International Journal For Technological Research In Engineering
Volume 5, Issue 11, July-2018 *ISSN (Online): 2347 - 4718*

TO STUDY THE SEISMIC PERFORMANCE OF AN EXISTING BUILDING AND PROPOSING SUITABLE RETROFIT MEASURE

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ABSTRACT: Recent earthquakes in India show that not only non-engineered but also engineered buildings in our country are susceptible even to moderate earthquakes. Indian Standard IS 1893 is revised in 2002. A number of buildings those were designed as per the previous code may not comply with the present code. Therefore evaluating seismic performance of a building and proposing suitable retrofit measure is an important area of study in this context. In the present study an attempt has been made to evaluate an existing building located in Kashmir (seismic zone V) using equivalent static analysis. Indian Standard IS-1893:2002 (Part-1) is followed for the equivalent static analysis procedure. Building is modeled in commercial software STAAD Pro. Seismic force demand for each individual member is calculated for the design base shear as required by IS-1893:2002. Corresponding member capacity is calculated as per Indian Standard IS456:2000. Deficient members are identified through demand-to-capacity ratio. A number of beams and column elements in the first floor of the present building are found to be deficient that needs retrofitting. A local retrofitting strategy is adopted to upgrade the capacity of the deficient members. This study shows that steel jacketing is an efficient way to retrofit RC members to improve flexure as well as shear capacity.

OBJECTIVES

To perform seismic evaluation of a residential building in Kashmir, J & K and provide methods for retrofitting of members in case the members fail under the load combinations prescribed in IS 1893-2002.

Scope of the study:

In the equivalent static procedure of seismic analysis, the seismic loads are applied to the centre of mass of the storey, but in STAADPro I have assumed the seismic loads to be nodal loads and applied it to nodes dividing the total lateral storey loads in equal proportion per node and not at
the exact centre of mass of the storey. While considering retrofit measures for the structure, analysis of structure post concrete jacketing was kept outside the scope of this study and only flexural analysis of members post steel plating was taken up. It was assumed that there would be sufficient adhesion between plates and concrete so that there is no failure due to bonding.

I. INTRODUCTION

1) Basics of Seismic evaluation

a) Response spectra: Interaction between ground accelerations and structural systems are reported through response spectrum. Plots peak responses over time for a range of single-degree-of-freedom (SDOF) systems subjected to a particular base motion as a function of their natural frequency ωi, or vibration period Ti. The resulting plot can then be used to pick off the response of any linear system, given its natural frequency of oscillation. Response spectra are used by earthquake engineers for analyzing the performance of structures in earthquakes, since many behave principally as single degree of freedom systems. The purpose of the response spectrum is to know the response of a single degree of freedom system if the ground moves as per the given accelerogram. An accelerogram is the recording of the acceleration of the ground during an earthquake. Response may mean any quantity like acceleration, velocity or deformation[1,2].

The figure below shows the accelerogram for the earthquake that hit the El-Centro city in Imperial valley of California.

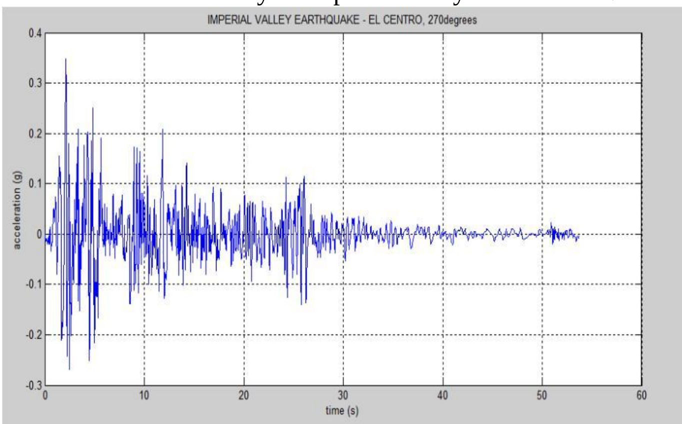


Figure 1: Accelerogram for the earthquake affecting El-Centro city in 1940 [3]

