CHAPTER-3

EXPERIMENTAL PROGRAMME

3.1. GENERAL

The primary aim of the experimental procedures adopted in the research was to assess the performance of rectangular slab when subjected to uniformly distributed load. In order to meet the objectives set out in *Chapter-1*, experimental study was needed to provide major input. So, an extensive experimental programme was planned to conduct tests on slabs with different retrofitting options.

The experimental program was divided into three phases. The first phase consisted of the health check-up of slabs before and after the flexural tests on control slabs. The second phase comprised of the retrofitting of the control slabs with Glass Fibre Reinforced Polymer, Ferrocement, and Mild Steel Plate. The third and the last phase incorporated the flexural tests carried out on the retrofitted slabs. The data had been expounded in the form of tables, graphs and charts.

3.2. TEST PROGRAMME

The outline of the experimental programme planned for the research work is presented in Fig. 3.1.

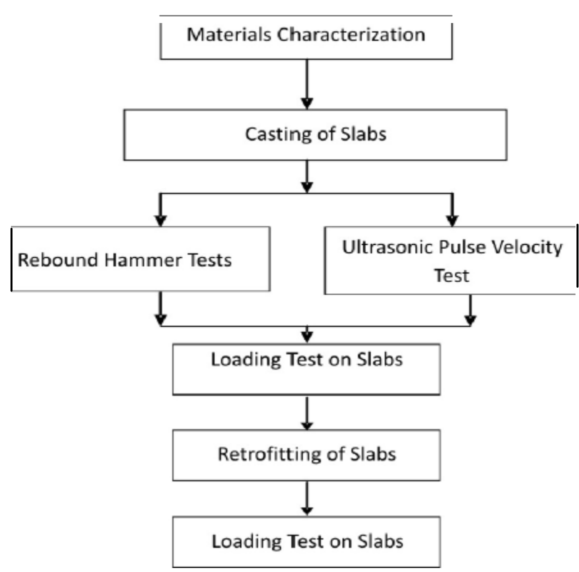


Fig. 3.1: Outline of the Test Programme

3.3. MATERIALS CHARACTERIZATION

Cement, fine aggregates, coarse aggregates, reinforcing bars were used in casting of slabs. The experimental investigation involved the retrofitting by the application of materials that comprises of Glass Fibre Reinforced Polymer (GFRP), Ferrocement and Mild Steel Plate. Primer was used for preparing base and Saturant was used for fixing fibres and mild steel plate with the slab.

3.3.1. Cement

Ordinary Portland cement (OPC) of 43 grade was used throughout the investigation. All tests were in performed in accordance with procedure laid down in IS: 8112 - 1989. The properties of cement are listed in Table 3.1.

Table3.1. Physical properties of Ordinary Portland Cement

Sr. No	Property	Experimental value	IS specifications (IS : 8112 - 1989)
1.	Standard Consistency	32	30 - 35
2.	Compressive strength (MPa) of 1:3 cement Sand Mortar with standard sand at a) 3 days b) 7 days c) 28 days	 23 34 43	 > 23 > 33 >43
3.	Setting time (in minutes) 1. Initial Setting Time 2. Final Setting Time	 90 170	 > 30 < 600
4.	Specific gravity of cement	3.15	3.10 - 3.15
5.	Fineness (specific surface) (cm^2 / gm)	2340	2250

3.3.2. Fine Aggregates

Ghaggar sand was used in the experimental investigations. The properties of fine aggregates are listed in Table 3.2.

Table 3.2. Properties of Fine Aggregates

IS Sieve Designation	% Weight passing	% passing for Zone-II (IS : 383-1970)
4.75 mm	100	90-100
2.36 mm	86	75-100
1.18 mm	78	55-90
600 microns	47	3 5-59
300 microns	20	8-30
150 microns	5	0-10

Fineness Modulus = 2.64

Unit weight (loose) = 15 kN/m^3

Unit weight (Dense) = 16 kN/m^3

3.3.3. Coarse Aggregates

Coarse aggregate of 10 mm maximum size having a fineness modulus of 7.94 and specific gravity of 2.94 was used.

