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FERROCEMENT BOX SECTIONS-VIABLE OPTION FOR FLOORS AND ROOF OF MULTI-STOREYED BUILDINGS

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ABSTRACT

A 5m x 9m size interior panel of a framed structure has been designed as beam-slab construction, flat slab construction and using ferrocement box sections for 5 kN/m^2 live load. The self-weight, floor/ roof height and cost of these options have been compared. It is found that the flat slab option is comparable in weight to the beam-slab option, about 58.2% less in floor height and 17.7% costlier than the conventional beam and slab construction. The ferrocement box section alternative is found to be 56.2% less in weight, comparable in floor height and 15.6% cheaper than the beam - slab construction.

The ferrocement box sections being light in weight need less strong supporting structures. Being a precast product, they also increase speed of construction and can be used in bad weather conditions.

Keywords: Beam-slab, flat slab, ferrocement box and comparison

1. INTRODUCTION

The floors and roofs of most buildings are constructed with reinforced cement concrete (RCC). The various options available for flooring and roofing purposes are the beam-slab system, channel sections, T-sections, ribbed sections, flat slabs and box sections. The channel sections, T-sections and ribbed slabs can be used for short span flooring purposes. While the remaining sections can be used for medium spans [1]. Shells can also be used for roofing purposes because of their curved shape and also as flooring after filling the haunches with light materials. But this option unnecessarily increases the self weight.

In conventional reinforced concrete construction, if an area wider than 4 meters is required to be covered then the beam-slab construction is normally adopted or one has to compromise on the cost by adopting flat slab type of construction. The reinforced concrete structures have a high self weight to live load ratio, which needs a stronger as well as costlier supporting structure. For longer spans, the material used should have a low self weight to live load ratio resulting in small dead weight stresses. The floors/ roof made with lighter materials also lead to a decrease in the cost of the formwork and the supporting

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structure.

Properties of concrete [2,3] are well known. RCC slabs are presently designed [4,5,6] by the Limit State Design approach, which includes flexure, shear and torsion or for Limit State of serviceability, which includes deflection and cracking. In Limit State of collapse, the dead load stresses are proportional to the self weight of the material for all type of support conditions. Therefore, choosing a lighter material will result in proportionately smaller stress. Also, use of materials with high tensile strength will further safeguard the product against the serviceability criterion for cracking.

Solid slabs are employed to transfer loads across the span by developing bending and shear stresses. Here the material of the slab is stressed to its maximum useful limit at the top and bottom surfaces e.g. at mid span in bending and at mid depth in shearing stress near the supports. Thus the local efficiency is only about 50%. The bending and shearing stresses are inversely proportional to the second moment of area about its centroid (or moment of inertia). For the same quantity of material used, box sections have the maximum moment of inertia and therefore result in smaller stresses. In reinforced concrete construction, the minimum thickness required for slabs, shells and folded plates is 75 mm. A reinforced concrete box constructed with this minimum thickness makes it a costlier option for flooring/ roofing purposes compared to the other options. Concrete box sections are, however, useful in bridges to resist heavy vehicular loads.

The deflections and stresses are generally inversely proportional to the moment of inertia, which depends on the shape of any section. A box section has a larger moment of inertia compared to solid sections for the same quantity of material used. Al-Sulaimani and Ahmed [7] presented the flexural rigidity and deflections characteristics of I- and box beams of ferrocement.

Ferrocement [8,9,10], a two-phase composite material, has a high tensile strength to self-weight ratio. Various properties of ferrocement have been investigated by the researchers [11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27]. The close spacing of the wire meshes (distribution) in rich cement sand mortar and the smaller spacing of wires in the wire mesh layers (sub-division) imparts ductility and leads to a better crack arresting mechanism in ferrocement. The surface area to volume ratio of its reinforcement (specific surface) is an order magnitude higher than that of ordinary reinforced concrete and results in a higher cracking strength for ferrocement. At service loads, ferrocement shows a higher number of cracks of small crack-width compared to a few wide cracks in reinforced concrete [28,29].

Because of the above facts, thin ferrocement slabs can be used for roofing/ flooring purpose on short spans. It has been shown that in ferrocement slabs, serviceability criterion for deflection governs the design [16, 30, 31, 32, 33]. Many researchers have carried out the investigations to extend the applicability of ferrocement for longer spans [34,35]. Investigations have also been carried out on prefabrication system for high rise buildings in Bangkok [36] and prefabrication and assemblage of light ferrocement panels [37].

Taking the above facts into account, beam-slab construction, flat slab option and ferrocement box section as an alternative to conventional construction (i.e. beam - slab construction) for a 5m x 9m interior floor panel of a multi-storeyed framed structure were designed and compared for cost, self-weight and floor heights.

