Detection of Weak Zones in Beams of Existing RC Structure Due to Consideration of Additional Seismic Forces

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.Abstract- **Throughout the globe there are lots of buildings which are vulnerable to damage or damaged by earthquake. There are many buildings which are either designed without consideration of seismic forces or need to be designed with consideration of revised code of earthquake. All such buildings are needed to be retrofied for additional seismic forces developed due to consideration of earthquake loads. The present study investigates the structural behaviour of an RC frame (G+2 Commercial building) under the additional load in the form of seismic forces. The structure is analyzed for two load cases. In first case (Gravity load case) structure is analyzed for only gravity forces and no seismic force is considered in this analysis while in second case (Seismic load case) structure is analyzed with consideration of seismic forces along with gravity forces. The analysis is performed by using structural analysis software i.e. STAAD Pro. The analysis results of structure for gravity and seismic load cases are compared to evaluate the effect of seismic forces on the RC structure. The seismic forces cause substantial change in beam and column forces in the structure. The results indicate that the significant increase is found in the shear force and bending moment in most of the beams. This increase of forces is more significant in plinth beams compared to roof beams. The weak and deficient members are identified and strengthened for the additional forces and moments. The strengthening of beams is done by connecting steel plates at top and bottom of the beams with shear connectors.**

Keywords- Concrete; Steel; Jacketing; Strengthening.

1. INTRODUCTION

Earth quake is one of the greatest natural hazards to life on this planet. The effects of the earthquake are very sudden with little or no warning to make alert against damages and collapse of the buildings. There is lots of building which are not designed for earthquake forces or many buildings which are designed for earthquake forces but later on due to change in earthquake code, these buildings need to be retrofied. This paper involves the strengthening demand of the RC structure by considering seismic forces in addition to gravity forces. The new construction can be built earth quake resistant easily by adopting proper design methodology and quality control in construction but old construction which is not design with code provisions posses' enormous seismic risk in particular to human life and historic monuments. Most of the losses of lives in previous earthquakes in different countries have occurred due to collapse of buildings, these buildings are generally non-engineered, those constructed without any concern with the engineer. Most of the small and residential buildings are built rapidly with little or without engineering inputs. So it is highly needed to increase its capacity to bear these forces caused due to earthquake. Many high rise buildings are highly vulnerable to earthquake due to more height and large occupancy. This thesis presents an attempt towards quantitative evaluation of seismic vulnerability of this particular type of buildings and proposes practical solutions to reduce it. The results, with and without strengthening measures, are compared to estimate the effectiveness of the various intervention options.

1.1 Literature Review

Several studies have been carried out to understand the influence of additional forces on the existing structure. These forces may be due to consideration of seismic force, wind load or due to any alteration in the building. Various experimental and analytical investigations have been carried out to understand the behaviour of the retrofitted structure and also to know the amount of retrofitting requires.

Gomes A. and Julio A. J. (1997) studied on strengthening design of RC beams by addition of steel plates, according to him the members which are not having sufficient reinforcement and good quality of concrete can be retrofied with providing external reinforcement. To have additional steel strength with low deformation of the strengthened element it is convenient to use low tensile strength steel. Adding the plates means increase inertia and the stiffness of element. Additional steel can be connected to beams or columns by inject epoxy resin. High strength steel bolts can be use at the anchorage zone; near the end of plate it is convenient.

Kothandaraman S. and Vasudevan G. (2009) has done experimental study on Flexural retrofitting of RC beams using external bars at soffit level keeping the reinforcement externally at soffit level is found to be viable and the moment carrying capacity of beams could be increased considerably. In case of under reinforced section the capacity can be increased as high as 70%. By doing this the moment carrying capacity can be increased than that of the section in which the entire reinforcement is embedded. It also reduces crack width and the deflection as compare to the reference beam.

Obaidat Y. T. et al (2009) studied on Retrofitting of reinforced concrete beams using composite laminates. According to him, the stiffness of the CFRP-retrofitted beams is enhanced compared to that of the reference beams. Providing externally bonded CFRP plates resulted in an increase in capacity of the maximum load. The crack width of the retrofitted beams are decreased compared to the reference beams.

Obaidat Y. T. (2011) studied on use of FRP for structural retrofitting of concrete beam. By his experiments and simulations he shows that retrofitting by FRP can increase load capacity and stiffness. The effect of retrofitting in flexure is more effective than in shear. On the other hand, these simulations showed that an increase in the amount of CFRP will in some cases decrease the maximum load capacity. This means that it is very important to understand the behaviour of a retrofitted structure since an unsuitable arrangement of CFRP can make the situation very dangerous.

Ruano G. et al (2012) has studied on Shear retrofitting of reinforced concrete beam with steel fibre reinforced concrete. The strengthen technique used with self compacting concrete matrix with steel fibre reinforced is feasible to apply at building elements. It is suitable to reduce the thickness of the steel jacketing, it also provides a good surface finish so that plastering can be optional. So it reduce the weight of the plaster or can say it compensate the weight. FRC improves the structural properties of building.

