Seismic Assessment & Retrofitting of RC Frame Buildings

An abstract of lecture delivered by Dr. Sudhir Kumar Jain, Director, IIT Gandhinagar under Healthy Construction Series organized by Dr. Fixit Institute of Structural Protection & Rehabilitation at Ahmedabad on 20th August 2009.Dr. Jain is an eminent personality in the field of Earthquake Engineering and also a member of the Team for developing a Rapid Visual Screening(RVS) method for seismic assessment for Indian RC framed buildings.

Seismic retrofit is the method of modification of existing structures to enhance their capability to resist earthquakes. It may be executed on concrete masonry, unreinforced masonry and concrete tilt-up construction. The need for retrofitting arises after the modification of Codes and various other causes as shown in the Fig 1.

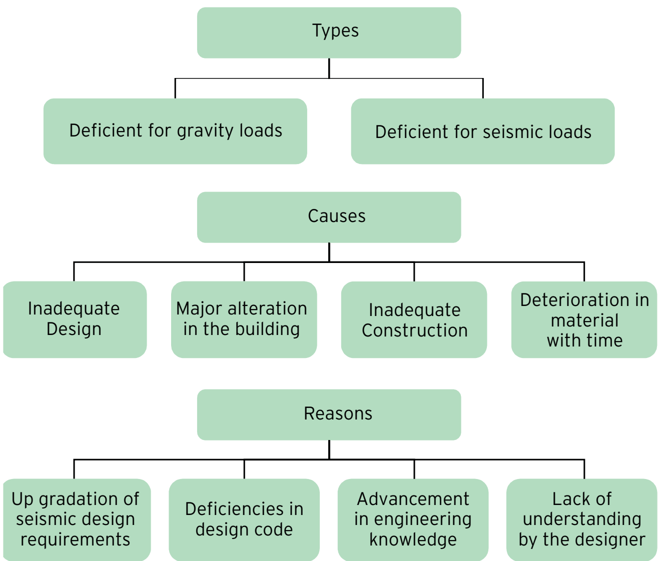

Fig.1 Types of deficient buildings their causes and reasons

The specifications of IS 1893 : 1984 for seismic resistant design have been inadequate for peninsular India. Even the masonry buildings were never adequately covered before 2002. The current version, IS:1893-2002, made substantial upgradation of seismic zones in order to avoid such surpries in future. Even IS 13920 – 1993 does not incorporate explicitly the specifications for strong-column weak-beam concepts, which are essential for structural survivability. The codes of practice do not include specifications for the design of beam-column joints, however guidelines are available in literature.

The 2002 version of IS 1893 has more clearly defined the irregularities (vertical and horizontal) in the configuration of buildings than the earlier version

Comparison of 1984 & 2002 versions of IS 1893

The deficiencies in the earlier Codes can be made by drawing a comparison with the latest codes.

The values of base shear coefficient A_h, where base shear $V_b = A_h$ W, Where W is total seismic weight of stucture, for a few cities in different seismic zones are compared for the current and previous versions of the code. It is assumed that I (Importance factor)= 1.0 and β = 1.0; the normalized shape of "C" (IS 1893 – 1984) is more or less similar to the shape of spectral acceleration of the 2002 version (it is the same in short period range). Two cases are considered for comparison, namely case I wherein K = 1.6 (1984 version) and R (Response reduction factor) = 1.5 (current version), and case II wherein K = 1.3 (1984 version) and R = 3.0 (current version). The base shear coefficients are listed in Table 1 for cases I and II, respectively.

Table 1. Comparison of base shear coefficients for few cities

CITY	IS : 1893 – 1984		IS 1893 (Part 1) : 2002	
	Case - I	Case - II	Case - I	Case - II
	K = 1.6	K = 1.3	R = 1.5	K = 3.0
Bhuj	A_h = 0.128 [Zone V]	A_h = 0.104 [Zone V]	A_h = 0.300 [Zone V]	A_h = 0.150 [Zone V]
Delhi	A_h = 0.080 [Zone IV]	A_h = 0.065 [Zone IV]	A_h = 0.200 [Zone IV]	A_h = 0.100 [Zone IV]
Kolkata, Mumbai	A_h = 0.064 [Zone III]	A_h = 0.052 [Zone III]	A_h = 0.133 [Zone III]	A_h = 0.067 [Zone III]
Chennai	A_h = 0.032 [Zone II]	A_h = 0.026 [Zone II]	A_h = 0.133 [Zone III]	A_h = 0.067 [Zone III]
Hyderabad, Bangalore	A_h = 0.016 [Zone I]	A_h = 0.013 [Zone I]	A_h = 0.083 [Zone II]	A_h = 0.041 [Zone II]