2. DESIGN EXAMPLES

A 5m x 9m interior floor panel, supported on 300mm diameter RCC columns in a multi-storeyed framed structure, has been designed as a reinforced concrete two-way slab along with the peripheral supporting beams, reinforced concrete flat slab and ferrocement box section along with rectangular longitudinal beams separately. The live load for the three designs was considered as 5 kN/m^2. M-20 grade concrete and tor steel reinforcement was used in the design of the two-way RCC slab and the flat slab.

Reinforced concrete beam-slab construction is conventionally used and does not need any further explanation. The section and reinforcement details for this design are shown in Figures 1 and 2.

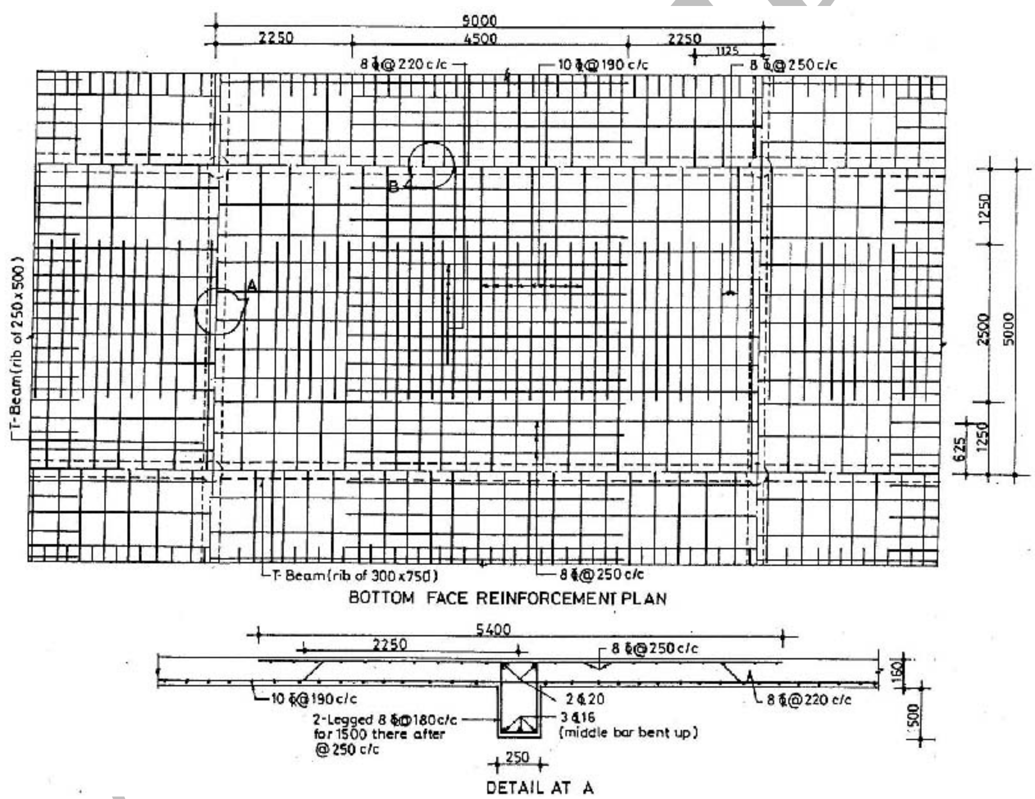

Figure 1. Design of R.C.C. beam-slab option

In the flat slab system, the load is carried by the slab and transferred directly to the columns. Columns of 300mm diameter are assumed without column heads. The thickness of slab was increased over the columns (drops) to prevent the punching of columns into the slab. The flat slab floor option has smaller depth and results in a reduction of the floor height. This option has self weight comparable to the conventional construction and requires a simple formwork. The absence of beams makes the installation of pipes and utilities easier. The section and reinforcement details are shown in Figures 3 and 4.