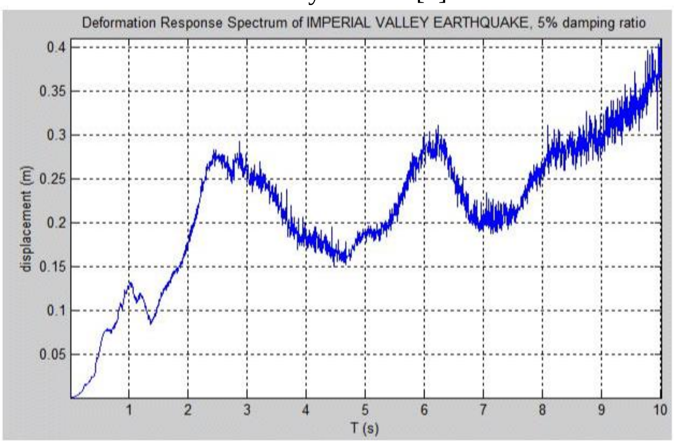


Figure 2: Deformation Response Spectrum for 5% damping ratio [3]

b) Design spectrum:
Response spectrums vary a lot even with a little change in natural frequency of the structure and so have very irregular shape with local maxima and minima. For design purposes, local maxima and minima are ignored because natural period of structures cannot be calculated very accurately. Thus design spectrum is a smooth response spectrum specifying level of seismic resistance required for design. It is a specification of the required strength of the structure.
The strength depends on the following factors:

- Frequency
- Maximum velocity
- Maximum displacement

Maximum acceleration
Design spectrum must also be accompanied by:

- Load factors, as different choices of load factors will lead to different seismic safety of the structure.
- Damping, variations in the values of damping used in the design will affect the design force.

Method of calculation of natural period of the structures, which depends upon the assumptions made while modeling.[2,4]

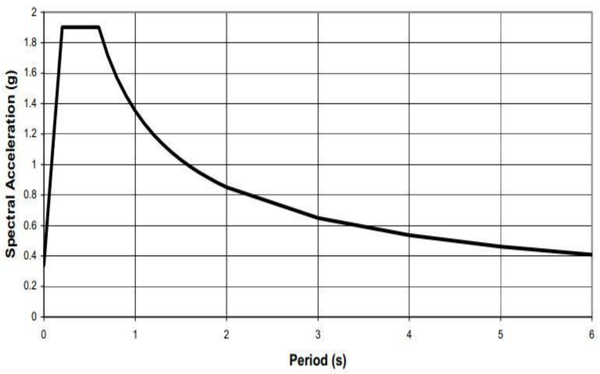


Figure 3: A typical design spectrum [5]

Methodology:

- The methodology adopted to perform the seismic evaluation of the building requires an understanding of equivalent lateral force procedure also recognized as equivalent static procedure in literature.
- An in depth knowledge of STAADPro software is required as the building was modeled in STAADPro and post analysis data obtained from it was used in the analysis of the structure.
- The demand to capacity ratio of members was calculated to analyze the seismic stability of the structure under the various load combinations in accordance with IS 1893-2002 (part 1)
- Suitable retrofit measures were proposed for beams and columns failing in shear and flexure

II. SEISMIC EVALUATION METHODS

A. Preliminary investigation
B. Detailed evaluation
Preliminary investigation:
The preliminary evaluation is a quick procedure to establish actual structural layout and assess its characteristics that can affect its seismic vulnerability. It is an approximate method based on conservative parameters to identify the potential earthquake risk of a building and can be used for screening of buildings for detailed evaluation. It also helps the design engineers to get acquainted with the building, its potential deficiencies and behavior. A site visit is done as a part of preliminary investigation in order to familiarize with the building and take note of the ground conditions which are not reported in the drawings.[6]
Detailed evaluation methods:

- Equivalent static method
- Response spectrum method

Response spectrum method:
Response spectrum analysis is a procedure for computing the statistical maximum response of a structure to a base excitation. Each of the vibration modes that are considered may be assumed to respond independently as a single-degree-of-freedom system. Design codes specify response spectra which determine the base acceleration applied to each mode according to its period (the number of seconds required for a cycle of vibration)
For example: the diagram below shows the Basic Seismic Hazard Acceleration Coefficient specified in NZS 4203 for deep soil sites. Each curve represents a different ductility factor. The design response spectrum is obtained by multiplying these curves by a structural performance factor, a risk factor, a zone factor, and limit state factor.

