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BEARING CAPACITY OF COMPRESSED STEEL REINFORCED CONCRETE STRUCTURAL ELEMENTS USING SHAPED PIPES WITH CAVITIES FOR ENGINEERING COMMUNICATIONS

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Abstract. In some cases, during the design and construction of buildings and structures, there is a need to hide engineering networks within the bearing structures. For this purpose it is advisable to use cavities for engineering communications in the compressed element section. At present, there are different techniques for calculating the compressed steel reinforced concrete elements bearing capacity under eccentric compression. Not all existing techniques make it easy to take into account the availability of cavities in the element section. The method of calculating the compressed steel-reinforced concrete elements bearing capacity under the eccentrical compression taking into account deformation under the load action is adopted for consideration. The given technique is presented on the example of calculation of compressed steel-reinforced concrete elements bearing capacity using rectangular shaped pipes. The method involves the compressed concrete work in three stages (elastic, elastic-plastic and plastic), and the work of steel rolled profile - in two stages (elastic and plastic). The cross-section is divided into a finite number of elementary sections of the shaped pipe and concrete. Further calculation is based on the the equilibrium condition fulfillment of the sum of the internal forces in each elementary section of the cross-section and the external load applied to the cross-section. This technique for calculating bearing capacity does not take into account the availability of cavities in the the element section, therefore, it is necessary to make changes in this technique. When making changes to the technique, the cavity size in the cross section is taken as such that corresponds to the finite number of the concrete elementary sections. Two variants of the section structural design (a steel pipe cavity with high-quality anticorrosive protection or a polymeric tube cavity) are offered for the use in construction. The article proposes the variant of the compressed element section structural design with a cavity of round shape, as well as an improved method for calculating the bearing capacity of compressed steel reinforced concrete elements upon the cavity availability in the cross-section for engineering communications.

Keywords: deformation, stress, bearing capacity, deflection, compression, steel-reinforced concrete.

Introduction. Steel-reinforced concrete structures, in which steel and concrete are rationally-combined, have recently become widespread in Ukraine and abroad. Available methods for calculating such structures do not take into account the possibility of cavities existence for technological or other purposes although such tasks often occur when designing buildings and structures.

The questions of the calculation theory and the results of investigations of steel reinforced concrete structures are considered in the works by L.I. Storozhenko [1], O.V. Nizhnik [2], V.A. Nastoiashchyi [3], V.V. Byba [4], O.A. Krupchenko [5] and other researchers. In these works a number of steel reinforced concrete problems have been covered, the calculation method of such structures is developed, taking into account deformation of elements under the external load influence. This technique does not take into account the availability of given size cavities in the section.

Purpose and tasks. In order to take into account the availability of cavities, in particular for engineering networks, the task was to make some changes to the methodology for calculating the bearing capacity of compressed steel reinforced concrete elements. The obtained method is shown on the example of of the compressed steel reinforced concrete element bearing capacity calculation using a shaped pipe.

Materials and methods of research. In order to solve the problem, three methods of calculating the bearing capacity of eccentrically compressed steel reinforced concrete structures were analyzed:

– according to the transformed section;

– taking into account the element deformation under the action of the external load;

– and the boundary states. For further research the calculation method was chosen taking into account the element deformation under the action of external load, since it allows enough easy to take into account the availability of cavities in the cross-section without the calculation algorithm complication.

Main material and research results. When conducting research, cavities for laying engineering communications (engineering cavities) were taken as cavities of a given size, which were taken into account as an integral part of the cross-section. In studies the execution of cavities under engineering communications was considered as possible in two main ways: using a steel pipe with high-quality anticorrosive coating and using a polymer pipe. Taking into account the availability of modern materials and products in the widespread use, it was further assumed that the cavities were formed by means of a polymer pipe and placed in the concrete part of the cross-section. The cavity diameter is assumed to be equal to the outer pipe diameter. The pipe availability in the calculations is not taken into account, i.e. it is assumed that the pipe will not receive the external load.

In compressed elements, regardless of the availability of engineering cavities, some element curvature occurs under the load (bending), therefore in the developed techniques of calculating compressed steel reinforced concrete elements the position change of the geometric axis under the load is taken into account.

