Concrete with Nano-Additives in thin Wall Shell Structures

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Abstract **– In the present paper physical and mechanical properties of glass fibre fibrous concrete as well as its technological possibilities in the production of definite shells have been studied. Production technology patented by RTU Concrete Mechanics Laboratory was used. This technology allows developing and obtaining different shells from fibrous concrete, including also dome structures and two-plane bended shells with smooth inner and outer surfaces. Concrete is spread in the necessary thickness on horizontal base, then the upper surface is leveled out and only then, applying pneumatic pressure, with the help of high elasticity material mould the necessary shell bending (height) is built. [1,2].**

Keywords **– shell production technology, concrete with nano-additives.**

I. Introduction

The beginnings of the dome structures can be found already in 27 B.C. in Rome, Italy, where the Pantheon was built. Marcus Agrippa started the construction of the Pantheon as a temple of all gods of Ancient Rome. The Pantheon is a cylindrical building with a portico, covered by a hemispherical dome. Nearly two thousand years after its construction the dome of the Pantheon is still the largest ferroconcrete dome in the world, the diameter of which is 43 metres; in the centre it has an opening for light of 9 meters diameter. Dome structure buildings can be found also at the beginning of the 1920s, when in 1926 the planetarium in the German town Jena opened its doors. The prospering period of concrete shell construction started in the 1930s when engineers like, for example, Felix Candela, Eduardo Torroja, Anton Tedesko and Pier Luigi Nervi developed and produced very elegant concrete shells.

Formation of concrete shell structures using traditional mould technologies is a labour consuming process and large amounts of auxiliary materials are used for mould production [8]. The production of thin wall concrete shells in the 1930s was started using board moulds that were assembled from straight elements, and this is a lengthy and very expensive process [3]. This construction process requires numerous qualified craftsmen (see Fig. 1). Besides, these moulds after removing cannot be used repeatedly. In the 1950s the American architect, inventor and engineer Richard Buckminster Fuller formulated a statement: - „more with less", or always strive to reach more by doing less. He believed that in the future dwelling houses of dome shape would help to solve the problem of dwelling shortage because they are lighter and much stronger than traditional buildings, thus there would be no worries about, for instance, the snow weight on the roof. Inside the dome shell no load bearing columns are needed.

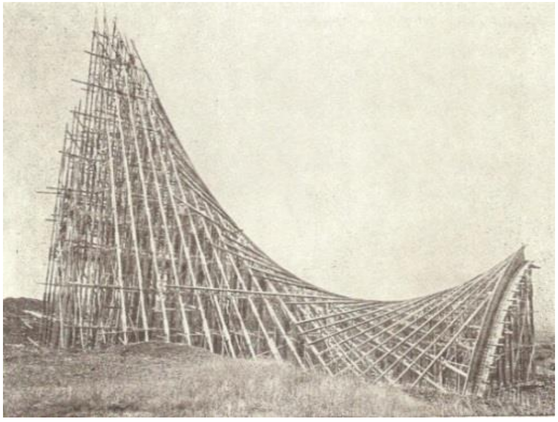

Fig.1. Mexico mould designed by Felix Candela [7]

Domes can be installed easily and quickly, they are antiseismic and endure external load. At present in the whole world there might already be about 300,000 dome buildings. In 1950 engineer Heinz Isler introduced a slightly different approach, using folding wooden bended sections, which could be repeatedly used several times, in the concrete shell formation. From 1960 the interest in concrete shell structures started to decline. The reason was that labour force costs went up rapidly. During the last ten years bent structures have again become popular due to new computer design and calculation software technologies (CAD, FEM, etc.).

Dome structures are lighter and much more durable than traditional buildings, thus there are no worries about, for example, the weight of snow on the roof. It has turned out that the strength of the building of spherical form is ensured by the fact that the whole structure consists of triangles of different size, which are statistically unchanging systems contrary to triangles, which change their form if load is exercised on their joints. Thus, a dome is like a strong shell, which inside needs no bearing columns. Thanks to the its hemispherical form the building conveys precipitation ideally; it does not catch the wind because it bends evenly around the dome, causing no additional load. Therefore, Arctic stations are often situated in dome-shaped buildings. Domes can be installed easily and quickly, they are antiseismic and endure external load.

