CAST IN PLACE PERMANENT FERROCEMENT FORMWORK FOR CONCRETE BEAMS AND COLUMNS

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Abstract- This study presents the viability of using ferrocement technology as a cast in place permanent form for concrete beams and columns. The new system consists of four phases; the preliminary phase where a modified reinforcement design of beam and column is processed, design phase where design parameters are set, construction phase and the application phase where possible loads are determined and then materials used are tested. A 0.485 water-cement and 1:2.75 cement-sand ratios respectively are used for the mortar mix and a ½” x ½” gauge 23 galvanized welded wire mesh for reinforcement. Construction phase includes the load testing of the fabricated 200mm x 300mm x 10mm prototype ferrocement plates using a Universal Testing Machine (UTM) and 100mm x 200mm x 2400m beam samples using Reaction Frame Test (RFT). Ferrocement form prototype has a nominal capacity of 0.015kN-m creating 0.02mm deformation while achieved during the actual test which has an impressive average capacity of 0.267kN-m for a deflection of 0.02mm, thus makes the design form applicable. A modified beam with 4-1” x 1” x ⅛” angle bars and has a capacity of 20.23kN-m and is comparable to a conventional beam with 4-12mmØ deformed rebars that has a capacity of 14.32kN-m. The comparative analysis shows a 31% cheaper cost in materials compared to conventional formwork without re-using materials and 9% cheaper costs when materials are used twice. The labor needed for the new system almost equalled to that estimated for conventional system when materials are used twice with only 4 to 5 percent savings. The new system is time efficient with 11 to 17percent savings in number of days as compared to using conventional formwork systems. The analyzed data shows that ferrocement as formwork is viable and has achieved the necessary requirements a good formwork must have. Furthermore, economic efficiency of this study goes beyond what is expected; granted that the new system is done in considering the project in its entirety.

Keywords- Alternative Formwork, Concrete Design, Ferrocement, Formwork System

I. INTRODUCTION

1.1 Background of the Study

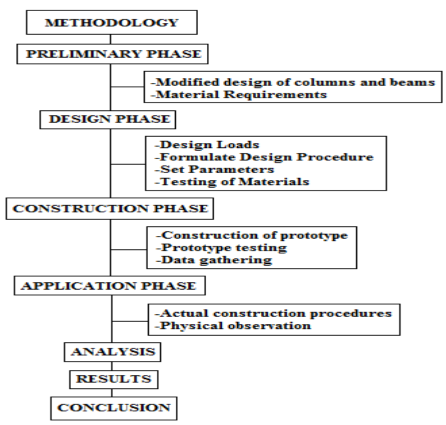
In the Philippines, a combination of lumber and plywood are the main materials mostly used for formworks, which could be reused for utmost four times. Considering that wood is still the cheapest material available in the country, wood formwork however requires high quality labor force and consumes most of the time for the concrete construction.

Form designers and builders are becoming increasingly aware of the need to keep abreast of technological advancements in other material fields in order to develop creative innovations that are required to maintain quality and economy in the face of new formwork challenges [7]. A formwork system is also defined as the total system of support for freshly placed concrete including the mould or sheathing which contacts the concrete as well as supporting members, hardware, and necessary bracing. Its cost accounts for 40 to 60 percent of the cost of the concrete frame and for approximately 10 percent of the total building cost [6]. Introducing ferrocement into the construction activities is one of the most efficient engineering technologies ever developed. Ferrocement can be considered the first application and the very origin of reinforced concrete technology [8]. Thus, this study as proposed highly intended to harness the properties and technological advantages of ferrocement to create and design an alternative formwork for concrete that is efficient and economically beneficial. These motivated the researcher to study and further develop this particular kind of technology and also to participate in a global call of using highly sustainable and economically competitive materials with high construction benefits.

II. METHODOLOGY

2.1 General Methodology

The diagram is the general guide for the whole process of this research.



