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**GOVERNMENT OF MAHARASHTRA**

## WRD HANDBOOK CHAPTER NO. 1

# FERROCEMENT TECHNOLOGY

**MAHARASHTRA ENGINEERING RESEARCH INSTITUTE, NASHIK-04**
**WATER RESOURCE DEPARTMENT**

GOVERNMENT OF MAHARASHTRA
WATER RESOURCES DEPARTMENT

## WRD Handbook Chapter No. 1

# FERROCEMENT TECHNOLOGY

**Maharashtra Engineering Research Institute,
Nashik 422004, India**

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# PREFACE

Ferrocement technology was used in 1848 to build boats. The durability and imperviousness of this material is useful in buildings and some water retaining structures. BIS has already published IS code No. 13356:1992 (Precast ferrocement water tanks up to10000 litres capacity). Maharashtra Engineering Research Institute has been doing research and testing of the components since 1979. This technology can be used in building components, irrigation structures and canals, rehabilitation and strengthening of old structures etc.

As there is no literature or consolidated compiled information available for the guidance of field engineers, hence this manual was a need of the civil engineers working in this field. Government of Maharashtra, WRD instructed to prepare manual for field engineers. As per Maharashtra Government resolution, Water Resource Department MSS 1114/(case no. 365 / 2014) MP-4 date:03/01/2015, Government formed a committee to prepare a WRD Handbook on ferrocement. This committee conducted six meetings and prepared the draft copy of this handbook. Accordingly the report containing draft manual was submitted to Government of Maharashtra and Government of Maharashtra accorded sanction vide letter dated 14/06/2018

This handbook will serve as a reference book to field engineers. This WRD handbook chapter no. 1 mainly contains description for following topics.

1. Materials
2. Equipment and Tools
3. Testing of materials (Field tests)
4. Laboratory Tests
5. Applications of ferrocement
6. Methods of construction
7. Design of ferrocement structures
8. Cost estimation of ferrocement structures
9. Standardization of ferrocement
10. Research work
11. Ferrocement use on experimental basis

This manual is prepared with great technical contribution from Dr Balkrishna Divekar, retired professor of engineering college and past chairman of Ferrocement Society of India, Pune and all the committee members as mentioned in Appendix 1. I take this opportunity to thank all committee members for their contribution. I am sure that this book will be useful for engineers from all departments of Government of Maharashtra to have basic introduction of ferrocement technology.

Since WRD has published its separate Manuals, CSR etc., the series of such Handbook Chapters is first one published by WRD. I am happy to publish this chapter of first WRD manual.

Hope, it shall be useful for the engineers for the successful implementation of the Ferrocement Technology in various departments of Government of Maharashtra considering its unique features such as imperviousness (crack free surface), slim components, mouldable to any shape (without formwork), sustainable to seismicity, eco-friendly, ease of construction, precasting, more strength to weight ratio and so many features.

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## LIST OF PWD HANDBOOK CHAPTERS

1. Materials.
2. Masonry.
3. Reinforced Concrete Construction.
4. Prestressed Concrete.
5. Plastering and Pointing.
6. Preparation of Projects and Engineering Geology.
7. Surveying.
8. Excavation.
9. Foundations.
10. Building.
11. Town Planning.
12. Roads.
13. C.D.Works and Bridges.
14. Ports and Harbours.
15. Runways and Air-strips.
16. Electrical Works Connected with Buildings.
17. Soil Mechanics.
18. Hydraulics.
19. Hydrology and Water Planning.
20. Masonry and Concrete Dams,
21. Earth and Composite Dams.
22. Instrumentation.
23. Spillways, Outlets, Gates and Hoists.
24. Canals.
25. Irrigation and Irrigation Management
26. Soil Survey of Irrigation Command, Land Drainage and Reclamation.
27. Hydro-power Scheme.
28. Construction of Tunnels.
29. Urban Water Supply.
30. Rural Water Supply.
31. Sanitary Engineering.
32. Construction Machinery.
33. Quality Control:
    Part I : Cement Concrete, Part II : Earth Work
34. Labour Laws.
35. Rate Analysis.
36. Construction Planning.
37. Part-I -Land Acquisition Part-II- Valuation.
38. Mathematical Data and Miscellaneous Information.
39. Colgrout Masonry works.
40. Placement of concrete
41. Ready Mix Concrete

## LIST OF WRD HANDBOOK CHAPTERS

WRD1. Ferrocement Technology

# Abbreviations

ASTM-American Society for Testing Materials

BIS- Bureau of Indian Standards

ACI- American Concrete Institute

NBC- National Building Code

$L_{cr}$- Spacing of cracks.

$C_r$ –Crack width

L –Bond length

$S_r$- Specific Surface- Parameter defined as ratio of area of contact of wires to the volume of mortar which is bound by them.

$V_r$- Volume fraction of steel

$V_s$-Volume of steel wires in cc per sqm of area.

$V_m$- Volume of mortar in length Lcr.

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# CHAPTER 1
# INTRODUCTION

## 1. 1 Introduction:

Ferrocement is the composite of Ferro (Iron) and cement (cement mortar). Ferrocement can be considered as a type of thin walled reinforced concrete construction in which small-diameter wire meshes are used uniformly throughout the cross section instead of discretely placed reinforcing bars and in which Portland cement mortar is used instead of concrete. In ferrocement, wire-meshes are filled in with cement mortar. It is a composite, formed with closely knit wire mesh; tightly wound round skeletal steel and impregnated with rich cement mortar as shown in fig 1.1.

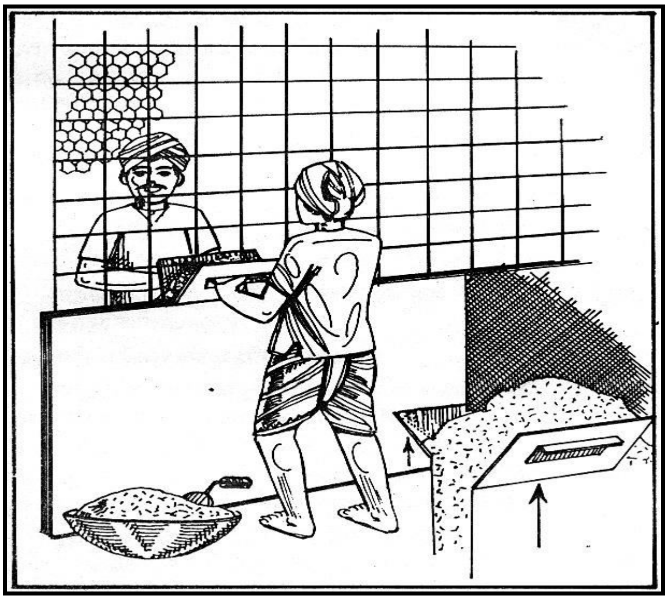


**Fig 1.1 Construction of ferrocement structure**

With Ferrocement it is possible to fabricate a variety of structural elements, may be used in foundations, walls, floors, roofs, shells etc. They are thin walled, lightweight, durable and have high degree of impermeability. It combines the properties of thin sections and high strength of steel. In addition it needs no formwork or shuttering for casting.

Ferrocement have applications in all fields of civil construction, including water and soil retaining structures, building components, space structures of large size, bridges, domes, dams, boats, conduits, bunkers, silos, treatment plants for water and sewage.

## 1. 2 Definition of ferrocement

Ferrocement is defined in different ways by different organizations.

**1)** According to United Nations High Commissioner for refugees (UNHCR), ferrocement is defined as ‘A thin walled construction, consisting of rich cement mortar with uniformly distributed and closely spaced layers of continuous and relatively small diameter mesh (metallic or other suitable material).’ (reference-UNHCR-Large ferrocement Water tank Manual July 2006).

2) ACI committee-549 describes it- ‘Ferrocement is a form of reinforced concrete using closely spaced multiple layers of mesh and/or small diameter rods completely infiltrated with, or encapsulated, in mortar. The most common reinforcement is steel mesh’ (reference – ACI 549.1R-93- Guide for the design, construction and repair of ferrocement)

## 1. 3 Historical background.

Ferrocement has a history of more than 170 years. The idea of impregnating closely spaced wire meshes with rich cement mortar is similar to the Kood (कूड) type of age-old method of walling. In Kood system, bamboo and reeds are tied closely together and filled in with a mix of mud and cow dung as a matrix. It is used in rural areas of India. Hence Ferrocement may be called as a modified form of Kood with standardized raw materials, systematic method of construction and reliable structural properties. Here the mesh is used in place of bamboo and reeds, and cement mortar instead of mud.

Ferrocement in the form of mesh-reinforced cement mortar was used in Europe by Mr. J. L. Lambot in France. He constructed a ferrocement rowing boat in 1848, in which reinforcement was in the form of flexible woven wire mat and small size bars. He had patented this process.

In the early 1940, Nervi of Italy used ferrocement for shipbuilding to overcome the shortage of steel plates in the world war-II. He also applied ferrocement techniques in buildings and warehouses. Ferrocement has been used in construction of domes, roofs of stadiums, opera houses and restaurants in Europe. In spite of Nervi’s demonstration of successful use of the material, no systematic studies were made till 1960, when its use as a boat building material was made in Australia, U.K., and South East Asian countries.

In 1972, National Academy of Science, U.S.A., established an Ad-hoc panel to study the use of ferrocement in developing countries. Its report on ‘Ferrocement-Applications in Developing Countries’, was published in 1973. It gave impetus to systematic study of ferrocement in United States. This was followed by American Concrete Institute, establishing committee 549 on Ferrocement in 1974. From then, considerable effort have been made by many individuals and Institutions all over the world to develop ferrocement as a construction material.

At Asian Institute of Technology, Bangkok, Thailand “International Ferrocement Information Centre” was established and a “Journal of Ferrocement” is regularly published by it.

## 1. 4 Basic Methodology of forming Ferrocement members

A ferrocement structure is formed by fabricating the mesh reinforcement to the shape and size of the structure first and then mortared and cured. Method of forming a ferrocement element is as follows:

1) **Welding skeletal steel framework.**

   A skeleton of steel bars is welded to the exact geometrical shape and size of the structure. This provides a rigid framework of the exact shape and size with correct line and level.

2) **Tying mesh reinforcement tightly over it to form cage.**

   Weld mesh and fine wire chicken mesh is tied over this welded skeleton by stretching and tying technique. ‘Tightly tying meshes’ is the key point in ferrocement construction.

3) **Impregnating the mesh cage with rich cement mortar, finishing and curing.**

The stiff cement mortar is filled in the mesh layers by pressfill method. In pressfill method, the mortar is to be pressed inside the meshes from both the sides.

All these steps in construction are to be followed in sequence. On large size constructions, one can work simultaneously on all the three operations.

## 1. 5 Advantages of Ferrocement

Ferrocement has following basic advantages over RCC

1) **Increase in bond strength:**

The transfer of load from steel to concrete and vice versa takes place through bond between the two materials. The bond depends upon the bond-stress of concrete and the area of contact between the steel and concrete. Bond stress of concrete depends upon the grade of concrete. It is hardly 6 $kg/cm^2$ for M15 concrete. The bond can be substantially increased if the contact area between steel and mortar is increased. For Ferrocement, it is achieved by use of small diameter wires and mortar.

2) **Bond area increase:**

Increase in bond area will result in more adhesion between steel and mortar, making it behave more like a homogeneous material and which has become very strong in tension due to increase in bond.

3) **Dispersion of steel wires:**

Ferrocement is formed by tying together a number of layers of continuous wire meshes. Volume of steel percentage is very large, may be up to 8 percent. Also the mortar cover over the meshes is hardly 3 to 5 mm. Hence, throughout the body of the composite, the wire reinforcement is fully dispersed. This leads Ferrocement to become more homogeneous. It results in improving the properties of Ferrocement in tension, flexure, impact resistance and crack resistance.

4) **Crack control:**

Meshes are fully bonded to mortar and spaced very near to the surface of Ferrocement. Such closely spaced fine wires, very near to the surface of Ferrocement, act as crack arrestors.

5) **Equal strength in both directions:**

The continuity and placement of equal mesh reinforcement in both directions make Ferrocement to achieve equal strength in two directions and to become strong in resisting diagonal tensions due to shear.

6) **Containment of mortar matrix in mesh layers:**

In Ferrocement, layers of wire meshes tightly tied together are impregnated with cement mortar. The matrix is held by the meshes in between and is contained by them.

7) **Formless construction:**

Tightly tied meshes in ferrocement can hold wet cement mortar when it is pressfilled in them. The consistency of cement mortar is very thick with very low water cement ratio. It won't come out of the meshes. Thus casting of Ferrocement does not need any formwork or shuttering. The other advantage of this aspect is no honeycombing will occur in pressfilling, as the mortaring is done in front of your eyes.

If the mesh is tied loosely or water cement ratio is not maintained to thick consistency or over-sanding is done, the mortar will flow down and will not be held by the meshes.

8) **Strength through shape:**

Ferrocrete structures are thin walled and may be hardly 25 to 50 mm in thickness. Hence, to take care of slenderness and buckling, Ferrocement is shaped in different forms to achieve its strength.

9) **Lightweight, homogeneous and versatile material**

Ferrocement structures have high equal strength in both directions. It can be moulded in any shape and size. Ferrocement is homogeneous, easy to work and can be made available in thin sections.

10) **High strength to weight ratio:**

Being a thin walled structure of high strength, strength to weight ratios in tension and compression of ferrocement are very high. Hence thin sections can take higher loads.

## 1. 6 Comparison of RCC and Ferrocement

Ferrocement composite has different features than Reinforced cement concrete. Features like thickness of products, matrix used in products, reinforcement, strength, structural behaviour etc. on which they are differentiated, is given in table 1.1

**Table 1.1 Comparison of RCC and Ferrocement**

| Sr. No. | Features | Reinforced Cement Concrete | Ferrocement |
|---|---|---|---|
| 1 | Thickness | Minimum 75mm | Thin walled, 25 to 50 mm. |
| 2 | Matrix material | Cement concrete | Rich cement mortar |
| 3 | Reinforcement | Steel bars > 6mm diameter Spaced distance apart | Continuous fine wire mesh dispersed throughout the body of the structure. |
| 4 | Strength | Weak in tension, bond and shear | High tensile strength, superior bond and shear strength. |
| 5 | Tensile strength | 4-6 kg/cm$^2$ | 80-90 kg/cm$^2$ |
| 6 | Strength to Weight Ratio | 15 to 50 | 45 to 90 |
| 7 | Casting process | Formwork and shuttering are quite essential. Due to forms honeycombing is likely to occur. | Tightly tied wire-meshes act as supporting mortar casting. Filling is dense and compact, no honeycombing. |
| 8 | Composition | Heterogeneous | Nearly Homogeneous |
| 9 | Gain of strength | Due to size, shape and reinforcement | Due to shape of the structure |
| 10 | Structural Behaviour | Rigid | Non rigid |

# CHAPTER 2
# TERMINOLOGY

**2.1 Ferrocement, Ferrocrete, Meshcrete and MBBM**: Ferrocement and ferrocrete are similar terms. In Spanish countries they call this as Ferrocemento. Some people call it as ferroconcrete. In Pune region the composite of mesh-reinforced rich cement mortar is popularly known as Ferrocrete. Originally in 1940, Nervi in Italy had named this composite of Ferro (iron) and cement (cement mortar) as "Ferrocemento". All over the world it is known as **"Ferrocement"**

The matrix of this composite is not plain cement but cement mortar in the form of micro-concrete. Hence, it is felt to include 'crete' and not 'cement' in the name of the composite and hence named it as **"Ferrocrete".**

Further it is suggested by many engineers, that it will be more meaningful if the composite is named as **"Meshcrete"** indicating mesh type of continuous reinforcement with micro-concrete as matrix.

In RCC, steel bars are embedded in concrete while in Ferrocrete wire-meshes are filled in with cement mortar. The mortar is confined in meshes which are placed very close to the surface of the member. In addition the bond between the mortar and wire meshes is very strong. Hence, to describe the true behavior of the composite it should be named as **Mesh Bound Bonded Mortar (MBBM)**.

In this handbook both the terms 'Ferrocement' and 'Ferrocrete' are used.

**2.2 Weld mesh**: It is the steel wire mesh having square or rectangular openings. The wires are welded in factory.

**2.3 Chicken mesh**: It is the thin wire mesh and has hexagonal openings. This is made by weaving the wires.

**2.4 Skeleton**: The shape of the ferrocement structure is given by skeleton or the steel frame. It is also called armature.

**2.5 Matrix**: The cement sand wet mix mortar when pressed in the gaps of the skeleton encasing the wiremeshes it becomes a matrix.

**2.6 Press filling**: The mortar is pressed from both sides of ferrocement wall to fill the gaps completely. It is called press filling. This is done with two plate trowels.

**2.7 Press spraying** : Mortar spraying machines are now available and for mass work or when only one surface of the ferrocement wall is available then the mortar is sprayed with pressure. The method is called press spray method.

**2.8 Volume fraction of steel ($V_r$)**: Volume fraction is the total volume of reinforcement, including skeletal steel, divided by the volume of the composite including the reinforcement and matrix. For a composite reinforced with square meshes, $V_r$ is equally divided into $V_{rl}$ and $V_{rt}$ for longitudinal and transverse directions respectively. $V_{rl}$ and $V_{rt}$ will be different in other types of meshes.

**2.9 Specific surface ($S_r$)**: The specific surface is the total bonded area of mesh reinforcement divided by the volume of the composite.

**2.10 Effective modulus of elasticity of reinforcing system ($E_r$)**: The elastic modulus of mesh reinforcement is not necessarily the same as the elastic modulus of wire from which it is made. The same type of behavior is seen with expanded metal and hexagonal mesh. These effects of straightening and tension stiffening are accounted by introducing a term effective modulus of elasticity ($E_r$) of the reinforcing system.

**2.11 Global Efficiency Factor**: The orientation of reinforcement is equally important, when the strength under biaxial loading is considered. Square meshes give equal strength in both directions, but at 45 degrees orientation the strength is 67 to 80 percent of the strength in the direction parallel to wires in welded mesh. For expanded metals, the strength in transverse directions is very low. For hexagonal meshes, strengths in transverse directions average to 57 percent of strength in normal directions. The effect of type of mesh and its orientation is accounted for by **Global efficiency factors**.

**2.12 Stress at first crack**: Different research workers have defined first crack in different manners and hence the stress value at first crack differs a lot. Even before loading, micro cracks exist in mortar matrix. When the micro cracks widen and propagate and progressively join together under load, they are detected by some means, visual or otherwise.

First cracking is defined by a crack width ranging from 0.005 mm to a value visible to naked eye of 0.03 to 0.10mm. In some studies, first cracking is defined as first deviation from linearity of the stress-strain curve in tension. It may be 900 to 1500 micro strain or the corresponding deviation of load-deflection curve in flexure or as a crack width of 0.075mm in flexural loading. In whatever way the first crack is defined, the first crack stress and the specific surface of the composite are having a definite relationship. First crack stress increases as the specific surface increases.

**2.13 Equivalent area concept and Equivalent stress concept:** When strains are same in steel and concrete, the stresses are in proportion of Es/Ec (m). So equivalent area of concrete is Ac + m As. Same is applicable for stresses.

**2.14 Influence zone of bond**: It is the volume of mortar around a steel wire up to which the bond is effective.

**2.15 Chord modulus of elasticity**: On stress-strain curve in tension the line joining the stress at first crack and yield point stress defines the Chord Modulus of Elasticity of ferrocement.

**2.16 Tension capsules and Compression blocks**: With standardized method of construction, ferrocement members in the form of capsules and blocks of assured tensile and compressive strength can be developed and used in field.

**2.17 Orientation of reinforcement**: The direction of reinforcement, i.e. longitudinal or transverse, horizontal or vertical etc.

**2.18 Fibre Reinforced Plastic** (FRP): The Fibre-reinforced plastic is a composite material made of a polymer matrix reinforced with fibres. The fibres are usually glass, carbon, aramid, or basalt.

**2.19 Column jacketing**: Encasing of concrete or brick columns by ferrocement layer from all sides.

# CHAPTER 3
# MATERIALS

## 3.1. Materials used in ferrocement structures

a) Skeletal steel in the form of angles, steel bars, welded wire fabrics or pipes.
b) Steel wire meshes for forming cages.
c) Rich cement mortar, as matrix in form of micro-concrete.

All these three raw materials are those which are commonly used in practice in construction of conventional buildings.

## 3.2. Skeletal steel

**a. In the form of steel bars:**

Skeletal steel as the name implies is generally used to give basic shape and size to the structure. If used only to give the form to the structure, the steel rods may be spaced wide apart, say even up to 500 mm. When they are not treated as structural reinforcement, they also act as spacers to the layers of meshes. In highly stressed structures, where the skeletal steel acts also as reinforcement, their spacing will be as per the structural design of the structure. Steel bars of 4 to 10 mm dia. are generally used. Sometimes angle framework may be used to support the structure.

**b. In form of welded bar fabric:**

Welded bar fabric may be used as skeletal steel for Ferrocement panels of large size. A wide range of permutations of bar sizes and spacings is available, from which the required design can be chosen. Welded bar fabric is available for bar diameters from 4 to 10mm, with spacing of bars from 50 X 50 to 300 X 300 mm square or rectangular in shape.

**c. Specifications:**

Steel bars to be used should be according to I. S. Specifications as follows:

i. Mild steel bars confirming to IS-432(Part I) 1982,
ii. Hard drawn steel wires confirming to IS-432 (Part II) 1982 and
iii. Hard drawn steel wire mesh fabric IS 1566-1982.

**d. Practical hints in selecting the skeletal steel:**

i. The steel area particularly at the location of welding of cross bars should not be more than 50% of the cross-sectional area of ferrocement. It is observed that when large diameter steel bars are used or angles are used, temperature cracks are formed along the line of steel bars.
ii. Bars of 6 or 8 mm diameter could be used for small structures, to maintain the rigidity of framework, the edge-bars may be 8mm dia. tor-steel, while the other bars may be 6mm dia. mild steel.
iii. The following table 3.1 and table 3.2 will be useful in placing an order in the market for steel bars:

**Table 3.1 Weights and lengths of steel bars.**

| Sr. No. | Bar dia. (mm) | Area (sq.mm) | Weight (kg/m run) | Length of Bars m/ 100 kg | Number of 10 m bars |
|---|---|---|---|---|---|
| 1 | 4 | 12.56 | 0.099 | 1010 | 101 |
| 2 | 5 | 19.64 | 0.154 | 649 | 64.9 |
| 3 | 6 | 28.27 | 0.22 | 454 | 45.4 |
| 4 | 8 | 50.26 | 0.39 | 256 | 25.6 |
| 5 | 10 | 78.54 | 0.62 | 160 | 16 |
| 6 | 12 | 113.1 | 0.887 | 112 | 11.2 |

**Table 3.2. Weights of skeletal bars per m$^2$ of panel for various spacing of bars**
(Calculation based on a panel size 3.0m X 3.0m)

| Spacing of bars grid size (mm x mm) | **Weight in kg per m$^2$ of panel for bar diameters** | | | | | |
|---|---|---|---|---|---|---|
| | 4 mm | 5 mm | 6 mm | 8 mm | 10 mm | 12 mm |
| 75 x 75 | 2.70 | 4.20 | 6.00 | 10.65 | 16.95 | 24.24 |
| 100 x 100 | 2.04 | 3.18 | 4.56 | 8.07 | 12.81 | 18.33 |
| 150 x 150 | 1.38 | 2.16 | 3.09 | 5.46 | 8.67 | 12.42 |
| 200 x 200 | 1.05 | 1.65 | 2.34 | 4.17 | 6.63 | 9.48 |
| 300 x 300 | 0.72 | 1.14 | 1.62 | 2.85 | 4.53 | 6.48 |
| 500 x 500 | 0.45 | 0.72 | 1.02 | 1.83 | 2.91 | 4.14 |

## 3.3. Steel wire meshes

Fine wire mesh reinforcement is the basic element of ferrocement, it controls the specific surface, which is an important factor in design. The number of layers of meshes, decide the thickness of the composite. Four basic types of meshes are in use.

a. Weldmesh
b. Fine wire mesh (woven square mesh/interlocked hexagonal wire mesh/Chicken wire mesh)
c. Expanded metal.
d. Crimped wire mesh.

### 3.3.1 Weldmesh

Welded wire mesh of rectangular pattern as shown in fig. 3.1 is formed by aligning wires perpendicularly and welding them at their intersections. Weldmesh is tied on skeletal steel framework and it provides a base for tying fine wire meshes on it. Its surface area is considered in calculating the specific surface of the composite. Weldmesh is designated by the spacing of wires or the size of openings, followed by the gauge of the wire in longitudinal and transverse directions. Thus a 100 mm x 100 mm x 12 g x12 g means a weldmesh of opening size of 100 mm x 100 mm and wire gauge used in longitudinal and transverse directions are 12 gauge. Weld meshes generally used in ferrocement structures are having opening sizes in mm as 25 x 25, 50 x 50,75 x 75, 100 x 100, and 150 x 150. The wire gauges may vary from 10 to 16. Rolls of weld meshes are available in widths of 900, 1200 and 1500 mm and in lengths of 15 m or 30 m.

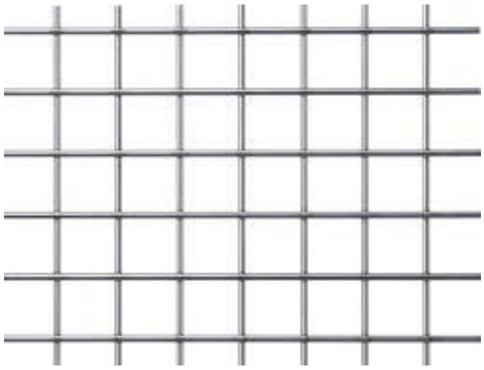


**Fig. 3.1 Welded mesh**

### 3.3.1.1 Practical hints in using weldmesh:

While using weldmesh, the following precautions should be taken:

1) Weldmesh should be cut only by a weldmesh cutter and not by chisel and hammer.
2) Weldmesh is available in form of rolls in market. When they are opened the weldmesh comes out in bent and curved form. It needs to be straightened out. Also when the roll is opened, it comes out with springing action, which may cause injury to the worker. So the roll should be opened in the reverse direction of its curvature.
3) While straightening the weldmesh, it should be hammered out with a light hammer. Do not hammer at the joints, the weld may get opened. Hammer the wires in between the welds in both directions.
4) It is better to weld the skeleton first and then tie weldmesh and chickenmesh over it.
5) While cutting the weldmesh, it should not be cut close to the weld, because there is a possibility of opening of all the welds in the line of welding and the wire strands may get separated. The cut should be taken at about half a centimetre away from the weld.
6) Along the length of the weldmesh rolls, at the top and bottom edges, small protruding of wire are left by the manufacturer. They should not be cut. These protruding are useful while tying chickenmesh on it.

### 3.3.1.2 Fine wire meshes /interlocked hexagonal wire mesh/Chicken wire mesh)

1) Woven square meshes are formed by weaving them on wire weaving machines and are having rectangular openings of size 13 mm X 13 mm, 19 mm X 19 mm, 25 mm X 25 mm, in them. Wire gauges used are 18 to 22 gauges. Generally they are ungalvanized. Rolls of 15 m or 30 m in length and widths of 900 mm or 1200 mm are available in market.
2) When square wire mesh is cut the ends of wires should be folded back immediately. Otherwise the mesh wires get loosened and separated.
3) Interlocked woven hexagonal wire meshes (also called chicken mesh) While weaving they are also interlocked due to which, they take a hexagonal shape. Their interconnections are not rigid. Chickenmesh is available in galvanized form as shown in fig 3.2, and in sizes of openings of 13 mm X 13 mm, 19 mm X 19 mm and 25 mm X 25 mm. Wire gauges from 20 to 26 are in use. Rolls of chickenmesh of 15 m or 30 m lengths and 900 mm, 1200 mm or 1500 mm widths are available in market.

**Fig. 3.2 Chicken mesh or hexagonal mesh**

**3.3.2.1 Practical hints in using chickenmesh:**

1) Chicken meshes have an advantage that they can be stretched and tightly tied over the weldmesh. A width of 900 mm of the mesh may get extended by about 50mm to 75mm.
2) Wires being interlocked in form of hexagonal net, geometrically it is not a rigid framework. Hence, its stretching in both directions is possible. While stretching and tying, care should be taken that the hexagonal shape of the mesh is maintained, by applying equal stretch in both directions. Square meshes cannot be stretched and tied tightly and so use of chickenmesh as fine wire reinforcement in ferrocement is recommended.
3) Along both the edges of the mesh, a straight wire is provided for convenience of weaving. At the time of using, these straight wires should be cut at some intervals. Otherwise they prevent stretching of the mesh by restraining their edges. This will result in bulging out of the mesh at its edges.

**3.3.2.2 Expanded metal:**

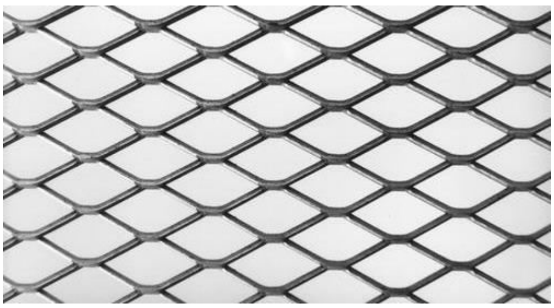


**Fig.3.3 Expanded Metal**

Expanded metal lath (XPM) as shown in fig 3.3 is formed by slitting thin gauged steel sheets and then expanding them in directions perpendicular to the slits. This expanded thin sheet takes the shape of a diamond. Among all the fine wire meshes, it is expanded metal, whose shape, size and structural properties can be assured exactly. Hence in many research projects, expanded metal lath is used and properties of ferrocement are established with it.

XPM mesh is designated by short diagonal (shortway of mesh –SWM), Long diagonal (longway of mesh –LWM) of the diamond, width of the strand and the thickness of the plate. Thus, 100 X 250 X 3.25 X 10g, XPM sheet means, 100mm SWM, 250mm LWM, 3.25mm strand thickness and the gauge of the plate is 10.

XPM sheets of various sizes are available in market. XPM sheets are very hard to cut and when a number of layers are to be used, it is very difficult to force mortar in all the interstices. Orientation of XPM mesh plays very important role in determining the tensile strength of ferrocement specimen. While forming XPM, by stretching the slotted sheet, the intersections of the strands get twisted and become weak in tension.

### 3.3.2 Crimped woven wires mesh (Watson mesh).

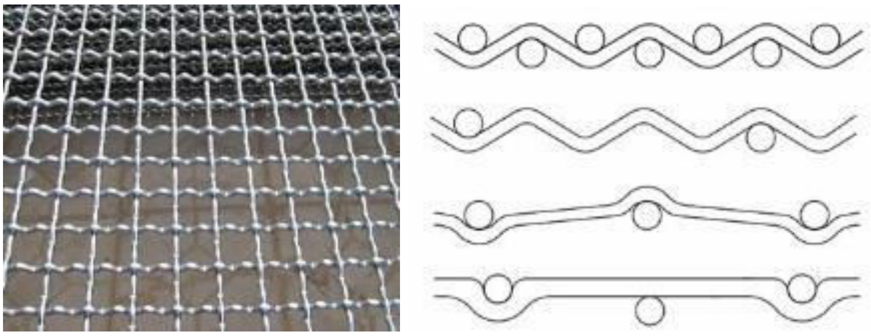


**Fig.3.4 Crimped woven mesh**

A three dimensional mesh formed by Watson is specially developed for boat building. In this a crimped creeper wire frictionally locks together three alternating layers of straight wires. It forms a mesh with total thickness of five wire diameters. The frictional locking of alternate layers of wire cause little spring-back action and enables the mesh to be easily formed into the desired shape. Transverse crimped wire holds the high tensile wires in the longitudinal direction. In this type of mesh, long stretches of straight wires without twists, crimps, pressings, punching or welding are available. This results in very strong mesh and permits complete flexibility. This is a three dimensional mesh with reinforcing members in all the three directions as shown in fig.3.4.

## 3.4. Cement Mortar

The matrix used in ferrocement primarily consists of mortar or micro concrete with hydraulic cement as binder, sand as fine aggregate and water. Normally the aggregate consists of well graded fine sand passing IS 2.36 mm sieve. If permitted by the size of the mesh and the distance between the mesh layers, small size coarse aggregate may be added to the sand. The mortar matrix usually comprises of more than, 90 percent of the ferrocement volume, and hence has a great influence on the behavior of the final product. Hence a great care should be exercised in choosing the constituent materials and in mixing and placing them.

### 3.4.1 Cement:

The cement should be fresh, of uniform consistency and free from lumps and foreign matter. It should be stored under dry conditions for as short duration as possible. Types of cement are ordinary Portland cement of various grades, rapid hardening cement, sulphate-resisting cement, white and coloured cement and pozzolana cement. The choice of any particular cement depends upon the site conditions.

Generally Ordinary Portland Cement of 43 or 53 grades is used in ferrocement. In coastal areas or for structures exposed to sea water or acidic industrial wastes sulphate resisting cements are recommended. If sulphate-resisting cements or admixtures are not available, rich cement mortar should be used and later the structure should be coated. Cement content in ferrocement is higher than in conventional reinforced concrete. For Ordinary Portland cement IS 8112: 2015 and IS 12269: 2015 should be referred.

### 3.4.2 Aggregates: Sand

#### 3.4.2.1 Natural Sand

Well graded and washed river sand passing 2.36mm IS sieve is most commonly used as fine aggregate in ferrocement. The maximum size of aggregate depends upon the size of mesh openings and the spacing between the layers of mesh. For 13mm mesh openings, 1/4th its opening size, that is less than 3.25 mm, should be the maximum size of the fine aggregate. For proper gradation fineness modulus of sand should be between 2.4 to 2.5 for maximum grain size of 1.18mm and it should be 2.9 to 3.0 for maximum grain size of 2.36 mm. As shown in fig 3.5, proper control over the grain size and fineness modulus will result in the least water requirement, with better workability and higher strength. Grading of sand, with cement of 43 grade and aggregate as crushed sand confirming to IS 383-1970 is given in table 3.3.

**Table 3.3 -Grading of sand for Grading zone II (as per IS 383:1970)**

| Sieve Size | | Grading limit |
|---|---|---|
| **ASTM** | **Particle size** | **% passing** |
| 4 | 4.75 mm | 90 to 100 |
| 8 | 2.36 mm | 75 to 100 |
| 16 | 1.18 mm | 55 to 90 |
| 30 | 600 microns | 35 to 59 |
| 50 | 300 microns | 8 to 30 |
| 100 | 150 microns | 0 to 10 |

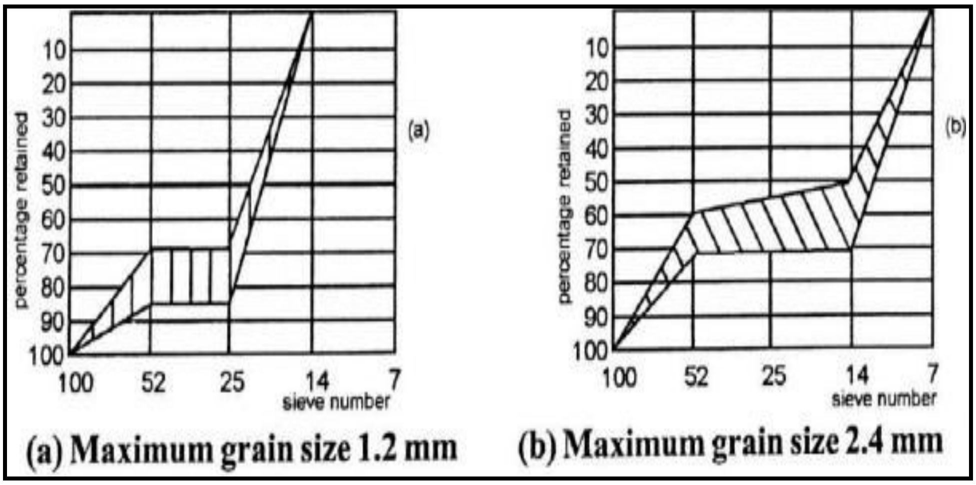



**Fig 3.5 Gradation of sand**

The fine aggregate should be clean, free from organic matter and relatively free from clay and silt. Hard, strong and sharp silica will give strong mortar, while rounded grains of river sand will result in smooth mortar finishes. IS 383-1970 for coarse and fine aggregates from natural sources should be referred to for specifications of natural sands.

#### 3.4.2.2 Crushed sand or manufactured sand

Crushed sand is a good substitute for natural sands. It is manufactured from quarried rock, by bringing down its particle size in the range of 4.75mm to 150 microns. Crushed sand is quite different than stone dust, which is a waste from stone crushers. Crushed sand has two important features; one is its gradation and the second is its particle size. Crushed sands are successfully used for various grades of concrete from M15 to M40.

### 3.4.3 Water

The mixing water should be fresh, clean and potable. It should be free from organic matter, silt, oil, sugar, chlorides and acidic materials. The value of pH should be close to 7.0. The salt water is not acceptable but chlorinated drinking water will do.

### 3.4.4 Admixtures

Chemical admixtures in ferrocement serve four purposes:

a) Water reduction which increases the strength and reduces the permeability. It can be achieved by using super plasticizers.
b) Waterproofing compounds may be used to get watertight structures.
c) Air entraining agents increase the resistance to freezing and thawing.
d) Suppression of galvanic action between galvanized steel and cement is achieved by using Chromium trioxide approximately 300 parts per million, in mixing water.

### 3.4.5 Proportioning of cement mortar

Normally rich cement mortars of mix proportions of (1:1.5) to (1:4) by volume are used in ferrocement. When sand content is increased, its water requirement goes up to maintain the same workability. To obtain strong, dense and mortars of such a consistency, which can easily penetrate the layers of meshes, trial mixes should be taken. Fineness modulus of the sand, water cement ratio and the sand cement ratio for the mix should be determined and used. Due to dispersion of wires throughout the body of ferrocement, problem of shrinkage is not there. Depending upon the method of application of mortar, its plasticity plays an important role.

Normally the slump of cement mortars should not exceed 50 mm to provide stiff mortar mix, which can penetrate meshes. For most applications, the 28 days compressive strength of moist cured cement mortars should not be less than 35 MPa.

Generally the mix proportions are specified by their weight but on small jobs mixes are made on volume basis. The bulging effects of moist sands must be allowed for, when the mixes are based on volume basis.

### 3.4.6 Practical hints for proportioning and mixing of cement mortars.

a) A simple field test to find out stiff consistency of mortar is to form a ball of the mortar in hand and when it is tossed up, it should retain its shape.
b) Another practical test is, when the trowel is inserted in the heap of the mix, it should stand erect.
c) To check silt content in sand, mix it with water, put it in a glass jar, shake it and allow it to settle. The thickness of the layer of the silt collected over sand will show percentage silt content in sand approximately.

d) Another simple test to check silt content, is to rub the wet sand on the palms of hand, the hands will get spoiled if the silt content is high.
e) One medium sized ghamela when filled in to its brim, with level surface, contains about 6 to 8 liters of sand.
f) A good homogeneous cement mortar mix has uniform gray cement-colour and smooth texture. All sand particles are fully covered with cement paste.
g) Compressive strength of ferrocement is the compressive strength of matrix. Hence extreme care should be taken while proportioning and mixing of mortar. If higher strengths are desired, steel fibers may be added or polymer mortars may be used.

### 3.4.7 Guidance of proportion of mortar

A quick guide for various mortar mixes by volume measure and by weight is given in tables 3.4 and 3.5

**Table 3.4 Cement Mortar mix by volume**

Dry mix of mortar = 1.33 x (wet mortar mix)

(Quantities per $m^3$ of wet mortar)

| Mix by volume | Cement (Liters) | Dry sand (Liters) |
|---|---|---|
| 1:1.0 | 666 | 666 |
| 1:1.5 | 533 | 800 |
| 1:2.0 | 444 | 888 |
| 1:2.5 | 380 | 952 |
| 1:3.0 | 333 | 1000 |
| 1:4.0 | 267 | 1066 |

**Table 3.5 Quick guide for mortar mix by weight for various types of sand**

| Mix by volume | Per bag of Cement (kg) | Sand in liters per bag of cement | | |
|---|---|---|---|---|
| | | Dry | River | Wet |
| | | Density 1600 kg /$m^3$ | Density 1800 kg / $m^3$ | Density 2000 kg / $m^3$ |
| 1:1 | 50 | 31.25 | 27.77 | 25.00 |
| 1:1.5 | 75 | 46.87 | 41.67 | 37.50 |
| 1:2 | 100 | 62.50 | 55.55 | 50.00 |
| 1:2.5 | 125 | 78.12 | 69.44 | 62.50 |
| 1:3 | 150 | 94.00 | 83.33 | 75.00 |
| 1:4 | 200 | 125.00 | 111.00 | 100.00 |

**3.4.8 Methods of Forming or casting:** Mortar filling is done by two ways

**Press fill method:** After making the skeleton of bars and tightly fitting of meshes, it is checked that there is movement of the meshes. The structure shall be strong enough for any shocks and vibrations. The mortar of cement to sand in 1:2 or 1:3 proportions is preferred. The water content shall be as less as possible. The test is that the mortar shall not flow but a ball of mortar can be prepared. The water to cement ratio normally is 0.35 to 0.40. The thick mortar is then pressed in the gaps of the meshes by using plate trowels. Two persons are required for pressing it from both sides. No air shall remain in the mortar. After 3 hours, the filled mortar becomes hard enough. The same surface can be plastered smooth after 1 day. This method is useful when both surfaces are available for press filling.

**Fig 3.6 Press Spray method**

**Press Spray method:** When only one surface is open, pressing of mortar from one side is also possible, provided other surface is closed by fixed surface of rock or wall as shown in fig. 3.6. For mass scale work sprayers of mortar are used. Water to cement ratio for such mortar is 0.50 to 0.60. The mortar is sprayed with pressure and it sticks in the gaps of meshes. The work of spraying is much faster than that done manually.

**3.4.9 Job requirements of skilled workers**:

Skilled workers required are welder for fabricating the skeleton, fitter to tie mesh and mason for mortaring.

