VISVESVARAYA TECHNOLOGICAL UNIVERSITY

“Jnana Sangama”, Belgaum-590 014

A Dissertation Project Report on

“STUDY ON BEHAVIOUR OF RCC ELEMENT WITH GFRP AT ELEVATED TEMPERATURE”

Submitted in partial fulfilment for the award of the degree of

BACHELOR OF ENGINEERING IN

CIVIL ENGINEERING

BY

Mr. Chandrashekhar R (USN 1CR16CV013)

Ms. Deepika T G (USN 1CR16CV016)

Mr. Manoj Kumar P (USN 1CR17CV407)

Ms. Jennifer Tondikatti (USN 1CR17CV425)

Under the guidance of

Mrs. Vibha N Dalwai

DEPARTMENT OF CIVIL ENGINEERING

CMR INSTITUTE OF TECHNOLOGY

(ITPL MAIN ROAD BENGALURU-560 037)

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C.M.R. INSTITUTE OF TECHNOLOGY

(#32, AECS Layout, IT Park Road, Bengaluru-560 037)

Department of Civil Engineering

Certificate

This is to certify that the project work entitled "STUDY ON BEHAVIOUR OF RCC ELEMENT WITH GFRP AT ELEVATED TEMPERATURE" has been successfully completed by Mr. CHANDRASHEKHAR R (USN 1CR16CV013), Ms. DEEPIKA T G (USN 1CR16CV016), MR. MANOJ KUMAR P (USN 1CR17CV407) and MS. JENNIFER TONDIKATTI (USN 1CR17CV425) bonafide students of CMR Institute of technology in partial fulfilment of the requirement for the award of degree of Bachelor of Engineering in Civil Engineering of the "VISVESVARYA TECHNOLOGICAL UNIVERSITY", Belgaum during the academic year 2019-2020. It is certified that all corrections indicated for internal assessment has been incorporated in the Report. The project report has been approved as it satisfies the academic requirements in respect of project work prescribed for the said Degree.

Mrs. Vibha N Dalwai	Dr. Asha M Nair	Dr. Sanjay Jain
(Assistant Professor)	HOD	Principal
	Department of Civil Engineering CMR Institute of Technology	CMR Institute of Technology

Name of the Examiners	External Viva	Signature with date
1.		
2.		

C.M.R. INSTITUTE OF TECHNOLOGY

(#32, AECS Layout, IT Park Road, Bengaluru-560 037)

Department of Civil Engineering

DECLARATION

We, Mr. Chandrashekhar R (USN 1CR16CV013), Ms. Deepika T G (USN 1CR16CV016), Mr. Manoj Kumar P (USN 1CR17CV407) and Ms. Jennifer Tondikatti (USN 1CR17CV425), bonafide students of CMR Institute of Technology, Bangalore, hereby declare that dissertation entitled "Study on Behaviour of RCC Element with GFRP at Elevated Temperature" has been carried out by us under the guidance of Dr. Asha M Nair (HOD), Mrs. Vibha N Dalwai (Assistant Professor), Department of Civil Engineering, CMR Institute of Technology, Bangalore, in partial fulfilment of the requirement for the award of degree of Bachelor of Engineering in Civil Engineering of the Visvesvaraya Technological University, Belgaum during the academic year 2019-2020. The work done in this dissertation report is original and it has not been submitted for any other degree in any university.

Mr. Chandrashekhar R (USN 1CR16CV013)

Ms. Deepika T G (USN 1CR16CV016)

Mr. Manoj Kumar P (USN 1CR17CV407)

Ms. Jennifer Tondikatti (USN 1CR17CV425)

ABSTRACT

Reinforced concrete structures often have to face modification and improvement of their performance during their service life. In such circumstances there are two possible solutions: replacement or retrofitting. The main problem encountered in steel reinforced concrete structures is the corrosion of steel bars which eventually results in the failure and disintegration of the structure. FRP rebar has been considered as an alternative for this since corrosion is a material problem. FRP rebar is gaining commercial value mainly because it is resistant to corrosive agents and does not let concrete rust or weaken. GFRP rebar is a variant. All reinforcing fibres for FRP's. Their advantages are high tensile strength and excellent to use fibre reinforced plastic (FRP) as replacement of steel rebar's.

However the problem of corrosion associated with the steel rebars reduced its live time and the solutions such as the coating of the steel rebars are costly. Recent technologies have resulted in alternative reinforcing materials such as GFRP materials commercially available in the form of bars or sheets that can be bonded in concrete members to fulfil several desired properties. The most important is that the corrosion resistance feature and the elongated strain to failure that give enough time to alert before failure takes place. The strength of conventional reinforced concrete gets progressively reduced due to the degradation of the steel bars.

GFRP rebars appears to be a promising alternative to steel reinforcement in concrete. GFRP Bars being high strength, low self-weight and non-corrodible remains to be the better replacement for steel bars.

The study focuses on properties of GFRP at an elevated temperature varying from 50°C -300° C. This study will give an idea about advantages and disadvantages about GFRP at elevated temperature over steel at elevated temperature.

Keywords*: GFRP (Glass Fibre Reinforced Polymer), elevated temperature.*

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Mr. Chandrashekhar R (USN 1CR16CV013)

Ms. Deepika T G (USN 1CR16CV016)

Mr. Manoj Kumar P (USN 1CR17CV407)

Ms. Jennifer Tondikatti (USN 1CR17CV425)

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Chapter 1

INTRODUCTION

1.1 Overview

Reinforced concrete structures often have to face modification and improvement of their performance during their service life. In such circumstances there are two possible solutions: replacement or retrofitting. The main problem encountered in steel reinforced concrete structures is the corrosion of steel bars which eventually results in the failure and disintegration of the structure. FRP rebar has been considered as an alternative for this since corrosion is a material problem. FRP rebar is gaining commercial value mainly because it is resistant to corrosive agents and does not let concrete rust or weaken. GFRP rebar is a variant. All reinforcing fibres for FRP’s. Their advantages are high tensile strength and excellent to use fibre reinforced plastic (FRP) as replacement of steel rebar’s.

However the problem of corrosion associated with the steel rebars reduced its live time and the solutions such as the coating of the steel rebars are costly. Recent technologies have resulted in alternative reinforcing materials such as GFRP materials commercially available in the form of bars or sheets that can be bonded in concrete members to fulfil several desired properties. The most important is that the corrosion resistance feature and the elongated strain to failure that give enough time to alert before failure takes place. The strength of conventional reinforced concrete gets progressively reduced due to the degradation of the steel bars.

GFRP composite materials are essentially composed of glass fibre filament and resin matrix .the filaments have a high tensile strength and high modulus of elasticity and are the most common of insulating properties.

GFRP rebars appears to be a promising alternative to steel reinforcement in concrete. These rebar’s performs well in application where long term resistance against corrosion, low conductivity to electrical and electromagnetic fields, high strength- weight ratio and other such characteristics are imperative.

GFRP Bars being high strength, low self-weight and non-corrodible remains to be the better replacement for steel bars. The behaviour of GFRP-RC members and steel RC members tends to vary. The disadvantages of FRP materials are relatively high cost compared to steel, lack of design standards and codes.

