FERROCEMENT APPLICATIONS IN REPAIR AND RETROFITTING OF BRICK MASONRY COLUMNS

A DISSERTATION

Submitted in partial fulfilment of the
requirements for the award of the degree
of
MASTER OF TECHNOLOGY
in
CIVIL ENGINEERING
(With Specialization in Building Science and Technology)

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Candidate's Declaration

I hereby certify that the work which is being presented in the dissertation entitled **"FERROCEMENT APPLICATIONS IN REPAIR AND RETROFITTING OF BRICK MASONRY COLUMNS"** in partial fulfillment of the requirement for the award of the degree of **Master of Technology** in **Civil Engineering** with specialization in **Building Science and Technology**, submitted in the Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee, is an authentic record of own work carried out during the period from July 2003 to May 2004 under guidance of **Dr. K.K. Singh** and **Prof. V.K. Gupta**, Professor, Structural Engineering, Department of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee, India.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Date: 20 June, 2004

Place: Roorkee

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Certificate

This is certified that the above statement by the candidate is true to the best of our knowledge.

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Last but not least, I find myself fortunate enough to express my love and gratitude to family and friends, who have always been a source of inspiration and strength to me.

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ABSTRACT

Brickwork is one of the traditional building material, used for the construction of masonry walls, columns etc. to resist mainly compressive loads. Ferrocement encasement can be applied with advantage to brick masonry to strengthen new construction. The wire encasement resists the lateral expansion of columns caused by vertical compression. This introduces lateral confinement, and structural properties of masonry are modified.

The objective of the present investigation is to experimentally study the behaviour of brick masonry columns. The main issue is to examine if jacketing of brick masonry column by ferrocement helps in providing a substantial strength increase as in case of concrete.

The experimental programme consists of casting of four plain brick masonry columns of 1.5 m height each and (22.5 X 22.5 cm.) in cross section then two of them were encased by ferrocement mesh in double layer . all specimen were cured for 28 days and then tested. All the test results are presented either in tabular form or in the form of graph and finally relevant conclusions are drawn. Also scope for future work is mention.

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INTRODUCTION

1.1 GENERAL:

Brickwork is one of the oldest building materials, used for the construction of walls, columns etc. to resist mainly the compressive loads. In India more than 35 % of buildings have been constructed in brick masonry. Brick masonry columns with or without steel reinforcement are provided commonly in low rise buildings. The column is one of the most important elements of the structure. In a typical building, columns are considered to be critical load bearing elements and hence considerable research has been done to protect column against external hazards. Sometimes the structures get damaged by fire, floods, cyclones or earthquakes. Their repair and retrofitting present special problems. There are also cases, where existing structures whether damaged or not; need upgrading of their strength for higher operating or expected loads or for enhancing their life or both. This can be achieved by suitable methods of repair/retrofitting. Ferrocement encasement can be applied with advantage to brick masonry columns in new construction and for repair or retrofitting in existing columns.

For repair, after proper inspection, diagnosis and assessment the loose or deteriorated material is first removed, and then the mesh layers wrapped around the columns and nailed on the existing concrete or masonry. The mortar can then be applied by plastering or by shotcreting. The mortar shrinks and gets a good grip on the existing material and due to the nailing there is further integral behavior between the present concrete / masonry and the ferrocement layers.

Ferrocement is used increasingly in many types of construction, when it is advantageous as compared to R.C.C. construction. One of the major advantages is that it can be cast into any complicated shape without costly formwork. Moreover, as the surface area of contact of cement mortar matrix to steel is more in ferrocement, it has better tensile characteristics in the precracking stages. In the past the main structural applications of ferrocement were for roofing i.e. domes, cylindrical shells, folded plates etc. Later it was used for load bearing purposes such as walls and columns both hollow and filled with concrete.

It is well known that confinement of concrete increases strength and ductility. The contribution of ductility is much more important in structural components used in earthquake resistant design. One of the most effective methods to improve the ductility is confinement of concrete or masonry. Use of ferrocement encasement for providing confinement of concrete has been studied in detail but in case of brick masonry its use is recent and requires theoretical and experimental investigations.

There is considerable increase in strength and ductility due to confinement of masonry, which enables its use for seismic retrofitting of masonry column. In many old buildings seismic effects have not been considered in designs or the code provision for seismic forces have undergone an upward revision. Encasing the end zones in ferrocement can retrofit the brick masonry of such buildings. In some buildings the strength of masonry reduces due to effects of aging or the usage of the building may change resulting in an increased load on the columns. In these cases the columns can be strengthened by encasing with ferrocement. Thus for a small increase in cross sectional area, a large increase in strength can be achieved. It appears that this technique is more cost effective than other techniques which also results in large increase of cross sectional area or requires structural changes in the building.

1.2 OUTLINE OF THE PRESENT STUDY:

The objectives of this investigation are to examine theoretically and experimentally the increase in strength and ductility of ferrocement encased brick masonry columns. The main issue is of confinement of the brick masonry core by wires of the mesh. Basically the confinement is divided into two categories i.e. active confinement and the passive confinement. Passive confinement of masonry by ferrocement encasement is a relatively new area. Thus the primary objective is to study the confinement of brick masonry columns due to ferrocement encasement, and to examine the increase in strength, ductility and the nature of stress-strain behavior of confined masonry and to propose a basis for the design of such columns.

Thus it was planned to test 15 short columns of square cross section size 23 cms x 23cms and height of 150 cms. 15 brick masonry pillars were cast and cured for 28 days. Out of these 4 were encased with single layer of wire mesh and 4 with double layers of ferrocement. Rest 7 columns were considered to test the effectiveness of ferrrocement for repair work. The plain specimens had first been loaded to failure and then wrapped in mesh and plastered i.e. encased in ferrocement. 3 specimens were wrapped with single layer wire mesh and 4 with double layer. These were cured for over 28 days and specimens were tested up to failure load.

The contents of the dissertation have been divided in five chapters. A brief description of these chapters is presented below:

Chapter 1 presents an introduction to ferrocement encased brick masonry columns and objective and parameters of studies.

Chapter 2 presents the literature review.

Chapter 3 describes the experimental programme, which includes materials used, specimen details, casting procedure and test programme.

Chapter 4 describes the results of the tests, theoretical procedure to calculate confined load and discussion of the results.

Chapter 5 gives the various conclusions drawn from the study and presents the scope of the further work.

LITERATURE REVIEW

2.1 BRICK MASONRY

2.1.1 Bricks

Structural properties of bricks primarily depend upon the composition of raw material which is clay, shale or a mixture of two, the firing temperature (900 – 1300° C) and the manufacturing process. Conventional bricks in India have a size 23cm x 11.5cm x 7.5cm whereas modular bricks have dimensions of 20cm x 10cm x10cm. Properties frequently investigated in case of bricks are compressive strength, tensile strength and the rate of water adsorption or suction.

Due to the brittleness and high porosity, bricks are generally weak in tension and their compression strength varies with porosity over a wide range. A coefficient of variation between 15% to 20% for any particular sample is quite typical. The coefficient of variation is defined as the ratio of standard deviation over the average value.

(a) ***Compressive Strength***

The compressive strength test is made on full or a piece of the brick, placed flat and loaded to failure in compression. Standard method of determining the crushing strength of bricks is laid down in IS: 3495-1976. This states that from any sample at least 10 bricks should be tested in a compression testing machine between two 3 mm plywood sheets. The bricks must be immersed in water for at least 24 hours prior to testing. Bricks with frogs must be filled with cement : sand mortar of suitable strength (1 cement, 1 clean sand). The bricks should be tested with the frog up in the testing machine and load should be applied at the constant rate.

Compressive strength of high strength engineering bricks range 55 to 124

MPa, medium strength bricks range from 27 to 48 MPa and low strength bricks ranges from 14 to 25 MPa.

(b) ***Water Absorption or Suction***

Water absorption by bricks influences the strength of bricks, specially the modulus of rupture significantly. It has an important effect on bond between the brick and the mortar. The several different criteria adopted for measurement of adsorption, the three important criteria are:

i. Absorption in 24 hour submersion,

ii. Absorption in 5 hour boiling and

iii. Initial rate of adsorption.

It is generally seen that most adsorption tests give similar results. The IS: 3495- 1976 prescribes water adsorption test on the basis of criterion (i) or (ii) given above.

2.1.2 Mortar

Properties of mortar affecting structural behavior of masonry construction may be listed as workability, strength and bond with bricks. Water rententivity of the mortar, which is the measure of the ability of mortar to retain water and prevent it form escaping into bricks, also assume significance in case of bricks with high suction. However, this requirement can be satisfied by taking a few precautions at site. The characteristic properties of a mortar depend upon proportions of its ingredient consisting of the inert material sand, the cementitious material like cement, lime or both and water. Well graded sand with rounded particles requires minimum cementitious material for a given strength. IS: 2250-1976 provides the necessary guidance for achieving desired workability in masonry mortars.

(a) *Strength of Mortar*

The setting and subsequent gain in strength of mortar is due to hydration taking place between the water added to the mix and some of the constituents in the cement. In testing mortar for the strength, the most important is compressive strength followed by the tensile bond strength. The compressive strength is measured by 70.7 x 70.7 mm cube in a compression machine. The factors which affect the compressive strength of mortar are the cement content of the mix, the water / cement ratio, the proportion of cement to sand and properties of sand itself.

2.1.3 Masonry

Strength characteristics of masonry are governed by the properties of constituent materials, their interaction and workmanship. Sahlin [20] has listed as many as 30 parameters which directly or indirectly influence the strength of masonry. Attempts made so far consider effect of only a few these parameters. There is thus still an uncertainty in the prediction of masonry strength from the properties of its constituents. Further, no control specimens have been standardized to determine, the basic compressive strength, tensile strength and shear bond strength of masonry. Basic strength may be defined as the strength obtained by testing a small control specimen where in the influence of slenderness ratio and eccentricity of load is absent or negligible.

(a) *Behavior of masonry in compression*

Masonry is a composite material with the brick as the building unit and the mortar as the jointing material. Properties of brickwork can be approximately deduced from the knowledge of its constituents. Fig.2.1 show a graph of brick strength against masonry work strength tested at 28 days. Test result of full bricks tested in direct compression [2] show that there is wide scatter in their values as alternate method i.e.

by smoothening their faces and capping with 1:3 c/s mortar, even there are large scatter of results. This is because the compressive strength varies enormously between batches from the same kiln and even of the individual bricks from the same burning.

Tests carried out in the Building Laboratory of Manchester University on six bricks obtained from a kiln at the same time showed the crushing strength to vary between 10 N/mm^2 and 16.6 N/mm^2. This variation is partly due to the different positions of bricks in the kiln. This variation is also shown by the following Figures in brackets which indicate the approximate crushing strength of the specimens wire-cut, pressed and hand made bricks (six of each type) from well known and reputable manufacturers. Wire-cut commons and facing (12.4 to 34.4 N/mm^2), pressed commons and facings (17.2 to 41.3 N/mm^2) and hand made facings (13.8 to 34.4 N/mm^2). Engineering bricks have crushing strength varying from 55 to 124 N/mm^2.

Test results of Muliyar[12] carried out on brick masonry prisms show that there is a considerable variation in the crushing strength. It is obvious because of the variation of its constituent materials i.e. brick, mortar and also the workmanship.

Thus it is clear that there is considerable scatter in the strength of bricks as well as brick masonry. The results of this thesis reported in subsequent chapters also show a similar scatter in the results. Due to this reason a high factor of safety is taken for the design of brick masonry. IS specification use a factor of safety of 4 for the strength of brick masonry determined by experimental testing.

Many tests carried out on brickwork cubes and on full size brick walls have produced a number of empirical formulae relating brick, mortar and brickwork strength. Bhandari (1982) has reviewed the literature on strength of brick masonry. He has presented different empirical relations correlating strength of brick mortar and brick masonry in a tabular form. Some if these expressions are:

(i) Hansson(1936) $f_m = \sqrt{f_b} + \sqrt[3]{f_j}$

(ii) Hermann (1942) $f_m = 0.45\sqrt[3]{f_j f_b^2}$

(iii) Brocker (1961) $f_m = \sqrt[3]{f_j}.\sqrt{f_b}$

(iv) CBRI (1975) $f_m = -10.386 + 3.886\sqrt{f_b}.\sqrt[4]{f_j}$

Where f_b = compressive strength of bricks (Kg/cm^2)

f_j = compressive strength of mortar (Kg/cm^2)

f_m = compressive strength of masonry (Kg/cm^2)

(b) ***Elastic Modulus***

Masonry is very nearly like a layered composite material hence; its elastic properties may be predicted analytically using principles of composite material [5], as follows.

$$E_m = \left(\frac{E_j.E_b}{v_j.E_b + v_b E_j} \right) \tag{2.1}$$

where E_m is modulus of elasticity of masonry when loaded normal to the bed joint and

E_b = modulus of elasticity of brick

E_j = modulus of elasticity of mortar

v_j = volume proportion of mortar in masonry

v_b = volume proportion of brick in masonry

Since the elastic constants for the constituents of masonry are not known, it is usual to relate the Young's modulus to the compressive strength of masonry. Value of the elasticity, E_m of masonry loaded in compression normal to bed joints, lies in the range of 400 to 1000 times its compressive strength

Sahlin [20] proposed the following relation determine E_m .

$$E_m = 700 \ f_m \tag{2.2}$$

Above equation overestimates E_m for the low strength mortars and unusual ratios of bricks and mortar.

Bhandari [2] have tested so many models of masonry and concluded that the value of modulus of elasticity for local materials and quality of workmanship is much less than that predicted by eq. (2.4) . Proposed equation by Bhandari are given below:

$$E_m = 307 \ f_m \quad \text{(linear)} \tag{2.3}$$

$$E_m = 2.16 \ f_m^2 + 184.5 \ f_m \quad \text{(parabolic)} \tag{2.4}$$

Both these relations can predicted the modulus of elasticity of low strength masonry accurately but parabolic equation is recommended for better prediction of correct value.

(c) Failure Mechanism

Failure in masonry under axial compression is normally by vertical splitting due to horizontal tension in the bricks [10]. Fig.2.2 shows a typical failure pattern in a brickwork wall. The reason for this type of failure is due mainly to the widely different strain characteristics of the masonry and the mortar joints. The mortar is less rigid than the brick and under load its tendency is to spread laterally to a greater extent than the brick. Due to bond action, the mortar is put in to a state of biaxial compression and the brick into biaxial tension. Fig.2.3 shows the free lateral expansion of brick and mortar due to externally applied stress σ_y and the resultant expansion of the composite. Failure in the brickwork occurs when the tensile stress in the brick reaches its ultimate tensile strength.

