Modeling Deflection in Reinforced Concrete One-way Slabs using Eurocode2 Model

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مُستخلص: تبحث هذه الدراسة في صلاحية طريقة دليل الممارسة الأوربي لنمذجة الانحراف في البلاطات الخرسانية المسلحة ذات الاتجاه الواحد. تم تطوير نموذج حسابي باستخدام برنامج ماتلاب لتطبيق الطريقة. تم التحقق من صحة أداء النموذج مقابل النتائج التجريبية في الدراسات السابقة. وأظهرت النتائج أن النموذج قادر على التنبؤ بانحراف البلاطات بسيطة الإسناد ذات الاتجاه الواحد. تم بعد ذلك إجراء دراسة لتحديد تأثير العوامل ذات الصلة بانحراف البلاطات، وقد وجد أن العامل الأكثر أهمية الذي يؤثر على الانحراف هو سمك البلاطة.

الكلمات المفتاحية: انحراف، دليل الممارسة الأوربي، نموذج، بلاطة ذات اتجاه واحد.

ABSTRACT This paper examines the validity of Euro code (EC2) method for modeling deflection in reinforced concrete one-way slabs. A numerical model which incorporates nonlinear effect due to cracking has been developed. A MATLAB program has been developed to implement the model. The performance of the model has been validated against experimental results in literature. The results show that the model is capable of predicting the deflection of simply supported reinforced concrete one-way slabs. A parametric study has then been carried out to quantify the influence of relevant parameters on slabs deflection. It has been found that most significant factor affecting deflection is the slab thickness.

Keywords: Deflection, Eurocode2, Model, One-way slab.

1. INTRODUCTION

Structural members must be designed to meet ultimate and serviceability limit state requirements to present adequate design with the best economical solutions. The serviceability limit state has become more important due to the increasing use of high strength materials in recent years, so material properties and the complexity of the design concept was taken into account [1].

The prediction of deflection is complex due to the difficulties involved in modeling the non-linear, inelastic behavior of the concrete, as well as the load history and environmental conditions [2],[3]. In most common cases of structures span to depth ratio is often used in different codes to ensure the deflection doesn't exceed the allowable limits. Originally deflection limits in most codes were developed from tests on simply supported

reinforced concrete beams and preliminary predictions for more complexes [1].

The accuracy in predicting deformation of reinforced concrete structures depends upon the method of analysis and its closeness to actual parameters used as input data. It is reported that deflection is influenced by many factors which can be classified into geometric factors (e.g. slab dimensions, slab thickness and span) material properties factors (e.g. Modulus of elasticity of concrete, reinforcing steel, tensile strength of concrete, and compressive strength) and construction factors (e.g. curing condition, variation in steel cover to slab thickness, age at striking, and construction load) [1], [4]. The aim of this study is to examine the validity of EC2 method for modeling deflection in reinforced concrete slabs, by developing a computer program and to identify

the influence of different factors that affect the slab deflection.

2. MODELING DEFLECTION USING EC2 METHOD

The Eurocode2 (EC2) uses a method for calculating deflections in cracked members by integration section curvature [5], [6]. Two limiting conditions are assumed to exist for the deformation of concrete sections: the uncracked and fully-cracked state. The actual curvature lies between that of an un-cracked section which behaves elastically and an idealized fully cracked section in which no tension develops in the concrete as shown in Fig.1. A dimensionless coefficient is used to represent the extent of section cracking (ζ) where in un-cracked section ($\zeta=0$) and increases to reach unity for fully-cracked section.

Fig. 1: Moment-curvature response of a reinforced concrete section

3. METHOD OF ANALYSIS

A MATLAB Program is developed to implement EC2 method for deflection calculation [7]. The following procedure is used to calculate the deflection:

- The slab is divided into equal sections; the bending moment is calculated for each section.
- The flexural curvature of un-cracked and fully-cracked sections are calculated using the following equations :

$$\frac{1}{r_1} = \frac{M}{E_{cm} \times I_1} \quad (1)$$

$$\frac{1}{r_2} = \frac{M}{E_{cm} \times I_2} \quad (2)$$

Where:

$\frac{1}{r_1}$ And $\frac{1}{r_2}$ are curvatures corresponding to bending moment for un-cracked and fully cracked sections, respectively.

