SEISMIC RESISTANT ROADS USING RUBBERIZED COIR MAT AS DAMPER

A PROJECT REPORT

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ABSTRACT

The upshots of the earthquake are whacking, number of fatalities, infrastructural damages and economic loss for people as well as the government. One major issue is the failure of roads. Constructing roads which are earthquake resistant is momentous, that the accessibility to the affected areas during earthquake can be provided. This elucidates the use of Rubberized Coir mat as damper.

In this study, we have chosen ten seismically active sites in and around Coimbatore city with Peelamedu as centre the study area has a radius of 30 km. PGA for the selected points within the zone is calculated by using the Regional Attenuation Model, with the use of characteristic Earthquake Magnitude (M_w) value at these points obtained from the past earthquake studies. The software analysis using PROSHAKE 2.0 is also done for the calculation of PGA for the ten seismic sites. The results of the theoretical analysis and software analysis are compared for with and without rubberized coir mat condition.

Laboratory test for the calculation of CBR value and Peak Ground Acceleration (PGA) for the various locations in Coimbatore is conducted. CBR test is employed for identifying the optimum depth at which the rubberized coir mat is provided so that the maximum CBR value is obtained. By using the CBR values, the conventional flexible pavement with the reinforcement of rubberized coir mat is designed. Further cost analysis is made upon comparing the conventional roads and reinforced rubberized coir mat roads.

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LIST OF SYMBOLS AND ABBREVIATIONS

M_W	-	Moment magnitude
MMI	-	Modified Mercalli Intensity scale
MSK	-	Medvedev Sponheuer Karnik scale
IS	-	Indian Standards
GIS	-	Geographic Information Sysytem
PI	-	Peninsular India
V_S	-	Shear wave velocity
SPT	-	Standard Penetration Test
N	-	Number of blows
PGA	-	Peak Ground Acceleration
PSHA	-	Probabilistic Seismic Hazard Analysis
CBR	-	California Bearing Ratio
UCC	-	Unconfined compression test
FESEM	-	Field Emission Scanning Electron Microscope
EDS	-	Energy Dispersive X-ray Spectroscopy
ASTM	-	American Society for testing and materials
OMC	-	Optimum Moisture Content
W_L	-	Liquid limit
W_P	-	Plastic limit

I_F	-	Flow index
I_P	-	Plasticity index
MASW	-	Multichannel Analysis of Surface Wave
A	-	Initial traffic
D	-	Lane distribution factor
n	-	Design life in years
VDF	-	Vehicle Damage Factor
IRC	-	Indian Road Congress
CVPD	-	Commercial Vehicles Per Day
GSB	-	Granular Sub Base
G.BASE	-	Granular Base
DBM	-	Dense Bituminous Macadam
BC	-	Bituminous Concrete
SDBC	-	Semi Dense Bituminous Concrete

CHAPTER 1
INTRODUCTION

1.1 GENERAL

Peninsular India has been subjected to 2001 Bhuj earthquake, Gujarat (M_w=7.7) caused the death of at least 20,000 people and injured more than 2,00,000 people. In this disaster rehabilitation, the rescue process became a nightmare as the roads didn't provide accessibility. Gujarat has a wide road network approximately 72,000 km. This concluded in whacking economic loss. As the road infrastructure was worst affected, it led to the late recovery of people. The aftermath of each and every earthquake is a series of damages followed by the loss of property and people.

All these years' improvements were gathered concerning the destruction of buildings and making them earthquake resistant in their design aspects. But the phase of providing accessibility at the time of distress has not been thought out. Even in the recent massive earthquake of magnitude (M_w=7.5) at Papua New Guinea on 28 February 2018, road accessibility was again the major issue here. The rationale is the initial number of people killed was believed to be 15, but later after a week the count raised to 67. Similarly in Japan, Tohoku earthquake (M_w=9.0 to 9.1) on March 11, 2011 created huge tremors. The gaping chasms of the Great Kanto Highway in Naka were repaired in just six days. This would have definitely resulted in huge economic loss. To make the roads effective as seismic resistant economically, we are introducing rubberized coir mat in sub grade to increase the strength of the roads.

1.2 EARTHQUAKE

An Earthquake is the shaking of the surface of the earth, resulting from the sudden release of energy in the Earth's lithosphere that creates seismic waves. The seismicity or seismic activity of an area refers to the frequency type and size of earthquakes experienced over a period of time. It is estimated that there are 500,000 detectable earthquakes in the world each year. 100,000 of those can be felt, and 100 of them cause damage.

CAUSATION OF EARTHQUAKE

The antecedents of Earthquake may be whether natural or manmade, but mostly caused by rupture of geological faults, volcanic activity, landslides, mine blasts and nuclear test. Earthquake epicentres occur mostly along tectonic plate boundaries, and especially on the Pacific Ring of Fire.

Of these the natural causes are, movement of tectonic plates in the outermost layer of earth's crust and mantle at a rate of 2 to 10 centimetre per year [tectonic earthquakes] ,the rock surrounding the centre of volcano is subjected to pressure due to the hot molten magma which pushes against these rocks thus resulting in fracture of these rocks and small earthquakes called volcanic earthquakes occur and finally rock faults , here earthquakes are caused by energy released during rapid slippage along the fault lines. Earth is also jeopardized by man-made activities resulting in earthquakes. These manmade sources are explosion earthquakes due to underground nuclear explosions and rock blasting in quarries, reservoir induced earthquakes and mining induced earthquakes.

Terminology

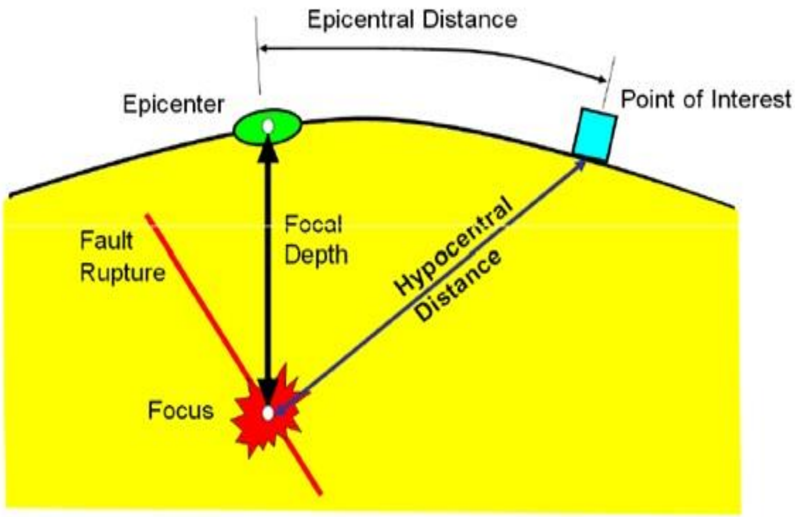

Fig. 1.1 Terminology of earthquake

- Focus (or) Hypocenter: An Earthquake's point of initial rupture, where the slip starts in a fault is called as focus or hypocenter.
- Epicenter: The epicenter is the point at ground level directly above the hypocenter.
- Focal Depth: The depth of focus from the epicenter.
- Epicentral Distance: Distance from the epicenter to any point of interest.
- Aftershock: An aftershock is an earthquake that occurs after a previous earthquake, the main shock. An aftershock is in the same region of the main shock but always of a smaller magnitude.
- Fore Shock: If an aftershock is larger than the main shock, the aftershock is re designated as the main shock and the original main shock is re designated as a foreshock.

1.3 TYPES OF EARTHQUAKE

Earthquakes caused by natural or manmade reasons are classified based on

1. Based on the tectonic plates

    Intra plate earthquake

    Inter plate earthquake

2. Based on the depth of focus

    Shallow focus earthquake

    Mid focus earthquake

    Deep focus earthquake

3. Based on the fault

    Dip-slip fault

    - Normal fault
    - Reverse fault

    Strike –slip fault

    Oblique slip fault

Based on the Tectonic Plates

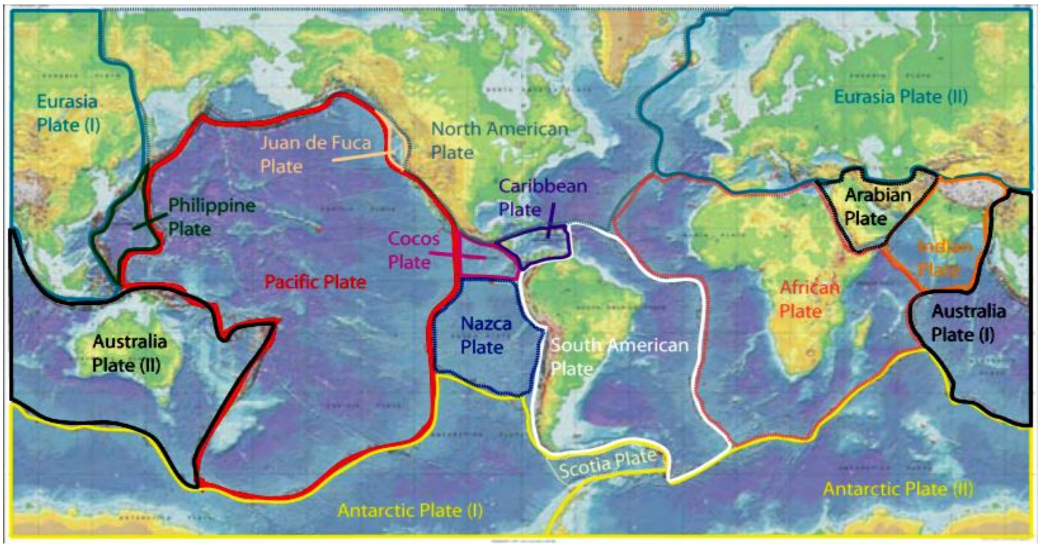

Fig. 1.2 Tectonic plates
(Source: https://earthquake.usgs.gov)

Most of the earthquake in the world occur along the boundaries of the tectonic plates and are called as Inter plate earthquakes. A number of earthquakes also occur within the plate itself away from the plate boundaries are called as Intra plate earthquakes.

Based on the Focal Depth

The majority of tectonic earthquakes originate at the ring of fire in depths not exceeding tens of kilometers.

- Earthquakes occurring at a depth of less than 70 km are classified as shallow-focus earthquakes,
- Earthquakes with a focal-depth between 70 and 300 km are commonly termed mid-focus or intermediate-depth earthquakes.
- Deep-focus earthquakes may occur at much greater depths (ranging from 300 up to 700 kilometers).

Based on the Fault

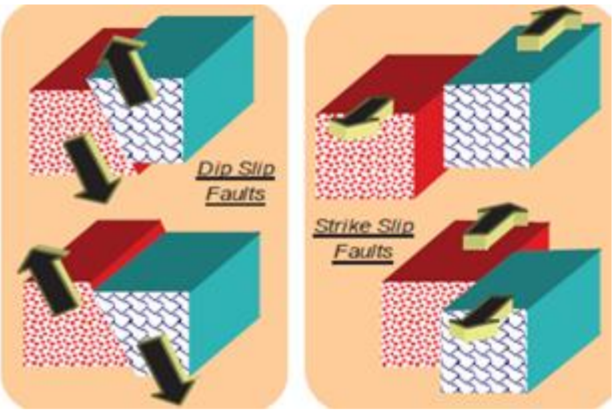

Fig. 1.3 Types of Faults

Dip- Slip

Normal and reverse faulting are examples of dip-slip, where the displacement along the fault is in the direction of dip and movement on them involves a vertical component. Normal faults occur mainly in areas where the crust is being extended such as a divergent boundary. Earthquakes associated with normal faults are generally less than magnitude 7.

Reverse faults occur in areas where the crust is being shortened such as at a convergent boundary. Reverse faults, particularly those along convergent plate boundaries are associated with the most powerful earthquakes; mega thrust earthquakes, including almost all of those of magnitude 8 or more.

Strike – Slip

Strike-slip faults are steep structures where the two sides of the fault slip horizontally past each other; transform boundaries are a particular type of strike-slip fault. Strike-slip faults, particularly continental transforms, can produce major earthquakes up to about magnitude 8.

Oblique Slip

Many earthquakes are caused by movement on faults that have components of both dip-slip and strike-slip; this is known as oblique slip.

1.4 INTENSITY AND MAGNITUDE OF EARTHQUAKE

Intensity is a qualitative measure of the actual shaking at a location during an earthquake, and assigned as Roman Capital Numerals. There are many intensity scales. Two commonly used ones are the Modified Mercalli Intensity (MMI) scale and the Medvedev- Sponhener – Karnik (MSK) scale. Both scales are quite similar and range from I(least perspective) to XII(most severe).The intensity scales are based on three features of shaking – perception by people and animals, performance of buildings and changes in natural surroundings.

