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ERECTING MULTISTORY BUILDINGS WITH MONOLITHIC REINFORCED CONCRETE SLAB FLOORS BY USING PRECAST LARGE-SIZED SPATIAL STRUCTURES

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Statement of the problem. Construction elements for erecting structures are conventionally flat elements, which are assembled at a construction site for erecting a structure. Such flat constructions elements cannot be too wide because their transportation with the use of conventional transportation means is not possible. It is therefore believed that it would be advisable to improve existing construction elements and methods for the erection of structures with their use.

Results and conclusions. The new construction technology based on the use of precast reinforced concrete large-sized spatial structures with variable geometry, allowing transportation without the special vehicles is set forth. After the delivery at the site and restoration of the geometry, a structure is mounted to the final position. As a result of only one mounting stage, load bearing and (or) enclosure structure, permanent formwork of a monolithic slab floor are erected. The major technological principles of the new construction technology provide the rigidity and seismic resistance of a structure compared with the monolithic construction method, free planning not restricting architectural and planning solutions, minimum frame works due to the use of the assemblied ferroconcrete permanent framework, etc. The proposed technology is confirmed by the author's priority.

Keywords: construction technology, precast reinforced concrete structures, spatial structures, transportation.

Introduction

Prototypes of a new construction technology are two existing ones – monolithic construction and precast concrete construction [1, 2]. Monolithic construction is currently one of the most common construction method where buildings are cast using reinforced concrete on site. By means of this method, frame and non-frame buildings, i.e. those with precast concrete retaining walls, are constructed. The mass of such buildings in proportion to brick ones has decreased by 15—20% thus allowing for most cost-effective foundations.

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Monolithic construction technology ensures reliability, durability, strength, fire and seismic resistance of buildings. In addition, it opens up countless possibilities for extraordinary architectural solutions, free planning, exquisite architecture pieces. To put it another way, this construction method complies with all engineering requirements for the construction of buildings and with no constraints for architectural and planning solutions. However, apart from the above advantages, this construction method has some disadvantages. Monolithic construction technology is labor-intensive, i.e. construction works require a lot of maintenance and engineering staff.

One of the most challenging and labor-intensive are manufacturing and installation of the mould of earth retaining structures, columns, walls and slabs resulting in a wide range of molds as well as industrial ones.

An example of that is some type of molds employed in monolithic construction:

- collapsible formwork (predominating);
- small-panel formwork;
- large-panel formwork mainly used for non-frame buildings;
- suspended formwork for rigid insulation structures;
- travelling formwork for linearly extending structures;
- jump formwork for high-rise structures;
- progressive formwork for horizontal and vertical forms;
- permanent formwork made of precast concrete, reinforcement concrete and plywood slabs, steel sheets, etc. Polystyrene foam formwork is becoming increasingly popular.

Manufacturing and installing formwork is the first step to be taken in monolithic construction. It is followed by: 1) insulation of structures; 2) pouring cement; 3) dismantling formwork transferring formwork elements.

Monolithic construction tends to:

- be labor intensive;
- take a great amount of time to be constructed;
- involve high construction costs.

Let us look more closely at precast concrete construction.

Frame panel construction. Frames of precast concrete buildings differ according to the used construction schemes:

- construction scheme with a complete frame and self-supporting retaining walls;

– construction scheme with an incomplete frame and retaining walls (generally low storey buildings);

– construction scheme for frames. For frames vertical loads and horizontal efforts a building is subjected to are absorbed by rigid precast concrete frames;

– construction scheme of articulated frames. Vertical loads are absorbed by the frame. Horizontal efforts are absorbed by a shuttering disk and transferred onto rigid vertical diaphragms, staircases, elevator shafts, i.e. stiffening cores.

Frames are based on systems consisting of pillars and girders. i.e. columns and beams. Along their height, columns are spliced with soldering of the ends of reinforcement bars released out of the column followed by pouring cement onto the joints.

Prefabricated frames are most common in this construction technology. However, for high-rises steel frames can be adopted. For unique construction, or if specially required, monolithic precast concrete frames can be used to enable more sophisticated construction solutions. Wall panels are not self-supporting. They are suspended on the frame as filler structures or rigid diaphragms. For an incomplete frame wall panels absorb loads but operate in conjunction with the frame.

