Cast Reinforced Concrete Frame of Buildings and Methods of Its Erection

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Abstract: A novel architectural construction system was developed for erection of cast reinforced concrete building and structures wherein non-removable void-forming inserts are used to reduce weight of not only cast reinforced concrete floors, but of all basic elements of frame building. This work studies a concreting process of frame curvilinear elements using fiber concrete wet spraying and of frame horizontal and vertical elements using self-compacting concrete. Both processes of cast reinforced concrete placing enable substantial own weight reduction of structures (foundations, columns, stiffeners, floor and coating disks), optimal rib topology within flooring disk in order to equalize stresses in floor slab and attainment of complicated internal configuration of columns and stiffeners.
Keywords: self-bearing framework; reinforcement cage; non-removable void-forming inserts; sprayed fiber concrete; self-compacting concrete.

1. Introduction

Architectural construction systems for high-rise apartment and public buildings in conjunction with existing construction industry are mostly based on framed design. Material of construction for building framework is usually cast or precast reinforced concrete or steel. Multi-layered walls, as a rule, are made of efficient non-reinforced materials at site as self-bearing or attached designs. Analysis of contemporary condition and development prospects of this type of buildings shows that on a par with search of new design solutions, buildings must meet the requirements of living comfort, environment friendliness, artistic expression of buildings and their elements, etc. Solution of this problem is a set of multi-factor and multi-criteria problems which in many cases contradict each other.

2. Analysis of publications

Cast reinforced concreting enables creation of any curvilinear forms, design and construction of unique architecture buildings with free arrangement of rooms, long spans and necessary floor height [1].

Cast reinforced concrete floors have a moderate thickness due to application of light inserts, thus reducing load on foundation and, respectively, building erection costs. Cast reinforced concrete bearing frame can withstand high loads, enabling construction of buildings with 30-40 and more stories. Recently standard modules made of various shape polymer materials as well as of foam polystyrene have become widely used as non-removable void-forming inserts [2-4].

All existing erection processes of cast reinforced concrete buildings are based on different types of formworks, including permanent ones. Process efficiency is mainly characterized by easy application in installation and dismounting, whereas reinforcing and concreting of formwork structures has much common features for all types of formworks.

Apart from advantages, such as low resource consumption, cast reinforced concrete has crucial drawbacks, first of all large labor consumption of works. Thus, the most important task in improvement of cast reinforced concrete technology application is reduction of its labor input. Total cast reinforced concrete structure erection process consists of three partial processes: formwork, reinforcement and concreting works. One of the main margins for labor input reduction lies in improvement of formwork and concreting works. Those works due to application of principally new approach to formwork system design in spraying placement of concrete, together with modern means of concrete placing mechanization and automation as well as application of self-compacting concrete, permit to reduce construction period, increase productivity and shorten labor consumption.

3. Purpose and statement of problem

The purpose of this work is development of a novel architectural construction system for erection of cast reinforced concrete building and structures as well as process of lightened structure erection by spraying placement of fiber concrete or application of self-compacting concrete.

The task of our work is study of cast reinforced concrete frame formation erected with non-removable void-forming inserts lied in structure elements (columns, walls, floors, etc.) and procedures of structure formation enabling application of minimum formwork types with absence of any downtimes, thus ensuring continuous concrete placing.

4. Practical designs

Ukraine has various architectural construction systems for large-scale civil construction: “RAMPA”, “ICAR”, “DOBOL” [5]. As further development of light-weight reinforced floor concreting technology is “MONOFANT” system [6] wherein inserts are used to reduce weight of not only floors, but of all elements of a framed building.

4.1. MONOFANT architectural and construction system

The proposed “MONOFANT” system (Figs. 1-7) possesses such characteristics:

-random (irregular) column arrangement;

- non-removable void-forming inserts used for substantial reduction of own weight of structures are made of various materials whose cost is by an order of magnitude less than that of reinforced concrete;

-complicated configuration in plane and heterogeneity of flooring disks;

-flooring disks may be installed in more than one plane;

-flat floors and ceilings;

-optimal topology of ribs within flooring disks enabling to equalize forces in flooring slab;

-complicated configuration of hollow columns.

