani, Brahmani, Rupnarayanai, Kansabati, Kasai, and Mahanadi. The Precambrian rocks occur extensively in the south-eastern part of the Orissa state. They are abruptly terminated against the north Orissa craton along Brahmani river valley by a series of east-west trending faults. Three boundary faults /lineaments limit them along their northern, western and eastern margins.

A. *Ground Checking of the Lineaments*

Identification of lineaments by ground checking that are encountered along the Kakinada to Balasore route and their characterization about the seismicity and to ensure the integrity of the any civil engineering structure from earthquake hazard. Satellite image processing and its interpretation was carried out to prepare a map of lineaments in about a 10 km wide strip along the coastal region (Figure 1). Ground checking of the lineaments are generally used in combination with detailed geo-technical information on soil, bedrock, and groundwater, slope stability, and scouring depths of rivers. Seventy-five (75) lineaments were identified along Kakinada - Balasore route from the space imageries and these were checked on the ground.

The major faults Konada-Kumili, Parvatipuram-Bobbilli, Nagavali and Vamsadhara and the lineaments Mahanadi, Rushikulya and Brahmoni are observed along the study area. During the ground checking these lineaments/fault zones have been observed with surface geological evidence such as faulting, shearing, deep weathering and uplifting etc. The rest of the lineaments are treated as unspecified lineaments which are covered with thick alluvium, vegetation and habitation. Based on the field logistics 45 lineament locations were selected for conducting geophysical surveys.

III. STUDY OF LINEAMENTS USING GEOPHYSICAL METHODOLOGIES

Structural lineaments are the important parameters and prominent indicators for disaster mechanisms. Generally, the lineaments may usually faults, fractures/joints or boundaries between stratigraphic formations. Lineaments are considered to be naturally occurring, mappable linear topographic features on earth's surface that may be formed by fractures in earth's crust, which can be joints, faults, or shear zones (Boyer and McQueen, 1964: O'Leary et al., 1976). These lineaments/faults behave actively or rejuvenate themselves causing further damage to the nearest localities and in the surroundings due to which there is a possibility of threat to the civil engineering constructions. Classification of the lineaments based on ground check is not always possible due to the presence of soil cover, cultivation, habitation and other manmade structures. Explorations of these lineaments at shallow sub surface using Geophysical methods greatly help in classifying them.

Therefore, seismic studies have been carried out near the identified lineaments, which are having geological concerns. The sites are selected across the lineaments because, it is important to study the soil thickness near them to understand the shallow sub surface geological processes like weathering phenomena, sediment deposition and erosion activities etc.

A. *Seismic Methods*

Seismic methods are considered as active geophysical methods and are carried out at parallel, sub-parallel / across the lineaments at 45 locations along coastal transect. In seismic survey, elastic waves are propagated through the earth's interior and the travel times of the waves are measured after return to the surface by refraction or reflection at geologically unknown boundaries (Layat et al., 1961: Blundun, 1956: Barthelmes, 1946). Keeping in mind the geology and physical properties of the rocks of the study area, MASW and seismic refraction methods were applied, and the sites are selected along the lineaments because, it is important to study the soil behavior near them to take the precautionary measures for construction purpose and also to minimize the loss of human lives and the property during earthquake. Seismic wave data can be effectively used to measure P and S-wave velocities of the earth materials. The P and S-wave velocities may vary for different geological formations based on their composition.

B. *Data Acquisition of MASW and Refraction Seismic*

MASW and refraction seismic data was acquired using 24-channel seismograph and sledge hammer was used as the source. Vertical component geophones with 4.5 Hz frequency were used for collecting the data. The record length is 1 sec with 0.25 milliseconds sample interval was used for both cases. In favor of MASW studies seventy-two (or 48) geophones were deployed on 2meter interval with the nearest source-to-geophone offset in the range 5 to 10m. Three to ten impacts were vertically stacked at each offset. 24-channels were activated for each shot gather and 2m distance rolled for the next shot using standard roll along technique. Notch filter was applied during data acquisition.

