

CALCULATION OF THE CONSTRUCTIVE NONLINEARITY OF RIBBED REINFORCED CONCRETE SLABS OF SELF-STRESSED COVERING PANELS

Anton HASENKO^{1*}, Volodymyr SEMKO², Serhii SKLIARENKO³

Abstract

Precast reinforced concrete constructions meet the requirements of industrialization, high manufacturability, and cost-effectiveness at a reasonably high level. The ribs in constructions perform load-bearing functions, and the slab part performs enclosing functions. Often before the installation of such structures at a construction site, they are mounted from assembly elements. The overall dimensions of the elements are limited by transportation requirements. During such an aggregated mounting, the assembly units work according to a calculation scheme that differs from an operational scheme. The structural nonlinearity of ribbed reinforced concrete slabs during transportation, mounting, and installation, and the operation of a combined spatial covering panel were investigated in this paper. The effects were identified, and a rational design of nodes connecting the individual prefabricated units into a spatial structure was developed. With the help of these nodes, it is possible to create unloading support moments, which will reduce the internal forces in the design cross-sections. The effects of changes in the width of the reinforced concrete slab shelves on the internal forces of the load-bearing ribs of a wall and a roof panel were investigated.

Address

- ¹ Dept. of Construction and Civil Engineering, Educational and Scientific Institute of Architecture, Construction and Land Development, "Yuri Kondratyuk Poltava Polytechnic" National University, Poltava, Ukraine
- ² Division of Structural Engineering, Institute of Building Engineering, Department of Civil and Transport Engineering, Poznan University of Technology, Poznan, Poland
- ³ "Poltava-Project" (private enterprise), Poltava, Ukraine

* **Corresponding author:** gasentk@gmail.com

Key words

- Combined spatial covering panel,
- Structural nonlinearity.

1 INTRODUCTION

Precast reinforced concrete meets the requirements of industrialization, high manufacturability, and cost-effectiveness at a reasonably high level (Tkachenko et al., 2019; Zielińska and Grębowski, 2015). Building structures made of reinforced concrete can perform both load-bearing and enclosing functions (Shahsavari and Tofghi, 2014). To simplify the installation technology and reduce the building construction time during the development of working drawings of prefabricated reinforced concrete structures, designers strive to combine their load-bearing and enclosing functions (Lam et al., 2009). This explains the emergence of a whole range of ribbed, prefabricated, reinforced

concrete structures, in which the ribs perform load-bearing functions (Abdel-Kareem et al., 2015; Sridhar and Prasad, 2019), and the slab part performs enclosing functions (Bouazid and Demagh 2011). Buildings made of such ribbed, prefabricated reinforced concrete structures are called "quick-mounted". The field of quick-mounted building exploitation is often limited to production buildings for agricultural or warehouse purposes. However, there are problems with providing housing for displaced persons in the conditions of a war and post-war periods (Łotysz, 2016); therefore, the adaptation of such buildings to dormitory-type residential buildings is an urgent issue.

1.1 Analysis of existing studies and publications on the specified problem

Quick-mounted buildings can have a wall or frame construction scheme. In the first case (wall construction scheme of the quick-mounted buildings), ribbed reinforced concrete panels for walls and roofing perform supporting and enclosing functions (see Fig. 1), which significantly reduce the number of mounting elements (Semko and Hasenko, 2020). In the second case (frame construction scheme of the quick-mounted buildings), it is first necessary to install load-bearing rod frame structures and then to install enclosing planar elements with stiffeners (Holly and Abraham, 2020; Pershakov, 2007). Such a mounting sequence leads to an increase in the number of mounting joints on the construction site, which complicates the building installation process and imposes some seasonal restrictions on its implementation.

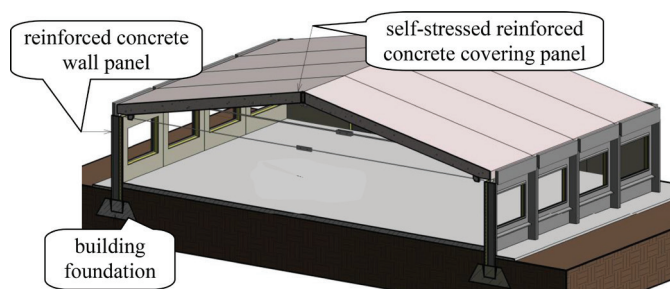


Fig. 1 Structural scheme of walls of quickly assembled buildings using prefabricated reinforced concrete panels

One of the restrictions related to the limit conditions for roofing and ribbed reinforced concrete panels for walls used for quickly-mounted buildings is the strict conditions regarding their overall dimensions. This is explained by the requirements for transporting the specified structures from factory warehouses to the construction site. However, despite these strict requirements for not exceeding the given dimensions of building structures, the manufacturing industry requires buildings to increase spans and expand the usable space inside a building (Semko et al., 2020). This problem is partially solved by carrying out the pre-mounting assembly of the individual elements delivered to the construction site into a spatial mounting unit (Faur and Mircea, 2011; Xiang et al., 2022).

One practical example of such structures is steel-reinforced concrete structures. The creation of these structures is based on the principle that each of the elements used is in its most favourable working conditions, namely, concrete in compression and metal in tension (Venglar et al., 2018). A typical spatial structure of the coating is a spatial cable-stayed steel-reinforced concrete structure, which consists of three-dimensional modules composed of a reinforced concrete slab and steel rods (Gasii, 2014). In addition to the modules, the structures created include steel rod elements of a lower belt, which only perceives tensile forces.

1.2 Highlighting the unresolved part of the specified problem

Prefabricated units of the steel-reinforced spatial concrete structures of long-span coatings at the stages of transportation, mounting, installation, and operation work according to various calculation schemes. This is explained by the imposition or destruction of in-

dividual boundary conditions (connections) or a change in the type of these connections at each of the specified stages (Semko et al., 2020; Sococol et al., 2021). Therefore, during the calculation of the structures considered, it is necessary to consider the so-called constructive nonlinearity of their work.

1.3 The purpose and tasks of the work

The purpose of the research is to determine the possibility of using typical ribbed reinforced concrete covering slabs to create a combined long-span triangular reinforced concrete covering system with a steel brace (see Fig. 2).

To solve the set purpose, based on the results of already conducted studies (Gomon et al., 2022; Semko and Hasenko, 2022; Sucharda and Konecny, 2018), the research task of this work was formulated, namely:

- to investigate the constructive nonlinearity of ribbed reinforced concrete covering slabs during the transportation, mounting, installation, and operation of the combined spatial covering panel;
- to identify the effect of and to develop a rational design of nodes connecting individual prefabricated units into a spatial structure, with the help of which it is possible to create unloading support moments, which will reduce the internal forces in the design cross-sections;
- to investigate the effect of the effective width of reinforced concrete slab shelves on changes in the internal forces in the load-bearing ribs of wall and roof panels.

1.4 Practical significance of the research results

The development of prefabricated reinforced concrete structures and their implementation in construction significantly increases the level of the industrialization of buildings and structures of an industrial or public purpose.

2 MATERIALS AND METHODS

Quick-mounted buildings with a wall construction scheme are considered (see Fig. 1). The transverse frame of such a building has a clear span of 18,000 mm between the inner surfaces of the wall panels. It is proposed to use a prefabricated reinforced concrete panel as a roofing structure with overall dimensions of 2980×18,730 mm (see Fig. 2). The connection point of the roofing constructions to the wall structures is a hinged fixed support that transmits both vertical and horizontal forces. The central axis of the supporting part of the roofing structure is located at a distance 315 mm outward from the inner surface of the wall panel (from the building's working span) and 145 mm from the outer edge of the longitudinal rib of the wall panel. These two distances explain the excellent value of the roofing panel dimensions compared to the working width of the room. The height of the roof panel in the ridge (including the mounting parts) is 2536 mm (Semko and Hasenko, 2020).

