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Time-Dependent Deflection of Prestressed Concrete Members of any Concrete Compressive Strength

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Abstract

The deflection of a member can be determined more accurately from the values of the mean curvatures of a number of sections using simple geometrical deflection-curvature relations taking into account the effect of tension stiffening. Thus, the* "The Proposed Mean Curvature" *idealization is derived in this work exclusively for prestressed concrete members taking into consideration the effect of cracking of these members. It shows better agreement with experimental data than the conventional models, which are established essentially for normal strength concrete and do not fit higher-strength concrete.

The computer program "PPCD" is developed in this work following the proposed model. Immediate and time dependent deflections of prestressed concrete beams can be computed. Concrete compressive strength, tension-stiffening effect, and time-dependent factors are included in this program. This program has been verified once to typical studied example with varying concrete compressive strengths and furthermore to an experimental data.

The results indicate that the accuracy of* The Proposed Model *in deflection predicting is acceptable for partially prestressed concrete members of any concrete compressive strength.

الخلاصـــــــة

الهطول لأي عضو من الممكن ايجاده بشكل اكثر دقة من قيم متوسط التقوس لعدد من المقاطع بأستخدام علاقات هطول-تقوس هندسية بسيطة مع الاخذ بنظر الاعتبارتأثير صلابة منطقة الشد. وهكذا فأن (متوسط تقوس مقترح) قد تم اشتقاقه في هذا البحث خاصاً للاعضاء المسبقة الجهد اخذين بنظر الاعتبار تأثير التشقق لهذه الاعضاء. وقد اظهر الاقتراح توافقاً مع نتائج الفحوص المختبرية بشكل افضل مع تلك الاقتراحات المعتمدة على النمذجة التقليدية المؤسسة على الخرسانة ذات المقاومة العالية.

تم تطوير برنامج حاسوبي ***(PPCD)*** *في هذا العمل بأتباع النموذج المقترح ويمكن منه حساب الهطول الأني والهطول المعتمد على الزمن للزمن في البرنامج. وقد تم اختيار البرنامج مرة بأستخدام مثال نموذجي بمختلف مقاومات الأنضغاط وأخرى على بيانات عملية.*

أشرت النتائج بان دقة النموذج المقترح بتوقع الهطول كانت مقبولة بالنسبة للاعضاء الخرسانية مسبقة الجهد جزئياً وبأي مقاومة انضغاط للخرسانة.

1. Introduction

When a concrete specimen is subjected to load, its response is both immediate and time-dependent. Under load, the deformation of a specimen gradually increases with time and eventually may be many times greater than its instantaneous value.

If temperature and stress remain constant, the gradual development of strain with time is caused by creep and shrinkage. Creep strain is produced by sustained stress whilst shrinkage strain is independent of stress. These inelastic and time-dependent cause increases in deformation and curvature, losses of prestress and redistribution of stresses and internal actions. Creep and shrinkage are often responsible for excessive deflection at service loads. Creep frequently causes excessive camber and/or shortening in prestressed members. In addition, shrinkage may unsightly cracking, which could lead to durability failures.

2. Effects of Time-Dependent Parameters on the Deflections

The time-dependent increase of strain in hardened concrete subjected to sustained stress is defined as creep. The shrinkage is the decrease of concrete volume with time after concrete hardening. Relaxation is the gradual reduction of prestressing steel stress with time under sustained strain.

Because of concrete creep and shrinkage and relaxation of prestressed steel, the stress in concrete and steel varies with time. The strains, and deformations, also change considerably with time due to the same effects and also due to cracking when concrete stress exceeds, tensile strength.

3. Development of Analytical Model to Predict the Time-Dependent Response of Prestressed Concrete Members

Cracks are generally expected to occur in partially prestressed structures, when tensile stresses exceed the strength of concrete in tension. Reduction in stiffness of members due to cracking must be considered in the calculation of displacements in partially prestressed concrete structures. This section presents methods to predict the curvature of cracked members subjected to axial force and/or bending moment. Also in this section a mean curvature is proposed to be used in the analytical model.

3-1 Tension Stiffening Effect

When the stress in concrete has never exceeded its tensile strength, the member is free from cracks. The reinforcement and concrete undergo compatible strains. This condition is referred to as **State 1,** and the immediate curvature due to bending moment **M** on a section is:

$$\psi_1 = \frac{M}{Ec \cdot I_1} \quad \text{...(1)}$$

where, **Ec** is the modulus of elasticity of concrete at time of application of **M**, and I_1 is the moment of inertia of the uncracked section transformed to concrete.

When the tensile strength in concrete is exceeded, cracks occur. At the location of crack, it is assumed that the tensile zone is fully cracked and the tensile stress is resisted completely by the reinforcement. This condition is referred to as State 2, and the immediate curvature of the cracked section is obtained from:

$$\psi_2 = \frac{M}{Ec . I_{cr}} \quad \text{.........} \quad (2)$$

where, Icr is the second moment of inertia of the transformed fully cracked section (ignoring the concrete in tension) about its centriodal axis.

Between the cracks, concrete bonded to the reinforcements tends to restrain deformations and reduce the curvature. The contribution of the concrete in tension zone to the rigidity of the member is referred to as tension stiffness and depends on the quality of bond of the reinforcing bars (or tendons), and load applying conditions. Because of **tension stiffening,** the deflections can be determined more accurately by the use of the mean curvature values ψ_m, smaller than ψ_2 but larger than ψ_1 (ψ_m represents the curvature at one section, not an average curvature for a member).

