Cost-effective design of long cylindrical shells of high-strength sand concrete

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Abstract. The use of high strength sand concrete (HSSC) is an alternative to high-strength crushed stone concrete. Its use is economically viable for those regions of Russia in which crushed stone belongs to imported building materials. So, crushed stone is supplied to the Republic of Tatarstan (RT) from the Ural, and local sand reserves are significant.

Authors give the information on the cost-effectiveness of designing prefabricated and monolithic long cylindrical shells from HSSC of B60 and B80 classes compared to heavy concrete of B20-B80 classes.

The determination of the forces in the shell elements was performed by using the LIRA-CAD software package (SP). The calculation of the elements of prefabricated shells was carried out in the stages of operation, manufacture, transportation and installation. It was carried out by an engineering method according to the methodology of current standards. Calculation of monolithic shells was performed using an SP. The density of heavy concrete, its strength and deformation characteristics were accepted according to the standards. The same characteristics for HSSC were based on the results of the experiments of the department “Technology of building materials, products and structures” (TBMPS) of Kazan State University of Architecture and Engineering (KSUAE).

The performed calculations showed that the use of HSSC of B60 and B80 classes compared with the heavy ones makes it possible to obtain a significant economic effect in the Republic of Tatarstan (RT). Namely: to reduce the consumption of steel (up to 30.6 % in prefabricated shells and up to 23.7 % in monolithic), concrete (up to 15.9 % in prefabricated shells and up to 14.0 % in monolithic) and the total cost of materials (up to 18.9 % in prefabricated shells and up to 20.3 % in monolithic).

Key words: high strength sand concrete, long cylindrical shells, stages of work, engineering method of calculation, a software package, economic efficiency.

1 Introduction

The study of new types of concrete has always been an urgent topic for many scientists and researchers in the field of construction. One of the promising areas is associated with obtaining and economic efficiency of the use of high-strength crushed stone and sand (fine-grained) concrete in reinforced concrete structures.

The issue of recycling the wastes of the metallurgical industry by their use in sand concrete [1] was considered. It was revealed that the presence of carbonate-containing additives in the blast furnace sludge promoted the formation of calcium hydrosilicates. This occurs during the hydrothermal treatment of concrete with the ongoing process of hydration of the cement and the interaction of calcium hydroxide with sand. Calcium hydrosilicates incorporate carbonate groups that are close to the
hydrosilicate phases in composition. This helps to increase the concrete strength by 11.2 %, density by 14 %, reduce water absorption by 5 %, and also minimize the scale of carbon dioxide corrosion.

Sand concrete was investigated by KSUAE employees [2]. They carried out studies of the density, strength and water absorption of such concrete made by the zone injection method. They used fractionated sand with a fineness modulus of 2.5 and Portland cement PC500 D0. By varying the water-cement and cement-sand ratios, the optimal compositions of fine-grained concrete for road purposes with strength of 40.8 to 72.3 MPa were obtained.

The effect of the composition of sand concrete on compressive strength was examined based on preliminary calculation of it using the absolute volume method and a computer model using the Maple 13 program [3]. As a result, second-order regression equations were obtained. They adequately estimate the compressive strength of concrete at the age of 28 days.

The effect of dispersed mineral additives on the strength of fine-grained concrete and the effect of contaminants in the sand, the dispersion of additives and the concentration of diopside on the mechanical properties of concrete were studied [4].

The effect of additives based on pickling solutions (PS) of steel mills containing iron salts and being nanomodifying on the structure and strength of fine-grained concrete was studied [5]. It has been experimentally established that the use of these additives compacts and strengthens the structure of concrete. It was revealed that in the presence of hydrochloric acid PS containing iron salts, calcium hydrosilicate structures are formed. They seal the system and contribute to a significant increase in compressive strength. The optimum content of the additive, which provides the maximum increase in the strength of concrete, was experimentally determined.

In [6], the dependence of the strength of a fine-grained concrete mixture on the shape and topography of the particle surface, the content of dusty and clay particles and impurities enveloping sand grains was studied.

