TECHNOLOGY FOR CONCRETE SHELLS FABRICATION REINFORCED BY GLASS FIBERS

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ABSTRACT

The use of fiberconcrete, leads to a variety of innovative designs as a result of its many desirable properties. Not only can it be cast in diverse shapes; but in thin –wall structural elements also, possessing high compressive strength and stiffness. The promise of thinner and stronger elements, reduced weight and controlled cracking by simply adding fibers is an attractive feature of fiber-reinforced concrete.

Key words: concrete shells, glass fibers, fiberconcrete, FEM modeling

INTRODUCTION

New form architecture has a thin concrete shell created in the form of cylinders, circles, paraboloids and hyperboloids. In order to achieve the required geometrically complicated forms and surfaces of textured concrete a flexible and adjustable formwork system is necessary **(**Krasnikovs A.et al., 2012, Lusis V. 2011, LapsaV.et al. 2010).
Pneumatic formwork with changeable lifting form adjustment and adjustment abilities allow the use of them effectively as complete flexible and adjustable formwork systems, in order to create geometrically complicated architecture forms, at the same time not losing the strength indexes of constructed surfaces. The new offered technology is foreseen for plain wall structures, that allows one to create and have different shells, including domelike structures, in one direction curved shell, in two directions curved shell etc., for example, for building roof covering structures (Figure 2). Its field of usage is in manufacturing and building of concrete and fibro concrete precast and monolith shells.
Pneumatic mould use is an approach with a set of advantages among thin wall structural element fabrication technologies. In the reported work, a flat surface of a non- inflated pneumatic mould was imposed and smoothed down (forming a thin layer of a glass fiberconcrete mix). Before concrete binding, the mould was inflated by air forming a moderate curvature shell. Till the moment when the concrete was hardened, air pressure in pneumatic mould was kept at a constant value. Then the air in the pneumatic mould was blown out and the shell was demoulded.

Two variants were observed:
a) the shell is reinforced by uniformly distributed short glass fibers (concretes with three different fiber concentrations were investigated);
b) the shell is reinforced by weft knitted glass fiber textiles (were fabricated in the laboratory). Simultaneously flat material samples were fabricated and experimentally tested. Composite materials elastic moduli as well as tensile strength were obtained.

Figure 1. Short glass fiber concrete is evenly placed on the surface of a rubber membrane (pneumatic mould)

With the goal to predict the mechanical behavior of produced thin fiberconcrete shells a detailed micromechanical investigation for single fiber and few fibers bundle pull-out micro-mechanics was performed numerically (using FEM modeling) and experimentally. The macro-crack opening structural model, based on data sets with information about single fiber and few fibers bundle pull-out micro-

Figure 2. Concrete shell fabrication reinforced by three layers of knitted glass fiber fabric

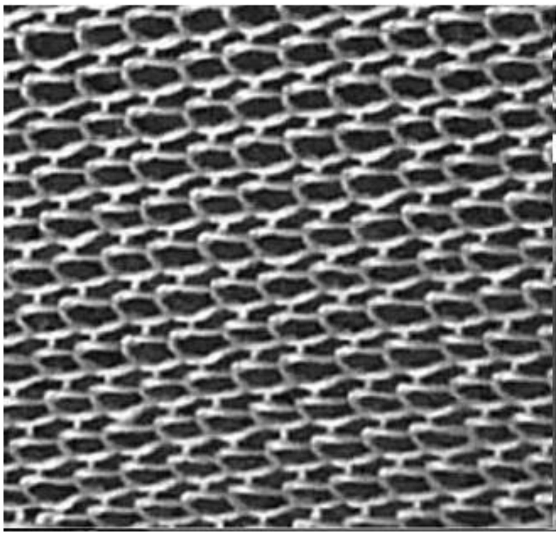

Figure 3. Knitted fabric for concrete shell reinforcement

mechanics, (that was elaborated earlier) was exploited predicting shell load bearing facility depending on the opening of a crack in the loaded shell.

Concrete is a brittle material, if we want to fabricate thin wall (few centimeters) construction elements (thin wall shells) made out of concrete we are forced to use a small diameter densely placed reinforcement. One solution can be - short AR glass fibers homogeneously distributed in the concrete, another – a few layers of knitted AR glass fiber fabrics (filled with concrete) and placed at an even distance one to another through the thickness of the structure.

MATERIALS AND METHODS

A pneumatic formwork with a changeable lifting was elaborated. Use of a pneumatic formwork advantages can be mentioned as follows:

1. Flexible shapes (being curved created surfaces are of architecturally and technologically complicated shapes);
2. Smooth concrete surface quality;
3. Transporting: formwork weight and volume of tissue is very small compared to wooden or steel formwork.