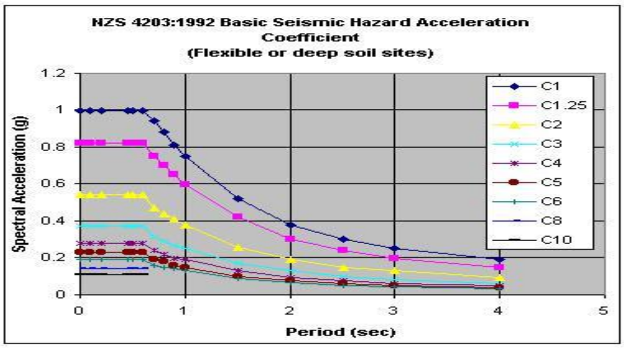


Figure 4: Basic seismic hazard coefficient specified in NZS 4203[7]

Having determined the response of each vibration mode to the excitation, it is necessary to obtain the response of the structure by combining the effects of each vibration mode because the maximum response of each mode will not necessarily occur at the same instant, the statistical maximum response, where damping is zero, is taken as the square root of the sum of the squares (SRSS) of the individual responses.
To explain the response spectrum concept, we consider a SDOF system in which an external action is applied like an applied force or support displacement. For the response spectrum, it is necessary to evaluate the value of the maximum response, which may be determined once the equation q(t) is fully known.The equation of displacement q(t) for a SDOF system with damping § and natural frequency w is

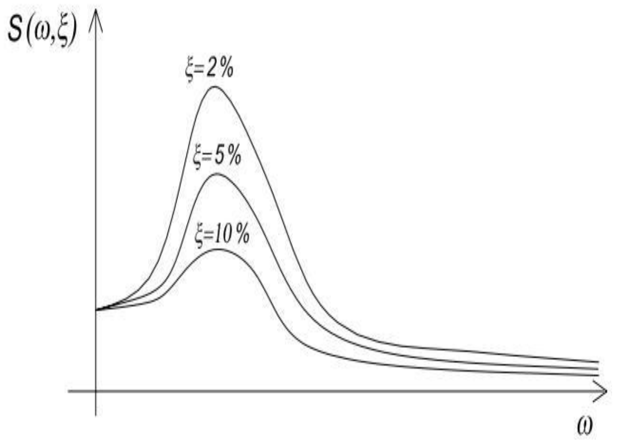


Figure 5: Typical representation of response spectrum[8]

Response spectrum analysis applied to MDOF systems[8] :

For direction J the maximum value of modal coordinates in terms of displacements, $Y'_{n,max}$ may be achieved if the displacement response spectrum $S_d(w,§)$ is known. $Y'_{n,max}$ is established from the response spectrum for the SDOF system with both the same natural vibration frequency, w_n and critical damping ratio $§_n$

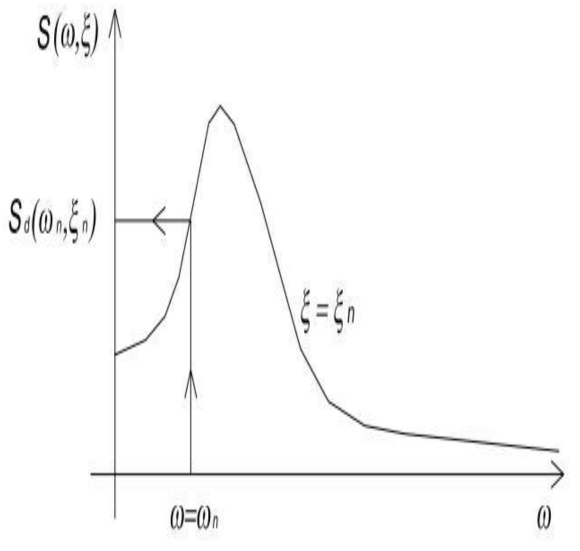


Figure 6: Explaining the response spectrum analysis procedure

Equivalent static method:

The equivalent static method is the simplest method of analysis because the forces depend on the code based fundamental period of structures with some empirical modifiers. The design base shear is to be computed as whole, then it is distributed along the height of the building based on some simple formulae appropriate for buildings with regular distribution of mass and stiffness.