A. **Welder:** For welding skeletons, a welder with knowledge of spot welding and line welding is sufficient. No special high-tech welding is involved and hence any ordinary welder will serve the purpose.

B. **Fitter:** For tying the mesh, any fitter, with a training of few hours, can undertake the job.

C. **Mason:** For mortaring, the mason needs training in press filling mortar in the mesh layers. Generally the masons are trained to plaster the walls by splashing mortar on them. It should be emphatically stressed, that mortaring of ferrocrete is not plastering, but it is impregnating the meshes with mortar. Any mason can pick up this skill within no time.

For finishing the surfaces a good plasterer will be required.

## 3.5 Casting by using a vibrator:

As the ferrocrete is thin walled, use of a needle vibrator is of no use. A wood orbital sander can be satisfactorily used for this purpose. It is very handy and is just like an electric iron used for pressing clothes. The sander has got a handle and a vibrating plate and it can be moved over the mortar to vibrate and compact it to its full depth. This orbital sander is very convenient to compact mortar in thin layers.

## 3.6 Curing

Curing of the ferrocement walls and components is done as specified for cement concrete. The hardening process is completed in 21 days. However as the thickness is less, cracks due to shrinkage may develop. For this, curing has to be properly observed. The covering of surface by wet cotton is always recommended. The curing plays a very important role in ferrocrete construction, as the structures are very thin walled and likely to get dried very quickly, particularly in summer season of the tropical countries.

In curing the structures like water tanks or containment vessels, they are filled in completely with water and cured for 21 days. For the first 8 to 10 days the mortar is seen wet and saturated with water. As it gets hardened with time, outer surface of the tank becomes bone-dry and indicates that the tank is getting cured properly. The tank should not be filled in full immediately after casting. Every day about 30 to 40 cm of height of the tank should be filled, till it is full. The curing of other ferrocrete structures can be done using wet gunny bags. For precast ferrocrete items, sprinklers or steam curing techniques may be used.

# CHAPTER 4
# EQUIPMENT AND TOOLS

## 4.1 Tools, plants and machinery

After consideration of the materials required for building a ferrocement structure, we have to consider various tools and equipment required for construction. The equipment required to fabricate and cast ferrocrete structures is given below.

Generally fabrication, welding and tying of ferrocrete cage is undertaken in factories. The work left at site is only mortaring, finishing and curing. For pre-casting of ferrocrete products separate plants and machinery are required.

## 4.2 For fabrication and welding of bar skeleton:

For cutting, straightening and bending of bars tools of a fitter are adequate as shown in fig 4.1. For small jobs a shearing chisel and a heavy hammer will serve the purpose but for large scale works, shear cutting machine should be preferred.


**Cutting** **bending** **welding**

**Fig. 4.1 Cutting, bending, welding the bar skeleton in ferrocement**

A single phase welding transformer will suffice the need of spot and line welding of bar skeleton. All the welder’s tools with safety measures will be required.

## 4.3 For tying mesh on bar skeleton

For cutting meshes, weld mesh cutters and chicken mesh cutters are used as shown in fig 4.2. For binding the mesh to bars, pliers and hooks are required. For stretching and tightening the mesh, mesh pullers in form of screw drivers are preferred as shown in fig 4.3. Stretching and tying mesh tightly is a very monotonous, tedious and time consuming job. It needs meticulous workers to finish it properly.

**Fig. 4.2 Cutting pliers**

**Fig 4.3 Pliers, hooks needed to stretch the meshes**

## 4.4 For mixing mortar:

On small jobs, hand mixing is done, and all the tools of a mason are used for it. For major jobs, a mortar mixer is preferred. A mortar mixer with spiral blades or paddles inside a stationary drum or a pan type of mixer can be used. A rotating drum mixer with fins fixed to the sides is not recommended. Mortar should be mixed in batches, in such a way that the mortar mixed in a batch should be used within an hour of its mixing. Retempering of the mortar should be prohibited.

**Fig. 4.4 Mortar mixer**

## 4.5 For mortaring the structure

As explained earlier, mortaring does not mean plastering the meshes. The mortar is to be pressed inside the gaps of meshes from both the sides. In hand working, plate trowels are used in addition to all the tools required by a mason as shown in fig. 4.5. A vibro-press is also developed by some professionals which assure full penetration of the mortar in the mesh layers and results in dense mortar filling. For large works guniting may be adhered to, with complete guniting system as shown in fig 4.6. A small size brush coater may be developed and tried as an alternative.

**Fig. 4.5 Trowels, Plumb, small vibrator to be fixed on plate trowel**

**Fig. 4.6 Guniting machine and nozzle**

## 4.6 Curing

For curing of ferrocrete structures, continuous moist curing is essential. Being a thin walled structure, ferrocrete gets dried early and hence an extra precaution is required in curing it. Small pump with nozzle is necessary for sprinkling as shown in fig 4.7. For precast products curing by sprinklers or by immersion in water tanks is recommended. For water tanks, which are cast at site, water can be filled inside the tank on the second day. But the level of water shall be increased daily by only 0.2 of the height of the tank. The tank shall not be filled full on the second day.

**Fig. 4.7 Curing hose, small nozzle, and water pump.**

## 4.7 For handling ferrocrete items:

For handling, hoisting and erection of small size articles like water tanks, a chain pulley block with a hoisting pole are used as shown in fig 4.8. A small capacity crane or hydra may be used to handle precast products. The hooks are to be attached to the precast component only at specified location. Otherwise cracks may develop.

**Fig 4.8 Chain pulley system, tripod and hydra crane**

# CHAPTER 5
# TESTING OF MATERIALS (FIELD TESTS)

## 5.1 Tests of raw materials in forming ferrocrete structures

a. Test of skeletal steel in the form of angles, steel bars, welded wire fabrics or pipes.
b. Test of steel wire meshes for forming cages.
c. Test of rich cement mortar, as matrix in the form of micro-concrete.

All these three raw materials are those which are commonly used in practice in construction of conventional buildings. They are easily available even at village level.

## 5.2 Tests of skeletal steel in the form of steel bars

Skeletal steel as the name implies is generally used to give basic shape and size to the structure. Steel bars of 4 to 10 mm dia. are generally used as shown in fig. 5.1. Sometimes angle framework may be used to support the structure.

**Fig. 5.1 Skeleton steel bars**

Steel bars and wire meshes to be used should be according to I. S. Specifications as follows:

| | | |
|---|---|---|
| Mild steel bars | : | IS-432(Part I) 1982 |
| Hard drawn steel wire mesh fabric | : | IS 1566-1982 |
| Fine wire meshes and welded mesh | : | IS 16014: 2012 |
| Mild steel wire confirming | : | IS 280-1978 |

Whenever a rebar under a high temp is quenched under controlled conditions and cooled in air subsequently, due to metallurgical transformation, two distinct phases (shades) show out. Tempered marten site in the form of a ring with definite width forms the outer case (ring), whereas the inner core remains pearlite / ferrite. The outer case (ring) and inner core are distinctly visible, when the cross-section of rebar is etched.

### 5.2.1 The Field Test – test procedure.

Following are the steps for carrying out the test-

1. Cut 'small length samples' from a few randomly selected TMT rebars of any lot, preferably in a cutting machine, if not, by hack-saw cutting.
2. Cross-sections of test samples shall be mirror finished with any suitable polishing device. An ideal polishing device is a unit with rpm of about 3000, where in emery sheet can be mounted on the rotating circular disc. Polishing of cross-sections shall be done for at least about 10 minutes.

3. The cross section shall be smeared (etched) with drops of 'Nitrol Solution'. It is nothing but a synthesis of '10 % of Concentrated Nitric Acid' and '90 % of Ethyl Alcohol'. Soon after etching, two distinct phases (Shades) with uniform thickness are clearly visible on the c/s, if the rebars are 'Genuine TMT Rebars'. If the two phases are not distinct, the rebars are either 'Substandard' or 'Fake' TMT rebars. Note: It is essential that the c/s need to be examined soon after etching. In case of delay, etching has to be redone.

## 5.3 Tests of Cement

The cement should be fresh, of uniform consistency and free from lumps and foreign matter. Types of cement are ordinary Portland cement of various grades, rapid hardening cement, sulphate- resisting cement, white and coloured cement and pozzolana cement. The choice of any particular cement depends upon the site conditions.

Generally ordinary Portland cement of 43 or 53 grade is used in ferrocrete. In coastal areas or for structures exposed to sea water, or acidic industrial wastes sulphate resisting cements are recommended. Pozzolana cement is generally not recommended.

For Ordinary Portland cement IS 269:2015 – (33 grade Ordinary Portland cement) should be referred.

### 5.3.1 Some hints to test the cement in field

1. **Date of Manufacturing:** As the strength of cement reduces with age, the date of manufacturing of cement bags should be checked.
2. **Cement Color:** The color of cement should be uniform. It should be typical cement color i.e. gray color with a light greenish shade.
3. **Whether Hard Lumps are Formed:** Cement should be free from hard lumps. Such lumps are formed by the absorption of moisture from the atmosphere.
4. **Temperature Inside Cement Bag:** If the hand is plunged into a bag of cement, it should be cool inside the cement bag. If hydration reaction takes place inside the bag, it will become warm.
5. **Smoothness Test:** When cement is touched or rubbed in between fingers, it should give a smooth feeling. If it felt rough, it indicates adulteration with sand.
6. **Water Sinking Test:** If a small quantity of cement is thrown into the water, it should float some time before finally sinking.
7. **The smell of Cement Paste:** A thin paste of cement with water should feel sticky between the fingers. If the cement contains too much-pounded clay and silt as an adulterant, the paste will give an earthy smell.
8. **Glass Plate Test:** A thick paste of cement with water is made on a piece of a glass plate and it is kept under water for 24 hours. It should set and not crack.
9. **Block Test:** A 25 mm × 25 mm × 200 mm (1"×1"×8") block of cement with water is made. The block is then immersed under water for three days. After removing, it is supported 150 mm apart and a weight of 15 kg uniformly placed over it. If it shows no sign of failure, the cement is good.

## 5.4 Tests of aggregates

Well graded and washed river sand passing 2.36 mm IS sieve is most commonly used as fine aggregate in ferrocrete. Grading of sand, with cement of 43 grade and aggregate as crushed sand confirming to IS 383-1970 (table 5.1) is given in table below.

**Table 5.1 Grading of sand for Grading zone II (as per IS 383:1970)**

| Sieve Size | | Grading limit |
|---|---|---|
| **By ASTM** | **By Indian Standards** | **% passing** |
| 4 | 4.75mm | 90 to 100 |
| 8 | 2.36mm | 75 to 100 |
| 16 | 1.18mm | 55 to 90 |
| 30 | 600microms | 35 to 59 |
| 50 | 300microns | 8 to 30 |
| 100 | 150 microns | 0 to 10 |

The fine aggregate should be clean, free from organic matter and relatively free from clay and silt. Hard, strong and sharp silica will give strong mortar, while rounded grains of river sand will result in smooth mortar finishes.

IS 383-1970 for coarse and fine aggregates from natural sources should be referred to for specifications of natural sands.

### 5.4.1 How to check quality of sand on field (Field Test on Sand)

1. Take a glass of water and add some quantity of sand in it. Then shake it vigorously and allow it to settle. If clay is present in sand, it will form a distinct layer at the top of sand.
2. In order to detect presence of organic impurities in sand, add sand to the solution of sodium hydroxide or caustic soda and then stir it. If colour of solution changes to brown, it indicates the presence of organic impurities.
2. Take a pinch of sand and taste it. If tasted salty then there exist some salt in sand.
3. Take sand and rub it against the fingers. If fingers are stained, it indicates that sand contains earthy matter.
4. The colour of sand will indicate the purity of sand. The size and sharpness of grains may be examined by touching and observing visually.
5. For knowing fineness, durability, void ratio the sand should be examined by mechanical analysis.

## 5.5 Crushed sand or manufactured sand:

Crushed sand is a good substitute for natural sands. It is manufactured from quarried rock, by bringing down its particle size in the range of 4.75 mm to 150 microns. Crushed sand is quite different than stone dust, which is a waste from stone crushers. Crushed sand has two important features; one is its gradation and the second is its particle size. Tests on natural and crushed sand are done by using same IS 383:1970.

Compared to natural sands, the crushed sands have the following special features:

a. Fines passing 150 micron sieve are restricted. The deleterious materials like clays, silts, inorganic and organic salts contained in natural sands affect the strength and durability of concrete. They also cause cracking and discolouring to the finished plaster surface.
b. The basic composition of particle sizes of natural sands hardly confirms with the gradation desired in the mix design. In crushed sands, different particle sizes are available which can be blended to the desired gradation curve.
c. The spheroidal shape of particles of natural sand offer less surface area for the cement to cover, as compared to the cuboidal shape of the crushed sand. Hence cement consumption is more in crushed sand.
d. Natural sand needs sieving. The sand available in market contains 15 to 25 % oversize particles which are of no use at site.
e. To remove clay, silt and deleterious matter natural sand needs washing.
f. The fines in crushed sands, passing 75 microns, are within limit of 20 % as specified in IS-383-1970. This fraction results in efficient aggregate packing and denser concrete mix. This increased efficiency in void filling in ultra-fine range of cement paste, closes the capillaries and decrease permeability of concrete.

## 5.6 Water

The mixing water should be fresh, clean and potable. It should be free from organic matter, silt, oil, sugar, chlorides and acidic materials. Water should have Ph more than or equal to 7.0. Salty water is not acceptable but chlorinated drinking water will do. Presence of salt in water such as chlorides reduces initial strength of concrete and causes rusting problem in steel used in construction. Therefore, testing of construction water is very essential.

In market construction water testing kits are available as shown in fig. 5.2.

**Fig 5.2 Construction water testing kits**

Construction Water Test Kit shall consist of all the necessary accessories and reagents to measure the following key parameters (Table 5.2).

**Table 5.2 Key parameters for water test kit**

| Product Name | Method | Range | No. of Tests |
|---|---|---|---|
| pH | Strip | 2.0-1.05 | 100 test |
| Total Hardness | EDTA Titrimetry | 1 - 25 ppm | 100 tests |
| Total Alkalinity | Acid-Base Titrimetry | 5-500 ppm | 100 tests |
| Chloride | Argentometry | 10 - 500 ppm | 100 tests |
| Calcium | EDTA Titrimetry | 0 - 600 ppm | 100 tests |
| Iron (Low range) | 1,10-Phenanthroline | 0 - 1 ppm | 100 tests |
| Silica | ............. | 0.5-2.5 mg/L | 100 tests |
| Ortho phosphate | Stannous Chloride | 0 - 1 ppm | 100 tests |
| Sulphite | Iodometry | 0 - 500 mg/L | 100 tests |

# CHAPTER 6
# LABORATORY TESTS

## 6.1 Testing of ferrocrete

Tests and observations which are commonly made in design, construction and subsequent service life of concrete structures are also applicable to ferrocrete structures. They include

1) Testing of physical, chemical and mechanical properties of component materials prior to their acceptance, like water purity, sieve analysis, strength of mesh etc.
2) Tests to control the properties of fresh mortar mix: like slump, air content etc.
3) Tests on structural properties of the hardened composite: like all types of strengths, cracking behavior, fatigue permeability etc.

## 6.2 Laboratory tests on materials like steel bars, cement and sand: These laboratory tests are carried out as per relevant IS codes as mentioned in table no. 6.1.

**Table 6.1 Material and relevant Indian standard code**

| Sr. No. | Materials | BIS code |
|---|---|---|
| 1 | Cement | 1. IS 650:1991 - Specification for standard sand for testing of cement<br>2. IS 3535:1986 - Methods of sampling hydraulic cement<br>3. IS 4031:1996 - Methods of physical tests for hydraulic cement<br>4. IS 4032:1985 - Method of chemical analysis of hydraulic cement<br>5. IS 8112:1989 - Specification for 43 grade ordinary Portland<br>6. IS 12269:1987 - Specification for 53 grade ordinary Portland |
| 2 | Sand (Natural / Crushed) | 1. IS 383:1970 - Specification for coarse and fine aggregates from natural sources for concrete<br>2. IS 2386:1963 - Methods of test for aggregates for concrete |
| 3 | Water | 1. IS 456:2000 - Code of practice for plain and reinforced concrete |
| 4 | Steel | 1. IS 432 : 1982 - Mild steel & medium tensile steel bars and hard drawn steel wires for concrete reinforcement |
| 4 | Welded mesh and chicken mesh | 1. IS 16014 : 2012 - Mechanically woven, double-twisted, hexagonal wire mesh gabions, revet mattresses and rock fall netting (galvanized steel wire or galvanized steel wire with PVC coating) – specification<br>2. IS 1566 : 1982 - Specification For Hard-Drawn Steel Wire Fabric For Concrete Reinforcement<br>3. IS 280:2006 – mild steel wire for general purpose |
| 5 | Mortar and Concrete | 1. IS 456:2000 - Code of practice for plain and reinforced concrete<br>2. IS 516:1959 - Method of test for strength of concrete<br>3. IS 2770:1967 - Methods of testing bond in reinforced concrete<br>4. IS 3085:1965 - Method of test for permeability of cement mortar and concrete<br>5. IS 5816:1999 - Method of test for splitting tensile strength of concrete<br>6. IS 14858:200 - Compression testing machine used for testing of concrete and mortar - specification |
| 6 | Canal lining | 1. IS 10430 : 2000 - Criteria for design of lined canals and guidance for selection of type of lining ( second revision) |
| 7 | Ferrocement water tank | 1. IS 13356 : 1992 – Code of practice for Precast Ferrocement water tanks up to 10000 liter |

## 6.3 Testing structural properties of ferrocrete

Four types of tests are recommended to predict the structural properties of ferrocrete.

1. Compressive strength of mortar
2. Flexural strength (Load-Deflection Curve)
3. Tensile strength of mesh reinforcement
4. Stress-Strain Curve of ferrocrete specimen in tension.

This last test provides information on the yield strength of the mesh system, its effective modulus and its reinforcing efficiency when encapsulated by a mortar mix.

### 6.3.1 Compressive strength of mortar

It may be determined from cube with surface area 50 sq. cm tested in accordance with I.S.516-1959.

### 6.3.2 Flexural strength of ferrocrete

Ferrocrete specimens should be tested as simply supported beams with third point loading as shown in fig. 6.1.

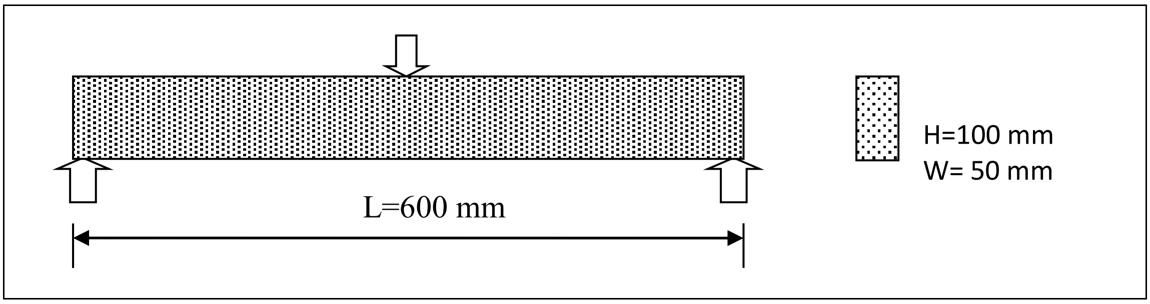



**Fig. 6.1 Sketch showing the test specimen**

### 6.3.3 Tensile properties of mesh reinforcement

Square or rectangular meshes can be tested directly in tension, however hexagonal meshes and the XPM cannot be tested without being encapsulated in mortar. In this case it is better to run a tensile test on ferrocrete material as described below in paragraph 6.3.4.

For square and rectangular meshes, the yield strength, the elastic modulus and ultimate tensile strength can be obtained from direct tensile tests on samples of wires or on flat coupons cut from the mesh. Testing has shown that the meshes show substantially different stress-strain response in different loading directions. The test should be according to the following guidelines.

a) The test specimen is prepared by embedding both ends of the rectangular coupon of the mesh in mortar over a length at least equal to the width of the sample. The mortar embedded ends serve as pads for gripping. The free portion of the mesh represents the test sample.
b) The width of test sample should be not less than 6 times the mesh opening or wire spacing measured normally to the loading direction.
c) The length of the test sample should be not less than 3 times its width or 150mm, whichever is larger.
d) Measurements of elongation, from which strains are calculated, should be recorded over middle half length of the mesh sample.
e) Yield strain of the mesh reinforcement is taken as the strain at the intersections of the best straight line fit of the initial portion of stress-strain curve and the best straight

line fit of the yielded portion of the stress-strain curve as shown in fig 6.2. The yield stress is then taken as the stress point on the original stress-strain curve at the yield strain found above.

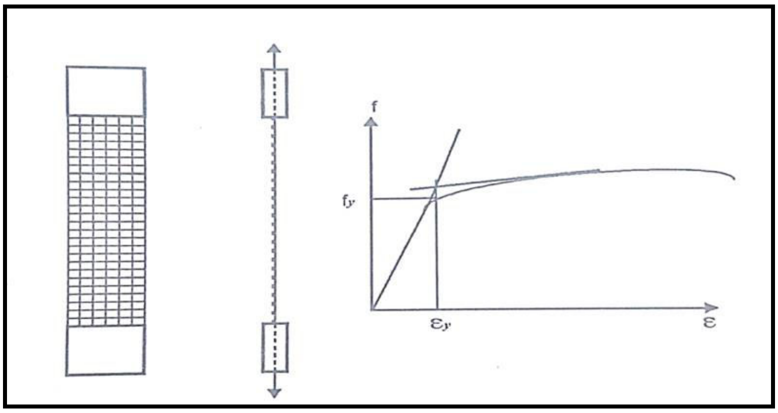



**Fig 6.2 Mesh tensile tests and stress strain curve**

**6.3.4 Tensile test of ferrocement**:

Direct tensile tests of ferrocement can be made using rectangular specimens satisfying the same minimum size requirements as mentioned in paragraph 6.3.3 for the mesh reinforcement. The test specimens should preferably be additionally reinforced at their ends for gripping. The middle half of the non-gripped portion should be instrumented to record the elongations as shown in fig 6.3.

A plot of the load elongation curve upto failure may be used to estimate the effective modulus of mesh system as well its yield strength, ultimate strength and efficiency factor. The yield strain and the corresponding stress should be determined according to the procedure described in paragraph 6.3.3.

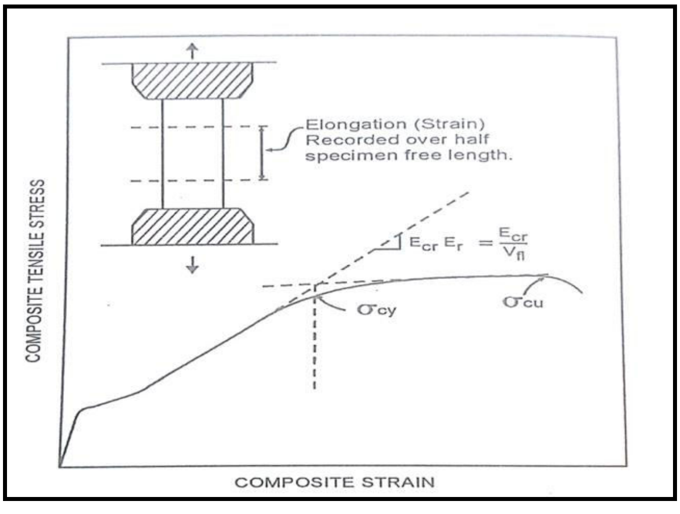



**Fig 6.3 Typical Stress Strain Curve of ferrocement in tension**

# CHAPTER 7
# APPLICATIONS OF FERROCEMENT

## 7.1 Application of ferrocement as per use

For different purposes ferrocement can be used in each and every civil engineering construction. Few applications are classified as below.

## 7.2 Liquid retaining structures

Water tanks: rectangular, circular, spherical, small and large size, open, covered, loft tanks, ground service reservoirs, underground and elevated, hopper and shell bottom.

Effluent treatment plants: septic tanks, clarifiers, settling tank, digesters, humus tanks, sludge-drying beds.

All the units in water purification plants, gobar- gas plants: KVIC type, Janata model, rain-water harvesting tanks, petal tanks, small dams, bandharas, Kolhapur type (KT) weirs and needles required for them.

Gutters and canals of parabolic section, water-proofing treatment to leaking dams on their upstream faces, cut-off trenches in earthen dams.

## 7.3 Soil retaining structures

Soil retaining walls, counterfort walls, grain silos, face wall panels and anchor plates for reinforced earth techniques.

## 7.4 Building components

Foundations-parabolic shaped, multi-bulbed under-reamed piles, RCC columns encased in ferrocrete, double walling for compound walls on expansive soils.

Walling-single wall, partition wall, double wall with cavity, thermally insulated soundproof walls, walls resisting rain penetration.

Single wall boxlike structures-garages, police chowki, water user association’s office, site office, stores, wayside shops, toilets, service units, godown, watchman’s cabin, animal sheds, bus shelters, telephone booths, cycle stands etc.

Double walled construction with inbuilt columns and beams, precast stiffened plates for cavity walls and hollow floors in construction of multistoried buildings, earthquake resisting structures. Lost formwork for RCC slabs, beams and columns.

Roofing:-flat roof with channel sections, sloping roofs. Shaped roofs like folded plates, cylindrical shells, domes, pagoda, vaults, umbrella, pyramidal, conical, corrugated catenary, gabled and hipped , thermally insulated, hollow floors with grid beams hidden inside forming box sectioned floors.

Flooring-jack arch, precast waffle plates, precast trough sections, ribbed slabs, grid floors, hollow floors, precast box sectioned large size hollow floors to replace large size pre-stressed core slabs.

Accessories- Chajja, lintel, weather-sheds, drop walls, sun-breakers and fins, canopy, lofts, cupboards, boxes for windows, staircase-folded and spiral, drainage chambers and covers, door and window frames, louvered window, precast service units, rainwater gutters, garden pots,

flower beds, decorative items for landscaping-ferrocrete trees, fountains, waterfalls, decorative compound walls, fence posts, decorative columns, panels and fascia, dust bins.

Waterproofing: for slabs, roofs, water tanks etc.

## 7.5 Large size space structures

Large size conduits for stream diversion and egg-shaped storm water drains, outfall sewers, precast canal sections in parabolic shapes, large size petal tanks with pull-back counterforts, spun pressure pipes, penstocks, Egg shaped digesters, chimneys, artistic farm houses.

## 7.6 Precast ferrocrete products

All types of small size units, in water retaining structures, building components and soil retaining structures

## 7.7 Special applications

Foldable ferrocrete elements, Lining to tunnels, tanks, basements, canals, Earthquake resisting structures, Precast pre-stressed girders of T, I, U sections, Polymerized ferrocrete railway sleepers, Hollow dams, Boats, wharfs and catamarans, Cold storage structures, Ferrocrete solar flat plate collectors, base units for parabolic and paraboloid solar concentrators, Portable bunkers, Cooling towers, Cladding steel framework, retrofitting of damaged buildings, Box girders for bridges, floating platforms.

## 7.8 Applications in Government departments

Normally Public Works Department and Water Resources Department use civil engineering constructions like dams, canals, buildings, roads or water supply schemes. Government engineers use common schedule of rates and derive estimates from these rates by adding for leads, lifts or any special provisions. In future ferrocement type designs will also be available for small dams, houses, canal linings etc. Some applications like retaining walls, buildings are common in many departments. So the applications are categorized in following three categories.

1) General- Building, retaining wall, Gardens and landscaping, Water tanks etc.
2) Public Works Department- Roads, bridges etc.
3) Water Resources Department- Cross drainage work, culvert, small bandhara, canal lining, water proofing of water retaining / carrying structures, cross drainage works, retrofitting of structure etc.

## 7.9 General application

### 7.9.1 Applications in Buildings

**Elevation treatments**: Architects need to construct curved shapes and aesthetic viewing structures. For this ferrocement is the solution. In fig 7.1 to 7.4 are the few examples of ferrocement banglow of different and difficult shapes using ferrocement technology.

**Fig 7.1 Pencil shaft of staircase (Symbiosis school, Pune)**

**Fig 7.2 Masjid in Nashik**

**Fig 7.3 Ferrocement fins at Satara Hospital**

**. Fig 7.4 Front elevation of a Banglow (Noida)**

**(Courtesy: Ferrocement Society, Pune)**

**Stairs**: Unlike RCC staircase very thin steps can be designed in ferrocement. Curved shapes and precast steps are also possible. Few photographs are shown in fig 7.5 and fig 7.6.

**Fig 7.5 Steps using ferrocement built near Katraj, Pune**

**Fig 7.6 Jadhav Farm House Gowe, Near Satara.**

**(Courtesy: Ferrocement Society, Pune)**

**Walls**: Practically any shape of wall is possible in ferrocement like in fig 7.7 to fig 7.9. HYPAR shapes are popular in architecture. Very thin section of walls increases the beauty of the building

**Fig 7.7 Nautilus House, Mexico**

**Fig 7.8 Oaxaca Building**

**Fig 7.9 Building in Kerala**

**(Courtesy: Ferrocement Society, Pune)**

**Domes and shells:** Various domes, shell, roofs in ferrocement are as per fig 7.10 to fig 7.12



**Fig 7.10 Shell roofs (Pune)** **Fig 7.11 Pyramidal roof** **Fig 7.12 Domes at Udaipur**

**(Courtesy: Ferrocement Society, Pune)**

**Jacketing of Columns and beams**: For old buildings where the columns are seen cracked jacketing with ferrocement makes them strong. It is found that the load carrying capacity is increased by 50%. Even beams are also sometimes seen in bad condition. The plaster of the beam is broken out. In such cases jacketing can be done by ferrocement and the restoration of the old building is possible thereby increasing the life of the building by approximately 20 to 25 years.

**Water proofing**: As the ferrocement layer is always water tight, many leaking RCC slabs and tanks need water proofing by ferrocement. Many canals and aqueducts can be lined by ferrocement. Additional load on the original structures due to water proofing by ferrocement is less than that by thick brick bat coba.

**Some Building applications**

**1) Bhalerao bungalow, Bhugaon near Pune**

Owner Mr. Bhalerao decided to construct a Farm House at Bhugaon near Pune. Its plan was made by the **Architects.** It is designed as single storied house with sloping roof. The roof area is totally about 500 $m^2$. In Plan the walls are either radial lines or arcs of the circles of different diameters and centers. Ridge line of sloping roof is also an arc. Steel Structure or RCC structure proved to be more costly and also more difficult. The Only best solution for the roof worked out as with Ferrocement. Roof and also walls were designed and are being done with double layer and Thermocol layer in between. **(Courtesy: Ferrocement Society, Pune)**

**Initial Design**:

i. **RCC Alternative:** In the Plan the building is a segment of a circle. Initially it was thought to be done in RCC. However cost of shuttering for roof was going too high due to its circular shape and slopes. Due to slopes and curvature it would have been very difficult to provide shuttering in exact form. It is practically impossible to make line of the shuttering. Normally concreting of the sloping slab is difficult as vibrating the concrete is difficult. So many times such slab leaks if proper water-proofing treatment is not provided. So this idea was discarded.

ii. **Structural Steel Alternative:.** Then it was thought to be done with steel structure. For steel structure it was possible to bend the sections with exact radius on bending machines. Then fabrication and erection works could have been done. However this would require bending machines on site with sufficient Electric Supply which is only possible with Gen set of more capacity. Cost of this whole thing was going high. Besides roofing with Pre coated or similar sheeting was not possible. So it was thought to be done with Bison Panels (Saw dust and Cement composite). Then these panels were to be covered with decorative Shingles. This system has certain short comings. Obviously costing was one of them and also water proofing was main concern. Repairing if needed would have been a big headache. Also this would require false ceiling work from bottom to have soffit plain.

iii. **Ferrocement Alternative:** Project Consultant was well aware of Ferrocement technology. So, he suggested and convinced the Owners and Architects about use of Ferrocement. Then the Ferrocement alternative was considered. It can overcome all the problems that were coming in RCC or steel structure. It was simpler, maintaining shape and dimensions was possible, leak-proof structure was easily possible, it is light weight than RCC, decorating the roof was with tiles etc is easily possible, making changes during construction is also possible. Then it was decided to go for Ferrocement Structure. The designer suggested double layered walls and also roof. This suggestion was welcomed by the Owners and the Architects.

**Fig 7.13 Bhalerao bungalow, Bhugaon near Pune**

**(Courtesy: Ferrocement Society, Pune)**

**2) House in Jabalpur**:

**Project details:**

| | | |
|---|---|---|
| **Name of the project** | : | 'Sumati Greens' |
| **Location of project** | : | Village Nigri – 25 kms. From Jabalpur on NH.7 |
| **Built up area** | : | Ground floor: 120 $m^2$and First floor: 145 $m^2$ |
| **Year of completion** | : | December 2012 |

This farmhouse building as shown in fig 7.14 rises up like a flower and attracts hordes of travelers who cannot stop themselves from pausing in their tracks curiously to have a closer look at this building.

The owner decided to build something unique and experimental. The building which is a farmhouse is a two storied structure 40 feet in diameter and houses two bedrooms and a kitchen cum lounge on the ground floor and a hall on the first floor with a balcony overlooking the gardens and the distant hills on the banks of river Narmada. There are eight fin walls surrounding the main structure which impart a petal like beauty to the structure and also dissipate the high wind pressure in the area throughout the year.

**Fig 7.14 House in Jabalpur**

**(Courtesy: Ferrocement Society, Pune)**

### 7.9.2 Retaining wall application

Retaining the earth fills is always a problem for engineers engaged in roads, bridges, canals and dams etc. Masonry retaining walls are now a day's obsolete. Concrete walls go very costly as the base width is increasing. The face wall is arch shaped and faced with convexity towards soil. These arch shaped walls are hardly 75 mm thick but take load of 6 to 8 meters of soil pressure.

Ferrocement retaining walls as shown in fig 7.15 have proved to be cheaper and cost saving. It is due to the shape which gives strength. Unlike RCC these walls are quite thin and are stiffened to account for their slenderness.

**Fig 7.15 Ferrocement retaining wall**

Thin counterfort retaining walls are already constructed in ferrocement at Talegaon near Pune as shown in fig 7.16. They have been proved to be cheaper by 40.50 percent as compared to traditional ones.

**Fig 7.16 Ferrocement counterfort retaining wall**

**(Courtesy: Ferrocement Society, Pune)**

### 7.9.3 Gardens and landscaping

**Sculptures:** Sculpture work is done at village in USA as well as at Houston, Texas as shown in fig 7.17.

**Fig 7.17 Small Belizean village USA sculpture, The Beatles sculptures on display at Adickes' Sculpture work in Houston, Texas.**

**Monuments:** Many symbolic monumental structures can be designed using ferrocement as shown in fig 7.18.

**Wavy roof of Vastad Lahuji Salve Health Centre, Aurangabad**

**A motor shed built in ferrocement at Auroville, Podicherry.**

**Fig 7.18 Monumental structures**

**Sit outs:** Different shapes are possible in gardens and parks for the visitors as a sit out. Photo in fig 7.19 below shows a sit out in Government college of Engineering, Salem.

**Fig 7.19 Sit outs**
**(Courtesy: Ferrocement Society, Pune)**

**Pergolas** as shown in fig 7.20

**Fig 7.20 Pergolas**

**Swimming pools** as shown in fig 7.21

**Fig 7.21 Swimming pools**

**Entrance gates** as shown in fig 7.22

**Entrance gate of Nal safari Ahmadabad**

**. Entrance gate of Mahindra Royal**

**Fig 7.22 Entrance gate**

**(Courtesy: Ferrocement Society, Pune)**

**Earth houses**: Underground houses as shown in fig 7.23 are very common in USA. In India also people have built such house. They are quite cool in summer also. The house is covered with earth and lawns above.

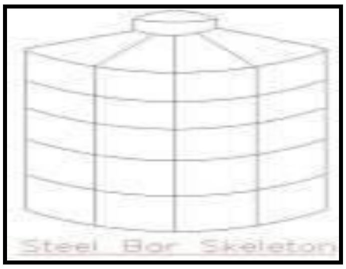
**Fig 7.23 Earth houses**

**Compound walls**: As shown in fig. 7.24, different shapes and designs are possible using ferrocement.

**Fig 7.24 Compound walls**

**(Courtesy: Ferrocement Society, Pune)**

**7.9.4 Water tanks**: This ferrocement material is basically water tight. So people used it for boat building. Last 50 years it is very popular in India and Singapore for water tanks. The durability of ferrocement tanks as compared to steel tanks is tremendous. Many shapes are possible for such ferrocement tanks. Popular are cylindrical. To contain a prescribed quantity of water, cylindrical tanks need lesser walling area. The walls are subjected to hoop stresses. RCC cylindrical tanks may be costly due to curvilinear formwork and higher steel percentage. Ferrocrete tanks with mesh reinforcement cast without formwork is definitely a cheaper alternative. But for large spans and large capacity the shape of wall has to be changed as in fig 7.25 and table 7.1 below.



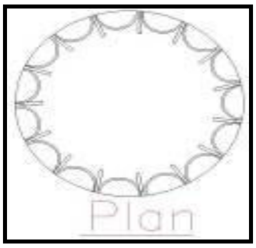



**Fig 7.25 Plan of rectangular tank, circular tank, petal tank**

**Table 7.1 Commonly used cylindrical tanks.**

| Sr. No | Dia in m. | Height m | Capacity litres | Surface area of closed tank $m^2$ |
|---|---|---|---|---|
| 1 | 0.60 | 0.90 | 250.0 | 2.92 |
| 2 | 0.90 | 0.90 | 575.0 | 3.81 |
| 3 | 0.90 | 1.25 | 800.0 | 4.80 |
| 4 | 1.25 | 0.90 | 1100.0 | 5.98 |
| 5 | 1.25 | 1.25 | 1525.0 | 6.97 |
| 6 | 1.25 | 1.25 | 2200.0 | 9.42 |

In rural area water tanks and storages are badly needed. If living in village people know this technology, which is very rural friendly, then they can build these tanks very easily thereby saving outside labour charges. In Maharashtra, nearly in all districts, one can find ferrocement tanks built by villagers. For the capacity of the tank, there is no limit. A water tank of 12 lakh liters is constructed with innovative design near Talegaon Dabhade, Dist Pune. The photo in fig 7.26 shows the petal type walls and counterforts to support the walls.

**Fig 7.26 Water tank near Talegaon Dabhade, Dist Pune**.

**(Courtesy: Ferrocement Society, Pune)**

## 7.11 Application in PWD

### 7.11.1 Applications in roads and bridges

**Roads**: Roads in slushy area or in BC soil can be built with ferrocement. Precast road pavements can be done by ferrocement. A very fast road construction in villages is possible using precast units. Roadside furniture like signboards and display signs can be done using ferrocement. Many times concrete roads need maintenance. The big potholes can be easily repaired using ferrocement.

**Flexible Pavements**

Due to the ease in precasting and thinness of the plates, it is possible to make precast ribbed plates as shown in fig 7.27.

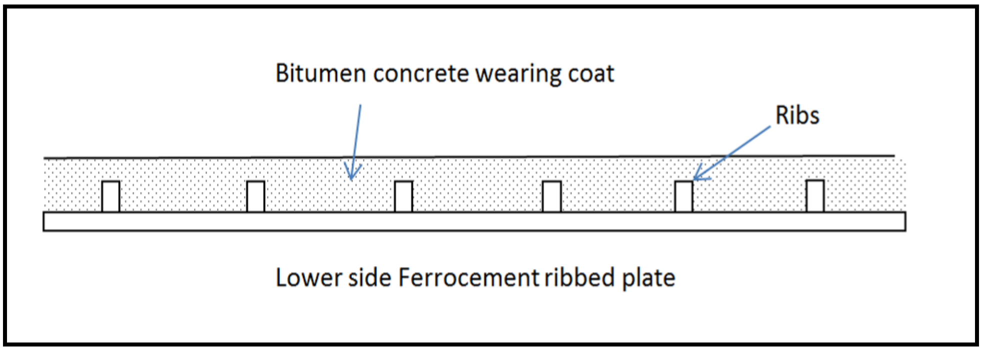



**Fig 7.27 Ferrocement ribbed plate**

The lower portion will be ribbed one and flat part will be based on compacted murum surface. The variations in soil reactions will be taken by flexible nature of plates. The bitumen carpet layer and wearing coat will be applied above the ribs thereby covering the ribs. Repairs and replacement of damaged part of pavement thus becomes very easy.

**Cross Drainage Works**: Culverts or pipe crossings can be precast with ferrocement. For fast construction of big culverts lost formwork of ferrocement is possible. Many times road on the pipe crossing is washed away. In such case, the ferrocement top layer to damaged pipes can be done without changing the pipes, thereby saving the costs.

**Culverts converted to dam to store water**: In Gujarat and Maharashtra water is scarce. In villages where the nallas flow in rainy season and there is no water in other seasons even for cattle. In order to recharge the groundwater the culverts are being converted in to small dams. Photo in fig 7.28 shows the road side small ferrocement dam near Aurangabad.

**Fig 7.28 Small ferrocement dam near Aurangabad**

**(Courtesy: Ferrocement Society, Pune)**

**Foot bridges**: As shown in fig 7.29, foot bridges are often needed for pedestrians to cross the heavy traffic roads. Such bridges with different attractive shapes are possible using ferrocement.

**Fig 7.29 Foot bridges**

**Foot bridges in Sri Lanka**: As shown in fig. 7.30, National Engineering Research and Development Centre of Sri Lanka have built footbridges and tested also. This research was focused on the application and development of ferrocement technology to construct cost effective foot bridges. The first phase of the study focused up to 20'.0" clear spans foot bridges for the pedestrians. The T-shaped section was selected for the bridge members. Section and the steel members and mesh layers were optimized by using FEM analysis. Also, the Model Code of Ferro Cement Design was referred. In the second phase of the study clear span extended up to 30'.0" and for three wheels and motorcycle users. Pre-stressed ferrocement made 30'.0" long beam was designed as bridge member. T-shape section was selected using FEM analysis as done in the first phase of the study. Load tests were carried out for bridge beams to check the strength in longitudinal and lateral directions. Pilot projects were done in both cases to check the performance.

