

# **RETROFITTING OF STRESSED RC BEAMS USING FERROCEMENT JACKETING**

**A Thesis**

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## **CERTIFICATE**

This is to certify that thesis entitled “**Retrofitting of stressed RC beams using ferrocement jacketing**”, being submitted by Ms. Navreet Kaur Deol, in partial fulfillment for award degree of Master **of Engineering in Civil (Structures) at Thapar University, Patiala** is a bonafide work carried out by her under our guidance and supervision and that no part of this thesis has been submitted for the award of any other degree.

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## **ABSTRACT**

Many existing structures located in seismic regions are inadequate based on current seismic design codes. In addition a number of major earthquakes during recent years have underscored the importance of mitigation to reduce seismic risk. Seismic retrofitting of existing structures is one of the most effective methods of reducing this risk. In recent years, a significant amount of research has been devoted to the study of various strengthening techniques to enhance the seismic performance of the existing reinforced concrete structures. Although, the seismic performance of the structures may be improved by retrofitting or rehabilitation only but the salient features of various retrofit techniques also need to be considered before selecting the retrofit schemes. Now day's reinforced concrete structures components are found to exhibit distress, even before their service period is over due to several causes. Such unserviceable structures require immediate enquiry into the cause of distress and suitable remedial measures, so as to bring the structures back to their functional use again. Ferrocement as a retrofitting material can be pretty useful because it can be applied quickly on the surface of the damaged element without the requirement of any special bonding material and also require skilled labour as compared to other retrofitting solutions presently existing.

Ferrocement is a versatile construction material and confidence in the material is building up resulting in its wider application especially in developing countries such as for housing, sanitation, agriculture, fisheries, water resources, water transportation freshwater and marine environment, biogas structure, repair and strengthening of older structures, and others.

In the present work model sized the beams are casted to study the effect of change of grade of concrete and stress level on retrofitted beams. For this two different concrete grades M20 & M40 were used and are subsequently stressed to two different stress levels of 50% and 75% of the max load carrying capacity.

# CHAPTER -1

## INTRODUCTION

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### 1.1 GENERAL

A large number of reinforced cement concrete structures around the world are in a state of serious deterioration today due to the effect of carbonation, chloride attack, etc. Moreover, many civil structures are no longer considered safe due to increased load specifications in the design codes, overloading or due to under design of existing structures or due to lack of quality control. In order to maintain efficient serviceability, older structures must be repaired or strengthened so that they meet the same requirements demanded of structures built today and in future. It is becoming both environmentally and economically preferable to repair or strengthen the structures rather than replacement, particularly if rapid, effective and simple strengthening methods are available. Different types of cement based materials are available in market for that job. However, ferrocement has due to higher tensile strength to weight ratio and a higher degree of toughness, ductility, durability and cracking resistance other conventional cement based materials. Initial investigation into the use of ferrocement as strengthening components for the repair and strengthening of reinforced concrete beams was carried out by *Andrews and Sharma (1998)*. The use of ferrocement laminates as strengthening components for the repair of beams was investigated by *Paramasivam et al (1998)*. However, the effectiveness of strengthening system depends on strengthening materials, applying methods and prevention of debonding between existing beams and strengthening materials. The controlling factor of strengthening reinforced concrete beams is to prevent the delamination or debonding of strengthened materials from existing beam. This debonding is caused due to slip action in the interface or due to different types of pilling action. *Dritsos, et al, Nassif H.H. and Najm, H* stated that if the slip and peeling actions were to be prevented, then the two different elements (the existing beam and strengthening materials) must act monolithically. In this case the capacity of this beam will be increased.

Ferrocement is ideally suited as an alternative strengthening component for the rehabilitation of reinforced concrete structures. According to the ACI Committee 549, Ferrocement is a type of thin wall reinforced concrete commonly constructed of hydraulic cement mortar reinforced with closely spaced layers of continuous and relatively small wire diameter mesh. *Paramasivam et al(1998)* reported that the purpose of the fine mesh was simply for crack control and was not relied upon to contribute to the structural strength of the member. Ferrocement laminates with skeletal bars can play a significant role in strengthening of reinforced concrete beams. For flexural strengthening, the Ferrocement laminates are cast onto the soffits (tension face) of the beams without any change in width of the beams. Compared with conventional reinforced concrete, ferrocement is reinforced in two directions; therefore, it has homogenous-isotropic properties in two directions. Benefiting from its usually high reinforcement ratio, ferrocement generally has a high tensile strength and a high modulus of rupture. In addition, because the specific surface of reinforcement of ferrocement is one to two orders of magnitude higher than that of reinforced concrete, larger bond forces develop with the matrix resulting in average crack spacing and width more than one order of magnitude smaller than in conventional reinforced concrete [2-3]. Other appealing features of ferrocement include ease of prefabrication and low cost in maintenance and repair. The renaissance of ferrocement in recent two decades has led to the publication of ACI design guideline "Guide for the Design, Construction, and Repair of Ferrocement" and publications such as "*Ferro-cement Design, Techniques, and Application*" and "*Ferrocement and Laminated Cementitious Composites*" (*Naaman, 2000*) which provide comprehensive understanding and detailed design method of contemporary ferrocement. However, the rapid development in reinforcing meshes and matrix design requires continuous research to characterize the new material and improve the overall performance of ferrocement. Thus far steel meshes have been the primary mesh reinforcement for ferrocement, but recently fiber reinforced plastic (FRP) meshes were introduced in ferrocement as a promising new alternative to steel meshes .

Compared with steel, FRP materials possess some remarkable features such as lightweight, high tensile strength and inherent corrosion resistance. However, unlike steel that has an elastic-plastic stress-strain relationship, FRP materials behave elastically up to failure, thus do not yield and lack ductility. To prevent brittle tensile flexural failure, FRP reinforced members are usually designed to be over-reinforced

so that the nonlinear deformation capacity as well as the strain-softening region of concrete matrix could be utilized. In fact, the over-reinforced condition is intrinsically satisfied for the range of reinforcement ratio used in practice in particular for thin ferrocement plates. As a laminated composite, ferrocement often suffers from severe spalling of matrix cover and delamination of extreme tensile layer at high reinforcement ratio, resulting in premature failure. Therefore, serviceability consideration rather than strength limit would dominate composite design. Adding discontinuous short fiber to cementitious matrix, which could bring significant improvement in ductility and shear capacity as well as moderate increase in tensile strength, turns to be a logical solution to solve or alleviate these problems.

## **1.2 RETROFITTING**

The strengthening and enhancement of the performance of deficient structural elements in a structure or the structure as a whole is referred to as retrofitting. Retrofitting of a building is not same as repair or rehabilitation. Repair refers to partial improvement of the degraded strength of a building after an earthquake. In fact, it is only a cosmetic enhancement. Rehabilitation is a functional improvement, wherein the aim is to achieve the original strength of a building after an earthquake. Retrofitting means structural strengthening of a building after or before an earthquake to a predefined performance. The seismic performance of a retrofitted building is aimed higher than that of the original building. A survey of existing residential building reveals that many buildings are not adequately designed to resist earthquake. In the recent revision of the Indian earthquake code, (IS1893-2002) many regions of the country were placed in higher seismic zones. As a result many buildings designed prior to the revision of the code may fail to perform adequately as per the new code. It is therefore recommended that the existing deficient buildings be retrofitted to improve their performance in the event of an earthquake and to avoid large scale damage to life and property.

### **1.2.1 Various materials for retrofitting**

The retrofit engineer needs to have information about these materials for designing the retrofit scheme.

The repair and retrofit materials can be classified into three categories:

#### **1.2.1.1 Grouts:-**

Grout is a flow able material, which can be injected into the structure member under pressure. The grout should have negligible shrinkage to fill the gap/void completely and it should remain stable without cracking, delamination or crumbling. Injection grout is used to fill interior space within concrete or masonry created due to cracks, voids or honey combs. Various types of grouts used are:-

##### **(i) Injection grout**

In case injection grouts can be used for strengthening of old masonry structures, in which mortar has degraded as well as in honey combed concrete. These are original material and grout must be ensured.

##### **(ii) Cement sand grout**

Cement sand grouts are cheapest. For injection purpose, the grout requires high water and cement contents. This result in shrinkage and cracking of grout at hardening. Suitable shrinkage compensating agents are required to minimize this .Use of cement- sand grout is very common in masonry buildings, but not very common in concrete.

##### **(iii) Sulfoaluminate grout**

In these grouts either shrinkage – compensating cement or anhydrous sulfoaluminate expensive additive is used with Portland cement. The dosages of additive are recommended at 6% to 10% by weight of cement.

##### **(iv) Polymer grout**

The polymer resins grouts are most commonly used in concrete. The commonly used polymers are polyester, epoxy, vinyl ester,, polyurethane and acrylic. Out of these epoxy is the most popular one. In case of underground and water seepage conditions, polyethane and acrylic resins are used. Polymer grouts can be injected by pre-mixing The resins and hardener and injecting the mix through a pressure gun fitted with a nozzle. The automatic injection machine has a con of the controlled supply of resin and the hardener through two separate pipes.

### **1.2.1.2 Bonding Agents**

These agents provide enhanced bond between existing concrete and new concrete and between concrete and reinforcement. These are very important for effective repair/retrofitting of systems. There are three methods available for enhancing the bond:

- (i) Application of adhesive at the interface.
- (ii) Surface interlocking
- (iii) Mechanical bonding

Polymer and epoxy is the adhesive used for bonding between old and new concrete and reinforcement. After removal of the concrete cover the existing concrete surface and steel are cleaned by sand or water blasting. After cleaning and drying, concrete and steel is painted by epoxy/polymer or polymer modified cement grout. If the new steel is to be welded, it is welded prior to coating of the concrete and steel. The coating provides enhanced bond between the old and the new material and reduce the risk of corrosion in steel as well.

### **1.2.1.3 Replacement and Jacketing Material**

In case of damaged structures, materials in some parts of members are to be replaced by new material. For strengthening existing members in deficient buildings, additional material including reinforcement is to be provided. The material used for replacement should have good bond with existing material and it should be non-shrinking. Variety of strengthening and replacement material is available.

#### **(i) Steel plate bonding**

Steel plate can be bonded to concrete members as external reinforcement to increase their strength. The plates are glued to the member surface by epoxies. This requires a careful preparation of the member surface and application of epoxy layer. Steel plates can also be provided in the form of jackets either by gluing to surface or by grouting.

#### **(ii) Polymer modified concrete and mortar PMM/PMC**

Polymers are long molecules hydrocarbons, built by combination of single units called monomers. The process is called polymerization. Small diameter particles of polymer emulsified in water are called polymer latexes. These latexes form continuous film at drying. The polymer can also be mixed in the form of redispersible powder in the dry cement aggregate mix. When water is added to the mixture, a process similar to that described above takes place. Some polymers are water soluble. The PMM/PMC has better workability and water retention properties than ordinary concrete/mortar. The main advantage of PMM/PMC is its improved adhesion and bonding with existing concrete and significantly reduced permeability.

**(iii) Fiber reinforced polymer/plastic**

Fibre reinforced polymer/plastic is a recently developed material for strengthening of RC and masonry structure. It has been found to be an effective replacement of steel plates for strengthening of columns by exterior wrapping. The main advantage of FRP is its high strength to weight ratio and high corrosion resistance. FRP plates are 2 to 10 times stronger than steel plates, while their weight is just 20% of that of steel. However, at present their cost is high. FRP composites are formed by embedding continuous fiber matrix in resin matrix. The resin matrix binds the fiber together and also provides bond between concrete and FRP. The commonly used polymers are carbon fibre reinforced polymer (CFRP), Glass Fiber Reinforced polymer (GFRP). These fibers are available in two forms (i) Unidirectional tow sheets (ii) Woven fabrics. The application of resin can be in situ or in the form of pre-fabrication of FRP plates and other shapes by pultrusion. On the other hand, prefabricated systems offer better quality control. It is important to note the difference between the properties of steel and FRP and it should be understood that FRP cannot be treated as reinforcement in conventional RC design methods.

**1.3 FERROCEMENT**

As explained earlier ferrocement is a term commonly used to describe a steel –and – mortar composite material. Essentially a form of reinforced concrete, it exhibits behavior so different from conventional reinforced concrete in performance, strength,

and potential application that it must be classed as a completely separate material. Ferrocement can be formed into a section less than 1 inch thick, with only a only fraction of an inch of cover over the outermost mesh layer. Conventional concrete is inch or so of concrete cover over the outermost steel rods. Ferrocement reinforcement can be assembled over a light framework into the final desired shape and mortared directly in place, even upside down, with a thick mortar paste. Conventional concrete must be cast into forms. These fairly simple differences lead to other, more remarkable differences. Thin panels of ferrocement can be designed to levels of strain or deformation, with complete structural integrity and water tightness , far beyond limits that render conventional concrete useless .Ease of fabrication makes it possible to form compound shapes with simple techniques ;with inexpensive material ; and , if necessary ,unskilled (but supervised) labour.

Ferrocement is a versatile construction material and confidence in the material is building up resulting in its wider application especially in developing countries such as for housing, sanitation, agriculture, fisheries, water resources, water transportation freshwater and marine environment, biogas structure, repair and strengthening of older structures, and others.

Considered to be an extension of reinforced concrete ,ferrocement has relatively better mechanical properties and durability than ordinary reinforced concrete. Within certain loading limits , it behaves as a homogeneous elastic material a and these limits are wider than for normal reinforced concrete reinforced concrete. The uniform distribution and high surface area to volume ratio of its reinforced results in better crack arrest mechanism i.e. the propagation of cracks are arrested resulting in high tensile strength the material.

### **1.3.1 Characteristics of Ferrocement**

Ferrocement is a high-quality structural material whose simple constituents and formation make it usable for many construction purposes in even the most underdeveloped societies. In no way an inferior product specifically for cheap uses, it is in some respects more sophisticated than prestressed concrete. Ferrocement usually uses a freestanding frame of wire mesh that is mortared in place on site. The wire mesh is formed into the desired shape (domes, simple curves, or compound curves). Supporting framework used to outline the shape can be wood, precast concrete, or a simple jig made from steel rods or pipes. These supports are usually very rudimentary

and serve only to outline the shape for the layers of wire mesh to be added next. They can eventually be removed or left in place to become part of the final structure.

The economy of ferrocement construction, compared with steel, wood, or glass-fiber reinforced plastic (FRP), depends greatly on the product being built, but ferrocement is almost always competitive, particularly in tropical developing countries where steel is expensive, frequently drains foreign exchange reserves, and requires sophisticated facilities and skilled operators. FRP is much more costly, creates a fire hazard, requires advanced technology, sophisticated materials, and skilled labor; and its ingredients are sensitive to tropical temperatures. Wood is almost nonexistent in many arid or deltaic countries. Even heavily forested countries such as Indonesia, the Philippines, and Thailand foresee serious shortages due to growing demands of an increasing world population. Furthermore, in the tropics wood are subject to rot, insects.

The relatively low unit cost of materials may be the greatest virtue of ferrocement. Worldwide, the costs of sand, cement, and wire mesh vary somewhat; but the greatest variable in construction costs is the unit cost of labor. In countries with high-cost labor, the economics of ferrocement often make it noncompetitive. But, according to UNIDO (United Nations Industrial Development Organization) experience has shown that where unskilled, low-cost labour is available and can be trained, and as long as a standard type of construction is adhered to, the efficiency of the labour will improve considerably, resulting in a reduced unit cost. Under these conditions, ferrocement compares more than favorably with other materials used in boatbuilding, such as timber, steel, aluminum or fiberglass, all of which have a higher unit material cost and require greater inputs of skilled labour.

### **1.3.2 Suitability to Developing Countries**

Although the increased interest in ferrocement for water and land use is fairly recent, successful examples of innovative applications, within a wide range of construction techniques and sophistication, already promise a major impact on developing countries for the following reasons:

1. Ferrocement may be fabricated into almost any conceivable form to meet the particular requirements of the user. This is particularly pertinent where acceptance of new materials may be dependent on their ability to reproduce traditional designs.

