GFRP Rebars in Reinforced Concrete Underground Water Tank: A Sustainable and Economical Alternative

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Abstract: **Glass Fibre Reinforced Polymer (GFRP) has been developed as a result of recent substantial technical breakthroughs in the construction sector, which have led to the creation of materials with desirable qualities. This research intended to examinethe strength characteristics of GFRP through a variety of tests, including elongation, tensile, and shear strength tests. Using specified ASTM regulations, a steel and GFRP underground water tank was constructed, and AutoCAD drawings and plans were made for a construction that will employ GFRP rebar. The financial viability of employing GFRP rebar over steel rebar in construction projects was assessed bycomparing the rate analyses of the design's reinforcements with those of steel rebar. Testing revealed that GFRPrebar has greater Tensile Strength and Shear Strength than traditional steel rebars of the same diameters. According to the results of the elongation test, the material had less elongation than typical steel rebar. The same- sized underground water tanks were designed twice, with steel used for one and GFRP Rebars for the other. While the steel structure's entire reinforcement weight was 3068.07 kg and costs 214766 Rs, the GFRP structure's total reinforcement weight was 697.5 kg and cost about 148572 Rs. A total cost efficiency of 30.82% was obtained by swapping steel rebars with GFRP reinforcements.**

Keywords: **GFRP, Rebar, Underground Water tank, Steel rebar, Reinforced Concrete.**

I. INTRODUCTION

In construction, GFRP, a durable and lightweight material, can serve the role of steel rebar. It is simple to handle and transport, which minimises costs and simplifies installation. Its increased tensile strength and lower tensile modulus lessen concrete cracking. GFRP has been utilised in several projects, including the pioneering 1956 building of a GFRP home at Tomorrowland in Disneyland California by MIT.

Batching, melting, fiberization, coating, and drying/packaging are the five phases in the manufacture of GFRP. Materials are precisely weighed and combined during batching. The mixture is refined to remove bubbles while melting takes place in a high-temperature furnace. Extrusion and attenuation during the fiberization process led to the development of filaments. Coating is done to make winding filaments easier and protect them from abrasion and breakage during handling. The filaments are then dried and formed into packets that may be processed further or transported.

The beneficial qualities of GFRP (Glass Fibre Reinforced Polymer) make it a perfect material for a variety of applications. First off, GFRP is mechanically stronger than steel since it has a greater specific resistance. Additionally, because of how lightweight it is, it is simple to install and doesn't require as much heavy structural framing, which lowers shipping costs.

Even at modest thickness, GFRP is an effective electrical insulator and extremely resistant to chemicals, acid rain, and salt water. GFRP is also inherently incombustible and does not produce smoke or pollutants when heated because it is a mineral substance. It is extremely durable and its low heat conductivity makes it extremely valuable in the construction sector. Additionally, GFRP has a high fatigue resistance, which makes it appropriate for use in earthquake-prone and highly cycled-loaded structures.

II. LITERATURE REVIEW

During the formulation of this paper, various research studies were of invaluable help. A program was carried out to gain insight into the flexural behaviour of concrete beams reinforced with glass fiber-reinforced plastic (GFRP) rebars by B. Benmoktane', O. Chaallalt and R. Masmoudi in 1995, which helped as a guideline us during the testing of the materials. An experimental study on 3.3 m long beams reinforced with two different types of GFRP rebars are presented and compared to that of conventional steel-reinforced concrete beams were done. In 2010, L.C. Hollaway published a paper that discusses the development of advanced polymer composite material applications in the civil/structural infrastructure and helped us understand the viability of the material in our structure. To understand the corrosion resistance, non-conductive and non-magnetic nature of the material a study conducted by Aditya S. Rajput and Umesh K. Sharma in 2017 was of great insight. In this study, a detailed experiments were performed with two prime motives of examining durability of Glass fiber reinforced polymer (GFRP) rebars in 6 different exposures (encompassing alkaline as well as real field exposures), and durability and serviceability of GFRP reinforced normal concrete beams in 3 different exposures. The cost efficiency of GFRP over steel rebars, and their relaxation properties, susceptibleness to creep rupture were understood through a paper published by Mohamed Zawam ; Khaled Soudki ; and Jeffrey S. West in 2017, a study into the short term behaviours and long term behaviours of members casted using GFRP bars was conducted. This paper presents the results of testing 12 beams as part of an ongoing program to investigate the long-term behaviour of GFRP prestressed concrete beams. This paper helped us understand the effects of various factors onto the members and its structural stability over various time spans. Iqbal, M., Zhao, Q., Zhang, D. et al. published a paper in 2021 which studied the Glass fiber reinforced polymer (GFRP) rebars reinforced in concrete are susceptible to degradation in harsh alkaline environments such as moist reinforced concrete and seawater and sea sand concrete. The residual tensile strength is reflected as an environment reduction factor and an extensive database comprising 715 tested specimens were collected from literature to develop GEP tree-based model. Aging tests of GFRP rebars were carried out in the laboratory to test the trained model. This was one of the most detailed experimentations carried out in the realms of GFRP materials. Using various strength testing methods derived from these papers and designing parameters our paper research and working was successfully assisted.