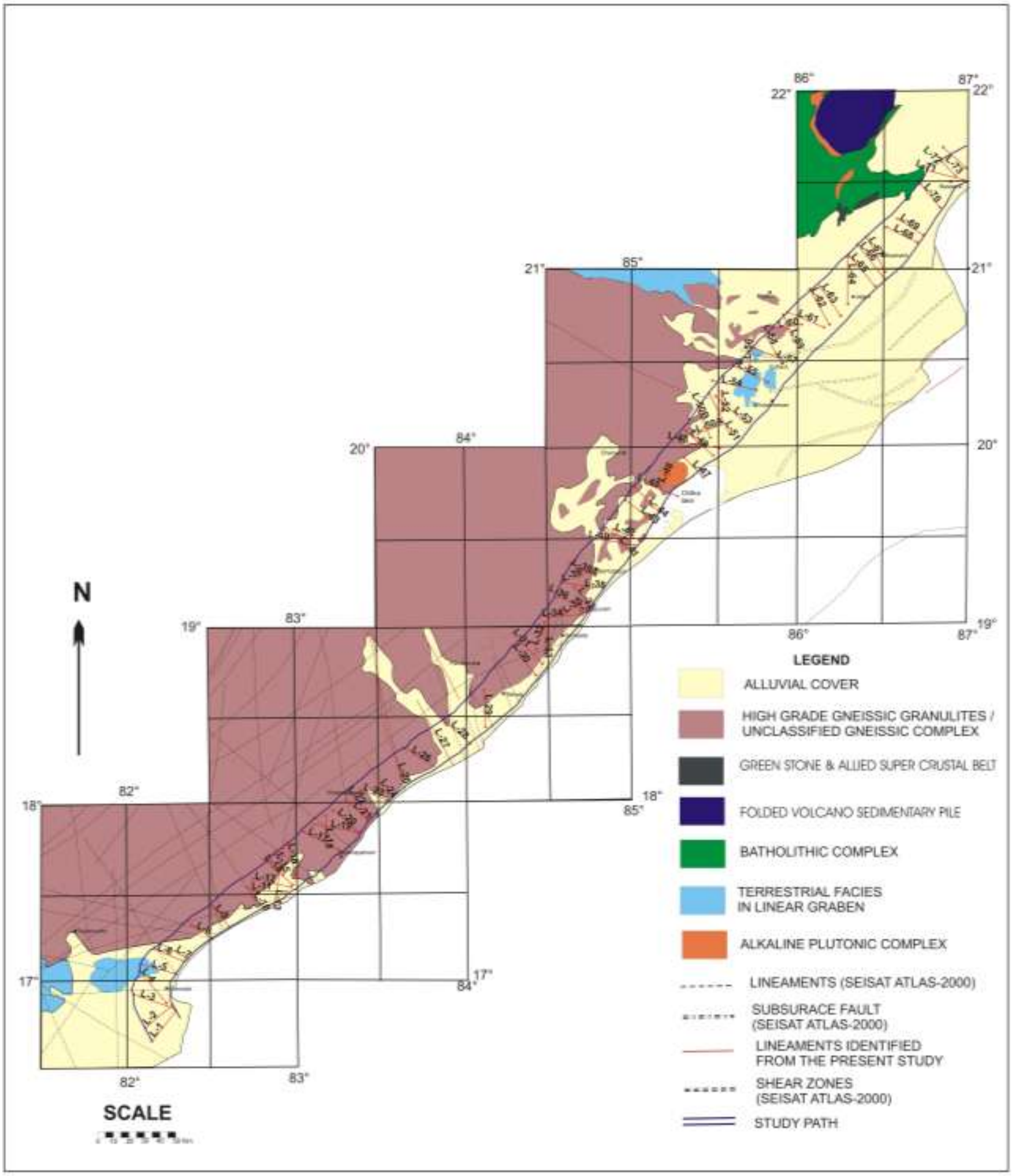


Figure 1: Map showing Geology with Lineaments along the coastal regions of Kakinada-Balasore transect

Refraction seismic survey has been carried out across the fault around 115m with 5m geophone spacing. Five sets of readings were taken for each profile, two in the forward, two in the reverse and one in middle. The long offset forward shots were recorded at 50m offset and same offset was used available for the reverse shot.

C. Multi Channel Analysis of Surface Wave Data Processing

Multi-channel surface wave data were processed by software SURFSEIS developed at the Kansas Geological

Survey (Park et al, 1999; Xia et al, 1999). Now, the software can only be used to process fundamental-mode Rayleigh waves. The entire process classically used to produce a shear wave velocity (Vs) profile through analysis of surface waves involves three steps: acquisition of ground roll, construction of dispersion curve (a plot of phase velocity versus frequency (f)), and back calculation (inversion) of the Vs profile from the calculated dispersion curve (Seshunarayana, T and Sundararajan, N, 2005).

Broadband ground roll must be produced and recorded with minimal noise to accurately determined the Vs profile. A variety of techniques have been used to calculate dispersion curves (Stokoe et al., 1994), each having its own unique advantages and disadvantages. Assuming vertical velocity variation, each frequency component of surface waves has a different propagation velocity (called phase velocity, C_f) at each unique frequency (f) component. These unique characteristic results in a different wave length for each frequency propagated. This property is called dispersion. The generation of dispersion curve is a critical step-in MASW method. Wave field transformation method converts the data from offset(x)-time domain (t) to phase velocity (P_f)–frequency domain (f). Every shot gather data was transformed to phase velocity–frequency domain and the dispersion curves are obtained for corresponding locations with a very high signal to noise ratio of about 80% and above. This fitting process will continue iteratively by changing the shear wave velocities from top to deeper layers. A least-square approach facilitates automation of the process.

D. Refraction Seismic Data Processing

The objective of refraction seismic interpretation is to measure the time of the "first break" that is, the time when a given geophone first moves in response to a seismic energy source. Seismic velocities can assist in the interpretation of geological layers as well as determining the depth to the bedrock. The amplitude of the arrival is the most useful property in picking the arrival. Frequency plays very little part in identifying the arrival (Hagedoorn, 1964). Simply stated, since time and relative distances of sources and geophones are known, the velocity of the subsurface can be calculated. Three layered depth model was obtained by using Seis-imager software. To invert the data time-term inversion method was applied (Dibiase, 2005).

The time-term inversion method is a simple travel-time inversion developed by 70s (Willmore and Bancroft, 1960) was widely used for seismic refraction crustal studies. Time-term inversion method has a potentiality to be a useful tool for detecting lateral velocity variation of a refractor. This inversion technique is the quickest and easiest but provides a very basic vertically layered velocity model and it provides an accurate enough model; further time spent on reciprocal and tomography methods would be redundant. This method is a quick and easy way to estimate the refractor depth. The matrix inversion error is less than 2 msec. First breaks were picked, and travel-time diagrams were created using pick win and plotrefa modules of the Seis Imager software. This method is based on a few simplifying assumptions, which may be valid in our case and it assumes discrete velocity layers as well as a horizontal refractor not for dipping layer case.

