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Failure Mechanism Of Bending Reinforced Concrete Elements Under The Action Of Transverse Forces

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ABSTRACT

The article under discussion reveals the formation and development of inclined sections in bent reinforced concrete elements under the action of transverse forces. It is established that the strength of the bending element depends on the shape of destruction. Criterion of strength in a flat stress-strain state has been used to evaluate the work of the bending element.

KEYWORDS

Transverse force, bending moment, concrete, reinforcement, inclined cracks, strength criteria, shear span, strength.

INTRODUCTION

One of the important issues in the study of bending elements reinforced with composite reinforcements is the formation and development of inclined cracks and element failure under the action of transverse forces. This issue is subject to careful study by researchers conducting research with the use of steel armature.

METHODS

As a rule, normal cracks first appear when a bending concrete element is loaded,

Then, in the area of bending moments and transverse forces, inclined cracks are created. Two types of inclined cracks are distinguished. One of the cracks starts from the stretched edge of the element and develops normally towards it and then slopes. It is established by experiments [1,2,5,7] that these cracks appear in the zone of large bending moments. Gradually, they spread to the support block.

As they approach the support block, the inclination of the element of these cracks to the longitudinal axis increases. Other cracks are formed within the cross-sectional height of the element with an inclination to the longitudinal axis. Immediately after formation, these cracks extend to a considerable length, then it gradually develops towards the compressed and stretched edges of the element, in the direction of the support block and the load.

Horizontal and weakly sloping cracks are formed at the stretched edge, at pre-support zones, from the point of intersection of longitudinal reinforcement of the inclined crack. Often, such cracks develop towards the support block and from it at the level of longitudinal reinforcement. At the compressed edge of the element there is a curvature of the inclined crack. Further contraction of the compressed zone does not occur and the crack develops parallel to the compressed face. At the stages of loading, close to failure, there are cracks beginning from the upper edge of the beam at the support block.

If inclined cracks are the main cracks in the area of transverse forces, the other cracks, such as horizontal and inclined cracks along the longitudinal armature, normal cracks at the stretched edge of the element should be considered additional, associated with the formation of the main cracks.

When the element breaks in an inclined section, in beams without transverse reinforcement, there is a development of inclined cracks in the zone of pure bending, and in beams with vertical clamps the top of the inclined crack is in front of the load.

At a large relative length of the section with a two-digit moment sequence (and), two main inclined cracks are formed, developing within both zones of action of moments of different signs, without going over the zero point of the moment sequence. At values only one inclined crack is formed, which diagonally intersects both zones of different signs, and at low values short inclined cracks are formed, which distinguish an inclined concrete strip between the support and the load.

When I-shaped concrete beams are loaded, inclined cracks are formed earlier than normal or simultaneously with them. The first inclined cracks appear in the beam wall, with an angle of inclination to the longitudinal axis of 30-40°. As the load increases, these cracks develop along the lower shelf towards the support block and new inclined cracks appear.

In beams without transverse reinforcement, the inclined cracks open up wide as soon as they appear, and once the load is removed, these cracks do not close completely. It has been determined that opening of inclined cracks depends on transverse reinforcement. In case of strong reinforcement only in stages close to fracture, inclined cracks open up gradually. Cracks, formed in the middle part of the cross-section height, arise when the value of the main tensile stresses of the concrete's tensile resistance is reached. Local stresses have a significant impact on the formation of inclined cracks near the support blocks and concentrated loads.

RESULTS AND DISCUSSION

The theory of strength and crack resistance of reinforced concrete elements under the action of transverse forces was most fully reflected in the works of A.S. Zalesov [4,5]. According to this theory, the formation of inclined cracks can be expressed by the condition that the combination of two main stresses $(\sigma_1 = \sigma_{г.c}$ и $\sigma_3 = \sigma_{г.p})$ or normal and tangential stresses $(\sigma_x, \sigma_y$ and $\tau_{xy})$ from the forces acting in the element reaches the calculated criterion of concrete strength under the flat stressed state.

The estimated criterion for the "compression-stretch" area is as follows:

on: $\frac{\sigma}{R_b} \leq 1-\lambda$ $\frac{\sigma_3}{R_{bt}} = 1$ (1)

on: $\frac{\sigma}{R_b} \rangle 1-\lambda$ $\frac{\sigma}{R_b} - \lambda\frac{\sigma_3}{R_{bt}} = 1$ (2)

where: $\lambda = 1-\upsilon$ $\upsilon = \frac{\sigma_1}{R_b}$

determining the boundary between equations (1) and (2) as a function of concrete strength (Fig. 1.)