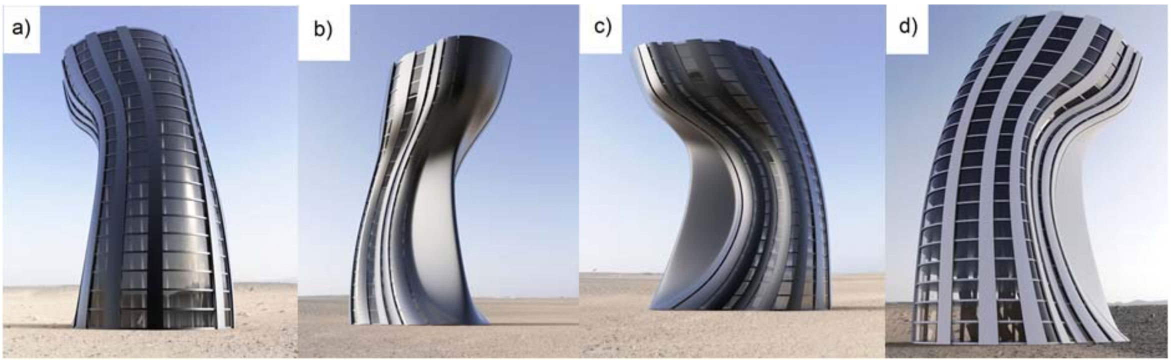


Fig.1 Framed building structure: a)-d) – views of building from different sides

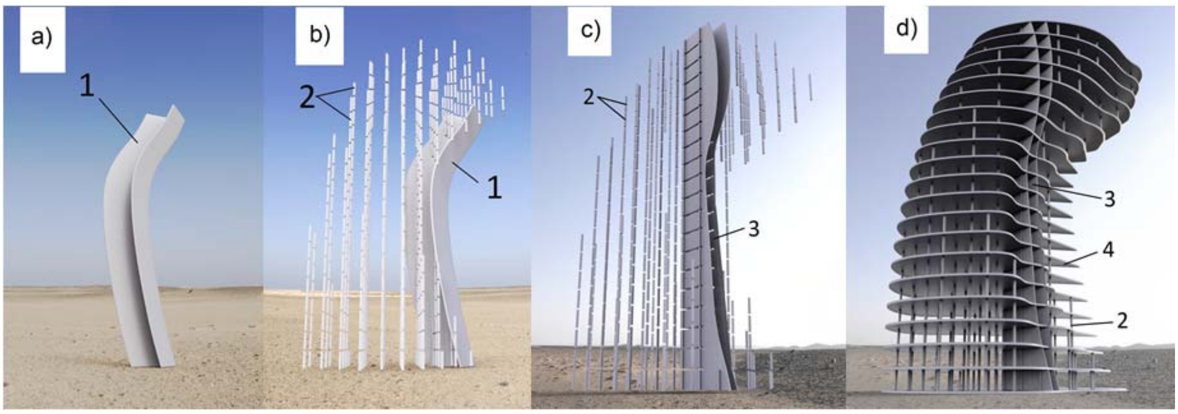


Fig.2 Elements of framed building: a) diaphragm design; b) floor arrangement of columns and diaphragm; c) arrangement of columns and brace for elevator shaft; d) arrangement of columns, elevator shaft brace and floors; 1 – V-diaphragm of framed building; 2 – columns of building; 3 – elevator shaft brace; 4 – floors of building

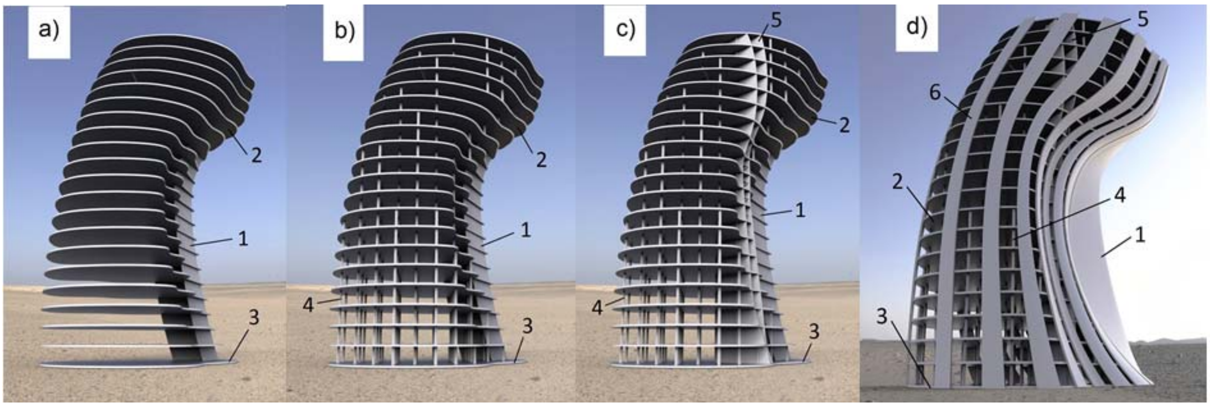


Fig.3 Elements of framed building: a) arrangement of diaphragm and floors; b) arrangement of diaphragm, floors and columns; c) arrangement of diaphragm, floors, columns and elevator shaft brace; d) building structure without glazing; 1 – V-diaphragm of building; 2 – floors of building; 3 – foundation of building; 4 – columns of building; 5 – elevator shaft brace; 6 – external braces