Magnitude is a quantitative measure of the actual size of the earthquake. Professor Charles Richter noticed that

- at the same distance, seismograms(records of earthquake ground vibration) of larger earthquakes have bigger wave amplitude than those of smaller earthquakes
- For a given earthquake seismograms at further distances have smaller wave amplitude than those at close distances.

Hence, he proposed the local magnitude scale, Richter scale. It is obtained from the seismograms and accounts for the dependence of wave form amplitude on epicentral distance. The other magnitude scales are Body wave Magnitude, Surface wave magnitude and Wave energy magnitude.

1.5 SEISMIC ZONES IN INDIA

Three chief tectonic sub-regions of India are the mighty Himalayas along the north, the plains of the Ganges and other rivers, and the peninsula. India lies at the north-western end of the Indo-Australian Plate. This plate is colliding against the huge Eurasian Plate and going under the Eurasian Plate.

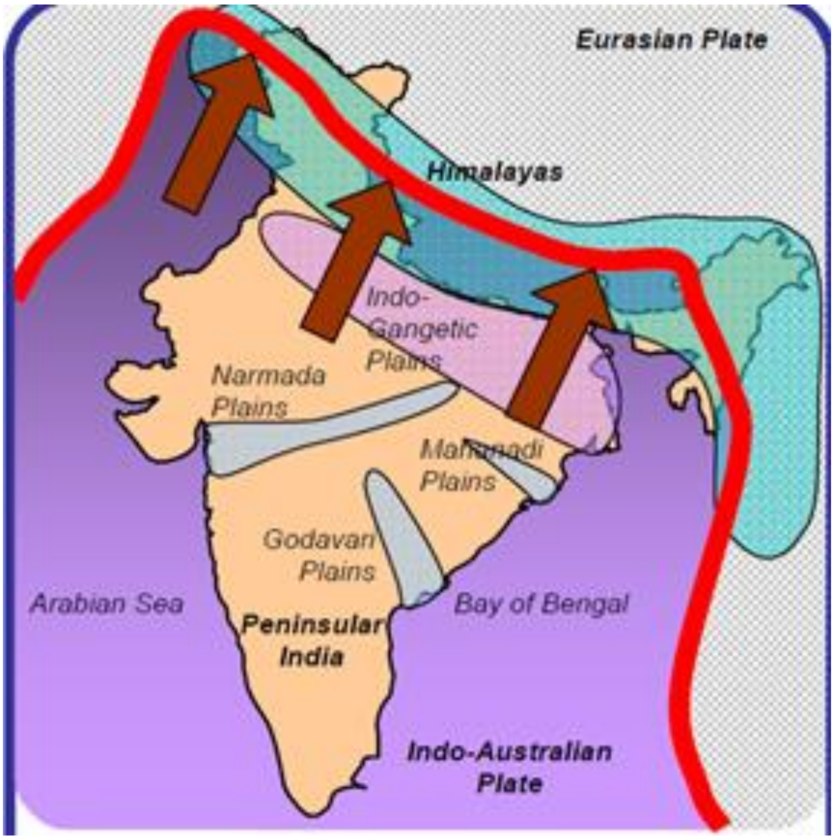

Fig. 1.4 Tectonic plate boundaries at India

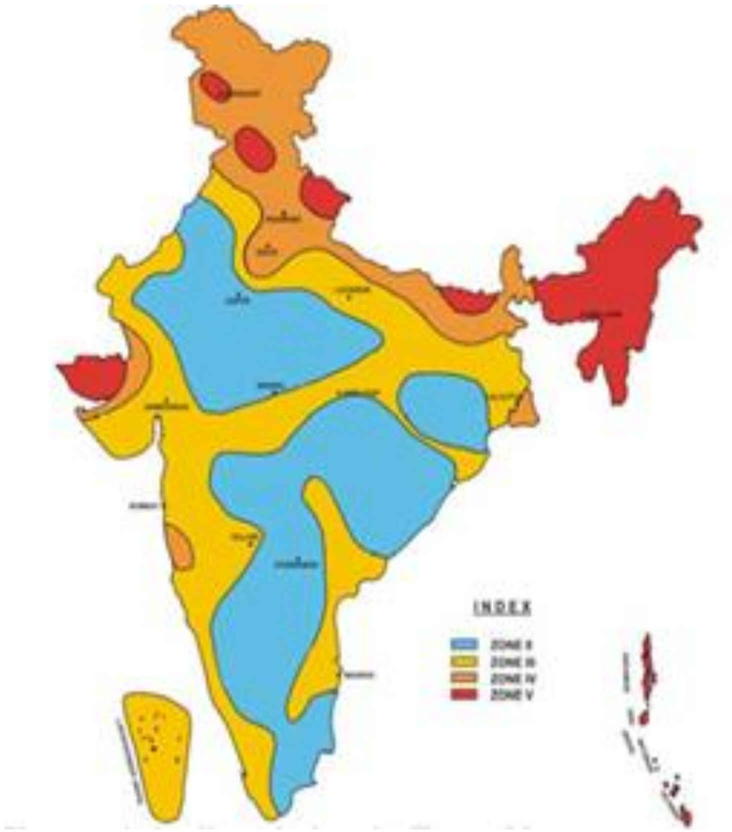

Fig. 1.5 Indian seismic zone map as IS 1893

Based on the levels of intensities sustained during damaging past earthquakes the seismic zones were published in the code IS 1893:1962, later revised in 2002, the zone map subdivided India into five zones – I, II, III, IV and V as the geology at different locations in the country implies that the likelihood of damaging earthquakes taking place at different locations is different.

1.6 GROUND SHAKE

Large strain energy released during an earthquake travels as seismic waves in all directions through the earth's layers, reflecting and refracting at each interface. These waves are of two types – Body waves and Surface waves. Body waves consist of Primary waves (P – waves) and Secondary waves (S – waves) and Surface waves consists of Love waves and Rayleigh waves.

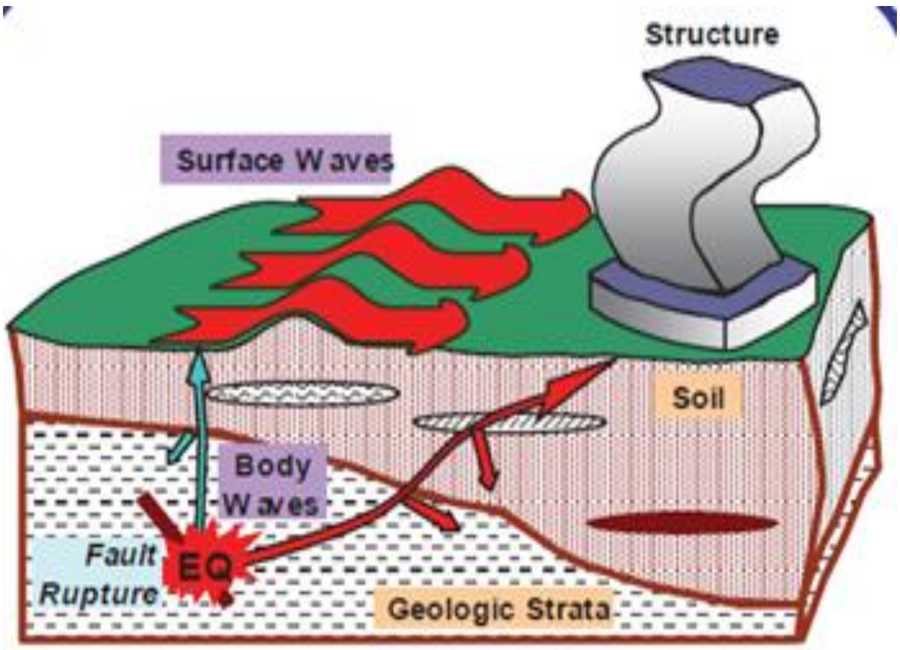

Fig. 1.6 Seismic waves at a site

Under P – waves, material particles undergo extensional and compression strains along the direction of energy transmission, but under S – waves, they oscillate at right angles to it. When P and S waves reach the earth's surface, most of their energy is reflected back. Some of this energy is returned to the surface by reflections at different layers of soil and rock. Shacking is more severe (about twice as much) at the earth's surface than at substantial depths.

Table 1.1 Richter and MMI scale table

Magnitude	Mercalli intensity	Average earthquake damages
1.0–1.9	I	Micro earthquakes, not felt, or felt rarely. Recorded by seismographs.
2.0–2.9	I to II	Felt slightly by some people. No damage to buildings.
3.0–3.9	III to IV	Often felt by people, but very rarely causes damage. Shaking of indoor objects can be noticeable.
4.0–4.9	IV to VI	Noticeable shaking of indoor objects and rattling noises. Felt by most people in the affected area. Slightly felt outside. Generally causes none to minimal damage. Moderate to significant damage very unlikely.
5.0–5.9	VI to VII	Can cause damage of varying severity to poorly constructed buildings. At most, none to slight damage to all other buildings. Felt by everyone.
6.0–6.9	VIII to X	Damage to a moderate number of well-built structures in populated areas. Earthquake-resistant structures survive with slight to moderate damage. Poorly designed structures receive moderate to severe damage. Felt in wider areas; up to hundreds of miles/kilometres from the epicentre. Strong to violent shaking in epicentral area.
7.0–7.9		Causes damage to most buildings, some to partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Felt across great distances with major damage mostly limited to 250 km from epicentre.
8.0–8.9		Major damage to buildings, structures likely to be destroyed. Will cause moderate to heavy damage to sturdy or earthquake-resistant buildings. Damaging in large areas. Felt in extremely large regions.
9.0 and greater	X or greater	At or near total destruction – severe damage or collapse to all buildings. Heavy damage and shaking extends to distant locations. Permanent changes in ground topography.

Human Effects

An earthquake may cause injury and loss of life, road and bridge damage, general property damage, and collapse or destabilization (potentially leading to future collapse) of buildings. The aftermath may bring disease, lack of basic necessities, mental consequences such as panic attacks, depression to survivors and higher insurance premiums.

1.7 PAST EARTHQUAKES IN INDIA

Date	Event	Time	Magnitude	Max. Intensity	Deaths
16 June 1819	Cutch	11:00	8.3	VIII	1,500
12 June 1897	Assam	17:11	8.7	XII	1,500
8 Feb. 1900	Coimbatore	03:11	6.0	X	Nil
4 Apr. 1905	Kangra	06:20	8.6	X	19,000
15 Jan. 1934	Bihar-Nepal	14:13	8.4	X	11,000
31 May 1935	Quetta	03:03	7.6	X	30,000
15 Aug. 1950	Assam	19:31	8.5	X	1,530
21 Jul. 1956	Anjar	21:02	7.0	IX	115
10 Dec. 1967	Koyna	04:30	6.5	VIII	200
23 Mar. 1970	Bharuch	20:56	5.4	VII	30
21 Aug. 1988	Bihar-Nepal	04:39	6.6	IX	1,004
20 Oct. 1991	Uttarkashi	02:53	6.6	IX	768
30 Sep. 1993	Killari (Latur)	03:53	6.4	IX	7,928
22 May 1997	Jabalpur	04:22	6.0	VIII	38
29 Mar. 1999	Chamoli	12:35	6.6	VIII	63
26 Jan. 2001	Bhuj	08:46	7.7	X	13,805
26 Dec. 2004	Sumatra	06:28	9.3	VII	10,749

Fig. 1.7 Past Earthquakes in India

With the above said data of the past earthquakes occurred in India, the most reviewed earthquake in India is Bhuj Earthquake of 2001.