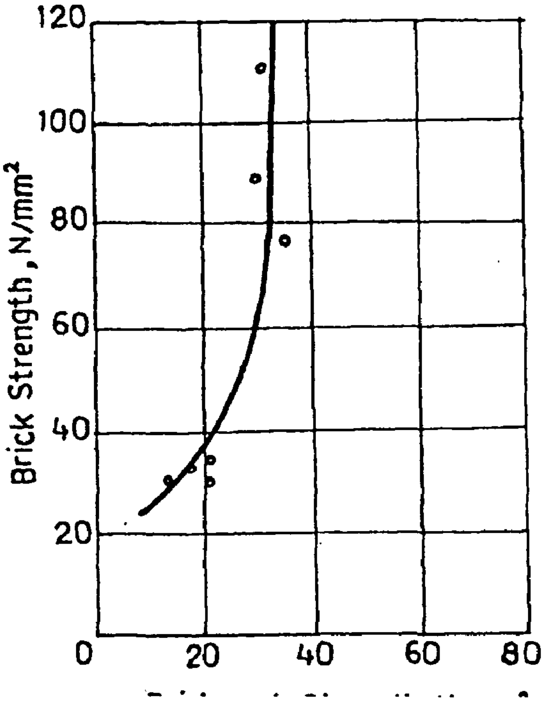


Fig2.1 Graph showing brick strength against brick

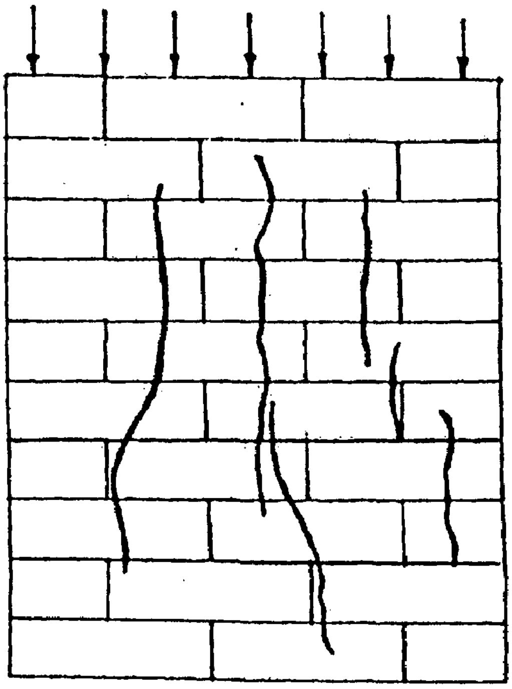


Fig 2.2 Typical Failure pattern in a brickwork wall

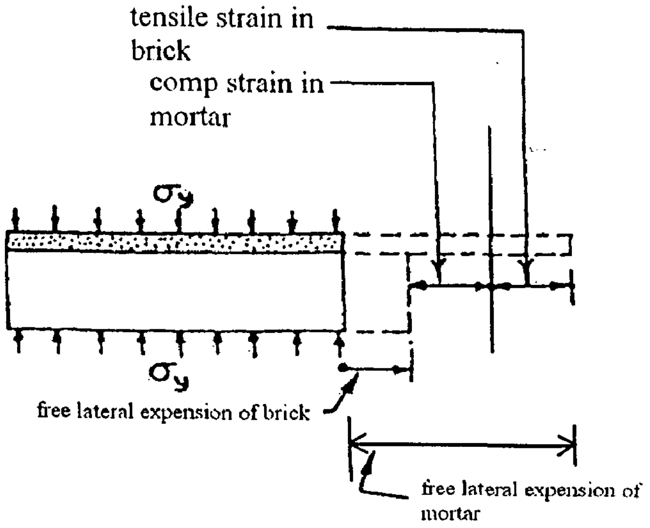


Fig 2.3 Lateral expension of brick and mortar under vertical stress

2.2.1 Definition:

Ferrocement is a highly versatile form of composite material made from cement mortar and layers of wire mesh or similar small diameter steel mesh closely bound together to create a stiff structural form. Ferrocement as a constructional material is gaining acceptance in different applications namely: housing, water supply and sanitation, agriculture and marine uses. This material which is a special form of reinforced concrete, exhibits a behavior so different from conventional reinforced concrete in performance, strength and potential application that it must be classified as a separate material.

The American Concrete Institute (ACI) Committee 549 on ferrocement [8] defines it as:

"Ferrocement is a type of thin wall reinforced concrete construction where usually hydraulic cement is reinforced with layers of continuous and relatively small diameter mesh. Mesh may be made of metallic material or other suitable materials."

The basic idea behind this material is that concrete can undergo large strains in the neighborhood of the reinforcement, and the magnitude of the strains depends on the distribution and subdivision of the reinforcement throughout the mass of the concrete. Within certain loading limits, ferrocement behaves as a homogeneous elastic material and these limits are wider than for normal concrete. The uniform distribution and high surface area to volume ratio of its reinforcement results in better crack arrest mechanism resulting in high tensile strength of the material.

2.2.2 Historical Development:

In 1850's J.L.Lambot of France constructed several rowing boats, from a material he called 'Ferrocement'. In the 1940's Nervi rediscovered ferrocement and he gave it a dimension never seen before. Ferrocement was accepted by the Italian Naval

Register and the Italian Navy and thus a number of ferrocement structures were built during world war II. In 1972, the National Academy of Sciences of USA set up an adhoc panel to study the utilization of ferrocement in developing countries [8].

During the past two decades, the application of ferrocement had widely extended to terrestrial applications. In 1977, Aurobindo Ashram of India built the first low cost roof in India. Many institutions in Asia, like the Asian Institute of Technology, Thailand, SERC, Roorkee (India), University of Roorkee, Roorkee (India), National University of Singapore, Singapore etc. have been actively engaged in research and development of ferrocement structures.

2.2.3 Advantages Of Ferrocement:

Advantages of ferrocement are given below:

1. Its basic raw materials are readily available in most countries.
2. The ability to be cast into any shape.
3. Rapid construction with no heavy machinery.
4. Low cost of construction.
5. Lower self-weight of elements.
6. High tensile strength.
7. Easy reparability.
8. Corrosion resistant.
9. Crack resistant.
10. High toughness.
11. Suitable for mass productivity.

2.2.4 How ferrocement is different from conventional reinforced concrete?

Ferrocement differs from conventional reinforced concrete in that is consists of closely spaced, multiple layer of mesh or fine reinforcing bars completely impregnated are specified as a minimum total volume fraction (3.6 percent volume of steel per unit volume of composite) and a minimum total specific surface area of steel (0. 16mm2/mm3) .The result is a thin walled composite material with a such higher volume fraction of steel than conventional reinforced concrete. The mechanical characteristic displayed approximate that of a homogeneous material and are different to the conventional concrete in terms of strength and deformation. Wall are usually much thinner than conventional reinforced concrete and the maximum cover of the reinforcing is as little as 5mm with 2mm being the average recommended cover.

2.2.5 Constituent Materials:

The constituent materials of ferrocement are cement, fine aggregate, water, admixtures and wire mesh.

(a) Cement

Various types of cements are used in ferrocement. Type I Portland cement can be used except in sulphate attack. Type II Portland cement (Portland pozzolana) gives low early and higher late strength. Type III cement (rapid hardening cement) is used when high early strength is desired. The cement should be fresh, free from foreign matters and of uniform consistency.

(b) Fine Aggregate:

Fine aggregate should confirm to ASTM standard C-33 and C-40 and IS 383-1970 grading zone II. The sand should be clean, hard, strong and free from organic impurities and deleterious substances. It should be capable of producing a sufficiently workable mix with a minimum water cement ratio to achieve a proper penetration into mesh layers.

There are three main parameters [6], which govern the composition of fine aggregates:

(i) Maximum size of grains.

(ii) Fineness modulus.

(iii) Specific surface area.

It has been found by experience that fine aggregate with maximum size of 2.36 mm and fineness modulus between 2.4 and 3.0 can be used satisfactorily. Specific surface area represents the grading of the aggregates. The desirable grading of aggregate is given in Table 2.2 as per IS: 383-1970

TABLE 2.1: IS: 383-1970 SPECIFICATION FOR FINE AGGREGATES GRADING ZONE II

I. S. Sieve Designation	Percent Passing
10 mm	100
4.75 mm	90-100
2.36 mm	75-100
1.18 mm	55-90
600 micron	35-59
300 micron	8-30
150 micron	0-10

(c) Water:

Water used in the mixing should be fresh and free from impurities like clay, loam, soluble salts which lead to deterioration in the properties of mortar. Potable water is fit for mixing or for curing of ferrocement structures.

(d) Admixtures:

Generally admixtures are used to alter or improve the properties of cement mortar. Commonly used admixtures in ferrocement are

(i) Water reducing admixtures.

(ii) Retarding admixtures.

(iii) Water reducing and accelerating admixtures. Addition of chromium trioxide is recommended to prevent galvanic corrosion of mesh in ferrocement. However it is recommended that prior testing of any admixture should be carried out before use for ferrocement structures.

(e) Reinforcing mesh:

Wire mesh is the essential component of ferrocement, which consists of thin wires, either woven or welded into a mesh, but the main requirement is that it must be easily handled and, if necessary, flexible enough to bend around sharp corners. The function of wire mesh and reinforcing rods is to act as a lath providing the form and support to the mortar in its green state. In the hardened state its function is to provide tensile strength [14]. Fig. 2.4 shows various types of wire meshes used in ferrocement. Currently used wire meshes are:

Welded Wire Mesh

Wires used in this mesh are made of low to medium tensile strength steel and are usually stiffer than hexagonal wire mesh. In this mesh, eighteen to nineteen gauge wires are normally used at a spacing of half an inch (1.25 mm) apart. This mesh is not usually preferred because of weak spots at intersections resulting from inadequate welding.

Hexagonal Wire Mesh

This mesh is also known as chicken mesh and is commonly used. It is fabricated from cold drawn wire mesh, which is generally woven into hexagonal pattern. The wire used in ferrocement is usually 0.5 mm to 1.0 mm in diameter, and the mesh opening vary from 10 mm to 25 mm. For most of the purposes the mesh need not be welded.

Woven Mesh

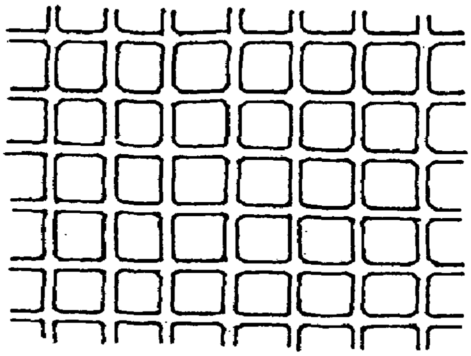
This mesh is usually used in ferrocement. In this mesh wires are woven into the desired grid size and have no welding at the intersections. This mesh is better than hexagonal or welded mesh. The mesh wires are not perfectly straight and a certain amount of waviness exists. It is difficult to hold in position but when stretched it confirms to the desired curves.

Expanded Metal Mesh

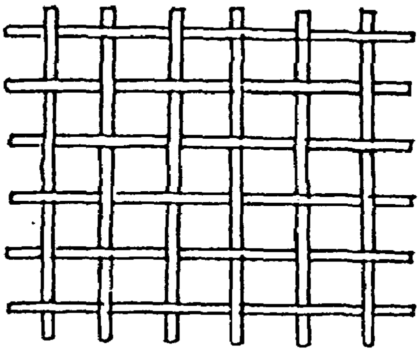
This mesh is formed by cutting a thin sheet of metal and expanded to form diamond shaped openings. It is not as strong as woven mesh, but on cost to strength ratio, this is advantageous. One minor disadvantage is that it tends to split due to 'scissors' action of diamond mesh. There is a limit the size and weight of expanded metal, which can be used in order to avoid this 'scissors' action; this mesh is also known as metal plasterer's lath known as metal plasterer's lath.

Watson mesh

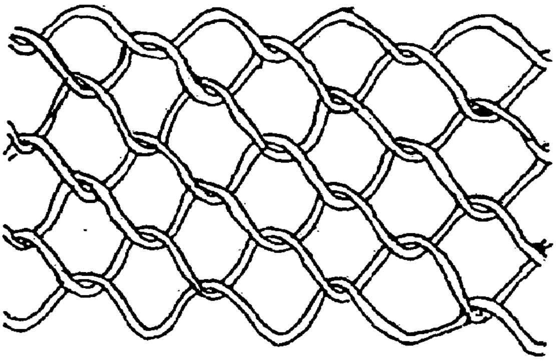
This is a new type of mesh, which has been developed in Newzealand. This mesh consists of straight high tensile wires and transverse crimped wires, which hold the high tensile wires together. The high tensile wires are placed in two planes parallel to each other and are separated by mild steel wires transverse to the high tensile wires. Thus a vast proportion of wires are straight without twists, crimps, pressings, punching and welds. This enables complete flexibility and freedom of shape.



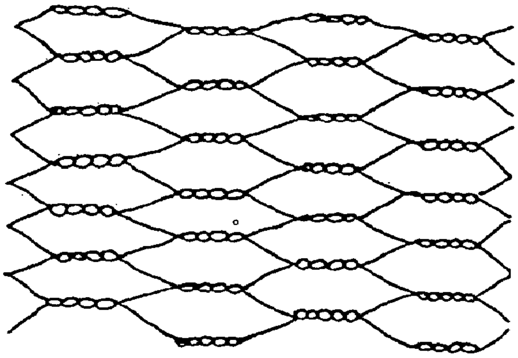
Welded mesh



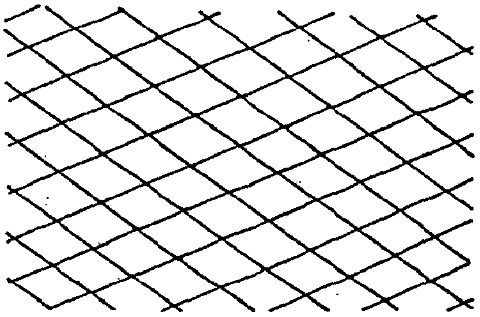
Woven mesh



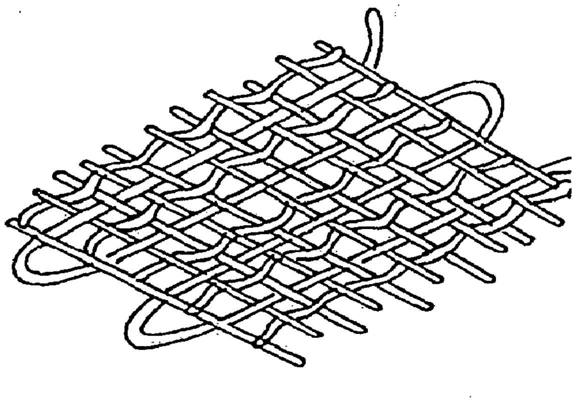
Chain mesh



Chicken mesh



Expended mesh



Waston mesh

Fig 2.4 Different types of mesh

(f) Skeletal Steel:

As the name implies this is generally used for making the framework of the structure upon which layers of mesh are laid. Both the longitudinal and transverse rods are evenly distributed to form the required shape. The rods are spaced as widely as possible up to 300 mm apart where they are not treated as structural reinforcement and are often considered to serve as spacer rods to the mesh reinforcement. In some cases skeletal steel is spaced as near as 75 mm center to center, thus acting as main reinforcing component with wire mesh in highly stressed structures.

