Deformation of the prefabricated monolithic cover from porous concrete reinforced with fiberglass fittings

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Abstract. The paper studies the properties and the possibilities of using definite size thin-walled fasciae from the lightweight concrete, reinforced with one-layer fiberglass fittings, by numerical methods. The object of the research is a standard element of the prefabricated monolithic reticular cover’s clothing under the plane stress. Plane prefabricated cells have a hexagonal shape and ribbing that make a basis for a common reticular framework after the assembly of the cover. Strength properties of the model are studied at different reinforcement degrees. The paper also researches the possibilities of increasing the fittings’ adhesion ability due to the regular curved structure. The comparison of different reinforcement variants is presented. The distributive function of the contour ribbing on the stressed state of the standard element is evaluated. The paper also gives recommendations on the use of discrete thin-walled reinforced elements as the elements of the bearings’ covers in the structure of multilayer or multilayer membranate constructions.

1. Introduction

Lightweight concretes with porous filler and porous concretes are often used as heat insulating layers in fencing building constructions. An effective usage of porous construction materials in the load-bearing constructions of a low-rise building is known in practice [1–6]. For instance, in Canada, they use SIP (structural insulating panel) in the construction technology; in our country, SIP got the name of “The Russian wall”. The practice shows that the constructional scheme “The Russian Wall” can be used as the load-bearings of the low-rise buildings’ walls, in girderless bridgings with the size up to 4×4 m. This technology principle is the method of monolithic construction of quick-built buildings, in which the walls and other load-bearing constructions are a monolith. The constructive unity of the components is provided with the creation of a common spatial reinforcing framework from plane nets in the outside layers of the shotcrete (the thickness is 50 – 60 mm), belonging to the class not lower than B20. The inclined reinforcing bars, going through the middle layer made from the foamed polystyrene with the thickness 100 – 120 mm, bind these nets. The ecological safety and higher strength characteristics of elements in the frames of “The Russian Wall” technology can be achieved if to substitute polystyrene. Polystyrene can be substituted with lightweight porous concretes with light high-strength non-corrosive fiberglass fittings [7–11]. This paper researches the variety of this system.

The fiberglass plastic fittings have a high ultimate resistance (R=1200 MPa), lasting and non-corrosive. The usage of fiberglass fittings is limited due to a relatively low module of the material’s elasticity and a weak adhesion to the concrete [12, 13]. Considerable longitudinal deformations
develop in the fittings of the long-length constructions at a low module of elasticity. Consequently, the fittings do not fulfill one of its main functions – to prevent the cracks from opening. Thus, the constructive elements, reinforced with fiberglass, must have small dimensions. A low adhesion of the fittings to the concrete leads to the development of creeping and relaxation in the concrete. Partially, this problem is solved due to the toothing of the fiberglass fittings’ surface, by application of the silica sand on the fittings’ surface. However, the issue of the guaranteed high adhesion during a maintenance period is not studied enough. The development of measures, improving joint work of the concrete with fiberglass fittings, is urgent [11].

The objective of the research is the development of lightened load-bearing membranate constructions from porous concretes and reinforced with fiberglass; the above-mentioned shortages are not critical in these constructions.

2. Materials and methods
The model of a spherical cover with the radius \(R=9\) m is schematically presented in Figure 1. The calculating model of the standard fascia of the clothing with the width \(h=2\) cm at \(r=0.25\) is presented in Figure 2. The cover is formed with the help of standard plane hexagonal elements (in the plan 1) with the thickness 2 cm. The elements have their own ribbing on the side faces, which are laid along the fitting tracks 2 and joint in the fitting nods 3 [14–20]. The constructive design of the cover is made in the way that their own hard ribbing of separate elements at the joining in the nods are united and form hard ribbing 4, which provide a spatial rigidness of the cover in general. The ribbing of separate elements is made from curved angle-bars of \(40\times40\times4\) cm, aluminium and fiberglass shapes.

![Figure 1. The reticular cover.](image1)

![Figure 2. A standard element of the reticular cover’s clothing.](image2)

The reinforcement of a standard plane hexagonal element is made as a single-layer square net from rectilinear fiberglass bars. The paper researches the effectiveness of the reinforcement when the bars of the net have a regular periodical curve along the length with the parameters \(a = 2\) cm, \(f = 0.4\) cm. The bar system of the reticular covers work for the curve and pressing and take the main external load; the strained state of standard elements are close to the plane strained one.

The most loaded standard element, being in the conditions of the even all-round compression, is studied. The order of the nodal forces’ values \(P\) in Figure 2 is preliminary determined. Normal tensions in the element of the singular cover’s surface are determined according to the formula, in which it is accepted that the intensity of the normal to the cover’s surface is \(\rho = 100\) kilogram-force/m\(^2\):

\[
\sigma = \frac{\rho \cdot R}{2h},
\]  

(1)
The nodal load $P$ for the element with the radius $r$ is presented in Figure 2 and is 0.118 kilogram-force.

To improve simultaneous work of the fittings with concrete the rectilinear fittings were substituted with the ones, which harmoniously change along the length. The ends of the bars in the reinforcing net are connected to the contour ribbing along the side faces of the standard element.