2. The basic raw materials for the construction of ferrocement viz-sand, cement, and reinforcing mesh-are readily available in most countries. Sand and cement are used in building and road construction, and mesh is used in agriculture (chicken netting) and housing construction (plastering lath).

3. Except for highly stressed or critical structures such as deep-water vessels, adequate ferrocement construction does not demand stringent specifications. A wide range of meshes can be used; both hexagonal and square meshes have produced successful structures. The cement is of standard quality used in building construction. Special grades are unnecessary.

4. Little new training is required for the laborers, providing a skilled supervisor is on hand. Cement construction techniques are widely known in developing countries, and indigenous construction workers often show a good aptitude for plastering. Transportation, logistics, and materials-handling are serious problems in developing countries, and ferrocement construction simplifies each one. Sand and water can usually be obtained in the region of the building site; and the quantity of cement normally required can be easily transported. Only the wire mesh may require transportation from distant production centers. Under extremely difficult conditions (such as in the roadless highlands of Nepal), wire mesh may be hand loomed on site from reels of straight wire, a technique apparently already in use in rural areas of the People's Republic of China. For simple, indigenous-type boat hulls and agricultural or construction uses, no well-developed or centralized building site is required (though it is an option for a builder). Construction can well be done on site at the riverbank, in the village, high in the mountains, or wherever needed.

6. Ferrocement withstands severe abuse. Authenticated reports tell of boat hulls wrecked on reefs and successfully surviving savage poundings. Afterwards, the ferrocement was easily and rapidly repaired on site. Only simple tools are needed to repair any damage to the mesh and only cement and sand are required to make a fresh mortar. Such repairs are usually good for the remaining life of most ferrocement products, though the more stringent requirements of deep-water boats may dictate that the repair be reworked by skilled labour.

### **1.3.3 Limitations of Ferrocement**

The disadvantage of ferrocement constructions is the labor intensive nature of it, which makes it expensive for industrial application in the western world. This "disadvantage" is the primary advantage for those who compete with western world corporations. High labor content fosters small-scale enterprises by employing low-cost marginal labor to fabricate artifacts which require large labor inputs. When large industrial corporations are outside their own economic system they must compete directly without government protection. Highly motivated ferrocement entrepreneurs build aqueducts, drainage systems, water and septic tanks, large flower pots for hotels and parks, water troughs, shade roofs, small houses, etc.

### **1.3.4 Constituent Materials**

The constituent materials of ferrocement are:

- a) Reinforcing Mesh
- b) Cement
- c) Aggregates
- d) Mixing Water
- e) Admixtures

#### **(a) Reinforcing Mesh**

One of the essential components of ferrocement is wire mesh. Different types of wire mesh are shown in Fig. 1.1 and they are available almost everywhere. These generally consist of thin wires, either woven or welded into the mesh but main requirement is that it must be easily handled and if necessary, flexible enough to be bent around sharp corners. The function of wire mesh and reinforcing rod is to provide the form and to support the mortar in its green state. In the hardened state, its function is to absorb the tensile stresses on the structure which the mortar on its own would not be able to withstand.

#### **(b) Cement**

The cement used should conform to IS specifications. There are several types of cements commercially available in the market of which ordinary Portland cement, OPC and Portland Pozzolana cement (PPC) are the most well known &

available everywhere. Cement of Portland variety produced today is satisfactory enough to serve the purpose of ferrocement construction.

**(c) Aggregates**

The most common aggregate used in ferrocement is sand .Sand should comply with IS standard is 383-1970 for fine aggregate. Aggregate is the term given to the inert material & it occupies 60 to 80 % of the volume of mortar. Aggregates to be used for the production of high quality mortar for ferrocement structure must be strong enough, impermeable & capable of producing a sufficiently workable mix with minimum water /cement ratio to achieve proper penetration of wire mesh.

**(d) Mixing water**

The quality of mixing water for mortar has a visual effect on the resulting hardened Ferrocement.Impurities in water may interfere with setting of cement and will adversely affect the strength of ferrocement.These impurity may also cause staining of its surface and may also lead to corrosion of reinforcement in ferrocement. Usually water that is piped from the public supplies is regarded as satisfactory.

**(e) Admixtures**

Admixtures are used to alter or improve one or more properties of cement mortar or concrete. Most of the admixtures are used to improve the workability, to lesson water demand & to prolong mortar setting. Admixtures can be classified into groups according to the effect they are expected to achieve. The commonly used admixtures are:

1. Accelerating admixtures
2. Retarding admixtures
3. Water reducing admixtures
4. Air entraining admixtures.

A new class of water reducing admixtures has emerged during last two decades, known as “super plasticizer” . There are the high range water reducers.

### **1.3.5 Design Requirements for Ferrocement**

#### **(a) Reinforcement**

The total volume of reinforcement in ferrocement ranges 5-8 % by volume of structural elements. The reinforcement used in ferrocement is of two types- skeletal steel & wire mesh. The skeletal steel comprises relatively large diameter (about 3 to 8 mm) steel rods spaced typically at 70 to 100 mm centre to centre. Skeletal reinforcement consists of either welded mesh or mild steel bars. The skeletal steel frame is made conforming exactly to the shape and geometry of the structure and is used for holding the wire mesh in position and as per the shape of the structure.

The wire meshes are usually 0.5 mm to 1.5 mm in diameter & spaced 5 mm to 25 mm apart & volume of mesh ranges from 0.2 % to 3 % of total volume of structural element. The wire mesh may be galvanized or ungalvanized. If the wire mesh is galvanized and used along with ungalvanized mild steel bars, then chromium trioxide at the rate of 100 to 300 parts per million by weight of water should be added in preparing the mortar. This effectively reduces the reaction between the galvanized mesh & the ungalvanized steel bars. Wire mesh reinforcement should conform to the ASTM standard A-185. The minimum yielding strength of wire should be  $450 \text{ N/mm}^2$  for smooth wires &  $480 \text{ N/mm}^2$  for deformed wires.

#### **(b) Matrix**

The matrix is a particulate composite consisting of fine aggregate bonded by the hydrated cement. Generally the matrix with cement to sand ratio of 1:1.5 or 1:2 is desirable for the ferrocement applications. Use of 1:3 ratio or even lean mixes is also reported.

#### **(c) Coatings**

To increase the durability of ferrocement, it may be protected by surface coatings, such as Acrylic, Latex, Polyester & cement based paints.

#### **(d) Cover**

Minimum cover to the outer most mesh layer is around 2 mm to 5 mm.

**(f) Water /Cement Ratio**

Water /Cement ratio typically ranges between 0.35 & 0.5 by weight.

**1.4 OBJECTIVE OF PRESENT WORK**

The main objective of this present work is to study the effect of change of grade and stress level on retrofitted beams. To carry out the investigation twenty beams were casted out of which four are control beams and tested to failure to find out the load carrying capacity. Two grades of concrete were used for the casting of beams i.e. M20 and M40. These beams are stressed to stress levels 50% and 75% of the maximum load carrying capacity and subsequently retrofitted with ferrocement to study the effect.

**1.5 ORGANIZATION OF THESIS**

The thesis has been organized into the following five chapters:

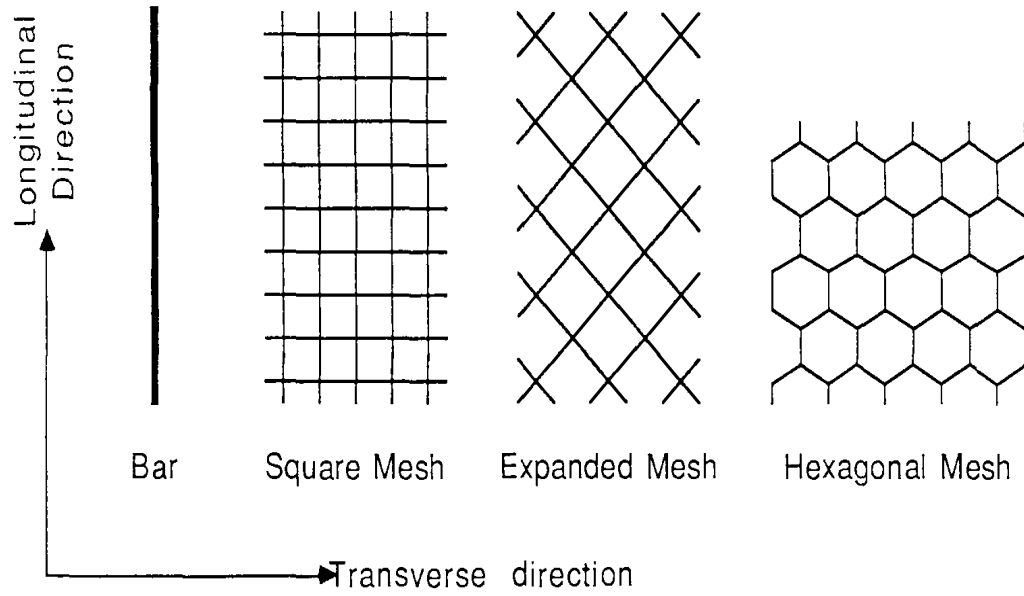
Chapter 1: This chapter deals with general introduction of retrofitting and ferrocement.

Chapter 2: This chapter deals with literature review leading to the need of the present study.

Chapter 3: This deals with experimental programme. In this properties of various material used in work have been discussed along with the details regarding the retrofitting carried out on stressed beams.

Chapter 4: This chapter deals with the results and discussion related to the work.

Chapter 5: This chapter presents the conclusions and also provides the scope of future work.



**Figure 1.1: Different types of mesh**

## CHAPTER - 2

### LITERATURE REVIEW

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#### 2.1 INTRODUCTION

Reinforced concrete is one of the most abundantly used construction materials not only in the developed world, but also in the remotest parts of the developing world. In the rural areas of the developing world, however, due to transference of expertise and technology know how, reinforced concrete poses a threat due to its abuse rather than use, and majority of the houses are constructed in traditional manner using indigenously developed techniques preferably following simpler and economical procedures. Unfortunately such non-engineered construction is mostly prevalent in earthquake prone areas of the developing world e.g. Turkey, Pakistan, India and Iran. The rural populations in the developing world have mostly to rely on local skill, material and technology. The transformation of non-engineered construction into an engineered one, therefore needs to be such that it could be sustained. The methodology should be simple in execution, offer better performance even when handled by less experienced workers, must involve materials, which are readily available, and yet durable, strong and economical. Ferrocement is one such material which has excellent ductility and become one of the main structural materials for retrofitting and strengthening of modest span reinforced concrete beams in such construction, specially, in earthquake prone areas.

Ferrocement over the years has gained respect in terms of its superior performance and versatility, and now is being used not only in housing industry but its potentials are being continuously explored for its use in retrofitting and strengthening of damaged structural members (*Singh and Kaushik et al 1998*). Ductility requirements are the main feature of an efficient earthquake restraint design process, and ferrocement being highly ductile material has led to its application in rehabilitation of the houses damaged by earthquake and the effectiveness of its use has been reported by many researchers.

*Andrew and sharma (1998)* in an experimental study compared the flexural performance of reinforced concrete beams repaired with conventional method and ferrocement showed superior performance both at service and ultimate load. The flexural strength and ductility of beams repaired by ferrocement was reported to be greater than the corresponding original beams and the beams repaired to be greater than the corresponding original beams and the beams repaired by conventional methods.

*AL-Farabi et al (1993)* while investigating the effectiveness of fiberglass bonded plates for capacity enhancement, reported increased strength and reduced ductility. Premature failure by plate separation was also identified as a potential problem at the plate curtailment place. Steel plates bonded by epoxy were used to repair shear cracked beams utilizing various forms of plate bonding by Basunbul et al (1993). The experimental investigation clearly demonstrated that the effectiveness of the repair primarily depends on how effectively the diagonal tension cracks in the shear damaged beams trapped. Flexural mode of failure was observed surpassing shear capacity for only those specimens where full enhancement of the shear zone was carried.

*G.C.Mays and R.A.Barnes (1995)* investigated the feasibility of using ferrocement as low permeability cover layer to reinforced concrete members located in environments where there is a high risk of reinforcement corrosion. This protective layer may be precast and could therefore act as permanent formwork to be poured in –situ concrete. It is found that the resistance to chloride penetration in accelerating ageing tests was enhanced by using SBR or acrylic bond coats. The use of permanent ferrocement formwork gave an increase in strength of 15% over conventional reinforced concrete.

*Ganesan and Anil (1993)* made experimental investigation on the strength and behavior of short confined concrete columns with and without ferrocement casing is presented. The columns were subjected to monotonic axial compression until failure. The primary variables considered in the study were the volumetric ratio of lateral reinforcement ( $\rho_s$ ) and volume fraction of mesh reinforcement ( $V_F$ ) the. They made an attempt to compare to compare the stress – strain characteristics of reinforced concrete columns with ferrocement as confinement (CFRC) and confined reinforced concrete (RC). This investigation revealed that the strength and strain at peak load of reinforced concrete could be enhanced by using ferrocement as confinement. Strength

and ductility are two important factors to be considered in the design of seismic resistant reinforced concrete structures. Under seismic conditions the structures may be subjected to large deformations. In the case of reinforced concrete columns, the behavior depend largely on the amount of confinement provided to the core concrete because of the spalling of the concrete cover at compressive strains of about 0.004. Many attempts have been made in the past to improve the strength and strain at peak load in the case of reinforced concrete specimens subjected to uniaxial compression .The experimental work consisted of casting and testing of fourteen reinforced concrete columns of 150mm×150×750mm size. Out of these, ten were confined with ferrocement. Four different values of volumetric ratio of transverse reinforcement  $\rho_s$ , namely 0.3%, 0.6%, 0.9% and 1.8% and three different values of volume fraction of mesh reinforcement ( $V_f$ ) viz., 1.2%, 1.8% and 2.4% were used. In case of RC specimens vertical cracks appeared at about one- third of the maximum load. As the load increased, the number of cracks increased and with of crack widened. Further increase of load resulted in spalling of cover unevenly.

*Hani H. Nassif, Husan Najam (2004)* had performed an experimental study to examine a shear transfer between composite layers. They have concluded that in order to provide Full composites action between both the layers a minimum of five studs is needed. They also concluded that beams having shear studs with hooks exhibited better pre-cracking stiffness as well as cracking strength than those with I- shaped studs and also beams specimens with square mesh exhibited better cracking capacity than the control beams as well a beams with hexagonal mesh.

*Mohammad Taghi Kazemi et al (2005)* had performed a study to e evaluate a retrofit technique for strengthening shear deficient short column concrete columns. Ferrocement Jacket reinforced with expanded steel mesh is used for retrofitting in this study. They had concluded that expanded meshes were more effective ties in shear strengthening of concrete columns and also specimens strengthened with expanded meshes showed distribution fine shear cracking even at large amounts of displacement ductility capacity.

*Abdullah A, Katuski Tskiguchi (2003)* had strengthened reinforced concrete columns with ferrocement jackets .They had used circular and square ferrocement jackets strengthening square reinforced concrete columns with inadequate shear resistance .They had concluded that by providing external confinement over entire length RC columns, the ductility is enhanced tremendously.

## 2.2 MECHANICAL PROPERTIES

*G.j.Al-Sulamani et al (1991)* studied the behavior of Ferrocement under direct shear by conducting compression tests on Z-shaped specimens reinforced with wire mesh producing pure shear on shear plane. Tests results indicate that Ferrocement under direct shear exhibits two stages of behavior (cracked and uncracked) while under flexure it exhibits a third stage i.e. plastic stage in addition. The cracking and ultimate shear stresses increase with increasing mortar strength and wire mesh reinforcement. Empirical equations have been developed here using regression on analysis to predict the cracking and ultimate shear stresses in terms of the mortar tensile strength  $f_t$  and  $V_f$ . It indicates that the shear stiffness in the uncracked stage is not significantly affected by the amount of wire mesh; it is mainly affected by the mortar strength. The shear stiffness in the cracked stage is affected by both amount of wire mesh and mortar strength. Ductility of ferrocement material under direct shear increases with increasing wire mesh reinforcement and decreases with higher mortar strength. The behavior of ferrocement in flexure has received adequate attention by many researchers and it has been observed to be similar to the reinforced concrete members. The behavior of ferrocement material under direct shear was investigated by conducting axial load tests on direct shear specimen. The direct shear specimen used in this study has Z-shape. It has width of 300mm; 100mm thickness height of 600mm. There is a triangular notch in the middle of each side of the specimen to force failure along the shear plane which has dimensions of 30mm×220mm. The wire mesh layers are placed to cross the shear plane. Regular reinforcing bars are placed top and bottom blocks of the specimens to avoid any premature failure of these end blocks. Ferrocement when subjected to flexure, exhibits three stages of behavior; uncracked, cracked and yield or ultimate stage. The third stage is an indication of the ductility that ferrocement possesses under flexure.