$A_h = V_b / W$

The Tables indicate an across the board increase in the values of the 2002 version. However, it is more pronounced for the cities upgraded to more severe zone such as Chennai, Bangalore and Hyderabad. The increase in those cases varies from 300 to 500 percent depending on the type of structural systems.

However, there is no change in the values in the two versions in the case of Mumbai and Kolkata, , if reduction factor R = 5 and K = 1 (for ductile shear wall with Special Moment Resisting Frame or Special RC Moment-Resisting Frame). Obviously, as per IS 1893 : 2002, no place in India is deemed to be free from earthquake hazards.

Features of IS 1893 : 2002 (Part 1)

This fifth version of the code has given clearer definitions of irregularities in the vertical (elevation) and horizontal (plan) directions in the configuration of buildings. They are briefly as follows:

- Plan irregularities causing torsion are re-entrant corners, diaphragm discontinuity, out of plane offsets and non-parallel systems.
- Vertical irregularities are caused by variations in lateral stiffness, mass, vertical geometry, in-plane discontinuity in vertical elements resisting lateral force and discontinuity in capacity like weak story.

Seismic Assessment

The seismic evaluation can be made by following procedures.

- Rapid Visual Screening Procedure: It is used to identify and create an inventory of buildings, to rank buildings that are potentially hazardous. But there is relatively poor correlation between RVS and actual performance building by building. Hence it is useful in a broad sense and for prioritizing the buildings.
- Approximate Seismic Evaluation.
- Detailed Assessment.
- Criteria developed under IITK-GSDMA Project on Building Codes.

The assessment can be made by Push over analysis where investigation to be carried out at horizontal load steps equal to 2% of their design capacities and the corresponding inelastic displacements to be calculated.

A Rapid Visual Screening (RVS) Method for Indian RC Frame Buildings

An inter-institutional collaboration between IIT Kanpur (Sudhir K Jain & Manish Kumar),Bengal Engg & Science University, Sibpur (Keya Mitra) and CEPT Ahmedabad (Mehul Shah) was being made to develop Rapid Visual Screening (RVS) method for seismic assessment for Indian RC Framed buildings. For developing RVS method 6670 buildings from Ahmedabad which is 250 km away from epicenter having shaking intensity of VII (MSK scale) in 2001 earthquake were assessed by CEPT, Ahmedabad. These buildings were assigned damage category (G0 to G5) and subset of 270 buildings were studied. Screening for different vulnerability features were made. Observed Performance Scores (OPS) such as G0=100, G1=85, G2=70, G3=50, G4=25, G5=0 were assigned depending on damage category. The vulnerability parameters were based on statistical regression analyses performed ,presence of basement, number of storeys, current building maintenance(to estimate original construction quality),asymmetric location of staircase,(with respect to plan),reentrant corners, open storeys, substantial overhangs, stub columns, and short columns. From these it was observed that taller buildings, buildings with basements and buildings with good maintenance performed better. The Performance Score can be calculated from the following equation(1).

Performance Score = Base Score+∑(VSxVSM) ....(Eq.1)

Where, VS=vulnerability scores, x_0 to x_9 as given in Table 2 and VSM= C0 to C8 as given in Table 3

Table 2. Vulnerability scores

CITY	Title	Score
x_0	Basement	Absent=0, Present=1
x_1	Number of Storeys	N≤5=0, N>5=1.
x_2	Maintenance	Good=0, Moderate=0.5, Poor=1
x_3	Asymmetry of staircase location with respect to plan	Absent=0, Present=1
x_4	Reentrant corners	Absent=0, Present=1
x_5	Open Storey	Absent=0, Present=1
x_6	Stub Columns	Absent=0, Present=1
x_7	Substantial Overhangs	Absent=0, Present=1
x_8	Short Columns	Absent=0, Present=1

Coefficients rounded off for convenience in usage:

Performance Score

$$= 80 + 5x_0 + 5x_1 -10x_2 - 5x_3 - 5x_4 - 5x_5 - 5x_6 - 5x_7 - 5x_8$$

Average absolute errors are 17.6% and 17.7%, respectively, for exact and rounded-off expressions.

