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Efficiency comparison of material usage in various approaches to design the columns made of reinforced concrete

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Abstract. This article touches on the topic of calculating pipe-concrete columns with a different approach when selecting a section of a suitable diameter. In the first case, the column was calculated under the influence of loads at the minimum permissible cross-section of the reinforcement, in the second case, the calculation was made with identical loads, but with an increased cross-section of the reinforcement rods, in both cases, the section of the steel pipe of the column was selected, considering compliance with all critical conditions and strength checks. According to the results of the study, we can say that the rational method of calculation, in terms of material consumption, is the first option with the minimum allowable cross-section of reinforcement, on average, the amount of metal spent on such a column will be 14.4% less than in the second option, but the required volume of concrete in this case will increase by 10.4%. Based on the results obtained, we can say that the first approach to calculation is more efficient in terms of metal costs, which is the prevailing factor in the design of steel-reinforced concrete structures.

Keywords: *steel-reinforced concrete, columns, calculations.*

1. Introduction

One of the most developing areas of the economy of Kazakhstan at the moment is construction. The country is actively introducing new technologies and methods aimed at accelerating construction processes, improving the reliability and safety of structures, as well as creating more technologically advanced and energy-efficient structures. This trend is observed not only in Kazakhstan, but also around the world, where the construction industry plays an important role in the development of the economy and infrastructure.

Within the framework of the study, special attention is paid to the analysis of the world experience in the use of steel-reinforced concrete structures, which have been widely distributed and recognized for their advantages. Reinforced concrete structures combine the strength and stability of steel elements with the advantages of concrete, such as fire resistance and durability. This makes them particularly attractive for the construction of buildings and structures with high requirements for reliability, safety and sustainability.

The use of steel-reinforced concrete structures extends to various types of buildings and structures. Bridges, ceilings of industrial and public buildings with heavy loads, as well as high-rise buildings and skyscrapers - all of them can be implemented using this type of structures. Kazakhstan is no exception and implements steel-reinforced concrete structures in the construction of various facilities. The example of such high-rise construction is Abu-Dabi Plaza in Astana, which has become a symbol of the modern architectural development of the country.

The study of world experience in the use of reinforced concrete structures is important for the development of high-rise construction in Kazakhstan and an increase in the number of unique buildings. Increasing the non-existent capacity, reducing deformability and ensuring high safety and reliability of structures are key aspects that must be considered when developing new projects and applying reinforced concrete structures in building constructions.

Thus, the study of world experience and the use of steel-reinforced concrete structures in the construction of Kazakhstan contributes to the development of the industry, improving the quality of construction and the creation of innovative, sustainable and modern structures that reflect the growing strength and progress. Needless to say, that the future of high-rise building is highly rely on steel-reinforced concrete elements, and ours deep understanding of their basic mechanical and designing principles.

1.1. What is steel-reinforced concrete?

Reinforced concrete structures are one of the most common materials used in the construction of buildings and structures. They are a combination of steel and concrete working in synergy to create a strong and stable structure. Kazakhstan is no exception and implements steel-reinforced concrete structures in the construction of various facilities. An example of such high-rise construction is Abu-Dabi Plaza in Astana, which has become a symbol of the modern architectural development of the country.

The main advantage of steel-reinforced concrete structures is their ability to withstand significant loads and provide high strength at a relatively low weight. This allows you to build lighter and more elegant structures than using only concrete or steel. Moreover, steel-reinforced concrete structures can be manufactured with high precision, which makes it possible to implement more complex shapes and design solutions.

However, some disadvantages of steel-reinforced concrete structures should be considered when using them. Improper design and construction can lead to corrosion of the material and, ultimately, to the destruction of the structure. This is due to the interaction of steel and concrete, which can cause oxidation and rusting processes. In addition, steel-reinforced concrete structures may be more expensive than alternative materials, which should be considered when planning the project budget.

