Nile Higher Institute for Engineering & Technology

Department of Civil Engineering

Project" "Properties and Strength of Materials

"Strengthening of Various Concrete Specimens with different configuration using G/C FRP Sheets"

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2023

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"Strengthening of Concrete Specimens with FRP Sheets"

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Acknowledgments

Before we start to wright this book, we should express our deepest feelings of thanking and appreciation to our supervisors who helped us throughout this year to complete this project, there are no words that can describe their effort and time to help us in this project.

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Eng. Amr Korat and Eng. Yasmeen Mohamed

We would like to express our deepest appreciation for their generous assistance, continuous encouragement, and helpful advice at all stages of this study.

At the end, we would like to thank our biggest supportive team - our parents - for their support through this year

The experimental part of this study was carried out at the laboratory of materials, Faculty of Engineering at Nile higher institute for engineering and technology. Special thanks to all technicians of the laboratory for their assistance during the conduct of this research works.

ABSTRACT

Many efforts have been conducted on the strengthening of existing structures due to load increase, under-designing, or poor construction. Therefore, strengthening methods have become a necessity to increase the capacity of the existing structures and meet the various serviceability requirements.

This study presents an elaborated characterization of the utilized specimens, the material properties, the testing setup, instrumentation, and the testing procedure. The experimental program included six-cylinder specimens 15Ǿ30 and seven of 10Ǿ20 , eight cube specimens, and nine PC beam specimens. The cylinder specimen was with a side length of 200 mm and a diameter of 100 mm and other was with a side length of 300 mm and a diameter of 150 mm. The cube specimen was with length sides of 150*150*150 mm. The beam specimens were with a length of 500 mm and a cross section of 100*100 mm. Specimens were loaded up to failure under increasing static loads. For the cylinder, cube, and beam specimens, cylinder and cube specimens were tested in terms of compressive strength, and beams specimens were tested in terms of flexure strength. The compressive and bending strength tests were carried out according to the Egyptian Code for Design and Construction of Reinforced Concrete Structures, **ECP 203-2018**.

All experiments were carried out in the Material Lab. of the Faculty of Engineering, Nile higher institute, Mansoura city.

The test results demonstrate that the investigated strengthening techniques can be used to for enhancing both the compressive and flexural behavior of concrete specimens with GFRP sheets and even that load capacity can be increased compared to the control un-strengthened specimens.

Chapter 1
INITIAL REPORT

1.1 Project Definition

The field of **strengthen of materials**, also called **mechanics of materials**, typically refers to various methods of calculating the stresses and strains in structural members, such as beams, columns, and shafts. Designers and contractors often come across problems, which call for special solutions involving concrete. **Cracking is a common** occurrence in concrete bridge decks and barrier or parapet walls. The presence of cracks leads to poor durability and shorter service life of the structure. The successful repair of cracks would reduce the deterioration effects resulting in longer service life. Prolonging the service life defers the rehabilitation or replacement of the bridge and the government sectors responsible for the management of multiple bridges would experience economic benefits. The result of longer service life is also indicative of sustainable practice.

- Literature review: The aim is to get knowledge about the current state of the art -to gain awareness of the state-of-the-art techniques in strengthening concrete structures, in general.
- General information: The aim is to understand the failure mechanisms to develop methods for strengthening that are more efficient.
- Experimental investigations: The aim is to perform experiments in laboratory-controlled environments to obtain a better understanding of the properties of concrete strengthened with FRP.

1.2 The Problem

Find properties of concrete strengthened with FRP with a different configuration of strip widths as well as lengths.

1.3 Study Objectives

In this research, the main objectives were mainly concentrated on:

- Conclude the best properties of FRP material.
- Conduct tests on both fresh and hardened concrete.
- Increase the load-carrying capacity of concrete without reinforcement.
- Compare the different test results to find the best/optimum strengthening configuration.

1.4 Existing Solutions

Using FRP, the current research test results were compared with other similar research results that carried out in the previous work to reach a better judgment of such material.

To understand the effect of using such materials in different fields, the following study has been investigated.

1.5 Design Constraints

The primary constraints faced during our research work are classified into the following categories:

1.5.1 Economic

There is a need to search for financial support sources for students, or full and/or partial grants to contribute for solving some of the problems that may be faced.

1.5.2 Environmental

No direct environmental constraints, but the process of concrete technology in general such as its production initiating from the process of cement manufacturing ending with a partial/total replacement of the defected/deteriorated concrete is significantly affecting the environment.

1.5.3 Sustainability

For the time being, there is nothing can constrain the sustainability as well as terminate it.

1.5.4 Ethical

During the different project stages, no ethical constraints were faced.

1.5.5 Health and Safety

There was some concern about the safety of students when dealing with concrete materials and saturated materials, especially the strengthening FRP materials as well as the application of its different techniques. Therefore, cares and the necessary precautions should be followed.

1.5.6 Social and Political

The establishment of several seminars and meetings involving both students and professors, which pose academic and administrative problems, and everyone, is working to provide appropriate solutions, which increase the social bond between students and their tutors.

<u>It is necessary to mention that</u> *all the experimental work starting from design stage, followed by production stage ending with testing stage for the specimens examined in this project is conducted according to both the Egyptian Code for Design and Construction of Reinforced Concrete Structures, ECP 203-2018, and Egyptian Code of Practice for The Use of Fiber Reinforced Polymer (FRP) in the Construction Fields, ECP 208-2005 requirements. Moreover, all Egyptian standards in the field of construction products are nearly harmonized with the international, European, or foreign standards.*

1.6 4.2 Concrete mix

The concrete mixture produced at the concrete laboratory by mix design using the absolute volume method. This method assumes that the absolute volume of concrete is the sum of the absolute volumes of For concrete i.e., the absolute volume of the constituent materials. cement, sand, gravel, and water is as follows:

C = 450 kg ***S*** = 550 kg ***G*** = 1065 kg ***W*** = 250 lit

"This amount for 1 Cubic meter"

Where:

***C**: weight of cement in kilograms needed per cubic meter of concrete.*

***S:** weight of sand in kilograms needed per cubic meter of concrete.*

***G:** weight of gravel in kilograms needed per cubic meter of concrete.*

***W:** weight of water in kilograms needed per cubic meter of concrete.*

This concrete mixture was designed to develop (35 MPa) for cube strength. The concrete mixing was done mechanically by mixing materials in a dry condition for two minutes, then gradually adding water and continuing the mixing for another two minutes. Table (3-3) gives the mass of the ingredients for a cubic meter of concrete. Figure (3-3) shows the components of the concrete mixture batch used in this study.

Chapter 2

Engineering Standards

Slump test

2-1 Test steps:

Before starting the test, it is necessary to ensure that the inner surface of the mold is clean, moist and without any

excess moisture. The mold is placed on a smooth, rigid, impermeable surface, in a completely horizontal position, and is not subject to vibrations and shocks. The mold is well fixed above the horizontal surface and it contains the oppression if used, then it is filled with three layers of concrete, each of which represents one-third of the height of the mold after compaction, then compacting each layer 25

times with the standard compaction rod, provided that the times of compaction are evenly distributed over the cross-section of the layer, and compaction is for each layer. up to its full depth, taking into account making sure that the compaction rod did not hit the bottom surface hard when compacting the first layer, provided that the compacting rod passes slightly when compacting the second and last layer to the layer directly below it, then the concrete is piled over the mold before compacting the upper layer. An additional amount of concrete should be placed on top of the mold during the compaction process. The

concrete surface is leveled by pricking and rotating the compactor bar. Then, while the mold is still installed, the bottom

surface is cleaned of any concrete that may have fallen on it or leaked from the bottom edge of the mold, and then the mold is removed

from the concrete by lifting it vertically slowly and carefully for a period of 5 to 10 seconds with the slightest movement. lateral or torsional of the concrete, and the whole process must be carried out from initiation of filling to lifting of the formwork Non-stop and completed within 150 seconds. Then the slump is measured immediately after the mold is lifted nearest 5 with using a ruler by setting the difference between The mold height is between the highest point in the tested sample, and the following should be noted:

1- It is possible to find out some indications about the cohesion and operability of the mixture after the completion of the slump measurement by lightly tapping on the sides of the concrete with a compaction rod, where concrete with good proportions of its components and with noticeable slumping occurs another gradual slump, but it happens to the concrete Poorly proportioned ingredients can fall flat.

2- The workability of the concrete mix changes with time as a result of cement sedimentation (cement interaction with water) and also as a result of moisture loss. Therefore, tests must be carried out on different samples at standard intervals after adding the mixing water if completely comparable results are to be obtained.

Density

2-2 Test steps:

1-1-1 Determine the mass of the sample:

- The mass of the sample as it was received in the laboratory (W): it is determined by its weight on the scale, then the reading (W) is recorded.
- The mass of the sample saturated with water (W): It is determined when weighing it after immersing it in water at a temperature of 20 ° C until two successive weights prove the time difference between them is 24 hours (the weight is considered constant if the change in it does not exceed 0.2% before weighing the sample and drying its surface with a damp cloth Oven-dry mass (W2): It is determined after drying the sample in a ventilated oven at a temperature of 100 °C until two

successive weights are fixed, the time difference between them is 24 hours (the weight is considered constant if

The change in it did not exceed 0.2%.
1-6-2- Determine the sample size:

Determining the size by displacement method is used for samples with irregular shapes, and this method is not suitable for samples whose nature requires not to change their moisture content, or light concrete containing large

voids, or concrete that does not contain small aggregates and has large voids. - The sample is saturated with water, then weighed and its weight (W) is determined in kilograms as in item (1-6-1-7)

- The sample is placed on the stand, then immersed in water, and its weight is determined while it is immersed in water, after getting rid of any air bubbles that are attached to the surface of the sample, and let it be (W) kg.

- The weight is corrected after subtracting the weight of the carrier empty while it is immersed in water to the same depth at which the weight of the sample was measured, and the corrected weight is (W) kg. The volume of the sample in cubic meters is determined by the relationship:

- Determining the size of the sample by direct measurement. In the event that the sample has a regular shape, its dimensions can be measured and the volume can be calculated from it, then the vernier caliper can be used for this purpose, with the dimensions recorded to the nearest mm.

Comp

7-2-5 Test steps:

The surface of the machine loading plate and the sample loading surface shall be cleaned.

- The sample is placed on the lower plate of the machine and its axis is adjusted to match the load axis of the machine - The error in adjusting the axiality should not exceed 1/100 of the length or diameter of the sample. – When the contact between the upper machine plate and the sample begins, the spherical support is adjusted to ensure an even distribution To load onto the sample loading surface.

- The load is increased regularly at a constant rate between 0.6 - 0.4 N/mm/sec.

The slow loading rate is used for low strength concrete samples, while the slow loading rate is used for low strength concrete samples Rapid loading of high strength concrete samples.

- When the sample formation begins to increase rapidly before it completely collapses, the tester must stop any modification in the loading rate and leave the sample forming under the influence of the load without changing the loading rate.

- The load is increased until complete collapse of the sample occurs and the collapse load is determined.

Flexure

7-4-5 test steps

The dimensions of the sample are measured and each dimension is calculated as an average of three measurements.

- The sample is placed in the testing machine on the two support pillars, so that the support or loading is not on a surface Casting. Loading does not begin until all supports are in uniform contact with the sample. Bearing the sample at a rate of 0.06 - 0.04 N/mm/sec regularly until fracture. The fracture load shall be specified for samples whose fracture surface is located in the middle third of the sample sea. The results in which the fracture appears outside the middle third of the sea must be excluded. - In the case of using gaskets between the abutments and the beam, this must be taken into account when calculating the stresses by increasing the

depth of the beam by the amount of gaskets, if the fracture occurred under the abutment.

3 Ch3: Introduction

3.1 Aggregates

3.1.1 Introduction to aggregates:

The volume of aggregate used in concrete represents three-quarters of the volume of concrete mass, and therefore it is the body of concrete that resists loads and various weather factors. therefore, the properties of the aggregate used greatly affect the properties and durability of concrete, as well.

Concrete consists of rocky granules held together by a cementitious substance. The name of aggregate is given to the rock granules that are generally gradual in size, such as sand and gravel. the aggregate in concrete represents 75% of the volume of the concrete block.

The aggregate helps the volume changes resulting from the formation and hardening of the cement.

3.1.2 Division of aggregates:

According to the source:

- Aggregate from natural sources: It is the aggregate taken from quarries without any change to its natural properties during the production steps.
- b- Aggregate manufactured according to certain processes: such as heat treatment to produce stretchy materials characterized by light weight, such as burn clay.
- c- Colored aggregate for architectural concrete: It is used for architectural and decorative purposes, such as glass and marble granules.

3.1.3 General properties of the aggregate:

3.1.3.1 For size:

- Small aggregate: It is the group of particles, most of which (95%) passes through the 4.76 mm standard sieve or sieve No. 5.

- b) Large aggregate: it is the group of particles, most of which (95%) of the standard sieve 4.76 mm or sieve No. 5
- c) Aggregate: a mixture of large and small aggregates.

The surface area of aggregate particles increases the smaller the aggregate particle size, small scale aggregate granules also require a larger amount of cement paste to coat them

3.1.3.2 For the shape:

1. Round: Like the sand of the desert.
2. Angular: Like breaking stones.
3. Irregular: such as gravel.
4. Padded: Like a stratified rock cut

e) Sticky.

3.1.3.3 For surface condition:

1. Vitreous: Like black flint.
2. Soft: like free gravel.
3. Rough: like a pumice stone.

The granules with shiny surfaces do not give cohesion with the cement paste, such as the

rubble with rough surfaces, and the higher the porosity in the aggregate, the lower the concrete strength.

3.1.4 Sinusoidal gradient:

It is to separate the different measured grains from the aggregate from each other and this is done by using the analysis by sieves by shaking the aggregate in a movement from the sieves arranged according to the size of its holes and placed on top of each other so that the largest of them are measured at the top and then weigh the reserved on each sieve and then calculate the percentage of the aggregate passing through Each sieve is then signed with a graphic mark between the size of the opening and the percentage of aggregate passing through it. This drawing expresses the extent of the volumetric distribution of the aggregate or the extent of the granular grading. The granular grading is divided into-:

- Graduated aggregate: it contains most of the sizes of the standard sieves.
- Well-graded aggregate: it contains the appropriate quantities of different sizes.
- Ungraded aggregate: It is the one in which there is no one or more of the different aggregate sizes and it appears clearly in the graph, as the gap is represented by a horizontal line.

Some of the different sizes of granules and standard sieves

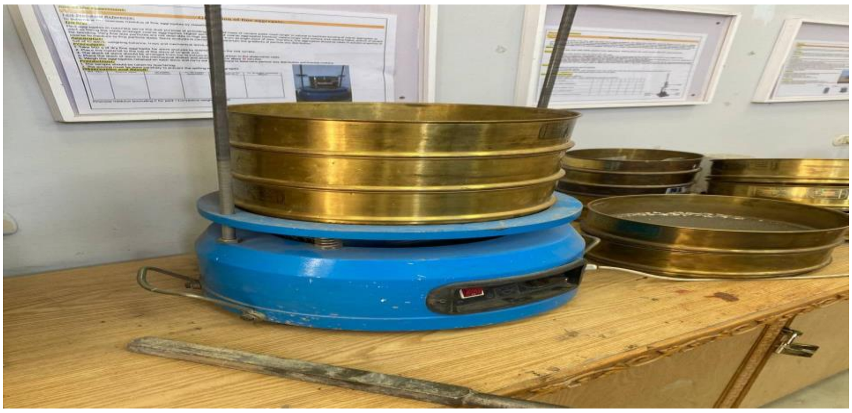


Figure 2-1 sieve test

3.1.5 Softness meter :-

It is the factor that describes the size of the average aggregate and it is used = a lot of work in the study of concrete aggregates.

- Fineness meter = sum of percentages reserved on the nine standard sieves divided by 100.
- Fineness meter for sand = (2 to 3.75).
- Calibrator for the smoothness of the gravel = (5 to 8).

It is the measurement of the smallest sieve hole that allows at least 95% of the large aggregate to be poured. The aggregate size in concrete structures must be no more than 40 mm or 1:3 thickness of the roof slab or 1:5 of the pure distance between the reinforcing steel. In ordinary concrete works, the nominal size is the largest aggregate is 40 mm, while in paving works, it is 65 mm ,block concrete 150 mm.

3.1.6 Volumetric increase of small aggregates-:

If we add water to the sand and then stir it, a thin layer of water envelops the sand grains and raises the grains away from each other as a result of the effect of the surface tension phenomenon, thus increasing the size of the sand. The required quantity, causing a change in the proportions of the concrete mix

3.1.7 Granular gradient of aggregate

The purpose of the experiment:

1- Determination of the size distribution of particles of large aggregate (gravel) and small aggregate (sand) by analysis using standard sieves.
2- Graphically showing the granular gradation of the aggregate and comparing it with the limits given in the standard specifications for concrete aggregate.
3- Determining the criteria of fineness and the largest legal size of the aggregate.
4- Finding the optimum granular gradient for the aggregate used in concrete mixtures to give a concrete mixture that is easy to operate and has high pressure resistance.

3.1.7.1 Used sieves:

- There is a set of standard sieves used, part for gravel and part for sand.
- In the case of small aggregates, the standard set of sieves used is: size 0.075, 0.149, 0.291, 0595, 1.190, 2.38, 4.76 mm.
- In the case of large aggregates, the standard set of sieves used are: size 4.76, 9.51, 19.05, 38.0 mm.
- In the case of mixed aggregates, the two sets of sieves are used together

3.1.7.2 Definitions:

- 4.76 mm sieve: This means that the sieve opening is a square with dimensions of 4.76 * 4.76, which is the sieve separating the large and small aggregates.
- Fineness meter: It is the sum of the percentages reserved on the nine standard sieves divided by 100 .Specifications specify the fineness criterion for the aggregate used to make concrete from (5-8).
- The largest nominal size: It is the smallest size of the sieve that allows the passage of at least 95% of the large aggregate or mixture

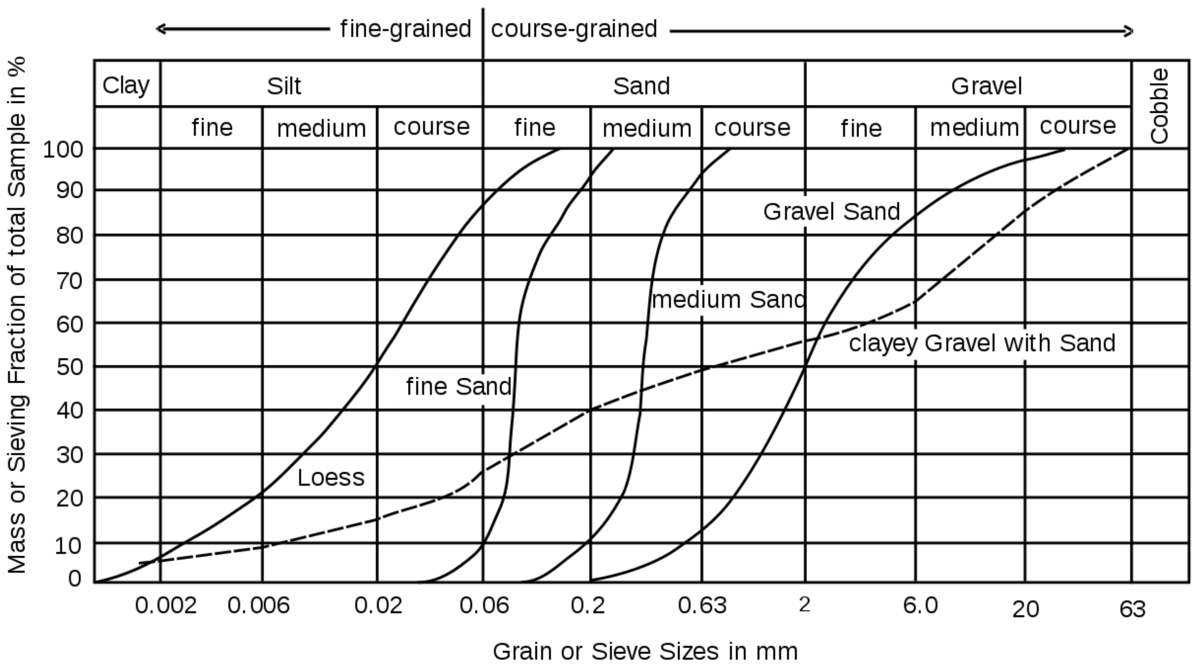


Figure 2-2 sieve analysis curve

3.1.7.3 Steps of the experiment-:

The test sample to be tested shall be prepared taking into account the following-:

1- The sample taken for aggregate tests must be fully representative of the group taken from it, as it is taken with approximately equal quantities of aggregates from different locations ,provided that this is from separate points on the sides of the source from the top, middle and bottom, provided that these quantities are fully representative of the majority of the grains.