I_1 and I_2 is un-cracked and fully-cracked second moment of area about the neutral axis.

x_1 and x_2 are distance from extreme fiber in compression to neutral axis .

$$I_1 = \frac{b \cdot h^3}{12} + b h * \left(\frac{h}{2} - x_1\right)^2 + (\alpha - 1) [A_s * (d - x_1)^2 + A'_s * (x_1 - d')^2] \quad (3)$$

$$x_1 = \frac{\frac{b \cdot h^2}{2} + (\alpha - 1) \times (A_s \times d + A'_s \times d')}{b \times h + (\alpha - 1) \times (A_s + A'_s)} \quad (4)$$

$$I_2 = \frac{b \cdot x_2^3}{3} + \alpha \times A_s \times (d - x_2)^2 + (\alpha - 1) \times A'_s \times (d' - x_2)^2 \quad (5)$$

$$x_2 = \frac{\frac{b \cdot x_2^2}{2} + \alpha \cdot A_s \cdot d + (\alpha - 1) \cdot A'_s \cdot d'}{b \cdot x_2 + \alpha \cdot A_s + (\alpha - 1) \cdot A'_s} \quad (6)$$

Where: α is modular ratio

$$\alpha = \frac{E_s}{E_c}$$

The modulus of elasticity of concrete calculated by:

$$E_c = 22 \times \left(\frac{f_{cm}}{10}\right)^{0.3} \quad (7)$$

Where:

$$f_{cm} = f_{ck} + 8$$

- The mean curvature $\frac{1}{r_m}$ is calculated by:

$$\frac{1}{r_m} = (1 - \zeta) \times \frac{1}{r_1} + \zeta \times \frac{1}{r_2} \quad (8)$$

Where:

$$\zeta = 1 - \beta \left(\frac{M_{cr}}{M}\right)^2 \quad (9)$$

Where: β is taken as 1.0 for first loading

M_{cr} is the cracking moment given by:

$$M_{cr} = f_{ctm} \times \frac{I}{y_{cr}} \quad (10)$$

$$f_{ctm} = 0.3 \times f_{ck}^{\frac{2}{3}} \quad (11)$$

$$y_{cr} = h - x_1$$

(12)

- The cumulative slope for each section is calculated using the trapezoidal rule

$$\theta_i = \theta_{i-1} + 0.5 \left(\frac{L}{N}\right) \times \left(\frac{1}{r_{i-1}} + \frac{1}{r_i}\right) \quad (13)$$

- The cumulative deflection for each section is calculated using the trapezoidal rule

$$a_i = a_{i-1} + 0.5 \left(\frac{L}{N}\right) \times (\theta_{i-1} + \theta_i) \quad (14)$$

The correct value of deflection for each section is calculated using the following equation:

$$a_m = a_b * \frac{x_i}{L} - a_i \quad (15)$$

Where: a_b is the cumulative deflection at the right support.

4. VALIDATION OF THE MODEL

The performance of the model has been validated using experimental results in the literature[8-9]. The slab is of 2.0 meter long with 550 mm width and 80 mm depth. The slab is reinforced at the bottom using four steel bars $\varnothing 10@160\text{mm}$ c/c each way. The slab was cast using a normal weight concrete, and natural sand and gravel as a fine and coarse aggregate respectively and concrete mix designed to achieve 30 N/mm^2 . The slab was tested on a simply supported condition with span equal to 190 cm. Line load were centered in mid span up to 14.715 kN . Throughout the loading tests, mid span deflections were measured while gradual loading was applied by means of hydraulic machine up to failure. Two pins were fixed at mid span, and distance between them was measured before and after loading to assess strains in slabs. Cracks also were observed either vertical or horizontal. Line load were centered in mid span as shown in Fig.2:

Fig. 2. Setting specimen and hydraulic loading jack

Fig.3 shows the variation in mid span deflection with load for the EC2 model and the experimental results. It can be seen that the developed model in MATLAB gives approximately similar results to experiment and thus capable of predicting the real behavior of deflection in reinforced concrete one-way slabs subjected to line load.

