BEHAVIOUR OF FERROCEMENT ENCASED BRICK MASONRY COLUMNS

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree

of

MASTER OF ENGINEERING

in

CIVIL ENGINEERING

(With Specialization in Structural Engineering)

By

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CANDIDATE'S DECLARATION

I hereby declare that the work which is being presented in the dissertation entitled, **"BEHAVIOUR OF FERROCEMENT ENCASED BRICK MASONRY COLUMNS"** in partial fulfilment of the requirements for the award of the degree of **Master of Engineering in Civil Engineering** with specialisation in **Structural Engineering**, submitted in the Department of Civil Engineering, University of Roorkee, Roorkee, is an authentic record of my own work carried out during January, 2000 to May, 2000 under the supervision of **Dr. K.K. Singh** and **Prof. V.K. Gupta**, Professors in the Department of Civil Engineering, University of Roorkee, Roorkee, India.

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

Date :

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(Ambhore Vinayak Parashram)

CERTIFICATE

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

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(Ambhore Vnayak Parashram)

ABSTRACT

Brickwork is one of the traditional building materials, used for the construction of masonry walls, columns etc. to resist mainly compressive loads. Ferrocement encasement can be applied with advantage to brick masonry columns to strengthen new construction. The wire mesh 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 jacketting of brick masonry columns by ferrocement helps in providing a substantial strength increase as in case of concrete.

The experimental programme consist 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 specimens 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.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

INTRODUCTION

1.1 GENERAL

The common brick is one of the oldest building materials and it is extensively used for load bearing walls in low rise buildings and for partition walls in high rise buildings. 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 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 columns against external hazards. Ferrocement encasement can be applied with advantage to brick masonry columns.

Brick work is advantageous in case where plenty of clay is locally available. Also it require minimum skilled labours and lifting devices are not required as in the case of stone work, since bricks are very light as compared with stone. Also Brick is having higher fire resisting capacity than concrete or stonework. It is easy to construct connections and openings in case of brickwork than stonework.

Ferrocement is used increasingly in many types of construction, when it is advantageous over 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 pre-cracking stages.

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 construction. 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.

Encasing the brick masonry columns by ferrocement, 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 OBJECTIVES AND ORGANISATION

The objectives of this investigation are to examine theoretically and experimentally the increase in strength and ductility of ferrocement encased brick masonry columns.

Thus it was planned to cast four brick masonry columns of square cross section (22.5 cm x 22.5 cm) and height of 150 cm each. After casting these two of them were encased with double layer of wire mesh. All specimens were cured for 28 days and tested upto failure load.

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

Chapter 1 presents an introduction to ferrocement encased brick masonry columns and objectives and parameter of the present study.

Chapter 2 presents review of the literature.

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

Chapter 4 presents results of the tests, theoretical analysis, cost comparison and discussion of results.

Chapter 5 gives the various conclusions based on the present study and scope for the future work.

cement. In testing of mortar for the strength, the most important is compressive strength followed by the tensile bond strength. The compressive strength is measured by 70.71 mm cubes 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 Behaviour of Brickwork in Compression

Brickwork is a composite material with brick as a building unit and mortar as a jointing material. Properties of brickwork can be approximately deduced from that of its constituents. Fig. 2.1 shows a graph of brick strength against brick work strength tested at 28 days. Test results of full bricks tested in direct compression [2] show that there is wide scatter in their values. This is because the compressive strength varies enormously between batches from the same kiln and even of the individual bricks from the same burning.

Test results of Muliyar [11] carried out on brick masonry prisms show that there is a considerable variation in the crushing strength. It is obvious because of the variation in the properties of its constituents.

Thus it is clear that there is considerable scatter in the strength of bricks as well as brick masonry. Due to this reason a high factor of safety is taken for the design of brick masonry. IS:1905-1987 recommends 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 brickwork walls have produced a number of empirical formulae relating brick, mortar and brickwork strength.

Bhandari (1982) has revived 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 of these expressions are :

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

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

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

(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)

2.1.4 Failure Mechanism

Failure in brickwork under axial compression is normally by vertical splitting due to horizontal tension in the bricks [9]. Fig. 2.2 shows a typical failure pattern in a brickwork wall. The reason for this type of failure is mainly due to the widely different strain characteristics of the bricks and mortar joints. The mortar is less rigid than the bricks and under load its tendency is to spread laterally to a greater extent than the brick. Due to bond action, the mortar is put into 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

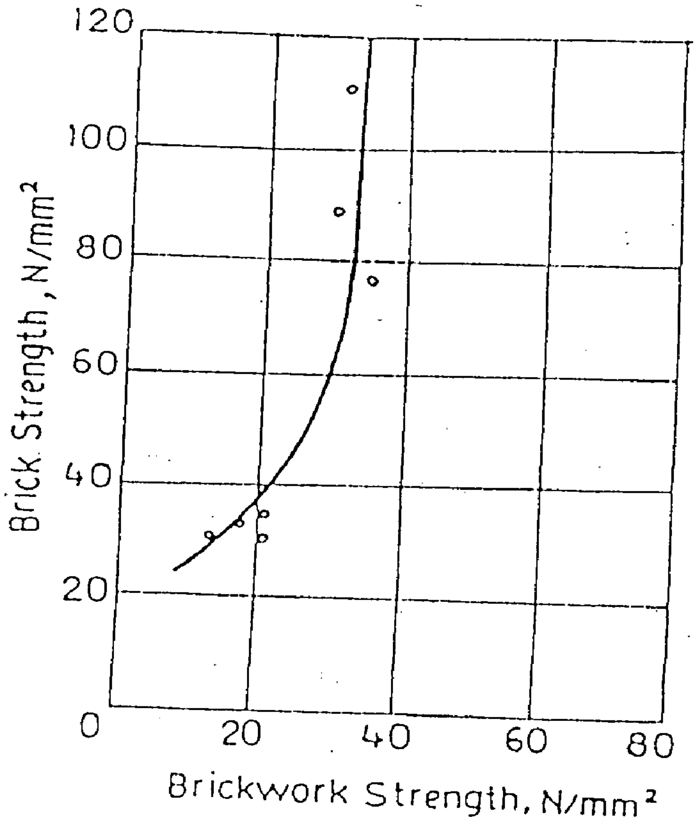

Fig.2.1 Graph showing brick strength against brickwork strength.

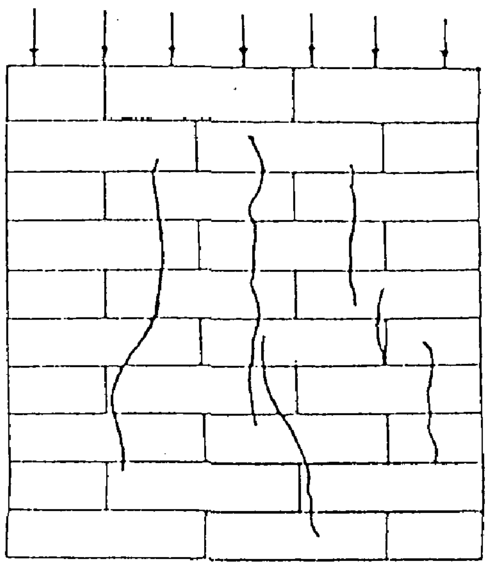

Fig.2.2 Typical failure pattern in a brickwork wall.

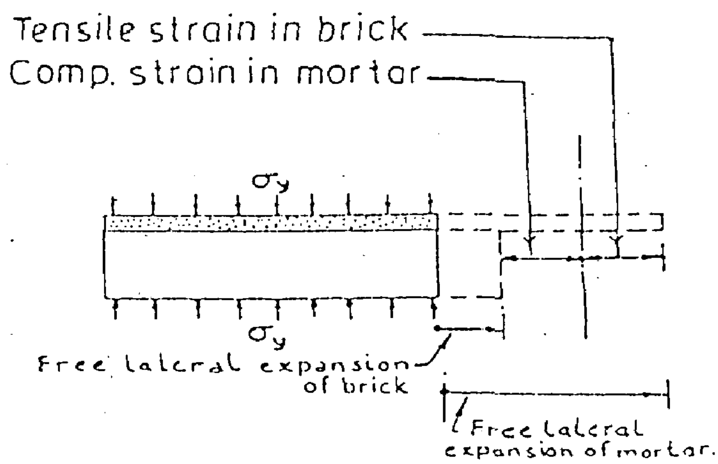

Fig.2.3 Lateral expansion of brick and mortar under vertical stress.

in the brickwork occurs when the tensile stress in the brick reaches its ultimate tensile strength.

2.2 FERROCEMENT

2.2.1 Definition

Ferrocement is a 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 construction material is gaining acceptance in different applications namely housing, watersupply and sanitation, agriculture and marine uses. This material which is a special form of reinforced concrete, exhibits a behaviour so different from conventional reinforced concrete in performance, strength and potential application that it must be classified as separate material.

The American Concrete Institute (ACI) committee 549 on ferrocement [7] defined it as : "Ferrocement is a type of thin wall reinforced concrete construction where usually a hydraulic cement is reinforced with layers of continuous and relatively small diameter mesh. Mesh may be made of metallic material or other suitable material".

The basic idea behind this material is that concrete can undergo large strains in the neighbourhood of the reinforcement, and magnitude of the strain 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 Advantages of Ferrocement

Advantages of ferrocement are listed below :

1. Availability of basic raw material
2. Ability to cast into any shape
3. Speedy construction without any heavy machinery
4. Low cost of construction
5. Reduced self weight of element
6. High tensile strength
7. Ease in repairing
8. Corrosion resistant
9. Crack resistant
10. Fire resistant
11. High toughness

2.2.3 Applications of Ferrocement

Various applications of ferrocement are listed in the Table 2.1.

Table 2.1 Applications of Ferrocement

Area	Application
Housing	Domes, wall panels, encased columns, corrugated sheets, folded plates etc.
Marine	Fishing boats, docks, buoys, coracles floating dry docks, floating brakewaters, floating shelters etc.
Rural energy	Biogas digesters and holders, solar applications, energy plant components.
Watersupply and Sanitation	Water storage tanks, prefabricated modules, ferrocement septic and sedimentation tanks.
Agricultural	Irrigation channels, storage tank for grains, canal lining.
Repair and Strengthening	Repairing beams, columns etc., damaged due to fire, corrosion etc.
Miscellaneous	Cyclone resistant houses and shelters, water proofing treatment, chimney and flumes.

2.2.4 Constituent Materials

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

Cement

Various types of cement can be uses in ferrocement are : Type I Portland cement can be use except in sulphate attack. Type II Portland cement (Portland Pozzolana) gives low early but high later strength. Type III (Rapid Hardening Cement) is used when high early strength desired. The cement to be used, should be fresh, free from foreign matters and of uniform consistency.

