# Third-Point Load Effect on Bending Moment of Slotted Ferrocement Beam

*Leoncio Mariano C. Acma[1]*

[1] Department of Civil Engineering, College of Engineering,
Central Mindanao University, Musuan, 8710 Bukidnon, Philippines

## ABSTRACT

Ferrocement is usually made from a mortar of Portland cement, sand and fine gravel applied to steel reinforcement which is provided in small aperture wire mesh and/or closely spaced small diameter bars or wires. This study aimed to determine the third-point load effect on bending moment of slotted ferrocement beams. It was conducted using a single-factor experiment with six levels of factors being employed. The experiments used five treatments with six replications. Results show that the provision of two or more layers of wire mesh reinforcement will lead to an increase in the flexural strength of the section and increase the number of layers of wire mesh reinforcement could allow the beam to exhibit ductile behavior. The number of cracks in the beam will increase, and the distance of such spacing will decrease. This behavior of cracking can effectively delay the occurrence of a failure in the specimen.

**Keywords:** *slotted ferrocement beam, modulus of rupture, third-point loading*

## INTRODUCTION

Ferrocement is usually made from a mortar of Portland cement, sand and fine gravel applied to steel reinforcement which is provided in small aperture wire mesh and/or closely spaced small diameter bars or wires (Skinner, 1995). Compared with conventional reinforced concrete, ferrocement is reinforced in two directions. The ferrocement has a high tensile strength and a high modulus of rupture benefiting from its unusually high reinforcement ratio. Also, the specific surface of the surface is one to two orders of magnitude smaller than in conventional reinforced concrete (Baetens & Guigon, 1996).

American Society of Testing of Materials (ASTM) C 78 is the standard test method for flexural strength of concrete using a simple beam with third-point loading. The results of the test method could be used to determine the compliance with specifications or as a basis for proportioning, mixing, and placement operations. It is used in testing concrete for the construction of slabs and pavements. The test method was adapted in this study to determine the flexural strength of the slotted ferrocement beam.

The flexural response of slotted ferrocement beam to third-point loading, it was found that the beam significantly responds to wire mesh reinforcement. The modulus of rupture increased, the spacing and width of cracks decreased and failure is not abrupt. However, the beam in this study was not able to exhibit the capacity to absorb loading larger than 1906.74 N and modulus of rupture of 5.51038 Mpa (Acma, 2003). The slotted ferrocement beam used in the study is a specialized beam and is one of the major components of the proposed housing system developed by the author (Acma, 2005). So far, there has been no similar studies conducted using this type of beam.

If the slotted ferrocement beam can carry a heavier load, it could be used to construct one-storey multiplex housing as well as two-story duplex housing and multi-storey tenement houses that are common low-cost housing units provided for the urban poor in major cities in the country. Hence, this study was conducted.

The study aimed to develop an empirical equation to be used in designing a structural ferrocement beam. It sought to find out if the provision of two, three, four, and five layers of wire mesh reinforcement would lead to an increase in the flexural strength of the section and if the slotted ferrocement beams would not experience sudden failure under working load.

## METHODOLOGY

The study used five treatments with six replications of wire mesh reinforcement such as one layer (S1), two layers (S2), three layers (S3), four layers (S4), and five layers (S5). A suitable concrete mixture of the aggregate-cement ratio of 1:2 and water cement ratio of 0.45 was prepared that could produce the desired consistency and workability of the mortar. Constituent materials include aggregates that conformed to the requirements of ASTM C 33 was made.

The gradation of the aggregates also conformed to the recommendation given in ACI 549.1-93. Wire mesh used was 6.4 x 6.4 x 0.51 mm square welded wire type and conformed to ACI 549.1-93 requirements. Deformed bar used was 10 mm diameter grade 36 while stirrups were 3.2 mm Galvanized Iron Wire spaced at 100 mm on centers. The mixing water used was fresh, clean and potable and relatively free from organic matter, silt, oil, sugar, chloride and acidic material and have a pH ≥ 7. Water used was taken from the water line of CMU.

Mortar Specimen was made of 6–50mm cube specimens per mix for the determination of compressive strength of the concrete. A total of 6 - beam specimens at six treatments each were poured in a span of 24 hours.  Moist curing for 28 days or pounding of the specimen inside a rectangular water tank was done before the samples were subjected to the testing required. Before the beam specimens were subjected to third-point bending tests, surfaces were painted all around with ordinary chalk so that cracks that would be developed during loading could be seen easily.