2- It is not taken from points where large particles are concentrated, as it usually happens at the bottom of the rubble, provided that the number of points from which the aggregate quantities are taken is not less than ten points. Quantity needed to take the test.

3- The sample taken is reduced to the necessary quantity by-:

   - Sample divider.

- By way of division:

  The sample is divided in this way by making a conical pile, provided that the rubble is piled up by placing it at the top of the cone and then letting it flow in an orderly manner on its sides, taking care not to move the center of the cone and returning the rubble scattered around the base to the sides of the pile.

This process is done three times, then the third conical pile is flattened, then the flat circular pile is divided into four sections by placing two plates of wood or metal on its surface in the form of two perpendicular diameters and then pressing them. This process is done one more time, until the necessary quantity for the test is obtained.

1. It was dried in a drying oven at a temperature of 110 ° C for about 24 hours, then its weight was determined.
2. A group of sieves are arranged on top of each other according to the size of their opening, so that the largest is the highest.
3. Sieves are placed on the mechanical shaking device, then the aggregate sample is placed over the upper sieve, and the sieves are covered with a special cover.
4. The vibrator is operated for 20 minutes, then the device is stopped, and the aggregates are weighed on each sieve.
5. The total reserved weight on each sieve is calculated as follows
   - Total retained weight on the sieve = retained on the same sieve + retained on the larger sieves
6. The percentage of reserved is calculated as follows:-
7. The percentage of passerine is calculated as follows:- - Passing percentage = 100 - reserved percentage
8. Draw the granular gradient curve and compare it with the specifications.

3.1.7.4 Features and measurements-:

The percentage of losses in the sample should not exceed 2% of the original sample weight.

Practical example-:

A sample weighing 3000 g was prepared, which is a mixture of small and large aggregates. Then it was sieved using the nine previously mentioned sieves.

Required-:

Divide the sample according to the size of the grains, draw the gradient curve, and find the criteria

for fineness and the largest legal size. The maximum size is 38 mm

- Conditions of the Egyptian Code for the selection of aggregates-:

1- The natural aggregate granules must be solid, durable, free from harmful substances, and not have a negative impact on the properties of concrete.
2- When using aggregates in structural elements exposed to wetness, it must be ensured that it is free of any siliceous materials.
3- The aggregate should be graded according to the Egyptian standard specifications with different sizes of particles and distributed uniformly in the comprehensive mixture.
4- Calibrated and distributed for small aggregates not less than 2.7 for pre-stressed concrete.
5- The largest nominal size of the aggregate shall not be more than 40 mm for reinforced concrete and not more than 25 mm for prestressed concrete.

3.2 Cement

3.2.1 Definition of cement-:

Cement is one of the most important non-metallic non- metallic materials in construction work (cement, lime, gypsum, etc.), and it is the material that has the property of cohesion and adhesion ,which binds particles of rocks, aggregates and building materials to form an integrated building block. The chemical composition of different types of cement is complex and diverse. All of them were consistent in the presence of lime, silica, alumina and iron oxide in varying proportions, and all types of cement agreed in the property of the ability to form and harden under water.

3.2.2 Types of cement:

3.2.2.1 Portland cement

Portland cement is the product of burning calcareous and clay materials after mixing them well ,then the combustion product (clinker) is ground, and it is not allowed to add other materials to the burning product except a percentage of gypsum and water

Portland cement also consists of a retirement crack (lime) and an acid crack (clay), which contains many types of mineral silica and contains iron and aluminum compounds, which are of great and technical importance in the production process

3.2.2.2 fast hardening Portland cement

It is a type of Portland cement and is faster in the hardening of - the earth and machines than ordinary Portland cement.

Quick cement is characterized by its smoothness and high quality because it contains tri-calcium silicate ratio of 4500-5000 cm2, which makes it similar to ordinary Portland cement, but differs in the composition of the materials by a small percentage.

It is also used in normal construction works, roads and cold weather, but not freezing. Because the hardener helps generate heat in order to protect the concrete from low temperatures that sometimes lead to the destruction of concrete.

3.2.2.3 Low-temperature Portland cement

- One of the types of Portland cement, which is called tank cement. The cement may be manufactured with materials and quantities that have a lower temperature than ordinary cement. Tri-calcium silicate and tri-calcium aluminate are also lower than ordinary Portland cement

- The strength of manufactured concrete is the same as that of ordinary cement with a lifespan of 7 days. It may be used in large and large buildings such as bridges, dams, concrete blocks , retaining walls and tanks

3.2.2.4 Cement kiln products

It is one of the types of Portland cement that produces less heat and is more resistant to chemical reactions.

Cement is also made by mixing clinker grinding, ordinary Portland cement, with kiln slag materials, which, according to British standards, make up less than 65% of the final cement.

3.2.2.5 construction cement

It is one of the types of Portland cement, and ordinary Portland

cement is added to it with few additives and softeners to be used in docks and marine facilities that do not need to absorb mortar quickly through bricks.

3.2.2.6 White cement

1- White cement is the most widely used and popular type of cement
2- White cement is made from iron-free compounds, limestone and limestone. Which is in manganese and iron in small quantities so as not to affect the color of the white cement
3- White cement is used in the steps of finishing an apartment on red bricks, interior decorations and exterior finishes. It is also used in small, large and various architectural projects.

3.2.2.7 Alumina cement

1- Alumina cement is a type of cement that differs in composition and properties from Portland cement. It is manufactured by mixing bauxite and slaked lime using clinker, which makes concrete and cement hard.

2- Aluminum cement is used in the manufacture of factory concrete for its durability. It also generates high heat through the cement hardening and making the concrete wet for 24 hours from the time the concrete hardens.

3.2.3 Properties of cement :

3.2.3.1 Softness

The smoothness of the cement affects the rate of its reaction. The finer the grains, the larger the surface area and the faster the reaction processes. Therefore, the smoothness of the cement leads to the cement gaining early and high resistance and size stability. It also improves the workability of concrete and reduces the amount of water .

3.2.3.2 reaction heat

Experiments have proven that there is a close relationship between the cement resistance rate and the temperature emission rate. The reaction temperature is of great importance for the concrete industry. The concrete mix that starts in an atmosphere of not less than 5 ° C can continue to solidify if adequate measures are taken to prevent the dispersion of hydration into the atmosphere even if it decreases. Atmospheric temperature, also when making block concrete, the temperature in the hollow of the concrete block is higher than on the outer surface in contact with the air, and this results in thermal stresses that lead to cracks in the concrete block

3.2.3.3 Contraction and expansion :

These two phenomena occur as a result of the internal forces associated with dryness and humidity. The cement paste shrinks if it dries up in the air, and its volume increases by a smaller percentage if it hardens in water. The value of shrinkage or expansion depends mainly on the ratio of water and cement in the mixture, in addition to other factors such as the relative humidity in the surrounding atmosphere and the amount of exposed surface. Shrinkage or expansion is accompanied by internal forces in both concrete and steel reinforcement, and cracks are generated that affect the resistance and construction properties.

3.2.3.4 setting and hardening of cement

1- Cement setting means the loss of plasticity of the cement paste (initial setting) and then start to harden enough to bear a certain weight (final setting). about 10 hours
2- Factors affecting setting time are chemical composition, gypsum percentage, temperature ,fineness, aeration of cement before grinding, amount of mixing water.

3.2.3.5 Cement Compression Resistance

The resistance of cement in pressure is the most important characteristic when used in facilities, and the pressure resistance of pure cement is greater than its resistance if mixed with sand, and the resistance increases with time for the continuation of cement reactions, also the resistance of cement in compression depends on the chemical composition, degree of burning ,age

3.2.4 Cement grade :

1- The compressive strength of cement mortar and the rate of acquisition of early resistance are distinguished through six ranks, where the resistance increases at a certain age by increasing the rank (32.5, 42.5, 52.5) and symbolizes the pressure resistance of cement mortar in mega pascals at the age of 28 days and the early resistance increases by using early-resistance cement (R) Compared to ordinary cement (N)
2- The rate of gaining pressure resistance increases as the smoothness of the cement increases to increase the surface area of the cement granules, with the stability of other factors. The rate

of gaining resistance also increases with an increase in tri-calcium silicate compared to cement that contains a higher percentage of calcium silicate compound. As for composite cements, their effect on resistance varies according to the type of cement. Clinker replacement material

3.2.5 Cement tests :

3.2.5.1 Softness test

100 -gm of dry cement is sieved with a 0.09 mm standard sieve (170 sieve) for 15 minutes (manual sifting) or 5 minutes (static vibrating sieves), then the cement reserved on the sieve is weighed, and the fineness is calculated in terms of the percentage of the weight reserved on the mentioned standard sieve. The specifications stipulate that the proportion of the reserved weight shall not exceed 10% of the cement

3.2.5.2 Cement specific weight determination test

A sample of cement is weighed and the density vial is filled with a liquid that does not react with the cement (kerosene or oil) up to a certain volume. Then the cement is placed inside the density vial (with light methods to expel air bubbles) and the volume is read on the capillary tube and the specific weight is calculated by dividing the weight of the cement by its volume

3.2.5.3 Water required cement paste of standard consistency

- A sample of cement weighing 400 g is prepared, to which an appropriate amount of water is added (estimated as a percentage of the weight of the cement) and the mixing process is carried out well to prepare the cement paste, noting that the mixing time is about 4 minutes, which is the period from the start of adding water to the cement until the start of filling the mold
- The vickat mold resting on a completely non-porous slab is filled at once with the previously prepared cement paste and

the surface is leveled with the edge of the mold with the weapon of the standard mixing trowel

- The mold with the dough is placed under the rod holding the needle of the vickat device, which slowly droops until it touches the surface of the dough and is then left to fall freely into the dough .
- The amount of penetration of the tip of the cylindrical needle into the cement paste is determined by determining the distance between it and the bottom of the vickat mold through the exercises on the ruler of the device. Several experimental doughs are reworked in different quantities until the amount of water that gives the standard paste is reached.

3.2.5.4 Cement mortar pressure test

- Devices : 7 cm rib cube of durable metal with polished surfaces, and electric vibrator
- Test method: The quantities needed to make cement mortar are prepared in a ratio of 3:1 (185 gm cement + 555 gm standard sand + 74 cm3 water, or 10% of the mortar volume). Then water is added to it and mixed well for 4 minutes, and the mold is placed assembled on the vibrating machine after it is completely fixed and a funnel is placed over it to facilitate filling
- The mortar, after mixing it, is placed directly in the mold, then the mold is shaken to compress the mortar for two minutes at the specified speed. The funnel is not lifted until after the shaking period ends.
- The mold is lifted and placed in an atmosphere with a relative humidity of not less than 90% and a temperature of about 20 ° C for 24 hours.

3.3 Types of concrete

There are many types of concrete used in the construction process, differing among themselves

in their composition and use as well as their engineering properties. The following is a brief

summary of the most important of those types used in the construction industries :

3.3.1 Plain Concrete

Ordinary concrete consists of rubble, cement and water without the presence of steel reinforcement, and therefore it is used in works that are not subject to tensile stresses to a degree greater than the concrete's bearing capacity for tensile strength, such as the work of cleaning mattresses under the foundations, the work of floors and concrete blocks such as marine fenders ,and some of its properties can be improved according to the purpose for which it is designed.

3.3.2 Reinforced Concrete

It is ordinary concrete used with steel reinforcement, so that the reinforcement can withstand the tensile stresses generated on the sector.

Figure 2-3:Reinforced concrete consists of ordinary concrete reinforced with reinforcement resist tensile stresses

3.3.3 Pre-stressed concrete

It is ordinary concrete that is loaded with pressure stresses after pouring and before being loaded with operational loads so that these stresses are enough to meet the tensile stresses that will result from the effect of operating loads and therefore do not need a main reinforcement steel to resist these stresses, because the final result of the stresses generated along the concrete sector are often pressure stresses Thus, the concrete is capable of bearing it as shown in Figure (2-8), and it is noted in this type of concrete that the concrete used must be of high pressure resistance in order to be able to withstand the pressure stresses affecting it before and after the application of operating loads on it, and due to the durability and resistance of this concrete With high loads, it is suitable for use in bridges and precast concrete elements.

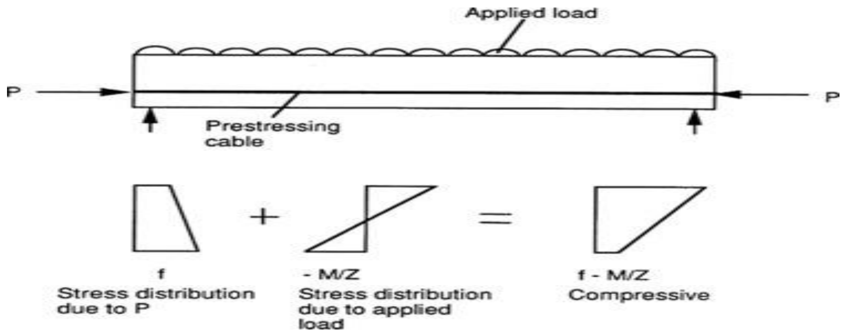


Figure 2-4 :Behavior of a concrete beam under the influence of pre-stressing

Steel bars used in pre-stressed concrete consist of Tendons, which are wires, strands of wire, or steel bars.

Pre-stressed concrete is divided into two types in terms of methods of stress gain:

First: Pre-tension method

In this method, concrete is given pre-stresses and is often used with precast concrete elements ,where steel cables are tightened in the molds to be poured before the concrete pouring process ,then concrete is poured into the molds around these cables and then left to harden while leaving the cables taut (within the limits of flexibility) and after the concrete has hardened, the tensile forces affecting the cables are removed as they try to shrink inside the hardened concrete, which leads to the generation of compressive stresses on the concrete through the cohesion forces between iron and concrete. This method is mainly used in factories pre-stressed precast units due to the availability of advanced methods of steam treatment and the production of a large number of units in the shortest time

Second: Post-tension method

In this method, empty ducts are installed inside the concrete with free-moving steel cables placed inside these tracks without tension, then concrete is poured around these pipes and left to harden and despite the absence of any cohesion forces between concrete and steel, after removing the tensile forces affecting the steel, this causes pressure stresses on the steel plates installed at both ends of the concrete element, which in turn are transmitted to the concrete by loading, then the spaces between the steel cables tracks are injected. From the inside, grout mortar that hardens and reduces the chance of cables loosening or rusting.

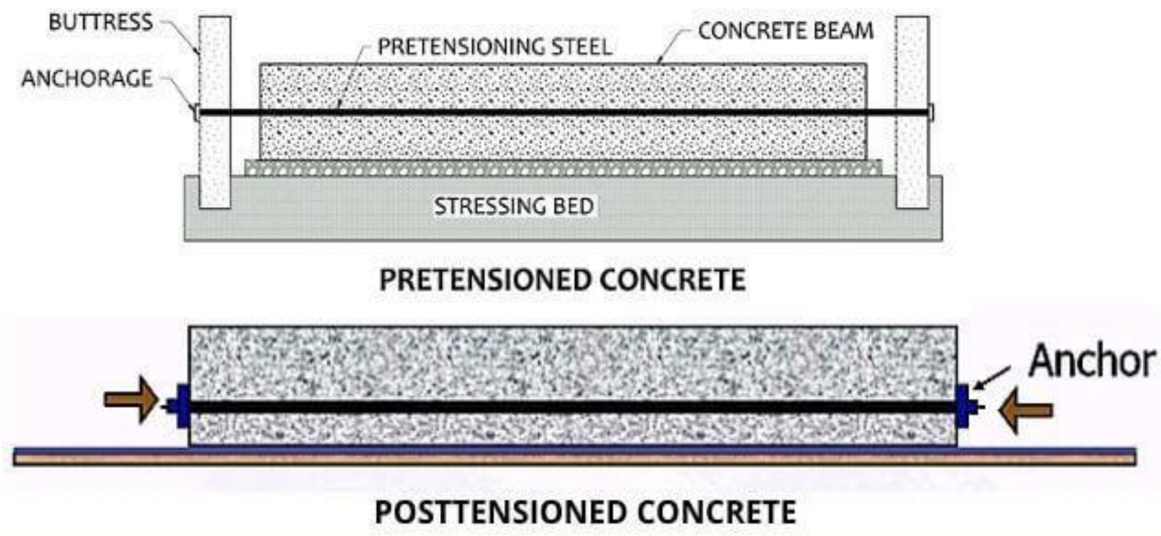


Figure 2-5 illustrate pre -tension and post tension concrete elements

3.3.4 Precast Concrete

It is reinforced, ordinary or pre-stressed concrete that is poured and treated in factories prepared for that, then it is supplied to the place of installation where it is installed and then ready for use ,through which it is possible to pour slabs, columns, walls, concrete blocks, fence units, stairs and one of the most important features of this concrete is the process of controlling the quality of concrete, where it is possible to control the following properties of concrete:

- Use of good graded aggregate.
- Use the optimal mixing ratio of water for the mixture.
- Conducting the process of mixing and compacting concrete in an engineering manner.
- Exact handling of items.
- Using the appropriate insulating materials and additives.

