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Flexural strength and punching shear resistance of ferrocement slab

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Abstract

An experimental investigation was carried out to study the flexural strength and punching shear resistance of some selected ferrocement slab elements. Ferrocement slabs were made with expanded metal mesh having three different thicknesses of 15 mm, 20 mm and 25 mm. For each thickness the number of mesh layer varied from one to three. The dimensions of the specimens were selected as 300×100×15 mm, 300×100×20 mm and 300×100×25 mm for flexural strength, and 300×300×15 mm, 300×300×20 mm and 300×300×25 mm for punching shear resistance. Cement mortar having cement, sand and water ratios of 1: 2 : 0.5 was used for casting the slabs. After 28 days of water curing, the specimens were tested for flexural strength and punching shear resistance. It has been found that with the increase in the number of layers the flexural strength increased. Among the selected slabs, the 15 mm thickness slabs with three layers of wire mesh exhibited the highest load bearing capacity in flexure. Similarly, the increase in the number of wire mesh layers resulted in an improvement in resisting the cracking load and the ultimate punching load of ferrocement slabs.

Keywords: Ferrocement, wire mesh, mortar, flexural strength, punching shear resistance

Introduction

Bangladesh is running short of building materials. With the rapid increase of the demand for housing, the existing stock of traditional building materials like timber, steel, bamboo, etc. would fall short of the supply if consumed arbitrarily. This is an urgent need today to develop construction techniques which consume a minimum of these materials. The development of ferrocement is a significant step in this direction where considerable amount of saving in consumption of the traditional building materials can be made. Ferrocement is a form of reinforced concrete made of wire mesh, cement, sand and water. It can be constructed with a minimum of skilled labour and utilizes readily available materials. It is a highly versatile form of reinforced concrete in which the matrix is hydraulic cement mortar and the reinforcement consists of closely spaced, multiple layers of small diameter wire mesh. The mesh may be made of metallic or other suitable materials. The reinforcing mechanism in ferrocement not only improves many engineering properties of the brittle mortar, such as tensile strength, cracking behavior and impact resistance, but also provides a high adaptability of complicated shapes. Because of its ease of application, it also has potential for strengthening or repairing of existing structures (Mansur and Pramasivam, 1986).

Extensive experimental and analytical studies have been undertaken for the last couple of years to establish the fundamental mechanical properties of ferrocement. The ultimate flexural capacity of ferrocement structures has been successfully predicted in a number of recent investigations (Hussin, 1991; Clerke and Sharma, 1991; Prakash and Said, 1992; Rahman and Awal, 2000). Little is known, however, on the quantitative evaluation of their deflections, crack distribution, and crack widths under load. Ferrocement members are fabricated in thin sections and thus their relatively large deflections may constitute an important design limitation. The problem of punching shear for concentrated load in reinforced concrete slab or around a column has been treated quite extensively in the past. Investigations include both concentric and eccentric punching under various boundary conditions. Relatively, very little research attention has been directed towards understanding the punching shear behaviour of ferrocement which, in the basic sense, is also a reinforced concrete; but with evenly distributed and uniformly dispersed reinforcing elements. An experimental investigation was, therefore, carried out in the Department of Farm Structure, Bangladesh Agricultural University to study the flexural strength and punching shear resistance of some selected ferrocement slab elements.

Materials and Methods

The very name ferrocement implies the combination of ferrous product with cement that consists of layers of wire mesh impregnated with a very rich mix (high ratio of cement to sand) of cement mortar. A brief description of the materials used for making ferrocement slabs is given below:

One of the most essential components of ferrocement is wire mesh. The primary function of wire mesh in the first instance is to act as a lath providing the form and to support the mortar in its green state. In the hardened state, it absorbs the tensile stresses on the structure which the mortar, on its own, would not be able to withstand. Different types of wire meshes like square, hexagonal chicken mesh etc. are readily available in the market. Expanded metal mesh having 12 mm opening and 0.6 mm wire thickness was used in this study. A typical expanded metal mesh is shown in Fig. 1.

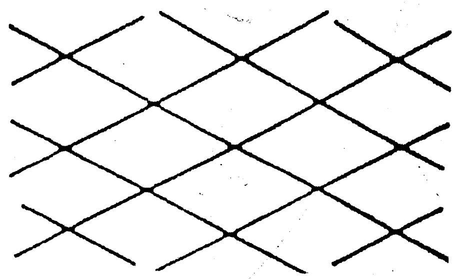


Fig. 1 Expanded types of wire mesh

Cement is a binding material in ferrocement slabs. There are several types of cement available commercially of which Portland composite cement (Shah Brand) was used throughout the research work.