*Mansur and Ong (1987)* have studied the behavior in shear of ferrocement reinforced welded wire mesh by conducting flexural tests on simply supported rectangular beams under two symmetrical point loads. The major variables of the study were the shear to span ratio  $a/h$ , volume fraction of reinforcement  $V_f$ , strength of mortar  $f_c$ , and the amount of reinforcement near the compression face. Their test results indicate the diagonal cracking strength increases as  $a/h$  ratio is decreased and  $V_f$ ,  $f_c$  and reinforcement near compression face are increased. Empirical equations are

proposed to predict the diagonal cracking strength of ferrocement. Ferrocement beams are found to be susceptible to shear failure at small  $a/h$  ratios when  $v_f$ ,  $f_c$  are relatively high. In general similar failure is preceded by the attainment of flexural capacity.

*P.Paramasivam et al 1988* reported the effect of arrangement of reinforcements on mechanical properties of ferrocement. The presence of wire mesh reinforcement in ferrocement improves crack resistance, impact strength, and toughness. Evenly distributing layers of wire mesh across the cross section of ferrocement is a tedious and labor intensive operation. In practice, it might be easier if the layers of wire mesh were bundled. The bundled reinforcement can be placed near the top and bottom surfaces or at the midsection of the element. The effects of the reinforcement arrangements on strength and deformational characteristics of ferrocement in direct tension and simple bending were studied experimentally. The conclusion is that a reinforcement arrangement in which the wire mesh is bundled and placed near the surfaces is preferred, from the point of view of first crack strength and crack characteristics. The uniform distribution and high –surface-area-to-volume ratio (specific surface) of the reinforcement in ferrocement results in improved crack control, impact resistance, and toughness, Evenly placing wire mesh reinforcement across the cross section of the ferrocement is a tedious and labor-intensive operation. In practice, it might be more economical if the layers of wire mesh were bundled and placed at the top and bottom faces or at the midsection of the element. The effect of this arrangement is of great interest, not only in terms of ultimate strength, but also in terms of first crack strength and cracking behavior. Fig 2.1 shows the different arrangement of reinforcement. Fig 2.2.1 shows the load deflection curve.

## 2.3 FERROCEMENT APPLICATIONS

*Martinelli, Hanai, Schiel (1991)* showed a set of applications that were developed by Sao Carlos Group. In those applications, thin walled long span structural elements were made with reinforced mortar, by using large opening meshes (50)mm. The steel content in reinforced mortar had been varied from  $200\text{kg/m}^3$  to as low values as found in reinforced concrete. In the same way it occurs at any types of structures, ferrocement structures must be designed to satisfy several performance requirements, such as strength, durability and so forth. Thinking ferrocement as a material to be applied to thin walled it is necessary to adjust the material properties to the construction type and acting forces in the structures, to obtain the proper strength, stiffness, cracking control, ductility and impact resistance.

The structural analysis should take the following aspects as references:

- a) Ultimate limit strength must be verified for the overall structures and its internal parts. Continuous reinforcing elements (meshes, wires and tendons) usually are the appropriate ones to assure the structural safety.
- b) The use of adequate structural shape dimensions of the sections, strength and modulus of elasticity of the mortar or micro concrete, reinforcement tensile strength and bond strength, cracking configuration, etc, will allow the proper stiffness.
- c) Cracking control should be done by employing pre-stressing, by selecting the type and properties of the meshes, wires and tendons, and by using fiber as secondary reinforcement. Also ductility and impact strength will be determined by those parameters.
- d) When high performance ferrocement is necessary, it will result the need of high reinforcement content, high specific surface of the reinforcement, a high performance mortar, and a small cover thickness. Moreover, special protection, ensures against corrosion will be necessary.
- e) In the most civil engineering applications, it be competitive ferrocement has to be applied as possible with lower content of meshes, but still using a high, at least medium performance, mortar or micro- concrete. A cover thickness much larger than the current ones which have been applied in ferrocement should be necessary to prevent corrosion of the reinforcement and to avoid too much expensive protection measures.

In the broadest meaning, we can say that ferrocement (or reinforced mortar, or fine grain reinforced concrete, or reinforced micro concrete) is a special type of reinforced concrete to be applied in thin walled construction and elements. This material results from the association of a small sized aggregates concrete with continuous reinforcing elements that may include discrete fiber as complimentary reinforcement.

## **2.4 FUTURE OF FERROCEMENT IN CONSTRUCTION**

Some questions are launched for argumentation on the future of ferrocement in construction which are factors that have inhibited the full development and dissemination of ferrocement technology e.g. is ferrocement cost- competitive? Is high structural performance always needed in ferrocement applications/is ferrocement durability reliable?

### **Durability**

Durability is the main question about performance of ferrocement and reinforced mortar elements. Reinforced corrosion particularly seems as a first problem to be solved to give a safe margin of quality assurance to thin walled construction. Ferrocement or reinforced mortar members are typically built with 3mm to 8mm reinforcement cover thickness. Despite relatively low water /cement ratio recommended for the mortar mix (0.38-0.45). This is not itself enough to ensure reinforcement protection against corrosion, even if it is in orderly aggressive environments. Direct not approaches to ferrocement durability problems are not given in a sufficient number.

### **Cost**

Ferrocement uses steel wires meshes that are about 2 to 5 times more expensive by weight than ordinary steel bars. The assemblage of those meshes medium level or non skilled labor, which is an advantage in developing countries where the cost of labor is relatively low. However, this work often takes much time and the productivity goes down. In prefabrication plants this lack of productivity can raise the cost and so ferrocement or reinforced mortar may become non competitive against other industrialized products. The tendencies are in general to reduce the mesh content or to substitute them for other substitute them for other suitable meshes and fibers that may reduce the production cost. There are examples of production rationalization, by using

long beds and stretching the meshes, or by using prestressing. Application of short fibers in conjunction with continuous wires also has been proved to be economical in many situations.

The application of pre-stressing techniques to ferrocement (or generally to thin walled reinforced mortar or “ fine grain concrete” has a great potential in the lightweight prefabrication and some of the precast concrete production techniques can be adopted to ferrocement. This also should reduce the cost, because mesh content and wiring labor could be minimized. Quality control is a very important aspect in pre fabrication, not only because a good quality of the elements must be reached, but also because quality control can reduce the cost.

## **2.5 FERROCEMENT FOR REPAIR AND STRENGTHENING OF STRUCTURES**

Defects, failure and general distress in the structure could be the result of structural deficiency caused by erroneous design, poor workmanship or overloading of the structure. It could also be caused by corrosion, fire and natural disasters. A damaged or distressed re-strengthening of structures because it improves crack resistance combined with high toughness, the ability to be cast into shape, rapid construction with no heavy machinery, small additional; weight it imposes low cost construction.

*Anwar, Nimityongskul, Pama and Robels-Austriaco (1991)* investigated the rehabilitation technique for reinforced concrete structural beam elements using ferrocement. The technique involved strengthening of the reinforced concrete beams by application of hexagonal chicken mesh and skeletal steel combined by ordinary plastering. The basic parameters involved were the amount of wire mesh applied, its geometrical configuration and the degree of distress in the beams. From the best test obtained, a design chart was developed to determine the parameters for rehabilitation of the beam elements. The rehabilitation offers several advantages; it is easier to work with as it requires no specialized labor or equipment.

It does not require any formwork. By using ferrocement, with small quantities, considerable improvements can be achieved. The dead weight of the rehabilitation material is almost negligible and hence it does not require catering for additional dead weight as it most of the other rehabilitation materials. In view of all these advantages, this method of using ferrocement is appropriate for rehabilitation of structural beams

elements. Ngoiro; a wooden ferry in New Zealand has been preserved as a historical artifact and moored in an inner harbor location at which she recently sank. Subsequent examination of the hull showed severe damage by gribble worm. Replanking of the hull was estimated to cost US \$ 30000 and US \$ 40000 and would have had limited durability. The ferrocement retrofit was estimated to cost US\$15000 to US\$ 16000 and would in contrast to the other options, provide long term durability. After consideration of the alternatives of replanking or fibreglassing, a retrofitted skin of ferrocement was selected on the ground of durability and cost.

### **2.5.1 Housing Applications**

Ferrocement technology is becoming more attractive construction particularly for roofs, slabs floors and walls because of its relatively low cost, durability and weather resistance. Its versatility further increases its utility for producing pre fabricated components required in housing. The fabrication techniques of ferrocement is easy to learn and ferrocement structures, if properly built, are practically maintenance free)

Ferrocement roofing units and other elements can be produced in factories or fabricated on site using local material and labor. On the site construction allows a one piece fabrication of structural components. Thus, in some cases, it proves to be more economical, more feasible and more practical than mass production in factories. It provides saving in the use of materials and labor for joining the smaller units. The result is a structure that is more stable, durable and requires little maintenance. Some researchers were also made on the use of ferrocement in beams and columns. Analytical and experimental, the system consists of top and bottom flanges connected by web there by leaving hollow spaces in between. The hollow section is selected mainly the passage of heat from outside. Based on the investigation the load deflection of the developed section is quite similar to that of a typical ferrocement element.

*Kaushik.etal(1997)* investigated the behavior of eight simply supported concrete steel and concrete ferrocement composite slabs of span 1.5m and 3.0 the results show that the ferrocement and corrugated galvanized iron (CG10 composite slabs can be safely used for roofing and flooring purpose. The ferrocement composites exhibit better performance as compare to CGI composite in terms of load carrying capacity, energy absorption capacity, ductility and recovery in unloaded. The cost analysis for composite elements of 3.0m span designed for the same ultimate load shows that the

CGI ferrocement composite slabs are economical than conventional reinforced concrete slabs by 5% and 20% approximately. The behavior and performance of composite ferrocement brick reinforced slab without ferrocement panels especially to be shaped into simple geometric forms was carried out by Mattone.

*Ahmed and Dawood(1994)* discussed the design, fabrication erection and construction techniques for shell-type ferrocement units to cover a large span gymnasium, to form a composite roof. Using ferrocement considerable savings in material cost, about 20% and a substantial reduction of construction time can be achieved. The test results show that the composite roof acts as a diaphragm and results in a reduced column section and is more durable than the conventional asbestos cement or galvanized iron sheets. Using this techniques major formwork is totally eliminated and the form chosen gives a neat and clean appearance.

*Anwar (1993)* presented the advantages and application of ferrocement for low cost housing especially in pkistan.Ferrocement roof and wall system provides a cheaper but durable solution. At the same time they give a more permanent look to the structure as compared to other low cost materials. There is a reasonable amount of economy achieved by using ferrocement.The wall units could be made in various shapes and sizes. In mass production, it is always advisable to adopt the same shape of units for roof as well as whatever the final decision could be made according to prevailing situation at the site. The procedure in repairing a ferrocement structure is simple. A physical damage such as a hole or big crack in the structure is repaired by first removing the plaster and loose material all around the hole. The wire mesh, if necessary, is cut and replaced. The new mesh is tied with the existing wire mesh with enough overlap for continuity. Economical evaluation as made. Tables 2.1to 2.4 shows the economic analysis of housing ferrocement wall panels and brick masonry roofing units are 40% cheaper than reinforced concrete roofs.

**Table 2.1 Ferrocement Wall panel Economic Analysis**

<b>NO.</b>	<b>Item</b>	<b>Unit</b>	<b>Quantity</b>	<b>Unit price (Rs)</b>	<b>Total price (Rs)</b>
1	Steel 6mm dia@300mmc/c both ways.	m	66	3.40	224.40
2.	Steel 6mm dia for anchorage	m	10	3.40	34.00
3.	Wire mesh (2 layers)	m <sup>2</sup>	18	20.00	360.00
4.	Binding wire	kg	1	20.00	20.00
4.	Portland cement	bag	4	110.00	440.00
5.	Sand	m <sup>3</sup>	0.28	45.00	12.60
Grand total					1091.00
Cost per m <sup>2</sup>					121.00

**Table 2.2 Brick Masonry Wall analysis**

<b>No.</b>	<b>Item</b>	<b>Unit</b>	<b>Quantity</b>	<b>Unit Price (Rs)</b>	<b>Total Price (Rs)</b>
1.	Bricks	pieces	990	1.00	990.00
2.	Portland cement	Bags	4.85	110.00	533.50
3.	Sand	m <sup>3</sup>	0.75	45.00	33.75
Grand total					1557.25
Cost per m <sup>2</sup>					173.03

**Table 2.3 Ferrocement Roofing Units**

No.	Item	Unit	Quantity	Unit price (Rs)	Total Price (Rs)
1.	Longitudinal Skeletal steel 4mm dia (bottom)	m	75	1.40	105.00
2.	Longitudinal skeletal steel 4mm dia(sides)	m	110	1.40	154.00
3.	Binding wire	kg	1	20.00	20.00
4.	Wire mesh	m <sup>2</sup>	37.5	20.00	20.00
5.	Transverse stirrups 3mm dia	m	80	0.84	67.20
6.	Portland cement	bags	5.5	20.00	750.00
7.	Sand	m <sup>3</sup>	0.28	45.00	12.60
Grand total					1713.80
Cost per m <sup>2</sup>					190.40

**Table 2.4 Reinforced Concrete Roof**

No	Item	Unit	Quantity	Unit price (Rs)	Total Price (Rs)
1.	Reinforcement steel 12.5mm dia @250 mm c/c	m	80	14.00	1120
2.	Portland cement	bags	6.5	110.00	715
3.	Sand	m <sup>3</sup>	0.5	450.00	225
4.	Coarse aggregates	m <sup>2</sup>	1	450.00	450.00
5	Shuttering	m <sup>2</sup>	9	10.00	90
Grand total					2600
Cost pr m <sup>2</sup>					66.40

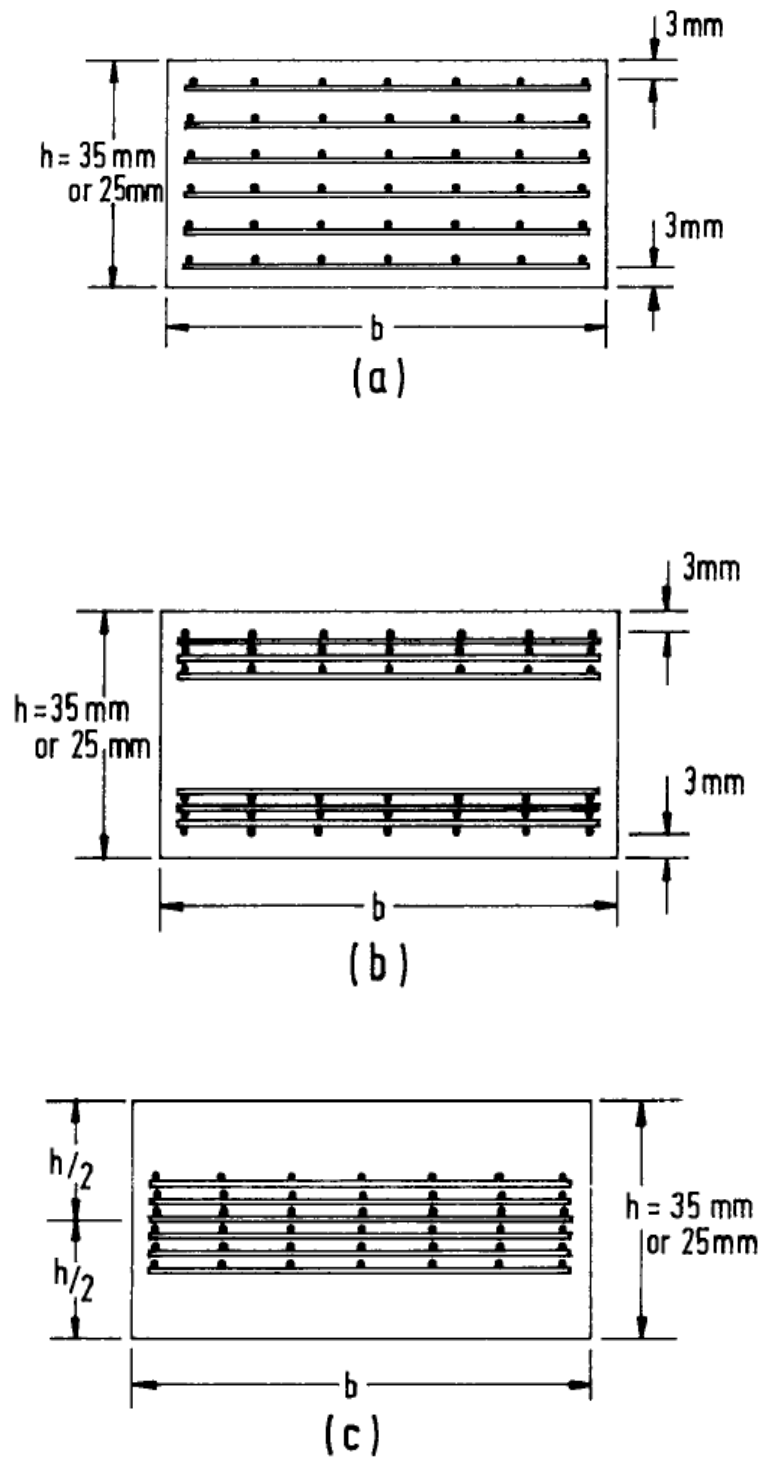


Fig 2.1:- Different arrangements of wire mesh in ferrocement.