Fine Aggregate

Fine aggregate should confirm to ASTM standard C-33 and C-40 and IS:383-1970 grading. 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 [5], 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. Grading limits of fine aggregates are given below :

Table 2.2 Grading limits of fine aggregates IS:383-1970

IS Sieve Designation	Percentage passing by weight for grading zones			
	I	II	III	IV
10 mm	100	100	100	100
4.75 mm	90-100	90-100	90-100	95-100
2.36 mm	60-95	75-100	85-100	95-100
1.18 mm	30-70	55-90	75-100	90-100
600 micron	15-34	35-59	60-79	80-100
300 micron	5-20	8-30	12-40	15-50
150 micron	0-10	0-10	0-10	0-15

Water

Water used in the mixing should be free from impurities like clay, loam, soluble salts etc. which lead to deterioration of mortar. In general, potable water is fit for mixing or for curing of ferrocement structures.

Admixtures

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

(i) Water reducing admixtures

(ii) Retarding admixtures

(iii) 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.

Reinforcing Mesh

Wire mesh is an 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 [13]. Fig. 2.4 shows various types of wire meshes used in ferrocement. Currently used wire meshes are :

(a) Welded mesh

(b) Woven mesh

(c) Chain mesh

(d) Chicken mesh

(e) Expanded metal mesh

(f) Waston mesh

(a) Welded Mesh

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

(b) Woven Mesh

This mesh is generally 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 and 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.

(c) Chain Mesh

This mesh is formed by woving wires in such a manner to form a chain. In this mesh there are no transverse wires.

(d) Chicken Mesh

This mesh is also known as hexagonal wire mesh and is commonly used. It is fabricated from cold drawn wires, 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.

(e) Expanded Metal Mesh

This mesh is form by cutting a thin sheet of metal and expanded to form diamond shaped openings. It is not as strong as woven mesh, but from cost to strength ratio, it is advantageous. There is a limit to the size and weight of expanded metal. This mesh is also known as metal plasterer's lath.

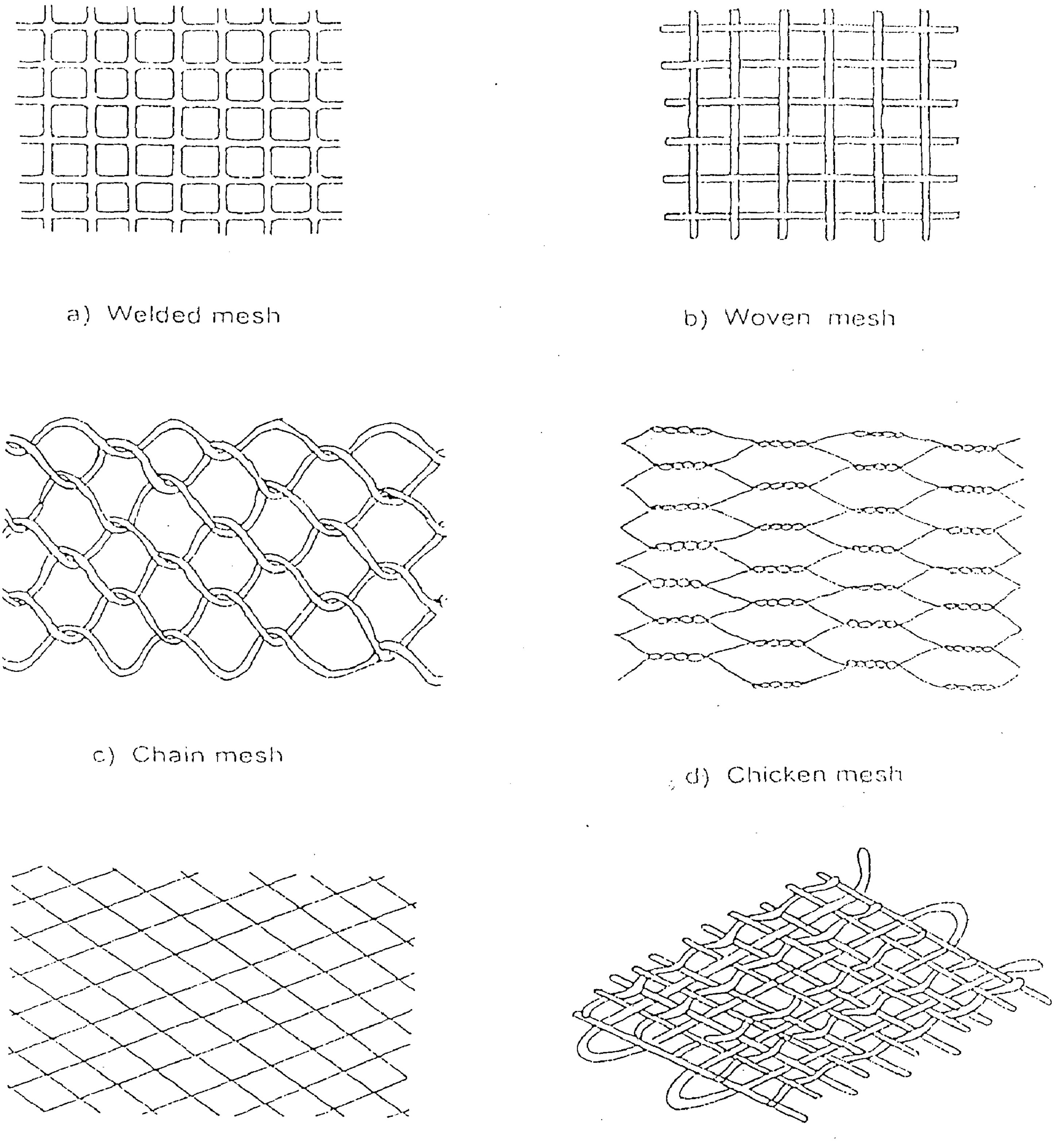

Fig.2.4 Different types of mesh.

(f) Waston Mesh

This is a new type of mesh, which has been developed in New Zealand. This mesh consists of straight high tensile wires and transverse crimped wires, which holds 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 is straight without twists, crimps, pressing, punching and welds. This enables complete flexibility and freedom of shape.

2.2.5 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 enable the matrix to assume the ductile characteristics of reinforcement. The strength always give 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 in tension and compression are described below :

Tension

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

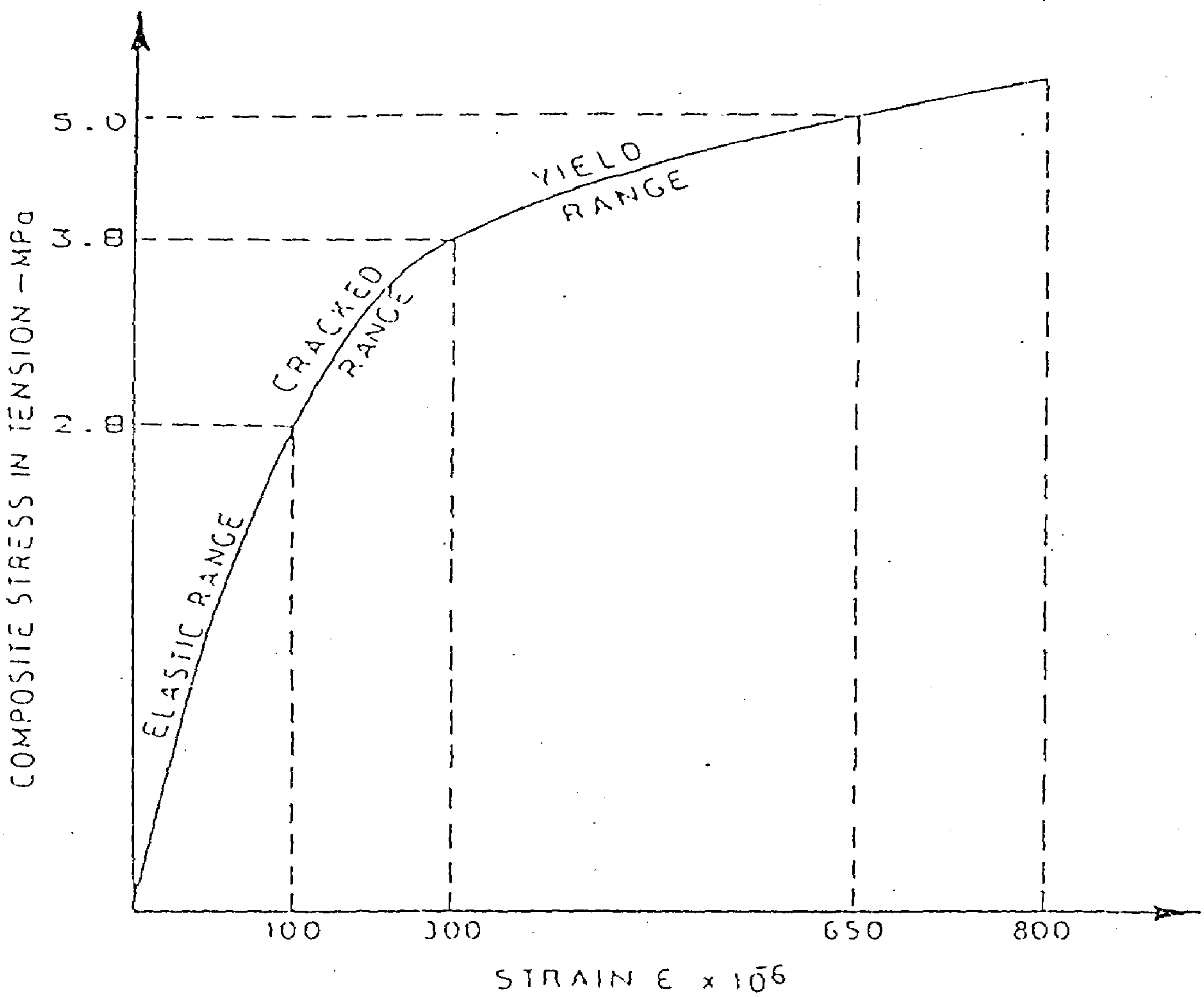

Fig. 2.5 Tensile stress-strain curve of ferrocement.

A brief description of tensile stress-strain curve of ferrocement at different levels is given below :

(a) 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.

(b) 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 have been observed to be a function of the specific surface of the reinforcement [21].

(c) Yield range

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

Compression

The stress-strain curve for ferrocement in compression is initially linear but becomes markedly curvilinear at a later stage. The curve can be idealised 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 [17].

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 behaviour 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 behaviour of an element loaded upto failure under flexure are shown in Fig. 2.7. These stages may be identified as the uncracked, cracked and yield stages. The stress 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 idealised bilinear stress-strain curve, or tri-linear stress-strain curve as the case may be, i.e. Figs. 2.5, 2.6, 2.7.