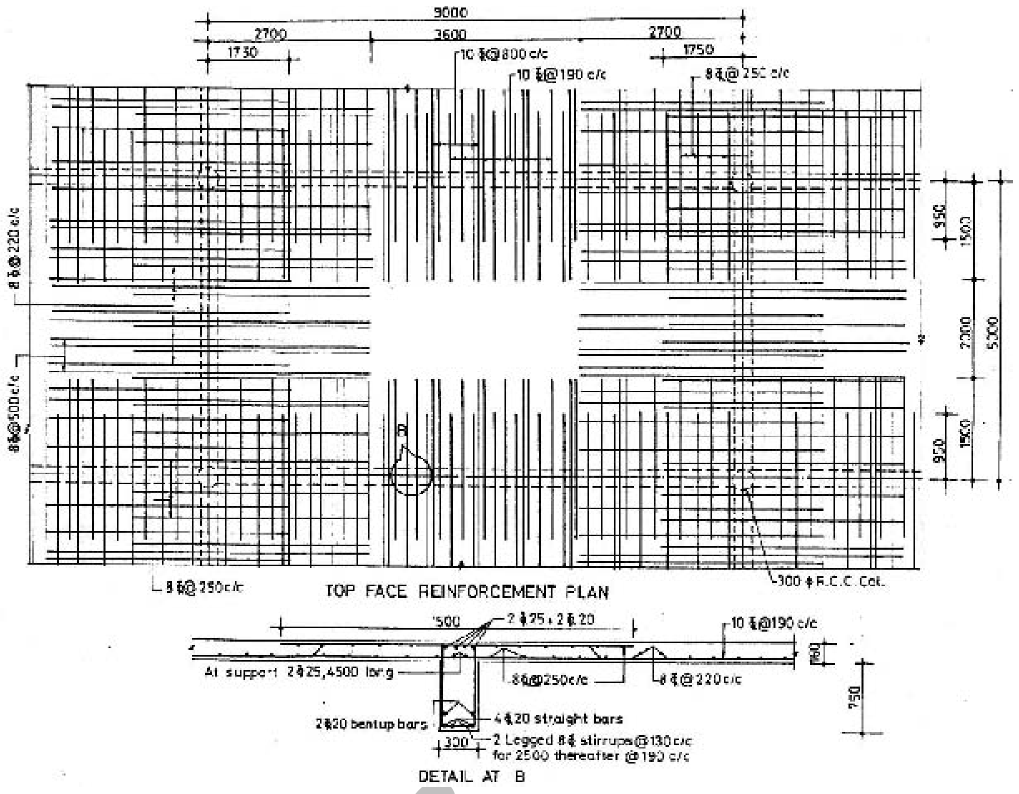

Figure 2. Design of R.C.C. beam-slab option

Table 1. Physical Properties Of Cement

S.N.	Characteristics	Result	As per IS: 8112-1989 [38]
1.	Fineness air permeability test (cm^2/gm)	2443	2250 (Minimum)
2.	Setting time (minutes)		
	Initial	85	30 (Minimum)
	Final	130	600 (Maximum)
3.	Compressive strength (MPa)		
	After 3 days	23.5	23.0 (Minimum)
	After 7 days	32.5	33.0 (Minimum)
	After 28 days	43.01	43.0 (Minimum)
4.	Specific gravity	3.216	-

The properties of the constituent materials used in the fabrication of the ferrocement box section are given in Tables 1-4. The Assembly of ferrocement box sections, joint details and reinforcement details of the proposed ferrocement box sections and supporting beams are shown in Figures 5 and 6. The load versus deflection and load versus crack-width relations obtained in actual load tests over 3.0m effective spans are shown in Figure 7 and Figure 8 respectively. This section is found to be relatively economical and lightest in weight.