Harmonic mean Shear wave velocity Calculation

The Uniform Building Code use V_S^{30} to classify sites according to type of soil for earthquake-resistant design. It is an important and critical parameter for site characterization studies. The site classification based on Vs^{30} is given by Federal Emergency Management Agency (FEMA, 1997). The average shear wave velocity is computed by using harmonic mean method as follows.

$$V_s^{30} = \frac{\sum_{i=1}^{n} d_i}{\sum_{i=1}^{n} \frac{d_i}{V_s}} \tag{1}$$

The above equation represents harmonic mean shear wave velocity (Vs) up to a depth of 30 m. Where d_i = thickness of the layer 'i' in meters and (Vs) is the shear wave velocity in the 'i'th layer in m/sec. Where di and Vs denote the thickness (in meters) and shear-wave velocity in m/s of the i th formation or layer in a total of N layers, existing in the top 30 m (Sitharam T.G and Anbazhagan P, 2005). Shear wave velocity (1-D) curves generated by "Surf-Seis" software was used for V_S^{30} computation. Average shear wave velocity (V_S^{30}) values are calculated for every 1 m interval along the profile. This method yields a more conservative estimate of ground motion, generally V_S^{30} decreases as the ground motion increases (David M. Boore, 2004).

IV. STIFFNESS CALCULATION FROM SHEAR WAVE VELOCITY

Soil stiffness is an important parameter when analyzing ground deformation in engineering earthworks. Soil stiffness is characterized by either small-strain shear-wave velocity or small-strain shear modulus. The stiffness profile is often expressed by shear-wave (S-wave) velocity change with depth because S-wave velocity is proportional to the shear modulus that is a direct indicator of stiffness. Therefore, precise analyses of shear strength of the soft grounds have been required and then various soft ground improvement methods have been developed to stabilize soft grounds. Typical methods include the finding of compressional wave velocity and shear wave velocity for stiffness computation but the dynamic elastic shear modulus Gmax can be determined by the following equation:

The stiffness measured using field seismic methods represent the maximum stiffness (Gmax) Mathews et al., 1997 is given by the formula:

$$\mathrm{Gmax} = \rho * Vs^2 \tag{2}$$

Where ρ is the density of the material (Standard density values have been taken in to consideration based on the local geology.), Vs is the shear wave velocity. It is expressed in terms of kilo-Pascal (kPa).

V. RESULTS AND DISCUSSIONS

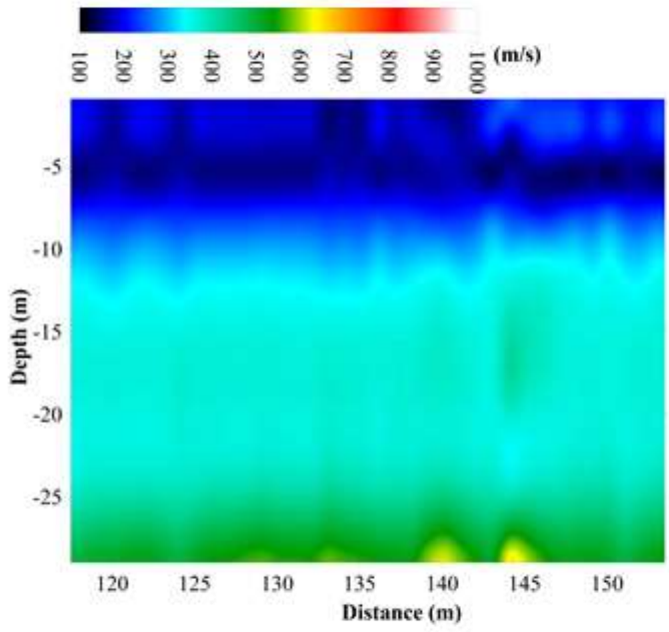
The results have been tabulated in Table: 1 for all the 45 lineament locations surveyed along the Kakinada-Balasore. The Liquefaction probability is considered as Moderate, Low and Nil based on the observed Vs values and water table levels for an earthquake of 6.0M near 25km from the lineament zones. Shear wave velocity (Vs), P-wave velocity (Vp), stiffness and Vs^{30} images pertaining to the lineament/fault locations i.e. L-24 (Konada-Kumili fault), L-28 (Vamshadhara shear zone), L-41 (Rushikulya Lineament), and L-62 (Bhaitarini lineament) have been shown in the Figure: 2 to 5.

Figure: 2 (a to d) represents the result at L-24; Konada-Kumilini fault and shows three-layer model. From the shear wave velocity section (Figure: 2a), it is observed that the Vs in the range 150- 200m/s up to 12m depth correspond to lose soil, Vs in the range of 350 to 400m/s represents the stiff soils and below 25m the observed Vs is >550m/s indicates weathered rock. The computed stiffness depth section (Figure: 2b) the first layer of loose soil shows <150kPa, second layer exhibits stiffness values in the range of 250-300kPa and whereas third layer shows higher stiffness values i.e. >650kPa. The computed harmonic mean shear wave velocity (Figure: 2c) is in the range of 250 – 300m/s indicates stiff soils. The P-wave velocity – depth section (Figure: 2d) shows top soil with 400m/s up to 8m depth, stiff soil with 1100m/s and hard rock with 3100m/s. The observed low Vs, Vp, stiffness and average Vs30 values up to 12m depth will need to be taken in to consideration for any civil structure against earthquake hazards like ground failure and liquefaction phenomena etc. across the Konada Kumilini fault.