**20 feet footbridge** | **Fixing of 30 feet ferrocement precast bridge** | **Completed bridge.**

**Fig 7.30 Foot bridges in Sri Lanka**

**(Courtesy: Ferrocement Society, Pune)**

**7.12 Applications in WRD:** The magic simple material called ferrocement which is rich cement mortar impregnated in hexagonal meshes can be very useful in water related construction departments. Water retaining, toughness, encasing, precasting, thinness are some of the properties that engineers will use wisely in water infrastructure constructions.

**Outcoating of steel pipes**

In practice engineers use guniting technique consisting of welded mesh wrapping and spraying the mortar by pressure on it. Approximately10 to 15 % of mortar is wasted in spraying.

**Method proposed for ferrocement outcoating of steel pipes. Operations involved-**

1) Remove garbage, deteriorated rough surface on the pipes and clean it.
2) Clean the surface by water jet.
3) 2 layers of meshes tied over one another should be spread over the pipe surface and hooked and grabbed. 10 cm length from each side of pipe will be kept untackled as the jointing action with welding etc will have to be done in future.
4) Spacers will be inserted to maintain the thickness of mortar to 20 mm.
5) Cement mortar should be pressed inside the mesh layers and finished sand.faced.
6) Ferrocement layer should be cured for at least 21 days as per fig 7.31.

**Fig 7.31 Outcoating of steel pipes**

**(Courtesy: Ferrocement Society, Pune)**

**RETROFITTING OF STRUCTURES**

Canals and roads always have culverts and bridges to cross the roads or drains. Abutments and piers are the main load carrying members. Old constructions of such cross drainage works invariably used stone masonry. In course of time the masonry joints are loosened as shown in fig 7.32. Load carrying capacity is reduced. Many mishaps have been reported as the pier is crushed or crumpled down all of a sudden. The traffic or the water supply is hampered. Break in service results in costs. Jacketing the piers with ferrocement is that way cost effective method as only 10% cost is to be incurred instead of building a new pier in the same place.

**Fig 7.32 Jacketing the abutments and piers**

**(Courtesy: Ferrocement Society, Pune)**

**Use of Ferrocement in Construction of Conduits**

Many irrigation canals run through or nearby cities or dense habitats. People nearby area always pollute the water and use the channel as a drain. Pune city has faced such problems and opted for closed conduits. Egg shaped conduit of ferrocement with a curved cover is always a feasible solution. Change in flow area is achieved by steps in cross section which allows variation in discharges. A nalla near Himali Society in Pune city is a case study as shown in fig 7.33 The extra width remaining is very valuable and can be utilized for traffic problems, vehicle parking, gardens, jogging tracks etc.

**Fig 7.33 Egg shaped conduits**

**(Courtesy: Ferrocement Society, Pune)**

**Parabolic canal sections**

Traditionally we build trapezoidal canals as we have cement concrete in mind. When you think of ferrocement parabolic cross section is not impossible. In fact it is the hydraulically more efficient section and structurally easier to construct. As shown in fig 7.34 for any depth the velocity of water remains constant and deposition of silt can be eliminated. Cracking will not be seen in such channels.

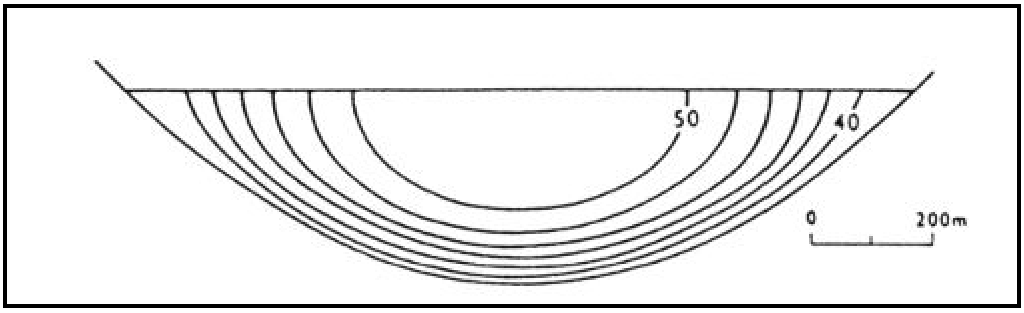



**Fig 7.34 Parabolic canal sections**

**Precast large size canal sections**

It is hydraulically established that parabolic section is the best section for canals, because its hydraulic mean depth of this section is independent of base width of the section. For any discharge non scouring and non silting velocities can be maintained In this section. In conventional system, the canal linings are provided to make them leak proof. Generally, it is done by laying concrete slabs and mortaring the joints. It is proposed that parabolic canal sections in the form of open gutters may be precast with spigot and socket joints and laid in the excavated canal section. For strengthening and maintaining the shape of the section, stiffeners can be provided on the outer face. Cost of such precast canals works out to be less than the cost of concrete slab lining.

**PVC pipe with outcoating**
With ferrocement outcoating it will now be possible to use plastic or PVC pipes of small thickness and outcoating them with required thickness of ferrocement. Structurally ferrocement can be designed for pressures and the inside of plastic pipe is naturally serving for smoothness thereby improving the flow characteristics. The cost of epoxy painting from inside is totally eliminated as no rusting is expected. Thus, the life of the pipeline is also assured to be non recurring and maintenance free.

**Replace prestressed pipes by ferrocement pipes**
Manufacture of prestressed concrete pipe involves a number of high tech and tedious operations. Ferrocement pipes can be designed for any pressures and cast with a single spin. Architect Nervi has already tested a ferrocement penstock for 320 meter of water head.

**Stiffened ferrocement plates**
Ribbed precast ferrocement plates can be cast for walling and floor panels. In mass housing speed of construction and mechanization plays important role. Precast ribbed panels are erected and joined at site and joints are filled in. They form cavity walls and hollow floors. Filling concrete in the joints so formed, is the only work to be done at site. So this system is best suited for mass scale housing. Dr. Divekar's residence in Model Colony, Pune is the case study.

**Ferrocement solar flat plate collectors**
Whenever workshop sheds with north light are constructed, the sloping side facing south can be built in thin ferrocement slab. Copper pipes are put inside these slabs. As shown in fig 7.35 when water is circulated through these pipes this ferrocement slab acts as a solar flat plate collector.

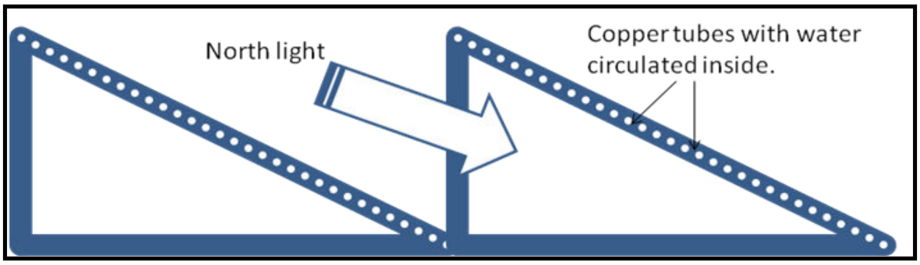



**Fig 7.35 Ferrocement solar flat plate collectors**

**Replace prestressed core slabs by ribbed plates**
Prestressed core slabs are used for large size unsupported slabs required for garages, large size halls etc. Large size ferrocement plate stiffened by ribs in two orthogonal directions can be precast. Two such plates when kept one above the other, with ribs abutting each other form a slab. The lower plate is designed as tension zone and the upper plate as compression zone. No prestressing or high tech precasting yards are necessary.

**Special applications like bunkers in war field**
Walls and roofs of bunkers and shelters at war field are required to be bullet proof. They should sustain blast loads of bombs. Ferrocement panels are already tested for bullet penetration and bomb blast. Number of layers of fine wire meshes impregnated and strongly bonded to rich cement mortar impart these properties of penetration and blast resistance to it as shown in fig 7.36. Ferrocement may bend but will not shatter

due to strong bond. Hence for building bunkers in field, ferrocement panel is an ideal material.

**Fig 7.36 A building for wireless system at Osmanabad Irrigation Colony, built under the Chief Engineer, WRD. in 1995. (Still in tact)**

**(Courtesy: Ferrocement Society, Pune)**

**Other applications** as shown in fig 7.37 to fig 7.40

**Fig 7.37 Osmanabad District. Ferrocement canal works constructed in 1996**

**Fig 7.38 Botarwadi small ferrocement Bandhara near Pune (2013)**

**(Courtesy: Ferrocement Society, Pune)**

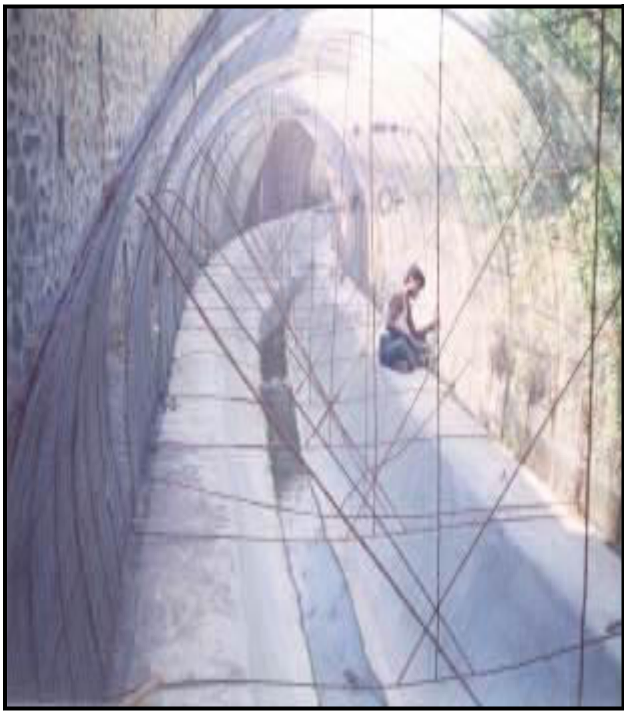


**Fig 7.39 Canal or nalla closing by huge ferrocement pipe cast in Situ near Pune**

**Fig 7.40 Ferrocement boats and pontoons in Pune area**

**(Courtesy: Ferrocement Society, Pune)**

# CHAPTER 8
# METHODS OF CONSTRUCTION

## 8.1 Ferrocement construction methods:

The steps in constructing ferrocrete structures are-

a) planning,
b) fabricating,
c) tying,
d) mortaring,
e) curing and
f) Handling and erecting.

Methods can be classified as-

1. Precast components
2. Cast in Situ construction
3. Composite construction
4. Layered system
5. Special purpose structures

A ferrocrete structure is formed by first fabricating the mesh reinforcement to the shape and size of the structure. It is then mortared and cured. A prime advantage of fabricating cage of mesh reinforcement is that it gives you the complete idea of the dimensions and the shape of the finished product. If required, changes can be made at this stage only.

## 8.2 Precast Components:

Small size building elements, water tanks etc. can be precast and assembled at site. The filling of joints is done at site after the joints are tightened by nut bolt system or grooving arrangement. In precast method, moulds are used to give shape to the components. Moulds are made from steel or fiber reinforced plastic (FRP). The durability of steel moulds shall be sufficient, as at least 5000 or more pieces can be cast in the lifetime of the mould. For FRP the mould normally is usable for 1500 castings. The edges of the mould shall be very clean so that the beauty of the component is increased. Chajjas, pipe sections, trapezoidal sections for small canals, small structures in field channels, like distribution boxes, turn outs, falls etc. can be manufactured as per the design using precast ferrocement method. Building Materials and Technology Promotion Council (BMTPC), New Delhi is working under Ministry of Housing and Urban Affairs, GOI. It has already developed a pattern of roofing ferrocement channel which can be used for floor and roof slabs as shown in fig 8.1 to 8.3..

**Fig 8.1 Ferrocement door shutters (BMTPC)**

**Fig 8.2 Ferrocement Water Tank 250 -10000 Litres. (BMTPC)**

**Fig 8.3 Ferrocement Roofing channels and mould (BMTPC)**

In Auroville also engineers are using precast chajjas, slab and channels for buildings. The quality of sand gives the components good finish. In Satara, Mandar tiles and fabricators have developed precast chajjas, toilet units and compound walls.

**8.3 Cast in Situ Methods**: For big size ferrocement structures normally skeletons are erected at site. Then the mortaring is done. The skeletons are fabricated in factory and assembled at site and mortared.

Following type of constructions are usually done by cast in situ method,

a. **Single wall**: For economical houses such single ferrocement walls can be constructed. Labour camps, temporary shelters, farm houses, security cabins can be constructed using single ferrocement walls.
b. **Stiffened wall**: ferrocement walls are thin and as such ribs on centre and all four sides can be provided so that the walls become stiffer. The buckling effect is totally reduced. Such precast components are also useful as slabs and walls.
c. **Ribbed floors/roofs:** Ribbing to the floors and slabs is possible using ferrocement.
d. **Double wall or cavity wall**: Cavity ferrocement walls are easy to construct. They are used when outside temperature is high and cool rooms are necessary. Soundproofing is also possible using cavity walls.
e. **All-in-one method** (Integral Construction): This is patented method developed by Dr B N Divekar in Pune. He has constructed his home using this method.

All-in-One (Patented method) is a novel and unique method of constructing structures and buildings, in which Ferrocement Paneled Cavity walls with inbuilt columns and stiffeners hidden inside the cavity and Ferrocement boxed hollow floors with inbuilt hidden grid beams are fabricated, erected, and cast simultaneously resulting in an integral construction of walls and floors with inbuilt three dimensional structural framework of columns, stiffeners, and beams. The traditional method of erecting, and casting of R.C.C framework of columns, beams, and slabs first, and then to build filler walls in it, is completely reversed here.

The Ferrocement walls are divided into panels and floors in box sections, the joints of which act as structural framework as shown in fig 8.4. Due to paneling of walls and boxing of floors and closer spacing of columns and beams, all the loads are equally distributed throughout the body of the structure resulting in lighter sections of columns and beams.

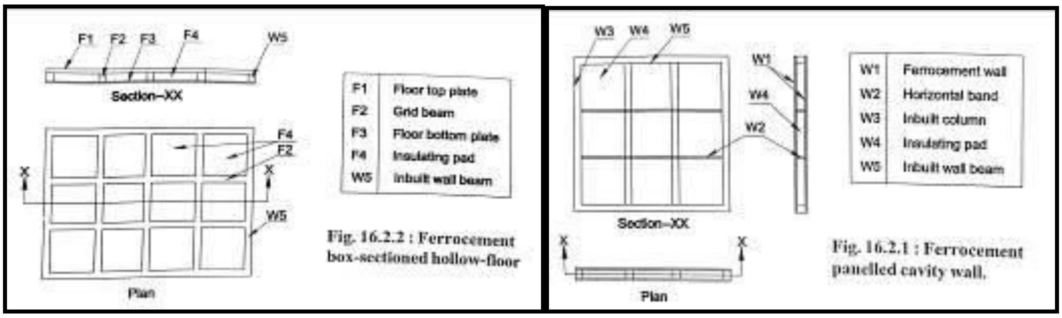



**Fig 8.4 Ferrocement panels and box sections**

A special feature of this method is that the material of construction of all components of the structure is the same, due to which transfer of loads, moments, and shear, torsion, and shock loads is very smooth.

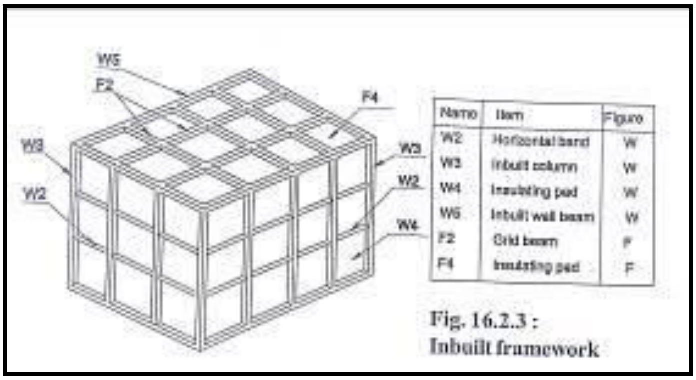



**Fig 8.5 Ferrocement column and beam**

Ferrocement itself is having enormous capacity to absorb the shock loads. In addition to it, the integral casting, box like construction , light weight due to thin walls with very high strength to weight ratio, high and equal strength in both directions and close knit three dimensional frame work make All-in-One the most ideal system for building structures in earthquake – prone areas.

Compared to traditional methods, the site work is reduced to only ten percent, resulting in saving of time of construction. All types of structures including multistoried buildings, silos, space structures, large size conduits, can be easily constructed by using this method.

Traditional building materials like stones, bricks, timber are completely eliminated in 'All-in-One'. Pollution of air, water and noise is reduced to zero. Hence All-in-One is eco-friendly method of construction.

## 8.4 Composite construction method

In this method ferrocement components are used partly with basic structure of RCC or structural steel. Two types can be explained as below,

a. **Lost formwork of ferrocement**: In RCC constructions cement concrete is always poured inside the formwork. Timber or plywood formwork can be replaced by ferrocement form work. Ferrocement elements are as thin as plywood say 18 mm to 30 mm. So if such formwork is used concrete can be poured and the formwork is not required to be removed. So, it is called lost formwork. The ferrocement forms are quite strong and they take tensile stresses. If designed properly the strength of such ferrocement formwork can be taken into account and the sizes of column and beam can be reduced.

b. **Walling and cladding**: Normally the RCC framework is constructed first before the walls. It is quite possible to build ferrocement walls in the framework of RCC. The walls are thin so the carpet area of the rooms increases. Ribbing of the walls is required depending upon the size of the wall. Curved walls are also possible. For elevation treatment ferrocement cladding or vertical fins can be constructed. In steel structures even ferrocement slabs can be cast on the structure.

## 8.5 Layered system:

Ferrocement in layered form is sometimes used for different purposes. The imperviousness property of the ferrocement is used for making water retaining structures leak proof. Many irrigation canals can be lined with ferrocement. Such experimental work is already done for canal near Kalwan, District Nashik in 2014 as shown in fig 8.6. Many buildings in the department now need waterproofing treatments. Ferrocement layer is found effective as the load increase on the existing slabs is minimal.


**Fig 8.6 Ferrocement canal lining at Kalwan, District Nashik in 2014**

Old buildings loose the load carrying capacity due to deteriorated columns. Ferrocement jacketing or encasing is done to increase the load carrying capacity. 50% additional load can be taken by old columns, if encased properly. Tensile strength of the ferrocement is more than 80 kg/cm$^2$. So the confined concrete gets more compressive strength. Many piers of irrigation aqueducts, bridges need jacketing. The old masonry piers get more strength by just jacketing them with ferrocement. The cost of such jacketing is much lower as compared to construction of a new structure. Such retrofitting and strengthening works are frequent in PWD and WRD.

## 8.6 Special Purpose Structures: Characteristics of the ferrocement can be used to construct special purpose structures with innovative designs.

A) **Space Structures**- Special shapes are possible in space structures. Domes, Shells, HYPAR shapes, Wave type roofs, Roofs of big size halls are possible in ferrocement. Some photos below fig 8.7 and fig 8.8 will show the variety in constructions.

**Fig 8.7 Space structure in ferrocement-1**

**Fig 8.8 Space structure in ferrocement-2**

B) **Retaining Walls**- Retaining walls built in RCC or masonry are quite bulky and have bigger base widths. The cost can be curtailed by 40 % using ferrocement retaining walls. The typical curved shape of the ferrocement wall can be designed with a thickness of 50 to 70 mm only as shown in fig 8.9. Such wall is already constructed, tested and found to be useful.

**Fig 8.9 Retaining walls**

C) **Petal Shaped Water tanks**- Big size water tanks with plane walls in RCC are normally constructed. The thickness of the tank wall is very large at the bottom. Ferrocement petal shaped walls have constant thickness up to 80 mm but they are petal shaped. The wall gets strength through the shape. A 12 lakh litre capacity ferrocement petal shaped water tank is already built near Talegaon, District Pune as shown in fig 8.10.

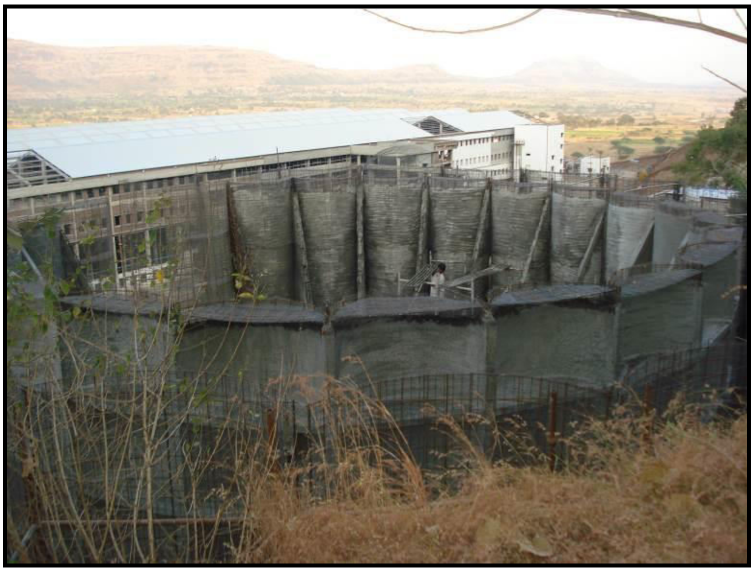


**Fig 8.10 Water tank near Talegaon, District Pune**

**D) Small dams and water retaining bandharas**: The petal shape and the strong ferrocement wall can be used for building dams. Such dams are already constructed in Pune, Nashik, Aurangabad districts. The overflow water is allowed to pass over the dam as shown in fig 8.11. No damage is seen in the constructed dams in last 3 years. In water Conservation Departments such dams can be constructed in villages under the ***Jal Yukt Shivar*** scheme. Many K T weirs are to be converted into overflowing dams. The needles need frequent maintenance. As such needle free weirs are necessary. Ferrocement walls can be constructed in place of the needles as shown in fig 8.12 and fig 8.13.


**Fig 8.11 Dams at Pune, India**

**Fig 8. 12 Dam at Mexico**

**Fig 8.13 Bhandhara constructed with ferrocement at Dhule, India**

# CHAPTER 9
# DESIGN OF FERROCEMENT STRUCTURES

## 9.1 Preamble: This chapter is divided into three parts:

A. Ferrocement designed as ferrocement
B. Design examples
C. Ferrocement designed as RCC.

## 9.2 Design, analysis and optimization.

When we analyze a structure, we assume that the dimensions of the structural members and the properties of the material of which the structure is composed are known. Behavior of the structure in the form of stresses, strains and deflections etc under given loadings is studied by analysis.

In designing a structure, geometrical configuration of the structure is determined to fulfill prescribed functions. We are at liberty to choose the form and the material of construction. The ferrocement structures can be shaped in such a way that the full section of the member and the full strength of the material can be utilized. Thus a flexural member can be shaped as an arch to use higher compressive strength of concrete and the full cross section of arch sharing the load.

An optimum design of a structure is one in which the prescribed goals are achieved with the minimum cost.

## PART A: FERROCEMENT DESIGNED AS FERROCEMENT

**9.3 Introduction**: Ferrocement is quite a different material than the conventional RCC or pre-stressed concrete. Its design considerations, basic assumptions and derivations of design equations should be based on its own characteristics. Basically ferrocement is a perfect two phase composite. The strong bond between wires and mortar gives birth to many unique properties. In addition thickness, shape and method of construction make a lot of difference. All these parameters controlling the design are given below.

**9.4 Parameters of design**: Various parameters and the methods of design based on them are presented below.

1. Due to thorough and uniform dispersion of fine wires over the cross section and strong bond between them, equivalent area concept can be utilized in deciding the center of gravity, neutral axis and moment of inertia of the section.
2. Strong bond also justifies use of equivalent area concept in design of structures subjected to direct compressive and tensile stresses.
3. Bond is measured in terms of specific surface ($S_r$) of the composite. Relationship between Specific surface ($S_r$), Volume fraction of steel ($V_r$) and wire diameter (d) can be established and used in design.
4. Specific surface and tensile strength of ferrocrete are related directly. For a particular specific surface and mortar mix of known strength, tensile strength of the composite can be obtained.
5. Specific surface also controls the crack widths and their spacing, in the zone of multiple cracking. A relation between them can be determined analytically.
6. Limitations of the effects of specific surface can be understood with the concept of influence zone of bond around the wires.

7. Relation between crack width and the stress in steel fibers can be established in form of an equation, from which curves are plotted and used directly in design of crack controlled structures.
8. Specific surface can be also related to the compressive strength of ferrocement, because tension created by it, needs to be nullified, for which additional compressive loads are required and so the compressive strength of composite also gets increased with the increase in specific surface.
9. By using 'Theory of Solutions', equations for tensile and compressive stresses in ferrocement in terms of the properties of the ingredient materials can be determined analytically. Beauty of this method is this that the properties of the ingredients, which can be easily tested and found in laboratory, are used in finding the stresses of the final product.
10. In all the previous studies the properties of ferrocement are tried to be interpreted in terms of the material properties of the ingredients with the help of mathematical models. Bond between the ingredients is completely neglected in "Theory of Mixtures' used by them in their design. A new concept of 'Theory of Solutions' is developed in which, the role of specific surface in calculating stresses in tension and compression of the composite, is established.
11. As specific surface controls both tensile and compressive stress of the composite, a method based on it can be used in design of flexural members. Being a homogeneous material, the stress pattern in bending and shear on the cross section of a member is altogether different than the one in RCC. The design gets simplified due to it.
12. In stress-strain curve in tension for ferrocement, locations of first crack stress and yield point stress can be ascertained by the equivalent stress method. The line joining them defines 'Chord Modulus of Elasticity' of the composite for zone of multiple cracking.
13. Based on this new concept, tensile stresses in ferrocrete for any particular strain can be easily calculated. All the designs of ferrocement structures are made for stresses in zone of multiple cracking, as the crack widths in this zone are negligibly small, they are much less than those prescribed in limit state of serviceability conditions of concrete structures.
14. From the area below stress-strain curve in tension of ferrocement, the work done in straining the composite from the first-crack stress to the yield-point stress is known. It is multifold in ferrocement than the one of RCC. This special property can be used in design of ferrocement structures subjected to dynamic loads, like earthquake resisting structures. This is a unique feature of ferrocement and designs based on this concept are introduced for the first time in design of structures subjected to dynamic loads.
15. In shaping a structure, the stress pattern over the section is changed from flexure or hoop tension to direct compression or membrane stresses. With ferrocement it is very easy to give different shapes to the structure and so this concept is used in design of shaped structures in ferrocement.
16. Due to standardized method of construction, the strengths of ferrocement composite, achieved through a particular mesh pattern in a mortar of known strength, are assured. This idea is used in developing 'Tension capsules' and 'Compression blocks' of standard strengths in tension and compression, which can be used for direct applications in field.

## 9.5 Behavior near to homogeneous: Thorough and uniform dispersion of the fine wires over the cross section, defines the homogeneous behavior of the composite physically.

1. In RCC the steel bars are placed in tension zone and if their equivalent area is depicted on the cross section, It will be clearly seen that the spread of the area is eccentric and its center of gravity and neutral axis passing through it will definitely be controlled by area of steel (m $A_s$). More the steel, lower will be the neutral axis (NA).
2. In ferrocement, the spread of fine wires is uniform and their projections, ($mA_s$), if shown on cross section will also very small and distributed uniformly over the cross section. This clarifies the homogeneity of the material and its C.G. and N.A. will always remain at half the depth of the section.
3. Even (a) for the equal meshes laid at the top and bottom of a beam or (b) for a section in which the meshes are spread all around the periphery or (c) for a section which is symmetrical about the vertical or horizontal axis, due to symmetry the N.A. will always lie at half the depth of the section.
4. Thus the N.A. for such a homogeneous material will be at half the depth.

## 9.6 Strong bond between wires and mortar up to failure makes it special

1. When fine wire meshes are used in place of steel bar reinforcement, two factors play an important role. The mesh reinforcement is continuous in both directions and spread all over the section. Also it is strongly bonded with mortar. Hence in pull-out test the mesh won't get pulled out but may yield and then break. The bond between wires and mortar is increased due to small diameter wires used in place of large diameter bars. The area of contact between the mortar and steel gets increased multifold. Due to this the bond between the two ingredients gets increased enormously.
2. Suppose a 20 mm dia bar in RCC is replaced by one mm diameter wires,400 wires will be required for the equivalent cross sectional area of bar and the contact area will increase 20 times that of steel bar. Increase in contact area due to wires of different gauges replacing bars of various diameters increases the bond strength to such an extent that the test samples in tension fail when the wires yield. So, the ultimate tensile strength of ferrocement becomes the yield strength of wires and allowing for factor of safety, the permissible tensile stress works out to more than 10 MPa.
3. Strong bond upto yield point of steel means the strains in wires and mortar, are same up to failure.

   Automatically,

   **Stress in steel = m (stress in mortar) and Equivalent area of mortar = ($A_m$ + $mA_s$)**
4. Equivalent area concept is used in design of structures subjected to direct stresses.
5. Equivalent stress principle is used in locating the points of first crack stress and the yield point stress in the stress-strain curve of ferrocrete in tension. The line joining them defines the 'Chord Modulus of Elasticity' of ferrocement.

## 9.7 Measure for specific surface: 

Bond can be measured in terms of the specific surface ($S_r$), a parameter defined as, ratio of area of contact of wires, to the volume of mortar, which is bound by them.

Its unit is contact area of wires / volume of mortar = $A_{contact}/V_m = mm^2/mm^3$.

While calculating the volume of mortar, only the volume contained by the meshes and cover on both sides is to be considered. Thickness of finishes in the form of plaster is not to be taken into account. Thickness built by the skeletal steel, mesh layers tied over it and a cover of 5 mm over them should be considered.

1. To find the volume of steel wires for meshes of different diameters and configurations is very difficult. A simple method is
   a. Find out the weight (W) in kg of mesh per $m^2$.
   b. Divide it by density of steel 7.85 $kg/cm^3$. and you get the volume of steel wires $V_s$ in $cm^3$ per $m^2$ of area.
   c. If this mesh is assumed to be embedded in one cm thick mortar, volume of mortar will be $100 x 100 x 1 = 10^4$ $cm^3$ per $m^2$ per cm thickness of mortar.
   d. So $V_r$= (W)/ ($7.85 \times 10^4$), for mesh laid in 1 cm thick of mortar per $m^2$. If the thickness of the mortar is increased to say 4 cm, this value will be multiplied by 1/4
   e. If the weights of different types of meshes are known, their $V_r$ values can be calculated as shown above per cm thickness of mortar.
2. Volume fraction of steel ($V_r$) = Vs/Vm is many a time prescribed in percentage. $V_r$ in ferrocement may be 0.8 to 8.0 percent. If the wire diameter is measured in mm, 8 percent steel has $V_r$= 0.08 $mm^3/mm^3$
3. Relationship between $S_r$, $V_r$ and wire diameter (d) can be established as follows:
   $S_r$= contact area/ $V_m$ = (3.14 d x 1)/ $V_m$. Per unit length of wire.
   $V_r$= (steel volume)) / $V_m$ = [( 3.14 d*2) /4] x 1 divided by $V_m$. Per unit length.
   **So $S_r/V_r = 4/d$**
4. In ferrocement composite, there may be number of layers of meshes of different types and diameters. Suppose the weights are W1, W2, W3 for meshes, $V_{r1}$, $V_{r2}$, $V_{r3}$ will be their volume fractions and if the diameters of their wires are d1, d2, and d3, values of $S_{r1}$, $S_{r2}$ and $S_{r3}$ can be separately calculated and added together to get the total $S_r$ of the composite.

## 9.8 Specific surface and tensile strength: 

Specific surface and tensile strength of ferrocement are related directly. More the $S_r$, more will be the bond. More bond means more adhesion between the particles which means higher strength in tension

1. Laboratory investigations of this property are already made and the curve showing stresses at first cracking and at crack stabilization stage against specific surface in tension test are given in curve by Antonie A. Naaman in his book.
2. The line joining the stress values at first crack and the stress at the crack stabilization, defines the 'Chord Modulus of Elasticity'. If we test a number of samples with varying Sr values, measure stresses at first crack and at the points of crack stabilization and plot their chord moduli, we will get permissible tensile stress values of ferrocement for different specific surfaces
3. The bond stress is dependent on strengths of mortar and as bond is a major factor influencing the first crack and stress at stabilization, the moduli will be different for different mortar mixes.
4. Tables of permissible tensile stresses of ferrocement for various $S_r$ values for different mortar mixes can be prepared and used directly.

5. By using 'Theory of Solutions", the values of first crack stress and the stress at crack stabilization can be calculated analytically, from which the 'Chord Modulus' and the permissible tensile stress in tension and compression can be obtained analytically also.
6. Experimental verification of this relation can be done by conducting tests on a number of samples.

## 9.9 Relationship: Relationship between specific surface, bond length ($L_b$), number of cracks in it (n), crack width ($C_r$) and their spacing ($L_{cr}$) can be established as follows:

**1.** Three phase behavior of ferrocement is an established fact. Upto the first crack the composite behaves as elastic, after the first crack in the multiple cracking zone, the composite starts behaving as an elasto-plastic material upto the yield point of wires. In this zone crack width remains constant, but the number of cracks, go on increasing as the tension in steel wires increases. At the yield point of steel wires the cracks stabilize and after yielding of steel, the composite goes in plastic stage.

**2.** This cracking behavior can be interpreted as follows.
With the tension in wire, it starts getting extended in length. Due to strong bond with mortar surrounding it, mortar also starts getting elongated. Due to elastic property of steel, the steel can sustain the elongation but the mortar being brittle, gets extended to a certain limit, beyond which it gets adjusted with the extension, by forming a crack in it. Like this as the wire length gets extended the number of cracks go on increasing. Average crack width of all these cracks is same and is within the limits of design.

**3. To evaluate the bond length $L_b$:**
The total tension in steel wires is transferred to the mortar through certain length called bond length.
Equating, the forces in steel wire and mortar, at the time of crack stabilization, we get Force in wire = (3.14/4) $d^2$ x $f_{sy}$) where $f_{sy}$ is yield point stress in steel.
And
force in mortar = contact area x $f_m$ spt.
But, the contact area is 3.14d X bond length ($L_b$) through which the tension is transferred to mortar.
So we get $f_{sy}$ x d/4 = $f_m$ spt x $L_b$ or
**$L_b$ = d/4 ( $f_{sy}/f_m$ spt).**
In this bond length, numbers of cracks are formed, with a spacing of $L_{cr}$ between them,
**To determine number of cracks (n):** At the stage of stabilization, the number of cracks are formed (n) can be calculated as below:
Each crack of width $C_r$ is formed with the spacing length $L_{cr}$. With the mortar cover (t) over the wire near surface of the sample, strain in the mortar at the surface of wire will be $C_r/t$ while the cracking stress in mortar will be $f_m$ spt for each crack. Stress in steel wire is $f_{sy}$. When it is transferred to mortar its equivalent will be ($f_{sy}$/m) which is the total stress to be transferred to mortar.
One important fact to be noted is that when the yield in steel wires has reached the stress in surrounding mortar may be $f_{sy}$/m. But the stress at which the mortar cracks, is $f_m$ spt. So $f_{sy}$/m cannot exceed stress $f_m$ spt.The crack width will increase if this value is exceeded. As the stress in wire increases, number of cracks, go on increasing.

At point of stabilization, (number of cracks) X (cracking stress for each crack) will be ($f_{sy}$/m) i.e n x $f_m$ spt = $f_{sy}$/m or **n = ($f_{sy}$/$f_m$spt)/m**

**To determine spacing of cracks $L_{cr}$ :**
n number of cracks are formed in bond length of $L_b$.
So spacing of cracks $L_{cr}$ = $L_b$/n.
Putting values of $L_b$ and n in this equation we get
$L_{cr}$ = [ d/4 x $f_{sy}$/fmspt ] / [($f_{sy}$/$f_m$spt)/m]
**i.e. $L_{cr}$ = m x d/4**

4. **To evaluate the crack width**:
At the yield point of steel, the crack formation is stabilized, and their average width is $C_r$ and they are formed at spacing $L_{cr}$
   a) Equating the work done, in forming crack of width $C_r$, by the tensile force in mortar of volume $V_m$ bound around the length between two cracks i.e. $L_{cr}$, with the work done in straining and elongating the wire with tensile force in it, we can get value of $C_r$.
   b) The tensile force in mortar is due to the bond transferred through contact area which will be ($f_{mb}$ x contact area).
   c) Cracking occurs when $f_{mb}$ = $f_{mt}$. Now $f_{mb}$ = $f_m$ spt
   d) Now the contact area = $S_r$ x $V_m$ ( $V_m$ being the Volume of mortar in length $L_{cr}$)
   So the work done in cracking= $f_m$ spt X $S_r$ x $V_m$ x $C_r$ -------(A)
   e) Elongation of wire = ($f_{sy}$/$E_s$) x $L_{cr}$
   f) Force in wire = 0.7854 $d^2$ x
   g) Work done in elongation = 0.7854 x $d^2$ x $f_{sy}$ x ($f_{sy}$/$E_s$) x $L_{cr}$
   but 0.7854 x $d^2$ x $L_{cr}$ = Volume of steel $V_s$, and $f_{sy}$=m $f_{mu}$
   So the work done in elongation = $V_s$ x m x$f_{mu}$ x ($f_{sy}$/$E_s$) --- -- (B)
   Equating A = B ,
   fm spt x $S_r$ x $V_m$ x $C_r$ = $V_s$ x m x $f_{mu}$ x ($f_{sy}$/$E_s$),
   As $V_s$/$V_m$ =$V_r$
   we get $S_r$ x $C_r$ = m x $V_r$ x ($f_{sy}$ /$E_s$)x ($f_{mu}$/$f_m$spt)
   or **$C_r$ = m x($V_r$/$S_r$) x ($f_{sy}$/$E_s$) x ($f_{mu}$/$f_m$spt)**

It can be seen that for a given mortar mix and type of meshes the crack width depends on the properties of the ingredients of ferrocement and it can be calculated analytically. This means that the crack width is in direct proportion of volume fraction of steel, m value, yield stress of steel, strength of mortar and in inverse proportion of specific surface, modulus of elasticity of steel and split tensile strength of mortar. These equations confirm the observations made by researchers in their earlier studies. The special feature of this equation is that the crack width of the composite is evaluated from the properties of the wires and mortar.

5. **To evaluate the bond length-an example**
For mortar of M30, with $f_{sy}$= 300 MPa, $f_m$ spt = 2.896 MPa, and wire dia 0.8 mm, we get $L_b$ = (300 x 0.80) /(4 x 2.896) = 28.71 mm.
**To find the spacing of cracks:**
Number of cracks will be ($f_{sy}$/m.$f_m$spt).
With mortar of M30, the number of cracks will be 300/(10 x 2.896) = 10.36.

They will be in bond length of 28.71 mm.

So the crack spacing will be $L_{cr}$ = 28.71 / 10.36 = 2.77 mm

## 9.10 Bond and tensile strength:

How does the bond between the wires and the mortar increases the tensile strength of the composite, can be explained as follows.

1. Tension in a material is the measure of adhesion, attraction or bond of particles with each other. Higher the bond, higher will be the tensile strength.
2. In hardened cement mortar, tensile strength increases with the mortar mixes of higher strengths.
3. Bond between the wire and mortar depends upon adhesion capacity of mortar with the steel wire. It is a function of the roughness of surface of wire and the strength of mortar. Rougher the surface more is the bond.
4. When the wire is pulled, the particles of mortar bonded with it will try to move along with the wire but the adjoining particles will try to resist it. Thus tension is created in mortar particles. Thus bond is transferred to surrounding mortar in form of additional tension created in it.
5. Thus bond adds more tension to the existing tension capacity of the mortar. When this transferred bond exceeds the limit of tensile strength of mortar, the particles get separated and a crack is formed. As more and more bond is transferred more cracks are developed.
6. When the ultimate tensile strength of mortar is reached, it fails and it occurs at the yield point of steel wires.

## 9.11 Compressive strength and specific surface:

1. Paul and Pama, had already indicated that stress-strain curve for ferrocement in compression should also follow the three phase behavior. Even after first crack the ferrocement specimen will go on taking load till the bond between the steel and mortar gives way.
2. Up till now, no detailed studies on this aspect are reported. This is because, for studying the behavior of brittle materials after first crack, the straining rate of the loading machine is required to be reduced. All the universal testing machines load the sample in compression at a constant rate of plunger movement i.e. at a constant rate of straining the specimen. In brittle materials, after the first crack load bearing capacity starts falling, but the machine goes on loading at same constant rate. Post-cracking behavior of the material is possible only when the loading rate is reduced to match drooping shape of the stress-strain curve.
3. It is observed that the strength of concrete gets increased, if it is confined in an enclosure of a material of high tensile strength. Such an encasement restrains the bulging out movement of the members in the lateral direction when loaded in compression axially, and due to which the compressive strength gets increased. The confining material should have high tensile strength for offering the restraint to bulging out.
4. Use of confining concrete by using Ferrocement Technique, makes it ductile and increases compressive strength even after the first crack.
5. Ferrocement is the right material for confining concrete. Its high tensile strength comes to help here, which is dependent on its specific surface. Higher the specific surface higher will be its tensile strength and higher will be the compressive load taken by confined concrete.

6. When ferrocrete with high tensile strength is tested in compression, additional compressive load will be required, first to nullify the tension in ferrocement and due to it, its compressive strength will get increased.
7. It can be looked upon as a reverse process of pre-stressing, which we adopt in concrete to improve its tensile strength.
8. Further studies on this property are required to be done.
9. By ‘Theory of Solutions’ this can be proved analytically but its experimental verification is quite necessary.

## 9.12 Relation between crack width and stress in steel fiber:

Relation between the crack width and the tensile stress in steel wire near the surface of the ferrocrete sample is already established.

1. In the previous studies it is plotted in the form of a curve by Shah and Balaguru (Ref: Ferrocement: Proceedings of the Fifth International Symposium) as shown in fig 9.1.