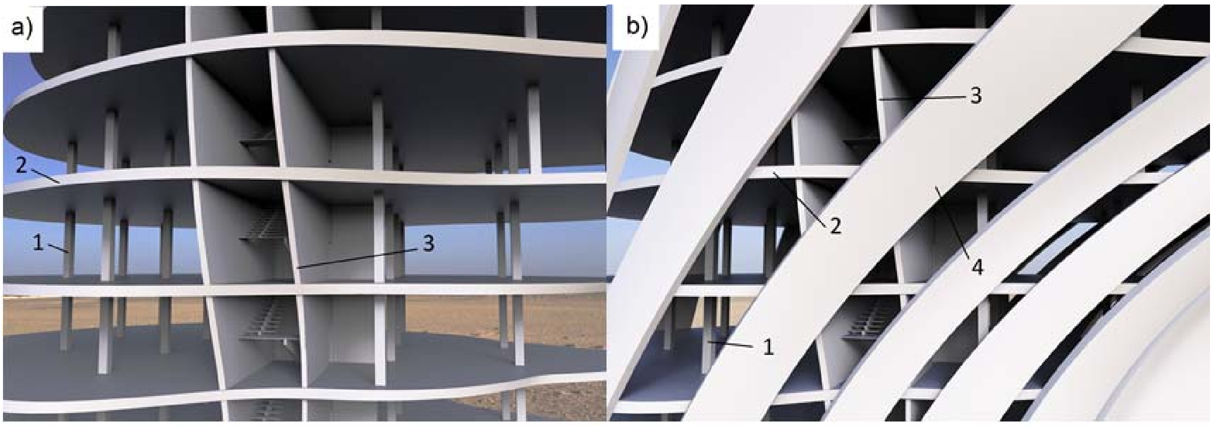


Fig. 4 Conjunction of frame elements: a) fragment of adjacent floors without external braces; b) fragment of adjacent floors with external braces; 1 – columns of building; 2 – floors of building; 3 – elevator shaft brace; 4 – external braces

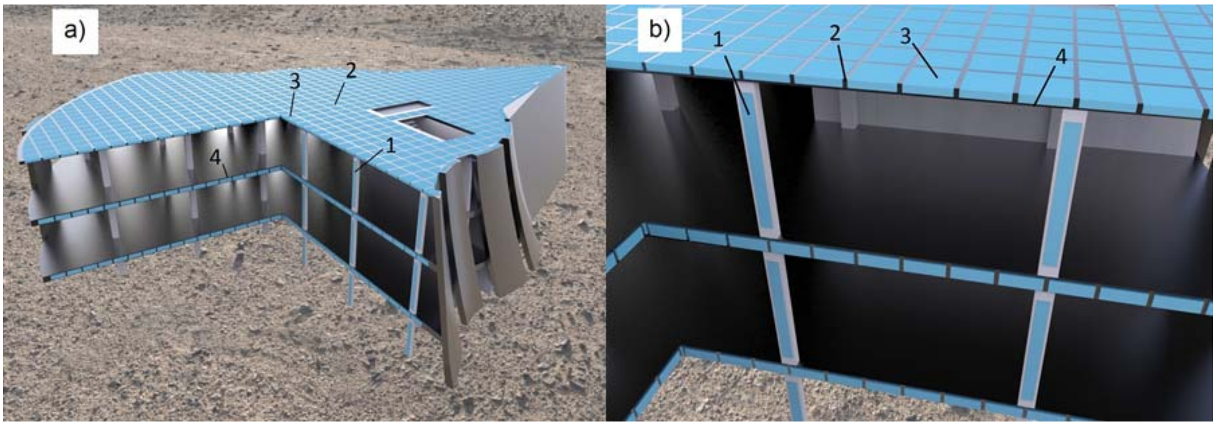


Fig.5 Design of frame elements: a) design of two bottom floors of building; b) section of floors and columns of building; 1 – insert in column; 2 – floor internal reinforcing ribs; 3 – insert in flooring slab; 4 – external reinforced concrete sheeting of floor