5. PARAMETRIC STUDY

A parametric study is carried out on simply supported reinforced concrete one-way slab using the MATLAB Program to determine the influence of relevant parameters on short-term deflection with quasi permanent load case. These parameters include compressive strength of concrete, area of reinforcement and slab thickness.

The properties of the slab used in the study are shown in Table 1

Fig. 3. Load versus mid span deflection in the model and the experiment

TABLE 1: PROPERTIES OF THE SLAB USED IN THE PARAMETRIC STUDY:

Parameter	value
Length of slab (L)	2000 (mm)
Width of slab (B)	1000 (mm)
Thickness of slab (h)	150 (mm)
Area of steel reinforcement (A_s)	1727 (mm^2/m)
Modulus of elasticity of the concrete (E_c)	33(kN/mm^2)
Modulus of elasticity of the steel (E_s)	200 (kN/mm^2)
Characteristic cylinder strength (f_{ck})	30 (N/mm^2)
Mean Characteristic tensile strength (f_{ctm})	2.9 (N/mm^2)
Quasi permanent load (w)	6.5 (kN/m^2)

A. EFFECT OF COMPRESSIVE STRENGTH OF CONCRETE:

To study the effect of concrete compressive strength on deflection, Values of compressive strength of concrete from 50% less to 200% greater than the standard value According to equations (7) and (11) both concrete tensile strength and the elastic modulus change from 63% to 159% and from 86% to 119% respectively. From Figure 4 it can be seen that the deflection decreases with increasing the compressive strength of concrete since increasing the compressive strength increases the concrete tensile strength and hence the amount of cracking. Also increasing concrete compressive strength increases the elastic modulus which reduces deflection. The increase of the compressive strength from 50% to 200% results in deflection decreases from 68% to 122% with respect to the original slab.

Fig. 4. Effect of compressive strength of concrete on short-term deflection

B. EFFECT OF AREA OF STEEL REINFORCEMENT:

It is common practice to provide more tension steel than required for flexure to reduce slab deflection. To study the effect of providing surplus tension steel on deflection, the steel area is increased from 50% to 200% of the reference slab. Figure 5 shows the effect of providing surplus tension steel area on deflection.

Fig. 5. Effect of area of steel reinforcement on short-term deflection

It can be seen that the deflection decreases with increasing the area of steel reinforcement. This because the increase in area of steel reinforcement leads to increase in moment of inertia which reduces the deflection. However, the effect is not significant since only 8% decrease in deflection corresponding to 150% increase in the area of reinforcement.

C. EFFECT OF SLAB THICKNESS:

To study the influence of slab thickness on deflection, the slab thickness is increased from 50% to 200% of the reference slab. Figure 6 shows the effect of slab thickness on deflection. It can be seen that the deflection decreases with increasing the slab thickness. This due to the fact that increasing slab thickness reduces the amount of cracking. The influence of the slab thickness is very significant;

Fig. 6. Effect of slab thickness on short-term deflection

6. CONCLUSIONS

A numerical model has been developed to model deflection in reinforced concrete simply supported one-way slab. The model has been developed using the sectional approach by implementing the EC2 method. The developed model is validated against experimental results of reinforced concrete one-way slabs subjected to line load. The validation show that the developed model is realistically capable of predicting deflection. The model is then use in a parametric study to investigate the effect of area of reinforcement, thickness of slab, and compressive strength in deflection of one way slabs. It was found that, the slab thickness has a very significant effect on deflection; however the effect of increasing tension steel is insignificant in reducing slab deflection. The Matlab program developed in this paper is only limited for modelling deflection in RC one way slabs. Predictions of deflection in RC two way spanning slabs are best made with finite element programs capable of cracked section analysis.

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