Test for Compressive Strength of cube mortar specimens with dimensions of 50 mm x 50 mm x 50 mm were subjected to compression testing using the Universal Testing Machine (UTM). The beam specimens were subjected to third-point load test using the UTM. The testing procedures conformed to ASTM C 78-84 or the Standard Test for Flexural Strength of Concrete.

In every aspect of the testing procedures and other activities, events were recorded using the digital camera. All cracks were documented. Visible cracks were measured using a micrometer caliper. Distances of cracks were measured by a measuring rule. Shorter crack spacings were measured using a caliper. Minute crack sizes were measured using a computer. Loading data were taken from the digital record of the software used in operating the UTM.

The compressive strength of mortar specimen is considered as a load in Newton divided by the average area in square millimeters producing a unit of compressive strength in Mpa. The unit weight of the mortar specimen was taken as the weight of the sample in kilogram divided by the volume of the specimen in a

cubic meter. The modulus of elasticity was computed using the standard empirical equation:

$$E_c = w_c^{1.5} 0.043 \sqrt{f_c'} \text{ ------------- (1)}$$

Where:

$E_c$ = Modulus of Elasticity of Concrete in MPa
$w_c$ = unit weight of mortar specimen in kg/m3
$f_c'$ = compressive strength of mortar specimen in MPa

The moment of failure was taken as the sum of the moment due to the weight of beam and moment due to load at failure and expressed in kN-m. Individual weight of the beam was measured and moment due to dead load was taken as equal to 0.15173W, where W was the weight of beam specimen in kN. Moment of the load at failure was taken as 0.175 P, where P was the load at failure in kN.

An empirical equation to determine the design moment applicable to the slotted ferrocement beam was developed. The equation was based on the results of the test and the theoretical computations following the assumptions and satisfaction of equilibrium and compatibility of strains. The empirical equation was fitted from the straight-line model of the simple linear regression equation with the form:

$$E(y) = \beta_0 + \beta_1 x \text{ --------- (2)}$$
$$E(y) = \beta_0 + \beta_1 x$$

Where: $E(y)$ = the random error component of the response variable

$\beta_0 = y - \text{intercept of the line}$

$\beta_1 = \text{slope of the line}$

$x = \text{the independent or the predictor variable}$

## RESULTS AND DISCUSSION

### Section Properties

Figure 1 shows the properties of the section. The overall width of the section is 80 mm, and overall depth is 75 mm. A slot is provided at the bottom portion of the beam with a dimension of 30 mm at the lower part and 25 mm at the top and overall depth of 25 mm.

The beam has an overall length of 1200 mm. During the actual testing, the unsupported length of the beam is 1050 mm providing a 75 mm allowance on each end for the necessary space for the reaction.

### Compressive Strength of Mortar

Table 1 shows the compressive strength of the concrete mortar conforming to ASTM C109 or the Standard Test Method for Compressive Strength of Hydraulic Cement Mortar using 50 mm cube specimen and the corresponding Modulus of Elasticity. Due to the special kind of aggregate gradation and higher cement-aggregate ratio, the amount of the compressive strength of mortar is greater than the conventional concrete mortar.

Table 1.
*Physical Properties of Hydraulic Cement Mortar*

| Sample | P at Failure (kN) | Unit Weight (Kg/m3) | Compressive Strength (MPa) | Modulus of Elasticity (Mpa) |
|---|---|---|---|---|
| 1 | 0106.8 | 2537.74 | 42.72 | 35,930.00 |
| 2 | 103.8 | 2584.90 | 41.52 | 36,413.53 |
| 3 | 93.18 | 2556.60 | 37.27 | 33,934.57 |
| 4 | 114.8 | 2537.74 | 45.92 | 37,251.184 |
| 5 | 110.0 | 2528.3 | 44.0 | 36,260.83 |
| 6 | 81.28 | 2521.3 | 35.512 | 32,440.89 |
| Average Value | | 2544.43 | 40.657 | 35,371.834 |