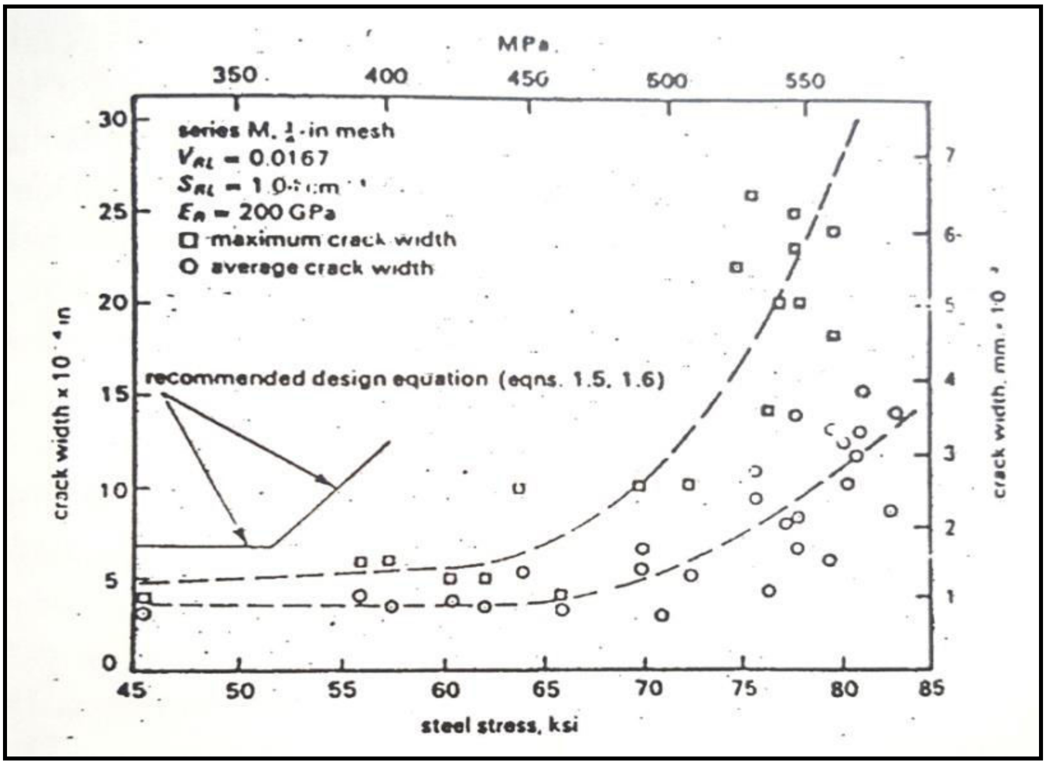



**Fig 9.1 Variation of crack width with tensile stress in wire**

**(Courtesy: Ferrocement Society, Pune)**

2. A comparative study of the average crack width and the stress in steel fibers for ferrocement and RCC are made and plotted in curve Shah and Balaguru (Ref: Ferrocement: Proceedings of the Fifth International Symposium).
3. The basis of design of certain structures is crack width. They are water retaining structures, silos, enclosing structures for hazardous wastes, structures built in saline soils or water, or ferrocement in layered form for waterproofing, for fire resistance, for improving weathering qualities, for retrofitting damaged structures or for protecting steel framework from rusting
4. The design of crack width controlled structures can be done by using these curves or by using the equations already derived.
5. It can be observed from these curves, that the stress in steel wires which can sustain a crack width of 0.1 mm in design of water tanks, (as is prescribed in specifications), is more than 350 MPa as against 100 MPa for RCC.

6. It clearly shows that ferrocrete structures can be designed for higher permissible stresses in steel which will reduce the area of steel to about 30 percent of the steel used in RCC.
7. In addition, in design of such critical structures, the other unique properties of ferrocrete like high strength-to-weight ratio, equal strength in two orthogonal directions, water-tightness and the best weathering qualities play equally important role.

## 9.13 Theory of Solutions

1. It is quite a new concept of interpreting properties of the composites from the properties of the ingredient materials. In RCC designs, 'Theory of Mixtures' is used. In it the two ingredients act as two discrete materials and share the load separately. There is no contribution from the bond between them as steel starts taking load only after cracking. In RCC, steel and concrete are just mixed and the theory is also named accordingly. It is just like sugar cubes and tablets of citric acid kept side by side. They will not get mixed with each other, retain their own tastes and will not create any special taste after mixing.
2. In ferrocement, it is just like sugar added to lemon juice and dissolved in water to produce delicious Sharbat. Taste of each ingredient is enhanced in the solution and, the final product is made still tastier by them. The mingling of the two ingredients in this is just like the bond between steel and mortar. And so a 'Theory of Solutions' is devised, which will account for the contribution of bond in enhancing the compressive and tensile strength of the composite.
3. Theory of Solutions is derived as follows.
   a. When a ferrocrete sample is subjected to tension test, at the point of stabilization of the cracks, the mortar and steel are subjected to their ultimate strengths
   b. At this point, $T_c$ (Total tension taken by composite of cross sectional area $A_m$) = $T_m$ (tension taken by mortar of area $A_m$) + $T_s$ (tension taken by steel wires in the direction of loading, of cross sectional area ($G_{bx}A_s$) + $T_b$ (Tension created in mortar of volume $V_m$ by bond transferred through the contact area in the length of crack spacing $L_{cr}$).
   c. If $f_c$, $f_m$, $f_s$ and $f_b$ are the stresses in composite, mortar, steel and bond in mortar, and Gb the global efficiency factor for the mesh, the equation reduces to $f_c A_m = f_m.A_m + f_s.G_b.A_s + f_b$(bonded area).
   d. Dividing them by $A_m$ we get $f_c = f_m + f_s$ x $(A_s/A_m) + f_b$.(Bonded area/$A_m$).
   e. Now from the relations $A_s/A_m = V_s/V_m = V_r$ and
   f. (Bonded area))/$A_m = S_r.V_m./A_m = S_r.A_m.L_{cr}/A_m= S_r.L_{cr}$.
   g. we get $f_c= f_m+V_r.G_b.f_s +f_b$ x $S_r.G_b.L_{cr}$.
   h. At the time of formation of cracks when the stress in mortar is $f_m$spt, the stress in steel will be m x $f_m$ spt. At the stabilization stage the values of $f_c$, $f_m$, $f_s$ and $f_b$ will be $f_c$ ult, $f_m$-spt, $mf_m$ spt and $f_m$ spt.
   i. So the equation for the ultimate stress in composite in tension can be presented in terms of the ultimate stresses in mortar and steel as follows: $f_c$-ult = $f_m$-spt + $V_r.G_b.m.f_m$ spt + $S_r.G_b.L_{cr}.f_m$-spt.= $f_m$ spt(1+ $m.V_r.G_b.$ + $L_{cr}.G_b.S_r$)

4. This shows that knowing the split tensile stress of mortar, m, $V_r$, $G_b$, $S_r$, the ultimate tensile stress of the composite can be calculated analytically. All these are the properties of the ingredients and hence from the properties of the ingredients ultimate tensile strength of ferrocement composite can be calculated.
5. Experimental verification of this theory is underway and the initial results are encouraging.
6. The experimental data of three phase behavior of ferrocement in compression is not at all available. It is assumed by all the designers that the design compressive strength of ferrocrete should be taken same as that of mortar.
   a. As mentioned earlier there is a definite increase in the compressive strength of ferrocrete due to increase in specific surface.
   b. The mode of failure as anticipated may be as follows: Under compression the role of meshes is to confine the mortar due to bond and increase its compressive strength. The meshes may be getting compressed along with the mortar up to a point at which the bulging out and splitting of mortar has started. Till that time the compressive load will be shared by mortar, steel and by bond.
   c. The bond has increased the tensile strength of ferrocrete, which will have to be compensated by the sample before it undergoes compressive load. When the compressive load exceeds crushing strength of mortar the sample will fail. Till that time the load will be shared by mortar, steel and bond. So the ultimate compressive strength of ferrocrete composite can be calculated on the same lines as is done for ultimate tensile stress and a similar equation can be derived.
   d. In this the ultimate stress in mortar under compression will be fm-ult. In compression test the stress in steel has not reached the yield point but it will be m times the ultimate strength of mortar and the bond stress will be split tensile strength of mortar. So the equation for ultimate strength of composite, in compression will be

$$f_c\text{- ult} = f_m\text{-ult} + V_r.\ G_b.m.(\ f_m \text{ ult.}) + Sr.L_{cr}.G_b.f_m\text{-spt}$$

$$f_c\text{,ult in compression} = f_m\text{ult}\ (1 + m.G_b.Vr) + S_r.L_{cr}.G_b.f_m \text{ spt}$$

   Sample calculation and ultimate compressive strengths of ferrocrete for various combinations of meshes can be worked out.

## 9.14 Design of flexure based on specific surface

1. It is already proved in the previous sections that the specific surface controls both compressive and tensile stress of the composite and their values can be calculated analytically. It is possible to conduct tests on the field samples for tensile and compressive strengths and their values can be related to specific surface of the composite.
2. In the case of ferrocement beams its behavior is quite different than RCC beam.
3. The various combinations of reinforcing meshes, stress distribution on section due to homogeneous nature, load deflection behavior and considerations given to high tensile strength of ferrocement used in tension zone, make all the difference.
4. In the load deflection curve, three phase behavior is observed and the design is based for zone of multiple cracking.
5. Ferrocement acts as a homogeneous material upto point of rupture and hence it can be designed just like a steel girder.

6. There is a full choice in selecting the shape and size of the beam. It may be solid rectangular, hollow rectangular, box section, I, T, L, Wide flange H beam etc.
7. The stress distribution in tension and compression is same as for the section of homogeneous beam.
8. It is possible to use ferrocement of different $S_r$ values in different zones of the beam.

## 9.15 Chord Modulus of Elasticity' for ferrocement composite:

The stress-strain curve in tension for ferrocrete can be used to find out Chord Modulus which can be used in design of structures.

1. Principle of superimposition of stress-strain curves of mortar and steel wires to get the curve for the final product can be used in ferrocement. Because of strong bond the strains in mortar and wires remain same up to the yield point of steel wires. So when the stresses in mortar and wires at the same strain are added the stress for the composite is known. This was applicable for the 'Theory of Mixtures' used in RCC.
2. In ferrocement, it is observed that this summation is not adequate and the contribution of bond at that strain must also be added to it to get the stress of the composite. This has given rise to the 'Theory of Solutions' and from it the values of the stresses of ferrocrete at the first crack and at the yield point of steel wires can be calculated.
3. The line joining these two points, which are the beginning and end of multiplying cracking zone (or in other words are the lower and upper limits of multiple cracking) gives us 'Chord Modulus of Elasticity' of ferrocrete.
4. In zone of multiple cracking the crack width is negligibly small and is within the serviceability conditions of stability.
5. Hence 'Chord Modulus' is the most appropriate parameter in design of ferrocement structures.

## 9.16 Stress-strain curve and the work done

From the stress-strain curve of ferrocement in tension as shown in following fig 9.2, the work done in straining the material from first crack to the yield point of steel can be calculated.

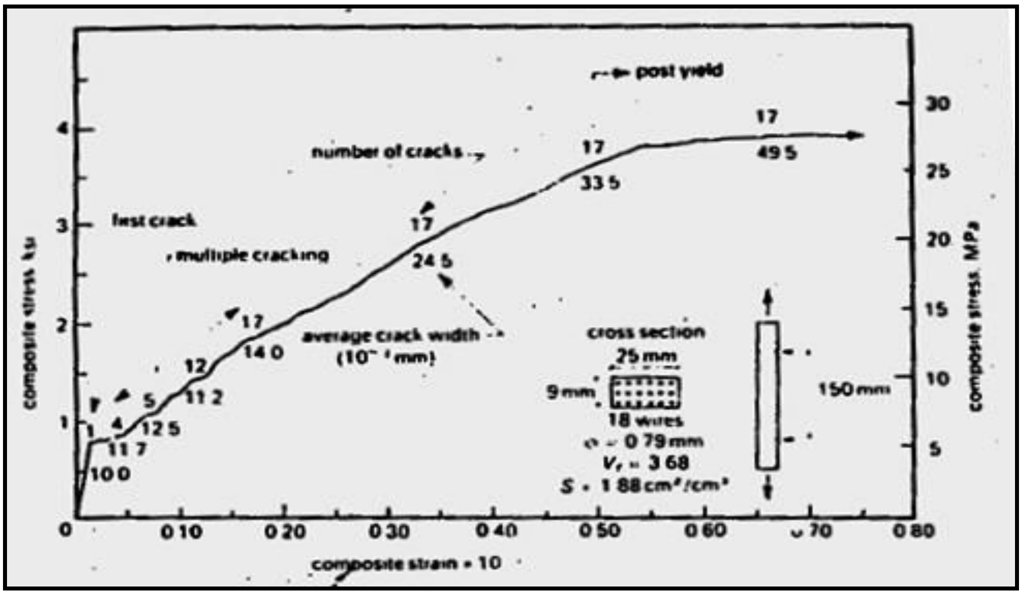



**Fig 9.2 Stress-Strain curve of ferrocement in tension**

1. Stress strain behavior of ferrocement in tension is shown by Shah and Balaguru (Ref: Ferrocement: Proceedings of the Fifth International Symposium). In the stress-strain curve the work done in stretching small length delta L. by the stress at that strain will be shown by small area=(Stress x Delta L). The total work done in straining the ferrocrete from first crack stress to yield point will be summation of such small areas, which is the area below the curve.
2. Now (stress) x (strain) is [force/area] x [elongation/ length] which has unit ($kg/cm^2$)x(cm/cm), which works out to be ($kgcm/cm^3$) , which gives work done in straining per cubic cm of ferrocement.
3. This is the property of the material indicating, its work absorbing capacity in straining the sample from first crack to yield point.
4. This capacity for RCC is only upto the first crack. For ferrocement it is multifold.
5. When a structure is subjected to dynamic loads, the dynamic force does some work on the structure and causes bending or deflection in it. The dynamic force multiplied by the displacement gives the work done on the structure by it. If the material of the structure has got adequate capacity to absorb this work, the structure can be designed for dynamic loads on the basis of this property.

## 9.17 Strength through shape

Shaping the structure changes the stress pattern over the section. This property can be fruitfully used in design of ferrocement structures.

1. Giving various shapes to a structure in ferrocement is very easy because the steel bar skeleton can be welded to any desired shape on which the meshes are tied.
2. No formwork is required in casting as the mesh-layers themselves act as open forms.
3. By changing the shape a flexural member can be converted into a compression member, a property in which mortar is very strong.
4. There are a lot of examples in nature of how it utilizes this concept in optimizing the material use. We can imitate nature and build many beautifully shaped and equally strong structures.

## 9.18 Tension capsules and Compression blocks:

This is the method of design where the laboratory work is directly applied on field.

1. When the method of fabricating and casting of ferrocement structures is standardized, with a particular mortar mix and arrangement of mesh layers, we can get a product of assured exact strength in tension and compression.
2. Tension capsules and compression blocks of particular size and strength can be produced and tested in laboratory.
3. For the desired strength of a member in field, multiples of such units can be used.
4. Precast ferrocement walling and floor panels of standard strength can be produced in factory and used directly in field. On the same lines hollow columns and hollow beams of standard strengths can be precast and used in field.
5. Thus, it can be seen that the rational methods of design of ferrocement will utilize its inherent properties and will provide optimized sizes of structures.

## PART B: DESIGN EXAMPLES

## 9.19 Important considerations in design:

1. The RCC structures are in form of solid or thick plates, like beams, columns and slabs.
2. Quite different is the case with ferrocement. The members are built by using thin walled elements and take form of hollow columns and beams, cavity walls and hollow floors. Single walls or the slab elements are thin and are stiffened by providing ribs.
3. In this respect ferrocement design is very close to design of steel structures where members are built by using plates, angles and rolled sections.
4. Ferrocement has higher strength in compression and tension. They depend on the composition of mortar and meshes used. When the compositions are changed, i.e mortar mix and the number of layers of meshes are changed, the strengths will have to be calculated and used. (It is not the case with RCC, standard strengths of concrete and steel bars are used in the design).
5. Ultimate tensile and compressive strengths of different ferrocement compositions can be calculated by using equations derived by using Theory of Solutions. By using proper factor of safety permissible stresses can be calculated.
6. As the properties, like N.A., M.I., are dependent on the shape of the member. While designing shaped structures in ferrocement, this aspect must be taken into account.

## 9.20 Guidelines for design of following structural elements are given below.

1) Plane walls in compression and tension.
2) Curved walls as compression members.
3) Hollow beams in form of channel sections.

### 9.20.1 Plane wall in compression

They can be in form of

a) Partition walls,
b) Sloping walls of pyramids,
c) Compound walls

Load carrying capacity of a plane wall of thickness ‘t’ in compression:

Load it can carry per m run = 100 x t x permissible compressive stress.

With mortar mix M20, the load carried 3.0 cm thick wall by mortar only will be

100 x 3.0 x 50 = 15 tonnes.

If mesh reinforcement is considered, it will be still higher.

These walls will have to be properly stiffened against buckling.

### 9.20.2 Plane walls in tension:

They can be in form of

a) Walls of rectangular water tanks
b) Suspended pardis or hanging walls
c) Plane walls retaining soil, water or any granular material
d) Walls subjected to wind load

**Steps in design:**

a) Assume thickness of wall depending on height and width
b) Find out the tensile stress to which these walls are subjected in the structure.
c) Select the composition of mortar mix and meshes which can be accommodated in the assumed wall thickness.
d) Find out the permissible tensile stress for this composition by using equations for ultimate tensile stress.
e) If required change the mesh composition which will have the required tensile stress.

### 9.20.3 Curved walls in compression:

When a plane wall is converted into a curved wall, with the loading on its convex face, it acts as an arch subjected to membrane compression. They can be in form of

a) Arch face walling for soil retaining walls and dam
b) Petals of circular water tank.
c) Waffle plates
d) Jack arch floor
e) Shell walls

**Steps in design**

a) In the case of arches the load is transferred to the supporting structure as reactions at the springing level of arch.
b) Find out the load, in the form of reaction, transferred directly to the support per m run
c) The load transfer is through direct compressive stresses.
d) Find out the thickness of walls as
   't' = (Load per m run) / (permissible compressive stress in mortar mix used
e) Considering the mortar only, find out the thickness.
f) If ferrocement walling is used the stress will be still less.

### 9.20.4 Hollow beams in form of box or channels section:

a) A solid beam in ferrocement is not practicable.
b) If the mortar near neutral axis is removed hollow beam is formed.
c) Top and bottom portions of the box act as flanges and the side walls as web.
d) The areas of the flanges are designed to take compression and tension.
e) The flanges are designed to take shear.

## PART C: DESIGN OF FERROCEMENT AS RCC.

**9.21 Design criteria**. Ferrocement deigned as RCC. All over world, ferrocement is treated as layered form of RCC and all the designs are made as RCC.

The analysis of ferrocement structure subjected to direct tension, compression, bending and their combinations, can be done as if it is a reinforced concrete member with layered reinforcement. This analysis can be based on

a) Limit state method
b) Working stress method
c) Serviceability conditions and
d) Experimental studies.

### 9.21.1 Limit state method of analysis.

In design of ferrocement structures, members should be proportioned for adequate strength in accordance with provisions specified in IS 456-1978, for partial factors for material strengths and loads.

1. While selecting characteristic strengths of mortar on ferrocrete, it should be noted that rich cement mortar will have very higher strengths even up to 60 MPa. In pressfill method of casting, unless the mortar is of very thick consistency, the meshes will not hold it. This automatically controls the strength. The probability of getting the designed strength consistently is much increased. In future it may be possible to reduce the partial safety factors for the mortar used.
2. While calculating characteristic strengths of mesh reinforcement global efficiency factors and orientation of mesh will have to be taken in account. Secondly it should be noted that yield strength and effective modulus of elasticity of wire meshes are different than those of steel bars.
3. In calculating characteristic loads, the reduction in dead loads due to use of ferrocement members will have to be noted.
4. All relevant limit states of collapse in flexure, tension, compression shear and torsion should be considered to ensure adequate degree of safety. In general the structures should be designed for most critical limit state and checked for the other limits. For ensuring this objective, the design should be based on characteristic values of material strengths and applied loads. Characteristic values should be based on statistical data, if available. Otherwise they can be based on experience.
5. In ferrocement when such a data is not available for cement mortar, treating mortar as micro concrete, characteristic values of concrete of the same grade can be safely used.

### 9.21.2 Working stress method.

All ferrocement structures may be analyzed by the linear classical theory of flexure to calculate internal actions produced by the design loads. Actually the classical theory of bending assumes that the composite is homogeneous, the bond between steel and concrete is perfect up to failure. Ferrocement satisfies these conditions hundred percent and hence the classical theory fits in perfectly in design of Ferrocement structures. For investigations of structure by working stress method, straight line theory of strain distribution on section in flexure can be used. Assumptions made in it are as follows.

a) Strains in cement mortar and reinforcement are directly proportional to their distance from neutral axis.
b) The stresses in wire reinforcement upto its yield strength are proportional to the strain and after yielding the steel stress is yield stress.
c) In RCC, the tensile strength of concrete is neglected in calculating flexural strength of cracked beam. (This is not the case with Ferrocement. In Ferrocrete, tensile strength of composite is substantial and hence must be considered in flexural design. In Ferrocrete beams in form of 'U' or Box sections, if steel bar reinforcement is provided in bottom flange and encased in Ferrocrete, tension taken by steel bars plus the one taken by Ferrocrete will have to be considered.)
d) Maximum usual compressive fiber strain is 0.003.
e) For strength calculations at ultimate load, parabolic stress-strain distribution in mortar can be approximated to a rectangular distribution using appropriate code of practice for RCC design.

In case of elastic analysis requirements for RCC specified in IS 456-1978 can be applied to ferrocement with the following modifications.

a) Modular ratios will change with mortar strengths. This will affect stiffness calculations when the area of reinforcement is to be transformed into equivalent mortar area.
b) According to strengths of mortars, the permissible stresses in tension, compression and shear will vary.
c) Type of mesh reinforcement will affect the effective modulus of elasticity of reinforcement.
d) Perfect bond between mortar and meshes in multiple cracking phase, will control the crack width. When the design is based on permissible crack widths, higher stresses in steel fibers can be used.

Permissible stresses in concretes, as given in IS 456-1978 should be used for ferrocement as mortar is micro concrete.

In analysis, the relative stiffness of members may be based on moment of Inertia of section determined on the basis of any one of the following

a) Gross section = The cross section of mortar ignoring reinforcement, or
b) Transformed section = The mortar cross section plus the area of reinforcement transformed on the basis of modular ratios, or
c) for cracked section = Area of mortar in compression plus the area of steel transformed on the basis of modular ratios.

**9.21.3 Design recommendations.**

For designing a ferrocement structure by limit state or working stress method, the following recommendations are made by ACI in their code of practice.

a) The allowable tensile stress in steel reinforcement may be generally taken as $0.60f_y$,where $f_y$ is the yield strength measured at 0.0035 strain
b) Values recommended by ACI. for $f_y$ and $E_r$ should be used for mesh reinforcement.
c) For water retaining and sanitary structures, it is preferable to limit the tensile stress upto 200 MPa. Unless crack width measurements on test model indicate that a higher stress would not affect the performance.
d) Allowable compressive stress in composite may be taken as 0.45 f'c, where f'c is the specified compressive strength of mortar measured on test sample of 3"x 6"size cylinder.
e) The total volume fraction $V_r$ in both directions shall not be less than 1.8 %. Total specific surface of reinforcement $S_r$ in both directions shall not be less than 0.80 $cm^2$ / $cm^3$. About twice these values are recommended.
f) The recommended average net cover of the reinforcement is about 2 mm. It is also recommended that for thicknesses more than 12 mm, the net cover shall not be more than 5 mm or o.25 x thickness.
g) It is recommended that the maximum crack width under working loads shall be less than 0.10 mm for non corrosive environment and 0.05 mm for corrosive environment or water retaining structures.
h) It should be noted that the crack widths of ferrocrete are much smaller than these values.
i) For ferrocrete structures to sustain a minimum fatigue life of 2 million cycles, the stress range in the reinforcement must be limited to 207 MPa. A stress range of 248 MPa may be used for one million cycles.

**9.21.4** Two separate articles on the topic of Use of Ferrocement in Earthquake Resisting Structures and Structural analysis and design of siphon using ANSYS have been attached on Appendix 3 and 4 to this handbook for additional information.

# CHAPTER 10
# COST ESTIMATION OF FERROCEMENT STRUCTURES

## 10.1 Cost estimation

We need following data before starting preparation of the estimate of a ferrocement structure.

A. Detailed drawings
B. Quantity statement
C. Sanctioned schedule of rates (Either CSR or DSR)
D. Various leads sanctioned by the competent authority for that site.
E. Specifications.

## 10.2 Factors governing the cost of structure

a. Specifications and units of measurements.
b. Materials-quality and their market rates.
c. Labour-skilled, unskilled. Their turnover and wages per day
d. Contingencies like water, transport, electricity and unforeseen items.
e. Overheads.
f. Profits expected.

**10.3 Drawings:** Drawings of the structure to be constructed are based on the designs. The dimensions of all components and the details of the meshes, bars etc shall be clearly shown in the drawings. Schedules showing the meshes shall be shown.

## 10.4 Components of estimate

**A. Materials**: Quantity and Rates

From the drawings, the quantities of the materials like steel, mesh, sand and cement can be calculated. For the skeletal steel, from the bar diameters and their spacing in two directions, the weight per unit area can be obtained. From the type and size of mesh and their number of layers, the area of mesh reinforcement can be calculated.

From the thickness of the Ferrocrete item, we can get volume of wet mortar in liters. When the mix proportion of the mortar is known, volumes of cement and sand for the dry mix can be calculated. The quantity of water and the additives can be obtained from the proportions prescribed in the specifications.

**B. Labour required**

The man-hours per unit of construction of ferrocrete items based on our experience is given in table 10.1. The wages of the skilled and unskilled labour will be as per the rates payable in that area. Labour component of ferrocrete items is on higher side, may go upto 20 % sometime.

**C. Contingencies**

Generally the ferrocrete items are fabricated and tied in factory, and then taken to the site for mortaring. Hence the cost of handling, transporting, hoisting and erecting of the cage at site, octroi, water charges etc are considered under contingencies. They vary from 5 to 8 %.

**D. Overheads**

The key to the best ferrocrete construction lies in its strict supervision. A full time supervisor at site is a must. His charges will have to be considered in addition to office and other expenses, while working out the overheads. Overheads may be taken up to 8 to 10 %.

**E. Profits**

Ferrocrete construction is a specialized job and profit margins expected in it are higher if the design is complicated.

**Table 10.1 Required skill person and their turnovers**

| S. No. | Work to be done | Skills | Turnover/8 hourday |
|---|---|---|---|
| 1 | Sieving sand | 2 female workers | 2-0 to 2-5 cubuc m. |
| 2 | Welding wall skeleton | 1 welder + 1 helper | 12 to 15 sq m. |
| 3 | Welding shaped skeleton | 1 welder + 1 helper | 10 to 12 sq m. |
| 4 | Tieing mesh- 3 layers | 1 tier + 1 helper | 10 to 12 sq m. |
| 5 | Pressfilling cement mortar | 2 masons + 2 helpers | 15 to 20 sq m. |
| 6 | Smooth plaster finish | 1 mason + 1 helper | 15 to 20 sq m. |
| 7 | Sandfaced rough plaster | 1 mason + 1 helper | 12 to 15 sq m. |

## 10.5 Cost analysis of a ferrocrete partition wall

Specifications for the item of ferrocrete partition wall are written as- “Fabricating and casting at site ferrocrete partition wall 30mm thick, with skeletal steel of 8 mm dia. Tor steel bars spaced at 500 mm center to center in both directions, over which one layer of weld mesh 100 x 100mm x 12 x 12g and three layers of chicken mesh 13 x 13mm x 24 x 24g, tightly tied and impregnated with rich cement mortar of (1:3) mix by volume, finishing both the faces with neat cement, curing etc complete.”

Table 10.2 shows the quantity of material that used in partition wall.

**Table 10.2 Quantity of material for ferrocrete partition wall**

| Sr. No. | Mix by Volume | Material | Quantities in liters for 10 sq m. of walling for thickness | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 13mm | 20mm | 25mm | 30mm | 40mm | 50mm |
| | | wet volume | 130.0 | 200.0 | 250.0 | 300.0 | 400.0 | 500.0 |
| | | dry volume | 173.0 | 266.0 | 333.0 | 400.0 | 532.0 | 665.0 |
| 1 | 1:1 | Cement | 87.0 | 133.0 | 167.0 | 200.0 | 266.0 | 333.0 |
| | | Sand | 87.0 | 133.0 | 167.0 | 200.0 | 266.0 | 333.0 |
| 2 | 1:1.5 | Cement | 69.0 | 107.0 | 133.0 | 160.0 | 213.0 | 266.0 |
| | | Sand | 104.0 | 160.0 | 200.0 | 240.0 | 320.0 | 400.0 |
| 3 | 1:2 | Cement | 53.0 | 89.0 | 111.0 | 133.0 | 177.0 | 222.0 |
| | | Sand | 116.0 | 177.0 | 222.0 | 266.0 | 354.0 | 444.0 |
| 4 | 1:3 | Cement | 43.0 | 67.0 | 83.0 | 100.0 | 133.0 | 166.0 |
| | | Sand | 130.0 | 200.0 | 250.0 | 300.0 | 400.0 | 500.0 |
| 5 | 1:4 | Cement | 35.0 | 53.0 | 67.0 | 80.0 | 160.0 | 133.0 |
| | | Sand | 140.0 | 212.0 | 268.0 | 320.0 | 424.0 | 532.0 |
| Please note that an allowance of 10% for bulking of sand is not made this table. One cement bag contains 35 liters of cement weghing 50 kgs. | | | | | | | | |

**10.5.1 Steps in cost analysis**

a) Study the specifications carefully
b) Decide the unit of measurement
c) Find out the quantities of material
e) Find out the man-days for labour
f) Find out the market rates for material and labour
g) Work out the cost of material and labour
h) Add contingencies, overheads and profit to it
i) Quote the rate per unit of measurement

**10.5.2 Specification**

In specification studies, note the spacing of skeletal steel, types and number of layers of mesh reinforcement and the mortar mix.

**10.5.3 Unit of measurement**

Let us work out the quantities for 10 sq meters of walling, say of size 5.0m X 2.0m.The rate will be quoted per sq meter of walling.

**10.5.4 Quantities of materials:**

Let us work out the quantities of materials of skeletal steel, mesh reinforcement and cement mortar per 10 sq meters as shown in fig 10.1..

a) Skeletal steel: 8mm dia tor steel bars @ 500mm c/c bothways.

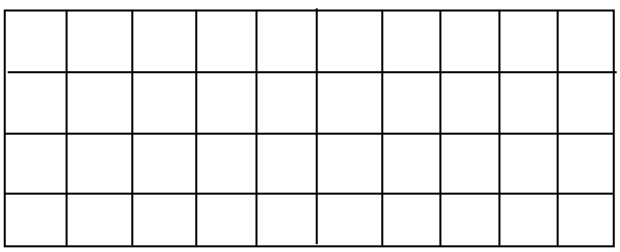


**Fig 10.1 Skeletal steel for 5m x 2m single wall**

Longitudinal bars:

Number of bars = 2000/500 + 1 = 5 nos of 5.0 m length = 25.0 m

Cross bars:

Number of bars = 5000/500 + 1 = 11 nos of 2.0 m length = 22.0 m

Total length of bars

= 47.0 m. add 5% for wastage. So length = 49.35 m say 50.0 m

Weight of steel bars

@ 0.39 kg/m for 50 m length for 8 mm dia = 50.0 x 0.39 =19.5 kg.

b) Weld mesh, one layer of 100 x 100mm x 12 x 12g, = 10.0 sq m. Allow 5% for wastage and overlaps. So area of weld mesh = 10.5 sq m.
c) Chickenmesh, 3 layers of 13 x 13mm x 24 x 24g. = 2 x 10.5 = 31.5 sq m.
d) Binding wire of 18g = 2.0 kg (from experience)
e) Welding rods on lump sum basis.
f) Cement mortar (1:3) mix by volume.

Thickness of wall 30 mm

Hence volume of wet mortar =10.0 x 0.03 =0.30 cubic m. = 300 liters.

*(As a quick guide, it should be noted that for one cm thickness of wall, mortar required is 10 liters per sq m of wall.)*

For dry mortar mix add 33% more to wet mix.

So volume of dry mix = 1.33 x 300 = 400 liters.

As the mix is (1:3) by volume,

The volume of cement= 400/ (1+3) x 1 = 100 liters = 2.86 bags,

and the volume of sand will be equal to 400/ (1+3) x 3 = 300 liters.

Allowing 10% for bulking of sand = 330 liters.

### 10.5.5 Labour:

Workout the man-days required for each item of work from the table below for 10 sq m of walling.

**Table 10.3 Required manpower**

| Sr.No. | Item of work | Manpower | Mandays |
|---|---|---|---|
| 1 | For welding | Welder<br>Helper | 1 manday<br>1 manday |
| 2 | For tying | Fitter<br>Helper | 1 manday<br>1 manday |
| 3 | For mortaring with finish | Mason<br>Helper | 2 mandays<br>2 mandays |
| 4 | For curing | Helper | 4 mandays |

**10.5.6 Market rates** for materials and labour in Pune, Nashik in September 2017 are as follows:

**Table 10.4 Market rates**

| Sr. No. | Particulars | Rate |
|---|---|---|
| 1 | Tor steel bars 8 mm dia, | Rs 45/- per kg |
| 2 | Weld mesh 100 x 100 x 12 x 12g | Rs 55/- per sq m. |
| 3 | Chickenmesh 13 x 13 x 24 x 24g | Rs 27/- per sq m. |
| 4 | Binding wire 18g | Rs 55/- per kg. |
| 5 | Cement | Rs 325/- per bag. |
| 6 | Sand (sieved) | Rs 3.00 per litre. |
| 7 | Welder | Rs 700/- per day |
| 8 | Fitter | Rs 700/-per day. |
| 9 | Mason | Rs 850/- per day |
| 10 | Helper | Rs 550/- per day. |

**10.5.7 Cost analysis for 10 sq m of walling**

**Table 10.5 Cost analysis of Single Wall 30 mm thick**

| **A) Material** | | | | | |
|---|---|---|---|---|---|
| **Sr. No.** | **Materials** | **Quantity** | **Per** | **Rate (Rs)** | **Amount (Rs)** |
| 1 | 8 mm dia M.S.bars | 19.50 | ` Kg | 45.00 | 877.50 |
| 2 | Weld mesh 100 x 100 | 10.50 | Sq m | 55.00 | 577.50 |
| 3 | Chicken mesh 13 x 13 | 31.50 | Sq m | 27.00 | 850.50 |
| 4 | Binding wire | 2 | Kg | 55.00 | 110.00 |
| 5 | Welding rods | L.S. | | | 80.00 |
| 6 | Cement | 2.86 | Bags | 325.00 | 929.50 |
| 7 | Sand | 330 | Liters | 3.00 | 990.00 |
| 8 | Additives | L.S. | | | 100.00 |
| | | | | **Total** | **4515.00** |
| **B) Labour** | | | | | |
| 1 | Welder | 1 | Mandays | 700/- | 700.00 |
| 2 | Fitter | 1 | Mandays | 700/- | 700.00 |
| 3 | Mason | 2 | Mandays | 850/- | 1700.00 |
| 4 | Helpers | 8 | Mandays | 550/- | 4400.00 |

| | |
|---|---|
| Total of (A) + (B) = | 12015.00 |
| Add contingency, overheads 18% = | 2162.70 |
| Total = | 14177.70 |
| Add profit 20% = | 2835.54 |
| Total cost for 10 sq m 30 mm thick wall = | 17013.24 |
| **Cost per sq m =** | **1701.32** |

## 10.6 Specifications for Ferrocrete structures

How to draft specifications for ferrocrete, the points to be considered and specimen specifications for some ferrocrete items are given here. Being a thin walled structure, it needs accurate working and strict supervision. The specifications should be drafted with due considerations to the following points.

a) a) Ferrocrete is used for applications in rural areas to intricate architectural forms. Generally the locally available sand is used for it. Sand is a natural product and we have no control on its quality. Hence for the local sand, strict quality control in form of washing, sieving, grading etc should be imposed in the specifications and strictly followed at site.
b) Relevant B. I. S. specifications for natural and artificially crushed sand should be used.
c) The cement, steel bars and all types of mesh reinforcements should be according to B. I. S. Specifications.
d) Giving correct form to the ferrocrete component is its basic requirement. Hence the correct size, shape, capacity and geometry of the element must be accurately specified and should be backed up by drawings, preferably in three dimensions.
e) Tying of mesh reinforcement tightly on the skeletal steel is a must, as no formwork is used in ferrocrete construction. It should be insisted in specifications and a thorough inspection of the mesh-tying item should be made compulsory.
f) Mortaring of mesh layers for their full penetration should be ascertained from time to time during casting. The height of the mortar to be filled in at a time should be prescribed. Hence a stage wise inspection of mortaring should be insisted in the specifications.

As an illustration, specifications for some ferrocrete items are given below.

### 10.6.1 Specifications for a Ferrocrete water tank

Fabricating and casting at site, a square ferrocrete water storage tank of size -

1250 x 1250 x 1250mm height(including freeboard of 100mm) and water capacity 1800 liters, with base 50mm thick, side walls and top 30mm thick, with folded roof slab with a rise of 150mm at the central manhole, the manhole being of size 500 x 500mm opening with a ferrocrete cap-like lid over it. The ferrocrete walling, base slab and roof slab should be formed of skeletal steel of 8mm dia torsteel bars, spaced at 300mm c/c horizontally and vertically as shown in the sketch, on which one layer of weldmesh of size 100 x 100mm x12 x 12g tied on outer face, with three layers of chickenmesh of size 13 x 13mm x 24 x 24g ,two of them on the outer face and one on the inner face, are tied tightly, the cage of meshes being fully impregnated with rich cement mortar of mix (1:2) by volume and finished smooth on the inner face and sand-face plaster on the outer face, curing, testing for watertightness etc complete.

### 10.6.2 Specifications for ferrocrete double wall (cavity wall)

Fabricating and casting at site, 150 mm thick ferrocrete double wall, also called cavity wall, consisting of two skin-wall elements of 25mm thick and an air-gap of 100 mm as shown in fig 10.2, the two skin-walls being connected by 6mm dia mild steel bars as connectors, spaced at 500mm c/c vertically and horinzontally, the ferrocrete skin walls being built of skeletal steel bars spaced at 500mm c/c bothways, on which single layer of weld mesh of 150 x 150mm x12 x 12g and two layers of chickenmesh of size 13 x 13mm x24 x 24g are tied tightly on the outer faces, and impregnated with cement mortar mix of (1:3) by volume, finishing the exposed surfaces, smooth or rough as directed by the engineer-in-charge, the casting being done by using sliding formwork, curing etc complete.

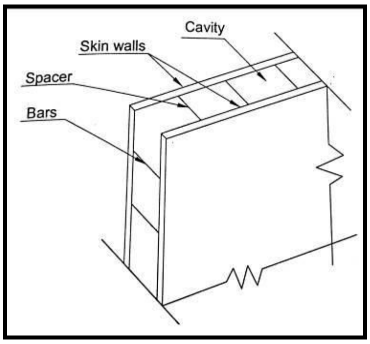



**Fig 10.2 Cavity wall**

### 10.6.3 Specification for a Ferrocrete hemispherical dome:

As shown in fig 10.3 Fabricating and casting at site 40mm thick ferrocrete hemispherical dome of base dia of 8.0m and central height of 2.0 m, anchored to a ring beam already cast in RCC by the owner, anchor bars of 8mm tor steel being already taken out from the ring beam at the time of its casting and left open for connecting them to the dome base, the shell of dome being fabricated skeletal steel cage of 8mm dia bars, spaced 400mm c/c circumferentially and 500mm c/c radially at the base, the mesh reinforcement consisting of 2 layers of weld mesh (one on each face) of size 100 x 100mm x10 x 10g and 4 layers of chickenmesh(two on each face) being tied tightly over the skeleton, and impregnated with cement mortar of (1:2) mix by volume, and finished smooth from inside and rough sand- faced from outside, curing etc complete, the scaffolding being supplied by the owner.

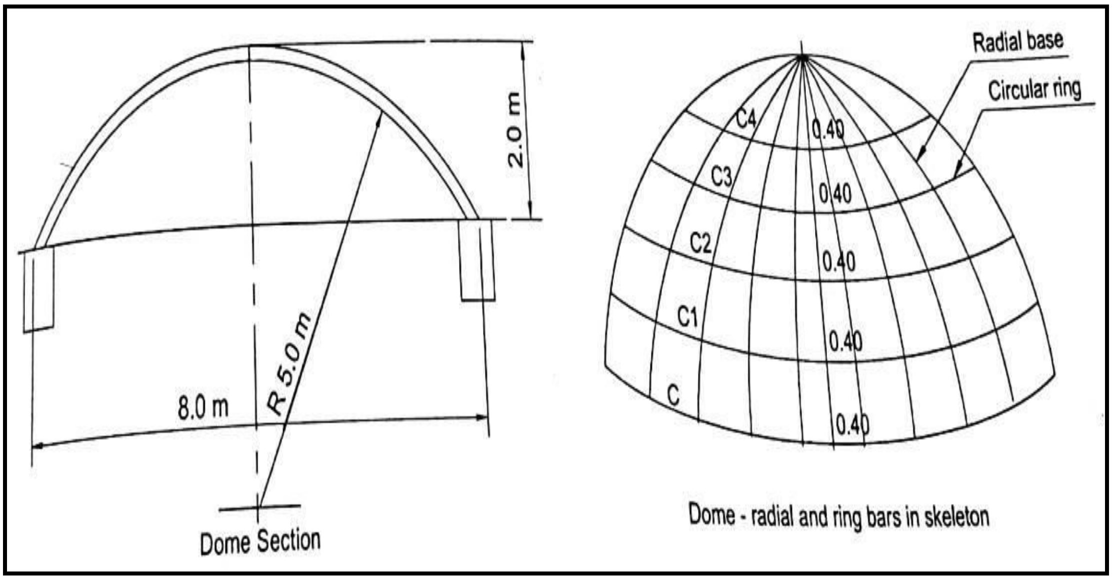



**Fig 10.3 Ferrocement hemisphere**

## 10.7 Increase in carpet area due to ferrocement walling

By building byelaws, all the external brick-walls must be of minimum 9 inches and internal walls of 6 inches thickness. A ferrocrete cavity wall of 6 inches thickness for external and 2 inches thickness for internal walls will increase the carpet area of building. This is illustrated by an example given below.