Figure 2-6:Installation of precast elements in a housing project

3.3.5 High strength concrete

It is concrete with a high-pressure resistance of more than 60 N/mm2, and it is obtained from the available local materials that are used in the manufacture of regular concrete, but this type of

concrete contains an additional substance, which is superplasticizers, which enables us to reduce

the mixing water to less Possible ratio and thus achieving the highest possible resistance to

pressure and at the same time obtaining a reasonable operability of the mixture that enables us to

process the casting smoothly, and one of the most important considerations in the manufacture of

high-resistance concrete is to choose materials that are homogeneous with each other to obtain

good concrete that has high resistance and durability as well as acceptable operability.

High-strength concrete is mainly used in high structures, bridges and water structures, in order to

take advantage of its high strength value to obtain the least space for sections and thus achieve the

lowest size and weight of the structure.

3.3.5.1 Fiber reinforced Concrete

It is ordinary concrete with added fibers distributed randomly throughout the concrete mass . These fibers are divided in terms of type into:

- Steel fibers, which are pieces of steel with a diameter of 0.5 to 0.8 mm and a length ranging from 3 to 8 cm
- Synthetic fibers such as polypropylene, polyester or acrylic and take the same measurements as steel.

The fibers improve the properties and resistance of concrete in both shear and tensile, as it reduces the width of the cracks and redistributes it, that is, it transforms the mechanism of failure in the value of the strength criteria of the material increases significantly, and fiber concrete is widely used in Military installations ,machine bases, road projects, and precast units. It is worth noting that fibers are not a substitute for steel reinforcement because they do not increase the tensile strength of concrete in bending by a large percentage

3.3.5.2 Self-compacting Concrete

It is a concrete that has a high degree of fluidity and fluidity as well as a high resistance to granular separation, and it can be poured effectively in narrow and crowded places with reinforcement without the need to use means of compaction such as vibrators, and the two basic elements for the manufacture of this concrete are additives to improve viscosity, and additives Reducing the mixing water (super plasticizer) in order to achieve the high fluidity of this concrete

Figure 2-7: Self compacting concrete

3.3.5.2.1 The main advantages of self-compacting concrete

- Ease of casting in sectors crowded with rebar and narrow sectors and therefore do not need to use vibrators.
- The ability to pour large quantities of concrete in short periods.

- No granulomatous separation.
- You do not need to level the surface after pouring in most cases.
- Do not give an opportunity to increase the mixing water due to its high fluidity.

The main properties required to obtain self-compacting concrete are:

1. First: a high degree of flow and liquidity, and this is achieved by the following:
    - The use of super plasticizers.
    - The use of gradient aggregates.
2. Second: a high degree of resistance to granular separation.
    - Reducing the nominal size of the largest aggregate.
    - Reducing the perfusion to the lowest possible degree by reducing the mixing water.
3. Third: It has a high capacity for casting and filling in narrow or crowded sectors with rebar under the influence of its weight.
    - Use of viscosity-improving additives.
    - Reducing the nominal size of the largest aggregate

3.3.5.3 Lightweight Concrete

Due to the heavy weight of traditional concrete, we note the high self-weight of the elements of origin, and therefore with the effect of operating loads, the impact load on the foundations is relatively large, and therefore there was a need to develop a new type of concrete with a specific weight less than traditional concrete, where the weight of light concrete reaches 20 kg / m3 It has been possible to manufacture structural concrete with a weight ranging from 14 to 19 kg / m 3 compared to 22-25 kg / m 3 for conventional concrete, and therefore the total weight affecting the foundations as a result of the self-weight of the structure is less. Light concrete can be classified into the following:

- Concrete free of fine materials: it consists mainly of cement and large graded aggregates only ,and sometimes air is added through additives. The density of this aggregate ranges from 2/3 to 3/4 the density of conventional concrete made of the same aggregates.
- Light aggregate concrete: It is the most common and can be used as construction concrete. The aggregate used in it is industrial, such as: expanded clay, vermiculite, and foam (polystyrene).

3.3.5.4 Heavyweight Concrete

It is a special concrete for the protection from nuclear and atomic radiation, as it works to reduce the effect of these radiations and their absorption, as a result of its weight and density. 40 kg/m3.

Iron pieces may be used as aggregate, with a density of 56 kg/m3, provided that the aggregate used meets the requirements of installation and radiation protection.

Since the aggregate consisting of iron pieces tends to separate when mixed and poured by traditional methods, in this case, heavy pre-compacted concrete is used, where the concrete mortar is pushed through the voids of the aggregate after compacting, compacting and saturating it with water so that the mortar displaces the existing water and fills the voids.

3.3.5.5 Shotcrete

It is concrete or mortar that is ejected with air pressure from the nozzle of the ejector cannon at a high speed to the surface to be covered as shown in Figure (2-14), and it is mostly used in restoration work and lining tunnels and canals, which are cases in which it is difficult to use traditional methods of concrete pouring.

In general, there are two ways to implement and pour ejected concrete, which are either by mixing on the dry, where the components of the concrete are mixed on the dry first, then water is added at the nozzle of the ejector cannon and pushed under air pressure to the surface to be poured, or the wet method is used where the ingredients are mixed with the use of water and then It is pumped to the surface, and in both methods, the surface to be concreted must be well prepared in order to achieve cohesion between the concrete and the surface

Figure 2-8:The process of pouring shotcrete for a concrete wall

To compensate for the loss in the cement content during the concrete extrusion process and it’s falling off as a result of reflux, the cement content in the concrete mixture is increased with the addition of setting accelerators in order to speed up the setting process of the extruded concrete the roof.

The disadvantage of this concrete is that it is exposed to shrinkage to a large extent, due to the increase in the proportion of water and cement content in it compared to the proportion of aggregates. To treat this, fibers are used with this concrete by mixing it with it in order to reduce shrinkage

3.3.5.6 Mass Concrete

It is concrete with large volumes and blocks and it is present when pouring dams and foundations that require large volumes of concrete or any other element for which the volume of concrete required is so large that it requires taking the necessary precautions as a result of heat generation resulting from cement hydration and the consequent shrinkage and cracking of concrete.

These precautions are represented in the items the following:

- Use of low heat emission cement, provided that the mixture is poor in cement.
- Using crushed ice in the mixture to cool the concrete.
- The presence of a network of pipes that pass inside the concrete block and through which cycles of cold-water pass to cool the concrete block around it.
- Casting on low-height layers to control temperatures.
- Surface insulation of concrete in order to reduce the difference between the temperature drop between the surface of the concrete and its interior.

Chapter 4:

4.1. Types of Construction Defects in Reinforced Concrete Structures :

Concrete is known to be a very versatile and reliable material, but some construction errors and construction negligence can lead to the development of defects in a concrete structure. These defects in concrete structures can be due to poor construction practices, poor quality control or due to poor structural design and detailing.

Common types of defects in concrete structures are honeycombing, form failure or misalignment of formwork, dimensional errors, rock pockets and finishing errors.

1 .Honeycomb and Rock Pockets

Honeycomb and rock pockets appear on the concrete surface where voids are left due to the failure of cement mortar to fill spaces around and among coarse aggregates.

Causes of honeycomb and rock pockets involve poor quality control during mixing; transporting; or laying of concrete, under or over-compaction of concrete, insufficient spacing between bars, and low cement content or improper mix design.

Honeycomb and rock pockets may reduce durability because they expose the reinforcement to the environment which may reduce the strength of the concrete sections.

If these defects are minor, they can be repaired by using cement mortar grout just after the removal of the formwork. If the repair work is delayed for more than 24 hours, epoxy bonded concrete replacement should be used.

Figure 4-1:Honeycomb

2. Defects due to Poor Formwork Installation

Formwork installation errors include misalignment, movement, loss of support, failure of forms that can lead to cracking and structural failure.

Settlement cracks develop due to concrete settlement caused by the loss of support during construction. Inadequate formwork support and premature removal of formwork are the major causes of loss of support during construction.

Defects due to formwork placement mistakes can be repaired with surface grinding to maintain the verticality of the structure if the error is minor. In case of major error, the concrete member shall be repaired by removing the concrete in the defective area and then reconstructing that portion of the structural member using suitable methods.

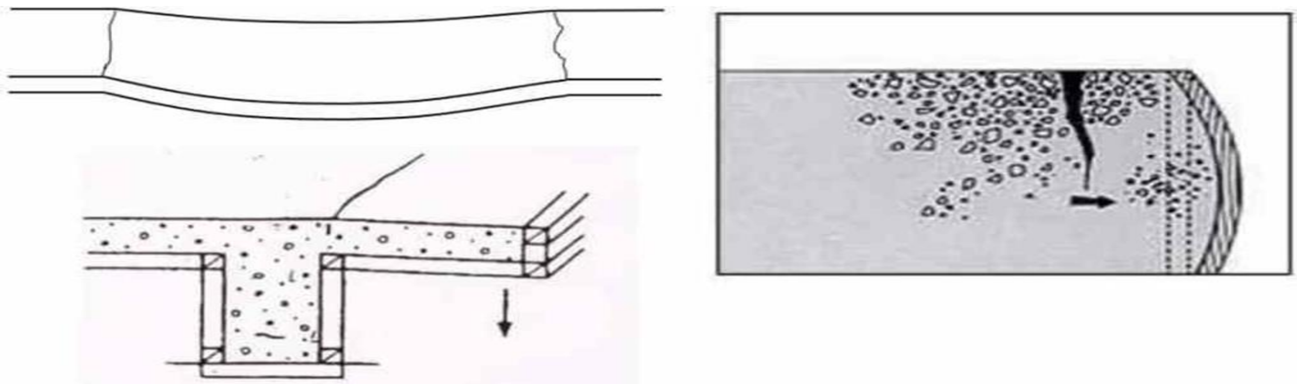


Figure4-2:Defects in Concrete due to Formwork Movement

3. Defects due to Concrete Dimensional Errors

Dimensional errors in concrete structures occur either due to the poor centering of a structural member or due to deviation from the specifications. In that case, the structural member can be used if it is acceptable for the intended purpose of the structure or can be reconstructed if it doesn't suffice.

4. Defects due to Finishing Errors

Finishing errors in concrete structures can involve over-finishing of the concrete surface or addition of more water or cement to the surface during finishing of the concrete. This results in the porous surface which makes the concrete permeable resulting in less durable concrete.

Poor finishing of concrete results in the spalling of concrete from surface early in their service life. Repair of spalling involves removal of defective concrete and replacement with epoxy bonded concrete.

5. Shrinkage Cracks

The formation of shrinkage cracks in concrete structures is due to the evaporation of water from the concrete mixture. The severity of this issue is based on the amount of water in concrete (as water quantity increases, the number of shrinkage cracks increases), weather conditions, and curing regime.

This problem can be tackled by considering suitable curing regime and adding a suitable amount of water to the concrete mixture.

Figure4-3 :Shrinkage Cracks

6.Defects due to Poor Reinforcement Placemen

Errors during reinforcement installation could lead to serious concrete deterioration. For instance, inadequate chair bars and insufficient tying of reinforcement would cause rebar movement which may lead to inadequate concrete cover and reduction in effect depth of the concrete section. As a result, the durability of the concrete structure is compromised and the structure would be vulnerable to chemical attacks.

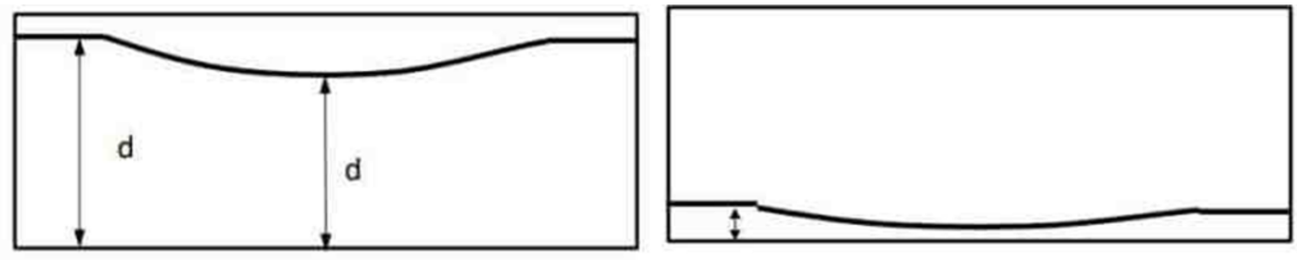


Figure 4-4: Reduction of Concrete Cover due to Reinforcement Movement

7. Bugholes

Bugholes or surface voids are small regular or irregular cavities formed due to the entrapment of air bubbles in the surface during placement and consolidation. They commonly occur in vertical cast-in-place concrete like walls and columns.

Both the number and size of bugholes vary and depend on form-facing material and condition, release-agent type and application thickness, concrete mix characteristics, and placement and consolidation practices.

Bugholes are considered as defects if their width and depth exceed 3.81cm and 1.27cm respectively.

Figure 4-5: Bugholes

<u>Cracks in Reinforced Concrete Slab</u>

Several factors like poor concrete quality, improper structural design, inappropriate steel bar spacing, large slab span, improper aggregates, etc. are responsible for the development of cracks in RCC slabs. While the issues pertaining to improper structural design can be eliminated in the design stage, the other factors can be avoided in the construction stage of the project.

1. Poor Concrete Quality

Compromising with the concrete quality is one of the reasons for crack developments in reinforced concrete slabs. Poor concrete quality results in lower concrete strength, specifically, the tensile strength. As a result, the tensile strength of concrete reaches its maximum limit at a very low magnitude of stress.

Incorrect water to cement ratio, inadequate concrete mixing, improper placement of concrete, and insufficient consolidation are factors that can jeopardize the concrete quality. Therefore, prepare and pour concrete according to the designated mix and follow proper concrete placement procedure.

2. Improper Structural Design

Another cause of crack development in an RCC slab is the low reinforcement ratio due to errors in the design stage. A lower reinforcement ratio yields a lower slab capacity to support loads. As a result, the RCC slab cracks at smaller loads.

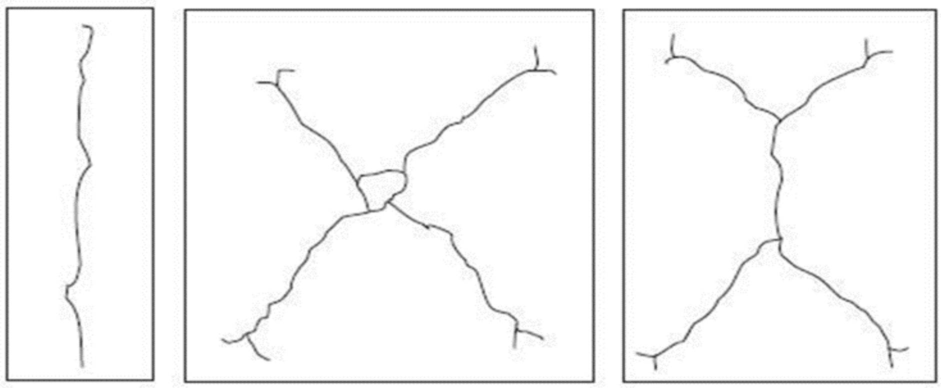


Figure 4-6: Patterns of Cracks in Reinforced Concrete Slabs Due to Improper Structural Design

3. Wrong Steel Bars Spacing

When the spacing between primary and distribution reinforcement is greater than the designated spacing, then cracks may develop in the RCC slab.

4. Insufficient Concrete Cover

Insufficient concrete cover reduces the required protection for steel bars. As a result, chloride attacks would cause steel corrosion, leading to cracking of concrete along steel bars.

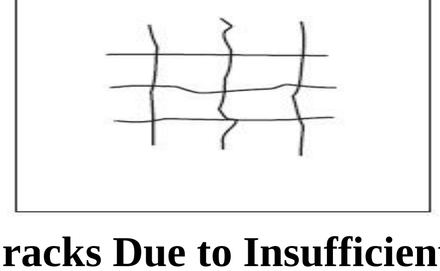


Figure 4-7: Cracks Due to Insufficient Concrete Cover

5. Improper Curing

Improper curing of concrete may cause concrete shrinkage and subsequently initiate cracks. Moreover, it could reduce the strength of the concrete. The cracks due to improper curing can be shallow fine cracks that are parallel to each other.

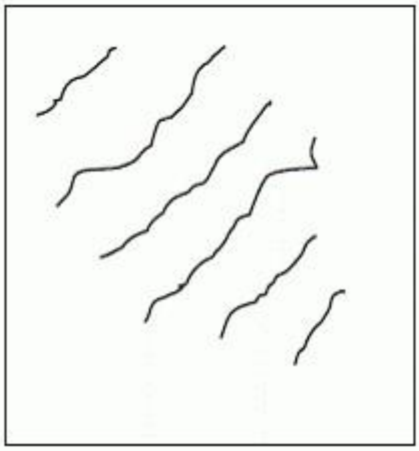


Figure 4-8: Shrinkage Cracks Appear on Slabs are Parallel to each Other

6. Wrong Material Selection

The selection of right concrete constituent, such as aggregate, is essential in reducing the risk of crack initiation in the reinforced concrete slab. The use of alkali-aggregate in concrete can cause the development of cracks. The map of cracks due to alkali-aggregate is shown below.

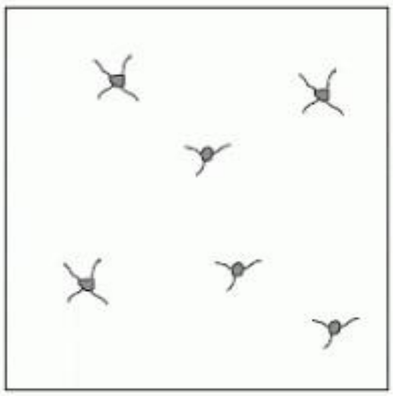


Figure 4-9:Cracks in Reinforced Concrete slab Due to Alkali-aggregate reactions

7. Severe Environmental Conditions

Sulfate attacks occur when the reinforced concrete slab is constructed in harsh environmental conditions, like, coastal areas. The pattern of cracks due to sulfate attack can be observed in the following figure.