Compared to non-frame construction, there are almost three times as many prefabricated elements, dismantling activities are more labor intensive. This technology is commonly employed for administrative and public buildings.

Large-panel non-frame construction. Large panel buildings are non-frame. There are three main schemes for large panel buildings:

– buildings with retaining exterior and interior, transverse and longitudinal separation walls;

– buildings with self-supporting exterior walls and retaining transverse separation walls;

– buildings with retaining exterior and interior longitudinal separation walls.

In buildings with longitudinal separation walls the retaining elements are internal longitudinal separation walls floor slabs are supported by. External panels of such buildings are made extra light and are merely fillers.

In large panel buildings thick transverse walls are stiffening diaphragms. Therefore the overall stiffness and stability of buildings is provided. It obviously restrains architectural and planning solutions and keeps the forms monotonous. Joints of panels manufactured using welding or compression clips followed by pouring cement and compression did not prove to be efficient.

Slab building. Practical enlargement of slabs gave rise to slab house construction. Buildings are assembled using prefabricated and factory-manufactured volume elements. There are such slabs as a glass, lid and lying glass.

Alignment and assembly is a lot easier in slab construction. Slabs can be installed using a grid and the gaps are filled with flat wall panels. This technology significantly accelerates construction times. Labor and material costs are considerably lower than those of the above. However, along with the above advantages of the method, there are major disadvantages as well: there is no possibility for free planning, architecture and forms are dull and uninspiring.

The size of slabs depends on road sizes. The maximum width of slabs cannot be over 2.5 meters and the distance between the walls in the rooms depends on these sizes respectively. The size of slabs also depends on the loading capacity of vehicles and lifting machines as slabs can be considerably heavy.

A comparison of the two construction methods yielded the following conclusions:

– precast construction overall outperforms monolithic construction in terms of technology and economics: reduced construction times, lower labor and construction costs;

– monolithic construction outperforms in terms of technology;

– monolithic construction technology complies with all the engineering and architectural requirements, i.e. those specified for the construction of buildings and does not restrain architectural and planning solutions.

1. New construction technology

A new construction technology supported by innovation in the design of modern multistorey accommodation, administrative and public buildings is patented [3].

Precast concrete large-scale spatial structures with a changing geometry for transportation are suggested as an original construction solution. What makes them so is their multifunctionality, i.e. spatial structures combine the functions of fillers and retaining structures with a permanent monolithic form.

Precast concrete large-scale spatial structure is factory-made and assembled using a few flat elements. Fig. 1 shows a transportation scheme for a spatial structure with three flat elements (3)+(2)+(3) as an example. The elements of formwork (3) and wall panel (2) are joined using an assembly element (4). This hinged joint helps the formwork (3) to rotate in relation to the wall panel (2). A holding bench (6) is fitted on the vehicle platform. A vertical element of a spatial structure is put into the bench, in this case it is a wall panel (2). Therefore the spatial element is stable on the vehicle platform.