3-2 Models for Tension Stiffening

Various methods have been proposed to account for tension stiffening in the analysis of concrete structure.

An effective moment of inertia, **Ie,** is the empirical equation proposed by Branson [1], which has been adopted by ACI Code [2] for many years:

$$I_e = \left(\frac{M_{cr}}{M}\right)^3 I_g + \left[1 - \left(\frac{M_{cr}}{M}\right)^3\right] I_{cr} \le I_g \quad \text{.........} \quad (3)$$

This equation can be used to interpolate between States 1 and 2 [the interpolation is between **Ig** (which is slightly smaller than I_1) and I_{cr}]. The value of obtained from the above equation can be used to determine a mean curvature for a member subjected to a constant moment M,

$$(\psi_m)_{ACI} = \frac{M}{E_c . I_c} \quad \text{.........} \quad (4)$$

CEB-FIP Model Code 1990 [3] has proposed an alterative model for tension stiffening which overcomes some of the inadequacies of Branson's method and which has much to recommend it. At applied moment M, the mean curvature is given by:

$$\psi_m = (1 - \zeta)\psi_1 + \zeta\psi_2 \quad \text{.........} \quad (5)$$

where:

$$\zeta = 1 - \beta\left(\frac{M_{cr}}{M}\right)^2 \quad \text{with} \left(M \geq M_{cr}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(6)}$$

in which; $\beta = \beta_1 . \beta_2$ with $\beta_1 = 1$ for high bond bars, and $\beta_2 = 1$ and **0.5**, respectively, for first loading (when calculating the immediate deflection due to a load) and for loads applied in a sustained manner or for a long number of cycles).

For more general case when the section is subjected to a normal force with or without bending moment, the interpolation coefficient, ζ may be expressed in terms of concrete stresses:

$$\zeta = 1 - \beta\left(\frac{f_{ct}}{\sigma_{1max}}\right)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(7)}$$

where; f_{ct} is the tensile strength of concrete;

σ_{1max} is the value of the tensile stress at the extreme fiber which would occur with the assumption of no cracking (State 1).

In the case of ACI Model**,** the interpolation coefficient L is replaced by the term [l-(Mc/M)^3] in Eq.(3).

4. Proposed Model for Mean Curvature of Cracked Partially Prestressed Concrete Members

4-1 Pre-and Post-Cracking Idealization

A theoretical model for predicting deflections of cracked partially prestressed concrete beams was developed by Alameh and Harajli [4]. Based on extensive result obtained using the analytical model, it was found that the phenomenon of tension stiffening in predicting the deflection response, particularly for partially prestressed members, can be best simulated for design purpose using an idealization similar to the PCI Design Handbook [5] bilinear load-deflection model. As shown in **Fig.(1)**. The proposed idealization represents two paths of load-deflection response: pre-cracking path with slope proportional to the gross moment of inertia Ig, and post-cracking path with "apparent" slope proportional to the cracked section moment of inertia Icr, calculated relative to the centroidal axis of the cracked transformed section.

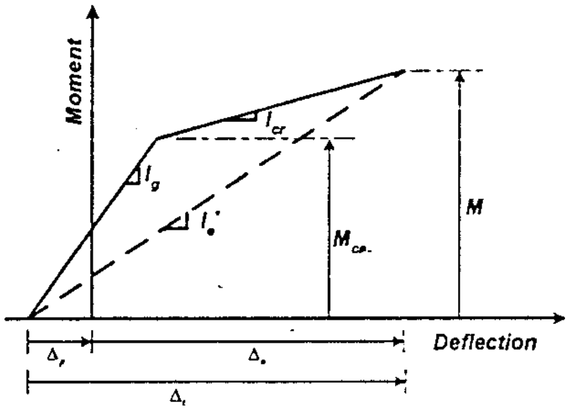

Figure (1) Proposed idealization of load-deflection response of partially prestressed beam

Unlike the PCI Design Handbook bilinear model (the post-cracking path is constant), the slope of the post-cracking path varies depending on the level of applied load at which deflection is being computed.

The corresponding idealization is facilitated by deriving an expression for **Ie*** to be used in conjunction with the concept modulus proposed by Branson and given as:

$$I_e^* = \frac{I_{cr}}{1-\left(\frac{M_{cr}}{M}\right)\left[1-\frac{I_{cr}}{I_g}\right]} \quad \text{.......... (8)}$$

The corresponding idealization of load deflection response shows better agreement with the experimentally observed deflections in comparison with other existing prediction methods.

4-2 The Proposed Model

The main objective of this study is to model analytically the service load-deflection response of cracked partially prestressed members with due consideration to the effect of tension stiffening. The model is derived based on the above-mentioned idealization of load-deflection response.

The proposed model for mean curvature can be obtained from this analytical model:

$$\psi_m^* = \left[1-\left(\frac{M_{cr}}{M}\right).\left(1-\frac{\psi_{ucr}}{\psi_{cr}}\right)\right].\psi_{cr} \quad \text{.......... (9)}$$

Therefore, the proposed model accounts for the effect of tension stiffening by taking into consideration the contribution of uncracked regions along the member length, evaluated from the effect of concrete tension stresses below the neutral axis position at the cracked sections (between the cracks).