The design lateral force obtained at each floor shall then be distributed to individual lateral load resisting elements depending upon the floor diaphragm action.

Following are the major steps in determining the seismic forces:

1) Determination of base shear: For the determination of seismic forces, the country is classified in four seismic zones:

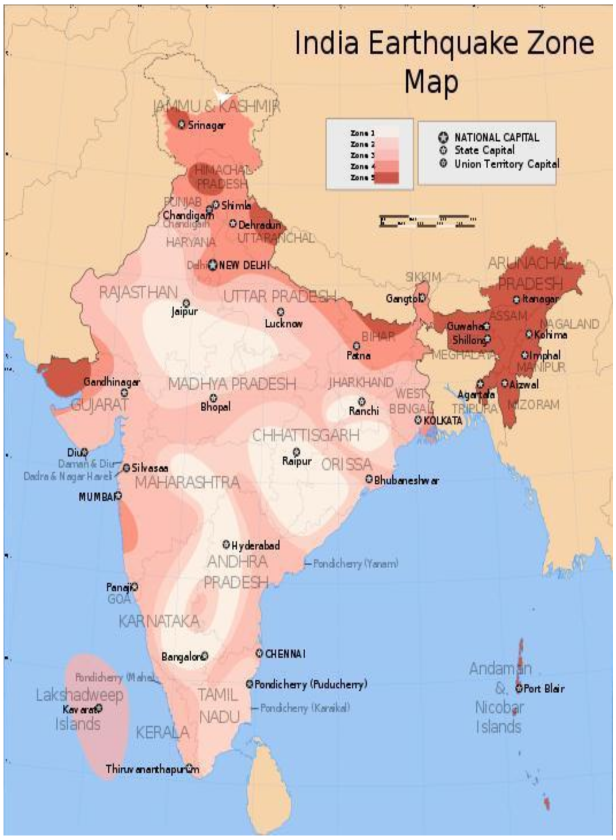


Figure 7: Showing seismic zones in India

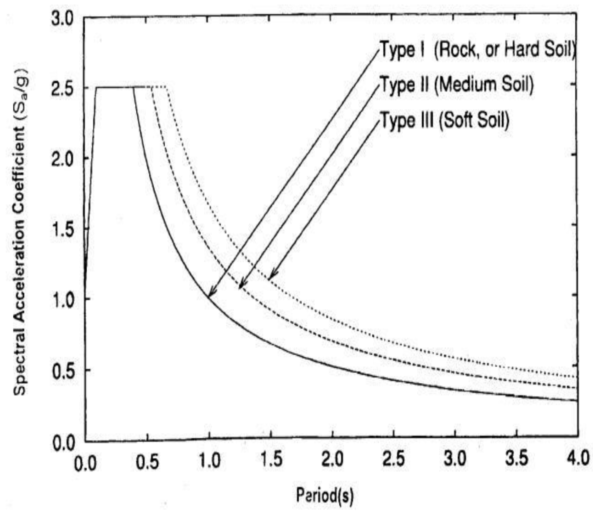


Figure 8: Response spectra for rock and soil sites for 5% damping [fig 2 of IS 1893:2002]

Lateral distribution of base shear: After the total design base shear is calculated, it is distributed along the height of the building. The base shear at any floor or level depends on the mass of the level and deformed shape of the structure. Earthquake forces can deflect a building into a number of shapes, the natural mode shapes of the building which in turn depend upon the degree of freedom of the building. A building can have infinite degree of freedoms but we convert it to finite degree of freedom by idealizing a multi storeyed building into a lumped mass model by assuming the mass of the building lumped at each floor level with one degree of

freedom in the direction of lateral displacement in which the structure is being analyzed per floor, resulting in degrees of freedom equal to the number of floors.[4]
The magnitude of the lateral force at a floor (node) depends on:
Mass of that floor
Distribution of stiffness over the height of structure
Nodal displacements in a given mode

III. BUILDING ANALYSIS

About the building:

Table 1: Building description:

