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Need of Geotechnical Assessments for Earthquake Resistant Structures: A Study at Jabalpur

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Abstract: Stability of any civil engineering structure is greatly depends upon its foundation. Mostly foundation of any structure designed with the consideration of types of soils and its safe bearing capacity. Ground water table is also an important point, that should keep in mind while design any foundation. The city of Jabalpur (23 ^{0} 10 ‘N: 79 ^{0} 57’ E: MSL 402 M) is a third largest city of Madhya Pradesh. Jabalpur is a town situated in the heart of Madhya Pradesh. Looking to the past tectonic record in the locality Jabalpur is seismically sensitive. The city is in an earthquake prone area and comes under earthquake zone III as per IS: 1893-1984. Jabalpur city is vulnerable to the occurrence of major earthquake like the one which took place earlier. A moderate earthquake struck central India on the morning hours of May 22, 1997. The epicentre of the earthquake was located about 12 km S-E to the city of Jabalpur. The earthquake caused considerable damage and loss of life. Jabalpur is a city having considerable verities in soil types, so it is necessary to design the foundation of the structures with the consideration of history of earthquake in this locality and variation of soils in this region. This study highlights the sensitivity of the area with respect to earthquake and discusses some important recommendations for safe constructions.

Keywords: Seismicity, Meizoseismal, Central Indian Tectonic Zone (CITZ), Lineament, NNF, NSF, vulnerability

I. INTRODUCTION

Earthquakes are probably the most devastating amongst all natural disasters. Earthquakes are caused due to sudden release of strain - energy in the crustal environment, in the interior of the earth. These are in response to internal tectonic processes and most of these are located at the plate margins. In India too, earthquakes are frequent along the Indian plate margin in Himalayan belt; though in the peninsular shield earthquakes are not uncommon. An earthquake of M 6.0 (IMD, USGS) occurred at 04 Hrs. 21 mm 30.8 sec (IST) on 22 May, 1997 in Jabalpur area of Madhya Pradesh. The epicentre of the shock lies at $23^0$08°N latitude and $80^0$06°E longitude near village Junwani, about 20 km south - east of Jabalpur. The focal depth of the earthquake was estimated at 35km. The earthquake took a toll of 39 lives and hundreds were injured. Property worth a few hundred crores was damaged. The main shock was followed by a series of aftershocks in the magnitude range of M_d 1.6 and M_d 4.4. It is probably for the first time in central India, a large town like Jabalpur with a population of about 12 lakh has come under the meizoseismal tract.The effects of the main event were widely felt over a radius of 500 km, covering parts of Madhya Pradesh encompassing Jabalpur, Mandla, Seoni, Balaghat, Shahdol, Chhindwara, Narsinghpur, Sagar, Damoh, Sidhi, Satna, Panna, Rewa, Betul, Bilaspur, Raipur, Sehore and Hoshangabad districts. In Maharashtra, it was felt in Nagpur and Bhandara districts and in Uttar Pradesh in Lalitpur district.

Maximum damage was registered in parts of Jabalpur district, the northern parts of Mandla and Seoni districts and eastern parts of Narsinghpur district of Madhya Pradesh.

Fig 1 Location of study area – Jabalpur

Fig 2. Location of Earthquake 22 May, 1997

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Fig 3. Epicentre point of Earthquake 22 May, 1997 at Jabalpur

The major brunt of the calamity was borne by the villages Kosamghat, Kuraria, Jamtara, Ghana, Temar, Bhita and certain parts of Jabalpur town, in Jabalpur district.

II. GEOTECTONIC SETTING OF THE STUDY AREA

In 1997 earthquake at Jabalpur the affected area spreads over 1, 00000 Sq.Km in parts of Madhya Pradesh, Maharashtra and Uttar Pradesh. The meizoseismal zone falls in the Central part of the Narmada Valley in Madhya Pradesh. It extends to north over the Vindhyan plateau and towards south, over the Satpura mountain chain. In the east, it covers the Baghelkhand upland, whereas on the west, it encompasses the Narmada valley.