3.3.4. Concrete Mix

Design concrete mix of 1:1.95:2.54 as per IS: 10262 – 1982 and 28 day compression strength of 32MPa was used for casting of slabs. Water - cement ratio of 0.54 was used for carrying out experimental work.

3.3.5. Water

Potable water was used in present study.

3.3.6. Steel

HYSD bars of Fe-4 15 and 8mm diameter were used as reinforcement.

3.3.7. Section of Slab

The two-way slab was taken for testing and investigation. The design detailing of the slab as per IS 456:2000 is given in the detailing sheet as under:

Slab S1 = (2.35x1.75) m x 75 mm

The slab is designed for load 20 kN/m^2

Bending moment in x direction $\alpha_x w(l_x)^2$ = 0.0816 x 20 x 1 .75^2 = 5 kNm

Bending moment in y direction $\alpha_y w(l_x)^2$ = 0.056 x 20 x 1 .75^2 = 3.43 kNm

Now depth of the slab from bending moment consideration (d) = 42.56 mm

Area of steel = 274.4 mm^2

Provide 8 mm ϕ @ 135 c/c along short span

Similarly provide 8 mm ϕ @ 170 c/c along long span

Slab S2 = (2.35x1.566) m x 75 mm

The slab is designed for load 20 kN/m^2

Bending moment in x direction $\alpha_x w(l_x)^2$ = 0.089 x 20 x 1.566^2 = 4.37 kNm

Bending moment in y direction $\alpha_y w(l_x)^2$ = 0.056 x 20 x 1 .566^2 = 2.74 kNm

Now depth of the slab from bending moment consideration (d) = 56 mm

Provide 8 mm ϕ @ 135 c/c along short span

and 8 mm ϕ @ 190 c/c along long span

The slab is specified in tabular form in Table 3.3 as under:

Table 3.3. Specifications of Slab

S.No	Slab	Size (m)	Thickness (mm)	Reinforcement	detail
				Along shorter span	Along longer span
1	S1	(2.35x1 .75)	75	8mm @13 5mmc/c	8mmφ@170mmc/c
2	S2	(2.35x1.566)	75	8mm @13 5mmc/c	8mm φ@190mmc/c

3.3.8. Retrofitting Materials

- **Externally Bonded Fibre Reinforced Polymer**

The use of outwardly bonded FRP has become progressively widespread for civil infrastructure applications in recent years. FRP bids several engineering benefits, and this becomes the cause of its worldwide applications that may include areas like rehabilitation and enhancement in strength due to low mass-strength ratio, easy treatment and so on to obtain high-performance mechanical systems.

As discussed in the literature review, Carbon Fibre Reinforced Polymer (CFRP) and Glass Fibre Reinforced Polymer (GFRP) are widely used as the strengthening materials in number of structures these days for various structural elements viz: slabs, columns, bridges etc.

In the present investigation, glass fibre sheet of width of 500 mm and in running length of 50 m was used. The sheet used had been bidirectional for two-way strengthening and its properties as supplied by the manufacturer are listed in Table 3.4. The main function of fibre matrix was to combine and protect the fibre against external environment into which the composite will be placed.

Table 3.4 Properties of GFRP Sheets

S.NO.	Properties	Value
1	Thickness	0.8 mm
2	Tensile Strength	2000 N / mm^2
3	Fibre Modulus	73 GPa
4	Fibre weight	Both directions 175g / cm^2
5	Fibre strain	4.3 %
6	Roll Length	50 m

- **Ferrocement**

Ferrocement is a composite material wherein the cement matrix is reinforced with wire-mesh distributed spatially. Due to thin wall construction, ferrocement structures can be made relatively light and watertight. Therefore, it is an attractive material for structures like shells, tanks, roofs, silos etc.

Following are the advantages that it offers over conventional structural material making it a separate material:

- It provides a crack free, tough, dependable surface free from danger of leakage and corrosion. This makes it a suitable lining material for canals etc.
- Ferrocement fabrication technique is so easy that common people could be trained in a short time to learn the construction skill. Thus, making the construction comparatively economical than other materials.
- High "tensile-strength to weight ratio" and durability makes it a versatile material.
- It could be more cost-effective through proper design and construction practice.

