STRUCTURAL VULNERABILITY ASSESSMENT OF OLD METROPOLITAN CITIES IN EARTHQUAKE DISASTER MITIGATION.

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ABSTRACT :

Modern civilization has faced frequent devastating disaster in the last decade due to major earthquakes. Thus, disaster mitigation becomes significantly important in recent times. Like any other disaster the mitigation philosophy may be categorized either in reduction of the hazard or/and improvement of the performance against it. Unlike other common disaster like cyclone or flood earthquake can’t be predicted with confidence. Hence, preparedness against earthquake is the only option to combat this deadly event. Updating the seismic zoning map in the form of microzonation is essential for a better understanding of seismic risk. More importantly the performance of existing structures against seismic activity has to be studied to quantify its seismic vulnerability. The structural aspect plays a vital role beside geological and geo-technical considerations in assessing its vulnerability against earthquakes. The past history of earthquake particularly the damage associated to the structures is important input in seismic vulnerability assessment. Structural classification, motion-damage relationship and loss computation are the three basic parts of seismic vulnerability assessment. The factors influencing the vulnerability assessment in the context of the location of a city is also important. The salient features of Calcutta, an old Indian metropolitan city are discussed in relating to seismic vulnerability as an example. The importance of structural aspect in seismic vulnerability assessment, particularly for old cities with lot of aged structure is significant. Thus structural vulnerability against earthquake is significantly important in seismic disaster mitigation and briefly discussed in this proposed paper.

KEYWORDS: Damage, Microzonation, Mitigation, Risk, Seismic Zone, Vulnerability.

1. INTRODUCTION

The world has witnessed devastating disasters to human civilization, particularly to the urban areas due to some major earthquakes in last decade. Though earthquake is a low probable event but it has high consequences. People often forget about seismic threat due to its rare occasion but must be considered seriously to avoid devastating disaster. During the last 15 years, India has experienced 10 major earthquakes that have resulted in huge loss of life mostly (more than 90%) due to collapse of man made structures. Substantial economical loss has also been incurred by the nation due to collapse of the infrastructural system. The damages and even the collapse of structures are mainly responsible for this huge loss of life, cost for repair & rehabilitation and the loss due to business interruption. Poor constructions of structures without understanding their seismic performances are mostly responsible for these catastrophic disasters. Thus, the concern of the effect of earthquakes on the structures becomes significantly important to the engineers in recent times. The disaster mitigation philosophy may be categorized either in reduction of the hazard or/and improvement of the performance against it. Unlike other natural hazards earthquake can't be predicted with confidence nor be prevented. Hence, preparedness against earthquake is the only option to combat this deadly event. Proper assessment of seismic vulnerability form its geological features to the detail structural aspect are important. The seismic zoning map is required to be updated with relevant information to the microzonation extent for a better understanding of seismic risk. More importantly the performance of existing structures against seismic activity is essential to be studied to quantify its seismic vulnerability. The structural classification, probabilistic motion-damage relationship and subsequent loss computation is important steps of seismic vulnerability assessment. Structural aspect plays a vital role beside geological and geotechnical considerations in assessing its vulnerability against earthquakes. The past history of earthquakes particularly the damage associated to the structures is very important input in seismic vulnerability assessment. The location of a particular area with respect to the probable earthquake epicenter is also an important factor in the vulnerability assessment. There are many other aspect which contributes seismic vulnerability are briefly discussed in this proposed paper. Particular attention has been given to the structural aspect of existing urban housing. The salient seismic features of Calcutta in the context of its earthquake disaster mitigation are discussed to demonstrate the importance of seismic vulnerability assessment. There are many aged ill-conditioned, closely spaced structures in Calcutta which seems to be highly vulnerable to seismic excitation. The importance of seismic vulnerability assessment of urban housing in seismic disaster mitigation is briefly discussed in this proposed paper.