For the "compression-compression" area, a simplified dependence is adopted:

$$\frac{\sigma_1}{R_b} = 1 \quad (3)$$

The forces acting in concrete are expressed as longitudinal and transverse components defined by normal and tangential stresses (σ_x, σ_y and τ_{xy}). Graphically obtained criterion is a series of curves that determine the limit values of tangent stresses depending on normal stresses σ_x and σ_y (Fig. 2).

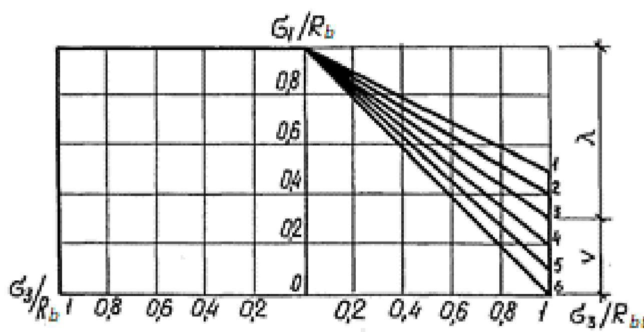

Fig.1. Calculated criterion of concrete strength at flat stress state in the coordinates of main stresses: 1 - B25 and below; 2 - B35; 3 - B40; 4 - B45; 5 - B55; 6 - B60[4].

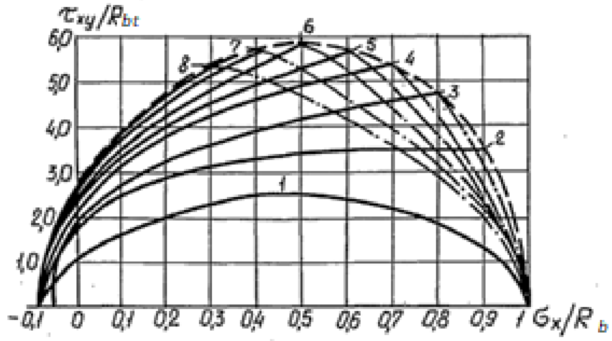

Fig. 2. Calculated criterion of concrete strength at flat stress state in the coordinates of normal and tangent stresses, at equal: 1–0; 2–0,1; 3–0,2; 4–0,3; 5–0,4; 6–0,5; 7–0,6; 8–0,7 [4].

Studies have demonstrated that in a wide range of mean values of normal voltages σ_x between zero and R_b limit tangent voltages τ^u_{xy} can be taken constant regardless of the value σ_x and changing only depending on the voltage σ_y. In this case, the highest value τ^u_{xy} reaches $0{,}5R_b$.

To assess the formation of inclined cracks, it is necessary to establish a scheme of the stress state in the element, expressed in the form of stress distribution σ_x, σ_y and τ_{xy} and calculated criterion of concrete strength.

The stress state in the reinforced concrete element before the formation of inclined cracks is influenced by the presence of normal cracks, work of stretched concrete over the crack, inelastic deformations of compressed and stretched concrete and violation of force transfer from concrete to reinforcement, which is observed after the formation of normal cracks in the zone of transverse forces. When constructing the calculated scheme of stress distribution it is necessary to take into account these factors, reflecting the specific features of the concrete element.

The distribution of stresses σ_x, σ_y and τ_{xy} and the height of the section in the general case has a curvilinear character. For determination of normal stresses σ_x, the following system of equations is solved:

$$\int_F \sigma_x dF = \sigma_s A_s \qquad (4)$$

$$M = \int_F \sigma_x z_x dA \qquad (5)$$

$$\frac{\varepsilon_b}{\varepsilon_s} = \frac{x_0}{h_o - x_o} \qquad (6)$$

where: x_0 – the height of the compressed concrete zone above a normal crack.

Theoretically, the value of tangential stresses can be determined from the increment of normal stresses along the length of the element:

$$\tau_{xy} = \int_0^x \frac{d\sigma_x}{dl} dx \qquad (7)$$

in general, the values of stresses σ_x depend on the value of edge stresses $\sigma_x^{\max}$ and the height of the concrete zone without crack x_b i. e. they are a function $\sigma_x^{\max}$ and x_b. Unknown $\sigma_x^{\max}$ and x_b are determined from the solution of the equation of equilibrium of longitudinal forces and moments in normal section and integration of their respective derivatives.