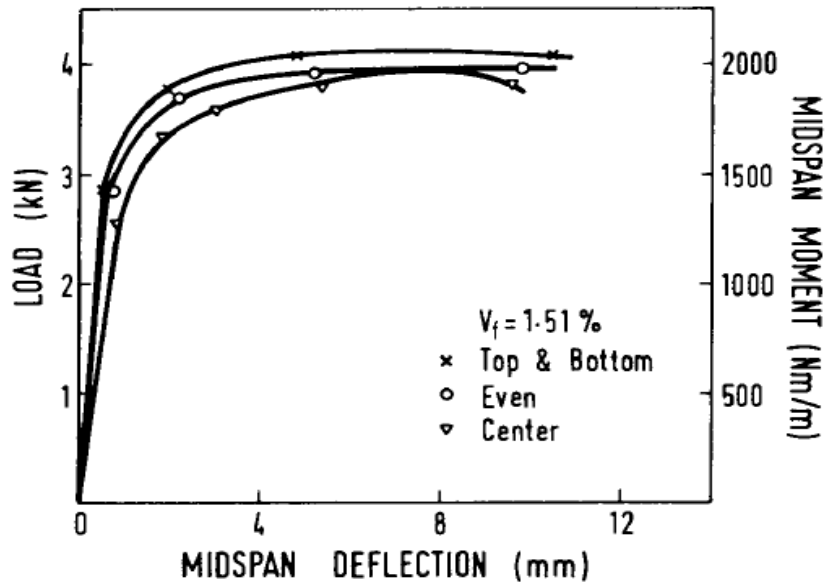


Fig2.2:- Load deflection curve for different arrangement of reinforcement.

## **CHAPTER - 3**

### **EXPERIMENTAL PROGRAMME**

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#### **3.1 INTRODUCTION**

The main objective of this experimental programme is to study the effect of change of grade of concrete and stress level on retrofitted beams. To carry out the investigation twenty beams were casted out of which four are control beams and tested to failure to find out the load carrying capacity. Two grades of concrete were used for the casting of beams i.e. M20 and M40. These beams are stressed to stress levels 50% and 75% of the safe load carrying capacity.

#### **3.2 TEST PROGRAMME**

The test programme so devised consists of three major aspects so as to study the behavior of retrofitted beams .The test programme involved:-

1. Determination of the basic properties of the constituent materials namely cement, sand, coarse aggregates and steel bars as per relevant Indian standard specifications.
2. Casting of twenty beams of size (150×150×700mm). Out of which ten are of M20 grade and remaining ten are cast using of M40 grade of concrete.
3. Two beams made of M20 grade and two made of M40 grade concrete are considered as control beams. The remaining in each category are stressed and retrofitted with ferrocement to find out the load carrying capacity of remaining sixteen beams. The stress levels maintained are 50% and 75% of the maximum load carrying found out by testing the control beams.

### **3.3 MATERIALS**

Cement, fine aggregates, coarse aggregates, reinforcing bars are used in casting of beams and GI woven wire mesh, cement slurry are used for retrofitting of these beams. The specifications and properties of the material are as under:

#### **3.3.1 Cement**

Portland pozzolana cement 43 grade of Ultra Tech make from a single lot was used for the study. The physical properties of cement as obtained from various tests are listed in Table 3.1. All the tests are carried out in accordance with laid down and checked for permissible limits as per IS : 8112-1989.

#### **3.3.2 Fine Aggregates**

Locally available sand was used as fine aggregates both in the preparation of cement mortar as well as for the concrete mix. The physical properties and sieve analysis results of sand are shown in Tables 3.2 and 3.3.

#### **3.3.3 Coarse Aggregates**

Crushed stone aggregates (locally available) of 20 mm and 10 mm are used throughout the experimental study. The physical properties and sieve analysis of coarse aggregates is given in Tables 3.4 to 3.6.

#### **3.3.4 Water**

Clean and potable water is used for casting the specimens in the present study. The water is relatively free from organic matter, silt, oil, sugar, chloride and acidic material as per Indian standards.

#### **3.3.5 Reinforcing steel**

Two types of bars of diameters 8mm and 6mm are used as reinforcement in beams. 8mm bars are used as tension reinforcement and 6mm bars are used as compression reinforcement. 2 legged 6mm diameter stirrups are used as shear reinforcement.

#### **3.3.6 Wire mesh**

GI woven wire mesh of diameter 2.4 mm with rectangular grids pattern is used for retrofitting the ferrocement jackets. The grid size of mesh was 25mm×50mm.

### **3.3.7 Concrete mix**

M20 and M40 grade concrete mixes are designed as per Indian standard recommended guidelines using the properties of materials as discussed above and presented in Table 3.1 to Table 3.6. The water cement ratio as designed for M20 grade mix comes out to be 0.5 and the mix proportion of material come out to be 1:1.5:3.29 with cement content quantity of 354 kg/m<sup>3</sup>. The water cement ratio as designed for M40 grade concrete comes out to be 0.36. The mix proportions came out to be 1:0.76:1.96 with cement content quantity equal to 450 kg/m<sup>3</sup>. Super plasticizer used comes out to be 0.1% of the quantity of cement for obtaining a medium workability (slump 50 to 70 mm).

### **3.3.8 Mortar Mix**

The range of mix proportion recommended for common ferrocement applications are cement: sand ratio by weight of 1:1.15 to 1: 1.25, but not greater than 1:3 and water cement ratio by weight of 0.35 to 0.5. The higher the sand content the higher the required water contents to maintain same workability. Fineness modulus of the sand, water cement ratio and sand – cement ratio were determined from trial batches to ensure a mix that can infiltrate the mesh and develop a strong and denser mortar. The proportions of cement –sand mortar used for ferrocement jackets was 1:3. The water – cement ratio for mortar was 0.5 for the given consistency of cement.

## **3.4 RCC beam design**

In the present study the RCC beams are designed using two grades of concrete i.e M20 and M40. The steel used was of 6mm of mild steel and 8mm of HYSD bars. The RCC beams are designed with limit state design considering it to be under –reinforced section. The longitudinal section of beam of size 150×150×700 mm cast using both grade concrete is shown in Fig 3.1.

## **3.5 CASTING OF BEAMS**

The casting of beams is done in single stage. The beams are cast in mould of size 150×150×700 mm. First the entire mould is oiled so that the RCC beams can be easily

removed from the mould. Spacers of size 25mm are used to provide uniform cover to the reinforcement .When the bars have been placed in position as per respective design, concrete mixture of desired grade is poured in the mould and vibrations are given with the help of a needle vibrator so that the mix gets compacted .The vibrations is done until the mould is completely filled and there is no gap left. The beams are removed from the mould after 48 hour .After demoulding the beams are cured for 28 days in the curing tank.

### **3.6 TESTING ARRANGEMENT**

All the beams were tested under simply supported end conditions. Two point loading is adopted for testing. The arrangement is shown in Fig 3.1. The testing of beams is done with the help of the universal testing machine (see plate 3.1). Two dial gauges are placed at quarter positions and one dial gauge is placed at the centre. The value of deflection is obtained from the dial gauges. Two control beams each of having M20 and M40 grade of concrete are tested to failure to find out the maximum load carrying capacity. Then the beams are subsequently stressed to different stress levels i.e 50% and 75% of the maximum load carrying capacity. These beams are then retrofitted using ferrocement with woven wire mesh. (see plate 3.2).

#### **3.6.1 Process of Retrofitting**

Firstly the surface of the beam is cleaned. After cleaning the surface, the cement slurry is applied as bonding agent to the surface of the beam. After the application of bonding agent retrofitting of beam is done by applying 25 mm thick cement mortar on the three faces of the beam. The beams are cured for 7 days before testing using the same procedure as of control beams testing of beams is done in order to calculate ultimate load and corresponding deflection. Plate 3.3 shows how the beams are pitched prior to retrofitting. Plate 3.4 shows the reinforcing GI woven wire mesh which is provided on the three sides, a 25 mm thick layer of ferrocement is provided to complete the jacketing process. The detailed results obtained from testing of control and retrofitted beams are presented and discussed in the following chapter.

**Table 3.1 Physical Properties of Cement**

Sr. No.	Characteristics	Experimental value	Specified Value as per IS: 8112-1989
1	Consistency of Cement	29 %	-
2	Specific gravity	3.05	3.15
3	Initial setting time	82 minutes	>30 minutes
4	Final setting time	390 minutes	< 600 minutes
5	Comp. Strength (N/mm <sup>2</sup> )		
	ii) 7days	34.00	>33
	iii) 28 days	45.90	>43
6	Fineness (Dry Sieving)	5.4 %	< 10 %
7	Soundness (mm)	2.5	<10

**Table 3.2 Sieve Analysis of Fine Aggregates**

Total weight taken = 1000 gm

S.NO	Sieve No	Mass Retained	Percentage Retained	Percentage passing	Cumulative %
1.	4.75	24	2.4	97.6	2.4
2.	2.36	18	1.8	95.8	4.2
3.	1.18	85	8.5	87.3	12.7
4	600μm	127	12.7	74.6	25.4
5	300μm	235	23.5	51.1	48.9
6	150μm	420	42.0	9.1	90.90

$\Sigma = 184.7$

$$F.M = 184.5/100 = 1.85$$

**Table 3.3 Physical properties of fine aggregates**

Sr.no	Characteristics	Value
1.	Specific gravity	2.56
2.	Bulk density loose(kg/lt)	1.48
3.	Fineness modulus	1.85
4.	Water absorption	2.06%
5.	Grading Zone	Zone III

**Table 3.4 Sieve Analysis of Coarse Aggregates (10 mm)**

Total weight taken = 3 kg

S.NO	Sieve No	Mass Retained(gm)	Percentage Retained	Percentage passing	Cumulative %
1	80mm	0	0	100	0
2	40mm	0	0	100	0
3	20mm	0	0	100	0
4	10mm	176	5.87	94.13	5.87
5	4.75	2626	87.50	12.5	93.37
6	Pan	1.98	6.63	$\Sigma C =$	101.94

$$\text{Fineness modulus} = \frac{\Sigma C + 500}{100} = \frac{601.94}{100} = 6.02$$

**Table 3.5 Sieve Analysis of Coarse Aggregates (20 mm)**

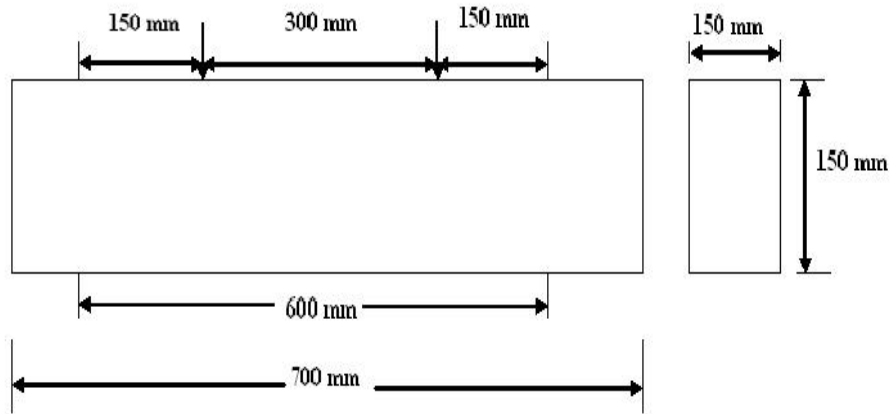
Total = 3 kg

Sr.no	Sieve No	Mass Retained(gm)	Percentage Retained	Passing percentage	Cumulative %
1	80	0	0	100	0
2	40	0	0	100	0
3	20	0	0	100	0
4	10	2924	97.47	2.53	97.47
5	4.75	69	2.30	0.23	99.77
6	pan	7	0.23	$\Sigma C =$	197.24

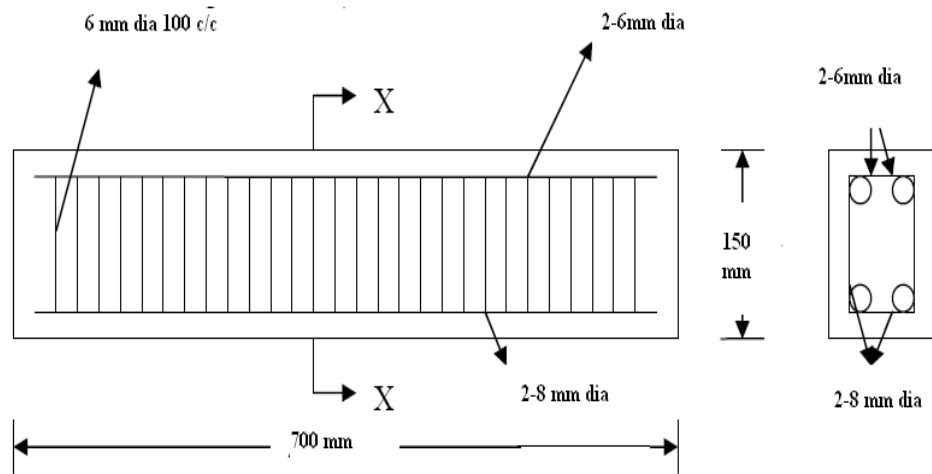
Fineness modulus =  $\Sigma C + 500 / 100 = 500 + 197.24 / 100 = 6.97$

**Table 3.6 Physical Properties of Coarse Aggregates**

Sr .no	Characteristics	20mm size	10mm size
1	Type	Crushed	Crushed
2	Specific gravity	2.7	2.43
3	Total water absorption	3.64%	1.643%
4	Fineness modulus	6.97	6.02