- **Steel Mesh for Ferrocement**

GI woven mesh with square grid was used for ferrocement. The grid size of mesh is (18x18) mm. The properties of wire mesh are listed in Table 3.5. as under

Table 3.5. Properties of wire mesh for Ferrocement

Mesh wire diameter, mm	0.7
Yield Strength, MPa	1010.0
Ultimate Strength, MPa	1035.0

- **Mild Steel Sheet**

Mild Steel sheet or plate of 2 mm thickness was used as a retrofitting material. The properties of mild steel sheet as given by the dealer are listed in Table 3.6.

Table 3.6. Properties of MS Sheet

Thickness of plate (mm)	2.0
Yield Strength, MPa	250.0
Ultimate strength MPa	415.0

3.3.9. Bonding materials

Primer

It is a 100 % solid epoxy resin based primer for use on porous mineral substrate. Primer assists adhesion either by partially penetrating pores of a porous surface or by forming a chemical link between the surface and a relatively high viscosity adhesive. Primers also bind and reinforce the weak surface layers of certain substrates such as concrete and stone. Properties of Primer as supplied by the dealer are discussed below in Table 3.7

Table 3.7. Properties of Primer

Mixed Density (kg / litre)	1.07
Mixed Ratio by weight (Base : Hardener)	100 : 50
Coverage (m^2 / kg)	4 – 6
Pot Life	40 minutes at 25 degree celcius
Ambient Temperature (degree Celcius)	2 – 50

- **Epoxy**

Epoxy of M-Brace was used which consisted of Base and Hardener as shown in Fig. 3.2. The properties of Epoxy as supplied by the dealer are discussed in Table 3.8.

Fig. 3.2: M-Brace Epoxy consist of Base and Hardener

Table 3.8. Properties of Epoxy

Mixed Density (kg / litre)	1.13
Mixed Ratio by weight (Base : Hardener)	100 : 40
Tensile Strength (MPa)	>17
Pot Life	25 minutes at 25 degree Celcius
Compressive Strength (MPa)	> 40

3.4. MAJOR EQUIPMENTS USED

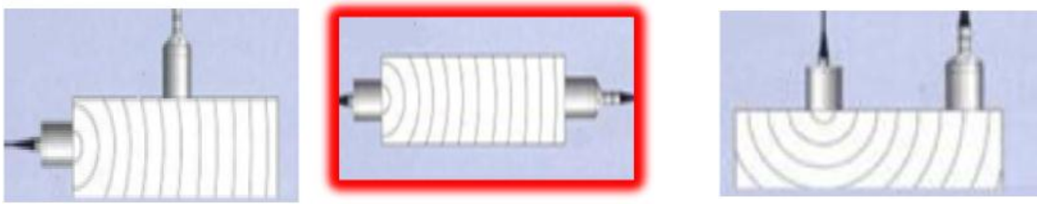
3.4.1 Reaction Frame

The Reaction Frame of Heavy Testing Laboratory of Civil Engineering Department of Guru Nanak Dev Engineering College, Ludhiana was used for predicting the behaviour of slab under uniformly distributed load. The casted slab was lifted with the help of crane of the frame and placed on the girder fitted with rollers from where it was rolled inside the laboratory to the place of the loading arrangement.

3.4.2. Ultrasonic Pulse Velocity Equipment

The Ultrasonic Pulse Velocity (UPV) method was used to evaluate the quality of concrete structure, measure of concrete uniformity and evaluate the properties of concrete. Besides that, UPV also can measure the transit time, presence of voids, path length, perpendicular crack depth and elastic modulus. UPV can be used not only for concrete but also for timber, ceramics, cast iron, and other materials. UPV is classified into three category of reading, direct test, indirect test and semi direct test as shown in Fig.3 .3. In the experimental investigation, direct method of testing (highlighted in red color) was used due to lesser thickness of the slab specimens.

The equipment used for the pulse velocity testing as a non-destructive testing was as shown in fig.3.4.



