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Algorithm For Calculation Of Multi Span Uncut Beams Taking Into Account The Nonlinear Work Of Reinforced Concrete

A.T.Mirzaahmedov
Dots.Fargona Polytechnic Institutes, Uzbekistan

S.G'.G'ulomiddinov
Fargona Polytechnic Institutes, Uzbekistan

ABSTRACT

An algorithm for calculating multi-span continuous beams is developed on the basis of the integral deformation modulus method. This takes into account the nonlinear and nonequilibrium properties of concrete deformation, the rheological equations of the mechanical state.

KEYWORDS

Computational algorithm, intermediate supports, canonical equations, concrete, elastic.

INTRODUCTION

The calculation algorithm is based on the method of integral modulus of deformations.A diagram of a multi-span continuous beam and the corresponding basic system are shown in Fig. 1.

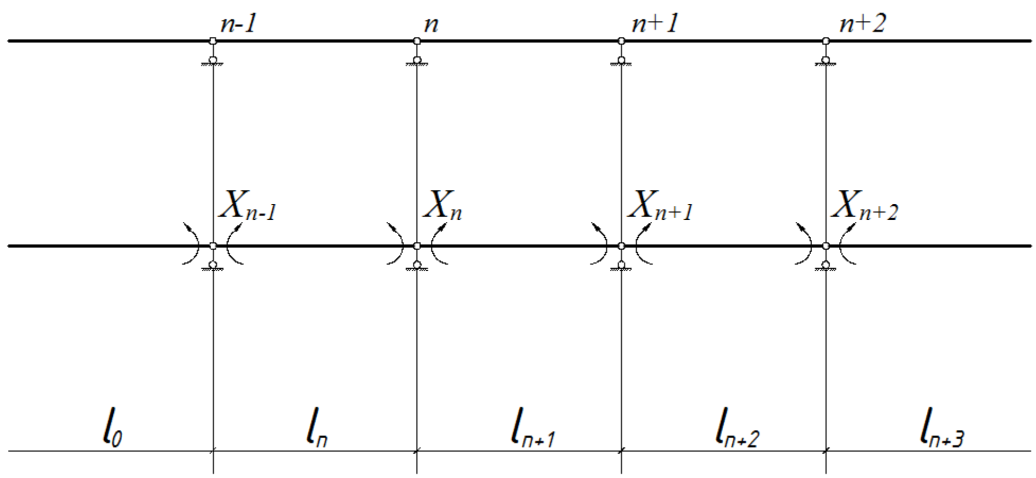

Fig. 1. Non-cutting continuous beam

It is believed that the beam can have variable sections. The load on it is set in the form of moments of the main system. The continuous beam is calculated by the force method, with the basic system composing the moments on the intermediate supports.

The system of canonical equations of the force method consists of equations of the type.

$$б_{n.n-1}\,\mathrm{X}_{\text{п}-1} + б_{n,n}\mathrm{X}_n + б_{n.n} + 1\mathrm{X}_n + 1 + \Delta_{n,\text{р}} = 0 \qquad (1)$$

The number of such equations is known to be equal to / n-2 /, where
P is the number of spans of a continuous beam.
Taking into account the variability of the stiffness of the elements, the coefficients of the canonical equations can be represented in vice

$$б_{n.n-1} = \frac{l_n}{\text{м}^3}\sum_{\text{к}=1}^{m}\frac{2m\text{к} - 2\text{к}^2 - m + 2\text{к} - 2/3}{D_{n.\text{к}-1} + D_{n.\text{к}}}$$

$$б_{n.n} = \frac{l_n}{\text{м}^3}\sum_{\text{к}=1}^{m}\frac{2\text{к}^2 - 2\text{к} + 2/3}{D_{n.\text{к}-1} + D_{n.\text{к}}}$$

$$б_{n.n+1} = \frac{l_{n+1}}{m^3}\sum_{\text{к}=1}^{m}\frac{2m\text{к} - m - 2\text{к}^2 + 2\text{к} - 2/3}{D_{n+1.\text{к}-1} + D_{n+1.\text{к}}}$$

$$\Delta_{n.p}=\frac{1}{3m^2}\left\{l_n\sum_{\text{к}=1}^{m}\frac{(3\text{к}-2)\text{M}^0_{n.\text{к}+1}+(3\text{к}-2)\text{M}^0_{n.\text{к}}}{D_{n.\text{к}-1}+D_{n.\text{к}}}+l_{n+1}\sum_{\text{к}=1}^{m}\frac{(3(m-\text{к})+2)\text{M}^0_{n+1.\text{к}-1}+(3(m-\text{к})+2)\text{M}^0_{n+1.\text{к}}}{D_{n+1.\text{к}-1}+D_{n+1.\text{к}}}\right\}$$

After solving the system of canonical equations of type (I) at each stage of the approximation, the numerical values of the extra unknowns Xn are obtained. This makes it possible, in any section n, to the value of bending moments for a given approximation number

$$\text{M}_{n.\text{к}}=\text{M}^0_{n,\text{к}}-\text{X}_n\frac{\text{К}}{m}-\text{X}_{n-1}\frac{m-\text{к}}{m}$$

Information about the diagrams of bending moments allows you to refine the stiffness of the beam sections, which are necessary for the next stage of approximation and. etc.