1.8 CASE STUDY ON BHUJ EARTHQUAKE

A most powerful earthquake of magnitude 7.7 struck the Kutch region of Gujarat on the 26thJanuary 2001. The causality rate is 13,805. The earthquake was felt over a large part of the country and as far as Nepal, Chennai, Delhi, Calcutta and Bombay. The number of injured is reported to be 1,66,000 of which 20,700 suffered serious injury. It is estimated that about 3,70,000 houses and huts were completely destroyed. The total financial loss is estimated as Rs.21,300 crores. A number of hospitals, telephone exchange buildings, water service buildings and soft storey buildings. The building collapsed mainly because of

- improper detailing
- supporting of columns on isolated and spread footings

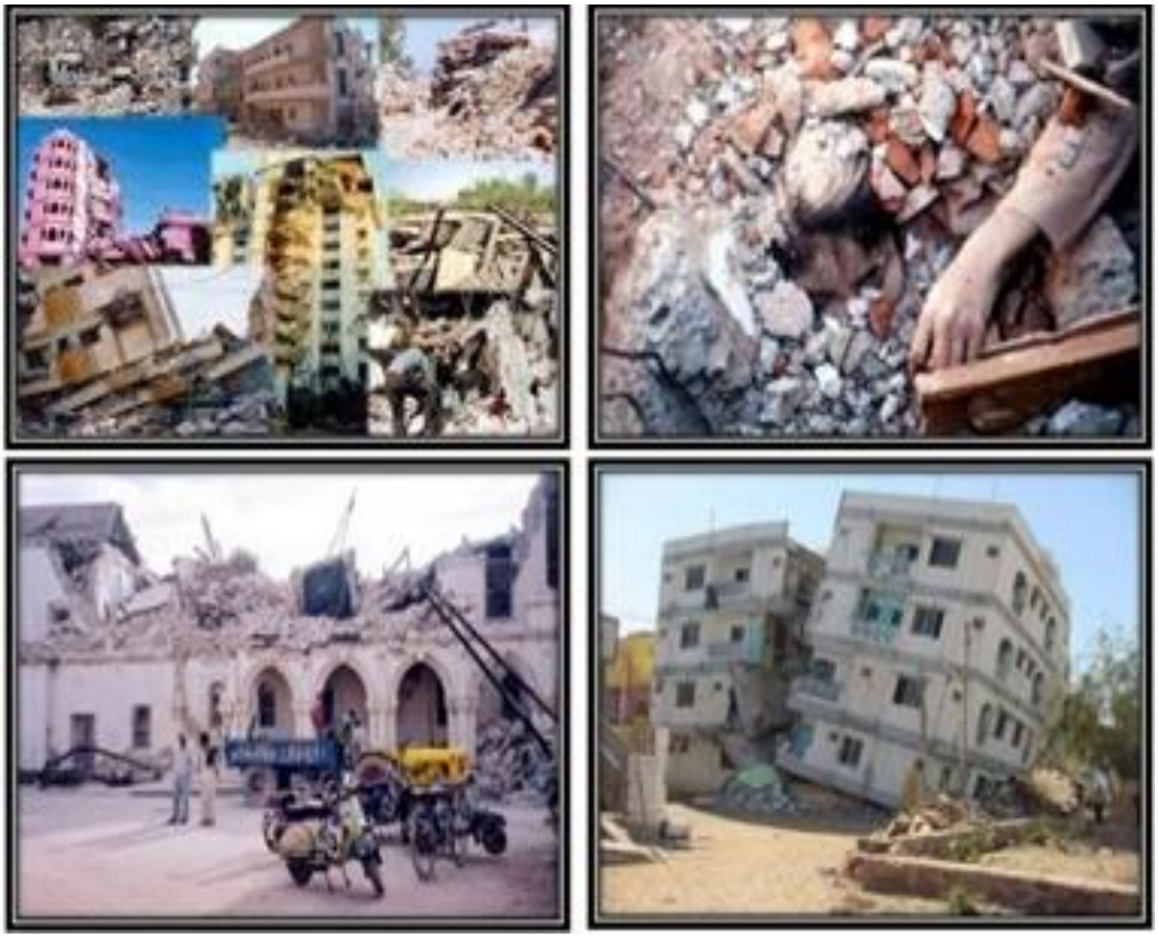

Fig. 1.8 Damages by Bhuj earthquake 2001

Current Scenario

The central and state governments announced numerous plans and activities. After the 2001 Bhuj Earthquake, many municipal authorities have started asking the structural engineer to certify that the building complies with the building codes.

Similar to Bhuj earthquake of 2001, another most important earthquake in South India is Coimbatore earthquake of 1900 with a magnitude of 6.0 in Richter scale, originating in the Palakkad fault. The major feature here is that the casualty rate is nil. The damages caused by this earthquake prove that Coimbatore is a seismically active region. Hence we have chosen Coimbatore (in and around) as our study area.

Road damages

The aftermath effects of the earthquake are very dangerous to the human life and also to the structures. This can be realized from the 2001 Bhuj earthquake, where 72,000 km long road network was destructed, gaping chasms of the Great Kanto Highway in Japan which occurred during Tohoku earthquake and also massive loss during February 2018 earthquake in Papua New Guinea. Its effects on the roads are also unpredictable. Due to this, the accessibility to the damaged are made impossible. All these loss and delay in reaching the required area after the earthquake increases the need for earthquake resistant roads.

CHAPTER 2
SELECTION OF STUDY AREA

2.1 Location of Study Area

Tamilnadu, a state with the low frequency of earthquakes and also the magnitude of earthquakes that have occurred in Tamilnadu over the past decade ranges from low to medium. Various cities like Chennai, Coimbatore, Cuddalore, Kanchipuram, Vellore and Salem have been categorized in zone III (Moderate damage risk zone) as per IS 1892:2002. Out of which we have chosen Coimbatore city as study area that has series of past earthquake and considerable damage to life and property in the past 200 years.

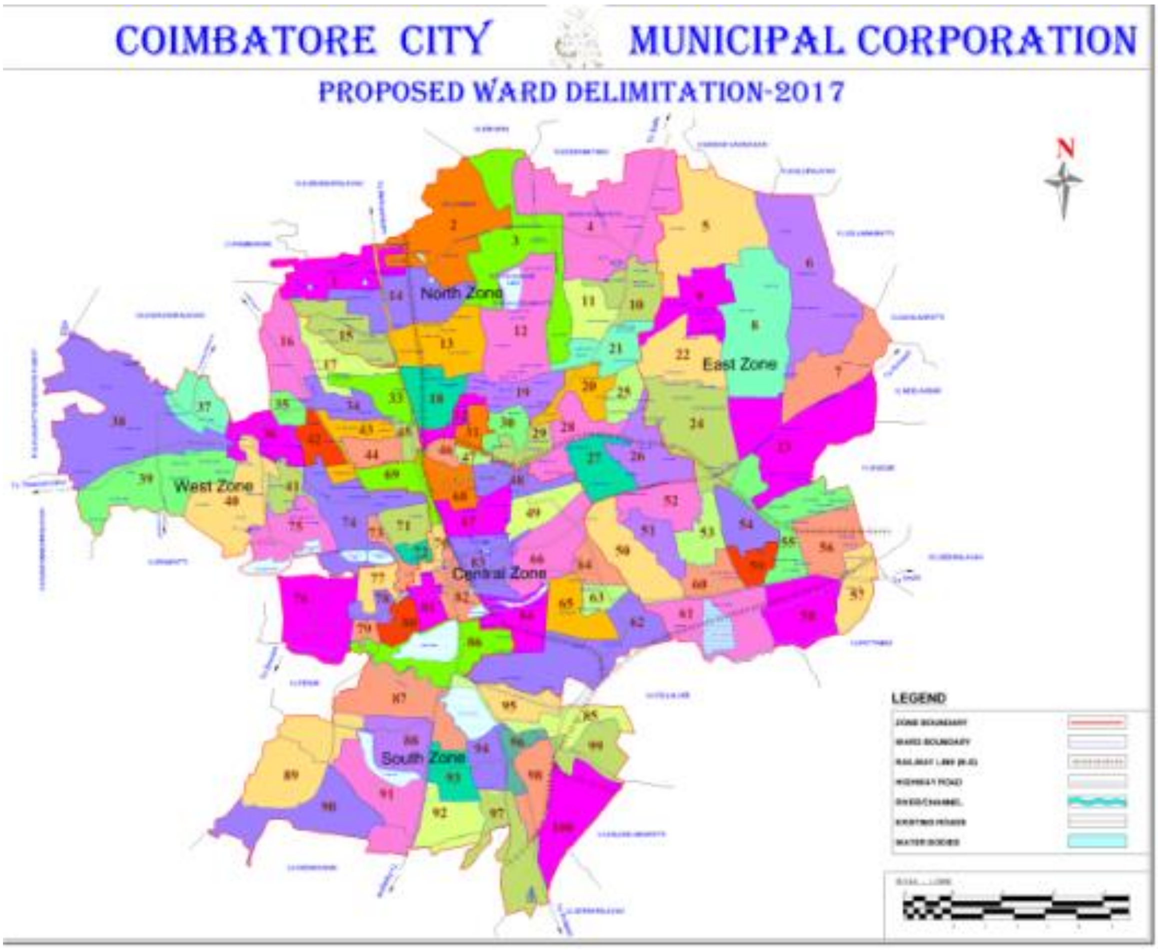

Fig. 2.1 Coimbatore city map

Coimbatore, the second largest city in Tamilnadu with an area of 642.12 km^2 located between 11˚1'2.5068" N and 76˚57'31.9860" E Geographically. It is situated on the bank of river noyyal, bounded by Western Ghats at an elevation of 411m (above the sea level). It is the one of the cities of Tamilnadu with the population growth at a rate of 0.04 million per year with a population of 1.85 million (till 2016). The north and western part of the study area is covered by Nilgiris and Western Ghats. The Coimbatore Corporation gets benefitted from the southwest monsoon.

2.2 Why Coimbatore?

Fast track developing cities with increasing population are most vulnerable to natural hazards. The hazard map provides an effective solution to take suitable mitigation action to minimize the loss in future. The first earthquake in Coimbatore occurred on February 28, 1890 with the magnitude M_w 5.7 at the location (ooty) 11.46˚ N and 76.6˚ E latitude and longitude respectively. Another earthquake occurred in 1972 at the location 11.0˚ N latitude and 77.0˚ E longitude (Coimbatore) with the magnitude of M_w 5.4. The above earthquakes had no major damage on life and property.

Unfortunately earthquake of a magnitude M_w 6.0 occurred near Coimbatore on February 8, 1900 which was one of the massive earthquakes. The epicenter of this earthquake was in Nalleppily (10.8˚N, 76.8˚E) in chittor taluk which is 29 km from Coimbatore. The impact of that earthquake was felt over 25,000 km^2. A major feature of the 1900 earthquake is that there was no casualty.

The reason for that the ancient houses were made of thatch or tiled roofs. In the recent construction, one can find that concrete is mostly used. It proves to be more dangerous because of its more dead weight. For this study, one predominant and problematic soil type of Coimbatore, black cotton soil has been considered. Black cotton soil is referred to as problematic because of its swelling nature when introduced to water.

The ultimate objective of the study is to reduce losses of life by providing accessibility to the damaged areas for rescue. Here we have chosen, Peelamedu as center and area with 30 km as radius covering the Coimbatore city.

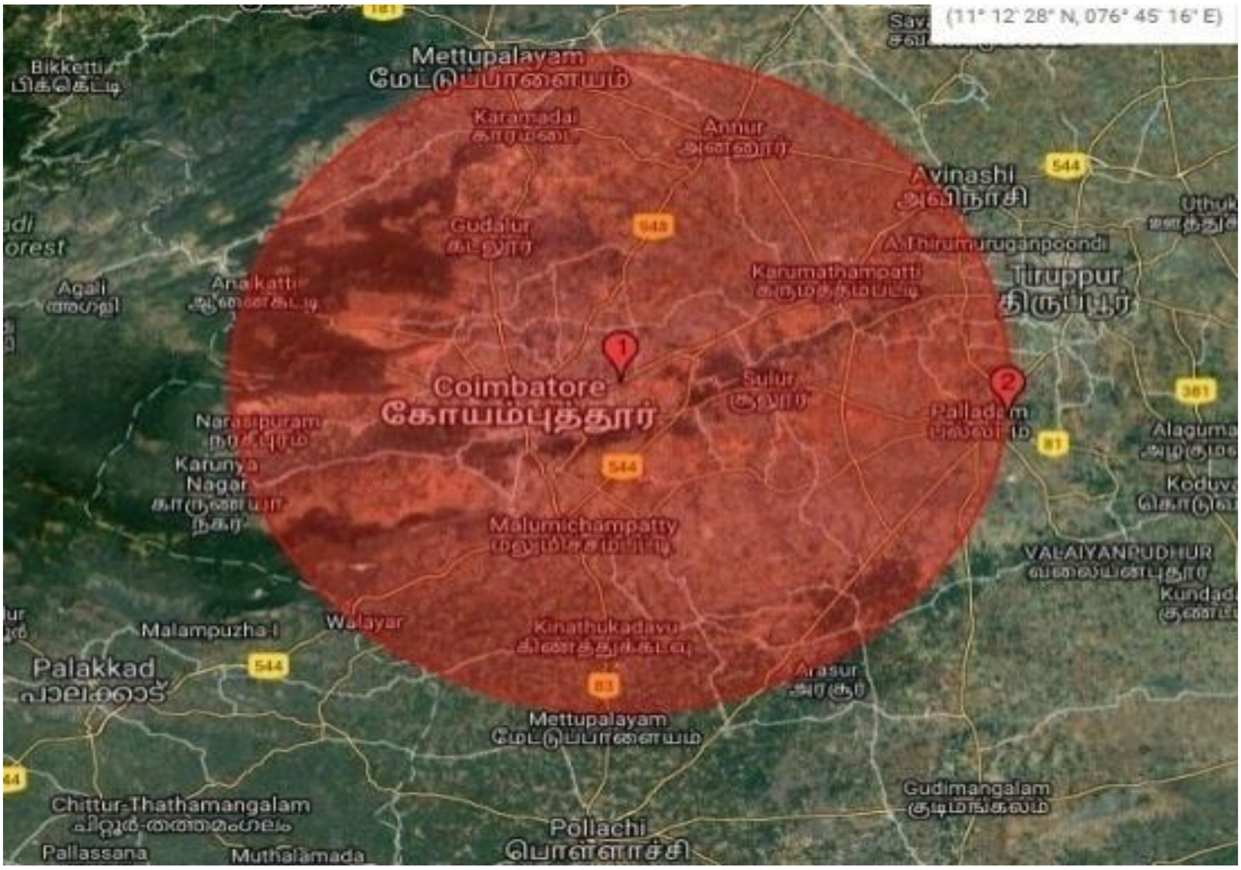

Fig. 2.2 study area of 30 km radius with Peelamedu as centre

Fig. 2.3 Nalleppily (Epicenter Of 1900 Earthquake)

2.3 Site selected for study in Coimbatore

For our study 10 seismically active sites of Coimbatore city was chosen with Peelamedu as centre and 30 km as radius covering the Coimbatore city. They are

Gandhipuram
Peelamedu
RS Puram
Singanallur
Periyakulam
Saibaba colony
Race course
GV residency water tank
Telungupalayam
Ganapathy

Fig. 2.4 seismically active 10 sites

Out of the 10 selected sites, Singanallur, Peelamedu, R.S.Puram, Saibaba colony and Telungupalayam are considered to be more prone to seismic hazard (Viswanathan KE et al, 2017).