The above equation can be expressed in terms of concrete stresses for general case:

$$\psi_m^* = \left[1-\left(\frac{f_{ct}}{\sigma_{1\max}}\right)\cdot\left(1-\frac{\psi_{ucr}}{\psi_{cr}}\right)\right]\cdot\psi_{cr} \quad \text{.. (10)}$$

The above equation can be rewritten in terms of ψ_1 and ψ_2 :

$$\psi_m^* = (1-\zeta)\psi_1 + \zeta\psi_2 \quad \text{.. (11)}$$

where:

$$\zeta = 1-\beta\left(\frac{f_{ct}}{\sigma_{1\max}}\right) \quad \text{... (12)}$$

4-3 Analytical Model Considering the Proposed Mean Curvature

The analytical model, proposed in this study for predicting short and long-term deflections of prestressed concrete members, is based on the requirements and compatibility (the procedure described in chapter three). It takes into consideration the effects of the different parameters that influence the deflections.

Partially prestressed concrete members are often designed in such away that cracking does not occur under the effect of dead load. Thus, cracking due to live load is of transient nature; hence the effects of creep, shrinkage, and relaxation of prestress steel need to be considered only for noncracked sections.

Thus, the procedure of analytical model can be preformed by the following steps:

Step (1): Determine the instantaneous strain and stress at to, with properties of transformed noncracked section.

Step (2): Calculate the time-dependent increments strain and stress during the period to t.

Step (3): Add the stress increments in steps 1 and 2 to obtain the stress distribution before the application of the live load and use this stress to determine the decompression forces N1, and M1 (represent the part of live load that will bring the stress in concrete to zero, NL = N1 + N2 and ML = M1 + M2).

The change in strain in the decompression stage is simply equal to minus the stress divided by E_c (t).

Step (4): Determine the remainder forces N_2 and M_2 which should be applied to a fully-cracked section. Therefore, the eccentricity and the corresponding depth of compression zone must be determined. The properties of fully-cracked section are used to determine the changes in strain and in stress in the cracking stage.

Step (5): The final axial strain and the curvature are determined by summing up the changes calculated in Steps 1 to 4. These values do not account for the tension stiffening.

Step (6): The final curvature must be adjusted to account for tension stiffening by **"The proposed mean curvature".**

Step (7): The deflection of a member can be determined from the value of curvature at a number of sections. Three sections are used to determine the deflection at the center of any member:

$$D_{center} = \frac{l^2}{96}\left(\psi_{e1} + 10\psi_c + \psi_{e2}\right) \quad \text{...} \quad (13)$$

(this equation, can be derived by double integration) The steps discussed above for analysis of the instantaneous and time-dependent stresses and strains and the changes in theses values of cracking involve repetitious calculations of section properties, which can be easily preformed by the use of programmable calculations.

4-4 Computer Program

A computer program **Partially Prestressed Concrete Deflection "PPCD"** in **FORTRAN** language for analysis of the time-dependent internal forces, stresses, strains and curvatures in cracked prestressed concrete is developed to represent the proposed model. The analysis is preformed in accordance with the procedure described in previous section.

The program is written in order to check the numerical accuracy of the worked cases presented in the following section. The flow chart of the program is shown in **Fig.(2)**.

5. Applications and Results

The values of the main time-dependent parameters that influence the deflections vary with concrete strength. Some Codes give guidance on the values of these parameters as a function of the specified concrete strength f'c. The analytical model presented in section four is applied to a typical example to show the influence of varying concrete strength f'c on the predicted deflections. Furthermore, the analysis procedure is verified by comparisons of predicted deflections with published experimental data.

The computer program "PPCD", based on the model analysis, is used to calculate the deflections.

5-1 Effect of Variation of Concrete Strength on Deflections

The effect of concrete strength on deflections will be examined by using the following studied case of prestressed concrete members (a typical example).

