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DETERMINATION OF THE LIMIT HEIGHT OF THE COMPRESSED ZONE OF STEEL-CONCRETE COMPOSITE SECTIONS

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Abstract: A brief review of power resistance of cross sections with a complex composition was made using the examples of steel-concrete composite structures. The features and difficulties that appear when calculate steel-concrete composite structures, materials of which have different strength characteristics, are noted. The procedure for calculation the limit height of the compressed zone for steel-concrete composite beam section is given.

Keywords: concrete, steel, reinforced concrete, steel-concrete composite structure, height of compressed zone

ОПРЕДЕЛЕНИЕ ГРАНИЧНОЙ ВЫСОТЫ СЖАТОЙ ЗОНЫ ДЛЯ ЖЕЛЕЗОБЕТОННЫХ СЕЧЕНИЙ С ЖЕСТКОЙ АРМАТУРОЙ

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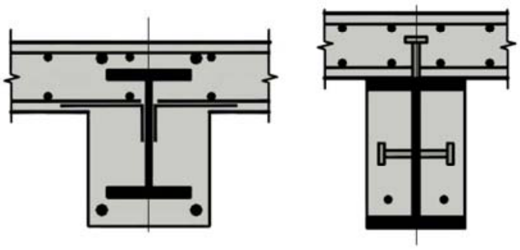
Аннотация: Выполнен краткой обзор работы поперечных сечений, имеющих сложную внутреннюю компоновку на примере сталежелезобетонных конструкций. Отмечены особенности и трудности расчетов в случае наличия в сечении материалов с различными прочностными характеристиками на примере определения граничной высоты сжатой зоны сталежелезобетонного сечения. Приведена последовательность расчета граничной высоты сжатой зоны поперечного сечения балки, армированной стержневой и жесткой арматурой.

Ключевые слова: бетон, сталь, железобетон, сталежелезобетонная конструкция, высота сжатой зоны

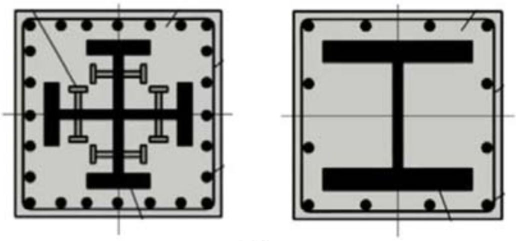
The developing construction industry offers a wide range of building materials and products, which gives the designer the opportunity to implement the most difficult architectural decisions. Often in modern construction practice, even one structural element can have a complex internal composition, including several materials with different strength characteristics. An example is the steel-concrete structures (Figure 1), which have great development in recent times [1, 2, 3, 4, 5].

Considering steel-concrete structures (columns and beams with fully concreted core [4, 5, 6, 7] – Figure 1) a fairly common design solution is a combination of modern flexible rebars (for example, class A500) with a rolled or welded profile of steel C255/C345. Thus, the design characteristics of the steel elements of the cross section may differ by 35 ... 80%. For some stages of strength calculation of normal cross sections of composite elements, the noted feature can cause some difficulties and complicate the calculation process.

In accordance with the current Building Code Russian Federation SP 63.13330 [8], the limit height of the compressed zone should be calculated for the entire cross section, taking into account the all reinforcement in tension. If the reinforcement is laid in several layers, it is assumed that reinforcement is concentrated in the center of its gravity (h_0 is calculated as a distance from the most compressed fiber to the center of gravity of the reinforcement in tension).



a)



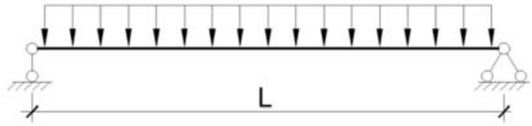
b)

Figure 1. Examples of cross sections of steel-concrete columns [2].

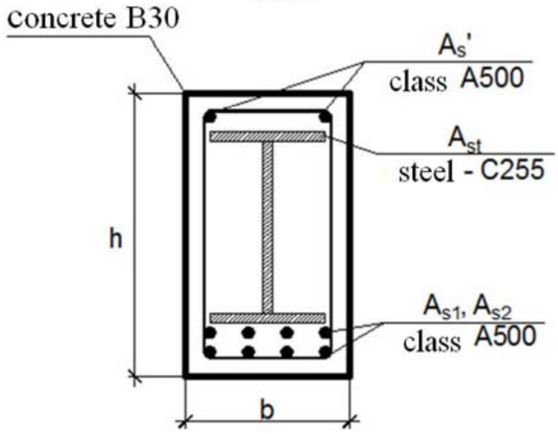
Also the formula for the limit height of the compressed zone, that is contained in SP 63.13330, assumes that the strains of the whole reinforcement in tension has reached a value corresponding to the yield strength of the material or exceed it.

In practice, this approach may cause the following difficulties. If some layer of reinforcement is located close to the boundary of the compressed zone, it is not clear whether the stresses in this reinforcement will have reach the design resistance when the structure is destroyed. It is possible that different layers of reinforcement work with different resistances and the formulas of the current Building Code do not allow describing this case correctly when calculating at the limit values of forces. This becomes especially apparent when calculating steel-concrete composite cross-section with a whole rolling profile. The second difficulty arises when using steels with different strength characteristics in the same section. Then, the reinforcement elements reach the yield point of strain-stress diagram at different deformation values despite the same elastic modules.