2.2 Preliminary Design

2.2.1 Modified Design of Beam and Column

The four corner longitudinal bars were replaced with angle bars and its stirrups/lateral ties were changed to a truss-like system using an 8mm diameter rebar as webs. The substitute angle bars functioned as guide and support for the ferrocement form to obtain beam and column's desired dimensions, and at the same time, these served as a bracing, shoring and supporting members for the formwork.

Figure 2.2 Modified Beam Functions: A) A Support System B) Covering of the Main StructureFigure 2.1 Methodology Diagram

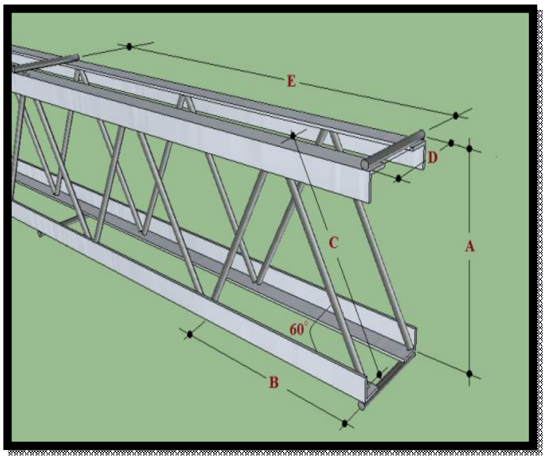


Figure 2.3 Modified Beam Reinforcements: A) Height B) Web member spacing C) Length of web D) Width E) Support spacing

Figure 2.4 Modified/Conventional BeamSampling, Making and Testing

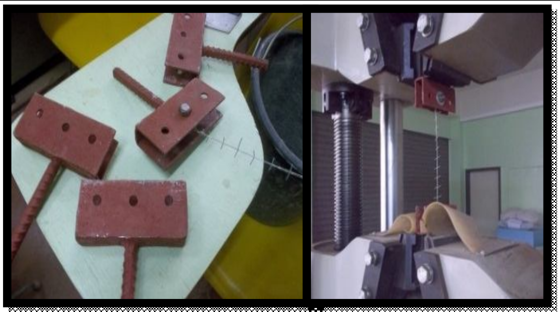


Figure 2.5½" x ½" Gauge 24 Welded WireMesh Tested in UTM

2.3 Design Phase

2.3.1 Design Procedure

The maximum deflection of ferrocement form was determined due to the applied loads, which led to the determination of the minimum thickness required for the section. From the theory of plates, the deflections, shear and the flexural conditions considered were substantially met by the desired section thickness of about 10mm.

Deflection played an important role in designing the ferrocement form using Eq. 1.1 and 1.2; the limiting maximum deflection required for any formwork system that was L/300 for concrete that provides permanent finish and L/200 for concrete surfaces with finishing. Equations 1.3 and 1.4 were used in checking the shear conditions as required by Eq. 1.5. Ultimate moment was determined using Eq. 1.6 and 1.7 to evaluate the flexural strength of designed ferrocement form. A_s, area of steel of mesh was then computed and consequently determined the number of layers required. The formwork's strength is dependent on the number of layers present in the matrix.

$$w_{max} = 0.00192\frac{P_u L^4}{D} \qquad \text{Eq. 1.1}$$

$$w_{max} = 0.00096\frac{P_u L^4}{D} \qquad \text{Eq. 1.2}$$

$$V_{max} = 0.147 P_u L \qquad \text{Eq. 1.3}$$

$$V_{max} = 0.420 P_u L \qquad \text{Eq. 1.4}$$

$$V_{max} = \emptyset \frac{1}{6} bh\sqrt{f'_c} \qquad \text{Eq. 1.5}$$

$$M_u = 0.1246 P_u L^2; \text{where } b > a \qquad \text{Eq. 1.6}$$

$$M_u = 0.048 P_u L^2; \text{where } b > a \qquad \text{Eq. 1.7}$$

The following values were needed as input of this part: number of mesh layers base on the designed loads, thickness of ferrocement which was determined earlier, global efficiency factor from the standard recommended by the ACI 549R, with an established clear cover of mortar over first layer and the diameter of wire mesh used.

