Effective Moment of Inertia Approach for Predicting Deflection of Concrete Beams Reinforced with Twisted Bamboo Cables

Akmaluddin*, Pathurahman

Abstract—This work investigated the deflection of 9 beams that were reinforced with twisted bamboo cables. The beams were simply supported and tested under two symmetrical points load monotonically. The beams with three different amount of bamboo reinforcement were considered. The beam section was 150x250 mm and clear span of 2750 mm. Cracking moment and crack moment of inertia values were affected significantly by the presence of bamboo reinforcement in the beam. Experimental results showed that cracking moment varies from 0.3 to 0.7 of ultimate moment. Ratio of experimental to theoretical cracking moment varies ranging from 0.90 to 1.42. A modified form of cracking moment of inertia was proposed. Thus an effective moment of inertia used for predicting deflection of bamboo reinforced beam was introduced. The model produced in this study gave better prediction than that of both the existing model and ACI equation in terms of reinforcement ratio between 0.72 % and 1.88 %.

Index Terms—Effective moment of inertia, reinforced concrete, beam, bamboo, deflection

I. INTRODUCTION

Bamboo is usually known as natural material with many advantages for people in most developing countries. The bamboos are normally used by people in rural area to construct their houses traditionally. With the development of bamboo preservation technique it is expected that the bamboo would be used more widely in the future, not only for the poor but also for middle income people. Thus, by utilization of the bamboo extensively as steel replacement in the concrete structural elements, then cost expenditure for the material construction, especially reinforced concrete elements, may be reduced.

In the reinforced concrete elements, steel reinforcement plays significant influences on the price of the reinforced concrete member of building construction. Thus, in developing countries, people should be encouraged to use the widely available bamboo as a replacement of steel in reinforced concrete element for construction of their houses. Low-cost housing program can be achieved as bamboo material has low cost, fast growing and broad distribution of growth [1]. The material is also considered a very promising alternate raw material because of its fast growth rate, short rotation age, and high tensile strength [2].

Studies concerning bamboo application in building construction have attracted attention from many researchers around the world since the 20th century. Hidalgo [2] has studied mechanical properties of bamboo when used as concrete reinforcement and has reported significant finding on the advantages of bamboo cable as reinforcement. In the same period, Ghavami [3] also reported the load carrying capacity of lightweight concrete beam reinforced with bamboo increased up to 400% compare to that of the concrete beam without bamboo reinforcement. Ten years later he also discussed bamboo as reinforcement in other structural concrete elements such as slabs and columns [4]. The application of bamboo as reinforcement in concrete for low-cost housing was studied by Akeju and Falade in Nigeria [5]. Bamboo splints were applied in this study. Beams behavior, flexural strength and mode of failure of the bamboo splint in concrete were discussed. Recently, three studies conducted in Japan, Bangladesh and Ghana have discussed fracture behavior and mechanical properties of bamboo reinforced concrete members [1], performance evaluation of bamboo reinforced concrete beams [6] and the effect of different stirrup used in the bamboo reinforced concrete beams [7] respectively. By considering studies that have been conducted by many researches as shown in ref. [1] – [7], it has led to increasing confidence for using bamboo as the replacement of steel in concrete members of building construction.

In conjunction with designing concrete beam section, two acceptance criteria must be satisfied; they are ultimate limit state (ULS) and serviceability limit state (SLS) condition. The first criterion was almost discussed in depth in the previous study by comparing the experimental and the theoretical capacity of the concrete beam section. However, not for the case of the second criterion it was lack of discussion. Thus this study aims to discuss not only bamboo beam capacity but also its serviceability limit state particularly its deflection. The deflection of simply supported beam under two-point loading can be computed by using (1).