Typical testing procedure for the determination of compressive strength of mortar is shown in Figure 2.
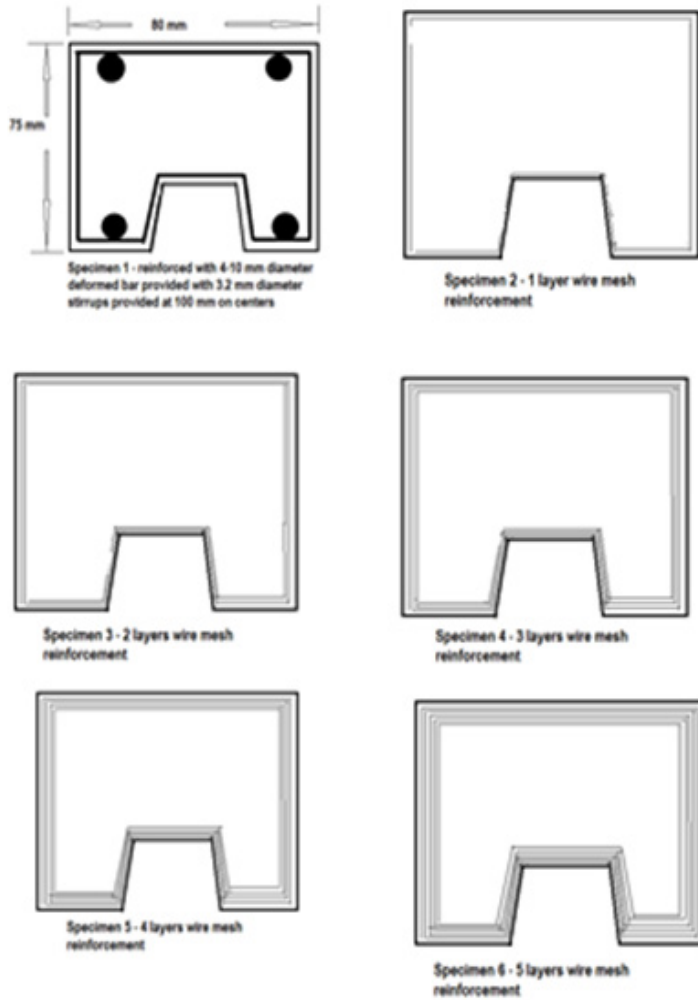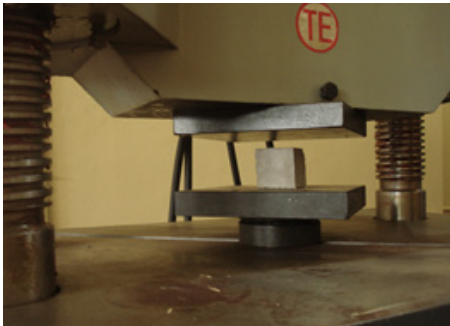
*Figure 1.* Section Properties of Specimen

a) Mortar specimen before loading          b) Mortar specimen at failure

*Figure 2.* Typical Testing Procedure for Compressive Strength of Concrete Mortar

## Flexural Strength of Slotted Ferrocement Beam

Testing of beam specimen followed the procedure set in the ASTM C 78-84 or Standard Test Method for Flexural Strength of Concrete (using a simple beam with third-point loading). The center of the support was set at 75 mm from each end of the 1200 mm long specimen providing an unsupported span of 1050 mm for the beam. The loading beam was set such that the load transmitted to the specimen was applied at one-third of the span or 350 mm from each support. The initial load in the UTM was set at 0 so that only the applied loadings are recorded in the digital reader provided in the software before the application of the load.



*Figure 3.* The Typical Set-Up of the Third-Point Load Tests Using the UTM

Figure 4 shows the result of the test for the load at failure in the graphical result of third-point bending. The load at failure in kN also increased as the number of layers of welded wire mesh reinforcement is increased from one layer to five layers. Using the simple linear regression equation as given in equation (2)