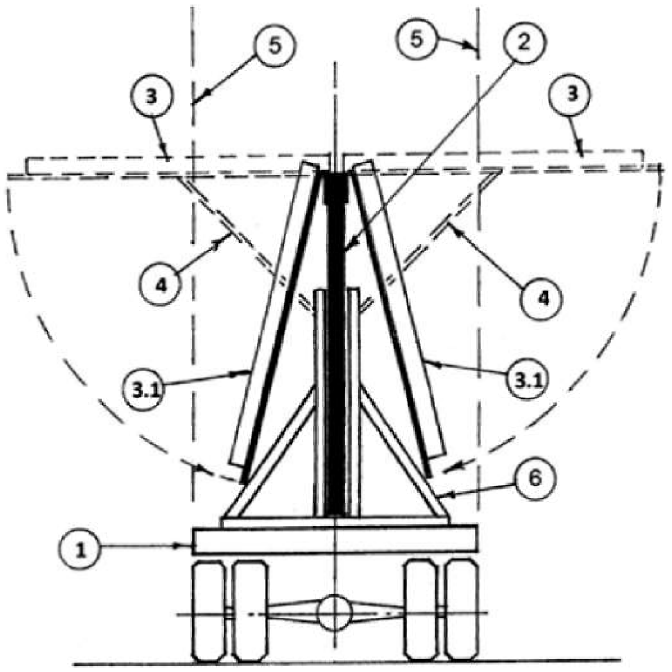

Fig. 1. Transportation scheme for a spatial structure:
1 is a vehicle; 2 is a prefabricated precast concrete thin-walled monolithic panel;
3 is a prefabricated precast concrete thin-walled monolithic form;
3.1 is a prefabricated precast concrete form, see (3) for a lowered position;
4 is a temporary supporting and joining element;
5 are lines of a vehicle size; 6 is a bench holding the wall panel vertically

Immediately prior to the transportation, the geometry is changed, i.e. the formwork elements (3) are rotated into the position (3.1). The elements of the spatial structure are kept within the vehicle. The dotted lines (5) in Fig. 1 are the vehicle. In this way the spatial element is transported from the manufacturing factory to the construction site. There the geometry of the spatial element is restored, i.e. the formwork elements are lifted from the position (3.1) into the horizontal position (3). The formwork elements (3) are fixed in the horizontal position using the assembly elements (4). The geometry can be changed using lifting assembly machine immediately on the vehicle platform.

2. Assembly of spatial elements

The next stage involves lifting and assembly of spatial elements into the design position. This assembly can be performed “from the wheels” after the geometry is restored. Fig. 2 shows the assembly of three spatial structures.

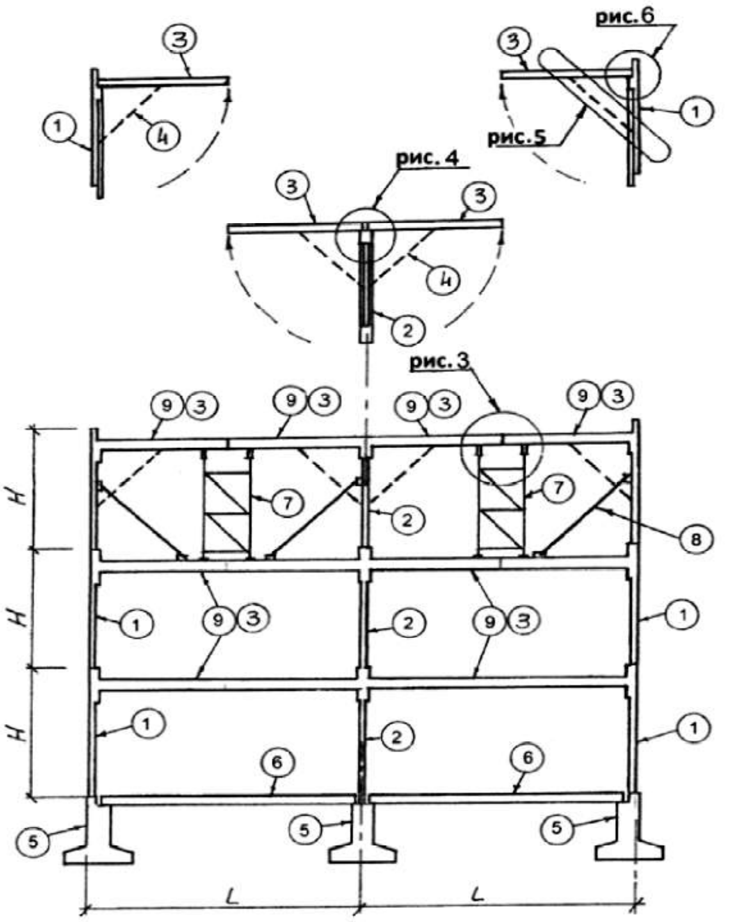

Fig. 2. Assembly scheme for spatial structures:
1 is a prefabricated precast concrete wall panel, internal;
2 is a prefabricated precast concrete, internal;
3 is a prefabricated precast concrete ribbed thin-walled permanent monolithic form;
4 is a temporary supporting and joining element;
5 are foundations; 6 is a monolithic or precast concrete construction;
7 is a temporary support for a precast concrete permanent form (3);
8 is an abutment for temporary fitting of wall panels on the assembly;
9 is a monolithic permanent precast concrete form (3)