The study focuses on properties of GFRP at an elevated temperature varying from 50°C -300° C. This study will give an idea about advantages and disadvantages about GFRP at elevated temperature over steel at elevated temperature.

1.2 Objectives

- Considered as new class of construction material.
- Corrosion resistant structural members.
- Use of alternative material to the steel reinforcement.
- Replacing of steel reinforcement as FRP so that usage of steel will reduce.
- To check the increased strength of the member when replaced with FRP bars.
- Structural members will be tested for resistance at elevated temperatures up to 250˚C

Chapter 2

LITERATURE

- Author: B.Benmokrane, O. Chaallal and R. Masmoudi
- Title: *"Glass Fiber Reinforced Plastic (GFRP) rebars for concrete structures"*

Summary: In this study, it has been demonstrated that GFRP composite materials are essentially composed of glass fiber filaments and resin matrix. The filaments have a high tensile strength and a high modulus of elasticity and are load bearing components. Glass fibers are the most common of all reinforcing fibers for FRPS. Their advantages are low cost, high tensile strength and excellent insulating properties. GFRP rebars appears to be a promising alternative to steel reinforcement in concrete, flexural behavior , ultimate load, deflection of GFRP reinforced beams was approximately three times greater than steel reinforced beams.

- Author: Mathieu Robert and Brahim Benmokrane
- Title: *"Behavior Of GFRP Reinforcing Bars Subjected To Extreme Temperatures"*

Summary: This study shows Corrosion of steel reinforced concrete members has stimulated the research on fiber-reinforced polymers to be used as an internal reinforcement for concrete structures. The behavior of glass fiber-reinforced polymer (GFRP) reinforcing bars subjected to extreme temperatures is very critical for applications in North America, especially in Canada. There is a high demand for experimental studies to investigate the thermal stability of strength, along with the ultimate elongation, and modulus of GFRP bars. This paper evaluates the variation of mechanical properties of sand-coated GFRP reinforcing bars subjected to low temperatures ranging from 0 to −100°C and elevated temperatures ranging from 23 to 315°C. Tensile, shear and flexural properties are investigated to get an overview of the thermal stability of mechanical properties of GFRP bars subjected to large variations of temperatures.

- Author: Shahaj Abdhul Adheem Jabbar and B.H. Farid
- Title: *"Replacement Of Steel Rebars By GFRP Rebars In Concrete Structures"*

Summary: This study in general shows GFRP reinforcing bar has higher tensile strength and higher corrosion resistance than steel rebar in addition, moderate flexural strength, these properties make GFRP is good alternative of steel in foundations application. According to the results, the mechanical characteristics can be concluded as the following: a. Tensile strength of bare GFRP bar is high, because they are anisotropic composite materials, GFRP rebar achieved yield tensile strength about 13% higher than that the steel rebar, while yield strain of GFRP is higher than steel about 58%. b. Bend strength of bare GFRP bar is good; where yield strength of GFRP rebar achieved 72% of steel rebar strength while yield strain of GFRP is higher than steel about 20%. c. Compressive strength of unreinforced concrete is 25.67 MPa; this value is acceptable according to British Standard specification. d. Flexural strength is good of sand coated GFRP RC at all curing ages. Increase of smooth GFRP RC flexural strength was about 76-81% and sand coated GFRP RC about 78-83% as compared with unreinforced concrete strength. However, strength of smooth GFRP achieved 71-75%, while sand coated strength achieved 77-82% of steel RC flexural strength. Decrease of flexural modulus of smooth GFRP RC around 66% and sand coated GFRP RC around 33% compared with steel RC. The flexural strain of Smooth GFRP RC is increased around 44% and sand coated GFRP around 14% as compared with steel RC at 28 day curing age.

- Author : Zein saleh, Matthew Goldston, Alex M. Remennikov, M. Neaz Sheikh

- Title: "*Flexural Design Of GFRP Bar Reinforced Concrete Beams*"

Summary: In this paper, two design codes for the flexural design of Fiber Reinforced Polymer (FRP) bar reinforced concrete beams have been reviewed and compared with the results of the experimental investigations of eight GFRP bar reinforced concrete (GFRP-RC) beams. It has been demonstrated that experimentally determined load carrying capacities, maximum deflections and energy absorbing capacities have been over- predicted by the relevant code recommendations for the under-reinforced and balanced GFRP-RC beams while being under-predicted for the over-reinforced GFRP-RC beams. This paper will provide a better understanding on the design methods in the two designers and rational suggestions for further improvements to the code design recommending's.

- Author: Tarek H. Almusallam

- Title: *"Load-Deflection Behavior Of RC Beams Strengthened With GFRP Sheets Subjected To Different Environmental Conditions"*

Summary: An investigation to examine the durability of reinforced concrete beams strengthened with glass fiber reinforced polymer (GFRP) laminates is performed. A total of 84 beam specimens were prepared for this study. The performance of these specimens was assessed through evaluating the flexural capacity and load-deflection relationships of the beams after placing them in different environments directly or indirectly with simulated field condition for a specified period of time. The specimens were divide into six categories which include controlled laboratory environment, outside environment (direct exposure), wet-dry normal water environment, wet-dry saline (NaCl) water environment and wet-dry alkaline (NaOH) environment. Each category consisted of unstrengthened and strengthened beams. The specimens of different wet-dry environment were exposure to a time cycle of two weeks inside the solution and two weeks outside the solution's the test results carried out after 6,12 and 24 months of exposure to different environment conditions, show that none of the aforesaid environmental conditions have a noticeable influence on the flexural strength of the beams.

- Author : Kiang Hwee Tan and Yuqian Zhou

- Title: *"Performance Of FRP-Strengthened Beams Subjected To Elevated Temperatures"*

Summary: The study shows flexural behavior of fiber-reinforced polymer (FRP) strengthened beams after exposure at elevated in an electrical furnace was investigated. Twenty five specimen making up unstrengthened beams were fabricated. Glass and basalt FRP systems were used with and without protective systems, which included a cement mortar overlay and two types of commercially available intumescent coatings. Typical temperature-time histories at the surface of FRP laminates, FRP-concrete interface, internal steel bars and center of beams were monitored by using two specimens. The other specimens were tested to failure under three-point bending after subjecting them to elevated temperatures. Test results indicated a general decrease in the initial stiffness and ultimate strength of the specimens with an increase in the exposed temperature. The protective systems appeared to preserve the structural integrity of glass FRP systems when the elevated temperature was less than approximately 700˚C Basalt FRP-strengthened beams exhibited smaller deterioration in ultimate strength than glass FRP-strengthened beams.

- Author: Venu R. Patil

- Title: *"Experimental Study Of Behavior Of RCC Beam By Replacing Steel Bars With Glass Fiber Reinforced Polymer And Carbon Reinforced Fiber Polymer"*

Summary: This study shows that RCC structures are usually reinforced with steel bars which are subjected to corrosion at critical temperatures and atmospheric conditions. Also the cost of steel reinforcement plays a significant role in any RCC construction. The rising prices of steel and their unavailability throughout the year have brought the contractors and engineers into a great trouble. The RCC structures can also be reinforced with other materials such as fibres specifically Glass Fibre Reinforced Polymer and Carbon Reinforced Fibre Polymer. This paper deals with the study of RCC beams when reinforced with the Glass Fibre Reinforced Polymer as a replacement of steel reinforcement and studying the behaviour of beam under flexure. The GFRP as an internal reinforcement has proved to be of great interest not only in India but worldwide.