The dome form in architecture is created by thin concrete shells made in the form of cylinders, spheres, paraboloids, hyperboloids, saddle shells. To make geometrically complicated forms and surface textures concrete needs to be poured into elastic and adjustable mould system. Reduction of concrete structure weight has become important with regard to additional saving of materials and transportation costs. However, a limiting factor regarding construction of such concrete shell structures is the capacity of concrete shell production, its labour consuming character and shortage of variable elastic mould systems. This research gives a new insight into the production process of concrete shells and introduces a new cost saving approach to the concrete shell production using innovative mould technologies.

Formation of any concrete structure requires moulds to give the structure the necessary form and dimensions. Moulds have temporary or constant structure [9]. Moulds can be made of different materials (wood, metal, concrete, fabric, etc.) and have different structures (fixed, removable – regulated, pushed, suspended, special block form). Research team looked for the forms of moulds that would facilitate and accelerate their installation considerably, as well as would allow reaching high quality work. When installing moulds particular attention is paid to the durability and stability of the mould structure. One solution of the problem is industrially manufactured and reusable mould elements. It is difficult to use flat and cylindrical bended mould elements for the formation of two direction bended shell surfaces, besides, it is practically impossible to get diverse spherical forms. To hide the imprint of such moulds in concrete an additional finish work is needed, which raises the construction costs.

A limiting factor regarding the acceptance of the concrete free form in designing is production capacity and adjustment of mould systems, but any changes of mould form or surface structure can be regarded as complicated, time consuming, labour consuming and thus also financially unprofitable. New forms to architecture are given by concrete shells made in the form of cylinders, spheres, paraboloids and hyperboloids. To put into practice the required geometrically complicated forms and surface texture concrete needs to be cast in the elastic and adjustable mould system. We searched and found a different approach to the formation of thin wall concrete shells by a less complicated production method, as a result of which smooth surfaces are obtained. The mould material in the production of such concrete shells is EPDM rubber (polymer EPDM, ethylene-propylene rubber is produced by polymerising ethylene, propylene and diene monomer, as a result polymer forms saturated linear macromolecules with paraffinic structure). Riga Technical University has patented technological processes of concrete shell production where no steel is used in concrete as reinforcement, moulds are made of highly elastic material and concrete is spread on the mould, levelled and only then raised at the work height according to the technology.

Elasticity and adjustability capacities of pneumatic moulds with variable rise and gravitation moulds with variable geometry forms allow using them efficiently as completely elastic and adjustable mould systems to form geometrically complicated architectural forms, at the same time not losing durability indicators of the constructed surfaces.

II. EXPERIMENTAL RESEARCHES

The following tasks were set to be completed in laboratory experiments:

a) to implement experimentally the RTU shell sample production technologies according to the Latvian invention patents No LV14277 and No LV 14308;

b) to develop and produce shell dome structures, to find out characteristic properties of shell production technologies and advantages and efficiency of technological processes, visual attraction of manufactured products and advantages of the produced goods.

Formation of samples

In the course of experiments fibrous concrete shells were produced with alkali-proof zirconium glass fibres ARGF spread evenly along the concrete bulk. The inventions concern the construction of fibrous concrete monolithic structures and production of prefabricated structures. The first shell producing technology corresponds to the invention patent No LV14277 of Riga Technical University “Technological process of concrete shell production” [5]. For this purpose a pneumatic mould was made with variable height. The mould structure (square at the mould base): veneer 1000×1000×9 mm, rubber sheet 1000×1000 mm, the frame border height 9 mm, air valve, air pump. A technological process is proposed for shell production, including the following operations: an elastic mould is prepared spreading an elastic material sheet on flat surface. The mould borders are fixed (the border height corresponds to the thickness of the produced shell) along the perimeter of the next shell. Fibrous concrete mixture is spread on the prepared flat surface of the mould and is levelled. The upper surface of concrete spread on the mould is smoothed.