2. PROPOSED WORK

The present study investigates the structural behaviour of an RC frame (G+2 Commercial building) under the additional load in the form of seismic forces. The structure is analyzed for two load cases. In first case (Gravity load case) structure is analyzed for only gravity forces and no seismic force is considered in this analysis while in second case (Seismic load case) structure is analyzed with consideration of seismic forces along with gravity forces. The analysis is performed by using structural analysis software i.e. STAAD Pro. The analysis results of structure for gravity and seismic load cases are compared to evaluate the effect of seismic forces on the RC structure. Weak zones are detected by comparing the results and retrofitting technique is suggested for the structure. Two cases for the compare of structure are

Case 1:- Structure with gravity loads only (STR-GR)

Case 2:- Structure with earthquake loads of Zone III in addition to gravity loads (STR-EQ).

2.1 Modelling

Modelling is done for the structure, the details of which is illustrated in table

Table 1 Details of structure for modelling

Structure type	RCC commercial building
Storey's	G + 2
Height of each storey	3.5m
Building plan size	21m x 12.5m
Building height	10.5m
Depth of foundation	1.5m below GL
Type of supports	Fixed
Slab thickness each	150mm
Column size each	300mm x 300mm
Beam size	200mm x 400mm
Type of wall separation	Glazed
Dead load of wall taken	Consider brick wall load
Live load on each floor	4 KN/m^2
Live load on terrace	1.5 KN/m^2
Seismic zone	Zone III
Live load with seismic force	50% (IS 1893:2002)
Type of existing steel	Fe 415
Characteristic strength of concrete (f_{ck})	25 N/mm^2

