

GLOBAL JOURNAL OF ENGINEERING SCIENCE AND RESEARCHES A STUDY ON SEISMIC EVALUATION AND FRP JACKETING ON EXISTING STRUCTURE

Chinnala Sharath Babu^{*1} & Shyamla Sunil Pratap Reddy²

^{*1}PG Scholar, Dept. of Civil Engineering, Vaagdevi College of Engineering, Warangal, India

²Professor, Dept. of Civil Engineering, Vaagdevi College of Engineering, Warangal, India

ABSTRACT

In the recent past, India has seen mass destruction due to failure of structures hit by earthquakes and consequently, lost a lot of lives. Hence, it is of utmost importance that attention be given to the evaluation of the adequacy of strength in framed RC structures to resist strong ground motions. In this project, a 50-year old four storey reinforced concrete structure has been considered, which lies in Zone II according to IS 1893:2000 classification of seismic zones in India. For non-structural members masonry infill has been assumed. In the Equivalent Static Method of analysis, the seismic load acting on the structure is assumed to be an equivalent static horizontal force applied to individual frames. The total force applied shall be equal to the product of the acceleration response spectrum and the seismic weight. It is used only for low to high rise buildings without significant coupled lateral-torsional modes.

The structure is designed in STAAD.Pro v8i, considering M15 concrete and Fe250 steel reinforcement for with and without earthquake loading conditions. The demand moments and shear have been noted down from the software analysis and compared to the capacities of the given section. FRP jacketing is the most appropriate method of retrofitting the failing members in the given 4-storey RC structure. The norms stated in ACI 440-2R.02 have been followed to calculate and suggest the method and scheme of application of FRPs to the member and also the number of plies to be used. Thereafter, an analysis has been done on the amount of efficiency achieved in dealing with the deficiency in the members. The FRP strengthening system has been checked for serviceability as well as creep-rupture limits since the entire modelling, analysis and design for the structure has been done using limit state design. The limitations of this project are that not much is known about the behavior of FRP materials and thus, no standardization has been achieved in it commercially. Also the code does not give a specific method of jacketing columns

Keywords: Equivalent Static Method, Demand Capacity Ratio, Flexural Capacity, Shear Capacity, Reinforced Concrete Structure, FRP Strengthening.

I. INTRODUCTION

Earthquakes around the world are single-handedly responsible for the destruction to life and property in large numbers. In order to mitigate such hazards, it is important to incorporate norms that will enhance the seismic performance of structures. According to the Seismic Zoning Map of IS 1893:2002, India is divided into five seismic zones, in ascending order of a certain zone factor which is assigned to them on the basis of their seismic intensity. The 4-storey RC Structure being analysed in this particular project is the main institute building of NIT Rourkela, which is located in the least susceptible zone i.e. zone II. However, considering that the primary structural system of the building is at least 50 years old, it was not designed according to the design provisions given in IS 1893:2002. Hence, it may fail in the event of any moderately strong tectonic activity in its vicinity. Studying the performance of the structure and suggesting suitable retrofit measures for the building would therefore be a necessity.

Stiffness, strength and ductility are the basic seismic response parameters taken into consideration while retrofitting. However, the choice of the technique to be applied depends on locally available materials and technologies, cost considerations, duration of the works and architectural, functional and aesthetic considerations/restrictions. Retrofit strategies are different from retrofit techniques, where the former is the basic approach to achieve an overall retrofit performance objective, such as increasing strength, increasing deformability, reducing deformation demands while the latter is the technical methods to achieve that strategy.

The choice of the type of FRP to be used is based on the tensile behaviour, stiffness, compressive behaviour, endurance to creep-rupture and fatigue, and durability. Carbon fibers are the best choice when it comes to using FRPs. It is flexible and can be made to contact the surface tightly for a high degree of confinement. The tensile strength and modulus of elasticity for carbon fibers is higher than that for glass or aramid fibers. It has the least coefficient of thermal expansion amongst FRP materials and is resistant to alkaline or acidic environments. Another advantage is that carbon fibers are highly resistive to creep-rupture under sustained loading and fatigue failure under cyclic loading. Fibers come in the form of flexible sheets which are impregnated in-situ in a matrix, typically a thermosetting polymer that also serves as an adhesive to the concrete structure. The matrix binds the fibers together, transfers the load onto the fibers and protects them from in-situ abrasion and adverse environmental effects. Epoxy resins, polyesters resins and vinyl esters are popularly used as matrix materials. Commercially available