The calculation of such structures allows the work of compressed elements in the elastic-plastic stage until the limit strains are reached. Determination of the element bearing capacity is performed by determining the deformations and stresses in the normal section. Two equilibrium equations (1) and (2) are used to determine the stress-strain state:

– equation of the sum of the projections of all forces on the longitudinal axis of the structure;

– equation of the sum of the moments relatively to any selected axis in the structure section, which is perpendicular to the plane of the bending moment action.

When calculating the structures in general, the structure section is considered as a set *m* of elementary concrete sections (with index *j*) without taking into account engineering cavities, with *p* elementary sections of the steel part of the structure (with index *k*) and *q* elementary sections of engineered cavities (with index *l*) in the concrete part of the section. The general view of the section is shown in Figure 1.

In this case, equations of equilibrium have the form:

$$N-\sum_{j=1}^{m}\sigma_{bj}A_{bj}-\sum_{k=1}^{p}\sigma_{rk}A_{rk}+\sum_{l=1}^{q}\left(d_l^2\cdot\frac{\pi}{4}\sigma_{b*l}\right)=0\ ; \tag{1}$$

$$N\ e-\sum_{j=1}^{m}\sigma_{bj}A_{bj}y_{bj}-\sum_{k=1}^{p}\sigma_{rk}A_{rk}y_{rk}+\sum_{l=1}^{q}d_l^2\cdot\frac{\pi}{4}\sigma_{b*l}y_{b*l}=0\ , \tag{2}$$

where *N* – external longitudinal force; *e* – distance from the force *N* to the selected axis, which is located within the section of the structure, in relation to which the moments of the internal forces in concrete and steel of the rolled section are determined; A_{bj} – area of concrete elementary sections (without taking into account engineering cavities); A_{rk} – area of the elementary sections of the rolled section steel; y_{bj} – distance from the selected axis to the gravity center of the concrete elementary sections (without taking into account engineering cavities); y_{rk} – distance from the selected axis to the gravity center of the elementary sections of the rolled section steel; σ_{bj} – tension on elementary sections of concrete (without taking into account engineering cavities); σ_{rk} – tension on elementary sections of steel of rolled sections; $d_l^2 \cdot \frac{\pi}{4}$ – area of elementary sections of concrete falling on engineering cavities; σ_{b*l} – tention on the elementary sections of concrete falling on engineering cavities; y_{b*l} – distance from the selected axis to the gravity center of the elementary sections of concrete falling on engineering cavities.

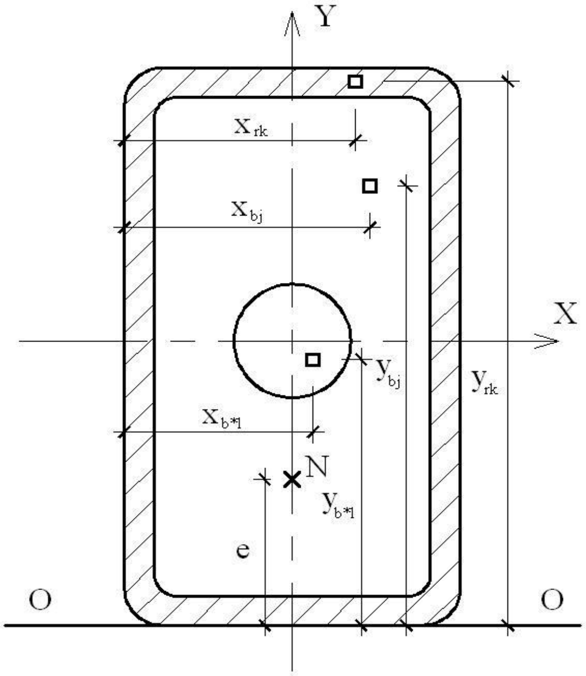

Fig. 1. Scheme of compressed steel reinforced concrete element cross section for a shaped pipe with a cavity for engineering communications

The deformation condition of a structure normal section is assumed in the form of a flat rotation with a linear distribution of deformations at a section height from the considered impacts. When carrying out the calculation it is conditionally assumed that deformations in concrete develop in three stages (elastic, elastic-plastic and plastic) according to linear laws.

According to this precondition of the calculation: ε_{b1} – deformation at the boundary of the elastic and elastic-plastic stage, ε_{b0} – deformation at the boundary of the elastic-plastic and plastic stage, ε_{b2} – boundary deformation at the plastic stage of work.