Fig. 2.5 Peelamedu study area (ward-2)

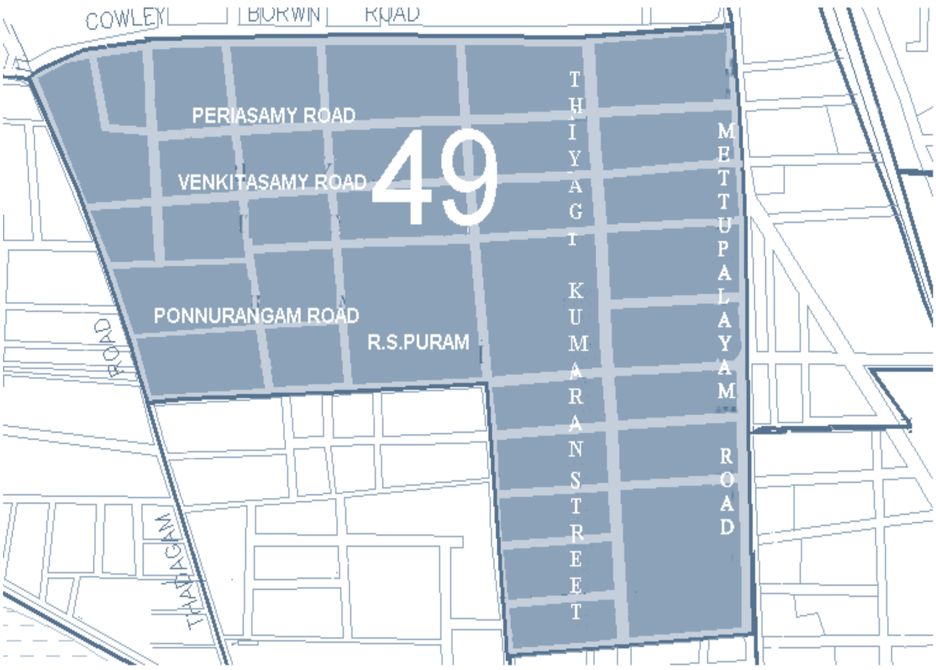

Fig. 2.6 RS Puram study area map (ward-49)

Fig. 2.7 Singanallur study area (ward-7)

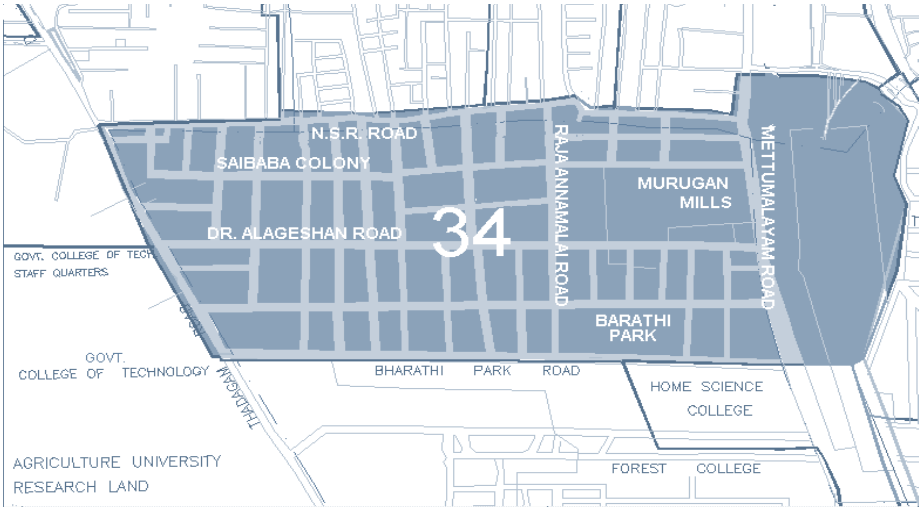

Fig. 2.8 Saibaba colony study area (ward-34)

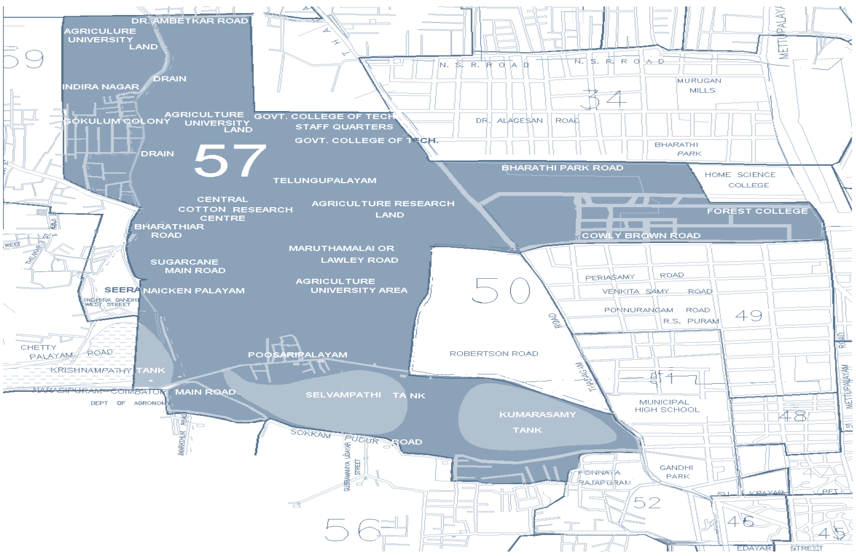

Fig. 2.9 Telugupalayam study area (ward-57)

CHAPTER 3
REVIEW OF LITERATURE

Panjamani Anbazhagan et al (2011) in his journal "Seismic hazard map of Coimbatore using subsurface fault rupture", explained the probable seismicity of Coimbatore region by preparing the seismic hazard map of the city using rupture based seismic hazard analysis. The eight zones which have been identified as the probable future earthquake zones of Coimbatore by them are considered for our study on Coimbatore.

Arun Bapat (2001) emphasized that the state of Tamilnadu of Peninsular India which was thought to be not seismically active region is also a seismic prone zone. He reached this conclusion from 1900 Coimbatore earthquake, saying that the seismic activity in this region has been on rise for past 15 years. He also said that the statistical analysis implies that such seismological events might occur in next 100 plus or minus years, making our study area, as one of the region which is expected to be prone to earthquake.

Gopalakrishnan S in his thesis "Seismic hazard analysis for Coimbatore Corporation using GIS", considered a study area with PSG College of technology as centre and a radius of 350km. He identified nearly 51 faults and 4 shear zones within the study area, and from his collection of data he established that the region under study had experienced 288 earthquakes with magnitude ranging between 2.9 as minimum value up to 6.2 as maximum value. He also identified the seismic risk zones within the study region from the prepared hazard map using GIS.

Iyengar R.N. & Raghukanth (2004) in their paper "Attenuation of strong ground motion in Peninsular India" gave an attenuation relationship to calculate the peak ground acceleration at any point of interest within India as it is a region specific parameter. This is because PI does not have sufficient strong motion records of past earthquakes. Also PI has a heterogeneous seismogenic character, so they developed a seismological model (Boore 1983) to overcome this hem. In addition to that they included the regional differences in the quality factor within PI by dividing it into three regions namely the Koyna-Warna, western-central, and southern region, and defined the respective quality factors.

Vishwanathan K E et al (2016) professed in his journal “Seismic hazard analysis and microzonation of Coimbatore corporation”, that seismic study is of great importance to determine the earthquake hazard in a region. He carried out the microzonation of Coimbatore city and he calculated the peak ground acceleration using regional attenuation relationship, with the help of magnitude (M_w) data from past earthquakes. The earthquakes considered were1900 Nalleppily (M_w=6) earthquake and 1972 Coimbatore earthquake (M_w=5.4). Then they prepared the seismic hazard map of Coimbatore city using PGA and bed rock depth maps.

The durability of coir against degradation is generally 15 times more than cotton and 7 times than that of jute. Coir offers longer resistance for the growth of microorganisms due to the presence of high lignin content (nearly 35 %).A study carried out at Indian Institute of Technology, New Delhi by **Venkatappa Rao et al (2006)**, revealed that when the coir geo-textile is placed in the weak sub grade, the sub grade stiffens and also it gains strength in a year or more under the action of vehicular loads and self weight of pavement. The coir geo-textile also prevents intermingling of soil and granular sub-base. Also the soil deforms only under high bearing pressure value when reinforced with coir geo-textile when compared with other geo-textile.

Baruah U.K. et al(2010) , after extensive studies on the soil of Assam revealed in their paper, “Road construction in Assam by using coir mat”, that use of coir mat in the sub grade level increases the bearing capacity and thus the CBR value of the soil. They also found that the thickness of pavement reduces by 75% if coir mat is placed above sub grade.

The ground motion is the main parameter which influences the seismic damage of an area. The amplification of ground motion depends on the site soil deposits. **Babu Kirar et al (2016)** said in their paper, “Correlation Between Shear Wave Velocity (Vs) and SPT Resistance (N) for Roorkee Region”, the characteristics of a ground motion in a site depends on the shear wave velocity (Vs) because it represents the stiffness of the soil. They established a relationship between Vs and number of blows (N) obtained from standard penetration test (SPT).And they also concluded that this empirical correlation can be used for seismic microzonation which is used for seismic hazard analysis.

Uma Maheswari et al (2008) established an empirical correlation between Vs and N for Chennai city in their paper titled, “Development of empirical correlation between shear wave velocity and standard penetration resistance in soils of Chennai city”. They calculated Vs from Multi Channel Analysis of Surface Wave (MASW) tests conducted at various sites and N values are also obtained from standard penetration tests at various sites of Chennai. As conducting filed tests for Vs determination does not prove to be economical always, they established this relationship between Vs and N for all type of soils using a simple regression analysis, which is used by us in our study.

S.Elayaraja et al (2015), in their research paper titled, “Evaluation of seismic hazard and potential of earthquake-induced landslides of the Nilgiris, India”, made use of software called SHAKE-2000 program which involves one-dimensional equivalent linear method to carry out the ground response analysis for the seven sites in Nilgiris. The seismic displacement analysis by Newmark’s method using SHAKE 2000 is done for all seven sites, based on which the potential of earthquake induced landslides is assessed. This research paper encouraged us the use of software for response spectrum analysis.

Sandip.S.Trivedi (2010) in his thesis on, “Seismic ground response analysis and microzonation studies for Ahmedabad region”, used the software called PROSHAKE 2.0, to carry out one dimensional equivalent linear ground response analysis for 54 sites and peak ground acceleration has been computed. He stated that this analysis is important as it is needed to determine the response of soil deposit to motion of bedrock and the effect of local soil condition on amplification of seismic waves.

CHAPTER 4
METHODOLOGY

4.1 GENERAL

The Earthquake damage basically depends on three groups of factors: earthquake source and path characteristics, local geological and geographical site conditions, structural design and construction features. An Earthquake study falls into the category of "applied research" and need information. It requires more information regarding site specific geological condition, ground response to earthquake motions and their effects on the safety of the constructions taking into the consideration of desire aspects (Anbazhagan et al 2009).