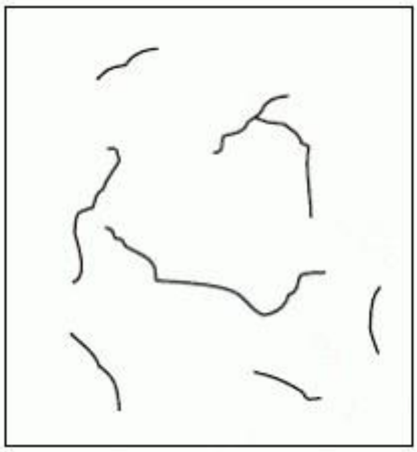
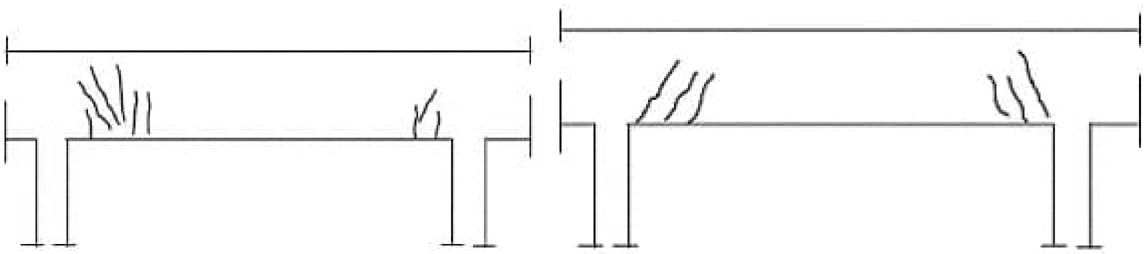


Figure 4-10:Cracks Caused by Sulfate Attack

Types of Cracks in Concrete Beams

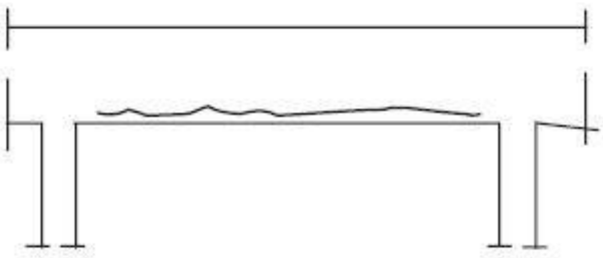
1.Cracks in beams due to increased shear stress

Cracks in concrete beams due to increase in shear stress appears near the support such as wall or column. These cracks are also called as shear crack and are inclined at 45 degrees with the horizontal. These cracks in beams can be avoided by providing additional shear reinforcements near the support where the shear stress is maximum. Shear stress is maximum at a distance of d/2 from the support where d is the effective depth of beam.



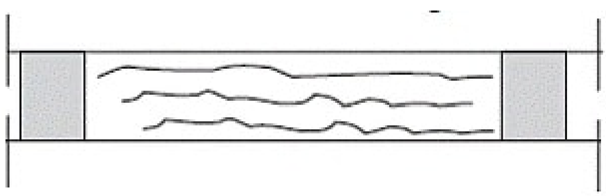
2. Cracks in concrete beams due to corrosion or insufficient concrete cover

Generally, beams are provided with slab at the top, so top of the beam is not exposed to environment. Bottom of the beam are exposed to environment and if the cover to reinforcement in insufficient, then corrosion of reinforcement takes place. So, cracks due to corrosion of reinforcement appear at the bottom of the beam. These cracks generally appear near the side face of the beam near the bottom reinforcement along the its length as shown in figure below. Cracks due to reinforcement corrosion can cause spalling of concrete in severe cases and can be prevented by good quality control during its construction by providing adequate rebar cover as per environmental conditions.



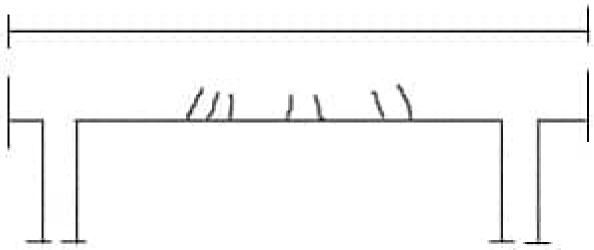
3.Cracks parallel to main steel in case of corrosion in beams

These cracks also appear due to corrosion of reinforcement but at the bottom face of the beam. These appear parallel to main reinforcements at the bottom. The cause of this corrosion is also due to provision of insufficient reinforcement cover which leads to corrosion of main reinforcement.



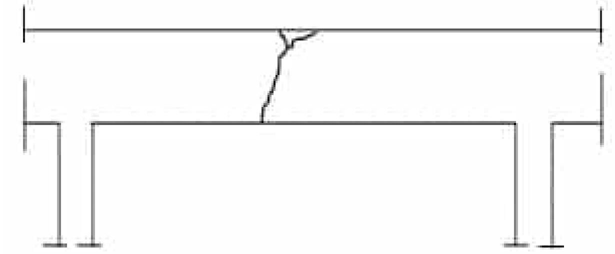
4. Cracks due to increased bending stress in beams

Cracks due to increased bending stress in beams appear near the center of span of the beam at an angle of 45 degree with horizontal as the bending moment is maximum at that point. If the reinforcement provided is insufficient for the load the beam is exposed to, bending stress increases which leads to increased deflection at the middle span of beam. Cracks due to increased bending moment can be prevented by providing adequate main reinforcement at the midspan of beam. Care should be taken during design of beam to consider all the probable loads and load combinations for its design. Under-reinforced section of beam is the main cause of this crack.



5. Cracks due to compression failure in beams

Cracks due to compression failure in beams appear at the top if the beam is over reinforced. In case of over-reinforcement, the beam has the capacity to bear higher bending stress, but at the same time, if the top reinforcement provided is insufficient to carry the compressive stress, the top of the beam gets cracked. This type of failure can be prevented by designing a balanced section in which the capacity of beam in compression is capable of carrying additional compressive stress.



4.2. Repair, retrofitting and rehabilitation techniques for strengthening of reinforced concrete beams

1. Introduction

In developing infrastructure, the premature disintegration of RC elements causes many problems in terms of strength and durability of the structure. The deterioration or degradation of RC structures could be evident by its poor serviceability causing excessive deflection, cracking, strength and stiffness degradation, etc. This could be mainly due to the design faults, poor construction practices, durability issues and unplanned increment in the service loading conditions. Hence, it is essential to strengthen the reinforced structural element to encounter the associated distresses. The awareness of the strengthening of RC structures has garnered prominence from the 1960s to the researchers (L'Hermite and Bresson 1967). Numerous research works have been carried out to develop different comprehensive strengthening materials and techniques over the years (Vesmawala and Kodag 2017, Marijana et al. 2018). However, those methods have several advantages and disadvantages relatively. The prime limitations of those methods are low strength to weight ratio, compatibility between the parent and repair material, corrosion and durability issues and failure modes. These limitations play a vital role to choose appropriate material and technology for strengthening.

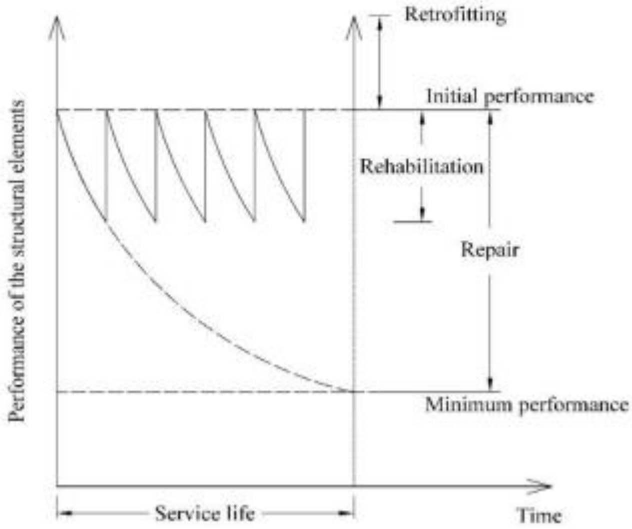
The maintenance of RC structures components throughout its life span and its up-gradation are the crucial situations for the construction sector, especially maintaining and upgrading of RC beams in the structure. (Alaee and Karihaloo 2003a, b). An RC beam is an integral part of the structural systems are more prone to damage during their service life due to various distressing factors. Therefore, these existing RC beams have to be strengthened to carry higher permissible loads and increasing service loading conditions, especially strengthening techniques for bridges are significant when the demand increases due to increased traffic loads and earthquake conditions. The primary objective of strengthening is life safety and serviceability in addition to the time, cost, and environmental restrictions behind the construction of new structures. For instance, the bridge structures are always desirable to strengthen instead of rebuilding it. Hence, the available promising strengthening techniques should be effectively identified to choose for suitable structural strengthening requirement and make use of its environmental and economic benefit. To address these problems, several researchers in the past have worked on various RC beam strengthening techniques and development of new repair materials. ACI Committee-224 suggests various repair procedures like resin injection, stitching, drilling and plugging, chemical grouting, epoxy sealing etc., (ACI 1993). The treatment for repairing of damaged RC beams varies with the nature of deterioration. For instance, the repair of RC structure for the damage due to corrosion of rebar is significantly varied from the damage due to the fire accident. The losses incurred due to fire accident are strength and stiffness . degradation, cracking, concrete spalling, unpleased serviceability, change in color etc., (Allen et al. 1992, Jumaat et al. 2006). On the other hand, the damage caused by corrosion of rebar is observed with the appearance of a longitudinal crack along the beam and rust stains on the surface. Hence, the material for strengthening is supplemented with suitable techniques tend to satisfy the required criteria for strength restoration or up-gradation. Also, there is a due consideration in cost and material available for the strengthening techniques. A different structural strengthening technique has been developed over the past four decades. The popular strengthening techniques are external steel plate attached with epoxy or anchorage bolts, concrete jacketing, wrapping with fiber reinforced plastics (FRP), external bar reinforcements, external prestressing and bonding of ultra-high performance concrete strip or overlay (Jones et al. 1980, Meier 1987, Crains and Zhao 1993, Diab 1998, Alaee and Karihaloo 2003a, Yaman 2016, Vesmawala and Kodag 2017). The severity and level of damage of RC structures could be determined from the available technical parameters like compressive strength, elastic modulus etc., to choose the suitable strengthening technique required for the distressed structural member. This paper reviews the popular and promising techniques developed for the strengthening of RC beams, along with their implications and key findings. This paper is divided into three main sections: (i) definitions of repair, retrofitting and rehabilitation of RC beams, (ii) existing strengthening techniques and its outcomes, and (iii) relative comparison over the existing techniques and its limitations.

2. Strengthening terminologies and reinforced concrete beams

2.1 Repair, retrofitting and rehabilitation:

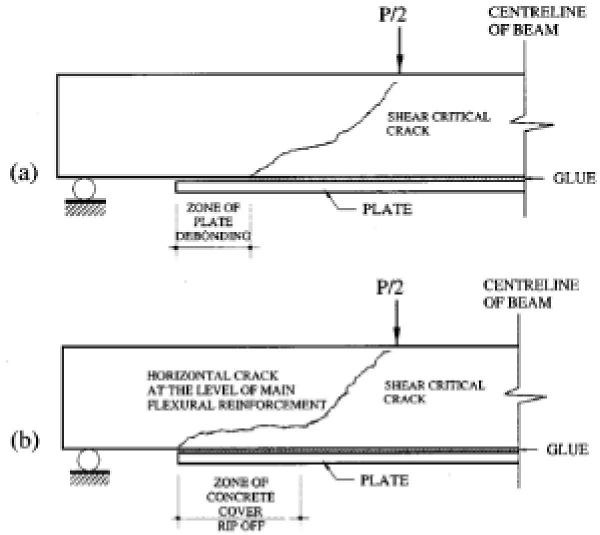
Definition:

Strengthening is a collective term used to refer repair, retrofitting and rehabilitation. These terminologies differ with respect to their own functions and attributes. Typically, repair is a process where the performance of the structure is minimally increased from their original performance or to meet the requirement provides aesthetic appearance without increasing the performance much. Typical repair works such as patching up of defects like cracks and fall of plastering, checking and repairing pipes and plumbing services. These repair works have been carried out by using resin injection, stitching, epoxy bonding, drilling and sealing, and chemical grouting (ACI 1993, CPWD 2011). On the other hand, retrofitting is the process intended to improve the performance of the structures like flexure, shear, ductility, service life, fatigue life etc.,. The improved performance by retrofitting is significant than the initial performance of the structural members for which the members were designed (Alaee and Karihaloo 2003a, Bhattacharjee 2011, Kyriaki et al. 2013, Murthy et al. 2018). Rehabilitation is the process explained by the name itself “Rehab” which is intended for restitution and restoration of strength or performance lost in the structures due to various distressing factors (Bruhwiler and Denarie)



2.2 Strengthening of reinforced concrete beam

A reinforced concrete beam is an integral part of the RC structural element which transfers the loads from the adjacent slabs and walls and the imposed live loads safely to the adjacent columns. Hence, a beam should be designed for significant safety and serviceability against the flexural and shear stresses developed in the structure at service conditions. In reality, the typical RC beams are subjected to various distressing factors like as design errors, construction errors, material deficiencies, operational errors and adverse environmental factors. Therefore, in some cases, a typical ultimate limit state of the structure is attained which leads to the complex stresses of shear and flexure induced in the RC beams. These complex stresses could be a problem to the RC beams due to the exceeded resistance capacity which may initiate the tensile cracks. The initiation of tensile cracks could be contributed mainly due to the tensile capacity of concrete which is comparatively lesser than its compressive strength. The behavior of RC beams subjected to adverse distresses mentioned above causing failure in flexure and shear by means of tensile cracks. Hence, it is essential to strengthen those critically damaged and damage prone beam elements to improve load carrying capacity and in-service performance in which it is designed (Meier 1987, Cairns and Zhao 1993, Alaee and Karihaloo 2003a).



3. Review on the existing beam strengthening techniques

Different strengthening methods for structural components are evolved over the past four decades are (i) externally bonded steel plates, (ii) concrete jacketing, (iii) fiber reinforced plastic (FRP) laminates or sheets, (iv) external prestressing/external bar reinforcement technique and (v) ultra-high-performance concrete (UHPC) overlay.

3.1 Steel plate bonding Steel plate bonding

is the oldest technique used to strengthen the RC structures. Steel plates and confined reinforcements were used as a retrofit with various configurations to withstand the flexural and shear capacity. Bonding of steel plates using epoxy was first pioneered by L'Hermite and Bresson (L'Hermite and Bresson 1967). The external bonding of steel plates in RC structure is precise and straightforward, which does not significantly reduce the clear story height, and it can be done under service condition of the structures (Parkinson 1978, Gemert 1981). The flexural behavior of distressed RC beams was studied by Jones et al. using the steel plates bonding (Jones et al. 1980). Based on the studies, it was found that the epoxy resin used for bonding the distressed RC beams and steel plate had maintained the composite action till failure.

Strengthening by external steel plate bonding significantly improved the structural performance of the cracked beams efficiently by restoring the stiffness and strength values compared to the original unplanted beams. The under reinforced and over reinforced RC beams are studied by strengthening with a glued steel plate (Jones et al. 1982).

It was concluded that the thick plate improves the ultimate strength drastically. However, thick plates are more prone to failures by separation due to the increase of self-weight of the section. The improvement in flexural strength is above 100% for the under reinforced beams with respect to control beams. The Rotherham Bridge was strengthened by Davis and Powell using this technique to improve its load carrying capacity (Davis and Powell 1984). The bridge was initially designed for maximum vehicle load of 100 tones and later to meet the increased demand, the strength was enhanced to 456 tones using this technique. Strengthening of RC structure with externally bonded steel plate has become famous and widespread due to its quick, less site disturbance while bonding, and versatile in dimension. However, this method has certain limitations such as, handling of heavy steel plates, corrosion of bonded steel plate, undesirable shear failure, and mainly debonding of steel plates (Jones et al. 1988, Swamy et al. 1989, Ziraba et al. 1994).

The debonding is one of the crucial problems which can lead to abrupt brittle failure. These debonding could be due to the high interfacial shear or normal stresses induced in the RC elements by the transfer of tensile stresses from the bonded steel plate. These transfer of tensile stresses results in debonding of plate or ripping of the adjacent concrete cover as shown in Fig. 2.

The generic and common problem associated with the steel plate is the corrosion due to the aggressive environmental conditions. Corrosion of steel plates adversely affects the bonding between the steel-concrete interfaces. Many researchers investigated to address the debonding of steel plate from the RC structures and suggested to use anchorage bolts and angle sections bonded over the side of the RC beams (Hussain et al. 1995, Adhikary and Mutsuyoshi 2002, Su and Zhu 2005, Wang and Su 2013). Performance of strengthened RC members is improved significantly by the addition of anchorage bolts in the bonded steel plates (Hussain et al. 1995). It was observed that the pattern of bolt arrangement influences the failure behaviour of strengthened RC elements. The failure behaviour of RC beams is not significantly changed due to the anchorage of bolts at the end plate. However, it helps in delaying the failure by debonding (Adhikary and Mutsuyoshi 2002). The flexural strength and ductility of coupling beams are sufficiently maintained after strengthening by the bolt anchorage techniques (Su and Zhu 2005, Su and Siu 2007, Su et al. 2010). Su et al. investigated the influence of bolt-plate configuration on strengthened RC beams as shown in Fig. 3.

Four different bolt side-plated (BSP) combinations were studied including ‘Strong Bolt Strong Plate’ (SBSP), ‘Weak Bolt Strong Plate’ (WBSP), ‘Weak Bolt Weak Plate’ (WBWP) and ‘Strong Bolt Weak Plate’ (SBWP). From the BSP studies, it was evaluated the post-elastic strength enhancement and displacement ductility for the different configuration of bolt plate arrangement. It was concluded that “Strong bolt weak plate” configuration enhances the strength and ductility significantly, whereas “Strong bolt strong plate” effects in abrupt brittle failure. It was suggested to limit the steel plate dimensions to avoid brittle mode of failure of RC beams. The moderately reinforced RC beams were strengthened using deep steel plates bolted at sides (BSP) significantly improved the flexural strength and energy absorption (Li et al. 2013, Li et al. 2015). It was also observed that the strengthening could be completely achieved by enhancing the shear in addition to flexural capacity. In general, strengthening of structural.

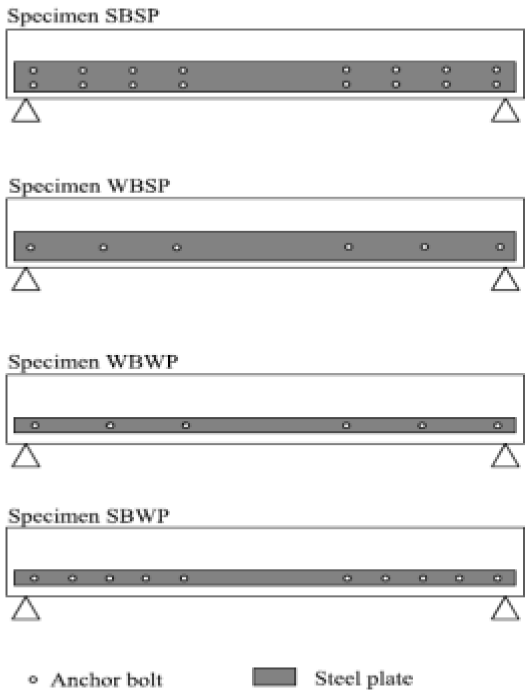


Fig. 3 Different Bolt-Plate configurations on Strengthened RC Beam

beams used to enhance the flexural capacity which may cause the shear deficiency in it. Hence, it is essential to handle the strengthening technique by considering both the shear and flexural stability. Later 90s, researchers worked on the shear strengthening of RC beams using steel plates (Swamy et al. 1996, Subedi and Baglin 1998). Suitable external bonded side plate technique can improve the serviceability and ultimate shear capacity. Steel jacket plates and small steel strips are used to strengthen RC beams by entirely encasing the shear zone to develop shear resistance and thereby failure was induced in flexural mode (Sharif et al. 1995). The web bonded steel plate is efficiently enhancing the ultimate shear strength with respect to the depth and thickness of the plate (Adhikary et al. 2000). Even 2 mm thin steel plate could enhance the shear capacity of the beam substantially if it provided with sufficient depth and anchorage bolt arrangements (Barnes et al. 2001). Also, it was observed that the depth of the bonded steel plate is an important criterion for shear strength enhancement of RC beams and the shear strength does not prominently rely on the thickness of the plate. Shear strength is improved by providing maximum depth of steel plate instead of its thickness (Adhikary and Mutsuyoshi 2006). Fig. 4 shows the typical strengthening scheme of RC beams using bonded steel and strength development over various schemes of steel plate techniques. From Fig. 4, it was observed that bolted plates show significant strength enhancement than the unbolted steel plates, especially the BSP resulted in 162% enhancement compared to control beams. RC beams strengthened with BSP technique was found to be nearly double the time of anchored plate at the soffit of the beams.