2.2.6 Properties of ferrocement:

Ferrocement is a homogeneous composite material which contains a high percentage of ductile steel wire with a high surface area to volume ratio in a brittle cement mortar matrix which enables the matrix to assume the ductile characteristics of reinforcement. The strength always gives an overall picture of the quality of ferrocement, as strength is directly related with the properties of its hardened cement paste and reinforcement. The strength characteristics of ferrocement are described below:

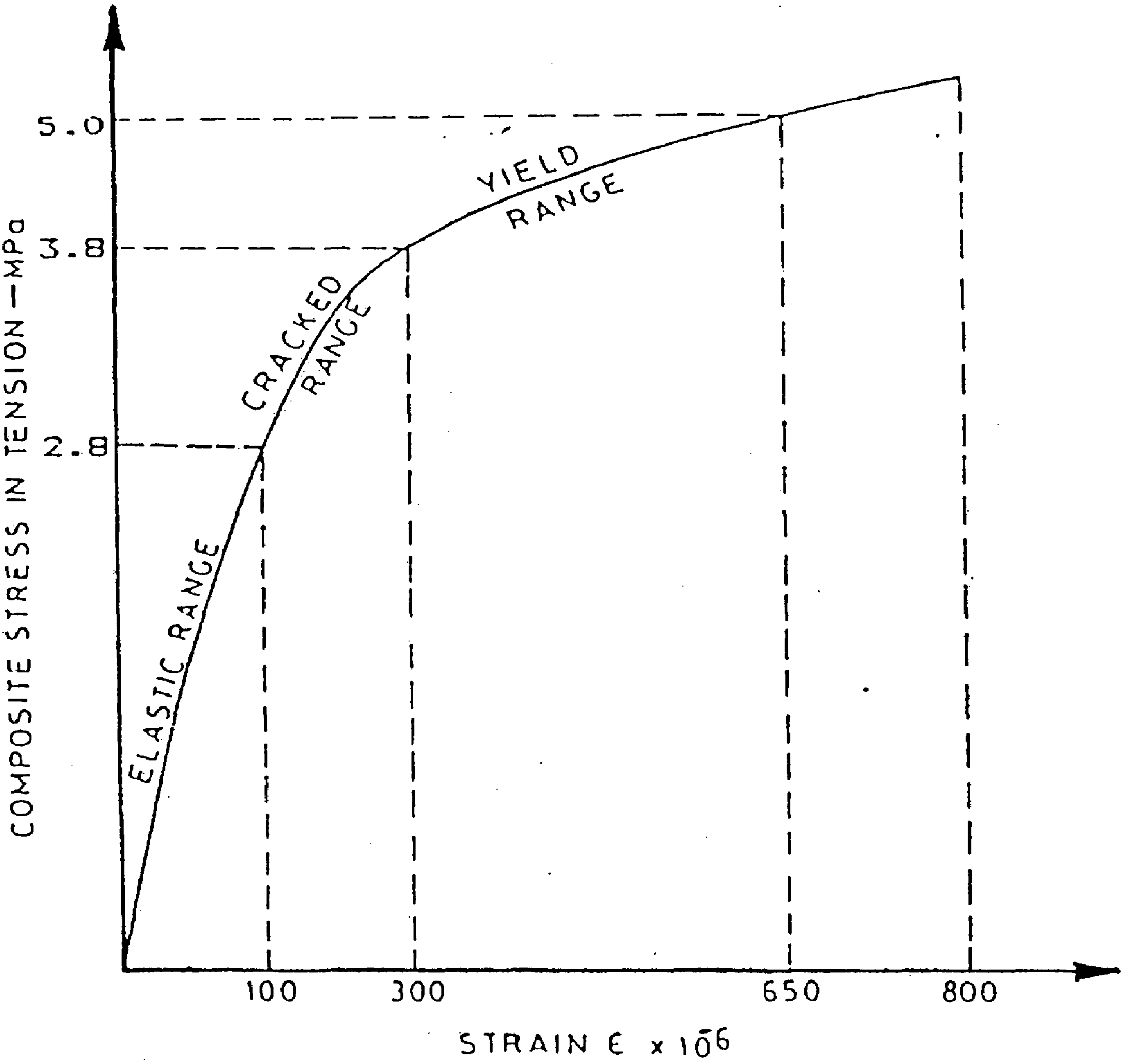


Fig 2.5 Tensile stress-strain curve of ferrocement

(a) Tension

When a ferrocement specimen is subjected to an increasing tensile load, three different stages of behavior are observed. These stages are classified according to the width of crack [3]. Experimental studies on the behavior of ferrocement specimens in tension yield stress strain curve as shown in Fig.2.5. This curve can be idealized by a tri-linear diagram as shown in Fig.2.5.

A brief description of the stress- strain curves of ferrocement at different levels is given below:

Elastic Range

The stress strain curve is essentially linear in this stage. There is no evidence of any crack formation even when observed with magnification. The limit of elasticity of ferrocement is also higher than that of the reinforced concrete. With an increase of stress, ferrocement becomes quasi-elastic. The micro cracks developed are invisible to the naked eyes.

Cracked Range

With a further increase in stress, the curve deviates from linearity and multiple cracks are formed rather than widening of cracks which occurred earlier. The cracks are very fine and crack width has been observed to be a function of the specific surface of the reinforcement [23].

Yield Range

Increasing the stress further causes an increase in the width of the cracks at a uniform rate as the maximum numbers of cracks have already been developed. Composite action between the mortar and reinforcement continues up to the attainment of crack width of about 100 microns and thereafter, the reinforcement carries all the tensile force.

(b) Compression

The stress strain curve for ferrocement in compression is initially linear but becomes markedly curvilinear at a later stage. The curve can be idealized by a bilinear diagram as shown in Fig 2.6. The ultimate failure takes place due to failure of the mortar as the wire mesh reinforcement is incapable of carrying any load due to buckling [18].

(c) Bending Of Ferrocement

The load deflection curve of a ferrocement element subjected to a monotonically increasing bending moment is generally tri linear as shown in Fig.2.7. The flexural behavior of ferrocement may be predicted either by considering ferrocement to be a composite material or by adopting reinforced concrete theory in which mortar and steel are considered to be acting separately. The composite analysis is applicable when the mesh layers are uniformly distributed over the cross section. The R.C. theory would be more accurate in case of non-uniform distribution of mesh layers over the cross section and when skeletal steel is present.

The three distinct stages in behavior of an element loaded up to failure under flexure are shown in Fig. 2.7. These stages may be identified as the uncracked, cracked and yield stages. The stress and strain distribution across the section at these different stages will be as shown in Fig.2.8. The analysis of a section can be carried out in a usual manner by considering compatibility of strains and equilibrium of forces and moments and using the idealized bilinear stress-strain curve in compression (Fig. 2.6) idealized trilinear stress strain curve in tension is shown Fig 2.5 [1,12].

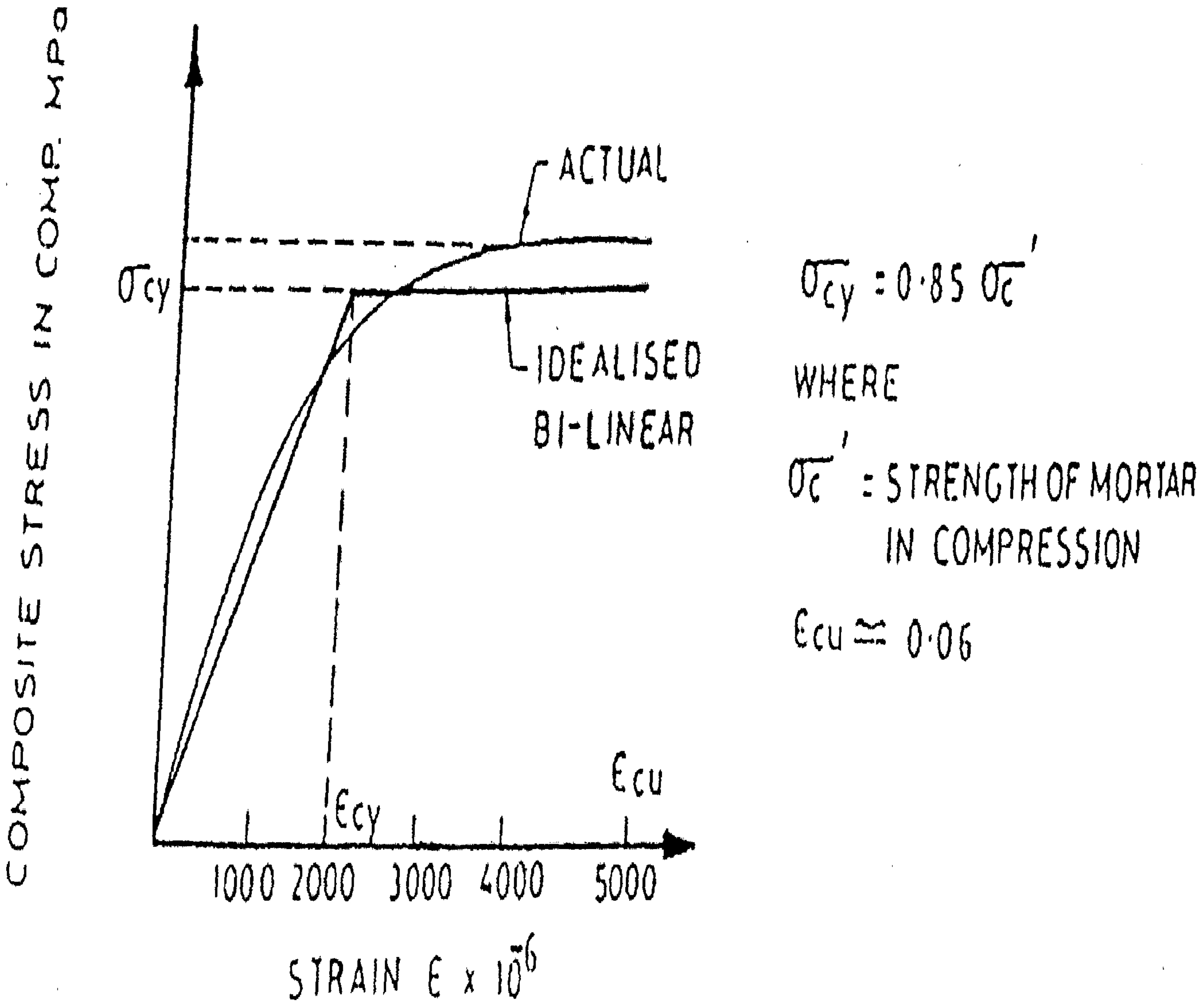


Fig 2.6 Compressive stress strain curve for ferrocement

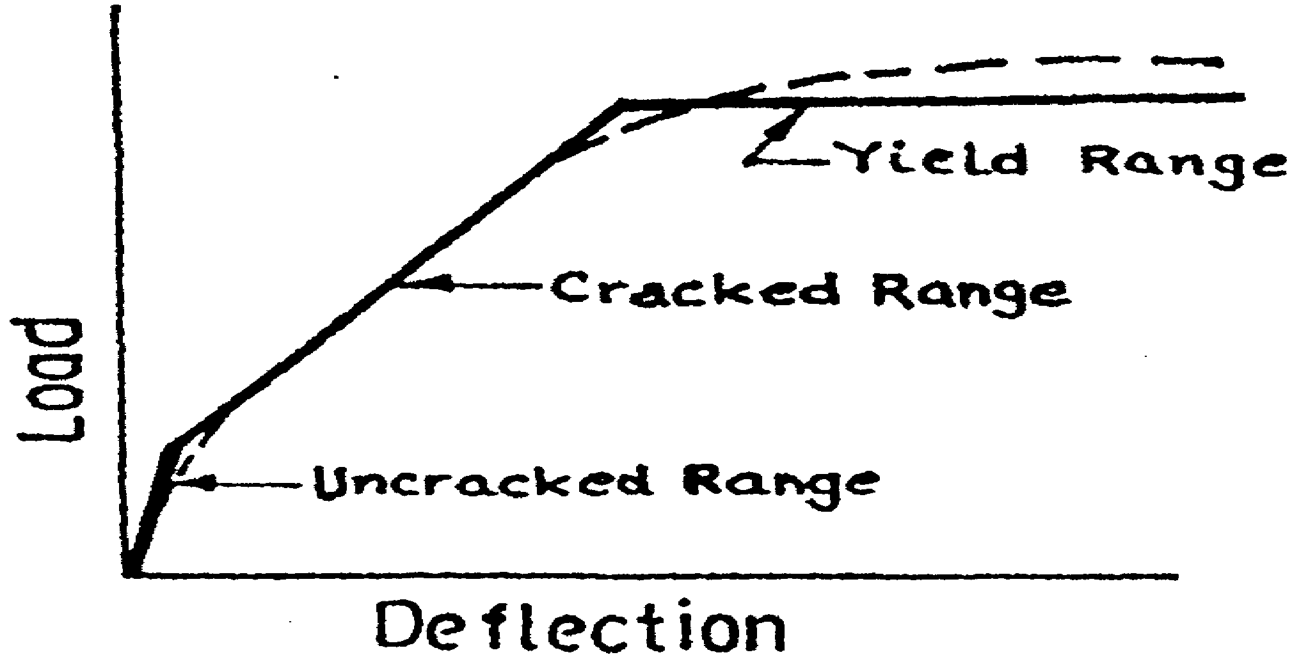
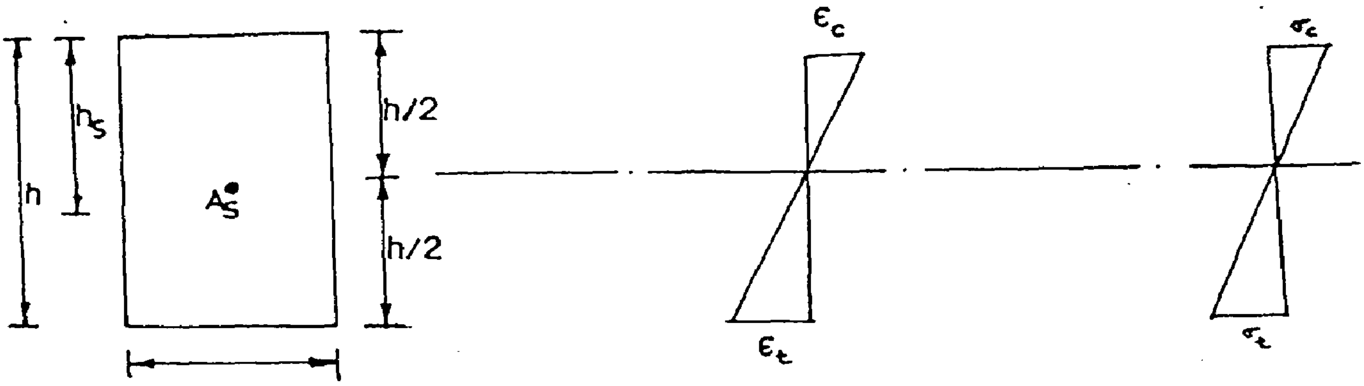
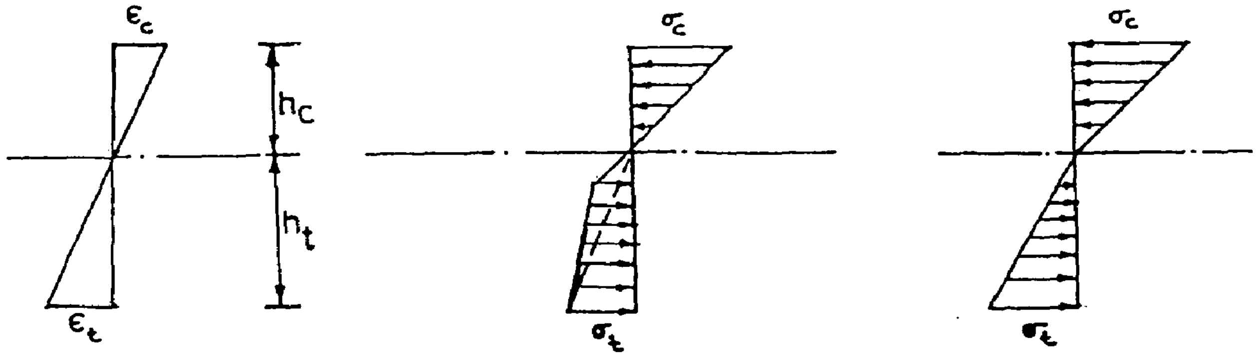