4.2 FLOW OF WORK

The work flow of the project seismic resistant roads using rubberized coir mat as damper for the study area (Coimbatore) is shown in the fig.4.1. The first step involves selection of the study area. The preliminary study on earthquakes of the area (Coimbatore) is done and ten sites within the study area were selected. The second step revolves at laboratory tests to be conducted on sub grade soil and rubberized coir mat. CBR values for the sub grade soil in the Coimbatore study area with and without rubberized coir mat is determined. Coir mat is introduced at varying depth and CBR values are determined.

In the next step, Peak Ground Acceleration (PGA) calculation for the selected ten sites using Regional Attenuation model method without rubberized coir mat is done. Probabilistic Seismic Hazard Analysis (PSHA) identified the particular seismic scenario upon which a ground motion hazard evaluation is based. The next step is determining the strong ground motion parameters using PROSHAKE 2.0 with and without introducing rubberized coir mat.

The next step illustrates the comparison of PGA obtained from theoretical method (Regional Attenuation model) and software analysis method (PROSHAKE 2.0) with and without introducing rubberized coir mat as damper. With the illustration from the above CBR values, flexible pavement is designed as per IRC: 37-2012. Finally, cost estimation for the flexible pavement is done and the cost comparison between with and without introducing coir mat in the flexible pavement is prepared.

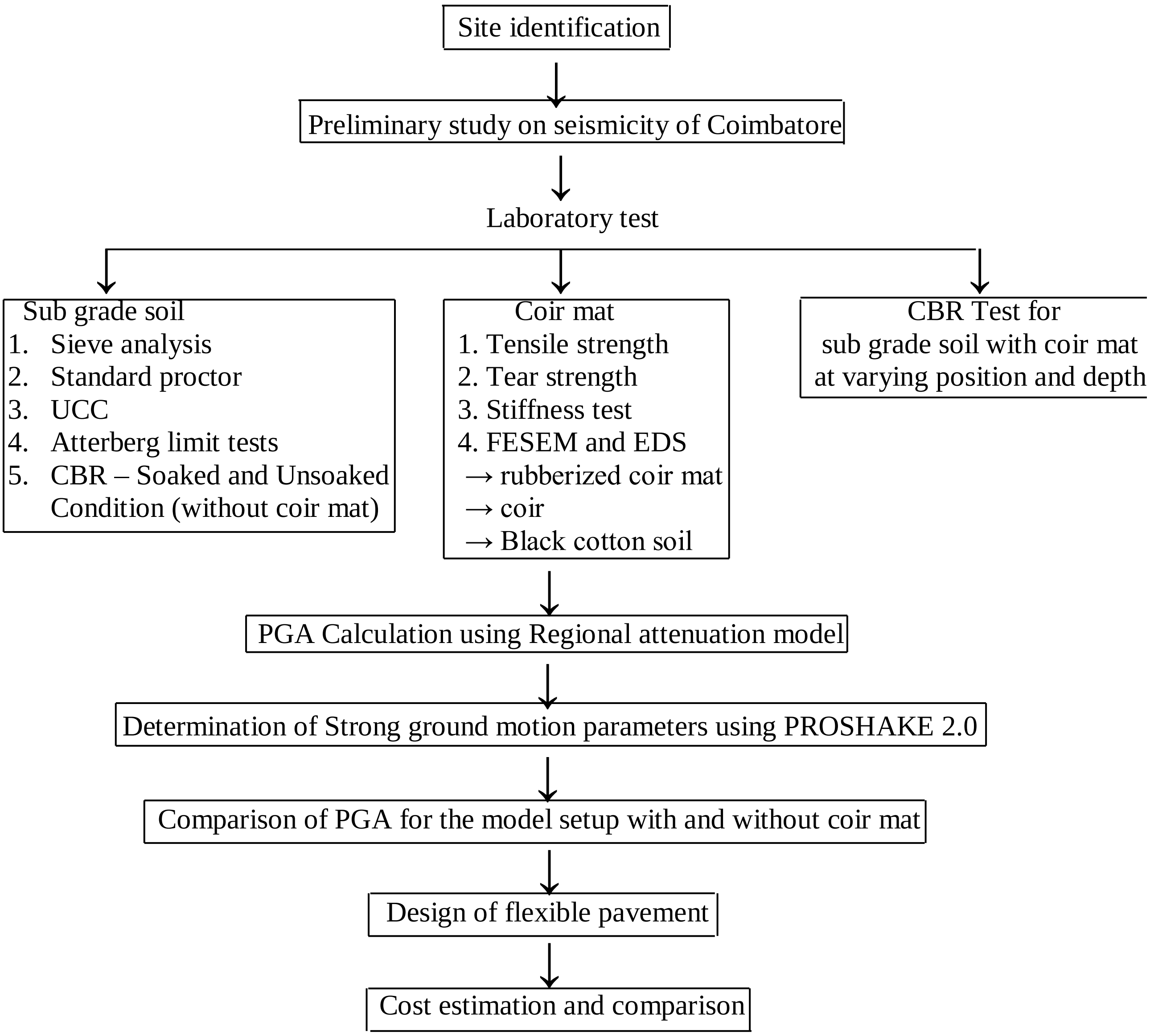

Fig. 4.1 Work flow chart

CHAPTER 5
MATERIALS USED

5.1 GENERAL

As the project is concerned with road, one important material to be taken into consideration is sub-grade soil. Here the testing soil samples were collected from Neelambur, Coimbatore, Tamilnadu. The soil collected is substantially black cotton soil, which is a clay soil. In order to fortify this weak class of soil we are reinforcing it with rubberized coir mat, which consists of 3 parts of coir for 1 part of rubber or latex. So the materials which are to be discussed are:

- Black cotton soil
- Coir
- Rubber

5.2 BLACK COTTON SOIL

Various laboratory tests like wet sieve analysis, standard proctor compaction test and Atterberg limits were conducted and the test results inferred that the selected soil type is clay soil and it is black cotton soil. This type of soil is mainly confined in parts of central India and to a small extent it is also found in southern India. The states where the deposits of black cotton soil is found are Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka and in some parts of Tamilnadu. These soils are residual deposits formed from basalt of trap rocks.

Black cotton soils are clays of high plasticity. They contain the clay mineral montmorillonite ($(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2 \cdot nH_2O$) predominantly, which is responsible for their high shrinkage and swelling characteristics. These minerals are products of volcanism and hydrothermal activity, and are composed of hydrous aluminum silicate in the form of extremely smaller particles. They take up water between their layers, causing swelling and change the interlayer spacing according to the mineral variety.

The shear strength of this soil is extremely low. The soils are highly compressible and have very low bearing capacity. So it is extremely difficult to work with this type of soil without any sort of improvement. It has the capacity of retaining water.

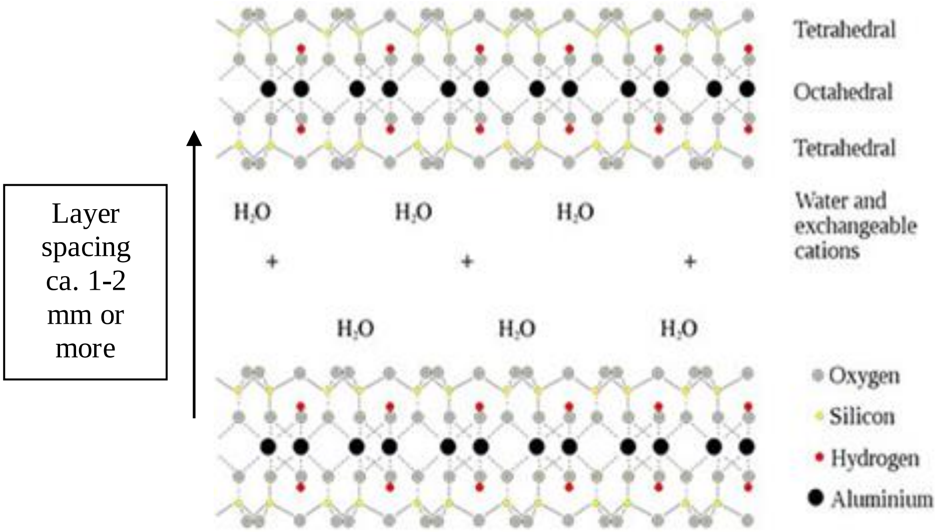

Fig. 5.1 Structure of montmorillonite

The physical properties of Black cotton soil vary from place to place 40 % to 60 % of the Black cotton soil has a size less than 0.001 mm. At the liquid limit, the volume change is of the order of 200 % to 300% and results in swelling pressure as high as 8 kg/cm^2 to 10 kg/cm^2. The structures on Black cotton soil bases develop undulations at the road surface due to loss of strength of the sub-grade through softening during monsoon. Due to its peculiar characteristics, it forms a very poor foundation material for road construction. Hence the soil can be replaced with non-expansive soil, but it does not prove to be economical always. Thus suitable stabilization method is to be adopted.

5.3 COIR

Coir is a biodegradable organic fibre material which is coarse, rigid and strong. The constituents of coir have been found to be mostly cellulose and lignin. Coir fibre is weather resistant and resistant to fungal and bacterial decomposition. The rate of decomposition of coir is much less than any other natural fibre. Also coir has high durability when compared to jute and cotton. It retains 20% of its strength even after one year, whereas cotton degrades totally in six weeks and jute in eight weeks. These characteristics are attributed due to the high lignin content in the fibre.

Coir in the form of woven mesh matting or non woven stitch bonded blankets is used in engineering applications in the geotechnical field. Its application includes erosion control, rainwater harvesting, stabilization of embankment, canal bund protection, river bank/seashore protection, reinforcement, road pavement, ground improvement.

Fig. 5.2 Natural coir fibre

Coir also proves to be a framer's product. Coir has high impact strength and is also environment friendly. Indian coir industry has a phenomenal share of 89% of global market for value-added coir products. Total coir fibre production is 2,50,000 tones, where India mainly the coastal region Kerala state produces 60% of total world supply of coir fibre. Coir exports from the country have also encountered an increase of 11% in quantity and 7% increase in value over the previous year. And today, coir and its products are exported to more than 80 countries and US is the single largest market with a share of more than 40% in the total export. So if we encourage the use of such natural product it will definitely contribute to the growth of economy of our country and also encourage farmers.

5.4 RUBBER

Rubber is a synthetic or natural material whose long, coiled, high-molecular weight chains have been cross-bridged by certain chemical ingredients to form a network. It is characterized by the ability to accept and recover from extreme deformation of 200 percent or more. The term elastomer includes natural rubber and the many synthetic materials that possess rubber-like properties.” The diagram below shows the chemical structure of natural rubber, *cis*-polyisoprene. Natural rubber is composed of long chains consisting of at least 10,000 similar chemical units.

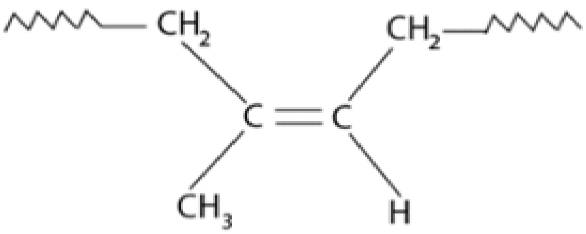

Fig. 5.3 Natural rubber chemical structure

Rubber is harvested mainly in the form of the latex from the rubber tree or others. Latex is the stable dispersion (emulsion) of polymer micro particles in an aqueous medium. Latex may be natural or synthetic. It can be made by polymerizing a monomer such as styrene that has been emulsified with surfactants. Latex as found in nature is a milky fluid found in 10% of all flowering plants. It is a complex emulsion consisting of proteins, alkaloids, starches, sugars, oils, tannins, resins, and gums that coagulate on exposure to air. The latex is a sticky, milky colloid drawn off by making incisions in the bark and collecting the fluid in vessels in a process called "tapping". The latex then is refined into rubber ready for commercial processing. Latex is the polymer cis-1,4-polyisoprene – with a molecular weight of 100,000 to 1,000,000 daltons. Typically, a small percentage (up to 5% of dry mass) of other materials, such as proteins, fatty acids, resins and inorganic materials (salts) are found in natural rubber. Polyisoprene can also be created synthetically, producing what is sometimes referred to as "synthetic natural rubber", but the synthetic and natural routes are different.

Natural rubber is used extensively in many applications and products, either alone or in combination with other materials. After the latex is processed, it becomes an elastomer with excellent mechanical properties. It has excellent tensile, elongation, tear resistance and resilience. It has good abrasion resistance and excellent low temperature flexibility. Without special additives, it has poor resistance to ozone, oxygen, sunlight and heat. It has poor resistance to solvents and petroleum products. Useful temperature range is -67° F to +180° F (-55° C to +82° C).In most of its useful forms, it has a large stretch ratio and high resilience, and is extremely waterproof.

