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Comparison of steel stirrup and GFRP stirrup with specific reference to structural feasibility, self-weight, and cost using 'Ansys' software.

Comparación de estribo de acero y estribo de GFRP con referencia específica a la viabilidad estructural, el peso propio y el costo utilizando el software 'Ansys'.

Ar. Dhage Yogesh Girish[1]

Student of M. Arch, 2nd Year, CTES College of Architecture, Chembur, Mumbai, India. email: ygdhage10@gmail.com

ABSTRACT

To get in collaboration with modern infrastructure; various research studies indicate for sustainable replacement of steel rebar with glass fibre reinforced polymer (GFRP) rebars. In standard column, share of steel is up to 8%. The steel reinforced structures create problems such as handling of steel, transportation, self-weight of steel, and importantly its cost whereas GFRP rebar has properties like high strength, corrosion resistance, durability, and light weight & cost effective in nature. This research paper enhances replacing the steel stirrups in Column with GFRP stirrups, investigates the feasibility through structural behaviour using ANSYS Software, checks reduction of self-weight & Cost and is ultimately targeted to light weight structures or floating offshore structures. To check the feasibility of replacement, reduction of self-weight and cost, this research is divided into three stages. In first and second stage, it shows selection of GFRP as replacement material and structural feasibility. In further stage, it shows comparison between square, rectangular and circular column having conventional reinforcement, Semi GFRP and full GFRP reinforcement, to check effective self-weight and cost reduction. When Conventional Column compared with Semi GFRP and full GFRP reinforced column, effective reduction showed in full GFRP column and self-weight reduced up to 6 % and cost decreased by 42%. The effective reduction percentage was noticed in rectangular column as compared to other shapes where slightly less reduction is observed.

Keywords: GFRP, Steel Replacement, Structural feasibility, Reduction of Self-weight, Cost effective.

RESUMEN

Para ponerse en colaboración con la infraestructura moderna; varios estudios de investigación indican la sustitución sostenible de las barras de refuerzo de acero por barras de refuerzo de polímero reforzado con fibra de vidrio (GFRP). En la columna estándar, la proporción de acero es de hasta el 8%. Las estructuras reforzadas con acero crean problemas como el manejo del acero, el transporte, el peso propio del acero y, lo que es más importante, su costo, mientras que las barras de refuerzo GFRP tienen propiedades como alta resistencia, resistencia a la corrosión, durabilidad, peso ligero y rentabilidad por naturaleza. Este trabajo de investigación mejora el reemplazo de los estribos de acero en la columna con estribos de GFRP, investiga la viabilidad a través del comportamiento estructural utilizando el software ANSYS, verifica la reducción del peso propio y el costo y, en última instancia, está dirigido a estructuras livianas o estructuras flotantes en alta mar. Para verificar la factibilidad de reemplazo, reducción de peso

propio y costo, esta investigación se divide en tres etapas. En primera y segunda etapa, muestra selección de PRFV como material de reemplazo y factibilidad estructural. En una etapa posterior, muestra una comparación entre columnas cuadradas, rectangulares y circulares con refuerzo convencional, Semi GFRP y refuerzo completo de GFRP, para verificar el peso propio efectivo y la reducción de costos. Cuando se comparó la columna convencional con Semi GFRP y la columna reforzada con GFRP completo, se mostró una reducción efectiva en la columna con GFRP completo y el peso propio se redujo hasta en un 6 % y el costo disminuyó en un 42 %. El porcentaje de reducción efectivo se notó en la columna rectangular en comparación con otras formas donde se observa una reducción ligeramente menor.
Palabras clave: GFRP, Sustitución de acero, Viabilidad estructural, Reducción del peso propio, Rentabilidad.

INTRODUCTION

The steel has its disadvantages like discharge of greenhouse gases which causes global warming. Increasing demand of steel has more disadvantages like high density and fluctuating cost. Instead of steel reinforcement, some fibre reinforcements have been introduced to rectify these issues like excessive self-weight and cost of structure. Fibre Reinforced polymer (FRP) is a combined material prepared with polymer matrix which is reinforced with fibres. The different types of fibre materials used for making reinforcements such as, Glass (FRP), Basalt (FRP), Aramid (FRP). In construction, stirrups are provided to hold main reinforcement together in RCC structure. In this research, Glass Fibber Reinforced Polymer (GFRP) rebars diagnosed as an alternate construction material for reinforcements by comparing tensile strength, modulus of elasticity, Density, compressive strength with BFRP, AFRP and CFRP. This research will talk about replacement of conventional stirrup by GFRP rebar, which will help to retain the strength of a column and will help to reduce self-weight and cost of total material of column by Considering load carrying capacity, load deflection, buckling and failure due to lack of confinement reinforcement.