The covering panel consists of two reinforced concrete ribbed slabs united into a triangular roofing structure with the help of a steel brace (see Fig. 3). The height of the longitudinal rib of the symmetrically located covering plates is 450 mm. The covering plates have built-in parts for reclining on wall panels, a brace fas-

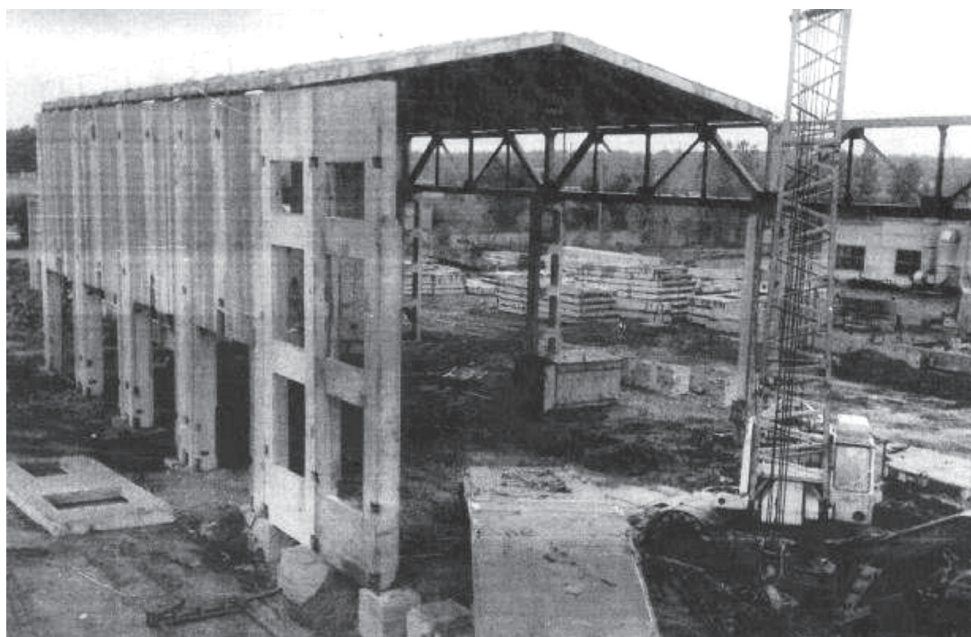


Fig. 2 Building with the use of prefabricated reinforced concrete covering panel during installation

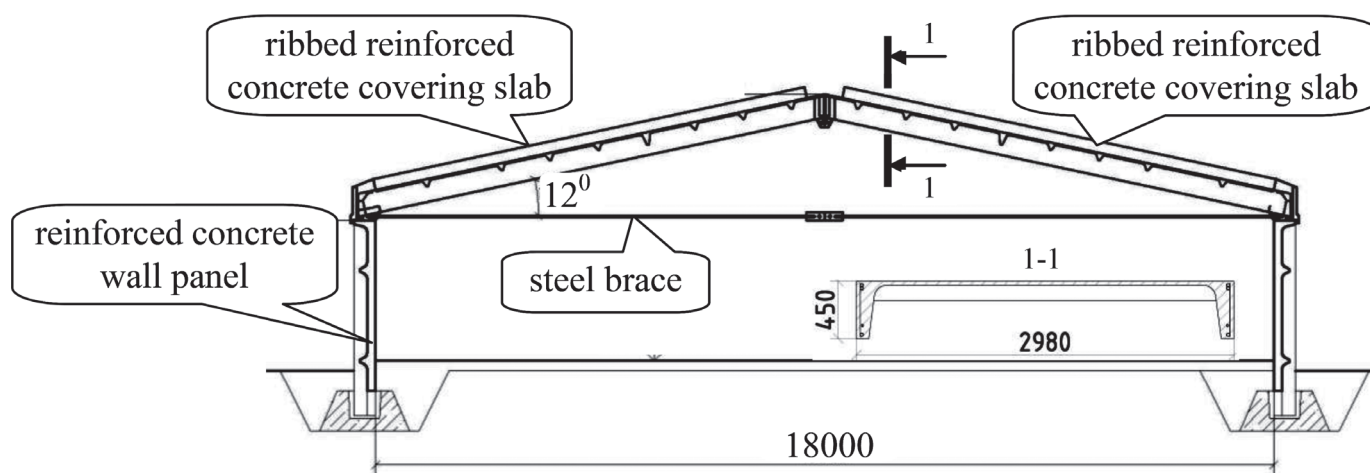


Fig. 3 General view of the covering panel of the prefabricated reinforced concrete

tening, and a ridge node formation to form a single hard disc of the covering.

The covering panel is transported to the construction site in the form of a set of two ribbed slabs with dimensions of 2980×9560 mm and four steel brace elements. Fig. 4 shows the scheme of the enlarging assembly of the spatial panel, the general view of which is shown in Fig. 3, from two ribbed reinforced concrete slabs and four steel brace elements. In node A of the eaves, a steel brace is attached to the ribbed slabs of the covering. In ridge node B, two ribbed plates are connected. The tightening of the brace before the installation of the roofing panel is ensured by its acceptance of the spreading force from the weight of the ribbed reinforced concrete slab. The stage of enlarging the assembly and the tensioning brace on the construction site is shown in Fig. 5.

Thus, the ribbed slabs will work according to several different calculation schemes (Semko et al., 2020), i.e.:

1. alternate installations of two ribbed reinforced concrete slabs on the mounting conductor;
2. brace tensioning from the self-weight of the ribbed reinforced concrete slabs covering and the creation of self-unloading bearing moments in the ribbed cover slabs at the hinged ridge assembly:
 - 2.1 lifting the assembled spatial panel of the cover with a hinged ridge assembly by the two extreme mounting loops;
 - 2.2 leaning the assembled spatial panel with a hinged ridge assembly on two extreme supports without any support on the ridge and the arrangement of a rigid comb node;
3. lifting the assembled spatial panel of the cover by the mounting loops with a rigid comb node and the brace installed after the enlarging assembly;
4. the operational position of the covering panel with a rigid comb node and brace installed on the wall panels.