At Moscow State University of Civil Engineering, sand concrete modified with a complex microdispersed additive was developed. The specified additive is obtained by co-grinding quartz sand, superplasticizer C-3 and calcium stearate [7]. On its basis, fine-grained concrete was obtained with compressive strength up to 50 MPa, bending up to 8.3 MPa, water absorption of 1.4 % and frost resistance of more than F75.

Scientists from the USA and Vietnam developed ultrahigh-strength concrete using local building materials, whose strength was 155 MPa at the age of 90 days [8]. The indicated strength was achieved with a silica particle content of 5 % with a natural set of strength. When hardening for 2 days at a temperature of 60 °C, and then 3 days at a temperature of 90 °C, the highest strength indicators were obtained.

Sands of natural origin have a variety of mineralogical compositions and chemical characteristics. The article [9] is devoted to the study of the effect of sand composition on concrete strength. Studies have shown that samples on sands with smectite type clays had lower strength compared to samples on other sands. Conversely, samples containing sands with Na₂O had the best strength indicators.

In [10], strength and hydrophysical parameters (water absorption, water resistance) of sand concrete modified with the “Gidropen Plug” waterproofing compound were investigated. It was experimentally established that this new type of concrete has high characteristics of water resistance and strength.

The development of high strength concrete using sand is presented in [11]. A new method for calculating the composition to obtain high strength concrete is proposed. It has been established that concrete made using sandstone has a higher strength than concrete based on river sand.

In [12], a review of studies on the effect of the use of sea sand and seawater on concrete properties is presented. It was found that concrete made on them is gaining strength faster than usual. However, the use of sea sand and seawater leads to rapid corrosion of steel reinforcement due to the presence of chlorides in them. It is proved that the use of polymer reinforcement instead of it in combination with mineral additives solves this problem.

In [13], the effect of cement with mineral additives from ground natural sand (sandy cement) and cement with mineral additives from granite screenings on the properties of heavy concrete is considered. It was experimentally established that concrete on sandy cement is characterized by an
increase in shrinkage deformations and an increased prepossession to crack formation. This leads to a decrease in compressive and tensile strength during bending, and a decrease in water resistance and frost resistance in comparison with concrete with cement with the addition of granite screening. In addition, they do not provide protective ability in relation to steel reinforcement.

At Voronezh State University of Architecture and Civil Engineering, the issue of calculating the deflections of beams with an upper layer of high-strength concrete was studied [14]. The upper layer of beams measuring 60×120(h)×1400 mm was made of high-strength concrete of B60-B90 classes with a height of 46...51 mm, and the lower stretched layer was made of concrete of B20...B30 classes. It is established that the use of high-strength concrete in a compressed zone leads to a decrease in sag. Recommendations on their calculation are given.

In [15], a calculation and research work was carried out to ensure the mechanical safety parameters of the One Tower high-rise residential complex 403.9 m high at the Moscow-City Moscow International Business Center. Structurally, the structure is a complex object in plan, consisting of an underground part (axial size – 186.9×37.2 m) with 4 underground floors, stylobate part (axial size – 166.95×30.7 m) of 12 floors and a high part (size in axles – 113.4×27 m) from 92 floors. The structural scheme of the high-altitude part is a monolithic reinforced concrete frame with a stiffness core and supporting columns. The calculation was performed using the ANSIS Mechanical SC. The supporting structures are designed from ordinary concrete of B50 class and high-strength concrete of B60 and B80 classes.

The effect of non-metallic waste on the properties of heavy concrete was considered in [16]. The physical, chemical and granulometric characteristics of screenings from quarries of the Sverdlovsk and Chelyabinsk regions were studied. The effective compositions of heavy concrete of B22.5-B40 classes with the use of screenings of crushed stone crushing and MC-Power Flow and Centrament Air 202 additives were developed and investigated. An assessment of the economic efficiency of the use of screenings from crushing rocks in heavy concrete was evaluated. At one of the Tyumen region enterprises of concrete goods, a pilot industrial check of the results in the production of reinforced concrete trays was carried out.