The properties like tear, abrasion resistance, hysteresis and creep depend upon the fillers that are used during vulcanization where the rubber molecules join together. The cross linking creates the molecular network that gives the rubber strength, elasticity and other important mechanical properties. Also the shear modulus of a rubber possesses very low value, which indicates that rubber can be permanently deformed. Natural rubber without any filler exhibits very little hysteresis (i.e. ability to convert some energy to heat when it is deflected) and as a result it provides energy dissipation or damping, when it is subjected to shocks or vibrations. Hence rubber proves to act as good damper.

5.5 RUBBERIZED COIR MAT

In general rubber can be used along with other fibre to form composites. As rubber is a good shock absorber which is already used as shock absorbent in buildings so the same can be adopted in roads also, so we have chosen rubber to be mixed with the natural coir fibre. This rubberized coir mat is used with aim of increasing the bearing capacity of the sub-grade soil and also to reduce the effect of ground motion which reach the surface.

The general industrial process for manufacture of rubberized coir mat is as follows; firstly the coir fibre is twisted and subjected to streaming process to increase the strength of the fibres. Then it is stored for few days after which the twisted fibres are fed into untwisting machine.

The coir fibres are pressed uniformly to form mat over which the latex is sprayed and then dried at 70ºc to 80ºc. The purpose of this latex is to reduce the deformation during service condition and to increase the load carrying capacity. The quality parameters for rubberized coir mat is given in IS 8391-1987.

Fig. 5.4 Rubberized coir mat

CHAPTER 6
LABORATORY TESTS

The laboratory tests for black cotton soil and the coir mat were carried out. Test for coir and rubberised coir mat were conducted at PSG COE INDUTECH laboratory at Neelambur, Coimbatore. The tests conducted were

Laboratory tests

Tensile test	Wet Sieve analysis
Tear strength test	Atterberg limits
Stiffness test	Standard Proctor Compaction test
FESEM with EDS	Unconfined compression test
	California Bearing Ratio (CBR) test

6.1 RUBBERIZED COIR MAT PROPERTIES

As Rubberized coir mat has been employed in the pavement sub grade to withstand the ground motions created, the properties of the rubberized coir mat are resolved in order to assure the stability.

6.1.1 Tensile Test

Standard: ASTM D 5034

Graph: Force in N vs. Elongation in %

The tensile test for rubberized coir mat is executed to determine the mechanical properties of materials such as strength, ductility, toughness, elastic modulus, strain hardening. The tensile test is carried out to determine the maximum tension the fibre is able to sustain before breaking. The elongation denotes elongation % of the fibre at break. Tear strength is given as

$$\frac{\text{Breaking load in kg X Length of sample in mm}}{\text{mass of fibres in mg}}$$

The strength is affected by

- Molecular structure
- Number and intensity of weak planes
- Coarseness or fineness of fiber
- Relative humanity
- Elasticity

When an external force is applied, it is balanced by the internal force developed in the molecular structure. The mechanical properties are expected to depend on the content or volume fraction of the fibres in the composite (rubberized) (Rao and Rao, 2007). Even a small change in physical nature of fibres for a given volume content of fibres may result in changes in mechanical properties (P.N.E Naveen and M.Yasaswi, 2013). The tensile strength increases with the increase in fibre length. According to Naveen (2013), the reasons are the chemical reaction at interface between filler particles and the matrix may be too strong transfer the tensile. Random variability of material properties affects the variability of whole structure (Justyna Ferenc, 2013).

Table 6.1 Tensile test results

Specimen ID	F_H (N)	ϵ_H (%)	t_{Test} (s)
S1	52.2	8.4	5.03
S2	37.2	3.8	2.58
S3	81.9	4.8	2.87
S4	67.9	3.8	2.68

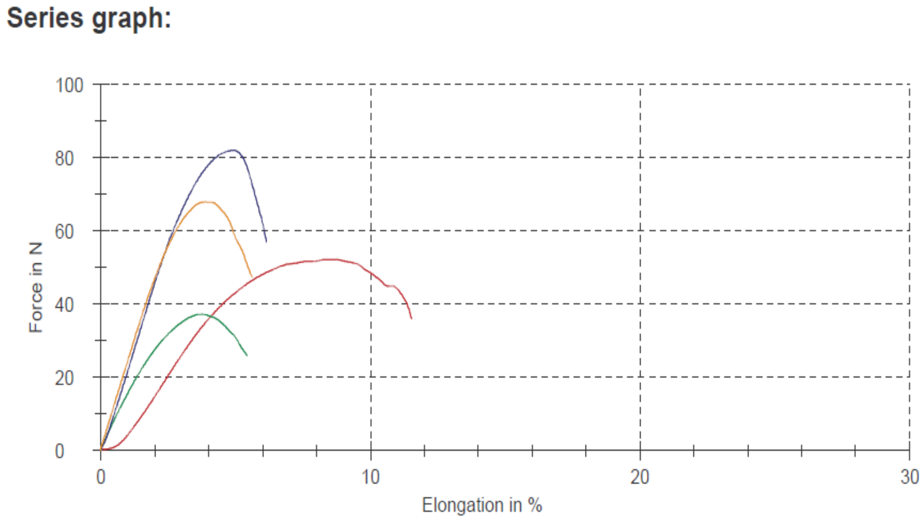

Fig. 6.1 Load Elongation Series Graph

Load – Elongation Graph

Initially as the load increases, elongation increases due to stretching of primary or secondary bonds, totally recoverable (elastic zone) leading to dimensional stability of the material. On further increase in load, the curve bends sharply at a point (say A) reaches maximum elongation stage and this point A is called yield point. After this plastic flow occurs, breaking of some secondary bonds, resulting in the rearrangement of molecules. The yield point is the weakest point of the specimen.

Table 6.2 Standard deviation and variance of tensile test results

MD (n = 4)	F_H (N)	ϵ_H (%)	t_{Test} (s)
x	59.80	5.20	3.29
s	19.30	2.20	1.17
v	32.35	41.52	35.45

6.1.2 Tear Strength Test

Standard: ASTM D 1424

Tearing strength for the material is carried out because to resist the load effects by vehicles and ground motion. Generally, tear strength is influenced by single thread (fibre) strength, the fibre finishes, grouping of threads (fibres) leads to higher resistance. Internal tearing resistance is the force perpendicular to the plane of material required to tear multiple fibres through a specified distance after tear has been started. High stretch makes it is difficult to localize or concentrate stress in a sufficiently small area that tear can be initiated. Tearing resistance shows an inverse correlation with both tensile strength and bursting strength.

Table 6.3 Tearing strength results

SAMPLE DESCRIPTION	**S.NO.**	**TEARING STRENGTH IN (N)**
RUBBERIZED COIR MAT	1.	50.2
	2.	60.6
	3.	55.2
	4.	56.5
	5.	55.2
	AVG	**55.54**

6.1.3 Stiffness test

Standard: ASTM D 1388

The stiffness test is carried out to determine the bending length. A horizontal strip of the material is allowed to bend like cantilever, index its own weight. As per pierce empirical equation, the bending length is the length of rectangular strip of material which will bend under its own mass to an angle of 7.1^{o}. The stiffness in bending is dependent on its thickness, higher the thickness, higher the stiffer.

Table 6.4 Stiffness test results

Sample Description	Bending Length (mm)
Rubberized Coir mat	63.5
	65.0
	72.5
	77.5
	67.5
Avg	**69.2**

6.1.4 FESEM for coir

The use of geosynthetics became more common in the construction industry to improve the performance. In the same view, rubberized coir mat has been chosen for our study.

Coir mat is a natural fibre with more number of producing unit especially in South India (Kerala, Karnataka and Tamilnadu). Rubberized coir is manufactured in the ratio of 3:1 (coir: rubber). The coir fibre is compounded by rubber latex. The rubber may be natural or synthetic. The latex of rubber plant is diluted such that 25% of solid rubber and the rest is water. Since coir is a natural fibre, the use of rubberized coir mat as an isolator at the sub grade proves to strong, light weight, cheap, eco-friendly, high durability and increased life span. Moreover, rubber acts as a damper (shock absorber). Hence, it is used in the construction of seismic resistant road design.

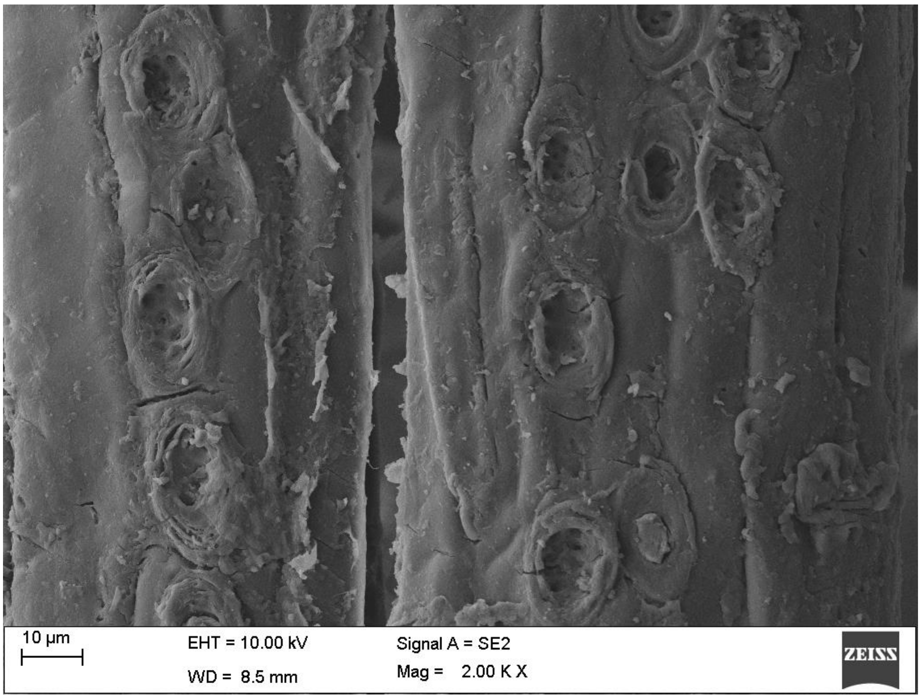

Fig. 6.2 FESEM - Natural coir fibre

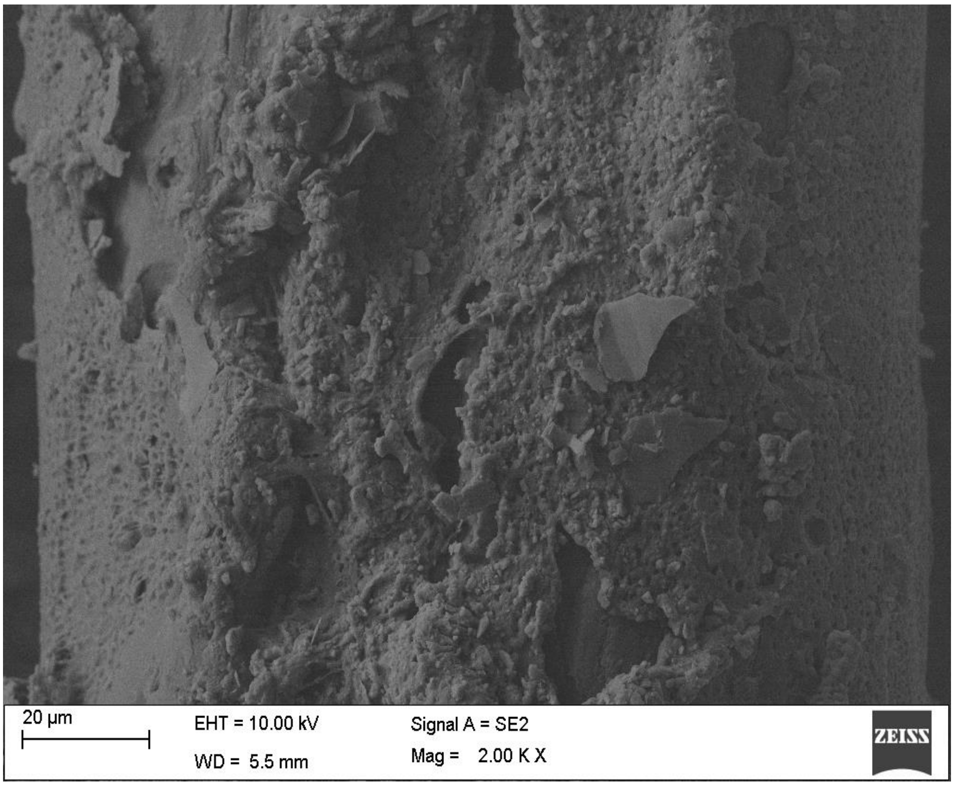

Fig. 6.3 FESEM - Rubberized coir mat

EDS for Coir

As discussed above, the coir mat is a composite of rubber and coir, EDS test is conducted to classify the chemical composition of each material separately. The composition of coir fibres is as follows:

Table 6.5 Coir chemical composition

Spectrum: COIR

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (3 Sigma) [wt.%]
Carbon	K-series	56.89	56.89	64.24	19.87
Oxygen	K-series	41.56	41.56	35.23	15.68
Aluminium	K-series	0.05	0.05	0.03	0.09
Silicon	K-series	0.26	0.26	0.12	0.12
Chlorine	K-series	0.15	0.15	0.06	0.10
Potassium	K-series	0.63	0.63	0.22	0.15
Copper	K-series	0.45	0.45	0.10	0.15
	Total:	100.00	100.00	100.00	

EDS for rubberized coir mat

In coir mat, the rubber used may be natural or synthetic. The rubber acts as a damper, as it is characterized by the ability to accept and recover (elasticity) from extreme deformation of 200% or more.