Objective

Present research project aims at doing seismic evaluation for the institute main building and suggesting how to retrofit the failing members, using FRP jacketing. The institute main building is currently the most prominent building in the institute area. However, since it was constructed some 50 years earlier, it wasn't designed to withstand earthquakes. A thesis done earlier reveals that the structure will invariably fail when subjected to earthquake loads. The Demand Capacity Ratio (DCR) was calculated for beams and columns, only in the first storey. A large number of beams and columns were found to fail under flexural capacity. However, most of these members were found to pass in shear.

1. Analyse the seismic performance of the structure according to the design generated by STAAD.Pro v8i.
2. Calculate the Demand Capacity Ratio of the members of the remaining three storeys
3. Calculate and suggest number of plies to be used for jacketing the failing members with FRP.
4. Check the efficiency of the failing members in sustaining the demand moment or maximum shear generated due to the earthquake forces, after retrofitting.
5. Check whether the suggested level of jacketing satisfies all the required limits of design and is feasible or not.

II. FRP STRENGTHENING OF CONCRETE MEMBERS

The design philosophy for such sections is coherence with limit state principles. This approach sets acceptable levels of safety against the occurrence of both serviceability limit states (excessive deflections, cracking) and ultimate-limit states (failure, stress rupture, fatigue).

While calculating the flexural resistance of a section strengthened with an externally applied FRP system, the following assumptions are made-

Design calculation are based on the actual dimensions, internal reinforcing steel arrangement, material properties of the existing member being strengthened

The strains in the reinforcement and concrete are directly proportional to the distance from the neutral axis, that is a plane section remains plane even after loading

- There is no relative slip between the concrete and the external FRP reinforcement
- The shear deformation within the adhesive layer is neglected since it is very thin with slight variation in thickness

- The maximum usable compressive strain in concrete is 0.003
- The tensile strength of concrete is neglected
- The FRP reinforcement has a linear elastic stress-strain relationship to failure

An additional strength reduction factor is used to compensate for the assumptions made.

According to the code ACI 440.2R-02, the following flexural failure modes are to be investigated in a FRP-strengthened section-

- Crushing of the concrete in compression before yielding of the reinforcing steel
- Yielding of the steel in tension followed by rupture of the FRP laminate
- Yielding of the steel in tension followed by concrete crushing
- Shear/tension delamination of the concrete cover (cover delamination)
- Debonding of the FRP from the concrete substrate

By applying limit state analysis, the internal strain and stress distribution for a rectangular section of concrete can be found out at the ultimate stage. Thereafter, the strain level in the FRP reinforcements can be determined. Since FRP materials are linearly elastic until failure, the stress in the FRP reinforcement will be dictated by the strain developed. The maximum strain for the FRP will be developed at the point at which concrete crushes, FRP ruptures or FRP debonds from the substrate.

After determining the depth of the neutral axis by trial and error method, the nominal flexural strength of the section with FRP external reinforcement can be computed and the stress in the existing steel can be determined, under service loads, based on cracked elastic analysis.

Consequently, the stress in FRP under service loads can be determined.

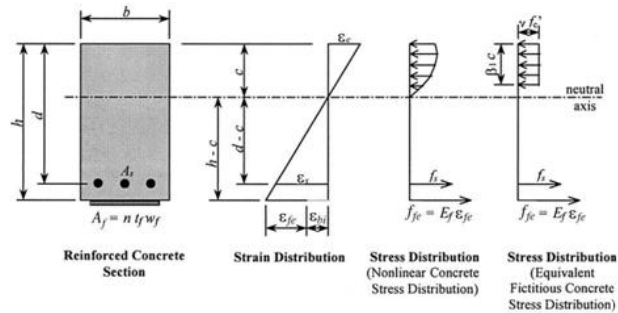


Fig 1 - Internal strain and stress distribution for a rectangular concrete section (FRP strengthened) under flexure at ultimate stage

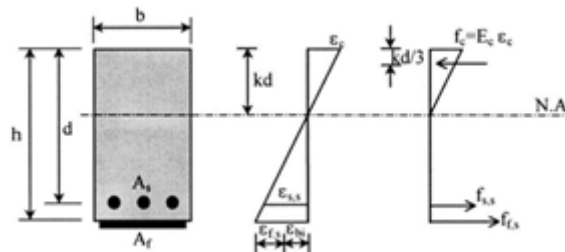


Fig. 2 Elastic strain and stress distribution

ACI- 440.2R-02 (Clause 11.3.2) mentions that confining rectangular sections with FRP is effective in improving the ductility of compression members but not in increasing their axial strength. Hence, due to lack of any suggested method, the design of FRP jacketing was performed only for the failing beams.