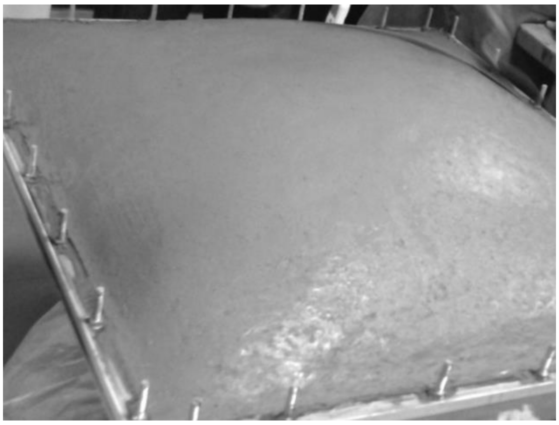

Fig.2. Pneumatic mould

Not allowing the stiffening of concrete mixture to start, air is pumped into the mould and the mould surface is raised till the set shell dimensions. The fresh concrete shell is lifted with the speed at which tension stress in fresh concrete mixture can still relax so that tension deformation of mixture would not exceed its limit deformations (see Fig.2).

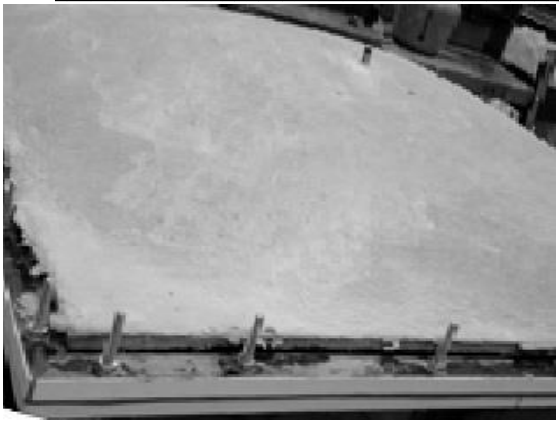

Fig.3. Shell unmoulding

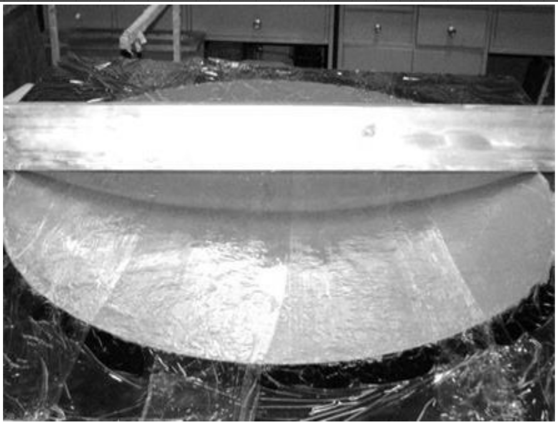

Fig.5. Gravitation mould

Shell is hardened not allowing mould deformations and therefore during concrete hardening the air pressure in the mould is checked and kept constant. When the necessary technological strength of concrete is reached, the shell is unmoulded, releasing the air from the pneumatic mould (see Fig.3). Another different shell production technology corresponds to the Latvian invention patent No LV14308 of Riga Technical University "Technological process of thin wall concrete shell production" [6], which was implemented experimentally. For this purpose a gravitation mould with variable geometry was made. The mould structure (circle at the mould base, see Fig. 4): veneer 1,000×1,000×9 mm, rubber sheet 1,000×1,000 mm, the frame border height 9 mm.

Fig. 4. Gravitation mould with variable geometry (circle at the base of mould)

Technological process includes the following operations:
A hard material frame is made, which corresponds to the horizontal projection borders of the produced shell. The height of the frame borders corresponds to the thickness of the produced shell. An elastic material sheet is fixed to the lower border of the frame, the dimensions of which correspond to the horizontal projection of the produced shell. The frame together with the fixed elastic material sheet is placed on the horizontal surface. Fibrous concrete layer, which corresponds to the shell thickness, is spread on the flat surface of the prepared mould, compressed and levelled. While the concrete mixture is in plastic condition, before the beginning of the stiffening process, the mould is captured by its frame and is lifted together with the concrete layer filled into it. Its floor of elastic material together with the filled in concrete layer is allowed to hang down in a bended way as far as elastic properties of the chosen floor material and the distributed load created by the filled in fresh concrete layer allow (see. Fig.5). Bending the mould down, the mixture inside it is slightly compressed and this condition reduces probable early cracking of the mixture. The lifted mould, together with the bent concrete layer in it, is placed on the supports, which are put under the mould frame. The shell is hardened, not allowing mould deformations. When the shell has hardened, it is unmoulded lifting it out from the mould. In case the shell is envisaged to be used turned upwards, then it is turned by 180°, transported and mounted on the construction object.