Tectonically the earthquake affected area encompasses two crustal provinces of Central Indian Shield, namely, the Northern Crustal Province (NCP) and the Southern Crustal Province (SCP). The two provinces are separated by a crustal level shear zone, referred as Central Indian Suture (CIS). The southern part of the NCP, containing the Satpura and Son-Narmada (SONA) valley geographic domains, is known as Central Indian Tectonic Zone (CITZ). The boundaries of the CITZ are marked by Narmada North Fault (NNF) in the north and CIS in the south. The main earthquake affected area lies in SONA lineament zone which forms the northern unit of CITZ. The SONA zone is about 1600 km long and 150 km - 200 km wide, extending from the southern margin of Kathiawar peninsula in the west to the margin of Vindhyan basin in the east. The zone has been a major locus of episodic tectonism with evidences of reactivation. The E-W to ENE-WSW trending Narmada and Tapti lineaments form a prominent tectonic belt (SONATA) in mid plate continental India. Narmada tectonic line and its presumed eastward extension, Son, have been considered as major Precambrian deep crustal features and possibly a palaeorift extending hundreds of kilometre in E-W direction. Pascoe (1959) recognized the Narmada lineament as a rift at its western end; however, its eastward extension and the relative timing of the Narmada rifting and Deccan Trap eruptions remained unknown.

Correlation of structural and geophysical data shows that the Son Narmada and Tapti lineaments together represent an intraplate rift with a central (Satpura Block) horst bounded on either side by grabens: the Narmada graben on the north and the Tapti graben to the south. In certain areas (especially in the Tapti area) the faults are listric. These listric normal faults cut across the basement, the Gondwana sedimentary formations, the overlying Deccan flows and the Quaternary alluvium

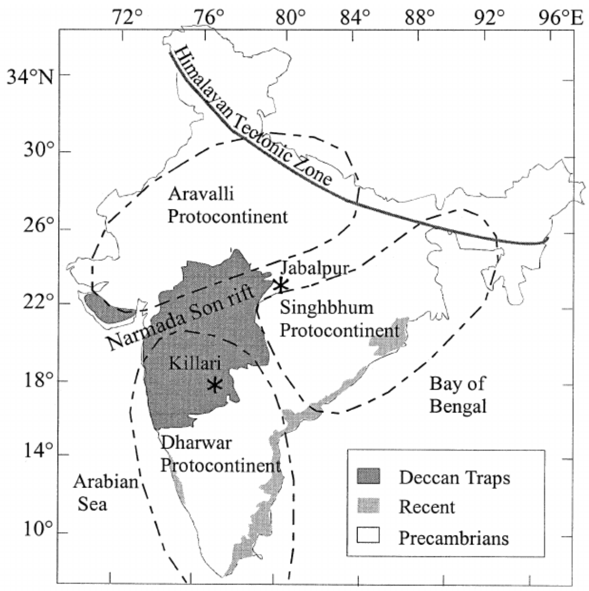

Fig 4. Generalized tectonic features of central India

III. SEISMICITY OF THE AREA

The major seismic events in Peninsular India during recent times are the Kutch earthquake of 1819 (M 8.3) Bihar earthquake of 1934 (M 8.4), Koyna earthquake of 1967 (Mb 6.0), Killari earthquake of 1993 (Mb 6.3) and the Jabalpur earthquake of 1997 (Mb 6.0). In addition to these, several earthquakes in the magnitude range 5.0-6.0 occurred in Peninsular India during the last 70 years.

The recent Jabalpur earthquake of 1997 falls under zone III of the seismic zoning map of India (IS 1893-1984,). Amongst the earthquakes of the SONATA belt, the prominent one is the Rewa (Son valley) earthquake of 1927. The seismicity pattern of the events has a distinct correlation with the ENE –WSW. Structural features of the terrain. From the earthquake location map it is apparent that many events were recorded in the steeply dipping NSF zone. The main shock of the Jabalpur earthquake of 22 May, 1997 and its aftershocks are also interpreted to have generated as a result of reactivation of the NSF at the crust mantle boundary. It is worth mentioning here that on October 31, 1993 an earthquake of magnitude 3.7 was recorded in the Jabalpur area, west of the epicentre of the present earthquake of May, 1997.