Spatial structures are assembled in the manufacturing factory using flat elements:

– *internal spatial structure.* An assembly unit (3)+(2)+(3) is assembled using three flat elements: formwork panel (3), wall panel (2), formwork panel (3);

– *external spatial structure.* An assembly unit (3)+(1) is assembled using two flat elements: formwork panel (3) and wall panel (1).

Unlike flat structures, one assembly of a spatial structure results in the installation of two elements at a time, i.e. the wall panel (1) or (2) and the monolithic permanent formwork (3).

A volume structure is both:

– a retaining structure,

– a filler

– and a precast concrete monolithic formwork (permanent form then becomes part of the monolithic precast concrete formwork).

The wall panels (1) and (2) of the spatial structures (3)+(1) and (3)+(2)+(3) are disjoined by rotating using temporary joining abutments (8). The wall panels are designed to include assembly joining supports at the top and bottom of the panels for accurate joining of the lower and upper wall panels. The upper wall panels are installed on the joining supports of the lower wall panels after cement is poured on the monolithic form. Therefore the upper joining supports are above the cement level of the monolithic form. The panels of the precast concrete form (3) are delivered on site as an assembly unit of the spatial structures (3)+(1) and (3)+(2)+(3). As the spatial structures are assembled in the middle of the formwork, its panels (3) are supported by a temporary steel support (7). Fig. 3 shows a support scheme for the formwork panel (3) on a temporary support (7).

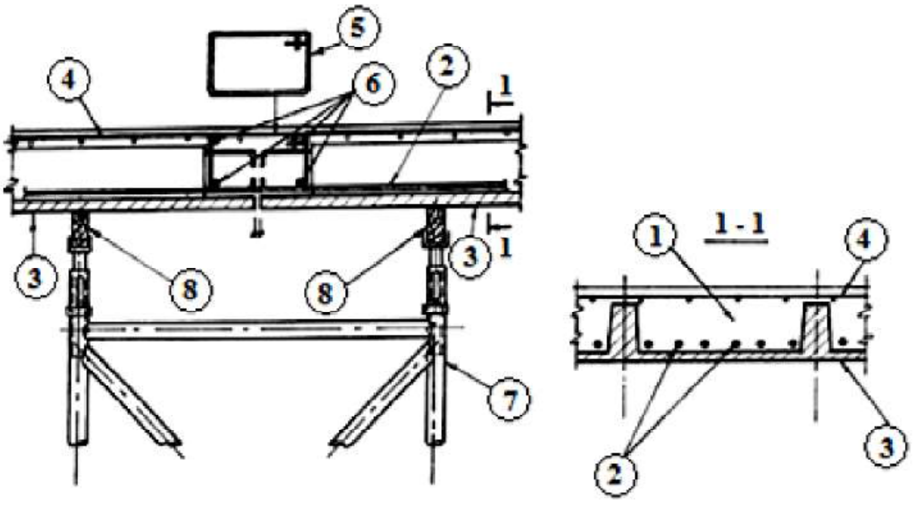

Fig. 3. Support scheme for the panels of precast concrete formwork in the middle of the span.
A part of the monolithic formwork and reinforcement example (see Fig. 2 for the position of the grid):
1 is monolithic concrete; 2 is a steel reinforcement (as specified in the design calculations);
3 is a prefabricated precast concrete thin-walled ribbed permanent formwork;
4 is a reinforcement grid (if necessary);
5 is a reinforced steel clip;
6 is a steel reinforcement designed as part of the project;
7 is a temporary support for assembling a prefabricated permanent formwork; 8 is a supporting bar