Fig 2.7 Typical deflection curve for ferrocement in bending



(a) Uncracked Range



(b) Cracked Range

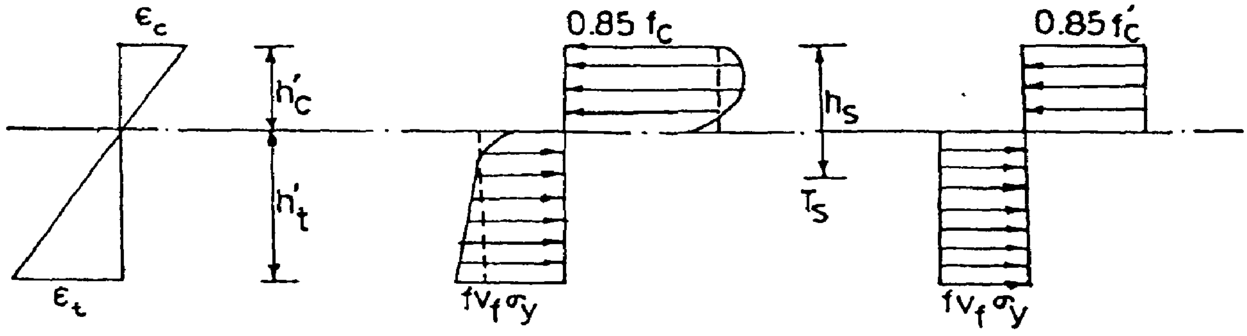


Fig 2.8 Stress strain distribution in ferrocement section

2.3 CONFINEMENT OF MASONRY

Masonry may be said to be confined, when under compression its tendency to expand transversely is resisted by lateral confining pressure. When a masonry specimen is subjected to an increasing axial load, it expands laterally due to the poisson's ratio effect. The importance of confinement can be understood from the fact, that it increases the strength of masonry as well as the ductility, and the stress train curve is modified. Studies have shown that strength increase due to confinement is a function of lateral confining pressure applied.

It has been seen that confinement of R.C. columns by closely spaced circular hoops or square ties or spiral reinforcement or mesh reinforcement results in a considerable increase in strength and ductility of such columns. For brick masonry also this has been investigated but on a limited basis

Reinhorn et al. (1985)[19] has used ferrocement for seismic retrofitting of masonry walls. Here due to increase cross sectional area and tensile strength of mesh wires, there can be increase in strength and ductility of masonry walls.

Priestly and Elder (1983) [17] report their test on grouted concrete blocks masonry using thin stainless steel plates embedded in the mortar beds to provide confinement. This helps to reduce the slope of the descending branch of the stress strain curve hereby increasing ductility. Loads were applied to low (0.000005/sec) and high (0.005 to 0.006/sec) strain rates. Strain readings were taken by means of potentiometers in the middle two third height of specimens. Good results were obtained for ascending portion of the curve but only one third of the results for descending regions were acceptable. The confining influence of the plates did results in lowering the slope of the descending region of the stress-strain curves. Whereas loading at high strain rates resulted in a strength increase and also increase in steepness of the descending region. Presence of thin stainless steel confining plates within the mortar bed improve ductility and modify failure mechanism. Incorporation of confining plate sin the mortar beds dramatically changes appearance of the failure mechanism. Vertical splitting of block virtually eliminated.

Singh et al. (1988) [21] have tested square brick masonry columns encased in ferrocement. These tests make it clear that there is confinement of masonry by the mesh layers present in ferrocement. Thus, the increase in strength of the column is due to increase in cross sectional area as well as due to confinement of masonry. There is a considerable increase in ductility as well which is important from seismic consideration, because unreinforced brick masonry otherwise have low ductility and low seismic resistance.

2.4 FERROCEMENT ENCASED BRICK MASONRY COLUMNS:

The ferrocement encasement of brick masonry columns can be required to increase the load carrying capacity, repair of columns distresses due to reasons mentioned in chapter 1 or to use these ferrocement encased brick masonry columns instead of RCC to achieve economy.

A short circular or square column is considered to comprise of a brick masonry core with or without reinforcement and a mortar casing with one or more layers of mesh. When loaded axially these columns undergo compressive strains in the vertical direction. Due to poisson's ratio effect tensile strains develop in the horizontal direction as well i.e. there is an increase in the cross sectional dimensions of the columns. The horizontal strands of the mesh resist this increase in dimensions by developing tensile stresses. The vertical strands develop compressive stress due to effect of applied axial load.

The design of brick masonry columns is done in accordance with the relevant BIS code [4] provisions. The procedure is to first of all determine the basic compressive stress of masonry, which depends upon the strength of bricks and the strength of the mortar. This may be done either experimentally or by using a table given in the code. To obtain the permissible compressive strength the basic stress is multiplied by the following factors :

The stress reduction factor which takes into account the slenderness ratio of the column with cross section less than 0.2 m^2 the shape modification factor which depends upon the height to width ratio of bricks. The code also provides an increase in permissible compressive stresses for eccentric vertical loads. Thus, with reference to the code provisions the column may be designed.

For design of ferrocement encased brick masonry columns [15] similar procedure can be followed. The main difference is that the basic compressive stress of brick is increased to allow for confinement and strength increase due to increase in cross sectional area. This increased basic compressive stress may be determined either experimentally or theoretically as described below.

The experimental procedure for basic compressive stress is described in appendix B of the code. Crushing strength f_m of brick masonry prisms is determined in a compression testing machine. The mortar and bonding arrangement of the prism must be the same as for the column. The prism should have a height of 40 cms at least and a height to thickness ratio lying in the range 2 to 5. This is multiplied by a factor to obtain the value corresponding to a height to thickness ratio of 5 in case it is less. The basic compressive stress f_b is 0.25 times f_m.

An identical procedure may be adopted for the encased prism. The encased specimens are to be tested with the two open (i.e.unencased) faces being subjected to

$$2T = d_m . \sigma_L \quad \text{or} \quad \sigma_L = 2\,T/\,d_m = T/\,r_m \tag{2.5}$$

Where,

$\sigma_L =$ lateral confining pressure

if nml is the number of mesh layers, S_p is the spacing of mesh wires, wyl is the yield load of a single mesh wire, then T will be given by,

$$T = \text{nml. Wyl}/\,S_p \tag{2.6}$$

$$\sigma_L = \text{nml. Wyl}/\,(S_p\,.\,r_m\,) \tag{2.7}$$

Substituting σ_L from the equation (2.7) in (2.4)

$$P_m = \pi\,(r^2\,\sigma_0 + r_m\,k_1\,.\,\text{nml. Wyl}/\,S_p\,) + A_{st}\,(Y_s - \sigma_c) \tag{2.8}$$

The strength increase due to confinement is proportional to the lateral confinement pressure σ_L and in case of brick masonry column it is expressed by equation below

$$f_{mc} = f_m + k_1\ \sigma_L \tag{2.9}$$

in which k_1 is 4.0 and σ_L the lateral confinement pressure. It depends on the horizontal mesh wires and not the vertical component of the yield load of wires per unit of section is considered.

(b) Square columns

Details of square column cross section are shown in Fig.2.9 (b). The dimensions d, d_o, d_c, and d_s are the sides of the columns, the outermost mesh layer, the core side and center to center distance between the longitudinal reinforcement. Dimension d_m is the mean of d_o and d_i and the resultant tensile force of the wire acts at this distance.

The behavior of a confined short square cross section is different from that of a circular section. In square section, the expansion of core is resisted by two means i.e. by direct tension and also by bending. Wires can offer low some bending resistance.

Confining pressures on core are non-uniform as shown in Fig 2.10(a)

Here $\sigma_L = 2\ T/d_m = 2\ nml.wyl / S_p . d_m$ (2.10)

(c) Strength of square confined column

Load carrying capacity of short column with mesh will be given by the equation:

$$P_m = d_o^2\, \sigma_o + (d-d_o)^2\, \sigma + d_m^2 . C_e . k_l . \sigma_L + A_{st}\ (Y_s - \sigma_c) \tag{2.11}$$

Where, d_o = Distance between outer layer of mesh

d = length of one side of section

d_m = mean distance of inner and outer side of mesh

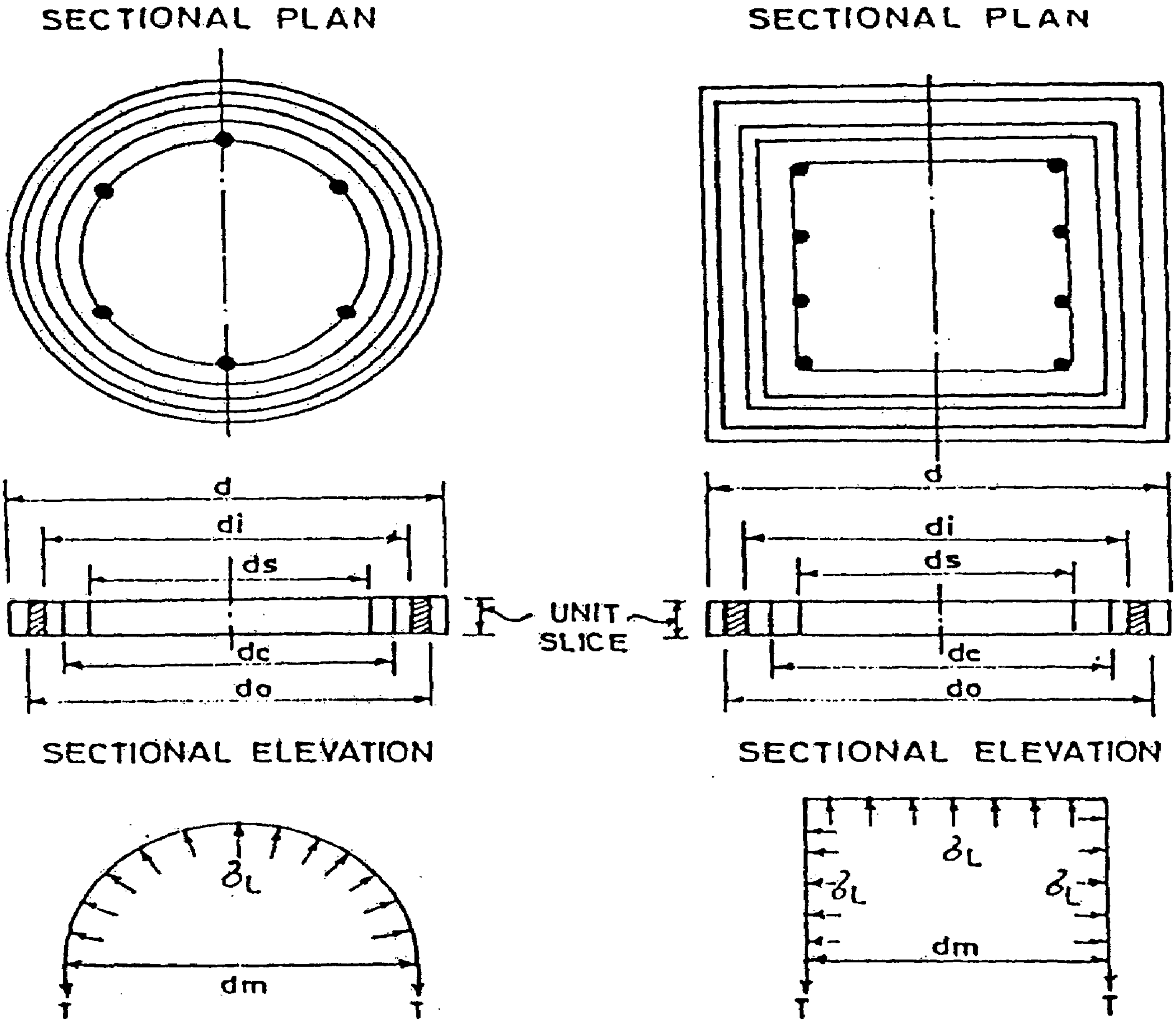
C_e = confinement effectiveness coefficient varies with (σ_L / σ_o) ratio and can be obtained from the graph (Fig 2.10(b))

The derivation for square as well as rectangle sections have been given in detail in reference [21]

In case of brick masonry core, strength increase due to confinement

$$f_{mc} = f_m + k_l . C_e . \sigma_L \tag{2.12}$$

in which σ_L is as given in eq.2.10 and d_m is as shown in Fig 2.9 (b) for the section, C_e coefficient for confinement effectiveness for square. The derivation for this coefficient have been given in reference [21] from which the graph of Fig.2.10(b) has been taken. Having determined C_e, equation 2.9 may be used to obtain f_{mc} and thus f_{bc} which is 0.25 times f_{mc}. Now the columns may be designed as per code provisions. Application of the above procedure for reinforced brick masonry column would be valid for axial loads only



(a) CIRCULAR SECTION (b) SQUARE SECTION

2.9 Details of square and circular columns

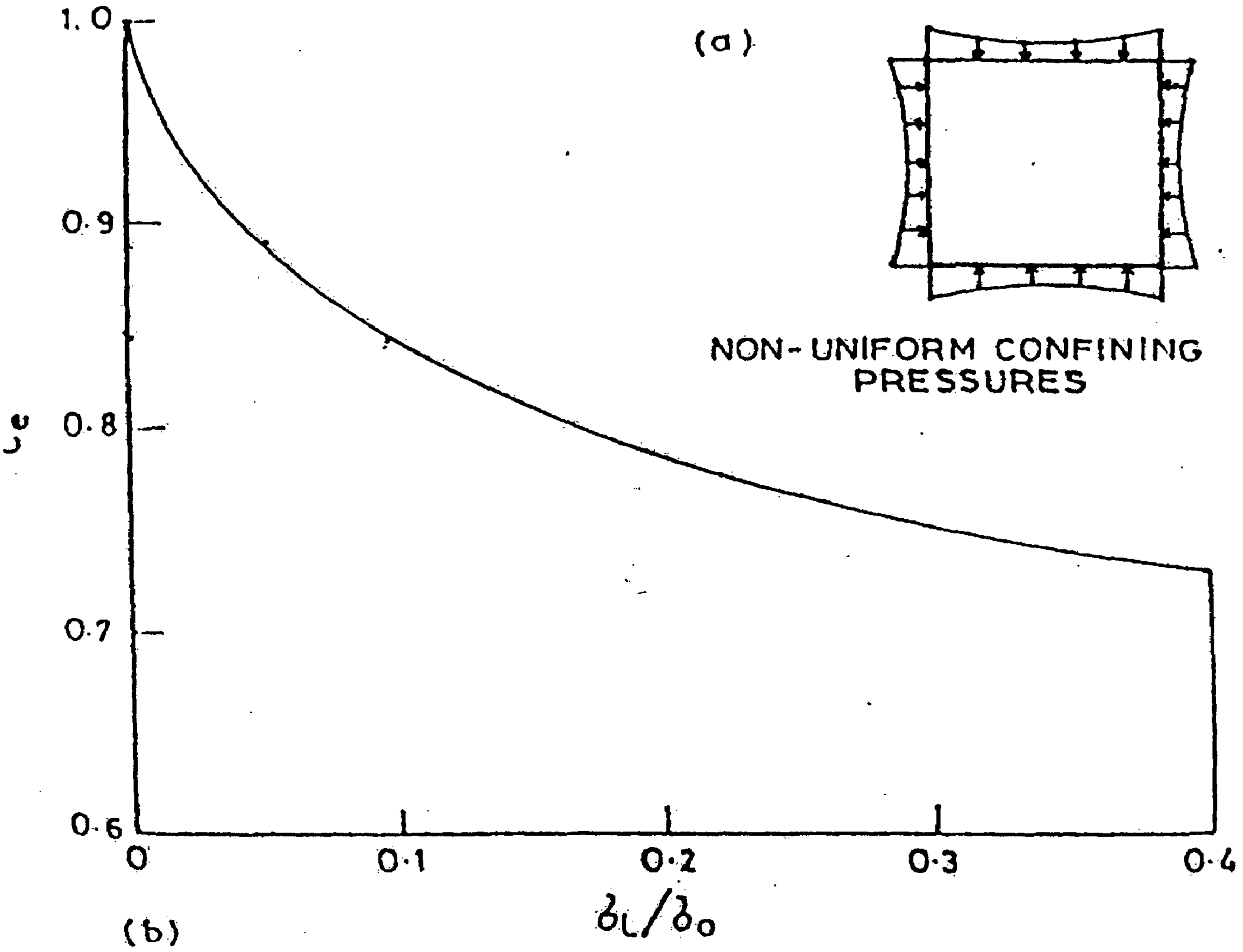


Fig.2.10 (b) Square section confinement effectiveness coefficient.