A building plan of an existing building in brickwork with the external dimensions in feet units is given in fig 10.4.

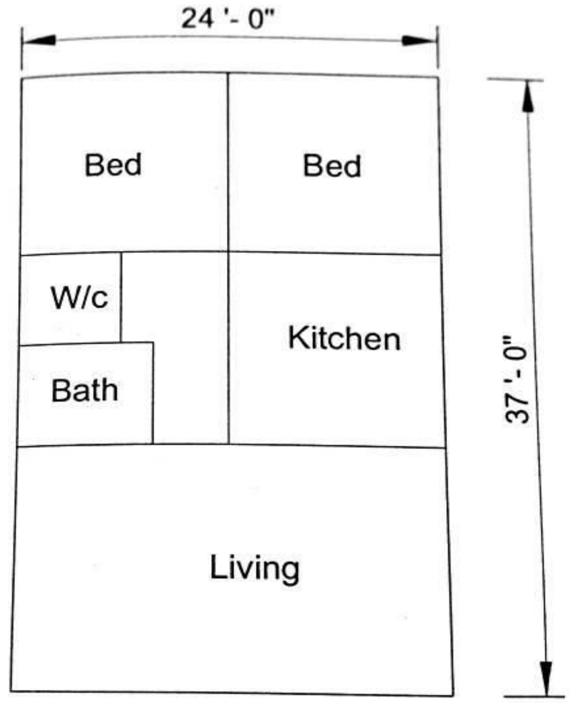



**Fig 10.4 Increase in carpet area.**

In this plan all the external 9 inches brick walls are replaced by 6 inches thick ferrocrete cavity wall and the internal walls 0f 6 inches thickness in brick are changed to 2 inches ferrocrete partition walls.

Now the plan area of the building = 24.0 x 37.0 = 888.0 sft

A. For the brickwalls:

Area of all the external walls = 2 ( 24.0 + 37.0 ) (0.75)=91.5 sft

Area of all internal walls = (2 (24.0 ) + 25.0 + 13.0 ) (0.50 ) = 43.0 sft.

Total area of brickwall = 134.5 sft =15.14 % of built up area.

B. For ferrocrete walling.

Area of external walls = 2 (24.0 + 37.0 ) ( 0.50 ) =61.0 sft

Area of partition walls =( 86.0 ) (0.167 )= 14.3 sft.

Total area of ferrocrete wall = 75.30 sft = 8.48 % of built up area.

Hence the increase in carpet area is 59.2 sft = 6.66 % of built up area. So when the house in this plan is to be sold on the basis of carpet area, the builder gets 6.66 % more carpet area by use of ferrocement technology.

## 10.8 Estimation in Government departments

In PWD and WRD common schedule of rates or Regional schedules are published for use of rates in estimation as shown in fig 10.5. Some ferrocement items are available in CSR. Engineers can derive the rates for the field use by adding the leads and lifts of material. They can add the percentage increase for the particular location importance, say tribal area, hilly area, corporation area etc. After analysis of the rates and finalization of measurements as per the design and drawings, one can write abstract. Then additions for contingent charges, local taxes etc can be added as application as per Government guidelines. Estimates and rate analysis has to be sanctioned by competent authorities before floating tenders.

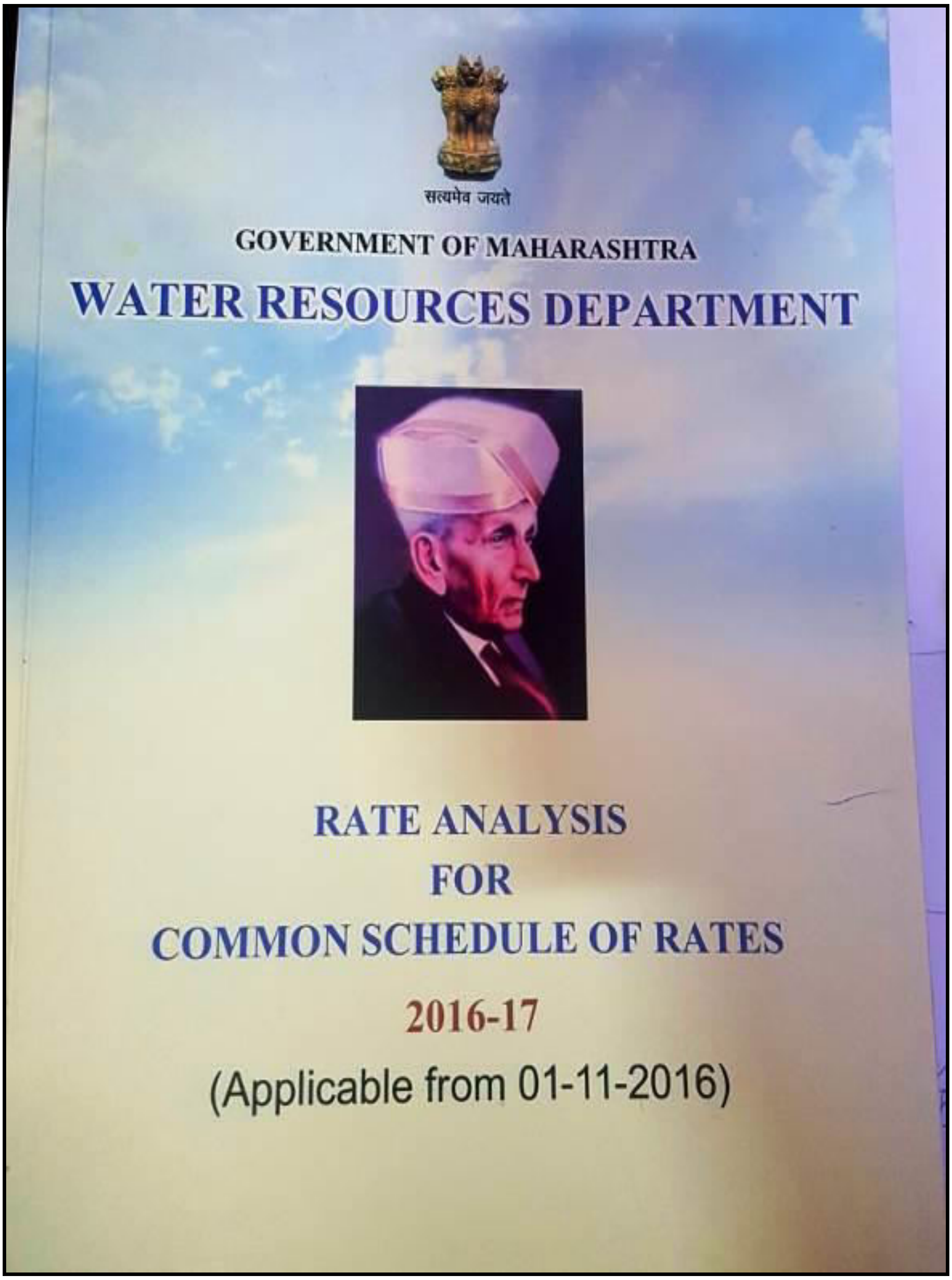



**Fig 10.5 Common schedule of rates for year 2016-17**

## FERROCEMENT WALLING

**Item No.41** :- Providing and Fixing and errecting, welding 8 mm MS bar @200 mm C/c both ways for ferrocement walling witu welded mesh of size 100x100x2.30 mm and chiken mesh 3 layers.

| | | | | |
|---|---|---|---|---|
| A | Material for :one Sqm | | | |
| 1 | MS bar for wall for 5m length and 1m height | | 21.84 | Kg |
| | Requirement of steel/Sqm | | 4.37 | Kg |
| 2 | Rate for MS fabrication of 15 Kg/Sqm | Rs. | 1129.00 | ./Sqm |
| 3 | Less painting | Rs. | -32.00 | ./Sqm |
| | | Total | 1097.00 | ./Sqm |
| 4 | Rate for 4.368 Kg/Sqm= 4.368/15*1097 | Rs. | 319.45 | ./Sqm |
| 5 | Welded Mesh 50x50x11 gauge | Rs. | 236.00 | ./Sqm |
| 6 | Add for binding wire | Rs. | 32.00 | ./Sqm |
| | Total | | 268.00 | ./Sqm |
| | Add : 10% OH Charges | | 26.80 | ./Sqm |
| | Total | | **294.80** | **./Sqm** |
| 7 | Chicken Mesh of 3 layers | | | |
| | For three layers 3x44=132.00 | Rs. | 132.00 | ./Sqm |
| A | Total 4 to 7 | Rs. | 746.25 | ./Sqm |

B Labour

| | Item | unit | Qty | Rate | Amount | |
|---|---|---|---|---|---|---|
| 1 | Fitter II class 1.5 Mandays @ Rs. 302/day | Day | 1.50 | 455.00 | 682.50 | |
| | Total for Labour | | | | 682.50 | ./10 Sqm |
| | Total for Labour for 1 Sqm | | | | 68.25 | ./Sqm |
| | Total A+B | | | | 814.50 | ./Sqm |
| | sundries 2% | | | | 16.29 | ./Sqm |
| | Over head Charges 10% | | | | 81.45 | ./Sqm |
| | Grand Total | | | | **912.24** | **./Sqm** |
| | Add for Labour Amminities 1% | | | | 9.12 | ./Sqm |
| | Total | | | | 921.36 | ./Sqm |
| | Say Rs | | | | **921.35** | **./Sqm** |



**Fig 10.6 Typical estimate of ferrocement walling-1**

**Item No.42 :-** Providing and casting Ferrocement wall in CM 1:3 including curing etc complete.

**A) For 30 mm thick wall**

| | | unit | Qty incl. wastage | Rate | Amount | |
|---|---|---|---|---|---|---|
| A | Material for :one Sqm | | | | | |
| 1 | Cement (0.35+0.35x 1% wastage) | Bag | 0.354 | 290 | 102.66 | ./Sqm |
| 2 | Sand 0.03*1.02 | Cum | 0.0306 | 608.66 | 18.62 | ./Sqm |
| 3 | Water | Th Lit | 0.6 | 32 | 19.20 | ./Sqm |
| | | | Total | Rs. | 140.48 | ./Sqm |
| | Total for Material | | | Rs. | **140.48** | **./Sqm** |
| B | Labour | | | | | |
| 1 | labour rate for 12mm thick laster | | | Rs. | 81.00 | ./Sqm |
| | For 30 mm | | 2.5 | 81 | 202.50 | |
| | Total for Labour for 1 Sqm | | | | **202.50** | **./Sqm** |
| | Total A+B | | | | **342.98** | **./Sqm** |
| | sundries 2% | | | | 6.86 | ./Sqm |
| | Total | | | | 349.84 | ./Sqm |
| | Add : Over head Charges 10% | | | | 34.98 | ./Sqm |
| | Grand Total | | | | **384.82** | **./Sqm** |
| | Add for Labour Amminities 1% | | | | 3.85 | ./Sqm |
| | Total | | | | 388.67 | ./Sqm |
| | Say Rs | | | | **388.65** | **./Sqm** |

**B) 40 mm thick**

| | | unit | Qty | Rate | Amount | |
|---|---|---|---|---|---|---|
| A | Material for :one Sqm | | | | | |
| 1 | Cement (0.47+0.47x 1% wastage) | Bag | 0.475 | 290.00 | 137.75 | ./Sqm |
| 2 | Sand 0.04*1.02 | Cum | 0.0408 | 608.66 | 24.83 | ./Sqm |
| 3 | Water | Th Lit | 0.6 | 32.00 | 19.20 | ./Sqm |
| | | Total | | Rs. | 181.78 | ./Sqm |
| | Total for Material | | | Rs. | **181.78** | **./Sqm** |
| B | Labour | | | | | |
| 1 | labour rate for 12mm thick laster | | | Rs. | 81.00 | ./Sqm |
| | For 40 mm | | 3.33 | 81.00 | 269.73 | |
| | Total for Labour for 1 Sqm | | | | **269.73** | **./Sqm** |
| | Total A+B | | | | **451.51** | ./Sqm |
| | sundries 2% | | | | 9.03 | ./Sqm |
| | Total | | | | 460.54 | ./Sqm |
| | Add : Over head Charges 10% | | | | 46.05 | **./Sqm** |
| | Grand Total | | | | **506.59** | ./Sqm |
| | Add for Labour Amminities 1% | | | | 5.07 | ./Sqm |
| | Total | | | | 511.66 | **./Sqm** |
| | Say Rs | | | | **511.65** | ./Sqm |



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**Fig 10.7 Typical estimate of ferrocement walling-2**

### C) 50 mm thick

| | | unit | Qty | Rate | Amount | |
|---|---|---|---|---|---|---|
| A | Material for :one Sqm | | | | | |
| 1 | Cement (0.583+0.583x 1% wastage) | Bag | 0.59 | 290.00 | 170.81 | ./Sqm |
| 2 | Sand 0.05*1.02 | Cum | 0.05 | 608.66 | 31.04 | ./Sqm |
| 3 | Water | Th Lit | 0.60 | 32.00 | 19.20 | ./Sqm |
| | | | Total | Rs. | 221.05 | ./Sqm |
| | Total for Material | | | Rs. | **221.05** | **./Sqm** |
| B | Labour | | | | | |
| 1 | labour rate for 12mm thick laster | | | Rs. | 81.00 | ./Sqm |
| | For 50 mm | | 4.17 | 81 | 337.77 | |
| | Total for Labour for 1 Sqm | | | | **337.77** | **./Sqm** |
| | Total A+B | | | | **558.82** | **./Sqm** |
| | sundries 2% | | | | 11.18 | ./Sqm |
| | Total | | | | 570.00 | ./Sqm |
| | Add : Over head Charges 10% | | | | 57.00 | ./Sqm |
| | Grand Total | | | | **627.00** | **./Sqm** |
| | Add for Labour Amminities 1% | | | | 6.27 | ./Sqm |
| | Total | | | | 633.27 | ./Sqm |
| | Say Rs | | | | **633.25** | **./Sqm** |



**Fig 10.8 Typical estimate of ferrocement walling-3**

# CHAPTER 11
# STANDARDIZATION OF FERROCEMENT TECHNOLOGY

## 11.1 Necessity of standardisation:

Up to 1970, ferrocement was used for small size water retaining structure. From 1980 onwards its use as a structural material for building large size structures like silos, egg-shaped conduits, digesters, effluent treatment plants, space structures like pyramids, domes and shells, multi-storeyed buildings, check dams, petal tanks, soil retaining walls etc has started and many constructions are going on all over India. Hence its standardization is necessary.

## 11.2 Ferrocement is NOT RCC and it cannot be covered under IS 456.

Though Reinforced with Steel, structural behaviour of Ferrocement is Miles Away from RCC. It is a single-material technology for all problems of construction industry. Ferrocement is homogeneous, ductile, high strength in Tension (about ten times that of RCC), compression and shear. Complete control over crack formation, water-tightness, strong bond between mortar and meshes, strength gained through shape, high energy absorption capacity, high impact and penetration resistance, As a method of thin walled construction, mortaring is to be executed by pressing the mortar in meshes and not by pour-cast method, form-free construction, lightweight construction, high strength-to-weight ratio, only three raw materials and skills required, enormous saving of material, labour and time of construction.

## 11.3 Different methods of construction

Site work reduced to the extent of 20 percent only. All the remaining work is done in factory.

Single wall, double wall, cavity wall and hollow floor system with in-built columns and beams, thermally insulated housing, formation of ‘I’ ‘T’ ‘U’, ‘+’ ‘wide-flange H-shaped in-built columns and beams’ are possible, ideal solution for Earth-quake resisting structures. Arch faced retaining walls, dams and petal tanks can be constructed at half the cost.

Prone for precasting, mass-scale housing with precast walling and floor panels in which joints are the structural members like columns and beams.

Design is more realistic and simple the material being homogeneous and ductile. It is based on the basic properties of meshes and mortar, like specific surface, volume fraction and strength of mortar. Crack controlled structures Standard design tables can be made available for field engineers.

## 11.4 International code: ACI 549-1R

This guide is based on technical information assembled by ACI Committee 549, Ferrocement, from current practice, developments, and advances in the field of ferrocement around the world. It represents a practical supplement to the state-of-the-art report (ACI 549R) published earlier by the committee. The guide covers materials for ferrocement, materials selection, and standards; design criteria and approaches; construction methods; maintenance and repair procedures; and testing.

The objectives of this guide are to promote the effective use of ferrocement in terrestrial structures, provide architects and engineers with the necessary tools to specify and use ferrocement, and provide owners or their representatives with a reference document to check the acceptability of a ferrocement alternative in a given application. This guide is consistent with ACI Building Code Requirements for Reinforced Concrete (ACI 318) except for the special characteristics of ferrocement, such as reinforcement cover and limits on deflection.

Ferrocement is a form of reinforced concrete using closely spaced multiple layers of mesh and/or small diameter rods completely infiltrated with, or encapsulated, in mortar. The most common type of reinforcement is steel mesh. Other materials such as selected organic, natural, or synthetic fibers may be combined with metallic mesh. This guide addresses only the use of steel reinforcement in a hydraulic cement mortar matrix.

Applications of ferrocement are numerous, especially in structures or structural components where self-help or low levels of skills are required. Besides boats and marine structures, ferrocement is used for housing units, water tanks, grain silos, flat or corrugated roofing sheets, irrigation channels, and the like (see ACI 549R).

Guide for the Design, Construction, and Repair of Ferrocement by ACI Committee 549 supplements two earlier publications (ACI 549R-82, State-of-the-Art Report on Ferrocement, and SP-61, Ferrocement--Materials and Applications). It provides technical information on materials and material selection, design criteria and approaches, construction methods, maintenance and repair procedures, and testing. The objectives are to promote more effective use of ferrocement in terrestrial structures, provide architects and engineers with the necessary tools to specify and use ferrocement, and provide owners or their representatives with a reference document to check the acceptability of a ferrocement alternative in a given application.

## 11.5 Formulation of Panel for ferrocement structure

The committee has requested the chairman of Cement and Concrete Sectional Committee CED 2, Bureau of Indian Standards, New Delhi that provide the documents related to ferrocement materials, designs, applications, quality control that used to finalize the draft of IS code 13356: 1992 Precast ferrocement water tank (Upto 10000 Liter capacity).

In 25th meeting of Cement and concrete sectional committee CED 2 dated 06/03/2017, the committee studied the suggestion received and constitute panel for formulation of Indian standard code of practice for design and construction using ferrocement. The details of this panel is as follows.

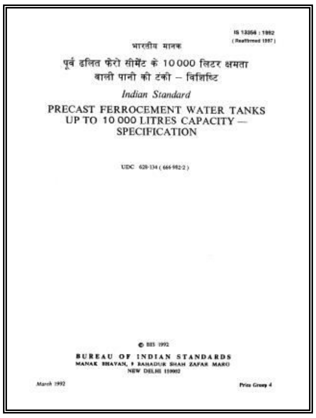
**Panel for Ferrocement construction CED 2:2/P9**

Shri. V.V.Arora, NCB (Convener)
Shri. R.C.Wason, In present capacity, New Delhi
Ferrocement Society, Pune
MERI, Nashik
CBRI, Roorkee
Shri. P.C.Sharma, In personal capacity, Ghaziabad
Dr. Ashok K.Jain, In personal capacity, Noida
NCB, Ballabgarh
SERC, Chennai

**(Appendix 6 Formulation of Panel for ferrocement**)

## 11.6 Previous BIS codes for ferrocement

Bureau of Indian Standards recognized the need of code on ferrocement in 1990. People were using this technology for water tanks construction. In villages also villagers were quite friendly with this technology as it was similar to bamboo strips woven together as a wall and covering it with wet soil mortar. In 1990 BIS committee published a code for water tanks of capacity up to 10000 liters as shown in fig 11.1. (Cement and Concrete Sectional Committee, CED 2)



IS 13356 : 1992
( Reaffirmed 1997 )

भारतीय मानक

पूर्व ढलित फेरो सीमेंट के 10 000 लिटर क्षमता
वाली पानी की टंकी – विशिष्टि

*Indian Standard*

PRECAST FERROCEMENT WATER TANKS
UP TO 10 000 LITRES CAPACITY —
SPECIFICATION

UDC 628·134 ( 666·982·2 )

© BIS 1992

BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

March 1992

Price Group 4

**Fig 11.1 IS code for ferrocement water tank of capacity up to 10000 litres (IS 13356: 1992)**

The foreword mentioned as below.

"Ferrocement is a versatile structural material possessing unique properties of strength and serviceability. It is made with closely-knit wire mesh, mild steel reinforcing bars and rich cement sand mortar. The materials required for making it, namely, cement, sand, wire mesh and steel skeletal bars are easily available in most places. It is possible to fabricate in ferrocement, a variety of structures which are thin, light, durable and possessing high degree of impermeability. Ferrocement can be easily moulded into any shape. The several applications of this material include storage structures, septic tanks, bio-gas plant digesters, pontoons, boats, ***roofs, wall panels***, manhole covers, drainage and irrigation units, shuttering for concrete construction, etc. Ferrocement water tanks exhibit a high degree of impermeability. They are ideally suited for residential and community uses. Construction of precast water tanks with ferrocement is an advantage where a large number of tanks have to be built because of the speed in erection and less requirement of skilled labour at site."

As such separate codes for non water retaining structures like walls, domes, shells, etc will be required. Recently BIS has invited a meeting under CED 2 committee and has decided to formulate such codes.

IS 10430:2000 is for canal lining. The methods of lining are mentioned in this code. Ferrocement lining is put under rigid lining.

## 11.7 National Building Code of India

The National Building Code of India (NBC) as shown in fig 11.2, a comprehensive building Code, is an instrument providing guidelines for regulating the building construction activities across the country. It is widely referred and used by state/local bodies regulating development and building construction activities, Government construction departments and agencies, private construction agencies/builders/developers, building professionals and consultants, academic and research institutions, and building material and technology suppliers throughout the country. The Code mainly contains administrative regulations, development control rules and general building requirements; fire safety requirements; stipulations regarding materials, structural design and construction (including safety); building and plumbing services; landscape development, signs and outdoor display structures; guidelines for sustainability, asset and facility management, etc.

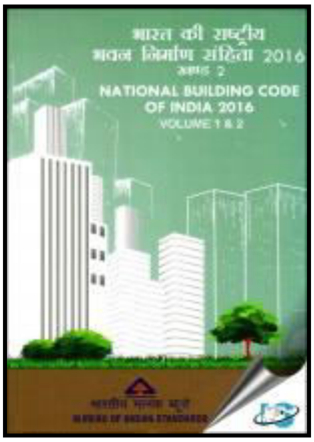



**Fig 11.2 National Building Code of India**

The Code was first published in 1970 at the instance of Planning Commission and then first revised in 1983. Thereafter three major amendments were issued to the 1983 version, two in 1987 and the third in 1997. The second revision of the Code was in 2005, to which two amendments were issued in 2015.

The Code now published in the fourth version representing the present state of knowledge on various aspects of building construction. The process of preparation of the Code has thrown up a number of problems; some of them were answered fully and some partially. Therefore, a continuous programme will go on by which additional knowledge that is gained through technological evolution, users views over a period of time pinpointing areas of clarification and coverage and results of research in the field, would be incorporated in to the Code from time to time to make it a living document. It is, therefore, proposed to bring out changes to the Code periodically.

Due to large scale changes in the building construction activities, such as change in nature of occupancies with prevalence of high rises and mixed occupancies, greater dependence and complicated nature of building services, development of new/innovative construction materials and technologies, greater need for preservation of environment and recognition of need for planned management of existing buildings and built environment, there has been a paradigm shift in building construction scenario. Considering these, a Project for comprehensive revision of the Code was taken up under the aegis of the National Building Code Sectional Committee, CED 46 of BIS and its 22 expert Panels; involving around 1 000 experts.

National Building code also mentions ferrocement as a building material.

**CPWD Manuals**: Manuals published by CPWD namely "Integrated Green Building", handbook for repairs and rehabilitation of RCC buildings, guidelines for sustainable habitats 2014, have mentioned ferrocement as useful and alternative low energy material.

## 11.8 Codes by Ferrocement Society:

Ferrocement Society is a Non- Government Body formed by Government Engineers, Academicians, expert professionals etc. Er M S Mundhe then Director General of MERI was the first President of the society, established in 2008. This society is promoting the ferrocement technology in civil engineers, students of architecture and engineering and professional engineers. This society has already published FS Code for ferrocement walling in 2014 as shown in fig 11.3. Few more codes for shells, domes etc are under preparation. The code is based on BIS 13356. The methods of construction for ferrocement are mentioned in the code. However this code needs to be approved from competent authority.

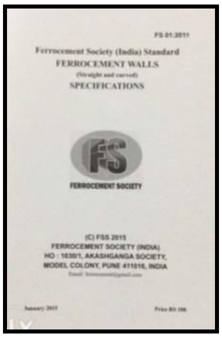



**Fig 11.3 FS Code for ferrocement walling in 2014**

## 11.9 Group discussions in FS 2017 4th National Convention on Ferrocement:

FS 2017 was organised in Peroor, Kerala during 12-16 May 2017. Many experts in ferrocement attended the convention. Dr Balaguru, USA, Angus Macdonald, USA, Dr B N Divekar, India, Er Jose Kurian, Chairman, BIS Committee, were also present. A group discussion on need of standardisation was organised. Er Jose Kurian, Chairman of BIS committee assured to expedite the finalisation of BIS code.


**Fig 11.4 4th National Conventions on Ferrocement**

# CHAPTER 12
# RESEARCH WORK

## 12.1 Research work of ferrocement in MERI, Nashik

The ferrocement subject was introduced in MERI in 1975. Some research was already carried out by then officers in MERI.

MERI has conducted many tests and experiments on ferrocement. A water tank and partition wall was constructed using ferrocement, which is still available for observation. Though micro cracks are seen on the water tank, there is no water leakage. 2 boats were constructed in MERI using ferrocement. The boats are still available for inspection. The rain water is collected in one of the boats but there is no leakage seen in these boats.

Technical Memorandum No. MT/146 Use of Ferrocement in Hydraulic Structure (1991)- After taking many tests like flexural test, impact test, split tensile test, direct tension test, compressive strength test etc., the then Director MERI, Er. P. K. Nagarkar has observed that ferrocement is better suited for thin wall structure.

Technical Memorandum No. MT/215 Use of Ferrocement in construction (1988)- Er. N. M. Dange then Director MERI has observed that there is no leakage in water tanks even in the joints. He mentioned the simplicity of ferrocement construction. Also ferrocement partition wall are of great use as they occupy less floor area giving maximum place for dwelling.

In Canal Lining, ferrocement lining was taken on experimental basis in 2014-15. Tapi Irrigation Development Corporation has executed 100 meter length of Punand Right Bank Canal near Kalwan. The canal had heavy leakage in this portion. After completion of the ferrocement lining the leakage was completely stopped. (The report is under finalization)

1) Technical memorandum No. **MT/146 Use of ferrocement in hydraulic structure**
   i. Ferrocement is more homogeneous and isotropic as compared to materials like concrete, reinforced concrete etc. and can be treated as a composite elastic material in the uncracked range.
   ii. Because of the smaller width of cracks and cracks closing considerably after the removal of load. It is the most advantageous characteristic of ferrocement is better suited for thin walled structures.
   iii. While considering a design for a homogeneous specimen and for the use of high strength mortar the cement aggregate ratio should be not leaner than 1:1.5 (cement: sand by wt.) and water cement ratio should be about 0.40.
   iv. The bending strength of slab increases substantially in direct proportion to the steel area, limited to about 2.5% by volume. There after the increase in the bending strength is nominal, particularly for larger desirable to have reinforcement more than 2.5% by volume as this will affect economy. However, if additional strength is desired, small diameter steel bars may be introduced.
   v. From the study, it is concluded that desirable degree of caution is to be exercised while deciding the size of the wire mesh. of the different commercially available meshes, the meshes with large opening i.e.12 mm ×12 mm for 14 G and 18 G and for 22 G 6 mm ×6 mm showed optimum homogeneity over reasonably large range, Also the bond between wire mesh and cement mortar was good and uniform throughout, which contributed to higher strengths. It is, therefore, felt that improvement in the properties of ferrocement may be achieved with more

suitable type of wire it is necessary to conduct series of tests on specimens made with larger and different size of wire.

vi. The ultimate strength in direct tension is controlled by the strength of wire mesh used. It is possible to utilize high strength wire mesh and obtain higher tensile strength. Ferrocement construction can be beneficial where its high tensile strength wrt weight ratio and superior cracking behavior is properly utilized. Such applications include boat, thin shells, thin pipes roofs, tanks.

vii. It is concluded that the wires having higher yield strengths provides good resistance to shock due to impact load. The dispersion of reinforcement promotes increase in impact load of resistance. The disintegrating fragments of structures are prevented by layers of mesh holding fragments together. Hence, it is essential that mortar strength and steel content should be at a practical maximum to withstand the day to day knocks, for example fishing boats, buoys etc.

viii. In order to prevent formation of air bubbles which will cause eventual rusting by providing room to moisture? Hence adequate vibration and adequate cover adjacent to surface is necessary. Especially for marine structure, suitable protective priming paint is almost essential in practice to give adequate protection to steel.

2) Technical memorandum No. **MT/215 Use of ferrocement in construction**

1. Ferrocement tank
   i. Ferrocement tank is cheaper than RCC, metal or synthetic rubber tank.
   ii. Through the tank is constructed in three stages, there is no leakage anywhere. The tank is perfectly impervious.
   iii. The raw material required for tank construction is readily available in the market. It requires no heavy or special type of machinery.
   iv. It requires no specially skilled persons. Ordinary masons and carpenter with the help of unskilled laborers can do this job.
2. Ferrocement Partition wall
   i. The construction of wall is very simple, requires no skilled labour or heavy machinery/equipment.
   ii. There is great shortage of open space for housing in urban area. In this limited available space ferrocement partition walls are of great use as they occupy less floor area giving maximum place for dwelling.

## 12.2 Research work on ferrocement

Two research papers are published on ferrocement are given in appendix 3 and appendix 4 respectively.

## 12.3 Different tests on ferrocement in progress.

Following 4 tests are being conducted in MERI.

1. Compressive strength of ferrocement
2. Flexural strength of ferrocement
3. Permeability of ferrocement
4. Split tensile strength of ferrocement

## 12.4 Compressive strength of ferrocement

### 12.4.1 Aim of the experiment:-

To analyse the compressive strength characteristics of ferrocement.

### 12.4.2 Materials / Equipment required:-

i. Cement : Ordinary Portland Cement 43 grade
ii. Sand: Passed by 2.36 mm IS sieve.
iii. Water: pH value > 7.0
iv. Steel:
   a. Welded mesh of size : Welded mesh of size 25 mm x 25 mm x 10 gauges
   b. chicken mesh of size ½ inch x ½ inch x 22 gauges
v. Compressive Testing Machine: Capacity 2000 KN

### 12.4.3 Assembly for compressive strength

Mould of size 150 mm x 150 mm x 150 mm is taken for compressive strength test as shown in fig. 12.1.

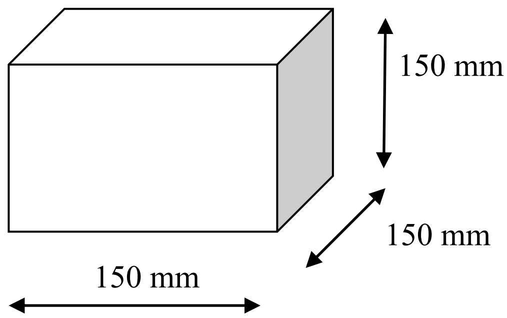
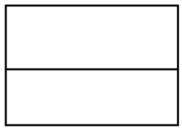
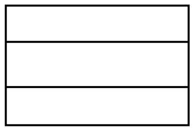
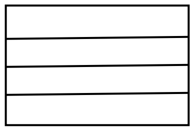
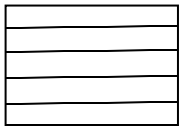
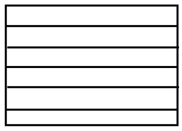



**Fig.12.1 Mould of compressive strength test**

### 12.4.4 Ferrocement cube for compressive strength:-

1) For comparison, cube specimens having dimensions 150 mm * 150 mm * 150 mm are casted using cement mortar in 1:3 proportion keeping w/c ratio 0.45.
2) Welded mesh is cut in dimension 149.00 mm x 149.00 mm. This welded mesh is laid with two layers of chicken mesh (cover the entire welded mesh in two layers one above the welded mesh and one below the welded mesh) and tied to form the steel skeleton. Likewise make the steel skeleton as per requirement as shown in table no. 12.1.
3) Cement mortar is prepared by using cement and sand in proportion 1:3 by weight & keeping w/c ratio 0.45. Then mould is filled with cement mortar up to a depth slightly more than 5 mm & compacted with the help of vibrating table to achieve uniform compaction.
4) The steel skeleton is then placed over the compacted layer. Then a layer of fresh cement mortar is placed & simultaneously vibrated with the help of vibrating table. In similar manner other layers can be filled with cement mortar.

**Table No. 12.1 Construction of specimen**

| Sr. No. | Specification of Compressive strength mould | Designation | Layer of skeleton steel | Figure |
|---|---|---|---|---|
| 1 | **Compressive strength mould with ferrocement mortar only.** The Compressive strength mould is filled with cement mortar in three layers. Each layer is compacted with the help of vibrating table. | CF0 | -- |  |
| 2 | **Compressive strength mould with skeleton steel layer.** Cement mortar is placed in the mould upto a depth slightly more than 75 mm & then vibrated/compacted. After compaction single skeleton steel layer is placed on that compacted mortar. Then Compressive strength mould is filled with cement mortar. | CF1 | 1 |  |
| 3 | **Compressive strength mould with two skeleton steel layers.** Above methodology is adopted for two skeleton steel layers. | CF2 | 2 |  |
| 4 | **Compressive strength mould with three skeleton steel layers.** Above mentioned methodology is adopted for three skeleton steel layers. | CF3 | 3 |  |
| 5 | **Compressive strength mould with four skeleton steel layers.** Above methodology is adopted for four skeleton steel layers. | CF4 | 4 |  |
| 6 | **Compressive strength mould with five skeleton steel layers.** Above methodology is adopted for five skeleton steel layers. | CF5 | 5 |  |

### 12.4.5 Compressive strength test procedure:-

i) Total 3 samples are prepared from each types of specimen. Preserve the test samples with moulds at a place free from vibrations for 24 hr from the time of addition of water to dry ingredients of mortar. After 24 hours kept the samples in water for 28 days curing. After 28 days remove the samples from water and wipe off the surface water.

ii) Clean the bearing surfaces of the testing machine. Keep the sample in compressive strength testing machine in such a way that the load is applied to a plane at right angles to a plane as cast. Apply the load without shock & increase continuously at a rate of 140 kg/min till the sample breaks down & no longer load is sustained.

## 12.5 Flexural strength of ferrocement

### 12.5.1 Aim of the experiment:-

To analyse the flexural strength characteristics of ferrocement.

### 12.5.2 Materials / Equipment required:-

i. Cement : Ordinary Portland Cement 43 grade
ii. Sand: Passed by 2.36 mm IS sieve.
iii. Water: pH value > 7.0
iv. Steel:
   a. Welded mesh of size : Welded mesh of size 25 mm x 25 mm x 10 gauges
   b. chicken mesh of size ½ inch x ½ inch x 22 gauges
v. Compressive Testing Machine: Capacity 2000 KN

### 12.5.3 Assembly for Flexural Test:-

Mould of size 50 mm x 100 mm x 600 mm is taken for flexural test as shown in fig 12. 2.

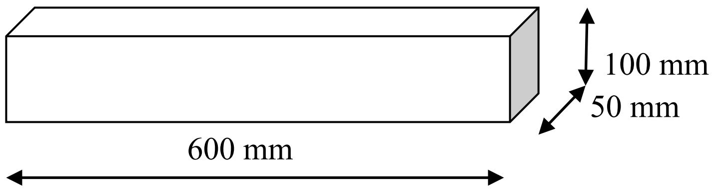
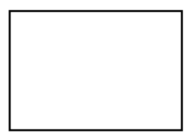


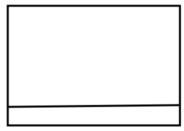
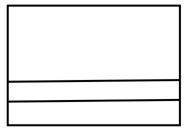

**Fig.12.2 Mould of flexural strength test**

### 12.5.4 Ferrocement Beam:-

1) For comparison, beam specimens having dimensions 100 mm * 600 mm * 50 mm are casted using cement mortar in 1:3 proportion keeping w/c ratio 0.45.
2) This welded mesh is laid with two layers of chicken mesh (cover the entire welded mesh in two layers one above the welded mesh and one below the welded mesh) and tied to form the steel skeleton. Likewise make the steel skeleton as per requirement as shown in table no. 12.2.
3) Cement mortar is prepared by using cement and sand in proportion 1:3 & keeping w/c ratio 0.45. Then cement mortar was placed in the flexural mould up to a depth slightly more than 5 mm & then compacted with the help of vibrating table so that uniform compaction is achieved.
4) The steel skeleton is then placed over the compacted layer. Then a layer of fresh cement mortar is placed & then simultaneously vibrated with the help of vibrating table. In similar manner other layers can be filled with cement mortar.

**Table No. 12.2 Preparation of Beam specimen**

| Sr.No. | Specification of Beam | Designation of Beam | Layer of skeleton steel | Figure |
|---|---|---|---|---|
| 1 | **Beam with ferrocement mortar only.** The beam mould is filled with cement mortar in three layers. Each layer is compacted with the help of vibrating table. | BF0 | -- |  |

| | | | | |
|---|---|---|---|---|
| 2 | **Beam with one skeleton steel layer.** Cement mortar is placed in the mould upto a depth slightly more than 5 mm & then vibrated/ compacted. Then one skeleton steel layer is placed on that compacted mortar. The beam mould is then filled with cement mortar in layers. Each layer is compacted with the help of vibrating table. | BF1 | 1 |  |
| 3 | **Beam with two skeleton steel layer.** Above methodology is repeated for two layers. | BF2 | 2 |  |
| 4 | **Beam with five skeleton steel layer.** Cement mortar is placed in the mould upto a depth slightly more than 5 mm & then vibrated/ compacted. Then steel skeleton is placed on cement mortar at regular interval. In each interval cement layer is placed in the mould and then vibrated. | BF5 | 5 |  |

**12.5.5 Flexural test procedure:-**

1) Total 3 samples are prepared from each types of specimen. Preserve the test specimens with moulds at a place free from vibrations for 24 hr from the time of addition of water to dry ingredients of concrete/ mortar then place the test specimen under water for 28 days. After 28 days, remove the test specimen's from water.
2) Place the specimen in the testing machine (align the axis of the specimen with the axis of the loading device). Apply the load without shock, increasing continuously. Increase the load until the specimen fails &record the maximum load applied to the specimen during test. Measure a = distance between line of fracture of beam & the nearer support.

## 12.6 Permeability of ferrocement

**12.6.1 Aim of the experiment:-**

To analyse the permeability characteristics of ferrocement.

**12.6.2 Materials / Equipment required:-**

i. Cement : Ordinary Portland Cement 43 grade
ii. Sand: Passed by 2.36 mm IS sieve.
iii. Water: pH value > 7.0
iv. Steel:
   a. Four Steel angle sections of thickness 50 mm. Two having length 1 m as well as two having length 0.8 m
   b. Mild steel bar of diameter 10 mm
   c. Welded mesh of size : Welded mesh of size 25 mm x 25 mm x 10 gauges
   d. chicken mesh of size ½ inch x ½ inch x 22 gauges
v. Permeability testing Machine

### 12.6.3 Assembly for taking out core for permeability test:

As shown in following figure no. 12.3, make the rectangular structure having dimensions 1000 mm x 800 mm. For this assembly use steel angle section (L-section) having thickness 50 mm.

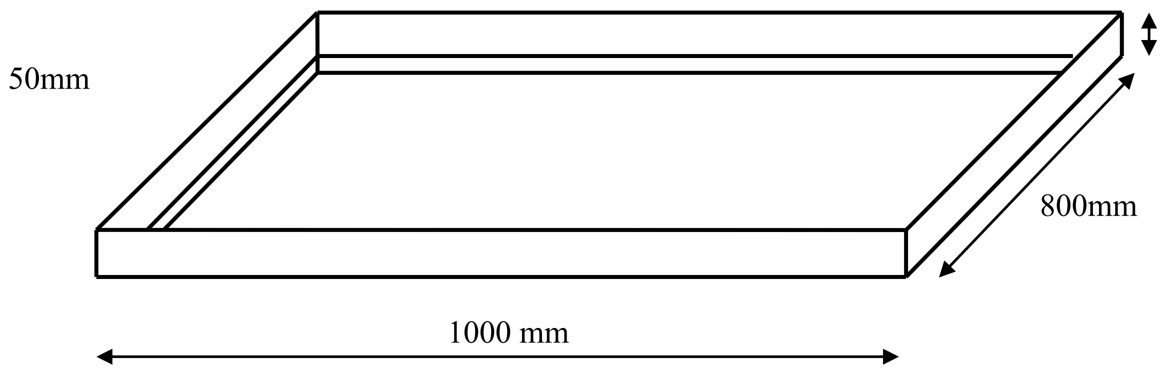



**Fig 12.3 Assembly for taking out core for permeability test**

### 12.6.4 Ferrocement core

1) As shown in figure 12.4, use 10 mm diameter steel bar & make a mesh like structure so that it can easily placed in ferrocement assembly.