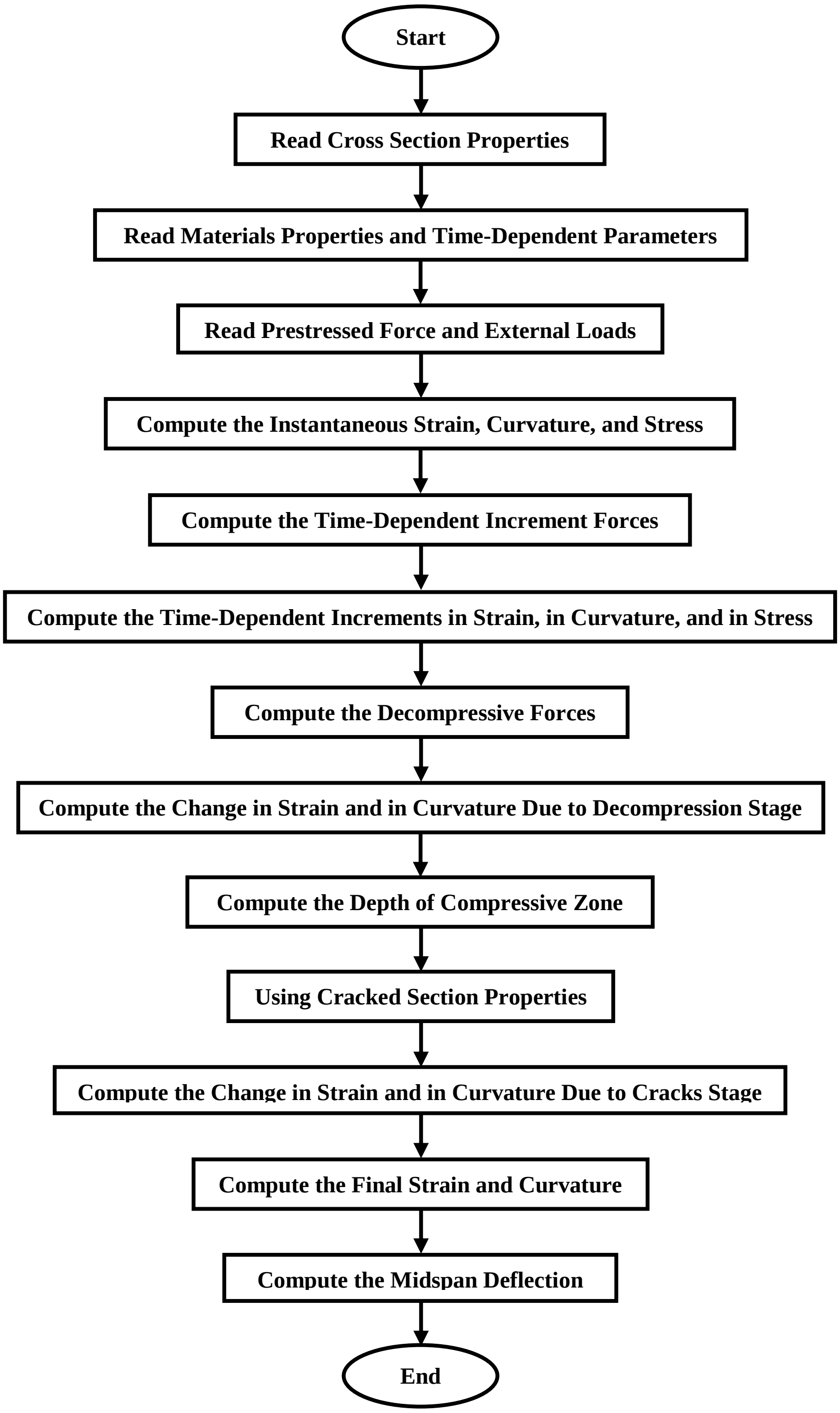

Figure (2) Flowchart of Program "PPCD"

5-1-1 Description of the Studied Case

Figure (3) shows the cross section and dimensions of a pre-tensioned partially prestressed T-beam. At age to = 28 days immediately after the prestress transfer, a uniform load is introduced and sustained for a long-time (t = several years). The maximum bending moment at mid span due to the sustained load is 700 KN.m. A long time after that, a uniform live load is applied, producing a moment at midspan equal to 400 KN.m and sufficient to produce cracking. The midspan deflections are predicted assuming different values of concrete strength (20-100 MPa) at age to= 28 days.

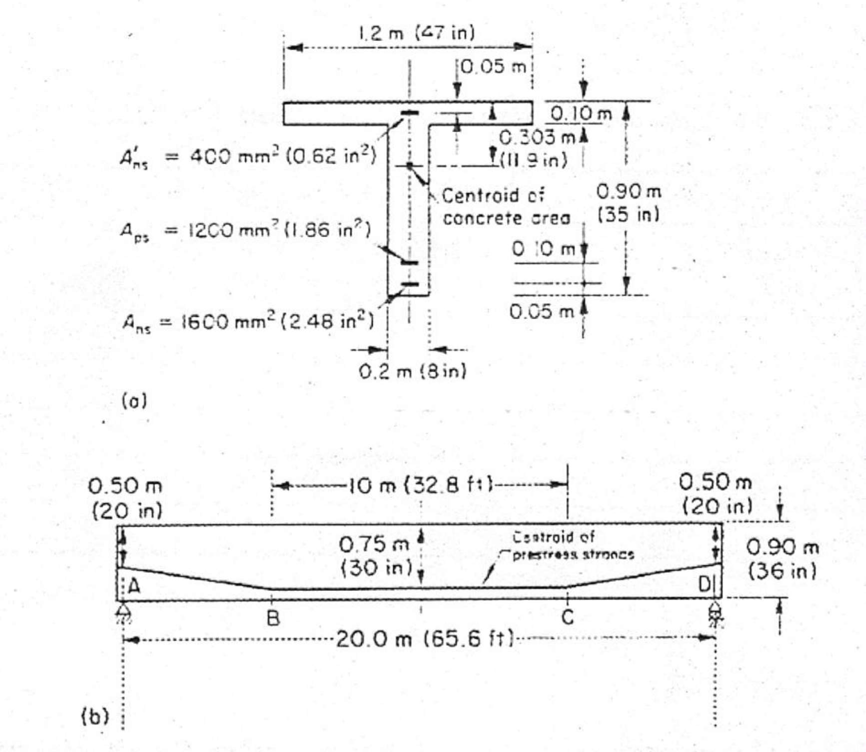

Figure (3) Cross section and dimension of prestressed T-beam in example

1. Material Properties

a) Concrete

The material properties for concrete are given in **Tables (1)** and **(2)**. All values in **Table (1)** are in accordance with ACI 209R-92 [6], and the values in **Table (2)** are calculated according to CEB-FIP MC-90 [3].