The properties of self-healing concrete were studied in [17]. It is noted that keeping reinforced concrete structures requires huge costs due to the need for regular repairs due to the formation of cracks. That is why the development proposed in [17] is relevant and revolutionary.

In [18], the influence of the introduction of basalt fibre into tensile concrete on its basic properties was considered. Tensile concrete was modified by an expanding sulfoaluminate type additive. It was revealed that the introduction of basalt fibre leads to an increase in the strength of the concrete composite due to the effect of spatially dispersed structure reinforcement and a change in fracture toughness. Due to the additive, the effect of simultaneous expansion and hardening is realized because of the binding effect of basalt fibre as a dispersed reinforcing element. This leads to increased impermeability and durability of this kind of concrete, which determines the prospects for their use for the repair of various kinds of buildings and structures.

The paper [19] presents the results of a study aimed at studying the structural behavior of beams made of self-compacting concrete with the addition of nanosilica (Nano-SiO\(_2\)) and nanomanganese ferrite (Nano-MnFe\(_2\)O\(_3\)). Laboratory tests are described, which determined the properties of a freshly prepared mixture (plasticity, permeability and resistance to delamination), mechanical properties (compressive strength, cracking and bending) and durability (permeability and diffusion of chlorides). The experiments showed that the use of nano-additives and the replacement of 25 % cement with fly ash improved the mechanical properties and increased the durability of self-compacting concrete. From the obtained mixtures, the most optimal were selected. Reinforced concrete beams were produced and tested for bending.

The selection of refractory concrete compositions was considered in [20]. Concrete with high refractory characteristics was obtained from a briquette based on forsterite concentrate from the Kovdor mining and processing plant waste and magnesite phosphate binder. As a result of the studies, the grain composition of the batch mixture was selected, the ratio of aggregate and binder was
determined to improve the structural properties of concrete, the influence of the composition and temperature of heat treatment of the briquette on the physicotechnical properties of the obtained materials was revealed.

The analysis of the work showed that none of them considered the issue of economic feasibility of designing building structures from high-strength sand concrete.

It is known that the properties of sand concrete are determined by the same factors as ordinary concrete, however, it has some features, primarily due to the high content of cement stone. This type of concrete has several noticeable advantages: increased compressive and tensile strength, high-quality structure and high processability; reduction of concrete cost up to 15-25% (due to the use of cheap local sand compared to concrete on imported large aggregate); the possibility of obtaining thin-walled and layered structures, decorative concrete and fibre concrete, as well as materials and products of variable density, in particular filtering, and many other advantages [21-25].

Sandy concretes also have disadvantages due to the large surface of the aggregates. Accordingly, cement consumption increases by 15-20% in comparison with equal-strength heavy concrete. Therefore, when using sandy concrete, it is necessary to introduce not only plasticizing, but also mineral additives into the composition, or use composite types of cement or cement of low water demand.

Besides, these types of concrete have increased air entrainment. It is necessary to select effective thinners or antifoam agents to reduce it. Air entrainment depends on the type of plasticizer. Thus, in studies [26], it was found that the Melflux 2651F additive underestimates the air absorption rate by 33%, the remaining additives (C-3, Sika VC5-800) only increase this indicator.

Sand concrete has recently been increasingly used due to the widespread availability of raw materials. So, according to the state report on the state of natural resources and the environmental protection of the Republic of Tatarstan (Russia) in 2016, sands for concrete products are available in 26 deposits of the republic. The explored reserves are estimated at 73.3 million m$^3$. According to the strategy of environmental safety of the Republic of Tatarstan and the development of the natural resource complex of the Republic for 2017-2021 and the future until 2030, the building materials industry should expand the range of products manufactured from local mineral raw materials.