Eq. 1.8 determined the compression force in the mortar stress block while Eq. 1.9 was the equation used for tensile forces carried by the mesh reinforcement. It was imperative that the compressive force and the tensile forces developed in the section due to the applied loading is equal that is, C = T, thus a trial and error method is engaged in this part of the analysis just to determine the right distance of the neutral axis from the extreme compression fiber, c.

$$C = 0.85 f_c' b \beta_1 c \qquad \text{Eq. 1.8}$$
$$T_{si} = f_{si} A_{si} \qquad \text{Eq. 1.9}$$

When the right value of the distance c, has been selected the calculation of the nominal capacity M_n of the ferrocement form using Eq. 1.10, then followed. Acceptance of design was achieved when computed nominal capacity was greater than the moment required.

$$M_n = \sum_{i=1}^{n} C_{si} \text{ or } T_{si} \left(d_i - \frac{\beta_1 c}{2}\right) \qquad \text{Eq. 1.10}$$

2.4 Construction Phase

2.4.1 Construction of Prototype and Testing

Figure 3.8 shows how the construction and the load testing of the prototypes were done.

Figure 2.7Prototypes Making and Testing

2.5 Application Phase

(a) The main bars (angle bars) and web members (deformed bars) were welded together forming a truss like system.

Figure 2.8Actual Modifications of Beams and Columns

(b) Placement of wire mesh

Figure 2.9 Actual Placement of Mesh

(c) The cement-sand ratio of 1:2.75 was used to create the mortar matrix. A one-way application of mortar to the mesh.

Figure 2.10Actual Application of Mortar

(d) The actual pouring of beam and column.

2.4 Cost Analysis

Comparative analysis was conducted to assess the new ferrocement formwork's economic advantages over the conventional formwork system.

III. RESULTS AND DISCUSSIONS

3.1 Design Work

Formulated procedures were thoroughly considered, tested and analyzed to achieve an adequate system that arrived with a reasonable outcome in order to create and design a permanent formwork system made out of ferrocement technology.

3.1.1 Modification Design for Concrete Beam and Column Reinforcement

The structural angles served as a guide where the cast in place permanent ferrocement formwork was attached on. However, some of the remaining required steel reinforcement area still used the ordinary steel bars.

A 100mm x 200mm x 2400mm beam samples were fabricated and tested for verification purpose to ensure no reduction in strength by way of modifying the reinforcement in structures would happen. An ordinary reinforced concrete beam was designed to sustain a two-point loading of about 10.30MPa.

The strengths of the reinforcing steels and concrete used in the design were obtained by the actual strength produced of the concrete and steel reinforcements respectively.

3.1.2 Reinforcement Modification of Test Beams

The beams were designed as simply supported with an effective section of 100mm x 200mm x 2400mm with 4-12mm diameter rebars as reinforcement placed on each corners of the rectangular section. The concrete cover was limited to 25mm, lesser than what was required of the new structural code of 40mm because of economy.

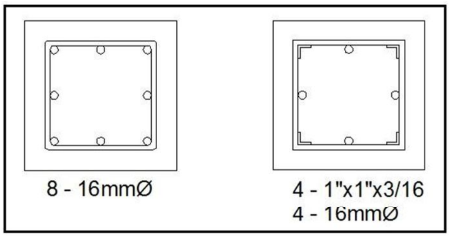


Figure 3.6 Sample Modification of Reinforcement

3.1.3 The Strength Test of Beams

Table 3.7 Reaction Frame Test Results for Beams

100mm x 200mm x 2400mm	Applied Force (KN)		Average (kN)	Designed Capacity (kN-m)	Actual Capacity (kN-m)
	1	2			
Conventional Beam	34.79	47.05	40.92	10.3	14.32
Modified Beam	56.71	58.89	57.8	10.3	20.23