The above equation is currently under revision based on more sophisticated statistical analyses (not ready for use yet).

Table 3. Values of VSM

Case	A	C0	C1	C2	C3	C4	C5	C6	C7	C8
Phase I	76.5	2.9	5.8	-13.0	-3.6	-5.3	4.2	-4.3	-	-9.3
Phase II	74.5	6.6	1.5	-3.8	0.07	-9.0	-5.2	2.1	-4.3	-2.5
Combined	76.3	5.2	4.9	-8.5	-2.4	-5.8	-3.5	-0.1	-	-4.4

Additional considerations were made for followings.

Analysis on several thousand buildings for building usage

- Non-residential buildings performed better
- x_9, such that x_9=1 for non residential, and 0 for residential
- Performance Score = 77.3 + 3.2x_9
- +5 points if building is non-residential

Seismic Zone

- +15 points for lower, -15 points for higher Seismic Zone

Soil Type

- +15 points for rocky soils
- -15 points for soft soils

Seismic Evaluation

Evaluation criteria as per IITK-GSDMA gudelines was made. Modifications of loads where made such as forces were reduced to 0.67 of new buildings for reduced life-span. Also modification of loads were made by taking Potential Casualties Occupancy Risk Factor as 1.25 for Essential building,1 for buildings with crowd and 0.75 for other buildings.

The knowledge factor m_k is given in Table 4.

Table 4. Knowledge factor

No	Description of Building	m_k
1	Original construction documents available, including post-construction activities, materials testing undertaken.	1.00
2	Documentation as above in (1) but originally specified values for materials	0.90
3	Documentation as above in (1), originally specified values for materials & minor deterioration of original condition	0.80
4	Incomplete but useable original construction documents and originally specified values for materials	0.70
5	Documentation as in (4) and limited inspection, and verification of structural members, materials test results with large variation	0.60
6	Little knowledge of details of component	0.50

During site visit verification and data collection of buildings for general information and structural system should be made. For general informations, dimensions, No. of storey's, year of construction, occupancy, adjacent buildings and general condition (deterioration of materials) should be considered.

The evaluation was made in 2 stages known as primary evaluation as stage 1 and detailed evaluation as stage 2.The primary evaluation is being made to test seismic robustness.The test is being carried out for configuration and global strength to check shear stress and axial stress of columns.

Seismic Retrofitting

Seismic retrofitting may range from 5% to 50% of the replacement cost of the building and depends on a number of factors such as type of building, existing seismic resistance of the building, level of strengthening being achieved, whether cost mean only structural cost, or refurbishment cost also and if the cost associated with loss of function of the building. However, seismic strengthening requirements should be economically feasible, technically viable and functional constraints. Here the factors to be addressed are configuration, stiffness, ductility and strength. But the configuration problems are to remove the problem by addition of structural elements at appropriate location i.e torsion irregularity. Seismic Strengthening can be made by reducing the demand (seismic force), increasing dissipation of energy (damping) and increasing the supply (strength).Load carrying systems can be improved by following ways:

- Addition of shear wall, braced frame, or moment-resisting frame outside the building
- Ensuring proper foundation to transmit large overturning moment
- Ensuring good connection between building and new elements
- Ensuring floor for transmitting the seismic load to the new elements

Concluding Remarks

A large number of buildings in the country are seismically deficient .Hence, there is need for further research and development work to size the problem and framing policy issues, economic issues and technology issues such as assessment methods and strengthening techniques In the meanwhile, there is also need to accumulate experience on seismic strengthening which is a specialized task. Further, each set of building poses unique set of constraints and problems which need to be studied in detail for seismic evaluation and retrofitting.