$$P(y)=10.492+ 0.00966x$$

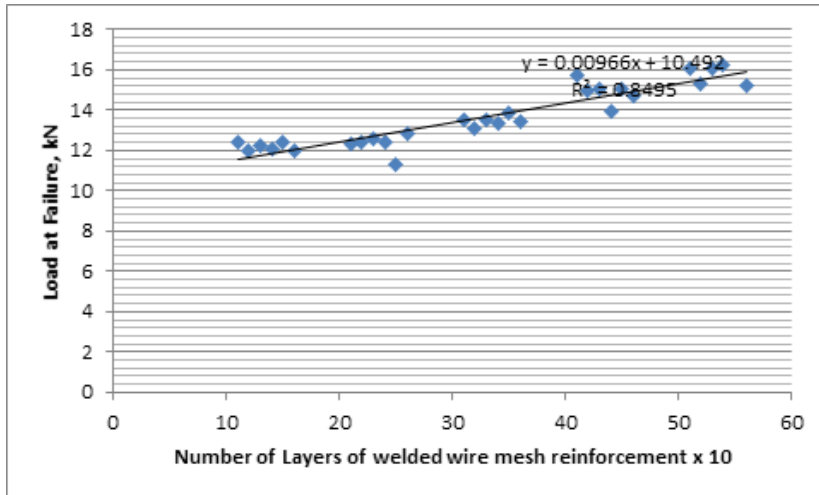The resulting equation has a variance of $R^2 = 0.8495$.



*Figure 4.* Graphical Representation of Load at Failure in kN for Treatments S1 to S5

The result shown in Figure 4 is used in computing the values of Bending Moments at failure by using the equation, $M = \frac{PL}{6}$ where P is the load at failure and L is the unsupported length which is equal to 1050 mm.

The graphical representation of result for bending moment at failure for Treatments S1to S5 was used in developing a relationship between the data for the bending moment at failure. Using the simple linear regression equation as given in equation (2), the data produced an equation for moment at failure of the form:

$$M(y)=2071.2+0.71351x$$
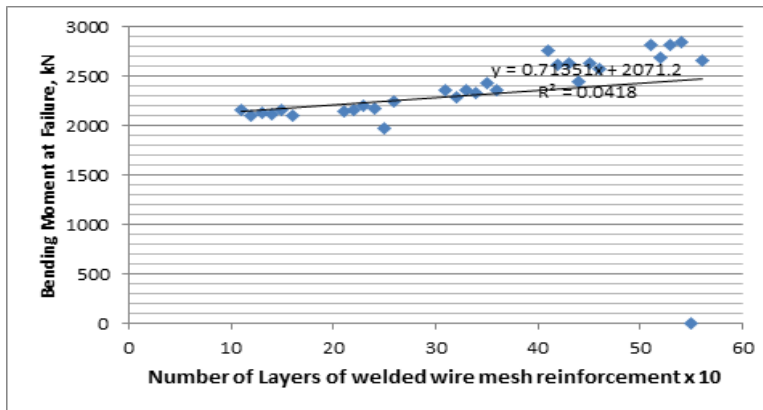
The resulting equation has a variance of $R^2 = 0.0418$



*Figure 5.* Graphical Representation of Result for Bending Moment at
Failure for Treatments S1 to S5

The summary data of the moment at failure is analyzed using two-factor ANOVA without replication. The result as shown in Table 3, indicated that there is a highly significant difference at 95% level of the row representing the treatments but no significant difference among the columns representing replications. The analysis shows that S2 has a higher moment at failure than S1; S3 has a higher moment at failure than S2 and so on.

Table 3.
*Analysis of Variance for Moment at Failure*

| Source of Variation | SS | Df | MS | F | P-value | F-crit | |
|---|---|---|---|---|---|---|---|
| Rows | 29840259 | 5 | 5968052 | 666.1784 | 9.57E-26 | 2.602987 | ** |
| Columns | 29396.95 | 5 | 5879.39 | 0.656282 | 0.659628 | 2.602987 | ns |
| Error | 223966 | 5 | 8958.639 | | | | |
| Total | 30093622 | 35 | | | | | |

| | | |
|---|---|---|
| CV= | 3.38 | |

The procedure for determining the flexural strength of the beam could be described briefly as follows: the location of the centroidal axis is determined using

the principle of the transformed area of the cracked section; the moment if inertia is then computed using the same principle; and the flexural strength is finally computed using the equation $(\sigma_m)_{bot} = \frac{M(h-c)}{I_{tr}}$. The summary of the moment of inertia of every specimen is provided in Table 4.