- Author: Ashok R. Mundhada and Arun D. Pophale
- Title: *"Effect Of Elevated Temperatures On Performance Of RCC Beams"*

Summary: The present work was aimed at assessing the response of reinforced concrete beams to elevated temperatures. Effect of fire on RCC is a relatively less explored area because of the lesser use of RCC structures in Europe/USA as compared to steel structures & because of the inherent fire resistance of RCC structures. Forty five RCC beam samples were cast with identical cross-sectional areas, length and grade of concrete and clear cover to reinforcement. Six specimens were tested for the flexural strength using UTM before heating at room temperature and the results were tabulated. Twelve specimens each were heated in an electrical furnace at 550˚C for 1 hour and 2 hour respectively without any disturbance. Same procedure was repeated for 750˚C and 950˚C. After heating, these specimens were allowed to cool to room temperature and then tested for flexural strength on an UTM. Change in appearance & weight loss was also studied. Results revealed fairly robust performance up to 550˚C. The drop in flexural strength & other parameters but not alarming up to 750˚C. Around 950˚C, the RCC members lost their fidelity on all counts.

- Author: Mohsen Kobraei and Mohd. Zamin Jumaat
- Title: *"Using FRP-Bars In Concrete Beams"*

Summary: The study shows the use of fibre reinforced polymer (FRP) reinforcements in concrete structures has increased quickly in the last 10 years because of their excellent corrosion resistance, high tensile strength and good non-magnetization properties. However, the low modulus of elasticity of the FRP materials and their non-yielding characteristics results in large deflection and wide cracks in FRP reinforced concrete members. Different applications of using fibre reinforced polymer composite for external and internal strengthening in concrete beams are reviewed in this paper. The main structural behaviours of beams have been reviewed and discussed briefly. Finally, general concluding remarks are made along with possible future directions of research.

Chapter 3

MATERIALS

3.1 Cement

Cement is a binder, a substance that sets and hardens and can bind other materials together. The word “cement” traces to the Roman’s, who used the term opus caementicium to describe masonry resembling modern concrete that was made from crushed rock with burst lime as a binder. The volcanic ash and pulverized brick supplements that were added to the burnt lime, to obtain hydraulic binder, were later referred to as cementum, cimentum, cament and cement. Although the percentage of cement in concrete is around 15%, the role of the cement is very important in the strength and durability of concrete.

3.1.1 Tests on Cement

a). Normal Consistency Test: Standard consistency of a cement paste is defined as that consistency which will permit a vicat plunger having 10mm dia and 50mm length to penetrate to a depth of 33-35mm from top of the mould.

Table 3.1 (a)

NAME	CAPACITY/ RANGE /SIZE	ACCURACY/LEAST COUNT
Vicat Apparatus	Should be made as per Is: 5513	—
Balance	1000 g	1g
Measuring Cylinder	100 ml	1ml

Fig: 3.1.1 (a) Vicat apparatus

Procedure:

1. Take 400g of cement and place it in the enamelled tray.

2. Mix about 25% water by weight of dry cement thoroughly to get a cement paste. Total time taken to obtain thoroughly mixed water cement paste i.e. "Gauging time" should not be more than 3 to 5 minutes.

3. Fill the vicat mould, resting upon a glass plate, with this cement paste.

4. After filling the mould completely, smoothen the surface of the paste, making it level with top of the mould.

5. Place the whole assembly (i.e. mould + cement paste + glass plate) under the rod bearing plunger.

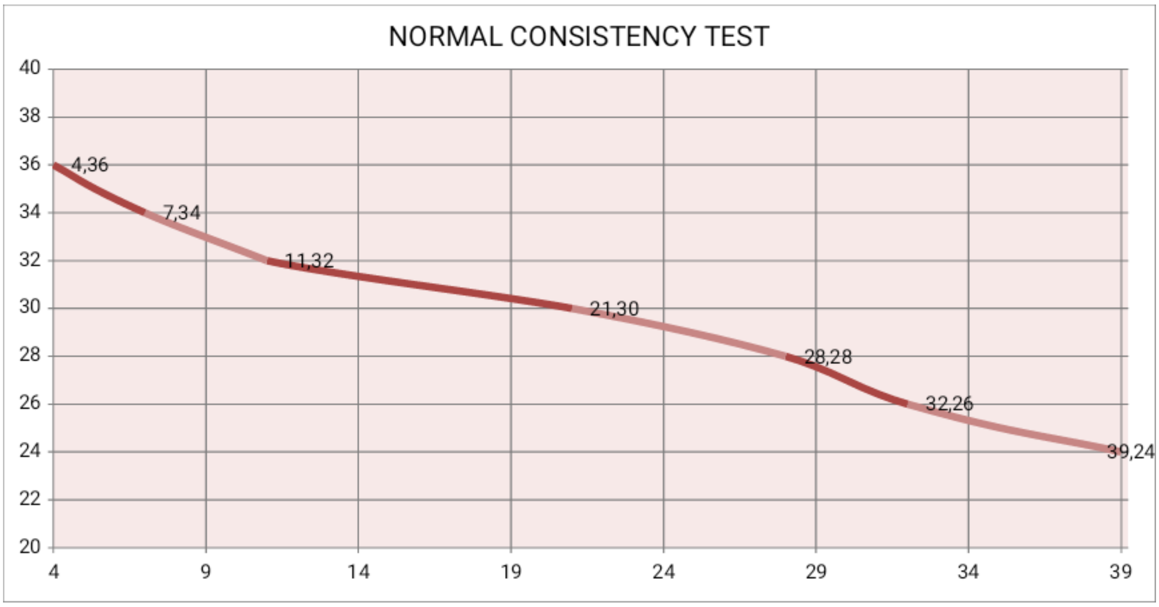
6. Lower the plunger gently so as to touch the surface of the test block and quickly release the plunger allowing it to sink into the paste.

7. Measure the depth of penetration and record it.

8. Prepare trial pastes with varying percentages of water content and follow the steps (2 to 7) as described above, until the depth of penetration becomes 33 to 35 mm.

Tabulations

% of water	Amount of water added (ml)	Depth of penetration (mm)
24	26	39
26	104	32
28	112	28
30	120	21
32	128	11
34	136	7
36	144	4



Graph 3.1

Result: The Normal consistency of the given sample is **35%**

b). Specific Gravity: Specific gravity of cement is the ratio of weight of volume of material to the same weight of volume of water.

Fig 3.1.1 (b) Le- Chatelier's apparatus

Procedure:

1. The bottle should be free from the liquid that means it should be fully dry. Weigh the empty bottle.
2. Next, fill the cement into the bottle up to top of the bottle around 50g and weigh with its stopper.

3. Add kerosene to the cement up to a top of the bottle. Mix well to remove the air bubbles in it. Weigh the bottle with cement and kerosene.
4. Empty the flask. Fill the bottle with kerosene up to the top and weigh the bottle.