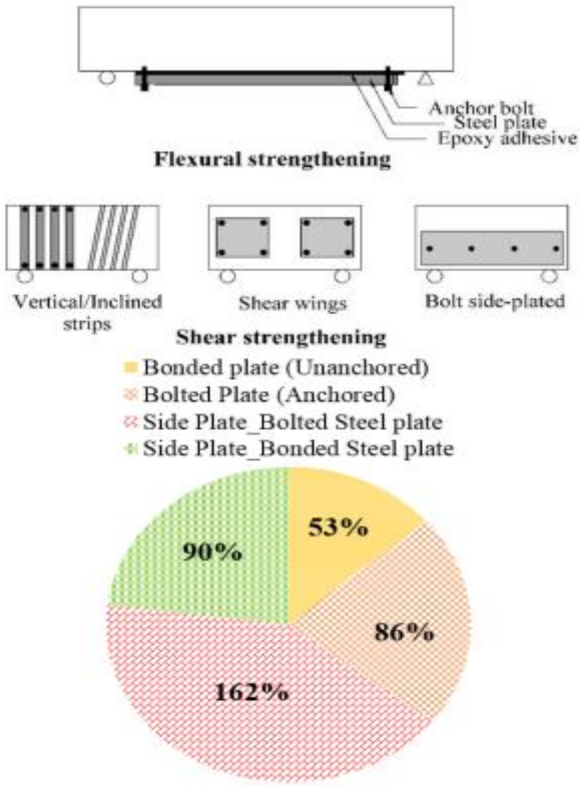


Fig. 4 Strengthening scheme of RC beams using bonded steel and strength development over various schemes

Concrete jacketing is the traditional technique used for strength restoration or up-gradation of damaged or poorly designed RC elements. Concrete jacketing is typically involved with the addition of encasing steel reinforcement over a parent structural member with a concrete jacket as shown in Fig. 5. Jacketing is mainly intended to improve the flexural and shear capacity of the damaged RC beams by increasing the percentage of tensile reinforcement. Jacketing could enhance the ductility which leads to strength recovery and restoration and changing the failure behaviour. The concrete section is enlarged by sprayed concrete which is the most common enlargement method. The load carrying capacity and stiffness of the strengthened RC beams by sprayed concrete has been improved significantly with respect to parent RC beam (Diab 1998). The additional concrete used for jacketing is preferably a pre-placed aggregate (PA) concrete since at cast in situ placing of concrete is extremely difficult. Also, PA concrete is essential for concrete jacketing because it keeps the drying shrinkage relatively low (50% than the normal concrete) which results in effective aggregate contact (ACI 1992).

The surface treatment between the parent concrete and the PA concrete could be either partially or fully roughened using impact tools to ensure the interfacial bonding between them. However, there is no significant variation in the

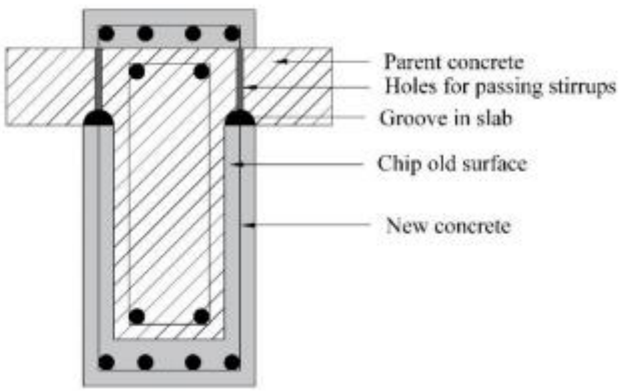


Fig. 5 Typical strengthening by section enlargement/ concrete jacketing

results with respect to surface treatment by partial and fully roughening (Cheong and MacAlevey 2000).

The flexural behaviour of severely damaged RC beams and RC jacketed beams have a similar trend with a significant change in ultimate strength. Welding interlocks the connection between longitudinal reinforcement of the damaged beam and the jacketed beam with Z bars which have a positive impact on strength enhancement (Altun 2004). In general, the interface surface is roughened significantly with the use of a bonding agent or an epoxy resin. Also, it is an essential requirement to perform jacketing technique using high skilled workmanship and the effective utilization of cost and time.

In concrete jacketing, the effective thickness could be reduced appreciably with the usage of concrete grout which is either self-compacting or high strength concrete (Julio et al. 2005). The main objective of this technique is to change the unusual premature failure modes which could then be succeeded in the structural element with the reversal of cyclic loading conditions. These loading conditions could stimulate the primary reinforcement to yield by flexure (Thermou et al. 2007). Partial jacketing techniques by the addition of concrete and steel reinforcement along the tension face of the RC beams with the use of shear connectors are the easiest and quickest method for strengthening (Shehata et al. 2009). The application of dowel connectors and micro concrete using bonding agent in RC jacketing beams improves the flexural capacity of beam significantly (Raval and Dave 2013).

The strengthening by means of the addition of thick concrete layer at the tensile zone improves the performance of RC beams in terms of stiffness and ultimate capacity. However, the technique of adding a thick concrete layer is monolithically effective only if the interface is appropriately prepared by sufficient roughening or chipping the surface to ensure the bond between the parent and strengthening layer (Raval and Dave 2013, Tsioulou et al. 2013). The performance of thin reinforced concrete jacketing with the use of self-compacting concrete is enhanced remarkably under monotonic and cyclic loading conditions than the conventional RC jackets (Chalioris et al. 2014). The enhancement could be due to its reduced thickness (Ultra thinner jacket and ease in placing), better microstructure, aesthetics, and certainly no serviceability

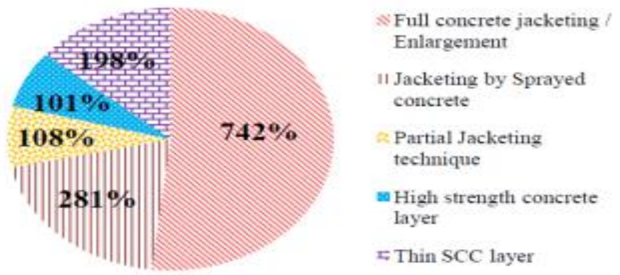


Fig. 6 Strength development over various schemes of section enlargement / concrete jacketing

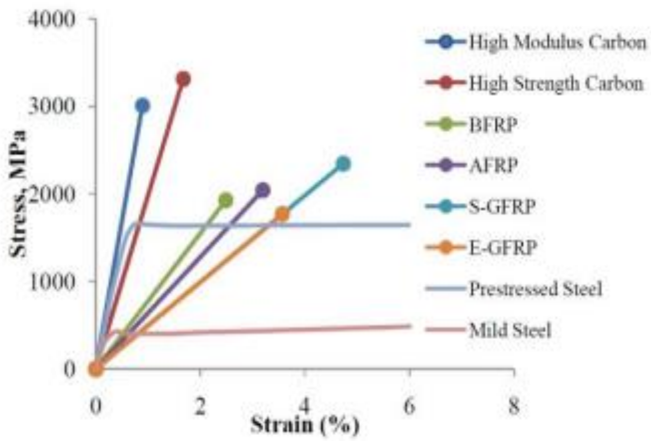


Fig. 7 Typical tensile strength and stress-strain relationship of FRP and steel reinforcement

issues. However, a marginal reduction in flexural strength of RC jacketed beam was observed when the member is subjected to a repeated cyclic loading in caparison to the strengthened beam subjected to monotonic loading. Fig. 6 shows strength development over various schemes of section enlargement/concrete jacketing. From Fig. 7, it was observed that full concrete jacketing shows tremendous strength development; however, poor serviceability leads to go for other partial jacketing techniques. From the results, strengthening by thin SCC layer found to be a feasible choice in terms serviceability with a strength development of around 200% compared to the control beams.

3.3 Fiber reinforced polymers

Fiber reinforced polymer (FRP) is a versatile material, contains composite polymers reinforced with single or multidirectional fibers. Initially, these FRPs were used in the fields of automotive sectors and aerospace industries in European countries. For the past three decades, it becomes popular in the field of civil engineering. FRP is first pioneered in the repair work of a bridge element to restore the original cross-sectional strength (Meier 1987). Various types of FRP materials are available in the construction sector, suitable for the strengthening of concrete elements. The FRP types are broadly classified based on the fiber composites; namely, carbon fiber reinforced polymer (CFRP), glass fiber reinforced polymer (GFRP) and aramid fiber reinforced polymer (AFRP). These FRP composite.

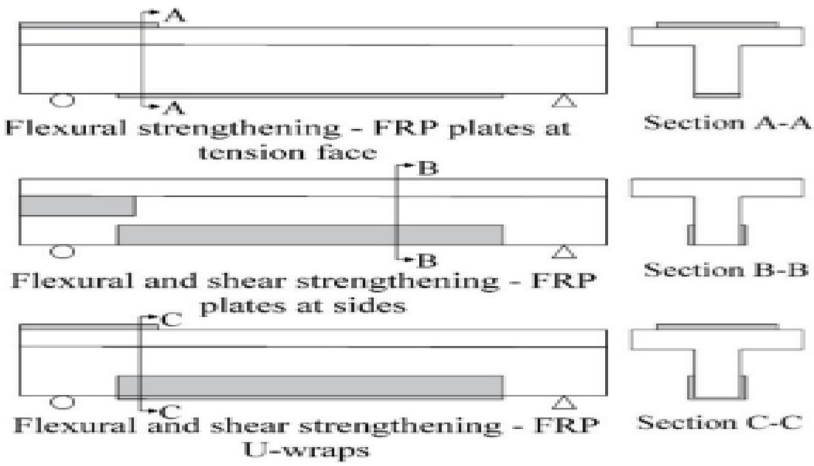


Fig. 8 Strengthening by externally bonded FRP laminates/ plates/U-wraps

laminates or sheets are bonded with the use of polymer matrix like adhesive epoxy, vinyl ester, polyester, etc. Extensive studies on the different FRP composites for the strengthening of RC elements were reported in the literature. This method became a promising technique due to their superior material properties like significant mechanical properties, high strength to weight ratio, corrosion resistance, easiness in handling, weathering resistance, better fatigue performance, versatile in size and shape, etc., (Ritchie 1988, Saadatmanesh and Ehsani 1990, An et al. 1991, Meier and Kaiser 1991, Karam 1992, Soheil and Javad 2016). Fig. 7 shows the typical tensile strength and the stress-strain relationship of various FRP and steel reinforcement.

The method of attaching FRP in the strengthening of RC elements is classified into two types. Wet lay-up is the first method which involves epoxy resin applied as cast in situ over the FRP sheets bonded with RC beams and slabs. The second method is pultrusion for producing plates by means of fabrication in factories and bonded to beams and slabs at the site using epoxy resin. Various RC structural elements strengthened using FRP composite plate or laminate bonding to enhance or restore the performance has been reported (Triantafillou and Deskovic 1991, Ross et al. 1994, Chakrabortty and Khennane 2014, Mesbah and Benzaid 2017, Hammad et al. 2018). Fig. 8 shows the typical strengthening of RC T-beam with the externally bonded FRP plates or laminate. The use of CFRP and GFRP composites enhanced the stiffness and the flexural capacity of the RC beams by about 118 and 97%, respectively (Ritchie et al. 1991). It was observed that there is no flexural failure in the maximum moment region for most of the beams, but debonding failure was observed at the plate ends.

Saadatmanesh and Ehsani investigated the GFRP strengthening RC beams with various adhesive epoxy which exhibits significant improvement in strength and ductility (Saadatmanesh and Ehsani 1990). The ductile adhesive epoxy was not responsible for the ultimate capacity because it is too flexible to influence the shear transmission between the parent material and the GFRP laminate. Though, the ultimate flexural strength is enhanced by about 110% with respect to the use of rubber-roughened epoxy with viscosity and consistency relatively similar to cement paste. The thickness of the laminates is also an important parameter studied and typically 1.0 mm thick CFRP laminate found to enhance the flexural capacity by 22% (Meier and Kaiser 1991). The deflection of the CFRP strengthened beams is found to be comparatively less than the control beams, but it is significant to predict the impending failure. However, the laminate is peeled off suddenly from the concrete surface due to the formation of shear cracks.

In the early 1990s, studies showed that the application of FRP laminates significantly enhanced the flexural capacity of RC beams with very less weight to strength ratio than the steel plate jacketing. Nearly, 2 kg of CFRP laminate was used for the repair of Bach Bridge instead of 175 kg steel plate (Meier 1987). Eventually, all the works on FRPs were carried out using merely a mobile platform instead of expensive scaffolding (Raghavachary 1992, Triantafillou and Plevris 1992, Ghaleb 1992). Also, a composite fabric made of AFRP, E-GFRP, and graphite fabrics were attached with RC beams by two-component epoxy resin which enhanced flexural capacity by about 57% and flexural stiffness by about 53%. The RC beams strengthened with E-GFRP and graphite fibers were failed due to tensioning of fabrics in maximum moment section, whereas the failure due to the reinforcement with aramid was by crushing of concrete at compression zone (Chajes et al. 1994).

Hence, FRP plates or laminates used for strengthening of RC structural component known to be very popular with the significant increase in rigidity and strength along with easiness in fixing and quick polymerization in the site. Among the FRPs, CFRP is very effective for flexural strengthening of beams with the provision of additionally required anchorage of the laminates to ensure perfect bonding. It was observed that there is a significant improvement in performance for CFRP strengthened beams which are about 3.33 times stronger than the unstrengthen RC beams (Duthinh and Starnes 2001, Esfahani et al. 2007, Varastehpour and Hamelin 1997, Razavi et al. 2015). It was also found that both the CFRP and GFRP composites enhanced the flexural strength of about 150% for the strengthened RC beams (Sheikh 2002).

The application of FRP laminates/plates or sheets for the strengthening and rehabilitation of reinforced concrete element are well specified in the design guidelines of ACI 440-02 and European fib bulletin (ACI 2008, fib 2001). Wrapping of FRP sheets enhances the flexural strength significantly in both the normal and prestressed concrete (PSC) beams (Dave and Trambadia 2004, El-Ghandour 2011). The failure load of the GFRP wrapped PSC beams increased from 25 to 41% with respect to the unwrapped PSC beams (Dave and Trambadia 2004). The promising anchorage techniques are to be developed to overcome the debonding failure through complete utilization of fiber strength over the small joint surface. This could profound

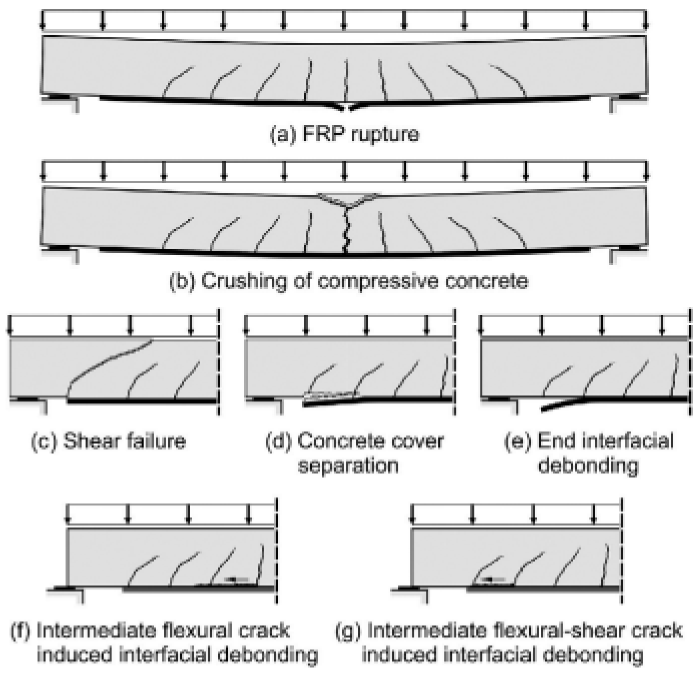


Fig. 9 Failure modes of FRP strengthened RC beams and its strength development over various schemes

the application of FRPs in the practical 3D joint strengthening (Engindeniz 2008). The flexural behaviour of RC structural component strengthened with CFRP plates was studied by equipping various FRP bonding and prestressing methods (Garden et al. 1998, Yang et al. 2009). It was observed that the ultimate strength of prestress-CFRP strengthened RC beams was nearly the same for both bonded and unbonded conditions. The ductility of the prestress-CFRP strengthened beams with an anchorage system is considerably high with the ductility index of above 3. Hence prestressed FRP exhibits superior structural properties such as enhanced flexural strength, reduced displacement, higher strength to weight ratio, enhanced ductility, resistance to corrosion and increased fatigue life makes it as a better choice of beam strengthening (Aslam et al. 2015).

Bonding of FRP strips for strengthening RC T-beam of 8.84 m long has investigated along with the mechanical fasteners which do not require any surface preparation. The flexural strength enhancement of about 15% with a maximum displacement of 63.5 mm at the mid-section for the strengthened beams bonded with one FRP strip was observed (Lamanna et al. 2012). On the other hand, the flexural enhancement is pronounced to 27% with respect to the beams strengthened with two FRP strips. The application of U-wrap CFRP laminates delays the delamination of concrete cover. However, the occurrence of premature debonding of CFRP laminates was observed at the mid-span of RC beams which could be due to the reduction in ductility of the laminates (Tahsiri et al. 2015). The externally bonded corrugated GFRP laminates are used for strengthening of RC beams which enhances the load carrying capacity to the greater extent than the plain GFRP sheets (Aravind et al. 2017).

Recently, FRP laminates or strips with near surface mounted (NSM) technique provides a practical solution to increase cracking resistance, yielding and maximum loads of beams failed in bending. Hence, CFRP laminates with NSM technique is an effective technique for the flexural strengthening of RC beams (Khalifa 2016, Dias et al. 2018). The flexural strength of RC beams is enhanced by the load range of 42 to 103% than the control beams. It is observed that a 34% increase in the yield load with respect to the control beams. However, there is a decrease in ductility is observed in using the NSM technique with respect to increasing in CFRP percentage. Recently, the studies were reported on the effectiveness of basalt FRP (BFRP) in the strengthening of RC beams (Chen et al. 2018, Gulsan et al. 2018). The experimental results showed that the external bonded BFRP is also an effective method to enhance the flexural strength of RC beams. The failure pattern varies with the anchorage, wrapping methods and adhesive used. The U-wrap of BFRP in the strengthening of RC beams attributed to the failure of RC beam by rupture of BFRP instead of debonding. Fig. 9 shows the different failure modes observed in the FRP strengthened RC beams and its strength development over various schemes.