EXPERIMENTAL PROGRAMME

The objective of this experimental programme was to study the effect of confinement and to obtain the compressive strength of axially loaded plain brick masonry columns as well as retrofitted brick masonry columns with the help of ferrocement and also check the increase in strength of already failed plain masonry columns after repairing them with the ferrocement. The main issue of this study is to examine is jacketing of brick masonry by ferrocement which helps in providing a substantial strength increase as in case of concrete. The main objective is to study of load-deformation curve, stress strain curve and cracking pattern particularly first appearance of visible cracks.

3.1 MATERIAL USED

Cement:

Ordinary Portland cement of grade 43 grade was used for mortar used in brick masonry and ferrocement casing. The cement was tested as per IS: 4031-1988 and results obtained there in are reported in Table 3.1

TABLE 3.1: TEST RESULTS OF CEMENT USED

S.No.	Characteristics	Test results	IS :8112-1989
1.	Fineness	5%	<10
2.	Specific Gravity	3.15	—
3.	Standard Consistency	27%	—
4.	Initial setting Time	32 mins.	>30
	Final Setting Time	138 mins.	<600
5.	Soundness	1	<10
6.	Loss on Ignition	3%	-
7.	Compressive Strength		
	3 days	31 N/mm^2	>23
	7 days	44 N/mm^2	>33

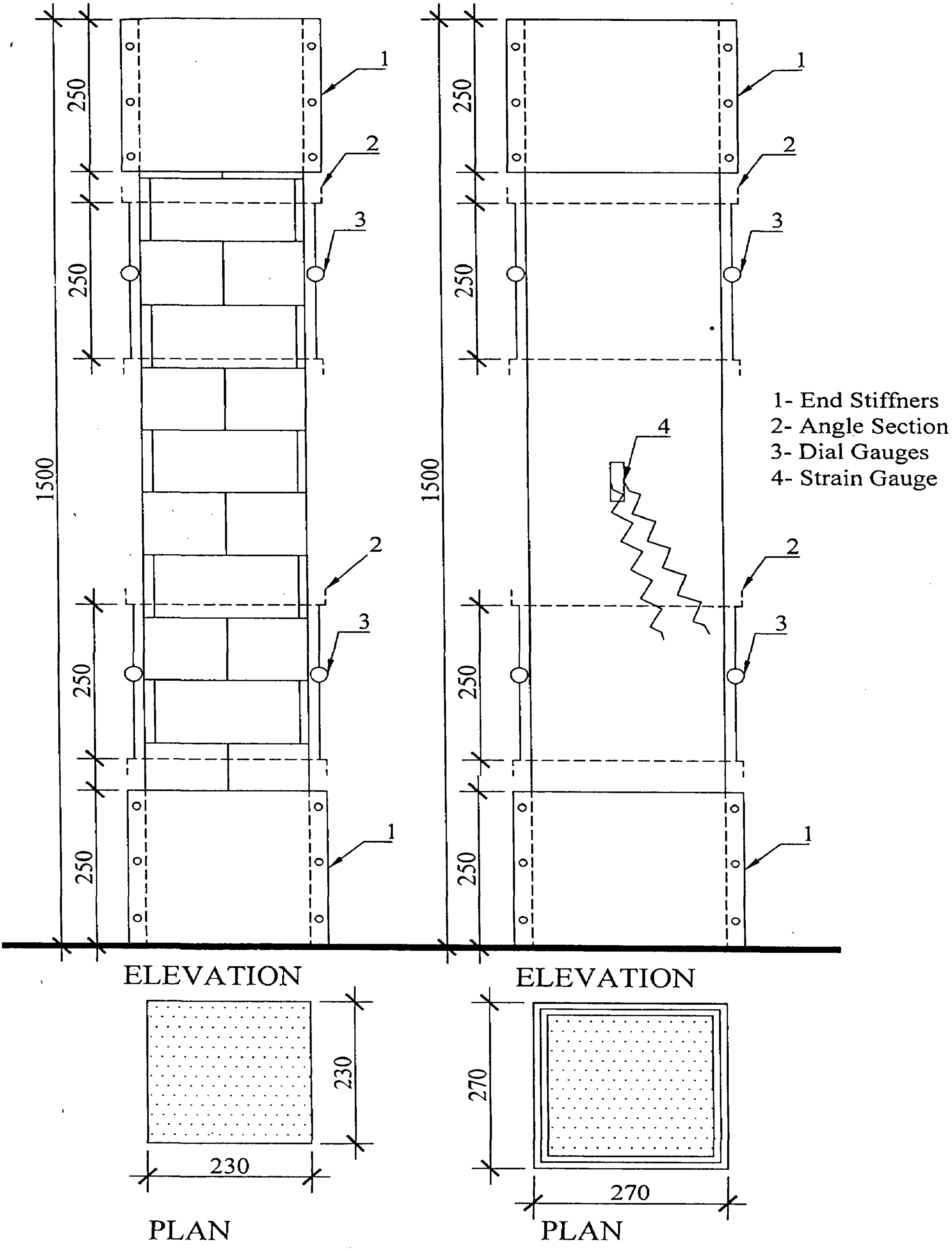


Fig. 3.1 Detail of Specimens

Fine Aggregate:

The sand used was river sand conforming to grading of zone III. The various properties of fine aggregate are given in Table 3.2.

TABLE 3.2: TEST RESULTS OF FINE AGGREGATE USED

I.S Sieve designation	% Wt. Retained	% Wt Passing
10 mm	0.0	100
4.75mm	2.01	97.99
2.36 mm	3.3	94.69
1.18 mm	8	86.69
600 μm	16.4	70.29
300 μm	32.06	38.23
150 μm	24.1	14.13
<150 μm	14.13	0

$$\text{Fineness Modulus} = \frac{\text{summation of cummulative wt. retained}}{100} = 2.97$$

Mortar Mix:

Mix proportion for mortar for brickwork was 1:4 cement, sand mortar and for ferrocement was 1:2.5 cement sand with a w/c ratio 0.55. Five cubes for each type of mortar were cast to determine the strength at 28 days. Test results are shown in Table 3.3

TABLE 3.3TEST RESULTS OF BRICKS AND MORTAR

Sl. No	Specimen	Compressive strength Mpa	Mean Strength Mpa
1	Brick	31.50, 27.35, 28.65, 26.81, 25.15	27.89
2	Mortar 1:2.5	11.20, 11.50, 10.80	11.16
3	Mortar 1:4	10.35, 11.00, 9.48	10.28

Wire Mesh:

The mesh used for repairing was galvanized steel wire woven mesh, having square openings of 9.35mm x 9.35mm. The diameter of the mesh wire was approximately 0.5 mm. Some sample wires of horizontal direction were tested to obtain the load deformation curve, the yielding and breaking loads of wire. The tests were carried out in Metallurgical Engineering Department using a tensometer. The results of tests on mesh wires are shown in Table 3.4

TABLE 3.4: TEST RESULTS OF MESH

Wire mesh sample	Yield Load (N)
1	267.4
2	265.6
3	266.6
Mean	266.5

TABLE 3.5: SPECIMENS DETAILS

S. No.	Specimen type	Nos.	No. of mesh	Dimensions (mm)
1	Plain brick columns	7	_	230 X 230 X1500
2	Repaired brick columns	3	1	270 X 270 X 1500
3	Repaired brick columns	4	2	270 X 270 X 1500
4	Retrofitted brick columns	4	1	270 X 270 X 1500
5	Retrofitted brick columns	4	2	270 X 270 X 1500
6	Mortar Cubes (1:2.5)	3	_	70.7X70.7X70.7
7	Mortar Cubes (1:4)	3	_	70.7X70.7X70.7

3.2 SPECIMENS DETAILS:

The selected test specimens were prisms. These were square in cross section having sides of 230 mm and a height of 1500 mm. The details of specimens are shown in Fig. 3.1 and Table 3.5. The quantities of mesh used were one and two layers. Mortar used for casting of brick masonry core was 1:4 cement sand mortar and for ferrocement it was 1:2.5 with w/c ratio 0.55. Six numbers (i.e. 3 for each type of mortar) of small cubes 70.7mm size were also cast to test the compressive strength of mortar used.

3.3 CASTING OF SPECIMENS:

First of all 15 plain brick masonry pillars were cast with alternate courses of one stretcher course and one header course, in eighteen courses (as shown in P.1). Mortar used was 1:4 cement sand mortar. These were cured for 28 days and then they were divided into two groups. First group was of 8 columns, which were encased in ferrocement without testing. In the second group 7 columns were there which were tested upto failure before encasing them with ferrocement. From the first group, four specimens were wrapped with single layer of wire mesh and four with double layers of mesh. 7 specimens of second group were repaired such that 3 were repaired with single wire mesh and 4 with double layer of wire mesh. Wire meshes were cut to proper size such that an overlap of 15 cm could be provided at the ends. The specimens were tested after 28 days curing.

3.4 TESTING OF SPECIMENS:

After 28 days of curing the plain specimens were tested upto failure and then these were repaired. These repaired specimens were tested after 28 days curing. Similarly remaining brick columns, which were wrapped with ferrocement, were tested after more than 4 weeks curing. All of the specimens were tested for axial loads using a loading frame, loading jack and proving ring arrangement as shown in P.2 for plain brick masonry columns and for ferrocement encased columns as shown in P.4.

The observations were made for failure loads, cracking and strains for plain brick masonry columns. For ferrocement encased columns measurements of strains were recorded by four dial gauges in pair of two on upper and lower part of the column on the opposite points and by electrical resistance strain gauges. The strain gauges were pasted on the all faces of each specimen as is shown in P.7, Fig. 3.1 and mean readings were recorded, at loading increments of 4 tonns. During the experiment steel plates of heights 25 cms and thickness of 6mm were used at the both ends of the column to prevent the local failure at ends.

DISCUSSIONS OF RESULTS

In this chapter, the results of the theoretical analysis and experimental investigations have been presented in the form of tables and figures. A number of photographs have been included to show the tested, untested specimens, test set up for different specimens, wire mesh encasement etc. The measurements were taken mainly for first crack load, failure load and deformation. This chapter also includes comparison and discussions of results. The limitations of theoretical and experimental analysis are examined, so that further investigation and scope for application can be identified. The review of literature given in chapter 2 has clearly brought out that information on the behavior of ferrocement encased brick masonry column is very limited. The derivations and formulae given in this chapter are mainly on the basis of review of literature given in chapter 2; particularly the experimental and theoretical behavior of confined brick masonry.

Test results of t load of wire mesh, fineness modulus of sand, initial and final setting time of ce be strength of mortar at 28 days have been included in chapter 3. Sectional dimensions of original and repaired columns are also included in Table 3.5 of chapter 3. Failure loads for columns are shown in Table 4.1 to Table 4.3. Sample calculations for assessing the strength increase of original ferrocement encased columns are included in Appendix

4.2 THEORETICAL ANALYSIS:

The theoretical calculations are carried out for original encased specimens for the effect of confinement. The peak compressive load in short circular columns corresponds to tensile yielding of the mesh wires in hoop direction. At this stage, core is subjected to a uniform lateral confining stress depending on the quantity of wires in the hoop direction and also their yield stress. It is assumed that vertical wires of the mesh do not contribute to compressive strength. The mortar in the strip between the innermost and outermost mesh layers is subjected to a confining stress, which varies across its width. Thus the confining stress at any point on this strip depends on the number of mesh layers lying outside that point. For simplicity it is assumed that the core plus half of the mortar strip between mesh layers is subjected to uniform lateral confinement and the other half is not subjected to any confining stress at all.

The column section details are shown in Fig. 3.1, Table 3.5 in which d, d_o, d_m are the dimensions of the side of column, outermost mesh layer, distance between centers of mesh layers.

Let T be the hoop tension forces in the wires per unit height of the column corresponding to yielding of the wire. Let the corresponding lateral pressure be σ_L consider the plain short column. Its total load carrying capacity is taken from test results. For simplicity mean strength is taken.

Strength of confined column: As explained in review of literature load carrying capacity in a short column with mesh causing confining pressures is given by equation 2.9 and σ_L can be obtained from equation 2.7 as given below:

$$\sigma_L = 2\ \text{nml.wyl} / \text{Sp.}\ d_m \qquad (2.7)$$

Where, d_m = distance between centers of mesh layers

wyl = yield load of wire mesh

nml = number of mesh layers

Calculations for strength increase due to confinement explained in detail in appendix and the results are shown in Table 4.2 and 4.3.

4.3 PRESENTATION OF RESULTS:

A total of 15 specimens were cast. 7 specimens were tested upto failure i.e. the maximum load capacity and then repaired with ferrocement such that three were having one mesh layer and four having two mesh layers. Again these were tested upto failure. The failure loads of plain specimens and repaired specimens are shown in Table 4.1(a) and Table 4.1(b)

The deformations were recorded with the help of dial gauges and electrical strain gauges were also used to determine the value of strains with the help of data logger. The smooth curves have been plotted for load-deformation and stress-strain behavior and are shown in Fig. 4.1 to Fig. 4.6. Graphs for load-deformation and stress-strain have been plotted for all the three (plain, repaired and retrofitted) type of specimens.