III. RESULTS

DCR Calculation for Beams

Moment Capacity of Beams

Table 1 -Ist Storey

Beam No.	Demand (kNm)	Capacity Sagging (kNm)	DCR Sagging	Result Sagging	Capacity Hogging (kNm)	DCR Hogging	Result Hogging
1	44.184	34.011	1.299109112	FAIL	34.011	1.2991091	FAIL
2	42.166	34.012	1.239738916	FAIL	34.012	1.2397389	FAIL
3	42.105	34.012	1.237945431	FAIL	34.012	1.2379454	FAIL
4	41.664	34.012	1.224979419	FAIL	34.012	1.2249794	FAIL
5	41.785	34.012	1.228536987	FAIL	34.012	1.228537	FAIL
6	42.158	34.012	1.239503705	FAIL	34.012	1.2395037	FAIL
7	41.522	34.012	1.220804422	FAIL	34.012	1.2208044	FAIL
8	44.431	34.01	1.306409879	FAIL	34.01	1.3064099	FAIL
11	44.328	35.622	1.244399528	FAIL	58.201	0.7616364	PASS
13	101.59	58.086	1.748958441	FAIL	125.645	0.8085479	PASS
14	102.405	50.328	2.034752027	FAIL	123.639	0.8282581	PASS
15	99.518	50.329	1.977349043	FAIL	112.7	0.8830346	PASS
16	92.931	40.971	2.268214103	FAIL	108.49	0.8565859	PASS
17	92.767	40.971	2.264211271	FAIL	108.49	0.8550742	PASS
18	98.034	50.328	1.947901764	FAIL	123.639	0.7929052	PASS
19	100.109	50.329	1.989091776	FAIL	110.541	0.9056278	PASS
20	92.615	44.856	2.064718209	FAIL	93.613	0.9893391	PASS
23	400.526	243.567	1.644418168	FAIL	460.281	0.8701771	PASS
24	109.261	75.889	1.439747526	FAIL	141.761	0.7707409	PASS
25	112.292	72.906	1.540229885	FAIL	127.291	0.8821676	PASS
26	106.209	69.672	1.524414399	FAIL	125.197	0.848335	PASS
27	97.311	51.021	1.907273476	FAIL	110.859	0.8777907	PASS
28	97.158	55.001	1.766476973	FAIL	111.248	0.873346	PASS
29	105.714	69.673	1.517287902	FAIL	126.993	0.8324396	PASS
30	107.219	69.673	1.538888809	FAIL	126.993	0.8442906	PASS
31	97.257	57.234	1.699287137	FAIL	122.974	0.7908745	PASS
35	306.418	301.599	1.01597817	FAIL	373.599	0.8201789	PASS
36	448.541	556.128	0.806542738	PASS	560.128	0.800783	PASS
37	294.079	190.597	1.542936143	FAIL	366.239	0.8029702	PASS
38	291.341	190.597	1.528570754	FAIL	366.239	0.7954942	PASS
39	292.528	190.597	1.534798554	FAIL	366.239	0.7987353	PASS
40	446.49	521.15	0.856739902	PASS	521.15	0.8567399	PASS