(a) **(b)** **(c)**

Fig. 3.3: UPV test for (a) semi-direct, (b) direct and (c) indirect test

Fig. 3.4: Ultrasonic Pulse Velocity Testing Machine

3.4.3. Rebound Hammer Testing Equipment

The rebound hammer that was used in this study was Schmidt’s hammer. The equipment was applied and pressed against the surface by keeping it perpendicular to the surface. The equipment that is used was shown in Fig.3 .5.

Fig. 3.5: Rebound Hammer

3.5. EXPERIMENTAL PROGRAMME

The present experimental research described the laboratory study of the on the performance of reinforced concrete slab subjected to uniformly distributed load when it was strengthened with GFRP, ferrocement and mild steel sheet. Their failure patterns were examined. The health monitoring of slabs with NDT techniques like rebound hammer test and ultrasonic pulse velocity test was done before and after the loading test on these slabs. The deflection values of the slabs were measured for control slabs as well as the retrofitted slabs, respectively.

In the present exploration, two sizes of slabs S1 (2350 x 1750 x75) mm and S2 (2350 x 1566 x 75) mm were casted and tested for the experimental program.

3.5.1. Casting of Slabs

Initially a total of eighteen slabs, that is nine slabs of each size S1 and S2 were casted. Out of these nine slabs of each size, three slabs were retrofitted with Glass Fibre Reinforced Polymer, the other three slabs were retrofitted with Ferro cement and the remaining three slabs were retrofitted with Mild Steel sheet. Similar procedure was adopted for the nine slabs of other size S2.

First of all, the frames were made. The slabs were reinforced using HYSD bars of 8mm diameter and it was laid with a bottom cover of 15 mm and side cover of 25 mm. When the bars were placed in position as per the detailing sheet in section 3.3.7., the concrete mix was poured and vibrations were given with the help of needle vibrator, so that the mix gets compacted. The reinforcement in the slabs is shown in Fig. 3.6. Then curing of slabs was done as shown in Fig.3.7. The vibration was done until there was no gap left. Then the finishing of slabs was done and the slabs were kept as such for 24 hours and then cured for 28 days.

(a) (b)

Fig.3.6: Reinforcement of Slabs

Fig. 3.7: Curing of slabs

3.5.2. Testing Methodology

Heavy Testing Laboratory was utilized for the experimental investigation. The lifting as well as the testing arrangement of the Reaction Frame of Heavy Testing Laboratory of Civil Engineering Department of Guru Nanak Dev Engineering College was exploited for the research. After 28 days of water curing, the slabs were lifted using the gantrycrane arrangement from the casting yard, and transferred to the reaction frame of the heavy testing laboratory. The slabs were lifted inside the laboratory with the help of arrangement that consisted of steel frame fitted with hooks to lift the slab. It was placed on the setup fitted with wheels that carried the slab inside the heavy testing laboratory to the Reaction Frame as shown in Fig. 3.8 and Fig. 3.9. and the slab was placed at the required position.

The bottom internal movable-beam of the reaction frame was fixed using the bolts to achieve the required size of the test slab-specimens. This beam along with the other outer lower-reaction beams of the frame will provide non-yielding support at all outer edges of the slab specimens. The concentrated reaction of hydraulic jack fixed at the upper movable reaction-girder of the frame was distributed as a uniform area load, acting over the top surface of the test slab by a load-transferring arrangement. In this arrangement, the mild-steel balls of 25 mm diameter were placed along an orthogonal grid at uniform spacing of 50 mm (Fig. 3.10). The wooden planks about 25 mm thick were stacked systematically over these steel balls. These planks transfer and distribute the reaction to a grid of uniformly placed steel balls and the reaction from this grid act as a uniform area load over the top face of the test slabs. The work that was in progression inside the laboratory is shown in Fig. 3.11. Dial gauge with least count of 0.01 mm was used to measure the vertical deflection at lower central position of the test slabs under gradually increasing load.

Manual hydraulic jack was pumped gradually to exert a uniform pressure over the total surface of the slab and this load was increased gradually in small increments. The vertical defection at lower central face of the slab was observed at each load increments. The bottom and the top face of the slab specimens were examined visually after each load increment to check the initiation of any possible cracking and any other unexpected behaviour like slippage, separation etc. The sequence of cracks was observed along with the corresponding load and dial gauge reading. The cracking pattern was reproduced on the paper.