In the first case the flat surface of a non-inflated pneumatic mould was spread out and smoothed down with a short glass fiberconcrete mix (Figure 1). In the second case the flat surface of a non-inflated pneumatic mould was covered by three layers of glass fiber knitted fabrics penetrated by fine aggregate concrete (Figure2).

Knitted fabric reinforced concrete matrix composites have grew rapidly during recent years. Such materials are exhibiting attractive mechanical properties including high energy absorption and impact resistance.

Yarns loops are arranged in structures. In woven fabric, threads traditionally run horizontally and vertically. Contrary, in the case of knitted fabric, strands form loops see Figure 3. A knitted fabric is highly deformable in all directions. Depending on the fibers used, some of them are more deformable than others. The reason is – yarns do not make straight lines anywhere in the knitted fabric. It is easy to recognize the possible motions in the fabric – threads sliding, loops twisting, bending and stretching leading to a technological advantage – excellent deformability, shape forming ability and flexibility, which allows it to be used in any complex shape mould without folds. Glass fiber weft knitted fabrics were investigated. Type E glass fiber yarns, produced by JSC "Valmieras stikla šķiedra" (Latvia), were used. The density of the glass was ρ = 2540 kg/m^3, diameter of the yarn d was determined and was equal to 0.37×10-3 m. Linear density of the glass yarn was calculated and was equal to275.6 tex. Value of the elastic modulus for glass yarn was obtained from the manufacturer and was 73.4 GPa **(**Krasnikovs A.et al., 2012).

Before concrete binding, the mould is inflated with air till its final shell shape size is obtained (moderate curvature shells were elaborated (shell surface maximal deviation from the plane was 110mm, see Figure 4). During concrete hardening the air pressure in the pneumatic mould sustains a constant value. After the concrete becomes hard, air in the pneumatic mould blows out and the shell is demoulded. Experimentally fabricated and investigated shells were curved quadratic plates

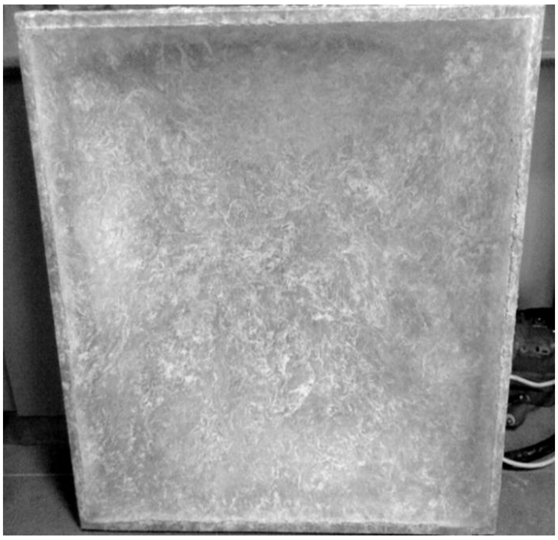

Figure 4. Short glass fiber concrete shell

with a thickness of 15mm. The horizontal plane created shells dimensions were 940x940 mm. Matured short glass fiber concrete shell is shown in Figure 4.

Stress –deflection fields numerical modeling in the shell under applied distributed surface load

Elaborated, reinforced by glass fibers, concrete shells were numerically simulated and loaded with external load distributed on shell's surface. Areas of maximal tensile and compressive loads were numerically recognized. The reinforced concrete shell geometry was numerically modeled.

SHELL GEOMETRY MODELING

The shell geometry that was used for numerical calculations, was created using parts of a geometrical arcs. Such shell's form approximates an actual shell's geometry, that was obtained experimentally, that is because a more detailed description of the geometry creation procedure must be completed. At the beginning a plane was created. The additional plane (Plane 2) parallel to the top plane was created at a distance of 110 mm and an additional point was created on plane 2 over the origin point. A 2D chart of the square form with the dimensions of 940×940 mm was created on the top plane. The origin coincides with the centre of the square. The additional planes (Plane 4 and Plane 5) were created on the diagonals of the 2D chart. See Figure 5. The 2D charts of the arc part, were obtained on planes: Plane 4, Plane 5, Front Plane, and Right Plane as shown in Figure 4. The 2D chart of the arc part was created by two points: the first point belongs to the square chart and the second point is located on Plane 2 and is the top point of shell.