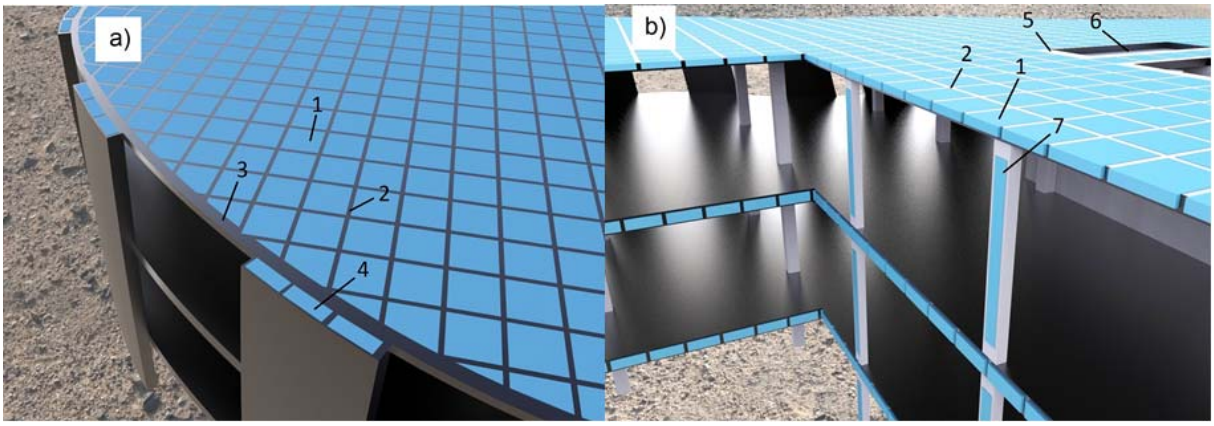


Fig.6 Design of frame elements: a) design of floor; b) design of floor with openings; 1 – insert in floor slab; 2 – floor internal reinforcing ribs; 3 – floor slab fringed with external reinforcing rib; 4 – insert in external braces; 5 – internal fringing with reinforcing rib; 6 – openings in flooring slab; 7 – insert in column

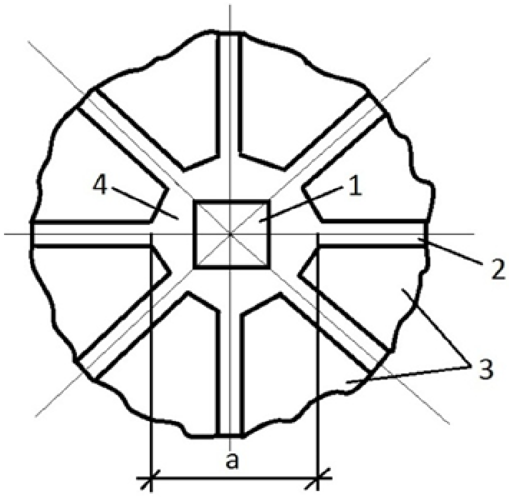


Fig.7 Flooring cap of framed building: 1 – column of building; 2 – internal reinforcing ribs of flooring slab; 3 – insert in flooring slab; 4 – cap

The peculiarities of the proposed architectural construction system are:
- random geometry of system;
- actually infinite number of possible spatial planning solutions;
- free internal arrangement;
- prescribed consumption of materials being observed;
- high bearing capacity of elements;
- limited deformability;
- small own weight;
- efficient erection technology, and many others.

Curvilinear structures are better erected under wet spraying process, which has some advantages as compared to dry spraying:
- reduced dusting;
- homogeneously placed concrete;
- operability at tight spaces;
- minimum concrete mortar recoil from surface;
- minimum cost of site protection.

Concrete mortar placing by wet spraying with non-metallic fiber enables substantial acceleration of cast reinforced concrete frame erection process due to reduced recoil and obtaining of a high tensile strength composite, which prevents cracking in stretched areas.

The proposed wet spraying process enables to compact concrete mortar without a vibrator and to perform structure concreting using only formwork “table” with a set of flexible elements and guides. Those process attributes are necessary to obtain structure elements of different shapes.

For erection of structures with predominantly horizontal and vertical shapes self-compacting concretes are best of all to obtain lightweight structures, as this enables substantial acceleration of concreting process due to absence of downtimes necessary in traditional concreting. The most important advantages are lack of mortar compaction due to its high mobility, thus, the mortar spreads and is compacted under its own weight, which enables mortar filling of the total space under non-removable inserts. As a consequence, time for formation of floor slab top surface is shortened as self-compacting concrete is capable of self-grading.

Both above described technologies may be applied in combination: curvilinear structures of framed building are made by concrete wet spraying, whereas horizontal floors are obtained by formwork placing of self-compacting concrete.

4.2. Process of curvilinear structure erection

For efficient erection of curvilinear building elements by wet spraying we proposed a self-bearing frame enabling establishment of random geometry structures as well as spraying of fiber concrete onto this frame which will subsequently gain necessary strength.

Self-bearing frame consisting of a spatial curvilinear reinforcing cage and non-removable void-forming inserts forms a prescribed curvature of building element. Foundation is made with protracted reinforcements to which the self-bearing frame is attached. The frame is assembled from external and internal curvilinear concrete fabric with rectangular or square nests, between nests curvilinear (matching frame shape) inserts of foam polystyrene or mineral wool are installed, whereas internal and external fabrics are interconnected with curvilinear flat skeletons having triangular cells.