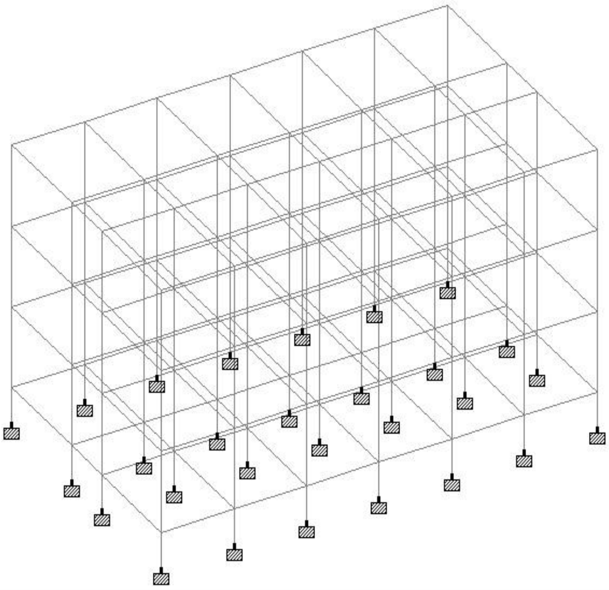

Fig 1 Isometric view of proposed structure

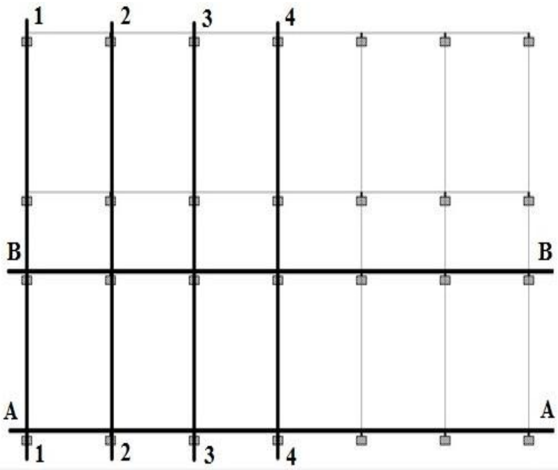

Fig 2 Sections where beams and columns are considered

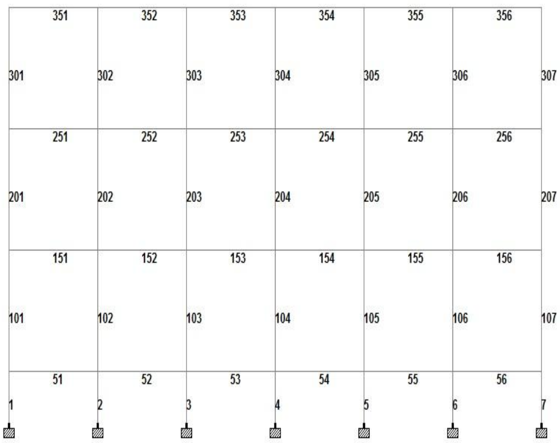

Fig 3 Member numbering at Section A-A

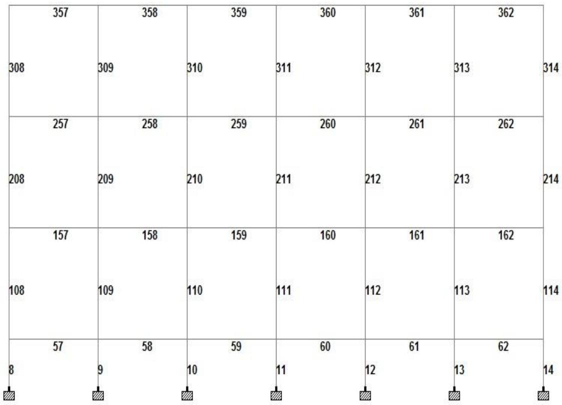

Fig 4 Member numbering at Section B-B

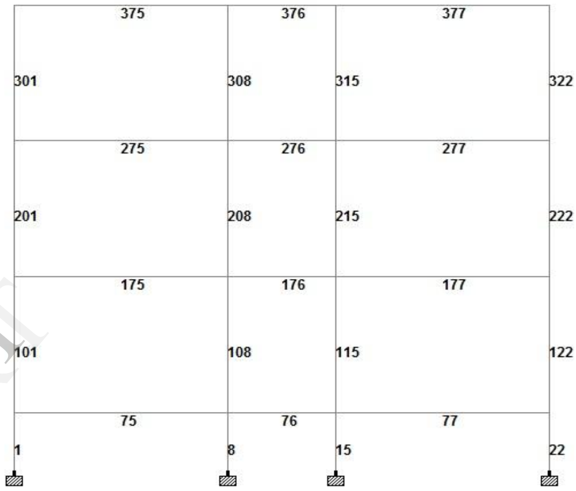

Fig 5 Member numbering at Section A-A

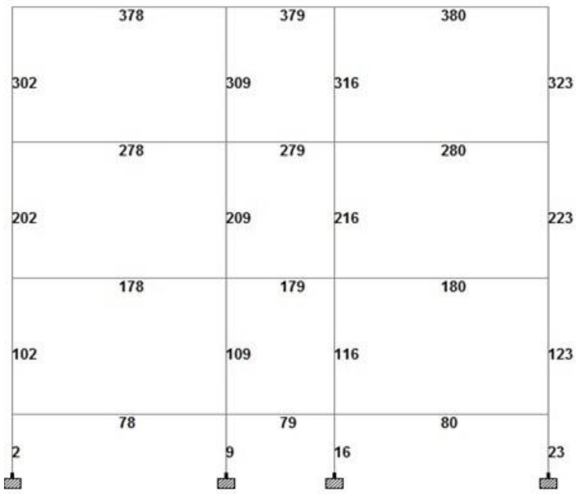

Fig 6 Member numbering at Section 2-2

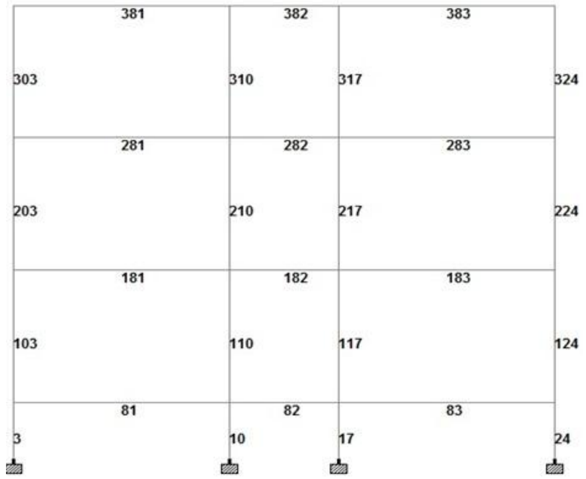

Fig 7 Member numbering at Section 3-3

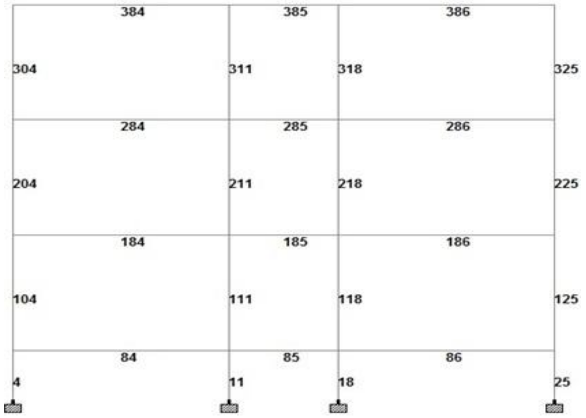

Fig 8 Member numbering at Section 4-4

2.2 Load calculation

Dead load and live loads are calculated and tabulated below.