Table 2 -2nd Storey

Beam No.	Demand (kNm)	Capacity Sagging (kNm)	DCR Sagging	Result Sagging	Capacity Hogging (kNm)	DCR Hogging	Result Hogging
77	41.635	33.966	1.225784608	FAIL	33.966	1.225784608	FAIL
78	39.868	33.966	1.173761997	FAIL	33.966	1.173761997	FAIL
79	39.349	33.966	1.158482011	FAIL	33.966	1.158482011	FAIL
80	38.981	33.966	1.147647648	FAIL	33.966	1.147647648	FAIL
81	38.954	33.966	1.146852735	FAIL	33.966	1.146852735	FAIL
82	39.358	33.966	1.158746982	FAIL	33.966	1.158746982	FAIL
83	39.193	33.966	1.153889183	FAIL	33.966	1.153889183	FAIL
84	41.485	33.966	1.221368427	FAIL	33.966	1.221368427	FAIL
87	39.57	16.443	2.406495165	FAIL	16.297	2.428054243	FAIL
89	94.49	69.548	1.358630011	FAIL	48.516	1.947604914	FAIL
90	97.854	69.548	1.406999482	FAIL	48.516	2.016942864	FAIL
91	94.792	69.548	1.362972336	FAIL	48.516	1.953829664	FAIL
92	87.456	69.548	1.257491229	FAIL	48.516	1.802621815	FAIL
93	87.048	69.548	1.251624777	FAIL	48.516	1.794212219	FAIL
94	93.008	69.548	1.337320987	FAIL	48.516	1.91705829	FAIL
95	95.088	69.548	1.367228389	FAIL	48.516	1.959930744	FAIL
96	86.691	69.548	1.246491632	FAIL	48.516	1.786853821	FAIL
99	394.924	970.763	0.406818142	PASS	409.104	0.965338887	PASS
100	99.675	40.446	2.464396974	FAIL	40.446	2.464396974	FAIL
101	106.372	40.446	2.62997577	FAIL	40.446	2.62997577	FAIL
102	100.11	40.446	2.475152055	FAIL	40.446	2.475152055	FAIL
103	90.447	40.446	2.236240914	FAIL	40.446	2.236240914	FAIL
104	90.01	40.446	2.225436384	FAIL	40.446	2.225436384	FAIL
105	99.33	40.446	2.455867082	FAIL	40.446	2.455867082	FAIL
106	100.827	40.446	2.492879395	FAIL	40.446	2.492879395	FAIL
107	89.468	40.446	2.212035801	FAIL	40.446	2.212035801	FAIL
111	302.934	480.549	0.63039149	PASS	313.796	0.965385155	PASS
112	440.714	137.43	3.206825293	FAIL	136.211	3.235524297	FAIL
113	290.215	136.436	2.127114545	FAIL	135.57	2.14070222	FAIL
114	287.427	129.37	2.221743836	FAIL	128.566	2.235637727	FAIL
115	288.638	129.37	2.231104584	FAIL	128.566	2.245057014	FAIL
116	438.591	137.43	3.191377429	FAIL	136.211	3.219938184	FAIL
117	289.386	129.37	2.23688645	FAIL	128.566	2.250875037	FAIL
118	354.727	107.096	3.312233884	FAIL	106.659	3.325804667	FAIL
385	44.394	37.192	1.193643794	FAIL	37.192	1.193643794	FAIL

