Seismic Retrofitting of Concrete Structures

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Abstract

According to the latest seismic zone map of India, about 59% of India's land area is vulnerable to moderate or severe seismic hazard, i.e. prone to shaking of MSK intensity VII and above. In the recent past, most Indian cities have witnessed an excessive rise in multi-storied buildings, super malls, luxury apartments, and social infrastructure largely owing to development. The rapid expansion of the built environment in moderate or high-risk cities makes it imperative to incorporate seismic risk reduction strategies in various aspects of urban planning and construction of new structures. During the period 1990 to 2006, India has experienced six major earthquakes that have resulted in over 23,000 deaths and caused colossal damage to property, assets, and infrastructure.

Keywords: Concrete structures, earthquake design, earthquake resistant methods, rehabilitation of structures, reduction strategies, seismic forces, seismic risk

I. INTRODUCTION

The entire Himalayan Region is extremely sensitive and hence vulnerable to earthquakes of magnitude exceeding 8.0 on the Richter Scale, and in a relatively short span of about 50 years, four such earthquakes have occurred: Shillong, 1897 (M8.7); Kangra, 1905 (M.8.0); Bihar–Nepal, 1934 (M8.3); and Assam–Tibet, 1950 (M 8.6).Scientific publications have revealed that very severe earthquakes are likely to occur anytime in the Himalayan Region, which can adversely affect the lives of several million people in India.

Traditional Non-Engineered Domestic Rural Construction

A majority of the buildings constructed in India, especially in suburban and rural areas, are non-engineered and are built without adhering to earthquake-resistant construction principles. Most contractors and masons engaged in the construction of these buildings are also not skilled enough with earthquake-resistant methods specified in building codes. Indigenous earthquake-resistant houses like the *bhongas* in the Kutch Region of Gujarat, *dhajji diwari* buildings in Jammu & Kashmir, brick-nogged wood frame constructions in Himachal Pradesh and *ekra* constructions made of bamboo in Assam are increasingly being replaced with modern Reinforced Cement Concrete (RCC) buildings, often without incorporating earthquake resistant design and often fail to comply with building codes and by-laws. Indigenous earthquake-resistant houses make use of indigenous technical knowledge and locally available materials in the construction of earthquake resistant buildings in suburban and rural areas.

TABLE I. GEOGRAPHIC AREAS IN SEISMIC ZONES

Seismic zones	% Geographical Area	Total Area
II	41.40	
III	30.40	58.6%
IV	17.30	
V	10.90	

II. BACKGROUND AND PROBLEM

In most earthquakes, the collapse of structures like houses, schools, hospitals, and public buildings leads to extensive loss of life and property. Earthquakes also destroy public infrastructure like roads, dams, and bridges, as well as public utilities like power, water, and waste water plants. Studies show that over 95% of the lives lost were due to the collapse of structures that were not earthquake-resistant. To reduce the risks posed by earthquakes in future there are building codes and other regulations which make it mandatory that all new