Figure 3.7 Conventional Beam Tested in RFTM

Figure 3.8 Modified Beams Tested in RFTM

3.1.3.1 Theoretical Prototype Design Computation

A. Vertical Loads + Hydrostatic Load (Beam)

Dead Load
Weight of Fresh Concrete (beam) =.176KPa
Weight of (Prototype) =0.218KPa
TOTAL = 2.394KPa
Live Load
Vibrating effect = 0.12KPa
Pu = 1.2DL+1.6LL = 6.713KPa
Hydrostatic Load

Given: $\rho = 2{,}218.48\ Kg/m^3$
$g = 9.81\ m/s^2$
$h = 0.2m$

$$P_u = \rho g h = (2{,}218.48)(9.81)(0.2) = 4.35KPa$$

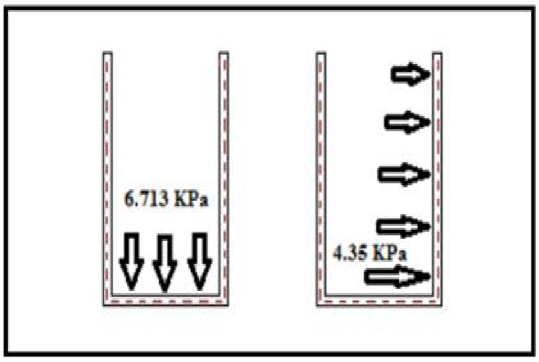


Figure 3.9 Design Loads

The theory of plates and shells for rectangular plate with two edges simply supported and two other edges clamped were utilized in the analyses.

3.2.3.1 Deflection Requirement

Formwork theory gave importance on its ability to minimize deflection when loads were applied. In this procedure, for a concrete surface with finishing, the maximum deflection limitation was L/200.

$$w_{max} = \frac{L}{200} = \frac{200}{200} = 1.00mm$$

Value of E or elastic modulus of concrete mortar was computed first to determine the flexural rigidity of plate, v = 0.3.

$$E = W_c^{1.5}(0.043)\sqrt{fc'} = 24{,}593.63MPa$$

$$D = \frac{Eh^3}{12(1-v^2)} = 0.00225$$

Maximum deflection for rectangular plate under hydrostatic load was computed as follows:

$$w_{max} = 0.00124\frac{P_u L^4}{D} = 0.019mm$$

Required maximum deflection allowed for a formwork was 1.00mm, ferrocement formwork alternatively attained 0.019mm when laterally loaded which is lesser than what is required, and therefore this section was highly acceptable.

3.2.3.2 Shear Requirement

Theoretical approach in computing shear followed the one-way shear design of reinforced concrete.

$$V_{max} = \emptyset\frac{1}{6}bh\sqrt{f_c'} = 1.37kN$$

Shear formula expressed in theory of plates and shells was for simply supported rectangular plates under hydrostatic load.
Where: b = 200mm and a = 300mm.

$$V_{max} = 0.20P_u L = 0.20(4.35)(0.30) = 0.26kN$$

The shear that the concrete mortar can carry was larger than what was developed due to the applied load or designed load, therefore the thickness of the plate, used in the creation of the prototype was satisfactory to carry the shear stresses.

3.2.3.3 Flexural Requirement

Ultimate moment from factored load was computed as: Where b < a.

$$M_u = 0.03P_uL^2 = 0.012KN - m$$

Nominal moment was determined to obtain flexural strength of rectangular plate laterally loaded.

$$M_n = \frac{M_u}{\emptyset} = \frac{0.012}{0.90} = 0.013KN - m$$

Where:
b = 200mm
L = 300mm
h = 10mm
d_b = 0.55mm
D = 12.50mm
Pu = 6.53KPa
f_c' = 29.96MPa

$$\beta_1 = 0.85 - \frac{0.05}{7}(fc' - 28) = 0.836$$

; since f_c'> 28MPa

f_y (mesh) = 426.96MPa

The effective steel area per 200mm of mesh was;

$$A_s' = \frac{\frac{\pi(0.55)^2}{4}(200)}{12.50} = 4.04mm^2$$

In the case of ferrocement design, similar in designing concrete structures, steel ratio was also obtained in determining the amount of reinforcement needed.