Table 2 Dead load and Live load on structure

Members	Load calculation	Load
Dead load of 200mm wall	0.2 x 3.1 x 20	12.4 kN/m
Dead load of 100mm wall	0.1 x 3.1 x 20	6.20 kN/m
Dead load of parapet wall of 100 mm	0.1 x 1 x 20	2.00 kN/m
Dead load of slab	0.15 x 25	3.75 kN/m^2
Live load on floors	By IS code	4.00 kN/m^2
Live load on roof	By IS code	1.50 kN/m^2

Table 3 Parameters for earthquake load

Sr. No.	Parameter	Value
1	Location (ZONE III)	Zone Factor = 0.16
2	Response reduction factor (Ordinary RC Moment Resisting Frame)	RF = 3
3	Importance factor (All General Building)	I = 1
4	Rock and soil site factor (Medium soil)	SS = 2
5	Type of structure (RC Frame Building)	ST = 1
6	Damping ratio	DM = 0.05

2.3 Methodology

1 Modelling of G+2 structures in staad-pro software.
2 Analyze this structure for the gravity forces only and noted down forces in all beams of the structure.
3 Apply the seismic force of Zone III in addition to gravity forces at the same structure and noted down forces in all beams of the structure.
4 Compare the results of both analysis and find deficiencies.
5 Retrofitting the beams for the additional forces and moments.

2.4 Load cases and combinations

According to IS 1893-2002

Load cases for analysis in staad-pro

Basic loads

LC 1:- EQ X = EQ in +X direction
LC 2:- EQ-X = EQ in -X direction
LC 3:- EQ Z = EQ in +Z direction
LC 4:- EQ-Z = EQ in-Z direction
LC 5:- DL = Dead load
LC 6:- LL = Live load

Combination of loads according to IS 1893:2002

LC 7:- 1.5 DL + 1.5 LL
LC 8:- 1.2 DL + 1.2 LL + 1.2 EQ X
LC 9:- 1.2 DL + 1.2 LL + 1.2 EQ-X
LC 10:- 1.2 DL + 1.2 LL + 1.2 EQ Z
LC 11:- 1.2 DL + 1.2 LL + 1.2 EQ-Z
LC 12:- 1.5 DL + 1.5 EQ X
LC 13:- 1.5 DL + 1.5 EQ-X
LC 14:- 1.5 DL + 1.5 EQ Z
LC 15:- 1.5 DL + 1.5 EQ-Z
LC 16:- 0.9 DL + 1.5 EQ X

LC 17:- 0.9 DL + 1.5 EQ-X
LC 18:- 0.9 DL + 1.5 EQ Z
LC 19:- 0.9 DL + 1.5 EQ-Z

3. RESULTS AND DISCUSSION

The effects of the earthquake forces on structure are studied in addition to gravity forces. The comparison of shear forces, bending moments and reinforcement is done for two cases i.e. for STR-GR and STR-EQ structure and their differences are tabulated to estimate the strengthening requirement for the additional load. Floor wise results are discussed for different beams. Subsequently the retrofitting method is used to strengthen the weak members.

In results STR-GR indicates the results of structure analyzed with gravity forces only and STR-EQ indicates the results of structure analyzed with earthquake force in addition to gravity forces.

3.1 Effects of additional seismic force on beams

The shear force, bending moment and area of reinforcing steel in beams of different storey's floors are presented and compared for gravity and seismic load cases.

3.1.1 Effect on shear force in beam

The shear force in both the cases as for STR-GR and STR-EQ are compared for beams at each floor.

a) Plinth beams

The shear force in plinth beams for gravity and seismic load cases are discussed. The increase in shear force due to application of earthquake forces in addition to gravity forces are shown in table 4.

Table 4 Comparison of Shear force Fy (kN) in plinth beams between gravity and seismic load case

Beam No	Shear force Fy		Increase in Shear force	% increase in shear force
	STR-GR	STR-EQ		
51	39.10	57.53	18.43	47.14
52	37.57	52.87	15.30	40.72
53	37.51	52.94	15.43	41.14
57	21.61	41.19	19.58	90.61
58	21.25	37.31	16.06	75.58
59	21.24	37.48	16.24	76.46
75	54.34	65.30	10.96	20.17
76	26.78	56.28	29.50	110.16
78	30.43	42.24	11.81	38.81
79	15.16	46.57	31.41	207.19
81	30.41	42.67	12.26	40.32
82	15.16	47.80	32.64	215.30
84	30.40	42.80	12.40	40.79
85	15.16	48.17	33.01	217.74

From the above comparison it is revealed that there is an increase in shear force Fy in all the beams. The maximum increase in shear force is found to be 33.01 kN in beam no 85 with percentage increase of 217.74%.

b) First floor beams

The shear force in first floor beams for gravity and seismic load cases are discussed. Increase in shear force due to application of earthquake forces in addition to gravity forces are shown in table 6.2.