Let us consider in more detail the definition of the limit height of the compressed zone of the steel-concrete cross-section of the beam, designed with the use of steels of different strengths (Figure 2).



a) calculation scheme of the considering beam



b) cross section

Figure 2. Steel-concrete beam designed with steel elements of different strength.

The section under consideration has dimensions $b \times h$. The beam is reinforced with rebars and rigid steel profiles. The core of cross section is made in the form of an I-beam of C255 steel. Rods of upper and lower reinforcement are made of rebars of A500 class. In the work, it is considered heavy concrete of compressive strength class C30.

According to SP 63.13330 [8] the limit height of the compressed zone is calculated by the following formula

$$x_R = \frac{0.8}{1+\frac{\varepsilon_{s,el}}{\varepsilon_{b2}}} h_0, \qquad (1)$$

where $\varepsilon_{s,el}$ is deformation of reinforcement in tension at stress value R_s ,

$$\varepsilon_{s,el} = \frac{R_s}{E_s},$$

ε_{b2} is deformation of compressed concrete at stress value R_b.

Thus, there are rebar elements of different strength and different deformation characteristics, located at different sites, in the cross section. Respectively, the limit heights of the compressed zone defined for the various steel elements of the section also differ. The schematic arrangement of the limit heights of the compressed zone for different section of the steel core (the section is divided into several parts through the height to obtain a more accurate result) and the reinforcement rods are shown in figure 3. The height of the compressed zone x of the cross section is marked with hatching in figure 3. The limit height of the compressed zone for the each steel element indicated as x_{R_i}.

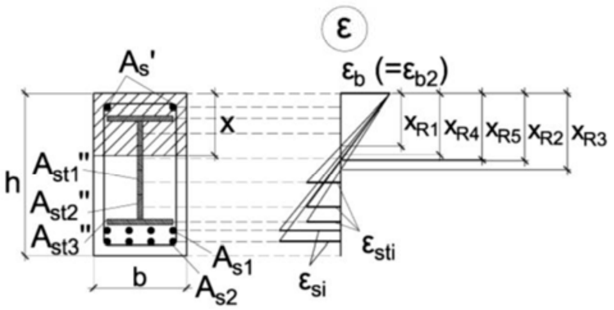


Figure 3. Steel-concrete cross section in bent. Determination of limit height of compressed zone.

When determining the limit height of the compressed zone of a cross section of a steel-concrete element, the following sequence of calculations should be accepted:

- determination of the limit height of the compressed zone x_R by formula (1) for each stretched section of steel reinforcement (steel core and rod reinforcement). At the same time, the profile of rigid reinforcement should be divided into parts through the height of the cross section.
- determination of the height of the compressed zone x, assuming that the stresses in the entire stretched reinforcement reached the yield strength of the material ($\sigma_s = R_s$);
- comparison of x and x_R for each stretched steel element of cross section. Selection of rod and rigid reinforcement elements for which $x > x_R$;
- recalculation of the height of the compressed zone excluding the elements for which $x > x_R$ since the stresses in them $\sigma_s < R_s$. In this case, the steel parts of the section should be excluded from the calculation one by one, starting with the element for which the difference between x and x_R s greatest. Besides, in the case whether of rigid reinforcement or symmetrical flexible reinforcement, the elements of the core or rod reinforcement should be excluded from the calculation, taking into account their symmetrical placement respectively to the current location of the boundary of the compressed zone at this stage of calculation or iteration.

Further, according to the mentioned technique, several iterations should be performed (if necessary) until the inequality $x < x_R$ is performed taking into account all the elements entered into the calculation. Then the stresses correspond to the yield strength of the material ($\sigma_s = R_s$) for the elements involved in the calculation. Further, when determining the limit moment in the cross section in order to obtain margin of safety, only the elements, in which the stress reach the value $\sigma_s = R_s$, should be entered into the calculation.

In the case when the cross section is strongly over-reinforced, and it is impossible to identify elements that work with full design resistance, it is possible to use the technique of the current SP 63.13330 [8], taking as the limit height of the compressed zone the smallest value ξ_{Ri} from those values that relate to the reinforcement taken into account in the calculation.

In order to obtain more accurate results, the stretched rebars and the stretched sections of the rigid reinforcement for which the $x < x_R$ inequality is true should be taken into account in the expressions for determining the height of the compressed zone and the limit bending moment, taking into account their real stress state. In this case, the stress in the rod and rigid reinforcement should be determined from the conditions of elastic operation of the material:

- plot the relative strain/stress diagram using two points: the ultimate strain/stress of concrete and the zero point (calculated height of the compressed zone);
- guided by the Euler–Bernoulli hypotheses, determine the strain / stress in the series of reinforcing bars (from the diagram);
- take into account the real strain / stress for all elements involved in calculation.

CONCLUSIONS

The problems of determination of limit height of the compressed zone of a cross section of a steel-concrete element are considered in the general form. The complexity of the calculation is that there is a reinforcement (rod and rigid core) of different strength and with different deformation characteristics, located at different levels through the height of cross section.

The sequence of calculation of the limit height of the compressed cross-sectional area of the beam reinforced with rod and rigid reinforcement is presented. Recommendations on possible improvements of calculations are given.

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