1.1 Earthquake

Earthquake is special types of ground motion, caused due to tectonic activity inside the earth that occurs without warning and involves violent shaking of the ground and everything over it. Earthquakes are uncertain in terms of their amplitude, frequency content and duration. Magnitude is the size of an earthquake in terms of its energy, while intensity provides the rating of the effect of an earthquake in terms of damage. Magnitude is location independent but intensity varies from place to place for the same earthquake. Richter's scale measure the magnitude of an earthquake in logarithmic scale of the maximum amplitude observed in Wood-Anderson seismograph located 100 Km from the epicenter. Intensity expressed in a qualitative descriptive manner for different type of structures in MMI (Modified Mercalli Intensity) or MSK (UNESCO) scale. Seismic risk refers to the potential of maximum size of earthquake at a particular site. Seismic hazards are the outcome of earthquakes, which cause destruction to human civilization. Hazardous effects of earthquake are ground failures like slope instability, subsidence & ground collapses, liquefaction; water waves like Tsunamis etc. and structural vibration. Seismic hazard due to ground shaking depends on the location of the structure with respect to causative faults, the regional & site specific geologic characteristics and selected earthquake hazard level. Parameters for earthquake load are Peak Ground Acceleration (PGA), Response spectrum or Time histories. Structures are subjected to multi-lateral dynamic forces which are cyclic in nature and caused reversal of stresses due to earthquake excitations.

1.2 Seismic Risk in India

The various seismic hazard levels with probability of exceedance are shown in Figure 1 in a general manner. The current seismic zone map of India according to IS 1893: 2002 is shown in Figure 2.

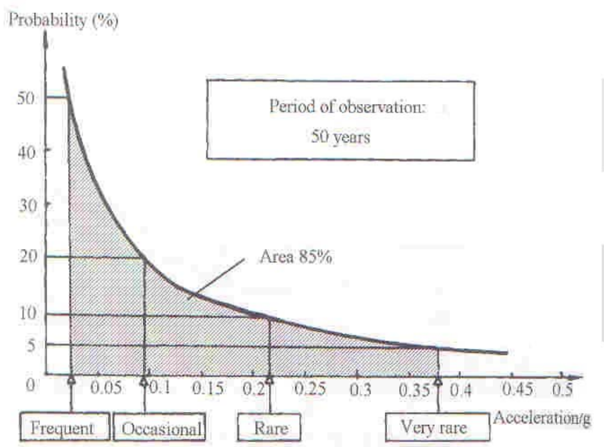


Figure 1: Probability of Exceedance Acceleration Function

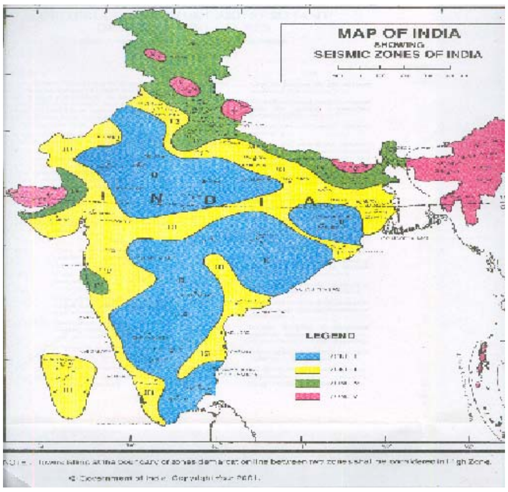


Figure 2: Seismic Zoning Map [IS 1893 2002]

It is noted that more than 59 per cent of land area of India is under the threat of moderate to severe seismic hazard. It indicates that those areas are prone to shaking of MSK Intensity VII and above. The above zoning map is based on the history and experiences of past earthquake and categorized in respect to damage risk as follows in Table 1.