b) Prestressing Steel and Nonprestressing Steel

- The tension in prestressed tendon before transfer =1250 kN
- The reduced relaxation for the period (t-to) = -90 MPa
- The modulus of elasticity for all reinforcements = 200 GPa

Table (1) Concrete properties for example according to ACI 209R-92*

Compressive strength (28days), (fc')28,MPa	Modulus of elasticity (28days), Ec(28), GPa	Modulus of rupture (28days) fr(28),MPa	Compressive strength (ultimate) (fc')u,MPa	Modulus of elasticity (ultimate), Ec(u), GPa	Modulus of rupture (ultimate) fr(u), MPa
20	24.0	2.7	23.6	26.1	2.9
40	34.0	3.8	47.2	36.9	4.1
60	41.6	4.6	70.8	45.2	5.0
80	48.1	5.4	94.4	52.2	5.8
100	53.8	6.0	118.0	58.4	6.5

***** *Creep coefficient = 1.71; shrinkage strain = -338'x10^{6}*

Table (2) Concrete properties for example according to CEB-FIP MC-90*

Compressive strength, fc', MPa	Modulus of elasticity(28days) Ec(28), GPa	Modulus of elasticity (long time), Ec(w)GPa	Creep coefficient C(w,28)	Shrinkage strain Esh	Tensile strength fci, MPa
20	30.3	34.2	3.1	-601	1.5
40	36.3	41.0	2.3	-473	2.4
60	40.7	46.0	2.0	-345	3.1
80	44.4	50.1	1.7	-217	3.8
100	47.5	53.7	1.6	-90	4.4

***** *RH= 50 percent.*

2. Scope of Analysis

To illustrate the effect of varying of concrete strength on the main time-dependent parameters and consequently on the deflections, two cases are to be considered:

- Ignoring the effect of varying of concrete strength on the creep coefficient and shrinkage strain (ACI209R-92).
- Considering the effect of varying of concrete strength on the creep coefficient and shrinkage strain (CEB-FIP MC-90).

3. Results of Analysis

To illustrate the results with respect to the effect of varying of concrete strength on the deflections, two cases must be considered:

- ***Ignoring the Effect of Varying Concrete Strength fc'***

The report of ACI 209R-92 [6] does not give the variation of creep coefficient and shrinkage strain with concrete strength. Thus, only the modulus of elasticity of concrete and tensile strength (modulus of rupture) are varied, as shown in **Table (1)**.

Considering the Effect of Varying Concrete Strength fc'

CEB-FIP MC-90 gives guidance on the values of creep coefficient and shrinkage strain as a function of the specified concrete strength.

It can be seen from **Table (2)**, that the increase in concrete strength causes a reduction of creep coefficient and absolute value of free shrinkage.

4. The Deflections

The concrete properties in **Tables (1)**, and **(2)** are used to obtain deflections in **Tables (3)**, and **(4)** respectively.

Tables (3) and **(4)** show the deflections at different times; instantaneous dead load deflections at time to and time-dependent deflections (after creep, shrinkage, and relaxation) for the period (t, to) .At these two load levels, cracking did not occur. With **CEB** parameters, cracking occurs when concrete strength is 20 and 40 MPa. Finally, the instantaneous live load deflections at time t are accounted for. At this load level, cracking occurs with all strength values. The deflections versus concrete strength are plotted in **Figs.(4)** and **(5)**. Immediately after the applying the live load, due to prestressing, the deflections are small and the variation in deflections with concrete strength is not significant. However, after the occurrence of creep, shrinkage, and relaxation the variation in deflections with concrete strength is significant. After applying the live load, the deflections also vary considerably with compressive strength. Varying the value of compressive strength influences the stresses existing before the application of live load and also varies the tensile strength of concrete.

It can seen by comparing **Figs.(4)** and **(5)** that the variation in deflections with concrete strength is more significant when the effect of strength on creep coefficient and shrinkage strain is considered.

When a proposed model for tension stiffening (Eq.(10)) is used (which is specified for partially prestressed concrete members that are associated with high strength concrete) with the obtained concrete properties according to **CEB-FIP** MC-9 [3], the results of deflection will be more accurate than using the common equation adopted by **CEB-FIP** MC-90 (Eq.(5)).

These results of deflections are shown in **Table (5)** and illustrated in **Fig.(6)**. It can be seen that cracking which might happen before the application of live load depends upon the concrete strength.

The comparison between the proposed model and the **CEB-FIP** equation is shown in **Fig.(7)**. This comparison shows that the deflection values obtained by using the **proposed model** for tension stiffening are smaller than those obtained by using the **CEB-FIP** equation, because it takes into account the effects of prestressing and high concrete strength.