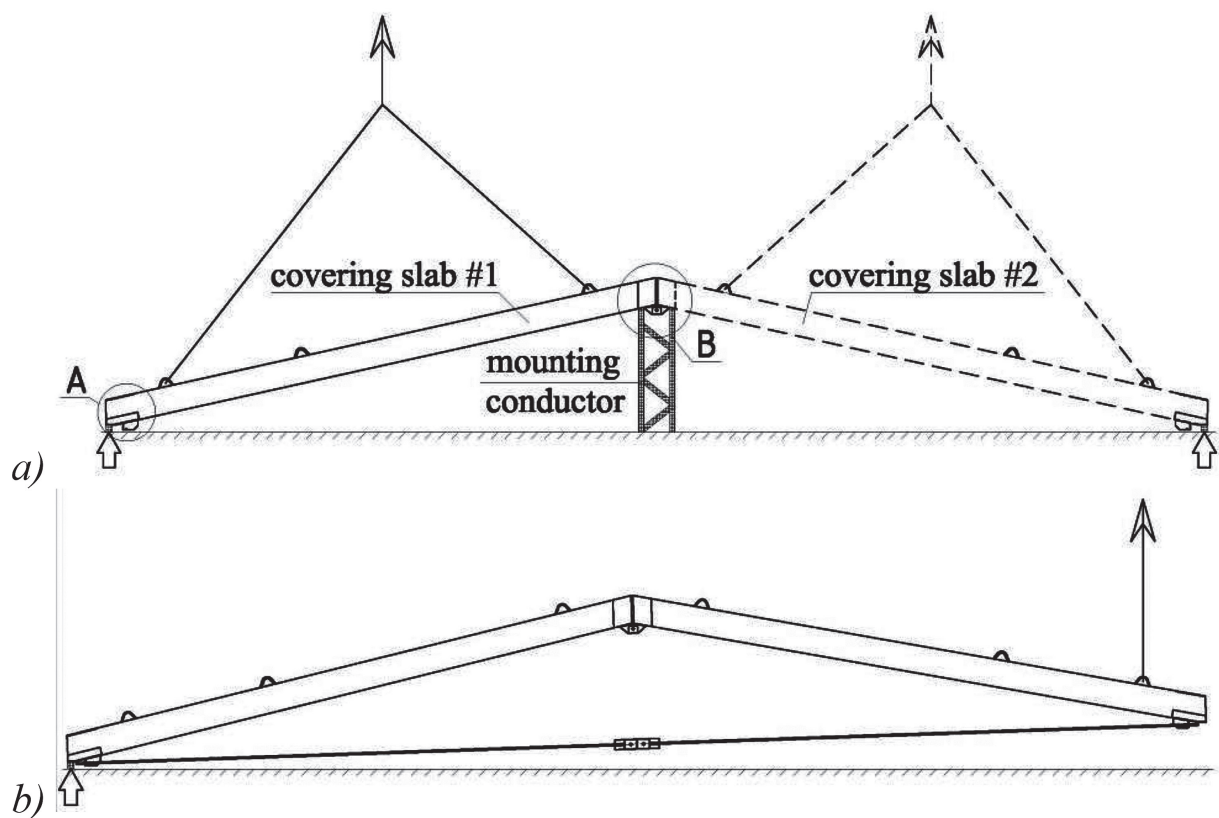


Fig. 4 Scheme of the enlarging assembly of the covering panel: a) installation of two ribbed slabs on the conductor; b) tensioning of the steel brace



Fig. 5 Enlarging assembly of the covering panel and tensioning of the brace on the construction site

3 RESULTS

3.1 General evaluation of the results obtained

On the basis of the research conducted, firstly, a rational design of the connection nodes of the precast reinforced concrete elements into a covering panel was developed, which allows for the creation of the unloading support moments; secondly, the constructively non-linear operation of the ribbed reinforced concrete slabs during the enlarging assembly of the covering panel was investigated; thirdly, the effect of the shape and dimensions of the cross-sections of the reinforced concrete roofing and wall panels calculated on any changes in their internal forces was investigated.

3.2 Development of a rational design of nodes connecting the prefabricated elements into a spatial covering panel

Usually, a ribbed reinforced concrete covering slab operates according to a single-span scheme with hinged supports. With such a calculation scheme, the maximum (calculated) value of the bending moment occurs in the middle of the span, and the moment at the supports is zero (see Fig. 7, c). As is well known, the span moment can be reduced by replacing the supports with rigid ones. In this case, the bending moment's maximum value will be on the supports and will be equal to two thirds of the bending moment's calculated value with the hinged scheme of supporting the plate and one third of the bending moment's calculated value in the middle of the span (see Fig. 10, c). Using the algorithm of reducing the span moment by creating support moments, eccentric nodes of the covering panel's mounting element connection were developed (see Fig. 6). The essence of creating eccentric connection nodes is to predict the distance e_1 between the geometric axis of the ribbed slabs and the brace axis in the eave nodes of the panel (see Fig. 6, a) and the distance e_2

between the geometric axis of the ribbed plates and the ridge joint of the combination of the two slabs (see Fig. 6, b).

3.3 Research on the constructive nonlinearity of the ribbed reinforced concrete floor slabs

Consider the process of the redistribution of the internal forces along the length of the ribbed reinforced concrete slabs.

Stage No.1 – installation of one cover plate on the mounting conductor. During this stage, two plates are installed alternately on the mounting conductor (see Fig. 7, a) with such calculations that it would be possible to assemble the ridge hinge and freely tighten the eave nodes. The reinforced concrete slab works as a *statically determined two-support single-span beam* (Fig. 7, b). The panel supports on the conductor are hinged. The load from the self-weight of the reinforced concrete slab is 13 kN/m (see Fig. 7, b). The maximum value of the bending moment is in the middle of the span; the fibres under tension are from the bottom of the plate; the bending moment at the supports is zero (Fig. 7, c). The heave of the panel by four mounting loops for installation on the mounting conductor is not a calculated case since, in this case, the span moment is reduced, and the moment in the places of suspension to the slings due to the small overhanging parts of the panel is negligible (see Fig. 8).

The preparation for the second stage of the enlarging assembly, i.e., the brace tension, is:

- assembly of the ridge joint of the two slabs;
- insertion of the brace's reinforcing rod into the eave nodes of the roofing panel;
- assembly of the two paired brace mounting elements into one.

After the ridge node is assembled and the brace is applied, the roof panel is ready to be tensioned by the self-weight of the two half-panels and the installation of a rigid comb node.

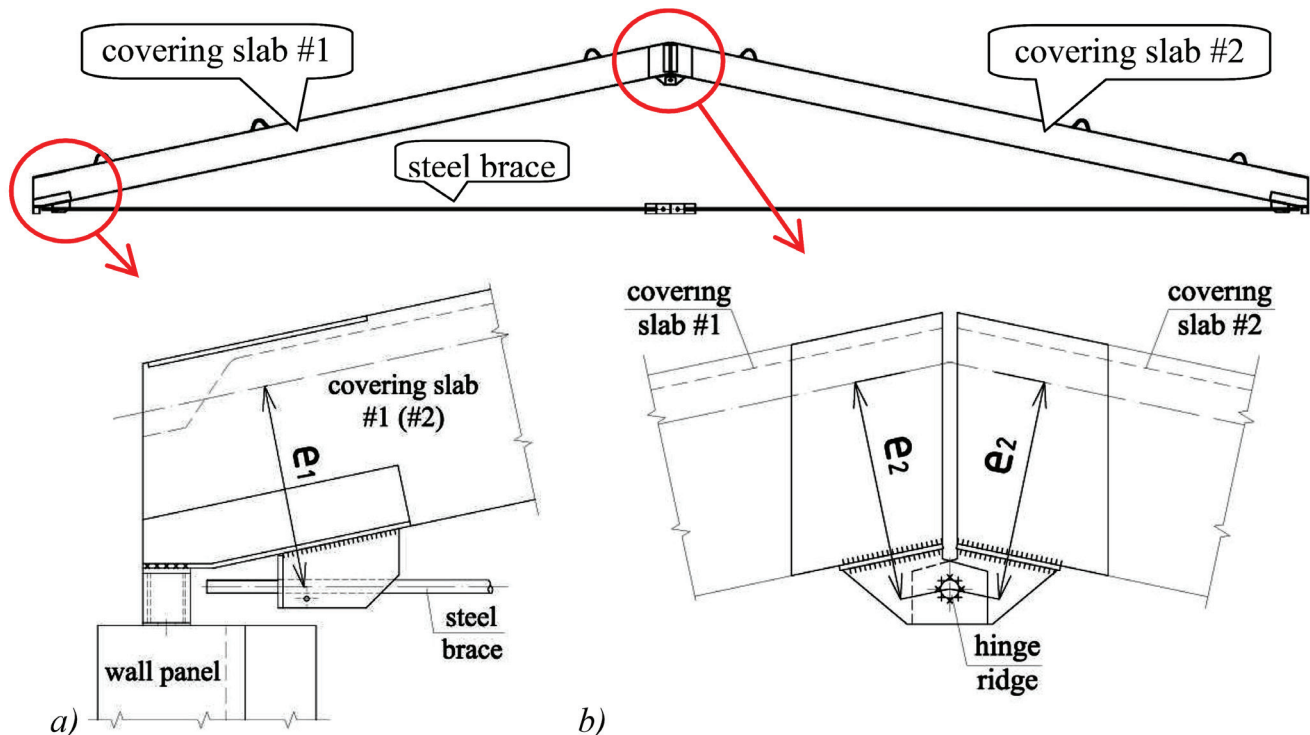


Fig. 6 Eccentric connection of the mounting elements of the covering panel to create unloading support moments in the ribbed slabs: a) eave unit connecting the plate and the brace; b) ridge connection of two plates

