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Calculation of Elements Considering Geometric and Physical Nonlinearity Bylumped-deformations Method

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Abstract: This article describes the use of multi-storey buildings and structures, which are one of the new promising areas. The use of prefabricated reinforced concrete, in comparison with full monolithic, dramatically reduces the labor intensity of work at the construction site. The prefabricated monolithic structure during the construction of statically indeterminate systems makes it possible to quite simply ensure the spatial rigidity of the building or structure as a whole, as well as to reduce the construction time in comparison with a complete monolith by several times, reduce the labor intensity of the production of works by about 1,5÷2 times and accordingly, the value of the object decreases. Plane and bending stress states are experienced by many structures of high-rise construction. These are beams - walls, and bracing systems, in which horizontal loads are perceived mainly by diaphragms and stiffening cores. There are various methods for solving problems for a plane and bending stress state, for example, the finite difference method, the finite element method, the limit equilibrium method and the method of concentrated deformations. The relevance in this work lies in the need to create a methodology for calculating reinforced concrete structures in multi-storey buildings and structures, based on the method of concentrated deformations (MSD) with implementation on computer technology, taking into account the influence of the expansion effect and real diagrams of deformation of concrete and reinforcement, at different loading times. It also describes in detail the formation of a flat and bending model for the analysis of reinforced concrete structures by the method of concentrated deformations, with a complete diagram of the deformation of concrete and reinforcement, taking into account geometric and physical nonlinearity, including a descending branch depending on the initial data. In addition, a comparison of the obtained results of analytical, theoretical and experimental research data is given.

Keywords: Calculation Model, Carrier Systems, Deformation, Voltage, Bend, Stretching, Geometric and Physical Nonlinearity

1. Introduction

For multistory civil and social housing the elements are being displayed as object of orientation for calculated and monitoring studies. The analysis of such studies confirms their similarity in relation to reference positions. However, they are different for their implementation methods. It is possible to figure out common constant tendency for them using computer technology and through improvement computation software and algorithm [1-4, 6-9, 10-13].

The relevance of the work lies in the need to create a methodology for calculating floor slabs supported along a contour in monolithic multi-storey buildings, based on the method of concentrated deformations (MSD) with implementation on computers, taking into account the effect of the expansion effect and real diagrams of deformation of concrete and reinforcement, at different loading times.

2. Method

Calculation of carrying capacity according to within standard section computes the external force intensity, is based on conditional scheme of voltage and deformations within concrete and reinforcing along the section [14, 15].

Calculation of formation of normal cracks is done basing on the positions different from calculation of carrying capacity and experimentally based data.

Calculation of reinforced elements consolidated by yielding bracing can be done with lumped-deformations method (Figure 1), which is widely described in the following papers [3-9].

In calculations of reinforced elements the simplicity of yielding bracing counting between the elements or within support structures is one of the advantages of this method.

In calculations of reinforced bending elements with lumped-deformations method the variable width parameters and for elements variable hardness parameters are assumed. It makes possible to accept elements which are larger than for finite-element method with the same accuracy grade of calculations. The significant difference of finite-element method from lumped-deformations method is the rigidity matrix formation.

These studies for improvement of element calculations are carried out under certain conditions with peculiar signs:

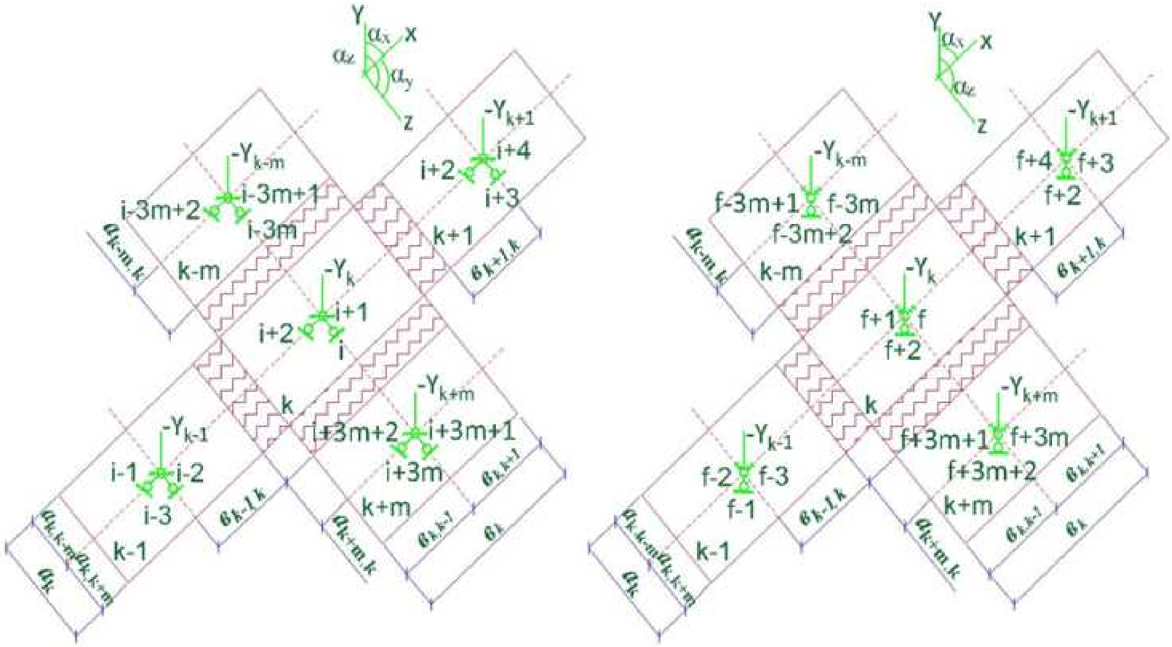

Figure 1. *Bending plate, connections of deflection method for plane and bending stress state.*

1) Using compete deformation diagrams in calculations «for single-axial concrete and reinforcing compression stretching under various operation modes»;
2) Consolidation of calculations of sections along with revelation of internal forces within statistically indeterminate systems;
3) Using computer technology in calculations.

Below is the overview of some of specified conditions.

In these prepares reinforced elements have their peculiar signs and are based on appropriate statements:

1) Concrete and reinforcing lengthwise deformation in the sections on all block steps are divided basing on plane deformation rule;
2) Lengthwise deformations and fitting normal voltage within concrete and reinforcing come out to be «average»;
3) Section of the element can be of any shape – rectangle, circle, W-shape, U-section and others (Figure 2).

Lengthwise deformation distribution rule inside concrete and reinforcing by rule of plane section hypothesis for strain-stress state is disputable. However, works on the stage preceding crack formation, that is accepted in works [14, 15], that is also true for the stage succeeding crack formation, but within sections between cracks and sections along crack; in other sites sections are surely bending.

For spaces between cracks according to plane section hypothesis the average value of concrete and reinforcing deformation is used. It is also acceptable the inclusion of some conditionally “stretchable” concrete which generally preserves integral stiffness properties of elements. Nevertheless, “stretchable” concrete included in calculations makes possible assessment of crack width like it is formulated in the study of Polyakov et al. [12].

For calculation of elemetns the similar application is not sufficient, that is explained with maximal physical schematism of this feature.

The significant stage in formation of calculation methos with non-linear working elements emerged due to use of computation equipment in application of iteration process. In calculations of carrying capacity and element stiffness it was allowed to apply comprehensive results similar to research data in maximum degree.