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\[ \delta = \frac{M \left(3L^2 - 4a^2\right)}{24EI} \]  \hspace{1cm} (1)

where \( M \) is the moment acting on the beam, \( a \) is shear span, \( L \) is beam span and \( EI \) is the flexural stiffness of the beam which is product of elastic modulus, \( E \), and moment of inertia, \( I \). The last two variables are subject to change during the course of loading. In concrete beam test, the modulus of elasticity will vary due to load increase. This is caused by the inelastic stress-strain behavior of concrete beyond the elastic limits, while the moment of inertia will vary when cracks on the beam occur due to the tensile strain greater than the cracking strain of concrete [8]. The cracked zones in a concrete beam are ineffective in resisting stresses originating from applied loads and moments. Therefore, cracking of concrete decreases resistance of a concrete beam to loading, leading to greater deformation in the beam. The decrease in the second moment of area of a concrete beam during the course of loading is taken into account by the effective moment of inertia approach. Changing variation of the effective moment of inertia is summarized in Fig.1.

Fig. 1. Moment of inertia variation at various load level

By referring to the figure, when the maximum moment (\( M_{cr} \)) in a beam does not exceed the cracking moment (\( M_{cr} \)), the beam is in the uncracked condition therefore \( I \) is taken as \( I_e \). This is shown by a linear line of \( IL_e \) equal to 1 in Fig. 1. Once \( M_e \) bigger than \( M_{cr} \), the overall moment of inertia of a concrete beam decreases gradually from the un-cracked moment of inertia (\( I_e \)) to the fully-cracked moment of inertia (\( I_{cr} \)). This gradual decrease is taken into consideration by the effective moment of inertia approach (\( I_e \)). The following effective moment of inertia expression was originally proposed by Branson [9] and was adopted by ACI [10] and presented as (2).

\[ I_e = I_{cr} + (I_e - I_{cr}) \left( \frac{M_{cr}}{M_a} \right)^3 \]  \hspace{1cm} (2)

The uncracked moment of inertia, \( I_e \), was considered equal to gross moment of inertia ignoring reinforcement and given as (3).

\[ I_e = \frac{1}{12} bh^3 \]  \hspace{1cm} (3)

where \( b \) and \( h \) are the width and height of the beam, respectively.

While the moment of inertia of the section in the fully cracked condition is given by (4).

\[ I_{cr} = \frac{1}{12} b c^3 + n A_t (d - c)^2 \]  \hspace{1cm} (4)

where \( c \) is the neutral axis depth of the fully-cracked section; \( n \) is the modular ratio of steel to concrete; \( A_t \) is the total cross-sectional area of the longitudinal reinforcement; and \( d \) is the effective depth of the tension reinforcement.

While cracking moment is given by (5)

\[ M_{cr} = \frac{f_e I_e}{y_i} \]  \hspace{1cm} (5)

where \( y_i \) is the vertical distance of the extreme tension fibers from neutral axis. Modulus of rupture, \( f_r \), in the (5) can be calculated by (6).

\[ f_r = 7.5 \sqrt{f_e} \]  \hspace{1cm} (6)

The equation above should be multiplied by 0.75 when applied to lightweight concrete.

Another expression of the effective moment of inertia was introduced by Fikry and Thomas [11] after considering ref. [12] and [13]. The expression is given by (7).

\[ I_e = I_{cre} + (I_e - I_{cre}) \ e^\rho \]  \hspace{1cm} (7)

where \( I_{cre} \) is modified form of (4) and \( \Phi \) is a variable representing function of loading and reinforcement ratio and given as (8) and (9) respectively.

\[ I_{cre} = (\alpha + \beta n \rho)^{\frac{1}{12}} \cdot \frac{bd}{L} \]  \hspace{1cm} (8)

\[ \Phi = \left( \frac{M_a}{M_{cr}} \right) \left( \frac{L_{cr}}{L} \right) \rho \]  \hspace{1cm} (9)

where \( \alpha \) and \( \beta \) are constants depending on the \( np \) value. \( \rho \) is reinforcement ratio, \( L \) is beam span. \( L_{cr} \) is cracking length of the beam and for this test beam is given by (10) [12].

\[ L_{cr} = L \left( 1 - \frac{M_{cr}}{M_a} \right) \times 2a/L \]  \hspace{1cm} (10)

Equation (7) - (9) was purely developed using data obtained in the journal paper, thus the author has verified and modified the expression using experimental work [14]. Recently the author has also modified the equation which valid to be used for pumice lightweight concrete beam reinforced with mild steel [15] as given by (11) and (12). These equations actually have replaced the form of (8) and (9) respectively.