In the section where moments are not large and normal cracks are not formed, the tangent stress epurora is expressed as a parabola along the entire height of the element.

The value of tangential stresses is determined from the equation of equilibrium of transverse forces in the considered normal section:

$$Q = \int_F \tau_{xy} dA \qquad (8)$$

Normal stresses σ_y arise from the local action of the load, concentrated or distributed and support reactions. The formula for determining stresses σ_y considering the size of the force support area and using a simplified method has the following form:

$$\sigma_y = \frac{P}{b(2{,}5x + l_{on})}(1 - \frac{x}{h_0})(1 - 0{,}4\frac{y}{x})$$

where: x - distance from the point of concentrated force application to the point under consideration vertically;

y - the distance from the edge of the support area to the point under consideration horizontally (Fig. 1).

Determining the stresses σ_x, σ_y and τ_{xy} from the load and comparing them with the calculated criterion of concrete strength, there is the size of the load and the place at which they coincide. This load will determine the formation of inclined cracks [4, 5].

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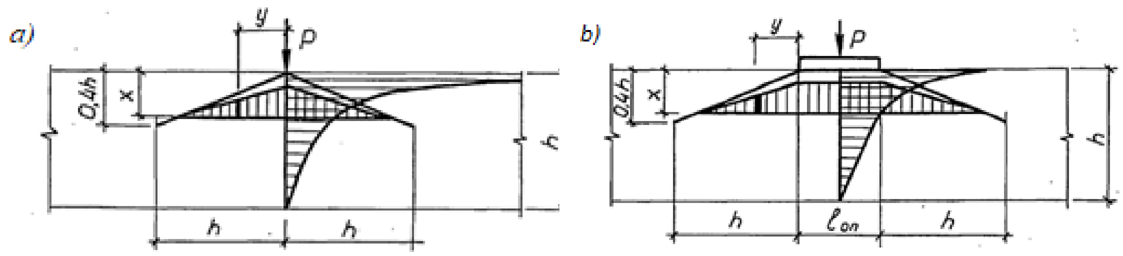

Fig. 3. Voltage distribution diagrams from the concentrated force:
a - without taking into account the support area, b - with regard to the support area [2,4].

The condition determining the development of inclined cracks is considered to be the achievement by combination of two stresses σ_1 and σ_3, or normal σ_x, σ_y and tangential stresses τ_{xy} at the apex of inclined crack of the calculated criterion of concrete strength under the flat stressed state.

When an inclined crack develops, the stresses in the concrete above increase and at the moment when they reach the estimated criterion of concrete's strength under the flat stressed state, the concrete crashes above the inclined crack. When normal stresses σ_x are reached on the upper compressed boundary of the concrete resistance element of R_b equal value, the concrete is crushed above the inclined crack. If there are limit values of tangential stresses τ_{xy} at the top of a slope crack, the concrete is broken over the slope from the cut. These types of fracture are called fracture over a compressed zone. Destruction of the element along the stretched zone occurs when the connection between longitudinal reinforcement and concrete is broken in the section from the lower end of the gradient crack to the end of the element. There are also various combined forms of destruction in the inclined section, including elements of the considered forms of destruction. Destruction may occur suddenly or calmly when reaching the limit state in the inclined section. Sudden nature of the destruction is observed in the rapid opening of a sloping crack, or instantaneous violation of the connection of concrete with the longitudinal reinforcement. Quiet fracture occurs with a slow and gradual development of a slope crack [4,6,7].

Inclined section, which occurs along the critical inclined crack, is characterized by two geometric parameters - the height of the compressed zone of concrete above the inclined crack X and the length of the inclined crack projection on the longitudinal axis of the element - "C".

In empirical research work of the bent concrete elements reinforced with composite armature, it is necessary to pay attention to the scheme of loading, transverse and longitudinal reinforcement, class of concrete, dimensions of element cross-section. Clarification of the influence of these factors will establish the nature of the formation and development of inclined cracks, eventually - on the strength of the bending element in the inclined sections.

CONCLUSION

Empirical determination and theoretical background of the target work on bending elements reinforced with combined and composite armature creates strong and reliable prerequisites for the development of practical methods for calculating their inclined cross-sections and the creation of a regulatory framework.

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