The chemical structure of rubber (cis- polyisoprene), consisting of at least 10,000 similar chemical units. When rubber is vulcanized with sulphur, they form a molecular network of polysulphidic cross links with higher rubber strength and elasticity.

Table 6.6 Rubberized coir mat chemical composition

Spectrum: COIR MAT

Element	Series	unn. C [wt.%]	norm. C [wt.%]	Atom. C [at.%]	Error (3 Sigma) [wt.%]
Carbon	K-series	66.85	66.85	75.62	23.37
Oxygen	K-series	24.22	24.22	20.57	9.81
Sodium	K-series	0.32	0.32	0.19	0.15
Magnesium	K-series	0.24	0.24	0.14	0.13
Aluminium	K-series	2.44	2.44	1.23	0.44
Silicon	K-series	2.50	2.50	1.21	0.40
Sulfur	K-series	1.24	1.24	0.52	0.22
Potassium	K-series	0.18	0.18	0.06	0.10
Calcium	K-series	0.19	0.19	0.06	0.10
Iron	K-series	0.42	0.42	0.10	0.13
Zinc	K-series	1.39	1.39	0.29	0.25
	Total:	100.00	100.00	100.00	

The composition of rubberized coir mat has proved to have high strength because its presence is about 22% of the total weight.

6.2 SOIL PROPERTIES

As the area chosen under study is Coimbatore, the predominant soil type, Black cotton soil has been considered. In order to determine the properties of the soil the following tests are conducted,

- Wet Sieve analysis
- Atterberg limits
- Standard Proctor Compaction test
- Unconfined compression test
- California Bearing Ratio (CBR) test

6.2.1 Wet Sieve Analysis

1 kg of dried black cotton soil is taken and soaked it for 24 hours, later the sample is stirred and washed with a jet of water by sieving it through a 4.75mm IS sieve. The material is washed until the wash water becomes clear. The material retained on the sieve is the gravel fraction. The wet sieve analysis has proven that the soil has high clay particles i.e, 64.8 % and the remaining 35.2% of sand particles.

6.2.2 Atterberg Limits

The water content corresponding to the transition from liquid state to plastic state is called as Atterberg limts. The tests are carried out to determine the limits,

- Plastic limit
- Liquid limit
- Shrinkage limit

Plastic Limit

Plastic limit is the water content below which the soil stops behaving as a plastic material. It begins to crumble when rolled into a thread of soil of 3 mm diameter. At this water content, the soil loses its plasticity and passes into a semi-solid state.

Air dried soil sample is taken and sieved through 425µ IS sieve. It is mixed thoroughly with distilled water such that it can be easily moulded with fingers. A ball is formed and rolled with fingers on a glass plate to form a soil thread of uniform diameter, without crack formation.

Fig. 6.4 Plastic limit

The water content at which the soil threads are formed without crumbling is called as Plastic limit. The plastic limit of the soil tested by us was found to be 26.9%. The plasticity index is 33.85%.

Shrinkage Limit

Shrinkage limit is the smallest water content at which the soil is saturated. It is also defines as the maximum water content at which a reduction of water content will not cause a decrease in the volume of the soil mass. In other words, at this water content, the shrinkage ceases. The shrinkage limit of the soil tested was found to be 13.24%. The shrinkage ratio is 19.96 %.

Fig. 6.5 Shrinkage limit

Liquid Limit

Liquid limit is the water content at which the soil changes from the liquid state to the plastic state. At the liquid limit, the clay is practically a liquid, but possesses a small shearing strength. The shearing strength at that stage is the smallest value. The liquid limit of soil depends upon the clay mineral present.

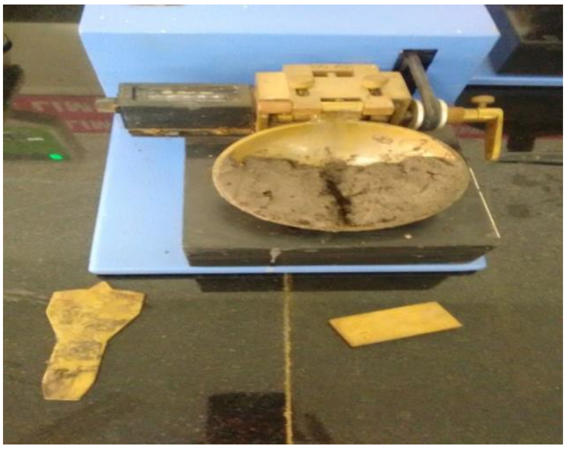

Fig. 6.6 Liquid limit

The stronger the surface charge and the thinner the particle the greater will be the amount of absorbed water and therefore, higher will be the liquid limit. It is determined by Casagrande's apparatus. The liquid limit of the soil tested by us was found to be 60.75%, at the 25^{th} blow. The flow index is 16.60%.

6.2.3 Unconfined Compression Test

The unconfined compression test is a special form of triaxial test in which the confining pressure is zero. The test can be conducted only on clayey soils which can stand without confinement. The test is generally performed on intact, saturated clay specimens.

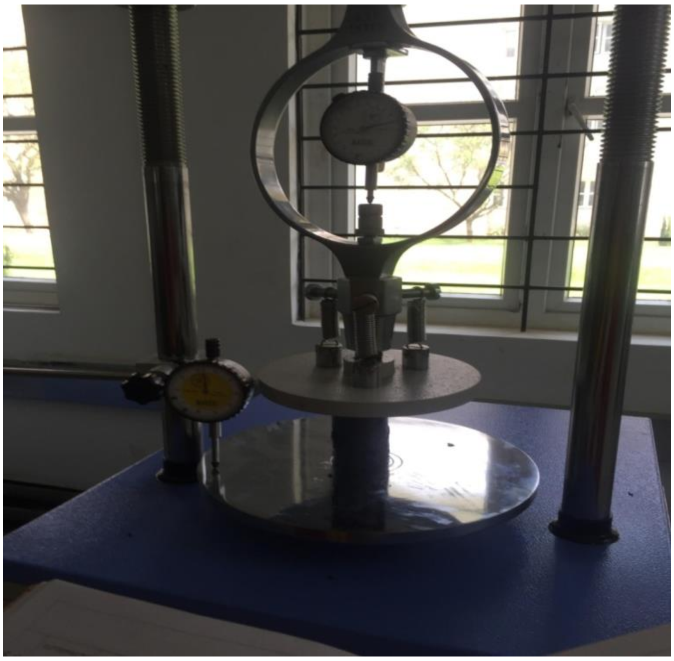

Fig. 6.7 Unconfined compression test

6.2.4 Standard Proctor Compaction

The tests provide a relationship between the water content and the dry density. The water content at which the maximum dry density is attained is obtained. The optimum moisture content (OMC) was found to be 16% and the maximum dry density is 1.603g/cc.

Table 6.7 Soil properties

Description	Results
Optimum moisture content	16.00 %
Maximum dry density	1.603 g/cc
Liquid limit (W_L)	60.75 %
Plastic limit (W_P)	26.90 %
Shrinkage limit	13.24 %
Flow index (I_F)	16.60 %
Plasticity index (I_P)	33.85 %
$I_{P(A\text{-}Line)}$	29.45 %
Unconfined compression strength	0.133N/mm^2
Cohesive strength	0.066N/mm^2

The above tabulated results implies that

- The range of OMC for clay soil is 14 % to 20 %. Hence the above soil is classified as clay soil.
- W_L > 50 %, indicates the soil is highly compressible and highly plastic.
- Also the Atterberg limit plots above the A- Line ($I_P > I_{P\ (A\text{-}Line)}$). So the soil is classified as CH.
- The CH soil has properties such as imperviousness, poor shear strength, high compressibility and poor workability. In order to overcome these disadvantages, we are incorporating coir mat in sub grade.

6.2.5 California Bearing Ratio Test (CBR)

CBR test is used to obtain the suitability of the sub grade material. The test results are correlated with thickness of various materials required for flexible pavements. This test is known for evaluating the strength properties of the sub grade soil. The CBR test is carried out in the laboratory on soil specimen compacted to desired density and soaked in water. The test consists of causing the plunger to penetrate the specimen at a rate of 1.25mm per minute. The load required for 2.5mm and 5mm penetration are noted.

The CBR test for soil with and without coir mat in both soaked and unsoaked state has been conducted. The CBR value of soil reinforced with coir mat shows a considerable increase. The coir mat has been placed at varying positions i.e. placing at different depth from top and bottom of the mould. When the coir mat is placed at a height of 1/3 of total depth of mould from top, the CBR value is found to be maximum. This can be justified as this provides maximum confinement to granular sub grade soil. The CBR values for different conditions with varying positions of coir mat are tabulated below.

Table 6.8 CBR Values

Description	**Penetration**	
	2.5 mm	**5 mm**
Without coir mat		
- unsoaked	3.13 %	2.68 %
- soaked	1.95 %	1.67 %
With coir mat Unsoaked		
- 1/3 from top	4.91 %	4.76 %
- 2/3 from top	3.53 %	3.25 %