Table 1: Categorization of Zone With Respect to Damage Risk

Zone	II	III	IV	V
Damage Risk	MMI VI	MMI VII	MMI VIII	MMI IX

The entire Himalayan belt is prone to great earthquakes of magnitude exceeding 8.0. Four such earthquakes have occurred within a relatively short span of about 50 years. These are 1897 Shillong (M8.7), 1905 Kangra (M8.0), 1934 Bihar-Nepal (M8.3), and 1950 Assam-Tibet (M8.6). There is high probability of the occurrence of very severe earthquakes in the Himalayan region, which could adversely affect the lives of several million people in India. The North-Eastern part of the country continues to experience moderate to large earthquakes at frequent intervals including the two great earthquakes mentioned above. The Andaman and Nicobar Islands are also situated on an inter-plate boundary and frequently experience damaging earthquakes. The regions of the country away from the Himalayas and other inter-plate boundaries were considered to be relatively safe from damaging earthquakes. However, in the recent past, even these areas have experienced devastating earthquakes, albeit of lower magnitude than the Himalayan earthquakes. The Koyna earthquake in 1967 led to the revision of the seismic zoning map resulting in the deletion of the non-seismic zone from the map. The areas surrounding Koyna were also re-designated to Seismic Zone IV, indicating high hazard. The occurrence of the Killari earthquake in 1993 resulted in further revision of the seismic zoning map in which the low hazard zone or Seismic Zone I was merged with Seismic Zone II, and some parts of deccan and peninsular India were brought under Seismic Zone III consisting of areas designated as moderate hazard zone areas. Detail studies of salient seismic features are required to make a more rational zoning of seismic risk. Details of major past earthquakes in India are shown in Table 2.

Table 2: Some Major Earthquakes in India in Last Two Centuries

Date	Earthquake	Time	Magnitude	Max. Intensity	Deaths in India
16 June 1819	Great Kachchh	11:00	8.3	IX	1,500
12 June 1897	Great Shillong	17:11	8.7	XII	1,500
4 April 1905	Great Kangra	06:20	8.0	X	19,000
15 January 1934	Great Bihar-Nepal	14:13	8.3	X	11,000
26 June 1941	Great Andaman	??	8.1	X	>1000
15 August 1950	Great Assam	19:31	8.6	XII	1,530
10 December 1967	Koyna	04:30	6.5	VIII	200
21 August 1988	Bihar-Nepal	04:39	6.6	IX	1,004
20 October 1991	Uttarkashi	02:53	6.4	IX	768
30 September1993	Killari (Latur)	03:53	6.2	VIII	7,928
26 January 2001	Bhuj	08:46	7.7	X	13,805
26 December 2004	Great Sumatra	06:28	9.3	XII	10,749
08 October 2005	Kashmir	09:20	7.4	X	1,308

Source: IMD, Govt. of India

There is a growing population in the urban areas and subsequent extensive constructions of housings have taken place all over the India. But the poor design and constructions incompatible to the seismic demands of most these urban housing appears to be highly vulnerable to earthquakes. The increase in earthquake risk is also caused due to a spurt in developmental activities driven by urbanization, economic development and the globalization of India's economy. Severe economic losses leading to the collapse of the local or regional economy after an earthquake may have long-term adverse consequences for the entire country in addition to huge life risk. This effect would be further magnified if an earthquake affects a mega-city, such as Delhi, Mumbai or Calcutta. Thus the seismic vulnerability assessment of urban housing in seismic disaster mitigation is important.

2.0 SEISMIC VULNERABILITY

Seismic vulnerability function defines loss as a function of seismic excitation. The Significance of seismic vulnerability assessment is very important particularly for the existing structures. The effect of earthquakes is damages to structures result in loss of life, loss in terms of cost & time required to repair and loss due to business interruption. It has great impact to the insurance industry in terms of solvency and profitability. In other words vulnerability analysis may be defined as damage prognosis and economic loss estimation in rupee value. The three basic steps for vulnerability analysis are

1. Structural Classification: Inventory creation of buildings and related infrastructures.
2. Motion – Damage Relationship: Types of structure and its possible damage due to hazard.
3. Loss computation: Calculation of equivalent economy loss due to earthquake hazard.

Vulnerability depends on several factors of geological parameters, soil characteristics viz. for seismic wave amplification &, liquefaction potential, soil-structure interaction, structural system, structural parameters, design considerations, constructional materials & practices. It also depends on the maintenance aspect and present condition of structure. The location is also important to ascertain the near field and far field effect of earthquake as shown in Figure 3, for the vulnerability assessment.