Tabulations

1. Weight of empty bottle, w1	322.6g
2. Initial level of kerosene in the flask, h1	0.8
3.Weight of empty bottle + kerosene + weight of cement poured in the flask	386.2 g
4.Final level of kerosene e after pouring cement, h2	20.9
5.Mass of cement taken (w2 – w1)	63.6g
6.Volume of kerosene displaced (h2 – h1)	20.1
7.Density of cement = mass of cement / volume displaced	3.164 g/cc
8.Specific gravity of cement = density of cement / density of water	3.164

Result: Specific gravity of cement = **3.164**

3.2 Fine aggregates

Fine aggregates are obtained from a variety of sources. The sources of aggregate are in variably close to their demand locality; it is difficult to transport the large quantity of aggregate (in tonnes) and there will be high cost of transportation. They can be sourced from pits, river banks and beds, the seabed, gravelly or sandy terraces, beaches and dunes. The other deposits that provide granular materials can be processed with minimal extra effort or cost. Sand and gravel, which are unconsolidated sedimentary materials, are important sources of natural aggregate. The occurrence of high quality natural sands and gravels within economic distance of major urban areas may be critical for viable concrete construction in those areas.

Fine aggregate (Sand) is a naturally occurring granular material composed of finely divided rock and mineral particles. It is defined by size, being finer than gravel and coarser than silt. Sand can also refer to a textural class of soil or soil type; i.e. a soil containing more than 85% sand-size particle by (mass).

In concrete 30- 40% of the volume is occupied by fine aggregate. Aggregate passes through 9.5mm sieve and almost passes through the 4.75mm sieve and predominantly retains on the 75-micron sieve. Most of the fine aggregate passes 4.75mm IS sieve and contains a huge amount of coarser materials.

Fine aggregate is generally considered to have a lower size limit of 0.07mm or 0.06mm. Originally, all natural aggregate particles are a part of larger mass.

3.2.1 Tests on Fine Aggregate

a). Specific Gravity of Sand: Specific gravity is the ratio of the weight in the air of a given volume of a material to the weight in air of an equal volume of distilled water. Specific gravity of river sand is around 2.5 and manufactured sand is around 2.7


Fig 3.2.1 (a) pycnometer

Procedure:

1. Take a clean, dry pycnometer, and find its weight with its cap and washer (W1).
2. Put about 500g of sand in pycnometer and find its weight (W2).
3. Fill the pycnometer and filled in sand as step2, with distilled water and measure its weight (W3).
4. Empty the pycnometer value, clean it thoroughly, and fill it with clean water only to the hole of the conical cap, and find its weights (W4).
5. Repeat the same procedure at least for three different samples.

Tabulations

	Trail 1	**Trail 2**
1.weight of pycnometer , w1g	657	657
2.weight of aggregate + pycnometer, w2g	957	957
3.weight of aggregate + pycnometer +water, w3g	1720.2	1719

4.weight of water + pycnometer, w4g	1532.2	1535
5.Specific gravity of sand = (w2 - w1)/(w2 - w1) - (w3 - w4)	2.68	2.59

Result: Specific gravity of sand **= 2.63**

b). Sieve Analysis: Sieve analysis helps to determine the particle size distribution of the coarse and fine aggregates. This is done by sieving the aggregates as per IS: 2386 (Part I) –1963. In this we use different sieves as standardized by the IS code and then pass aggregates through them and thus collect different sized particles left over different sieves.

Fig 3.2.1 (b) Sieve analysis apparatus

Procedure:

1. Using the sieve sizes required by the specification, arrange sieves in descending order with the largest size on top.

2. If using a mechanical sieve shaker, place the set of sieves on top and pour the prepared aggregate on to the top sieve, cover the stack of sieves and pan, turn on the machine, and set it to shake for at least 5minutes.

3. If hand sieving, start with the largest size, and progress toward the smaller sieve sizes; move the sieves in lateral and vertical motions accompanied by a jar ring action to keep the material moving

continuously over the surface of the sieves. Hand manipulation without forcing particles through the sieve is permitted.

4. For either mechanical or hand sieving, sieve the material until not more than 1% by mass of the residue on any individual sieve will pass that sieve during 1 minute of continuous hand sieving.

5. Using a scale with a capacity large enough to obtain the mass of the total sample, determine the mass of the fine aggregate to the nearest 0.1 g and coarse aggregate to the nearest 1g.

6. First, determine the mass of the aggregate retained on the largest sieve size and record the value.

7. Add the contents of the next largest sieve size on the scale, obtain the cumulative mass of the two sizes and record this mass.

8. Finally, add the contents of the next size, and repeat this operation until the contents of the smallest sieve size used is empty, and cumulative mass has been obtained and recorded.

9. When the specifications require percent passing, record the weights retained on each sieve individually.

Tabulations

Sl. No	IS sieve size	Empty wt. of sieve, kg	Wt. Of sieve + sand, kg	Mass of sand retained, kg	% retained on each sieve	Cumulative % retained	% passing
1	4.75	0.373	0.373	0	0	0	100
2	2.36	0.288	0.288	0	0	0	100
3	1.18	0.36	0.545	0.185	37	37	63
4	0.6	0.361	0.464	0.103	20.6	57.6	42.4
5	0.3	0.317	0.379	0.062	12.4	70	30
6	0.15	0.3	0.37	0.07	14	84	16
7	pan	0.288	0.368	0.08	16	100	0

The results should be calculated and reported as: The cumulative percentage by weight of the total sample. The percentage by weight of the total sample passing through one sieve and retained on the next smaller sieve, to the nearest 0.1percent. The results of the sieve analysis may be recorded graphically on a semi-log graph with particle size as abscissa (log scale) and the percentage smaller than the specified diameter as ordinate.

3.3 Coarse aggregate

The material which is retaining on BIS test sieve No.480 is termed as coarse aggregate. The broken stone is generally used as coarse aggregates. The nature of work decides the maximum size of the aggregate. For the thin slabs and walls, the maximum size of coarse aggregate should be limited to one– third the thickness of concrete section. The aggregate to be used for cement concrete work should be hard, durable and clean. The aggregate should be completely free from lumps of clay, organic and vegetable matters, fine dust, etc. Crushed coarse aggregate are collected from local source. The size varying from 20 to 4.75mm. Aggregates were in saturated surface dry (SSD) condition and these are prepared to meet the requirements of IS code.

3.3.1 Tests on Coarse Aggregate

a). Impact Value Test: For determination of the aggregate impact value of coarse aggregate, which passes12.5mm IS sieve and retained on10mm IS sieve. Referencing Standards IS: 2386 (Part IV) -1963 Methods of test for aggregate for concrete Part IV Mechanical Properties.

Fig 3.3.1 (a) Impact Value Test Apparatus

Procedure:

1. The cylindrical steel cup is filled with 3 equal layers of aggregate and each layer is tamped 25 strokes by the rounded end of tamping rod and the surplus aggregate struck off, using the tamping rod as a straight edge.

2. The net weight of aggregate in the cylindrical steel cup is determined to the nearest gram (WA) and this weight of aggregate is used for the duplicate test on the same material.