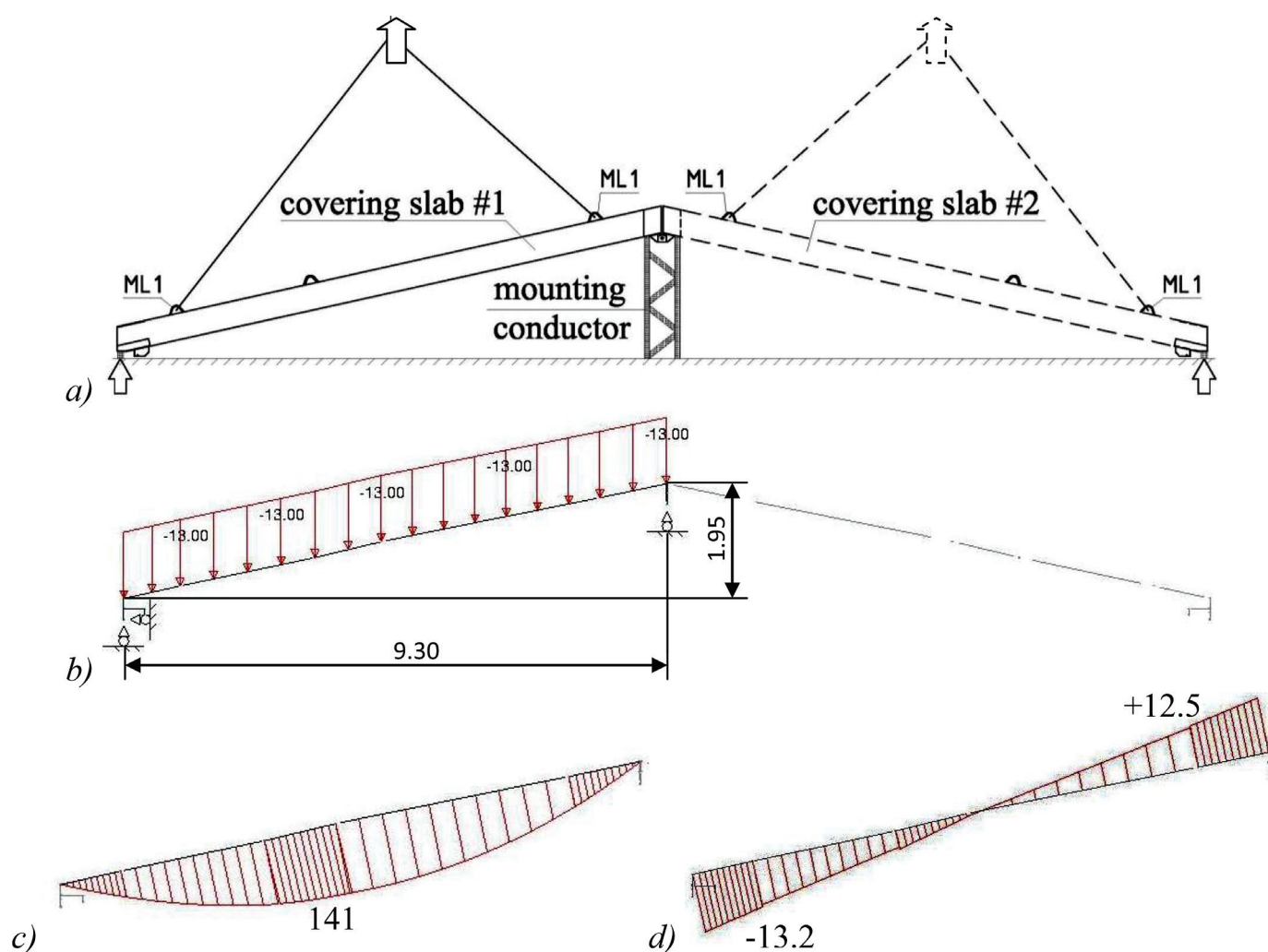


Fig. 7 Installation of two slabs on a mounting conductor for their enlarging assembly: a) installation scheme; b) calculation scheme; c) bending moment diagram, kNm; d) axial force diagram, kN

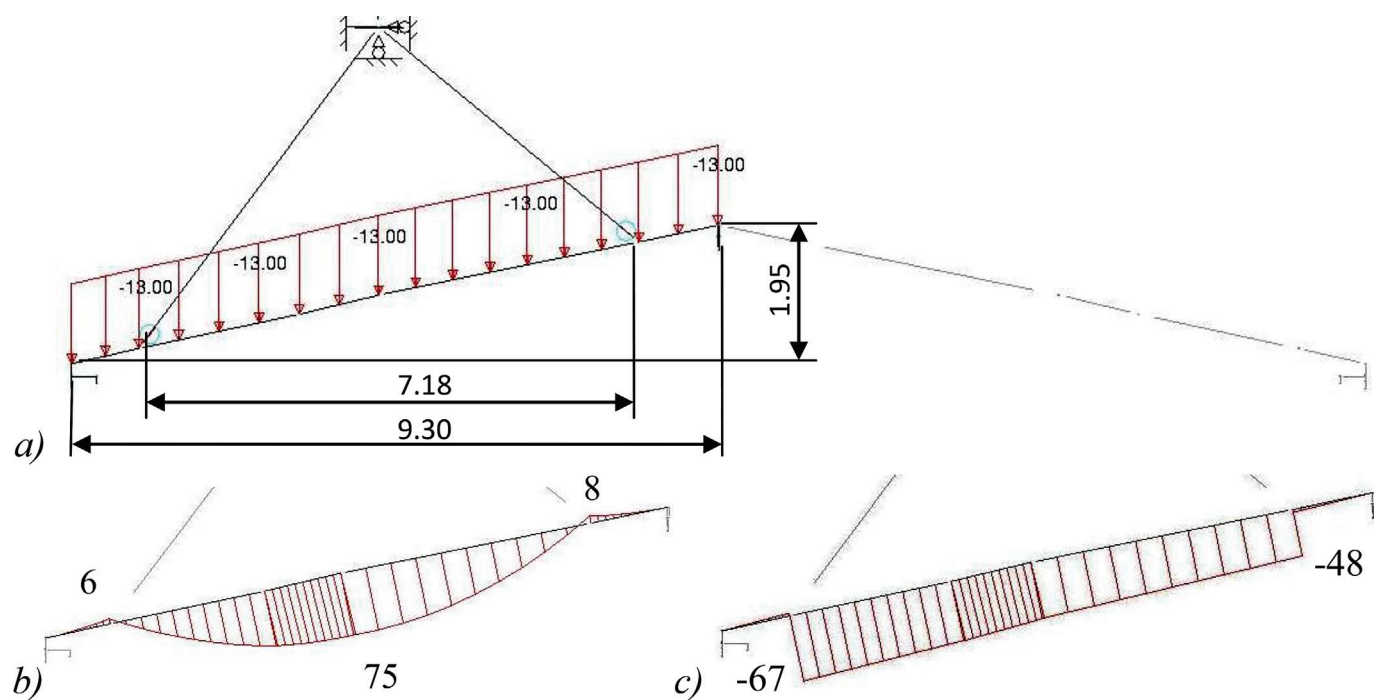


Fig. 8 Lifting one slab by the mounting loops: a) calculation scheme; b) bending moment diagram, kNm; c) axial force diagram, kN

Stage No.2 – carrying out brace tensioning from the self-weight of the reinforced concrete slabs and creating self-unloading supporting moments in the slabs at the hinged ridge node. The roof panel is raised at one end by the two extreme (closer to the supports) mounting loops ML1 (see Fig. 9, a); the mounting conductor is pulled out, and the brace is tightened at the hinged ridge node under the weight of the two plates. The load distributed along the length from the self-weight of the reinforced concrete slab is 13 kN/m (see Fig. 9, b and Fig.10, b). This is how the brace absorbs the reaction of the horizontal support from the weight of the roofing panels. Then the panel is lowered onto the extreme supports (see Fig. 10, a) without any support on the ridge. At this stage, we have a *statically determined frame with one closed circuit and three hinges*, i.e., on the ridge and at the two ends of the brace (in the places where the brace is attached to the reinforced concrete slabs).