\[ I_{cr} = 0.36 \ (n\rho)^{0.25} \times \frac{1}{12} \cdot \frac{bd}{L} \]  \hspace{1cm} (11)

\[ \Phi = \left( \frac{M_a}{M_{cr}} \right) \left( \frac{L_{cr}}{L} \right) (1.41 + 0.44 \rho) \]  \hspace{1cm} (12)

From the author previous study, it was concluded that the amount and characteristic of reinforcement in a beam section will affect significantly the effective moment of inertia of the beam. While concrete compressive strength did not straight forward affect the moment of inertia but indirectly influences the cracked moment of inertia represented by a modular ratio. Thus, as previously discussed of the potential use of bamboo as reinforcement of concrete beam, therefore this study aims is to improve the \( I_e \) expression of (7) in order to be valid for
predicting concrete beam reinforced with twisted bamboo cables.

II. SCOPE AND LIMITATION

This study is experimental in nature. Present research focus on development of model for short term deflection prediction of beam reinforced with twisted bamboo cables. Bamboo specimens were dried to produce such a moisture content of about 15%. The performance of the bamboo used was investigated in terms of tensile strength, water absorption, and unit weight. Two types of concrete ie normal weight and pumice lightweight concrete were used. Physical and mechanical properties of the concrete were also investigated in terms of unit weight, fine modulus, mud content, compressive strength and elastic modulus. Rectangular beams section reinforced with twisted bamboo cables of 0.72 %, 1.08 % and 1.88 % reinforcement ratio were investigated. The beams were loaded under two symmetrical points load. In addition, the load-deflection curves produced from the beam tested were used to study beams behavior under loading, crack development and ultimate load variation. Finally, a modified model was developed. The model was applicable to predict short term bamboo beam deflection with reinforcement ratio between 0.72 % and 1.88 %.

III. EXPERIMENTAL PROGRAM

Beams of normal weight concrete (NC) and lightweight concrete (LC) were considered. Nine beams consisted of 6 NC and 3 LC beams were tested in this study. The beams details and designation used are presented in Fig. 2 and Table I respectively. The beams were varied in tension reinforcement and concrete strength. The NC beams consisted of two concrete compressive strengths of 17 and 30 MPa while the LC beams were made using concrete compressive strength of 17 MPa.

<table>
<thead>
<tr>
<th>Beam_ID</th>
<th>Type of concrete</th>
<th>$f'_c$ (MPa)</th>
<th>Tension bar</th>
<th>Compression bars</th>
</tr>
</thead>
<tbody>
<tr>
<td>NC17-2</td>
<td>Normal Weight Concrete (NC)</td>
<td>17</td>
<td>0.72 %</td>
<td>0.12 %</td>
</tr>
<tr>
<td>NC17-3</td>
<td>1.08 %</td>
<td>0.12 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NC17-5</td>
<td>1.88 %</td>
<td>0.13 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NC30-2</td>
<td>0.72 %</td>
<td>0.12 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NC30-3</td>
<td>30</td>
<td>1.08 %</td>
<td>0.12 %</td>
<td></td>
</tr>
<tr>
<td>NC30-5</td>
<td>1.88 %</td>
<td>0.13 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LC17-2</td>
<td>Lightweight Concrete (LC)</td>
<td>17</td>
<td>0.72 %</td>
<td>0.12 %</td>
</tr>
<tr>
<td>LC17-3</td>
<td>1.08 %</td>
<td>0.12 %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LC17-5</td>
<td>1.88 %</td>
<td>0.13 %</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The beams ID presented in column (1) of Table I can be explained as follows. For example, beam ID NC17-2 means that the beam was manufactured using normal weight concrete of 17 MPa of concrete compressive strength and contain 2 amounts of bamboo cables. Thus, in the next discussion of the beams will refer to the beam identification as presented in the table.

A. Materials

The NC and LC used herein were designed and prepared. Care was taken to ensure the appropriate mix proportion of cement, coarse aggregate, pumice of 10 mm maximum size and water content as given in Table II.

