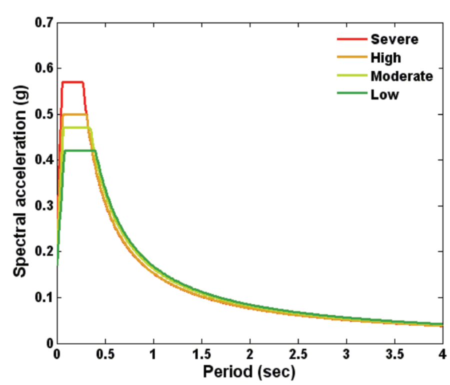
14 Hazard & Risk Implications and Mitigation Measures in Kolkata

14.1 Introduction

Seismic Hazard, Vulnerability and Risk has emerged as an important issue in high risk urban centers across the globe and is considered an integral part of earthquake induced disaster mitigation practices. The adopted seismic risk framework is a multidimensional concept based on seismic hazard which include Seismological, Geological, Geotechnical & Geophysical database and the Vulnerability exposures *viz.* Population Density, Landuse/Landcover, Building Typology, Building Height & Building Age judiciously integrated on Geographical Information System.

Seismic Hazard Microzonation map of the city of Kolkata depicts a 'Severe' zone mostly in Saltlake, New Town areas, a 'High' zone mostly in Barabazar, Anandapur, Belgachiya, Bagdoba areas of the expanding City, a 'Moderate' zone in most parts of South and West Kolkata and 'Low' zone elsewhere. The proposed Zone Factors (Z_F) for Seismic Hazard subzones in Kolkata with corresponding Design Response Spectra and Liquefaction Susceptibility (L_S) are depicted in Table 14.1.

Table 14.1 **The proposed Zone Factors (Z_F) for Seismic Hazard subzones in Kolkata with corresponding Design Response Spectra and Liquefaction Susceptibility (L_S)**

Hazard Level	Z_F (g)	L_S	Design Response Spectra (IBC, 2009)
Low	0.20	LPI=0	
Moderate	0.27	0< LPI≤7	
High	0.30	4< LPI≤16	
Severe	0.34	LPI> 15	

Four broad divisions of Socio-Economic Risk Index (SERI) have been identified in Kolkata with Risk Index defined as $0.75<SERI\leq1.0$ indicating severe risk condition in BBD Bag, Saltlake, Barabazar, Baguiati areas, $0.50<SERI\leq0.75$ indicating high risk mostly in central Kolkata, $0.25<SERI\leq0.50$ moderate risk in most part of West Kolkata, while $SERI<0.25$ presents a completely risk free regime.

Unplanned urbanization defying building codes are continuously increasing the earthquake vulnerability of Kolkata necessitating an assessment of the same by identifying those factors contributing to seismic risk when exposed to high Probabilistic PGA level at the surface of the city of Kolkata. Most of the structural vulnerability index in the City range from 0.25 to 0.75 indicating moderate to high vulnerability level. Detailed analyses and ground truthing reveal that most of the buildings in the City are 1-4 storied where the resonance frequency of the soil column is between 1.0-2.0 Hz. It is observed that an index >0.5 is of higher vulnerability level in terms of both height and severity of structural damage being constructed on swamps and artificially non-engineered fills. Four broad divisions have been identified in the City with Structural Risk Index (SRI) defined as $0.75<SRI\leq1.0$ indicating severe risk condition in Saltlake, Park Street, Barabazar, Baguiati areas, $0.50<SRI\leq0.75$ indicating high risk mostly in Behala, Dum Dum, Alipur, Jadavpur, Dhakuria regions, $0.25<SRI\leq0.50$ moderate risk mostly in Bali, Kona, Kalighat and part of West Kolkata, while $SRI<0.25$ presents a completely risk free regime.