When lifting the assembled panel with the hinged ridge node by the two extreme (closer to the supports) mounting loops ML1 (see Fig. 9, a), the maximum moment occurs on the mounting loop ML1 at a distance of 1 m from the support – the fibres under tension are on the top of the panel (see Fig. 9, c); this moment is created by the self weight of the plate console and the brace tension force (see Fig. 9, b).

When resting an assembled panel with a hinged ridge node on two extreme supports without any support on the ridge (see Fig. 10, a), the maximum moments occur at the supports of the slabs below, and the ridge fibres under tension are on the top of the panel (see Fig. 10, c). The moment on the supports is created by the brace tension force and the moment on the ridge is created

by the compressive force on the upper reinforced concrete belt of the roofing system applied to the central hinge (see Fig. 10, b). These two forces (at the supports and on the ridge), which are applied with eccentricity relative to the geometric central axis of the reduced cross-section of the slab, create self-unloading support moments in the reinforced concrete slabs. After the brace tensioning, the side plates are welded onto the comb node; i.e., the node becomes rigid. The roof panel in the form of a triangular roofing system with the brace is ready for installation on the wall panels.

It should be noted that the effect of the instantaneous concrete creep from the action of the load on it will be quite insignificant; therefore, it was ignored during the analysis of the redistribution of the internal forces in the roofing system. The study of the effect of the long-term concrete creep on the redistribution of internal forces in the roofing system was not considered to be a task of these studies.

Stage No.3 – lifting the assembled panel by the mounting loops ML2 with a hinged ridge node and installed brace. During the installation, the roof panel is lifted by the mounting loops ML2 using a 4-branch sling or a traverse with two 2-branch slings (Fig. 11, a). Before the final lowering of the roofing panel onto the wall panel and the welding of the embedded parts, it is necessary to ensure the tensioning of the brace so that it accepts the spacer from the self weight of the reinforced concrete slabs. In this case, we have a *once statically indeterminate frame with one closed circuit and two mortised hinges* at the two ends of the brace (in the places where the brace is attached to the reinforced concrete half-panels) (Fig. 11, b). The maximum moment in the half-panels occurs at the mounting loop ML2, i.e., from above the panel (see Fig. 11, c);

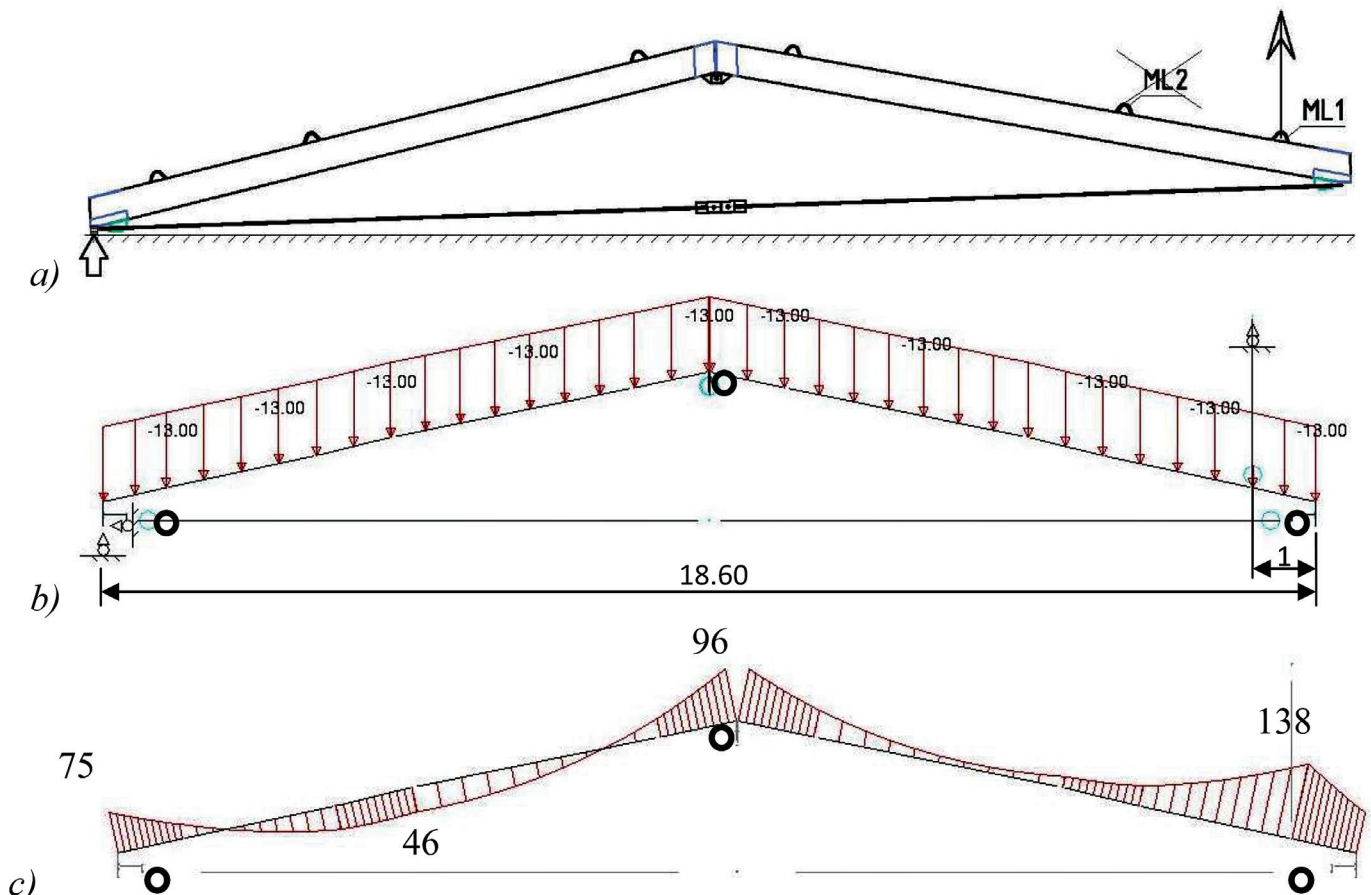


Fig. 9 Lifting the assembled panel with a hinged ridge node by the two extreme (closer to the supports) mounting loops ML1: a) slinging scheme; b) calculation scheme; c) bending moment diagram, kNm