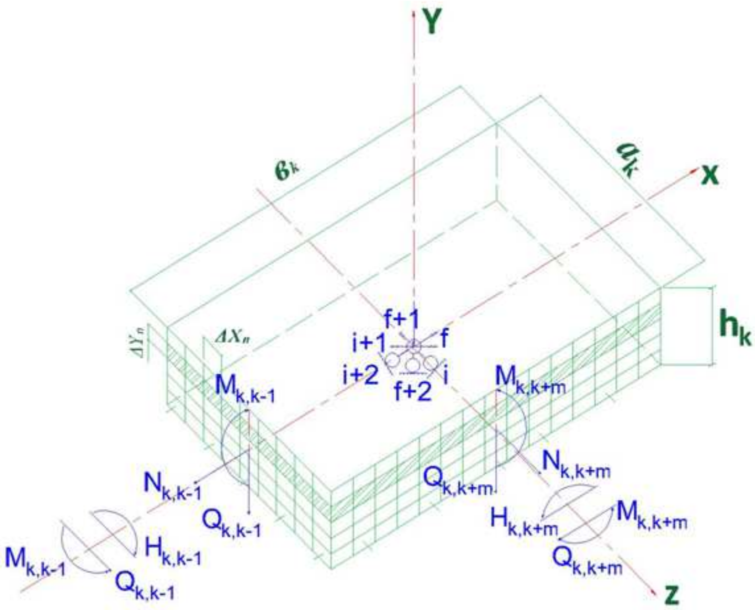

Figure 2. *Calculation model for rectangle-shape section.*

In calculations of carrying capacity demonstrated in these papers it was accentuated that stretched concrete is effective together with complete deformation diagramm «$\sigma_{вt}$–$\varepsilon_{вt}$» capturing the descending branch of full length inside locality from output date (Figure 3).

From the point of view of concrete stretching capacity without increased deformations it is acceptable to admit as classic the image of stretched concrete in the elements, accordingly, after appearance of deformations inside concrete $\varepsilon = \varepsilon'_{вt}$ and stress $\sigma_{вt} = R_{вt}$ it excludes the stretching, a result the crack appears inside sections.

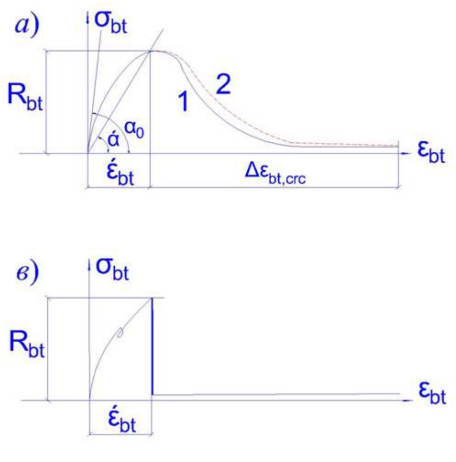

Figure 3. *Deformation diagrams «$\sigma_{вt}$ – $\varepsilon_{вt}$» for concrete stretching: a) the first case of concrete, б) the second case of concrete.*

Basing on the aforementioned, some disadvantages should be figured out:

1) Calculations should present the consideration of strain-stress state in all sections and to detect if there are cracks inside concrete or not;
2) In high precision calculation (iteration) the «recycling» may take place, i.e. formation of cracks in stretched concrete results in changed parameters of unstable sections.

Nonetheless, inclusion of «stretchable» concrete into calculation method should have appropriate grounds.

Let's imagine that application of «stretchable» concrete calculation method and use of specific conditions makes possible to obtain the outcomes equal to those ones in calculation method of limitedly stretchable concrete. In calculation of elements one need to consider not only geometric nonlinearity but also physical nonlinearity.

In slight eccentricity of normal force N relatively concrete principal strain axis can be not large on the border under less stress and, accordingly, deformation chord modulus is closer to the initial one, i.e. $E'_m = E_m$.

Therefore, physical nonlinearity coming through the middle of element stiffness under conditions of consideration of deformation degree «diverge» from normal force action line N thus exceeding initial eccentricity.

As a result of physical nonlinearity the maximal figures of deformed state of element «approach» the normal force action profile N having reduced initial eccentricity at the same time.

According to lumped-deformation method physical nonlinearity on the certain load stage and in any other element is accepted by default that in section stiffness matrix there are several elements not equal to zero, and appropriate size is determined by the size of deformed state in section.

According to [3-10], diagrams «σ_m - ε_m» for concrete and reinforcing in single-axe stressing and stretching are accepted in the common format:

$$\sigma_m = E'_m \cdot \nu_m \cdot \varepsilon_m = E_m \cdot \varepsilon_m \quad (1)$$

Where: ν_m– coefficient of flexible deformation of materials (concrete and reinforcing).