III. OBJECTIVES

- To Carry out Shear Strength, Tensile Strength, and Elongation Test on GFRP Rebar.
- Design Of Underground Water Tank Structure using:

1. Steel (Using ASTM).
2. GFRP (Using ASTM).

- Cost Estimation of Reinforcement.
- Overall Cost Comparison Between Steel Structure and GFRP Structure.

IV. METHODOLOGY

The research study's methodology is presented in a visual format through Figure 1, which outlines the chronological steps taken throughout the study. This flowchart conveys the various activities involved in the study, helping to demonstrate the systematic approach taken in the research. The subsequent sections provide in-depth details regarding the UG Water Tank design, elaborating on the specifics of the study's methodology.

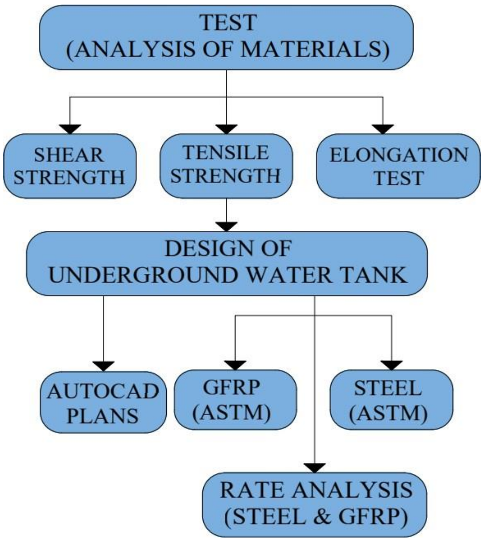

Fig. 1 Methodology Chart

A. Testing of GFRP rebar

i. Tensile Strength Test and Elongation Test

The Tensile strength test and Elongation test on GFRP rebars was conducted following the **ASTM D7205** standard procedure.

Fig. 2 Tensile Strength test

Fig. 3 Elongation Test

TABLE I: Tensile Strength of GFRP Rebar

Sample no.	Dia of Bar (mm)	Load (kN)	Tensile Strength (N/mm^2)	Avg. Tensile Strength (N/mm^2)
01	8	58	**1187.30**	**1192.22**
02		58	**1176.34**	
03		57	**1213.02**	
04	10	90	**1087.25**	**1091.13**
05		92	**1100.00**	
06		92	**1086.14**	
07	12	108	**1189.43**	**1195.31**
08		105	**1205.37**	
09		106	**1191.15**	
10	14	140	**1098.72**	**1159.58**
11		145	**1190.35**	
12		145	**1189.67**	
13	16	190	**1192.22**	**1159.55**
14		192	**1091.13**	
15		190	**1195.31**	

TABLE II: Elongation of GFRP Rebar

Sample no.	Dia of Bar (mm)	Load (kN)	Elongation (%)	Avg. Elongation (%)
01	8	58	**3.92**	**3.86**
02		58	**4.00**	
03		57	**3.68**	
04	10	90	**3.72**	**3.77**
05		92	**3.89**	
06		92	**3.71**	
07	12	108	**4.00**	**3.93**
08		105	**3.84**	
09		106	**3.96**	
10	14	140	**3.83**	**3.87**
11		145	**4.00**	
12		145	**3.79**	
13	16	190	**4.00**	**3.84**
14		192	**3.81**	
15		190	**3.73**	

ii. Shear Strength Test

The Shear Strength test on GFRP rebars was conducted following the **ASTM D7617/7617** standard procedure.