In order to understand the implication of Probabilistic Seismic Hazard with 10% probability of exceedance in 50 years at surface level the same has been exposed to buildings and essential facilities. The building stock used in this study consists of 554,907 buildings with different occupancy classes such as, residential, commercial, residential-commercial, religious, governmental and educational. Damage probability of different model building types have been computed in five different damage states *viz.* none, slight, moderate, extensive and complete in terms of damaged area or number of damaged buildings. Out of 554,907 buildings of Kolkata approximately 34% is expected to suffer from ‘moderate’ damage followed by ~26% ‘complete’, ~18% ‘extensive’, and 15% ‘slight’ damage. Approximately 7% buildings are seen to be seismic resistant in the City. The estimated building damage is converted to economic loss by using the available inventory database of the City, including the floor area, construction cost estimates per square meter provided by the local competent authorities (KMDA). Construction cost for individual model building type has been provided for each geounit and a complete economic loss profile for the City has been generated. The estimated possible loss for this maximum probable hazard scenario is about 231 billion Rupees for the city of Kolkata only from building damage point of view. The damage is also estimated for the essential facilities like Schools, Hospitals, Police Stations and Fire stations. Out of 1455 Schools 66% is expected to exceed ‘slight’ damage, 23% will exceed ‘moderate’ damage and 11% of the School buildings will exceed ‘complete’ damage state. From 1060 Medical care facilities in the City 48% of the buildings is expected to exceed ‘slight’ damage, 28% will exceed ‘moderate’ damage and 24% will exceed ‘extensive’ damage state. The estimation of damage for 17 Fire stations in the City indicates that 67% of these facilities will exceed ‘slight’ damage, 22% will exceed ‘moderate’ damage and 11% will exceed ‘extensive’ damage state. Out of 62 Police stations considered in the present analysis 64% is expected to exceed 'slight' damage, 23% will exceed 'moderate' damage and 13% will exceed 'extensive' damage state.Transportation network of the City will face 'slight' to 'moderate' damage states while exposed to the probabilistic hazard level assessed in this study. The economic loss projected for the Highway, Railway, Bridges, Ferry and Bus terminals is about 76 billion Rupees for the City.

For developing earthquake hazard mitigation strategy infrastructures will be considered in two major categories:

- existing structures including RCC Structure/ Masonry / Historical buildings.
- new infrastructure for development.

14.2 User Manual for the Atlas

IS 1893 (Part 1): 2002 - Criteria for Earthquake Resistant Design of Structures deals with general provisions and buildings. The calculation of the design seismic forces can be performed by either the static or the dynamic analysis and the guidelines for which the dynamic analysis is to be performed are mentioned in the standard manual. In both of the two methods response spectra as shown in Table 14.1 is to be used. Though India is divided into four seismic zones based on PGA, only one set of response spectrum has been specified for the entire country. The design force is calculated based on the Zone Factor, Importance Factor, Response Reduction Factor, S_a/g based on the soil conditions and time period of the building and the seismic weight of the building. The present Atlas provides the response spectrum for different locations of Kolkata which takes care of the soil conditions available there. The method of force calculation being the same the present Atlas will help the designers to calculate the design forces at a particular site with more accuracy and for the specific soil conditions without merely assuming the soil conditions as hard, medium or soft.

14.3 Basic Considerations in Seismic Resistant Design

The basic instinct of any structure is to safely transfer any load acting at any point in the superstructure to the soil on which it is supported through the different structural load resisting elements and foundations. Seismic forces are inertial forces in a structural system that is generated within the system due to propagation of waves through the soil and which in turn excites the structural system. A regular and continuous load path should be provided in the buildings so that the flow of loads from the superstructure to the substructure can take place with ease. The building framing layout and the load resisting system should be jointly decided by the architect, structural and the geotechnical engineers to derive maximum functional and structural utility from the building as well as minimize its structural vulnerability to earthquake force. The different attributes of a seismic resistant structure may be listed as - good configuration, sufficient strength and stiffness, adequate ductility and higher level of redundancy and robust foundation system with adequate stiffness and damping to reduce the amplification in response due to dynamic soil structure interaction. Both strength and serviceability requirements are to be simultaneously satisfied. Buildings with simple, regular configuration with uniform distribution in mass and stiffness in plan as well as in elevation behave well during earthquakes. Though stiffer structures will encounter higher design seismic forces it has been observed that their performance has been quite good in the past earthquakes provided they rest on firm soil. Precast, flat plate buildings generally suffer higher damages whereas, buildings with shear walls perform well during earthquakes as due to relative higher stiffness of the shear walls it attracts more force reducing damage to secondary structural components of the building. The structural elements as well as the joints should have sufficient ductility to yield in case of overloading and not collapse as a whole. Reinforced concrete can be made ductile only in flexural mode of failure and hence failure in other modes like compression, shear, torsion or bond should be avoided. For effective seismic design the behavior of the material even up to the point of failure should be considered as the actual seismic force that can be many times higher than the design seismic force. Generally the vertical structural elements need to be stronger to prevent overall collapse *i.e.* stronger columns and weaker beams.