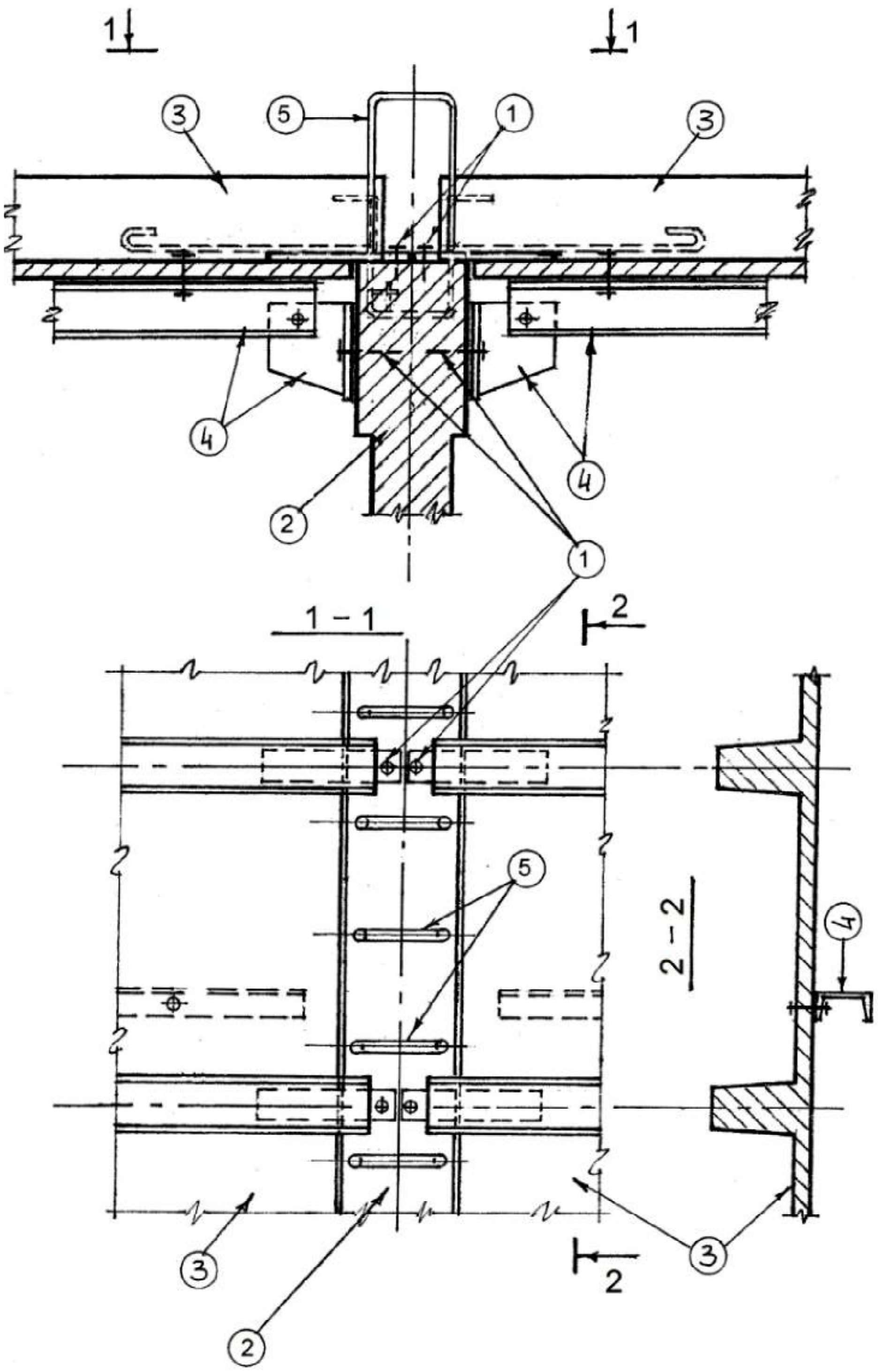

Fig. 4. Support scheme for a prefabricated precast concrete formwork (3) on an internal wall panel (2) (see Fig. 2 for the position of the grid):

1 are anchor bolts; 2 is an internal wall panel;

3 is a prefabricated precast concrete thin-walled ribbed monolithic formwork;

4 is a temporary monolithic and joining element;

5 is a steel reinforcement clip for a joining horizontal belt embedded in a prefabricated precast concrete item

In the middle of the span on the temporary support (7) the monolithic formwork (3) is joined with a counter formwork (3). As a result, there is a continuous formwork layer of prefabricated precast concrete thin-walled ribbed formwork panels (3) between the supporting wall panels.