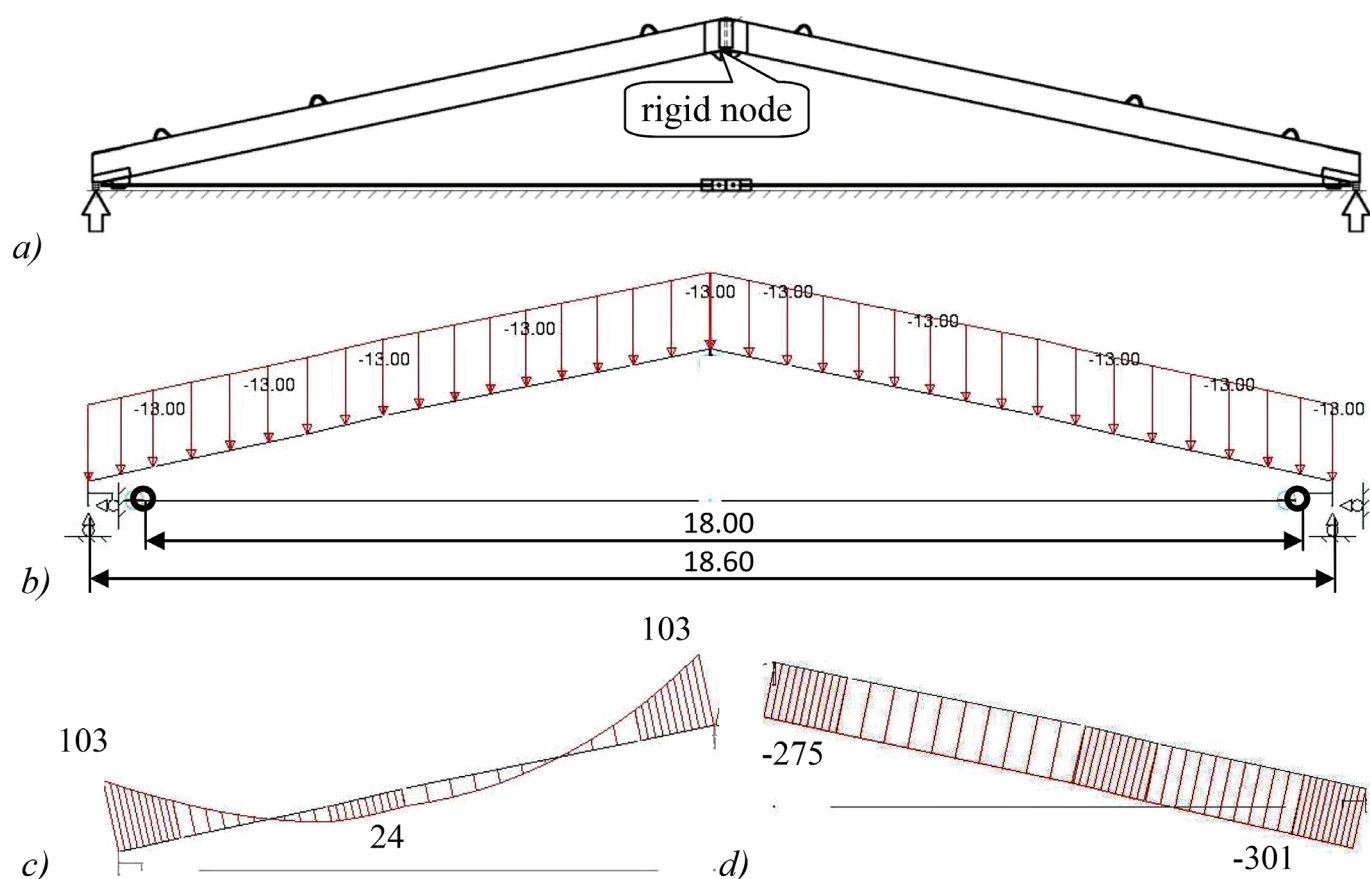


Fig. 10 Dismantling the middle support with the hinged fixed end supports and hinged ridge node: a) layout of supports; b) calculation scheme; c) bending moment diagram, kNm; d) axial force diagram, kN

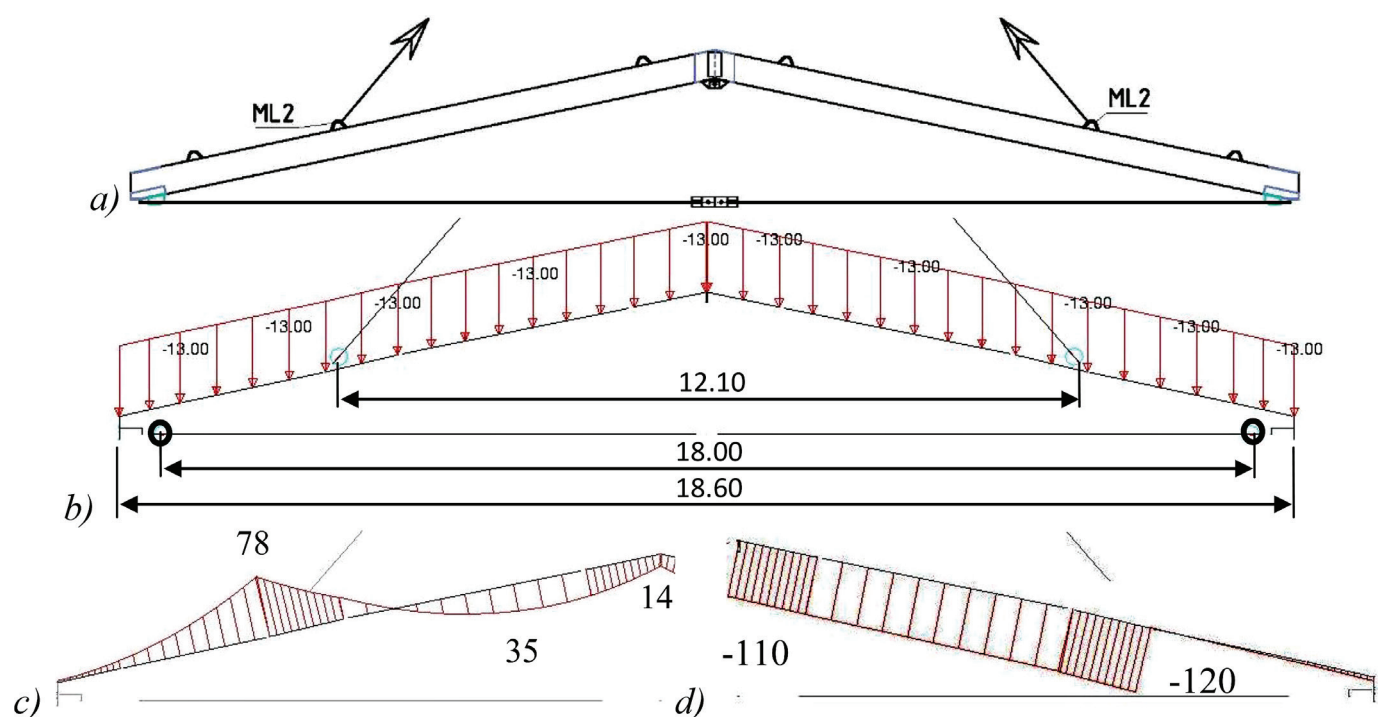


Fig. 11 Lifting the assembled panel by the mounting loops ML2 with a hinged ridge node and installed brace: a) slinging scheme; b) calculation scheme; c) bending moment diagram, kNm; d) axial force diagram, kN