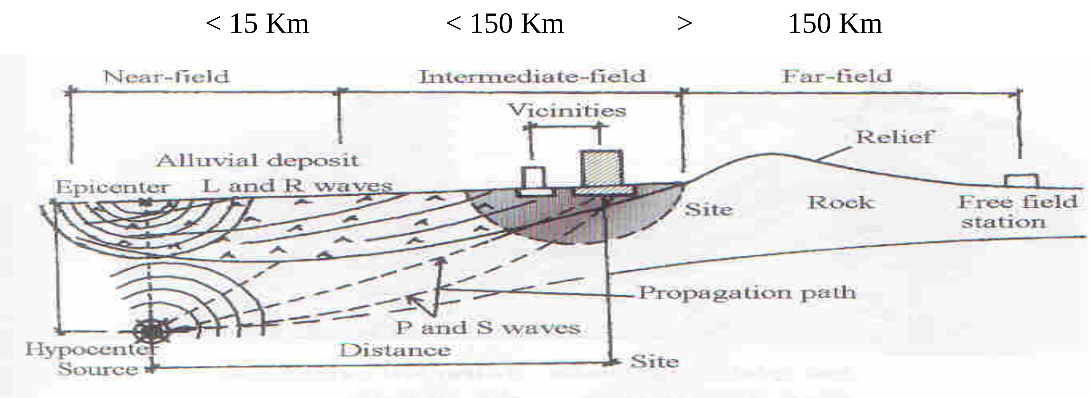


Figure 3: Schematic Diagram of Near Field and Far Field Effect

The various influencing seismic characteristics will be different at different locations for the same earthquake. The main influencing geological feature is fault rupture direction for near field and soil stratification for far field. The impulse type ground motion will come into effect for near field, while cyclic type motion will play role for far field. Vertical component of the ground motion play significant role and high velocity degree is a common feature for near field only. Fundamental mode influences primarily in case of far field where as superior mode governs in near field. The ductility demands are depending on the structural rigidity and soil condition for near and far field respectively. The duration of earthquake is relatively large at far field than at near field as shown in the Figure 4.

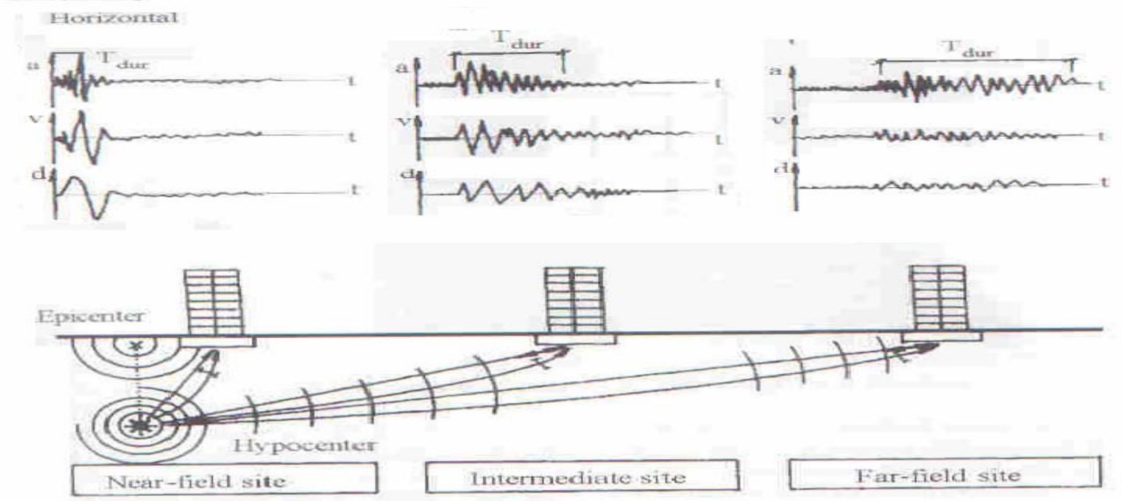


Figure 4: Distinction of Horizontal Response between Near and Far Field.