TABLE III: Shear Strength of GFRP Rebar

Sample no.	Nominal Día. of Bar (mm)	Shear Strength (N/mm^2)
1	10	**169.45**
2		**168.08**
3		**171.61**
4		**170.63**

B. Design of UG Water Tank (Using GFRP Rebars)

The water tank design was carried out in accordance with the guidelines and provisions specified in **ACI 318, ACI 224, ACI 440, ACI 350**:

Assuming the following data:

Water depth- (h) = 2.65 m, Freeboard = 150 mm, Total height of tank (H) = 2.65 + 0.15 = 2.8m, Capacity = 150 m^3 , Provide tank dimensions: **11.35m x 5m x 2.8m,** Roof slab thickness: 150 mm.Base slab thickness: 250 mm, Wall Thickness: 250 m

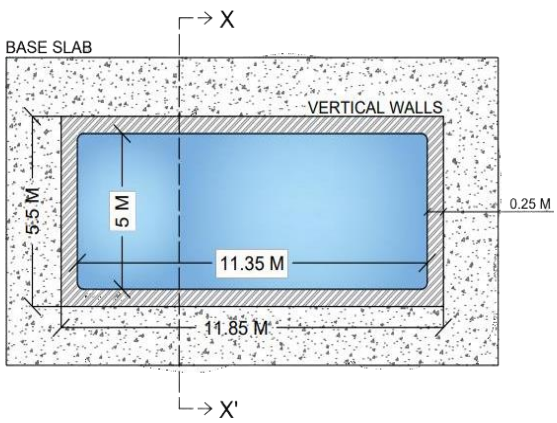

Fig. 4 Top View of UG Water Tank

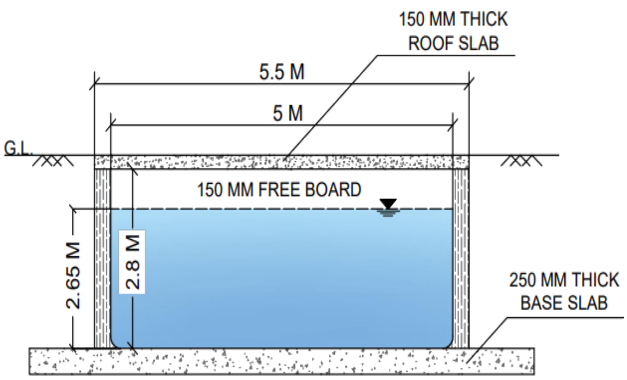

Fig. 5 Section of UG Water Tank

- **Design of Roof slab:**

Total load = 6.036 kN/m^2

Max bending moment, Mu = 20.8 kN.m

Area of steel, Arf = 141.37 mm^2 **(As per ACI 440.1R-06),**

Distribution Steel = 450 mm^2 **(As per ACI 350-01: Clause 14.3.2)Provide, 12mm ϕ @ 250 mm c/c**.

- **Design of Vertical Wall:**

Case 1: Water tank is full & surrounding soil is dry.Net Max Pressure on wall = 12534.67 N/ m^2

Max bending moment = 6.55 kN.m

Ultimate moment = 10.48 kN.mArea of steel, Arf = 36.5 mm^2

Provide, 12mm ϕ @ 150 mm c/c.

Case 2: Water tank is empty & surrounding soil is water logged.

Net Max Pressure on wall = 36320 N/m^{2}Max bending moment = 18.98 KN.m Ultimate moment = 30.368 KN.m

Area of steel, Arf = 750 mm^2

Provide, 12mm ϕ @ 150 mm c/c.

- **Design of Base slab:**

Total load per meter run = 55.625 KN.

Provide, 12mm ϕ @ 150 mm c/c as Main & Distribution steel.