3. The cup is fixed firmly in position on the base of the machine and the whole of the test sample is placed in it and compacted by a single tamping of 25 strokes of tamping rod.

4. The hammer is raised until its lower face is 380mm above the upper surface of the aggregate in the cup, and allowed to fall freely on to the aggregate 15 times.

5. The crushed aggregate is removed from the cup and sieved on 2.36mm IS sieve until no further significant amount passes in one minute.

6. The fraction passing the sieve is weighed to an accuracy of 0.1g (WB).

Tabulations

	Trial 1 (kg)	Trial 2 (kg)
1.Weight of empty mould	0.61	0.61
2.Weight of mould + aggregate	0.935	0.93
3.Weight of aggregate, W1	0.319	0.32
4.Weight of aggregate passing through 2.36 mm sieve, W2	0.088	0.09
5.Weight of aggregate retained on 2.36 mm sieve	0.231	0.23
6.Aggregate impact value in %	27.5862069	28.125

Result: The Aggregate impact value is **27.86%**

(b) Specific Gravity of Coarse Aggregate: Specific gravity is defined as the ratio of weight of aggregate to the weight of equal volume of water. The specific gravity of an aggregate is considered to be a measure of strength or quality of the material. Aggregates having low specific gravity are generally weaker than those with high specific gravity. Specific gravity of coarse aggregate is found using the wire basket method.

Fig 3.3.1 (b)

Procedure:

1. Take about 2kg of the coarse aggregate sample and the place in a wire basket. Now immerse the basket into a tank of distilled water.
2. The entrapped air is removed from the sample by lifting the basket 25mm above the base of tank and allowing to drop 25 times at the rate of about one drop per second.
3. The basket and aggregate is then left immersed completely in water for next 24 hours. Then weighed while suspended in water (w1).
4. The aggregate in the basket is then removed from water and allowed to drain for few minutes and then transferred to an absorbent cloth.
5. The empty basket is then jolted in water again for 25 times and weighed (w2).
6. The surfaced dried aggregate is then weighed (w3). While some amount of aggregate are let to oven dry at 110˚C.
7. After 24 hours the oven dried aggregates are weighed as (w4).

Tabulations

1. Weight of saturated aggregate and basket in water, w1 g	1940
2. Weight of basket in water, w2 g	694
3. Weight of saturated aggregates in air, w3 g	2000
4. Weight of oven dried aggregates in air, w4 g	1990
5. Specific Gravity = w4/(w4-(w1-w2))	2.67

Result: Specific gravity of coarse aggregate is **2.67**

3.4 Steel and FRP (Fibre Reinforced Plastic)

a) Steel: An alloy composed primarily of iron, steel is one of the defining materials of the last two centuries. Traditionally, steels were combinations of iron and carbon, but there are now many classes of steel, alloy of iron with other materials and exclude carbon. The key attributes of a steel are that it be iron- based and formable into permanent shapes.

Steel is typically measured by a number of qualities, including its hardness, machinability, and resistance to wear. Various alloys provide different advantages and are therefore used for certain applications where those qualities are useful. For instance, stainless steel, an alloy containing at least 10.5% chromium and usually nickel, is corrosion resistant, and suits a wide range of medical applications.

Steel can be shaped in an endless assortment of forms. However, most steel is produced form a chinning in bars, steel rods, sheets, balls and tubes.

b) FRP: Fibre-reinforced plastic (FRP) (also called fibre- reinforced polymer, or fibre reinforced plastic) is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass (in fibre glass), carbon (in carbon fibre reinforced polymer), aramid, or basalt. Rarely, other fibres such as paper, wood, or asbestos have been used. The polymer is usually an epoxy, vinyl ester, or polyester thermo setting plastic, though phenol formaldehyde resins are still in use.

FRP’s are commonly used in the aerospace, automotive, marine, and construction industries.

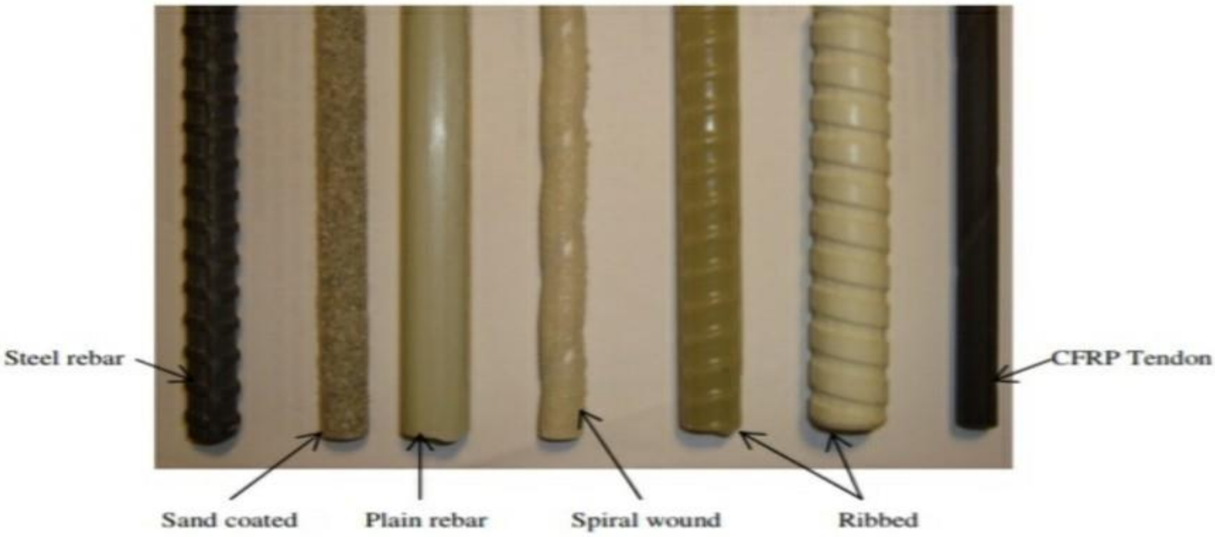


Fig 3.4 Different types of commercially available GFRP rebars

CHAPTER 4

DESIGN REQUIREMENTS

4.1 CONCRETE MIX DESIGN

The process of selecting suitable ingredients of concrete and determining their Relative amounts with the objective of producing concrete of the required, strength, durability, and workability as economically as possible, is termed the concrete mix design. The proportioning of ingredient of concrete is governed by the required performance of concrete in 2states, namely the plastic and the hardened states. If the plastic concrete is not workable, it cannot be properly placed and compacted.

The property of workability, therefore, becomes of vital importance. The compressive strength of hardened concrete which is generally considered to be an index of its other properties, depends upon many factors, e.g. quality and quantity of cement, water and aggregates; batching and mixing; placing, compaction and curing. The cost of concrete is made up of the cost of materials, plant and labour. The variations in the cost of materials arise from the fact that the cement is several times costly than the aggregate, thus the aim is to produce as lean mix as possible. From Technical point of view the rich mixes may lead to high shrinkage and cracking in the structural concrete, and to evolution of high heat of hydration in mass concrete which may cause cracking. The actual cost of concrete is related to the cost of Materials required for producing a minimum mean strength called characteristic Strength that is specified by the designer of the structure. This depends on the Quality control measures, but there is no doubt that the quality control adds to the Cost of concrete. The extent of quality control is often an economic compromise, and depends on the size and type of job. The cost of labour depends on the workability of mix, e.g. a concrete mix of inadequate workability may result in a high Cost of labour to obtain a degree of compaction with available equipment.