In India concrete has an edge over structural steel as a construction material. Concrete is unique amongst all the construction materials as it is made insitu with locally available raw materials. Concrete has proved its worth as a construction material over the last century which has made us take an unsympathetic, and somewhat taken for granted attitude towards this material leading to poor performance of RC buildings in the recent past. Hence to make our buildings seismic resistant more care and caution is to be taken during the different steps of concrete production including good ductile detailing of the reinforcements. The constituent materials for concrete also need to be properly selected to result in an effective earthquake resistant structure. Though higher grades of concrete are being used nowadays the grade of reinforcements should not preferably be very high as it can lead to problems with respect to serviceability and ductility requirements. Grades of steel up to Fe 500 are used throughout the globe in reinforced concrete. Use of higher grades should be done only with proper consideration to the serviceability and strength aspects. Especially the flexural elements which act as ductile links in the system should yield before failure in any other mode is initiated.

14.4 Consideration of Dynamic Soil Structure Interaction (DSSI)

In terms of consideration of DSSI, recommendations in IS-1893 Part 1-IV are somewhat ambiguous. Code recommends that "*DSSI need not be considered for the case when the structure is resting on rock or on stiff soil having* $N \geq 50$". However, if consideration of DSSI is mandatory or otherwise for other types of soil code is tactfully non-committal on the issue.

Recent researches prove that in many cases severe damage to structure occur due to the dynamic amplification of seismic force and DSSI, especially when the structure is resting on a soil stratum having lower global structural stiffness compared to that of the soil. In such cases specialist opinions are to be sought from engineers/consultants conversant with this topic to quantify the adverse effect if any due to this aspect and take necessary mitigation steps as advised to ensure the functionality of the structure. In such case the DSSI consultant is to be involved from the very outset of the project during functional planning stage and not at a later stage when the architectural or the structural configuration has all been frozen and one has little room to play. Considering in Kolkata metropolis majority of structure is resting on soft to medium soil consideration of DSSI would certainly remain an important issue to ensure their seismic susceptibility.

14.5 Seismic Retrofitting Strategies for Reinforced Concrete Buildings

Similar to human beings structures also age and wear out with time. The strength of a deteriorated structure can be improved by different methods like repair, rehabilitation and retrofitting. A relative comparison between the different methods can be presented using the following Figure 14.1.

Seismic retrofitting of building structures is one of the most important aspects for mitigating seismic hazards especially in earthquake prone countries. Retrofitting may be defined as methods to upgrade the earthquake resistance up to the level of the present day codes by appropriate techniques. Retrofit specifically aims to enhance the structural capacities (strength, stiffness, ductility, stability and integrity) of a building to mitigate the effect of a future earthquake. The term seismic retrofit is used in the specific context of enhancing the resistance of a vulnerable building to earthquakes. Sometimes the terms seismic rehabilitation, seismic upgradation and seismic strengthening are used in lieu of seismic retrofit. The building need not be deteriorated or damaged.

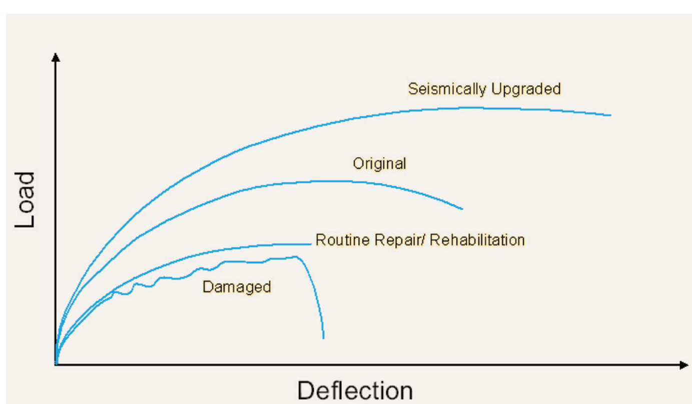


Figure 14.1 **A relative comparison between the different methods.**

The need of seismic retrofitting of buildings arises under two circumstances: (i) earthquake damaged buildings, and (ii) earthquake vulnerable buildings that have not yet experienced severe earthquakes. The problems faced by a structural engineer in retrofitting earthquake damaged buildings may be listed as: (a) there is a considerable dearth of experience and data on retrofitted structures, (b) absence of consensus on appropriate retrofitting methods for old and new structures, (c) how to properly address the wide range of parameters involved like type of structures, condition of the structural elements, type of damage, amount of damage, location of damage, significance of damage, condition under which a damaged element can be retrofitted *etc.* Structural retrofitting is a site and structure specific task. In addition, experimental and analytical research is urgently needed to strengthen different techniques of retrofitting.