Building type	Reinforced concrete frame
Usage	Residential apartment
Location	Kashmir, J & K
Year of construction	1999
Number of stories	Open ground + 4
Plan dimensions	25.2 m X13.95 m
Building height	15 m

Table 2: Grade of Materials

Concrete	M 15
Reinforcing Steel	Fe 415

Modeling in Staad Pro:
Nomenclature:
I adopted a scientific approach to modeling in STAAD. In my approach I did not use any shortcut commands and worked only through the Staad editor. The most important part of modeling was the nomenclature of nodes, beams and columns. A proper nomenclature of nodes, beams and columns is very important as it gives you the exact idea where that member is located in the entire structure and has an added advantage while debugging. The nodes were named by giving their x, z co-ordinates a specific number and the y coordinate (along the height) was according to the floor number.
For example:
Node no: 15010 – is a level 1 node (first no) with x co-ordinate attributed to no. (50) and z co-ordinate attributed to no. (10)
From the figure below it can be seen that just by the node number we can know the exact position of any node.

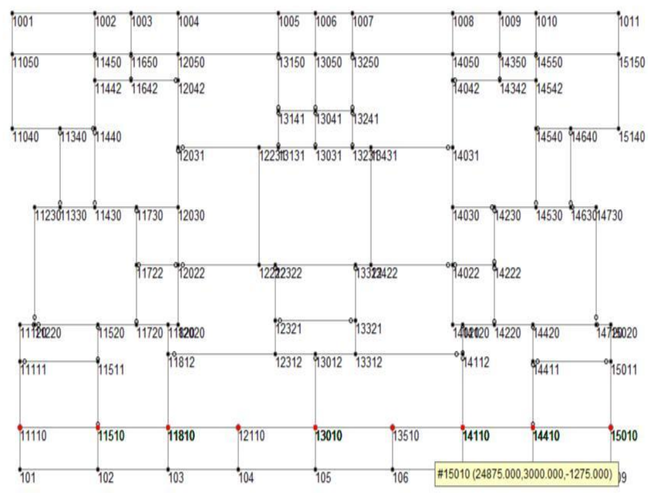


Figure 9: Highlighting all nodes of same z level (10) of level 1 (1)

Here all (10) nodes – 111(10) to 150(10) denote that they have the same z co-ordinate (1275 mm) and are of the first level (1).

Table 3: showing process of nomenclature of nodes in X direction

X in metre	Allotted no.	X in metre	Allotted no.
0	10	24.875	50
0.325	11	25.2	51
0.925	12	3.55	15
3.425	14	21.65	44
6.475	18	9.4	21
6.9	20	15.8	35
10.275	22	5.1625	17
10.925	23	20.0375	42
12.6	30	23.225	46
14.275	33	1.975	13
14.925	34	11.075	31
18.3	40	14.125	32
18.725	41	4.925	16

21.775	45	20.275	43
24.275	47		

Table 4 : showing process of nomenclature of nodes in Z direction

Z in metre	Alloted no.
-1.275	10
-3.525	12
-4.4	20
-6.225	22
-8	30
-9.825	31
-10.4	40
-11.875	42
-12.675	50
-3.275	11
-4.525	21
-10.9375	41

Now for example a node 15010 will have x co-ordinate (50) value (from table 3) = 24.875m, z coordinate (10) (from table 4) value = 1.275 m, which is verified from figure 11

Example 2: if a first level node would have existed having 3.425 m X coordinate and 8 m coordinate, its nomenclature would have been: (1),(14),(30) i.e. 11430