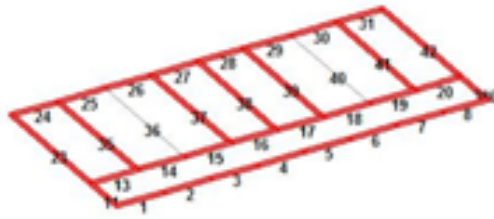
Table 3 -3rd Storey

Beam No.	Demand (kNm)	Capacity Sagging (kNm)	DCR Sagging	Result Sagging	Capacity Hogging (kNm)	DCR Hogging	Result Hogging
153	32.794	33.966	0.965494907	PASS	33.966	0.965494907	PASS
154	32.611	33.966	0.960107166	PASS	33.966	0.960107166	PASS
155	32.97	33.966	0.970676559	PASS	33.966	0.970676559	PASS
156	32.597	33.966	0.959694989	PASS	33.966	0.959694989	PASS
157	32.457	33.966	0.95557322	PASS	33.966	0.95557322	PASS
158	32.859	33.966	0.967408585	PASS	33.966	0.967408585	PASS
159	33.18	33.966	0.976859212	PASS	33.966	0.976859212	PASS
160	32.423	33.966	0.954572219	PASS	33.966	0.954572219	PASS
163	32.127	16.443	1.95384054	FAIL	16.297	1.971344419	FAIL
165	74.554	69.548	1.071979065	FAIL	48.516	1.536688927	FAIL
166	80.358	69.548	1.155432219	FAIL	48.516	1.656319565	FAIL
167	77.532	69.548	1.114798413	FAIL	48.516	1.59807074	FAIL
168	70.557	69.548	1.014507966	FAIL	48.516	1.454303735	FAIL
169	69.716	69.548	1.002415598	FAIL	48.516	1.436969247	FAIL
170	75.755	69.548	1.089247714	FAIL	48.516	1.561443647	FAIL
171	77.483	69.548	1.114093863	FAIL	48.516	1.597060763	FAIL
172	69.493	69.548	0.999209179	PASS	48.516	1.432372825	FAIL
175	362.301	970.763	0.373212617	PASS	409.104	0.885596328	PASS
176	76.084	40.446	1.881125451	FAIL	40.446	1.881125451	FAIL
177	85.568	40.446	2.115610938	FAIL	40.446	2.115610938	FAIL
178	80.124	40.446	1.981011719	FAIL	40.446	1.981011719	FAIL
179	71.249	40.446	1.761583346	FAIL	40.446	1.761583346	FAIL
180	70.217	40.446	1.736067844	FAIL	40.446	1.736067844	FAIL
181	79.147	40.446	1.956856055	FAIL	40.446	1.956856055	FAIL
182	80.246	40.446	1.984028087	FAIL	40.446	1.984028087	FAIL
183	68.936	40.446	1.704395985	FAIL	40.446	1.704395985	FAIL
187	275.402	480.549	0.573098685	PASS	313.796	0.877646624	PASS
188	429.371	137.43	3.124288729	FAIL	136.211	3.152249084	FAIL
189	264.009	136.436	1.935039139	FAIL	135.57	1.947399867	FAIL
190	262.013	129.37	2.025299528	FAIL	128.566	2.037964936	FAIL
191	262.65	129.37	2.03022339	FAIL	128.566	2.04291959	FAIL

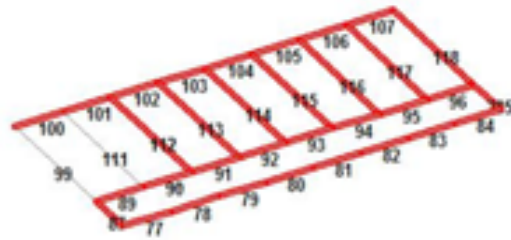
Table 4- Terrace

Beam No.	Demand (kNm)	Capacity Sagging (kNm)	DCR Sagging	Result Sagging	Capacity Hogging (kNm)	DCR Hogging	Result Hogging
229	17.826	33.966	0.524818937	PASS	33.966	0.524818937	PASS
230	22.182	33.966	0.65306483	PASS	33.966	0.65306483	PASS
231	21.264	33.966	0.626037803	PASS	33.966	0.626037803	PASS
232	20.986	33.966	0.617853147	PASS	33.966	0.617853147	PASS
233	20.92	33.966	0.615910028	PASS	33.966	0.615910028	PASS
234	21.106	33.966	0.621386092	PASS	33.966	0.621386092	PASS
235	21.8	33.966	0.641818289	PASS	33.966	0.641818289	PASS
236	17.114	33.966	0.503856798	PASS	33.966	0.503856798	PASS
239	26.452	16.443	1.608708873	FAIL	16.297	1.62312082	FAIL
241	32.311	20.766	1.555956853	FAIL	20.766	1.555956853	FAIL
242	37.358	20.766	1.798998363	FAIL	20.766	1.798998363	FAIL
243	34.641	20.766	1.668159491	FAIL	20.766	1.668159491	FAIL
244	29.257	20.766	1.408889531	FAIL	20.766	1.408889531	FAIL
245	29.388	20.766	1.41519792	FAIL	20.766	1.41519792	FAIL
246	33.476	20.766	1.612058172	FAIL	20.766	1.612058172	FAIL
247	35.213	20.766	1.695704517	FAIL	20.766	1.695704517	FAIL
248	28.521	20.766	1.373446981	FAIL	20.766	1.373446981	FAIL
251	181.786	124.965	1.454695315	FAIL	124.361	1.46176052	FAIL
252	34.818	40.446	0.860851506	PASS	40.446	0.860851506	PASS
253	42.967	40.446	1.06233002	FAIL	40.446	1.06233002	FAIL
254	38.097	40.446	0.941922563	PASS	40.446	0.941922563	PASS
255	31.638	40.446	0.782228156	PASS	40.446	0.782228156	PASS
256	31.923	40.446	0.789274588	PASS	40.446	0.789274588	PASS
257	37.402	40.446	0.924739158	PASS	40.446	0.924739158	PASS
258	39.093	40.446	0.96654799	PASS	40.446	0.96654799	PASS
259	30.256	40.446	0.748059141	PASS	40.446	0.748059141	PASS
263	177.643	129.279	1.374105617	FAIL	128.6	1.381360809	FAIL
264	182.458	106.074	1.720101062	FAIL	105.328	1.732283913	FAIL
265	170.208	140.375	1.212523598	FAIL	139.656	1.218766111	FAIL
266	168.496	140.375	1.200327694	FAIL	139.656	1.206507418	FAIL