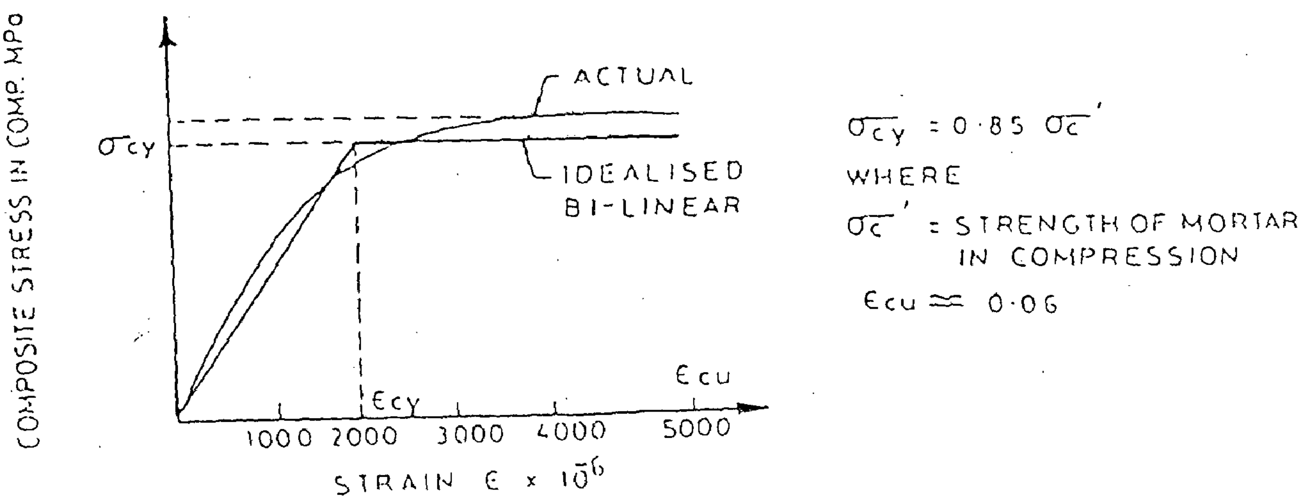

Fig.2.6 Compressive stress-strain curve of ferrocement.

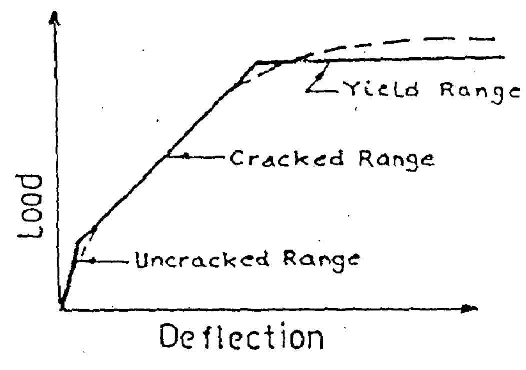

Fig.2.7 Typical load deflection curve for ferrocement in bending.

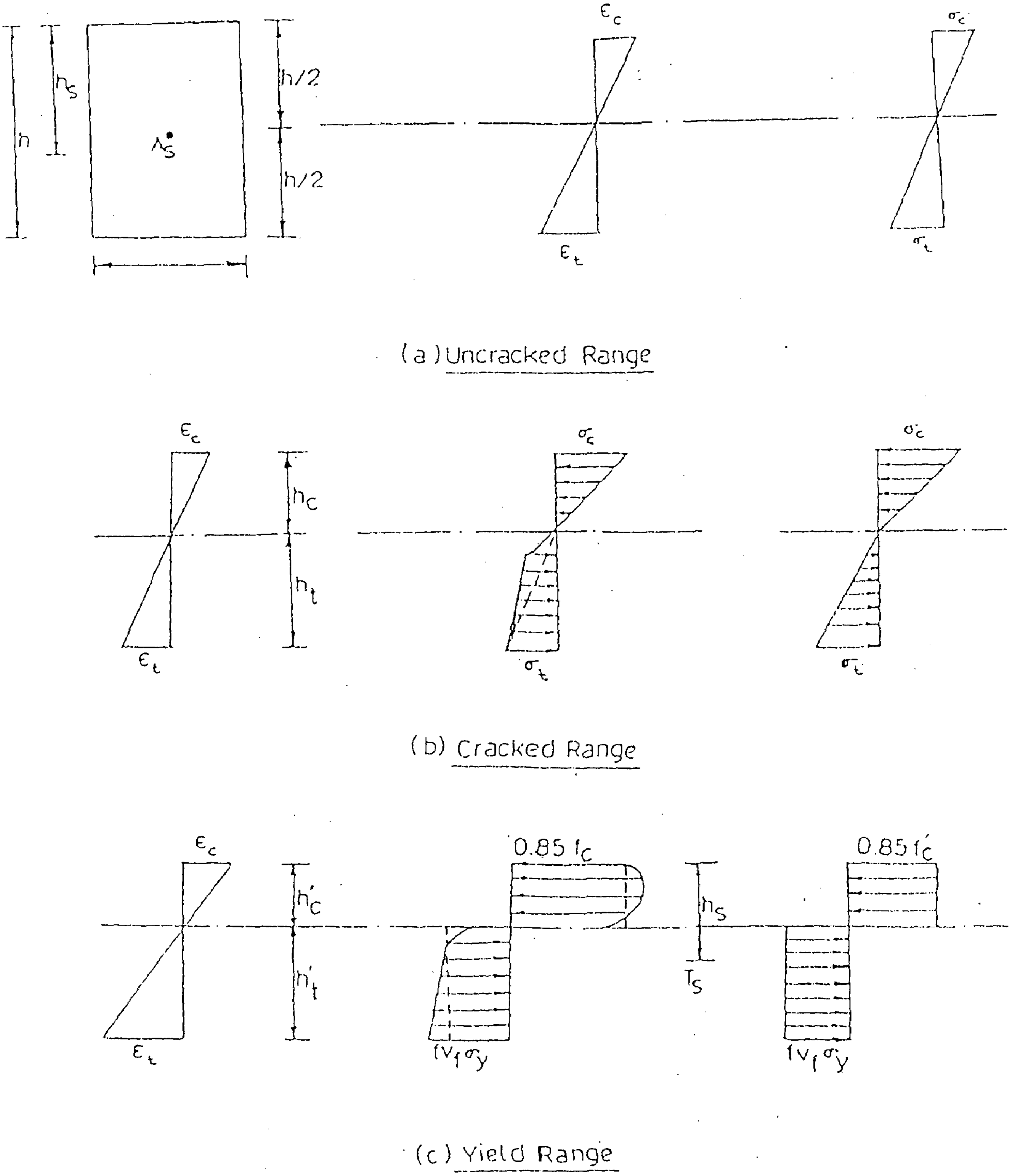

Fig.2.8 Stress strain distribution in ferrocement section.

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 poission'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-strain 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) [18] has used ferrocement for seismic retrofitting of masonry walls. Here due to increased cross sectional area and tensile strength of mesh wires, there can be increase in strength and ductility of masonry walls.

Priestley and Elder (1983) [16] report their test on grouted concrete block 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 at 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 result 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 plates in the mortar beds dramatically changes the physical appearance of the failure mechanism. Vertical splitting of block is virtually eliminated.

Singh et al. (1988) [20] have tested square brick masonry columns encased in ferrocement. These tests make it clear that there is confinement of the masonry by the mesh layers present in the ferrocement. Thus, the increase in strength of the column is due to increase in cross sectional area as wells 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 is used to increase the load carrying capacity, repair of columns or to use these ferrocement encased brick masonry columns as replacement of RCC columns 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 possion's ratio effect tensile strains develop in the horizontal direction i.e. there is an increase in cross sectional dimensions by developing tensile stresses. The vertical strands develop compressive stress due to the 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 brick and the strength of mortar. This may be done either experimentally or by using a table given in the code. To obtain the permissible compressive strength the basic compressive stress is multiplied by the following factors; the stress reduction factor which takes into account slenderness ratio of the column and the eccentricity of the load, the area reduction factor for 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 codal provisions the column may be designed.

For design of ferrocement encased brick masonry columns [14] similar procedure can be followed. The main difference is that the basic compressive stress of brick masonry is increased to allow for confinement and strength increase due to increase in cross sectional area. This increased basic compressive stress may be determined experimentally or theoretically as described below.

The experimental procedure for basic compressive stress is described in appendix B of 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 at least 40 cms height 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 the compressive load. The failure stress can be corrected to correspond to a height to width ratio of 5. This is f_{mc} the strength of confined masonry. This value can now be used to either design the column or determine its strength as the case may be using procedure given in the code.

For theoretical determination of f_{bc} the confined basic compressive stress, formulation of confined concrete are of help [19]. Columns with circular section are treated differently from columns with square or rectangular section, as in case of the latter the confinement is somewhat less effective than in the circular case. Both, the circular and square sections are described below :

Circular Columns

The column section details are shown in Fig. 2.9(a) in which dimensions d, d_o, d_i, d_c, d_s are the diameters of the column, outermost mesh layer, innermost mesh layer, core and reinforcing cage respectively and d_m is the mean of d_i and d_o.

Strength of confined column

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

$$P_m = \pi (r^2 \sigma_0 + r^2_m K_1 \sigma_L) + A_{st} (Y_s - \sigma_c) \qquad (2.1)$$

Where,

r	=	radius of column
r_m	=	mean radius of column
Y_s	=	yield stress in steel wires
$\sigma_c\, \sigma_0$	=	are peak stress of confined and unconfined column
K_1	=	strength increase factor
A_{st}	=	area of reinforcement

In order to determine σ_L consider the equilibrium of the half portion of casing as shown in fig. 2.9 (a).

i.e. $2T = d_m. \sigma_L$

or $\sigma_L = 2T/d_m = T/r_m$ (2.2)

Where,

σ_L = lateral confining pressure

If N_{ml} is number of mesh layers, S_p is the spacing of mesh wires W_{yl} is the yield load of single wire of mesh, then T will be given by,

$$T = N_{m1}. W_{y1}/S_p \qquad (2.3)$$

$$\therefore \quad \sigma_L = N_{m1}. W_{y1}/(S_p. r_m) \qquad (2.4)$$

Substituting σ_L from eqn (2.4) in eqn (2.1)

$$\therefore \quad P_m = \pi (r^2 \sigma_0 + r_m K_1 N_{m1}. W_{y1}/S_p) + A_{st} (Y_s - \sigma_c) \qquad (2.5)$$

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 the equation below;

$$f_{mc} = f_m + K_1 \sigma_L \tag{2.6}$$

wherein,

K_1 = strength increase factor generally taken as 4.0

σ_L = the lateral confinement pressure

The lateral confinement pressure depends on the horizontal mesh wires and not the vertical wires. In case of chicken wire mesh or some inclined mesh the horizontal component of the yield load of wires per unit of height of section is considered.