Here: $E_m = \nu_m \cdot E'_m$; $\nu_m = e^{m\cdot(\varepsilon/\hat{\varepsilon})^{-m^{-1}}}$; $m = \ln(R_в / E_в \cdot \hat{\varepsilon})$.

On the non-plastic working state, if axial coordinates are displaced towards main coordinate then physical nonlinearity approaches the main one and is considered as major.

From here it follows that in the order of product for the demonstrated conditions the interest is not accepted, therefore, the accepted outcomes may have some faults which size is determined with abstract calculated situation.

In particular, calculation using deformed scheme of elements will be the same that for resilient elements with the only difference that for definite iteration on formation of vector of additional joint moments, the elements of stiffness matrix and external stiffness matrix will be calculated at the same time.

Calculation of reinforced elements on the carried out basis of aforementioned will be implemented by program and algorithm using computer technology.

Herein, the following tasks will be completed:

1) Determination of parameters, i.e. accuracy ω with minimal number of iterations;
2) Figuring out rational technique for division of sections into elementary quads;
3) Checkup the required schemes for the subject of division of reinforced elements into lumped-deformations method elements;
4) Checkup of calculations of deformations and displacements of reinforced elements in resilient works considering deformation of calculation under different support-and-load conditions of.

The mentioned tasks were resolved using data from different experiments inherent calculations conditions.

3. Result

Example 1: Let's consider rectangle section with single-layer reinforcement under conditions of symmetrical bending (Figure 4).

It is required to determine the carrying capacity of normal sections using lumped-deformations method and to compare with experimental data.

Finding the vector according carrying capacity, i.e. formed stage-by-stage along with vector increase {F} (stages accepted 0,1·{F}*exper), under which destructions appeared, i.e. reached vector {F}max. Then vector {F}*was used between {F}*- 0,1·{F}*exper and {F}* with accuracy Ω = 0,01.

Vector loading stages {F}* are determined basing on approximate calculation, therefore, it should be implemented, relatively assuming that accuracy of iteration calculation Ω = 0,01 in estimated vector calculation {F}*slightly transforms the desired result.

It follows thence, on slight loading stages iteration process with accuracy ω = 0,01 are opposing fast, on the first stages - for 5-7 iterations and for accuracy on final stages several decades of iterations will be required. The destruction reveled by calculation data should be assumed accordingly as destruction of concrete: in stretched reinforcing the stress comes over the yield point but does not reach temporary resistance ($\sigma_{s,calc.}$= 382,226 Mpa), herein deformation was 2,2%.

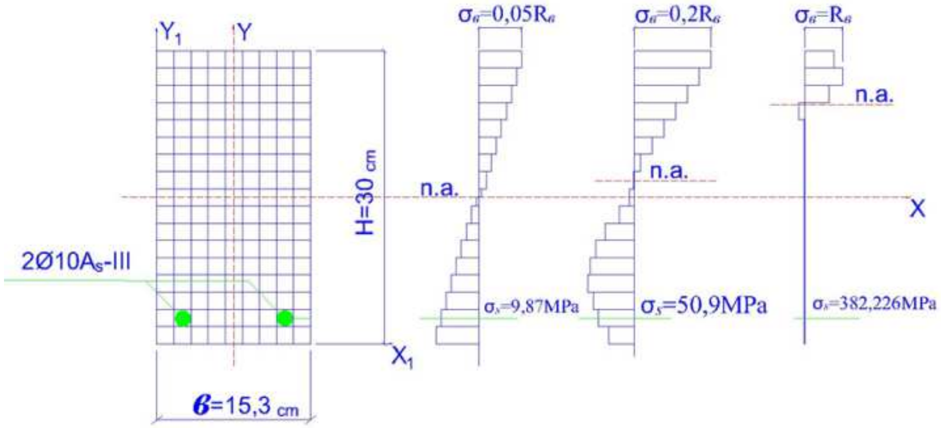

Figure 4. *Bending Element with Single-layer Reinforcing.*

Therefore, we can confirm that stress-deformed state of element accepted in calculation accords with the stage of destruction, and the result of destructing moment is close to experimental, i.e. less than experimental by 8,8%.