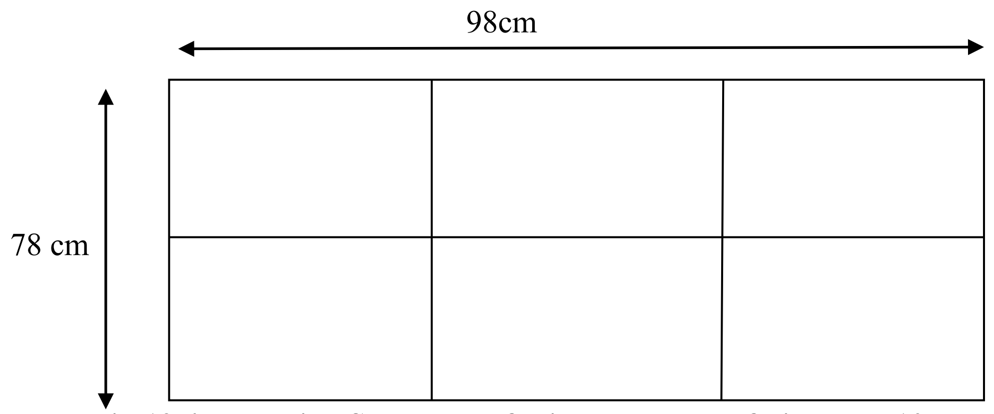



**Fig 12.4 Mesh like Structure of mild steel bars of diameter 10 mm**

2) As shown in following table no. 12.3, welded mesh and chicken mesh of particular dimension are laid and tied on above mesh like structure to form the steel skeleton.

**Table No. 12.3 Permeability test Materials**

| Sr. No. | Thickness of ferrocement core | Welded mesh | Welded mesh layer | Chicken mesh | Chicken mesh layer |
|---|---|---|---|---|---|
| 1 | 30 mm | 50mm x 50mm x 10 gauge | 1 | ½ inch x ½ inch x 22 gauge | 3 |
| 2 | 50 mm | 25mm x 25mm x10 gauge | 2 | ½ inch x ½ inch x 22 gauge | 4 |

3) The welded mesh and chicken mesh of specific dimensions (dimensions are as per aforesaid table no. 1 ) are laid and tied on the above mesh like structure as shown in figure 12.5.

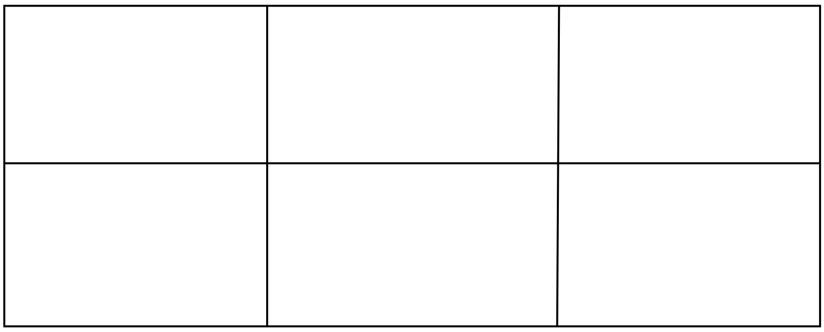


**Fig 12.5 Lay and tie the welded mesh and chicken mesh on the mesh like structure**

4) The assembly then filled with cement mortar. Cement mortar is prepared by using cement and sand in proportion 1:3 & keeping w/c ratio 0.45. Then cement mortar was placed in the assembly up to a depth slightly more than 5 mm & then compacted with the help of vibrating table to achieve uniform compaction. The appearance of assembly is shown in following figure no.12.6.

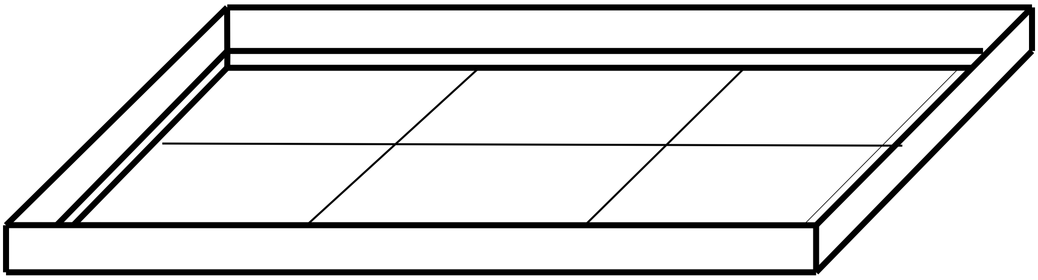


**Fig 12.6 Placing of steel skeleton above 5mm layer of cement mortar in the assembly**

5) Then a layer of fresh cement mortar is placed on this steel skeleton & vibrated with the help of vibrating table. After 24 hours, ferrocement specimen is removed from the assembly & then placed in a curing tank for 28 days. After 28 days curing, specimen is removed from curing tank & kept for SSD Condition. The appearance of ferrocement specimen after compaction is shown in figure 12.7(a) and 12.7(b).

**Fig 12.7(a) Ferrocement permeability specimen for 30 mm thickness**

**Fig 12.7(b) Ferrocement permeability specimen for 50 mm thickness**

6) As shown in figure no.8, for comparative study of permeability test of ferrocement specimen and plane cement mortar specimen, the assembly shown in figure no.12.8 is filled with cement mortar only.

**Fig 12.8 Ferrocement permeability specimen for 50 mm thickness**

7) As shown in figure no.12.9, the cores of diameter 150 mm will be drilled from ferrocement specimen by using core cutter.

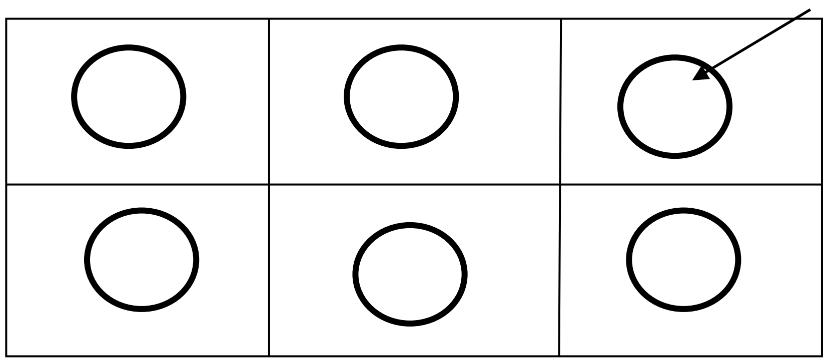



**Fig 12.9 Permeability cores are taken out from ferrocement specimen**

8) Clear the cores, thoroughly with a stiff wire brush to remove all mesh pieces that comes out of cores as shown in fig 12.10.

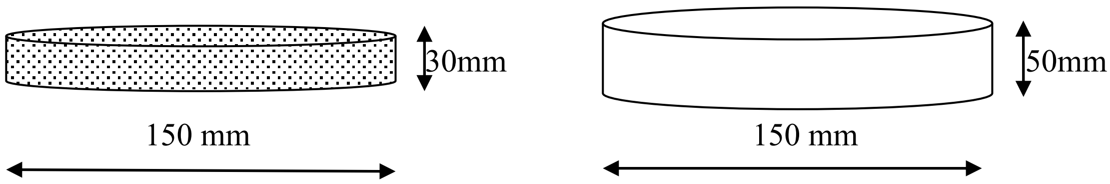



**Fig 12.10 Permeability cores**

### 12.6.5 Permeability test procedure:-

1) Sealing the specimen:
   i) Measure the dimensions of the specimen to the nearest 0.5 mm. centre the specimen in the permeability cell with the lower end resting on the ledge.
   ii) Pour the suitable molten sealing compound on the surface of the specimen. Rest of the space between the cover plate of permeability cell and top surface of specimen shall be filled with coarse standard sand (Ennore sand) or sealing compound like rosin and wax as shown in fig 12.11.
   iii) Pour water on the exposed face of the specimen & if it leaks, take out the specimen by heating & reseal it till complete water tightness is achieved.
2) Apparatus Assembling:
   i) After ascertaining that a satisfactory seal is obtained, connect the cell assembly with the reservoir.
   ii) Open the drain clock, water inlet cock, & allow the desired water passed freely through the drain cock so that remove the air inside this assembly.

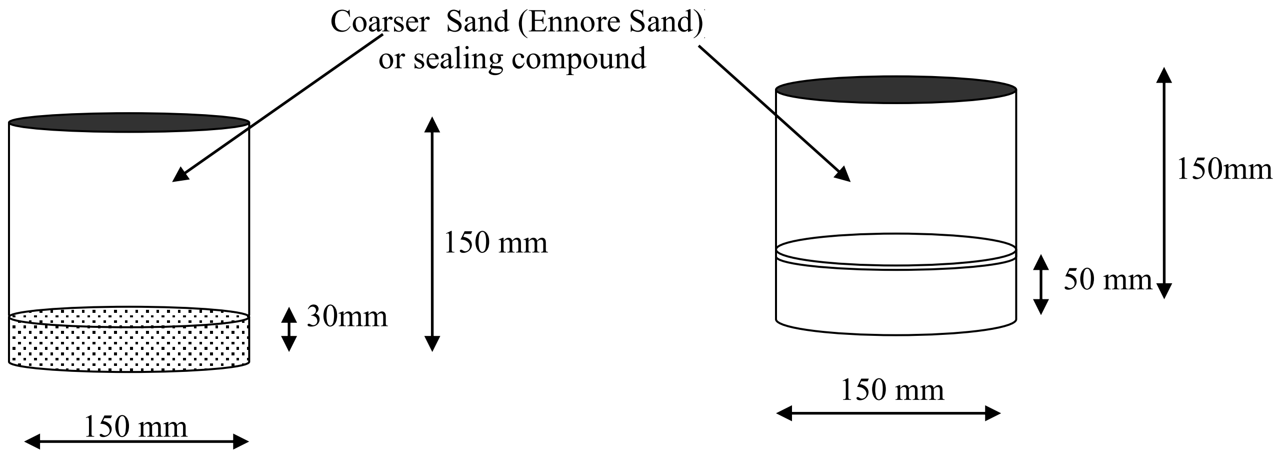



**Fig. 12.11 Permeability test specimen**

3) Running the test
   i) Apply the desired water pressure to the water reservoir & record the initial reading of the gauge glass. At the same time, keep a clean empty bottle duly weighted below the funnel for collecting the percolating water through the specimen.
   ii) At periodical intervals, observe quantity of water percolates. Conduct the steady state of flow has been reached. The outflow is considered as average of all the outflows measured during this period of 100 hours.

## 12.7 Split tensile strength of ferrocement

### 12.7.1 Aim of the experiment:-

To analyse the split tensile strength characteristics of ferrocement.

### 12.7.2 Materials / Equipment required:-

i. Cement : Ordinary Portland Cement 43 grade
ii. Sand: Passed by 2.36 mm IS sieve.
iii. Water: pH value > 7.0
iv. Steel:
   a. Welded mesh of size : Welded mesh of size 25 mm x 25 mm x 10 gauges
   b. chicken mesh of size ½ inch x ½ inch x 22 gauges
v. Compressive strength testing Machine

### 12.7.3 Ferrocement split tensile mould:-

Mould of diameter 150mm and height 300mm is used for this test as shown in fig.12.12

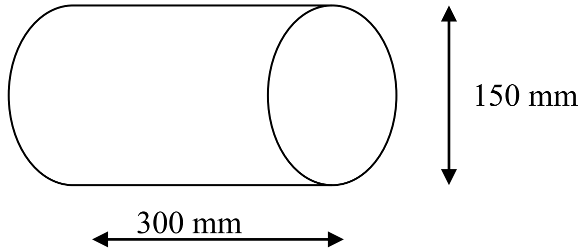
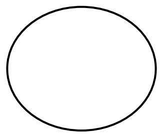
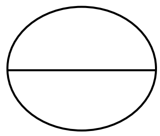
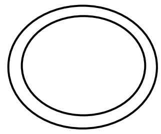
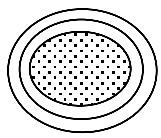



**Fig 12.12 Split tensile strength mould**

**12.7.4 Ferrocement core for split tensile strength:-**

1) For comparison, cylindrical specimens having dimensions 150mm * 300 mm are casted using cement mortar in 1:3 proportion keeping w/c ratio 0.45.
2) Welded mesh is cut in dimension 149.00 mm x 300.00 mm. This welded mesh is laid with two layers of chicken mesh (cover the entire welded mesh) and tied to form the steel skeleton.
3) This steel skeleton will be placed in cylindrical mould in a vertical position as shown in table no. 4. Then cement mortar is prepared by using cement and sand in proportion 1:3 & keeping w/c ratio 0.45. Mortar will be laid after the steel skeletons are placed inside the cylinder.
4) For circumferential laying, make a cylindrical structure of chicken mesh of diameter 145.0 mm and placed inside the core as shown in table no. 4. After that mortar is laid. Likewise other cylindrical structure of diameter 140.0 mm will be made and placed inside the core and mortar is laid.

**Table no. 12.4 Construction of specimen**

| Sr. No. | Designation of specimen | Designation of specimen | Fig |
|---|---|---|---|
| 1 | Full mortar | S0 |  |
| 2 | A Steel skeleton at centre along longitudinal axis and placed horizontally. | S1 |  |
| 3 | One layer of Chicken mesh circumferentially lay round inside the core. | S2 |  |
| 4 | Two layers of Chicken mesh circumferentially lay round inside the core. | S3 |  |

**12.7.5 Split tensile strength test procedure:-**

1) Total 3 samples are prepared from each types of specimen. Preserve the test specimens with moulds at a place free from vibrations for 24 hr from the time of addition of water to dry ingredients of concrete/ mortar then place the test specimen under water for 28 days. After 28 days, remove the specimen from water and wipe off the surface water from the specimens
2) Clean the bearing surfaces of the testing machine. Keep the core in horizontal position sandwiched between two steel plates. Apply the load without shock & increase continuously at a rate of 140 kg/sq.cm./min till the specimen breaks down & no longer load is sustained.

# CHAPTER 13
# FERROCEMENT USE ON EXPERIMENTAL BASIS

## 13.1 Necessity of use of ferrocement

RCC, masonry in bricks, stones etc are already being used by field engineers in government works. Ferrocement technology is going to add the options and creativity for the planning and executing engineers. Considering different uses by PWD and WRD engineers following are enlisted.

## 13.2 Ferrocement uses for PWD

1. Walls and shells, Dome shape roofs, pyramid shaped roofs.
2. Elevation treatment items like pergolas, fins
3. Curved portions of structure like hyperbolic paraboloid.
4. Staircases, precast steps.
5. Chajjas
6. Sandwich walls.
7. Gutter sections or lining.
8. Water tanks, septic tanks
9. Foot bridges
10. Bio gas plants
11. Silos
12. Swimming pools, tanks
13. Strengthening of old columns and beams
14. Water proofing of buildings.
15. Sign Boards
16. Watchman cabins
17. Common toilet blocks
18. Earthquake resistant buildings
19. Increasing fire resistance
20. Bunkers, blast resistant structures.

## 13.3 Ferrocement uses for WRD.

1. Foot bridges on canals
2. Lining to canals
3. Precast lining sections
4. Leakage proofing of the dam walls
5. Construction of small dams
6. Precast structures for CADA works
7. Raising heights of the K T Weirs.
8. Arch type bandharas.
9. Lining to tunnels
10. Retaining walls
11. Sign boards
12. Water proofing of buildings
13. Pontoons for reservoirs
14. Septic tanks and water tanks.
15. Lift Irrigation schemes, pipes, pump houses.

**13.4** Though the list is shown here the uses are unlimited. Engineers can think of using ferrocement where slim sections are required, where leakage is to be stopped, where extra strength is needed, where earthquake forces are more and so many such special situations.

# CHAPTER 14
# REFERENCES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2. 'State of art report on Ferrocement' and 'Guide for design, construction and repair of ferrocement' Reports by ACI Committee 549, No. 549-R-97.
3. Ferrocrete Technology-A construction Manual by Dr B N Divekar
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6. CPWD circular for crushed sand
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18. FS Code No 001: 2014 Code for ferrocement walling.
19. Divekar B. N., 'Spun Ferrocrete Pipes can replace Prestressed Concrete Pipes' Workshop on Improvement in quality and productivity in cement concrete pipes. Jan 1991. Spun Pipe Manufacturer's Association of Maharashtra.
20. Joseph, G.P., George. Z. Shreenath, H.G., 'Ferrocement as substitute for timber' Asia-Pacific Symposium on Ferrocement Applications for Rural development- Roorkee (India).April 1984.
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23. CPWD guidelines for sustainable habitats 2014.
24. Integrated Green Design-by CPWD
25. IS 383:1970 - Specification for coarse and fine aggregates from natural sources for concrete
26. IS 432 : 1982 - Mild steel & medium tensile steel bars and hard drawn steel wires for concrete reinforcement
27. IS 2386:1963 - Methods of test for aggregates for concrete
28. IS 456:2000 - Code of practice for plain and reinforced concrete
29. IS 516:1959 - Method of test for strength of concrete
30. IS 13356 : 1992 – Code of practice for Precast Ferrocement water tanks up to 10000 liter.

# APPENDIX 1

## LIST OF FERROCEMENT COMMITTEE MEMBERS

***(Maharashtra Government Water Resource Department***
***Miscellaneous-2014/(Case No. 163/2014)/NWS-3 Date:09/02/2017)***

| Sr.No. | Name | Organization |
|---|---|---|
| 1 | Shri. R.E.Upasani | Chief Engineer,<br>Central Design Organization, Nashik and<br>Chairman of committee |
| 2 | Shri. C.N.Hangekar | Retired Chief Engineer,<br>Water Resource Department, Maharashtra Government and Committee member |
| 3 | Shri.Rajendra Pawar | The Then Chief Engineer,<br>Planning and Hydrology, Nashik and<br>Committee member |
| 4 | Shri. D.T.Thube | Chief Engineer,<br>Mumbai Metropolitan Region Development Authority, Mumbai and Committee member |
| 5 | Shri. R.V. Shrigiriwar | Superintending Engineer,<br>Maharashtra Engineering Research Institute, Nashik and Committee member |
| 6 | Shri.M.S.Bendre | Superintending Engineer,<br>Dams, Central Design Organization, Nashik and<br>Committee member |
| 7 | Shri. V.P.Ramgude | Superintending Engineer,<br>Maharashtra Engineering Training Academy, Nashik and Committee member |
| 8 | Shri. R. G. Mundada | Superintending Engineer,<br>Gates, Central Design Organization, Nashik and<br>Committee member |
| 9 | Shri. A.R.Naik | Superintending Engineer,<br>Quality Control Circle, Aurangabad and<br>Committee member. |
| 10 | Shri. G.B.Nannor | Executive Engineer,<br>Kukadi Irrigation Division No. 1, Narayangaon and<br>Committee member. |
| 11 | Shri. S.S.Awasthi | Executive Engineer,<br>Quality Control Division, Nanded and<br>Committee member. |
| 12 | Shri. Arunkumar Lawane | Retired sectional Engineer,<br>Water Resource Department, Maharashtra Government and Committee member |
| 13 | Shri. B.N.Divekar | Private consultant, shivaji nagar, Pune<br>(Expert in Ferrocement) and<br>Committee member |
| 14 | Shri. A.S.Mahire | Scientific Research Officer,<br>Material testing Referral Laboratory, MERI, Nashik and<br>Member Secretary of committee. |

## Special Invitee

| Sr.No. | Name | Designation |
|---|---|---|
| 1 | Shri. D.R.Joshi | Chief Engineer, WRD |
| 2 | Shri.D.B.Sale | Superintending Engineer, WRD |
| 3 | Shri.S.D. Bhagat | Superintending Engineer, WRD |
| 4 | Shri. Girish Sangle | Retired Sectional Engineer, WRD and<br>Secretary of Ferrocement Society |
| 5 | Shri. Milind Kulkarni | Principal Consultant and<br>Member of the Ferrocement Society |

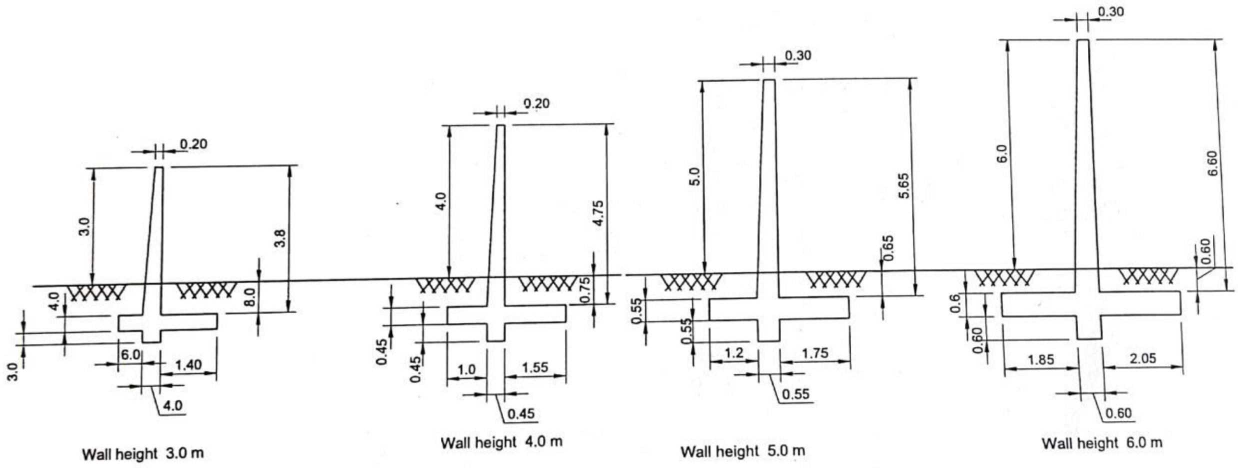
## Vote of thanks

| Sr.No. | Name | Designation |
|---|---|---|
| 1 | Shri. M.V. Patil | Assistant Research Officer,<br>Material Testing Referral Laboratory, MERI, Nashik |
| 2 | Mrs. Y.G. Bagul | Scientific Officer,<br>Material Testing Referral Laboratory, MERI, Nashik |
| 3 | Shri. D.C. Jadhav | Assistant Engineer Gr.II<br>Material Testing Referral Laboratory, MERI, Nashik |
| 4 | Mrs. B.B.Shinde | Assistant Engineer Gr.II<br>Material Testing Referral Laboratory, MERI, Nashik |

# APPENDIX 2
# COST ESTIMATES OF FERROCEMENT ITEMS

In this appendix we have given sample estimates of retaining walls, water tank, canal lining, staircase, dome and shell. The rates and costs for two cases are compared, viz. RCC and ferrocement, considering the market rates for the same year.

### 1.0 Cost details of RCC cantilever retaining wall

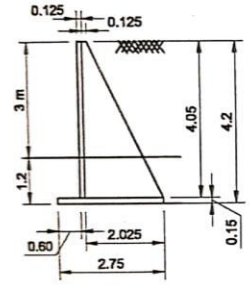



**Cost estimates of RCC cantilever retaining walls for various heights**

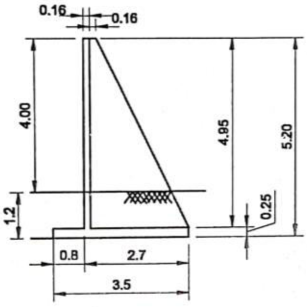
*[rates are based on the basis of market rates for the year 1996]*

| Sr No | Item | Rate | Unit | Quantities and costs for 4.50 m length for wall height of | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 3.00 m | | 4.00 m | | 5.00 m | | 6.00 m | |
| | | | | Qty | cost | Qty | cost | Qty | cost | Qty | cost |
| 1 | Excavation | 34.41 | Cum | 21.95 | 755.30 | 26.66 | 917.37 | 33.44 | 1150.67 | 37.73 | 1298.29 |
| 2 | PCC (1:3:6) | 964.03 | Cum | 1.44 | 1388.20 | 1.74 | 1677.41 | 3.11 | 2998.13 | 3.51 | 3383.75 |
| | Cement used | | bags | 6.64 | 0.00 | 8.02 | 0.00 | 14.33 | 0.00 | 16.18 | 0.00 |
| 3 | RCC (1:2:4) | 1919.45 | Cum | 10.00 | 19194.50 | 13.95 | 26776.33 | 20.94 | 40193.28 | 25.79 | 49502.62 |
| | Cement used | | bags | 64.80 | 0.00 | 90.40 | 0.00 | 135.70 | 0.00 | 167.11 | 0.00 |
| 4 | Steel for RCC | 17465.00 | tonne | 0.72 | 12574.80 | 1.21 | 21132.65 | 2.17 | 37899.05 | 3.22 | 56237.30 |
| 5 | Murum Filling for 4.5 m | 40.00 | Cum | 33.00 | 1320.00 | 36.00 | 1440.00 | 48.00 | 1920.00 | 51.65 | 2066.00 |
| | Total for 4.5 m | | | | 35232.00 | | 51963.76 | | 83969.00 | | 112187.96 |
| | Cost per running meter | | | | 7830.00 | | 11548.00 | | 18660.00 | | 25000.00 |
| | Cost per Sqm of walling | | | | 2610.00 | | 2887.00 | | 3732.00 | | 4167.00 |

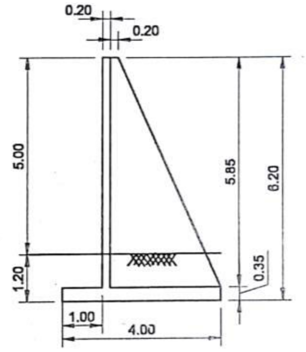
## 2.0 Cost details of Counterfort RCC retaining wall



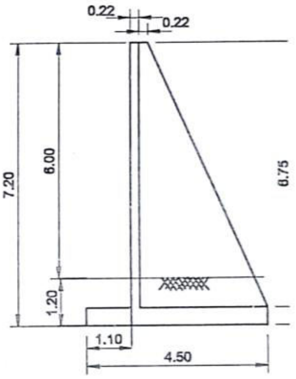

Wall height 3.0m
Counterfort spacing 2.50m c/c




Wall height 4.0m
Counterfort spacing 2.0m c/c




Wall height 5.0m
Counterfort spacing 2.50m c/c




Wall height 6.0m
Counterfort spacing 3.0m c/c

### Cost estimates of RCC counterfort retaining walls for various heights

*[rates are based on the basis of market rates for the year 1996]*

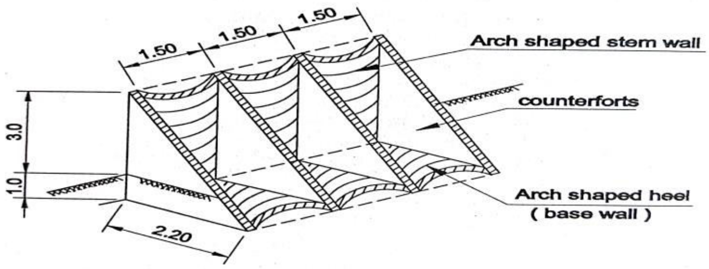
| Sr No | Item | Rate | Unit | Quantities and costs for 4.50 m length for wall height of | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 3.00 m | | 4.00 m | | 5.00 m | | 6.00 m | |
| | | | | Qty | cost | Qty | cost | Qty | cost | Qty | cost |
| 1 | Excavation | 34.41 | Cum | 19.85 | 683.04 | 24.84 | 854.74 | 30.18 | 1038.49 | 33.62 | 1156.86 |
| 2 | PCC (1:3:6) | 964.03 | Cum | 1.24 | 1195.40 | 1.91 | 1841.30 | 2.15 | 2072.66 | 2313.60 | 2230379.81 |
| | Cement used | | bags | 5.72 | 0.00 | 8.80 | 0.00 | 9.91 | 0.00 | 11.06 | 0.00 |
| 3 | RCC (1:2:4) | 1919.45 | Cum | 8.49 | 16296.13 | 13.92 | 26718.74 | 20.34 | 39041.61 | 25.89 | 49694.56 |
| | Cement used | | bags | 55.01 | 0.00 | 90.20 | 0.00 | 131.80 | 0.00 | 167.76 | 0.00 |
| 4 | Steel for RCC | 17465.00 | tonne | 0.62 | 10828.30 | 1.21 | 21132.65 | 2.11 | 36851.15 | 3.10 | 54141.50 |
| 5 | Murum Filling for 4.5 m | 40.00 | Cum | 40.50 | 1620.00 | 56.80 | 2272.00 | 64.54 | 2581.60 | 75.36 | 3014.40 |
| | Total for 4.5 m | | | | 30622.87 | | 52819.44 | | 81585.07 | | 110318.99 |
| | Cost per running meter | | | | 6805.00 | | 11788.00 | | 18130.00 | | 24515.00 |
| | Cost per Sqm of walling | | | | 2268.00 | | 2934.50 | | 3626.00 | | 4086.00 |

## 3.0 Designed sizes of ferrocrete counterfort retaining walls

## Ferrocrete Counterfort retaining wall

## Cost estimates of Ferrocrete counterfort retaining walls for various heights

*[rates are based on the basis of market rates for the year 1996]*




Dimensions of Ferrocrete Retaining Walls

| Sr No | Height h *(Unit meter)* | Total Height H (h+d) | Base 0.55H | Heal Area *(unit Square meter)* | Stem Area *(unit Square meter)* | Counterfort 1.5 m c/c *(unit Square meter)* | Total Area *(unit Square meter)* |
|---|---|---|---|---|---|---|---|
| 1 | 3 | 4.00 | 2.20 | 9.90 | 18.00 | 17.60 | 45.50 |
| 2 | 4 | 5.00 | 2.75 | 12.38 | 22.50 | 27.50 | 62.38 |
| 3 | 5 | 6.00 | 3.30 | 14.85 | 27.00 | 39.60 | 81.45 |
| 4 | 6 | 7.00 | 3.85 | 17.33 | 31.50 | 53.90 | 102.73 |

| Sr No | Item | Rate | Unit | Quantities and costs for 4.50 m length for wall height of | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 3.00 m | | 4.00 m | | 5.00 m | | 6.00 m | |
| | | | | Qty | cost | Qty | cost | Qty | cost | Qty | cost |
| 1 | Excavation | 34.41 | Cum | 10.50 | 361.31 | 12.98 | 446.64 | 14.85 | 510.99 | 17.55 | 603.90 |
| 2 | PCC (1:3:6) | 964.03 | Cum | 1.40 | 1349.64 | 1.59 | 1532.81 | 2.77 | 2670.36 | 4.34 | 4183.89 |
| | Cement used | | bags | 6.45 | 0.00 | 7.33 | 0.00 | 12.77 | 0.00 | 20.00 | 0.00 |
| 3 | Cement Mortar (1:3) | 225.80 | Cum | 48.00 | 10838.40 | 62.38 | 14085.40 | 81.45 | 18391.41 | 102.73 | 23196.43 |
| 4 | Mesh Layers | 175.80 | Sqm | 48.00 | 8438.40 | 62.38 | 10966.40 | 81.45 | 14318.91 | 102.73 | 18059.93 |
| 5 | Murum Filling | 40.00 | Cum | 45.50 | 1820.00 | 64.88 | 2595.20 | 89.10 | 3564.00 | 122.85 | 4914.00 |
| | Total Cost for 4.5 m wall | | | | 22754.94 | | 31499.13 | | 41874.73 | | 55158.75 |
| | Cost per running meter | | | | 5057.00 | | 7000.00 | | 9305.00 | | 12257.50 |
| | Cost per Sqm of walling | | | | 1685.67 | | 1750.00 | | 1861.00 | | 2042.92 |

## 4.0 Cost comparison of different types of retaining walls per m run of wall

| Sr No | Wall height *(Unit meter)* | RCC Cantilever | | RCC Counterfort | | Ferrocement Counterfort | |
|---|---|---|---|---|---|---|---|
| | | | % | | % | | % |
| 1 | 3 | 7830 | 115.06 | 6805 | 100.00 | 5057 | 74.31 |
| 2 | 4 | 11548 | 98.38 | 11736 | 100.00 | 7000 | 59.64 |
| 3 | 5 | 18660 | 102.92 | 18130 | 100.00 | 9305 | 52.00 |
| 4 | 6 | 25000 | 102.00 | 24515 | 100.00 | 12258 | 50.01 |

## 5.0 Cost and material consumption per sqm of walling of various types

**Cost comparison per sqm, cement and steel consumption**

| Sr No | Wall height *(Unit meter)* | | RCC Cantilever | RCC Counterfort | Ferrocement Counterfort |
|---|---|---|---|---|---|
| 1 | 3 | Cost per Sqm | 2610 | 2268 | 1685 |
| | | Cement Bags | 5.3 | 4.5 | |
| | | Steel in Kg | 53.33 | 45.92 | |
| 2 | 4 | Cost per Sqm | 2887 | 2934.5 | 1750 |
| | | Cement Bags | 5.47 | 5.5 | |
| | | Steel in Kg | 67.22 | 67.22 | |
| 3 | 5 | Cost per Sqm | 3732 | 3626 | 1861 |
| | | Cement Bags | 6.67 | 6.3 | |
| | | Steel in Kg | 96.64 | 93.78 | |
| 4 | 6 | Cost per Sqm | 4167 | 4086 | 2042 |
| | | Cement Bags | 6.79 | 6.62 | |
| | | Steel in Kg | 119.26 | 114.81 | |

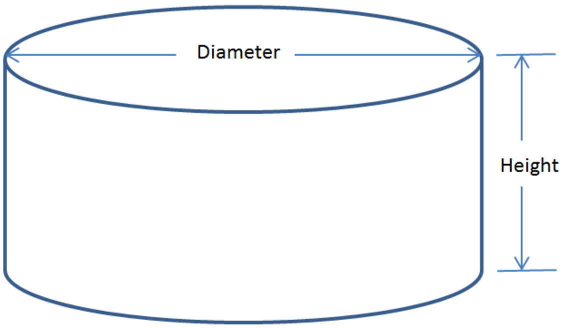
**Notes-**

A For all the heights there is enormous saving in using ferrocrete counterfort wall.
B For height above 5.0 m, the ferrocrete wall costs less than 50% than RCC Counterfort wall
C For RCC Cantilever and RCC Counterfort walls there is not much difference in cost
D Per square meter of Ferrocrete Walling there is no much difference for heights from 3 to 6 m

**6.0 Cost estimate of 75000 liter water tank:**

A typical water tank having circular shape in plan, can be designed and constructed in RCC or Ferrocement. The costs are compared here for both these cases.

Diameter of the tank = 26 feet   Height of the tank is =   5 feet   Capacity = 75000 liter




| | | Ferrocement | | | | | RCC | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Qty | Unit | Rate | Amount | | Qty | Unit | Rate | Amount |
| 1 | Excavation | 2662.32 | Cft | 15 | 39934.76 | | 2595.29 | Cft | 15 | 38929.28 |
| 2 | Bottom Shahabad | 414.09 | Sft | 60 | 24845.66 | | 527.24 | Sft | 60 | 31634.40 |
| 3 | Raft | | | | | | 14.70 | Cum | 7000 | 102900.00 |
| 4 | Plastic Sheet Below | 414.09 | Sft | 10 | 4140.94 | | 527.24 | Sft | 10 | 5272.40 |
| 5 | Ferrocement area | 1181.86 | Sft | 225 | 265917.99 | | | | | 0.00 |
| 6 | RCC Pardi 300 thick | | | | | | 63.00 | Sqm | 3500 | 220500.00 |
| 7 | RCC Reinforcement steel | | | | | | 2564.10 | Kg | 65 | 166666.50 |
| 8 | Ribs - Length | 325.26 | Rft | 225 | 73183.77 | | | | | 0.00 |
| 9 | RCC Slab at top | | | | | | 31.36 | Sqm | 1750 | 54880.00 |
| 10 | Plaster from inside | 1169.57 | Sft | 40 | 46782.89 | | 1183.60 | Sft | 40 | 47344.00 |
| 11 | Outside Plaster | 1206.49 | Sft | 60 | 72389.33 | | 1060.51 | Sft | 60 | 63630.34 |
| 12 | Carting out soil | 19.97 | trips | 1200 | 23960.86 | | 19.46 | Trips | 1200 | 23357.57 |
| | Total | | | | 551156.20 | | | | | 755114.48 |
| | Add | | | Design Fee | 27557.81 | | | | Design Fee | 37755.72 |
| | | | | | 578714.01 | | | | | 792870.20 |

| Cost per liter | | | |
|---|---|---|---|
| **Type** | **Cost Rs** | **Capacity** | **Rate/liter** |
| Ferrocement | 578714 | 75000 | 7.72 |
| RCC | 792870 | 75000 | 10.57 |

# ESTIMATE

P.W.D. 229 e.

Division ARUNAVATI PROJECT DIVISION, DIGRAS

SANCTIONED ESTIMATE No. OF 2014-15

**Maharashtra State**

**FUND HEAD:-** VIDARBHA IRRIGATION DEVELOPMENT CORPORATION NAGPUR

**MAJOR HEAD:-**

**MINOR HEAD :-**

**SERVICE HEAD:-**

**DEPARTMENTAL HEAD:-**

**Name of work :-** **Providing & constructing CC Canal Lining in K.M. No. 1 and 2 of Sawangi minor of Arunavati Right Bank Canal**

Estimate framed in the office of the Executive Engineer, Minor Irrigation Division, Pandharpur, for the probable expenses that will be incurred in LINING OF CANAL

**Rs. 1885036**

Administratively approved under:
No. Dated
Technically sanctioned under:
No. Dated

Estimate prepared by : Sectional Engineer and
Checked by Engineer, , Sectional Engineer.

(Call of Authority)

**GENERAL DESCRIPTION**

AS PER SEPERATE NOTE ATTACHED

Note:- The abstract should be signed at the end by the Executive Engineer and the Sub Divisional Engineer and if necessary, by the Superintending Engineer. The signature should be dated.
I
(Including year.)

Sub Divisional Officer Executive Engineer, Name of work :–Providing & constructing CC Canal Lining in K.M. No. 1 and 2 of Sawangi minor of Arunavati Right Bank Canal

# A B S T R A C T

| Quantity | Unit | Description of Item | Rate | Unit | Amount |
|---|---|---|---|---|---|
| 746.96 | Cum | **Item No.1:** Excavation including dressing in hard murrum/ hard man / kankar / pebbles (including boulders of size less than 0.1 cum) exceeding 1.5m in width including depositing the material as directed with all leads and lifts. | 50.85 | Cum | 37982.66 |
| 75.45 | Sqm | **Item No.2:** Providing and laying in situ mechanised lining in M-15 (20 MSA)(28 days cube compressive strength not less than 15N/sqmm) grade cement concrete with clean, hard, graded aggregates for canal side and bed using vibrating cylindrical type mechanical paver including cost of all materials, machinery, labour, cleaning with batching plant and transit mixer placing in position, finishing with all slope of canal including scaffolding, formwork, compaction, curing, by cutting grooves, filling with sealing compound and providing porous plugs, preparation of sub grade excluding royalty of materials etc. with initial lead of 50 m and lift of 1.5 m | 5992.80 | Sqm | 452156.76 |
| 203.72 | Sqm | **Item No.3:** Providing and laying in situ mechanised lining in M-15 (20 MSA)(28 days cube compressive strength not less than 15N/sqmm) grade cement concrete with clean, hard, graded aggregates for canal side and bed using vibrating cylindrical type mechanical paver including cost of all materials, machinery, labour, cleaning with batching plant and transit mixer placing in position, finishing with all slope of canal including scaffolding, formwork, compaction, curing, by cutting grooves, filling with sealing compound and providing porous plugs, preparation of sub grade excluding royalty of materials etc. with initial lead of 50 m and lift of 1.5 m | 6275.10 | Sqm | 1278331.99 |
| 139.58 | Cum | **Item No.4:** Royalty Charges as per Revenue and Forest Department's notification dated 11/02/2010 as Maharashtra Minor Mineral Extraction Rules, 2010 and as per insruction in general notes on CSR 2012-2013 for items of lime stone, lime shell, stones, rubble, stone dust, shingles, gravel, murum, kankar and ordinary sand, ordinary clay, ordinary earth (to be used for embankment and filling), slate and shell etc. | 70.67 | Cum | 9864.29 |
| 3470.70 | Sqm | **Item No.5:** Providing and laying Tarpaulin of 500 gsm as per rate contract specifications, before laying the steel skeleton. | 0.00 | Sqm | 0.00 |

| | | |
|---|---|---|
| | | 1778335.70 |
| Add for insurance | 1% | 17783.36 |
| Add for Supervision, quality testing charges and Consultancy from Ferrocement Society,. | 5% | 88916.79 |
| | | 1885035.84 |

Astt Ex. Engineer
Arunavati Project Sub Division No 2
Digras

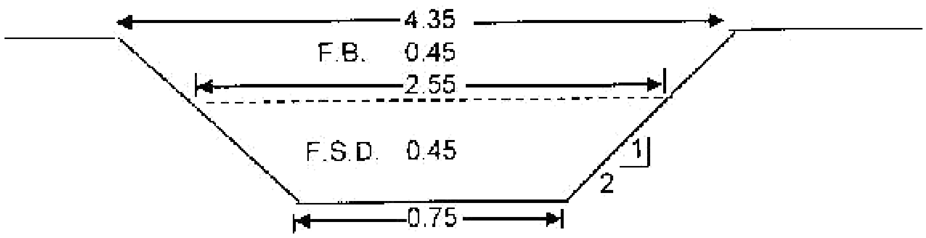
Executive Engineer

Name of Work : -

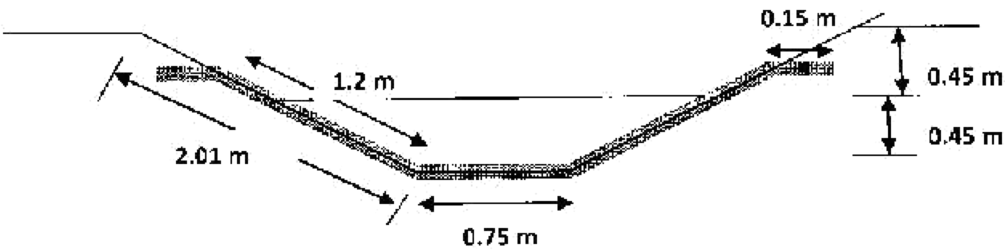
0

**HAYDRAULIC DATA**
**( Sawangi minor of Arunavati Right Bank Canal)**

| | | | |
|---|---|---|---|
| Canal Discharge | = | | Cusecs |
| Bed width | = | 0.75 | |
| Full Supply Level | = | 0.45 | |
| Free board | = | 0.45 | |
| Bed Gradient | = | 1 : | 2500 |




**DRAWING FOR LINING**




**Area of lining of CC Lining= 1006 x (0.15+1.2+0.75+1.2+0.15) =1006 m x 3.45 m = 3470.70 sqm**
Area of tarpaulin below the lining is same as above.
Thickness of plastic paper will be 500 gsm, and thickness of ferrocement lining will be 50 mm.
This will ensure 100% arresting the seapage.