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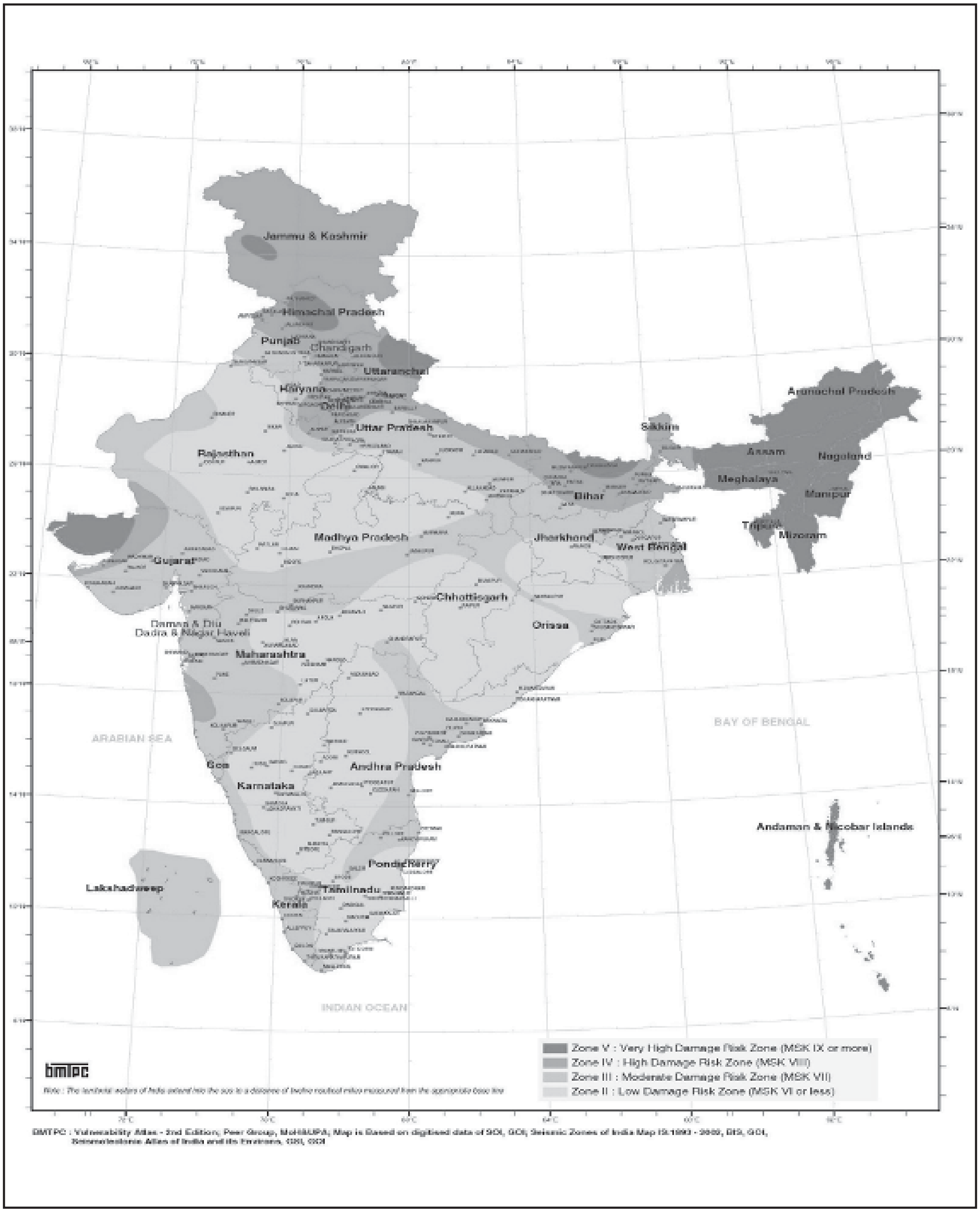
Fig. 1. Seismic Zones in India



construction of structures in earthquake-prone areas in the country must be built in accordance with earthquake-resistant construction techniques and prevailing seismic codes.

Existing buildings must undergo retrofitting (strengthening) because:

❖ Older buildings have been designed for seismic action that corresponds to approximately 50% of that of newer buildings.

❖ The determination of action of force on structural elements included simple omission due to lack of adequate calculating means. It was impossible to create a global standard for structural analysis.

❖ The design of the element of a structure often followed processes that have been revised (inaccurate models, an absence of a capacity design, the significance of ductility, insufficient minimum and maximum structural element detailing requirement, etc.

III. OBJECTIVE AND SCOPE

The objective of seismic retrofitting is to provide basic principle and basic requirements regarding the retrofitting (strengthening) of older RC Frame construction. This makes sure that structures which are prone to damage or damaged during earthquake are made earthquake resistant.

In accordance with the developed Indian standards seismic codes:

IS:1893(Part 1)-2002	Indian Standards Criteria for Earthquake Resistant Design of Structures: Part 1 General Provisions and Buildings
IS:4326-1993	Indian Standard Code of Practice for Earthquake Resistant Design and Construction of Buildings
IS:13920-1993	Indian Standard Code of Practice for Ductile Detailing of Reinforced Concrete

Fig. 2 (a). Comparison of older insufficient min and max structural elements with the designed element using today's developed Indian Standards