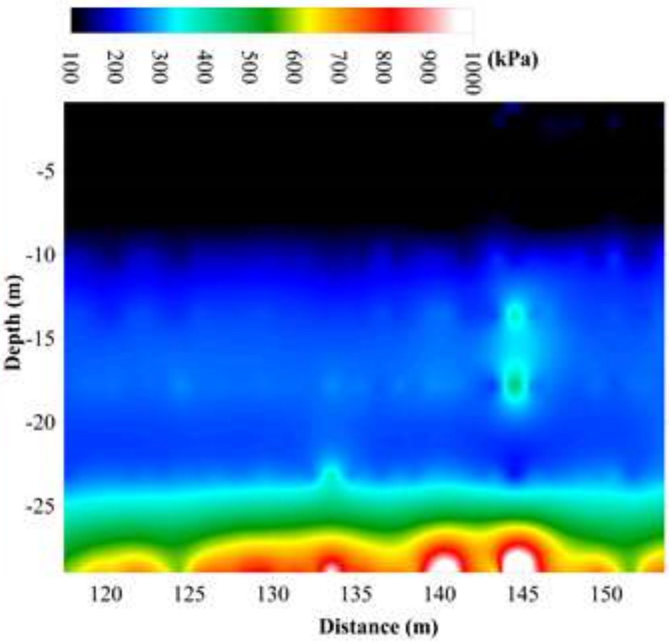
Figure: 3 (a to d) correspond to the result at L-28; Vamsadara shear zone/fault. The shear wave velocity (Figure: 3a) at this zone shows two-layer model, with Vs in the range 150- 180m/s below 10m depth correspond to lose soil, Vs in the range of 200 to 350m/s represents the stiff soils at 10 to 20m depth. The computed stiffness values (Figure: 3b) for the first layer (loose soils) is <150kPa and for second layer (stiff soils) in the range of 250-300kPa. The determined harmonic mean shear wave velocity for 20m depth is in the range of 180 – 300m/s (Figure: 3c). The P-wave velocity – depth section reveals top soil with 400m/s up to 8m depth, stiff soil with 1100m/s and hard rock with 2800m/s (Figure: 3d). The Vamsadara shearzone/fault zone exhibits low Vs, Vp, stiffness and shear wave velocity (Vs) values up to 20m depth will be useful geotechnical parameters which need to be taken in to consideration for future urban developments at this zone.

Figure: 4 (a to d) shows the result at L-41; Rushikulya fault zone. The shear wave velocity image (Figure: 4a), reveals first layer as stiff soil with Vs: 200- 300m/s up to 8m depth, second layer – hard and compact rock below 8m depth with Vs in the range of 650 to 1000m/s. The stiffness depth section (Figure: 4b) represents first layer with 150 to 250kPa and second layer in the range of 600-1000kPa. The computed harmonic mean shear wave velocity (Figure: 4c) at this location is in the range of 550 – 650m/s. The P-wave velocity – depth section (Figure:4d) shows top soil with 400m/s up to 5m depth followed by stiff soils/weathered rock with 1800m/s at 5 to 18m depth. Below 20m higher V_P values (3200m/s) were noticed. The high Vs, Vp, stiffness and average shear wave velocity (Vs30) values were observed at this fault zones.

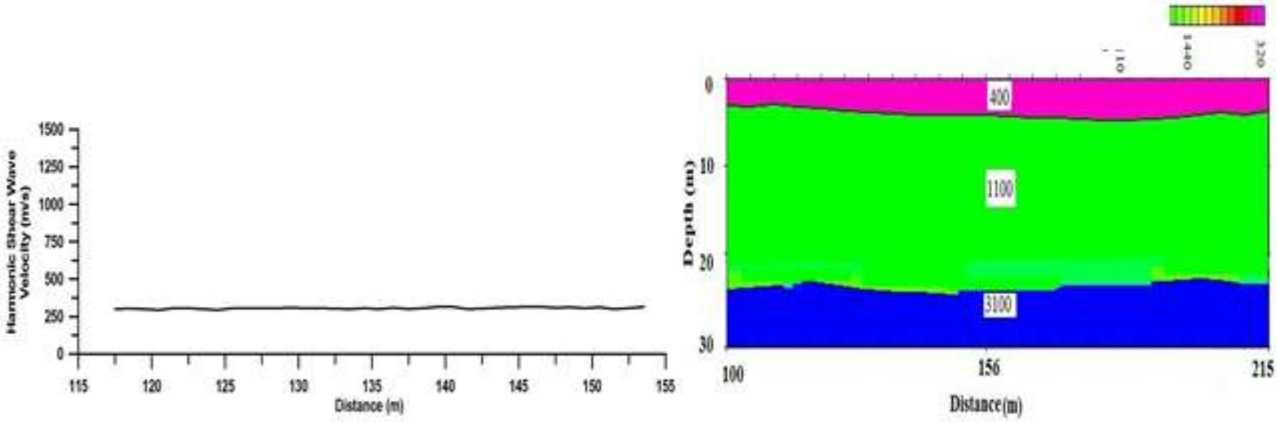
Figure: 5 (a to d) represents the result at L-62; Brahmoni/Baitarani fault zone. The shear wave velocity depth section (Figure: 5a) represents single layer of alluvium with low Vs value (150-300m/s) and corresponding harmonic mean shear wave velocity (Vs) (Figure: 5c) is in the range of 250 to 300m/s. The computed stiffness values (Figure: 5b) for this layer is <150kPa represents loose alluvium. The P-wave velocity – depth section (Figure: 5d) shows top soil with 400m/s up to 10m depth and stiff soil with 1100m/s below 10m depth. The observed geotechnical parameters Vs, Vp, stiffness and average shear wave (Vs) values for 15m depth will be the cruisial for any civil structure of national project at this fault zone.