IS zoning map does not reflecting issues like frequency of earthquake, development of construction technique, age of buildings, soil deposits and most importantly the details in finer aspect say at one square kilometer grid. Thus the development of microzonation is significantly important. These microzonation is required to be developed first at the geological level and then at the structural level incorporating the salient structural aspect for the existing structure to assess.

3.0 SEISMIC REQUIREMENT: STRUCTURAL ASPECT

The structural aspect plays a significant role in its vulnerability against earthquake. Lateral load resisting systems are employed to take care off the lateral cyclic random loading.

3.1 Classification of Structural Systems

Structural classification may be based on the structural form and material used etc. The common structural systems for seismic resistance are frame system, wall system and dual system of frame & shear wall as shown in Figure 5. Different types of frame systems viz. moment frames, braced frames, tube frames etc. are used as the lateral load resisting systems.

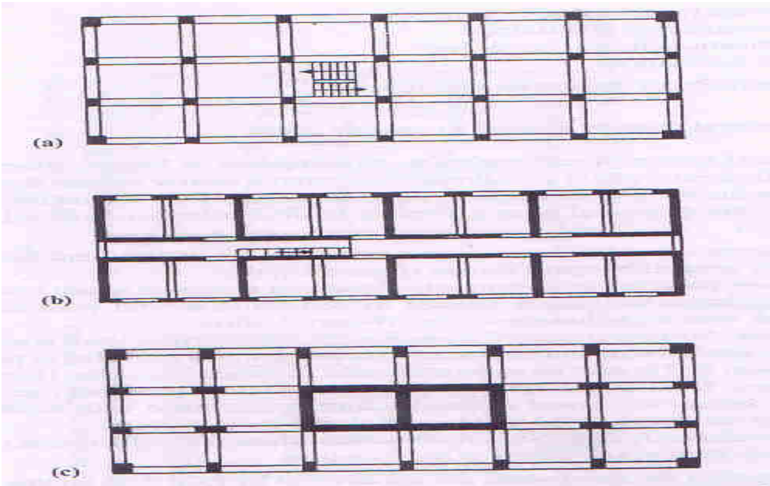
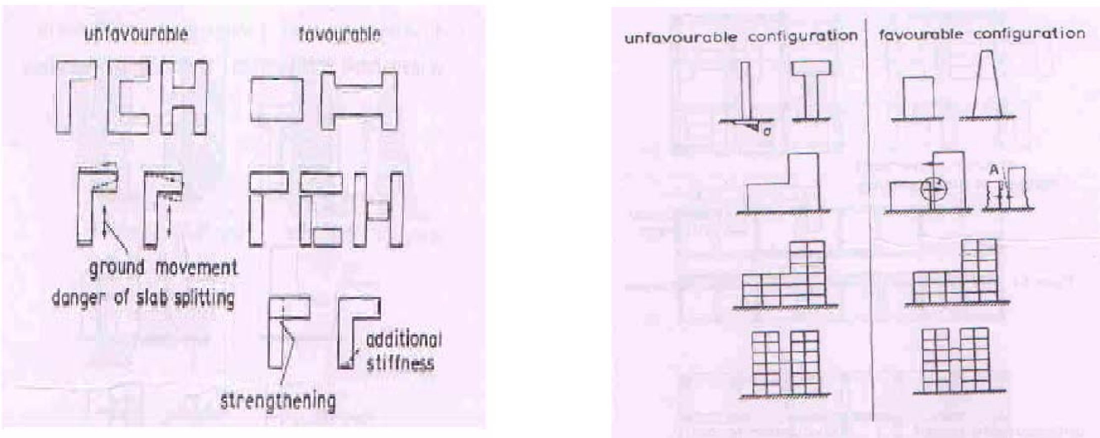


Figure 5: Common Lateral Load resisting Structural Systems (a) Frame (b) Shear wall (c) Dual (core & frames)

The factors influencing seismic resistance in respect of structural forms are simplicity, length in plan, shape in elevation, uniformity & symmetry, redundancy, bi-lateral resistance & stiffness, torsion stiffness, diaphragm action at story levels, failure modes and foundation condition. The unfavourable & favourable structural plan & elevation in the context of seismic vulnerability are shown in Figure 6.