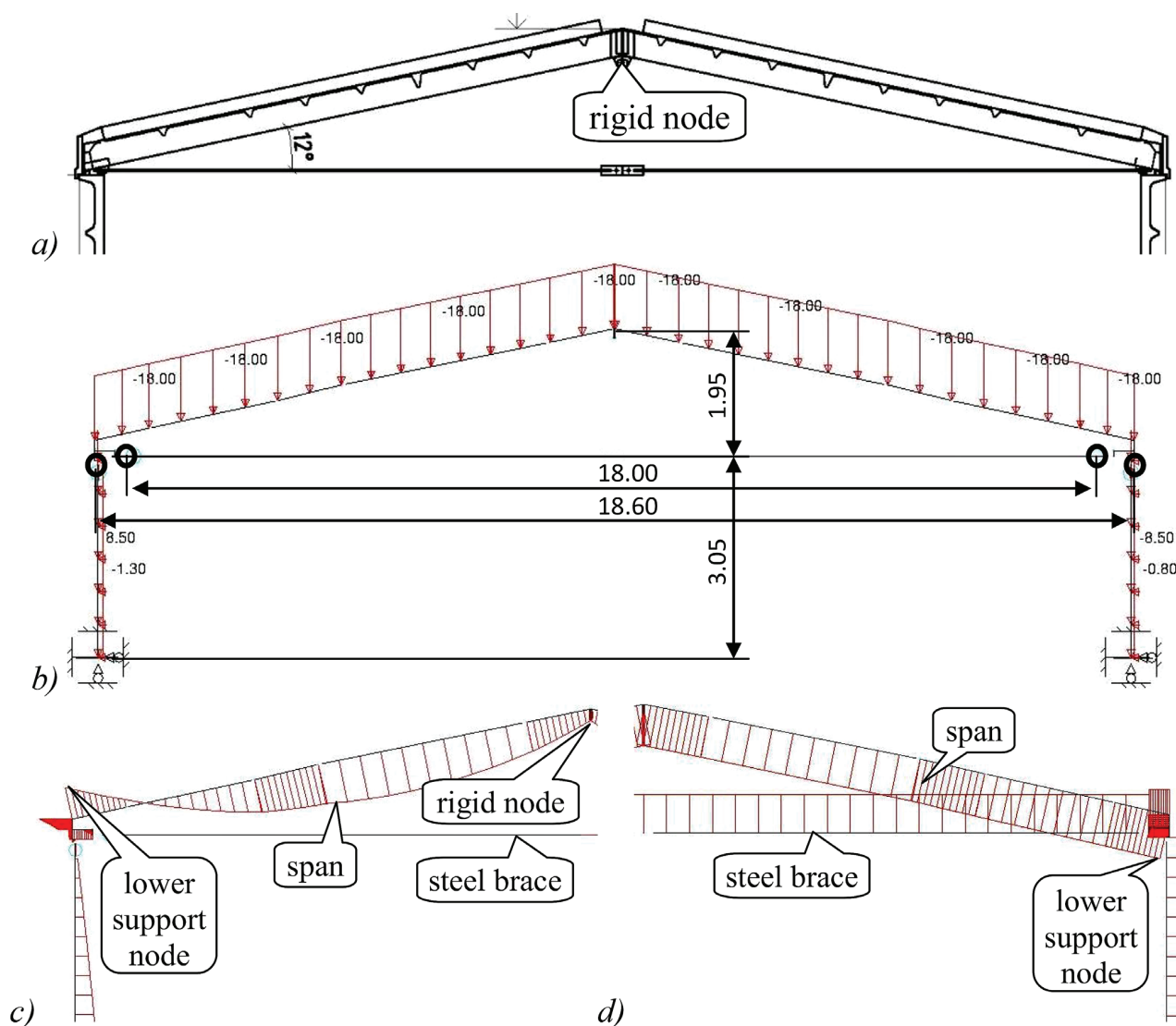


Fig. 12 Operational position of the plate: a) schematic drawing; b) calculation scheme; c) bending moment diagram, kNm; d) axial force diagram, kN (value internal forces – Tab. 2)

this moment is created by the self weight of the overhanging parts of the plate (see Fig. 11, b). In this case, the tension in the brace is close to zero.

Stage No.4 – operational position of the plate (with a hinged ridge node and installed brace), taking into account the operation of the wall panels. At this stage, we have a twice statically indeterminate frame with two closed contours and two hinges in each contour (at the sites of the brace fastened to the covering slabs for the closed contour of the triangular roof arch and at the sites of the abutment of the roofing panel on the wall panels for the lower contour). The junction of the wall panels to the foundations is taken as rigid (see Fig. 12, a).

At this stage, *taking into account the work of the shelves*, the maximum bending moment occurs: the fibres under tension are on the bottom of the slab on the span; the fibres under tension are on the top of the panel on the supports; *without taking into account the work of the shelves*, the moment in the span (the fibres under tension are on the bottom of the panel) and the moment at the supports (the fibres under tension are on the top of the panel) are practically the same (see Fig. 12, c). The moment in the span is created

by the evenly distributed self weight of the panel, the weight of the light roof and any snow (the total evenly distributed vertical load in this case is equal to 18 kN/m – see Fig. 12, b), and the forces on the support (the brace tension and vertical support reaction). The moment on the supports is created by the brace tightening force, and the vertical support reaction of the panel is created from an evenly distributed load of 18 kN/m applied with eccentricity (see Fig. 12, b). The vertical load is applied to the wall panels; it is equal to the support reaction from a uniformly distributed load (the self-weight of the slabs, the structure of the light roof, and any snow).

3.4 Study of the effective width of the reinforced concrete slab shelves on any changes in the internal forces in the load-bearing ribs of the wall and roof panels

Since the walls and covering panels can contain holes in the shelves, for example, for the arrangement of a window or door openings, the use of the stiffness of two types of reinforced concrete elements is ana-

lyzed in the calculation schemes discussed above, i.e., rectangular elements, which are equal to the size of two ribs, and T-section elements, which include a shelf. The effective width of the shelf was determined according to the location of the zero bending moment points:

$$b_{eff} = b_w + 2 \cdot (0.2 \cdot b_i + 0.1 \cdot l_0), \quad (1)$$

where b_w is the width of the two edges of the plate from below;
 b_i is the width of the shelf on each side of the reduced T-shaped section;
 l_0 is the distance between the points of the zero bending moments on the diagram.

The combinations of the stiffness set analyzed are shown in Table 1, where they are used in the corresponding calculations. The results of the calculations (see Table 2) show that the most dangerous options for covering reinforced concrete slabs are the following options:

- all the frame elements work by considering the inclusion of shelves (stiffness set #1 – Fig. 13, a). In this case, we have the most significant supporting moment in the g slabs – the fibres under tension are on the top of the slab (Fig. 12, c). It should be noted that the load that causes this moment is evenly distributed over the roof, without taking into account possibility of the formation of snow bags behind the aeration devices along the roof (Fig. 12, b);
- the slab work with the inclusion of shelves in the work and wall panels without taking into account the shelves (ribs only) (stiffness set #9 – see Fig. 13, b). In this case, we have the largest span moment in the covering plates – the fibres under tension are on the bottom of the panel (see Fig. 12, c). The load that causes the formation of this moment is

Tab. 1 Stiffness sets for the operational calculation scheme (Stage № 4)

Stiffness set №	Left wall panel	Left covering panel	Right covering panel	Right wall panel
Set #1	T-section	T-section	T-section	T-section
Set #2	T-section	T-section	T-section	Rectangle
Set #3	T-section	T-section	Rectangle	T-section
Set #4	T-section	Rectangle	T-section	T-section
Set #5	Rectangle	T-section	T-section	T-section
Set #6	T-section	T-section	Rectangle	Rectangle
Set #7	T-section	Rectangle	T-section	Rectangle
Set #8	T-section	Rectangle	Rectangle	T-section
Set #9	Rectangle	T-section	T-section	Rectangle
Set #10	Rectangle	T-section	Rectangle	T-section
Set #11	Rectangle	Rectangle	T-section	T-section
Set #12	Rectangle	Rectangle	Rectangle	T-section
Set #13	Rectangle	Rectangle	T-section	Rectangle
Set #14	Rectangle	T-section	Rectangle	Rectangle
Set #15	T-section	Rectangle	Rectangle	Rectangle
Set #16	Rectangle	Rectangle	Rectangle	Rectangle

Tab. 2 Internal maximum forces in the roofing slabs and brace for the operational calculation scheme (Stage No.4) (the diagram of the location of the cross-sections calculated, see Fig. 12, c)

Stiffness set	Lower support node			Span		Ridge node			Brace
	N, kN	M, kNm	Q, kN	N, kN	M, kNm	N, kN	M, kNm	Q, kN	N, kN
Set #1	-342	-116	89	-326	144	-308	30	-67	302
Set #2	-354	-104	95	-336	156	-319	34	-60	310
Set #3	-373	-105	90	-354	138	-335	-14	-70	319
Set #4	-372	-105	90	-354	138	-334	-14	-70	319
Set #5	-354	-104	90	-336	156	-320	34	-71	309
Set #6	-364	-94	88	-345	142	-336	-14	-80	328
Set #7	-373	-102	89	-355	140	-336	-12	-80	331
Set #8	-385	-106	82	-357	121	-350	-23	-80	332
Set #9	-356	-105	89	-338	160	-322	34	-68	315
Set #10	-373	-102	89	-356	140	-336	-12	-80	328
Set #11	-375	-94	88	-355	142	-336	-14	-80	328
Set #12	-386	-101	86	-367	125	-352	-25	-68	343
Set #13	-375	-95	88	-357	142	-337	-13	-81	334
Set #14	-375	-94	88	-357	142	-337	-12	-81	335
Set #15	-386	-106	86	-367	122	-352	-22	-68	343
Set #16	-389	-101	85	-371	124	-354	-26	-69	350