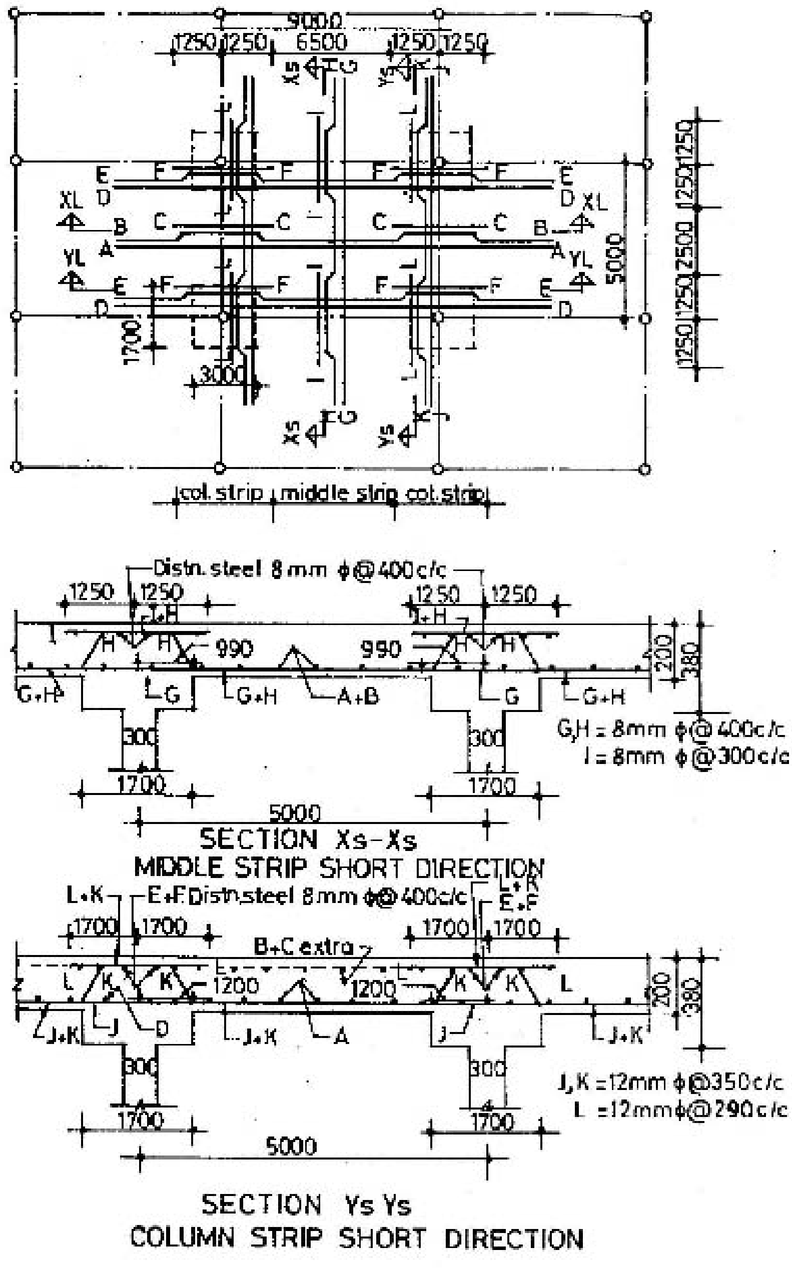

Figure 3. Design of R.C.C. flat slab option

Table 2. Sieve analysis and physical properties of sand

IS sieve designation	Cumulative % retained on each sieve
4.75 mm	0.07
2.36 mm	1.90
1.18 mm	39.23
600 micron	68.57
300 micron	94.37
150 micron	98.03

Fineness Modulus = 3.02
Specific gravity = 2.63
Moisture content (%) = 0.5
Water absorption (%) = 0.8
Grading zone = I (As per IS: 383 – 1970) [39]

Table 3. Strength Properties Of Skeletal Steel Bars And Wire Mesh

S. N.	Particulars	Yield strength or 0.2 % Proof stress (MPa)	Ultimate strength (MPa)	Modulus of elasticity (Mpa)
1.	Machine woven square GI mesh 6.35mm x 6.35mm size and average wire diameter 0.8mm	522.8	522.8	2.1×10^5
2.	Plain mild steel bars, 6.0 mm diameter	372.0	372.0	2.0×10^5

Table 4. Strength Properties Of Mortar

Cement : Sand : Water (by weight)	1 : 1.5 : 0.35
Average compressive strength at 28 days (MPa)	56.5
Average cylinder compressive strength at 28 days (MPa)	40.6
Average modulus of elasticity at 28 days (MPa)	9968.75
Average flexural strength (MPa)	3.7
Average poisson's ratio	0.18
Average cracking strain (μ) *	371