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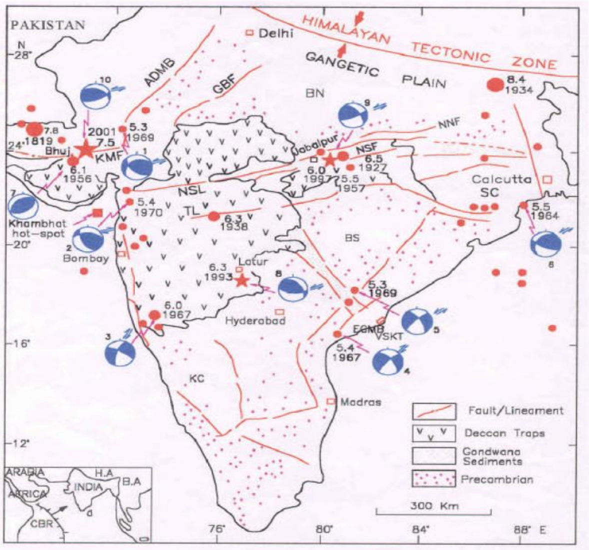

Fig.5 Past Earthquakes in Central India

A brief description of significant earthquakes in the Son-Narmada zone is as under

(1) Son Valley, June 2, 1927, Magnitude 6.5: The earthquake was felt as far as Ranchi, Dehri-on Sone and Allahabad. The radius of perceptibility was about 350 km.

(2) Satpura, March 14, 1938; Magnitude 6.3: The earthquake was felt over a very large area of about 1,000,000 km2. The radius of perceptibility was about 500 km. It was felt as far as Delhi in the north and Belgaum in the south. Towards east and west, however, it does not appear to have been felt much beyond Seoni and Bhavnagar, respectively. A hot spring near Chopda was reported to have disappeared after the shock. An intensity of VIII (MM Scale) has been assigned to meizoseismal area.

(3) Balaghat, August 25, 1957, Magnitude 5.5: The earthquake was felt at Nagpur, Mandla, Gondia, Umaria, and Jabalpur.

(4) Broach, March-23, 1970, Magnitude 5.4 The earthquake occurred near the junction of the Panvel, Narmada, Girnar, and Cambay seismic zones. 26 persons were killed and another 200 people suffered injuries due to collapse of buildings. The loss of property was heavy at Broach, where more than 2,500 houses suffered damages. The earthquake was felt in southern Gujrat and at Bombay. The radius of perceptibility was about 170km. The damage caused by the earthquake was confined to a narrow belt, 10 to 15 km wide, along the Narmada River. In Borbhatta village, several fissures in the ground opened and through these large amounts of sand and water gushed out. The general direction of these fissures was ENE-WSW although some isolated fissures were aligned north-south. Maximum intensity of VII (MM Scale) was recorded. On past seismicity, nature of faults, geotectonic manifestations etc. and indicated that once in hundred years, strong earthquakes may recur at the location of earlier earthquakes.

IV. MAJOR DAMAGES DURING 22 MAY, 1997 EARTHQUAKE IN JABALPUR

The seismic hazard map of India was updated in 2000 by the Bureau of Indian Standards (BIS). Apart from the merging of Zones I and II into Zone II in the latest map, there are no major changes from the BIS 1984 map. Zone III stretches across the length of the state, and includes all the districts that lie in the Narmada and Son Valleys. As per the seismic zoning map of India (IS 1893-1984,) Jabalpur falls under zone III. The maximum distress due to Jabalpur earthquake was experienced in an area of about 400 km2 which formed the eye of disaster covering historical town of Jabalpur and surroundings. Villages of Kosamghat, Jamtara - Kuraria, Ghana etc., which suffered the maximum damage. The zone has a length of 32 km extending from Amjhar in the east to Tilwaraghat in the west and a maximum width of 16 km between Ghana in the north and Pararia in the south. More than 80% of the houses have undergone total collapse in rural area. About 20-50% structures have shown partial collapse in the entire area.

