V - 195

PREDICTION OF THE ULTIMATE FLEXURAL STRENGTH OF CONTINUOUS PC BEAMS WITH EXTERNAL PRESTRESSING

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1. INTRODUCTION

The ultimate flexural strength of externally prestressed members depends on the tendon stress at ultimate state, which is member dependent rather than section dependent as in the beams with bonded tendons. As such, there is a necessity for a rational design equation to predict the tendon stress at ultimate of such beams. Based on a comprehensive parametric study, a new design equation was proposed to predict the ultimate strength of single span PC beams [1]. This paper describes how the proposed equation could be extended to predict the tendon stress of continuous beams with various loading configurations.

2. BASIS OF THE PROPOSED METHODOLOGY

The general form of the ultimate tendon stress for unbonded tendons can be expressed as follows:

$$f_{ps} = f_{pe} + \Delta f_{ps} \quad (1)$$

Where f_{ps} is the ultimate tendon stress, f_{pe} is the effective initial prestress and Δf_{ps} is the increase of tendon stress. Based on the concept of strain reduction coefficient Ω_u, Naaman proposed a design equation for unbonded beams which reduces to a simplified section dependent analysis [2]. Considering the change in tendon position at ultimate state, Mutsuyoshi [3] proposed the idea of depth reduction factor R_d, for the prediction of the ultimate strength of beams with external prestressing. Using the concepts of Ω_u and R_d a new design equation was proposed based on an extensive parametric study as follows [1]:

$$f_{ps} = f_{pe} + E_{ps}\Omega_u\varepsilon_{cu}\left(\frac{d_{pu}}{c} - 1\right) \leq f_{py} \quad (2)$$

Where Ω_u is defined as the ratio of the strain increase in unbonded tendon to that of concrete at the tendon level at the critical section and can be obtained from the following equation:

$$\Omega_u = \frac{0.21}{(L/d_{ps})} + 0.04\left(\frac{A_{ps,int.}}{A_{ps,tot.}}\right) + 0.04 \quad \text{for one-point loading} \quad (3a)$$

$$\Omega_u = \frac{2.31}{(L/d_{ps})} + 0.21\left(\frac{A_{ps,int.}}{A_{ps,tot.}}\right) + 0.06 \quad \text{for third-point loading} \quad (3b)$$

The ultimate tendon position d_{pu} ($= R_d d_{ps}$) can be computed from R_d, given by the following expression:

$$R_d = 1.14 - 0.005\left(\frac{L}{d_{ps}}\right) - 0.19\left(\frac{S_d}{L}\right) \leq 1.0 \quad \text{for one-point loading} \quad (4a)$$

$$R_d = 1.25 - 0.010\left(\frac{L}{d_{ps}}\right) - 0.38\left(\frac{S_d}{L}\right) \leq 1.0 \quad \text{for third-point loading} \quad (4b)$$

In the above equations, Ω_u and R_d are functions of span-to-depth ratio (L/d_{ps}), deviator distance-to-span ratio (S_d/L) and ratio of internal bonded tendon ($A_{ps,int}/A_{ps,tot}$).

Experimental investigations have shown that the increase in the ultimate tendon stress in unsymmetrically loaded continuous beams are significantly small compared to the fully loaded beams. This could be attributed to the smaller deflection of the lightly loaded span in the unsymmetrical loading. A reduction factor is proposed in this study, to incorporate the above feature. Based on a non-linear analytical methodology, a computer program was developed to predict the flexural behavior of continuous beams with external tendons [4]. Using this program, the effect of partial loading on the ultimate behavior of continuous beams was studied by conducting a parametric analysis. For evaluation purpose a 2-span

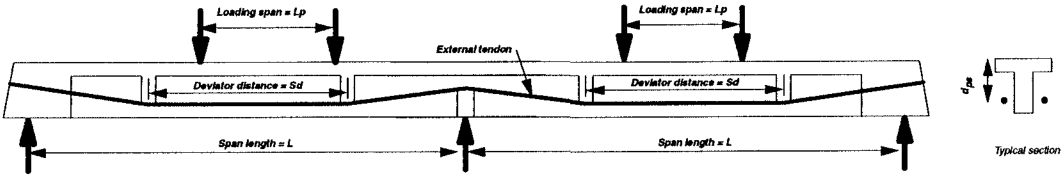

Fig. 1 Model of 2-span continuous PC beam used in the parametric evaluation

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beam with two point loads on each span was used as shown in Fig. 1. The span-to-depth ratio (L/d_{ps}), was varied from 15 - 30 and the loading on right span was varied from 0 - 100% while the left span was fully loaded. The combination of the above two variables led to a total number of 55 cases that were evaluated in this study.