*** Direct tensile strength**

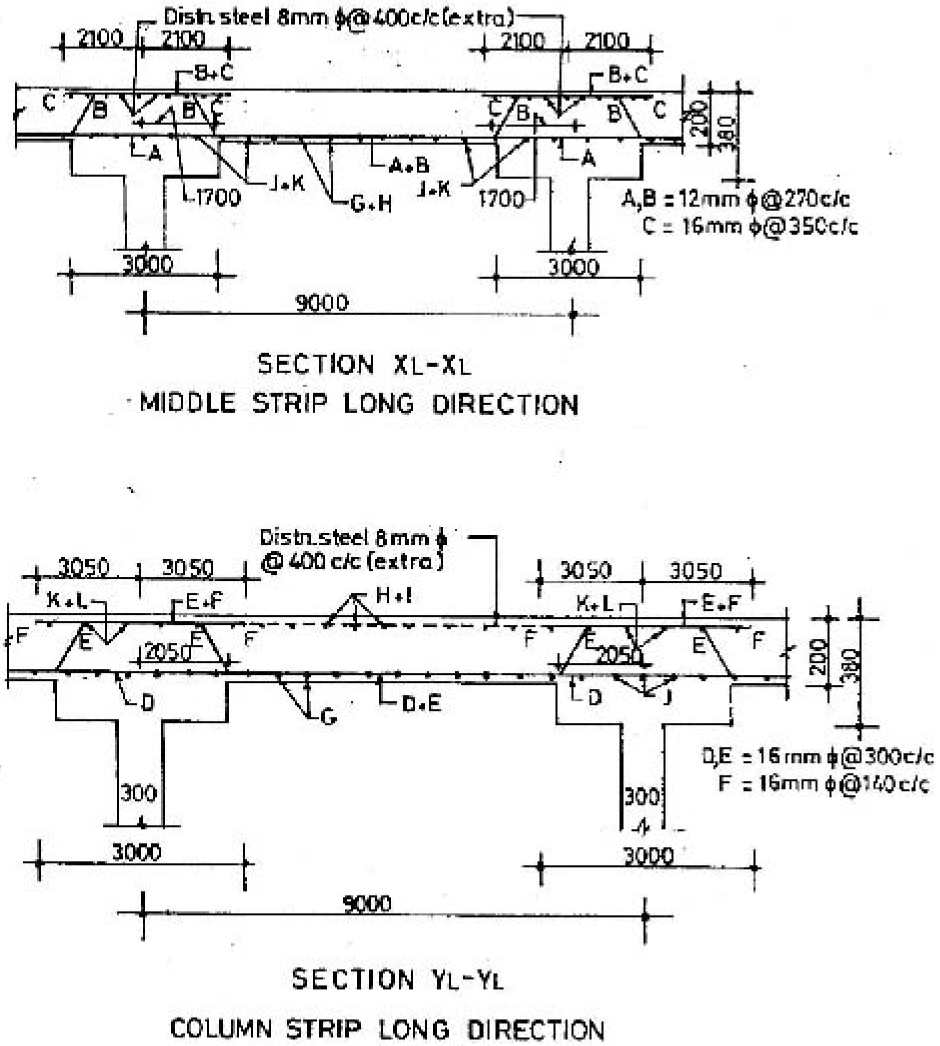

Figure 4. Design of R.C.C. flat slab option

3. COMPARISON OF DESIGNS

The details of the constituent materials required along with their costs, formwork cost and labour cost for each of the three options considered have been compared in Table 5. On the basis of costs for all the three options it is found that the flat slab option and the ferrocement box section option are costlier and cheaper than the beam-slab construction by 17.7% and 15.6% respectively.

The table also shows the dead weight of the three options. A comparison of weights shows the relative values are to be 100%, 101.1% and 43.8% for the beam-slab option, flat slab and ferrocement box sections option respectively.

A comparison also shows the depth of the beam-slab and ferrocement box section options have comparable floor depths (910mm), while the flat slab option is thinner than the previous two options (380mm).

In beam-slab type construction and flat slab type option, the cost of formwork varies from 12 to 18 percent of the material cost while very nominal formwork is required for ferrocement precast box sections. Also repeated use of the formwork reduces the cost of the formwork. The small cost of formwork, makes the adoption of ferrocement box sections a financially attractive option. This has been included in the cost comparison.

In conventional reinforced concrete construction, the dead weight of a floor varies from 80 to 100% of the live loads on the floors. In case of ferrocement box sections the weight varies from 35 to 50% of the conventional floor weight. Hence the use of ferrocement box sections lead to an economy in the supporting structures also.

Table 5. Comparison of various parameters of three alternative floors (5m x 9m)

Description		**Rate (Rs.)**	**R.C.C. beam-slab option**		**R.C.C. flat slab option**		**Ferrocement box section**	
			Quantity	**Cost (Rs.)**	**Quantity**	**Cost (Rs.)**	**Quantity**	**Cost (Rs.)**
Cement		135.00/bag	79.00Bag	10665.00	79.00Bag	10665.00	61.80Bag	8343.00
Sand		292.00/m^3	4.10 m^3	1197.20	4.11 m^3	1200.12	3.22 m^3	939.66
Coarse aggregate		300.00/m^3	8.20 m^3	2460.00	8.22 m^3	2466.00	1.51 m^3	453.00
Tor steel	8mm ϕ	16.70/kg	272.29kg	4547.24	141.53 kg	2363.55	29.33 kg	489.81
	12mm ϕ	16.00/kg	Nil	0.00	345.05kg	5520.80	Nil	0.00
	Other ϕ's	16.20/kg	494.42kg	8009.60	583.25kg	9448.65	273.91 kg	4437.34
Mild steel	6mm ϕ	15.00/kg	Nil	0.00	Nil	0.00	169.01 kg	2535.15
Binding wire, 0.9mm ϕ		22.00/kg	4.50 kg	99.00	4.50kg	99.00	7.00 kg	154.00
Wire mesh 6.35x6.35 mm, 0.8mm ϕ		26.00/kg	Nil	0.00	Nil	0.00	239.23 kg	6219.98
Labour		30% of materials cost		8093.41		9528.94	38%	8957.33
Formwork		15% of materials cost		4046.71		4764.47	2%	471.44
Water charges		1% of materials + labour + formwork		391.18		460.57		330.01
Contractor's profit		10% of materials + labour + formwork		3911.82		4605.65		3300.07
Total cost (Rs.)				43421.16		51122.74		36630.76
Cost (Rs. / m^2)				964.91		1136.06		814.02
Self weight (t / m^2)				0.547		0.553		0.239
Depth of floor (mm)				910		380		910