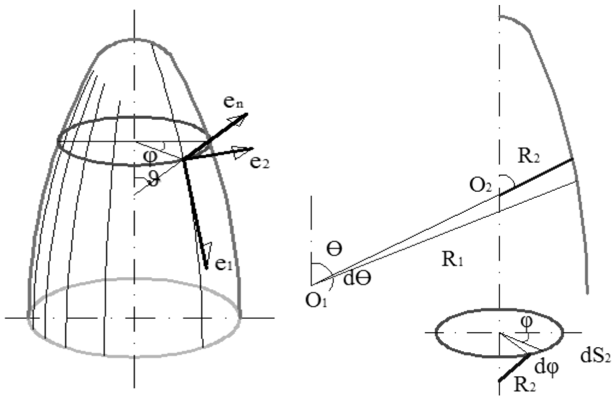

Fig.6. Calculation chart

Simplified theory of momentless rotation shells

Kirkhof's hypothesis should be regarded as the foundation of the theories, which afterwards were developed by H. Aron in 1874 and A. Low in 1888. Intensive development of these theories was started in 1930s and many scientists were engaged with these theories.

A simplified theory of momentless shells is used [4] to understand application of thin wall fibrous concrete in structures, to study the most rational forms from the point of view of structural mechanics and economics. The momentless rotation shell calculation model is presented in Fig.6.

Free form rotation shells

θ = coordinates of the central surface point, not the turning angle
are assumed as curve coordinates

$$\alpha_1 = \theta, and\ \alpha_2 = \varphi \implies$$
$$ds_1 = R_1 d\theta, and\ ds_2 = R_2 sin\theta\ d\varphi \quad (1)$$

Hence follows,

$$A_1 = R_1\ ; and\ A_2 = R_2 sin\theta \quad (2)$$

Radiuses $R_1\ and\ R_2$ are only θ function and they are connected with the following differential coherence:

$$\frac{dR_2\, sin\theta}{d\theta} = R_1\, cos\theta \quad (3)$$

Taking into consideration (2) (assessing that R_1 and R_2 do not depend on φ) and (3), we can write an equilibrium equation [4] as follows:

$$\begin{cases} \frac{1}{R_1 R_2 sin\theta}\left[\frac{\partial(N_1 R_1 sin\theta)}{\partial\theta} + R_1\frac{\partial S}{\partial\varphi} - N_2\frac{\partial R_2 sin\theta}{\partial\theta}\right] + q_1 = 0 \\ \frac{1}{R_1 R_2 sin\theta}\left[R_1\frac{\partial N_2}{\partial\varphi} + \frac{\partial(S R_2 sin\theta)}{\partial\theta} + S\frac{\partial(R_2 sin\theta)}{\partial\theta}\right] + q_2 = 0 \\ \frac{N_1}{R_1} + \frac{N_2}{R_2} - q_n = 0 \end{cases} \quad (4)$$

or,

$$\begin{cases} \frac{1}{R_1}\frac{\partial N_1}{\partial\theta} + (N_1 - N_2)\frac{tg\theta}{R_2} + \frac{1}{R_2 sin\theta}\frac{\partial S}{\partial\varphi} + q_1 = 0 \\ \frac{1}{R_1}\frac{\partial S}{\partial\theta} + 2\frac{ctg\theta}{R_2} + \frac{1}{R_2 sin\theta}\frac{\partial N_2}{\partial\varphi} + q_2 = 0 \\ \frac{N_1}{R_1} + \frac{N_2}{R_2} = q_n \end{cases} \quad (5)$$