4.2 Requirements of Concrete Mix Design:

- The requirements which form the basis of selection and proportioning of mix

Ingredients are the minimum compressive strength required from structural consider at ion.

- The adequate workability necessary for full compaction with the compacting

Equipment available.

- Maximum water cement ratio and/or maximum cement content to give adequate durability for the particulars site conditions.

- Maximum cement content to a void shrinkage cracking due to temperature cycle in mass concrete.

4.3 Types Of Mixes:

i. Nominal Mixes

In the past the specific at ions for concrete prescribed the proportions of cement, fine

And coarse aggregates. These mixes of fixed cement aggregate ratio which ensures adequate strength are termed nominal mixes. These offer simplicity and under normal circumstances, have a margin of strength above that specified. However, due to the variability of mix ingredients the nominal concrete for a given workability varies widely in strength.

ii. Standard mixes

The nominal mixes of fixed cement aggregate ratio(by volume) vary widely in strength and may result in under or over rich mixes. For this reason, the minimum compressive strength has been included in many specifications. These mixes are termed standard mixes. IS456 2000 has designated the concrete mixes into a number of grades as M10, M15, M20, M25, M30, M35 and M40. In this designation the letter M refers to the mix and the number to the specified 28day cube strength of mix in N/ mm2. The mixes of grades M10, M15, M20 and M25 correspond approximately to the mix proportions (1:3:6), (1:2:4), (1:1.5:3) and (1:1:2) respectively.

iii. Designed Mixes:

In these mixes the performance of the concrete is specified by the designer but the Mix proportions are determined by the producer of concrete, except that the minimum cement content can be laid down. This is most rational approach to the selection of mix proportions with specific materials in mind possessing more or less unique characteristics. The approach results in the production of concrete with the appropriate properties most economically. However, the designed mix does not

Serve as a guide since this does not guarantee the correct mix proportions for the prescribed performance. For the concrete with undemanding performance nominal or standard mixes (prescribed in the codes by quantities of dry ingredients per cubic meter and by slump) may be used only for very small jobs, when the 28day strength of concrete does not exceed 30N/mm2. No control testing is necessary reliance being placed on the masses of the ingredients.

4.4 Factors Affecting the Choice of Mix Proportions:

The various factors affecting the mix design are

- **Compressive strength**

It is one of the most important properties of concrete and influences many other describable properties of the hardened concrete. The mean compressive strength required at a specific age, usually 28days, determines the nominal water cement Ratio of the mix. The other factor affecting the strength of concrete at a given age and cured at a prescribed temperature is the degree of compaction. According to Abraham's law the strength of fully compacted concrete is inversely proportional to the water cement ratio.

- **Workability**

The degree of workability required depends on three factors. These are the size of the section to be concreted, the amount of reinforcement, and the method of Compaction to be used. For the narrow and complicated section with numerous corners or in accessible parts, t concrete must have a high workability so that full compaction can be achieved with a reasonable amount of effort. This also applies to the embedded steel sections. The desired workability depends on the compacting Comparative Study on behaviour of RCC Elements and GFRP as Steel replacement equipment available at the site.

- **Durability**

The durability of concrete is its resistance to the aggressive environmental conditions. High strength concrete is generally more durable than low strength concrete. In the situations when the high strength is not necessary but the conditions of exposure are such that high durability is vital, the durability requirement will determine the water cement ratio to be used.

- **Maximum nominal size of aggregate**

In general, larger the maximum size of aggregate, smaller is the cement requirement for a particular water cement ratio, because the workability of concrete increases with increase in maximum size of the aggregate. However, the compressive strength tends to increase with the decrease in size of aggregate. IS456: 2000 and IS1343:1980 recommend that the nominal size of the aggregate should be as large as possible.

- **Grading and type of aggregate**

The grading of aggregate influences the mix proportions for a specified workability and water-cement ratio. Coarser the grading leaner will be mix which can be used. Very lean mixes not desirable since it does not contain enough finer material to make the concrete cohesive. The type of aggregate influences strongly the aggregate cement ratio for the desired workability and stipulated water cement ratio. An important feature of a satisfactory aggregate is the uniformity of the grading which can be achieved by mixing different size fractions.

- **Quality Control**

The degree of control can be estimated statistically by the variations in test results. The variation in strength results from the variations in the properties of the mix ingredients and lack of control of accuracy in batching, mixing, placing, curing and testing. The lower the difference between the mean and minimum strengths of the mix lower will be the cement content required. The factor controlling this difference Comparative Study on behaviour of RCC Elements and GFRP as Steel replacement is termed as quality control.

4.5 Mix Proportion Designations:

The common method of expressing the proportions of ingredients of a concrete mix is in the

Terms of parts or ratios of cement, fine and coarse aggregates. For e.g., a concrete mix of proportions1: 2: 4 means that cement, fine and coarse aggregate are in the ratio 1: 2: 4 or the mix contains one part of cement, two parts of fine aggregate and four parts of coarse aggregate. The proportions are either by volume or by mass. The water cement ratio is usually expressed in mass factors to be considered for mix design.

- The grade designation giving the characteristic strength requirement of concrete.
- The type of cement influences the rate of development of compressive strength of concrete.
- Maximum nominal size of aggregates to be used in concrete may be as large as possible within the limits prescribed by IS456: 2000.
- The cement content is to be limited from shrinkage, cracking and creep.
- The workability of concrete for satisfactory placing and compaction is related to the size and shape of section, quantity and spacing of reinforcement and technique eused for transportation, placing and compaction.

4.6 Data for Mix Design:

The following basic data are required for concrete mix proportioning:

- Exposure condition of the structure under consideration (for guidance see Table 3 of IS 456: 2000).
- Grade designation: Minimum grade of concrete to be designed for the type of exposure condition of the under consideration (for guidance refer table 1).
- Type of cement, viz., Ordinary Portland cement (OPC), Portland Pozzolana Cement (PPC), Portland Slag Cement (PSC) etc.
- Maximum nominal size of aggregate to be used, viz. 40mm, 20mm and 12. 5mm.
- Minimum cement content (for guidance see Table3, 4, 5and 6 of IS 456:2000)
- Maximum water cement ratio (for guidance see Table3and5of IS456: 2000)
- Degree of workability desired.
- Maximum temperature of concrete at time of placing.
- Early age strength requirements, if required.
- Type of aggregate viz. Granite, Basalt, Natural river sand, Crushed stones and etc.
- Maximum cement content.
- Use of admixture, its type and condition of its use.

4.7 Mix Proportion Calculations As Per IS 10262:2009

IS456:2000 recommends that minimum grade of concrete shall not be less than M20 in reinforced concrete work. Design mix concrete is preferred to nominal mix. If design mix concrete cannot be used for any reason on the work for grades M20 or lower, nominal mixes which is likely to involve higher cement content maybe used with the permission of engineer in charge. However, all concrete above M20 grade for RCC work must be design mixes.