Fig. 3.8: Slab being taken inside the Laboratory

Fig. 3.9: Reaction Frame of Heavy Testing Laboratory

Fig. 3.10: Steel balls used for load conversion

Fig.3.11: Work in Progression

NON DESTRUCTIVE TEST RESULTS BEFORE LOADING TEST

Initially, the non - destructive testing of the slabs was done. For conducting Rebound Hammer (RH) test and Ultrasonic Pulse Velocity (UPV) test, points were marked at the center and corners as well as at some suitable distance of 40 cm from center of the slab in both the directions as shown in Fig. 3.12.

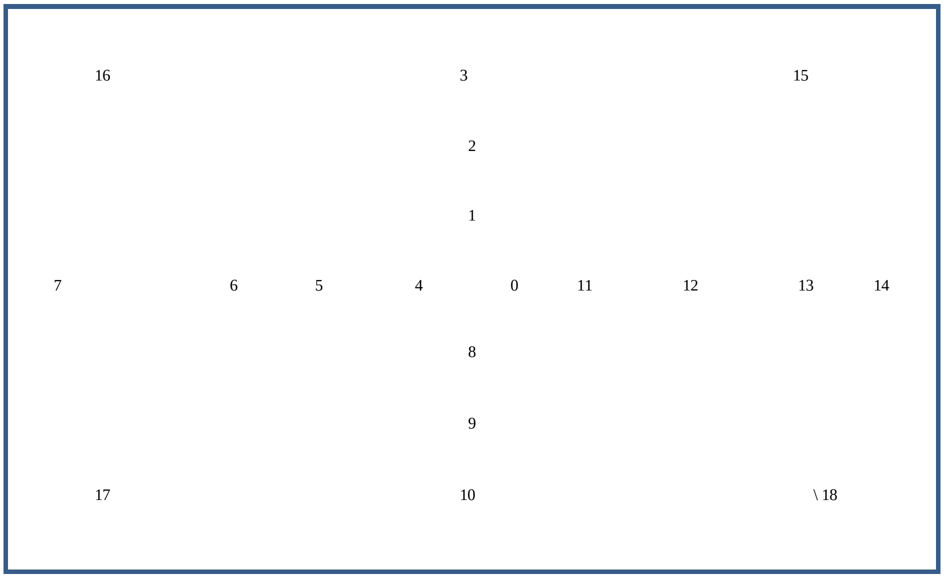


Fig. 3.12: Points Marked for NDT

REBOUND HAMMER TEST (RH)

To conduct Rebound Hammer test at these points, Digital Rebound Hammer was used as shown in Fig. 3.5. earlier. The test was performed as per IS 13911 and the reading was noted by keeping the hammer in vertical position to the bottom surface of the slab.

ULTRASONIC PULSE VELOCITY TEST (UPV)

For Ultrasonic Pulse Velocity Testing, the testing was done as per IS 13911 by keeping the transmitter and the receiver at the points on the opposite sides of the slab. The reading on the machine as shown earlier in Fig. 3.4 gave the value of time (in microseconds) taken by the waves to travel through the thickness of the slab.

Testing Setup

To achieve the objectives, the experiments were carried out where the slabs were casted and tested for non-destructive testing by using rebound hammer test and ultrasonic pulse velocity test. Then the slabs were intentionally damaged under uniformly distributed load. Then the slabs were again tested for non-destructive testing. Subsequently, the slabs were retrofitted using GFRP, ferrocement and mild steel plate and were again tested under loading.

A total of 18 slabs; nine slabs of each size S1 and S2 were casted and cured for 28 days. Every three of the nine slabs of each size S1 and S2 were retrofitted with GFRP, ferrocement and mild steel. Each set of these three slabs was designated as S11, S12 and S13 for the slab S1 and S21, S22, S23 for the slab S2.