Square Column

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 column, the outermost mesh layer, the core side and centre to centre distance between longitudinal reinforcement. Dimension d_m is mean of d_o and d_i and the resultant tensile force of the wires acts at this distance.

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

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

Here, $\sigma_L = 2T/d_m = 2N_{m1}.W_{y1} / (S_p.d_m)$ (2.7)

Strength of square confined column

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

$$P_m = d^2_0\ \sigma_0 + (d - d_0)^2\ \sigma + d^2_m.\ C_e.K_1.\ \sigma_L + A_{st}\ (Y_s - \sigma_c) \qquad (2.8)$$

Where,

d_i	=	distance between innermost layers of mesh
d_0	=	distance between outermost layers of mesh
d	=	length of one side of section
d_m	=	mean of d_i and d_o
C_e	=	confinement effectiveness coefficient varies with (σ_L/σ_0) ratio and can be obtained from graph Fig. 2.10 (b)

The derivations of square as well as rectangular sections have been given in detail in reference [20]. In case of brick masonry column, strength increase due to confinement is,

$$f_{mc} = f_m + K_1\ C_e\ \sigma_L \qquad (2.9)$$

Where, σ_L is as given by eqn (2.7) and for square section, C_e coefficient for confinement effectiveness. The derivation for this coefficient have been given in reference [20] 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 column may be designed as per codal provisions. Application of the above procedure for reinforced brick masonry columns would be valid for axial load only.

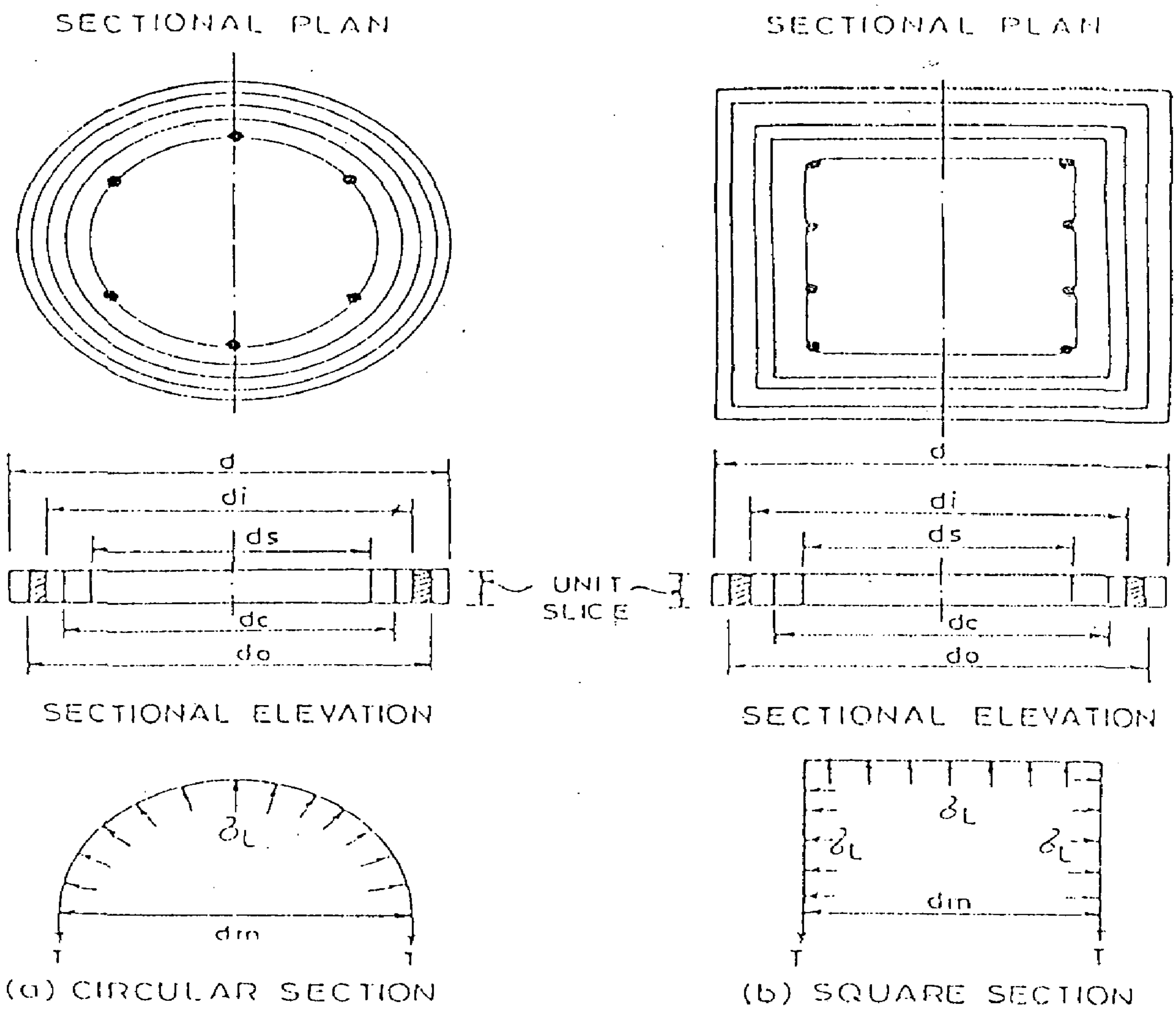

Fig.2.9 Details of square and circular column

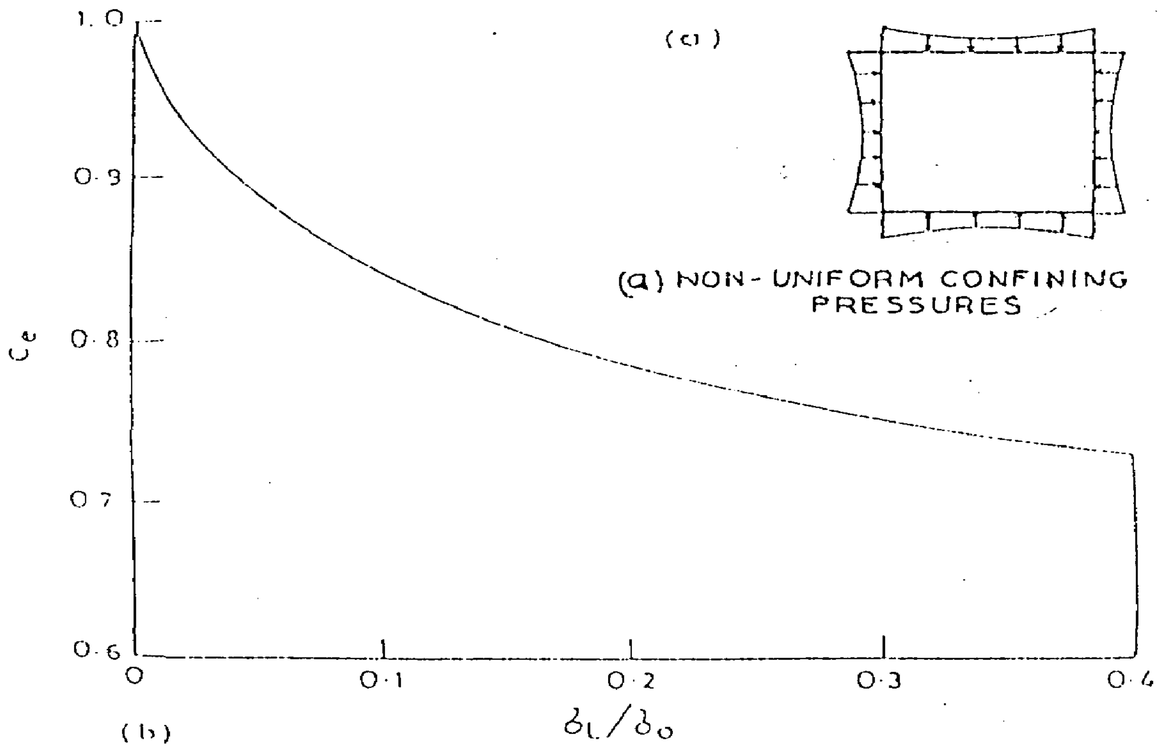

Fig.2.10 (b) Square section confinement effectiveness coefficient.

EXPERIMENTAL PROGRAMME

The main objective of this experimental investigation was to study the behaviour of ferrocement encased brick masonry columns and comparison of that with plain brick masonry columns. Also to examine, whether the jacketing of brick masonry by ferrocement helps in providing a substantial increase in strength and ductility as in the case of concrete. To study the load deformation behaviour and cracking pattern was also one of the objectives.

3.1 MATERIALS USED

Cement

Ordinary Portland Cement (C-53) was used throughout this experimental investigation. Various tests were conducted on the cement for determining its physical properties. The properties of cement such as fineness, specific gravity, standard consistancy, setting times, soundness and compressive strength are deduced experimentally and listed in table 3.1, along with standard values recommended by relevant code.

Table 3.1 : Properties of Cement Used

S.N.	Properties	Test Results	IS:8112-1989
1.	Fineness	7.5%	<10%
2.	Specific Gravity	3.2	3.14
3.	Standard Consistency	28%	30% (approx.)
4.	Setting time		
	Initial	42 min.	>30 min.
	Final	150 min.	<600 min
5.	Soundness	2.5 mm	<10 mm
6.	Compressive strength		
	3 days	31 MPa	>23 MPa
	7 days	45 MPa	>33 MPa
	28 days	58 MPa	>53 MPa

Fine Aggregate

Sieve analysis was carried out on used fine aggregate and grading observed is presented in tabular form.

Table 3.2 : Grading of Fine Aggregate Used

I.S. Sieve Designation	Wt. Retained (gms)	% Wt. Retained	% Wt. Passing
10mm	0.00	0.0	100
4.75mm	0.00	0.0	100
2.36mm	0.00	0.0	100
1.18mm	40	8	92
600 micron	70	14	78
300 micron	150	30	48
150 micron	130	26	22
<150 micron	110	22	0

$$\text{Fineness Modulus} = \frac{\sum \text{cumulative wt. retained}}{100} = 1.60$$

Mortar and Bricks

Mix proportion for mortar for brickwork was 1:4 (cement : sand) and that for ferrocement was 1:2.5, with w/c ratio of 0.55. Three cubes for each type of mortar were cast to determine strength at 28 days. Results obtained are presented in the tabular form.

Table 3.3 : Compressive Strength of Bricks and Mortar

S.N.	Specimen	Compressive Strength, MPa	Mean Strength, MPa
1.	Bricks	27.35, 25.50, 31.50, 32.75, 24.65	28.35
2.	Mortar 1:2.5	11.80, 11.00, 10.20	11.00
3.	Mortar 1:4	10.68, 9.50, 9.32	9.83

Wire Mesh

The mesh used was galvanised steel wire woven mesh, having square openings of about 11.36 mm x 11.36 mm. The diameter of the wire was 1.5 mm. Some sample wires from horizontal direction of mesh were cut, kinks are removed and tested to obtain the load-deformation curve, the yield load, the maximum load and the breaking load. The tests were carried out in Metallurgical Engineering Department using a tensometer. The results obtained are presented in Table 3.4. A typical load deformation curve obtain for one of the sample is given in Fig. 3.1.