- The step by step mix proportioning procedure is as follows:

Target means compressive strength for mix proportioning

$f'ck = fck + 1.65 x S$

Where f' ck =Target mean compressive strength at 28days,

f ck=characteristic compressive strength at 28days,

S=Standard deviation N/ mm^2

Standard deviation shall be calculated for each grade of concrete using atleast 30 test strength of samples (taken from site) when a mix is used for the first time. In case sufficient test results are not available, the values of standard deviation given in Table 1 may be assumed for proportioning the mix in the first instance. As soon as sufficient text results are available, actual standard deviation shall be calculated and used to proportion the mix properly.

Note: The above values correspond to site control having proper storage of cement;

Table3.5 Assumed Standard Deviation

Grade of concrete	Standard deviation N/mm2
M10	3.5
M15	3.5
M20	4
M25	4
M30	5
M35	5
M40	5
M45	5
M50	5
M55	5

- **Water cement ratio:**

Concrete made to day contains more than four basic ingredients. Use of both chemical and mineral admixtures has changed the properties of concrete both in fresh and hardened state for good. Even quality of both coarse and fine aggregates in terms of grading, shape, size and texture has improved with the improvement in crushing technologies. Therefore, for a given set of materials, it is preferable to establish relationship between compressive strength and free water cement ratio. If such a relationship is not available. maximum water cement ratio for various environmental exposure conditions given in Table5 of IS456:2000 may be taken as a starting point .Any water cement ratio assumed based on the previous experience for a particular grade of concrete should be checked against the maximum values permitted from the point of view of durability and lower of the two shall be adopted.

- **Water content:**

The quantity of water considered per cubic meter of concrete decides the workability of

The mix. Use of water reducing chemical admixtures in the mix helps to achieve increased workability at lower water contents. Water content given in table 2 of the standard is the maximum value for a particular maximum nominal size of aggregate (angular) which will achieve a slump in the range of 25mm to50mm.

Depending on the performance of an admixture (conforming IS9103:1999) which is proposed to be used in the mix, a minimum of 20% of water reduction shall be considered in case of super plasticisers. Use of poly Carboxylic (PCE) based super plasticiser’s results in water reduction up to 30%. Water content per unit volume of concrete is required to be reduced with aggregate size increase, use of rounded aggregate, reduction in water cement ratio and slump, water content per unit volume of concrete is required to be increased when there is increased temperature, cement content, fine aggregate content and water cement ratio.

- **Calculation of cementitious content :**

Water content calculated in step III is divided by the water cement ratio selected in Step II, to arrive at cement content or cementations content (if mineral admixtures Are used). The total cementations content so calculated should be checked against the minimum content for the requirements of durability and the greater of the two values is adopted. The maximum cement content alone (excluding mineral admixtures such as fly ash and GGBS) shall not exceed 450Kg/ m^3 as per clause no 8.2.4.2 of IS 456: 2000

Volumes are based on aggregate in saturated surface dry condition

Note: Volume coarse aggregate per unit volume of total aggregate needs to be changed at the rate of +0. 01 for every +0. 05 change in, water cement ratio.

- **Estimation of coarse aggregate proportion:**

Table 5. 3 of the standard gives volume of coarse aggregate for unit volume of total aggregate for different zones of fine aggregate (as per IS 383:1970) for a water cement ratio of 0. 5 which requires to be suitably adjusted for other water cement ratios. This table is based on ACI 211. 1–1991 “Standard practice for selecting proportions for normal, heavy weight and mass Concrete”. Aggregate of essentially the same nominal maximum size, type and grading will produce will produce concrete of satisfactory workability when a given volume of coarse aggregate per Unit volume of total aggregate is used. It can be seen that for equal workability, the volume of coarse aggregate in a unit volume of concrete is dependent on nominal maximum size, water cement ratio and grading zone of fine aggregate.

- **Combination of different sizes of coarse aggregate fractions:**

Coarse aggregates from stone crushers are normally available in two sizes viz., 20mm (popularly called as size) and 12. 5 mm (popularly called asV2” size). Coarse aggregates of different sizes can be suitably combined to satisfy the graduation requirement (cumulative percent passing) of table 2 in IS 383:1970 for the given maximum nominal size of aggregate

- **Estimation of fine aggregates proportion**

In steps mentioned above, all ingredients of concrete are estimated except the coarse and fine aggregate content. These quantities are determined by finding out the absolute volume of cementitious materials, water and the chemical admixture; by dividing the mass by their respective specific gravity, multiplying by 1/ 1000 and subtracting the result of the summation by unit volume. The value so obtained is the volume of total aggregate. Volume of coarse aggregate for unit volume of total aggregate is already estimated in step V. the content of coarse and fine aggregate per unit volume of concrete are determined by multiplying with their specific gravities and multiplying by 1000.

4.8 Mix design calculations:

MIX DESIGN

Grade designation	M30	
Type of cement	OPC 53 grade	
Nominal size of aggregate	12mm	

min cement content	320 kg/m^3	
max W/C ratio	0.45	
workability	100 mm slump	
exposure condition	severe	
method of concrete	pumping	
type of aggregate	crushed angular aggregate	
Test data for material		
specific gravity of cement	3.17	
specific gravity of CA	2.68	
specific gravity of FA	2.63	
fine aggregate confining to grading zone 2 of table IS 383		
Target mean strength		
F'ck	Fck+1.65*S	
	30+1.65*5	S=5 from table no 2
	38.25 N/mm^2	
W/C ratio for M30=0.45	From table IS:456	
Selection of water content		
water content a/c to IS:10262-2009 for 10mm aggregate=208 litre		
estimated water content for crushed angular aggregate= 186ltrs		
estimated water content for 100mm slump	197.16	
Total water content	**197 ltrs**	
Cement content calculation		
W/C ratio	0.45	
C	438.1333333	
C	440 Kg	
Estimation of coarse aggregate & fine aggregate		
volume of CA corresponding to 10mm size and FA (zone 2)		
W/C ratio =0.50		
W/C ratio should be increased by 0.05 proportion of volume of CA or decreased by 0.01 or vice versa		
corrected proportion of volume of CA	0.6+0.01=0.61	
For pumpable concrete volume of CA	**0.549**	
Volume of FA	**0.451**	

Mix calculation		
Volume of concrete required (a)	**1m^3**	
Volume of cement (b)	**0.138801262**	
Volume of water (c)	**0.197**	
Volume of all in aggregate	a - (b + c)	
	0.664198738	
d	**0.664m^3**	
mass of coarse aggregate	d*volume of CA*Sp. gravity of CA*1000	
	976.95648	
Total mass	**977 Kg**	
mass of fine aggregate	d*volume of FA*Sp. gravity of FA*1000	
	787.59032	
Total mass	**788Kg**	
Mix proportioning for M30 grade		
Cement	**440 Kg/m^3**	
Water	**197 Kg/m^3**	
Coarse aggregate	**977 Kg/m^3**	
Fine aggregate	**788 Kg/m^3**	
Volume of materials required		
volume of concrete	472500000	
	0.4725 m^3	
add 20% wastage	0.567	
volume of concrete	**0.567 m^3**	
cement	249.48	**250 Kg**
water	111.699	**112 Kg**
coarse aggregate	553.959	**554 Kg**
fine aggregate	446.796	**447 Kg**