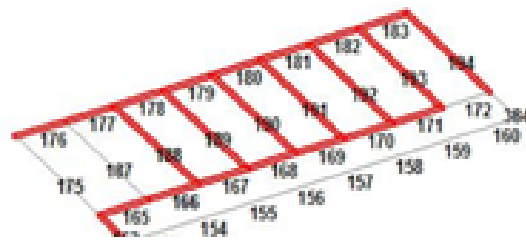
First Storey



Second Storey



Third Storey



Terrace

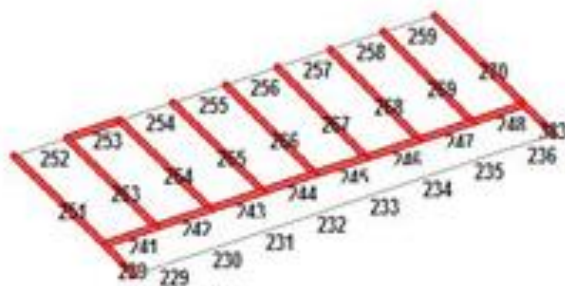


Fig. 3 Beams Failing due to Flexural Capacity

Shear Capacity of Beams

Table 5- 1st Storey

Beam No.	Max Shear (kN)	Shear Resisted (kN)	DCR	Result
1	57.278	131.97	0.434022884	PASS
2	52.439	131.97	0.39735546	PASS
3	52.464	131.97	0.397544897	PASS
4	52.069	131.97	0.394551792	PASS
5	52.035	131.97	0.394294158	PASS
6	52.506	131.97	0.397863151	PASS
7	51.974	131.97	0.393831931	PASS
8	56.553	131.97	0.428529211	PASS
11	34.446	119.133	0.289139029	PASS
13	102.93	131.97	0.779949989	PASS
14	113.103	131.97	0.85703569	PASS
15	111.837	131.97	0.847442601	PASS
16	106.236	131.97	0.805001137	PASS
17	106.308	131.97	0.805546715	PASS
18	110.865	131.97	0.84007729	PASS
19	112.105	131.97	0.849473365	PASS
20	107.247	131.97	0.812661969	PASS
23	231.938	220.076	1.053899562	FAIL
24	113.554	152.455	0.744836181	PASS
25	113.181	152.455	0.742389558	PASS
26	110.244	152.455	0.723124857	PASS
27	102.256	152.455	0.670729068	PASS
28	102.539	152.455	0.672585353	PASS
29	109.94	152.455	0.721130825	PASS
30	110.66	152.455	0.725853531	PASS
31	104.293	152.455	0.684090387	PASS
35	171.364	293.98	0.582910402	PASS
36	296.167	285.796	1.036288122	FAIL
37	170.205	293.98	0.578967957	PASS
38	168.774	293.98	0.574100279	PASS
39	169.559	293.98	0.576770529	PASS
40	295.45	253.308	1.166366637	FAIL
41	169.327	293.98	0.575981359	PASS
42	104.764	198.252	0.528438553	PASS
386	34.178	75.522	0.452556871	PASS