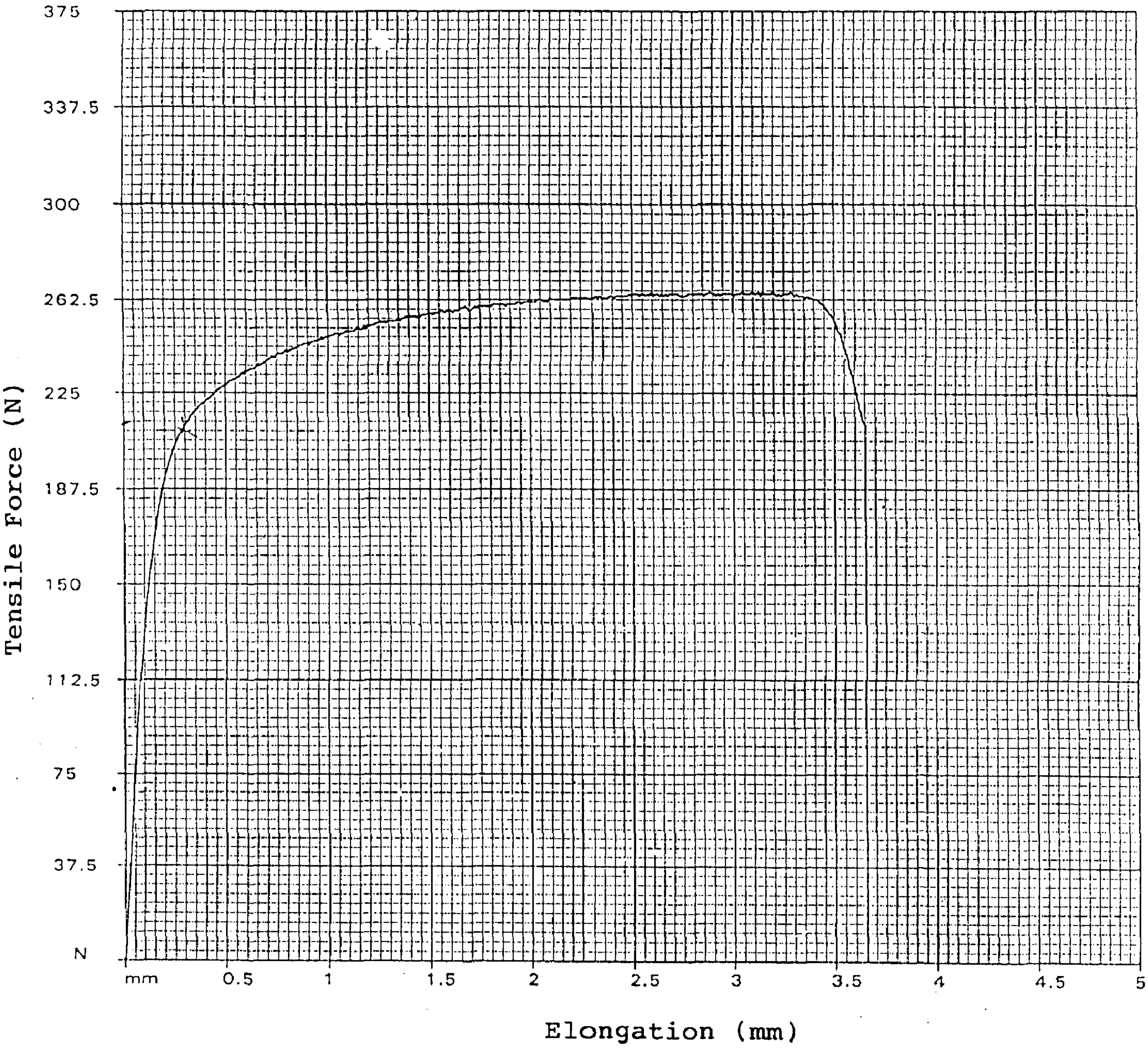

Fig. 3.1 A typical load elongation curve for a wire mesh

Table 3.4 : Test Results of Wire Mesh

Sample No.	Yield Load (N)	Maximum Load (N)	Breaking Land (N)
1	217.50	277.50	161.25
2	206.25	262.50	138.75
3	213.75	265.83	213.75
4	213.75	264.17	211.87
5	210.00	255.00	135.00

Mean Yield Load = 212.25 N

3.2 SPECIMENS DETAILS

The test specimens were square in cross section, having sides of 225mm for plain brick masonry columns and 270mm for ferrocement encased brick masonry columns and height of 1500 mm for both. The details of specimens are shown in Fig. 3.2. The mesh used was in two layers. Mortar used for casting of brick masonry was 1:4 cement : sand mortar and that for ferrocement was 1:2.5 with w/c ratio of 0.55. Six numbers (i.e. 3 for each type of mortar) of small cubes having surface area $50cm^2$ were also cast to test the compressive strength of mortar used which is given in Table 3.3.

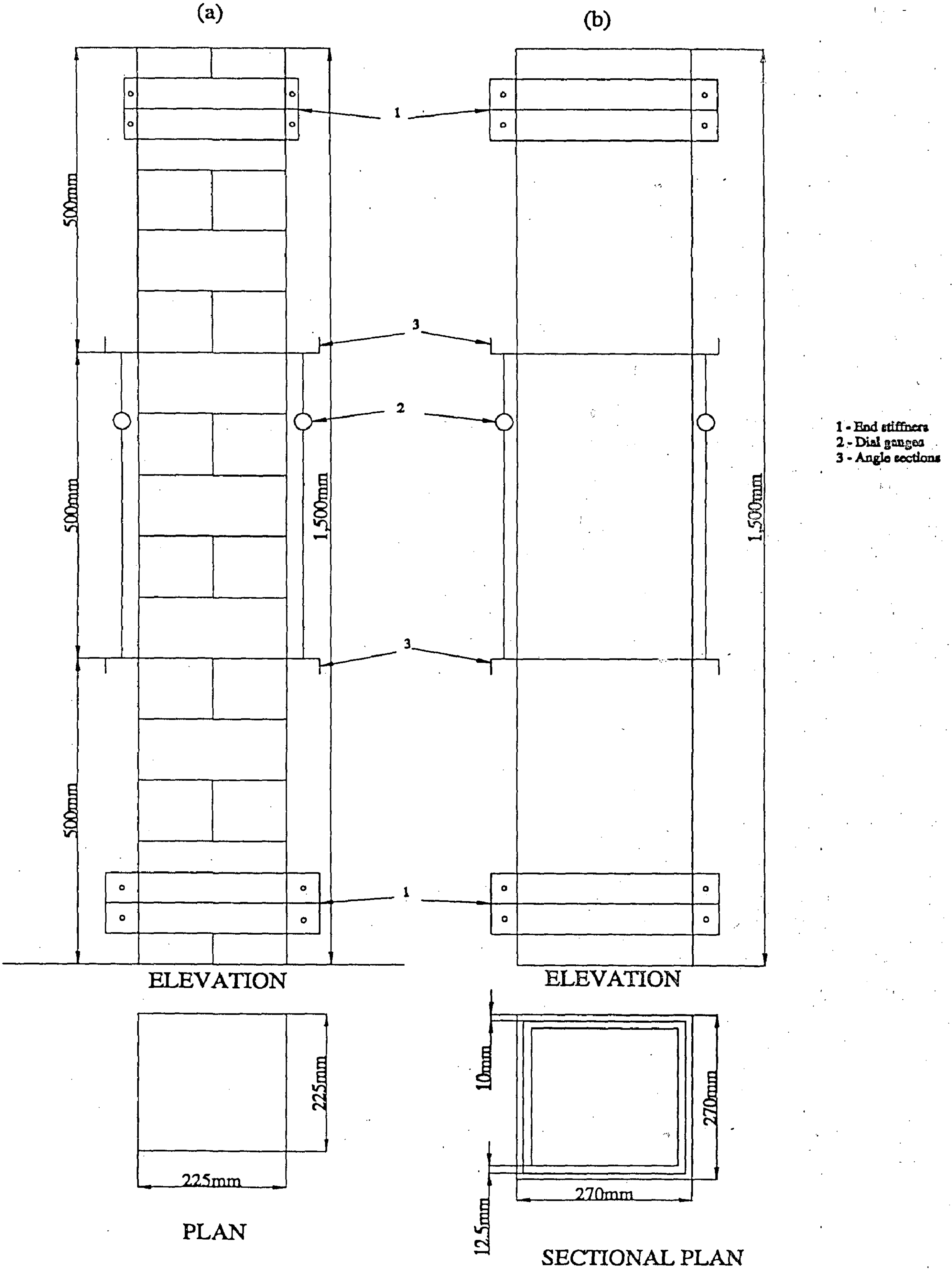

Fig. 3.2 Details of the specimens

3.3 CASTING OF SPECIMENS

First of all four plain brick masonry square columns with 225 mm sides and 1500 mm height were cast with alternate courses of headers and stretchers. Mortar used at this stage was 1:4 cement : sand mortar.

Out of these four plain brick masonry columns two were encased with ferrocement mesh of double layer in 1:2.5 mortar. All of these specimens were water cured for 28 days.

While jacketing by ferrocement mesh about 15 mm of overlap was provided to assure adequate bonding. Then mortar with 1:2.5 cement sand was pressed by hand. Bricks used in casting were initially soaked in water so as not to absorb water from mortar and alter the w/c ratio and hence to prevent any reduction in strength.

Curing of all the specimens done with jute bags covered around all the specimens as the temperature was quite high during the casting.

Brick masonry columns initially cast upto about 1m height and rest of the courses were laid after about 24 hrs. so that mortar achieve its initial strength to withstand against the self weight.

3.4 TESTING OF SPECIMENS

Alter 28 days of curing all the specimens were tested upto failure. Experimental set up is as shown in the plates 3.2 and 3.3, in which end stiffners two at each end are used to improve end conditions and hence to avoid any premature failure of the specimen. The position of the stiffners are shown in Fig. 3.2. Vertical deformations were recorded by two dial gauges set on the opposite sides at about mid height as shown in the Fig. 3.2.

The mean readings were recorded at loading increment of 2 tonnes (20kN) and plotted. The crack pattern observed is shown in plate [illegible].4 and [illegible].5.