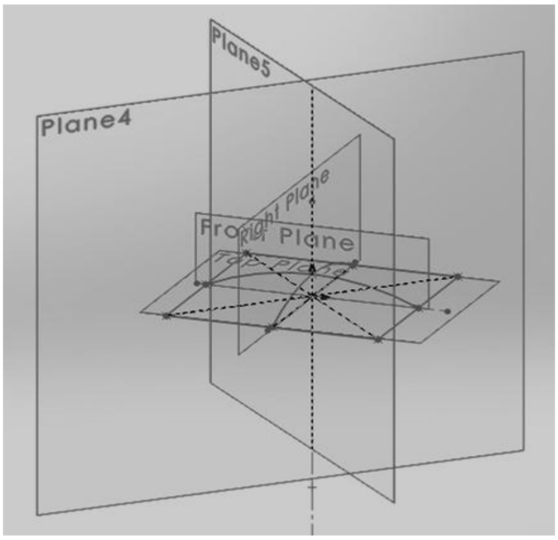

Figure 5. 2D charts of arc part were obtained on planes: Plane 4, Plane 5, Front Plane and Right Plane

The arc part is coincident with the first point and is tangential to second point.

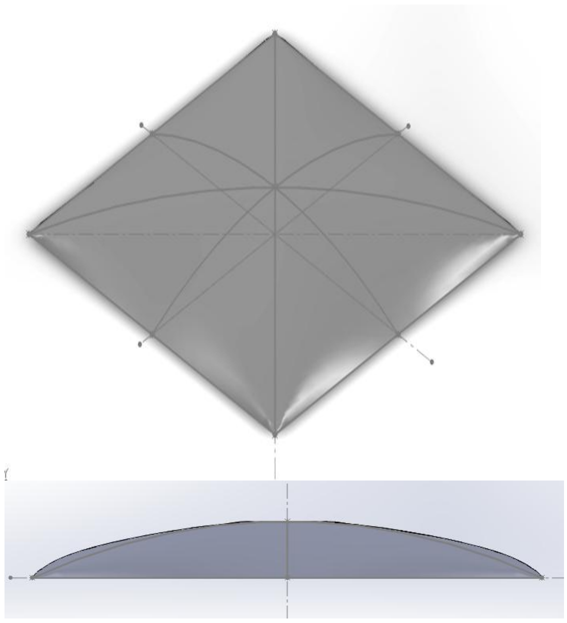

Figure 6. Created shell geometry

The surface-fill operation was used as a patch boundary and a square sketch, as constrain curves, were used with four arc parts. Shell modeling results were shown in Figure 6. The 2D chart of the square with the dimensions of 970×970 mm was created on the top plane. The origin coincides with the centre of the square.

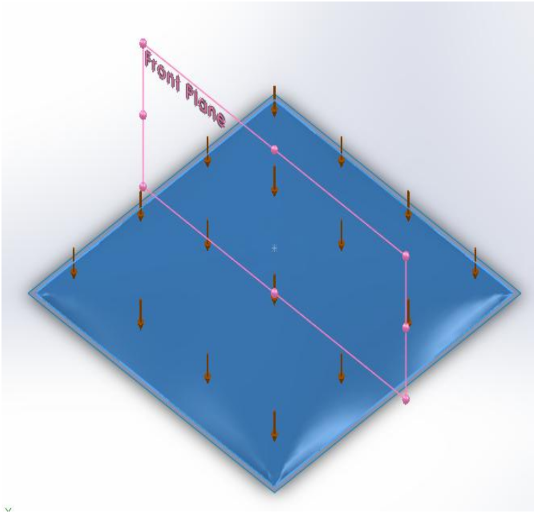

Figure 7. Applied distributed force

A surface-loft operation was used for modeling the technological edge of the shell, as profiles were used from the square chart with the dimensions of 940×940 mm and the square chart with the dimensions of 970×970 mm. On the upper surface of the shell distributed force equal to 1MPa was applied. The force applied direction was strictly vertical (see Figure 7).