Eight specimens which were encased in ferrocement (4 with 1 layer and 4 with 2 layers of mesh) were tested upto failure. Theoretical increase in failure loads due to ferrocement jacketing is shown in Table 4.2 and Table 4.3. This also shows the ratio of experimental and theoretical loads. Percentage increase in mean failure loads is tabulated in Table 4.4.

4.4 COMPARISON AND DISCUSSIONS OF RESULTS:

The purpose of this study was to examine the strength increase due to ferrocement jacketing of brick masonry columns. Results are discussed below for strength and crack pattern. The strength of plain columns was found to vary in the range 200 kN to 300 kN with mean being 233.5 kN. As discussed earlier in chapter 2 strength of masonry shows large variations. That is why IS code practice is use factor of safety 4 for compressive strength of masonry. Elastic modulus of the brick masonry is worked out E =2903 N/mm^2 with the help of experiment. This is in close agreement of the value reported by the different authors.

The strength of original ferrocement encased columns wrapped with single layer of wire mesh was found to range between 485 to 510 kN with mean being 495 kN, whereas for double mesh columns strength variation was from 525 to 570 kN with mean 545 kN and standard deviation being 20.66. It was found that strength increase due to additional one layer is significant. But the values of Elastic Modulus in the both cases are close. The higher value of elastic modulus in confined columns than the unconfined columns shows that increase in strain values is less with increase in loads in case of confined specimens.

The strength increase due to ferrocement jacketing is 112 % for specimens with single mesh and 133 % for specimens with double mesh. Percentage increase in failure loads due to ferrocement encasement of brick masonry columns are shown in Table 4.4. Comparing the results, it is clear that there is a considerable increase in failure loads and the strength of brick masonry columns when they are encased in ferrocement.

Strength of repaired ferrocement encased columns which were repaired with single layer of wiremesh showed a considerable increase in strength with values ranging from 460 kN to 525 kN having mean strength of 493 kN. Increase in failure loads was 111 % that of plain brick masonry columns. Some columns were repaired with double mesh layers to see the effect of additional layer of mesh. Strength of these columns was found to vary in the range of 505 kN to 555 kN with mean being 525 kN. Increase in strength was about 125.

In case of plain specimens first visible crack appeared at about 95 to 100% of the failure loads of specimens, while for ferrocement encased specimens the first crack were observed at about 40 to 60% of the failure loads for both i.e. original and repaired ferrocement encased specimens with single and double layer of mesh. When the loads were increased after the visibility of the first crack, dial gauge readings for deformation got disrupted. The cracks were widened due to increase in loads and the snapping sound was heard. This was followed by bulging of the casing and finally the specimen stopped taking more loads. So it can be concluded that in case of ferrocement encased specimens the first crack appears much earlier than failure / final cracks. This is not so as in case of plain brick masonry columns. The crack patterns of specimens of each group are shown in the photograph. It can be seen that cracks are mostly vertical. Finally it can be concluded that there is considerable strength increase due to ferrocement encasement for both original and repaired specimens. Increase of strength increases with respect to number of mesh layers and proper placing of mesh. Ferrocement encased specimens take more loads than plain specimens while maximum strain values are nearly same. So it can be concluded that ferrocement encasement provides strength increase and ductility to the plain brick masonry columns.

Table 4.1: Experimental strength of plain and repaired specimens

Type of specimen		Specimen with single layer of mesh			Specimen with double layer of mesh			
		I	II	III	IV	V	VI	VII
Plain specimen	Strength (kN)	225	205	294	215	261	232	203
	Elasticity Modulus (E) N/mm^2	3125	3290	2875	2869	2500	2750	2918
Repaired specimen	Strength (kN)	463	491	521	507	512	528	554
	Elasticity Modulus (E)	4018	5165	4732	4818	4690	40909	4328
Ratio of (II)/(I)	Strength (kN)	2.05	2.18	1.77	2.35	1.96	2.27	2.72

Table 4.2: Comparison of theoretical and experimental failure loads of retrofitted specimens (single mesh)

Specimen	Mean Column Strength (I)	Strength increase due to		Total (I+II+III) (Theoretical)	Experimental	Ratio (Exp./Theo)	Elastic Modulus (E) N/mm^2
		Confinement (Theoretical) (II)	Area increase (Theoretical) (III)				
I	233.5	51	220	504.5	486	0.96	4417
II					507	1.00	3750
III					491	0.97	5119
Mean	233.5				495	0.97	4428

Table 4.3: Comparison of theoretical and experimental failure loads of retrofitted specimens (double mesh)

Specimen	Mean Column Strength (I)	Strength increase due to		Total (I+II+III) (Theoretical)	Experimental	Ratio (Exp./Theo)	Elastic Modulus (E) N/mm^2
		Confinement (Theoretical) (II)	Area increase (Theoretical) (III)				
I II III	233.5	100	220	553.5	568 528 539	1.02 0.95 0.97	4500 4490 3818
Mean	233.5				545	0.98	4256

Table 4.4: Mean strength increase due to encasement of various types of specimens

Specimens	No. of mesh layers	Mean failure load (kN)	Elastic modulus (E) in N/mm^2
Plain specimens	_	233.5	2903
Repaired specimens	1	491	4638
	2	525	4481
Retrofitted specimens	1	495	4428
	2	545	4256