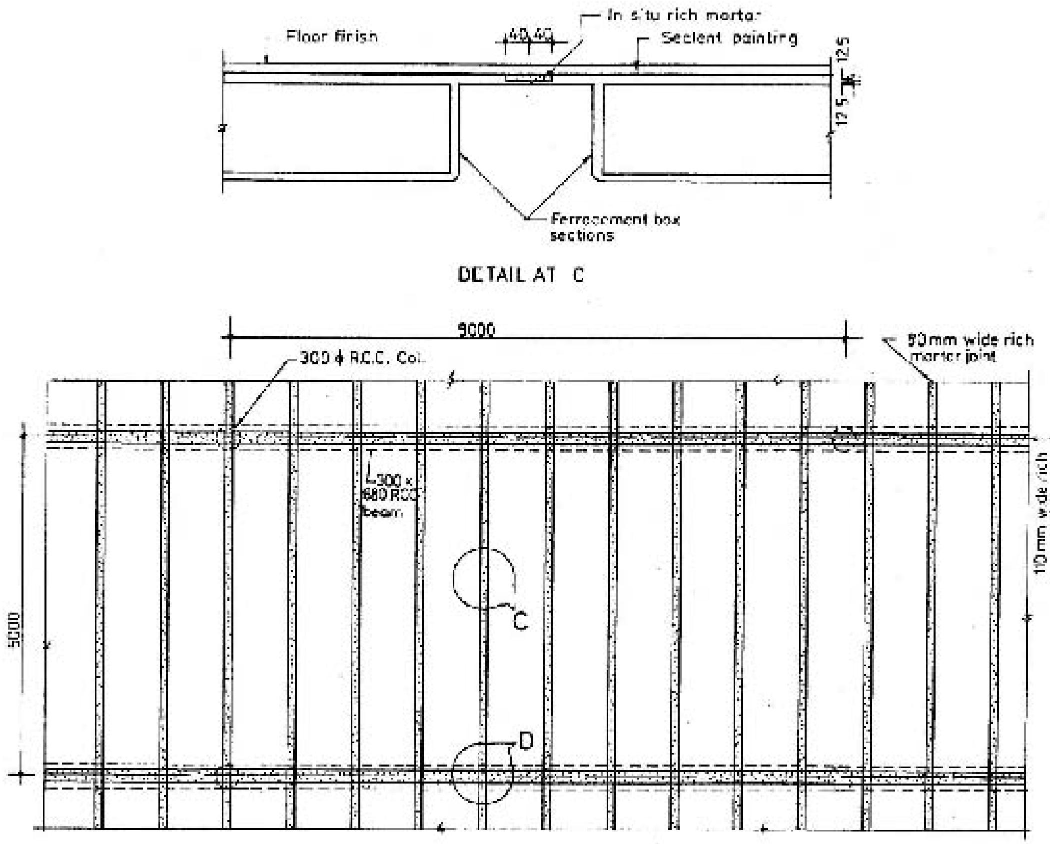

Figure 5. Assembly of ferrocement box sections (Top plan)

Cracking of the RCC and ferrocement elements is necessary for effective use of the reinforcement provided. The cracking depends on the distribution of the reinforcement in the tension zone. Closer placement of reinforcement reduces the distance between the cracks. Cracking is also related with the cover provided to the reinforcement. An increase in the cover thickness leads to an increase in the spacing of the cracks and also the crack-widths.

In case of cyclic and sustained loading, the time effect further increases the crack-widths but does not change the spacing between the cracks. The time dependent deformations are mainly due to creep and to a much smaller extent shrinkage. At service loads, the ferrocement products display a higher number of cracks of smaller crack-width compared to few wider cracks in reinforced concrete construction.

Ferrocement box sections are precast products and have a better finish and quality. Also the material is used efficiently and economically. Mostly, the material is used in the flanges to resist the bending stresses, making the product efficient. Precast products save money and time. Prefabrication technology is better than cast-in-situ option at places with adverse climatic and weather conditions like sub-zero temperatures, inclement weather in rainy season and hot and dry condition as obtained in the deserts.