The need of retrofitting of existing earthquake vulnerable buildings may arise due to one or more than one of the following reasons *i.e.* (a) the buildings have been designed according to a seismic code, but the code has been upgraded in later years, (b) building designed to meet the modern seismic codes, but deficiencies exist in the design and or construction, (c) essential buildings must be strengthened like historical monuments and architectural buildings, (d) important buildings like hospitals, fire stations, telephone exchanges *etc.* whose service is assumed to be essential even just after an earthquake, (e) buildings, the use of which has changed through the years, (f) buildings that are expanded, renovated or rebuilt. Various techniques of seismic retrofitting have been developed and used in practice. The basic concepts of these techniques of retrofitting are aimed at: (a) upgradation of the lateral strength of the structure, (b) increase in the ductility of structure, (c) increase in stiffness of the structure. The decision to repair and strengthen a structure depends not only on technical considerations but also on a cost/benefit analysis of the different possible alternatives. It is suggested that the cost of retrofitting of a structure should remain below 25% of the replacement as major justification of retrofitting.

The method of retrofitting principally depends on the horizontal and vertical load resisting system of the structure and the type of materials used for the original construction. It also relies on the technology that is feasible and economical. The understanding of mode of failure, structural behavior and weak and strong design aspects as derived from the earthquake damage surveys exercise considerable influence on selection of retrofitting methods of buildings. Usually the retrofitting method is aimed at increasing the lateral resistance of the structure. The lateral resistance includes the lateral strength or stiffness and lateral displacement or ductility of the structures. The lateral resistance is often provided through modification or addition of retrofitting elements of an existing structure in certain areas only. The remaining elements in the structure are usually not strengthened and are assumed to carry vertical load only, but in an earthquake, all components at each floor, retrofitted or not, will undergo essentially the same lateral displacements. While modified or added elements can be designed to sustain these lateral deformations, the remaining non-strengthened elements could still suffer substantial damage unless lateral drifts are controlled. Therefore, caution must be taken to avoid an irregular stiffness distribution in the strengthened structure. Consequently, it is suggested that the design of retrofitted schemes should be based on drift control rather than on strength consideration alone.

There are two ways to enhance the seismic capacity of existing structures. The first is a structural level approach of retrofitting which involves global modifications to the structural system. The second is a member level approach of retrofitting or local retrofitting which deals with an increase of the ductility of components with adequate capacities to satisfy their specific limit states. Based on the above concept the available techniques of retrofitting of reinforced concrete buildings may be classified as shown Figure 14.2.

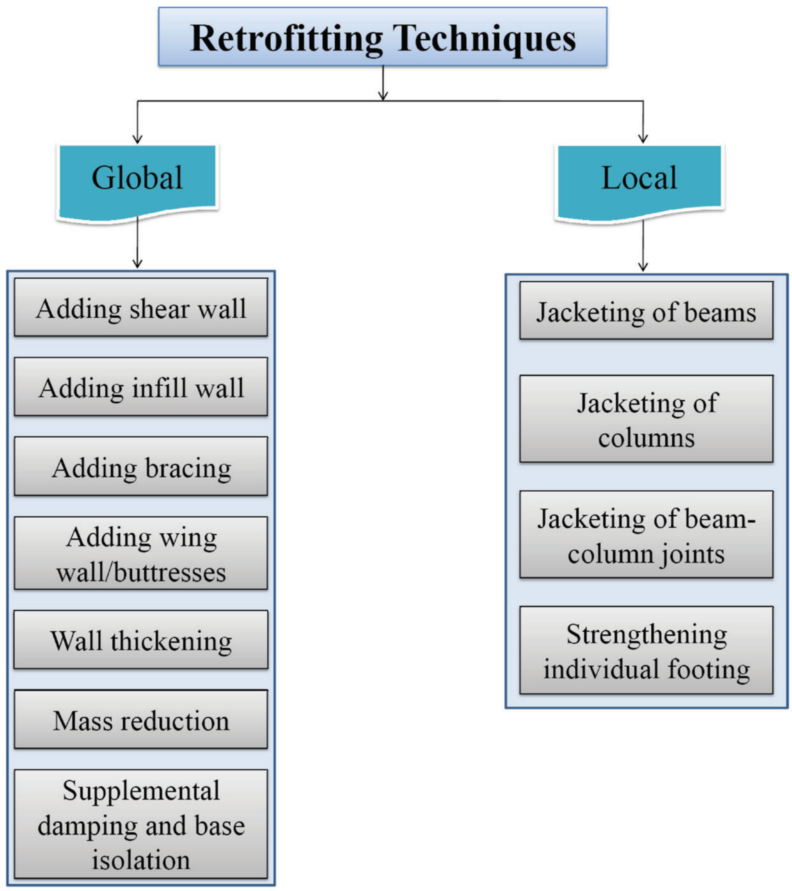


Figure 14.2 **Global and Local retrofitting methods.**