(a) Shear wave velocity depth section

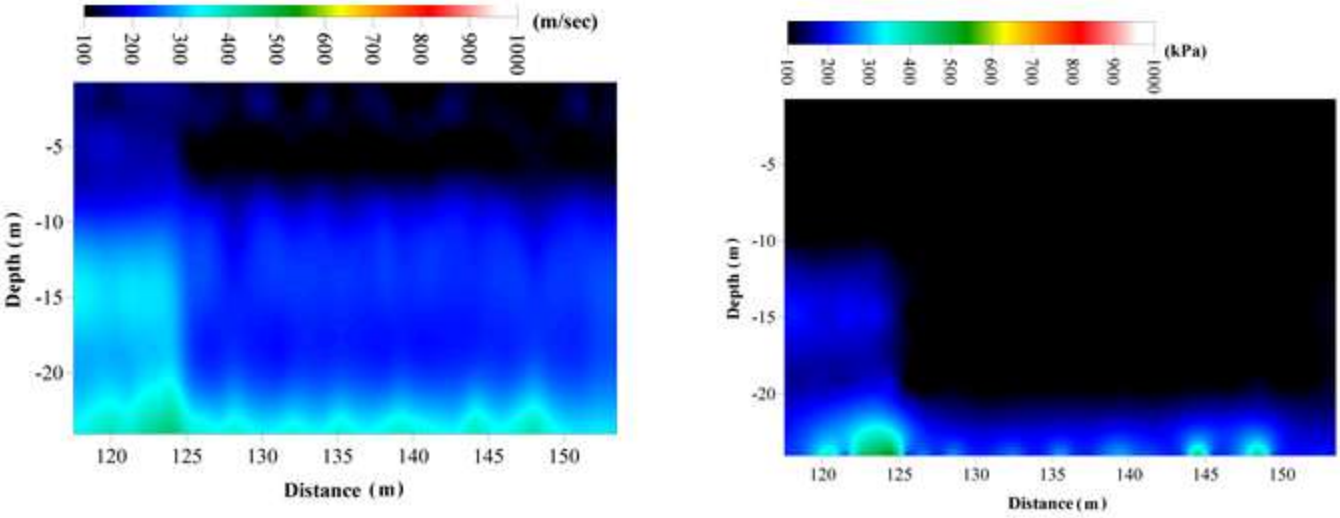


(b) Stiffness depth section

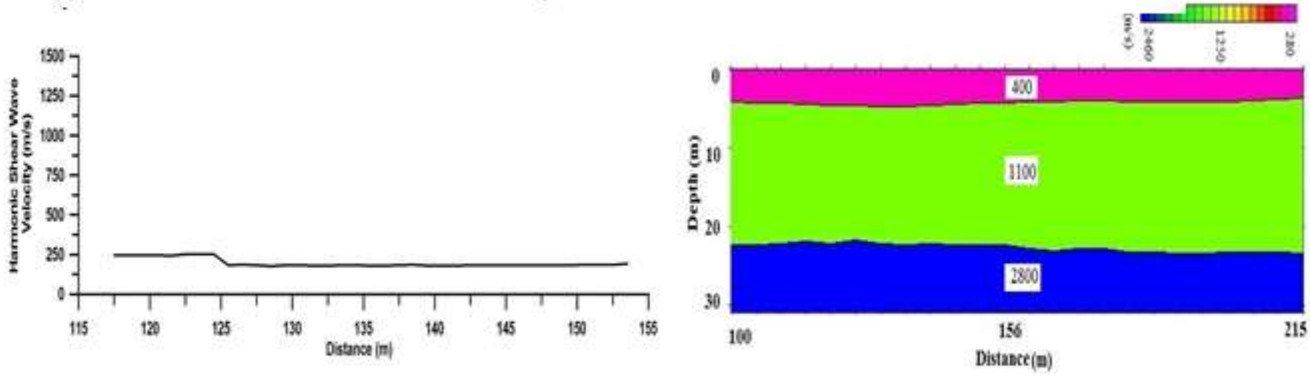


(c) Harmonic mean shear wave velocity (d) P-wave velocity depth section

Figure 2: Correspond to (a) shear wave velocity–depth section, (b) stiffness depth section, (c) harmonic mean shear wave velocity obtained from Vs and (d) p-wave velocity-depth section at Kustira village across the Konada-Kumilini fault.