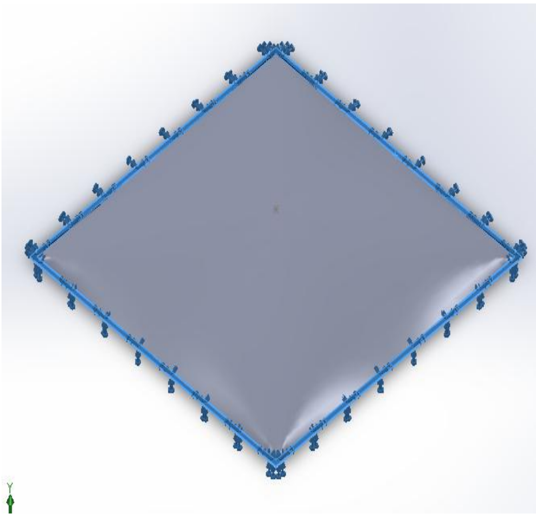

Figure 8. Shell boundary conditions

The shell was freely supported along its entire free edge see Figure 8. The shell was meshed see Figure 9. Looking at Figure 9 it is easy to recognize the shell's geometric deviations, experimentally obtained by inflating fiberconcrete

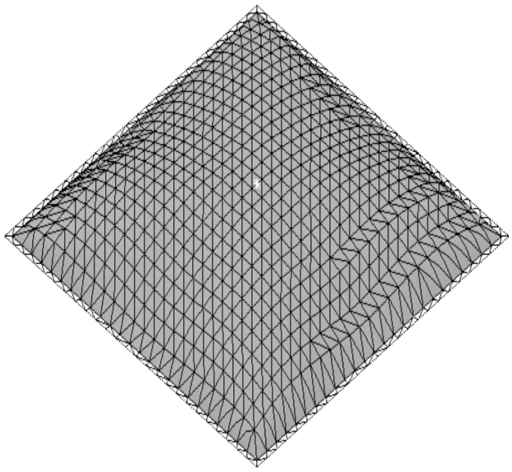

Figure 9. Meshed Shell

shell by air – small depressions between every two corners. Calculated shell's top point vertical deflection for short fibers concrete shell was 2.72 mm and for concrete shell reinforced by three knitted glass fiber fabrics was 2.718 mm.
Vertical displacement view is shown in figure 10. Membrane stresses (stresses according to Mises)

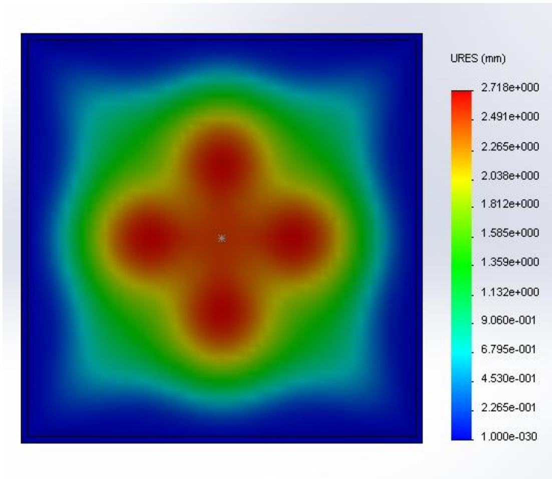

Figure 10. Vertical displacement in loaded shell. Top view

in loaded shell are shown in Figure 11. Missed stresses were described only as equivalent stress form (because the shell's material is not metal). Stretched zones at the middle of each side of the shell can be observed as potential places of macro-crack formations.

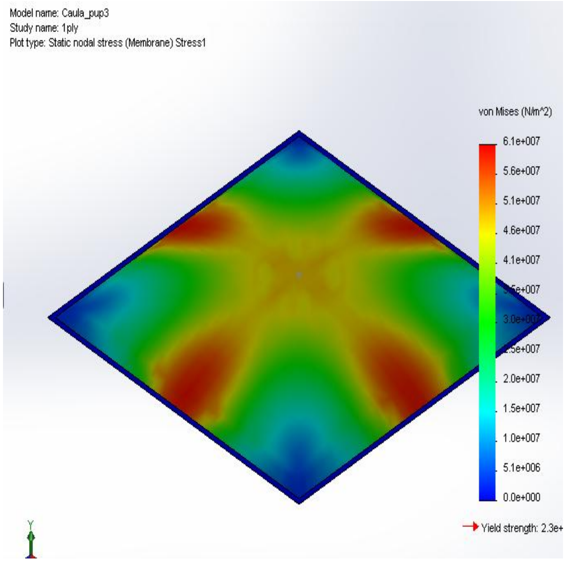

Figure 11. Membrane stresses (equivalent stresses according to Mises) in loaded shell isometric view

CONCLUSIONS

Existing views about techniques and technology of constructions built from monolith concrete mostly are based on plane construction building experience. Pneumatic formworks with changeable lifting provide an ideal concrete solution for formwork adjustment without any restricting factors connected to complicated geometry. Shells reinforced by chopped glass fibre bundles as well as by knitted glass fibre fabric were fabricated. The sells load bearing capacity was numerically investigated, applying distributed force on the upper surface of the shell. Theoretical results were compared with the data obtained in the experiments.

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