To test this technology we made four curvilinear shells in the form of cylinder, sphere, nodoid and hypar fragments. The shells had size in plan 2.2 x 2.2 m and were 1.1 m to 1.6 m high. Shell walls were 26 cm thick, of this 16 cm referred to non-removable void-forming inserts and 5 cm from outside and inside was reinforced concrete filling (Fig. 8, 9).

Maximum diameter of flat skeleton reinforcing bars equaled 2-4 diameters of external and internal cage rebars (Fig. 9e).

Curvilinear flat skeletons form a rigid rib cage between external and internal curvilinear concrete fabrics of triangular or rectangular nests with maximum side length of 100 cm. Arrangement of inserts ensures within self-bearing frame filling of space between curvilinear flat skeletons with 5 cm gaps between inserts (Fig. 9f).

Inserts are fixed within self-bearing frame so that the distance from insert edge to center of gravity of external and internal curvilinear concrete fabrics be at least 1 cm. 5cm thick foam polystyrene sheets are cut at machine so that curvilinear elements were formed in sheet plane to be glued into a separate insert of necessary curvature (Fig. 8e). Curvilinear elements may be glued along the length of their components to ensure optimal pattern cutting of foam polystyrene sheets with minimum rejects.

Strips of Rabitz-type steel-wire fabric or a slotted sheet are attached to curvilinear flat skeletons in the plane of internal curvilinear concrete fabric to form together with inserts a continuous screen for fiber concrete spraying. The orifice size of slotted sheet depends on maximum filler particle size in fiber concrete. For particle sizes of 0-5 and 5-10 mm orifice size may be 7 x 50 or 8 x 49 mm.

The specified thickness of building curvilinear elements may be 40-50% of design value due to insert making from foam polystyrene, thus ensuring minimization of structure weight. To control the thickness of concrete layer being sprayed from outside and inside, chips of rebars are put into inserts at the distance of about 10 cm from each other, serving as tags (Fig. 9f).

First mortar is sprayed from outside to the gap between inserts till the level of placed mortar exceeds the level of inserts, then the top and bottom of curvilinear element are concreted (Fig. 10).

Fiber concrete is wet sprayed with a continuous flow concrete pump with a poppet valve and horizontal arrangement of cylinders (Fig. 10a). All works on preparation of cast reinforced concrete shells by wet spraying were performed at Stalkonstrukciya Company test ground in Kharkiv.

Due to correct selection of fiber concrete mortar composition and usage of a ring packing nozzle zero recoil of mortar was achieved during deposition on self-bearing frame, which substantially facilitated spraying process.

The curvature of obtained building element shape is controlled with previously prepared templates. In order to ensure smooth surface of reinforced concrete shells an additional 5-7 mm layer of fiber concrete was sprayed and rubbed before concrete setting began (Fig. 11).

The total concreting process runs in two stages: first a layer of fiber concrete is sprayed from outside of cast reinforced concrete shells, then from inside.

Fig.8 Elements of self-bearing frame for concreting of reinforced concrete shells: a) frame elements for cylinder fragments; b) frame elements for sphere fragments; c) frame elements for nodoid fragments; d) frame elements for hypar fragments; e) foam polystyrene sheet cutting machine; f) process of insert installation within frame

4.3. Process of rectangular structure erection

Let us describe concreting process of lightweight structure horizontal and vertical element using self-compacting concrete which was tested at reinforced concrete structures plant, Zhilstroy-2 Company in Kharkiv.

Wooden formwork was made for concreting of a horizontal element (145 x 145 cm, 34 cm high) and a vertical element (145 x 34 cm, 145 cm high) (Figs. 12, 13).

Preparation to concreting consisted in definition and check of formwork geometry, formwork lubrication, installation of reinforcement cage together with insert and check of basic geometric dimensions.

In order to fix the insert in horizontal element we proposed to change top and bottom horizontal fabric by adding of 4 reinforcement bars, 10 mm diameter, to each fabric. They were so arranged in fabric plane to establish sufficient rigidity of fabric to maintain the insert in the process of element concreting (Fig. 12a, g). Such design ensures movement of workers along fabric in the course of concrete placing without damaging foam polystyrene insert. Additional bar chips 10 cm long were welded vertically to bottom fabric at crossing of bars; bar chairs were put on them to ensure insert location relative to horizontal bottom fabric (Fig. 12b). Plastic chairs form a protective layer between formwork and horizontal bottom fabric (Fig. 12c). Insert was introduced inside concrete fabric by putting it on vertical bar chips (Fig. 12d).

After that top horizontal fabric was knitted (Fig. 12e-g). At crossings of 10 mm rebars bar chips 10 cm long were vertically introduced into the insert so that they might be fixed with knitting wire and a chair installed between the insert and top horizontal fabric (Fig. 12h).