Chapter 5

METHODOLOGY

5.1 Design of beam with steel reinforcement

f_{ck}	30	N/mm^2
f_y	500	N/mm^2
Width (b)	150	mm
Depth (D)	150	mm
Eff depth (d)	130	mm
Span (L)	700	mm
Eff length (l)	600	mm
LOAD CALCULATION		
Dead load	0.81	KN/m
Live load	37.5	KN
MOMENT & SHEAR FORCE CALCULATION		
Moment	5.66145	KN-m
shear force	18.993	KN
Mu_{lim}	10.11465	KN-m
M<Mu_{lim}	**Hence Singly Reinforced Beam**	
CHECK FOR DEPTH		
d	130	mm
A_{st}		
Mu_{lim}	10.11465	KN-m
A_{st} (tension)	-48.333333	a
A_{st}	56550	b
	-10114650	c
a_{st}	220.368159	
	949.631841	
a_{st}(min)	33.15	mm^2
a_{st}(max)	900	mm^2

No.of bars	2.80545079	3 no's
a_{st} prov	235.65	mm^2
CHECK FOR SHEAR		
shear stress	0.974	N/mm^2
% steel	1.20846154	
permissible stress	0.7	N/mm^2
V_{us}	5343	N
a_{sv}	100.544	
spacing	1064.15182	
min spacing	300	mm
	97.5	≈90mm

5.2 Design of beam with GFRP reinforcement

f_{ck}	30	N/mm^2
f_y	700	N/mm^2
Width (b)	150	mm
Depth (D)	150	mm
Eff depth (d)	130	mm
Span (L)	700	mm
Eff length (l)	600	mm
LOAD CALCULATION		
Dead load	0.81	KN/m
Live load	37.5	KN
MOMENT & SHEAR FORCE CALCULATION		
Moment	5.66145	KN-m
shear force	18.993	KN
Mu_{lim}	5.9319	KN-m
$M<Mu_{lim}$	**Hence Singly Reinforced Beam**	
CHECK FOR DEPTH		

d	130	mm
A_{st}		
Mu_{lim}	5.9319	KN-m
A_{st} (tension)	-72.95555556	a
A_{st}	60970	b
	-5931900	c
a_{st}	112.412901	
	723.3013847	
a_{st}(min)	23.68	mm^2
a_{st}(max)	900	mm^2
No.of bars	1.431099949	2 no's
a_{st} prov	226.224	mm^2
shear stress	0.974	N/mm^2
% steel	1.160123	
permissible stress	0.692	N/mm^2
V_{us}	5536	N
A_{sv}	100.544	
spacing	1437.874	
min spacing	300	mm
	97.5	≈90mm

Fig 5.2 GFRP reinforcement (left) and steel reinforcement (right)

5.3 Bar Bending Schedule

Beam designation	Beam No	Dia of the bar	Length of one tension reinforcement (m)	extra length/ bar	Total length/ dia/ bar	No of tension bars	Total length for one beam	Total length for one beam (steel)	Total length for one beam (GFRP)
Beam with Steel Reinf	**B1**	10mm	0.8	0.2	0.96	3	2.88		
	B2	10mm	0.8	0.2	0.96	3	2.88		
	B3	10mm	0.8	0.2	0.96	3	2.88		
								8.64	
Beam with GFRP Reinf	**G1**	10mm	0.8	0.2	0.96	2	1.92		
	G2	10mm	0.8	0.2	0.96	2	1.92		
	G3	10mm	0.8	0.2	0.96	2	1.92		
								0	5.76
			Shear reinforcement						
			a=0.102	b=0.102	c=0.0500	No of stirrups			
Shear Reinf Steel reinf	**B1**	8mm	0.204	0.204	0.1	4	2.032		
	B2	8mm	0.204	0.204	0.1	4	2.032		
	B3	8mm	0.204	0.204	0.1	4	2.032		
								6.096	
Shear Reinf GFRP reinf	**G1**	8mm	0.204	0.204	0.1	4	2.032		
	G2	8mm	0.204	0.204	0.1	4	2.032		
	G3	8mm	0.204	0.204	0.1	4	2.032		
									6.096
			Hanger bars						

Beam with Steel Reinf	**B1**	10mm	0.8	0.2	0.96	2	1.92		
Anchor bars	**B2**	10mm	0.8	0.2	0.96	2	1.92		
	B3	10mm	0.8	0.2	0.96	2	1.92		
								5.76	
Beam with GFRP Reinf	**G1**	10mm	0.8	0.2	0.96	2	1.92		
Anchor bars	**G2**	10mm	0.8	0.2	0.96	2	1.92		
	G3	10mm	0.8	0.2	0.96	2	1.92		
									5.76
							Total	**20.496**	**17.616**
								(STEEL)	(GFRP)

Chapter 6

RESULTS

6.1 Preliminary Test Results:

Sl No.	Tests	Results
1.	Specific gravity of cement	3.17
2.	Normal consistency of cement	35 %
3.	Slump of concrete	True slump
4.	Specific gravity of fine aggregate	2.63
5.	Specific gravity of coarse aggregate	2.68
6.	Impact value of coarse aggregate	27.8 %
7.	Compressive strength of concrete cubes at 7 days and 28 days respectively	19.5 N/ mm^2 and 29.4 N/mm^2

6.2 Compressive Strength of Concrete

Compressive strength is the capacity of material or structure to resist or withstand under compression. The Compressive strength of a material is determined by the ability of the material to resist failure in the form of cracks and fissure.

Fig 6.2 Compression Testing for Specimen

Procedure:

1. Place the prepared concrete mix in the steel cube mould for casting.

2. Once it sets, after 24 hours remove the concrete cube from the mould.

3. Keep the test specimens submerged under water for stipulated time.

4. As mentioned the specimen must be kept in water for 7 or 14 or 28days and for every 7days the water is changed.

5. Ensure that concrete specimen must be well dried before placing it on the UTM.

6. Weight of samples is noted in order to proceed with testing and it must not be less than 8.1Kg.

7. Testing specimens are placed in the space between bearing surfaces.

8. Care must be taken to prevent the existence of any loose material or grit on the metal plates of machine or specimen block.

9. The concrete cubes are placed on bearing plate and aligned properly with the centre of thrust in the testing machine plates.

10. The loading must be applied axially on specimen without any shock and increased at the rate of 140 kg/ sq. cm/min, till the specimen collapse.

11. Due to the constant application of load, the specimen starts cracking at a point & final break down of the specimen must be noted.

12. The compressive strength of concrete is given by, σ = Load/area.

Tabulations

Cube No.	Failure load in KN (For 7 days)	Compressive strength N/mm^2 (For7days)	Failure load in KN (For 28 days)	Compressive strength N/mm^2 (For 28 days)
1	445	19.77	660	29.33

2	430	19.11	645	28.66
3	440	19.55	630	28

Results: 1. The average Compressive strength of concrete cubes at 7 days = **19.5 N/mm^2**

2. The average Compressive strength of concrete cubes at 28 days = **29.4 N/mm^2**

Chapter 7

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