3. PROPOSED EQUATION AND ITS EVALUATION

The result of the parametric evaluation is summarized in Fig. 2. It is observed that for lower load ratio, the increase in tendon stress ratio was almost negligible. However, for load ratio above 0.5 it is significant. Using a curve fitting method the best fit obtained for the reduction factor λ can be expressed by the following relationship:

$$\lambda = \left(\frac{P_p}{P_u}\right)^5 \qquad (5)$$

Where P_p is the partially applied load and P_u is the ultimate design load in the span under consideration. To incorporate the effect of different span lengths the above equation can be extended by proportionally distributing the reduction factor among each span, as given below:

$$\lambda_n = \sum_{i=1}^{n} \frac{L_i}{L_t}\left(\frac{P_p}{P_u}\right)^5 \qquad (6)$$

Where n is the total number of spans, L_i is length of the i^{th} span and L_t is the total length of the tendon between anchorage points. The reduction factor expressed in Eq.(6) is introduced in the basic expression given by Eq.(2) and the modified equation for continuous span beams shall be as follows:

$$f_{ps} = f_{pe} + \lambda_n E_{ps}\Omega_u\varepsilon_{cu}\left(\frac{d_{pu}}{c} - 1\right) \leq f_{py} \qquad (7)$$

From Eq.(7), using the similar procedure of single span beams the ultimate tendon stress and strength can be calculated as explained in [2]. Figs (3) and (4) show the accuracy of the new design equation with the experimental results [5]. Compared with the AASHTO (1994) recommendation which is based on Naaman's equation, the proposed equation predicts the ultimate tendon stress and flexural strength of continuous beams with a better accuracy.

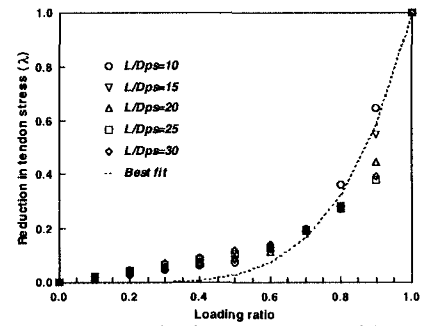

Fig. 2 Reduction in tendon stress with loading ratio

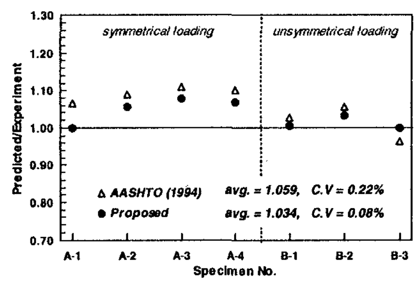

Fig. 3 Comparison of ultimate tendon stress

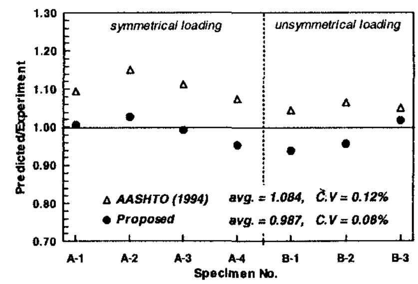

Fig. 4 Comparison of ultimate strength

4. CONCLUDING REMARKS

A design equation is proposed to predict the ultimate tendon stress for continuous beams with external prestressing based on a parametric evaluation. The following conclusions were drawn from this study.

- The ultimate tendon stress in partially loaded continuous beams are considerably small compared to the fully loaded beams. This is incorporated in the proposed design equation by introducing a reduction factor. Evaluation with experimental data shows good correlation.
- It is recommended that the accuracy of the proposed equation should be evaluated with other experimental investigation available for continuous PC beams.

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