Two variants of reinforcing the standard element of the reticular cover are studied:

I– the reinforcement with rectilinear bars with a square pitch of the net;

II– the reinforcement with lightly curved bars. Along with this, the pitch of the distribution of reinforcing bars varied.

The reciprocal impact of efforts in a slightly curved longitudinal fittings and normal tensions, transversal to it, in the binding material are well illustrated in Figure 3. The figure presents a radially curved fragment of the fittings with the length $a$, and having a radius of curvature $\rho$ and a rise of the curved fragment $f$; the angle $\theta$ is rather insignificant. Due to the small size of the fragment normal tensions $\sigma$ were accepted approximately identical along the whole length $a$, supposing that the transversal load is $q=\sigma=\text{const}$.

![Figure 3](image)

**Figure 3.** The reciprocal impact of the normal tension in the concrete and longitudinal fittings.

From the equation of static balance for the singled out element we obtain:

$$\Sigma Y=0$$

$$2N\sin\theta - Q = 0$$

Taking into account $Q=\sigma a$ at a low value $\theta$ it is obtained:

$$N=\frac{Q}{2\sin\theta}=\sigma a/2\theta$$

The analysis of the formula’s (4) structure shows that a very substantial interconnection can be implemented between a longitudinal effort $N$ in the curved fittings and tensions, transversal to the longitudinal axis, in its vicinity $\sigma$. At small values of the angle $\theta$, the value of which can be implemented with the help of variations of the parameters $a$ and $f$, formula (4) gives very big values for $N$. Figure 4 presents the final-element model of a standard element, obtained in the program Lira SAPR.
3. Results and discussions
The plasticity module of the porous concrete depending on its structure and the conditions of its moulding and strengthening can change in the limits $E_b = 2 \times 10^3 - 9 \times 10^3$ MPa. The main part of the calculations were done by the program Lira SAPR at $E_b = 6 \times 10^3$ MPa; this corresponds approximately to the average value of the elasticity module change’s interval. The pitch of distributing the reinforcing bars varied, and the diameter’s value of the fiberglass fittings was taken fixed ($d = 6$ mm, the fittings’ elasticity module $E_a = 55 \times 10^3$ MPa).

For each fitting’s distribution pitch, the percentage of reinforcement $\mu$ of the cross section’s square of the clothing’s element in the diametral section was determined.

Figures 5–8 present the distributions of the fields with maximum normal tensions $\sigma_y$ in the corner of the clothing’s panel, accordingly, with the distribution pitch: $b = 8; 4$ and $2$ cm. The isofields for $\sigma_x$ have analogous regularities.

**Figure 5.** Isofield $\sigma_y$ t/m$^2$

(the pitch of the reinforcement is 8 cm).

**Figure 6.** Isofield $\sigma_y$ t/m$^2$

(the pitch of the reinforcement is 4 cm).
Figures 5–8 illustrate the influence of the tensions’ concentrators in the knots of the fracture contour. The data from Figure 8 evidence a considerable role of the standard element’s contour bars, which redistribute the efforts among the reinforcement and the binding concrete. The tensions in the element without ribbing increase more than three times. The anchorage of reinforcing bars matters greatly to fiberglass fittings.

The character of the maximum tensions’ change depending on the reinforcement degree is presented in Figure 9.

Figure 7. Isofields $\sigma_y$, t/m² (the pitch of the reinforcement is 2 cm).

Figure 8. Isofields $\sigma_y$, t/m² (the pitch of the reinforcement is 2 cm) without contour ribbing in the element.

Figure 9. The change of maximum tensions at different elasticity modules of the binding concrete depending on the reinforcement of the cover: 1– $E = 9 \times 10^3$ MPa; 2 – $E = 6 \times 10^3$ MPa; 3 – $E = 4 \times 10^3$ MPa; 4 – $E = 2 \times 10^3$ MPa.
Figure 10 illustrates the tensions, changing cyclically, in the plane of the curved reinforcing bars. The character of changes is obvious at low values of the elasticity module of the binding materials (Figure 11).

![Figure 10](image1.png)

**Figure 10.** The character of distribution of normal tensions $\sigma_n$ in the vicinity of the curved fittings at $E = 6 \cdot 10^3$ MPa and $\mu = 0.7\%$.

![Figure 11](image2.png)

**Figure 11.** Isofields of the horizontal movements for $E = 2 \cdot 10^3$ MPa and $\mu = 0.7\%$.

The obtained dependences of the element’s stressed state at a different reinforcement percentage matter not only to the given specific element. The obtained dependences can be used as the reference reinforcement parameter while using porous concrete with fiberglass plastic.

4. **Summary**

The calculations’ results evidence that for the elements of a small size, being in the stressed state close to the plane and being reinforced with the fiberglass fittings, the conditions of strength and rigidity are provided in wide intervals of changing the reinforcement degree and the module of the concrete’s elasticity.

The researches show that the periodic curve of the reinforcing fiberglass bars provides the self-anchorage of the working fittings effectively. This allows rejecting additional anchorage details from steel on the ends of the reinforcing bars.
It is found out that ribbings on the sides of the covering’s fascia considerably lower the level of the element’s stressed state in general due to the efforts’ redistribution and the decrease of the tension concentrators’ influence.

5. References

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