In this regard, the use of sand concrete is an important task for manufacturers of reinforced concrete, since most of the European territory of Russia (Moscow, Moscow Region, Volga Region, Vologda, etc.) does not have coarse aggregate deposits or deposits of sedimentary rocks, which are limited for use in reinforced concrete. Also, the extraction of stone and its processing for crushed stone require large amounts of electricity and a large number of workers. There is also an environmental aspect to the problem of using crushed stone: in the production of crushed stone of a fraction of more than 5 mm, a huge number (up to 20-30%) of screenings of a fraction of less than 5 mm are formed, which form multi-ton dumps, occupying large territories and upsetting the ecological balance of the regions. Only a small amount of such waste is used as raw material for the preparation of limestone flour and mineral powder for asphalt concrete. The destruction of the mountains during its mining leads to irreversible climatic changes in Karelia, the North Caucasus and the Urals. Using sand as filler causes less environmental damage than using crushed stone.

In the world practice of construction, high-strength and ultra-high-strength heavy concretes of a new generation are increasingly used. They can significantly reduce the cross-sections of elements, save concrete and reinforcement [27-28]. The implementation of the special technical properties of these concretes has opened up almost limitless possibilities for the construction of unique buildings and structures around the world. In Russia, the use of high-strength and ultra-high-strength concrete began much later than in Western European countries, the USA, Canada and Japan. One of the most notable objects built using concrete of B80...B90 classes, so far, are the buildings of the “Federation” complex of “Moscow City” MIBC. At the construction sites of the complex, concrete with a prismatic strength of 87-106 MPa with a cement flow rate of 460-550 kg/m$^3$ of concrete was used [29].

An alternative to high-strength heavy concrete is high-strength sand concrete (HSSC) [30]. This concrete is a composite material that includes quartz sand, a highly active binder and effective modifiers. A decrease in the amount of cementitious material in the concrete is achieved by grinding
some of the sand, using plasticizing additives, and autoclaving the products. As chemical additives, plasticizers (S-3/2.5, Sika VC5-800/2.5, Metflux 2651/2.5) are mainly used, which can significantly reduce the water demand of the concrete mixture and cement consumption [23].

The use of HSSC has the following advantages: higher initial and final strength, early stripping and preliminary compression, which makes it possible to use the element earlier; a decrease in building thickness or an increase in the bearing capacity of structures working in bending; higher density, water and gas impermeability due to the low content of capillary pores, which leads to greater durability; higher wear resistance; increased corrosion protection of valves due to the slow spread of carbonization; increased resistance to chemically active substances; the creation of more “elegant” contours with an increase in the length of the spans of structures working on bending (long-span bridges).

The introduction of high-strength sandy concrete using fractionated river sands of the Republic of Tatarstan and chemical additives is an alternative to traditional concrete, which requires expensive high-strength crushed stone imported from the Urals.

Based on fractionated sands of local deposits of the Kama, Volga and Vyatka rivers, the TBMPMS department of KSUAE developed compositions of high-grade sand concrete B60-B80 [31]. The project “High-strength sand concrete” was included in the list of innovative projects and developments in the field of building materials and technologies of the Ministry of Construction, Architecture and Housing of the Republic of Tatarstan. In 2017, on the instructions of the President of the Republic of Tatarstan, together with the State Housing Fund, the Department of TBMPS of KSUAE continued work on high-strength sand concrete. In particular, the scientists of this department, together with the specialists of Kazan Giproniaaviaprom OJSC, completed an alternative design of the supporting frame of an 18-storey residential building in the “Salavat Coopere” complex of Kazan from high-strength sand concrete of B80 class instead of the initial project of heavy concrete of B25 class. As a result, savings in concrete amounted to 20 %, for steel reinforcement – 29 % [32].

Despite these advantages, today in the Republic of Tatarstan and Russia the problem of the widespread use of the new generation HSSC is the insufficiently fast development of methods for calculating load-bearing structures made from it. In this regard, the use of such concrete is limited to the manufacture of small pieces and all kinds of decorative architectural and finishing products, as well as coatings for roads, airfields and floors of industrial buildings.