The computed flexural strength of Treatment S1 to S5 has higher values and steady increasing, albeit, at smaller rate of increase. It should be noted that the flexural strength of the beam is tensile stress that can be provided by the beam fiber in tension. The provision of wire mesh as reinforcement can provide and increase the capacity of the concrete in tension. This result is consistent with the previous work of Acma (2003) that the modulus of rupture increased with increasing number of layers of wire mesh reinforcement.

Figure 6 shows the graphical representation of the result of flexural strengths for Treatments S1 to S5. The data led to the formulation of the equation,
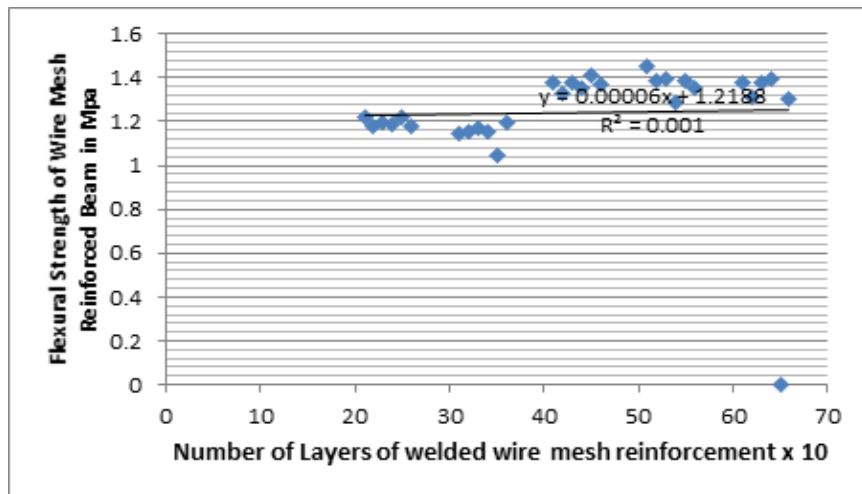
$$f(y) = 1.12188 + 0.00006x$$

With a variance R2 = 0.001.



*Figure 6.* Graphical Representation of Result for Flexural Strength for
Treatments S1 to S5

Table 4.
*Analysis of Variance for Flexural Strength*

| ANOVA Source of Variation | SS | Df | MS | F | P-value | F-crit | |
|---|---|---|---|---|---|---|---|
| Rows | 2.040132 | 5 | 0.408026 | 284.1943 | 3.511E-21 | 2.602987 | ** |
| Columns | 0.00522 | 5 | 0.001044 | 0.72711 | 0.6096354 | 2.602987 | ns |
| Error | 0.035893 | 25 | 0.001436 | | | | |
| Total | 2.081245 | 35 | | | | | |
| CV= | | 3.18 | | | | | |

## Ductility Behavior of Slotted Ferrocement Beam

The number of cracks developed in Treatment S6 or beams reinforced with deformed bars is numerous. However, these cracks are located closer to the support or the cracks emanated from the support and continued diagonal towards the direction of the applied load. Figure 7a shows the typical illustrations of such crack while Figure 7b shows the cracks developed in the support started from the lower extreme fiber which is tension and continued to the extreme top fiber which is compression. The cracks are also larger and tend to show delamination of the concrete fiber. Careful evaluation of such crack showed that there was an actual separation of the reinforcing bar from the concrete. Such type of cracks signified that the beam failed in shear and that the beam might not have utilized the ductile behavior of the reinforcement.



(a)                                                     (b)

Figure 8a shows that the single large crack which indicated that the beam failed abruptly starting from Treatment S3 or beams with three layers of wire mesh reinforcement. It further showed an increase in the number of cracks located in the

middle third or in between the location of the applied loads. These cracks are finer and spaced closer to each other.