RESULTS AND DISCUSSION

4.1 GENERAL

In this chapter, the results of the theoretical analysis and experimental investigations have been presented in the form of graphs and tables. Also number of photographic plates have been given to show investigation pictorially at various stages. The readings are taken at interval of 2 tonnes and load Vs deformation for each specimen are plotted. The ultimate failure load is recorded for each specimen and presented in tabular form. This chapter also includes comparison between theoretical and experimental results and discussion of the results obtained. To identify the scope for application and future investigations the limitations of theoretical and experimental investigations are examined. The review of literature given in chapter 2 has clearly brought out the information on the behaviour of ferrocement encased brick masonry columns. The formulae used for theoretical analysis in this chapter are taken directly from review of literature.

Test results for wire mesh, fine aggregate, cement and mortars are presented in chapter 3. Sectional dimensions of plane brick masonry and ferrocement encased brick masonry are also given in chapter 3. Failure loads for all columns are shown in table 4.1 and table 4.2 along with theoretical failure load. Sample calculations for assessing the strength increase in ferrocement encased columns are included in appendix.

In earlier reported tests [22] the specimens tested had aspect ratio (height to width ratio) of approximately 2. In the present investigation the aspect ratio has been increased to 6. In earlier tests [22] there was considerable scatter in failure load of plain as well as encased specimens. The scattering of results as seen in earlier investigation [22] is eliminated by using end stiffness and hence avoiding any premature failure due to poor end conditions.

4.2 THEORETICAL ANALYSIS

The theoretical analysis is carried our for ferrocement encased columns to assess the effect of confinement. The peak compressive load in a column corresponds to tensile yielding of the mesh wires in peripheral direction. At this stage the core is subjected to a lateral confining stress depending on the quantity of wires in the peripheral direction and also their yield stress. It is assumed that vertical wires of mesh do not contribute to compressive strength. The mortar in the strip between two 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.

Let T be the hoop tension force in the wires per unit height of the column corresponding to yielding of the wire and corresponding lateral pressure be σ_L. For plain brick masonry columns, total load carrying capacity is taken from test results.

Strength of confined column, as explained in review of literature load carrying capacity is given by equation 2.8 and σ_L can be obtained from equation 2.7 as given below.

The strength increase due to confinement is given by equation 2.9.

$$f_{mc} = f_m + K_1 C_e \sigma_L$$

Where,

σ_L = $2 N_{m1}. W_{y1}/S_p.d_m$

Wherein,

d_m = mean distance between centres of mesh layers.

W_{y1} = yield load of wire mesh

N_{m1} = number of mesh layers

Calculations for strength increase due to confinement and area increased are given in detail in appendix.

4.3 PRESENTATION OF RESULTS

In all four specimens were cast. Two of them were encased with two layers of ferrocement mesh. After 28 days of curing all of them are tested upto failure load. The failure load of plain and ferrocement encased columns are presented in Table 4.1. A comparison between failure load of ferrocement encased columns and that obtained from theoretical analysis is given in Table 4.2.

The deformation were recorded at an increment of 2 tonnes (20 kN) with electrical dial gauges. The results obtained are presented in the form of graph from Fig. 4.1 to 4.5. Graphs for load-deformation have been plotted for all the specimens.

Theoretical increase in failure loads due to ferrocement jacketting is shown in Table 4.2 in which the ration of experimental to theoretical failure load is also given.

Table 4.1 Experimental Strength of Plane and Ferrocement Encased Specimens

Specimen Designation	Failure Load (kN)	Mean Load (kN)
Plane Brick Masonry		
1	170	175
2	180	
Ferrocement Encased Brick Masonry		
1	390	400
2	410	

Strength increased due to encasement

= 400 - 175

= 225 kN

Percentage strength increased due to encasement

= (225/175) x 100

= 128%

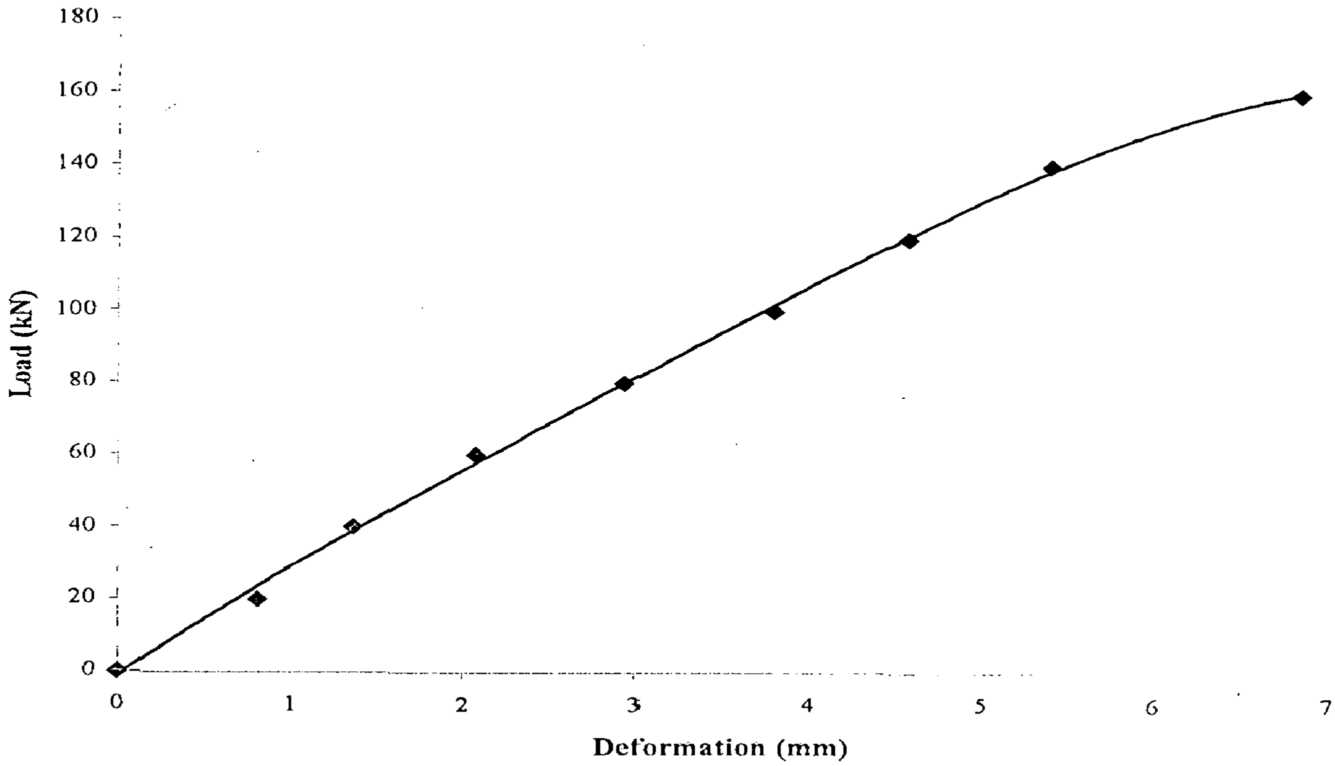

Fig. 4.1 Load Vs Deformation (Plain Specimen no. 1)

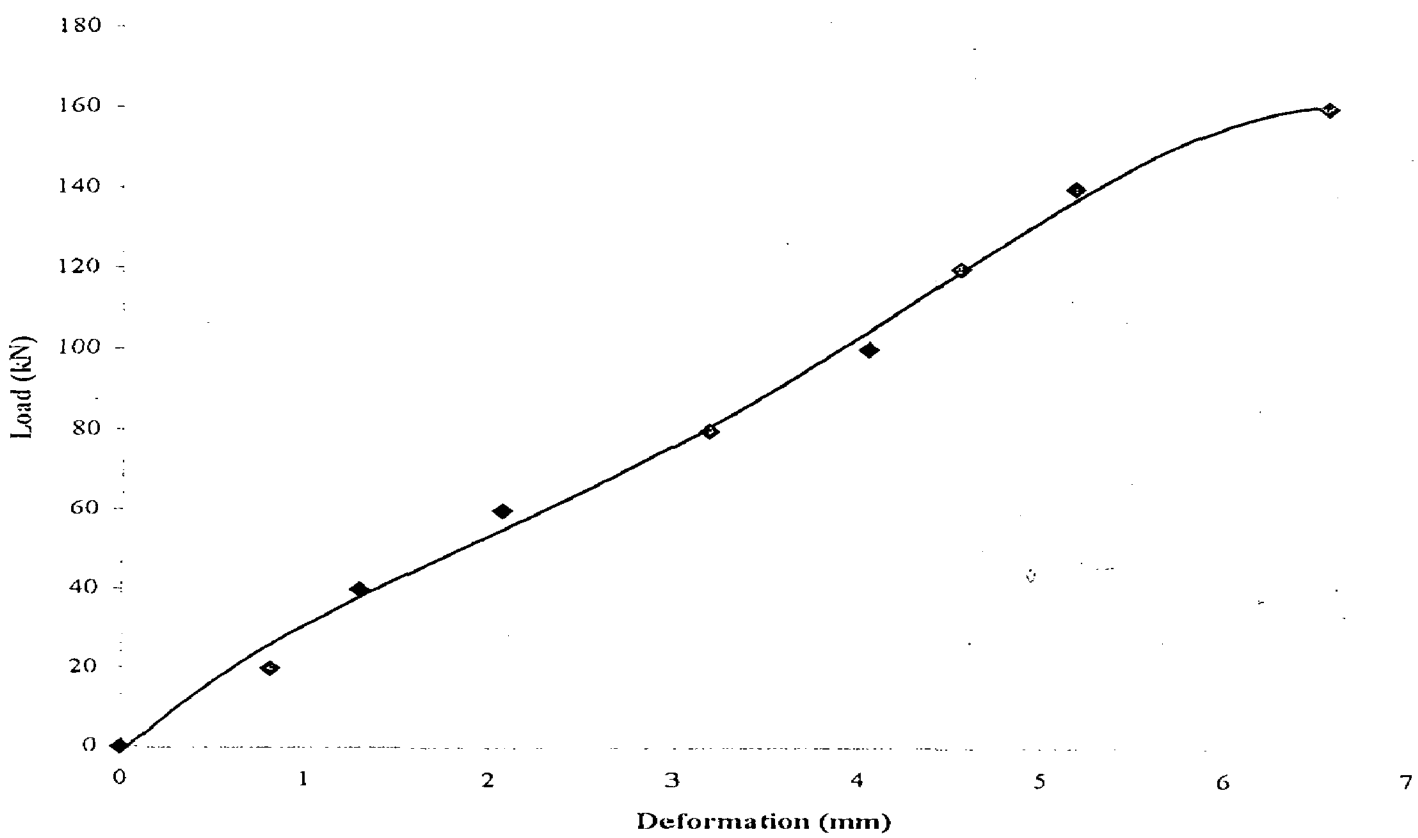

Fig. 4.2 Load Vs Deformation (Plain Specimen no. 2)