Table 5 Comparison of Shear force (kN) in first floor beams between gravity and seismic load case

Beam No	Shear force Fy		Increase In Shear force	% increase in shear force
	STR-GR	STR-EQ		
151	58.35	67.40	9.05	15.51
152	55.47	67.05	11.58	20.88
153	55.32	67.42	12.10	21.87
157	58.93	69.01	10.08	17.11
158	55.61	62.04	6.43	11.56
159	55.41	62.30	6.89	12.43
175	88.83	88.83	0.00	0.00
176	35.87	69.19	33.32	92.89
178	99.11	99.11	0.00	0.00
179	33.32	64.68	31.36	94.12
181	99.15	99.15	0.00	0.00
182	33.32	66.29	32.97	98.95
184	99.15	99.15	0.00	0.00
185	33.32	66.75	33.43	100.33

From the above comparison it is revealed that there is an increase in shear force Fy in all the beams. The maximum increase in shear force is found to be 33.43 kN in beam no 185 with percentage increase is 100.33%.

c) Second floor beam

The shear force in second floor beams for gravity and seismic load cases are discussed. Increase in shear force due to application of earthquake forces in addition to gravity forces are shown in table 6.31.

Table 6 Comparison of Shear force (kN) in second floor beams between gravity and seismic load case

Beam No	Shear force Fy		Increase in Shear force	% increase in shear force
	STR-GR	STR-EQ		
251	57.57	65.61	8.04	13.97
252	55.39	60.83	5.44	9.82
253	55.31	60.92	5.61	10.14
257	57.75	60.99	3.24	5.61
258	55.50	56.96	1.46	2.63
259	55.37	56.93	1.56	2.82
275	88.48	88.48	0.00	0.00
276	35.87	57.41	21.54	60.05
278	98.34	98.34	0.00	0.00
279	33.32	52.29	18.97	56.93
281	98.34	98.34	0.00	0.00
282	33.32	53.49	20.17	60.53
284	98.34	98.34	0.00	0.00
285	33.32	53.83	20.51	61.55

From the above comparison it is revealed that there is an increase in shear force Fy in all the beams. The maximum increase in shear force is found to be 21.54 kN in beam no 276 with percentage increase of 60.05%.

d) Third floor beam

The shear force in third beams for gravity and seismic load cases are discussed. Increase in shear force due to application of earthquake forces in addition to gravity forces are shown in table 6.4.

Table 7 Comparison of Shear force (kN) in third floor beams between gravity and seismic load case

Beam No	Shear force Fy		Increase In Shear force	% increase in shear force
	STR-GR	STR-EQ		
351	22.79	25.78	2.99	13.12
352	22.70	24.55	1.85	8.15
353	22.34	24.19	1.85	8.28
357	29.51	29.82	0.31	1.05
358	28.41	28.41	0.00	0.00
359	28.14	28.14	0.00	0.00
375	38.21	38.21	0.00	0.00
376	13.44	19.78	6.34	47.17
378	53.93	53.93	0.00	0.00
379	15.84	21.14	5.30	33.46
381	54.01	54.01	0.00	0.00
382	15.84	21.56	5.72	36.11
384	54.01	54.01	0.00	0.00
385	15.84	21.67	5.83	36.80

From the above comparison it is revealed that there is an increase in shear force Fy in all the beams. The maximum increase in shear force is found to be 6.34 kN in beam no 376 with percentage increase of 47.17%.

3.1.2 Effect on bending moment in beam

Bending moment and corresponding reinforcement area of steel in beam are discussed. Sagging moment and hogging moment both are compared for the two cases as for STR-GR and STR-EQ. Maximum of two hogging moments from both ends are taken for the comparison.

a) Plinth level beams

Table 8 Comparison of bending moment Mz (kNm) and corresponding reinforcement area Ast (mm^2) between Gravity and Seismic analysis in beams at plinth level

Beam no	STR-GR				STR-EQ (Zone III)				Increase in moment/ reinforcement			
	Max. hogging moment	Max. Sagging moment	Ast Top	Ast Bottom	Max. hogging moment	Max. Sagging moment	Ast Top	Ast Bottom	Hogging moment	Sagging moment	Ast Top	Ast Bottom
	1	2	3	4	5	6	7	8	(5-1)	(6-2)	(7-3)	(8-4)
51	-23.00	12.61	226	226	-53.00	24.40	565	226	-30.00	11.79	339	0
52	-22.08	10.86	226	226	-48.72	16.31	452	226	-26.64	5.45	226	0
53	-21.89	10.94	226	226	-48.96	16.36	452	226	-27.07	5.42	226	0
57	-12.34	6.91	226	226	-45.32	29.64	402	339	-32.98	22.73	176	113
58	-12.41	6.21	226	226	-40.61	20.84	339	226	-28.20	14.63	113	0
59	-12.42	6.18	226	226	-40.84	21.04	339	226	-28.42	14.86	113	0
75	-42.68	26.20	402	226	-67.26	31.80	603	339	-24.58	5.60	201	113
76	-17.30	0.00	226	226	-54.69	26.18	565	226	-37.39	26.18	339	0
78	-24.18	14.00	226	226	-53.24	22.74	452	226	-29.06	8.74	226	0
79	-8.60	0.87	226	226	-48.85	33.52	452	339	-40.25	32.65	226	113
81	-24.19	13.92	226	226	-54.57	23.13	565	226	-30.38	9.21	339	0
82	-8.49	0.98	226	226	-50.30	35.11	452	339	-41.81	34.13	226	113
84	-24.19	13.92	226	226	-54.94	23.26	565	226	-30.75	9.34	339	0
85	-8.49	0.99	226	226	-50.75	35.57	452	339	-42.26	34.58	226	113