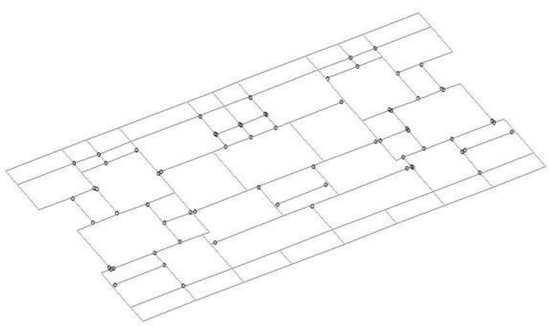


Figure : Showing member release of first floor beams

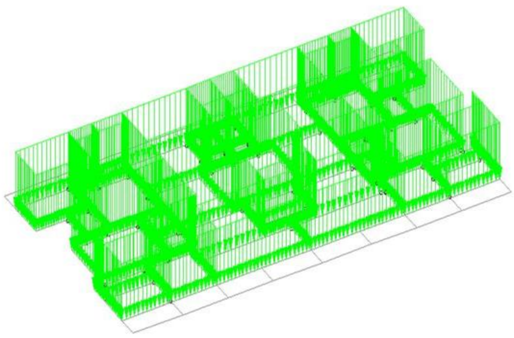


Figure : Showing application of brick load

Seismic weight calculation

Weight Calculation								
sl no.	category	no.	length (m)	breadth (m)	height (m)	volume (m3)	density (T/m3)	weight (T)
1	columns	28	0.5	0.4	3	0.6	2.5	42
2	beams	110	0.5	0.25*	0.5	0.0625	2.5	18
3	slab	-	24.55	11.4	0.15	~42.0	2.5	81
4	brick load	-	212.58	0.2	2.4	102.03	2	205
5	imposed load			taking 25% of total live load				26.27
				sesimic wt for all floors except roof			=	372.27 Tonnes
				seismic wt. for roof			=	222.50 Tonnes
				total seismic weight			=	2083.85 Tonnes
	0.25* is taken as an average							
	~slab volume is reduced by bricks and effective value is 32.38							

Calculation of base shear

calculation of base shear			
factors	formula	value	remarks
Z		0.36	zone V value from Table 2 of IS 1893:2002
I		1	residential building value from Table 6 of IS 1893
R		3	from Table 7 of IS 1893:2002
T	0.075(h)^0.75	0.655	h= 18 m from foundation
Sa/g	Sa/g = 1.36/T	2.075	
Ah	Ah=Z*I*Sa/2Rg	0.125	Ah = design horizontal seismic coefficient
W		2083.85 T	Total Seismic wt. of Building
Vb	Vb= Ah W	259.44 T	Design Base Shear

Distribution of base shear along vertical direction

Floor	Calculation of Seismic force per storey in X direction	V_b per storey
1st	13401.8	18.87
2nd	30154.0	42.45
3rd	53607.0	75.47
4th	83761.0	117.93
Roof	72090.0	101.50

Distribution of base shear per node in X and Z directions for each floor

Seismic forces per node (T)

Floor	X direction (5 nodes)	Z direction (9 nodes)
1st	3.77	2.10
2nd	8.49	4.72
3rd	15.09	8.39
4th	23.59	13.10
Roof	20.30	11.28

Load combinations applied

Table 9: Load combinations as per IS 1893:2002 (part 1)

1.5 (DL+LL)
1.2(DL+LL EL)
1.5(DL EL)
0.9DL 1.5EL

After the loading is completed, the structure was analyzed in STAAD.

Member force details were taken from it as input data for calculating demand to capacity ratios

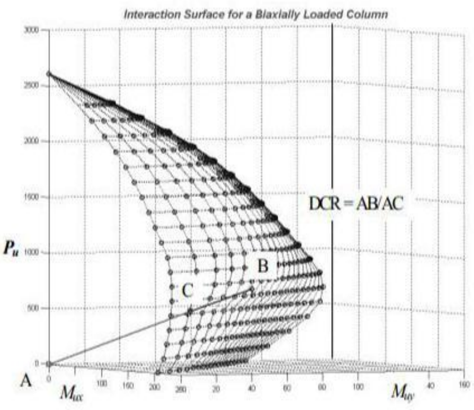


Figure: dcr of column under biaxial bending[10]

Results:
The results obtained for the dcr values and the status of the members in the building are discussed below. The results are for beams of level 2 and random columns were selected (specifically the foundation ones) and their dcr values were calculated.
Status of beams of level 2 in flexure