Table (3) Calculated midspan deflections for the example*

Fck MPa	After dead load		Before live load		After live load	
	Deflection mm	Crack Y/N	Deflection mm	Crack Y/N	Deflection mm	Crack Y/N
20	7	N	39	N	92	Y
40	5	N	28	N	77	Y
60	4	N	24	N	69	Y
80	3	N	20	N	64	Y
100	2	N	18	N	60	Y

* *Concrete properties are according to ACI 209R-92.*

Table (4) Calculated midspan deflections for the example*

Fck MPa	After dead load		Before live load		After live load	
	Deflection mm	Crack Y/N	Deflection mm	Crack Y/N	Deflection mm	Crack Y/N
20	7	N	56	Y	117	Y
40	5	N	36	Y	92	Y
60	5	N	27	N	76	Y
80	4	N	20	N	63	Y
100	4	N	15	N	53	Y

* *Concrete properties are according to CEB-FIP MC-90.*

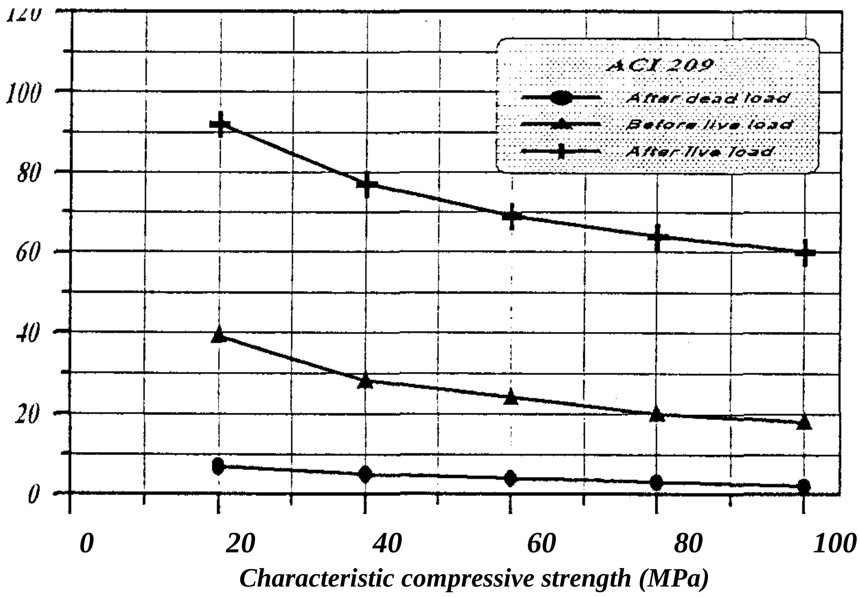

Figure (4) Effect of concrete strength on deflection by using material properties calculated according to ACI 209R-92 and ACI 209 model

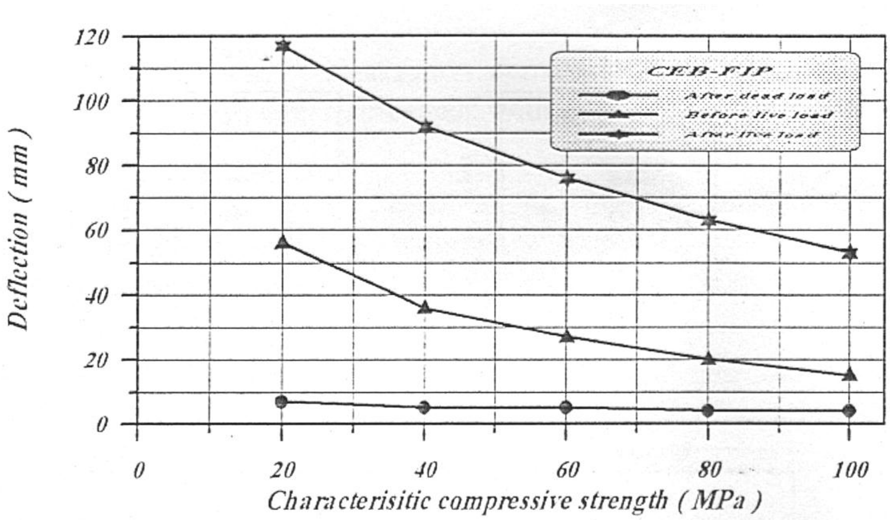

Figure (5) Effect of concrete strength on deflection by using material properties calculated according to CEB-FIP MC-92 and CEB model

Table (5) Calculated midspan deflections using the proposed model* for the example

Fck MPa	After dead load		Before live load		After live load	
	Deflection mm	*Crack Y/N*	*Deflection mm*	*Crack Y/N*	*Deflection mm*	*Crack Y/N*
20	7	N	56	Y	110	Y
40	5	N	36	Y	85	Y
60	5	N	27	N	69	Y
80	4	N	20	N	58	Y
100	4	N	15	N	51	Y

* *Concrete properties are according to CEB-FIP MC-90.*

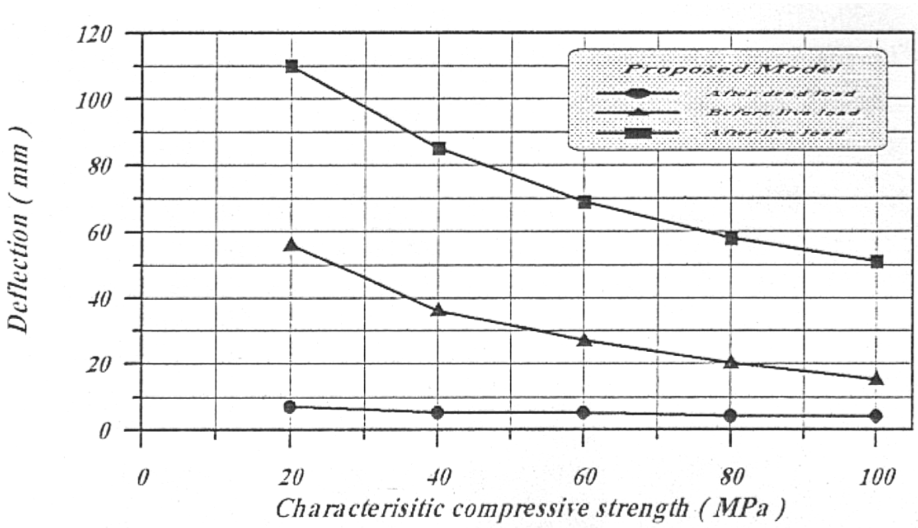

Figure (6) Effect of concrete strength on deflection by using material properties calculated according to CEB-FIP MC-92 and proposed model