DCR Calculations for Columns

Flexure Capacity of Columns

Table 6- 1st Level

Column No.	Demand (kNm)	Capacity (kNm)	DCR	Result
352	26.384	25.515	1.034058397	FAIL
353	25.952	25.515	1.01712718	FAIL
354	32.554	25.515	1.275876935	FAIL
355	25.699	25.515	1.007211444	FAIL
356	34.657	25.515	1.35829904	FAIL
357	40.312	25.515	1.579933373	FAIL
358	32.443	25.515	1.271526553	FAIL
359	26.559	25.515	1.040917108	FAIL
360	24.558	25.515	0.962492651	PASS
363	82.374	18.88695	4.361424158	FAIL
364	140.198	18.88695	7.423009009	FAIL
365	216.939	22.308	9.72471759	FAIL
366	131.476	16.70625	7.869869061	FAIL
367	129.861	16.70625	7.773198653	FAIL
368	130.832	16.70625	7.831320614	FAIL
369	215.495	22.308	9.659987448	FAIL
370	130.419	16.70625	7.806599327	FAIL
371	163.128	14.3055	11.40316661	FAIL
374	209.662	9.443475	22.20178483	FAIL
375	135.942	9.443475	14.39533646	FAIL
376	212.667	44.616	4.766608392	FAIL
377	131.501	16.70625	7.871365507	FAIL
378	130.029	16.70625	7.78325477	FAIL
379	131.595	16.70625	7.876992144	FAIL
380	214.062	22.308	9.595750403	FAIL
381	130.962	16.70625	7.839102132	FAIL
382	158.025	9.537	16.569676	FAIL

FRP Design Calculations

Table 7- Beams on 1st Storey

Beam No.	Demand Moment (kNm)	ΦM_n (kNm)	$f_{s,s}$ (N/mm ²)	$f_{f,s}$ (N/mm ²)	No. of plies
1	44.484	73.606	42.843	8.704	2
2	42.166	73.603	46.409	9.429	2
3	42.105	73.603	45.787	9.302	2
4	41.664	73.603	44.652	9.072	2
5	41.785	73.604	44.652	9.072	2
6	42.158	73.603	45.841	9.313	2
7	41.522	73.605	44.381	9.016	2
8	44.431	73.607	40.465	8.221	2
11	44.328	44.581	65.29	13.465	3
13	101.59	105.26	61.986	12.615	6
14	102.405	105.248	66.404	13.514	6
15	99.518	105.254	64.868	13.201	6
16	92.931	105.28	58.09	11.822	6
17	92.767	105.281	57.412	11.684	6
18	98.034	105.259	64.401	13.106	6
19	100.019	105.255	64.472	13.121	6
20	92.615	105.28	55.364	11.267	6
23	400.526	402.935	196.815	38.647	11
24	109.261	116.137	49.397	9.973	5
25	112.292	116.12	52.977	10.696	5
26	106.209	116.134	49.01	9.895	5
27	97.311	116.155	42.166	8.513	5
28	97.158	116.158	41.036	8.285	5
29	105.714	116.132	50.264	10.148	5
30	107.219	116.134	48.792	9.851	5
31	97.257	116.154	41.951	8.47	5
35	306.418	400.504	71.041	13.987	2
37	294.079	325.429	87.786	17.267	2
38	291.341	315.971	89.603	17.622	2
39	292.528	315.971	89.885	17.678	2
41	294.893	315.972	89.787	17.658	2
42	220.503	232.143	91.712	18.007	5
386	42.932	48.863	41.931	8.651	4

IV. CONCLUSION

The analysis of beams by Equivalent Static Method revealed that most of the beams failed in flexural capacity. The number of failing beams decreased with increasing storeys. However, the number of beams failing in shear capacity were very less i.e. beams 23, 36, 40 in 1st storey; 112, 116, 118 in 2nd storey; 188, 192 in 3rd storey. For columns too, the analysis revealed that most of them failed in flexural capacity but were safe in shear.

1. Based on the above observations, the immediate need to counter deficiency in flexural capacity was identified and the FRP jacketing scheme was suggested only for beams, failing in flexure. Due to the high tensile strength and stiffness, stability under high temperatures and resistance to acidic/alkali/organic environments, carbon fiber was chosen as the FRP material to be used.
2. FRP strips that are commercially available are not made to a universal standard but a localized standard as set by the manufacturing company. Thus, the dimensions considered for the strips were strictly as per a design example in ACI 440.2R-02. The code states though, that wider and thinner FRP strips have lower bond stresses and hence, provide higher level of strength. Also, the plies were assumed to be bonded to the soffit of the beam using wet layup technique. A more confining wrapping scheme would have increased the strength further and hence, decreased the amount of FRP required.
3. The FRP design method used in this project is essentially trial and error where the value of the depth of neutral axis has to be assumed and compared with the value obtained. Thus, efforts were made so that the number of plies to be applied to a continuous series of beams, say in the longitudinal or transverse direction, would remain the same. This would ensure feasibility of application of the FRP system to the beams

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