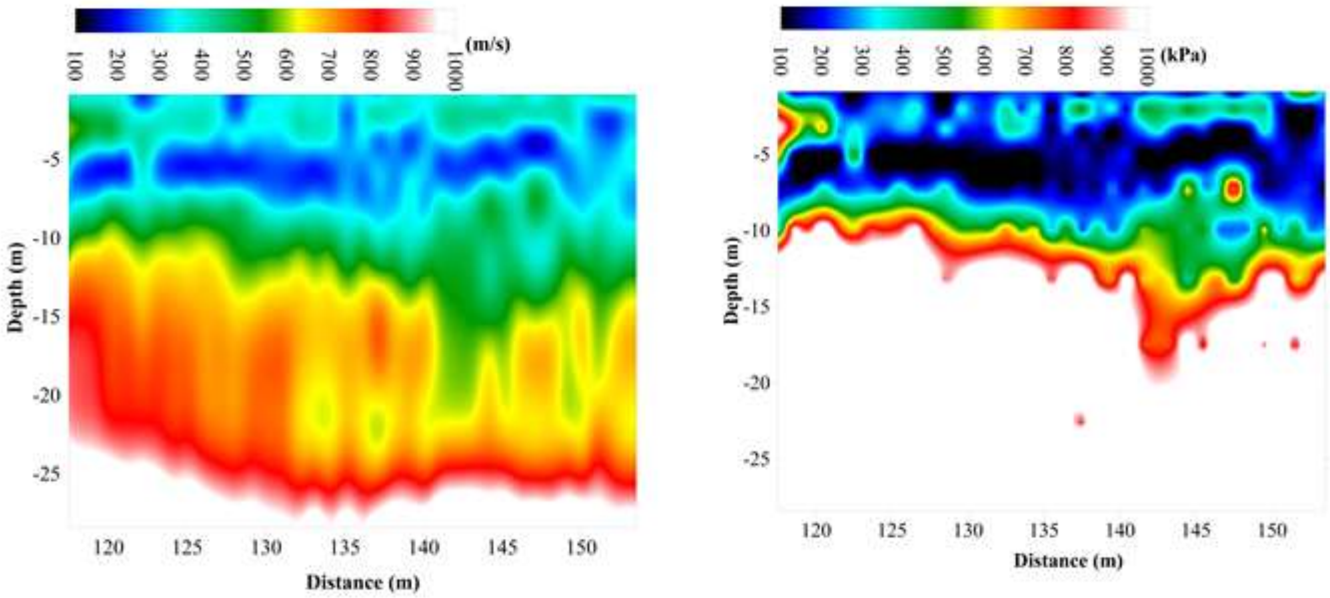


(a) Shear wave velocity depth section (b) Stiffness depth section



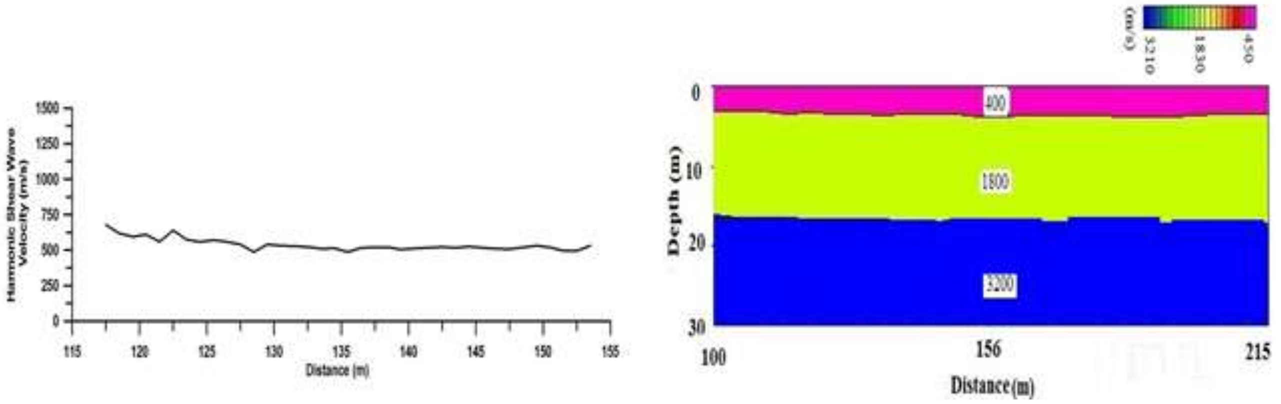
(c) Harmonic mean shear wave velocity (d) P-wave velocity depth section

Figure 3: Represent (a) shear wave velocity–depth section, (b) stiffness depth section, (c) harmonic mean shear wave velocity obtained from Vs and (d) p-wave velocity-depth section at Lukalam area along Vamsadhara fault section.