In accordance with the foregoing, it is necessary to continue work on the design of various building structures from HSSC. The only criterion for the effectiveness of its application should be economic feasibility. In this regard, the topic considered in the article is relevant for the development of the construction industry both in the Republic of Tatarstan and in Russia as a whole.

The aim of the research, the results of which are given in this article, was to identify the economic efficiency of designing prefabricated and monolithic long cylindrical shells from HSSC of B60 and B80 classes compared to heavy concrete classes B20-B80.

2 Materials and methods

2.1 General information about long cylindrical shells

For long cylindrical shells, the condition \( l_1 / l_2 \geq 1 \) is valid, where \( l_1 \) is the span of the shell, \( l_2 \) is the wavelength or width of the shell (figure 1).

There are two schemes for the division of prefabricated shells (figure 2). In the first scheme, the shells are assembled from side beams with a span length of \( l_1 = 18, 24 \) and 30 m, curved ribbed panels with a length of span of wave \( l_2 = 12 \) m and tightening of diaphragms resting on the side beams (figure 2a). In the second scheme, the shells are made of curved ribbed panels with adjacent parts of the side beams of half wavelength \( l_2 / 2 = 12 / 2 = 6 \) m and tightening of diaphragms, the span of the shell is \( l_1 = 18 \) and 24 m, wavelength \( l_2 = 12 \) m (figure 2b).
Figure 1. General form of the prefabricated long cylindrical shell:
1 – side element; 2 – cylindrical panels; 3 – tightening of the end diaphragm.

Figure 2. Diagrams of the division of prefabricated reinforced concrete long cylindrical shells:
a – from side beams, curved ribbed panels and puffs of diaphragms;
b – from curved ribbed panels with an onboard element and puffs of the diaphragms;
1 – curved ribbed panel measuring 3×12 m; 2 – the same, 3×6 m; 3 – tightening 12 m long;
4 – the same, 6 m; 5 – side beam length of the span of the shell.

In both schemes, the width of the panels is 3 m, the thickness of their plates is taken to be at least 30 mm, and the reinforced longitudinal edge of the end panels serves as the upper belt of the end diaphragms. The first scheme is characterized by the simplicity of manufacture and installation.

2.2 Constructive solutions of the studied shells, applied materials and calculation methods
Prefabricated shells. For research, the prefabricated shell design was chosen according to the first division scheme (Fig. 2a). In the “Manual on the design of reinforced concrete spatial structures of coatings and floors (to SP 52-117-2008 “Reinforced concrete spatial structures of coatings and floors. Design rules” (Russian standard)), a technique for determining efforts by an engineering method is given for it. However, this methodology does not take into account various schemes for applying snow load and generally does not take into account the wind effect recommended by SP 20.13330 “Loads and impacts” (Russian standard). Therefore, to determine the forces arising in a cylindrical shell, the
calculation must be performed in a PC, which will allow applying the specified types of loads. However, before using the SC, it was necessary to verify the comparability of the calculation results to determine the efforts received in the SC and the engineering method. To perform the calculations, LIRA-SAPR SC was chosen, which implements the finite element method based on the displacement method.

The efforts were determined and compared using the example of a separate shell with a span of 30 m and a wavelength of 12 m made of heavy concrete of classes B20 (curved panels) and B30 (side beams and diaphragm tightening), designed in the Republic of Tatarstan.

The geometric characteristics of the shell elements were adopted in accordance with the recommendations of the norms. The panel plate is outlined in an arc of a circle with a lifting arrow of 1500 mm, its thickness is 40 mm, the height and width of the transverse intermediate ribs are 150 mm and 50 mm, respectively, the height and width of the transverse ribs on the support are 200 mm and 100 mm, respectively, length transverse ribs – 2780 mm, their pitch – 3000 mm; the height of the longitudinal ribs is 200 mm, the width is 100 mm, the length is 12350 mm. The section of the arch of the end diaphragm is 200×480 (h) mm, the section of the tightening is 200×400 mm. The side beams are made of an I-section; on the support, their section is rectangular 300×800 (h) mm. The geometric dimensions of the shell in the middle of the span are shown in figure 3. The cross section of the columns is 400×400 mm.