**Name of Work :-** **Providing & constructing CC Canal Lining in K.M. No. 1 and 2 of Sawangi minor of Arunavati Right Bank Canal**

## MEASUREMENT

**Item No.1:** Excavation including dressing in hard murrum/ hard man / kankar / pebbles (including boulders of size less than 0.1 cum) exceeding 1.5m in width including depositing the material as directed with all leads and lifts.

Sawangi minor
The channel is deposited with silt, shrubs etc. so cleaning is necessary.

| | | | | | |
|---|---|---|---|---|---|
| Ch | 0 m to | 1006 = | 1008 m | | |
| 1006 X | 2.55 + 0.75 | / 2 | | 0.45 | **746.96** Cum |

$$1006 \times \frac{2.55 + 0.75}{2} \times 0.45 = 746.96 \text{ Cum}$$

**Item No.2:** Providing and laying in situ mechanised lining in M-15 (20 MSA)(28 days cube compressive strength not less than 15N/sqmm) grade cement concrete with clean, hard, graded aggregates for canal side and bed using vibrating cylindrical type mechanical paver including cost of all materials, machinery, labour, cleaning with batching plant and transit mixer placing in position, finishing with all slope of canal including scaffolding, formwork, compaction, curing, by cutting grooves, filling with sealing compound and providing porous plugs, preparation of sub grade excluding royalty of materials etc. with initial lead of 50 m and lift of 1.5 m

A **Length of 10 cm thick lined cross section =** 0.75 m
(As per sheet attached)

| | | | | |
|---|---|---|---|---|
| Quantity of Concrete | 1006 | 0.1 m | 0.75 m | 75.45 Cum |

[quantity of sand = 75.45 X 0.5 = 37.725 Cum]
[quantity of cement = 75.45 X8.24/20 = 31.0854 tonne]

**Item No.3:** Providing and laying in situ mechanised lining in M-15 (20 MSA)(28 days cube compressive strength not less than 15N/sqmm) grade cement concrete with clean, hard, graded aggregates for canal side and bed using vibrating cylindrical type mechanical paver including cost of all materials, machinery, labour, cleaning with batching plant and transit mixer placing in position, finishing with all slope of canal including scaffolding, formwork, compaction, curing, by cutting grooves, filling with sealing compound and providing porous plugs, preparation of sub grade excluding royalty of materials etc. with initial lead of 50 m and lift of 1.5 m

**Length of 7.5 cm thick lined cross section =** 2.70 m
(As per sheet attached)

| | | | | |
|---|---|---|---|---|
| Quantity of Concrete | 1006 | 0.075 m | 2.7 m | 203.715 Cum |

[quantity of sand = 203.715 X 0.5 = 101.86 Cum]
[quantity of cement = 203.715 X8.24/20 = 83.93 tonne]

**Item No.4:** Royalty Charges as per Revenue and Forest Department's notification dated 11/02/2010 as Maharashtra Minor Mineral Extraction Rules, 2010 and as per insruction in general notes on CSR 2012-2013 for items of lime stone, lime shell, stones, rubble, stone dust, shingles, gravel, murum, kankar and ordinary sand, ordinary clay, ordinary earth (to be used for embankment and filling), slate and shell etc.

| | | | | |
|---|---|---|---|---|
| Item No.3 | 279.17 Sqm | X | 0.5 | 139.58 Cum |

**Item No 5** Providing and laying Tarpaulin of 500 gsm as per rate contract specifications, before laying the steel skeleton.

3.45 1006 = 3470.7
Quantity as per Item No.1 3470.70 Sqm

SAWANGI MINOR OF ARUNAVATI RIGHT BANK CANAL

**Name of work :-**

**Providing & constructing CC Canal Lining in K.M. No. 1 and 2 of Sawangi minor of Arunavati Right Bank Canal**

## LEAD STATEMENT

| Sr. No. | Material | Location Of Quarries | Lead in Km. | Lead Charges | Unit |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | Sand | Loni | 20 | 253.53 | Cum |
| 2 | Cement | Digras | 11 | 115.80 | M.Ton |
| 3 | Steel | Digras | 11 | 127.30 | M.Ton |

**CERTIFICATE**

The above leads are personally varified by me and found correct. The material is not available within lesser lead than shown in the above lead statement.

| | | rate | Proposed | lead charges |
|---|---|---|---|---|
| 1. Cement | Rs. | 6720 /tonne | 6835.80 | 115.80 /tonne |
| 2. Steel | Rs. | 61000 /tonne | 61127.30 | 127.30 /tonne |
| 3. Sand | Rs. | 700 /cum | 953.53 | 253.53 /cum |

## SAWANGI MINOR of ARUNAVATI RIGHT BANK CANAL

**Name of Work : - Providing & constructing CC Canal Lining in K.M. No. 1 and 2 of Sawangi minor of Arunavati Right Bank Canal**

## RATE ANALYSIS

**Item No.1:** Excavation including dressing in hard murrum/ hard man / kankar / pebbles (including boulders of size less than 0.1 cum) exceeding 1.5m in width including depositing the material as directed with all leads and lifts.

| | | | | | Rs. per Sqm |
|---|---|---|---|---|---|
| | **(A) Lift 0m to 1.50m** | | | | |
| A. | Basic Rate vide WRD CSR 2013 - 2014 "2- Excavation" I.No. 2 Page No 2 | | | | 40.35 |
| | | | | Total | 40.35 |
| B. | Add 15% extra for discharges <1 00 cumecs | on Rs. | 40.35 | | 6.05 |
| C | Add 1% for Labour Welfare | on Rs. | 40.35 | | 0.40 |
| D. | Add 10% for Tribal area | on Rs. | 40.35 | | 4.03 |
| | | | | Total Rs. | 50.83 |
| | | | | **Say Rs.** | **50.85** |

**Item No.2:** Providing and laying in situ mechanised lining in M-15 (20 MSA)(28 days cube compressive strength not less than 15N/sqmm) grade cement concrete with clean, hard, graded aggregates for canal side and bed using vibrating cylindrical type mechanical paver including cost of all materials, machinery, labour, cleaning with batching plant and transit mixer placing in position, finishing with all slope of canal including scaffolding, formwork, compaction, curing, by cutting grooves, filling with sealing compound and providing porous plugs, preparation of sub grade excluding royalty of materials etc. with initial lead of 50 m and lift of 1.5 m

| | | | | | | Rs. per Cum |
|---|---|---|---|---|---|---|
| A. | Basic Rate vide | CSR 2016-17 Concrete Works Item No 26. Page 48 | | | | 5160.90 |
| B. | Add lead charges for | | | | | |
| | (i) Cement | 0.412 tonne@ Rs. | 239.90 / M.ton | | | 4.94 |
| | (ii) Sand | 0.500 Cum @ Rs | 466.23 /Cum | | | 233.11 |
| | | | | | Total | 5398.95 |
| C | Add 1% for labour welfare | | on Rs. | 5398.95 | | 53.98 |
| D | Add 10% for Tribal area | | on Rs. | 5398.95 | | 539.89 |
| | | | | | Total | 5992.82 |
| | | | | | **Say Rs.** | **5992.80** |

**Item No.3:** Providing and laying in situ mechanised lining in M-15 (20 MSA)(28 days cube compressive strength not less than 15N/sqmm) grade cement concrete with clean, hard, graded aggregates for canal side and bed using vibrating cylindrical type mechanical paver including cost of all materials, machinery, labour, cleaning with batching plant and transit mixer placing in position, finishing with all slope of canal including scaffolding, formwork, compaction, curing, by cutting grooves, filling with sealing compound and providing porous plugs, preparation of sub grade excluding royalty of materials etc. with initial lead of 50 m and lift of 1.5 m

| | | | | | | Rs. per Cum |
|---|---|---|---|---|---|---|
| A. | Basic Rate vide | CSR 2016 17 Concrete Works Item No 26, Page 48 | | | | 5415.20 |
| B. | Add lead charges for | | | | | |
| | (i) Cement | 0.412 tonne@ Rs. | 239.90 / M.ton | | | 4.94 |
| | (ii) Sand | 0.500 Cum @ Rs | 466.23 /Cum | | | 233.11 |
| | | | | | Total | 5653.25 |
| C | Add 1% for labour welfare | | on Rs. | 5653.25 | | 56.53 |
| D | Add 10% for Tribal area | | on Rs. | 5653.25 | | 565.32 |
| | | | | | Total | 6275.10 |
| | | | | | **Say Rs.** | **6275.10** |

**Item No 5**

| | | | | | Rs. per Sqm |
|---|---|---|---|---|---|
| | As per attached rate contract of GOM Rate per GSM= | 0.264 | | | |
| A | For 500 gsm tarpaulin paper material cost= | 500 gsm | | | 132.00 |
| B | Transporting, laying in place labour charges 15% | | | | 19.80 |
| | | | | Total | 151.80 |
| C | Add 1% for labour welfare | on Rs. | 151.80 | | 1.51 |
| D | Add 10% for Tribal area | on Rs. | 151.80 | | 15.18 |
| | | | | **Total** | **168.49** |

# ESTIMATE

P.W.D. 229 e.

Division ARUNAVATI PROJECT DIVISION, DIGRAS

SANCTIONED ESTIMATE No. OF 2014-15

**Maharashtra State**

**FUND HEAD:-** VIDARBHA IRRIGATION DEVELOPMENT CORPORATION NAGPUR

**MAJOR HEAD:-**

**MINOR HEAD :-**

**SERVICE HEAD:-**

**DEPARTMENTAL HEAD:-**

Name of work :– **Providing & constructing FEROCEMENT Canal Lining in K.M. No. 1 and 2 of Sawangi minor of Arunavati Right Bank Canal**

Estimate framed in the office of the Executive Engineer, Minor Irrigation Division, Pandharpur, for the probable expenses that will be incurred in LINING OF CANAL

**Rs. 6390938**

Administratively approved under:
No. Dated
Technically sanctioned under:
No. Dated

Estimate prepared by : Sect.Engineer and
Checked by Engineer, , Sectional Egnineer.

(Call of Authority)

**GENERAL DESCRIPTION**

AS PER SEPERATE NOTE ATTACHED

Note:- The abstract should be signed at the end by the Executive Engineer and the Sub Divisional Engineer and if necessary, by the Superintending Engineer. The signature should be dated.

I

(Including year.)

Sub Divisional Officer Executive Engineer,

**Name of work :-** **Providing & constructing FEROCEMENT Canal Lining in K.M. No. 1 and 2 of Sawangi minor of Arunavati Right Bank Canal**

# A B S T R A C T

| Quantity | Unit | Description of Item | Rate | Unit | Amount |
|---|---|---|---|---|---|
| 746.96 | Cum | **Item No.1:** Excavation including dressing in hard murrum/ hard man / kankar / pebbles (including boulders of size less than 0.1 cum) exceeding 1.5m in width including depositing the material as directed with all leads and lifts. | 50.85 | Cum | 37982.66 |
| 3470.70 | Sqm | **Item No.2:** Providing, fixing and erecting including welding 8 mm M.S. Bar at 200 mm c/c both ways for Ferrocement walling with welded mesh of size 100x100x2.3 mm and chicken mesh 3 layers of 24 gauge including binding with wire etc. complete with all leads & lifts. | 922.10 | Sqm | 3200332.47 |
| 3470.70 | Sqm | **Item No.3:** Providing and casting Ferrocement wall of 50mm thick in C.M. 1:3 including curing etc complete with all leads & lifts. | 632.10 | Sqm | 2193829.47 |
| 173.54 | Cum | **Item No.4:** Royalty Charges as per Revenue and Forest Department's notification dated 11/02/2010 as Maharashtra Minor Mineral Extraction Rules, 2010 and as per insruction in general notes on CSR 2012-2013 for items of lime stone, lime shell, stones, rubble, stone dust, shingles, gravel, murum, kankar and ordinary sand, ordinary clay, ordinary earth (to be used for embankment and filling), slate and shell etc. | 70.67 | Cum | 12263.71 |
| 3470.70 | Sqm | **Item No.5:** Providing and laying Tarpaulin of 500 gsm as per rate contract specifications, before laying the steel skeleton. | 168.49 | Sqm | 584778.24 |

| | | |
|---|---|---|
| | | 6029186.55 |
| Add for insurance | 1% | 60291.87 |
| Add for Supervision, quality testing charges and Consultancy from Ferrocement Society, | 5% | 301459.33 |
| | | 6390937.74 |
| | | 6390938 |

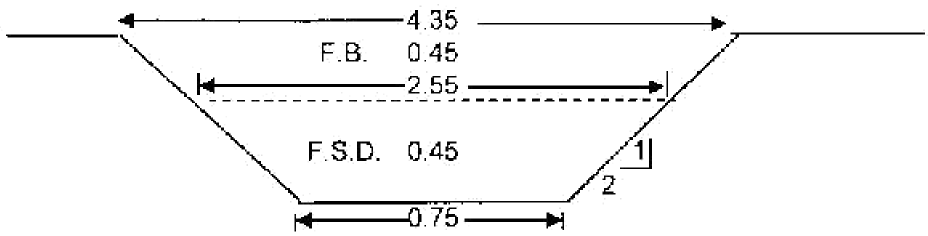
Astt Ex. Engineer
Arunavati Project Sub Division No 2
Digras

Executive Engineer

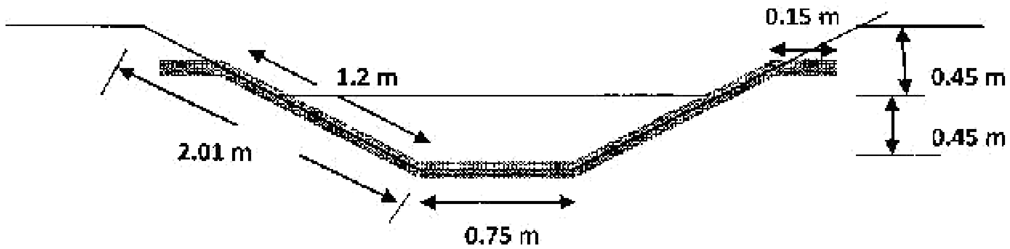
Name of Work : - Providing & constructing FEROCEMENT Canal Lining in K.M. No. 1 and 2 of Sawangi minor of Arunavati Right Bank Canal

**HAYDRAULIC DATA**
**( Sawangi minor of Arunavati Right Bank Canal)**

| | | | |
|---|---|---|---|
| Canal Dischar | = | | Cusecs |
| Bed width | = | 0.75 | |
| Full Supply Le | = | 0.45 | |
| Free board | = | 0.45 | |
| Bed Gradient | = | 1 : | 2500 |




**DRAWING FOR LINING**




**Area of lining of Ferrocement= 1006 x (0.15+1.2+0.75+1.2+0.15) =1006 m x 3.45 m = 3470.70 sqm**
Area of tarpaulin below the lining is same as above.
Thickness of plastic paper will be 500 gsm, and thickness of ferrocement lining will be 50 mm.
This will ensure 100% arresting the seapage.

**Name of Work :-** **Providing & constructing FEROCEMENT Canal Lining in K.M. No. 1 and 2 of Sawangi minor of Arunavati Right Bank Canal**

## MEASUREMENT

**Item No.1:** Excavation including dressing in hard murrum/ hard man / kankar / pebbles (including boulders of size less than 0.1 cum) exceeding 1.5m in width including depositing the material as directed with all leads and lifts.

Sawangi minor
The channel is deposited with silt, shrubs etc. so cleaning is necessary.

| | | | | | |
|---|---|---|---|---|---|
| Ch | 0 m to | 1006 = | 1006 m | | |
| | 1006 X | (2.55 + 0.75) / 2 | | 0.45 | **746.96** Cum |

**Item No.2:** Providing, fixing and erecting including welding 8 mm M.S. Bar at 200 mm c/c both ways for Ferrocement walling with welded mesh of size 100x100x2.3 mm and chicken mesh 3 layers of 24 gauge including binding with wire etc. complete with all leads & lifts.

| | | | |
|---|---|---|---|
| Length of lined cross section = (As per sheet attached) | 3.45 m | | |
| Length of canal section = | 1006.00 m | | |
| Quantity | 1006.00 X | 3.45 | 3470.70 |
| | | | 3470.70 Sqm |

**Item No.3:** Providing and casting Ferrocement wall 50mm thick inj C.M. 1:3 including mixing morter, casting in position and curing with all leads & lifts as directed

Quantity as per Item No.1 — 3470.70 Sqm

**Item No.4:** Royalty Charges as per Revenue and Forest Department's notification dated 11/02/2010 as Maharashtra Minor Mineral Extraction Rules, 2010 and as per insruction in general notes on CSR 2012-2013 for items of lime stone, lime shell, stones, rubble, stone dust, shingles, gravel, murum, kankar and ordinary sand, ordinary clay, ordinary earth (to be used for embankment and filling), slate and shell etc.

| | | | | |
|---|---|---|---|---|
| Item No.3 | 3470.70 Sqm | X | 0.05 | 173.54 Cum |

**Item No 5** Providing and laying Tarpaulin of 500 gsm as per rate contract specifications, before laying the steel skeleton.

Quantity as per Item No.1 — 3470.70 Sqm

## SAWANGI MINOR OF ARUNAVATI RIGHT BANK CANAL

**Name of work :–**

**Providing & constructing FEROCEMENT Canal Lining in K.M. No. 1 and 2 of Sawangi minor of Arunavati Right Bank Canal**

## LEAD STATEMENT

| Sr. No. | Material | Location Of Quarries | Lead in Km. | Lead Charges | Unit |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| 1 | Sand | Loni | 20 | 253.53 | Cum |
| 2 | Cement | Digras | 11 | 115.80 | M.Ton |
| 3 | Steel | Digras | 11 | 127.30 | M.Ton |

### CERTIFICATE

The above leads are personally varified by me and found correct. The material is not available within lesser lead than shown in the above lead statement.

| | | rate | Proposed | lead charges |
|---|---|---|---|---|
| 1. Cement | Rs. | 6720 /M.ton | 6835.80 | 115.80 / M.ton |
| 2. Steel | Rs. | 61000 /M.ton | 61127.30 | 127.30 / M.ton |
| 3. Sand | Rs. | 700 /cum | 953.53 | 253.53 /cum |

## SAWANGI MINOR of ARUNAVATI RIGHT BANK CANAL

**Name of Work :** · **Providing & constructing FEROCEMENT Canal Lining in K.M. No. 1 and 2 of Sawangi minor of Arunavati Right Bank Canal**

# RATE ANALYSIS

**Item No.1:** Excavation including dressing in hard murrum/ hard man / kankar / pebbles (including boulders of size less than 0.1 cum) exceeding 1.5m in width including depositing the material as directed with all leads and lifts.

| | | | | | Rs. per Sqm |
|---|---|---|---|---|---|
| | **(A) Lift 0m to 1.50m** | | | | |
| A. | Basic Rate vide WRD CSR 2013 - 2014 "2- Excavation" I.No. 2 Page No 2 | | | | 40.35 |
| | | | | Total | 40.35 |
| B. | Add 15% extra for discharges <1.00 cumecs | on Rs. | 40.35 | | 6.05 |
| C. | Add 1% for Labour Welfare | on Rs. | 40.35 | | 0.40 |
| D. | Add 10% for Tribal area | on Rs | 40.35 | | 4.03 |
| | | | | Total Rs. | 50.83 |
| | | | | **Say Rs.** | **50.85** |

**Item No.2:** Providing, fixing and erecting including welding 8 mm M.S. Bar at 200 mm c/c both ways for Ferrocement walling with welded mesh of size 100x100x2.3 mm and chicken mesh 3 layers of 24 gauge including binding with wire etc. complete with all leads & lifts.

| | | | | | Rs. per Sqm |
|---|---|---|---|---|---|
| A. | Basic Rate vide Pune Region DSR 2013-14 Section IV, Cement Concrete Item No.33 , Page No. 18 | | | | 830.20 |
| B | Add load charges for steel 4.368 kg @ Rs 127.30 / M.ton | | | | 0.55 |
| | | | | Total | 830.75 |
| C | Add 1% for labour welfare | on Rs. | 830.75 | | 8.30 |
| D | Add 10% for Tribal area | on Rs. | 830.75 | | 83.07 |
| | | | | Total | 922.12 |
| | | | | **Say Rs.** | **922.10** |

**Item No.3:** Providing and casting Ferrocement wall of 50mm thick in C.M. 1:3 including curing etc complete with all leads & lifts.

| | | | | | Rs. per Sqm |
|---|---|---|---|---|---|
| A. | Basic Rate vide Pune Region DSR 2013-14 Section IV, Cement Concrete Item No.36 , Page No 18 | | | | 555.20 |
| | Deduct royalty charges for sand | 0.05 X | 35.34 | | -1.76 |
| B. | Add lead charges for | | | | |
| | (i) Cement 0.583 Bags @ Rs. | 115.80 / M.ton | | | 3.37 |
| | (ii) Sand 0.05 Cum @ Rs | 253.53 /Cum | | | 12.67 |
| | | | | Total | 569.48 |
| C | Add 1% for labour welfare | on Rs. | 569.48 | | 5.69 |
| D | Add 10% for Tribal area | on Rs. | 569.48 | | 56.94 |
| | | | | Total | 632.11 |
| | | | | **Say Rs.** | **632.10** |

**Item No 5** Providing and laying **Tarpaulin** of 500 gsm as per rate contract specifications, before laying the steel skeleton.

| | | | | | Rs. per Sqm |
|---|---|---|---|---|---|
| | As per attached rate contract of GOM Rate per GSM= | 0.264 | | | |
| A | For 500 gsm tarpaulin paper material cost= | | 500 gsm | | 132.00 |
| B | Transporting, laying in place labour charges 15% | | | | 19.80 |
| | | | | Total | 151.80 |
| C | Add 1% for labour welfare | on Rs. | 151.80 | | 1.51 |
| D | Add 10% for Tribal area | on Rs. | 151.80 | | 15.18 |
| | | | | **Total** | **168.49** |

## Cost Comparison for Ferrocrete Structures Vs RCC Structures

| RCC Work | | | | | | | Ferrocrete Work | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sr No | Item of Work | Quantity | Unit | Rate | Amount | | Sr No | Item of Work | Quantity | Unit | Rate | Amount |
| A | **Staircase - One Tread ( 250 mm ) + one Riser ( 175 mm )** | | | | | | | | | | | |
| 1 | Shuttering Cost :- Materials depreciation + Labour | 0.655 | Sqm | 1000 | 655 | | 1 | Shuttering Cost :- Materials depreciation + Labour | 0 | 0 | | 0 |
| | Considering 1.0 Mt. width of Staircase :- for one tread and riser Bottom of staircase will be 300 mm wide so shuttering area required = 0.3 X 1 for bottom of waist slab + 175 x 1 for riser + 0.30 x 0.3 X 2 of waist slab & step side | | | | | | | | | | | |
| 2 | Cost of Concrete | 0.066875 | Cum | 5400 | 361.125 | | 2 | Ferrocrete Cost | 0.46875 | Sqm | 2850 | 1335.93 |
| | Concrete Volume = 0.30 X 0.15 for waist slab + 0.25 x 0.175 X 1/2 triangular side of step | | | | | | | Area = (0.25 + 0.175) tread & Riser + (0.25*0.175*2*0.5)sides | | | | |
| 3 | Reinforcement Steel :- Say @ 75 Kg. / Cu.Mt of Concrete | 5.015 | Kg | 75 | 376.17 | | 3 | Reinforcement Steel :- Say @ 75 Kg. / Cu.Mt of Concrete | 0 | Kg | 75 | 0 |
| | | | | | | | | | | | | |
| | | | | | 1392.29 | | | | | | | 1335.93 |
| 4 | Supervision Cost | 10% of above Cost | | | 139.22 | | 4 | Supervision Cost | Considered in above Rate | | | |
| | | | | | **1531.526563** | | | | | | | **1335.93** |

| RCC Work | | | | | |
|---|---|---|---|---|---|
| Sr No | Item of Work | Quantity | Unit | Rate | Amount |
| B | **Dome of 5.0 Mt. Dia.** | | | | |
| 1 | Shuttering Cost :- Materials depreciation + Labour | 39.31 | Sqm | 2000 | 78624.53 |
| | Total area of Dome= 423 Sft | | | | |
| 2 | Cost of Concrete | 5.89 | Cum | 5400 | 31842.93 |
| | Concrete Volume = considering 150 mm thickness min. | | | | |
| 3 | Reinforcement Steel :- Say @ 75 Kg. / Cu.Mt of Concrete | 442.26 | Kg | 75 | 33169.72 |
| | | | | | |
| | | | | | 143637.19 |
| 4 | Supervision Cost | 10% of above Cost | | | 14363.71 |
| | | | | for 423 Sft | 158000.91 |
| | | | | Per Sft | 373.52 |

| Ferrocrete Work | | | | | |
|---|---|---|---|---|---|
| Sr No | Item of Work | Quantity | Unit | Rate | Amount |
| | | | | | |
| 1 | Shuttering Cost :- Materials depreciation + Labour | 0 | 0 | | 0 |
| | | | | | |
| 2 | Ferrocrete Cost | 39.31 | Sqm | 2850 | 112039.96 |
| | Area = (0.25 + 0.175) tread & Riser + (0.25*0.175*2*0.5)sides | | | | |
| 3 | Reinforcement Steel :- Say @ 75 Kg. / Cu.Mt of Concrete | 0 | Kg | 75 | 0 |
| | | | | | |
| | | | | | 112039.96 |
| 4 | Supervision Cost | Considered in above Rate | | | |
| | | | | for 423 Sft | 112039.96 |
| | | | | Per Sft | 264.86 |

| RCC Work | | | | | | Ferrocrete Work | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sr No | Item of Work | Quantity | Unit | Rate | Amount | Sr No | Item of Work | Quantity | Unit | Rate | Amount |
| C | **Shell Roof** | | | | | | | | | | |
| 1 | Shuttering Cost :- Materials depreciation + Labour | 46.46 | Sqm | 1500 | 69702.60 | 1 | Shuttering Cost :- Materials depreciation + Labour | 0 | 0 | | 0 |
| | Total area of Dome= 423 Sft | | | | | | | | | | |
| 2 | Cost of Concrete | 6.97 | Cum | 5400 | 37639.40 | 2 | Ferrocrete Cost | 46.46 | Sqm | 2850 | 132434.94 |
| | Concrete Volume = considering 150 mm thickness min. | | | | | | Area = (0.25 + 0.175) tread & Riser + (0.25*0.175*2*0.5)sides | | | | |
| 3 | Reinforcement Steel :- Say @ 75 Kg. / Cu.Mt of Concrete | 522.76 | Kg | 75 | 39207.71 | 3 | Reinforcement Steel :- Say @ 75 Kg. / Cu.Mt of Concrete | 0 | Kg | 75 | 0 |
| | | | | | | | | | | | |
| | | | | | 146549.72 | | | | | | 132434.94 |
| 4 | Supervision Cost | 10% of above Cost | | | 14654.97 | 4 | Supervision Cost | Considered in above Rate | | | |
| | | | | for 500 Sft | **161204.69** | | | | | for 423 Sft | **132434.94** |
| | | | | **Per Sft** | **322.40** | | | | | **Per Sft** | **313.08** |

**Conclusions-**

The comparison of costs involved in both the cases is as summarized below.

**Cost comparison of different Applications RCC visa viz Ferrocement**

Amounts in Rupees

| Sr No | Name of Application | RCC cantilever | RCC counterfort | Ferrocement |
|---|---|---|---|---|
| 1 | 3 m high Retaining wall per sqm | 2610 | 2268 | 1686 |
| 2 | 4 m high Retaining wall per sqm | 2887 | 2935 | 1750 |
| 3 | 5 m high Retaining wall per sqm | 3732 | 3626 | 1861 |
| 4 | 6 m high Retaining wall per sqm | 4167 | 4086 | 2043 |
| 5 | Water Tank per litre | 10.57 | | 7.72 |
| 6 | Canal Lining per sqm | 543.12 | | 1662.80 |
| 7 | Stair Case per step of size 250 x 175 mm and 1 meter width | 1532 | | 1336 |
| 8 | Dome 5m diameter per sft | 373.52 | | 264.86 |
| 9 | Shell 5 m diameter per sft | 322.40 | | 313.08 |

# APPENDIX 3
## USE OF FERROCEMENT IN EARTHQUAKE RESISTING STRUCTURES

**ABSTRACT**
Earthquake resistant design is a challenge for mega projects.In design and analysis of structures which can resist earthquake, all the codes prescribe ways and means of improving the gravity loaded structures to withstand horizontal forces. Nowhere an effort is made to find a material and a system of construction which will sustain gravity as well as horizontal forces equally well. A timber trelliswork with plywood planks fixed over it on both sides will give an ideal system but for its strength and susceptibility to fire. In ferrocement cavity wall construction, the same idea is developed further. Stiffened ferrocement plates are put in place of plywood planks and three dimensional grid work of horizontal and vertical stiffeners in form of joints act trellis work.  An effort is made here to develop this idea and provide the best earthquake resisting structure in ferrocement.

**1.0: Earthquake effects on buildings:**

The actual effect of earthquake on structures is understood by its action and the static and dynamic effects.

**1.1: Action of earthquake on structures:**

During an earthquake the ground surface moves in all directions. The most damaging effect is generally due to the movements in direction parallel to the ground surface.

When the earthquake wave passes from one medium to the other, its velocity, displacement and acceleration are modified. If the succeeding medium is softer having low density and elastic modulus, these effects go on increasing.

The earthquake transmits an oscillatory motion to all earth particles and to the structures standing on it. The structures may get vibrations in vertical and two orthogonal horizontal planes. They result in increasing the direct and shear forces, bending and torsion moments and the stability of the structure is in danger.

Because of the reserve strengths of the structures due to their safety factors, the vertical vibrations are mostly taken up by the structures. But they cannot be totally ignored.

An important consideration of the earthquake forces is that they are dynamic in nature.

**1.2: Static and dynamic effects:**

Static force is one which is constant with respect to time. Static forces are stated by their magnitude, direction and the manner in which they are dispersed, say uniformly distributed or concentrated.

In static loads, distinction is made between dead load and live load. In live load its duration is considered for a limited time. Also time dependent stresses in materials like fatigue, creep and progressive settlement of clayey soils are accounted for in it.

Analysis of dynamic loads and their effects on structures should include their time dependent nature. The force acting on a body for some time duration, results in work done. This work done represents the energy capacity of the material and is equal to (force) x (distance)  or (stress) x (strain) and is obtained by the load-deflection or the stress-strain curves for the material.

Besides the energy capacity, the other important property in evaluating the dynamic resistance is the fundamental period of the structure in harmonic motion.

While considering effects of dynamic loads on structures, not only the dynamic properties of material but also the dynamic behavior of the structure is considered. The same dynamic load will produce different effects on different structures.

**1.3: Dynamic effects on structures:**

Loads which involve motion, such as wind, earthquake, moving vehicles, walking people and vibrating machines have a dynamic effect on the structures. For analysis the dynamic properties of the structure will have to be considered.

These properties are determined by size, weight, relative stiffness, fundamental period of the structure, type of support and the degree of elasticity of the materials of structure and the various damping devices which are introduced in the system.

Dynamic load sources deliver an energy load to the structure. Wind load causes impact due to kinetic energy of the moving air. In the case of earthquake or vibrating machinery mass of the structure is the source of dynamic load.

Dynamic effects on structures may be of many types. Some of them are listed below.

a) Work equilibrium condition, in which work imposed on the structure by load, equals the work done by the structure in resisting it.
b) Unstabilising effects: They occur when the dynamic load disturbs the stability of the structure.
c) Harmonic effects: When the load is cyclic in nature harmonic effects are produced. Relations between these motions and the harmonic properties of structure may cause various effects like fluttering of objects, the resonant bouncing of floors, swaying of buildings during earthquakes etc.
d) Failure under repeated loading: A structure may successfully resist a single peak load of earthquake but may fail later under even smaller shocks. This is because the first impact has consumed some energy absorption capacity of the structure by yielding to some extent or by brittle cracking. This reduced energy of the structure is not able to withstand even lighter shocks later.

A major consideration in design for dynamic loads is the response of the structure as a whole. The structure may remain intact but some part of it like plaster, ceilings, window shutters, partition walls etc may fail. Hence the important design consideration is that the structure should be tied together and should act as one integral unit to resist dynamic loads.

**2.0: Design of earthquake proof buildings:**

Recommendations from different codes and structural designers for the design of earthquake proof buildings are summed up below.

2.1: Lightweight:

Buildings should be as light as possible. The lightweight should not be achieved at the cost of strength, thermal insulation or human comfort.

2.2: Closed shape:

A square or compact rectangular plan is preferred. The ratio of length to breadth should not exceed three. A closed shaped plan is better than an open ‘U’ or ‘L’ or ‘T’ shaped plan.

2.3: Tying together:

All parts of the building should be firmly tied together and stiffly braced at corners in such a way that the whole unit will tend to move as one unit.

2.4: Projections:

Parapets, cornices, cantilevers and projections more than 750mm long should be avoided. For such projections the ‘C’ value is multiplied by five.

2.5: Tall structures:

Chimney-like structures should be of RCC or steel and should be well tied with the main structures.

2.6: Rigid joints:

For rigidity all the masonry work should be done in cement mortar. A rigid member comes to rest quickly and hence rigid joints are recommended.

2.7: Masonry walls:

All internal and external walls should be tied together at each floor level. A RCC band at window sill level and lintel level will be an added advantage.

2.8: Diagonal braces:

The rigidity of the structures is effectively increased by providing diagonal braces.

2.9: Centre of gravity:

The centre of gravity of the whole structure should be as low as possible. While designing a building it should be seen that the centre of gravity and the centre if rigidity coincide. Otherwise the horizontal motion will cause a considerable torsion in the building. Having different parts of buildings to have different heights or too much variation in areas of openings will lead to torsional bending.

2.10; Overturning:

The overturning moment of the structure due to seismic forces shall not exceed 50% of the moment of stability, both calculated by using the same loads.

2.11: Adjacent buildings:

Adjacent buildings or the parts of the same building, which are different in mass and stiffness should be separated by a gap or should be rigidly interconnected. This gap should be filled in with fragile material. This separation should be taken up to the top of the foundation. Foundation of a group of buildings may be continuous.

2.12: Pressure on foundation:

The maximum pressure on foundation from dead, live and seismic load should not exceed 1.10 times safe bearing capacity of the supporting soil.

2.13: No uplift:

Moments due to seismic force should not cause uplift in any part of the foundation. The seismic force increases with the mass of the structure and hence the roofs and the upper storeys of the buildings should be lightweight.

2.14: Important buildings:

Buildings which are of post earthquake importance like hospitals, waterworks, fire-stations etc should be designed with ‘C’ value 1.5 times the value recommended in the code.

2.15: Load bearing walls:

All buildings with load bearing walls in stone, brick or block masonry should be provided with continuous bands of reinforced concrete all around external, internal and partition walls at levels of plinth, window sill, lintel and below slab. Such bands should be for the full width of the walls and minimum 150mm thick.

Height to width ratio of masonry wall should not exceed 1.50. Total height of load bearing wall should not exceed 12.0 meters.

2.16: Hollow wall construction:

Two leaf walls with air gap are not advised in the seismic region.

2.17: Hollow block masonry:

The thickness of hollow block load bearing masonry walls shall not be less than 200mm for single storeyed and not less than 300mm for two storeyed buildings.

2.18: Cross walls:

Cross walls should not be less than 2/3 thick of the external walls. Cross walls possess greater rigidity than the frames put in the same direction.

2.19: Solid RCC walls:

Practically a wall of 125mm thickness can be cast in concrete. A 200mm thick RCC solid wall will usually cover all the earthquake requirements. They should be built monolithic with the floor slabs. Nominal reinforcement of 10mm dia. @ 300mm c/c vertically and 6mm dia @ 300mm c/c horizontally will be adequate for practically all storeyheights.

2.20: Arch roofs:

Arched roofs of any type are not permitted as differential movement of any support will cause complete collapse of the structure.

2.21: Gable ends:

No gable ends should be permitted and ends of the sloping roofs should be hipped.

2.22: RCC framed structure:

In this the full load is taken by the framework and no portion is transferred to the walls. The main beams should be reinforced at top and bottom with minimum 0.7% of reinforcement on each side and stirrups provided throughout the length.

Slenderness ratio of the columns should not exceed 15.0 and its main reinforcement should not be less than 1.25 % of the effective area.

Floors and roofs should be cast integral with the supporting beams.

External columns should have diagonal bracings either of beams or by diagonal reinforcement in the slabs.

2.23: Timber structures:

Small buildings of one or two storeys with built up area not exceeding 350 sq m with well braced timber frames on sound foundations will withstand all earthquake forces. Only they should be protected from fire.

**3.0: Ferrocement with earthquake resistant properties:**

Structural properties of ferrocement are well established. Now those properties from the viewpoint of earthquake resistance are discussed below.

**3.1: Lightweight construction;**

Mass density of ferrocement is same as reinforced concrete but its thin walled construction reduces its weight. A double wall of ferrocement stiffened panels, with leaf walls of 25 mm thick and wall height 3.0 m, will weigh hardly 375 kg per m run. From table 8.4 one can compare this weight with weights of the other masonry walls. Compared to 230mm thick brickwall, weight of ferrocement wall is 1/3 rd, while it is 1/4$^{th}$ that of (100+100)mm thick concrete block masonry cavity wall.

Considering the ferrocement hollow floor system per sq m, the weight of 150mm thick RCC slab is 375 kg, while that of hollow ferrocement floor is 200 kg only.

Dead weight of a ten storeyed ferrocement building will be equal to 4 storeyed conventional building.

**3.2: Energy absorption:**

Considering the stress-strain curve for ferrocement in direct tension, and load-deflection curve in flexure, the ductile behaviour and the energy absorption capacity of ferrocement will be clearly marked.

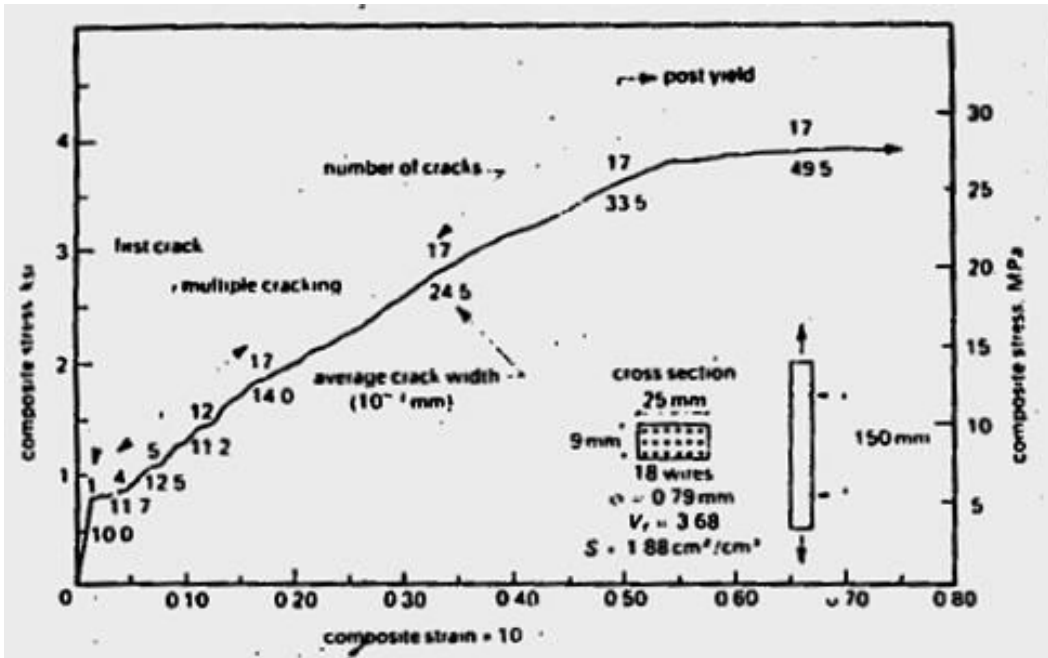


**Figure 1.1** Stress-strain curve of ferrocement in tension

It is very clear from the curves that the failure is not brittle.

Comparing the areas under these curves with those for RCC, it will be seen the energy absorption capacity of ferrocement is tenfold.

In the three stage behavior of ferrocement, the load bearing capacity of the sample is not at all reduced even in the second stage of multiple cracking. This means that even after first cracks, ferrocement is in a position to take further loading.

For earthquake resistance this property is of much importance.

**3.3: Equal strength in both directions:**

In conventional constructions, the structural elements are designed for gravity loads and are stiffened or braced to take horizontal loads.

Earthquake resisting structures are supposed to take vertical gravity loads as well as horizontal quake loads simultaneously.

Ferrocement structures are reinforced with equal reinforcement in both directions and have equal strength in vertical and horizontal directions when used as walling elements. Due to equal reinforcement in both the directions, the shear strength of the ferrocement panels is very high.

**3.4: High strengths in tension, compression and shear.**

The recommended values of properties of ferrocement are as follows.

Ultimate tensile strength ------------up to 34.50 MPa
Allowable tensile stress ------------up to 10.30 MPa
Modulus of rupture ----------- up to 55.10 MPa
Compressive strength ---------- 27.60 to 68.90 MPa.

Due to higher compressive strengths of rich cement mortars, its bond and shear strength are also increased. In field even with ordinary river sands, mortars of compressive strengths of 35.0 to 40.0 MPa can be easily obtained.

**3.5: Mortar encased in meshes:**

The press-fill method of casting makes the mortar to penetrate fully the mesh layers and the mortar gets completely encased in them. If a ferrocement member cracks or fails there is no possibility of separation of mortar from the meshes.

In conventional constructions, the plaster, particularly of ceiling, gets separated easily and falls down due to earthquake forces. This type of failure will never occur with ferrocement.