(a) Shear wave velocity depth section

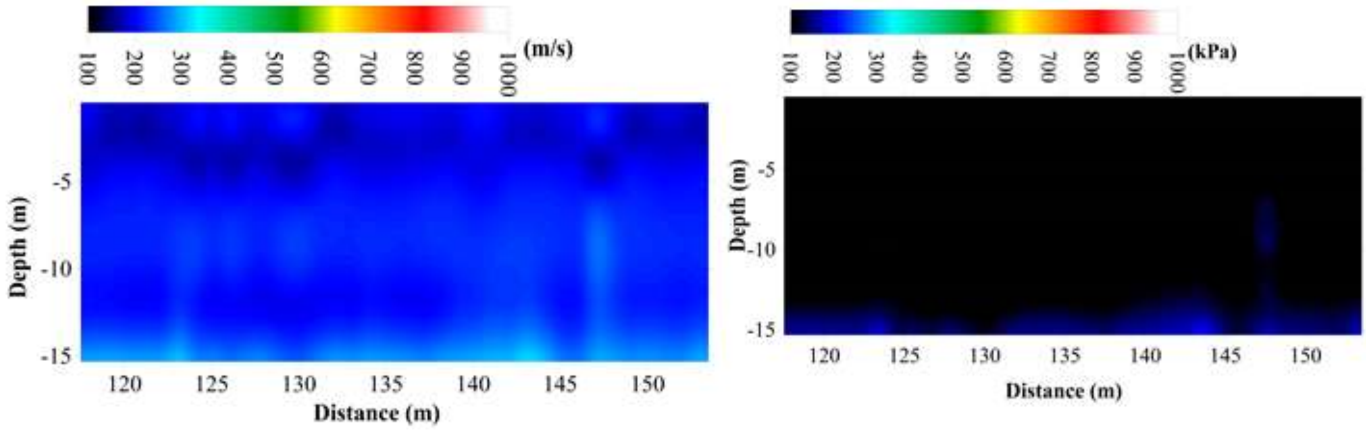
(b) Stiffness depth section



(c) Harmonic mean shear wave velocity

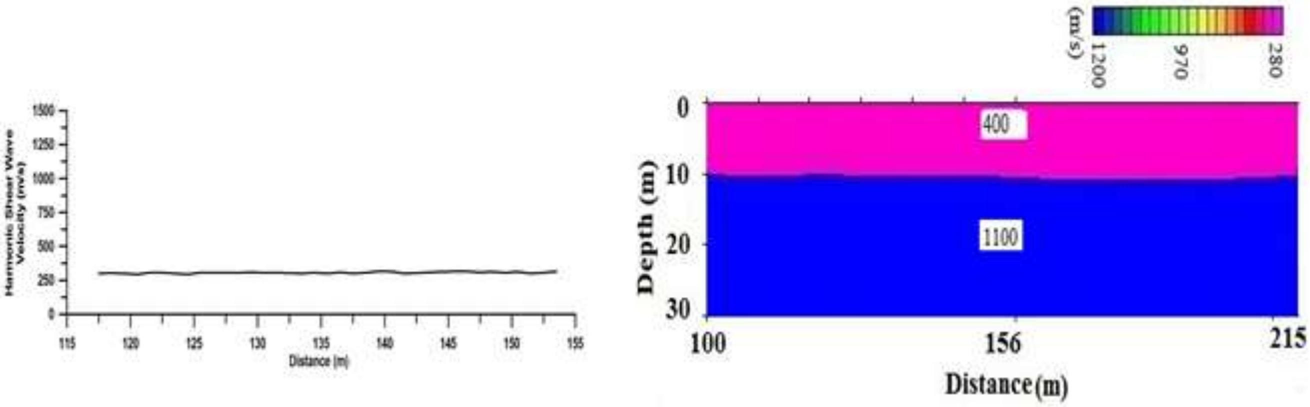
(d) P-wave velocity depth section

Figure 4: Correspond to (a) shear wave velocity–depth section, (b) stiffness depth section, (c) harmonic mean shear wave velocity obtained from Vs and (d) p-wave velocity-depth section near Raipur village along Rushikulya fault.



(a) Shear wave velocity depth section

(b) Stiffness depth section



(c) Harmonic mean shear wave velocity (d) P-wave velocity depth section

Figure 5: Represent (a) shear wave velocity–depth section, (b) stiffness depth section, (c) harmonic mean shear wave velocity obtained from Vs and (d) p-wave velocity-depth section along Brahmoni/Baitarani River.

TABLE 1. Description of results from MASW and Refraction studies along Kakinada – Balasore transect

Nearest Village/ Lineament No.	**Ground check Location of the lineament**	**Direction of fault /lineament**	**Vp in m/s**	**Depth to bed rock in m (Vp)**	**Expected water table level (m)**	**Harmonic shear wave velocity m/s**	**Liquefaction probability**
Kesavapuram (L–1)	17° 09’ 56.66” 82° 17’ 04.53”	N40°E S40°W	400-2500	>40	3-5m	100-200	Moderate
Vemulavada (L– 3)	16° 52’ 04.24” 82° 10’ 52.55”	N70°W S70°E	400-1800	>40	3-5m	100-200	Moderate
Karakuduru (L – 4)	16° 57’ 12.69” 82° 10’ 16.11”	N40°W S40°E	200-1700	>40	5-6m	100-200	Moderate
Gollaprolu (L – 7)	17° 09’ 56.66” 82° 17’ 04.53”	N60°W S60°E	200-1800	>30	5-8m	250-500	Low
Aratlakota (L – 9)	17° 20’ 34.61” 82° 34’ 49.47”	N40°W S40°E	400-1800	>30	10-12m	250-650	Low
Kottaagraharam (L – 10)	17° 27’ 51.33” 82° 46’ 46.80”	N40°W S40°E	300-1700	>40	20-25m	250-350	Moderate
Elamanchili (L – 12)	17° 33’ 03.08” 82° 52’ 24.29”	N10°W S10°E	500-2500	>40	25-30m	100-300	Moderate
Bangarayyapeta (L – 14)	17° 37’ 26.03” 82° 53’ 54.75”	N50°W S50°E	500-3000	>25	25-30m	150-800	Nil
Venkupalem(L - 16)	17° 43’ 04.65” 82°58’ 33.85”	N15°W S15°E	300-3700	>15	25-30m	150-800	Nil
Antakapali(L – 17)	17° 48’ 29.72” 83° 07’ 05.40”	N65°W S65°E	500-4400	>20	30-40m	400-1500	Nil
Gavarapalem(L – 18)	17° 50’ 34.45” 83° 11’ 12.39”	N-S	500-4800	>15	25-30m	350-1000	Nil
Pandrangi(L –21)	17° 58’ 02.28” 83° 21’ 49.44”	N45°W S45°E	400-4800	>10	25-30m	300-1000	Nil
Singavaram(L – 24)	18° 04’ 41.11” 83° 31’ 11.79”	N40°W S40°E	300-4300	>15	20-25m	180-800	Nil
Kamavaram(L – 25)	18° 08’ 49.1” 83° 36’ 34.09”	N20°W S20°E	400-2500	>15	20-25m	300-1000	Nil
Adapaka(L - 26)	18° 15’ 50.76” 83° 44’ 26.34”	N60°W S60°E	300-4200	>10	15-20m	1000	Nil
Dusi(L – 27)	18° 21’ 41.65” 83° 51’ 38.26”	N35°W S35°E	400-5100	>10	15-20m	180-650	Moderate
Lukalam(L – 28)	18° 25’ 4.87” 83° 56’ 49.7”	N50°W S50°E	300-2500	>30	15-20m	100-350	High
Kurudu(L – 29)	18° 33’ 39.16” 84° 07’ 56.55”	N-S	300-4900	>25	25-30m	100-800	Nil
R.K.Puram(L – 30)	18° 48’ 32.86” 84° 21’ 34.18”	N40°W S40°E	700-4300	>15	25-30m	250-1000	Nil
Goppili(L -31)	18° 52’ 00.12” 84° 23’ 44.32”	N41°W S41°E	400-4800	>15	25-30m	800-2000	Nil
Chilipi (L – 32)	18° 54’ 46.42” 84° 26’ 52.87”	N20°E S20°W	300-5500	>15	15-20m	150-600	Low
Sinkuli(L – 33)	18° 55’ 33.67” 84° 29’ 16.95”	N5°W S5°E	400-4700	>20	10-15m	250--900	Nil
Nuvagaon (L – 35)	19°05’ 36.36” 84° 38’ 48.63”	N65°E S65°W	400-3500	>30	15-20m	180-350	Low