As the monolithic formwork is installed between the formwork ribs (3), a calculation reinforcement (2) is placed. If necessary, there are vacuum-forming shell. A construction reinforcement (4) is placed along the top of the ribs. The reinforcement is performed as specified in the project solution.

As indicated above, the panels of the prefabricated precast concrete formwork (3) are delivered on site as an assembly unit of spatial structures (3)+(1) and (3)+(2)+(3). The prefabricated precast concrete formwork (3) is joined with the wall panel using a temporary assembly unit (4).

The assembly element (4) serves three functions:

- temporarily connecting the formwork (3) with the wall panel
- rotating the formwork (3) in relation to the wall panel;
- fixing the formwork (3) horizontally.

Fig. 4 shows a support scheme of the prefabricated precast concrete formwork (3) on the internal wall panel (2).

The geometry of the spatial structure, i.e. rotation of the prefabricated precast concrete formwork (3) in relation to the wall panel is changed using hinged movable joint designed as part of the assembly element (4). Fig. 4 shows a temporary joint of the assembly element parts (4) to the wall panel (2) and formwork (3) using anchor bolts. A hinge between the assembly element part (4) helps the system to rotate; an assembly element part fixes the formwork horizontally.

Fig. 5 shows a scheme of fixing formwork (3) horizontally.

The geometry of a spatial structure is restored using a fixed abutment (assembly elements parts), i.e. after it is lifted into the horizontal position by rotating the formwork (3), the fixing abutment (4) is joined to the formwork holding it in this position.

A prefabricated precast concrete monolithic formwork (3) is supported by the wall panel immediately by rigid ribs protruding above the formwork slabs.

Fig. 6 shows a support scheme for the formwork panel by the wall panel and support grid of formwork immediately on the wall panel. An anchor bolt (2) joins the wall panel and formwork panel (3) and is installed following the restoration of geometry.

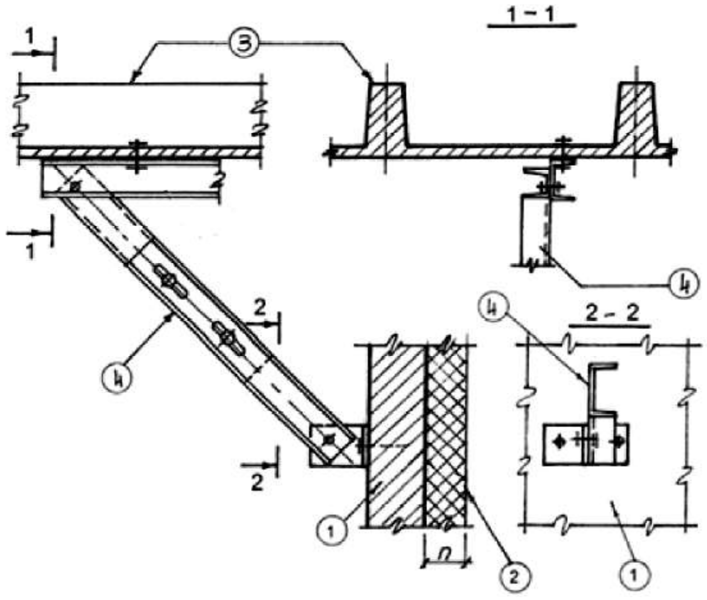

Fig. 5. Scheme for fixing a prefabricated precast concrete panel (3) horizontally (see Fig. 2 for the position of the grid):
1 is the external wall panel; 2 is a heater of external wall panels;
3 is a prefabricated precast concrete thin-walled ribbed monolithic formwork;
4 is a temporary support and joining assembly element (fixing abutment)