<table>
<thead>
<tr>
<th>Type of concrete</th>
<th>Target $f'_c$, MPa</th>
<th>Mixture proportion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>w/c</td>
<td>Cement kg/m³</td>
</tr>
<tr>
<td>NC</td>
<td>17</td>
<td>0.58</td>
</tr>
<tr>
<td>LC</td>
<td>30</td>
<td>0.45</td>
</tr>
<tr>
<td>LC</td>
<td>17</td>
<td>0.4</td>
</tr>
</tbody>
</table>

Bamboo cables were produced by twisting 3 bamboo splints with size of ± (5 mm x 8 mm). The technique used was adopted from ref. [2] and clearly can be seen in Figure 3. For more convenient, then the original picture presented in ref. [2] was re-drawing as presented in Fig. 3.

Fig. 2. Experimental setup and details of test beams: (a) beam cross section and (b) demounted mechanical gauge point for reading strain of concrete beam surface
The bamboo used were locally known as “bambu Galah”. The bamboos were measured their properties including ultimate tensile strength, $f_{ub}$, unit weight, $\gamma$, elastic modulus, $E_b$ and moisture content. Test results of the bamboo properties were obtained prior to the beam tested. The average values obtained are presented in Table III.

### Table III. Bamboo Reinforcement Details

<table>
<thead>
<tr>
<th>Bamboo properties</th>
<th>Bamboo with nodes</th>
<th>Bamboo without nodes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_{ub}$ (MPa)</td>
<td>109</td>
<td>186</td>
</tr>
<tr>
<td>$\gamma$ (gr/cm$^3$)</td>
<td>0.878</td>
<td></td>
</tr>
<tr>
<td>$E_b$ (N/mm$^2$)</td>
<td>6830</td>
<td></td>
</tr>
<tr>
<td>Moisture content (%)</td>
<td>15.12</td>
<td></td>
</tr>
</tbody>
</table>

As bamboo is a natural material, it was difficult to maintain the size of bamboo splint to be constant throughout its length. Thus, the bamboo cable diameter was estimated by (13).

$$\phi_b = \sqrt{\frac{4W}{\pi \gamma l}}$$

(13)

where $W$ and $l$ are weight and length of bamboo cable specimen respectively. $\gamma$ is unit weight of the bamboo cable. Thus it was obtained that for the bamboo cable specimen with length of 60 cm, the bamboo cable average weight was 61.32 gr. Thus, by using (13) it was obtained bamboo diameter of 12.1 mm. Therefore, the number of reinforcement contained in beam section can be expressed in general term as tension reinforcement ratio of 0.72 %, 1.08 % and 1.88 % for beam containing 2, 3 and 5 bamboo cable respectively as can be seen in Table I.

### IV. RESULTS AND DISCUSSION

#### A. Behavior of Twisted Bamboo Reinforced Concrete Beam

The bamboo reinforced concrete beam behavior can be explained using NC30-3 beam as a beam representation. From visual observation during a testing of the beam, it was found that the beam is un-cracked until reach the value of load of 12 kN. During this course the load deflection curve is linear (Fig. 4a). This is also supported by the strains reading on the beam surface which start to spread at load 12 kN (Fig.4b). After loading increased greater than 12 kN, concrete beam surface start to crack produced a large increase in deflection. This is caused by the stiffness of the beam was lost greatly. In the concrete beam surface at bottom of the beam start to experience tension strain and in contrast with top surface of...
the concrete beam where they experience compression strain as can be seen in Fig. 4b. The more load given the more stiffness reduced as a result greater deflection occur. Finally, the beam was failure at loading of 20 kN with produced deflection of 20 mm as can be seen in Fig. 4a. At ultimate load the maximum tensile strain occurs at the bottom of the beam and then narrowed to the top and turned into compressive strain at the top of the beam. This can be seen clearly in Fig. 4b.

**B. Experimental Beams Capacity**

The beams capacity was studied through load-deflection curve. From this curve it can be obtained first cracked moment and ultimate moment capacity of the beam. It was obtained that the cracking moment varies from 0.3 to 0.7 of the ultimate moment. While the measured cracking moment was varies from 0.9 to 1.42 of theoretical cracked moment calculated using by (5) as can be seen in Table IV column (5).