C. Detailing of UG water tank (GFRP Rebar)

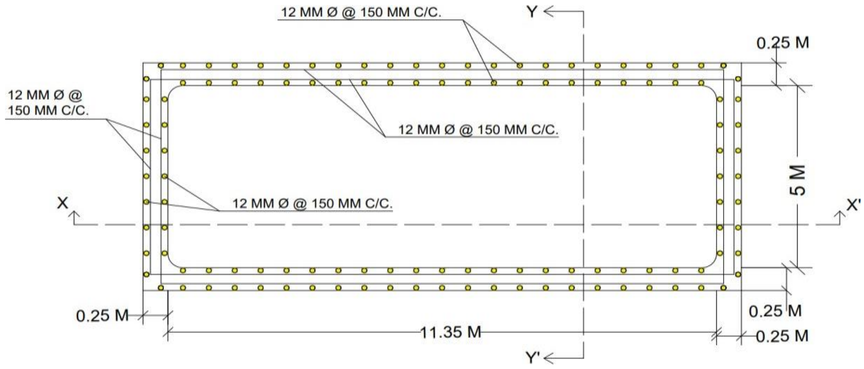

Fig. 6 Detailing of UG Water Tank (Top View)

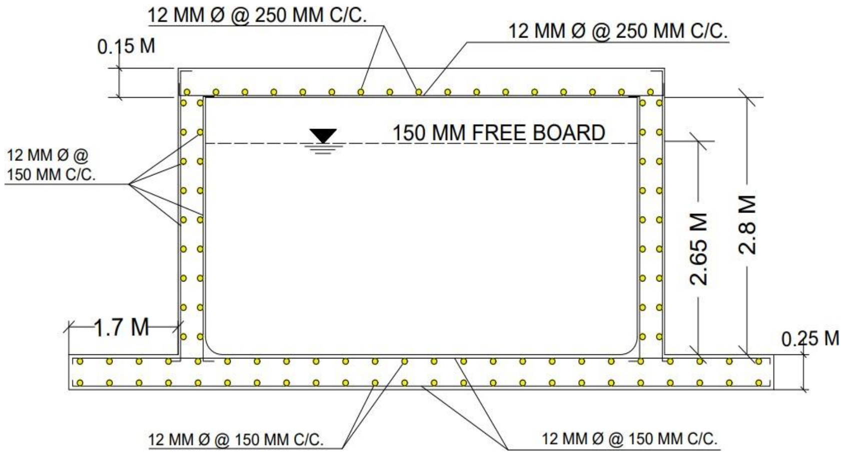

Fig. 7 Detailing (Section X-X')

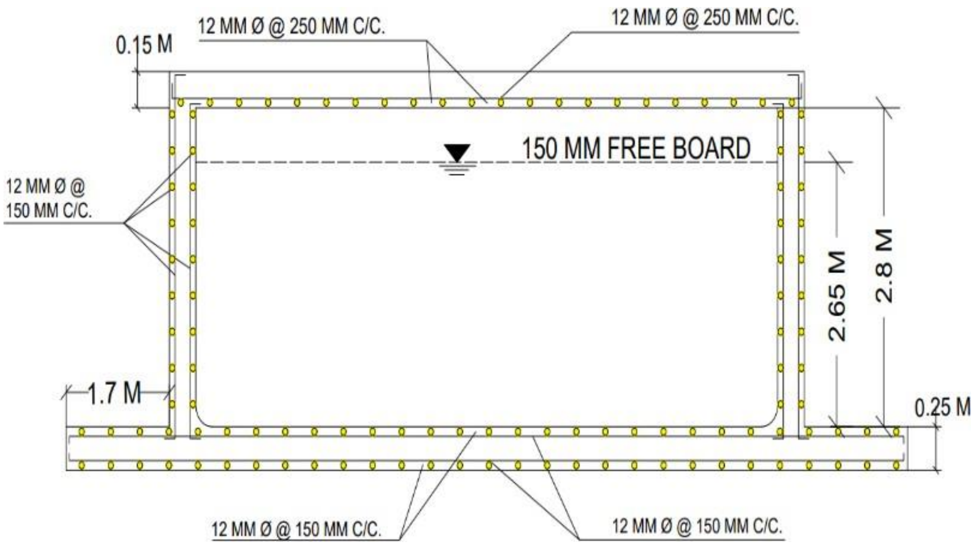

Fig. 8 Detailing (Section Y-Y')

D. Design of UG Water Tank (Using Steel Rebars)

The steel reinforcement designed using **ACI 318, ACI 350**, and **ACI 224** for a water tank with the same dimensions as the original GFRP reinforced tank resulted in identical reinforcement sizes and spacing.