(a) (b)

Figure 6: Unfavourable and Favourable Structural Plan (a) and Elevation (b).

Housing buildings preferred to be regular in plan with no reentrant corners and no discontinuities as irregularities lead to stress concentrations. Concrete shear walls should span full distance between the adjacent columns. All elements forming the structure including foundation should be interconnected. Short columns because of mezzanines or stiff masonry walls below windows should be avoided. Flat slab systems without any beams should be avoided in general. Seismic action must be taken by shear walls or core for better seismic performance. Large openings in the infill system such as open ground floors and slab weakness, which endangers its diaphragm action, is required to be avoided. The unfavourable and favourable structural configurations which greatly influence the vulnerability against earthquake are shown in Figure 7.

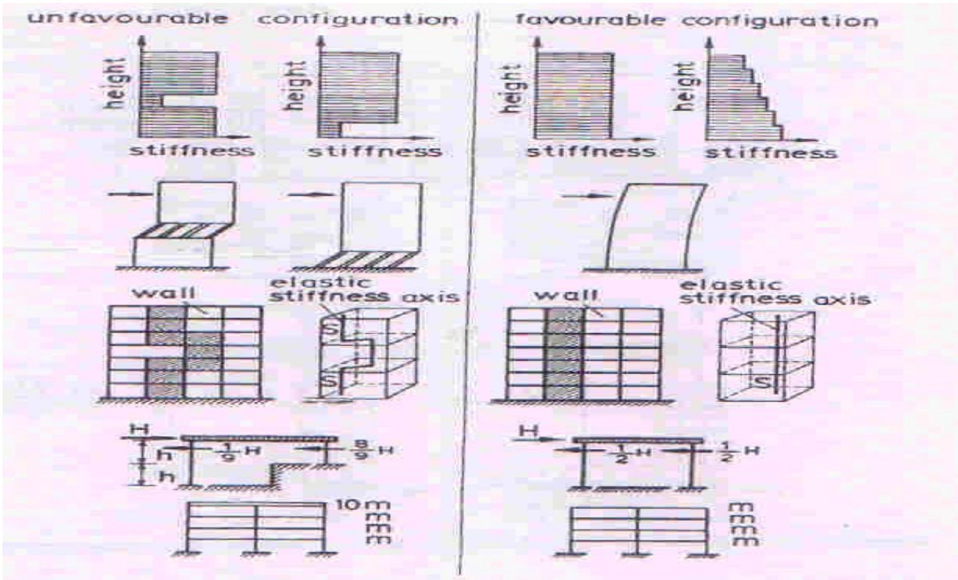


Figure 7: Unfavourable and Favourable Structural Configuration.

Structures with 'strong columns and weak beams' recommended. It is noted that coaxial columns and beams having nearly same width performed better. Beam offsets increases the seismic vulnerability. Structures having a second line of defense with ductile frames are preferred to reduce its vulnerability against earthquake. Construction site and foundation soil is required to be free of risks of soil rupture, slope instability, and permanent settlement caused by liquefaction or densification during an earthquake. All footings at the same level and of same type are expected to perform better against seismic activity. Interconnections of footings by a mat or by a set of grid beams provide better seismic resistance. It is noted and reported my many researchers that soft story and weak story buildings are highly vulnerable to earthquakes.

3.2 Motion – Damage Relationship

The most important part of vulnerability analysis is the development of the motion-damage relationship. Various parameters have been used by the different researchers to define the damage as

- Damage Ratio (DR) = Number of building damaged / Total number of buildings.
- Damage Factor (DF) = Repair cost / Replacement cost.
- Damage Probability Matrix (DPM) = Damage factor for different ground motion. Damage probability matrix for a particular type of structure may define the motion-damage relationship with respect to the damage factor. There is other way of expressing the motion-damage relationship such as fragility curve.

3.3 Fragility Curve

The probability of various levels of component damage as a function of some measure of the seismic hazard is expressed as a fragility curve. The fragility curves are plotted to examine the sensitivity to variability of some parameters about their average value. Development of data on conditional damage exceedance of a structure for given peak ground acceleration establishes fragility levels which are useful in design of new structures and retrofit decisions on existing structures. Fragility curves with specified confidence bounds for various of damages may be developed .