From Table IV, it can be seen that ratio cracked moment to ultimate moment decreased with the increasing the tension reinforcement at similar beams. Thus the cracking moment value was significantly affected by the presence of reinforcement in the beam. In contrast with the ratio between observed and theoretical cracked moment, this produced average ratios close to 1. Therefore, the cracked moment was not taken into consideration to be improved.

**C. Comparison between Experimental and Prediction**

Measured deflection of all beams tested in this study were compared to deflection calculations by using (1) with (7) through (9) approach. The comparison results are presented in Fig. 5. It can be seen from the figure that almost all predicted deflection underestimate the experimental deflection. This results showed that (7) through (9) approach must be improved in order to the equations are suitably used for predicting bamboo reinforced beam deflection.

**D. Moment of Inertia Improvement**

In this study the model improvement is built using the beams subjected to two symmetrical points load as described previously.

It was obtained from the previous results of the author studies [14]-[16] that when the load acting less than cracking load, \( M_a < M_{cr} \), the section is uncracked condition, therefore \( I_e \) equal to \( I_g \). However, by increasing the load until reach the yield load, \( M_a = M_y \), the condition of section is fully cracked thus \( I_e = I_{cr} \). For this reason \( I_{cr(exp)} = I_{cr(exp)} \), therefore the experimental values of \( I_e \) is given as (14).

\[
I_{cr(exp)} = \frac{M_y (3L^2 - 4a^2)}{24E_e \delta_{exp}} \tag{14}
\]

The values of experimental \( I \) obtained are normalized and plotted alongside the theoretical \( I_e \) against \( M_a/M_{cr} \) as shown in Figure 6.

**TABLE IV**

<table>
<thead>
<tr>
<th>Beam ID</th>
<th>( M_{a(exp)} )</th>
<th>( M_{cr(exp)} )</th>
<th>( M_{cr(th)} )</th>
<th>( M_{cr(exp)}/M_{a(exp)} )</th>
<th>( M_{cr(exp)}/M_{cr(th)} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
<td>(5)</td>
<td>(6)</td>
</tr>
<tr>
<td>NC17-2</td>
<td>6.18</td>
<td>4.30</td>
<td>3.99</td>
<td>0.70</td>
<td>1.08</td>
</tr>
<tr>
<td>NC17-3</td>
<td>10.75</td>
<td>5.38</td>
<td>3.99</td>
<td>0.50</td>
<td>1.35</td>
</tr>
<tr>
<td>NC17-5</td>
<td>16.13</td>
<td>4.84</td>
<td>3.99</td>
<td>0.30</td>
<td>1.21</td>
</tr>
<tr>
<td>NC30-2</td>
<td>10.75</td>
<td>5.38</td>
<td>5.30</td>
<td>0.50</td>
<td>1.01</td>
</tr>
<tr>
<td>NC30-3</td>
<td>16.13</td>
<td>6.45</td>
<td>5.30</td>
<td>0.40</td>
<td>1.22</td>
</tr>
<tr>
<td>NC30-5</td>
<td>24.73</td>
<td>7.53</td>
<td>5.30</td>
<td>0.30</td>
<td>1.42</td>
</tr>
<tr>
<td>LC17-2</td>
<td>5.38</td>
<td>2.69</td>
<td>3.00</td>
<td>0.50</td>
<td>0.90</td>
</tr>
<tr>
<td>LC17-3</td>
<td>7.53</td>
<td>3.23</td>
<td>3.00</td>
<td>0.43</td>
<td>1.08</td>
</tr>
<tr>
<td>LC17-5</td>
<td>10.75</td>
<td>3.23</td>
<td>3.00</td>
<td>0.30</td>
<td>1.08</td>
</tr>
</tbody>
</table>

**Fig. 4.** Load-deflection curve (a) and load vs strain (b) of typical beam tested.

**Fig. 5.** Comparison of experiment and calculated deflection using existing model (7).

**Fig. 6.** Variation of \( I_e \) at various load level
From Fig. 6 it can be seen that the theoretical values of $I_e$, are not always higher than the experimental values but the experimental values of $I_e$ are greater than the theoretical values of $I_{cr}$ over the range of $M_a/M_{cr}$. This suggested that the theoretical evaluation of $I_{cr}$ need to be modified.