Well graded coarse sand commonly used for making concrete is good enough to prepare mortar for ferrocement work (Anon, 1976). River sand passing ASTM sieve No.4 and having fineness modulus of 2.04 was used for preparation of cement mortar.

Ferrocement construction unlike other sophisticated engineering construction requires minimum of skilled labor and utilizes readily available materials. However, proper attention was paid to control the quality of construction. The major steps in ferrocement construction are cutting and placing of wire mesh, mortar mixing, and application of mortar and finally curing. A brief description of these steps for the ferrocement constructions is given below. However, the detail description of the materials used and the method of construction has been discussed elsewhere (Khan, 2006).

Expanded type of wire meshes were cut into a rectangular size of 296×96 mm and square size of 296×296 mm for making ferrocement slabs. The mesh segments were made by cutting with scissor and were straightened by smooth hammering.

Three different sets of mesh layers were arranged for making ferrocement slabs. In first set one layer of mesh was placed at the center of the slab. In the second and third set two and three layers of wire meshes were placed respectively in such a way that the spacing among the layers remains equal, as shown in Fig.2.

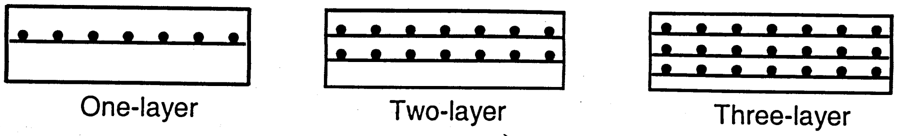


Fig. 2 Arrangement of wire mesh in ferrocement slabs

Mixing of the mortar should be done in such proportions as to give consistently the desired strength. The proportion of cement-sand generally varies from 1 part cement with 1.5 to 2 parts sand by weight. The water-cement ratio is to be maintained as low as possible to give the material a consistent quality and workability, it is to be maintained at nearly 0.4 by weight if possible (Paul and Pama, 1978). In the present study a cement-sand proportion of 1:2 was selected and for all mixes a water-cement ratio of 0.5 was maintained. Sand was properly sieved and thoroughly dry-mixed with cement using trowel. Then the requisite amount of water was added and mixed until a uniform mix was obtained. The mortar was mixed in trays in such a manner that each batch of mortar was plastered within an hour after mixing.

The strength and durability of ferrocement structure largely depend on the plastering work. The ground was cleaned and a polyethylene sheet was spread over the area. Besides preventing direct contact of wet mortar with the ground this sheet provided an additional option of ease of shifting of the slab to another near by location, if so desired at a later date. At first about 5 mm thick layer of mortar was laid in the wooden mould, then the mesh prepared earlier was placed over the wet mortar and moved so that the mortar layer penetrate into the bottom layer of mesh in the slab and can get an effective clear cover of 5 mm. The surface was leveled with a wooden float in such a manner that the thickness of slab was maintained. Mortar application was accomplished by using the trowel.

To obtain a good quality of hardened mortar, curing in a suitable environment is very important. The curing operation of ferrocement slab was started 24 hours of completion of plastering. The slabs were kept in water for 28 days before testing.

There were two types of tests involved in this study. One was flexural strength and another was punching shear resistance. For flexural strength the specimens were placed between two supports spaced 275 mm apart in a loading frame as shown in Fig. 3. The load was applied at a constant rate. The specimens for punching shear resistance were placed on the square type frame (Fig. 4). The support was situated 25 mm apart from each side. The punching load was applied centrally at a constant rate. Maximum crushing load for both flexural strength and punching shear resistance were obtained from the Universal Testing Machine.