**Fig:-3.1 Loading arrangement**



**Fig 3.2 Reinforcement details for both M20 and M40.**



**Plate – 3.1: Universal testing machine**



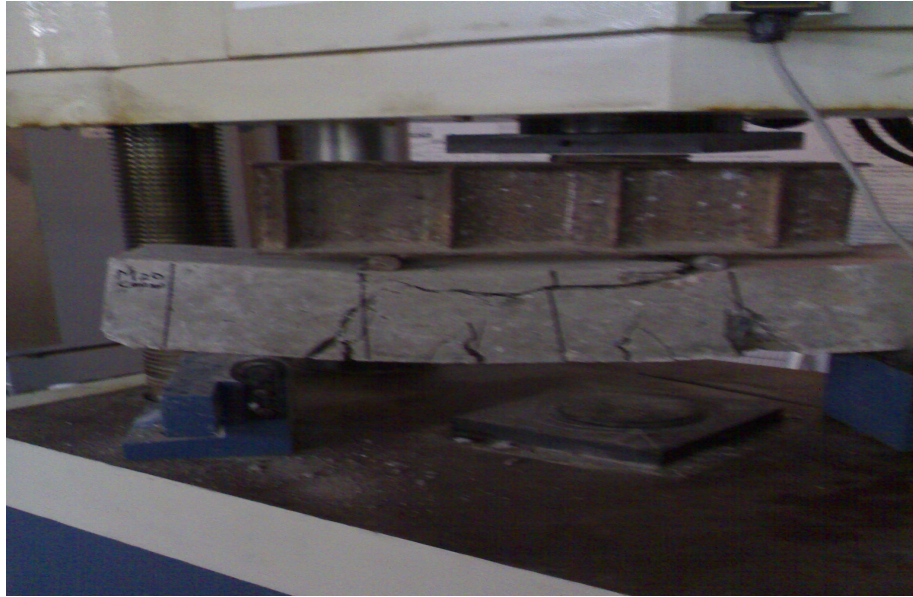
**Plate -3.2: Wire mesh jackets**



**Plate – 3.3: Pitching of beams**



**Plate -3. 4: Wrapping of wire mesh on beam**



**Plate -4.1: Testing of M 20 control beam**



**Plate – 4.2: Testing of M40 control beam**



**Plate -4.3 Testing of M40 retrofitted beam up to 50% of ultimate load.**



**Plate -4.4: Stressing of M20 beam upto 75% of ultimate load**

## **CHAPTER - 4**

### **RESULTS AND DISCUSSION**

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#### **4.1 INTRODUCTION**

In the present work the effect of stress level and different grades of concrete on the strength of the retrofitted beams is studied. For the purpose the beams are cast using different concrete grades M20 and M40 and these are then subsequently stressed to predecided stress levels of 50% and 75% of the maximum load. These stressed beams are then retrofitted with ferrocement jackets using GI woven wire mesh. The beams are retrofitted with two layers of woven wire mesh jackets. A comparative study on the strength variation of the retrofitted beams and control beams is done with above parameters and is presented in the subsequent sections.

#### **4.2 TESTING METHODOLOGY**

Firstly the control beams are cast using M20 and M40 grades of concrete. After curing them for 28 days these beams are then tested to failure under a two point loading system using the universal testing machine. Subsequently, a set of four beams of M20 grade of concrete are stressed to 50% of the maximum load carrying capacity of the beam. And the remaining four are stressed to 75% of the maximum load carrying capacity of the beam. Then, a similar number of M40 grade beams are stressed to 50% and 75% of the maximum load carrying capacity of the control beam.respectively.The average maximum load as noted from the load deflection curve comes out to be 140 kN for each of the two M40 grade beams and 106 kN for each of the two M20 grade concrete beams. The respective beams are then stressed to 50% i.e. to 53 kN for M 20 grade concrete beams & 70 kN for beams using M 40 grade concrete of the maximum load and 75% i.e.79.5 kN for beams using M20 grade concrete & 105 kN for beams using M40 grade concrete.

Then the retrofitting of the beams is done with cement mortar of thickness 25 mm using two layers of woven wire mesh of diameter 2.4 mm bonded on three sides for all the beams. After one week of curing the beams are tested again using same method as adopted for the control beams and the corresponding results in the form of load deflection curves are presented in the following section. The beams designations provided are as under:-

**1. M20 BEAMS STRESSED TO 50%**

These are designated as Retrofitted beam R1, R2, R3, R4

**2. M20 BEAMS STRESSED TO 75%**

These are designated as retrofitted beams P1, P2, P3, P4

**3. M40 BEAMS STRESSED TO 50%**

These are designated as retrofitted beams Q1, Q2, Q3, Q4

**4. M40 BEAMS STRESSED TO 75%**

These are designated as retrofitted beams S1, S2, S3, S4

The effect of change in concrete grade and stress levels on strength parameters of retrofitted beams is discussed in following section.

**4.3 EFFECT OF STRESS LEVELS ON RETROFITTED BEAMS**

**4.3.1 For Beams using M20 grade concrete.**

Figures 4.1 & Fig 4.2 shows the load deflection behavior of one control beam and four retrofitted beams cast using M20 grade and stressed to 50% & 75% of maximum load respectively. Fig 4.3 shows the average load deflection curves for control and retrofitted beams stressed to 50% and 75% of max load carrying capacity. Fig 4.4 shows the average trilinear curves for control beam as well as for retrofitted M 20 grade concrete stressed to 50% and 75% stress levels. The values of  $P_y$ ,  $P_{max}$ ,  $P_u$  are calculated from the load deflection graphs obtained after testing of beams. Here  $P_{max}$  is the maximum load.  $P_y$  is the yielding load and  $P_u$  is the ultimate load which is taken to be 85% of the max load. The values of  $P_{max}$ ,  $P_u$ ,  $P_y$  so calculated are tabulated in Table 4.1.

**a) For beams stressed to 50% stress level**

For the four beams subjected to 50% of maximum load & subsequently retrofitted the average maximum load increases to 136.25 kN which is found to be 28.2% higher than that of control beams. The average value of ultimate load is increased to 115.70 Kn which is nearly 28% higher than control beam. On the other hand, the value of yield load increased to 98.75 kN which is 21.5% higher than the control beam. The average ductility ratio of the four retrofitted beams i.e 2.02 is less than that of control beam. On considering & comparing the deflection values for retrofitted and control beams it is observed that although the deflection corresponding to the maximum & yield loads increased by 35.3% and 14.7% respectively, The deflection corresponding to ultimate load reduced by 13.5%. This indicates a reduction in the ductility of the retrofitted system which is also supplemented by the fact that the failure observed in the retrofitted beams is a compression failure. The above facts are also validated by the calculations made for ductility ratio and energy absorption can be seen from Table 4.1. Similarly the average value of energy absorption decreased by nearly 26% than the control beam.

**a) For beams stressed to 75% stress level**

For the four beams subjected to 75% of maximum load & subsequently retrofitted the maximum load increases to 145 kN which is found to be 3.5% higher than control beams. The average value of ultimate load increased to 123.38 Kn which is nearly 36.6% than control beam. On the other hand, the value of yield load increased to 107.9 Kn which is 32.8% higher than the control beam. The average ductility of the four retrofitted beams i.e 1.97 is less than that of control beam. On considering & comparing the deflection values for retrofitted and control beams it is observed that although the deflection corresponding to the maximum & yield loads increased by 33.29% and 10.9% respectively, The deflection corresponding to ultimate load reduced by 17.5%. This indicates a reduction in the ductility of the retrofitted system which is also supplemented by the fact that the failure observed in the retrofitted beams is a compression failure. The above facts are also validated by the calculations made for ductility ratio and energy absorption can be seen from Table 4.1. Similarly, the average value of energy absorption decreased by 9.8% than the control beam.

### **For Beams using M40 grade concrete.**

Fig 4.5 & Fig 4.6 show the load deflection behavior of one control beam and four retrofitted beams cast using M40 grade and stressed to 50% & 75% of max load. Fig 4.7 shows the average load deflection curves for control and beams stressed to 50% and 75% of max load carrying capacity. Fig 4.8 shows the average trilinear curves for control beam as well as for retrofit M 40 grade concrete stress to 50% and 75% stress levels. The values of  $P_y$ ,  $P_{max}$ ,  $P_u$  are calculated from the load deflection graphs obtained after testing of beams. Here  $P_{max}$  is the maximum load.  $P_y$  is the yielding load.  $P_u$  is the ultimate load and it is taken as 85% of the maximum load. The values of  $P_{max}$ ,  $P_u$ ,  $P_y$  so calculated are tabulated in Table 4.1.

#### **a) For beams stressed to 50% stress level**

For the four beams subjected to 50% of max load & subsequently retrofitted the average maximum load increases to 166.66 kN which is found to be 19% higher than control beams. The average value of ultimate load increased to 141.65kN which is nearly 19.1% higher than the control beam. On the other hand, the value of yield load increased to 124.5 Kn which is 24.5% higher than the control beam. The average ductility of the four retrofitted beams i.e 1.66 is less than that of control beam. On considering & comparing the deflection values for retrofitted and control beams it is observed that although the deflection corresponding to the maximum reduced by 31.9% and yield load deflection increased by 46.6% respectively, The deflection corresponding to ultimate load reduced by 41.5%. This indicates a reduction in the ductility of the retrofitted system which is also supplemented by the fact that the failure observed in the retrofitted beams is a compression failure. The above facts are also validated by the calculations made for ductility ratio and energy absorption can be seen from Table 4.1. Similarly, the average value of energy absorption decreased by 9.8% than the control beam.

#### **b) For beams stressed to 75% stress level**

For the four beams subjected to 75% of max load & subsequently retrofitted the average maximum load increases to 151.83 kN which is found to be 8.45% higher than control beams. The average value of ultimate load increased to 129.27kN which is increased by 8.71% than control beam. On the other hand, the value of yield load increased to 132.08 kN which is 32.08 % higher than the control beam. The average ductility of the four retrofitted beams i.e 196 is less than that of control beam. On considering & comparing the deflection values for retrofitted and control beams it is observed that although the deflection corresponding to the maximum increased by 20.9% and yield load deflection increased by 48.8% respectively, The deflection corresponding to ultimate load reduced by 16.98%. This indicates a reduction in the ductility of the retrofitted system which is also supplemented by the fact that the failure observed in the retrofitted beams is a compression failure. The above facts are also validated by the calculations made for ductility ratio and energy absorption can be seen from Table 4.1. Similarly, the average value of energy absorption decreased by 11% than the control beam.

#### **4.4 EFFECT OF GRADE OF CONCRETE ON RETROFITTED BEAMS.**

The following section present the effect of grade of concrete on the strength and deflection parameters of retrofitted beams subjected to varying stress levels.

##### **4.4.1 For beams stressed to 50% stress level**

Fig . 4.9 shows the average load deflection curves for control and retrofitted beams stressed to 50% stress level & Fig 4.10 shows the trilinear curves for the same beams.

From a comparative point of view it is observed that the average ultimate load of M20 retrofitted beams increased from 90.3 kN (control) to 115.70 kN and the average maximum load increased from 106.25 Kn control) to 136.25 kN, where as, the average yielding load increased from 81.25 kN (control) to 98.75 kN. On the other hand, for beams retrofitted using M40 grade concrete the average maximum load for 50% stressed beam increased from 140 kN (control) to 166.67 kN for retrofit beam and the

value of ultimate load increased from 119(control) to 141.65 kN and the value of yielding load increased from 100kN (control) to 124.5 kN.From the graph we can judge the effect of M40 and M20 grade of concrete on retrofitted beams.Thus,it can be said that for 50% stress levels the percentage increase in the maximum and ultimate load is more for M 20 grade concrete beams whereas as the increase in loads is more for M40 grade beams at yield point. This indicates that beams using lower grades of concrete are better suitable for retrofitting if enhancement in load carrying capacity is the main concern. On comparing ductility ratio of the two types of beams using different grades, it is observed that although ductility reduces both as compared to control beams, but the reduction is same for both concrete grades. This indicates that the ductility ratio is insensitive to grade of concrete at 50% stress level. On considering the energy absorption values it is observed that reduction is much less (16.5%) for M20 concrete grade beams as compared to M40 grade retrofitted beams (40.6%) indicating again that lower grade of concrete perform better when retrofitted.

#### **4.4.2 For beams stressed to 75% stress level**

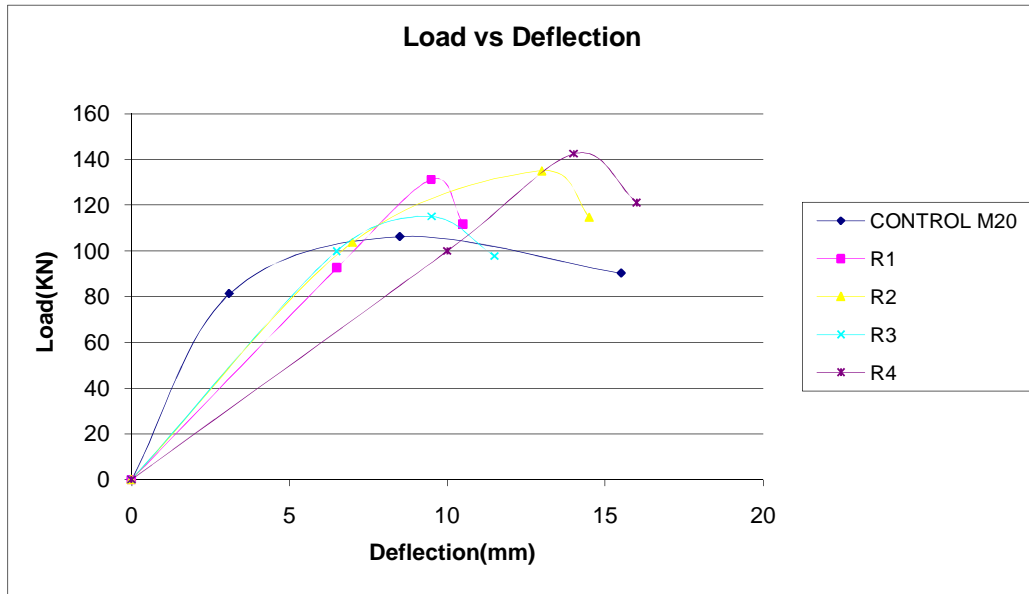
Fig . 4.11 shows the average load deflection curves for control and retrofitted beams stressed to 75% stress level & Fig 4.12 shows the trilinear curves for the same beams.

From a comparative point of view it is observed that the average ultimate load of M20 75% stressed beams increased from 90.3 kN(control) to 123.38 kN. And the average maximum load increases from 106.25 (control) to 145 kN. The value of average yielding load increases from 81.25 (control) to 107.9 kN.On the other hand, for beams retrofitted using M40 grade concrete the average maximum load of 75% stressed beam increases from 140 kN(control) to 151.83 kN for retrofit beam. And the value of ultimate load increases from 119(control) to 129.37 kN.The value of yielding load increased from 100kN(control)to 132.08 kN.From the graph we can judge the effect of M40 and M20 grade of concrete on retrofitted beams. Thus it can be said that for 75% stress levels the percentage increase in the maximum and ultimate is more for M20 grade concrete beams. Whereas the increase in load is same for M40 grade beams at yield point. On comparing the ductility ratios of the two types of beams using different grades, it is observed that although ductility reduces for both as compared to control beams, but the values are same for both concrete grades. This indicates that the ductility ratio is insensitive to grade of concrete at 75% stress

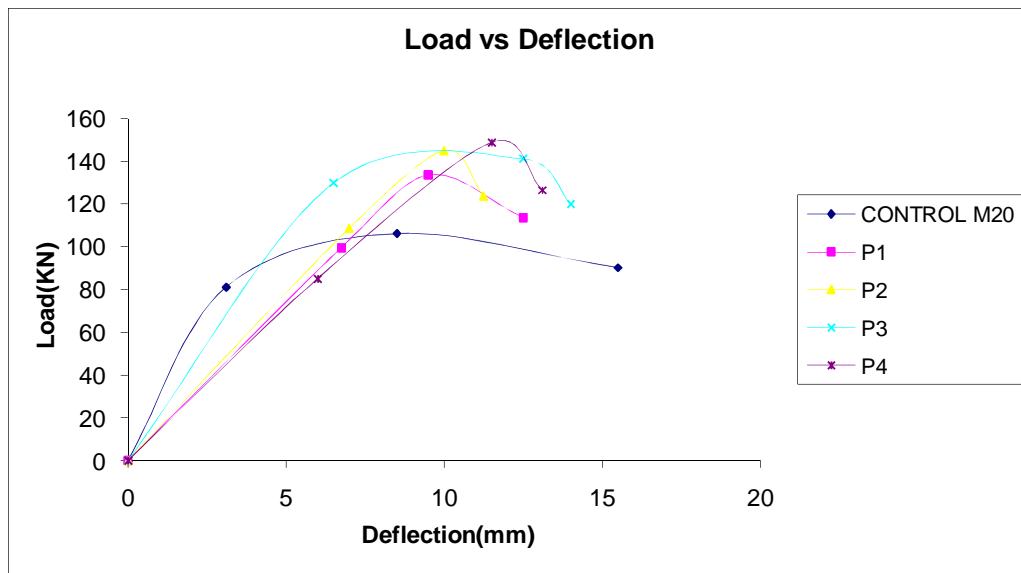
level. On considering the energy absorption values it is observed that reduction is almost same in case of both grades of beams. For M20 it is 9.8% and for M40 it is 10.23%. Indicating that energy absorption capacity at higher stress levels is insensitive to grade of concrete.