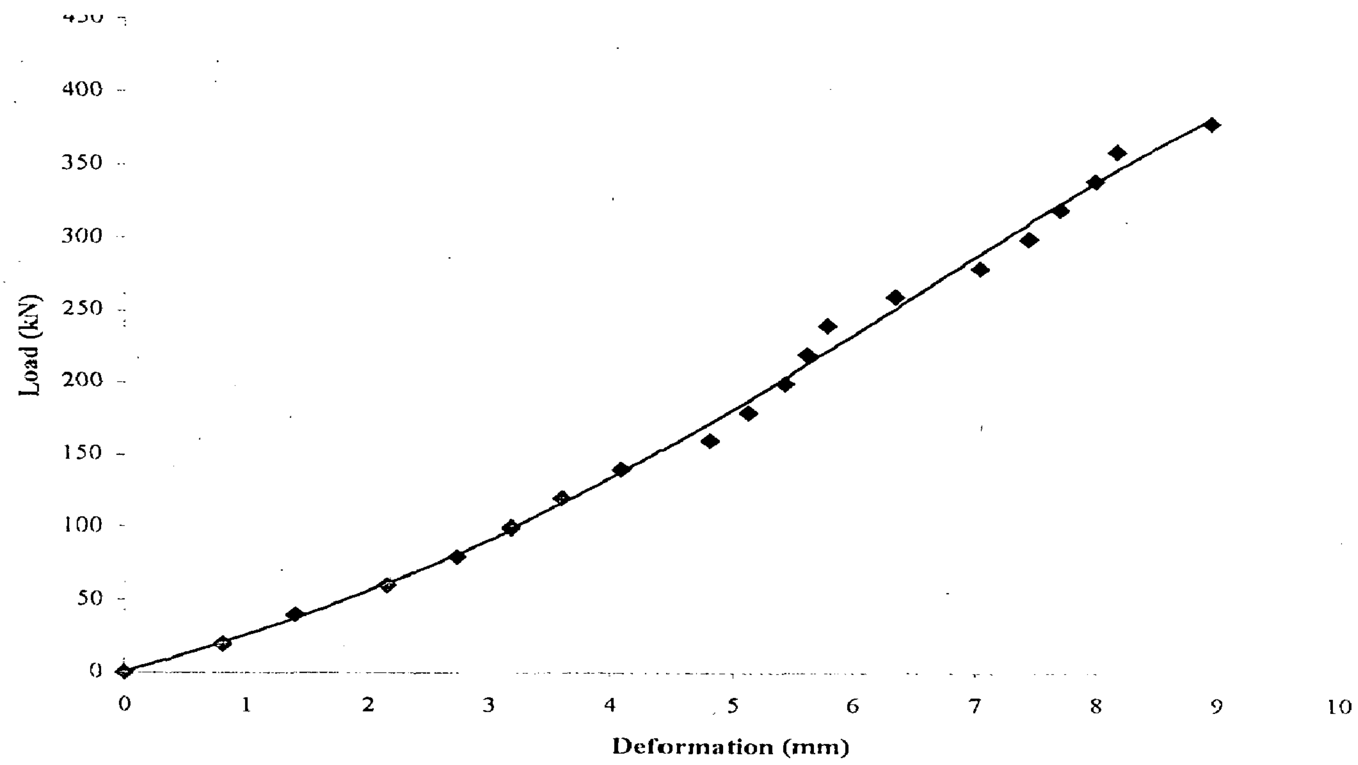

Fig. 4.3 Load Vs Deformation (Encased Specimen no. 1)

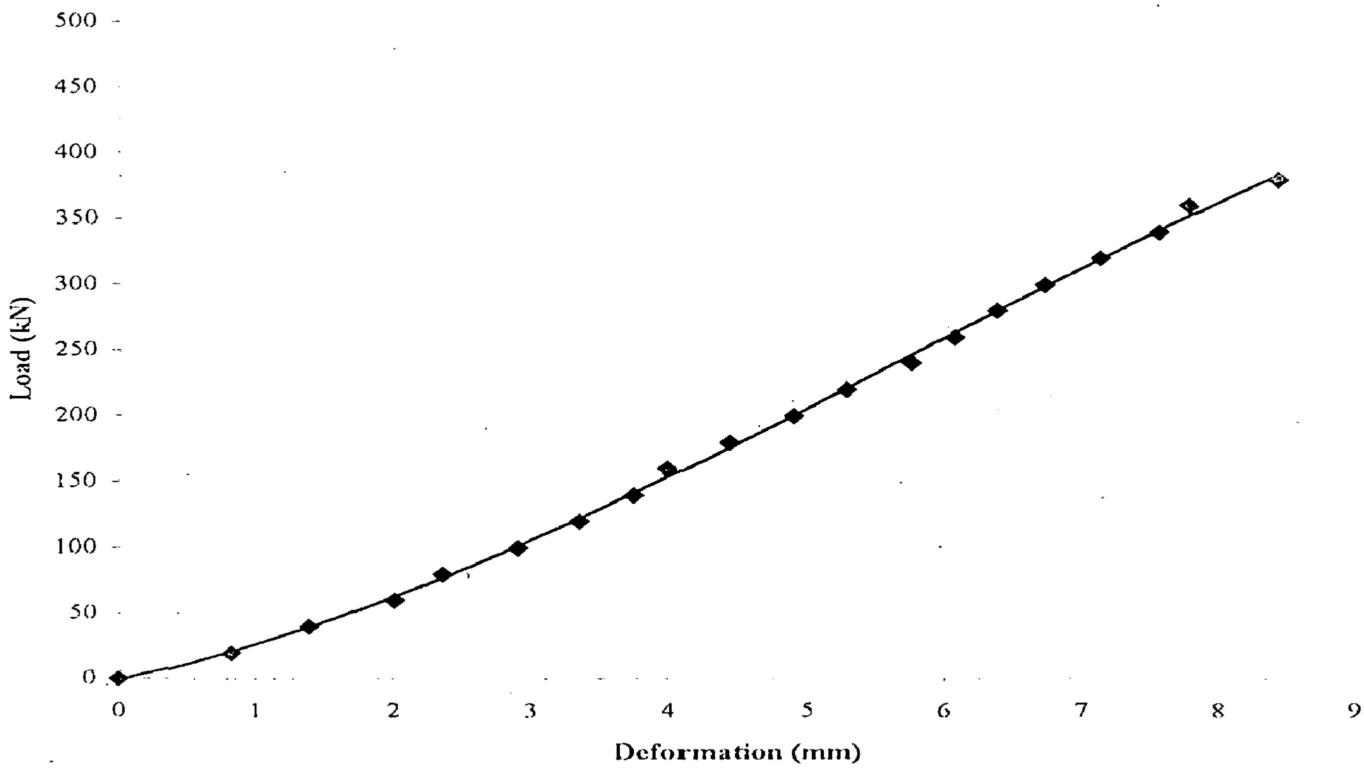

Fig. 4.4 Load Vs Deformation (Encased Specimen no. 2)

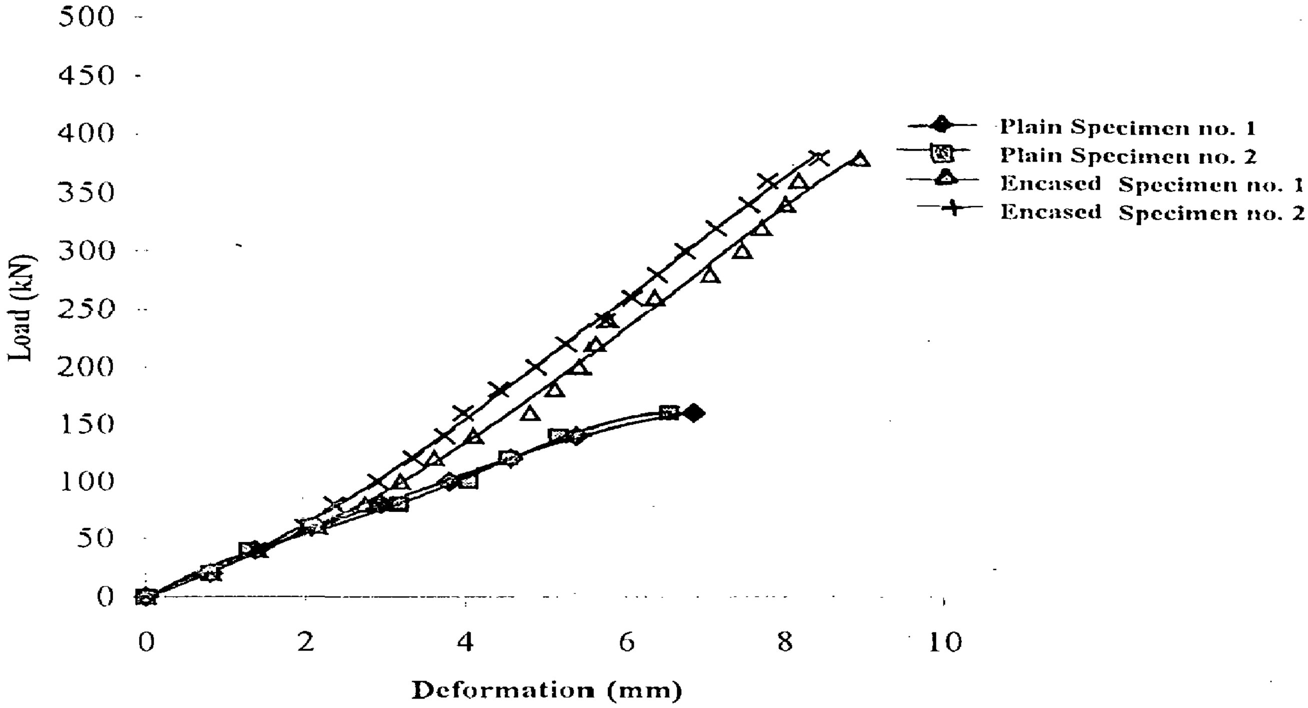

Fig. 4.5 Load Vs Deformation (All Specimens)

Table 4.2 Theoretical and Experimental Failure Loads (kN)

Plain Specimens (Exp.) (I)	Theoretical Strength Increased due to		Total (Theo.) (I+II+III)	Experimental	Ratio (Exp./Theo.)
	Confinement (II)	Area increase (III)			
175	58.1	130.6	363.7	400	1.09

4.4 DISCUSSION OF RESULTS

The purpose of this investigation was to examine the strength increase due to ferrocement encasement of brick masonry columns. Results obtained are discussed below for strength and crack behaviour.

The mean strength of plain brick masonry columns was found to be 175 kN and that of ferrocement encased columns was found to be 400 kN. It states that the increase in strength due to encasement is more than double.