$$\rho_{min} = \frac{1.4}{f_y} = \frac{1.4}{426.96} = 0.003279$$

$$\rho_{bal} = \frac{0.85fc'}{f_y}\beta_1\left(\frac{600}{600 + f_y}\right) = 0.029$$

$$\rho_{max} = 0.75\rho_{bal} = 0.75\rho_{bal} = 0.02175$$

Where:

$$m = \frac{f_y}{0.85fc'} = \frac{426.96}{0.85(29.96)} = 16.77$$

$$Rn = \frac{M_n}{bh^2} = \frac{0.013}{(0.20)(0.01)^2} = 0.650MPa$$

$$\rho = \frac{1}{m}\left[1 - \sqrt{1 - \frac{2mRn}{f_y}}\right] = 0.0015$$

Computed steel ratio was less than the minimum steel ratio required therefore ρ_{min} was used when area of steel was determined.

$$A_s = \rho hb = 6.56mm^2$$

Number of mesh layers was determined then with the computed area of steel.

$$N = \frac{A_s}{A_s'} = \frac{6.56}{4.04} = 1.62 \approx 2 \text{ layers}$$

3.2.3.4 Flexural Strength Analysis of Ferrocement Section

From the recommended design procedure by ACI 549, the following procedures were followed;

A. Determine values of f_y and choose standard recommended value of E_r and η.
f_y = 426.96MPa
E_r = 200000MPa
η = 0.50

B. Calculate factor defining depth β_1, volume fraction V_f and effective area of steel A_{si}.

$$\beta_1 = 0.85 - \frac{0.05(f_c' - 28)}{7} = 0.836$$

$$V_f = \frac{N\pi d_b{}^2}{2hD}100\% = \frac{2\pi(0.55)^2}{2(10)(12.5)} = 0.76\%$$

$$A_{si} = \frac{\eta V_f bh}{N} = 3.80mm^2$$

C. Calculate the depth to each reinforcing layer equally spaced with clear cover.
d_1 = 3.0mm
$d_2 = h - d_1$ = 10.0 – 3.0 = 7.0mm
d” = $d_1 - 0.5d_b$ = 2.725mm

D. Determine the distance from the extreme compression fiber to the neutral axis c by trial and error. Assumed c = 0.7632mm

$$\varepsilon_y = \frac{f_y}{E_r} = \frac{426.96}{200000} = 0.002135$$

$$\varepsilon_{cu} = 0.003$$

$$\varepsilon_{s1} = \frac{d_1 - c}{c}\varepsilon_{cu} = 0.008792 > \varepsilon_y$$

$$\text{If } \varepsilon_{si} \le \varepsilon_y; \text{then } f_{si} = E_r\varepsilon_{si}$$

$$\text{If } \varepsilon_{si} \ge \varepsilon_y; \text{then } f_{si} = f_y$$

$$f_{s1} = 426.96MPa$$

$$\varepsilon_{s2} = \frac{d_2 - c}{c}\varepsilon_{cu} = 0.024516 > \varepsilon_c$$

$$f_{s2} = 426.96MPa$$

Calculate internal forces then and check accuracy of the design by ensuring that the summation of all compressive forces was equal to the summation of all tensile forces.

$$C = 0.85f_c'b\beta_1c = 3{,}246.41kN$$

$$T_{s1} = f_{s1}A_{s1} = 1{,}623.015kN$$

$$T_{s2} = f_{s2}A_{s2} = 1{,}623.015kN$$

Check c: C = $T_1 + T_2$

3,246.411 kN ≅ 3246.029kN, therefore the value of c is correct.

E. Calculate nominal capacity

$$M_n = \sum_{i=1}^{n} C_{si} or T_{si}\left(d_i - \frac{\beta_1 c}{2}\right)$$

$$M_{n1} == 4{,}351.097N - m$$

$$M_{n2} == 10{,}843.16N - m$$

$$M_n = M_{n1} + M_{n2} = 0.015kN - m$$

Since the computed nominal capacity of ferrocement section is greater than the required moment then it is safe to conclude that the design is acceptable.