NDT before Loading Test

Non-destructive testing before loading test was carried out to assess the degree of deterioration and to perform retrofitting with different retrofitting options. To conduct Rebound Hammer test at these points, Digital Rebound Hammer was used and the reading was noted by keeping the hammer in vertical position at the bottom surface of the slab as shown in Fig. 3.13.

Fig. 3.13: Rebound Hammer Test

For Ultrasonic Pulse Velocity Testing, the testing was done by keeping the transmitter and the receiver at these points at the top and the bottom surface of the slab. The reading on the machine as shown earlier in Fig. 3.4 gave the value of time (in microseconds) taken by the waves to travel through the thickness of the slab. This reading was then converted into the velocity of waves and then checked for the quality of concrete against the standard values.

Testing Procedure

In the experimental programme the slabs were tested using loading arrangement of the Reaction Frame. This load was applied at an equal increment of 5 kN and then converted to uniformly distributed load. The value of load was recorded from the loading gauge. The value of deflection was measured using dial gauge. The test was conducted till the cracks were initiated throughout the surface of the slab. Thereafter non-destructive testing of the slabs was again carried out. Then the retrofitting of the slabs was done by Glass Fibre Reinforced Polymer (GFRP), Ferrocement, and Mild Steel (MS) plate.

NDT after Loading Test

Thereafter, the reading by Rebound Hammer Test and Ultrasonic Pulse Velocity Test were again taken by applying the same procedure as mentioned earlier. This procedure was helpful in assessing the extent of deterioration and the need of retrofitting of the slabs. The damage index was calculated from these tests and retrofitting was done on the specimens.

3.6. STEPS FOR PREPARING SURFACE FOR RETROFITTING

After testing the slab, following steps were followed for retrofitting:

Grinding: Slab was grinded with the help of grinder. The purpose of the grinding was to expose the aggregates so as to have a better adhesion of the aggregates with the fibre sheet.

Priming: Priming was done after grinding process. Priming was done with the help of primer. Primer used was MBrace primer of BASF Company. Ratio of base and hardener used in the primer was taken from the data sheets supplied by the company. In this case, it was B:H::100:50. Both base and hardener were properly mixed and were applied on the grinded surface with the help of aluminium strip. After applying the primer it was cured for 24 hours.

Application of Epoxy

Thereafter, the surface was cleaned and was made dust free to fix the GFRP sheet to the slab. Adhesive used was MBrace Saturant. The saturant was mixed in the ratio of B:H::100:40 (Fig.3.14). After mixing base and hardener, a translucent blue liquid was formed known as epoxy and it was applied to the slab. GFRP `sheet was then laid on the top of the epoxy.

Fig.3.14: Application of Epoxy

Retrofitting with GFRP

Epoxy was applied on the slab and then first sheet was applied on the slab. Thereafter, second sheet was applied as shown in Fig. 3.15. A total of four sheets were required to cover the entire slab. Then it was rolled properly till epoxy started coming out. Roller also made the proper bond between slab surface and GFRP sheet and this is better indicated in Fig.3 .16. After retrofitting, the slabs were left as such for 72 hours and then were tested with the procedure as mentioned earlier.

Fig.3.15: Placing of GFRP

Fig.3.16: Rolling of GFRP

Retrofitting with MS Sheet

After mixing base and hardener a translucent blue liquid was formed known as epoxy and it was applied to the slab. MS sheet was then laid on top of the epoxy (Fig.3.17).

Fig.3.17: Placing of MS Sheet

Retrofitting with Ferro cement

For Retrofitting, wire mesh was used at the tension face of the slabs. First of all cementmortar was laid. Then layer of wire mesh was placed as shown in Fig.3 .18.

Then, again cement mortar mix was laid. The slabs were then compacted and then cured for 28 days.

Fig.3.18: Retrofitting with Ferrocement

Testing Procedure

After that, a uniformly distributed load was applied to the slab and testing was done by the same testing procedure as it was done before retrofitting. Load-deflection curves were drawn and results were interpreted.

3.7. CLOSURE

The experimental investigation were set to meet the objectives set in *Chapter-1.*The experimental study included the health check-up of the slabs and retrofitting of the slabs with different options. The results were incorporated in the form of tables and graphs.