**Table 4.1 Data of control and retrofitted beams**

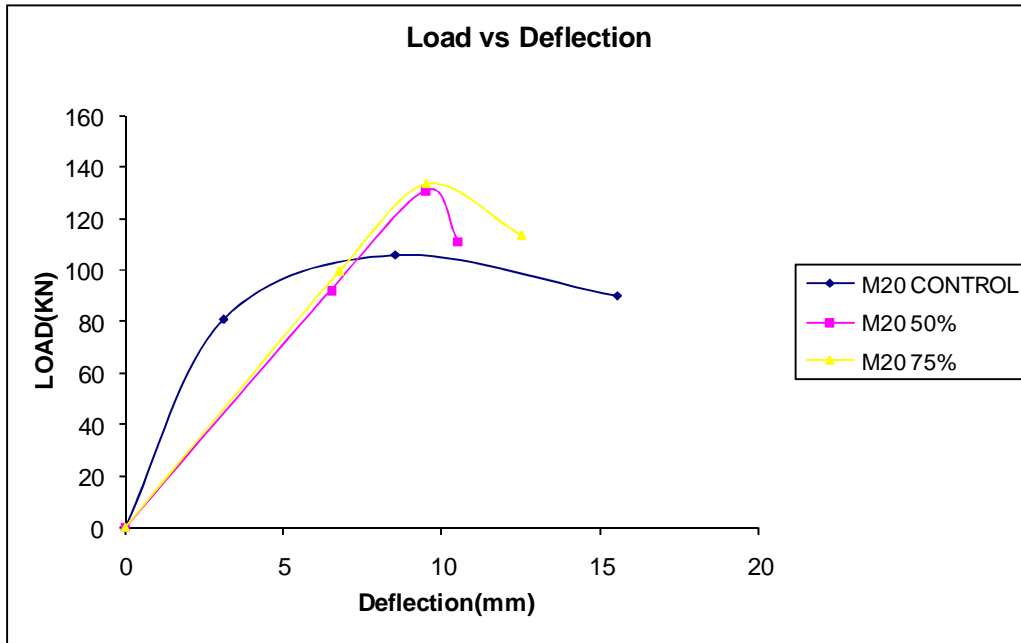
<b>S.No</b>	<b>P<sub>y</sub> (Kn)</b>	<b>P<sub>u</sub> (Kn)</b>	<b>P<sub>max</sub> (kN)</b>	<b>Δ<sub>y</sub> (mm)</b>	<b>Δ<sub>u</sub> (mm)</b>	<b>Δ<sub>max</sub> (mm)</b>	<b>Ductility ratio</b>	<b>Energy absorption kNmm</b>
M20 CONTROL	81.25	90.3	106.25	3.1	15.5	8.5	5	1239.86
M40 CONTROL	100	119	140	3.75	15.25	11.25	4.06	1528.25
M20 50%	98.75	115.70	136.25	7.66	13.66	12.16	2.02	1035.3
M20 75%	107.9	123.38	145	6.5	12.78	11.33	1.97	1117.39
M40 50%	124.5	141.65	166.66	5.5	8.91	7.66	1.66	906.8
M40 75%	132.08	129.37	151.83	5.58	12.66	13.61	1.96	1371.90



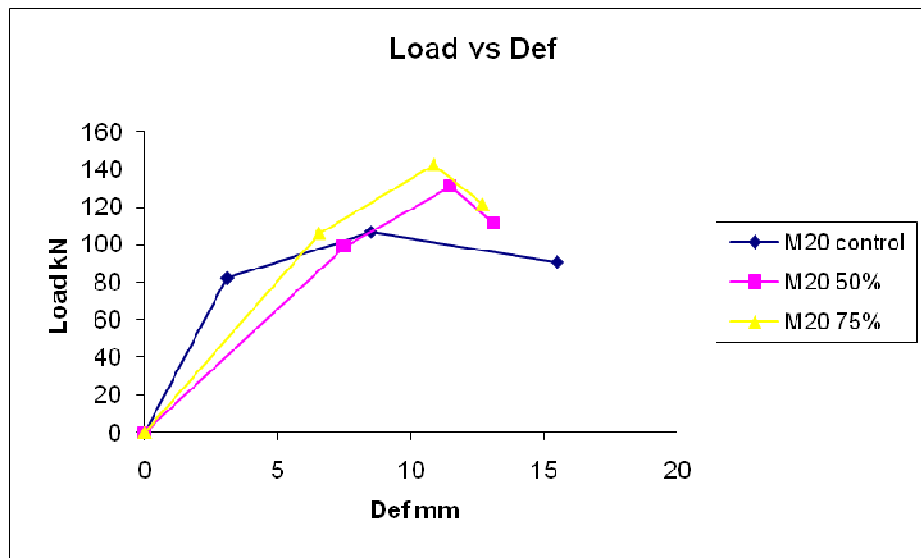
**Fig 4.1 Comparison b/t Control beam M20 and beams stressed to 50 % of max load carrying capacity**



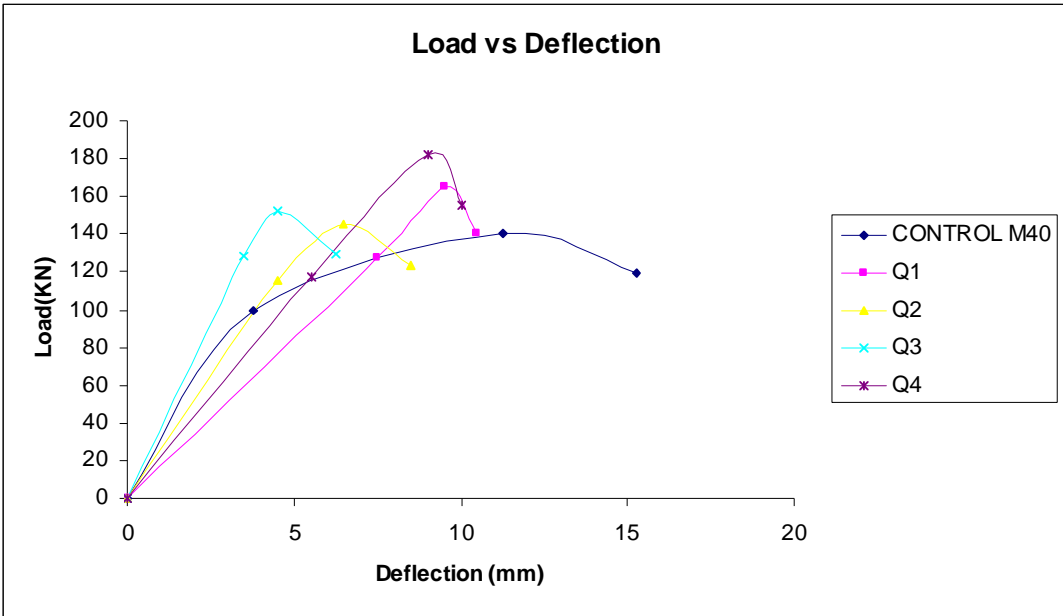
**Fig 4.2 Comparison b/t Control beam M20 and beams stressed to 75% of max load carrying capacity**



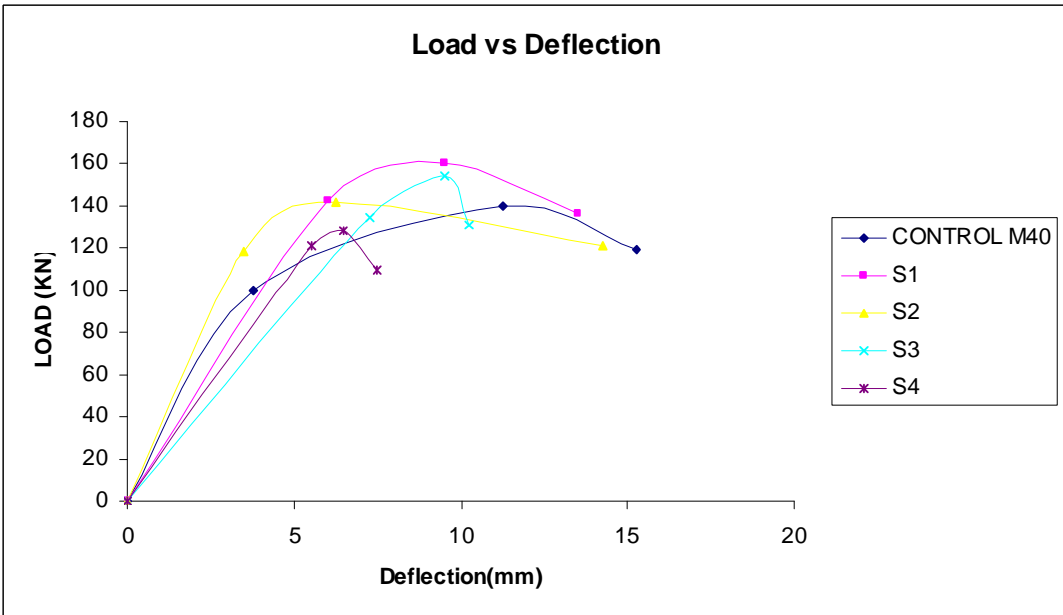
**Fig 4.3 Comparison b/t Control beam M20 and Retrofitted beams M20 stressed to 75% & M20 stressed to 50%**



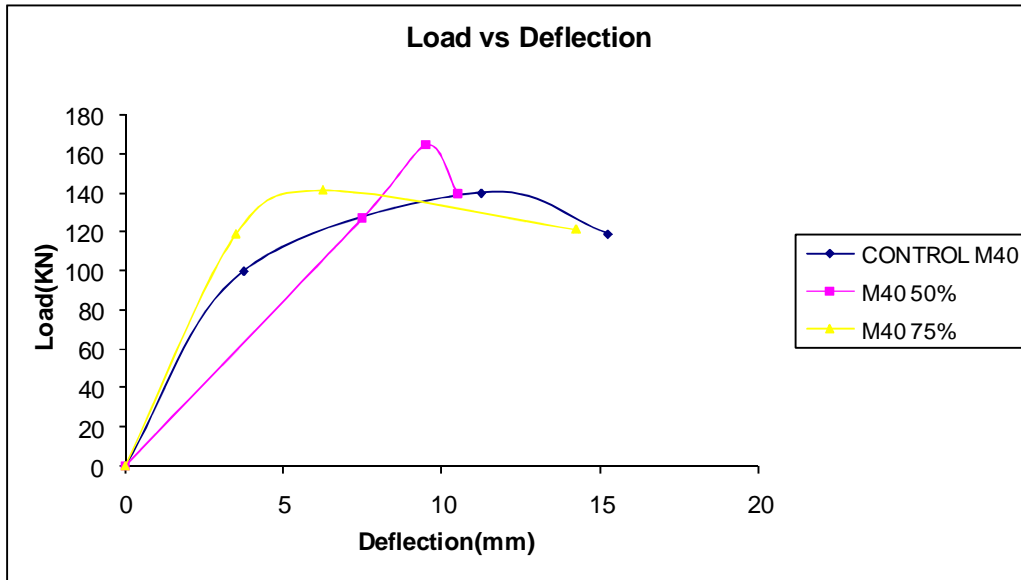
**Fig4.6 Trilinear curve for M20 control beam and retrofitted beams stressed to 50% and 75% stress level.**



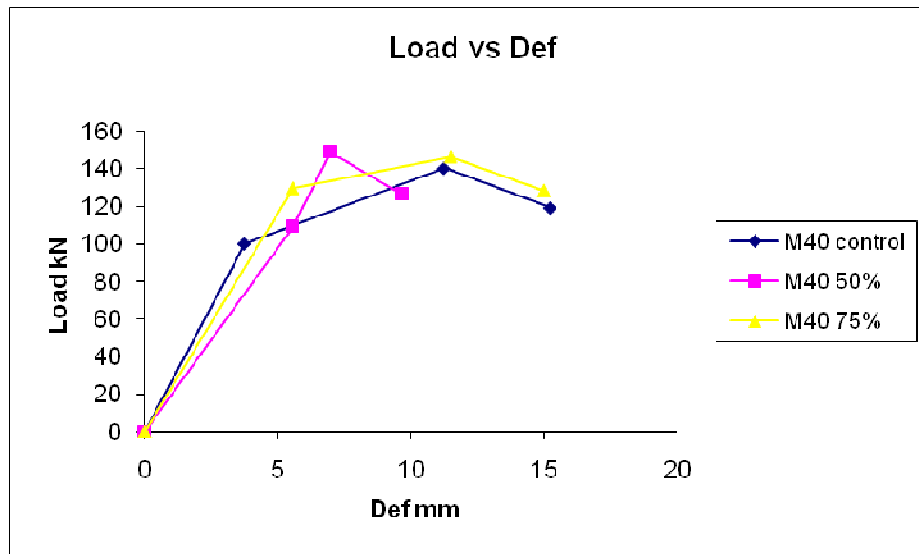
**Fig 4.5 Comparison b/t Control beam M40 and beams stressed to 50% of max load carrying capacity**



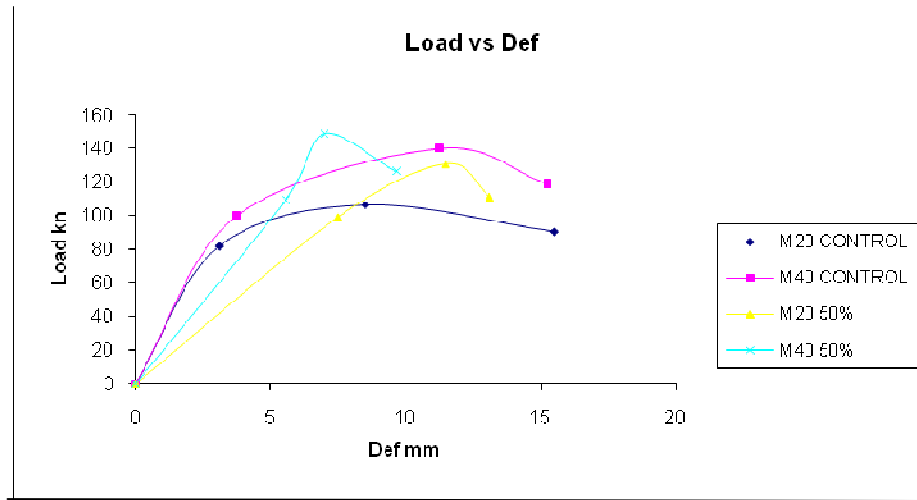
**Fig 4.6 Comparison b/t Control beam M40 and beams stressed to 75% of max load carrying capacity.**