For heavy concrete, these deformations have the following meanings:

$$\varepsilon_{b0} = -0{,}002\,; \tag{3}$$

$$\varepsilon_{b1} = \frac{\beta_{b1} f_{cd}}{E_{cd}}\,; \tag{4}$$

$$\varepsilon_{b2} = -0{,}034\,, \tag{5}$$

where β_{b1} – coefficient of concrete deformation, which is equal to 0.6 for heavy concrete. Deformations in the steel of a rolled section with a physical yield point are conditionally developed in two stages (elastic and plastic) according to linear laws. According to them ε_{r0} – deformation at the boundary between the elastic and plastic stages of rolled steel, ε_{r2} – boundary deformation at the plastic stage of the rolled steel work.

These deformations are determined according to the following formulas:

$$\varepsilon_{r0} = \frac{R_y}{E_y}; \tag{6}$$

$$\varepsilon_{r2} = \frac{\beta \ R_y}{E_r}; \tag{7}$$

where β – deformation coefficient of the rolled section steel, which is accepted depending on the steel grade.

To take into account the effect of changing the compressed element geometrical shape under the action of the load, the following expression is adopted as the full distance e_f from the force N to the selected axis, according to which the internal moments in concrete and steel rolled sections are determined:

$$e_f = e + f \ , \tag{8}$$

where f – compressed element deflection, which is determined by the formula:

$$f = r - \sqrt{r^2 - \frac{1}{4} l_{ef}^2}, \tag{9}$$

where l_{ef} – compressed element height.

The calculation of compressed element deformations is performed by determining the longitudinal deformation at the level of the selected axis ε_0 from the equilibrium equations, which are taken up as the calculation basis. According to the known deformation value ε_0, deformations of concrete ε_{bj} (without taking into account engineering cavities), those of steel ε_{rk} ε_{rk} and concrete (which should be in place of engineering cavities) ε_{b*l} are determined by the following formulas:

$$\varepsilon_{bj} = \varepsilon_0 - \frac{1}{r} y_{bj}; \tag{10}$$

$$\varepsilon_{rk} = \varepsilon_0 - \frac{1}{r} y_{rk}; \tag{11}$$

$$\varepsilon_{b*l} = \varepsilon_0 - \frac{1}{r} y_{b*l}, \tag{12}$$

where $\frac{1}{r}$ – curvature in the considered section.

Then the above-mentioned equilibrium equations (1) and (2) can be written as:

$$\mathrm{N} = c_{11} \cdot \varepsilon_0 + c_{12} \cdot 1/r \ ; \tag{13}$$

$$\mathrm{N} \cdot e_f = c_{21} \varepsilon_0 + c_{22} \cdot 1/r \ \cdot \tag{14}$$

Coefficients c_{11}, c_{12}, c_{21}, c_{22} are determined by the formulas:

$$c_{11} = E_{cd} \sum_{j=1}^{m} \nu_{bj} A_{bj} + E_r \sum_{k=1}^{p} \nu_{rk} A_{rk} - E_{cd} \sum_{l=1}^{q} \left(d_l^2 \cdot \frac{\pi}{4} \nu_{b*l} \right); \tag{15}$$

$$c_{12} = -E_{cd} \sum_{j=1}^{m} \nu_{bj} A_{bj} y_{bj} - E_r \sum_{k=1}^{p} \nu_{rk} A_{rk} y_{rk} + E_{cd} \sum_{l=1}^{q} \left(d_l^2 \cdot \frac{\pi}{4} \nu_{b*l} y_{b*l} \right); \tag{16}$$

$$c_{21} = E_{cd} \sum_{j=1}^{m} \nu_{bj} A_{bj} y_{bj} + E_r \sum_{k=1}^{p} \nu_{rk} A_{rk} y_{rk} - E_{cd} \sum_{l=1}^{q} \left(d_l^2 \cdot \frac{\pi}{4} \nu_{b*l} y_{b*l} \right); \tag{17}$$

$$c_{22} = -E_{cd} \sum_{j=1}^{m} \nu_{bj} A_{bj} y_{bj}^2 - E_r \sum_{k=1}^{p} \nu_{rk} A_{rk} y_{rk}^2 + E_{cd} \sum_{l=1}^{q} \left(d_l^2 \cdot \frac{\pi}{4} \nu_{b*l} y_{b*l}^2 \right). \tag{18}$$

where ν_{bj} – elasticity coefficients of elementary sections of concrete (without taking into account engineering cavities), which are determined depending on the deformation in elementary sections ε_{bj};. ν_{rk} – elasticity coefficients of the elementary sections of rolled section steel, which are determined depending on the deformation in elementary sections ε_{rk}; ν_{b*l} – elasticity coefficients of the elementary sections of concrete (that should be in place of engineered cavities), which are determined depending on the deformation in the elementary sections ε_{b*l}.