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b) First floor beams

Table 9 Comparison of bending moment Mz (kNm) and corresponding reinforcement area Ast (mm^2) between Gravity and Seismic analysis in beams at first floor

Beam no	STR-GR				STR-EQ (Zone III)				Increase in moment/ reinforcement			
	Max. hogging moment	Max. Sagging moment	Ast Top	Ast Bottom	Max. hogging moment	Max. Sagging moment	Ast Top	Ast Bottom	Hogging moment	Sagging moment	Ast Top	Ast Bottom
	1	2	3	4	5	6	7	8	(5-1)	(6-2)	(7-3)	(8-4)
151	-36.27	22.66	339	226	-70.68	37.30	628	339	-34.41	14.64	289	113
152	-35.35	18.53	339	226	-64.86	22.10	565	226	-29.51	3.56	226	0
153	-34.91	18.71	339	226	-65.45	22.10	603	226	-30.54	3.36	264	0
157	-38.96	25.07	339	226	-69.37	42.10	628	402	-30.41	17.05	289	176
158	-37.78	20.44	339	226	-63.09	24.40	565	226	-25.31	3.92	226	0
159	-37.16	20.72	339	226	-63.70	24.80	565	226	-26.54	4.11	226	0
175	-73.03	52.63	678	452	-93.22	52.60	904	452	-20.19	0.00	226	0
176	-33.08	0.00	339	226	-73.70	31.80	678	339	-40.62	31.80	339	113
178	-86.00	64.96	804	565	-99.69	65.00	942	565	-13.69	0.00	138	0
179	-37.49	0.00	339	226	-75.02	36.40	791	339	-37.53	36.44	452	113
181	-85.99	65.07	804	565	-100.90	65.10	981	565	-14.91	0.00	177	0
182	-37.65	0.00	339	226	-77.07	38.40	791	339	-39.42	38.43	452	113
184	-85.99	65.08	804	565	-101.30	65.10	981	565	-15.26	0.00	177	0
185	-37.66	0.00	339	226	-77.66	39.00	791	339	-40.00	39.01	452	113

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c) Second floor beam

Table 10 Comparison of bending moment Mz (kNm) and corresponding reinforcement area Ast (mm^2) between Gravity and Seismic analysis in beams at second floor

Beam no	STR-GR				STR-EQ (Zone III)				Increase in moment/ reinforcement			
	Max. hogging moment	Max. Sagging moment	Ast Top	Ast Bottom	Max. hogging moment	Max. Sagging moment	Ast Top	Ast Bottom	Hogging moment	Sagging moment	Ast Top	Ast Bottom
	1	2	3	4	5	6	7	8	(5-1)	(6-2)	(7-3)	(8-4)
251	-34.96	22.60	339	226	-56.50	26.70	565	226	-21.54	4.13	226	0
252	-35.04	18.69	339	226	-54.17	18.70	565	226	-19.13	0.00	226	0
253	-34.9	18.70	339	226	-54.08	18.70	565	226	-19.18	0.00	226	0
257	-37.28	24.68	339	226	-54.70	26.10	565	226	-17.42	1.40	226	0
258	-37.33	20.70	339	226	-52.12	20.70	452	226	-14.79	0.00	113	0
259	-37.12	20.69	339	226	-51.99	20.70	452	226	-14.87	0.00	113	0
275	-72.7	52.07	678	452	-82.64	52.10	791	452	-9.94	0.00	113	0
276	-32.15	0.00	339	226	-58.53	17.40	565	226	-26.38	17.35	226	0
278	-85.78	63.27	791	565	-90.84	63.30	904	565	-5.06	0.00	113	0
279	-34.94	0.00	339	226	-57.85	22.00	565	226	-22.91	21.98	226	0
281	-85.77	63.28	791	565	-91.78	63.30	904	565	-6.01	0.00	113	0
282	-34.97	0.00	339	226	-59.28	23.50	565	226	-24.31	23.51	226	0
284	-85.77	63.28	791	565	-92.04	63.30	904	565	-6.27	0.00	113	0
285	-34.97	0.00	339	226	-59.70	23.90	565	226	-24.73	23.94	226	0

d) Third floor beam

Table 11 Comparison of bending moment Mz (kNm) and corresponding reinforcement area Ast (mm^2) between Gravity and Seismic analysis in beams at third floor