Example 2. Complete the calculation of carrying capacity and stiffness of reinforced elements of rectangle section (B·H =15,3x30,5 cm, length 3 meter) and loaded with concentrated forces in 2 points.

Material specifications: concrete -$R_в$ = 29,5 Mpa, $R_{вt}$= 1,6 Mpa, $E_в$ = 39500 Mpa; $\hat{\varepsilon}_в$ = 2,5%; reinforcing- 2Ø16 grade A-III with R_y= 359 Mpa, R_{su} = 498 Mpa, E_s= $2\cdot10^5$ Mpa.

Calculations completed using computer technology (Figure 5). Reinforced element in the bay is divided into 11 elements by lumped-deformations method with three variance degrees, with length 0,35meter and 0,3 meter. By calculations destructing load was P^* = 33 kN, experimental number $P^*_{экс.}$= 33,3 kN.

On resilient stage of work the element curvature in mid of bay are different from analytical ones by +0,547%, angular displacement in support elements by +0,8%, curvature in mid of bay by 0,01%.

Therefore, calculations of curvature by proposed method under comparatively small number of elements are more accurate using the lumped-deformation method.

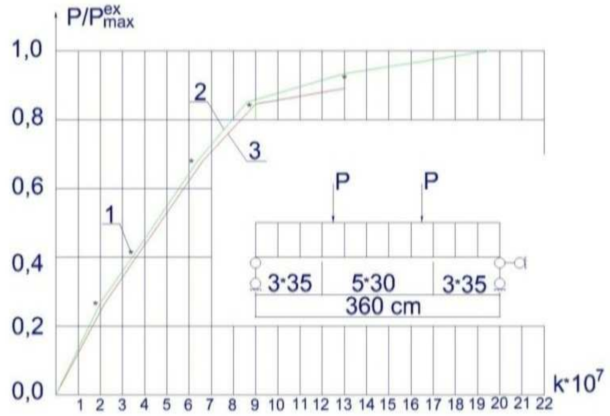

Figure 5. *Changing long axis curvature under loading: 1 – by SNiP, 2 – by lumped-deformations method, 3 – in experiment.*

Figure 6, represents epures of curvature and bending tilt moments for two loading staged under load that is 70% and 96% of destructive load accordingly.

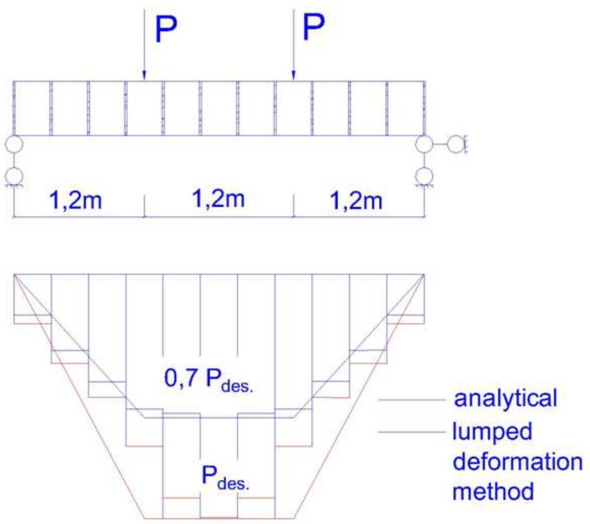

Figure 6. *Moments of Tilts Epures.*

It follows thence, along with increasing loading curvature pure gradually deflecting from tilt moments epure. Under load equal to 70% of destructive it was +1,3% and under load 96% of destructive load it was +17% comparing to calculations using lumped-deformations method.

4. Conclusions

1) Calculations are using complete deformation diagrams «σ – ε» for concrete and reinforcing considering descending branch under various load conditions.
2) Calculation statements in these studies are based on parameters of stiffness calculated comparatively, voluntary accepted coordinate axes.
3) According to developed algorithm it is possible to resolve the task to examine carrying capacity of statistically indeterminate element under predetermined loads and accepted section size, concrete and reinforcing grade, as well as external load duration.

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