The calculation takes into account the nonlinear and nonequilibrium properties of concrete deformation, the rheological equations of the mechanical state, which are written according to S.V. Aleksandrovsky [1].

The algorithm of the above calculation methodology will be performed in the following order.

1. Determination of elastic bending moments: After solving the system of canonical equations (1), elastic supporting bending moments are obtained.

2. Calculation of the section stiffness:

$$D=E_b^{\text{ин}}\left[\frac{bx^3}{12}+bx\left(q-\frac{x}{2}\right)^2\right]+\beta_S^{\cdot}E_S^{\cdot}A_S^{\cdot}(q-a^{\cdot})^2+\frac{\beta_S}{\Psi_S}E_SA_S(h_o-q)^2$$

Where $E_b^{\text{ин}}$- integral modulus of elasticity of concrete;

b - cross-sectional width;

x – the height of the compressed zone of the concrete section;

q – distance of the center of gravity of the reduced section from the compressed face;

$\beta_S^{\cdot}\beta_S$ – deformation nonlinearity function of reinforcing steel;

Ψ_S – coefficient taking into account the work of tensile concrete between cracks;

$E_S^{\cdot}E_S$ – modulus of elasticity of reinforcement;

$A_S^{\cdot}A_S$ – cross-sectional area of reinforcement;

$a^{\cdot}$ – cover height;

h_o – useful section height.

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3. Determination of bending moments in any section П, К:

$$M_{n.\kappa} = M^0_{n,\kappa} - X_n \frac{К}{m} - X_{n-1} \frac{m - \kappa}{m}$$

4. Calculation of the coefficient that takes into account the work of tensile concrete between cracks:

а/при M < M_{bt}

$$\Psi_s = a_{g.m} + b_{g.m} \left(\frac{M}{M_{np}} \right)^{c_{g.m}}$$

б/при M > M_{bt}

$$\Psi_s = 1{,}3 - S\frac{M_b}{M}$$

Where $$M_{b.m} = 0{,}8 + W_{b.m} R_{b.m}$$

Here $$W_{b.m} = 0.292\, bh^2$$

0.8 - coefficient taking into account the effect of shrinkage on the tensile strength of concrete;
$W_{b.m}$ – elasti c-plastic moment of resistance of the concrete section before cracking;
$R_{b.m}$ – design concrete resistance.
$a_{g.m}$ – coefficient calculated by the formula

$$a_{g.m} = \Psi_0 = \left(1 + \frac{E_{b.o} J_{b.p}}{E_S J_S} \right)^{-1}$$

Here

$E_S, E_{b.o}$ – initial moduli of deformations of reinforcing steel and concrete;
$J_S, J_{b.p}$ – moments of inertia of the tensile zone of concrete and tensile reinforcement relative to the axis passing parallel to the neutral axis through the center of gravity of the section.
$b_{g.m}$ – coefficient equal

$$b_{g.m} = \frac{\Psi_m - \Psi_0}{\left(\frac{M_m}{M_{np}} \right)^{c_{g.m}}}$$

Here $$\Psi_m = a_{n.m} + b_{n.m} \left(\frac{M_m}{M_{np}} \right)^{c_{g.m}}$$

M_T – moments of cracking for the calculated reinforced concrete section;

$$M_{np} = M$$

$C_{g.m}$ – coefficient calculated by the formula

$$C_{g.m} = \frac{b_{n.m}C_{n.m}}{\Psi_m - \Psi_0}\left(\frac{M_m}{M_{np}}\right)^{C_{n.m}}$$

Here $$b_{n,m} = -S\frac{M_b}{M_{np}}$$

S – coefficient characterizing the profile of the bar reinforcement and the duration of the load;

$$C_{n.m} = -1$$

5. Condition check:

$$|\Psi_{s.i}| - |\Psi_{s.i} - 1| > \xi$$

Where ξ – a measure of the accuracy of the calculation.

If the specified condition is satisfied, then the calculation ends, otherwise, it is repeated from point 2

6. Calculation of the moment of resistance of a reinforced concrete section:

$$W = \frac{bx^2}{2 - \eta_\delta} + \frac{\beta_S E_S}{\Psi_S^2 E^{bp}} A_S \frac{(h_0 - x)^2}{x} + \frac{\beta_S^{\prime} E_S^{\prime}}{E^{bp}} A_S \frac{(x - a')^2}{2}$$

Where Π_δ – normal stress nonlinearity parameter;
E^{bp} – temporary modulus of elasticity of concrete.