Beam no	STR-GR				STR-EQ (Zone III)				Increase in moment/ reinforcement			
	Max. hogging moment	Max. Sagging moment	Ast Top	Ast Bottom	Max. hogging moment	Max. Sagging moment	Ast Top	Ast Bottom	Hogging moment	Sagging moment	Ast Top	Ast Bottom
	1	2	3	4	5	6	7	8	(5-1)	(6-2)	(7-3)	(8-4)
351	-13.16	10.76	226	226	-21.16	11.80	226	226	-8.00	1.04	0	0
352	-15.21	8.57	226	226	-22.11	8.57	226	226	-6.90	0.00	0	0
353	-14.96	8.17	226	226	-21.65	8.17	226	226	-6.69	0.00	0	0
357	-18.71	14.70	226	226	-25.42	14.70	226	226	-6.71	0.00	0	0
358	-20.01	11.47	226	226	-25.33	11.50	226	226	-5.32	0.00	0	0
359	-19.79	11.22	226	226	-24.95	11.20	226	226	-5.16	0.00	0	0
375	-31.43	25.94	339	226	-36.6	25.90	339	226	-5.17	0.00	0	0
376	-16.10	0.00	226	226	-23.63	2.03	226	226	-7.53	2.03	0	0
378	-46.49	39.59	402	339	-46.88	39.60	402	339	-0.39	0.00	0	0
379	-23.54	0.00	226	226	-29.54	0.00	339	226	-6.00	0.00	113	0
381	-46.49	39.78	402	339	-47.42	39.80	402	339	-0.93	0.00	0	0
382	-23.82	0.00	226	226	-30.28	0.30	339	226	-6.46	0.30	113	0
384	-46.48	39.79	402	339	-47.57	39.80	402	339	-1.09	0.00	0	0
385	-23.83	0.00	226	226	-30.44	0.00	339	226	-6.61	0.00	113	0

Table 8 shows the bending moment and corresponding reinforcement area for plinth beams. Here the increase in hogging moment is maximum for beam no 85 as the value is increased by 42.26 kNm. Maximum increase in sagging moment is in the same beam with the value is increased by 34.58 kNm. The increase in reinforcement area for maximum increase in hogging moment at this level beams is 339 mm^2 in beam no 51, 76, 81, 84 and increase in reinforcement area for maximum increase in sagging moment at this level beam is 113 mm^2 in beam no (57, 75, 79, 82, 85).

Table 9 shows the bending moment and corresponding reinforcement area for first floor beams. Here the increase in hogging moment is maximum for beam no 176 as the value is increased by 40.62 kNm. Maximum increase in sagging moment is in beam no 185 with the value is increased by 39.01 kNm. The increase in reinforcement area for maximum increase in hogging moment at this floor beams is 452 mm^2 in beams no 179, 182, 185 and increase in reinforcement area for maximum increase in sagging moment at this level beam is 176 mm^2 in beam no 157.

Table 10 shows the bending moment and corresponding reinforcement area for second floor beams. Here the increase in hogging moment is maximum for beam no 276 as the value is increased by 26.38 kNm. Maximum increase in sagging moment is in beam no 285 with the value is increased by 23.94 kNm. The increase in reinforcement area for maximum increase in hogging moment at this floor beam is 226 mm^2 in beams no 251, 252, 253, 257, 276, 279, 282, 285 and there is no increase in reinforcement area for sagging moment in any beam.

Table 11 shows the bending moment and corresponding reinforcement area for third floor beams. Here the increase in hogging moment is maximum for beam no 351 as the value is increased by 8 kNm. Maximum increase in sagging moment is in beam no 376 with the value is increased by 2.03 kNm. The increase in reinforcement area for maximum increase in hogging moment at this floor beam is 113 mm^2 . In beams no 379, 382, 385 and there is no increase in reinforcement area for sagging moment in any beam.

3.2 Strengthening of beams

Strengthening of beams is done for the flexure and shear, to reach the strength of the structural member up to the require strength.

3.2.1 Strengthening of beams for flexure

Retrofitting is done for beams by adding steel plate of equivalent area of reinforced bars. Plate is designed for the additional area of steel required.

Equivalent mild steel area

The additional area of reinforcement bars are found by the comparison of both analysis, but this required steel is of tor steel, but as retrofitting is done by the mild steel plate, the area of equivalent mild steel plate is to be found by force equilibrium.

For tor steel (Fe 415 N/mm^2) area up to 400 mm^2

A_{st_1} = 400mm^2, f_{y_1} = 415 N/mm^2 ,

f_{y_2} = 250 N/mm^2

A_{st_2} = Area of Mild steel

So $A_{st_2} = (\frac{415}{250}) \times 400 = 664\ mm^2$

Similarly equivalent area of mild steel, as given in table below

Design of steel plate for required additional reinforcement

Select different range from the tables for additional Ast (mm^2) of f_y = 250 N/mm^2

Table 12 Plate sizes showing for different range of equivalent mild steel area

Serial Number	Additional reinforcement area required (Fe 415)	Corresponding mild steel area required (Fe 250)	Plate size used
1	Up to 400	664	100 x 8
2	400-600	996	100 x 10
3	600 -800	1328	100 x 12

3.2.2 Design of shear connector for flexure

Shear connector has to be design for every beam column joints for the maximum moment in that beam. Shear connector will transfer the additional force coming at existing reinforcement level to the outer plate which is designed for different beams. So the amount of force is to be found for which shear connector will be design. These connectors are used for either top plate for hogging moment or bottom plate for sagging moment. As every beam will have different additional moment, the force for which shear connector will design will be different. Here the design of shear connector is design for the maximum moment developed among all the beams of the structure.