In addition to strengthening and rehabilitation of the flexural deficiency of RC beams, it is also essential to restore its shear deficiency using FRP composites. Many studies were reported on the enhancement of shear strength of RC beams bonded with FRP composites (Uji 1992, Alexander 1996, Chaallal et al. 1998, Khalifa and Nanni 2000, El-shafie 2014). The shear failure predominantly occurs in two ways, (i) FRP rupture at tensile zone and (ii) debonding of FRP from concrete. The FRP composites are known for enhancing the flexural capacity and ductility of the RC beams; however, it is deficient in shear which could lead to peeling off and debonding of the composite. From the experimental data of the above investigations, the strengthening technique by FRP like wrapping, U-jacketing, and side bonded plate is failed due to initial debonding followed by FRP rupture. The beam failed when the FRP is peeled off from the beam surface which reduces the ductility of the member. The debonding mode of failure is mainly due to the non-uniformity of the shear crack formed in the FRP intersection (Chen and Teng 2003).

The strengthening of RC beams was carried out with externally bonded carbon fiber fabrics (CFF) strips with different orientations (45° and 90°) which significantly reduces the shear deficiencies (Diagana et al. 2003). The application of GFRP inclined strips enhanced the shear strength of beams significantly. It is evident that the behaviour of U-wrapped RC beams is superior to the beam bonded by GFRP strips on the sides alone. Shear strengthening and rehabilitation of the RC beams using FRP inclined strips enhanced the strength and stiffness by reducing the shear cracks. Hence, it is a vital requirement for the strengthening of RC beams to increase both the flexural and shear capacity of the members. The various schemes of externally bonded GFRP and CFRP sheets are used to improve the flexural-shear capacity of the RC beams (Dong et al. 2013). The sheets bonded at the bottom, and lateral sides of the RC beams enhanced the flexural strength and shear strength by 125% and 74% respectively.

The end anchorage of externally bonded CFRP wraps can restore the designed strength of RC beams (Frederick et al. 2015). The enhanced behaviour of external bonded CFRP with end anchorage could be mainly attributed to the additional end anchorage and its increased resistance to the premature debonding. The cement-based composites are used instead of an epoxy-based system to bond the FRP on the RC beams for strengthening (Azam et al. 2017). The cement-based composites consist of CFRP grid embedded in mortar and called it as carbon fabric reinforced cementitious mortar (CFRCM). The performance of these cement-based composites is better than the conventional epoxy bonded system by possessing enhanced shear strength for the strengthened RC beams. The CFRP grid embedded in mortar shows excellent bonding behaviour with the concrete surface leads to promising shear strengthening system.

Also, numerous studies were reported in the literature on the flexural fatigue behaviour of beams strengthened by repair materials using laminates and plates of CFRP, GFRP and so on. The behaviour of CFRP strengthened RC beam was studied under static and fatigue loading (Shahawy and Beitelman 1999). The improvement in the fatigue behaviour, stiffness, and capacity directs the significantly extended fatigue life of RC beams with the strengthening of CFRP laminates. The fatigue performance of the concrete beams strengthened with CFRP laminates was investigated. It was observed that internal steel reinforcement plays a key role in governing failure of CFRP strengthened RC beams due to the occurrence of fatigue facture of steel reinforcements. Therefore, the criterion required for fatigue strengthening using CFRP plates was suggested that the stress range of rebar should be limited than the permitted range in an un-strengthened beam (Barnes and Mays 1999).

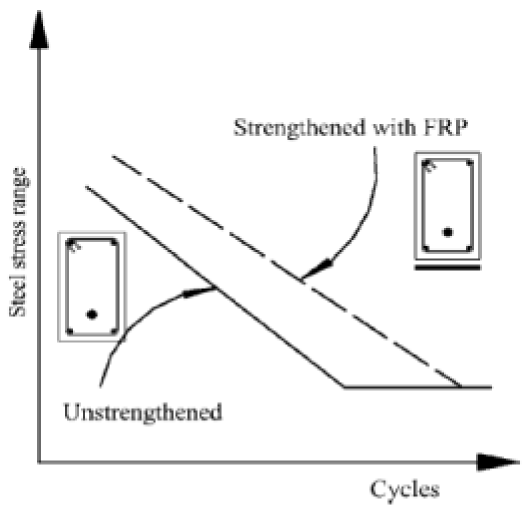


Fig. 10 Typical steel stress range versus no. of cycle's curves for strengthened and un-strengthened RC beams

The similar works with CFRP were carried out and observed that the fatigue life of the RC beams had been enhanced with the usage of FRP plates and laminates which significantly reducing the stresses taken by the internal steel reinforcement (Aidoo et al. 2004). It was also observed that the quality of the bond between the parent and strengthening materials limits the fatigue life. Similar experiments on CFRP strengthened RC beams were performed by various researchers (Papakonstantinou et al. 2001, Quattlebaum et al. 2005, Gheorghiu et al. 2006, Wang et al. 2007, Kim and Heffernan 2008, Ferrier et al. 2011, Oudah and El-Hacha 2012). The common observation in all of them is that the fatigue life of the strengthened RC beams with externally bonded FRP, exhibit enhanced fatigue life and residual strength with respect to the unstrengthen beams. Perhaps, the failure mode of strengthened RC beams remains unchanged. The enhancement in the fatigue life could be due to the decreased stress concentration acting on the internal reinforced steel. Fig. 10 shows the typical S-N curves of strengthened and un-strengthened reinforced concrete structures.

Fayyadh and Razak investigated the flexural stiffness change and the effectiveness of the CFRP strengthened RC beams under different damage levels on static and fatigue loading (Fayyadh and Razak 2012). The principal study was to examine the flexural stiffness change after the strengthening on each incremental load steps. The datum stiffness taken as extreme stiffness comprised by the strengthened RC beams and the reduction of the stiffness was observed with the further loading. However, the common mode of fatigue failure observed in the RC beams is rupture of tensile reinforcement followed by FRP failure. The fatigue behaviour of pre-damaged RC beams after strengthening results in the reduction of fatigue life. Strengthening of RC beams with NSM bar effectively tolerates the applied fatigue load even after the rupture of reinforcing steel bars (Mahal et al. 2016). The behaviour of pre-cracked RC beams is taken care effectively by NSM CFRP strengthening technique compared to beam without pre-crack.

However, strengthening by bonded FRP plate was found to be a more efficient technique in improving the fatigue life of pre-cracked beams. Strengthening by prestressed CFRP improves the fatigue behaviour of RC beams due to the reduction in the strain of the reinforcing steel and decreased displacement compared to no prestressed CFRP strengthened beam (Peng et al. 2016). The RC beams strengthened with non-prestressed CFRP were failed by debonding of CFRP from the concrete. There is no debonding in prestressed CFRP.

3.4 External reinforcement/prestressing

External prestressing was one of the most powerful techniques for strengthening and rehabilitation of damaged or distressed RC beams of bridges. The strengthening technique by external prestressing tendons has become popular due to (i) economic strengthening application; (ii) layout of tendons is easier and precise, and (iii) faster construction. The strengthening of RC beams with a moderate amount of external prestressing tendons enhanced the flexural capacity of about 146% without affecting the ductility and ultimate flexural deformation (Harajli 1993). The external prestressing tendons are effectively taking care of crack behaviour and serviceability of flexural members at severe load conditions. Hence, strengthening by external prestressing tendons reduces the width of cracks or closing the cracks and significantly reduces the deformation at service loading conditions. The external prestressing technique substantially reduces the deformations of RC beams due to the service load because of its stiffer load deformation behaviour. The deviated profile of external reinforcement increased the flexural resistance compared to the straight horizontal profile. Additionally, the external prestressing technique enhanced the fatigue life of the RC beam subjected to repeated loading conditions. There is a considerable reduction in stress level in the internal steel reinforcement of RC beams with no indication of shear distresses.

Strengthening and rehabilitation by the use of external unbounded reinforcement is a widely used technique for the RC beams introduced by Cairns and Co-investigators (Cairns and Zhao 1993, Cairns and Watson 1993, Cairns and Rafeeqi 1997, Cairns and Rafeeqi 2002, Cairns and Rafeeqi 2003). This concept has originated from the observation of the structural behaviour of RC beams with exposed bars during repair. Eventually, the RC beams with exposed reinforcement could enhance the strength of the shear deficient beam. The external reinforcement technique is popular due to its simplicity in the connection process, speedy application, and less disturbance during strengthening at service conditions. The factors influencing the behaviour of strengthened RC beams with externally unbonded reinforcement include (i) loading setup, (ii) depth of external unbounded reinforcement, and (iii) bonded reinforcement proportions.

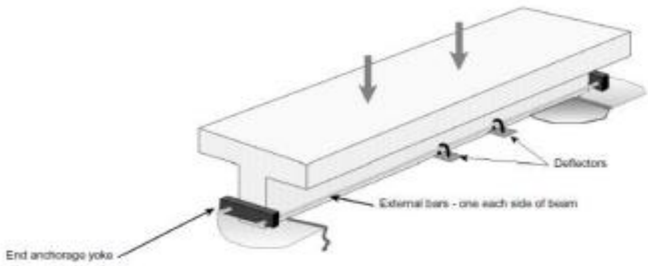


Fig. 11 Typical strengthening technique of RC beams with external reinforcement

By considering the above-said factors, it can be possible to obtain twice the ultimate strength of the RC beams with the application of external unbonded steel reinforcement. Typically, the enhancement in flexural strength is about 85% with the incorporation of external steel reinforcement strengthening technique for RC beams (Cairns and Rafeeqi 1997). However, it was observed that there is a significant reduction in ductility of RC beams. Fig. 11 shows the schematic representation of RC beams strengthened with external unbonded reinforcement. The strength of lightly reinforced RC beams has more advantage in enhancing the performance than that of the heavily reinforced RC beams (Cairns and Rafeeqi 2002). Hence, the percentage of bonded reinforcement is a critical parameter which decides the effectiveness of strengthened RC beams with external unbonded reinforcement.

A high strength tension bar with anchor pins and a saddle are used for strengthening the RC beams (Shin et al. 2007). The performance of strengthened RC beams is assessed by varying the bar arrangements, (i) V-shape (2 Bars, 1 deviator) and (ii) U shape (3 Bars, 2 deviators). This method is effective in enhancing the stiffness once the cracking starts and also there is a little enhancement in stiffness before the first crack. Strengthening of RC beams with externally unbonded high strength bars with deviator enhanced the flexural strength in the range of 42-112%. The effect of increasing the geometric ratio of externally unbonded reinforcement than the bonded reinforcement has been studied (Khalil et al. 2008). The increase in the geometric ratio of unbonded reinforcement varies from 100 to 178% of the bonded reinforcement; the ultimate strength is enhanced from 28 to 47%. The efficiency of this method is ensured by avoiding the local concrete failure against the end anchorage yoke.

The limitations of anchorage of external unbonded bars are (i) difficulty in obeying deflection behaviour of beam, (ii) requirement of deviator at higher span to depth ratio to elude the effective depth reduction, and (iii) stronger yoke requirement to withstand a huge concentrated load. These drawbacks were addressed by incorporating the external bars at the tension face of the RC beams to exclude the anchorage and deviators (Vasudevan and Kothandaraman 2014). The external reinforcement is attached to the tension face by oval-shaped grooves filled with chemical adhesives and the bars are lapped by continuous welding to reflect the lapping at real-time application. The ultimate moment capacity of the strengthened RC beams with external reinforcement is enhanced to 140% without reducing the ductility. The strength enhancement is mainly attributed to the increased effective depth of external bars. Fig. 12 shows strength development over various schemes of external reinforcement / prestressing technique. Embedded external reinforcement at the soffit of the RC beams was found to be.

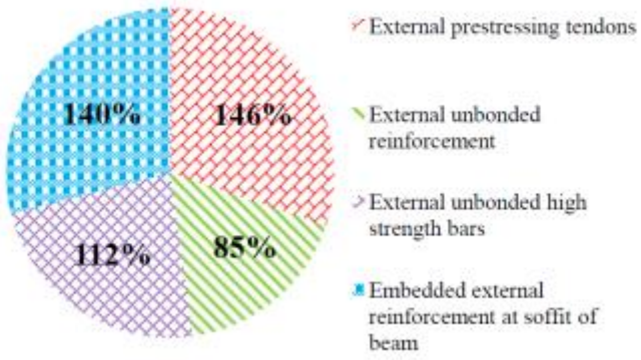


Fig. 12 Strength developments over various schemes of external reinforcement / prestressing technique

Chapter 5: Reinforcement of concrete using Carbon Fiber & Glass Fiber

5.1 Calculating quantities

For each mixture:

Type	quantities
Cement	15.750 kg.
Water	8.75 kg.
gravel	37.275 kg.
sand	19.250 kg.

5.2 filtering the gravel

5.3Prepare Models


150 MM
150 MM
150 MM
150 MM


BLUE

5.4 Mixing concrete

5.4 slump test

5.5 sections


30/4

5.6 treat Samples

5.7 Materials

Carbon Fibre:

Glass Fibre

5.8 smoothing the concrete

5.9 using the Carbon Fiber & Glass Fiber


99.9%
كلوريل
Clorel

5.10 Testing the Concrete strength

Aim of the experiment:

To determine the compressive strength of 1:3 cement and sand mortar cubes after 3 days and 7 days curing .

Test Standard Reference:

To determine " compressive strength "of 1:3 cement , sand mortar cubes after 3 days and 7 days curing

Theory:

The compressive strength of cement is determined in order to verify whether the cement conforms to I.S code specifications and whether it will be able to develop the required compressive strength of concrete. According to the IS:269-1985, the ultimate compressive strength of cubes of cement and sand mortar in 1:3 proportion containing (P/4 + 3.5) % of water should be as follows:

After 3 days: Not less than 11.5 N/mm2 ---- After 7 days: Not less than 17.5 N/mm2

Apparatus:

Universal testing machine or compressive testing machine, cube mold (7.16 cm side), vibrating machine, measuring cylinder trowels, non-porous plate and balance with weight box.
Compressive Testing Machine .

Procedure:

1. Taken the weight of the materials required. The material for each cube shall be mixed separately and quantities for one single cube are follows:
cement = 185 gm, sand = 555 gm, water = (P/4+3.5) % of weight of cement and sand, where P is the % of water for standard consistency = 30%
2. Placed on a non-porous plate, the mixture of cement and sand in the proportion 1:3 by weight and mixed it dry with a trowel for one minute. Then mixed it with water until the mixture is of uniform color.
3. Placed the assembled mold in the table of vibrating machine and firmly put it in the position by means of suitable clamp.
4. Immediately after mixing the mortar filled the entire quantity of mortar in the mold and compacted by vibration.
5. The period of vibrating should be ten minutes in the specific speed of 120 to 140 vibrations per minutes.
6. Removed the mold from m/c and kept it at a temperature of 27±2o C in an atmosphere of at least 90% relative humidity for 24 hours after completion of vibrating.
7. At the end of that removed the cube from the mold and immediately submerged in clean and fresh water and kept there until they are tussled.

Precautions:

1. Inside of the cube molds should be oiled to prevent the mortar from adhering to the sides of the mold.
2. Test three cubes for compressive strength at the periods mentioned under the relevant specification.
3. Perform the standard consistency test of cement prior to this experiment.

Observation and Result:

Testing: Tested the cubes at the end of 3 days and 7 days.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10.697 kN
4.813 Mpa
03/01/2022 12:56
810


11.373 kN
5.118 Mpa
60
03/01/2022 12:59


30.590 kN
13.765 Mpa
60
03/01/2022 13:03


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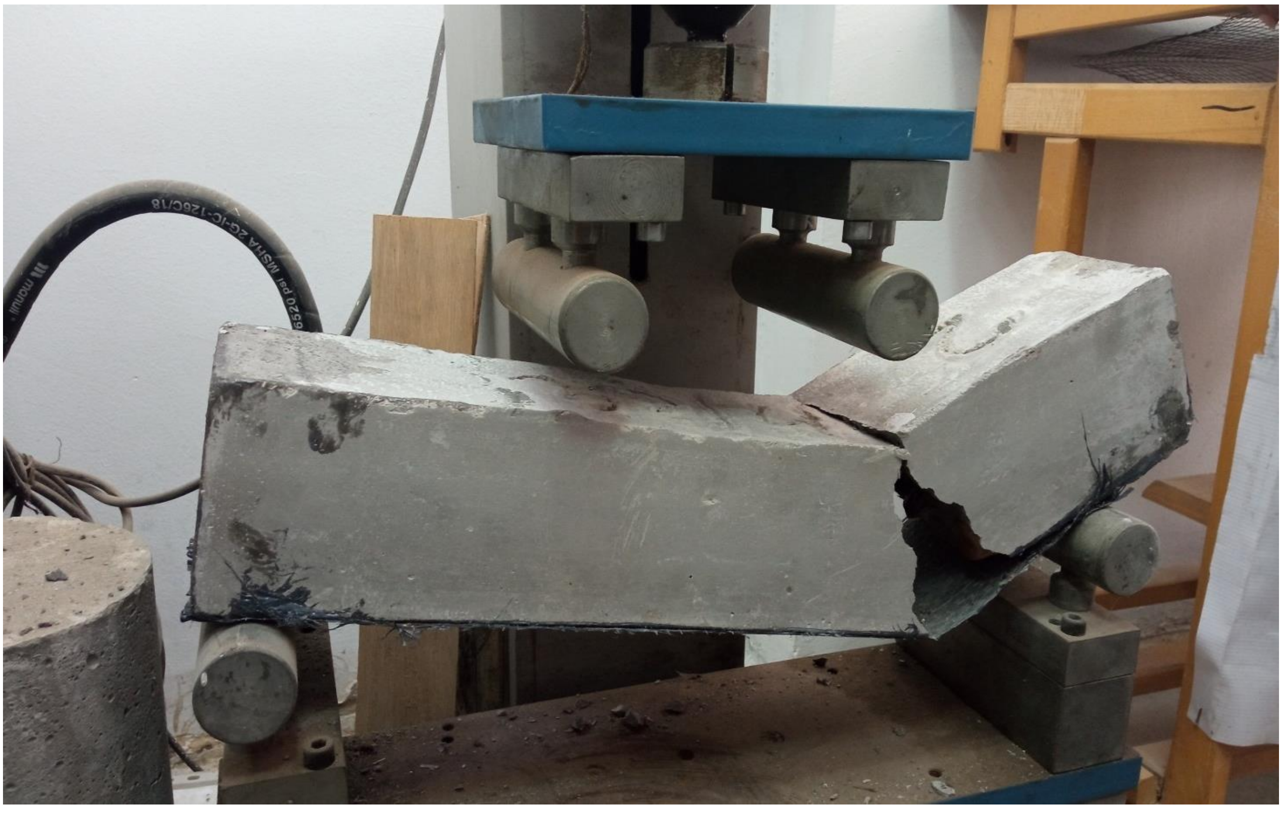