![Figure 3. The geometric dimensions of the prefabricated long cylindrical shell in the middle of the span l₁=30 m: a – section of the shell; b – section of the side beam; 1 – prestressing fittings.](image)

Previously, in order to determine the thickness of the insulation, a thermotechnical calculation of the roof was performed, and also the shell was checked for stability.

The following efforts were determined and compared: the longitudinal forces N, acting at the cross-sectional points of the flange at an angle of 45° to the generatrix (in the longitudinal direction of the end, second and third from the end of the panels), the forces N and the bending moments M in the transverse...
direction of the average along the span of the panel (in these zones, in comparison with others, the greatest efforts arise), forces N and moments M in the arch, force N in tightening the diaphragm.

The analysis of the results showed that: 1) the difference in the efforts determined by the engineering method and in the LIRA-CAD software is from –8.7 % to 19.4 %; 2) the values of the efforts determined in the LIRA-SAPR software package, only in 2 cases out of 36 (6 %) were lower than the values determined by the engineering method. Based on this, it was concluded that this difference is acceptable. Therefore, in the future, LIRA-SAPR was used to determine the efforts, taking into account the wind effect and various schemes for applying the snow load.

Using an SC, efforts were determined in the elements of three-span three-wave shells measuring 18×12 m, 24×12 m, 30×12 m. The options for applying the snow load were taken according to SP 20.13330 (Russian standard), and the wind effect was determined as the sum of the average and ripple components.

Based on the efforts obtained, elements of three-span three-wave shells with dimensions in the plan of 18×12 m, 24×12 m and 30×12 m of heavy concrete of B20, B30, B40, B60, B80 classes and HSSC of B60 and B80 classes were calculated.

The lower tensile reinforcement of the side beam is adopted from ropes Ø12 K1500 (the method of tension is mechanical on the form stops), the longitudinal structural is from class A240C, the transverse from A400C. The tensile upper and lower reinforcement of the end diaphragm is made of Ap600C, the tensile tightening reinforcement is made of Ø9, Ø12 K1500. The longitudinal reinforcement in the columns is made of A400C, the transverse reinforcement is made of A240. The lower tensile reinforcement of the longitudinal edges of the panel is from Ap600 (the tension method is electrothermal on the form stops), the longitudinal and transverse longitudinal ones are from A240C, the longitudinal and transverse in transverse ribs are from A500C and B500C, respectively, the reinforcement of the cap grid from A500C and A400C.

Calculations were made for groups I and II of the limiting states of the side beam (under operation), panels (at the stages of operation, manufacturing, transportation, and installation), arches and tightening of the diaphragm (at the stage of operation), columns (at the stage of operation). The purpose of the calculations was to determine the required amount of reinforcement in the elements of the shells. Moreover, in the case of using HSSC, if design requirements allowed, the sizes of the sections of the elements changed. These calculations were carried out by an engineering method according to the methodology of current standards – SP 387.1325800 “Reinforced concrete spatial structures of coatings and floors. Design Rules” (Russian standard) and SP 63.13330 “Concrete and reinforced concrete structures. Key Points”. The density of heavy concrete, its strength, and deformation characteristics were taken according to SP 63.13330, and the strength and deformation characteristics of HSSC were taken according to the results of experiments at the TBMPS department of KSUAE. The strength and deformation characteristics of reinforcement were adopted by SP 63.13330. Based on the calculation results, the design of shell elements was performed.

For each calculated three-span three-wave shell, technical and economic indicators were determined for the consumption of materials (concrete and reinforcement) and their cost concerning the Republic of Tatarstan, including the total, and their comparison was made for cases of manufacturing of shells from heavy concrete and HSSC. The composition of heavy concrete and HSSC of various classes was adopted according to the results of developments at the TBMPS department of KSUAE.