7. Calculation of stresses by the formula:

$$\mathfrak{S} = \frac{M}{W}$$

8. Calculation of the normal stress nonlinearity parameter:

$$\eta_\delta = 1 - (1 - f_0)\left(\frac{\mathfrak{S}}{R_b}\right)^{M6}$$

Where $f_0 = \frac{E_R}{E_0}(0 < f_0 \ll 1)$ – the parameter of nonlinearity of the relationship between stresses and strains in a uniaxially loaded specimen, determined by the ratio of two tangential deformation moduli in a given loaded mode;

E_R – tangential modulus of deformation at the moment of destruction;

E_0 – initial deformation modulus;

m_6 – the parameter reflecting the rate of increase in the curvature of the diagram of normal stresses as the level of the inhomogeneous stress state / m_6 grows can be taken equal to $\frac{1}{1,5}m_{\mathcal{N}}$; m_M=5,7-0,005R_{np}

R_b – bending strength of concrete.

9. Condition check:

$$|\eta_{\delta.i}| - |\eta_{\delta.i} - 1| > \xi$$

If the specified condition is met, then the calculation ends, otherwise, it is repeated from point 6.

10. Calculation of nonlinearity of deformation of reinforcing steel:

$$\beta_S = \left[1 + \eta_s \left(\frac{\mathfrak{S}_s}{R_{\frac{b}{s}}}\right)^{m_s}\right]^{-1}$$

Where η_s and m_s – deformation nonlinearity parameters;

$\mathfrak{S}_s$ – stress determined by the formula

$$\mathfrak{S}_s = \frac{M}{h_0 - \frac{x}{3}} A_S$$

11. Calculation of the height of the compressed zone of a concrete section:

$$X = \frac{1}{2A}\left(\sqrt{B^2 + 4AC} - B\right);$$

Where

$$A = \frac{bE^{bp}}{1 + \eta_6}$$

$$B = \frac{\beta_s}{\Psi_s} E_s A_s + \beta_s' E_s' A_s'$$

$$C = \frac{\beta_s}{\Psi_s} E_s A_s h_0 + \beta_s' E_s' A_s' a'$$

12. Condition check:

$$|X_i| - |X_{i-1}| > \xi$$

If the specified condition is met, then the calculation ends, otherwise, it is repeated from point 6.

13. Determination of the value of the temporary modulus of deformation:

$$E^{bp} = \frac{1}{R_1}$$

$$R_1 = R_2 - \frac{1}{\mathfrak{S}} \sum_{j=1}^{i} \left[1 + \eta_n \left(\frac{\mathfrak{S}_i}{R_b}\right)^{m_n}\right] \{ (C_0 + A_0 e^{-JR4}) \left[1 - e^{-J(R3-R4)}\right] - (C_0 + A_0 e^{-JR5}) \left[1 - e^{-J(R3-R5)}\right] \}$$

Here

$$R_2 = \frac{\mathcal{E}_y}{\mathfrak{S}} + \frac{\left[1 + \eta_\kappa \left(\frac{\mathfrak{S}}{R_б}\right)^{m_n}\right]}{E_м}$$

Here

$$R_h = (d - c\alpha)R_b$$

Where d=1.25 and C=0,25 /according to N.F. Davydov and O.M. Donchenko / [3];

$$\alpha = \frac{x}{h_0}$$

$\mathcal{E}_y = \alpha_y \eta_4$ – shrinkage deformation,

Where $\alpha_y = \eta_1 \eta_2 \eta_4 \alpha_y^c$ – limiting relative shrinkage deformation.

Here $\alpha_y^c, \eta_1, \eta_4$ – shrinkage coefficients / is taken from table. [2];

$$R_3 = m \frac{t - t_0}{10} + t_0$$

$$R \quad = i_1 \frac{t - t_0}{10} + t_0$$

$$R_5 = (i_1 - 1)\frac{t - t_0}{10} + t_0$$

Where

$$i_1 = 1 \div m$$

m – time interval from t_0 to t.

14. Calculation of the integral modulus of deformations:

$$E^{uн} = \Phi E^{bp}$$

Where

$$\Phi = \frac{3 + \eta_\delta}{2 + 2\eta_\delta}$$

15. Calculation of the distance of the center of gravity of the reduced section from the compressed face:

$$q = \frac{E^{uн} bx\,\frac{x}{2} + \beta_s' E_s' A_s' a' + \frac{\beta_s}{\Psi_s} E_s A_s h_0}{E^{uн} bx + \beta_s' E_s' A_s' + \frac{\beta_s}{\Psi_s} E_s A_s}$$

16. Checking the condition:

$$|M_i| - |M_{i-1}| > \xi$$

If the specified condition is met, then the calculation ends, otherwise, it is repeated from point 2.

17. Checking the condition:

$$m \gg \xi$$

If the specified condition is satisfied, then the calculation ends, otherwise m = m + 1 and is repeated from point 2.

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