In order to avoid disadvantages and maximize the advantages of steel-reinforced concrete structures, it is necessary to consider the features of this material at each stage of design and construction. It is important to carry out a comprehensive load analysis, considering the durability and corrosion resistance of the structure. It is also necessary to apply modern methods of corrosion protection, such as coatings, cathodic protection and other technologies, in order to extend the service life of the structure and ensure its reliability.

Finally, it is necessary to have a good understanding of the strength and stability of steel-reinforced concrete structures in various operating conditions. This includes studying the effects of external factors such as climatic conditions, humidity, chemicals and dynamic loads. Based on these data, it is possible to optimize the project and select the appropriate materials and technologies to achieve the necessary strength and durability of the structure.

In general, steel-reinforced concrete structures represent an important and widely used material in modern construction. Proper design, construction and operation of such structures make it possible to create durable, stable and aesthetically attractive structures capable of coping with a variety of loads and operating conditions.

The effectiveness of steel-reinforced concrete structures is due to the interaction of two materials - concrete and steel, and their joint work. Steel-reinforced concrete structures can be classified into four main types according to their structural solution and the nature of their work:

1. Structures where rigid steel profiles (rolled, welded or bent) are located outside the reinforced concrete part of the structure
2. Structures in which rigid steel profiles are located inside the reinforced concrete part of the structure - such structures are known as reinforced concrete structures with rigid reinforcement.
3. Structures including rigid steel profiles or rolled sheets located around the cross-section perimeter (pipe-concrete structures) or along one or more faces.

Structures where thin-walled steel flat or profiled sheets are located on one or two sides of a reinforced concrete structure and serve simultaneously as a permanent formwork and working reinforcement.

In this paper, different approaches to the selection of a section of a steel-reinforced concrete column of a square section with the same design loads and material characteristics were considered.

The task was set to identify the most economical and material-intensive design option while maintaining the required strength characteristics of the column. Two design variants were compared, in the first design variant the minimum possible cross-section of the longitudinal reinforcement was used, with a reinforcement coefficient of less than 2%, in the second variant the maximum possible cross-section of the longitudinal reinforcement, a reinforcement coefficient of 4% or more, was used for simplified calculation.

An algorithm was used for the manual calculation of a quadrant steel-reinforced concrete column made of hot-rolled seamless pipe with internal reinforcement consisting of hot-rolled longitudinal and transverse reinforcement. Calculations were made with the selection of the column section satisfying the conditions of strength and stability.

According to the results of the study, it can be said that in the first version of the calculation of the column as a whole, there is a reduction in metal costs by 8-9%, but an increase in the area of the concrete section by an average of 25-26%, as a result of an increase in concreting costs and an increase in the cross-sectional area of the column as a whole.

2. Materials and methods

When calculating and designing structures made of reinforced concrete, it is required to initially study a large amount of material on this topic, as well as to prepare and think over the research methodology itself as a whole

To begin with, I would like to touch on the materials collected and read for the development of this study. In this study, the following scientific works were used and analyzed:

Research in the field of calculation and operation of steel-reinforced concrete structures was carried out in different years: Travush V.I., Konin D.V., Rozhkova L.S., Krylov A.S., Kaprielov S.S., Chilin I.A., Martirosyan A.S., Fimkin A.I., etc.

Travush V.I., Konin D.V., Rozhkova L.S., Krylov A.S., Kaprielov S.S., Chilin I.A., Martirosyan A.S., Fimkin A.I. [2] in their study «Experimental studies of steel-reinforced concrete structures operating on off-center compression» tested various models of columns for off-center compression and central compression, followed by an analysis of the obtained results, their comparison and conclusions regarding additional anchoring of the steel core in concrete.

Travush V.I., Kaprielov S.S., Konin D.V., Krylov A.S., Kashevarova G.G., Chilin I.A. [4] in the work «Determination of the bearing capacity for shear of the contact surface «steel-concrete» in steel-reinforced concrete structures for concretes of various compressive strength and fiber concrete». They consider the issues of working on the shear of the contact surfaces of the LCB models, and also give the calculated adhesion resistance of steel elements of rigid reinforcement with concrete and a comparison of similar data in Eurocode 4.