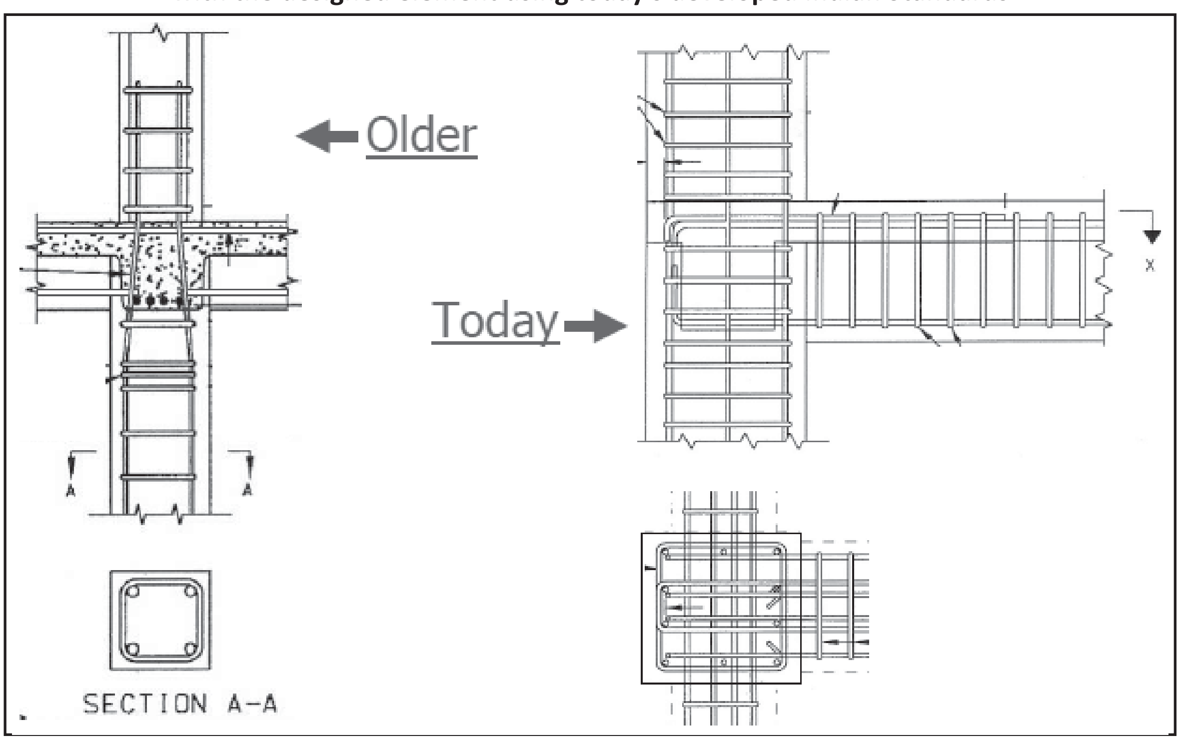
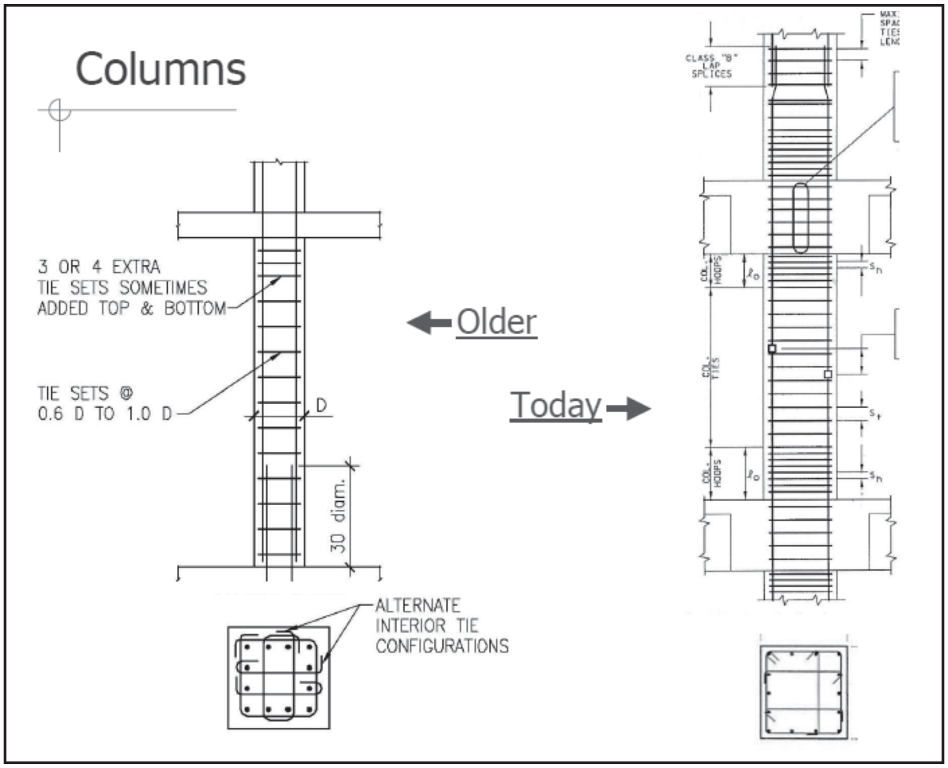