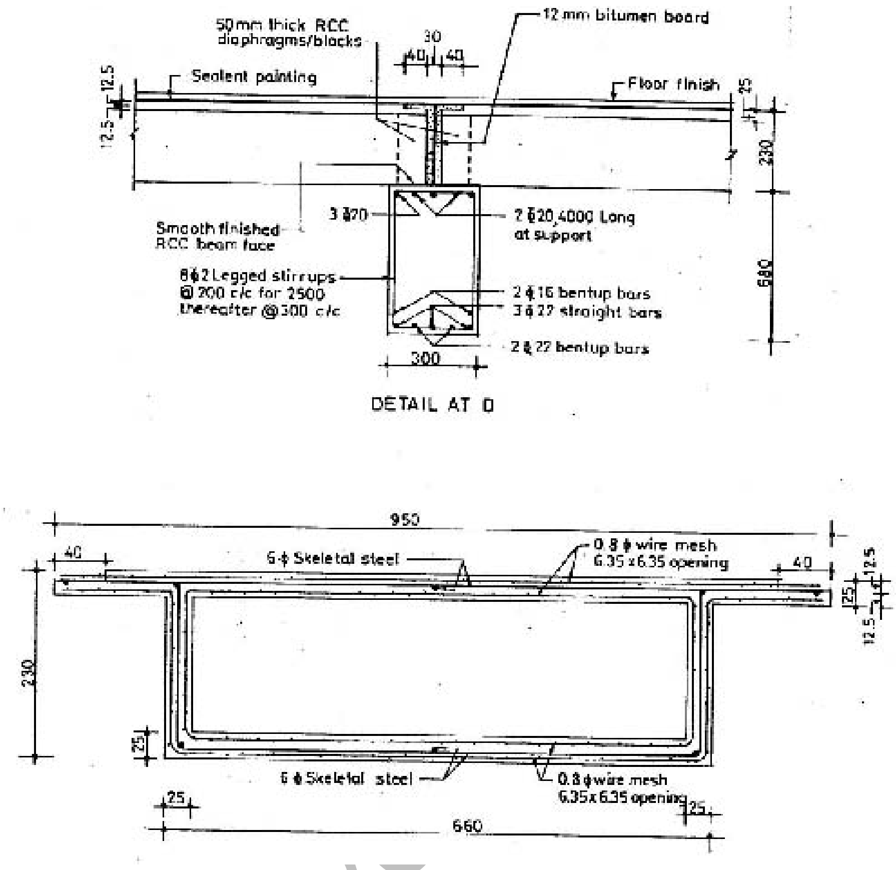

Figure 6. Details of ferrocement box section

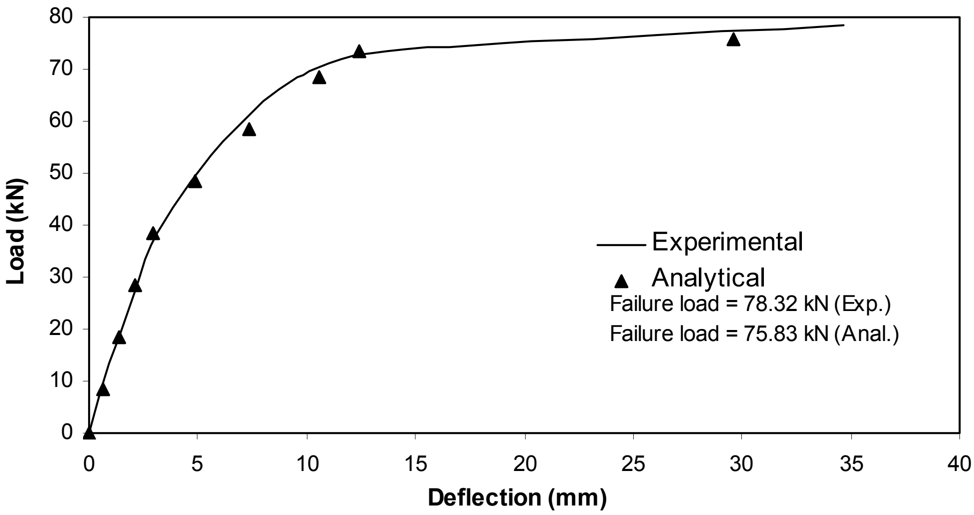

Figure 7. Load vs mid span deflection-ferrocement box section 230mm deep

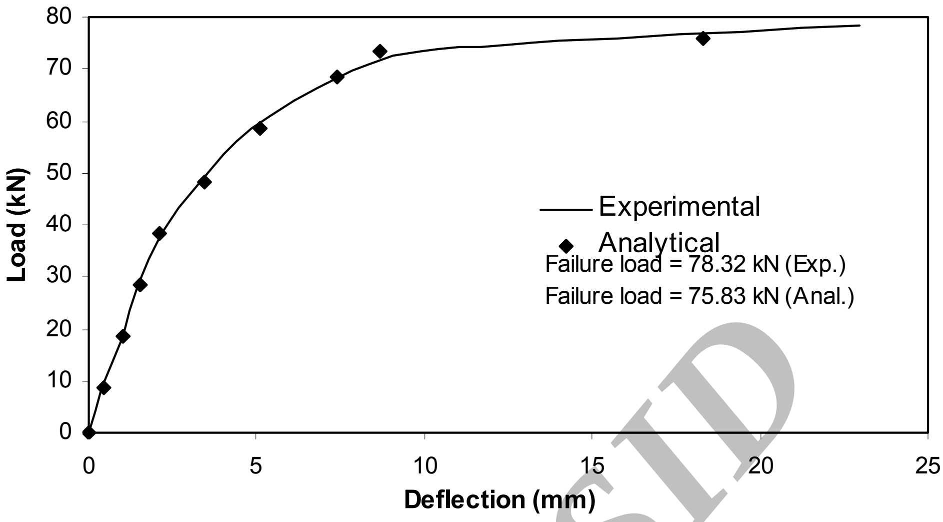

Figure 8. Load vs quarter span deflection-ferrocement box section 230mm deep

4. TESTING OF FERROCEMENT BOX-SECTIONS

A ferrocement box specimen (shown in Figure 6) was tested over an effective span of 3000mm and failed at an imposed load of 7.86 t due to snapping of wire meshes in the bottom flange at the mid span. The same model was also analysed by the finite element method. Its analytical and experimental deflections at mid span and quarter span are shown in Figs. 7 and 8 respectively. A capacity check based on the Limit State of collapse shows that this section can be used over 5740mm effective span.

The predicted maximum crack-widths based on the expression given by Logan and Shah (1973) [12] and Naaman's equation (1979) [40] along with experimental values are plotted in the Figure 9. Assuming that the creep coefficient increases the crack-widths by 60 percent on an average, the failure load at a crack width of 0.19 mm (0.3mm/ 1.6) was 5.70 t. By applying the serviceability criterion for crack-width, the same section can be use for an effective span of 5630mm.

The deflection limit of span/ 250 including the long-term effects of creep and shrinkage based on crack control has already been taken into account. The deflection, span/ 350 or 20mm that is permitted in RCC elements after the construction of partitions and finishes is, however, not exceeded. This section can be used safely over an effective span of 5630mm as a one way element. In the present study, it is used over an effective span of 5000mm.