Beams status in flexure

beam no.	beam type	dcr	status
21101	1b3	2.08	fail
21102	1b3	1.99	fail
21103	1b3	1.66	fail
21104	1b3	1.60	fail
21105	1b3	1.59	fail
21106	1b3	1.57	fail
21107	1b3	1.74	fail
21108	1b3	1.87	fail
21111	1b6	0.01	safe
21112	1b6	0.01	safe
21121	1b4	-0.15	safe
21122	1b4	1.82	fail
21123	1b4	1.84	fail
21124	1b4	1.06	fail
21201	1b8	0.01	safe
21202	1b8	-0.97	safe
21203	1b8	-1.07	fail
21204	1b8	1.52	fail
21205	1b8	1.94	fail
21206	1b8	1.65	fail
21207	1b8	-0.26	safe
21208	1b8	-0.68	safe
21209	1b8	-0.70	safe

21210	1b8	0.01	safe
21211	1b6	0.01	safe
21221	1b5	0.01	safe
21222	1b5	1.87	fail
21223	1b5	2.43	fail
21224	1b5	1.67	fail
21225	1b5	2.46	fail
21226	1b5	1.87	fail
21227	1b5	0.01	safe
21301	1b9	2.45	fail
21302	1b9	1.17	fail
21303	1b9	-1.02	fail
21304	1b9	2.40	fail
21305	1b9	0.01	safe
21306	1b9	-0.69	safe
21307	1b9	-0.50	safe
21308	1b9	0.01	safe
21311	1b4	1.15	fail
21312	1b4	1.54	fail
21313	1b4	-0.74	safe
21314	1b4	-0.72	safe
21315	1b4	1.51	fail
21316	1b4	1.13	fail
21401	1b5	2.24	fail
21402	1b5	-0.12	safe
22402	1b5	-2.33	fail
22403	1b5	2.44	fail
22404	1b5	-1.68	fail
22405	1b5	-2.11	fail
22411	1b13	1.14	fail
22412	1b13	0.01	safe
22421	1b7	0.01	safe
22422	1b7	0.01	safe
22431	1b5	0.01	safe
22441	1b12	0.01	safe
22442	1b12	0.01	safe
22451	1b15	-0.87	safe

Local retrofitting methods

From the results obtained above for this building, it is clear that the members will fail under the applied load combinations as per IS 1893:2002 (part 1) and we have to provide retrofitting in the building. The scope of my study is limited to local retrofitting measures.

4.1 Retrofit of columns:

Retrofit methods of columns include:

- Concrete jacketing
- Steel jacketing
- Fibre reinforced polymer wrapping

The columns in this structure can be retrofitted by concrete jacketing, which is the most popular method of seismic retrofit in columns. There are two main purposes of jacketing of columns:

It increases the shear capacity of columns

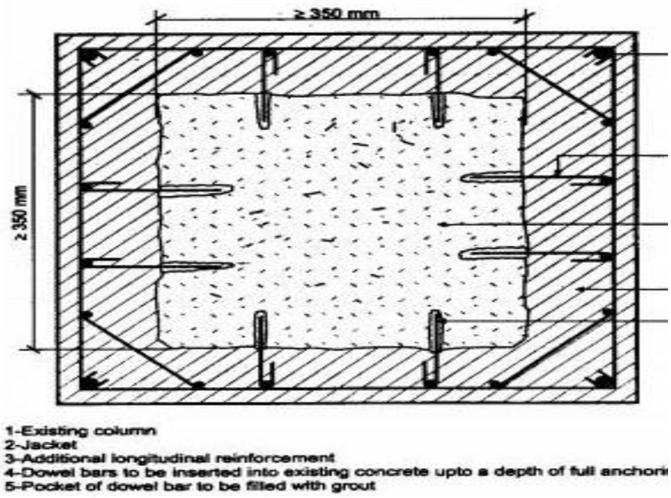
It improves the flexural strength of columns by the longitudinal steel of the jacket made continuous through the slab system and anchored with the foundation.

It is achieved by passing the new longitudinal reinforcement through holes drilled in the slab and by placing new concrete in the beam column joints

The method is straightforward and increases both strength and ductility. But the composite deformation of the existing and the new concrete requires adequate dowelling to the existing column. The mix design of the new concrete, surface preparation of the existing column and the choice of bonding material are also important.

The disadvantages of concrete jacketing are:

- Drilling of holes
- Increase in size of the column
- Placement of ties at the beam-column joint



Retrofit of beams:
Beams can be strengthened by:

- Concrete jacketing
- Steel plating
- Use of FRP bars
- External prestressing

In this structure we can use concrete jacketing as well as steel plating. The scope of my study is limited to retrofitting of beams by steel plating. In steel plating, steel plates are glued to beams to improve their flexural and shear capacities. It increases the strength and stiffness of the beams and reduces the crack width[10].