In case of plane specimens first visible crack appeared at about 95% of failure load i.e. very close to failure, while for ferrocement encased specimens the first crack was observed at about 40 to 60% of the failure loads. 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 specimens stopped taking more load. So it can be concluded that in case of encased specimens the first crack appears much earlier than failure or final crack. This is not so as in case of plain brick masonry columns. The crack pattern of both type of specimens i.e. plain and encased are shown in plate 4 and plate 5. It can be seen that cracks are mostly vertical.

Finally it can be state that there is significant increase in strength due to ferrocement encasement. Ferrocement encased specimens take more loads than plain specimens while maximum strain values are nearly same. In other words it can be said that ferrocement encasement provides increase in strength and ductility of plain brick masonry columns.

STRUCTURAL ENGINEERING SECTION
DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF ROORKEE, ROORKEE

Dated : January 29th ,2001

M.E. THESIS VIVA VOCE

1.	**Candidate**	:	Mr. Ambhore Vinayak Parashram
2.	**Topic**	:	Behavior of Ferrocement Encased Brick Masonry Columns
3.	**Venue**	:	Conference Room; C. E. Deptt.
4.	**Time & Date**	:	3-00 PM on January 31st ,2001

All interested are cordially invited to attend.

K. K. Singh
(Dr. K. K. SINGH)
Professor of Civil Engg.

Copy to:

1. Head, Deptt. of Civil Engg.
2. Chairman, Board of Examiners.
3. Dean, Academic.
4. External Examiner
5. Chairman, PGAPC.
6. O. C. M. E. (Structural Engg.)
7. Faculty of Structural Engg. Section
8. Shri Jai Prakash for arranging for OHP
9. Care-Taker for reserving Conference Room from 3.00 PM to 4.00 PM on January 31st ,2001
10. M.E.I and M.E.II (Structural Engg.) attendance is compulsory

K. K. Singh
(Dr. K. K. SINGH)
Professor of Civil Engg.

Plate 1 All specimens in group ready for testing

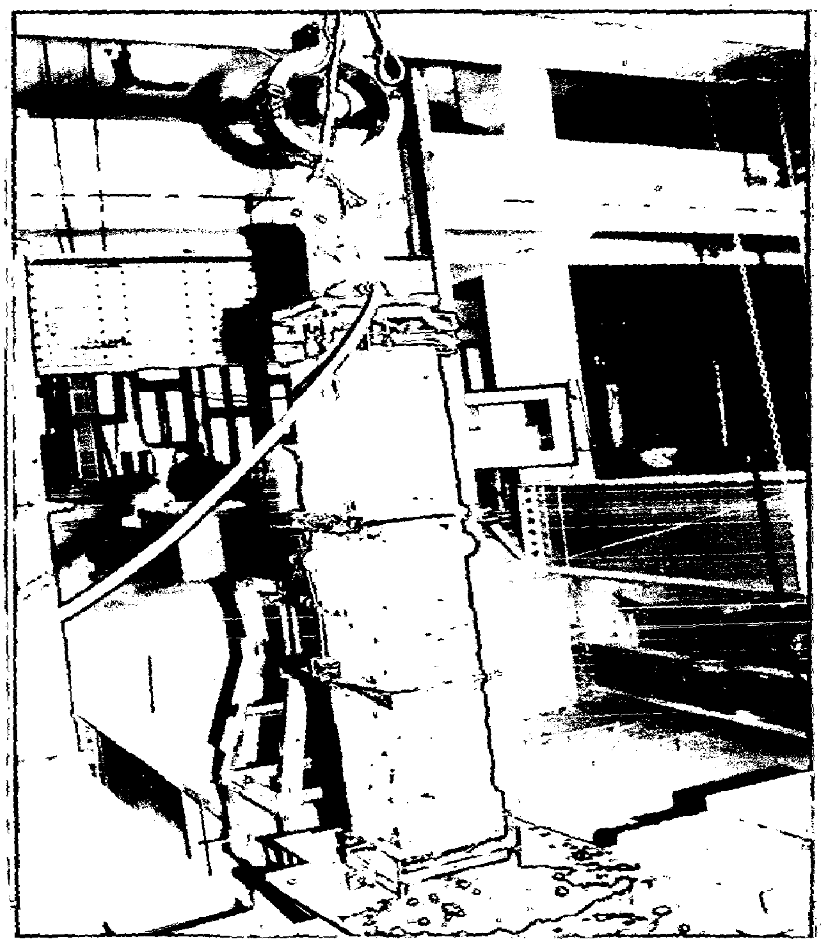

Plate 2 Experimental set up for plain columns

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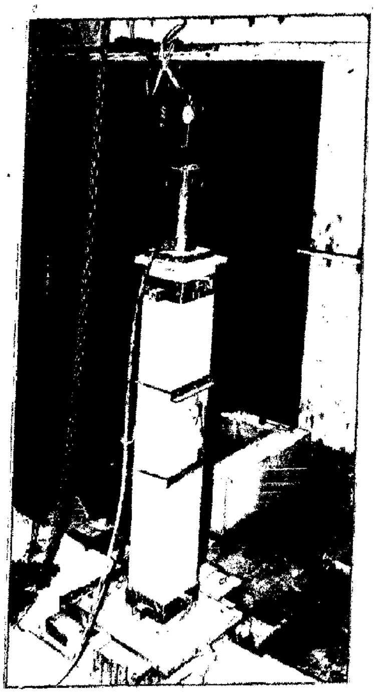

Plate 3 Experimental set up for encased columns

Plate 4 Crack pattern in plain column

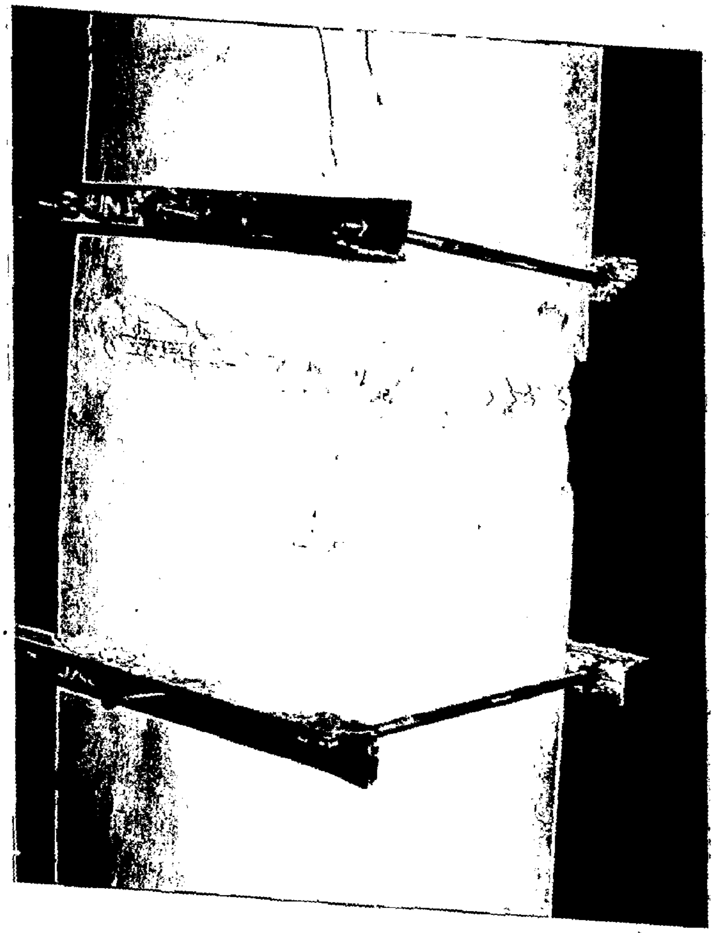

Plate 5 Crack pattern in encased column

CONCLUSIONS AND FUTURE SCOPE

5.1 CONCLUSIONS

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 use for strengthening new construction and for retrofitting.
2. The confinement formulae of concrete used for theoretical analysis were approximately valid, however for accurate prediction, confinement behaviours of masonry needs to be examine extensively.
3. Ultimate failure of plain brick masonry columns occurs 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.
4. As the load carrying capacity of encased columns was found out much higher than that of plain columns at approximately same maximum strain. So it can be said that there is considerable increase in ductility due to ferrocement encasement.
5. On the basis of above conclusions, design of confined brick masonry columns can be done with grater confidence. However testing for other conditions is needed for proposing design guidelines.

6. The strength increased due to lateral confinement is also true for the height to width ratio of 6.0 as investigated in the present study.
7. The test results for failure loads have a very small scatter which is due to the end stiffness which avoid premature failure due to poor end conditions.

5.2 FUTURE SCOPE

Some significant conclusions have been drawn above, which will be of help in strengthening and retrofitting of plain brick masonry columns. However from the literature review it is clear that experimental investigation on confinement of brick masonry is extensively limited. Hence it is specifically necessary to investigate the confinement behaviour 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 investigations.
2. The present study 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. Behaviour of reinforced brick masonry under confinement needs to be examine experimentally for axial as well as eccentric loads.

APPENDIX

SAMPLE CALCULATIONS FOR THEORETICAL ANALYSIS

Sample calculations are given in this appendix to explain the procedure for assessing the theoretical strength of ferrocement encased specimens. The strength of encased column is the sum of strengths of plain masonry column and increase in strength due to confinement and area increased. Here the strength of plain masonry column is taken as the mean strength.

Number of mesh layer = 2

Lateral confining pressure,

$\sigma_L = 2.N_{m1}.W_{y1}/(S_p.d_m)$

Where,

N_{m1} = number of mesh layers

W_{y1} = yield load of a wire of mesh

S_p = spacing of mesh wires

d_m = mean distance of inner and outer mesh

$\therefore \sigma_L = 2 \times 2 \times 212.25 / (12.85 \times 250)$

$= 0.264 \text{ N/mm}^2$

Axial compressive stress of plain columns,

$$\sigma_o = \frac{\text{Mean failure load}}{\text{c / s area}} = \frac{175000}{225 \times 225} = 3.457$$

$$\therefore \sigma_L/\sigma_o = \frac{0.264}{3.457} = 0.076$$

From Fig. 2.10 (b), $C_e = 0.88$ (corresponding to $\sigma_L/\sigma_o = 0.076$)

$\therefore$ Increase in strength due to confinement

$= K_1 \times C_e \times \sigma_L \times d^2_m$

$= 4.0 \times 0.88 \times 0.264 \times 250^2$

$= 58080$ N $= 58.08$ kN

Increase in strength due to area increase,

= Mortar strength x are increased

$= 11.00\ (250^2 - 225^2)$

$= 130625$ N

$= 130.625$ kN

Total increased in strength $= 58.08 + 130.625$

$= 188.705$ kN

Theoretical failure load $= 175 + 188.705$

$= 363.705$ kN

Experimental failure load $= 400$ kN

Ratio of Experimental to Theoretical Failure Load

$$= \frac{400}{363.705}$$

$= 1.09$

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