The detailing of the underground water tank reinforced with GFRP rebars was done by referring to ACI 440.1R-15 and ACI 440.6-08, ensuring that the design and construction of the tank followed the established guidelines for the use of FRP in concrete structures.

E. Rate Analysis

i. Rate Analysis of GFRP Reinforcement

To estimate the cost of using GFRP reinforcement, the prevailing rates mentioned in the DSR, which is a commonly used schedule of rates by local governments in India for determining the cost of construction materials and services, were considered. The weight of the GFRP reinforcement per running meter was taken as 0.206.

TABLE IV: Cost Analysis of GFRP Reinforcement

Srno	Description	Día ofbar (mm)	Number	Cutting length	Total Length(m)	Quantity (kg)
01	Roof Slab (Main GFRP)	12	47	5.57	261.79	53.92874
02	Roof Slab (Distribution GFRP)	12	23	11.42	262.66	54.10796
03	Vertical Walls (MainGFRP)	12	228	2.87	654.36	134.79816
04	Vertical Walls (Dist.GFRP-Longer Span)	12	20	11.42	228.4	47.0504
05	Vertical Walls (Dist.GFRP-Shorter Span)	12	20	5.57	111.4	22.9484
06	Base Slab (Main GFRP)	12	104	8.97	932.88	192.17328
07	Base Slab (Distribution GFRP)	12	61	15.32	934.52	192.51112
	Total Quantity of GFRP					**697.51806 kg**
	Total Cost of GFRP @ ₹213/kg					**148571.3468 Rs**

ii. Rate Analysis of Steel Reinforcement:

The cost of using steel reinforcement was calculated by using the current rates listed in the DSR, a schedule of rates that Indian local governments often utilise to calculate the cost of construction as well as services. The weight of the Steel reinforcement per running meter was taken as 0.89.

TABLE V: Cost Analysis of Steel Reinforcement

Srno	Description	Día of bar (mm)	Number	Cutting length	Total Length(m)	Quantity (kg)
01	Roof Slab (Main Steel)	12	58	5.57	323.06	287.5234
02	Roof Slab (DistributionSteel)	12	23	11.42	262.66	233.7674
03	Vertical Walls (MainSteel)	12	228	2.87	654.36	582.3804
04	Vertical Walls (Dist.Steel- Longer Span)	12	20	11.42	228.4	203.276
05	Vertical Walls (Dist.Steel- Shorter Span)	12	20	5.57	111.4	99.146
06	Base Slab (Main Steel)	12	104	8.97	932.88	830.2632
07	Base Slab (DistributionSteel)	12	61	15.32	934.52	831.7228
	Total Quantity of Steel					**3068.0792 kg**
	Total Cost of GFRP @ ₹70/kg					**214765.544 Rs**

V. CONCLUSION

Glass Fiber Reinforced Polymer (GFRP) rebars are gaining popularity in construction due to their higher shear strength, making them a suitable replacement for steel rebars. With a shear strength of 170 N/mm^2, GFRP rebars outperform steel rebars with 120 N/mm^2 of the same diameter. However, their lower elongation of 4% compared to steel rebars with 25% elongation means that they require prefabrication as they are not suitable for on-site bending.

Apart from their high shear strength, GFRP rebars also have a higher tensile strength of approximately 1000 N/mm^2 compared to steel rebars with 500 N/mm^2. This makes them safe from tension and ideal for use in construction, as evidenced by their use in the construction of an underground water tank structure. Not only are GFRP rebars effectiveand safe to use, but they are also cost-efficient. A cost comparison revealed that the GFRP structure for the water tankwas 30.82% more cost-efficient than the steel structure, with a cost of ₹1,48,572 compared to ₹2,14,766 for an identicalsteel structure.

In conclusion, the higher shear and tensile strength of GFRP rebars, coupled with their cost-efficiency, make them a promising alternative to steel rebars for construction purposes.

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