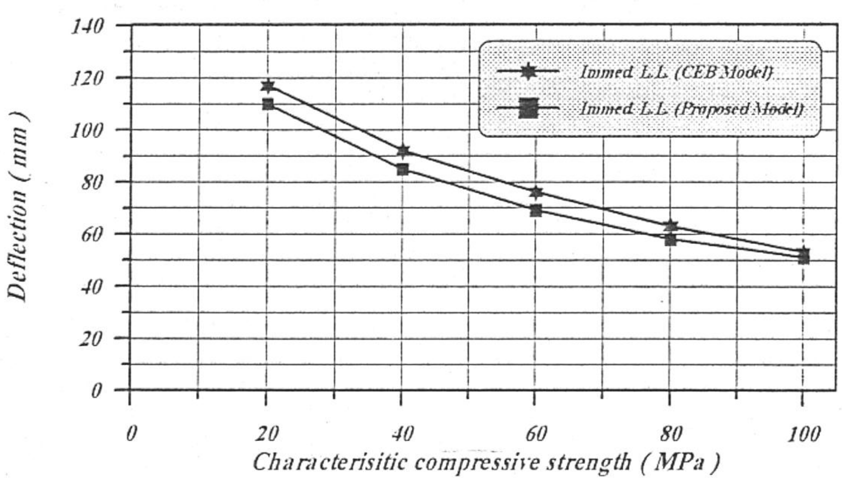

Figure (7) The comparison between the CEB-FIP model and the proposed model with concrete properties are according to CEB-FIP MC-90

5-1-2 Comparison between Proposed Theoretical Model and Test Results

Most of the currently available laboratory test results have been obtained from partially prestressed beams with the same concrete strength. Tests for beams with various concrete strengths were not found in the literature. However, one of the useful laboratory tests is used and described in this section to explore the efficiency of the proposed model and to compare the proposed model with other models.

1. The Experimental Study

Prestressed concrete beams tested by Hutton and Loov [7] for measuring the long-time deflections under sustained load are used here. **Figure (8)** shows the cross sections and loading condition of two partially pre-tensioned beams (1P-2R-2), and (2P-1R-2).

The experimental results will be discussed in the following section. In this section the hypothetical situation is described, as follows:

a) Gravity loads

- Dead load moment = 0.58 kN. m
- Live load moment = 9.59 kN.m

b) Concrete Properties

- ***fc'*** (to = 7 days) = 46.9 MPa
- ***fc'*** (t = 114 days) = 51.7 MPa
- $(\varepsilon_{sh})_{experimerntal} =- 460 \times 10^{-6}$ m/m

Table (6) gives the concrete properties according to *ACI 209R-92,* and *CEB-FIP MC-90* Model Codes.

c) Prestressing and Nonprestressing Steel Properties

- The tension in prestressing tendon before transfer for beam (1P-2R-2) = 48.41 kN, and for beam (2P-1R-2) = 98.12 kN
- The reduced relaxation for the period (t, to) = -90 MPa

- The modulus of elasticity of prestressing steel = 193 GPa
- The modulus of elasticity of non-prestressing steel = 200 GPa

The model analysis is performed once using the creep coefficient, modulus of elasticity, and tensile strength of concrete in accordance with *ACI 209R-92 Code,* and once using the corresponding values according to *CEB-FIP MC-90.* The computer program **"PPCD",** developed in this work, is used to calculate the immediate and long-time deflections for beams (1P-2R-2), and (2P-1R-2). **Table (7)** compares the measured deflections and the immediate live load deflections determined by different models, and the corresponding difference in percent is included.