3.3 Loss Computation

The direct economical loss may be evaluated either from the damage probability matrix or based on the fragility curves as developed. In addition indirect economy loss viz. due to business interruptions etc. may be evaluated.

4.0 CALCUTTA: SEISMIC FEATURES

The city Kolkata earlier named Calcutta is situated at the bank of river Ganges, India was developed more than 300 years ago. According to Indian code it is in zone III but very near to zone IV. It is also near to the Himalayan range and Assam belt where seismic risk is very high (Zone V). The expected PGA with 10% probability of exceedance is 0.08g to 0.13g.

4.1 Past Earthquakes

The history of past earthquake damages at Calcutta as available is shown in Table 3. Most damaging earthquake at Calcutta was in 1897 Assam earthquake (8.7 Richter scale) which did widespread damages. Damage level of VII in MMI scale was recorded at Calcutta, even though the epicenter is far at Assam from the Calcutta city. It clearly indicates that the far field seismic effect is prominent and required to be duly considered in seismic vulnerability assessment.

Table 3: Past Earthquake Damages at Calcutta as per Available Information

Year	1737	1811	1822	1828	1845	1851	1861	1897	1906	1934	1950	1964
Detail	300000 died *	MMI (VI)	MMI (VII)	MMI (VII)	MMI (VII)	MMI (VII)	MMI (VIII)	MMI (VII)	MMI (VI)	Strongly felt	Buildings damaged	MMI (V)

* There are different opinions regarding the cause of this disaster other than earthquake and number of deaths.

4.2 Salient Features of Far Field Effect

Soil at Calcutta is mostly alluvial deposits which may lead to high probability of seismic wave amplification under favourable condition. The salient features of far field effect in the context of Calcutta are shown in Figure 8.

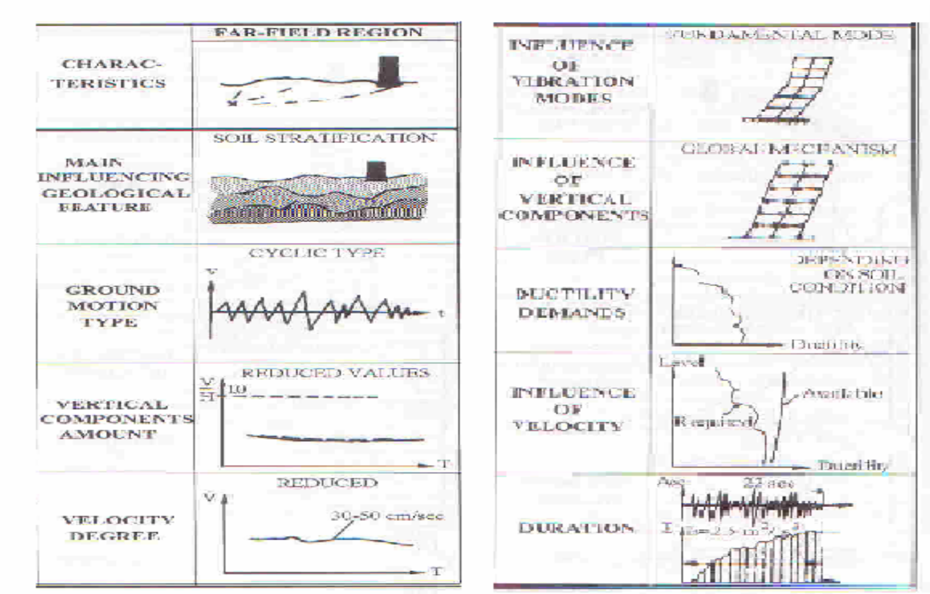


Figure 8: Characteristics of Far Field Region (mostly applicable to Calcutta)