In order to fix the insert in vertical element we proposed in the same way to change vertical lateral fabrics by adding of 4 reinforcement bars, 10 mm diameter, to each fabric (Fig. 13a-c). To arrange the insert in vertical plane it was pierced with four rebars of sufficient length to be fixed with knitting wire along edges, and then a chair was installed between insert and vertical lateral fabrics (Fig. 13d, e).

Fig.9 Self-bearing frames for concreting of reinforced concrete shells: a) frame for cylinder; b) frame for sphere; c) frame for nodoid; d) frame for hypar; e) view of flat skeleton fragment; f) arrangement of inserts within self-bearing frame

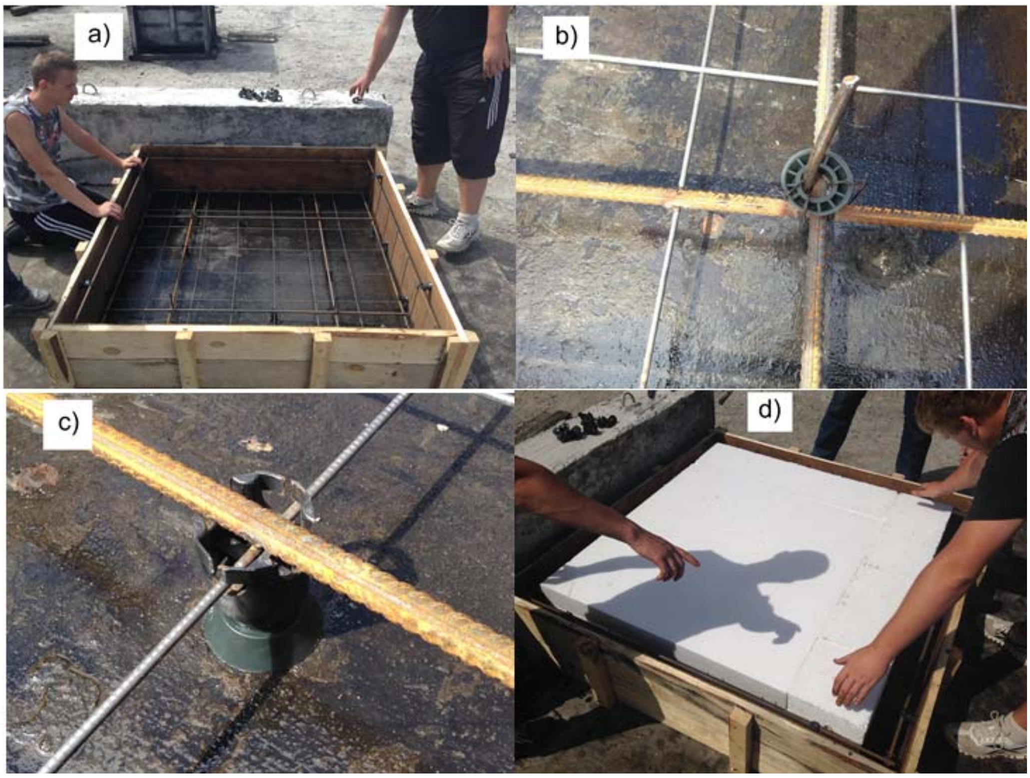
Fig.10 Concreting process of cast reinforced concrete shells: a) spraying plant, b) seams filled; c) external cladding sprayed; d) first concrete layer sprayed on frame from outside; e) appearance of sprayed concrete before deposition of finish layer; f) internal cladding sprayed

Protective layer between formwork and fabric was formed by plastic chairs (Fig. 13f). Formwork was stabilized against displacement and destruction under pressure of fed concrete mortar by installing of a concrete slab and wooden spacers from one side (Fig. 13g, h).

In the course of test concreting of a horizontal element downtime between first layer placing (bottom cladding below the insert) and second layer placing (outline ribs and cladding above the insert) was only 5-10 minutes, which caused concrete fabric together with insert to float up (Fig. 14).

Laboratory test was performed to determine floating-up force under placing of self-compacting concrete mortar (Fig. 15).