We can rewrite the equation system [4], taking into consideration (2) (assessing that $R_1\ and\ R_2$ do not depend on φ) and (3), as follows:

$$\begin{cases} \varepsilon_1 = \frac{1}{R_1}\frac{\partial u_1}{\partial\theta} + \frac{\omega}{R_1} = \frac{1}{Eh}(N_1 - \mu N_2) \\ \varepsilon_2 = \frac{1}{R_2 sin\theta}\frac{\partial u_2}{\partial\varphi} + \frac{1}{R_1 R_2 sin\theta}\frac{\partial R_2 sin\theta}{\partial\theta}u_1 + \frac{\omega}{R_2} = \\ = \frac{1}{Eh}(N_2 - \mu N_1) \\ \omega = \frac{R_1 sin\theta}{R_1}\frac{\partial}{\partial\theta} + \left(\frac{u_2}{R_2 sin\theta}\right) + \frac{R_1}{R_2 sin\theta}\frac{\partial}{\partial\varphi}\left(\frac{u_1}{R_1}\right) = \\ = \frac{2(1+\mu)}{Eh}S \end{cases} \quad (6)$$

or,

$$\begin{cases} R_1\varepsilon_1 = \frac{\partial u_1}{\partial\theta} + \omega = \frac{R_1}{Eh}(N_1 - \mu N_2) \\ R_2\varepsilon_2 = \frac{1}{sin\theta}\frac{\partial u_2}{\partial\varphi} + \frac{1}{R_1 sin\theta}R_1 cos\theta u_1 + \omega = \\ = \frac{R_2}{Eh}(N_2 - \mu N_1) \\ \omega = \frac{R_2 sin\theta}{R_1}\frac{\frac{\partial u_1}{\partial\theta}R_2 sin\theta - u_2\frac{\partial R_2 sin\theta}{\partial\theta}}{R_2^2 sin^2\theta} + \frac{R_1}{R_2 sin\theta}\frac{\frac{\partial u_1}{\partial\varphi}R_1}{R_1^2} = \\ = \frac{2(1+\mu)}{Eh}S \end{cases} \quad (7)$$

And finally,

$$\begin{cases} R_1\varepsilon_1 = \frac{\partial u_1}{\partial\theta} + \omega = \frac{R_1}{Eh}(N_1 - \mu N_2) \\ R_2\varepsilon_2 = \frac{1}{sin\theta}\frac{\partial u_2}{\partial\varphi} + u_1 ctg\theta + \omega = \frac{R_2}{Eh}(N_2 - \mu N_1) \\ R_2\omega = \frac{R_2}{R_1}\frac{\partial u_2}{\partial\theta} - u_2 ctg\theta + \frac{1}{sin\theta}\frac{\partial u_1}{\partial\varphi} = \frac{2R_2(1+\mu)}{Eh}S \end{cases} \quad (8)$$

Support ring

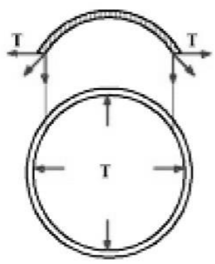

Fig.7. Forces in dome walls (non-orthogonal cross-section).

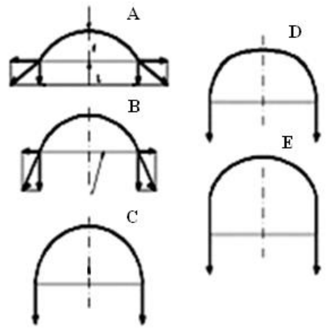

Fig.8. Forces in different form dome walls.

Following the above and studying cross-sections of spherical domes at different heights in more detail we see that at small *f/l* relation a significant shear T appears and the smaller this relation, the bigger is the force of horizontal axis. It means that when supporting domes of such type of geometry are used, very thick support walls will be needed or a special structure should be fabricated to bear such load. Such structures are called support rings and they are attached to the shell. From the direction of support shear it is clear that these support rings will function under tension. An analogue of this system is an arch with the tension rod (see Fig. 7 and 8). There are several solutions to this problem.

If the shell is made of concrete, the easiest way out is to insert steel reinforcement support ring in it, exposing it to tension.

Making ellipsoids for this type of shells at any *f/l* relations T can be equal to 0. Therefore it is important that the support parallel coincides with diametral ellipsoid plane.