Figure 8b shows the 13 micro typical flexural cracks in Specimen 56 that exhibited the ductile behavior of the slotted ferrocement beam cracks. Upon closer inspection of Specimen 56, the cracks located at the middle part are vertical (Figure 9b) and the cracks located on the extreme left and extreme right are diagonal (Figure 9a) that exemplified a characteristic of the beam that failed due to flexural stress. The spacing and width of cracks significantly decreased when the number of layers of wire mesh increased. This observed ductility behavior of the slotted ferrocement is consistent with the observations in the study of Acma (2003).
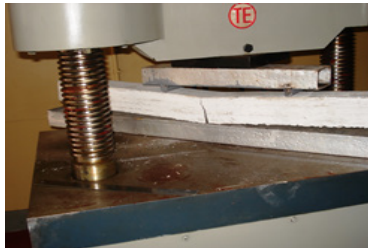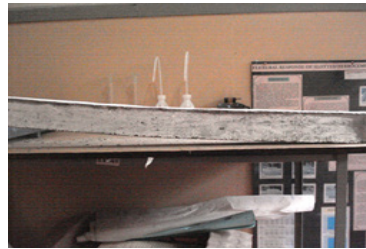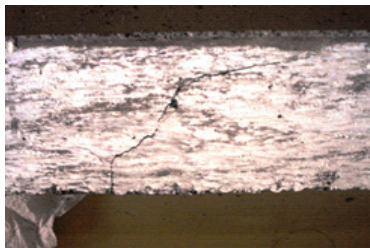


|      (a)      |      (b)      |

Figure 8. Typical Cracks at Failure for Beams Reinforced with Welded Wire Mesh



a) Diagonal cracks at extreme left   b)Vertical cracks along the middle third of beam

Figure 9. Closer Evaluation of Cracks for Specimen 56 in Treatment S5

## CONCLUSION

From the results of this study, an empirical equation for the determination of bending moment at failure of the form is $M(y)=1836.2 +16.902x$.

The resulting equation has a variance of $R^2 = 0.8495$. In the equation developed, x is the independent or predictor variable represented by the number of layers of wire mesh divisible by 10. Likewise, an empirical equation for the flexural strength at failure of the form is $f(y)=1.12188+ 0.0006x$ with a of variance $R^2 = 0.001$. The unknown x is the variable representing some layers of wire mesh divisible by 10. However, the two equations still need to be verified by continuing research that analyzes further the third-point load effect on bending moment for slotted ferrocement beam considering increased number of wire mesh layers. The following conclusions are drawn: First, the provision of two or more layers of wire mesh reinforcement will lead to an increase in the flexural strength of the section. Second, the increased number of layers of wire mesh reinforcement could allow the beam to exhibit ductile behavior. The number of cracks in the beam will increase, and the distance of such spacing will decrease. This behavior of cracking can effectively delay the occurrence of a failure in the specimen.

## RECOMMENDATION

The following recommendations are based on the results of the study on third-point load effect on bending moment of slotted ferrocement beam. It is suggested that similar studies be conducted using: an increased number of wire mesh to verify further the strength of the slotted ferrocement beam; a welded wire mesh with a spacing of at least 12.5 mm to provide a wider space for the mortar to flow; and a wire mesh layer cut at the bottom around one-half of the beam thickness.

# REFERENCES

ACI Committee. (1993). *Guide for the Design, Construction and Repair of Ferrocement.* Detroit: American Concrete Institute.

Acma, L.M.C. et al. (2003). Flexure response of slotted ferrocement beams to third-point loading. *The Mindanao Forum 20*(1): 203-220.

Acma, LMC. (2005). *Verification of ferrocement modular housing system.* Unpublished manuscript, Civil Enginering Department, Central Mindanao University, Maramag, Bukidnon.

American Society for Testing and Materials (2001). *Standard test method for the preparation of aggregates.* Pennsylvania, USA: Author .

American Society for Testing and Materials. (2002). *Standard test method for flexural strength of concrete (using a simple beam with third-point loading).* Pennsylvania, USA: Author.

American Society for Testing and Materials. (1984). *Standard test method for compressive strength of hydraulic cement mortar using 50 mm cube specimen.* Pennsylvania, USA: Author.

Baetens, T. & Guigon, G. (1996). Prefabricated ferrocement doors and shutters. J*ournal of Ferrocement 26*(3): 205 – 209.

Naaman, A.E. & Shah, S.P. (1971). Tensile test for ferrocement. *ACI Journal Proceedings 68*(9): 693-698.

Shah, S.P. & Naaman, A.E. (1978). Crack control in ferrocement and its composition with reinforced concrete. *Journal of Ferrocement 8*(2):67-80.

Skinner, B. (1995). Ferrocement water storage tank. *Proceedings: 21st WEDC Conference on Sustainability of  Water and Sanitation System.* Kampala, Uganda.