This section can be used economically as an alternative even to one-way slabs (for any length beyond 5500mm) of 5500mm width, while the reinforced concrete options would need to be redesigned with an increased depth. The two-way slab is found to be the thinnest but costlier. Therefore, in medium span floors, the ferrocement box section is probably the best choice.

Ferrocement as a material offers savings in maintenance cost and increases the speed of construction. Immediate repairs are also possible in case of any damage.

Ferrocement products offer impermeability or in other words the rate of penetration of water is very low. This slow rate of penetration of moisture increases the threshold time for the start of corrosion and also the durability of the structural component is enhanced.

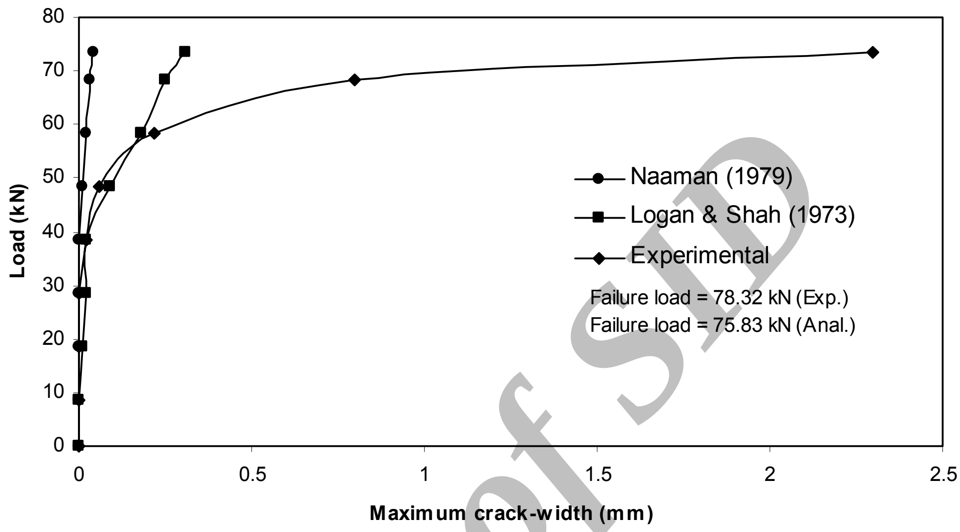

Figure 9. Load vs maximum crack width-ferrocement box section 230mm deep

5. CONCLUSIONS

1. The ferrocement box sections supported on R.C.C. beams are found to be 15.6% cheaper than the beam and slab construction, while the flat slab option is 17.7% costlier.
2. The ferrocement box section is found to be 56.2% lighter than the beam and slab construction, while the two reinforced concrete options are comparable in weight. The use of ferrocement box sections will economize on the supporting structure also due to their lower self weight.
3. The ferrocement box sections supported on R.C.C. beams and the beam - slab construction have comparable floor depths (910mm), while the flat slab option is smallest in floor depth (380mm).
4. At service loads, ferrocement shows a large number of cracks of smaller crack-width compared to few wide cracks in reinforced concrete.
5. Being a precast product, use of ferrocement box section will increase the speed of construction and also make the construction of buildings feasible in bad weather conditions.
6. The use of ferrocement box sections with higher ductility will make the structure less prone to seismic damage.

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