MATERIAL AND METHODS

Material study: Glass Fibre Reinforced Polymer (GFRP) includes high-quality corrosion resistant vinyl ester resin that increases the durability. It is a low-cost material made from glass fibres in a polymeric matrix. The fibres provide the main load carrying capability of the material and the polymer serves to protect the fibres and permit load transfer.

Advantages and limitations:

1) Non-Corrosive and Non-conductive and excellent fatigue resistance. So, performs very well in cyclic loading situations. Good impact resistance and it is Non-magnetic. Since it is Light weight and cost-effective saves cost in transport, handling, machineries, and extra labour.
2) LIMITATIONS - GFRP rebars are difficult to bend as compared to steel rebars, so stirrups cannot cast on site. To cast stirrups moulds and machineries are needed. It can only bend in minimum 600mm diameter.

Figure 1: GFRP stirrup casting in mold with GFRP fibers
(https://www.researchgate.net/publication/344870833_EXPERIMENTALSTUDIES_ON_REPLACEMENT_OF_STEEL_STIRRUPS)

1. Literature Study

Sr. No.	Author	Year	Title
1	Jawad fayaz, Bisalahalli	2019	Structural behaviour of concrete beams and columns reinforced with waste plastic incorporated gfrp (wpgfrp) rebars
2	Antonio Nanni, Francisco J. De Caso y Basalo	2019	Bond Behavior of GFRP Rebars in Reinforced Concrete Members under Flexure
4	Morteza Khatib, Francisco J. De Caso y Basalo	Aug-16	SEACON: Redefining Sustainable Concrete
5	Hindawi Publishing Corp.	2015	Tensile Strength of GFRP Reinforcing Bars with Hollow Section
6	David Trejo, Paolo Gardoni, Jeong Joo Kim,	Dec-09	LONG-TERM PERFORMANCE OF GFRP REINFORCEMENT: technical report
7	Hung-Liang Chen, Gangarao Hota	Sep-08	Steel versus GFRP rebars

|Stage-1 (frp selection)

Table 1Comparison of all FRP (http://5.imimg.com/data5/SELLER/Doc/2021/1/YS/IC/JX/2263299/frp-rebar.pdf)

PROPERTIES	STEEL	AFRP	BFRP	CFRP	GFRP
Tensile Strength (MPA)	390	1720	600-1500	3430	1100
Modulus of Elasticity, (GPA)	200	35	50-65	37	55
Bond Strength (MPA)	16	NA	NA	18	25
Thermal Conductivity	46	NA	NA	1.00	0.35
Linear Expansion coeff.	13-15	4.00		11-13	9-12
Density	7800	1450	1900	1560	1900
Relative Elongation	25	1.4	1.2	1.3	3
Compressive Strength	250	300	320	290	382

Table 2 Weight comparison of steel and GFRP rebar (https://www.constructioncost.co/how-to-measure-weights-of-steel-bar-reinforcement.html)

		STEEL REBAR			GFRP REBAR		
Diameter	Field	1 linear meter weight (KG)	Length at 1 ton (m)	Load Capacity (KG)	1 linear meter weight (KG)	Length at 1 ton (m)	Load Capacity (KG)
6	0.283	0.222	4.5	1.01	0.059	16.94	3.12
8	0.503	0.395	2.5	1.826	0.108	9.2	5.5
10	0.785	0.617	1.6	2.814	0.15	6.6	8.6
12	1.131	0.888	1.1	4.05	0.255	3.9	11.3
14	1.539	1.208	828	5.56	0.32	3	15.3
16	2.011	1.578	634	7.2	0.42	2.37	20.12

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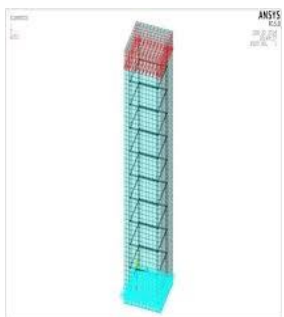
Observation and conclusion – stage (1)

Table 2 represents material properties of steel, AFRP, BFRP, CFRP and GFRP rebar. Tensile strength of AFRP is more than all other rebars. Modulus of elasticity is more in GFRP as well as it has less thermal conductivity. AFRP bars has lowest density and GFRP rebar has higher relative elongation and compressive strength as compared to other FRP bars. AFRP and GFRP rebars can be effective alternatives for steel rebars but availability of GFRP rebar in market and manufacturing of the same is better as compared to AFRP rebar, hence this research is to consider GFRP as alternate material for steel rebar.