Danapur (L – 37)	19° 10’ 18.37” 84° 41’ 44.22”	N35°W S35°E	400-4100	>35	10-15m	180-1000	Nil
Chandanapur (L –38)	19° 13’ 45.01” 84°43’ 2.03”	N80°W S80°E	400-5700	>25	15-20m	180-1000	Nil
Chirakunjupalli (L – 39)	19° 18’ 3.70” 84° 44’ 14.06”	N65°E S65°W	500-4800	>15	15-20m	250-1000	Nil
Raipur (L –41)	19° 29’ 26.34” 84° 55’ 12.26”	N50°W S50°E	400-3200	>15	15-20m	300-1000	Nil
Raipada (L – 44)	19° 42’ 57.31” 85° 05’ 51.17”	N45°W S45°E	300-5600	>20	15-20m	300-1200	Nil
Banpur (L – 45A)	19° 46’ 32.37” 85° 07’ 54.17”	N65°W S65°E	700-5200	>10	10-15m	250-1000	Nil
Panaspur (L – 47)	19° 48’ 43.87” 85° 11’ 34.43”	N35°E S35°W	800-2900	>15	10-15m	350-1000	Nil
Natima (L – 49)	20° 02’ 12.00” 85° 24’ 1.72”	N50°W S50°E	500-2600	>20	10-15m	250-450	Low
Khurda road (L -51)	20° 12’ 55.92” 85° 31’ 1.96”	N30°W S30°E	400-3500	>20	10-15m	180-800	Nil
Mahanadi River (L – 55)	20° 27’ 5.55” 85° 39’ 5.14”	N65°W S65°E	500-3400	>15	5-10m	300-1000	Nil
Orando (L – 57)	20° 33’ 4.92” 85° 47’ 6.12”	N70°W S70°E	400-2300	>20	15-20m	300-800	Nil
Koranji (L – 59)	20° 39’ 53.53” 85° 56’ 37.35”	N20°W S20°E	400-2500	>10	15-20m	450-1000	Nil
Kustira(L – 62)	20° 49’ 24.01” 86° 06’ 35.50”	N30°W S30°E	300-4400	>20	15-20m	180-350	Moderate
Routarapur (L – 63)	20° 52’ 17.48” 86° 12’ 17.5”	N35°W S35°E	500-1800	>30	15-20m	250-450	Low
Jutana (L – 64)	20° 58’ 37.3” 86° 17’ 17.5”	N-S	400-1700	>40	15-20m	200	Moderate
Targa (L – 65)	21° 01’ 49.42” 86° 20’ 48.09”	N40°W S40°E	400-1700	>25	15-20m	250-650	Low
Naiparigadia (L - 66)	21° 05’ 6.56” 86° 24’ 7.68”	N40°W S40°E	300-2900	>35	15-20m	250-800	Nil
Johotpada (L – 67)	21° 07’ 7.81” 86° 26’ 13.67”	N30°W S30°E	500-2300	>35	15-20m	350-800	Nil
Dularpur (L – 68)	21° 14’ 5.76” 86° 34’ 8.81”	N65°W S65°E	500-1500	>40	20-25m	100-400	Low
Patapara (L – 70)	21° 25’ 57.9” 86° 46’ 22.54”	N40°W S40°E	300-2100	>40	15-25m	300-700	Low
Mukundaour (L – 71)	21° 33’ 9.92” 86° 51’ 5.42”	N80°W S80°E	500-2100	>40	15-25m	250-500	Low
Kendudiha (L – 73)	21° 35’ 41.23” 86° 54’ 20.29”	N50°W S50°E	400-1700	>40	15-20m	150-700	Low

TABLE 2. V_P and V_S values for different rocks/formations

P- wave velocity m/sec	**Shear wave velocity m/sec**	**Description of the rocks**
>4000	>1500	Hard rocks
1200-2500	760-1500	Weathered rocks
600-1200	360-760	Very dense soils and soft rocks
300-600	180-360	Stiff soil
<300	<180	Soft soils

VI. CONCLUSIONS

In this study reveal that the lineaments L-27, L-28, L-41, L-55, L-62, and L-64, are geologically and seismically active zones along the Kakinada-Balasore transect and L-27, L-28, L-62, and L-64 are showing low Vs zone is ranging from 180m/s-350m/s which indicates presence of soft soils with >20m, moderate Vs zone is 300-500m/s and high Vs zone is >600 m/s having shallow bed rock up to <10m to <5m.

- From the obtained P-wave velocities (Vp) indicates that depth to bed rock is gradually increasing from site no.1 to 45 (i.e., South to North). The expected liquefaction probability at 45 locations along the route is low to moderate levels if an earthquake occurs with a magnitude of 6M in the vicinity of the 25km from the lineament zones.
- The obtained shear wave velocity (Vs), p-wave velocity (Vp), stiffness and liquefaction safety factors are of worth in the seismic hazard assessment of coastal region, as well as the analysis or identification of structural lineament using integrated geological and surface geophysical studies will provide valuable information to assess the reliability of the civil engineering structures against earthquakes.
- The acquired results of the study will help in understanding the soil behavior during earthquakes near the lineament and it will be useful for establishing the power plants, dams, irrigation lines, nuclear power projects in the vicinity of the seismogenic lineaments/faults along

the coastal parts i.e. from Kakinada to Balasore of the Indian subcontinent. The estimated geotechnical parameters will help in safe design of the structures for long term functioning and it will be providing valuable information to take required precautions to minimize the local site effects during earthquake.

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