Monolithic shells. Calculation and design of detached monolithic long cylindrical shells with plan dimensions of 18×12 m, 24×12 m, 30×12 m, 24×18 m, 30×18 m, 30×24 m from heavy concrete of B30, B40, B60, B80 classes and HSSC of B60 and B80 classes were made.

The geometric parameters of the shell elements were taken according to the recommendations of the norms and based on the experience of design practice. The height to the bottom of the tightening of the end diaphragm is assumed to be 11.4 m. All longitudinal reinforcement is conventional of A400 class, transverse and structural reinforcement class is A240.
The calculation, which consisted of determining the required amount of reinforcement, was performed in the LIRA-SAPR SC with the application of wind and various snow load schemes. The deflection of shell elements was determined in an SC. The reinforcement scheme of the core elements of the shell was set based on the analysis of the diagrams of the forces acting in them. So, reinforcing the tightening of the diaphragm and the column was assigned symmetrical, and the reinforcement of the arch and the side beam – asymmetric.

In the manufacture of the shell and columns of heavy concrete, their reinforcement was taken according to the results of the calculation of the PC “tuned” to SP 63.13330, and in the manufacture of them from HSSC reinforcement was determined as follows. Since the deformation and strength characteristics of HSSC and heavy concrete of the same classes differ, that is why they were set directly in the PC. This was possible only when the PC was “tuned” to the currently inactive SNiP 2.03.01-84* (Russian standard), in which the method of calculating longitudinal reinforcement according to the group I of limiting states is identical to the method of SP 63.13330, and the method of calculating transverse reinforcement and calculation of crack resistance is excellent. Also, the values of $R_s$ and $R_{sc}$ in SNiP 2.03.01-84* and SP 63.13330 are slightly different. Therefore, when determining the reinforcement directly in the slab and side beam, at first, the required longitudinal reinforcement was adjusted according to the values of $R_s$ and $R_{sc}$, then manually calculated by the crack resistance to the forces obtained in the LIRA-SAPR software. The calculation of transverse reinforcement was carried out manually according to the method of SP 63.13330. The selection of longitudinal and transverse reinforcement in the columns was carried out based on the results issued by the LIRA-CAD software, taking into account the adjustment of the values of $R_s$, $R_{sw}$ and $R_{se}$ and design requirements.

The design of the shell elements was carried out in accordance with the required number of fittings and the design requirements of the standards. The construction of the shell plate was carried out by the main and additional fittings. The main reinforcement consisted of one or two nets laid along the entire contour of the plate (with a plate thickness in the ridge of up to 100 mm, one mesh was adopted, with a larger thickness two), and additional – in the form of grids installed, if necessary, along the contour, as well as separate rods in the middle zone and oblique rods in the corners.

3 Results
The analysis of the calculation results showed that when using HSSC: 1) the crack opening width compared with the use of heavy concrete of the same classes decreases, and in some cases cracks do not form at all because of its greater tensile strength; 2) the need for design fittings is reduced or completely eliminated (in the latter case, it was assigned according to design requirements); 3) the thickness of the shelf curved panels decreases.

4 Discussions
In the scientific and technical literature, only information about the economic efficiency of designing from the HSSC 18-storey residential building in Kazan was found.

5 Conclusions
The use of high-strength sand concrete (HSSC) is an alternative to high-strength crushed stone concrete. In the scientific and technical literature, there is no information about the design of long cylindrical shells from it.

The performed studies allow us to conclude that the use of high-strength sand concrete (HSSC) of B60 and B80 classes, compared with heavy ones, when designing the shells discussed in the article allows to obtain a significant economic effect, namely, to reduce the consumption of steel (up to 30.6 % in prefabricated shells and up to 23.7 % in monolithic), concrete (up to 15.9 % in prefabricated casings and up to 14.0 % in monolithic) and the total cost of materials (up to 18.9 % in prefabricated shells and up to 20.3 % in monolithic).

In this regard, we can conclude that the results obtained are novel, and the results of the studies can be recommended for use in construction practice.
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