Stage – 2 (software simulation)

FINITE ELEMENT ANALYSIS METHOD - Finite element analysis method (FEA/FEM) is the process of simulating the behaviour of specimen under given condition, so that it can be assessed. It is the basis of modern software simulation, with the results shown on a computer-generated colours scale as shown in below 'figure 3'. To generate the result on specimen, specimen need to divide in meshing and detailed report generated, and result shown in coloured format 'figure 2'.



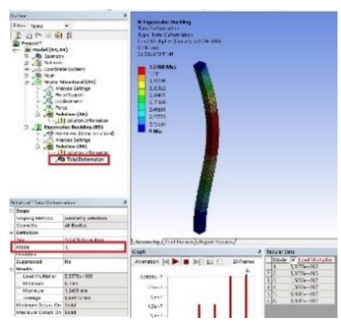


Figure 2: Meshing in Ansys   Figure 3: Result of specimen – shows in color coding

1.1 STEP BY STEP PROCEDURE FOR FEM USING ANSYS SOFTWARE

1.1.1 Simulation for spacing and different shape of columns is shown in table 3.

Table 3 Specimen taken for simulation

Shape	Sr.no.	Model No.	Size (mm)		Area	Height (mm)	Main Bars	Dia of links & spacing
			Width	Length				
Rectangular	1	RC- 6-114	300	943	282900	1200	6 bars of 12 mm	6 mm dia @ 114 mm c/c
	2	GFRP RC 6 - 114						
Square	1	SC- 6-114	532	532	283024	1200	6 bars of 12 mm	6 mm dia @ 114 mm c/c
	2	GFRP SC 6 - 114						
Circular	1	CC- 6-114	600 diameter		283024	1200	6 bars of 12 mm	6 mm dia @ 114 mm c/c
	2	GFRP CC 6 - 114						

To check feasibility of GFRP stirrup, table shows comparison of RC specimen and GFRP reinforced specimen having stirrup spacing of 114, 142, 190, 285 c/c. this spacing carried out in rectangular, square, and circular column by keeping same cross section area, height, concrete grade, vertical main bar, etc.

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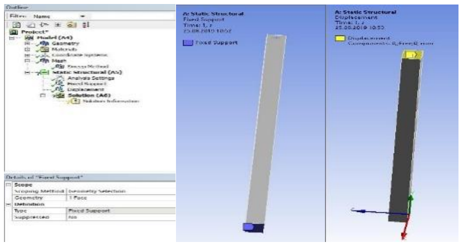


Figure 4: Applying properties and boundary conditions

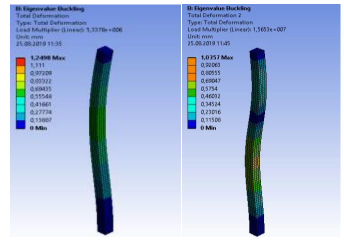


Figure 5: Maximum buckling

Providing meshing to specimen and applying material properties of steel and GFRP along boundary conditions from top and bottom to avoiding deformation. From the above test of specimen, image shows that maximum bending or buckling of specimen.