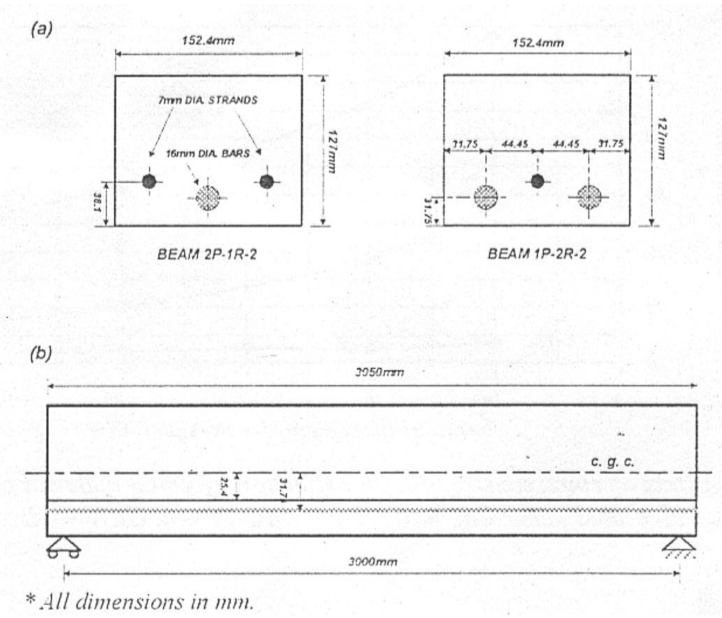

Figure (8) Cross section and dimension of experimental beams*

Table (6) The concrete properties for Experimental beams

Concrete properties according to	Modulus of elasticity $E_c(t_0)$, GPa	Modulus of elasticity $E_c(t)$, GPa	Modulus of rupture $F_r(t)$, MPa	Telsile strength F_{ct}, MPa	Creep Coefficient $C(t,t_o)$
ACI 209R-92	32.2	33.8	4.07	-	1.47
CEB-FIP MC-90	38	39.1	-	2.68	1.75

2. Verification Using Experimental Study

The efficiency of the model analysis is demonstrated in the following by comparing the calculated deflections with experimental values reported by Hutton and Loov [7]. They measured deflections during. 114 days of sustained load on four beams with the same size and the same concrete strength, but with different prestressing forces. Two of these beams are partially prestressed beams [(1P-2R-2), and (2P-1R-2)], and others are fully prestressed beam

(3P-OR-2), and ordinary reinforced concrete beam ***(OP-3R-2).***

The beams (1P-2R-2) and (2P-1R-2) are selected to apply the analytical model proposed in this study.

Table (7) Predicted long-term deflections by using different models for the experimental beams

Using the	Beam (1P-2R-2)		Beam (2P-1R-2)	
	After live load deflection, mm	*Difference (percent %)*	*After live load deflection, mm*	*Difference (percent %)*
ACI Model	26.9	12.6	26.8	15.0
CEB-FIP Model	26.1	8.8	25.8	10.7
The proposed Model	24.4	2.1	23.9	2.6

The measured deflection = 23.9 mm./The measured deflection = 23.3 mm.

Table (7) and **Fig.(9)** compare the measured immediate live load deflections with values determined by *ACI 209R-92* model, *CEB-FIP MC-90* model, and *the proposed* model. The corresponding absolute percentage difference values are: 12.6 %, 8.8 %, and 2.1 % for beam (1P-2R-2); and 15.0 %, 10.7 %, and 2.6 % for beam (2P-1R-2) respectively.

The previous comparisons indicate that the accuracy of the proposed model in deflection prediction of prestressed concrete beams is more acceptable than other models adopted by current Codes.

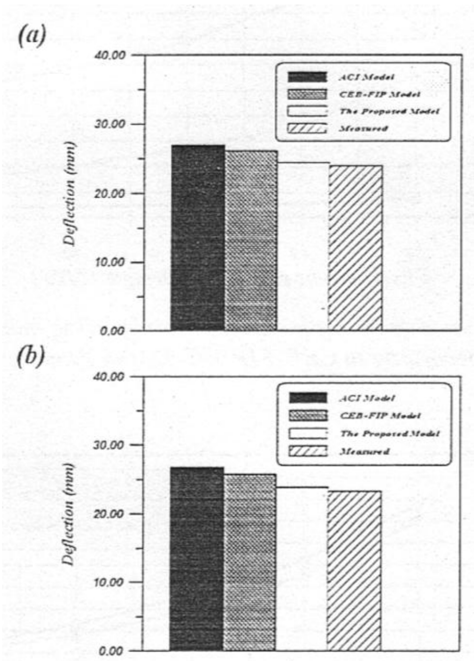

Figure (9) The measured and predicted long-term deflection by different models for the experimental study:
(a) For 1P-2R-2 beam, and (b) For 2P-1R-2 beam

6. Conclusions

Based on the results of this work, the following conclusions can be drawn:

1. The effects of time-dependent factors cause increment forces and deformations in prestressed beams; which may be greater than the instantaneous forces and deformations. Furthermore, strains increase and stress redistribution takes place.

2. The "Proposed Mean Curvature" idealization derived exclusively for prestressed concrete members is adopted and shows better agreement with experimental data than the conventional models (e.g. Branson's).

3. A computer program ***"PPCD"*** is developed in this work following the proposed model. Immediate and long-time deflections of prestressed concrete beams can be computed. Concrete compressive strength, tension-stiffening effect, and time-dependent factors are included in this program.

4. The effect of varying compressive strength on deflection is significant, especially before and after applying the live load. This is related to the influence of concrete strength on time-dependent factors such as creep, shrinkage, and relaxation of steel.

5. Tension stiffening effect, included in the proposed model and associated with high strength concrete usually used in prestressed concrete members is seen to yield more accurate results, as given below:

- ***For beam (1P-2R-2)***

The percent difference with experimental data is only 2.1 % compared with 8.8 % for CEB-FIPMC-90 model, and 12.6 % for ACI 209R-92 recommendations.

- ***For beam (2P-1R-2)***

The percent difference with experimental data is only 2.6 % compared with 10.7 % for CEB-FIPMC-90 model, and 15.0 % for ACI 209R-92 recommendations.

6. Effects of prestressing and high-strength compressive strength of concrete are included in the model. The models of rigidity evaluation[0,31] originally derived for normal strength concrete is not suited for high-strength concrete which is usually the case for prestressed concrete members.

7. Reference

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