The concrete elasticity coefficients (without taking into account engineering cavities and that should be in place of engineering cavities) are calculated by the following formulas:

$$\text{where } |\varepsilon_{bj}| \le |\varepsilon_{b1}| \qquad \nu_{bj} = 1\,; \tag{19}$$

$$\text{where } |\varepsilon_{b1}| < |\varepsilon_{bj}| \le |\varepsilon_{bo}| \qquad \nu_{bj} = \frac{f_{cd}}{E_{cd}}\left[\frac{1-\beta_{b1}}{\varepsilon_{bo}-\varepsilon_{b1}}\left(1-\frac{\varepsilon_{b1}}{\varepsilon_{bj}}\right)+\frac{\beta_{b1}}{\varepsilon_{bj}}\right]; \tag{20}$$

$$\text{where } |\varepsilon_{bo}| < |\varepsilon_{bj}| \le |\varepsilon_{b2}| \qquad \nu_{bj} = \frac{f_{cd}}{E_{cd}\,\varepsilon_{bj}}. \tag{21}$$

The steel elasticity coefficients of the shaped pipe are calculated according to the following formulas:

$$\text{where } |\varepsilon_{rk}| \le |\varepsilon_{r1}| \qquad \nu_{rk} = 1\,; \tag{22}$$

$$\text{where } |\varepsilon_{r1}| < |\varepsilon_{rk}| \le |\varepsilon_{r2}| \qquad \nu_{rk} = \frac{R_y}{E_r\,\varepsilon_{rk}}. \tag{23}$$

The procedure for determining the strains of compressed elements under a given load is as follows:

1. The coefficients c_{11}, c_{12}, c_{21}, c_{22} are calculated by the formulas (15-18) at full distance e_f from the force N to the selected axis, according to which the internal moments in concrete and steel of the rolled section $e_f = e$ and the concrete and steel elasticity coefficients of the rolled section are determined $\nu_{bj} = \nu_{rk} = \nu_{b*l} = 1$.

2. From the solution of the equilibrium equations (13) and (14) we determine the deformation value at the level of the selected axis ε_0 and the curvature in the concrete section $\frac{1}{r}$.

3. Deformations of concrete and steel are determined for each elementary section ε_{bj}, ε_{rk} and ε_{b*l} by the formulas (10-12) according to the obtained deformation values at the level of the selected axis and the curvature in the concrete section.

4. According to the received deformations in concrete and steel of rolled section, new values of elasticity coefficients of concrete and rolled section steel ν_{bj}, ν_{rk}, ν_{b*l} are determined by the formulas (19-23).

5. When obtaining new values of the elasticity coefficients of concrete and rolled section steel. we calculate the new values of the coefficients c_{11}, c_{12}, c_{21}, c_{22} by the formulas (15-18).

6. We calculate the specified distance from the point of the load application N to the selected design axis, for which the internal moments in concrete and steel of the rolled section e_f are determined taking into account the deflection f by the formulas (8) and (9).

7. We determine again the values of ε_0 and $\frac{1}{r}$ from the solution of equations (13) and (14).

The calculation process is repeated until the difference in the deformation values in each elementary section received by the new and the previous calculation, will be less than a certain predetermined value, which is considered as the calculation accuracy.

Conclusions. The proposed technique of calculation of compressed steel reinforced concrete elements allows to determine the bearing capacity of elements when changing the position of the vertical axis, provided that there are cavities for engineering communications. This technique displays the deformation pattern of a compressed element close to the actual one, since it takes into account the influence of the deflection on the compressed element deformation.