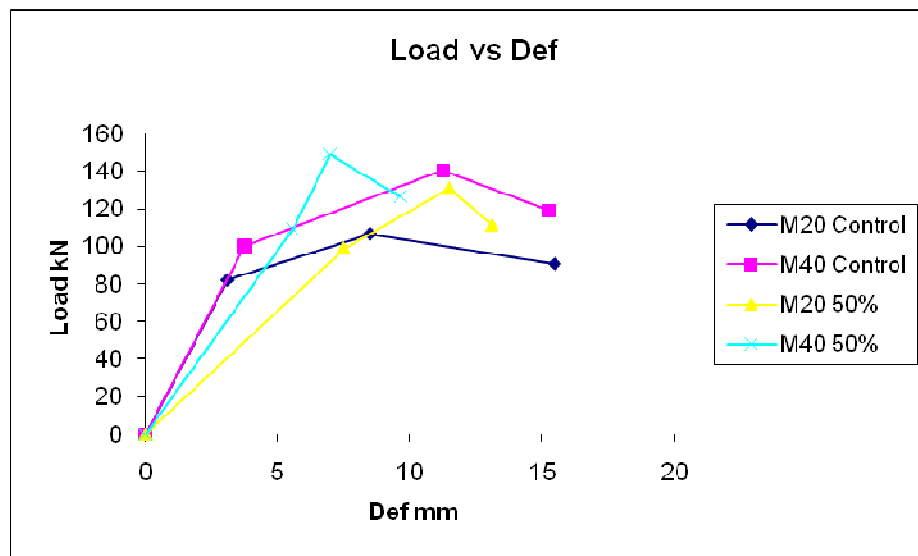
**Fig 4.7 Comparison b/t Control beam M40 and Retrofitted beams M40 stressed to 75% & M40 stressed to 50%**



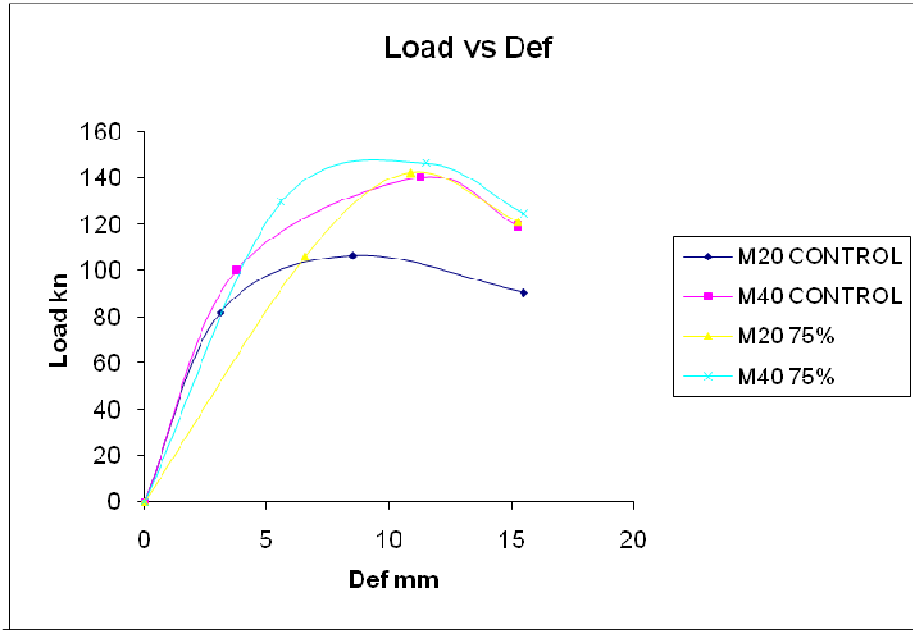
**Fig 4.8 Trilinear curve for M40 control beam and retrofitted beams stressed to 50% and 75% stress level.**



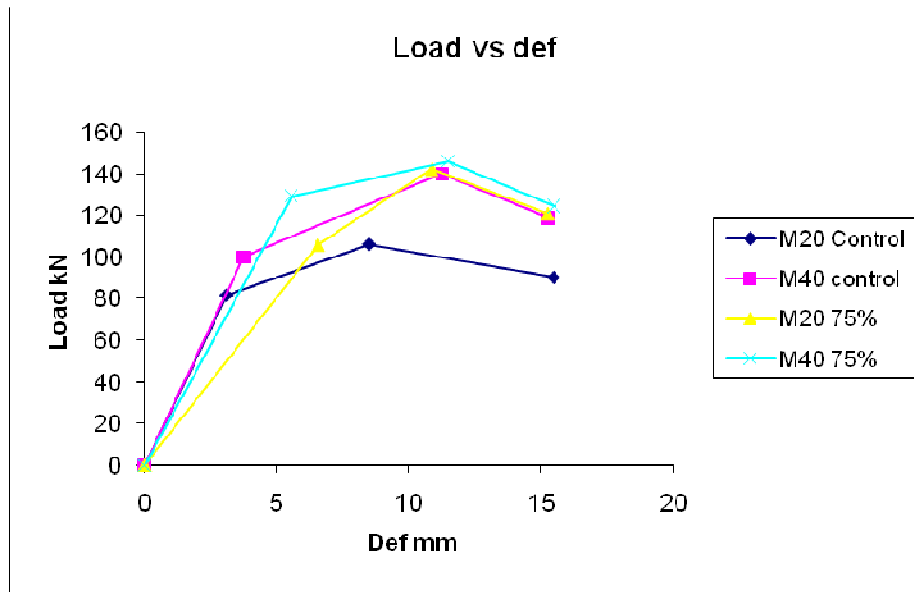
**Fig 4.9 Comparison of M20,M40 control beams and retrofitted beams stressed to 50% stress level.**



**Fig 4.10 Trilinear curve for M20, M40 control beams and retrofitted beams stressed o 50% stress level.**



**Fig 4.11 Comparison of M20, M40 control beams and retrofitted beams stressed to 75% stress level.**



**Fig 4.12 Trilinear curve for M20, M40 control beams and retrofitted beams stressed to 75% stress level.**

## CHAPTER -5

## CONCLUSIONS

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### 5.1 General

In the present work the effect of stress level and different grades of concrete on the strength of the retrofitted beams is studied. For the purpose the beams are cast using different concrete grades M20 and M40 and then subsequently stressed to predecided stress levels of 50% and 75% of the maximum load. These stressed beams are then retrofitted with ferrocement jackets using two layers of GI woven wire mesh. The beams are retrofitted with two layers of woven wire mesh jackets. From this study following conclusions can be drawn.

### 5.2 Conclusions

1. The load carrying capacity of retrofitted beams for both grades of concrete, increased significantly as compared to control beams.
2. Beams using lower grades of concrete are more suitable for retrofitting from the stand point of increasing the maximum & ultimate load carrying capacity.
3. The increase in yield load for retrofitted beams is insensitive to grade of concrete.
4. The deflection for retrofitted beams at yield and maximum load points increased as compared to M 20 grade beams.
- 4 There is reduction in ductility and energy absorption for both categories of beams which is due to compression failure observed in retrofitted beams.
- 5 Ductility ratio at lower stress levels of 50% is insensitive to grade of concrete.
- 6 .Ductility ratio at higher stress levels is the same irrespective of grade of concrete.
- 7 The failure of retrofitted beams for both grades of concrete is in compression rather than in tension as no cracks are observed.
- 8 Reduction in energy absorption capacity at higher stress levels is insensitive to grade of concrete.

### **5.3 Scope for further work**

- 1) In the present study M20 and M40 grades of concrete are used. Effect of higher grade can be taken up for future work.
- 2) In the present study ordinary Portland cement is used. Other mineral admixtures like fly ash, GGBS, silica fume s replacement of cement for carrying out future work.
- 3) In the present study only two layers of woven wire mesh are wrapped. Effect of more number of layers can also be studied.

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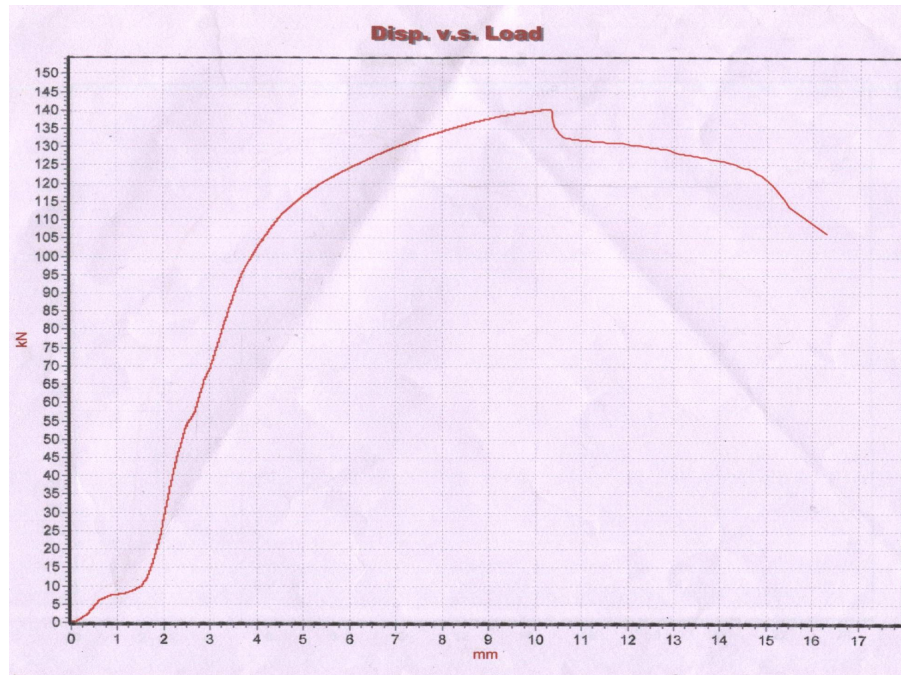
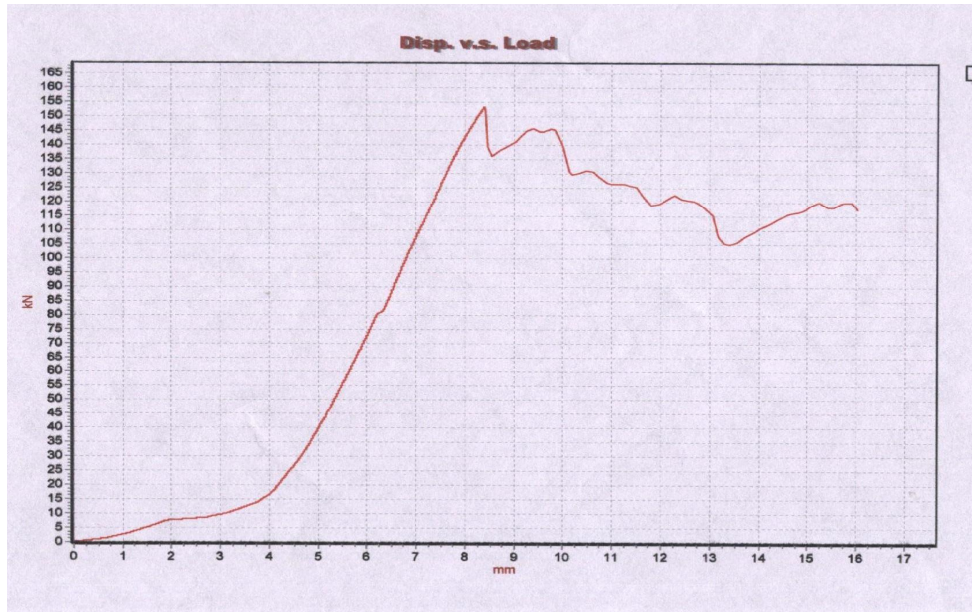


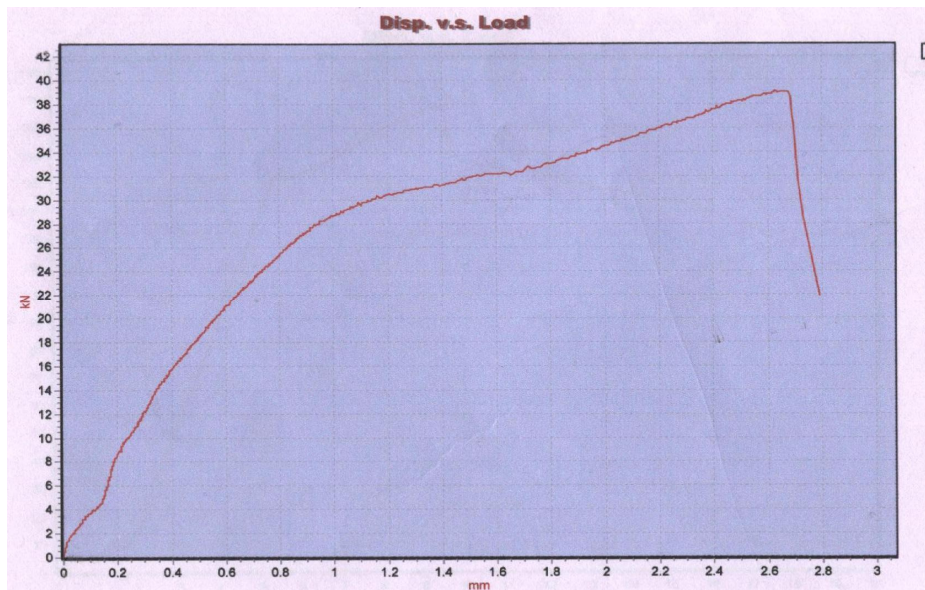
Figure 1. Load vs. Deflection curve for M40 control beam



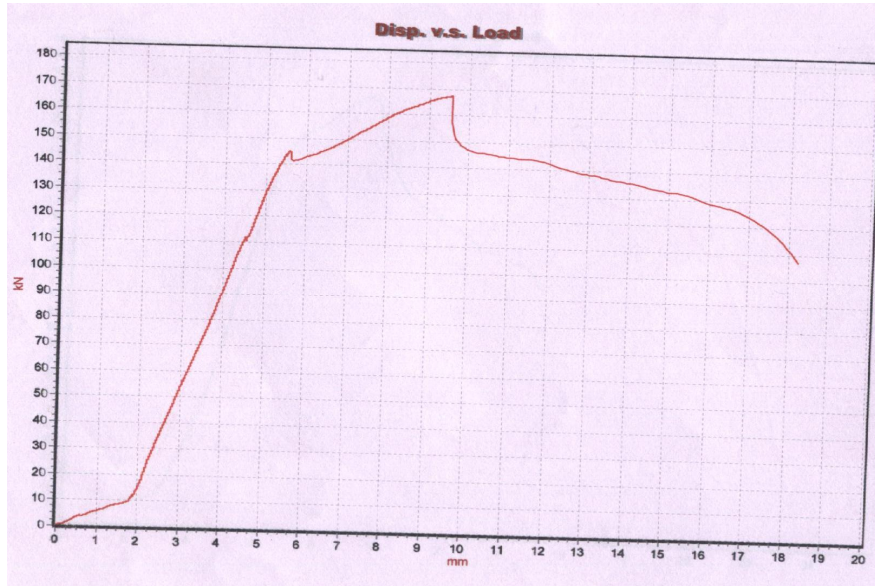
Figure .2 Load vs. Deflection curve for M20 control beam



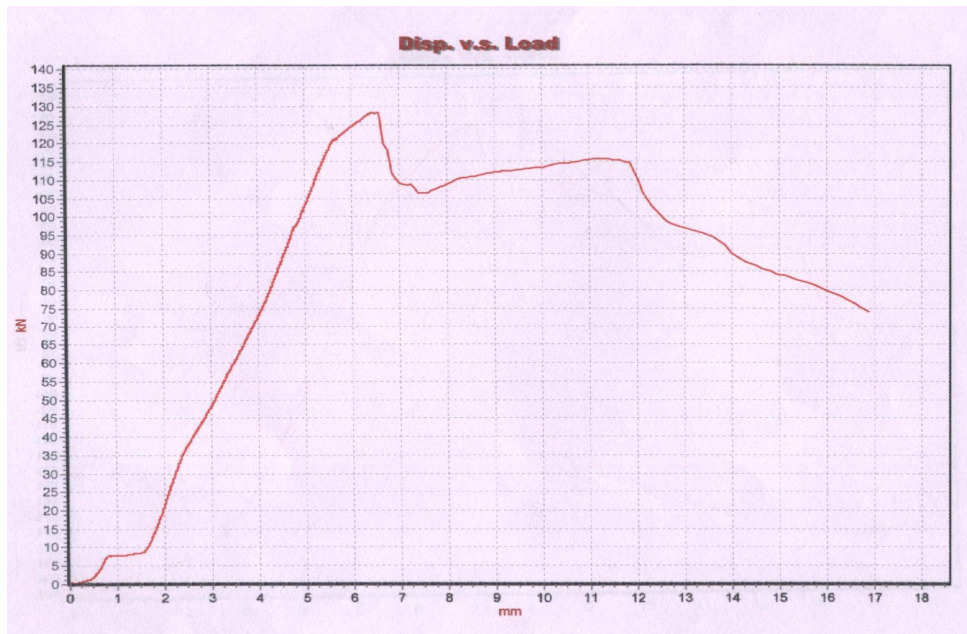
**Figure 3** Load vs. Deflection curve for M40 75% stressed.