The foreign work Jun Wang, Yuxin Duan, Yifan Wang, Xinran Wang and Qi Liu «Analysis and Modification of Methods for Calculating Axial Load Capacity of High-Strength Steel-Reinforced Concrete Composite Columns» [15] (Analysis and modification methods for calculating axial compressive strength of columns made of reinforced concrete) provides experimental tests and analysis of the strength characteristics of various configurations of columns reinforced with a double I-beam in the center.

The Finnish author Karol Bzdawka in his work «Composite column – calculation examples» [16] gives examples of calculating steel-reinforced concrete columns with a steel outer contour of round, square and rectangular sections.

In international European standards «SFS-EN 1994-1-1(2) Eurocode 4: Design of composite steel and concrete structures. Part 1-1: General rules and rules for buildings Part 1-2: General rules. Structural fire design» [13, 14] considered the basic rules for the design and calculation of steel-reinforced concrete structures according to European standards.

I.I. Vedyakov, D.V. Konin, A.S. Krylov, L.S. Rozhkova, S.B. Krylov in his work «Methodological guide for the calculation and design of steel-reinforced concrete structures with rigid reinforcement» they give 2 illustrative examples of the calculation of CFS columns with rigid I-beam fittings, as well as with rigid fittings in the form of a solid core.

Also, there was a lot of authors that helped me gain basic knowledge of this specific topic, and the general understanding of building construction and mechanical principles of construction elements. I cannot include them all, but you can acquaint with them in the scientific library of Satbayev University.

The main methods for obtaining individual research indicators:

1 Collection of theoretical information

The study of various literary sources, the analysis of existing information, the comparison of various sources of information

A literary review of this scientific article was presented above, which noted the work of the authors, whose ideas were used as the main theoretical basis for the calculation of columns made of reinforced concrete. There are also a lot of practical guidelines for the calculation of columns made of steel profiles, as well as from reinforced concrete, have become an important part of the collection of theoretical information. The fundamentals of concrete behavior during compression compression, the effect of the cage when pouring concrete mixture, the connection and joint work of steel and concrete were studied.

2 Mathematical analysis and calculation

Numerical modeling of a building with the subject of research in the software complexes LyraSAPR/ SCAD/ MidasGen. Load collection and calculation according to Eurocodes using LyraSAPR/ SCAD/ MidasGen software packages. Statistical analysis of the results of numerical modeling.

The analysis and verification of the calculated material were carried out in software complexes for the calculation of structures by the finite element method. This made it possible to compare the manual calculation with the calculation in the software package to exclude the human factor and large discrepancies in the calculations.

The calculation was based on columns with the following initial geometric parameters, as well as with the following material parameters:

The cross section of the column was adopted as a steel rolled seamless pipe of square section, the length of the column is three point six meters. The number of longitudinal reinforcement rods varies from 4 to 8 pieces, depending on the required cross-section parameters, the transverse rods have a diameter of six millimeters with a protective layer of concrete of fifty millimeters.

The characteristic resistance of the steel of the external hot-rolled pipe is three hundred and fifty-five mega Pascal, with a load reliability coefficient of one, thus the calculated resistance of the pipe wall is equal to three hundred and fifty-five mega Pascal, the modulus of elasticity of the steel was taken equal to two hundred ten thousand mega Pascal. The characteristic resistance of the steel of the longitudinal reinforcement is equal to five hundred mega Pascals, with a load reliability coefficient equal to one whole fifteen hundredths, thus the calculated resistance of the longitudinal reinforcement is four hundred thirty-five mega Pascal The modulus of elasticity of the longitudinal reinforcement material was taken equal to two hundred ten thousand mega Pascals.

The characteristic resistance of concrete was taken to be equal to forty mega Pascals, with a load reliability coefficient equal to one whole five decimals, thus the calculated compressive resistance of concrete is equal to twenty-six whole shears and seven hundredths mega Pascals. The modulus of elasticity of concrete was taken to be equal to thirty-five thousand mega Pascal with a cement strength class N, and a load application time of 28 days.