In the urban area the campus of Jawaharlal Nehru Agricultural University, situated in Adhartal area in the northern part of the city suffered the maximum damage during the 1997 earthquake. Residential buildings in the campus, rest house and hostel building suffered badly damaged. In Gokalpur area about 2000 houses were damaged. Survey of India colony and provident fund building also suffered damage in Vijay Nagar area. Himgiri apartment a four storied building adjoining Grover Hospital in Wright Town area of Jabalpur, tilted on one side and rested against the adjacent building. One of the main RCC pillars of the constructions broke down causing partial sinking and tilting of the entire structure and caused panic for the residents and neighbours.

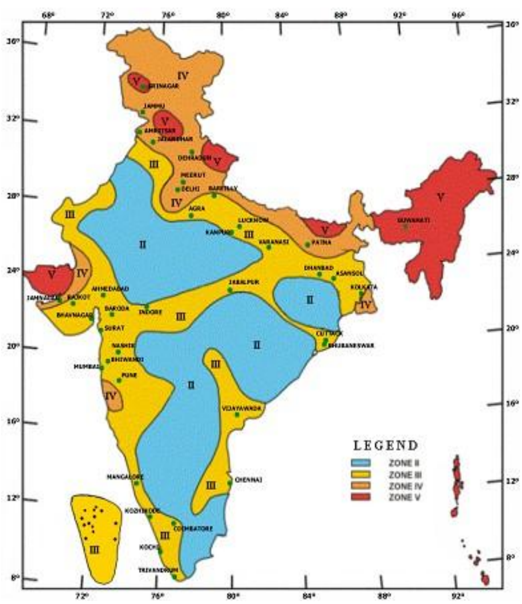

Fig.6 Earthquake Zone Map of India

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An over head water storage tank near Gullaua pond was also affected in 1997 earthquake. At the time of the earthquake, the tank was at full capacity and due to dynamic loading signs of distress was developed. Higher grade of damage was noticed along the edges of Ganga Sagar tank, this tank is constructed on the soil having maximum over thin alluvial cover. Other areas of Jabalpur like Madphaiya , Phool Sagar , Supatal , Imarti Tal, Baksera Talab , Bagha Talab, Garha, Purwa , Dhanwantari Nagar, Balsagar etc where the maximum lane were obtained by ponds reclamation were greatly suffered in that earthquake. At Sanjeevani Nagar, Geological Survey of India office building was subjected to severe damages.

Fig.7. Damaged building at Agriculture University

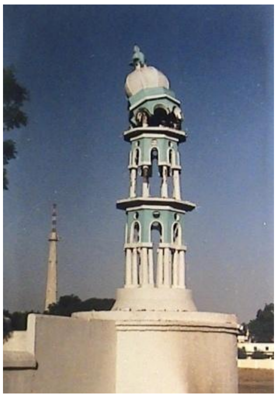

Fig 8 Damaged Clock Tower Fig 9 Mosque Tower at Sadar

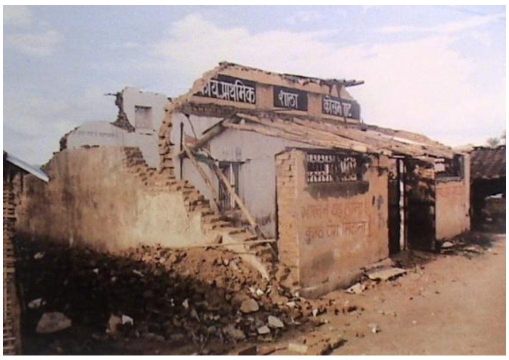

Fig 10. Damaged school building at Kosamghat (Centre of 1997 EQ)

V. NEED OF GEOTECHNICAL INVESTIGATION FOR EARTHQUAKE RESISTANCE STRUCTURES

An adequate assessment of site: geologic and geotechnical conditions is one of the most important aspect before starting any civil engineering construction particularly in a earthquake prone area like Jabalpur, it is a prime duty of a civil or structural engineer that he must have to thoroughly investigate to allow identification and assessment of all geotechnical hazards, including liquefaction related hazards. Identification of liquefaction hazard at a site firstly requires a thorough investigation and sound understanding of the site geology, recent depositional history and geomorphology.