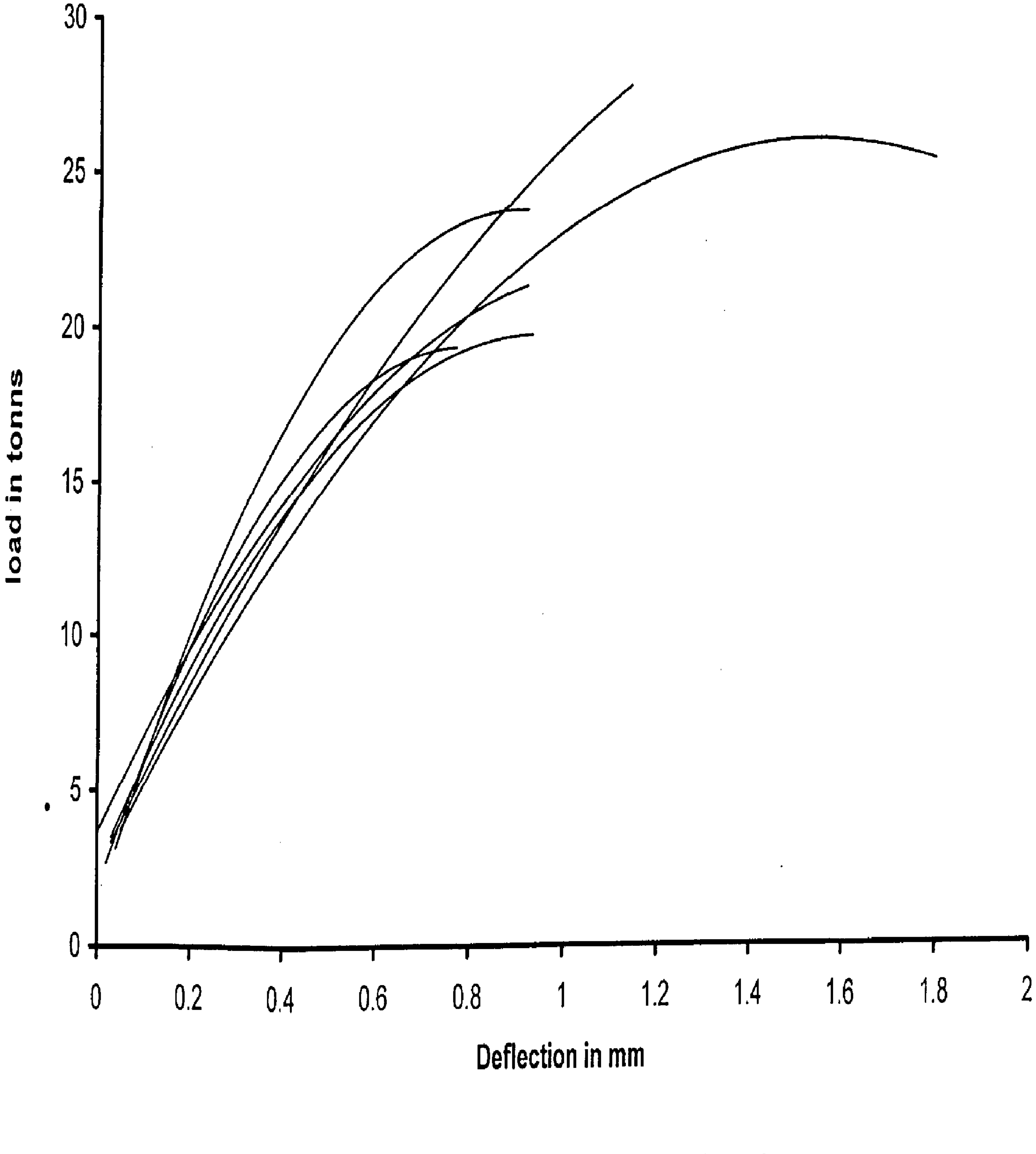


Fig 4.1 Load Vs Deflection curve for plain specimens

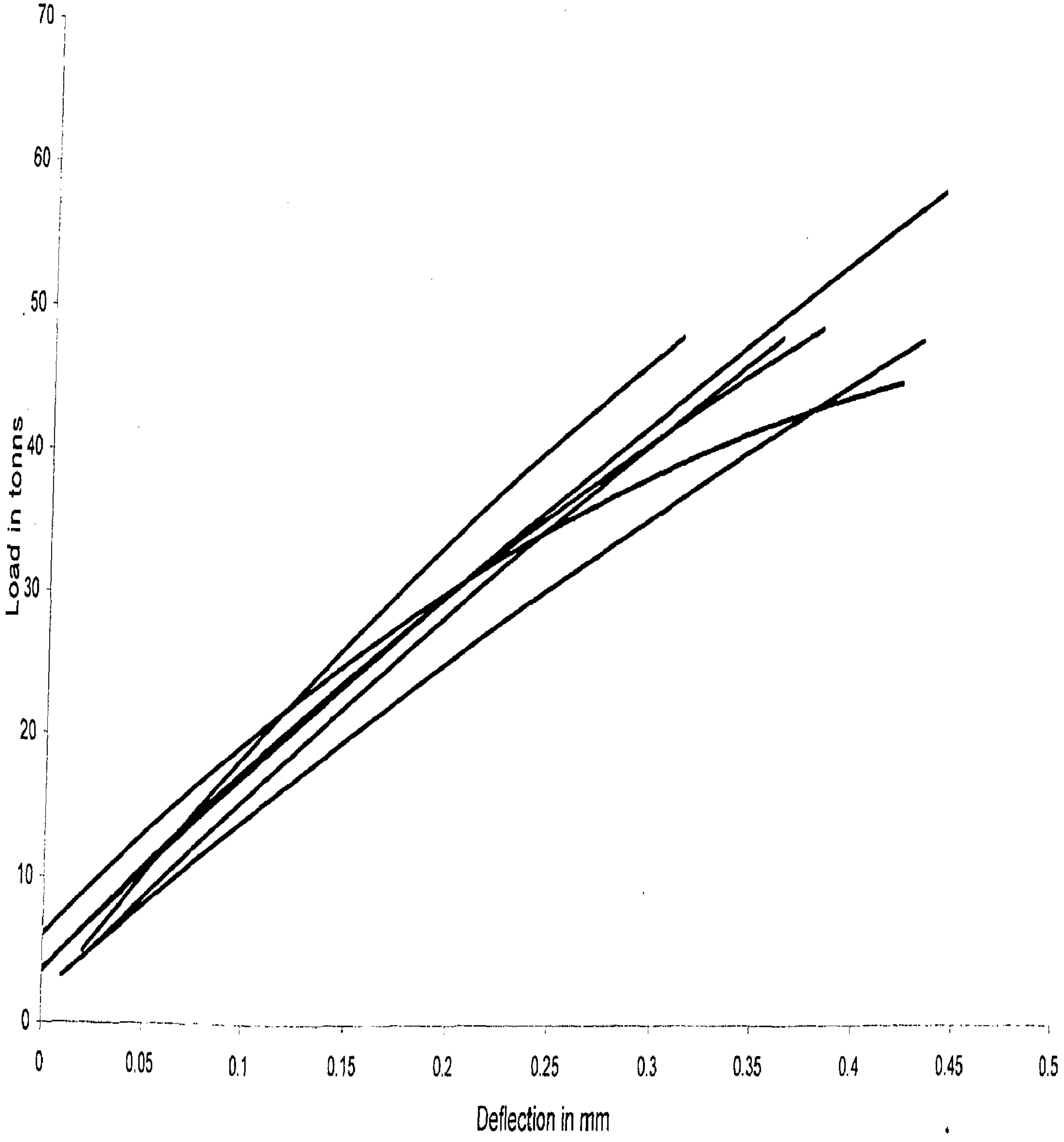


Fig 4.2 Load vs Deflection curve for retrofitted specimens

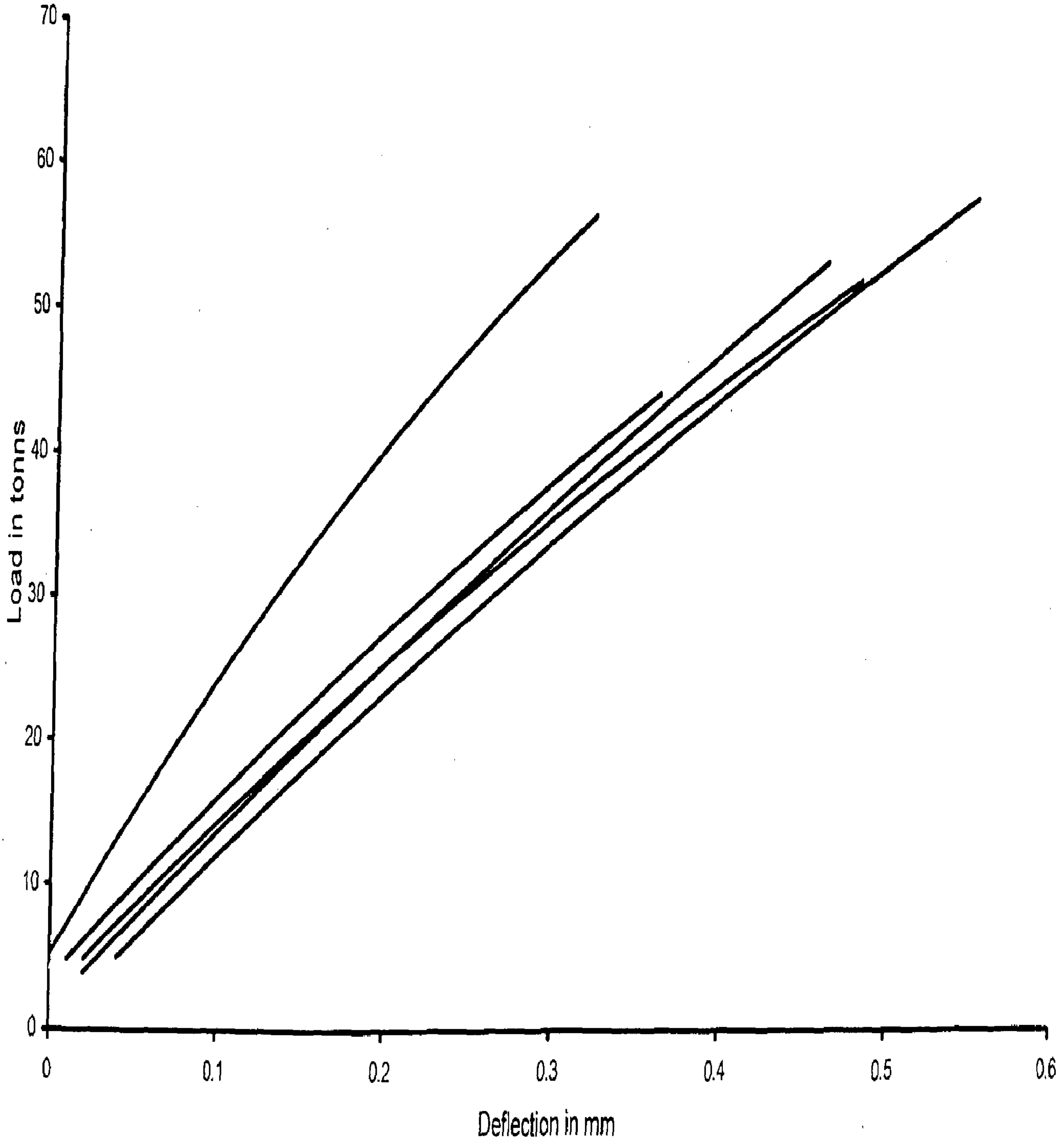


Fig 4.3 Load vs Deflection curves for Repaired specimens

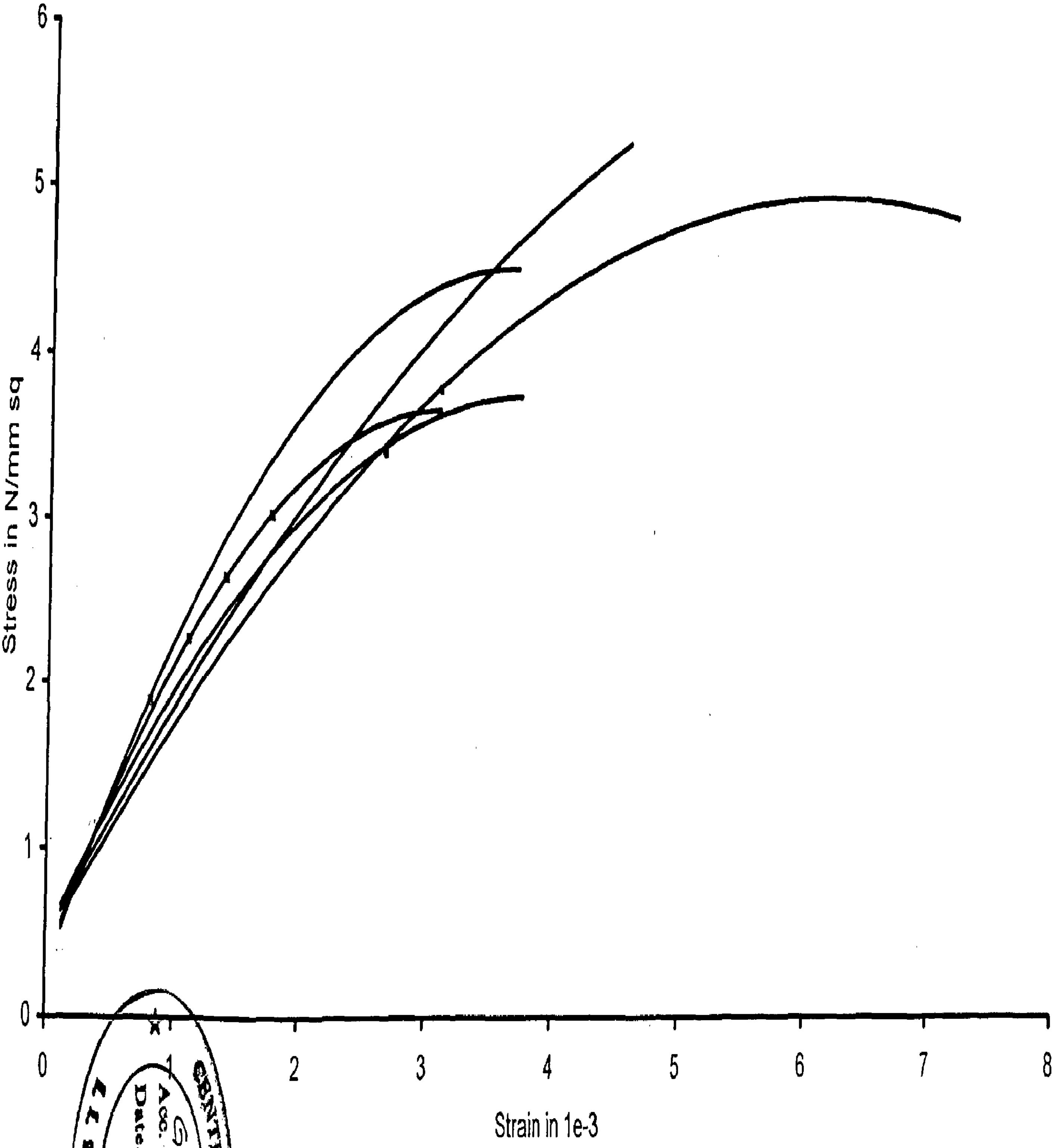


Fig 4.4 Stress vs Strain curve for plain specimens

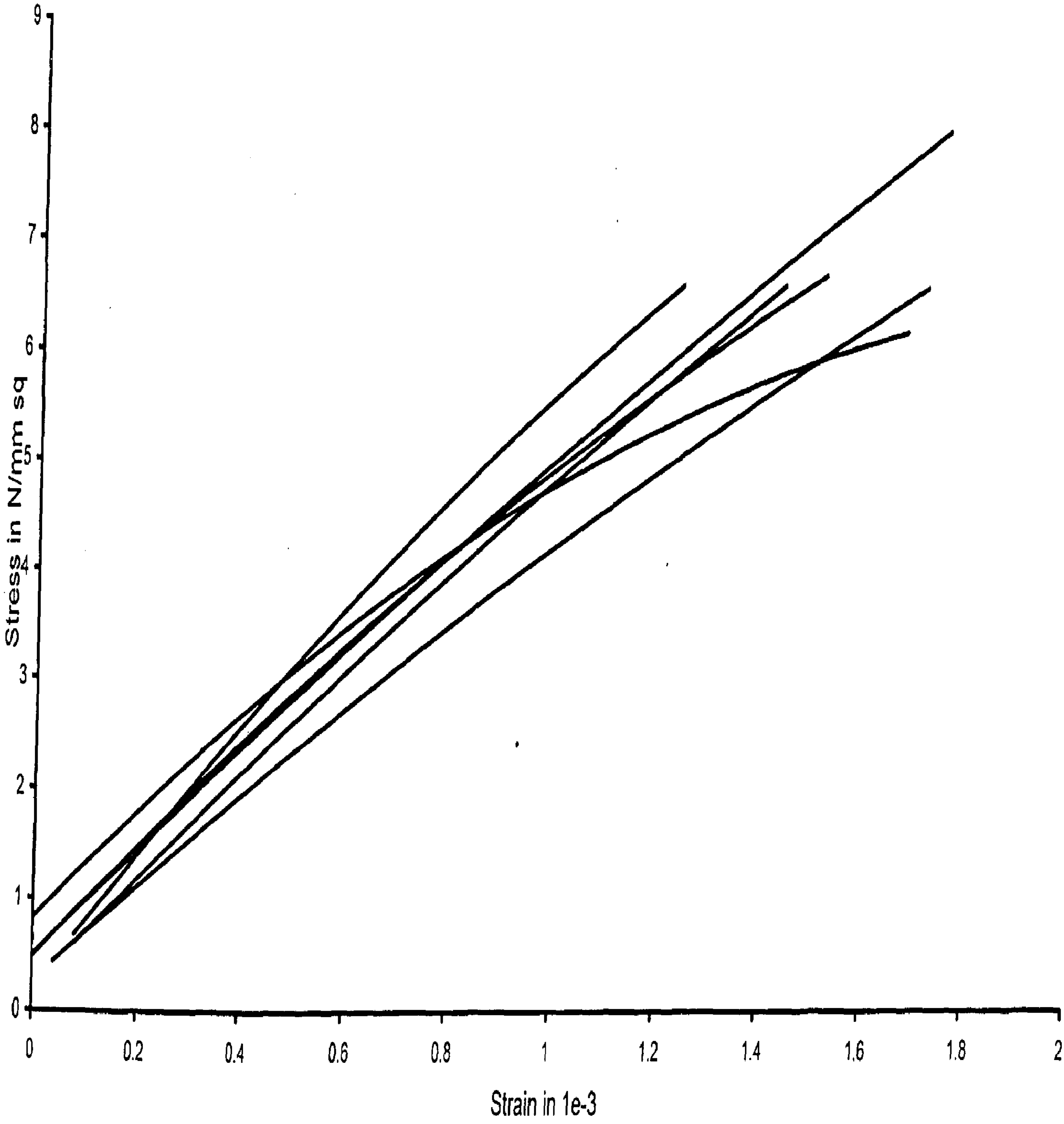


Fig 4.5 Stress vs Strain curve for Retrofitted specimens

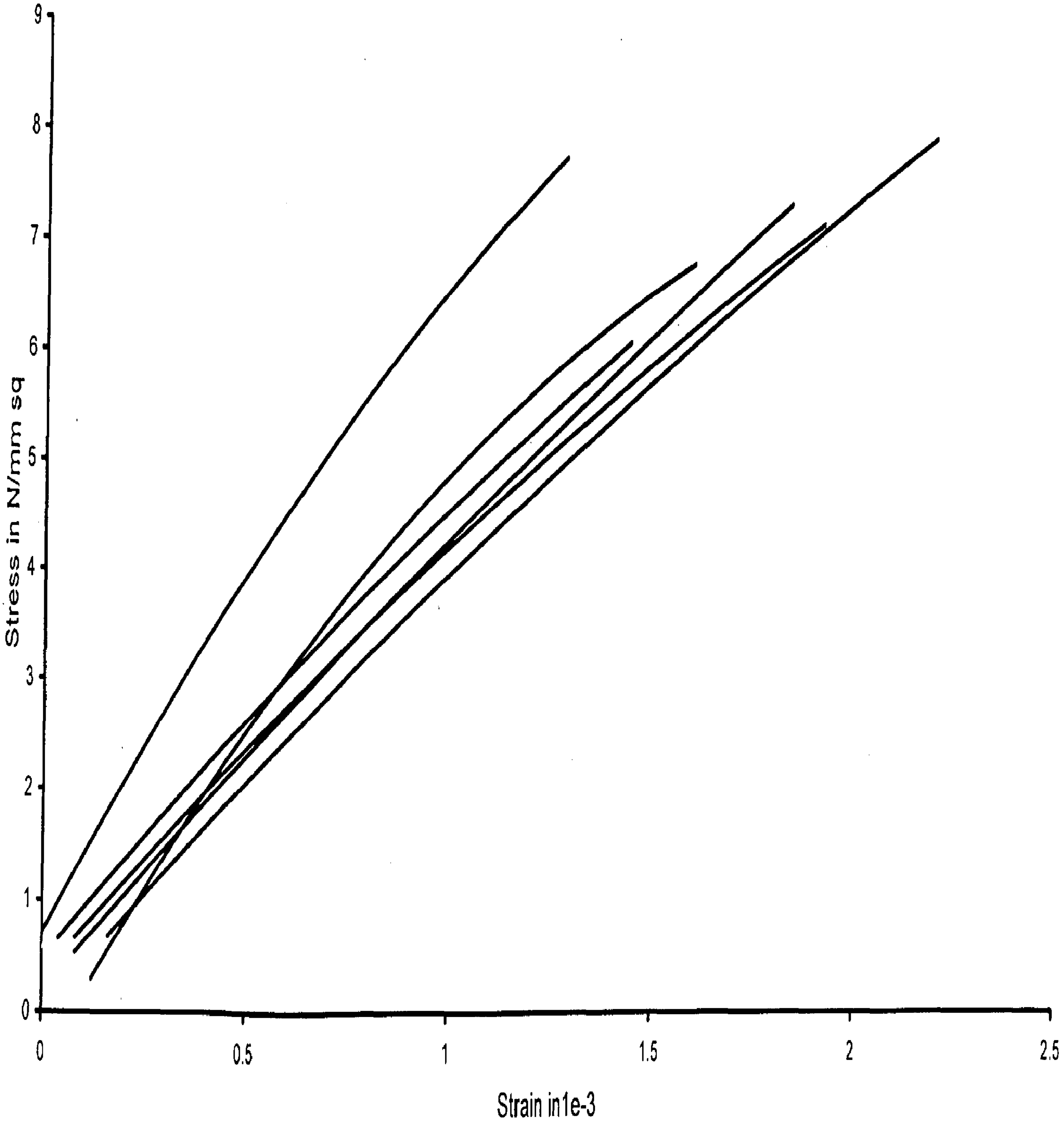


Fig 4.6 Stress vs Strain curves for Repaired specimens

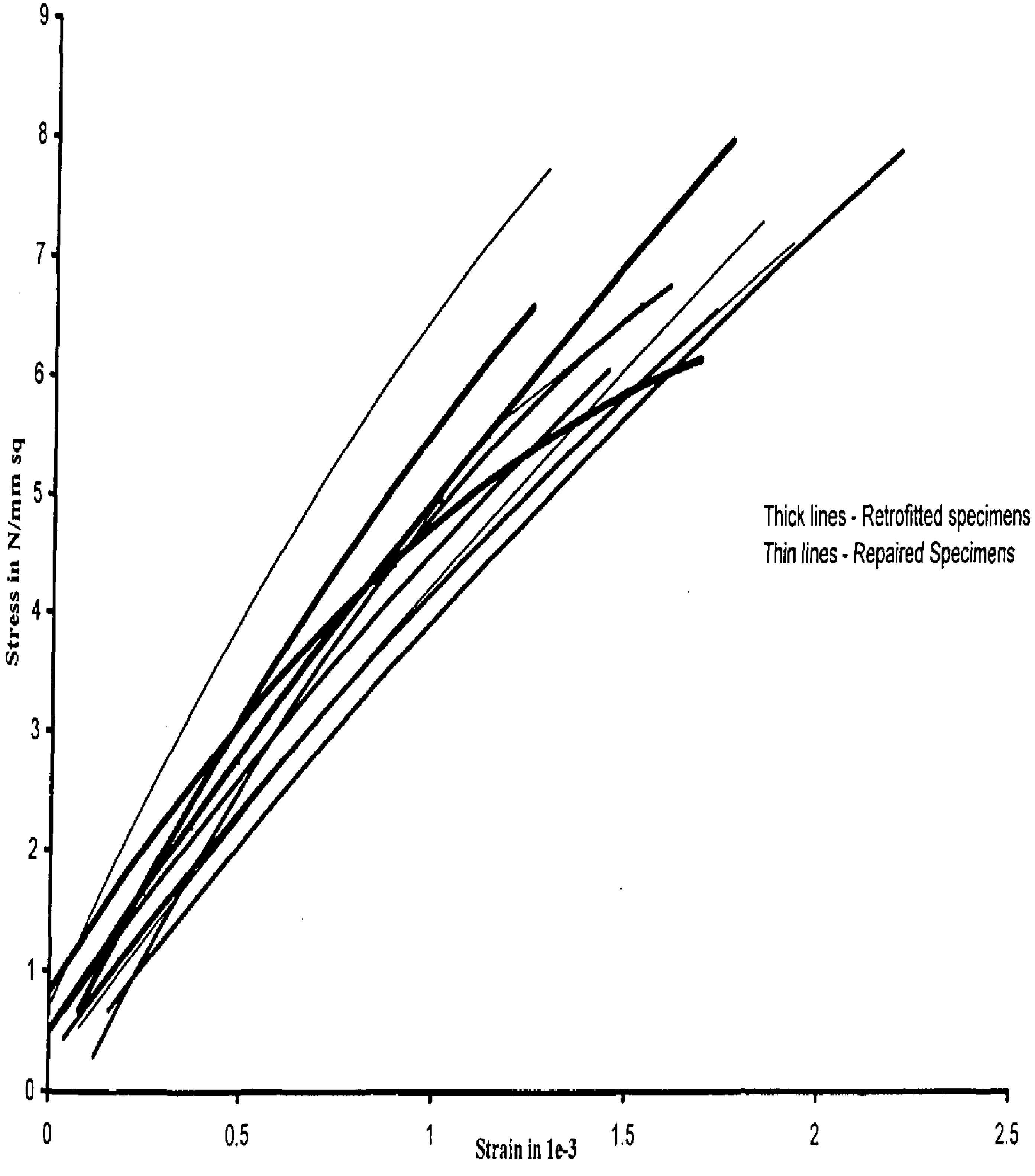
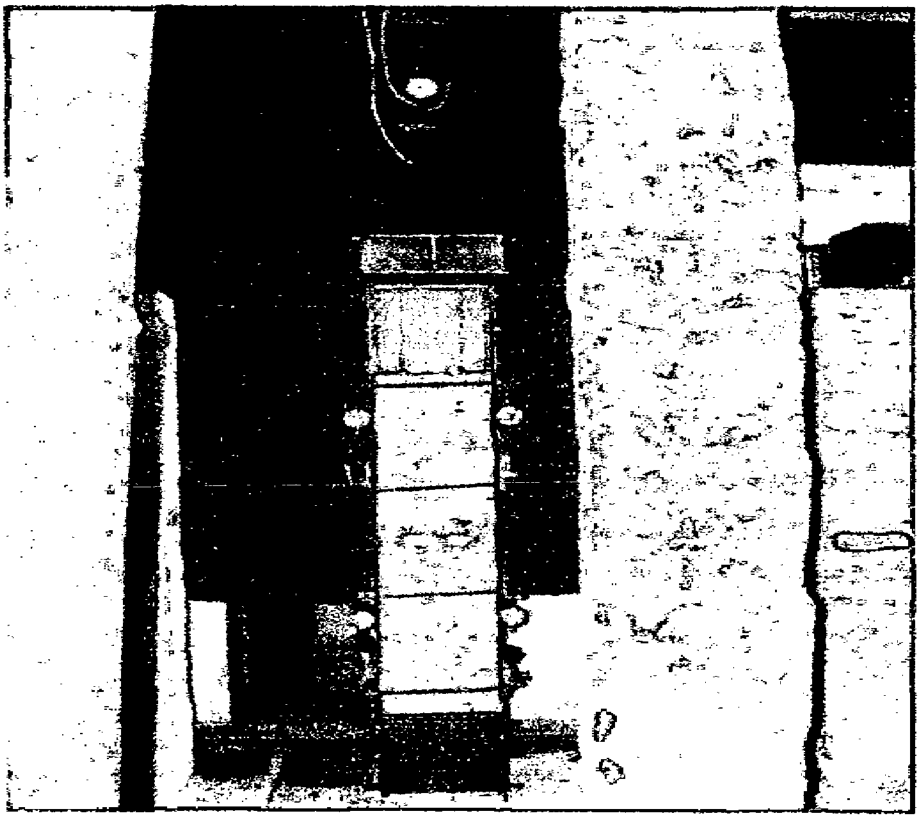


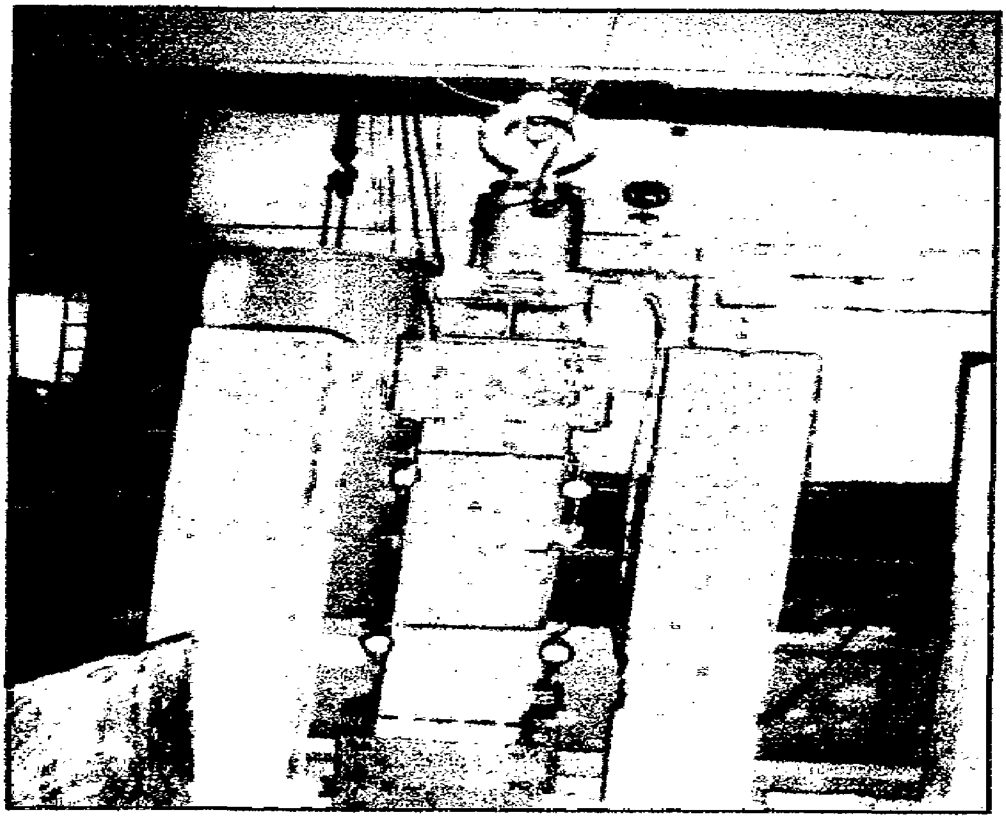
Fig 4.7 Stress strain curve for repaired and rettrofitted specimens

P.1 Plain brick masonry columns ready for testing



P.2 Test setup of plain brick masonry columns

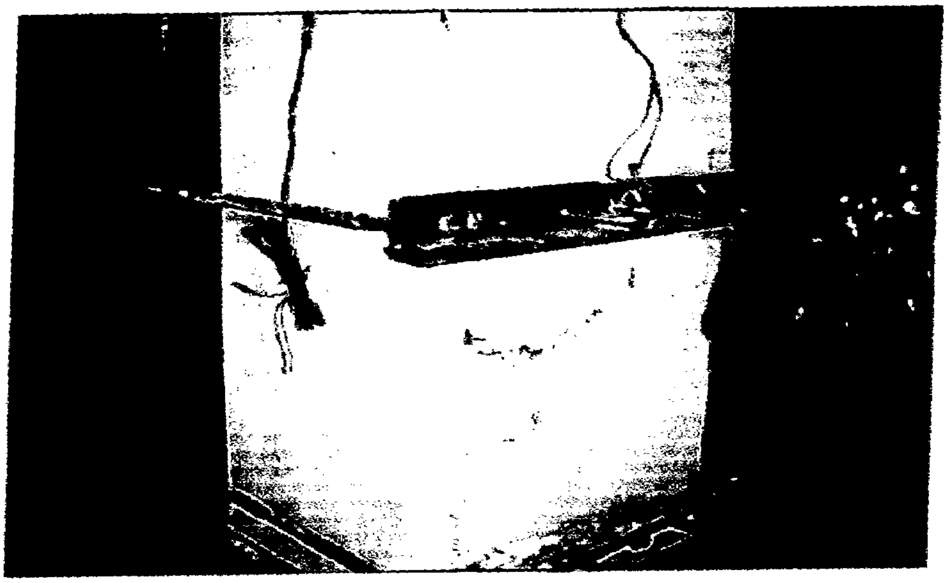
P.3 Ferrocement Encased specimens



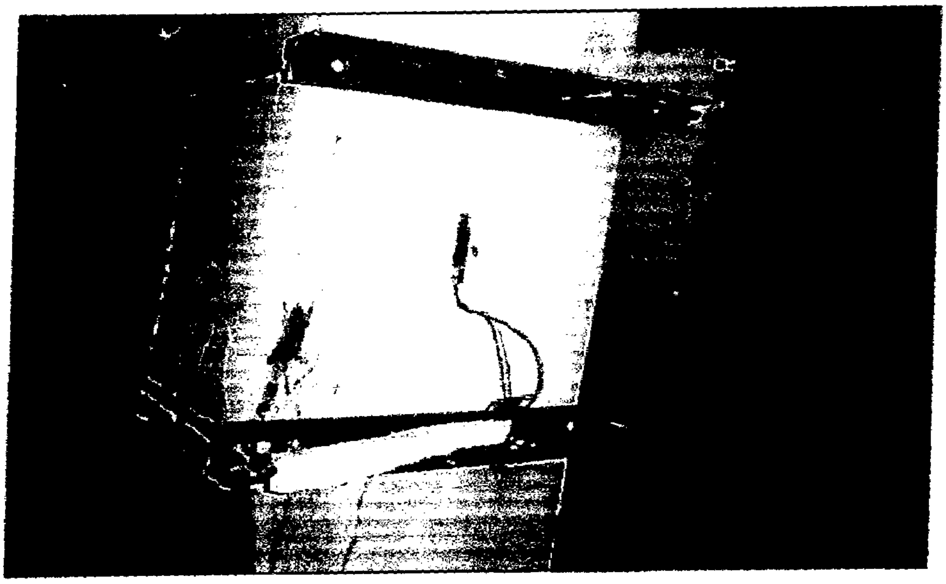
P.4 Test for testing ferrocement encased column

P.5 Appearance of first crack in plain column

P.6 Failed column before the stage of collapse



P.7 Splitting of mortar layer



P.8 Failure of wrapped specimen

CONCLUSION AND FUTURE SCOPE

5.1 CONCLUSION:

On the basis of this experimental investigation and discussion the following conclusions are drawn:

1. Ferrocement encasement of short unreinforced brick masonry columns is found to be very effective in increasing the strength; hence it can be used for strengthening new construction work and for retrofitting.
2. Ferrocement has shown to be highly effective in restoring the strength of damaged brick masonry pillars. Hence, it can be used to repair column damaged due to various causes as long as the column has not collapsed.
3. The confinement formulae of concrete used for prediction of strength increase of masonry were approximately valid. However for accurate prediction, confinement behavior of masonry needs to be examined extensively.
4. There is a high variation in the value of elastic modulus of brick masonry as many authors says.
5. Ultimate failure of plain brick masonry columns occur very shortly after appearance of first visible crack, while that of ferrocement encased columns occurs much after the first visible crack. So it can be concluded that ferrocement casing takes initial axial compressive loads and fails before the core fails.
6. On the basis of above conclusion, design of confined brick masonry columns can be done with greater confidence. However testing for other conditions is needed for proposing design guidelines.

7. The strength increase due to lateral confinement is also true for the height to width ratio of 6.0 as investigated in the present study.

5.2 FUTURE SCOPE

Some significant conclusions have been drawn above, which will be of help in strengthing and retrofitting of plain masonry columns. However from the review in chapter two is clear that experimental investigation on confinement of brick masonry are extremely limited. Hence it is specifically necessary to investigate the confinement behavior of brick masonry for the following:

1. The value of strength increase factor k_1 has been adopted as 4, the value used in case of concrete. Possibly this factor may have a different value for brick masonry. This needs experimental investigation preferably using circular brick masonry pillars.
2. The present test covered short columns and results can be extrapolated to longer specimens as in case of concrete. However it would be better to conduct test on brick masonry columns of about 3 meter height which would be the normal height used in practice.
3. Behavior of reinforced brick masonry under confinement needs to be examine experimentally for axial as well as eccentric loads.

APPENDIX

Results of strength increase are given in table 4.2 and 4.3. Sample calculations are given in this Appendix to explain the procedure for assessing the theoretical strength of original ferrocement encased specimens. The strength of encased column is the sum of strength pf plain brick masonry column and increase in strength due to increase in cross sectional area and confinement by wire mesh. Here the strength of plain masonry column is taken as mean column strength of plain brick masonry columns.

In order to illustrate the procedure for strength increase of original encased column, two example of one mesh layer and two mesh layers columns are considered below:

A) *SAMPLE CALCULATION FOR ORIGINAL ENCASED COLUMN WITH SINGLE MESH LAYER*

Compressive strength of mortar (1:2.5) = 11.00 Mpa

Mean tested strength = 233.5 kN

As the strength of confined masonry is given by eq.(2.12)

$f_{mc} = f_m + k_1 \cdot C_e \cdot \sigma_L \cdot d_m^2$

Uniform confining stress eq.(2.10)

$\sigma_L = 2\ nml.wyl / S_p \cdot d_m$

$= 2 \times 1 \times 266.0 / 9.35 \times 250 = 0.228$

$\sigma_m = 233.5 \times 1000 / (230)^2 = 4.41\ N/mm^2$

$\sigma_L / \sigma_m = 0.051 \rightarrow C_e = 0.89$

Increase in strength due to confinement:

$= k_l \times C_e \times \sigma_L \times d_m^2$

$= 4.0 \times 0.89 \times 0.228 \times (250)^2 = 50.72$ kN ≈ 51 kN

Increase in strength due to area increase:

= Increase in area x mortar strength

$= 11.00\ (270^2 - 230^2) = 220$ kN

Total increase in strength = 271 kN

Theoretical failure load = 233.5 + 271 = 504.5 kN

B) *SAMPLE CALCULATION FOR ORIGINAL ENCASED COLUMN WITH DOUBLE MESH LAYER*

No. of mesh layers = 2

$\sigma_L = 2\ \text{nml.wyl} / S_p\ .\ d_m$

$= 2 \times 2 \times 266 / 9.35 \times 260 = 0.437\ \text{N/ mm}^2$

$\sigma_m = 233.5 \times 1000 / (230)^2 = 4.41\ \text{N/mm}^2$

$\sigma_L / \sigma_m = 0.099 \rightarrow C_e = 0.845$

Increase in strength due to confinement:

$= k_l \times C_e \times \sigma_L \times d_m^2$

$= 4.0 \times 0.845 \times 0.437 \times (260)^2 = 99.84$ kN ≈ 100 kN

Increase in strength due to area increase:

= Increase in area x mortar strength

$= 11.00\ (270^2 - 230^2) = 220$ kN

Total increase in strength = 320 kN

Theoretical failure load = 233.5 + 320 = 553.5 kN

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