So for this, we have

Force = $\frac{\text{moment}}{\text{Lever arm}}$ ……………………………….……….eq^n 1

Here lever arm L.A. = (d-0.42x_u) ………………….eq^n 2

But for x_u ,

M = 0.36 f_{ck} x b x_u x (d-0.42x_u) …………….……eq^n 3

Maximum additional moment = 42.26 kNm

Calculation of force for this maximum additional moment is given below,

Finding x_u for max of sagging and hogging moment by eq^n 3

Max hogging moment = -42.26 kNm

Therefore we have,

42.26 x 10^6 = 0.36 x 25 x 200 x_u x (367 – 0.42x_u)

42.26 x 10^6 = 660600x_u-756 ${x_u}^2$

x_u = 69.50 mm

Put this x_u in eq^n 2

L.A. = 367 – 0.42 x 69.50

L.A. = 337.81 mm

Now additional force which is to be carried by stud

F = $\frac{M}{L.A.}$

F = $\frac{42.26 \times 10^6}{337.81}$

F = 125099.91 N

Therefore,

F = 125.10 kN

Now designing the shear connector for the above force using IS 11384:1985 code

From table 1, we have

For 22 mm diameter of stud, 100 mm height and for M25 concrete

Strength of Shear connector F = 77.5 kN
Provide 2 shear connectors to resist the design shear force.

3.2.3 Strengthening of beams for shear

Plates are used at side face of the beams for resist additional shear force.
The maximum force is taken among all the beams and from all the floors as 33.01 kN.
Take mild steel plate as Fe 250. Permissible stress for mild steel plate in shear is 140 $\mathrm{N/mm^2}$

Area of steel plate = $\frac{\text{Force}}{\text{Permissible stress in plate}}$

So As = $\frac{33010}{140}$ = 235.79 $\mathrm{mm^2}$
Assume depth of the plate is 200 mm
So thickness of plate will be $\frac{235.79}{200}$ = 1.179 mm≈ 2 mm
But for the practical purpose take plate of size 200mm x 4mm.

3.2.4 Design of shear connector for shear

To transfer the shear stresses from existing shear reinforcement to outer plate, Shear connectors are used according to IS: 11384-1985.
As the maximum additional shear force among all the beams and from all the floors is 33.01 kN. So for this,
By table 1 of IS: 11384-1985 gives the Design strength of shear connectors for different concrete strengths.
Strength of shear connector for 12mm dia. and 62mm height used in M25 is 25.50 kN. So, 2 shear connectors are needed at a particular section to resist shear force of 33.01 kN.

4. CONCLUSION

The present study investigates the structural behaviour of an RC frame (G+2 Commercial building) under the additional load in the form of seismic forces. The structure is analyzed for two load cases. In first case (Gravity load case) structure is analyzed for only gravity forces and no seismic force is considered in this analysis while in second case (Seismic load case) structure is analyzed with consideration of seismic forces along with gravity forces. The seismic forces cause substantial change in beams forces in the structure.

4.1 Effects of additional seismic forces on beams

The results indicate that the significant increase is found in the shear force and bending moment in most of the beams. This increase of forces is more significant in plinth beams compared to roof beams. The comparison of critical value of shear force, hogging moments and sagging moments at each floor level is depicted in table 7.1.

Table 13 Effects of additional seismic forces on beams

Comparison of maximum shear force (kN) in beam			
	Max shear force		
Floor	STR-GR	STR-EQ	% increase
Plinth beam	54.35 (LC 3)	65.30 (LC 12)	20.15
First floor beam	99.15 (LC 3)	99.15 (LC 7)	0
Second floor beam	98.34 (LC 3)	98.34 (LC 7)	0
Third floor beam	54.01 (LC 3)	54.01 (LC 7)	0
Comparison of maximum hogging moment (kNm) beam			
	Max hogging Moment		
Floor	STR-GR	STR-EQ	% increase
Plinth beam	-42.68 (LC 3)	-68.54 (LC 14 & 15)	60.59
First floor beam	-86.00 (LC 3)	-102.60 (LC 14 & 15)	19.30
Second floor beam	-85.77 (LC 3)	-93.02 (LC 14 & 15)	8.45
Third floor beam	-46.49 (LC 3)	-48.09 (LC 14 & 15)	3.44
Comparison of maximum sagging moment (kNm) in beam			
	Max sagging moment		
Floor	STR-GR	STR-EQ	% increase
Plinth beam	26.20 (LC 3)	37.29 (LC 14 & 15)	42.33
First floor beam	65.08 (LC 3)	65.08 (LC 14 & 15)	0
Second floor beam	63.28 (LC 3)	63.28 (LC 14 & 15)	0
Third floor beam	39.79 (LC 3)	39.79 (LC 14 & 15)	0

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