Fig. 2 (b). Comparison of older insufficient min and max structural elements with the designed element using today's developed Indian Standards



	Structures Subjected to Seismic Forces
IS:13935-1993	Indian Standard Guidelines for Repair and Seismic Strengthening of Buildings
SP:22(S&T)-1982	Indian Standard Explanatory Handbook On Codes for Earthquake Engineering - IS:1893-1975 & IS:4326-1976

A. *The process of redesigning and strengthening an existing building*

There are three main stages in the process of redesigning an existing building :

1) ***Ist Stage:*** The first stage involves determining the structural system, the identification of any damage and estimation of other factors such as the vertical loading and mechanical characteristics of the construction material, and also the assessment of the seismic capacity of the structure. The evaluation of any damage to, or imperfection in individual element will not be of any benefit if the pathology of the whole structure has not been appraised.

This should be confirmed by an analysis that will estimate the seismic capacity of the building. Apart from using a more specialized method to assess the capacity of the structure, either an approximate method or one of the more advanced inelastic methods should be selected to assess the deformation characteristics of the individual elements of the structure.

2) IInd Stage: The second stage, which deals with decision making for the intervention, perhaps involves the most difficult part of the process. This is because a number of factors are involved that are not easy to quantify. All the parameters that have to be evaluated can influence the decision between any of the following three critical choices

❖ No intervention or repairs only if the structure is damaged
❖ The strengthening of the structure and
❖ The demolition and construction of a new structure.

If strengthening is selected, the search for a suitable solution can be done in one or two ways. In the first way, the strengthening of whole structure can be considered and the objective would be to decrease the stress in the weaker element to a level lower than their capacity. In the second way, the strengthening of individual weaker element of the structure may be considered and the objective would be to increase the strength, the ductility, or any other lacking characteristics.

3) *IIIrd Stage*: The third stage deals with the design intervention. It includes the structural design and detailing of the repaired and/or strengthened element. Thus, use of new element in collaboration with the older ones creates a new multi-phase composite element for which the structural design may often be different from the usual process of designing monolithic element of reinforced concrete.

B. *Strategies for seismic strengthening*

Results from the pushover analysis of a building can be easily converted to terms of base shear and top displacement. Base shear top displacement curves illustrate the capacity of a structure. On the other hand, from code requirements that describe seismic activity in terms of acceleration or displacement response spectra, the seismic performance demand of a building can be expressed by the curve (s), depending on the equivalent viscous damping- of the structure. Curve (s) designates boundary between safe and unsafe structural behavior.

Plots of base shear against top displacement for the three basic strategies of seismic strengthening are shown in fig. 3. Curve (a) illustrates the behavior of the structure before strengthening, curve (b) shows behavior of the structure after increase in strength and stiffness. Curve (c) demonstrates the behavior of the structure after strengthening by rectifying local and increasing ductility. Curve (d) depicts the behavior of the structure after strengthening, increase in strength, stiffness, and ductility.

C. *Techniques for seismic strengthening*

A conventional strengthening scheme consists of one/many strengthening techniques to remedy structural deficiency. Such schemes are specific to structural system and material type. This depends on the different documents of different countries that are as follows:

- ❖ FEMA 273 (USA)
- ❖ New Zealand Draft Code (NEW ZEALAND)
- ❖ Euro code 8 (UK)
- ❖ SERC Report (INDIA)