3.1.4 Actual Prototype Result

Theoretical design results, a 200mm x 300mm x 10mm prototype was expected to have a carrying nominal moment capacity of 0.015kN-m with a corresponding 0.02mm deformation.

Comparing this behavior to the results achieved during the actual tests which produced an average actual moment capacity of 0.267kN-m for the same deflection limit of 0.02mm, it was deduced that the prototype behavior on actual load testing satisfied the required strength and capacity needed in a formwork for concrete system.

The results showed that the designed ferrocement form satisfied and even surpassed the standard requirement both from formwork principles and ferrocement design procedures; hence it is safe to conclude that the new formwork design is effective and attainable.

3.2 Ferrocement Formwork Systems Actual Application

A. The beam and column's modified reinforcement was fabricated and assembled individually.
B. Foundation reinforcements were connected to the modified reinforcement for columns.
C. Beam assemblies were then interconnected to the already set column reinforcements by welding the sections at the joints.

Figure 3.12Modified Beam and Column's Reinforcement Connection

D. Two layers were tied using #16 tire wires was shaped according to the designed geometry of beams and columns.
E. Plastering of the mortar matrix to the mesh reinforcement was done by an unskilled and skilled labor.
F. Provided that the weather was not cold and raining, as early as 6 hours after plastering on actual construction, the ferrocement form was able to sustain the load without observable deflection or bursting due to the freshly poured concrete.

Figure 3.14The Final Output of the Column using Ferrocement Formwork System

3.4 Comparative Analysis

3.4.1 Material and Labor Cost

Based on material cost only, the ferrocement formwork system is 31% less compared to conventional system without re-using of materials and 9% less if the materials for formwork is allowed to be used twice, which proves that the ferrocement formwork is cheaper compared to that of the conventional system, in terms of material requirement. When it comes to labor cost, the labor needed for the new system almost equalled to that estimated for conventional system when materials are used twice with only 4 to 5 percent savings.

The new formwork system for the proposed residential building is the cheapest among the three systems therefore economy wise and thus making the system cost effective.

3.4.2 Time Efficiency

Actual number of days for completion was 24 days. Installation of wire mesh and plastering of mortar were the two activities that required more time to finish as these were done by using unskilled laborers. The advantage of this system was that it requires no additional time and labor in removing formwork materials after concreting.

This new system was about 20 to 21 percent cheaper in terms of material cost when formworks would not be re-used, however this system also required more time and thus increased the labor cost.

CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

(a) Designed and applied procedures of the ferrocement formwork were efficient and therefore are safe to conclude that it is applicable.
(b) Construction procedures were developed, followed and implemented during application phase thus the new formwork system's applicability in actual is satisfactory.

(c) Projected maximum time of 24hrs for a formwork to be used was achieved and is ideally and actually possible.
(d) Economic Efficiency of this study as discussed in results and discussion goes beyond as what was expected, granted that the new system was done in consideration of the project entirety. Direct costs may vary when assumed by portions.

4.2 Recommendations
(a) Design loads for sample beam and column were reduced purposely for this study to minimize the area of reinforcements for a simpler presentation. If in any case larger area of steel will be modified, revisions will be the same. A portion of the total of area of steel will be deducted and modified to angular sections.
(b) Modified reinforcements presented an unexpected outcome subsequently more effective than the standard reinforcements. Further studies regarding this matter could lead to a much better result.
(c) If ferrocement forms will be used for circular sections as columns, modification of reinforcements is no longer necessary.
(d) Wire Mesh installation can be done with unskilled worker only.
(e) Though an 8hr cured ferrocement form was a failure during laboratory tests, it was achieved and done in actual construction provided that the weather condition was not rainy or cold.
(f) Though the technology is simple enough for an unskilled labor to work, the time it will take to finish the job may differ. Labor costs could be reduced if skilled worker would do the plastering of mortar.
(g) It is important to follow the procedures and manual properly to realize the economic efficiency of the new formwork system.

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