Support shear T of the domes with different types of meridians but similar shell cross-section height f will be different. These are factors that must definitely be taken into consideration when designing domes. It should be noted that when forming a hard connection between the ring and the shell, the connection place will be exposed to the bend momentum and the theory of momentless shells [4] gains a recommendation character, calculating stresses and deformations in the shell using some of moment or semi-moment shell theories.

There are some practical conclusions:

The dome support ring fibres stretch. Besides, at different relations they can function in one case under tension, in another – compression. There is only one solution ensuring functioning of momentless shell, i.e. when compression of the respective support ring and forces of fibre tension of the respective dome at the place where they join are similar.

Then:

To ensure momentless functioning of the dome with a support ring, the normals of the turning angles of the middle shell surface at the support ring and diametral plane turning angles on the same plane at the support ring cut should coincide.

It becomes clear that domes having no transitional joints under the pressure of fibres of all rings cannot function as momentless.

In such domes a bend deformation appears in the zone of support ring. Yet they are quickly fading (border effect) when the support ring is removed along meridian. In this case to avoid the border effect one should refuse the support ring and all loads should be transferred to tangential stresses.

If the ring fibres near the support ring are stretched, then such support ring materials and such cross-sections can be found, which create the equilibrium of ring fibre and ring deformations.

$$\varepsilon^{\text{sup.ring}} = \varepsilon_2^{\text{shells}} \qquad (9)$$

It is crucial to note that strength provisions should be ensured simultaneously. The ring material elasticity module E and strength characteristic values are important to ensure stiffness parameters (9) as well as durability parameters.

Very often it is not rational to observe stiffness parameters (9) and from the point of view of material economy and due to designing considerations to allow the border effect, certainly assessing it.

Below (see Fig. 9) several diagrams of dome forces analysed by V.V.Novozhilov [4] are given.

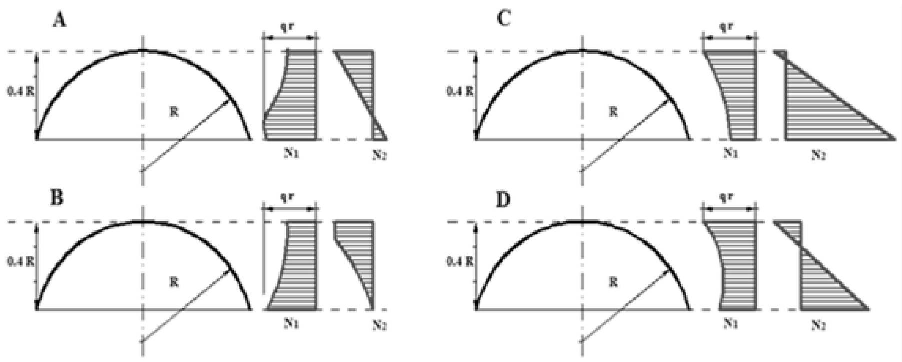

Fig.9. Diagrams of different dome forces

$$T = N_1^0 cos\theta_0 = 0.375qR\ (A)$$
$$T = N_1^0 cos\theta_0 = 0.487qR\ (B)$$
$$T = N_1^0 cos\theta_0 = 0\ (C)$$
$$T = N_1^0 cos\theta_0 = 0.190qR\ (D)$$

As we see, values N_1 and θ_0 in each dome are individual. For spherical dome see formula (9) but parabolic and ellipsoid formulas can be given as follows, see formulas (10, 11):

$$\begin{cases} N_1 = -\frac{qR_0}{3}\left(\frac{1}{cos^2\theta} + \frac{1}{1+cos\theta}\right) \\ N_2 = -qR_0\left[1 - \frac{1}{3}\left(\frac{1}{cos^2\theta} + \frac{1}{1+cos\theta}\right)\right] \end{cases} \qquad (10)$$

$$\begin{cases} N_1 = -\frac{qa}{2}\frac{\sqrt{1-\varepsilon^2 cos^2\theta}}{sin^2\theta}\begin{Bmatrix} \frac{(1-cos\theta)(1+\varepsilon^2 cos\theta)}{1-\varepsilon^2 cos^2\theta} + \frac{1-\varepsilon^2}{\varepsilon} \\ ln\left[\sqrt{\frac{1+\varepsilon}{1-\varepsilon}}\sqrt{\frac{1-cos\theta}{1+cos\theta}}\right] \end{Bmatrix} \\ N_2 = -\frac{qa\ cos\theta}{\sqrt{1-\varepsilon^2 cos^2\theta}} - \frac{1-\varepsilon^2\ cos^2\theta}{1-\varepsilon^2}N_1 \end{cases} \qquad (11)$$