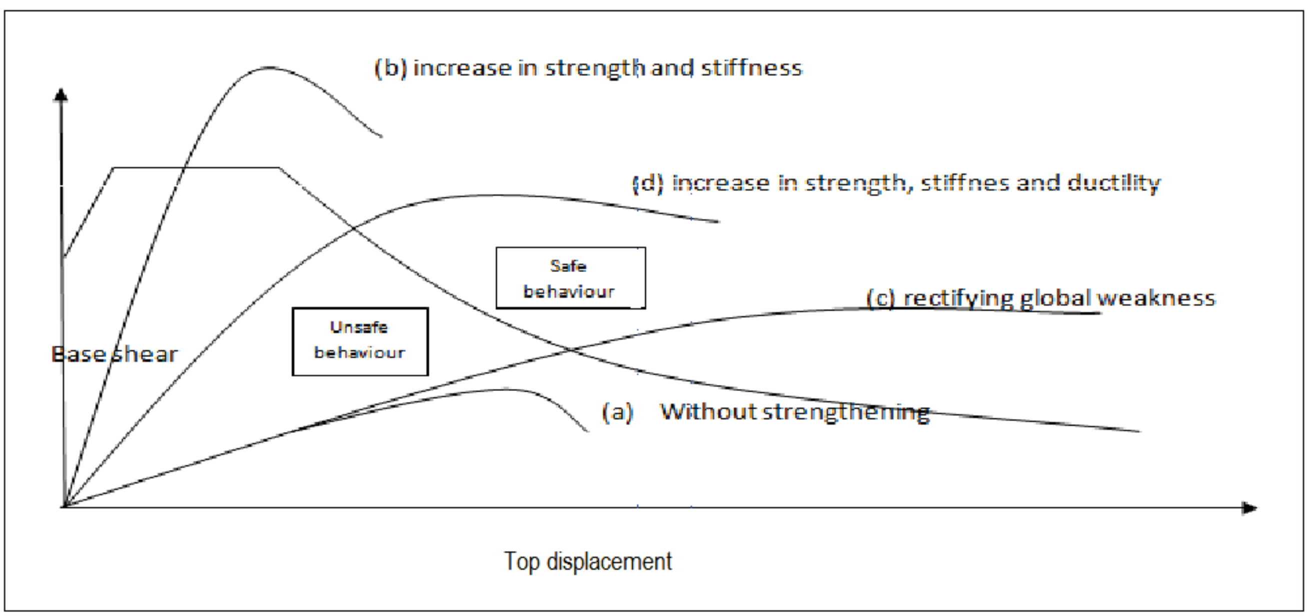
According to SERC report, strengthening of RC members can be done in the following ways:

1) RC Members:

(a) Strengthening of RC columns by jacketing, and by providing additional cage of longitudinal and lateral tie reinforcement around the columns and casting a concrete ring.

(b) In case of jacketing a reinforced concrete beam,

Fig. 3. Strengthening strategies



stirrup can be held by drilling holes through the slab.
(c) Strengthening of RC shear walls can be done in the same manner.
(d) Strengthening inadequate sections of RC column and beams by removing the cover of old steel, welding new steel to old steel, and replacing the cover.
(e) Strengthening RC beams by applying prestress.

2) Strengthening of Foundations

(a) Introducing new load bearing members including foundations to relieve the already loaded members.
(b) Improving the drainage of the area to prevent soaking of foundation directly and draining off the water.
(c) Providing apron around the building to prevent soaking of foundation directly and draining off the water.

Further, the design and analysis of such schemes/techniques are quite complex and require a great level of sophistication than ordinarily required for new components/elements. of such schemes/techniques are quite complex and require a great level of sophistication than ordinarily required for new components/elements. All documents of structural strengthening such as FEMA 273, NZDC, Eurocode 8, etc. provide a general framework of rehabilitation process and do not provide much specific design/detailing procedure.

Fig. 4. Application of conventional strengthening methods

(a) additional shear wall (b) additional foundations (c) jacketing (d) additional columns

(d) Adding strong elements in the form of reinforced concrete strips attached to the existing foundation part of the building.

IV. CONCLUSION

A detailed seismic evaluation of structural system of existing building needs to be performed to determine the nature and extent of deficiencies, which may lead to undesirable performance in future earthquakes. This evaluation also helps to decide whether structural modifications are required at few locations in the structure for deficient components only or interventions are needed at the structure level so that its global behavior is improved and thus seismic demands on components are reduced. The success of strengthening scheme is very much dependent on the choice of strengthening techniques, which are very specific to structural type and materials of construction.

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