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Chapter 6 : Results of Flexure

Flexural strength, also known as modulus of rupture, or bend strength, or transverse rupture strength is a material property, defined as the stress in a material just before it yields in a flexure test.[1] The transverse bending test is most frequently employed, in which a specimen having either a circular or rectangular cross-section is bent until fracture or yielding using a three-point flexural test technique. The flexural strength represents the highest stress experienced within the material at its moment of yield. It is measured in terms of stress

6.1 Introduction

When an object is formed of a single material, like a wooden beam or a steel rod, is bent it experiences a range of stresses across its depth at the edge of the object on the inside of the bend (concave face) the stress will be at its maximum compressive stress value. At the outside of the bend (convex face) the stress will be at its maximum tensile value. These inner and outer edges of the beam or rod are known as the 'extreme fibers'. Most materials generally fail under tensile stress before they fail under compressive stress

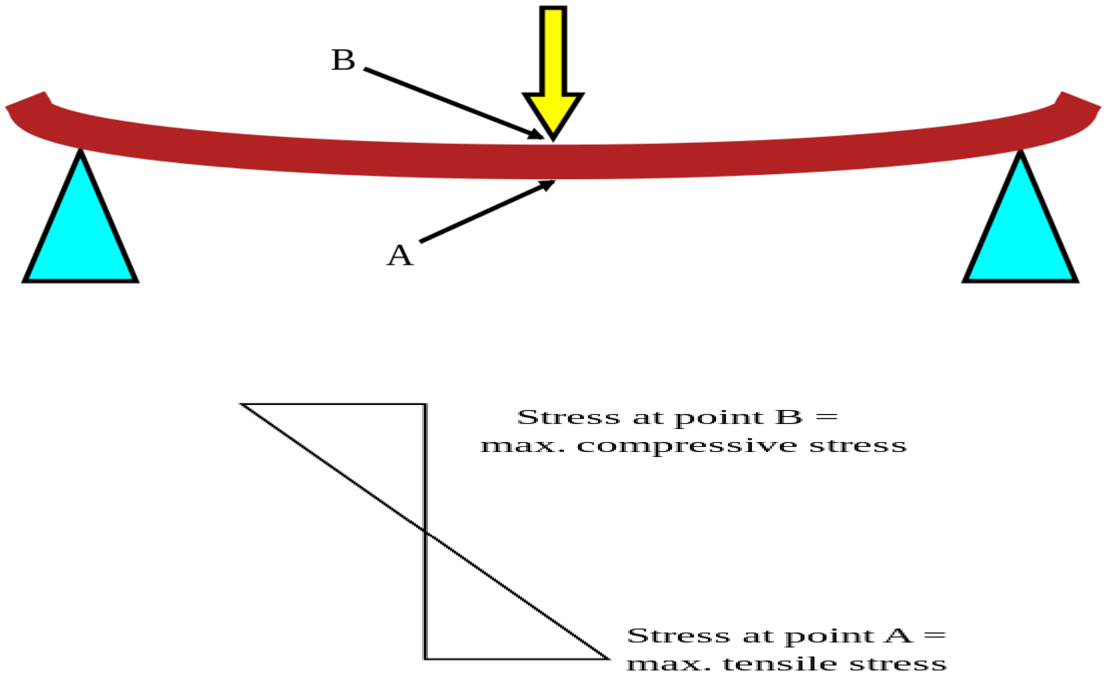
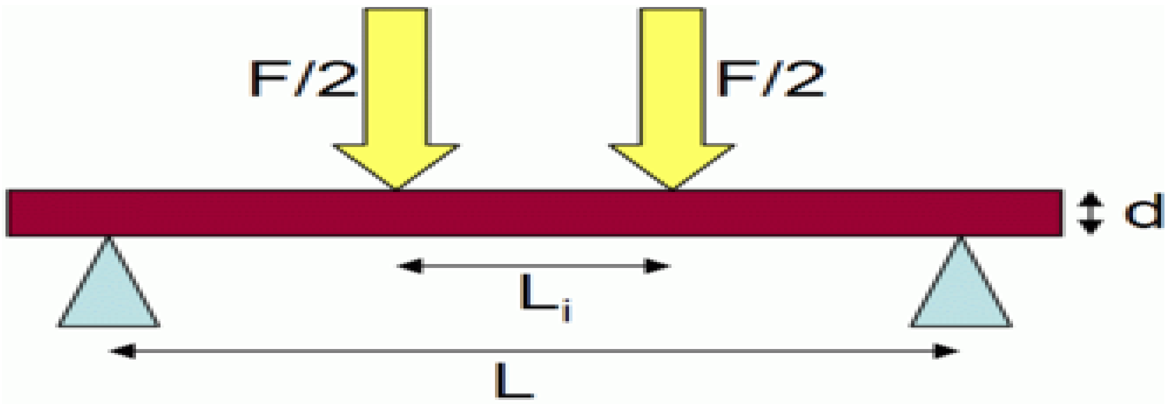


Figure5-1 stress distribution trough beam thickness

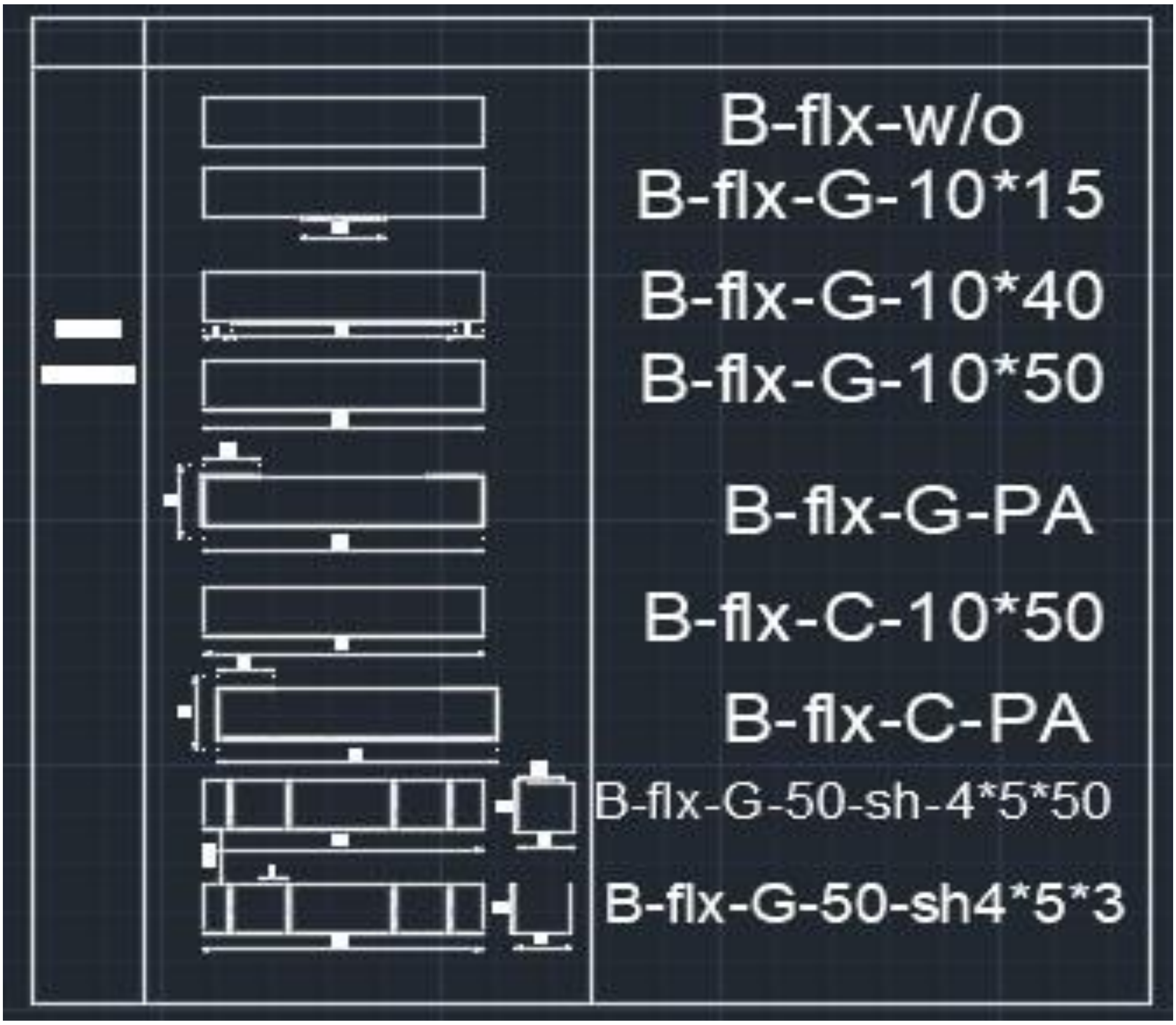
6.2 Flexural tensile strength

The flexural strength would be the same as the tensile strength if the material were homogeneous. In fact, most materials have small or large defects in them which act to concentrate the stresses locally, effectively causing a localized weakness. When a material is bent only the extreme fibers are at the largest stress so, if those fibers are free from defects, the flexural strength will be controlled by the strength of those intact 'fibers'. However, if the same material was subjected to only tensile forces then all the fibers in the material are at the same stress and failure will initiate when the weakest fiber reaches its limiting tensile stress. Therefore, it is common for flexural strengths to be higher than tensile strengths for the same material. Conversely, a homogeneous material with defects only on its surfaces (e.g., due to scratches) might have a higher tensile strength than flexural strength.

If we don't take into account defects of any kind, it is clear that the material will fail under a bending force which is smaller than the corresponding tensile force. Both of these forces will induce the same failure stress, whose value depends on the strength of the material.



6.3Beams Name



6.4 Beams weight

beams	weight (kg)
B-flx-w/o	11.255
B-flx-G-10*15	11.360
B-flx-G-10*40	11.370
B-flx-G-10*50	11.165
B-flx-G-PA	11.345
B-flx-C-10*50	11.160
B-flx-C-PA	11.390
B-flx-G-50-sh 4*5*50	11.175
B-flx-G-50-sh4*5*30	11.405

Results of flexure specimens

NAME	TYPE	DIM (cm)	Force (KN)	Strength (Kg/cm^2)	Increase ratio
B-FLX-G	W/O	10*10*50	3.34	15	-
B-FLX-G	10*15	10*10*50	4.62	20.7	38%
B-FLX-G	10*40	10*10*50	7.65	34.28	129%
B-FLX-G	10*50	10*10*50	10.7	47.95	220%
B-FLX-G	PA	10*10*50	16.5	73.94	393%
B-FLX-C	10*50	10*10*50	19.7	88.73	492%
B-FLX-C	PA	10*10*50	30.6	137.7	818%
B-FLX-G	Sh 4*5*50	10*10*50	13.6	61.4	309%
B-FLX-G	Sh 4*5*30	10*10*50	11.3	51.18	241%

NAME	TYPE	Strength (Kg/cm^2)	Failure Shape
B-FLX-G	W/O	15	
B-FLX-G	10*15	20.7	
B-FLX-G	10*40	34.28	
B-FLX-G	10*50	47.95	
B-FLX-G	PA	73.94	

B-FLX-C	10*50	88.73	
B-FLX-C	PA	137.7	
B-FLX-G	Sh 4*5*50	61.4	
B-FLX-G	Sh 4*5*30	51.18	

SUMMARY AND CONCLUSION

6.1 Introduction

The main objective of this study is to investigate the behavior of concrete specimens strengthened with different configurations of G/C FRP sheets under monotonic loading using both compression and bending test. Primarily, the experimental study concentrates on the behavior of simple specimens with a focus on how the different strip width configurations affect such behavior. Through this investigation, it was possible to assess the best strengthening technique for different specimen types based on the compared results illustrated in details in the previous chapter. According to the aforementioned, the following sections provide detailed conclusions obtained from experimental evidence as well as recommendations for future research.

6.2 General Conclusion

The aim of this mechanism is to ensure that students are familiar with the latest and recent techniques and materials and to exchange local experience of each other. From the results and observations presented in this study, the following conclusions can be highlighted from each phase of the investigation:

1. Generally, the results of the test demonstrate that the strengthening systems can be used to strengthen concrete specimens with GFRP/CFRP sheet strips and even that load capacity can be increased compared to the control un-strengthened specimen.
2. Load-carrying capacities for Round-specimens (cylinders) strengthened with GFRP were increased by 8.24%, 10.6%, 65.9 and 9.4% whenever strengthening cylinder specimen of 150 mm*300mm with GFS-50 mm at both top and bottom ends, GFS-50 mm at top, middle and bottom, GFS-FH (Full height) and GFS-50 mm at middle only. Furthermore, about
3. 129% increase is gained whenever strengthening the control specimen with CFS-FH (Full height).
4. Moreover, 56.2%, 113%, and 137% strength increase as a result of strengthening the control cylinder specimen of 100 mm*200mm with GFS-50mm at both top and bottom ends, GFS-50 mm at top, middle and bottom, GFS-FH (Full height). One can easily notice the effect of specimen dimensions (both x-sec and height).
5. For non-round compression specimens, (cubes 150*150*150mm) the strength increase of 8.6%, 28.6%, and 31.4% are gained after strengthening

the cubes GFS-50 mm at middle, top and bottom, and GFS-FH (Full height). Furthermore, the ultimate load carrying capacity increases explicitly for the specimen by 38.6% whenever strengthening the cubes with GFS-100 mm at middle. Comparing the gained strength, 8.6% and 38.6% indicates the significant effect of GFS height.

6. • In the strengthened beam specimens, strips of 100mm width are used for all specimens. The flexural strength is increased by 38%, 129%, 220%, 393% are gained as a result of strengthening beams alongst its tension side with GFS of 150mm, 400mm, 500mm and 900mm length as a perfect anchor respectively. Moreover, 241% and 309% are gained as a result of strengthening the beams with both flexural strip alongst its full length and shear strengthening strip GFS-U shape-50*300mm for the first beam and GFS-50mm*500mm as a closed stirrup strips respectively.
7. On the other hand, 492% and 818% strength increase are gained as a result of strengthening beams alongst its tension side with CFS of 500mm and 900mm on the tension side as a perfect anchor respectively.

6.3 Future studies recommendations

Based on the findings of this work, the following areas are suggested for future investigation:

- Further experimental tests should be undertaken to investigate the behavior of strengthened RC beam and column specimens with both GFRP and CFRP strips under static loads.
- As the current study is conducted using Glass FRP strips, it is recommended to investigate the bond behavior between FRP and the concrete surface.
- Further researches are required to examine the structural behavior of RC specimens with different dimensions and strengthening techniques using different FFP materials.
- The empirical design equations for every investigated RC element should be derived taking into account the volume (both area and thickness) of strengthening materials.
- Exchange experience is urgently needed through establishing a mechanism for mutual attendance of some meetings for graduated students all over the world, especially for both in the European Union and in Egypt.

Appendix

Slump test

٦-٢-٦ خطوات الاختبار

يراعى قبل البدء في الاختبار التأكد من أن السطح الداخلي للقالب نظيف ورطب وبدون أي بلل زائد. يوضع القالب على سطح ناعم جاسئ غير منفذ وفي وضع أفقي تماماً وغير معرض للاهتزازات والصدمات.

يثبت القالب جيداً فوق السطح الأفقي وبه القمع إذا استخدم ، ثم يملأ بثلاث طبقات من الخرسانة تمثل كل منها ثلث ارتفاع القالب بعد الدمك ثم تدمك كل طبقة ٢٥ مرة بواسطة قضيب الدمك القياسي على أن تكون مرات الدمك موزعة بالتساوي على المقطع المستعرض للطبقة ويكون الدمك لكل طبقة حتى كامل عمقها مع مراعاة التأكد من أن قضيب الدمك لم يصطدم بقوة بالسطح الأسفل عند دمك الطبقة الأولى ، على أن يمر قضيب الدمك قليلاً عند دمك الطبقة الثانية والطبقة الأخيرة إلى الطبقة التي أسفلها مباشرة ، ثم تكوم الخرسانة فوق القالب قبل دمك الطبقة العليا.

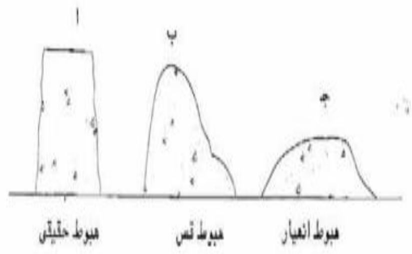
يراعى وضع كمية إضافية من الخرسانة فوق قمة القالب خلال عملية الدمك. ويجرى تسوية سطح الخرسانة بوخز ودوران قضيب الدمك. ثم مع استمرار تثبيت القالب ، ينظف السطح السفلي من أي خرسانة تكون قد وقعت فوقه أو تسربت من الحافة السفلية للقالب ثم بعد ذلك ينزع القالب من الخرسانة برفعه رأسياً ببطء وعناية في مدة ٥ إلى ١٠ ثوان بأقل حركة

جانبية أو التوائية للخرسانة ، ويجب أن تجرى العملية الكاملة من بدء الملء حتى رفع القالب دون توقف وبحيث تتم في غضون ١٥٠ ثانية.

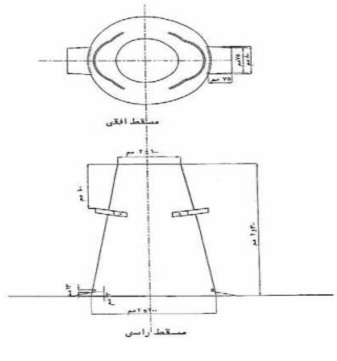
ثم يقاس الهبوط مباشرة بعد رفع القالب لأقرب ٥ مم باستخدام المسطرة بتعيين الفرق بين ارتفاع القالب وبين أعلى نقطة في العينة المختبرة ويجب ملاحظة الآتي :

١- يمكن معرفة بعض الدلالات عن تماسك وتشغيلية الخلطة بعد الانتهاء من قياس الهبوط وذلك بالطرق خفيفا على جوانب الخرسانة بقضيب الدمك حيث يحدث للخرسانة ذات النسب الجيدة لمكوناتها وذات الهبوط الملحوظ هبوط تدريجي آخر ولكن يحدث للخرسانة ذات نسب المكونات الرديئة أن تقع منهارة.

٢- تتغير تشغيلية الخلطة الخرسانية مع الزمن نتيجة تميؤ الأسمنت (تفاعل الأسمنت مع الماء) وأيضاً نتيجه فقد الرطوبة. ويجب لذلك عمل اختبارات على العينات المختلفة عند فترات زمنية موحدة بعد إضافة ماء الخلط إذا أريد الحصول على نتائج مقارنة تماماً.