3. Results and discussion

The results of my research turned out to be sufficiently clear so that it was possible to trace certain patterns between the cost of materials per conventional unit of payload, which the column of a hypothetical building, given in the calculation and described in the second section, can withstand.

In all iterations of the calculation of the first variant of column construction, longitudinal reinforcement does not exceed 2%, in the second design variant, longitudinal reinforcement of more than 4% is used in all iterations of the calculation. These design principles were chosen in order to compare the efficiency of increasing the cross-section of the reinforcement with an increase in the cross-section of the outer pipe of a steel-reinforced concrete column.

Next, calculations were carried out for two variants of column construction with the selection of suitable cross-sections of longitudinal elements based on the principles of column design established by us earlier. The calculations were made in accordance with the norms of Eurocode 4.

Based on the results obtained, graphs of the dependencies of the cross-sectional areas of the longitudinal steel elements, as well as the cross-sectional area of the concrete part of the column on the applied design loads were compiled. These graphs clearly show an increase in the cross-section of the concrete part of the design variant with a percentage of reinforcement less than two, as well as a corresponding decrease in the cross-section of the steel part of the column.

In the second design variant, we can observe the opposite picture, the cross-section of the bulk of the column decreases, but the cross-section of the longitudinal steel elements increases noticeably, which accordingly increases the cost of materials.

Figure 1. Graph of the dependence of the total cross-sectional area of longitudinal steel elements on the total design load on the column

Figure 2. Graph of the dependence of the cross-sectional area of concrete on the total design load on the column

4. Conclusions

The use of steel-reinforced concrete structures has a number of advantages. Firstly, they have high strength and are able to withstand significant loads. Secondly, such structures provide stability and durability, which is especially important for bridges, buildings and reservoirs. Thirdly, steel-reinforced concrete structures make it possible to achieve an optimal combination of materials, taking advantage of both steel and concrete.

In conclusion, steel-reinforced concrete structures represent an effective solution for various engineering tasks. They have strength, rigidity and stability, and also provide the opportunity to combine the advantages of steel and concrete. The correct selection and use of connecting elements are key factors for achieving optimal performance of such structures.

It has been established that, compared with traditional structures, reinforced concrete structures have a wide range of characteristics that make them attractive in various fields of construction

1. Lower weight compared to reinforced concrete structures: Steel-reinforced concrete structures have a lower mass compared to traditional reinforced concrete structures. This reduces the load on the foundation and improves the overall stability of the building or structure.

2. Increased rigidity compared to steel structures: Steel-reinforced concrete structures have high rigidity, which means that they can resist large deformations without significant changes in their shape. This is especially useful in cases where it is necessary to minimize floating deformations and ensure accuracy and reliability in the operation of structures.

3. Reduction of steel consumption compared to steel structures: Steel-reinforced concrete structures require less steel compared to all-steel structures. This is due to the use of concrete as the main material, which has good compressive strength, which reduces the amount of steel needed.

4. Compliance with modern manufacturing and installation technologies, simplicity of nodal connections: Reinforced concrete structures meet the requirements of modern manufacturing and installation technologies.

During the research and analysis of the conducted calculation, the following conclusions were formulated. When calculating and designing a steel-reinforced concrete column, with a longitudinal reinforcement of less than 2% of the cross-sectional area, a reduction in the cross-section of longitudinal steel elements by an average of 8-9% is clearly observed in comparison with the second layout option. But it is also worth noting that in the first version of the layout, the area of the concrete section increased by an average of 25-26% compared with the second calculation option.

Based on the results obtained, we can confidently say that an increase in longitudinal reinforcement in the column is slightly less effective in using the strength characteristics of steel than an increase in the cross section of a steel pipe, but significantly reduces the consumption of concrete and the cross-sectional area of the column as a whole.