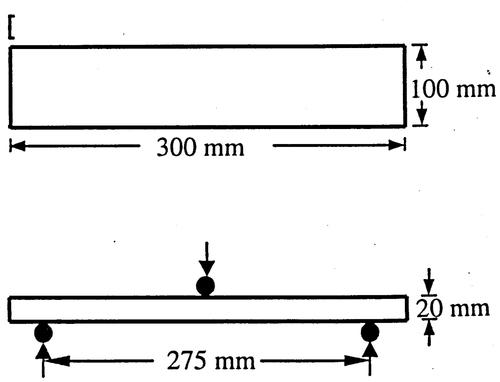


Fig. 3. Flexural test specimen with loading arrangement

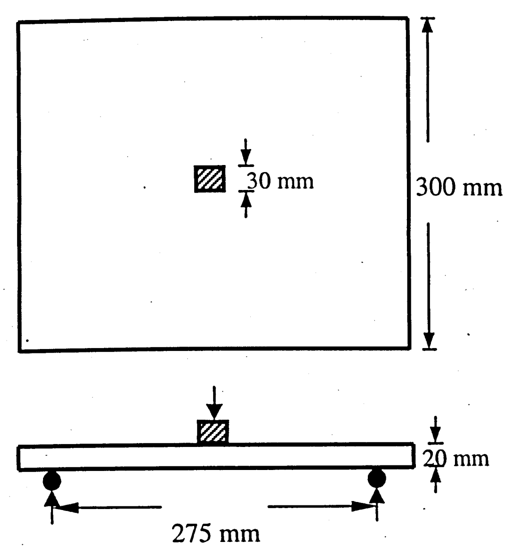


Fig. 4. Punching shear specimen with loading arrangement

Results and Discussion

The formation of cracks is considered to be an important parameter in the serviceability of a structure. In this study crack width has been found to be inversely proportional to the number of wire meshes layers (Table 2). However, no correlation has been found in regard to the number of crack with the specific surface area (Figs. 5-7).

Table 1 summarizes the average flexural strength of ferrocement slabs having various thicknesses and mesh layers. It has been observed that with the increase in slab thickness the flexural strength decreased irrespective of number of mesh layers. Similarly, higher values were also observed in slabs having higher amount of reinforcement. For example, slab having three layers of wire mesh with 15 mm thickness exhibited flexural strength of 16.2 N/sq.mm; whereas 25 mm thick slab having three layers showed lower value i.e. 8.5 N/sq.mm.

The average punching loads for ferrocement slabs having various thicknesses and mesh layers have been shown in Table 2. It is seen that with the increase in the slab thickness the ultimate punching load also increased irrespective of number of mesh layer. Similarly, higher values were found in slabs having higher amount reinforcing mesh. For example, slab having one layer of wire mesh with 15 mm thickness exhibited an ultimate punching load of 2158 N; whereas 25 mm thick slab having three layers of mesh showed a higher value of 4267 N.

Table 1. Flexural strength of ferrocement slabs

Sample designation	No. of layer	Span length (mm)	Breadth (mm)	Thickness (mm)	Flexural load (N)	Flexural strength (N/sq.mm)
E-I-15	1	275	100	15	830	10.2
E-I-20	1	275	100	20	872	6.0
E-I-25	1	275	100	25	1266	5.6
E-II-15	2	275	100	15	845	10.4
E-II-20	2	275	100	20	1325	9.1
E-II-25	2	275	100	25	1482	6.6
E-III-15	3	275	100	15	1325	16.2
E-III-20	3	275	100	20	1630	11.2
E-III-25	3	275	100	25	1926	8.5

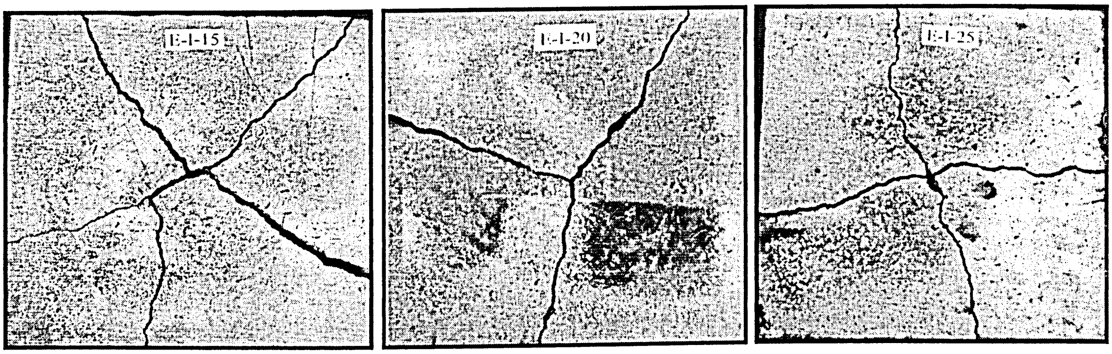
E = Expanded type wire mesh; I, II, III = Number of layers
15, 20, 25 = Slab thickness in mm

Table 2. Punching shear resistance of ferrocement slabs

Sample designation	Slab thickness (mm)	No. of radial cracks	Average width of radial cracks (mm)	Ultimate punching load (N)
E-I-15	15	5	1.08	2158
E-I-20	20	3	1.33	2600
E-I-25	25	4	1.50	4267
E-II-15	15	4	0.92	3041
E-II-20	20	3	1.42	4601
E-II-25	25	4	1.25	5788
E-III-15	15	□	-	4150
E-III-20	20	3	1.17	4817
E-III-25	25	3	1.17	5886