5.1.2. Simulation for Rectangular, Square and Circular column

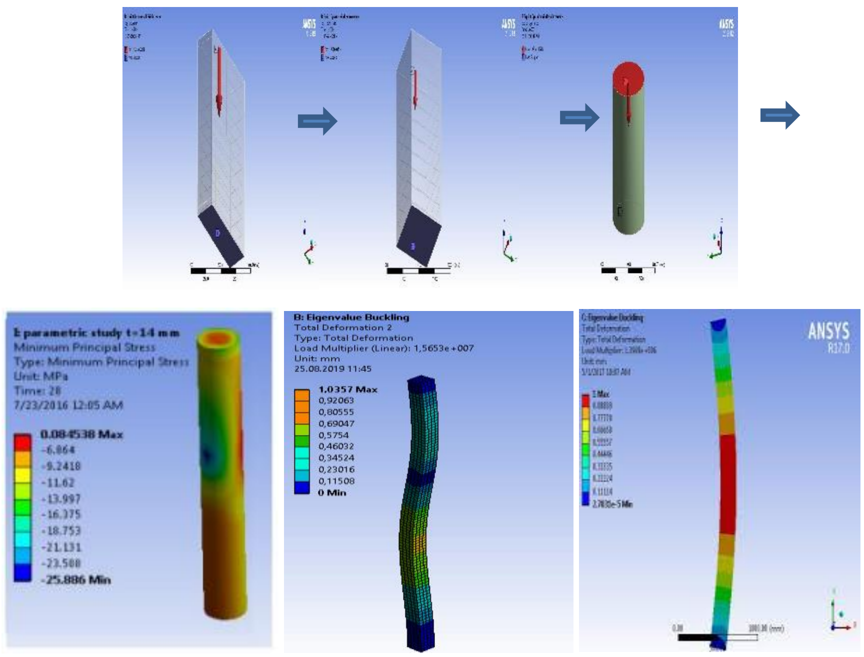
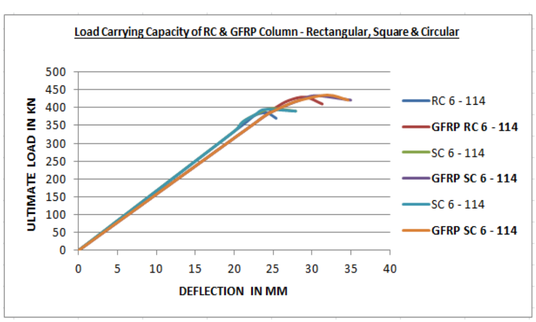
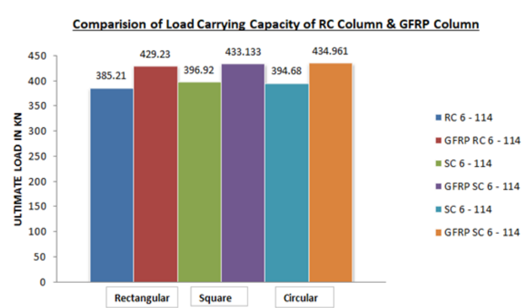


Figure 6: Process of Simulation - Meshing of rectangular, Circular and square specimen with application of boundary conditions and final result of Stress Distribution and Deformation

5.1.3. OBSERVATIONS



Graph 1: Observation graph of square, rectangular and circular specimen between RC and GFRP



Graph 2: Bar char of observation showing load carrying capacity of RC column and GFRP column in all three shapes

As conclusion, load carrying capacity of GFRP rectangular column increased by 11.42% as compare to Rc Column, whereas in square column and circular column, it increased by 10.9% and 10.2% respectively. By increasing spacing between stirrups / links along length of column, load carrying capacity of GFRP column decreased. Hence spacing between links should be maximum 200 mm. Specimen which had spacing below 200mm, shown exact replacement for Steel stirrups but as spacing increases above 200mm, GFRP showed the limitation. Increasing diameter of link by 2 mm, load carrying capacity slightly increased by 4.5%. In every shape of column load carrying capability mulltiplied by means of 10% to 11.5% and in rectangular column, it shows 0.5 % more as compared to circular and square. So, use of GFRP stirrup can be adopted and utilize in any shape of column. Weight of GFRP rebar is less, so self-weight of column and load on structure may reduce by some amount.

STAGE 3 (CALCULATION OF SELF-WEIGHT AND COSTING IN SPECIMEN)

GENERAL CONSIDERATIONS

a. Assuming, renctangular, squarish and circular column having cross section area of 0.28 sq.meter. Total height is 3m having 8 nos of main vertical bar and 8mm dia stirrups on 150 c/c.
b. Table shows the comparison between Conventional column, Column with GFRP stirrup and Column with GFRP main and GFRP stirrup for self-weight reduction, material quantity and cost reduction.
c. It calculates the self weight of columns by adding weight of concrete, weight of main bar stirrups. In terms of cost, it considers the cost(market rates) per keg of steel and GFRP rebar and calculates the cost.