The level of investigation should be appropriate to the geomorphology of the site, the scale of the proposed development, the importance of the facilities planned for the site, and the level of risk to people and other property arising from structural failure and loss of amenity. There are various techniques available for sub-surface exploration.

Assessment of ground water level is also a very important point for liquefaction assessment, so it is also a prime need to assess the ground water level of the locality. Geotechnical investigations for proposed sites should be generally divided into three separate phases to minimize costs and for developing the necessary data at each stage of the approval, design, and construction of a project:

A. Preliminary Investigations

At planning stage if we get adequate information regarding appropriate site, it greatly affect the overall safety of the structure as well as economics of the project. This investigation should provide a first general impression of the engineering and geological aspects of the proposed site and should determine if further study of the site is required.

The field work generally would include preliminary field geologic mapping, some preliminary hand auger holes for soil and overburden sampling, a limited number of core holes into rock and possibly some preliminary seismic refraction lines. This information and data would also be used to plan the type, location, and amount of explorations and laboratory testing required for future, more detailed investigations.

B. Initial Investigations

These investigations would be undertaken to provide more detailed information on foundation characteristics on a particular site or several sites, and to provide data for preliminary considerations of the design requirements and construction methods.

This phase of field investigation should include surface and subsurface exploration and sampling through borings, test pits, test trenches, material testing, geologic mapping, and additional geophysical surveys to supplement drilling. Data developed from these activities should be used to compare alternative sites, to analyse different types of structures that might serve the same purpose, and to develop economic evaluations of the sites.

C. Final Investigations:

These investigations would be primarily composed of detailed drilling, sampling, and testing concentrated on specific features at the selected project site; and should be specifically planned to provide the engineer with information that is necessary to design structures, estimate quantities, determine rates of construction progress, develop cost estimates, and prepare plans and specifications.

VI. CONCLUSION

In summary, it must be remembered that no matter how well a project's structures have been engineered, if the foundation conditions are not understood and taken into account, structural safety problems could occur. In peninsula India the state of Madhya Pradesh, along with Gujarat and Maharashtra, has suffered from frequent earthquakes, both deadly and damaging, although not located on or near any plate boundaries. All the earthquakes here, as in all of peninsula India, are intraplate events. Most of the activity is confined to the Narmada-Son fault zone which runs across the state. Looking to the past earthquakes and tectonic history of the study area it shows that the region is moderately seismic and we cannot denied the possibility of earthquake in future also. In this regions seismic frequency and/or intensity, where destructive quakes occur, the actual danger to structures may be much greater because the seismic hazard is often not well understood or is not given the attention it deserves. Therefore, it is imperative that more than just a cursory evaluation be given to data to be used in performing stability analysis for civil engineering constructions. The study to define the seismic hazard for proposed constructions should include the following:

1. Seismological investigations: Studies are made of the past occurrence of earthquakes in the general region of the site, and on that basis estimates are made of the probability of future earthquakes.

2. Geological investigations: In this investigation an evaluation should made of the tectonic processes in the general site region. Faults in the general region are identified and the degree of activity of the faults should estimate.

3. Site soils and geology investigations: Investigations are made of geological formations, soil deposits and rock at the site area to assess their possible behaviour during earthquake shaking, and how they might affect the stability of a structure to resist earthquakes.

4. Liquefaction Investigations: Where liquefaction potential may need to be evaluated, Field and laboratory tests should be performed. These tests can be an aid to determining the cyclic stress levels which may cause liquefaction of a soil. Judgment based on the information provided by the above investigations must then be used to establish appropriate earthquake design criteria for the project.

Finally by following all geotechnical investigations required for particular project in earthquake prone areas and by applying the engineered design and I.S.Code provisions, we can safely construct stable and earthquake resistant structures.

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