Fig.11 Cast reinforced concrete shells obtained by wet spraying: a) concreted cylinder fragment; b) concreted sphere fragment; c) concreted nodoid fragment; d) concreted hypar fragment



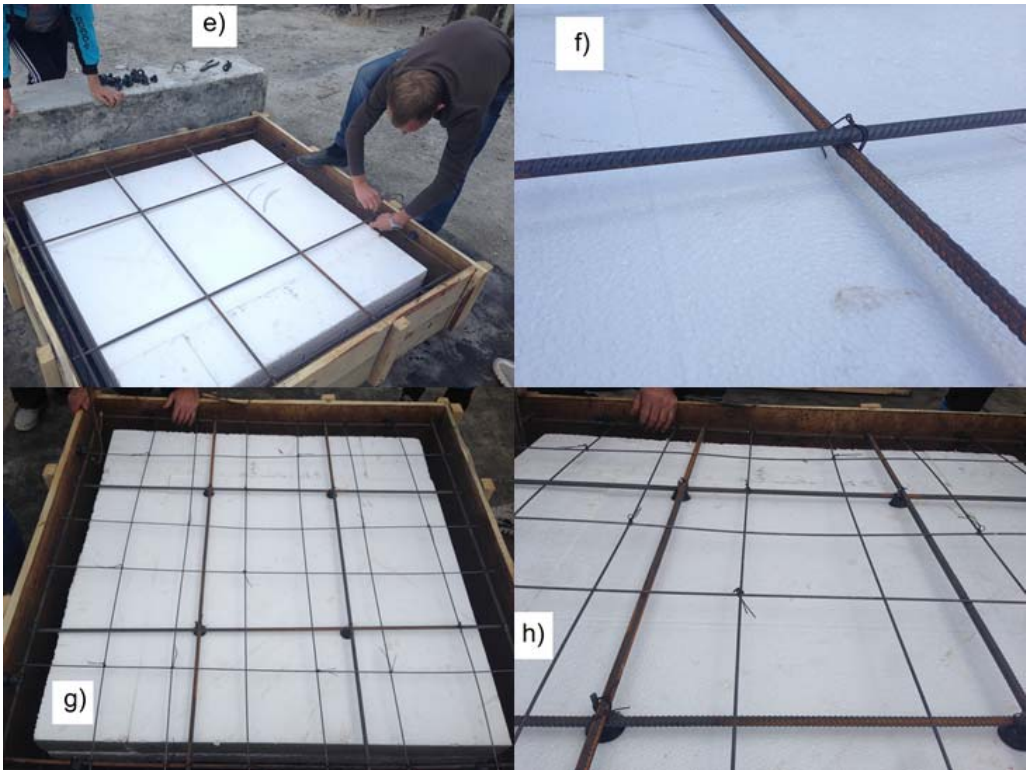


Fig.12 Concrete fabric and insert fixing process in manufacture of lightweight structure horizontal elements: a) installation of concrete fabric to designed position; b) bottom fabric design for insert fixation; c) chair ensuring thickness of protective layer for bottom fabric; d) installation of insert to designed position; e) top fabric braces maintaining insert in designed position; f) connection of rebars with knitting wire; g) top fabric design; h) insert fixation with top fabric