Where,

$$\varepsilon^2 = 1 - \frac{b^2}{a^2}\ , a\ and\ b\ pole\ of\ the\ ellipse$$

It can be concluded that the most appropriate solution is to find a support ring with relatively small stiffness, which ensures momentless shell functioning.

III. Results of Experiment

Two types of shells were made. In the samples short 6 mm glass fibres (concrete matrix composite was reinforced with alkali resistant zirconium glass fibres) were used. Such shell material is mechanically nonlinear and has high dynamic energy absorption capacity. Using innovative moulds with variable geometry, which allow forming and producing shells, two dome type shells were produced with smooth inner and outer surfaces; one shell was produced with the help of “pneumatic” method and the other with the help of “gravitation” method.

The course of experiments showed the positive properties of technological processes of fibrous concrete shell production and their efficiency:

No reinforcement, which considerably extends the construction time and increases working costs significantly, is needed on the construction site;

These moulds can be used repeatedly, which considerably reduces construction costs;

One mould can be used for the production of different forms of structures;

Reinforcement on the building site is unnecessary, which reduces working costs;

Mould installation time decreases considerably, which reduces construction time;

During concrete placement it is possible to control and ensure thickness of layer of the spread concrete mix;

When concrete has been laced, there is no need to level and grind surfaces of the structure;

Roofs and waterproof coverings can be made for such structures, which are very complicated to be made with traditional methods and which require much longer time, more human resources and higher material consumption;

They can be introduced in industrial production, thus increasing the quality of structures and facilitating the control of technological processes;

Moulds are mobile and relatively light.

The advantages and constructive efficiency of production technologies of innovative concrete shells reinforced with alkali resistant zirconium glass fibres were analyzed. Shell production technology provides new opportunities in modern architecture, which are nearly impossible to use applying traditional moulds.

Conclusions

Having analyzed the calculation results, the following conclusions can be drawn:

Shells on already existing structures should be optimally designed so as to as much as possible avoid a massive support ring and support shear, which is theoretically possible. Theoretically it is possible to replace any roof covering with a momentless fibrous concrete shell dome.

Construction elements serving as shell auxiliary elements can be designed in the shell zone where stresses are the lowest or material resistance reserve is the highest (compression).

It is possible to use materials than can replace steel for support ring reinforcement, because the support ring functions in sheer tension.

After the analysis of experimentally gained results and experience one can conclude that concrete shell production technologies from the technical and economic point of view is an efficient solution, giving wide and new possibilities to modern architecture to create thin wall concrete elements of different complicated forms. Innovatory mould technologies in the production of monolith thin wall concrete structures will allow reducing labour consumption significantly (work for mould preparation, reinforcement and concrete placement) thanks to the simplicity of the constructive solution.

The proposed technologies are plastic and varying easily the form of elastic moulds it is possible to produce concrete shells of most diverse forms – different types of domes and vaults, the geometry of which can be formed in such a way that bending moments in both shell directions would be minimum or excluded at all. This, in its turn, allows making shells of minimum thickness, much lighter and cheaper than can be made using traditional construction technologies. Shells of considerable radius can be made and these structures can be made of any height. Theoretical calculations show that it is possible to produce a fibrous concrete shell of the covering with 30 m radius without additional supports inside the structure. This kind of roofing is among the cheapest, most long lasting and requires minimal maintenance costs.

The construction rate is much faster, comparing even to the simplest roofing structures. The shell production costs are 2 to 10 times cheaper and fibrous concrete shell can be made of the most widely spread construction material. The production technology of fibrous concrete thin wall shells using elastic material moulds is not only possible but it is also very advisable to introduce it into the construction practice. Theoretical and experimental researches prove economic and practical safety and profitability of the technology.