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НЕСУЩАЯ СПОСОБНОСТЬ СЖАТЫХ СТАЛЕЖЕЛЕЗОБЕТОННЫХ ЭЛЕМЕНТОВ ИЗ ПРОФИЛЬНОЙ ТРУБЫ С ПОЛОСТЯМИ ПОД ИНЖЕНЕРНЫЕ КОММУНИКАЦИИ

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Аннотация. В некоторых случаях во время проектирования и строительства зданий и сооружений возникает необходимость спрятать инженерные сети внутри несущих конструкций, для этого целесообразно применять пустоты под инженерные коммуникации в сечении сжатого элемента. В данное время существуют разные методики расчета несущей способности сжатых сталежелезобетонных элементов при внецентренном сжатии. Не все существующие методики позволяют легко учитывать в расчете наличие пустот в сечении элемента. Для рассмотрения принято методику расчета несущей способности сжатых сталежелезобетонных элементов при внецентренном сжатии с учетом деформирования под действием нагрузки. Указанная методика представлена на примере расчета несущей способности сжатых сталежелезобетонных элементов из прямоугольных профильных труб. Методика предусматривает работу сжатого бетона в три стадии (упругая, упруго-пластическая и пластическая), а работа стального прокатного профиля – в две стадии (упругая и пластическая). Поперечное сечение разбивается на конечное число элементарных участков профильной трубы и бетона. Последующий расчет основывается на выполнении условия равновесия суммы внутренних усилий в каждом элементарном участке сечения и внешней нагрузки, приложенной к сечению. Даная методика расчета несущей способности в существующем виде не учитывает наличие пустот в сечении элемента, поэтому возникает необходимость внести изменения в данную методику. При внесении изменений в методику принимается размер полости в поперечном сечении соответствующий конечному числу элементарных участков бетона. Для использования в строительстве предложено два варианта конструктивного решения такого сечения (полость из стальной трубы с качественной антикоррозионной защитой или полость из полимерной трубы). В статье предложено вариант конструктивного решения сечения сжатого элемента с полостью круглой формы, а также усовершенствованная методика расчета несущей способности сжатых сталежелезобетонных элементов при наличии в поперечном сечении конструкции полости под инженерные коммуникации.

Ключевые слова: деформация, напряжение, несущая способность, прогиб, сжатие, сталежелезобетон.

НЕСУЧА ЗДАТНІСТЬ СТИСНУТИХ СТАЛЕЗАЛІЗОБЕТОННИХ ЕЛЕМЕНТІВ ІЗ ПРОФІЛЬНОЇ ТРУБИ З ПОРОЖНИНАМИ ПІД ІНЖЕНЕРНІ КОМУНІКАЦІЇ

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Анотація. В деяких випадках під час проектування та будівництва будівель і споруд виникає необхідність приховати інженерні мережі всередині несучих конструкцій, для цього доцільно застосовувати порожнини під інженерні комунікації в перерізі стиснутого елемента. В даний час існують різні методики розрахунку несучої здатності стиснутих сталезалізобетонних елементів при позацентровому стиску. Не всі існуючі методики дозволяють легко враховувати в розрахунку наявність порожнин в перерізі елемента. Для розгляду прийнято методику розрахунку несучої здатності стиснутих сталезалізобетонних елементів при позацентровому стиску з урахуванням деформування під дією навантаження. Вказана методика представлена на прикладі розрахунку несучої здатності стиснутих сталезалізобетонних елементів із прямокутних профільних труб. Методика передбачає роботу стиснутого бетону в три стадії (пружня, пружньо-пластична і пластична), а робота сталевого прокатного профіля – в дві стадії (пружня і пластична). Поперечний переріз розбивається на скінчену кількість елементарних ділянок профільної труби і бетону. Подальший розрахунок заснований на виконанні умови рівноваги суми внутрішніх зусиль в кожній елементарній ділянці перерізу і зовнішнього навантаження, прикладеного до перерізу. Дана методика розрахунку несучої здатності в існуючому вигляді не враховує наявність порожнин в перерізі елемента, тому виникає необхідність внести зміни в дану методику. При внесенні змін в методику приймається розмір порожнини в поперечному перерізі таким, що відповідає скінченому числу елементарних ділянок бетону. Для використання в будівництві запропоновано два варіанти конструктивного рішення такого перерізу (порожнина зі сталевої труби з якісним антикорозійним захистом чи порожнина з полімерної труби). В статті запропоновано варіант конструктивного рішення перерізу стиснутого елемента з порожниною круглої форми, а також удосконалена методика розрахунку несучої здатності стиснутих сталезалізобетонних елементів при наявності в поперечному перерізі конструкції порожнини під інженерні комунікації.

Ключові слова: деформація, напруження, несуча здатність, прогин, стиск, сталезалізобетон.

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