4.3 Existing Structures

Calcutta being an old & historical city possesses important ancient & monumental structures. It is the gate of eastern corridor with rich cultural heritage. The population density of this metropolitan city is too high which prompted the construction of huge number of buildings, mostly aged & poorly conditioned at present and does not confirm to the stipulations of present seismic code. The extension of floors and or plan areas of existing buildings without proper lateral load resisting system further increase their seismic vulnerability. There are many masonry structures which are highly vulnerable against earthquakes. Isolated foundation adopted in many situations also increases its vulnerability. There are many closely spaced structures at Calcutta, which may results in the pounding effect due to earthquakes. The common design philosophy mostly adopted for these frame structures were to satisfy the gravity load only. Thus, the seismic vulnerability of Calcutta is important due to poor seismic design & construction practices, considering all the geological, geo-technical and structural characteristics.

5.0 CONCLUSION

The damage and collapse of housing buildings & infra-structural system due to earthquake is mostly responsible for the huge loss of lives and economy, particularly at the urban areas. Thus the role of civil engineering towards earthquake disaster mitigation becomes significantly important in recent times. It is noted that preparedness against earthquake is the only viable option to combat this deadly event. Seismic vulnerability assessment is an important tool to mitigate earthquake disaster to a great extent. The past history of earthquake particularly the damage associated to the structures is very important input in seismic vulnerability assessment. The structural classification and subsequent their damage evaluation are also important beside geological and geotechnical considerations in seismic vulnerability assessment. Probabilistic approaches may address the problem of structural damage assessment for various probable ground motions in a much better way to account the uncertainties associated with limited observations, model assumed and all other variations. Similarly, the seismic risk evaluation and subsequent seismic vulnerability can be updated with the probabilistic model. The seismic vulnerability of Calcutta is demonstrated considering the salient seismic features. It seems to be alarming considering the far field effect and the condition of existing structural aspects. Keeping in view the recent devastating seismic disasters involving huge loss of lives and economy, it may be inferred that earthquake disaster mitigation is not only our social and moral responsibility but also the question of professional survivability to answer. Seismic vulnerability assessment is one of the most significant steps towards earthquake disaster mitigation and the architects & civil engineers have a great role to play for the sustainability and survivability of our urbanization.

ACKNOWLEDGEMENT

Author wishes his thanks to national programme on earthquake engineering education (NPEEE), ministry of human resource development, government of India for awarding him a fellowship for conducting a part of this research. He also wishes his gratitude to Jadavpur University, Calcutta, and University of Arizona, Tucson, USA for allowing and providing him all the necessary facilities.

REFERENCES

[1] Ang, Alfredo H-S. and Tang, Wilson H., *Probability concepts in Engineering Planning and Design.* John Wiley & Sons, Inc.1975.

[2] Bandyopadhyay, D. and Haldar A., Seismic Vulnerability Assessment: Condition Updating of Existing Structures using Bayesian Approach. *Proceedings of 2nd International Congress of Computational Mechanics and Simulation,* IIT, Guwahati, December 8-10, 2006.

[3] Benjamin, Jack R. and Cornell, C. A., *Probability, Statistics and Decision for Civil Engineers.* McGraw-Hill Book Company.

[4] Bilham, R. *The 1737 Calcutta Earthquake and Cyclone Evaluated.* Bull. Seism. Soc. Amer. Vol. 84/5, (1994), pp.1650-1657.

[5] Box, George E. P. and Tiao, George C., *Bayesian Inference in Statistical Analysis.* Addison-Wesley Publishing Company 1973.

[6] Faber, M.H., *Reliability based assessment of existing structures.* Prog. Structural Engineering Mater 2000.

[7] Gioncu and Mazzolani, *Seismic Considerations,* 2002

[8] India Metrological Department (IMD). *Earthquake Reports.* 2008.

[9] Paulay, T. & Priestley, J. N., Seismic Design of Reinforced Concrete and Masonry Buildings, 1992.

[10] Penelis, G. G. & Kappos, A. J., *Eartquake-resistant Concrete Structure*, 1997.

[11]Sohn, H. et al. *A Review of Structural Health Monitoring Literature: 1996 – 2001*. Los Alamos National Laboratory Report, Engineering Science and Applications Division, Los Alamos National Laboratory, 2002.