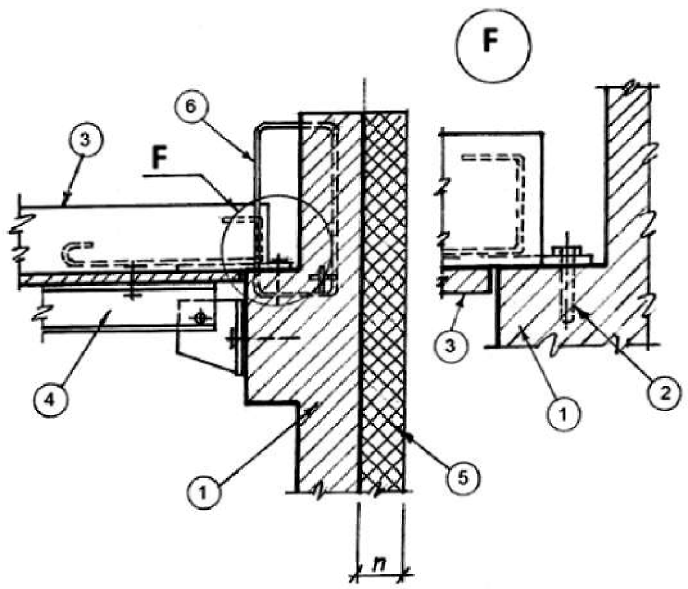

Fig. 6. Support scheme of the panels of prefabricated precast concrete formwork on the external wall panel:
1 is an external wall panel; 2 is an anchor bolt;
3 is a prefabricated precast concrete ribbed thin-walled monolithic formwork;
4 is a temporary support and joining assembly element; 5 is a heater of external wall panels;
6 is a steel reinforcement clip for a joining horizontal belt

3. Joining of elements

The construction of another floor can be divided into three types:

1) transportation and assembly of spatial structures, their temporary dismantling;

2) installation of joints of wall panels, horizontal monolithic belts and vertical joining monolithic columns;

3) installation of monolithic precast concrete shuttering in a permanent precast concrete formwork:

– reinforcement of the shuttering as specified by the project solution;
– cement-pouring of the shuttering, placement of the concrete mix.

At the second stage of the construction of another floor following the assembly of spatial structures and their temporary dismantling, the wall panels are rigidly joined horizontally and vertically. Horizontal joints are monolithic precast concrete belts that rigidly join the upper and lower wall panels. For that there are connection bars (see Fig. 4.6) at the top and bottom of the wall panels. Vertical joints between the wall panels are monolithic precast concrete columns with continuous vertical reinforcement.

The construction of wall panels means vertical joining gaps. During the assembly these joining gaps make the formwork for monolithic columns of a vertical joint. The formwork of joining columns is formed automatically during the installation of wall panels. A two-sided formwork of joining columns is in the joint of the internal wall panels. A three-sided formwork of joining columns is in the joint of the wall panels (Fig. 7).

Joining monolithic columns are constructed during the installation of vertical joints of external and internal wall panels which are a part of the spatial structures. The columns make the walls stable prior to the pouring of the monolithic shuttering and a combination with a monolithic precast concrete shuttering provides the overall rigidity of the construction scheme of a building. This simplified and reliable joining option for external wall panels has been made possible since new insulation materials hit the market.

Conclusions

A new technological construction method for multi-storey buildings is generated by selection and development of advantages offered by monolithic and precast construction [4—10]. The major construction solution is a calculation scheme with retaining walls, rigid disks of monolithic shuttering and stiffness cores:

– retaining walls can be transverse and longitudinal;
– staircases, elevator shafts can be rigid cores.