شكل (٦-٢-٣) أشكال الهبوط المتوقعة للخرسانة الطازجة



شكل (٦-٢-١) شكل مخروط الهبوط

Flexure

٧-٤-٥ خطوات الاختبار

- تقاس أبعاد العينة ويُحسب كل بعد كمتوسط لثلاثة قياسات.
- تُوضع العينة بماكينة الاختبار على دعامتى الارتكاز بحيث لا يكون الارتكاز أو التحميل على سطح الصب .
- لا يبدأ التحميل حتى تتلامس جميع الدعامات بانتظام مع العينة .
- تُحمل العينة بمعدل ٠,٠٦ ± ٠,٠٤ نيوتن/مم^{٢}/ثانية بانتظام حتى الكسر.
- يُعيــن حمل الكسر للعينات التى يقع سطح كسرها بالثلث الأوسط لبحر العينة.ويجب استبعاد النتائج الذى يظهر الكسر بها خارج الثلث الأوسط للبحر.
- فى حالة استخدام حشوات بين الدعامات والكمرة يجب أخذ ذلك فى الاعتبار عند حساب الإجهادات بزيادة عمق الكمرة بمقدار الحشوات وذلك إذا وقع الكسر تحت الدعامة.

Density

٧-١-٦ خطوات الاختبار

٧-١-٦-١ تحديد كتلة العينة

- كتلة العينة كما تم استلامها بالمعمل (W_0) : تحدد بوزنها على الميزان ثم تسجل القراءة (W_0).
- كتلة العينة المشبعة بالماء (W_1) : تحدد عند وزنها بعد غمرها فى الماء عند درجة حرارة ٢٠ ± ٢ °م حتى يثبت وزنان متتاليان الفارق الزمنى بينهما ٢٤ ساعة (يعتبر الوزن ثابتا إذا كان التغير فيه لايتعدى ٠,٢ %). قبل وزن العينة يجفف سطحها بقطعة قماش رطبة.
- كتلة العينة الجافة بالفرن (W_2) : تحدد بعد تجفيف العينة فى الفرن المهوى عند درجة حرارة ١٠٥ ± ٥ °م حتى يثبت وزنان متتاليان الفارق الزمنى بينهما ٢٤ ساعة (يعتبر الوزن ثابتا إذا كان التغير فيه لايتعدى ٠,٢ %).

٧-١-٦-٢ تحديد حجم العينة

- تحديد الحجم بطريقة الإزاحة: يستخدم للعينات ذات الأشكال غير المنتظمة. وهذه الطريقة لا تصلح للعينات التى تتطلب طبيعتها عدم تغيير محتواها من الرطوبة أو الخرسانة الخفيفة المحتوية على فراغات كبيرة الحجم أو الخرسانة التى لا تحتوى على ركام صغير و بها فراغات كبيرة الحجم.
- تشبع العينة بالماء ثم توزن ويعين وزنها (W_1) كجم كما فى البند (٧-١-٦-١)
- توضع العينة على الحامل ثم تغمر فى الماء ويعين وزنها و هى مغمورة فى الماء بعد التخلص من أى فقاعات هواء تكون ملتصقة بسطوح العينة و ليكن (W_3) كجم.
- يتم تصحيح الوزن بعد طرح وزن الحامل فارغا و هو مغمور فى الماء لنفس العمق الذى قيس عنده وزن العينة وليكن الوزن المصحح (W_4) كجم.
- يحدد حجم العينة بالمتر المكعب من العلاقة:

$$V = (W_1 - W_4) / 1000$$

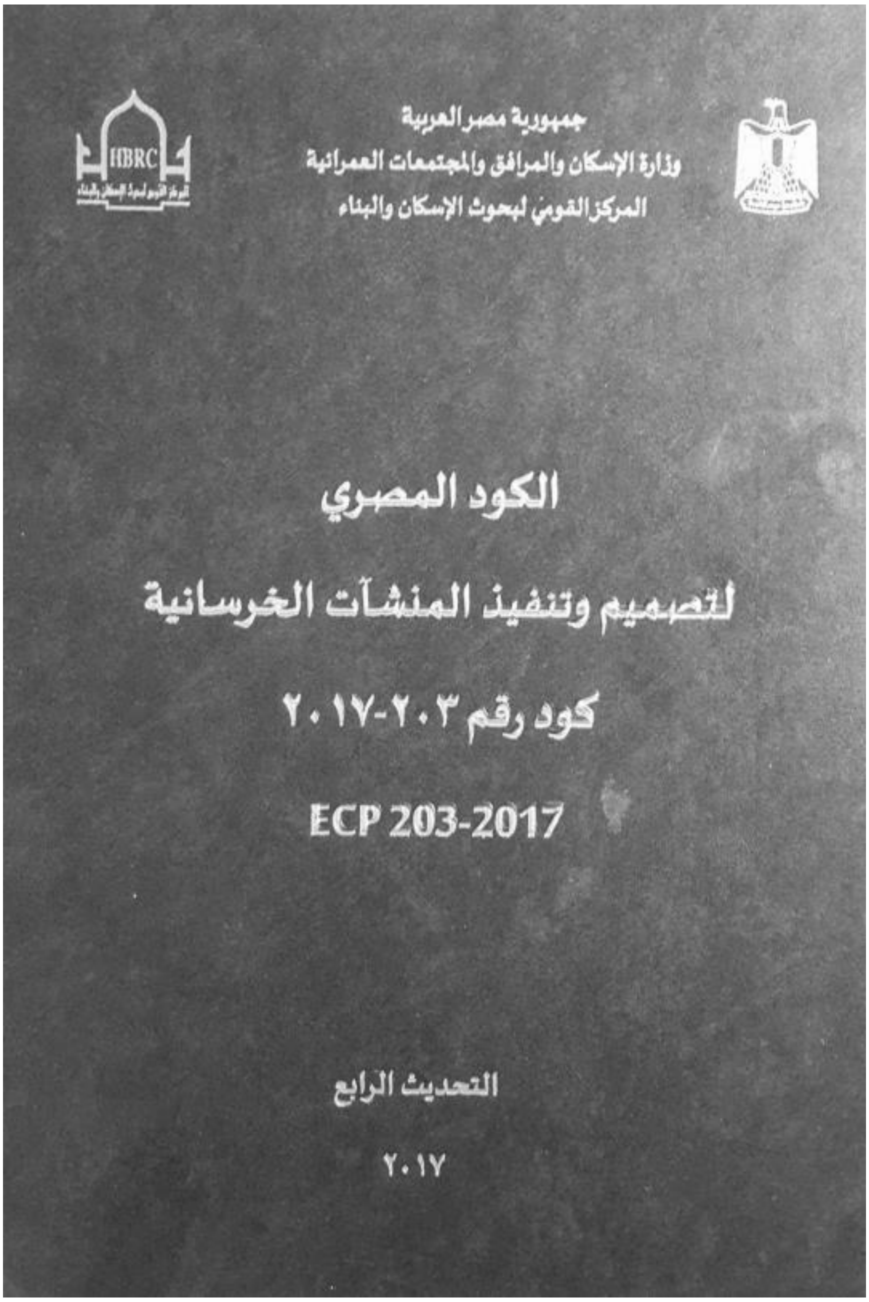
- تحديد حجم العينة بالقياس المباشر: فى حالة ما إذا كانت العينة تتمتع بشكل منتظم يمكن قياس أبعاده وحساب الحجم منها فإنه يمكن استخدام القدمة ذات الورنية فى هذا الغرض مع تسجيل الأبعاد لأقرب مم.

Compression

٧-٢-٥ **خطوات الاختبار**

- يتم تنظيف سطحى لوحى تحميل المكنة و كذلك سطحى تحميل العينة.
- توضع العينة على اللوح السفلى للمكنة مع ضبط محورها لينطبق على محور تحميل المكنة - يجب ألا يتعدى الخطأ فى ضبط المحورية ١/١٠٠ من طول ضلع العينة أو قطرها.
- عـــندما يبدأ التماس بين لوح المكنة العلوى و العينة يتم ضبط المرتكز الكروى لضمان توزيع منتظم للحمل على سطح تحميل العينة.
- يتم زيادة الحمل بشكل منتظم بمعدل ثابت يتراوح بين ٠,٦ ± ٠,٤ نيوتن/مم^{٢}/ثانية.

- يســـتخدم معـــدل التحمـــيل البطـــيء لعينات الخرسانة ذات المقاومة المنخفضة بينما يستخدم معدل التحميل السريع لعينات الخرسانة ذات المقاومة المرتفعة.
- عندما تبدأ تشكلات العينة فى التزايد بسرعة قبل أن تنهار تماما يجب أن يوقف القائم على الاختبار أى تعديل فى معدل التحميل و أن يترك العينة تتشكل تحت تأثير الحمل دون تغيير معدل التحميل.
- يتم زيادة الحمل حتى يحدث الانهيار التام للعينة و يحدد حمل الانهيار.



The proportions of the concrete mix were used according to the Egyptian code ECP203

جمهورية مصر العربية

وزارة الإسكان والمرافق والمجتمعات العمرانية

مركز بحوث الإسكان والبناء

الكود المصرى لتصميم وتنفيذ المنشآت الخرسانية

الملحق الثالث

دليل الاختبارات المعملية لمواد الخرسانة

اللجنة الدائمة للكود المصرى

لتصميم وتنفيذ المنشآت الخرسانية

كود رقم ٢٠٣

إصدار ٢٠٠٢

All test steps were applied in accordance with the third appendix to the Egyptian code "ECP 203"
(laboratory test guide).

The Egyptian Arabic Republic

Ministry of Housing, Utilities and Urban Communities

Housing and Building Research Center

The Egyptian code for the design and implementation of concrete structures

Third appendix

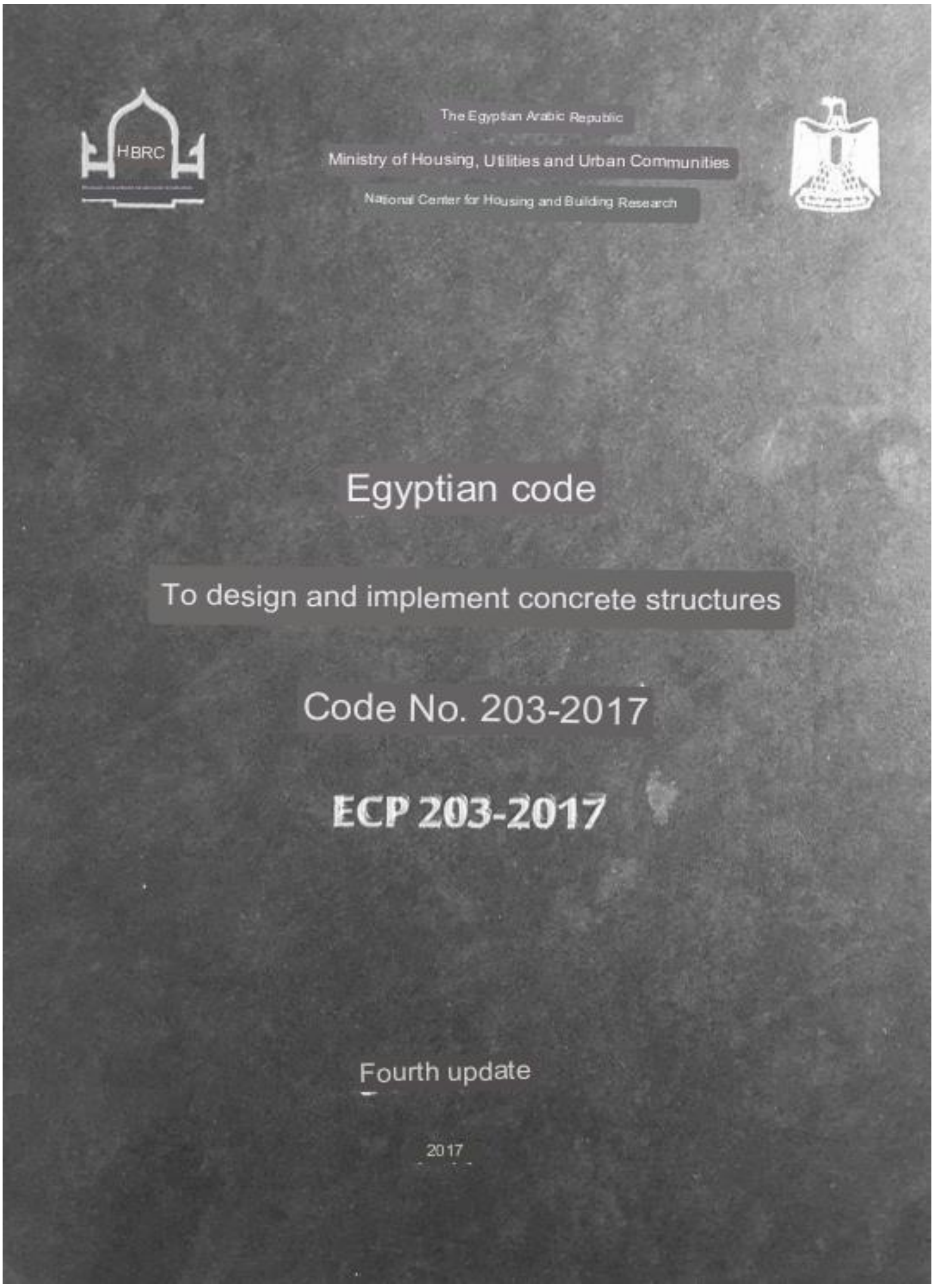
Manual of Laboratory Tests for Concrete Materials

The Standing Committee of the Egyptian

Code for the Design and Implementation of Concrete

Structures, Code No. 203

٢٠٠٢ Issuance



The Egyptian Arabic Republic

Ministry of Housing, Utilities and Urban Communities

National Center for Housing and Building Research

HBRC

Egyptian code

To design and implement concrete structures

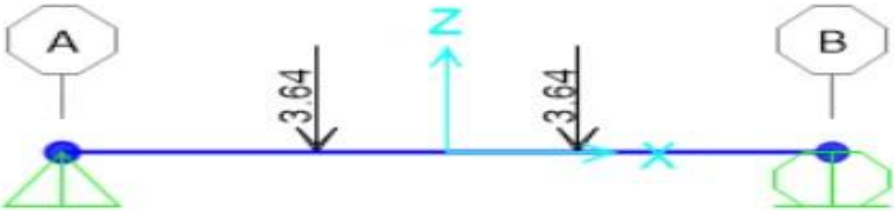
Code No. 203-2017

ECP 203-2017

Fourth update

2017

Beams force:



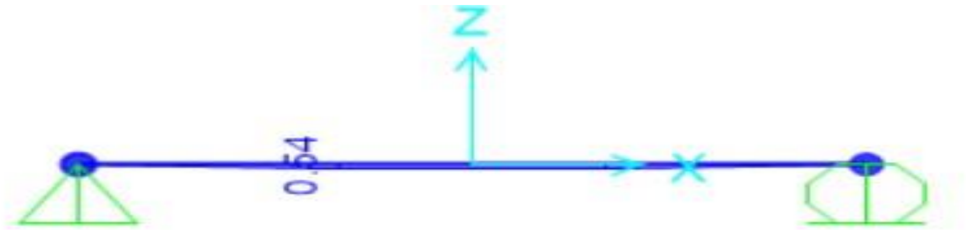

68.4
68.4


56.85
56.85

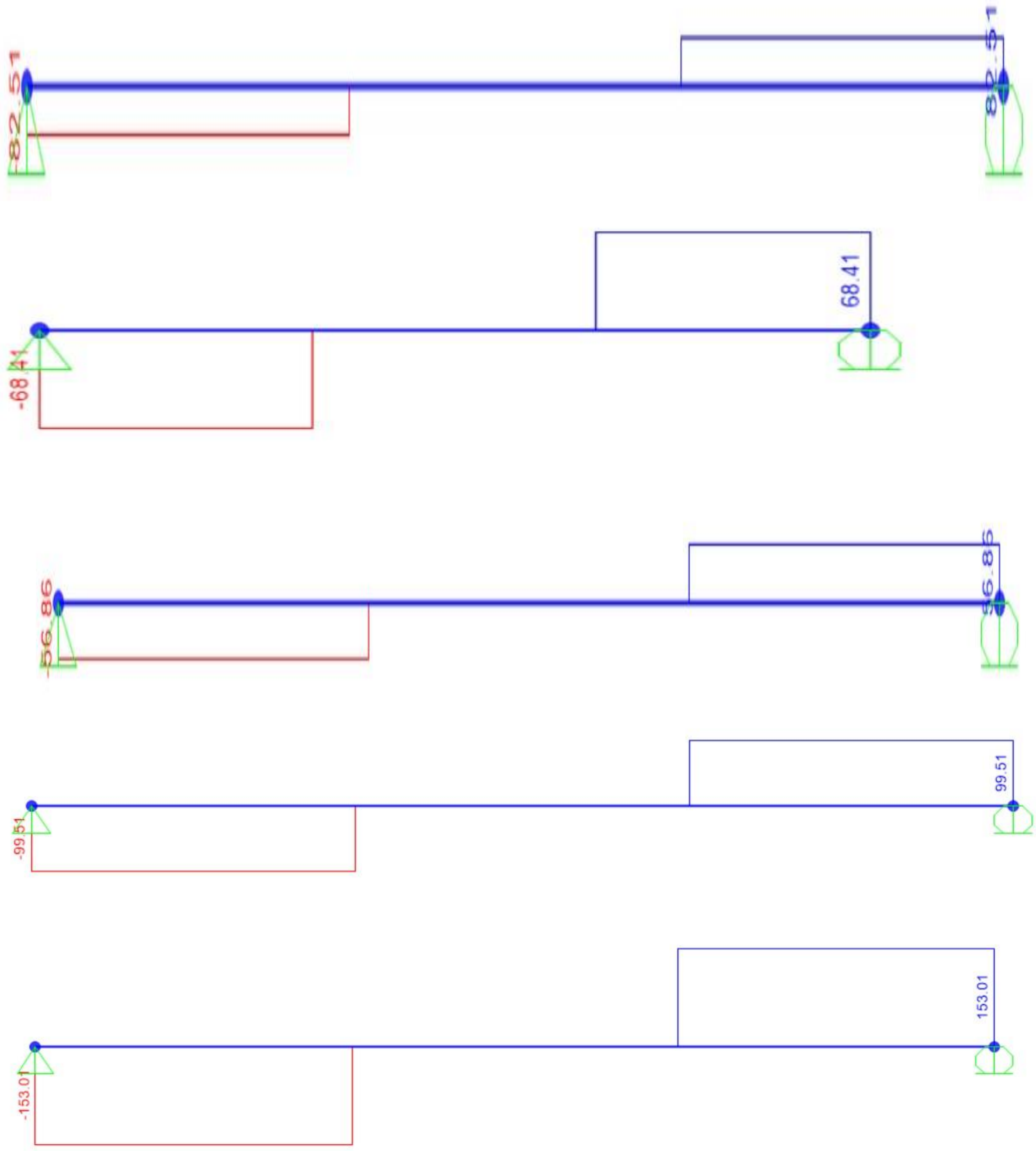

99.5
99.5


153.
153.

Moment Diagram



5.6Shear diagram


-82.51
82.51
-68.41
68.41
-56.86
56.86
-99.51
99.51
-153.01
153.01


15.750


150 MM


2023.05.03 11:13


2023.05.03 11:24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ZEYAD
07/06/2023 10:47

The content of the book

Chapter 3

Chapter 4

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