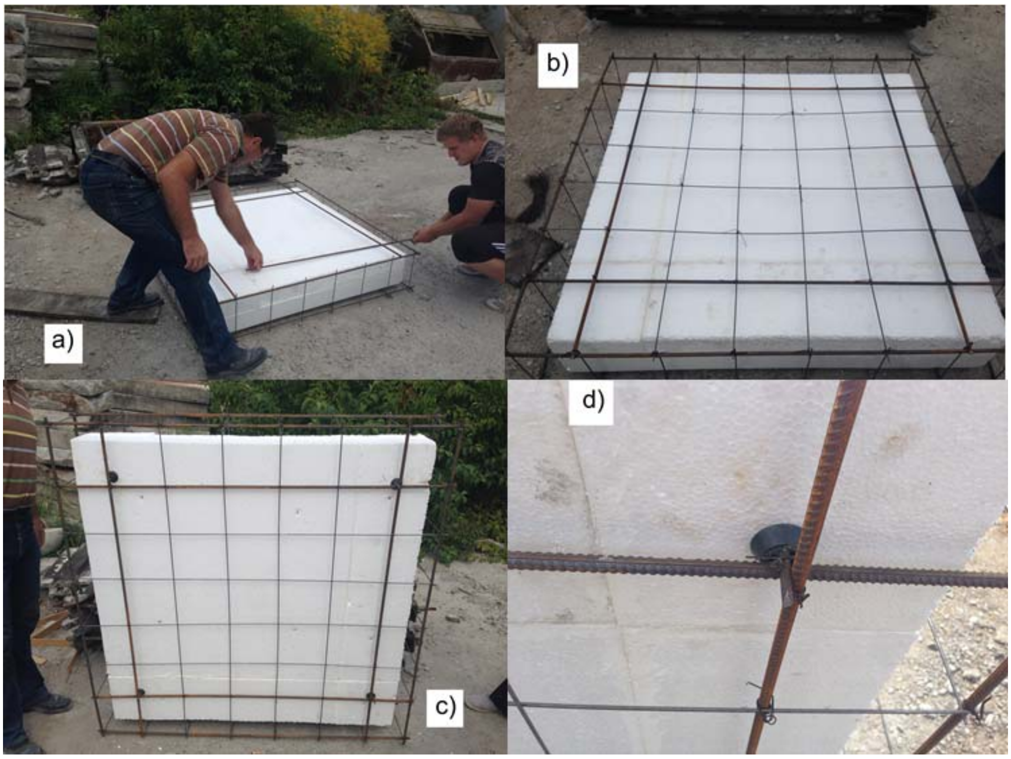


Fig.13 Concrete fabric and insert fixing process in manufacture of lightweight structure vertical elements: a) braces of vertical fabrics for maintaining insert in design position; b) vertical fabric design; c) insert fixation at four points; d) insert attachment to vertical fabrics; e) ready block consisting of concrete fabric and insert; f) chair ensuring thickness of protective layer for vertical fabric; g) top view of formwork for concreting; h) side view of formwork for concreting

Fig.14 Concreting of lightweight structure horizontal element: a) loading of self-compacting concrete mortar to bucket; b) mortar placing to form slab bottom cladding below insert; c) mortar placing to form ribs and slab top cladding; d) floating-up of concrete fabric together with insert

Fig.15 Experimental determination of insert floating-up force: a) foam polystyrene insert; b) insert cantledge; c) space filling with self-compacting concrete; d) insert floats up

A prismatic foam polystyrene insert (29 x 21 cm, 10 cm high, 6 l capacity) was placed into a 15 l plastic vessel so that the distance from vessel bottom and walls to the insert was 4 cm (Fig. 15a). Above the insert a cantledge was placed (Fig. 15b). By pouring self-compacting concrete mortar under the insert and between vessel walls we determined the weight of cantledge necessary to prevent the insert from floating up (Fig. 15 c, d).

The experiment showed that under continuous feed of mortar weight of cantledge necessary to prevent the insert from floating up was 9 kg (for 3-5 minutes). Under reduced rate of mortar feed to the vessel (within 8-10 minutes) weight of cantledge necessary to prevent the insert from floating up was 6 kg. If downtime between placing of the first (bottom below insert) and second (ribs around insert) concrete layers made more than 25-30 minutes, the insert became anchored in bottom layer and could not float up even without cantledge.

On the basis of laboratory experiments lightweight structure concreting process with usage of self-compacting mortars was amended. To ensure maintaining concrete fabric with insert at place under continuous feed of mortar cantledge weight must be approximately 1.5 times higher than static lift, thus, for insert volume of 312.5 l (dimension 125 x 125 mm, 20 cm high) it would be 470 kg. For vertical element concrete fabric with insert must be rigidly attached to underlying concrete-filled structures with the help of protruding bars. An alternative to maintain concrete fabric with insert at place may be two-layer concreting with a downtime of at least 30-45 minutes between concreting of slab bottom below insert and of the bulk of horizontal element.

The proposed amendments of lightweight structure concreting process were tested under repeated concreting of horizontal and vertical elements (Fig. 16). In first layer placing its thickness was such that enabled insert bottom to be immersed into mortar by 1.0-1.5 cm. Downtime between placing first and second layers was 45 minutes.

Substantial peculiarities of foam polystyrene insert fixation are due to the fact that insert geometry may be destroyed or damaged by process loads in the course of concreting (weight of mortar feed plus weight of workers). Therefore, in concreting of structures with inserts the fall height of concrete mortar must never exceed 50 cm.

Fig.16 Concreting of lightweight structures using self-compacting concrete in one stage and two layers: a) placing first mortar layer below insert; b) placing second layer for horizontal element; c) placing second layer for vertical element; d) installation of erection loops for horizontal element; e) installation of erection loops for vertical element; f) shrouding of concreted structures with film for concrete to gain strength; g) stripping of formwork from horizontal element; h) stripping of formwork from vertical element

5. Conclusions

Fiber concrete spraying technology enables construction of one- and multi-storey civil and industrial buildings possessing curvilinear walls, floors and other elements.

Design of self-bearing framework consisting of spatial curvilinear concrete fabric and non-removable void-forming inserts established a rigid structure with minimum erection cost and improves process opportunities of sprayed fiber concrete application for off-formwork concreter.

The proposed erection method for elements of curvilinear-shaped buildings permits to reduce construction cycle, increase labor productivity and reduce labor consumption due to lack of costly removable individual formwork and necessity of concrete mortar compaction.

Our research in concreting process of lightweight structure horizontal and vertical elements using self-compacting concrete enables its application at construction of civil and industrial facilities.

The described processes may be applied in combination to expand the opportunities for construction of buildings and structures under “MONOFANT” system which enables a substantial reduction of own weight of structures (foundations, columns, braces, flooring and coating disks), optimal topology of ribs within flooring disks in order to equalize forces in flooring slab and establish a complicated internal configuration of columns and braces.

6. References

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