**3.6: Plaster finish:**

In ferrocement the cover is hardly 3 to 5 mm and is a part and parcel of the ferrocement wall. There is no possibility of this finishing coat of plaster getting separated from the main structure. At the most there may be surface cracks.

**3.7: Strength to weight ratio:**

For M 25 mortar for a cavity wall with (25+25)mm wall thickness, the strength to weight ratio is more than 80.Compared to conventional construction in bricks, it is 3 to 4 times more. Hence a lighter but still more stronger structure is possible with ferrocement.

**3.8: Crack control:**

Relationship between crack-width and the steel fiber stress is well established in ferrocement. Hence a ferrocement structure can be designed for a specified crack-width. In a ferrocement structure, designed for earthquake resistance, the crack pattern even under impact loading can be anticipated.

**3.9: No spalling out:**

In earthquakes fatal accidents due to separation and falling down of plaster are very common. In ferrocement structures, even at the time of ultimate failure, it won't break into pieces. The member may undergo heavy deflections, but the mortar contained in the meshes will not fall down.

**3.10: Similar to timber:**

Timber is the material to resist earthquake forces. Its lightness and the resilience are the key properties.

It is already pointed out that ferrocement is a material much similar to timber. The mesh reinforcement is used in place of cellulose fibers and mortar plays the role of pith in timber. It is an artificially and scientifically made timber which has added advantages of strength and fire resistance.

**3.11: No sudden failure:**

Actually if we consider from the viewpoint of reinforced concrete, ferrocement is an over reinforced member and should fail suddenly. Actually the strong bond between the mortar and the wire meshes tend to make ferrocement a homogeneous material and its failure is ductile and not brittle. A ferrocement structure may deflect, deform in shape but won't fail all of a sudden.

**3.12:Shear walls:**

Ferrocement can resist membrane stresses in direct compression and tension nicely, due to its two way reinforcement, thorough dispersion of steel and homogeneous nature. So a ferrocement wall can resist horizontal loads very easily as shear walls.

The integral working of stiffened ferrocement plates and the in-built framework helps in resisting strongly the horizontal shear forces.

**3.13: Semi-flexible material:**

Ferrocement is not very rigid as reinforced concrete. Due to slender sections and homogeneous nature of material slight flexibility is observed in ferrocement members. The stress-strain curves also show its ductile behavior. Due to flexible nature some energy is absorbed by ferrocement without loosing much of its strength.

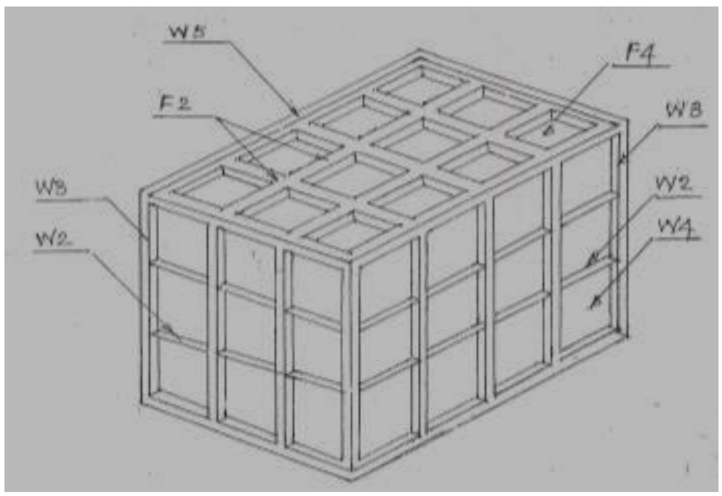
Research indicates that the prefabricated houses of ferrocement showed a good seismic behavior under static cyclic. The vulnerability analysis conducted up to a peak ground acceleration of 0.90g shows that it is an adequate system for strong earthquakes. The state of predominant damage is the minor state. from this point of view the houses prefabricated of ferrocement are a good alternative for the house of low cost in developing countries.

Tests using half size brick masonry models on vibration tables under earthquake like base motions have conclusively proven that retrofitted masonry buildings with ferrocement will become adequately earthquake resistant and will neither collapse nor severely crack in the seismic zone IV earthquake Intensities.

**4.0: Ferrocement earthquake proof buildings:**

A system of parallel ferrocement cavity walls and box sectioned ferrocement hollow floors is developed, wherein precast walling and floor panels are used.

This system with its points of merit is detailed below.




INBUILT FRAMEWORK- ISOMETRIC VIEW(Ferrocement walling and floors not shown)

**4.1: Closed framework:**

The vertical and horizontal stiffeners in for of closely spaced columns and beams in cavity walls and tee beams in hollow slabs, form a perfectly closed three dimensional in-built framework. The members of this framework are cast as joints between the precast walling and floor panels and are cast at the same time of erection of walls and floors. Hence the unit of ferrocement plate walls and floors along-with the built-in framework act together as a single integral unit.

| Name | Item | Figure |
|---|---|---|
| W2 | Horizontal Band | W |
| W3 | In built column | W |
| W4 | Insulating Pad | W |
| W5 | Inbuilt wall beam | W |
| F2 | Grid beam | F |
| F4 | Insulating pad | F |

**4.2: Continuity:**

When the stiffened plates are erected and jointed by bolts or jointed by epoxy, to form cavity wall, a boxlike formwork is automatically formed for the vertical columns. In multi-storeyed buildings this boxlike formwork is continuous from floor to floor. Welded steel bar cage is put in this box formwork and concrete is cast in it. Floor to floor continuity of reinforcement and concrete can thus be achieved.

At the top of cavity wall, a trough-like formwork is automatically formed due to ribs and edge projections. Welded bar cage, as beam reinforcement, is put in it and concreted. The beams are continuous over all the adjoining walls and hence continuity of reinforcement and concrete in beams is maintained at floor level.

In hollow ferrocement floor slabs, a trough-like formwork is automatically formed when the precast base-plates and the void-forming channel sections are laid. Reinforcement for the Tee beams and the flange is welded and laid in this formwork and concreted. These Tee beams are continuous throughout the floor slab. In case of larger spans for slabs, a grid beam floor can be introduced.

At the interconnections of columns, wall beams and the floor beams, one time casting of concrete will provide rigid joints for the framework. Hence a continuity of the framework with rigid joints is achieved. This will provide a continuous and uninterrupted path for horizontal and vertical loads.

**4.3: Tying together:**

The vertical stiffener columns, the wall beams and the Tee beams are interconnected and are tied together with continuous reinforcement and concreted at a time..

The faces of ribs and edge projections of precast ferrocement walling plates, floor base plates and void forming channel should be kept rough and unfinished. These rough surfaces of the formwork will provide good bond with the concrete. If required the meshes on these surfaces may be kept open to have still better bond of precast panels with concrete-in-situ.

Thus the connections between the precast panels and the in-situ-concrete will be perfect. Hence all the members of the building, even with precast panels, will work as an integrally cast structure and will resist earthquake loads as one single unit.

**4.4: Box action:**

When the three dimensional grid of columns, beams and Tee-beams along with the precast walling and floor panels are connected together, every room in the building acts as a box unit and the whole building consists of boxes tied together.

Hence the whole building acts as a big closed boxlike unit which is strengthened by individual boxes of rooms.

**4.5: Frame members confined in ferrocement:**

The formwork for the columns, beams and tee beams is formed by the ribs and the edge projections of precast panels. Concrete is poured in these forms. Thus the formwok acts as a lost formwork and becomes an integral part of the columns, beams and tee-beams.

This confinement of concrete makes it behave under triaxial stress conditions and increases its strength.

**4.6: Ties at all levels:**

When cavity walls are formed by cast-in-situ method as stated in article 8.3, at each horizontal level of foundation, plinth, window sill, lintel and slab base ferrocement bands of 50 to 75 mm thickness are provided. They hold together two skin walls as well as impart strength to them by reducing the effective length of the compression member.

When precast walling panels are used, the panels themselves are stiffened by horizontal and diagonal ribs. Two skin walls are bolted together and jointed by in-situ concrete. The spacing of ribs is calculated to provide for the slenderness for different end conditions.

**4.7: Closely spaced framework:**

In cavity walls the spacing of columns may be 600 to 1200mm depending upon the width of the wall panel. Hence the span of the wall beams reduces to the width of the panel and the vertical joints between panels are spaced very closely.

In hollow floors, the width of panels decides the spacing of tee beams which is also very close. Hence the three dimensional framework has members which are spaced very closely. Indirectly the sizes of the members reduces to 100x100mm to 150x150mm with nominal reinforcement. For example, the wall beam for a span of 600 to 1200mm, becomes a lintel of size 100x100mm.

This closely knit framework with rigid joints act as a trellis work and resists the earthquake forces properly.

**4.8: Homogeneous material:**

Due to perfect bond between mesh and mortar, ferrocement behaves as a homogeneous material. Loads shared by the two constituent materials are to their fullest capacity. Due to this the composite strength is also very high, which is an advantage in earthquake resistance.

**4.9: Ferrocement for all the building elements:**

All the elements of the building including walls, beams and columns are made up of a single material namely ferrocement. Same thermal properties avoid differential thermal cracking at joints. Same elastic properties help in smooth transfer of loads and moments through the joints. Distribution of moments in members is smooth due to it.

**4.10: Cavity wall to resist earthquake:**

Generally a conventional cavity wall in brick or block masonry is not recommended in earthquake prone areas. The skin walls in them are brick-on-edge type with a number of joints in both directions. They are slender in section and not so stable as self standing units. The ties hold the two leaf walls together. These walls are designed for gravity loads only and cannot stand horizontal forces. Hence they are not allowed in earthquake prone areas.

Such is not the case with ferrocement cavity walls. Though thin in section they are already stiffened by horizontal, vertical and diagonal ribs. The two leafs are bolted together strongly and jointed together by in-built framework of columns and beams. The ferrocement plates have equal strength in both directions and are cast for the full wall height without any joints. Their strength to weight ratio is the highest possible. A 25 + 25mm ferrocement cavity wall can take load of number of story .

These walls are firmly attached to a closely knit in-built framework, and the walls, floors and the framework act together to resist forces in vertical as well as in horizontal directions. Hence a ferrocement cavity wall is strongly recommended for earthquake resisting multistoried structures.

**5.0: Ferrocement earthquake resisting structures already constructed**

**5.1 Single wall ferrocement house**

A number of single wall and cavity wall ferrocement houses are built by the author.

An earthquake resisting model house was constructed by the author in 1993 after the Latur earthquake in Maharashtra. A report of this work was sent to Central Building Research Institute, Roorkee (India) for their comments.

**5.2 Cast-in-situ Method**-(Also known as All-in-one method)

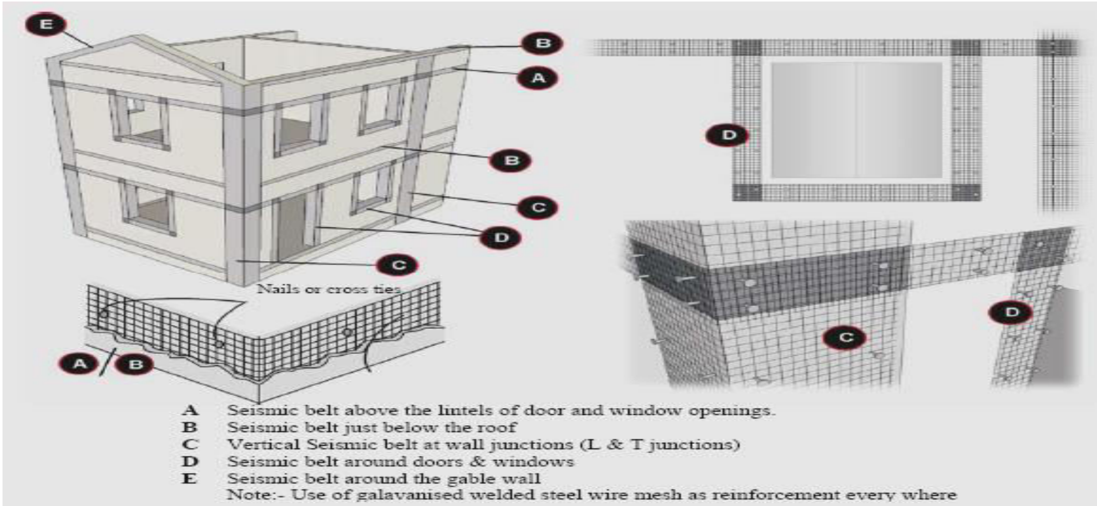
All-in-One (TM) is a novel and unique method of constructing structures and buildings, in which Ferrocement Paneled Cavity walls with inbuilt columns and stiffeners hidden inside the cavity and Ferrocement boxed hollow floors with inbuilt hidden grid beams are fabricated, erected, and cast simultaneously resulting in an integral construction of walls and floors with inbuilt three dimensional structural framework of columns, stiffeners, and beams. The traditional method of erecting, and casting of R.C.C framework of columns, beams, and slabs first, and then to build filler walls in it, is completely reversed here.

The Ferrocement walls are divided into panels, and floors in box sections, the joints of which act as structural framework. Due to paneling of walls and boxing of floors and closer spacing of columns and beams, all the loads are equally distributed throughout the body of the structure resulting in lighter sections of columns and beams. A special feature of this method is that the material of construction of all components of the structure is the same, due to which transfer of loads, moments, and shear, torsion, and shock loads is very smooth. Ferrocement itself is having enormous capacity to absorb the shock loads. In addition to it, the integral casting, box like construction , light weight due to thin walls with very high strength to weight ratio, high and equal strength in both directions and close knit three dimensional frame work make All-in-One the most ideal system for building structures in earthquake – prone areas.

Compared to traditional methods, the site work is reduced to only ten percent, resulting in saving of time of construction. All types of structures including multistoried buildings, silos, space structures, large size conduits, can be easily constructed by using this method. Traditional building materials like stones, bricks, timber are completely eliminated in All-in-One .Pollution of air, water, and noise is reduced to Zero. Hence All-in-One is **“The Number One”**eco friendly method of construction.

**5.3 DETAILS OF RETROFITTING ELEMENTS as suggested by Government of Delhi and UNDP**

1. Ferro-Cement Plating
2. Providing Horizontal Seismic Belts
3. Vertical Seismic Belt at Corners
4. Providing Vertical Reinforcement at Corners, Junctions of Walls.




Overall arrangement of seismic belt

**6.0: Conclusions:-**

6.1 As a material of construction, ferrocement is a homogeneous and ductile material with enormous capacity of energy absorption. It is an artificially formed timber and is an ideal material for earthquake prone area.

6.2 Method of constructing structures by using ferrocement cavity walls and hollow floors within built framework is the best system with stiffened shear walls and floors automatically formed in it. This system can be used in form of precast or cast-in-situ method of construction.

6.3 For retrofitting structures damaged due to shock loading ferrocement is the only reliable alternative.

Thus ferrocement as a material and construction method are ideal for building structures in earthquake areas.

# APPENDIX 4

## STRUCTURAL ANALYSIS AND DESIGN OF SIPHON USING ANSYS

**Abstract—** Whenever two flow lines i.e. canal and the river or drain crosses each other, the CD work is constructed. The siphon type of CD work is constructed in the field when the river or the drain flows above and the canal flow is made underground below the river. The canal flow is taken below the ground through the rectangular box section. Such box section has top slab to take the load of the river flow and bottom slab to take the load of canal flow. Moreover, these two slabs are subjected to loads from top and bottom surface. During the worst loading condition, the main reinforcement is required to be provided at top and bottom of these slabs. This not only increases the thickness of the slab but also reduces the net flow area and also disturbs the hydraulic functioning of CD-works.

Present work consists of replacing the R.C.C. box section of the canal flow with ferrocement box section for reducing the thickness and increasing the cross sectional area for smooth hydraulic functioning of the siphon.

The section in ferrocement is analyzed in ANSYS and subsequently optimized design is carried out. Also, the comparison of structural performance between R.C.C. section and ferrocement section is done.

The analysis and design concludes that the ferrocement section in the form of arch of the CD-work proves to be efficient structurally and hydraulically.

**Keywords:-** ANSYS , ferrocement, Siphon.

**1. Introduction**:A cross drainage work is a structure which is constructed at the crossing of a canal and a natural drain, so as dispose of drainage water without interrupting the continuous canal flow. Cross-drainage works are necessary in irrigation projects.

There are many different types of CD works**.** The present subject deals with design and analysis of siphon.

**1.1 The field problem** : In siphon type of CD work, the drain is taken over the canal such that the canal water runs below the drain, the FSL of the canal is sufficiently above the bed level of the drainage trough, so that the canal flows under siphoning action under the trough. Such structure is known as a canal siphon or a Siphonas shown in Figure 1.

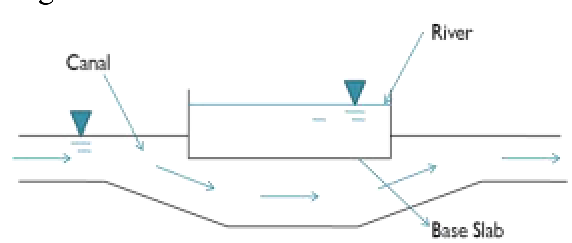



**Figure 1: Siphon**

In the siphon, the canal bed is depressed and a ramp is provided at the exit. The section of the canal below the trough is constructed with reinforced cement concrete in the form of tunnel which acts as siphon.

When siphon type of cross drainage work is constructed using reinforced cement concrete which requires large amount of steel, cement, sand and aggregates and reinforced concrete sections have large thickness .Due to large thickness of the slab, the area of flow reduces and as there is reduction in flow area ,velocity of flow increases. Due to more velocity of flow, there is scouring on the downstream side due to which the head loss increases. Using traditional reinforced concrete as a construction material for siphon leads to the problems which can be summarized as --

(i) Main reinforcement is required on both the sides.

(ii) Thickness of slab is more.

(iii) Due to increased thickness, net flow area of the canal water reduces.

(iv) Reduced flow area leads to increase in the velocity of water.

(v) Increased velocity leads to more losses.

(vi) Dead weight of the structure is more.

(vii) Material required is more.

(viii)Cost of construction increases leading to uneconomic construction.

**1.2 Loading conditions:**Following worst loading cases may occur during functioning of for siphon loading.

**1.2.1 Nonexistence of water in the river and canal is full:** In this case ,when there is no water in the river and cannel is running full, canal water offers heavy upward pressure on the trough of the siphon as shown in Figure 2

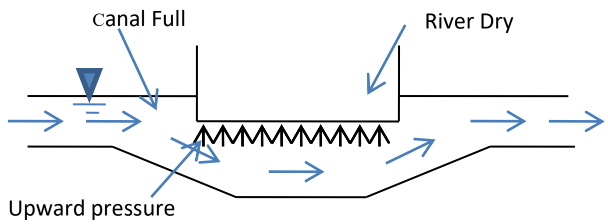



**Figure 2: River dry and canal full**

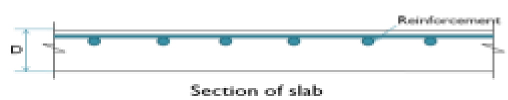



**Figure 3: Reinforcement in slab**

Due to the heavy upward pressure on trough ,top reinforcement requires concrete cover and higher depth of the concrete slab to resist the water pressure on the trough of siphon as shown in Figure 3

**1.2.2 Nonexistence of water in the canal and river is running full:** In this case, when there is no water during worst condition in the canal and river is running full, river water offers heavy downward pressure on the trough of the siphon as shown in Figure 4.

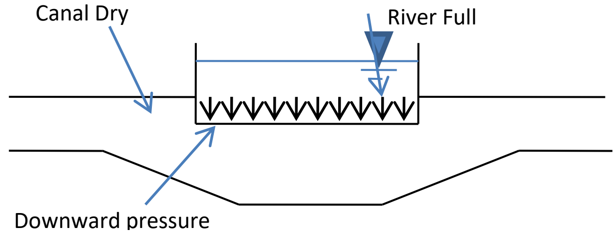



**Figure 4: River full and canal dry**

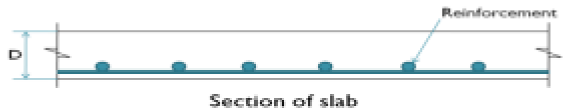



**Figure 5: Reinforcement in slab**

Due to the heavy water pressure on trough bottom, reinforcement requires concrete cover and higher depth of the concrete slab to resist the water pressure on the trough of siphon as shown in Figure 5.

**1.2.3 Combination of above two cases:** From the above two worst conditions, due to heavy water pressure from the both up and down sides, main reinforcement is required on both the sides of the trough slab as shown in the Figure. This will increase the cross section of roof slab of siphon. Due to increasein depth of section, net flow area will get reduced due to which there will be increase in the velocity of the flow.

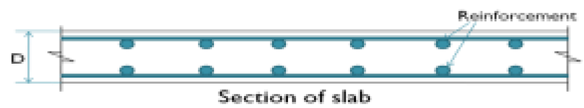



**Figure 6: Combined reinforcement in slab**

**2 Solution proposed:**Considering above field problem, there is need to reduce the thickness of the section and economize the construction. The R.C.Csiphonsectionis proposed to be replaced by usingferrocement so thatthe thickness of the section will be reduced and the construction will become economical, as ferrocement requires less thickness as compared to reinforced cement concrete.Above problems can be minimized and solved by adopting ferrocement for construction of siphon. By adopting ferrocement following is achieved

- Thickness of the section will be reduced.
- Area of flow will be increased and the losses will be reduced.
- Less material and thickness will be required.
- Dead weight of the structure will be reduced.

**3. The approach adopted:**Structural design of trough slab of siphon is done for RCC and ferrocement. RCC slab design is done using working stress method and for design of ferrocement slab method recommended by ACI code is used.The design sections of RCC and ferrocement are modeled and analyzed using ANSYS workbench.

**3.1. R.C.C.Design of siphon trough:** A field case study is considered as mentioned below for the analysis. The field data of a siphon is obtained. From this data, the load and moment are calculated;the obtained parameters are used for designing the equivalent ferrocement section. Couple of trials are presented to get optimized ferrocement section.

**3.1.1 Load calculations:**

-Downward water load acting (2.7m water load) = 27 kN/m$^2$

-Load due to self-weight of slab = 0.8 x 24 = 19.2 kN/m$^2$.

-Total downward load (no uplift) = 27 + 19.2 = 46.2 kN/m$^2$.

Maximum sagging bending moment in slab due to downward load (no uplift)

$$M = \frac{W\, l^2}{10} = \frac{46.2\ x\ 1^2}{10} = 4.62\ \text{kNm}$$

Design of slab is done by usual method used for the design of RCC slab. Using M25 concrete and with depth of 100mm and 8mm ø @ 80mm c/c.

### 3.2 Design of ferrocement slab, using ACI method

The computation of the nominal moment strength of ferrocement sections can be time-consuming unless a computer is used. For evaluation, Naaman and Homrich derived a non-dimensional equation to predict the nominal moment strength of ferrocement beams subjected to pure bending.

$$\frac{M_n}{f'_c \text{bh}^2 \eta} = 0.005 + 0.422\left(\frac{v_f f_y}{f'_c}\right) - 0.0772\left(\frac{V_f f_y}{f'_c}\right)^2 - (\text{ACI 549, page 11})$$

where,

$M_n$= moment capacity of ferrocement section.

$V_f$= volume fraction of reinforcement.

b= width of ferrocement section.

h= thickness of ferrocement section.

$f'_c$=compressive strength of mortar= 0.45 X 40 = 18MPa.

$f_y$= yield strength of mesh reinforcement =0.6X450 = 270MPa.

$\eta$ = global efficiency factor of embedded reinforcement = 0.45.

Checking a ferrocement section of different thickness for the worst loading condition, using different layers of 10 gauge (d=3.175mm) of welded wire mesh and mortar grade of M40 **Trial. I:** Thickness of 50mm, using 4 layers of mesh

$\boxed{M_n = 8.76\ \text{kNm} > 4.62\ kNm}$ Not ok

**Trial.II:** Thickness of 40mm, using 2 layers of mesh.

$\boxed{M_n = 4.09\ \text{kNm} < 4.62 kNm}$ Not ok

**Trial.III:** Thickness of 50mm, using 2 layers of mesh.

$\boxed{M_n = 4.66\ \text{kNm} > 4.62\ kNm}$ Ok

Therefore ferrocement slab of 50 mm thickness, with 2 layers of 10 gauge mesh and M40 grade of mortar can resist the moment (4.62 kNm) generated due to the applied load (46.2 kN/$m^2$).

**4.Software analysis:** There are various FE analysis software packages available such as ANSYS, Abaqus, Stad-pro, SAP, ADINA, Advance Design, Open Sees, COSMOL Multi physics etc.The ANSYS is used for the analysis of siphon in present work.ANSYS is a general-purpose finite-element modeling package for numerically solving a wide variety of structural problems. In general, a finite-element solution may be broken into the following three stages.

**a) Preprocessing:**This involve defining of the problem and major steps in preprocessing are

(i) Define key points / lines / areas / volumes.

(ii) Define element type and material / geometric properties.

(iii) Mesh lines / areas / volumes as required.

The amount of detail required will depend on the dimensionality of the analysis, i.e., 1D, 2D, axis-symmetric, and 3D.

**b) Solution:**This involves assigning loads, constraints, and solving. It is necessary to specify the loads (point or pressure), constraints (translational and rotational), and finally solve the resulting set of equations.

**c) Post processing:**This involves further processing and viewing of the results. At this stage,following parameters can be obtained..

i)Lists of nodal displacements,

ii)Element forces and moments,

iii)Deflection plots,

iv)Stress contour diagrams or temperature maps.

ANSYS is used for the analysis of siphon in RCC and ferrocement, for different conditions as

i) Canal full and river full.

ii) Canal full and river empty.

iii) Canal empty and river empty.

**4.1 Material properties:**Material properties are required for the ANSYS analysis. Table 1, 2 and 3 shows these properties which were used.

**Table 1 :Properties of concrete**

| Material properties | M 25 |
|---|---|
| Modulus of elasticity (E) MPa | 25000 |
| Poisons ratio (μ) | 0.18 |

**Table 2 :Properties of mortar**

| Material | Modulus of elasticity (E) MPa | Poisons ratio (μ) |
|---|---|---|
| M 40 | 36047 | 0.20 |
| M 35 | 33720 | 0.20 |
| M 30 | 31219 | 0.18 |
| M 25 | 28500 | 0.18 |

**Table 3: Mechanical properties of steel meshes (ACI 549)**

| Yield strength (MPa) | Modulus of elasticity (Gpa) |
|---|---|
| 450 | 200 |

**5.Results:**The specimens of experimental work were tested under Universal Testing Machine and the results of various parameters are presented below

**5.1 Defletions:**From the analysis of reinforced concrete slab, ferrocement slab and ferrocement arch slab total deformation are obtained. As the pressure is applied normal to the slab, deflection is along the direction of the load applied. Total deformation of slab is as in Table 4.

**Table 4 :Deflection**

| Model | Deflection (mm) |
|---|---|

| | |
|---|---|
| RCC | 0.3759 |
| 2 Mesh M40 | 0.2889 |
| 2 Mesh M35 | 0.3079 |
| 2 Mesh M30 | 0.3314 |
| 2 Mesh M25 | 0.3613 |
| 1 Mesh Arch M40 | 0.0287 |

**5.2 Maximum stress:** In this maximum principal stress of the siphon trough slab for concrete, ferrocement and arch slab are obtained. As the pressure is applied normal to the arch and opposite ends are fixed, maximum principal stress occurs at the point below the application of load and maximum stress is concentrated below the applied load. Maximum principal stress occurs in steel and the results are shown in Table 5.

**Table 5: Maximum principal stress**

| Model | Maximum principal stress (MPa) | |
|---|---|---|
| | Concrete/Mortar | Steel |
| RCC | 2.006 | 25.999 |
| 2 Mesh M40 | 10.396 | 27.378 |
| 2 Mesh M35 | 9.0585 | 37.29 |
| 2 Mesh M30 | 8.9742 | 38.548 |
| 2 Mesh M25 | 8.9555 | 39.43 |
| 1 Mesh Arch M40 | 0.2481 | 2.819 |

**5.3 Maximum principal elastic strain:** In this maximum principal elastic strain of the siphon trough for concrete, ferrocement and arch slab is obtained. As the pressure is applied normal to the slab and opposite ends are fixed, maximum principal elastic strain occurs near the support. Maximum principal elastic strain occurs in the concrete for R.C.C. and in mortar for ferrocement as in Table 6. Minimum value of strain in ferrocement is 0.00035 as per ACI 549.

**Table 6 :Maximum principal elastic strain**

| Model | Maximum principalelastic strain | |
|---|---|---|
| | Concrete/Mortar | Steel |
| RCC | $85.98 \times 10^{-5}$ | $34.59 \times 10^{-5}$ |
| 2 Mesh M40 | $34.48 \times 10^{-5}$ | $20.06 \times 10^{-5}$ |
| 2 Mesh M35 | $29.49 \times 10^{-5}$ | $19.15 \times 10^{-5}$ |
| 2 Mesh M30 | $28.40 \times 10^{-5}$ | $18.88 \times 10^{-5}$ |
| 2 Mesh M25 | $27.08 \times 10^{-5}$ | $13.74 \times 10^{-5}$ |
| 1 Mesh Arch M40 | $1.139 \times 10^{-5}$ | $1.667 \times 10^{-5}$ |

**6. Validation:** The above analytical results were validated with the experimental results. In order to validate the analytical results, experimental casting and testing wasdone .

**6.1 Experimental work:** In the experimental work ,arch beams of dimensions as 1m span, 0.3m rise and 0.025m thickness were cast. These formworks were used for the casting of arch slab. In casting and testing of arch slabs following steps were followed:

i)Install the welded wire mesh of 12guage and opening size of 14 x 14mm and place it properly in the center of the mold and cast mortar of proportion 1:2, with w/c ratio 0.4.

ii)Pour the mortar in the wooden form and adjust the mesh.

iii)Remove the specimens from the wooden forms 24 hours after the casting and keep them for the curing.

iv)After the curing period is complete the specimens were tested in the universal testing machine (UTM) of 100kN capacity.

v)The specimens were placed for testing as shown in Figure 7

vi)The arch is supported as hinged supports on both sides and the load in the form of line load is gradually applied.

**Figure 7- Testing of arch specimen**

**6.2. Comparison of experimental and analytical results:** Experimental and analytical results are compared in the Table 7 on the basis of deflection criteria.

**Table 7:Comparison of experimental and analytical results**

| Sr.No. | Specimen | | Load (N) | Experimental Deflection (mm) | Analytical Deflection (mm) |
|---|---|---|---|---|---|
| 1 | Rapid curing | FAR 1 | 1500 | 0.450 | 0.4411 |
| 2 | | FAR 2 | 1500 | 0.425 | 0.4411 |
| 3 | Normal curing | FAN 1 | 1500 | 0.750 | 0.4411 |
| 4 | | FAN 2 | 1500 | 0.850 | 0.4411 |

**7. Discussions:** From the experimental and analytical investigations, following observations were made

i) From the experimental setup, the arch acts as the two hinged arch and the load is gradually

applied on the top, the load gets transferred to the supports.
ii) The first crack is observed below the point of application of load.
iii) From the analytical observations, it can be observed that maximum stress is at the same point where the first crack is observed as shown in Figure 8 and 9

**Figure 8. Crack on the bottom of arch**

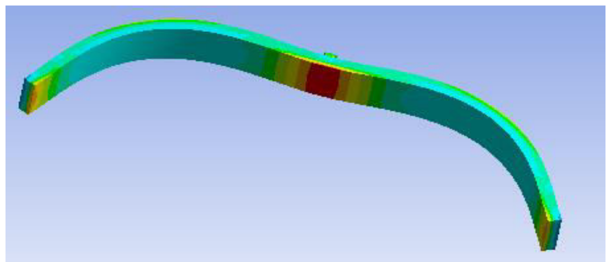


**Figure 9. Maximum stresss on the bottom of arch**

iv) The experimental results endorse the location of the cracks on the top face of the arch near support as seen in Figure 10 and 11.

**Figure 10. Crack on the top face of arch**

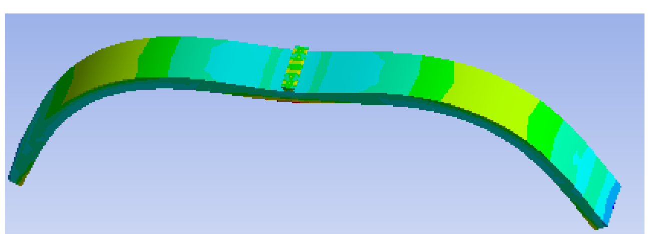


**Figure 11. Stress on the top face of arch**

**8 Conclusions:** On the basis of experimental and analytical observations, following conclusions can be made --

1. Trough of the siphon traditionally made up of RCC, can be replaced with ferrocement.
2. Asferrocement can be formed into any shape and size, it can be formed into arch shape and arch action can be utilized in the construction of the trough slab of siphon.
3. By using the shell shape for trough slab, tensile stress generated in straight slab gets

converted to compressive stresses due to arch action of the shell shape.
4. As the thickness of ferrocement section is very small, dead weight also reduces which leadsto reduction in the weight of the structure.
5. From the studies made on conventional reinforced cement concrete, it has been observed drawbacks like inconsistent quality, strength and also the mold ability is not possible with R.C.C. for irregular shapes and profiles. Water exerts lot of load and stresses on the trough slab, which is resisted by conventional RCC trough slab by adopting large thickness..
6. From the observations, it can be concluded that deformations in RCC are more as compared to ferrocement. The staggered fashion reinforcement pattern by use of wire mesh plays important role for proper distribution of stresses as compared to the concentrated reinforcing pattern of conventional reinforced concrete with steel bars. Thus, ferrocement will be a good alternative material for construction of future siphon troughs overcoming the problems faced by conventional siphon.

# APPENDIX 5

## PHOTO SECTION: VARIOUS FERROCEMENT WORKS CONSTRUCTED ACROSS INDIA

**Seminar on Ferrocrete in MERI Auditorium in January 2007**


**Seminar on Ferrocrete in MERI Auditorium in January 2007**

**A boat built in MERI Nashik in 1980**


**Water tank built in MERI Nashik in 1988**

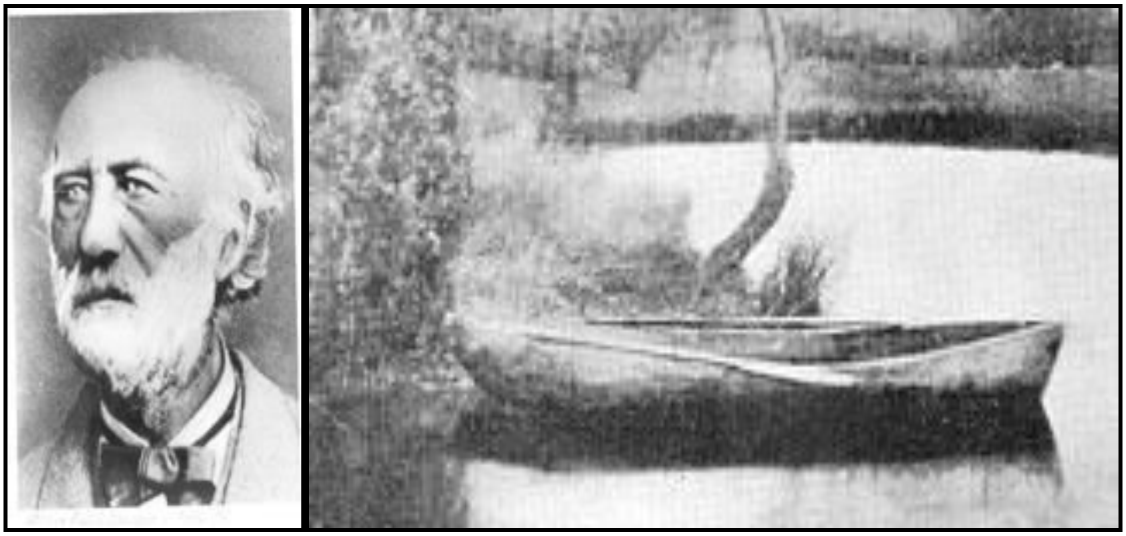
**Typical Ferrocement Staircases.**

**Ferrocement House built in Chenganasserry, Kerala.**

**Ferrocement house built in Village Gove, Dist.Satara, Maharashtra.**

**Ferrocement house built in Village Gove, Dist.Satara, Maharashtra.**

**Ferrocement dam in Sakri, DistDhule.**



**In the 1840s, Joseph Louis Lambot of France began to put metal reinforcing inside concrete. The ferrocement dingy built by Lambot in 1849**

**Ferrocement dam in Mexico**

# APPENDIX NO.6

# Formulation of Panel for ferrocement

GOVERNMENT OF MAHARASHTRA
WATER RESOURCES DEPARTMENT
**CHIEF ENGINEER**
CENTRAL DESIGNS ORGANISATION
Dindori Road, Nashik-422004
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E-mail : metanashik@gmail.com
"Please Visit to WRD Website -
https://wrd.maharashtra.gov.in"

सत्यमेव जयते

महाराष्ट्र शासन
जलसंपदा विभाग
मुख्य अभियंता,
मध्यवर्ती संकल्पचित्र संघटना,

दिंडोरी मार्ग, नाशिक - ४२२००४
फोन नं. : (०२५३) २५३०६२१
फॅक्स नं : (०२५३) २५३०२५१

No.CECDO /MTRL/MERI/ Ferrocement/ 131 /2017 Date: 11/02/2017

To,
The Chairman,
Cement and Concrete Sectional Committee CED 2,
Bureau of Indian Standards, Manak Bhavan,
9 Bahadur Shah Zafar Marg, New Delhi-110002

**Sub:** Information of ferrocement technology

**Ref:** 1) BIS code No. 13356:1992 (Reaffirmed 1997) Precast ferrocement water tanks upto 1oooo liters capacity specification
2) Maharashtra Government Resolution No. 163/2014/ Nivas-3 Date: 02/11/2016

**Respected Sir,**

The word ferrocement is now used worldwide as a construction method / construction material. In India, its applications are in hydraulic structures particularly in storing, retaining and conveying water as well as in public works department as building components, bridge components etc.

By the reference No.1, BIS has already published the IS code for Precast Ferrocement water tanks (Upto 10000 Liter capacity). In this code, shape and dimension of ferrocement water tank, materials required for constructing the ferrocement water tank, design and construction procedures are given for the ferrocement water tank. This code also covers testing procedures for the ferrocement water tank. While formulating this draft, much knowledge and experience of construction field is discussed as well as scrutinized by BIS committee. The committee for this IS code no. 13356: 1992 was Precast Concrete Products Subcommittee CED 2:9 under Cement and Concrete Sectional Committee CED 2.

At state level, ferrocement committee is formed by Government of Maharashtra vide reference No. 2 to prepare manual incorporating properties, applications as well as design philosophy of ferrocement technology to our practicing engineers. So please provide the documents related to ferrocement materials, designs, applications, quality control that used to finalize the draft of above said IS code. This will help this committee to a great extent in formulating the manual.

It is therefore requested to provide the documents at the earliest.

Thanking You.

Yours
**sd**
**Chief Engineer**
**Central Design Organization,**
**and Chairman ferrocement committee**

भारतीय मानक ब्युरो

BUREAU OF INDIAN STANDARDS

# MINUTES

**30 March 2017**

**Subject: Minutes of Twenty-fifth Meeting of Cement and Concrete Sectional Committee, CEO 2 in Joint Session with:**

**Twenty-fourth Meeting of Cement, Pozzolana and Cement Additives Subcommittee, CEO 2:1, and**
**Twenty-third Meeting of Concrete Subcommittee, CEO 2:2**

**We are glad to enclose herewith a copy of the Minutes of the Twenty-ffith Meeting of Cement and Concrete Sectional Committee, CED 2 held in joint session with Twentyfourth meeting of CED 2:1 and Twenty-third meeting of CED 2:2 on 06 March 2017 in New Delhi. The Minutes have been duly approved by Shri Jose Kurian, Chairman, CED 2.**

**Comments, if any, confined to the accuracy of recording may please be sent to the undersigned at the earliest, preferably within two weeks time. If no reply is received within the above period, we may be permitted to presume your approval of the Minutes as recorded.**

**Your Faithfully**
**sd**
**(Divya S)**
**Secientist 'B' (Civil Engg)**
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## 5.2 Ferrocement

The Committee studied the suggestion received. Dr Bhupinder Singh, IITR informed about literature of International Ferrocement Information Centre, AIT Bangkok, which, he suggested may be utilized appropriately. Dr Subrato Chowdhury mentioned that ferrocement is a system and should be named suitably so as to avoid any possible confusion with cement. Dr Shashank Bishnoi, IITD shared his experience of having inspected buildings constructed using ferrocement technology, and highlighted about the problem of higher rate of corrosion. Shri P. C. Sharma mentioned that SERC, Roorkee and IITR had conducted a five year study on corrosion in ferrocement, and opined that, if proper type of wire mesh (and not chicken mesh) is used, the corrosion can be held in check. He went on to say that there were 40 to 45 years old water tanks and roofing units which are still standing intact.

The representatives of Ferrocement Society and MERI mentioned that there are a number of three storeyed buildings, silos and digestors which have been successfully constructed, and the technology is suitable for large scale application.

After detailed discussions, it was decided to formulate an Indian Standard Code of Practice for Design and Construction using Ferrocement. To take up the work, the following Panel was constituted:

**Panel for Ferrocement Construction, CED 2:2/P9**

**Shri V. V. Arora, NCB (Convener)**

Shri R. C. Wason, In personal capacity, New Delhi

Ferrocement Society, Pune

MERI, Nashik

CBRI, Roorkee

Shri P. C. Sharma, In personal capacity, Ghaziabad

Dr Ashok K. Jain, In personal capacity, Noida

NCB, Ballabgarh

SERC, Chennai

Subsequent to the meeting, the nomination from the Ferrocement Society was received as Dr. Paramsivam and Shri Ranjit Sinha, as the principal and alternate member respectively.

The Committee authorized the Panel to make other necessary cooptions as may be necessary.

The Ferrocement Society agreed to send a detailed note and the proposed contents for discussion in the first meeting of the Panel.

## APPENDIX NO.7

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