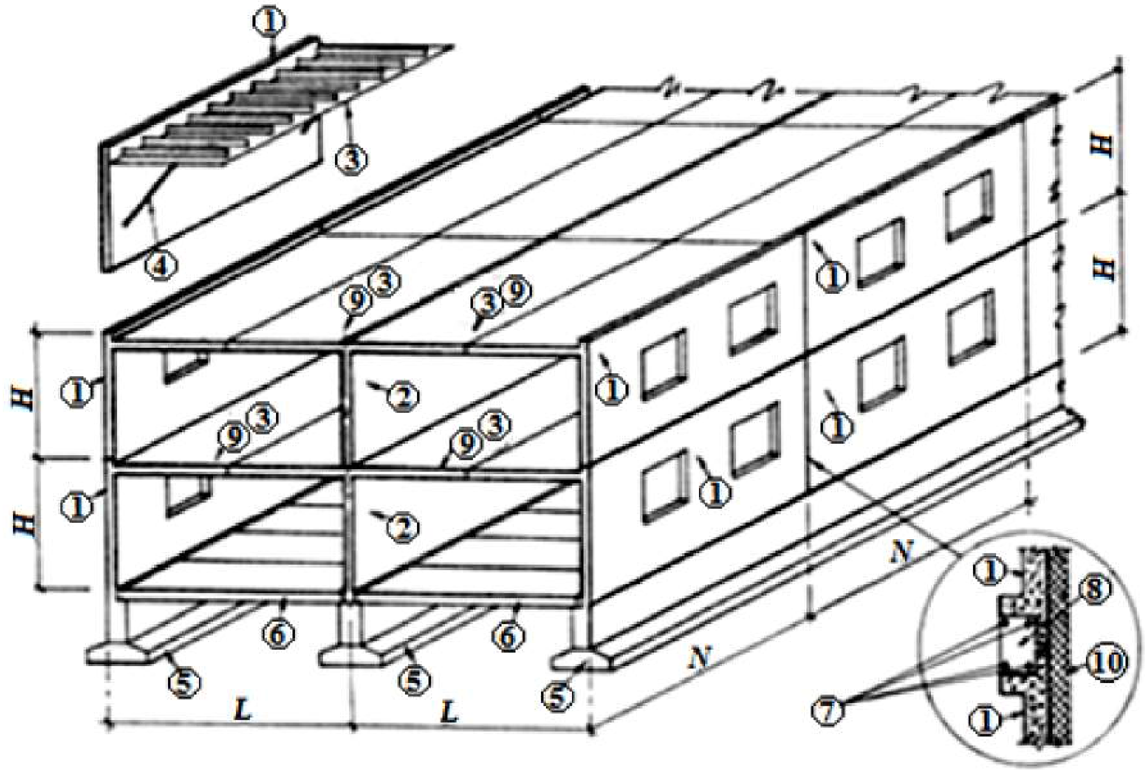

Fig. 7. Construction scheme for a building using spatial structures.
Grid of the vertical joint of external wall panels:
1 is a prefabricated precast concrete wall panel, external; 2 is a prefabricated precast concrete wall panel, internal; 3 is a prefabricated precast concrete thin-walled ribbed permanent form for monolithic shuttering; 4 is a temporary supporting and joining assembly element; 5 are foundations; 6 is a shuttering using monolithic or precast construction; 7 is a steel longitudinal reinforcement of a monolithic joining reinforcement column; 8 is a monolithic joining column; 9 is a monolithic shuttering in a permanent prefabricated precast concrete formwork (3); 10 is a heater of external wall panels

Wall panels rigidly joined by horizontal belts, vertical joining columns and monolithic shuttering can absorb horizontal force loads. A construction scheme employing retaining walls can be used as an alternative to a frame scheme making it possible to apply a combination of construction schemes, e.g.:

- braced frame construction scheme;
- space frame construction scheme;
- complete frame construction scheme;
- incomplete frame construction scheme;
- construction scheme for one of several floors.

The major technical principles of the new construction technology based on the use of prefabricated precast concrete large-size spatial structures allow for:

– rigidity and seismic resistance of a structure just as in monolithic construction;

– free planning with no restraints to architectural and planning solutions;

– a combination of precast and monolithic concrete, i.e. monolithic precast concrete is both a construction element and a joining bond; prefabricated elements and monolithic construction are made into one;

– minimum labor costs of formwork due to the use of prefabricated precast concrete permanent;

– reliability, flexibility and quality of technological solutions on the scale of monolithic construction as well as the number of construction scheme options;

– comparison in terms of technique and economics: construction times, labor and material costs, etc.

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