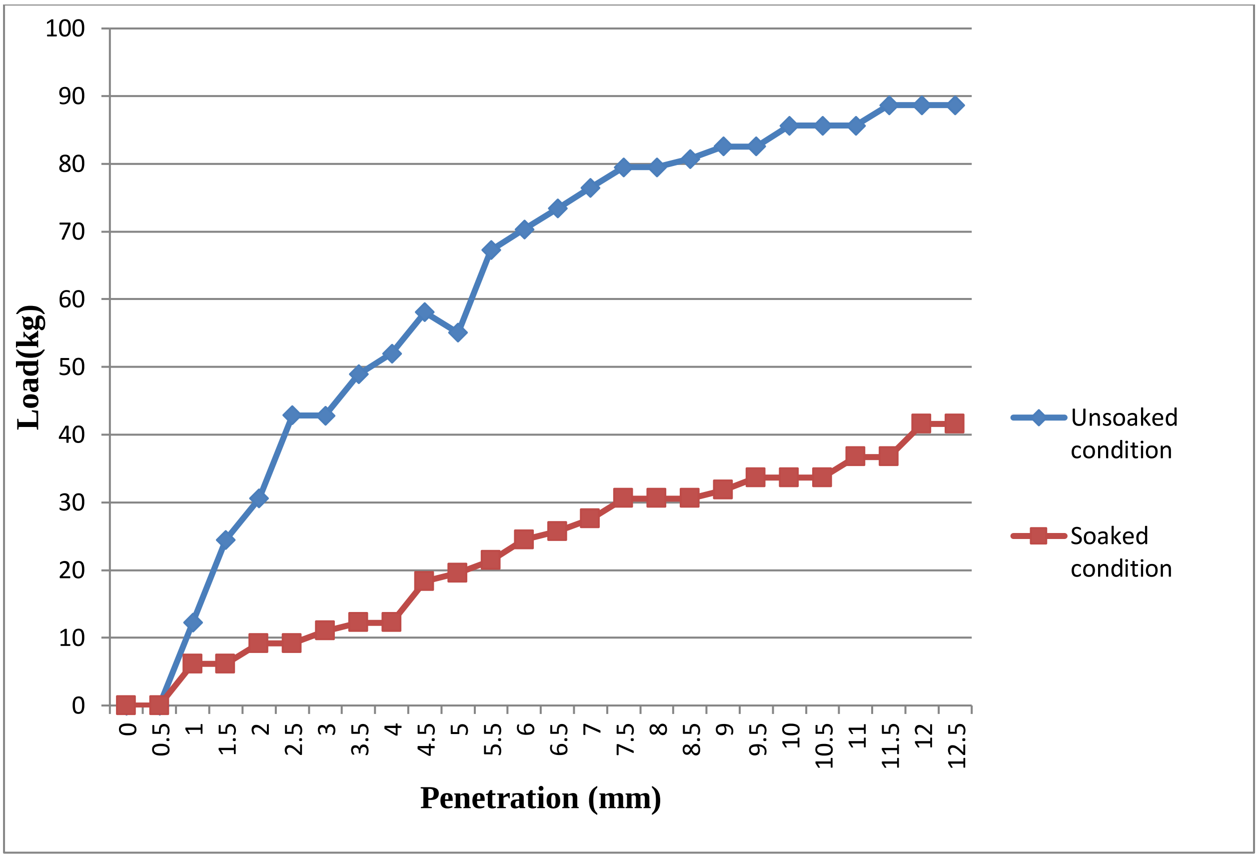

Fig. 6.8 CBR for soaked and unsoaked soil condition

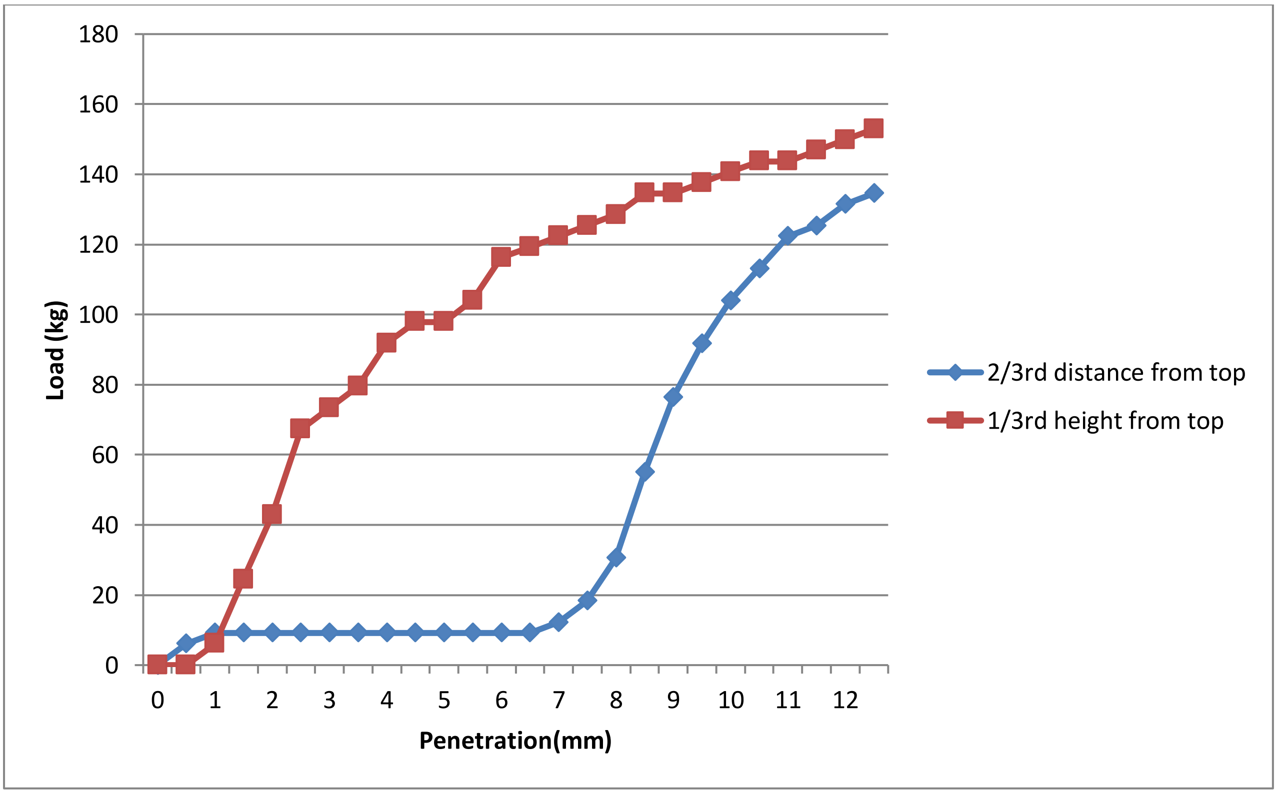

Fig. 6.9 CBR with coir mat at varying depth (soaked)

CHAPTER -7
THEORETICAL CALCULATION OF PGA USING REGIONAL ATTENUATION

REGIONAL ATTENUATION MODEL

In order to determine the seismic scenario at a particular area, quantitative estimation of ground shaking is carried out. Seismic hazard analysis is executed either deterministically or probabilistically. According to Kramer (1996), in Deterministic Seismic Hazard Analysis (DSHA), a particular scenario is assumed and in Probabilistic Seismic Hazard Analysis (PSHA), uncertainties in earthquake size, location and time of occurrence are unambiguously determined. Most of the stable continental regions in the world have poor strong ground motion data which are not representing the existing seismic hazards in the region (Menon et al, 2010).

Similarly, there is no ground motion predictive equation before 2004 for Peninsular India (PI) particularly in South India. (P Anbazhagan and A Parihar, 2012). Predictive relationships for the parameters that decrease with increasing distance such as peak acceleration and peak velocity are often referred to as attenuation relationships. Since peak acceleration is the most commonly used ground motion parameter, many peak acceleration attenuation relationships have been developed. All are best suited to conditions similar to those in the databases from which they have been developed. Earlier relationships were given by Campbell in 1981, Boore et al in 1993 which is for Western North America etc. But the databases for south Indian earthquakes are very meagre and there are no attenuation relationships that are more confined to this particular zone. Hence we have decided to adopt the attenuation relationship developed by Iyengar and RaghuKanth for the peninsular India.

An empirical attenuation relationship for PI (below 24ºN latitude) and for three sub regions within PI namely, Koyna-warna, Southern India and Western central India based on the statistically simulated seismological model (Iyengar and RaghuKanth, 2004). The relation given by Iyengar and RaghuKanth, 2004 is for rock site without considering soil condition and also correlates the application of Probabilistic Seismic Hazard Analysis (PSHA). The attenuation relation given by the authors makes use of the information regarding the source magnitude for each source will be chosen from the maximum reported past earthquake close to that source and shortest distance from each source to the area under study, as arrived from the newly prepared seismo tectonic map. In this study, Peak Ground Acceleration (PGA) at rock sites has been estimated considering relation given by Iyengar and RaghuKanth (2004), which is given below

$$\ln y = c_1 + c_2(M - 6) + c_3(M - 6)^2 - \ln R - c_4 R + \ln \epsilon \quad ..(1)$$

Where, y - Peak ground acceleration (PGA) (g)

M - Moment magnitude

R - Hypocentral distance (km)

Since PGA is known to be distributed nearly as a lognormal random variable, ln y would be normally distributed with the average of (ln ϵ) being almost zero. Hence, with ϵ = 1, coefficients for the southern region are as follows (Iyengar and RaghuKanth, 2004).

$c_1 = 1.7816$;

$c_2 = 0.9205$;

$c_3 = -0.0673$;

$c_4 = 0.0035$;

$\sigma (\ln \epsilon) = 0.3136$ (taken as zero)

As R is the hypocentral distance from the epicentre to the point of interest in km, we convert the latitude and longitude of the site into Cartesian coordinates , after we can find the hypocentral distance between two points using the formula given below,

$$R = \sqrt{(x - x_o)^2 + (y - y_o)^2 + (z - z_o)^2}$$

Where x_o, y_o, zo - Cartesian coordinates of the point of epicenter (Nallepilly, Kerala)

x, y, z - Cartesian coordinate of point of interest. We have chosen Nallepilly as the point of epicentre, which is the epicentre of 1900 Coimbatore earthquakes with latitude of 10.8ºN and longitude of 76.8ºE. The latitude and longitude values are converted to Cartesian coordinates using the following relation,

X= R* cos (lat) * cos (lon)

Y= R* cos (lat) * sin (lon)

Z= R*sin (lat)

Where R is the approximate radius of earth (6371KM)

The table below displays the PGA which has been calculated for the 10 chosen seismically active sites using the above relationship. And also the hypo central distance of the 10 sites from the epicenter is also calculated.

Table 7.1 PGA using Regional Attenuation method

No	Location	Latitude	Longitude	Cartesian Coordinates			R (km)	PGA (g)
				x	y	z		
1.	Gandhi puram	11˚0’50.5”	76˚58’6.66”	1410.11	6092.59	1217.17	30.08	0.1366
2.	Peelamedu	11˚1’54”	77˚0’ 38”	1403.78	6093.67	1219.10	35.77	0.1126
3.	Singanallur	10˚59’56”	77˚1’54”	1403.46	6094.46	1215.52	33.61	0.1208
4.	R.S.Puram	11˚0’38”	76˚57’1”	1412.07	6092.22	1216.79	28.59	0.1445
5.	Periya kulam	10˚59’11.1	76˚57’16.7”	1411.72	6092.82	1214.16	26.73	0.1531
6.	Saibaba Colony	11˚1’16.6”	76˚56’25.8”	1412.06	6091.75	1217.96	28.99	0.1423
7.	Race course	11˚0’28.8”	76˚59’7.14”	1408.35	6093.13	1216.52	30.74	0.1334
8.	GV Residency	11˚0’45.9”	77˚0’45”	1405.44	6093.70	1217.04	33.14	0.1227
9.	Telungu palayam	10˚59’38”	76˚55’35”	1414.69	6091.97	1214.98	25.60	0.1556
10.	Ganapathy	11˚3’3.66”	76˚59’28.2”	1407.53	6092.38	1221.21	34.85	0.1160

CHAPTER 8

COMPUTATIONAL ANALYSIS (PGA)

PROSHAKE 2.0

The peak ground acceleration which is one of the ground motion parameters has been calculated using the software called Proshake 2.0. This software involves defining the properties of soil layers within the profile to be analyzed, specifying the characteristics of input motion that will be applied to the soil profile, defining the quantities to be computed and displayed, and documenting the input data. The input data fed in this software includes

- Unit weight
- Shear wave velocity (V_S)
- Maximum Shear Modulus (G_{max})
- Angle of friction
- Plasticity index
- Cohesive force (strength correction)
- Coefficient of lateral pressure at rest

Site response studies using Shear wave velocity

The damage due to earthquake is not the same for all regions, is indeed site specific. This damage depends on the ground motion. The response parameters in a site due to ground motion are also a function of shear wave velocity (V_S). V_S indicates the stiffness of the materials in the subsurface layers. This is because for the same magnitude of earthquake, the ground amplification changes with layers of soil. It is generally proven that the top 30 m of soil influence the ground motion. Hence V_{S30} is calculated generally which is used for seismic site classification as per the National Earthquake hazard Reduction Program (NEHRP).

Table 8.1 PGA using the software PROSHAKE 2.0

No	Location	Latitude	Longitude	Soil thickness (m)	Type of soil	N- Value	V_s (m/s)	Proshake 2.0	
				Ref. Gopalakrishnan thesis book (2012)				Without coir mat PGA(g)	With coir mat PGA (g)
1.	Gandhipuram	11°0’50.5”	76°58’6.66”	0.948 1.272 0.790	Clay Gravel Crystalline rock	4 36 50	145.164 281.246 310.477	0.130	0.093
2.	Peelamedu	11°1’54”	77°0’ 38”	0.986 0.814 0.900	Clay Gravel Crystalline rock	3 40 50	133.123 290.308 310.477	0.115	0.092
3.	Singanallur	10°59’56”	77°1’54”	0.400 0.490 0.480	Clay Gravel Crystalline rock	5 32 50	155.250 271.450 310.477	0.119	0.089
4.	R.S.Puram	11°0’38”	76°57’1”	0.910 1.120 0.830	Clay Gravel Crystalline rock	8 44 50	178.840 298.757 310.477	0.136	0.093
5.	Periyakulam	10°59’11.1”	76°57’16.7”	1.100 0.410 0.680	Clay Gravel Crystalline rock	8 44 50	178.840 298.757 310.477	0.140	0.092
6.	Saibaba Colony	11°1’16.6”	76°56’25.8”	0.750 1.025 0.990	Clay Gravel Crystalline rock	5 36 50	155.250 281.246 310.477	0.133	0.094
7.	Race course	11°0’28.8”	76°59’7.14”	0.528 0.662 1.560	Clay Gravel Crystalline rock	6 39 50	164.010 288.104 310.477	0.129	0.114
8.	GV Residency	11°0’45.9”	77°0’45”	0.500 1.030 1.300	Clay Gravel Crystalline rock	7 38 50	171.790 285.860 310.477	0.122	0.098
9.	Telungu palayam	10°59’38”	76°55’35”	0.939 1.114 0.730	Clay Gravel Crystalline rock	6 32 50	164.010 271.450 310.477	0.142	0.093
10.	Ganapathy	11°3’3.66”	76°59’28.2”	1.230 1.370 1.000	Clay Gravel Crystalline rock	3 38 50	133.123 285.860 310.477	0.115	0.092