The complexity of calculations for strength and stiffness, the need to take into account two-stage construction work, cracking, creep of concrete, shear of heterogeneous materials along the contact surface and other specific factors: Steel-reinforced concrete structures require more complex calculations for strength and stiffness due to the interaction of various materials and taking into account specific factors such as cracking, the creep of concrete and the shear of materials over the contact surface.

The need to take these factors into account in the design and construction of steel-reinforced concrete structures can increase the complexity of the project and require more attention to detail. However, correct calculations and consideration of these factors can guarantee the safety and durability of structures.

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References

[1] Jun Wang, Yuxin Duan, Yifan Wang, Xinran Wang & Qi Liu. (2021). Analysis and Modification of Methods for Calculating Axial Load Capacity of High-Strength Steel-Reinforced Concrete Composite Columns. *Materials, 14(22), 6860.* https://doi.org/10.3390/ma14226860

[2] Bzdawka, K. (2010). Composite column – calculation examples. *Tampere University of Technology*

[3] EN 1994-1-1. (2004). Eurocode 4: Design of composite steel and concrete structures – Part 1-1: General rules and rules for buildings. *Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC*

[4] EN 1994-1-2. (2005). Eurocode 4: Design of composite steel and concrete structures – Part 1-2: General rules - Structural fire design. *Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC*

[5] ENV 13381-1. (2002). Test methods for determining the contribution to the fire resistance of structural members – Part 1: Horizontal protective membranes

[6] ENV 13381-2. (2002). Test methods for determining the contribution to the fire resistance of structural members – Part 2: Vertical protective membranes

Болат темірбетон бағандарын жобалаудың әртүрлі тәсілдерінде материалдарды пайдалану тиімділігін салыстыру

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Аңдатпа. Бұл мақалада диаметрдің көлденең қимасын таңдау кезінде әр түрлі тәсілмен құбырлы бетон бағандарын есептеу тақырыбы қозғалады. Бірінші жағдайда арматураның минималды қосымша қимасы бар жүктемелердің әсерінен бағананы есептеу жүргізілді, екінші жағдайда бірдей жүктемелермен есептеу жүргізілді, бірақ арматура өзектерінің қимасы ұлғайтылды, екі жағдайда да барлық критикалық күйлер мен беріктікті тексеруді ескере отырып, бағанның Болат құбырының қимасы таңдалды. Зерттеу нәтижелері бойынша материалды сыйымдылыққа байланысты есептеудің ұтымды әдісі арматураның ең аз рұқсат етілген қимасы бар бірінші нұсқа деп айтуға болады, орташа есеппен мұндай бағанға жұмсалған металл көлемі екінші нұсқаға қарағанда 14.4% - ға аз болады, бірақ бұл жағдайда бетонның қажетті көлемі 10.4%-ға аз болады.
Негізгі сөздер: *болат темірбетон, бағандар, есептеу.*

Сравнение эффективности использования материалов при различных подходах проектирования колонн из сталежелезобетона

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Аннотация. В этой статье затрагивается тема расчета трубобетонных колонн с различным подходом при подборе сечения подходящего диаметра. В первом случае был произведен расчет колонны под действием нагрузок при минимально допустимом сечении арматуры, во втором случае был произведен расчет с идентичными нагрузками, но с увеличенным сечением стержней арматуры, в обоих случаях был произведен подбор сечения стальной трубы колонны с учетом соблюдения всех критических состояний и проверок на прочность. По итогам исследования, можно сказать, что, рациональным методом расчета, в плане материалоемкости, является первый вариант с минимально допустимым сечением арматуры, в среднем объем металла, затраченный на такую колонну, будет в 14.4% меньше, чем во втором варианте, но требующийся объем бетона в таком случае возрастет на 10.4%. Исходя из полученных результатов, можно сказать, что первый подход к расчету является более эффективным с точки зрения затрат металла, что является превалирующим фактором при проектировании конструкций из сталежелезобетонна.
Ключевые слова: *сталежелезобетон, колонны, расчет.*

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