It was decided to consider the effect of compressive strength, $f'_c$, and reinforcement ratio, $\rho$, on the value of $I_{cr}^{\exp}$. However, factor $f'_c$ is eliminated in equation using the term $n\rho$ instead. Thus by plotting average ratio $I_{cr}^{\exp}/\frac{1}{12}bd^3$ against $(n\rho)^{0.25}$ as shown in Figure 7 which give the best fit of the data and produce another alternative for $I_{cr}$. From regression analysis this produces new $I_{cr}$ as given by (15).

$$I_{cr} = 0.18 (n\rho)^{0.25} \times \frac{1}{12}bd^3$$  \hspace{1cm} (15)

Fig. 7. Regression analysis which produced (15)

To fix the data it also need to modify the factor $\Phi$ in the expression presented in (7). Therefore, experimental value of factor $\Phi$ was obtained by re-arranging (7) and gives results as given by (16).

$$\Phi_{exp} = \ln \left( \frac{I_{cr}^{\exp} - I_{crm}}{I_{cr} - I_{crm}} \right)$$  \hspace{1cm} (16)

Substituting (15) into (16) to obtain experimental $\Phi$ values. The $\Phi$ values divided by $\left( M_a/M_{cr} \right) (L_{cr}/L)$ were defined as C and plotted against reinforcement ratio as shown in Figure 8. From regression analysis this produce equation as given by (17).

$$\Phi_m = -\left( \frac{M_a}{M_{cr}} \right) \left( L_{cr}/L \right)(1.54 + 0.58\rho)$$  \hspace{1cm} (17)

$L_{cr}/L$ in (17) is function of load condition. The values of $L_{cr}/L$ for two symmetrical points load is given by (18).

$$\frac{L_{cr}}{L} = 1 - \frac{M_a}{M_a} \left( \frac{2a}{L} \right)$$  \hspace{1cm} (18)

Fig. 8. Regression analysis for the factor $\Phi$

By substituting (18) into (17) produce replacement form of the (17) as given by (19).

$$\Phi_m = -\left( \frac{M_a}{M_{cr}} - 2a \right) \left( M_{cr}/M_a \right)(1.54 + 0.58\rho)$$  \hspace{1cm} (19)

Finally, a proposed model for the calculation of effective moment of inertia, $I_e$, of either normal or lightweight concrete beam reinforced with twisted bamboo cables is given, ie by applying (7) with modification parameter appropriate of (15) and (19) for $I_{cr}$ and $\Phi$ respectively.

E. Validation to the Experimental Data

Load deflection curve for some beams tested are presented in Fig. 9 to Fig. 13. It can be seen from the figures that deflection predicted by ACI and model existing or by (7) give overestimate prediction to experimental values. Whilst model proposed in this study has good agreement with the experimental value. Figure 10 shows both ACI and by (7) still overestimate the deflection variation from almost 50 % of the ultimate load level. However, the proposed model produced more accurate prediction. Similarly with Fig. 11 and 12, the proposed model produces better prediction than that of both the ACI and by (7).
The proposed model produces more accurate estimation of deflection when used for the deflection calculation of normal weight concrete beam compared to deflection calculations of the lightweight concrete beam. This clearly can be seen in Fig. 9, Fig. 10, and Fig. 12 for NC30-5, NC17-5 and NC17-3 respectively. It can also be seen respectively in Fig. 11 and Fig. 13 for LC17-5 and LC17-3.

At last, to show the results produced by the proposed model, a comparison between experiment deflection and deflection calculated by the proposed model for all the beams test are presented. The deflection considered was deflection due to loading at 50 to 70% of ultimate load level. This is considered as serviceability load level. The results show that vast majority of the predicted deflection within the range of ±20% limit as given in Fig. 14.

The model proposed in this study has good agreement with the experimental value and give better accuracy than that of the existing model, Therefore the model valid to be used for analyzing deflection of twisted bamboo reinforced concrete beam in terms of reinforcement ratio between 0.73% and 1.88%.

To obtain more comprehensive conclusion, then further research is needed to verify this model using one-way bamboo reinforced concrete elements with reinforcement ratio higher than 2%. The possibility improvement of the model for predicting deflection of beam with T section must also be proved by carrying out experimental work.
REFERENCES