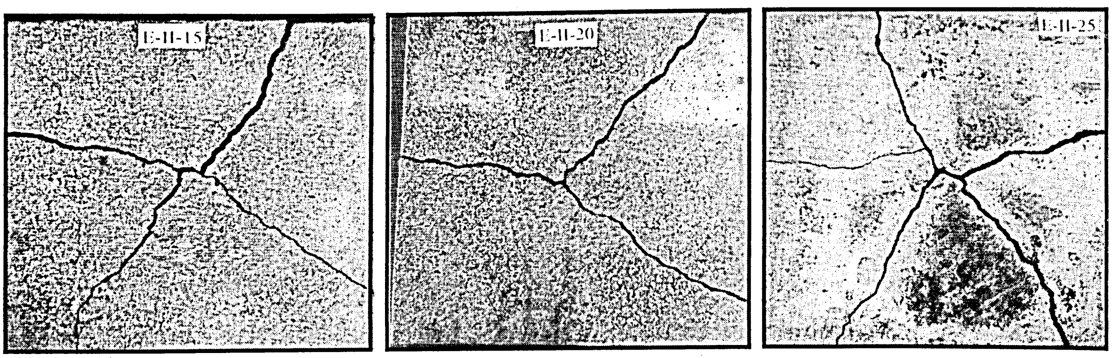
E = Expanded type wire mesh; I, II, III = Number of layers
15, 20, 25 = Slab thickness in mm; □ = Top face fully punched

There appears to be a good correlation between flexural load and punching load. It has been shown that with the increase in flexural load the punching load was found to increase in all cases irrespective of number of layers and thickness of slab; the relationship is shown in Fig. 8.



(a) 15 mm thick slab (b) 20 mm thick slab (c) 25 mm thick slab

Fig. 5 Failure pattern of bottom surface of one layer wire mesh ferrocement slabs



(a) 15 mm thick slab (b) 20 mm thick slab (c) 25 mm thick slab

Fig. 6 Failure pattern of bottom surface of two layers wire mesh ferrocement slabs

(a) 15 mm thick slab (b) 20 mm thick slab (c) 25 mm thick slab

Fig. 7 Failure pattern of bottom surface of three layers wire mesh ferrocement slabs

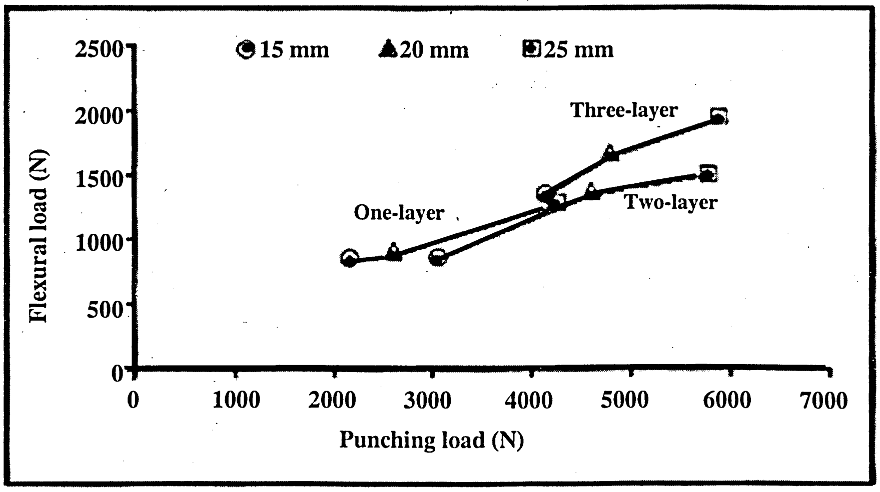


Fig. 8 Relation between flexural and punching loads

Conclusion

In spite of some limitations on technical facilities in the department, this study may be concluded with the following remarks:

- Among the selected slabs, 15 mm thick slabs with three layers of wire mesh showed the best performance in terms of load bearing capacity in flexure.
- It has been observed that with the increase in the number of layer and thickness, ferrocement slabs showed higher values of punching shear loads. The increase in the number of wire mesh layers resulted in the change in cracking pattern and improvement of ultimate punching loads of ferrocement slabs.
- There has been a good correlation between flexural and punching loads. In all cases punching load was found to increase with the increase in flexural load.

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