Table 4 Comparison of self-weight and material cost between in all three shapes

		CIRCULAR COLUMN			SQUARE COLUMN			RECTANGULAR COLUMN		
Sr. no.	Properties	Conventional	GFRP stirrup	GFRP 6ain bar & stirrup	Conventional	GFRP stirrup	GFRP 6ain bar & stirrup	Conventional	GFRP stirrup	GFRP 6ain bar & stirrup
1	Column size	0.6 M DIA	0.6 M DIA	0.6 M DIA	0.532 X 0.532	0.532 X 0.533	0.532 X 0.534	0.3 X 0.943	0.3 X 0.944	0.3 X 0.945
2	Crs. Area (in sq.m)	0.282857	0.282857	0.282857	0.283	0.283	0.283	0.2829	0.2829	0.2829
3	Height	3	3	3	3	3	3	3	3	3
4	Volume	0.84857	0.84857	0.84857	0.849	0.849	0.849	0.8487	0.8487	0.8487
5	Weight of concrete in kg	1437	1437	1437	1437	1437	1437	1437	1437	1437
6	Weight of main rebar 16 mm dia in kg for 8 bars	37.87	37.87	10.1	37.87	37.87	10.1	37.87	37.87	10.1
7	Length of stirrup 8mm dia	1.889	2.198	2.198	2.248	2.128	2.128	2.606	2.486	2.486
8	Weight of one strirrup in kg	0.746	0.237	0.237	0.887	0.229	0.229	1.03	0.268	0.268
9	Weight of 20 strirrup in kg	14.92	4.74	4.74	17.74	4.58	4.58	20.6	5.36	5.36
10	Total weight of column in kg	1489	1479	1451	1492	1479	1451	1495	1480	1452
11	Total weight reduced in kg comparing with conventional in kg	NA	10	38	NA	14	41	NA	15	43
12	Total weight reduced in kg comparing with conventional in kg in percentage			2.54%			2.74%			3.00%
13	Weight of stirrup reduced in kg as compared with conventional in kg	NA	10.18	NA	NA	13.16	NA	NA	15.24	NA
14	Weight of stirrup reduced in kg as compared with conventional in %	NA	68.30%	NA	NA	73.68%	NA	NA	74%	NA
15	Cost of concrete (rs. 4000/cu.m) (1.8 rs / kg)	2586	2586	2586	2586	2586	2586	2586	2586	2586
16	Cost of 16 mm dia main bar (tata steel – 67.74/kg)	2537	2537	NA	2537	2537	NA	2537	2537	NA

17	Cost of 16 mm dia main bar (GFRP – 130/kg)	NA	NA	1313	NA	NA	1313	NA	NA	1313
18	Cost of 10 mm dia STIRRUP(tata steel - 67.55/kg)	999			1188			1380		
19	Cost of 10 mm dia sirrup(GFRP - 97/kg)		459.78	459.78		444.26	444.26		519	519
20	Total material cost of column	6122	5582	4358	6311	5567	4343	6503	5642	4418
21	Total material cost of column reduced in percentage	NA	8.82%	29%	NA	12%	31%	NA	13%	32%

RESULT

For this research, three stages were carried out. In 1st stage of material finalization,comparison of FRP proves that GFRP is effective material. In 2nd stage of software simulation, Software proves that GFRP rebar can replace to steel stirrup or conventional stirrup through structural behaviour.

In 3rd stage of self-weight and cost calculation, table shows comparison of conventional column, Column having GFRP stirrups & Column having GFRP stirrup as well as GFRP main bars in all three shapes. Circular column is provided with GFRP stirrup then the total weight is reduced by 10 KG (0.7 %), whereas square column & rectangular column resulted with 14 KG (0.9%) & 15 KG (1.0%) respectively as compared with total weight of conventional column. When square column is provided with GFRP stirrups and GFRP main bar then the total weight is reduced by 41 KG (i.e. 2.74%), whereas Circular and rectangular column resulted with 38 KG (2.54 %) & 43 KG (3.0%) respectively as compared with total weight of conventional column. In terms of costing, when column reinforced with GFRP stirrup and main bar, cost reduced by 29%, 31% and 32% in circular, square and rectangular shape respectively.

DISCUSSION

From stage 1, stage 2 and stage 3, we can conclude that, it is possibe to replace steel stirrup with GFRP stirrup as well as it reduces the material costing upto 35%. Here we can say that, GFRP reinforced column can be applicable to large scale project where column sizes are more, so self-weight can be reduced upto 8% to 9 %. Glass fiber reinforced polymer reinforced column reduces the self-weight of column, due to this, Cross section area of column may reduce as well as it can reduce size of the footing. Since it is lighter in nature, it will give considerable cost reduction in transportation, site handling, labor handling, and it may shorten the construction timeline.

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