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Vitālijs Lūsis, Andrejs Krasņikovs, Irina Boiko, Anita Geriņa-Ancāne. Betons ar nano-piedevām plānsienu čaulu konstrukcijām.
Viens no betona veidiem ir fibrobetons. Svarīgs arguments ir fibrobetona ekonomiskums — ar to var ietaupīt tiešā veidā, atsakoties no ierastajām stiegrām, kā arī no cilvēka — stiegrotāja darba apmaksas. Savas īpašības šis kompozītmateriāls var elastīgi mainīt atkarībā no maisījuma sastāvdaļām, sagatavošanas veida un cietēšanas apstākļiem. Betona nozares attīstību veicina dažādi savstarpēji saistīti faktori. Viens no tiem ir ražotāju centieni panākt lielāku materiāla stiprību, lai samazinātu betona izlietojumu. Tāpēc būvniecības praksē parādās arvien plānākas betona konstrukcijas, vieglāki paneļi, čaulas, ko lieto nesošajās konstrukcijās vai elementos, kam jākalpo smagos apkārtējās vides apstākļos. Pētīta tehnoloģijas iespējamība pielietot rūpnieciskajā ražošanā un būvražošanā, kā arī stiklšķiedru fibrobetona fizikāli mehāniskās īpašības variējot ar fibru sastāvu, lai noteiktu visoptimālāko betonmasas sastāvu konkrētu čaulu izgatavošanā, lai panāktu betonmasas vienmērīgu izklāšanos čaulu izcelšanas procesā, pētot materiāla īpašības. Tehnoloģijā čaulu izgatavošanā tiek izmantotas stikla šķiedras (bieži sauktās par fibrām) pēc RTU patentētās betona čaulu izgatavošanas tehnoloģijas. Darbā apskatīta: veidņu tehnoloģija ar maināmo ģeometriju, čaulu veidošanas tehnoloģijas īpašības, tehnoloģiskā procesa novitāte. Šī tehnoloģija ļauj izveidot un iegūt dažādas čaulas no fibrobetona, tai skaitā arī kupolveidīgās konstrukcijas un divās plaknēs izliegtās čaulas ar gludu iekšējo un ārējo virsmu. Betons tiek vajadzīgajā biezumā uzklāts uz horizontālās pamatnes, pēc tām tiek nogludināta augšējā virsma un tikai tad, izmantojot pneimatisko spiedienu, ar augstas elastības materiāla veidņa palīdzību tiek uzcelts nepieciešamais čaulas izliekums (augstums).

Виталий Лусис, Андрей Красников, Ирина Бойко, Анита Геринявя-Анцане. Бетон с нанодобавками для создания тонкостенных оболочек.
Одним из видов бетона является фибробетон. Важным аргументом является эффективность фибробетона - это помогает экономить напрямую, не используя арматуру, а также является экономией на оплате труда арматурщиков. Этот композитный материал может изменить свои свойства легко в зависимости от ингредиентов смеси, видов добавок и условий твердения. Росту бетонной отрасли способствует различные факторы. Усилия производителей по достижению более высокой прочности материала с целью сокращения объёмов использования бетона один из них. Поэтому производство все более тонких бетонных конструкций, легких панелей используемых в несущих конструкциях и элементах, которые должны служить под воздействием тяжелых условий окружающей среды, возникающих в строительной практике. Исследованы технологические возможности использования строительных материалов с нано добавками и новых технологий промышленного производства тонкостенных оболочек, а также физические и механические свойства фибробетонных конструкций с нано добавками и разным содержанием стекловолокна. В исследовании рассматриваются следующие вопросы: технология опалубки с изменяемой геометрией; свойства технологии производства тонкостенной фибробетонной оболочки; новизна технологического процесса. Технология производства оболочек запатентованная РТУ позволяет разрабатывать и получать различные конструкции из фибробетона, в том числе и купола, двухплоскостные изогнутые оболочки с гладкой внутренней и внешней поверхностью. Бетон необходимой толщины укладывают на горизонтальном основании, его верхняя поверхность выравнивается, и применяя пневматическое давление или воздействие гравитации опалубка изгибается до проектировочной формы, при помощи опалубки с изменяемой геометрией с применением материала высокой эластичности необходимого изгиба оболочки (высота) построен.