Advantages of steel plating:

- Addition of steel plates is simple and can be rapidly applied
- Does not reduce the storey clear height significantly
- Can be applied while the building is still in use
- Relatively small increase in size of the existing section

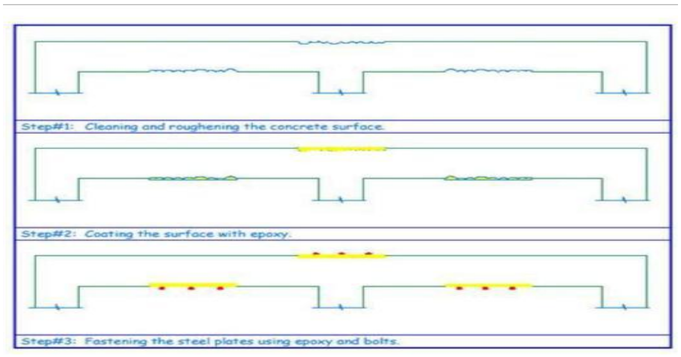


Figure : Showing steps of steel plating[11]

Steel plating:
Sample Calculation:
Beam no: 21311
Size : 200 X 500 mm
Type: 1b4
Original capacity = 272.43 KNm
Target Capacity = 315 KNm
Steel plate of thickness 2mm added to both tension and compression face $d_p = 2$ mm

d = effective depth of beam = 500 – d_c (40 mm) = 460 mm

$f_{pc} = f_{pt}$ = strees in steel plate in compression and tension corresponding to strain e_{cs}

$e_{cs} = 0.0023$ (calculated while calculating neutral axis)

$f_{pc} = f_{pt} = 340$ N/mm^2 for Fe 415

providing width of steel plate = b = width of beam – 2(50 mm side cover) = 100 mm

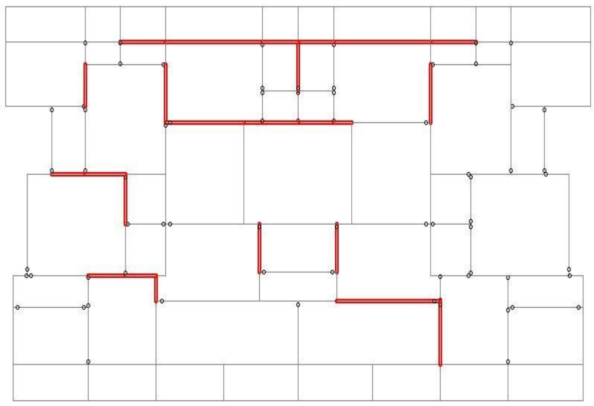


Figure : showing beams of 1st floor eligible for steel plating

Summary

The purpose of this project was to assess the seismic vulnerability of an existing RC structure and to provide for retrofit in case the members fail. The building under study in this project was an existing multi-storeyed residential building in Kashmir. The plan and reinforcement details of the building were provided. I modeled the building in STAAD Pro software and applied seismic load combinations to it. Equivalent static procedure as per Indian Standard IS 1893:2002 (Part 1) was used to compute the seismic forces. The members' adequacy was assessed by computation of their dcr (demand to capacity ratio) values. The demand of individual members was obtained after analysis from STAAD Pro software and the capacity for the corresponding members was calculated, the ratio of the two gave the dcr values. The simple concept that if the dcr of any member is greater than one would result in the failure of that member under the applied loads was used to find out the status of the members under flexure and shear.

IV. CONCLUSION

The results for first floor beams and a large sample of columns showed that a number of beams and all the foundation columns checked were found to be deficient under the applied seismic load combinations. Number of beams failing under flexure was more than the number of beams failing under shear. The dcr of columns under biaxial bending gradually decreased with height, although it was greater than one in most of the cases.

For providing retrofit measures for the deficient members, concrete jacketing was found to be a suitable method for retrofitting of columns. It was also concluded that steel plating would be an efficient method of retrofitting of a number of deficient beams.

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