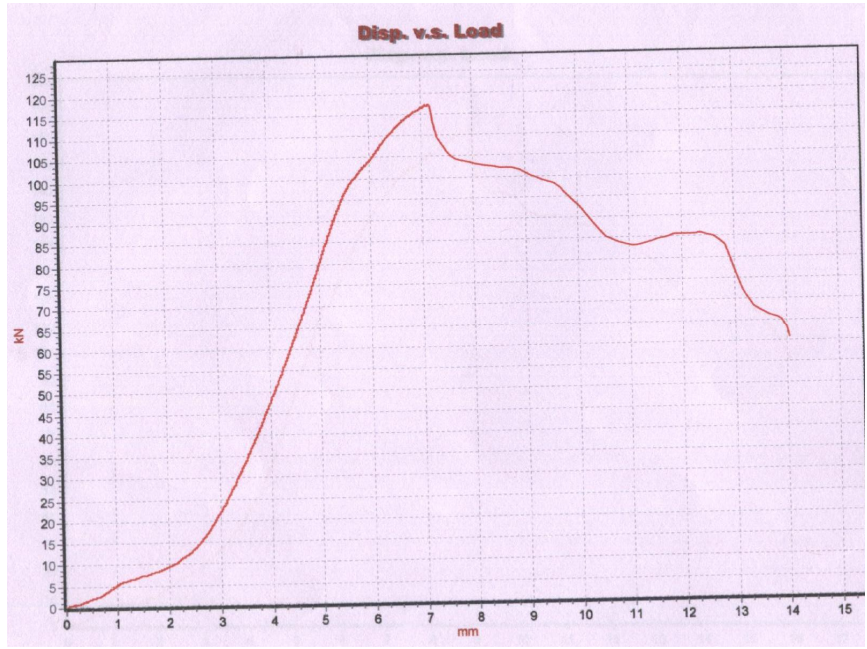
**Figure 4** Load vs. Deflection curve for M40 75% stressed.



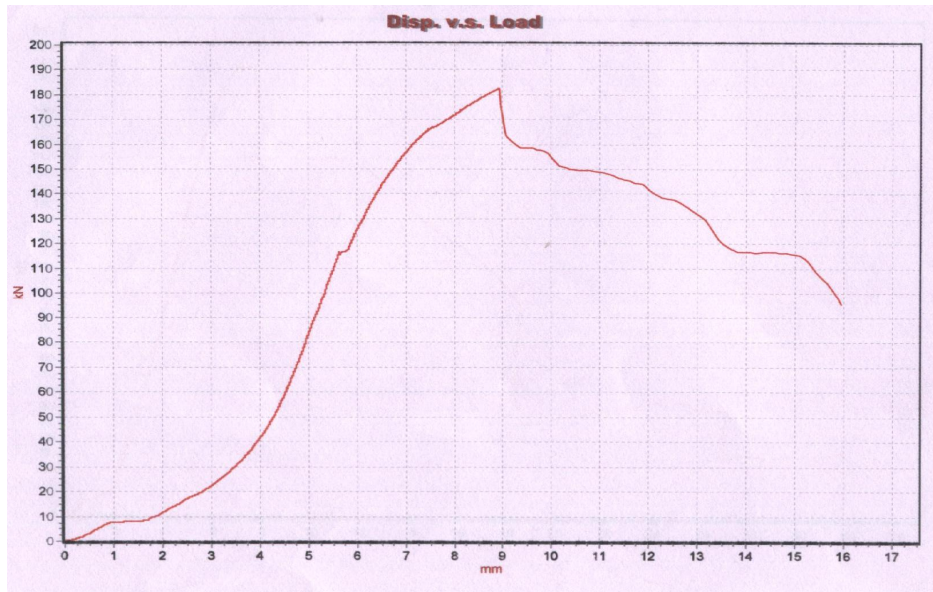
**Figure 5 Load vs. Deflection curve for M40 75% stressed.**



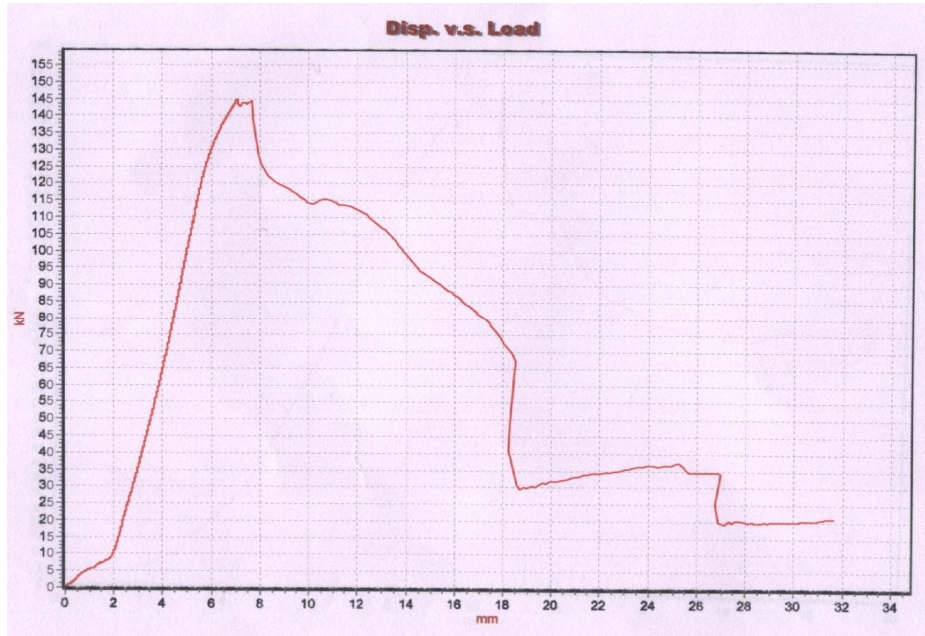
**Figure 6 Load vs. Deflection curve for M40 75% stressed.**



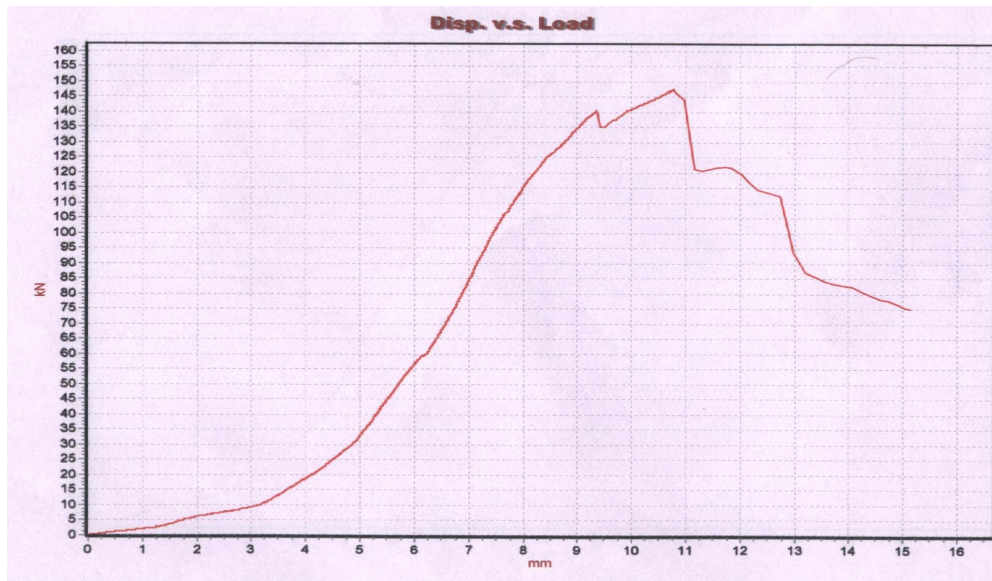
**Figure 7: Load vs. Deflection curve for M 40 50% Stressed.**



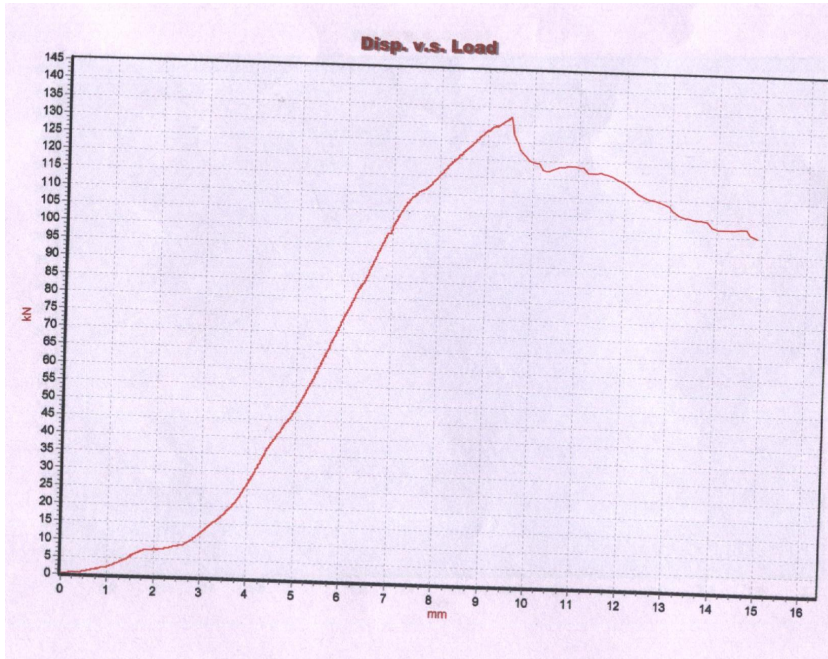
**Figure 8: Load vs. Deflection curve for M40 50% Stressed.**



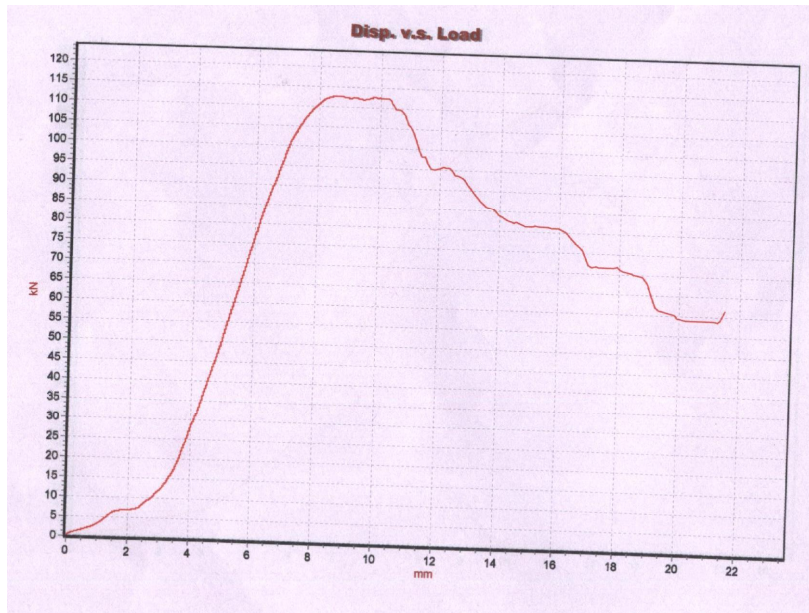
**Figure 9: Load vs. Deflection curve for M40 50% Stressed.**



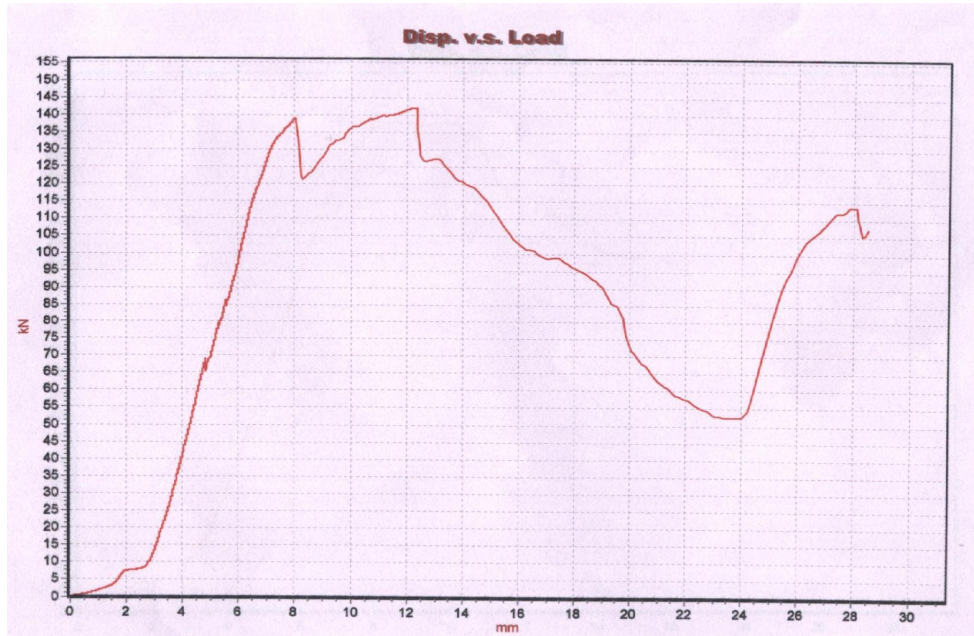
**Figure 10: Load vs. Deflection curve for M20 50% Stressed.**



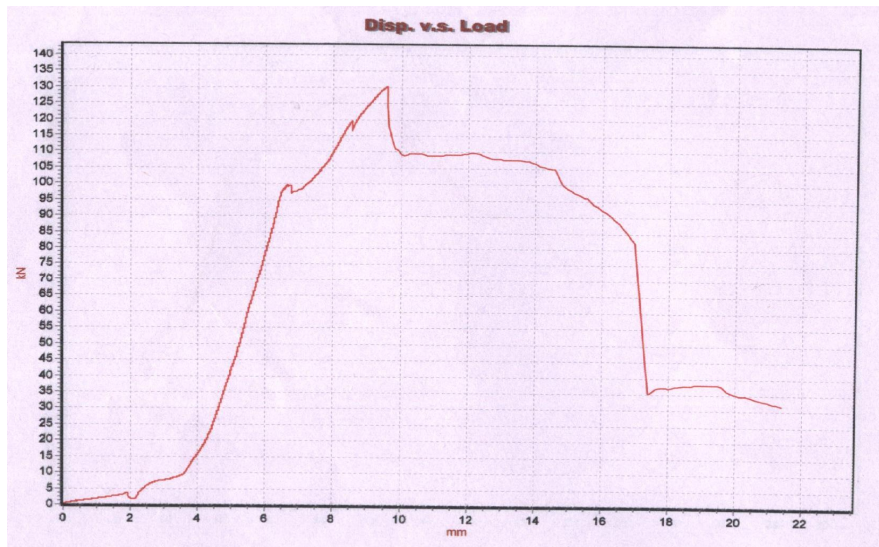
**Figure 11: Load vs. Deflection curve for M20 75 % Stressed.**



**Figure 12: Load vs. Deflection curve for M20 50 % Stressed.**



**Figure 13: Load vs. Deflection curve for M20 75 % Stressed.**



**Figure 14: Load vs. Deflection curve for M20 50 % Stressed**