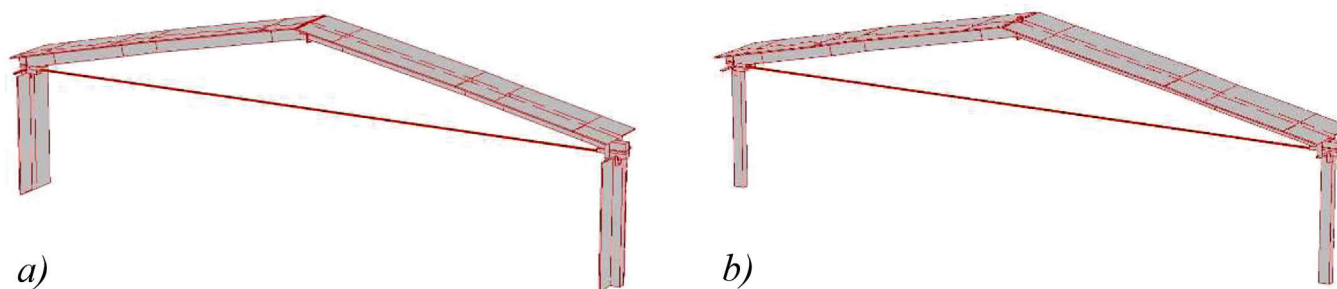


Fig. 13 Schematic representation of the cross sections (stiffnesses) of the wall and covering panels accepted for the calculations: a) set #1; b) set #9

unevenly distributed, taking into account the possibility of snow bags behind the aeration devices;

- c) rectangular sections of the ribs (stiffness set #16) have the most minor form of inherent stiffness. We have the most significant tensile forces in the brace.

4 CONCLUSIONS

The research conducted made it possible to solve important scientific and practical issues in the development of prefabricated reinforced concrete structures that increase the level of the industrialization of buildings and structures of an industrial or public purpose.

The novelty of the development of the design of the triangular reinforced concrete covering system with steel bracing is, firstly, a study of the creation of unloading support moments to the adjacency of the steel brace in the eave nodes of the reinforced concrete slabs with eccentricity and the arrangement of a combination of the conical nodes of two reinforced concrete slabs with eccentricity; secondly, a study of the constructively nonlinear operation of ribbed reinforced concrete slabs during the enlarging installation of the spatial panel of the covering; and thirdly, a study of the effect of the shapes and sizes of the cross-sections of the reinforced concrete roof and wall panels calculated for any changes in their internal forces.

The possibility of manufacturing roofing slabs of a given span in a standard spread formwork intended for the production of serial ribbed reinforced concrete slabs with overall dimensions in a plan of 3×12 m is shown.

The structural and technological scheme of the triangular reinforced concrete roofing system with a steel brace described allows for the creation of preliminary self-stresses (stresses from its own weight) in it, namely:

- 1) supporting moments in the eave nodes of the reinforced concrete slabs due to an increase in the shoulder of the force pair from the brace to the neutral axis of the compressed concrete zone;
- 2) a zero bending moment in the ridge node due to the arrangement of the ridge hinge below the neutral axis of the compressed concrete zone and the optimal angle of the roof's slope;
- 3) preliminary tension of the steel brace and a significant part of its elongation even before the operational position of the structure due to the appearance of a horizontal bearing reaction in the triangular roofing system from the self weight of the reinforced concrete roofing slabs, which allows for reducing the amount of the horizontal bearing reaction from the operational load on the wall structures.

REFERENCES

- Abdel-Kareem, A.H. – Abousafa, H. – El-Hadidi, O.S. (2015) *Behavior of a confined tension lap splice in high-strength reinforced concrete beams*. Slovak Journal of Civil Engineering, Vol. 23, No. 3, pp. 1-8. <https://doi.org/10.1515/sjce-2015-0011>
- Bouazid, T. – Demagh, K. (2011) *Practical method for analysis and design of slender reinforced concrete columns subjected to biaxial bending and axial loads*. Slovak Journal of Civil Engineering, Vol. XIX, No. 1, pp. 24-32. <https://doi.org/10.2478/v10189-011-0004-1>
- Faur, A. – Mircea, C. (2011) *Hybrid connections – the sustainable approach for prefabricated frame structures*. Proceedings of Concrete Solutions, 4th International Conference on Concrete Repair, CRC Press, pp. 227-233.
- Gasii, G.M. (2014) *Technological and design features of flat-rod elements with usage of composite reinforced concrete*. Metallurgical and Mining Industry, Vol. 4, pp. 23-25.
- Gomon, S. – Romanyuk, V. – Ziatyuk, Y. – Marchuk, V. – Nalepa, O. (2022) *Effective methods to strengthen the bending reinforced concrete elements*. Acta Sci. Pol., Architectura, Vol. 21 (1), pp. 51-56. <https://doi.org/10.22630/ASPA.2022.21.1.6>
- Holly, I. – Abrahoim, I. (2020) *Connections and joints in precast concrete structures*. Slovak Journal of Civil Engineering, Vol. 28, No. 1, pp. 49-56. <https://doi.org/10.2478/sjce-2020-0007>
- Ivanyk, I. – Vikhot, S. – Vybranets, Y. – Ivanyk, Y. (2018) *Theoretical research into spatial work of a steel-reinforced-concrete statically indeterminate combined structure*. Eastern-European Journal of Enterprise Technologies, Vol. 5/7 (95) pp. 13-22. <https://doi.org/10.15587/1729-4061.2018.143023>
- Lam, J.Y.K. – Ho, J.C.M. – Kwan, A. (2009) *Maximum axial load level and minimum confinement for limited ductility design of concrete columns*. Computers and Concrete, Vol. 6, pp. 357-376. <https://doi.org/10.12989/cac.2009.6.5.357>
- Lotysz, S. (2016) *Reconstruction of war damaged buildings - a problem that still stands: the case of the National Economy Bank in Warsaw restored during the Second World War*. Civil and environmental engineering reports, Vol. 23(4), pp. 111-124. <https://doi.org/10.1515/ceer-2016-0056>
- Pershakov, V.M. (2007) *Каркасні будинки з тришарнірних залізобетонних рам (Skeleton structures with three-hinged concrete frames): monograph*. K.: NAU. 301 pp. ISBN 978-966-2071-01-6 [in Ukrainian].
- Semko, O.V. – Hasenko, A.V. (2020) *Architectural and constructive decisions of a triangular reinforced concrete arch with a self-stressed steel brace*. Zb. nauk. pr.: Tsentral'noukrayins'kyu naukovo-y visnyk. Tekhnichni nauky. Kropyvnyts'kyu: KNTU, Vol. 3(34), pp. 209-217. [https://doi.org/10.32515/2664-262X.2020.3\(34\).209-217](https://doi.org/10.32515/2664-262X.2020.3(34).209-217)
- Semko, O.V. – Hasenko, A.V. (2022) *Classification of self-stressed steel-concrete composite structures*. Lecture Notes in Civil Engineering, Vol. 181, pp. 367-374. https://doi.org/10.1007/978-3-030-85043-2_34
- Semko, O.V. – Hasenko, A.V. – Krutybich, O.V. (2020) *Перерозподіл внутрішніх зусиль під час укрупнювальної збірки залізобетонної арки із затяжкою (Redistribution of internal forces during the reinforcement assembly of a reinforced concrete arch with tightening)*. Abstracts of the 72nd scientific conference NUPP, pp. 106-107 [in Ukrainian].
- Semko, O.V. – Hasenko, A.V. – Kyrychenko, V.A. – Sirobaba, V.O. (2020) *The rational parameters of the civil building steel frame with struts*. Lecture Notes in Civil Engineering, Vol. 73, pp. 235-243. https://doi.org/10.1007/978-3-030-42939-3_25
- Shahsavari, V.L. – Tofghi, S. (2014) *Uncertainties concerning the free vibration of inhomogeneous orthotropic reinforced concrete plates*. Slovak Journal of Civil Engineering, Vol. 22, No. 3, pp. 21-30. <https://doi.org/10.2478/sjce-2014-0014>
- Sococol, I. – Mihai, P. – Toma, I.-O. – Olteanu-Donțov, I. – Venghiac, V.-M. (2021) *Stress-strain relation laws for concrete and steel reinforcement used in non-linear static analytical studies of the moment resisting reinforced concrete (RC) frame models*. Buletinul Institutului Politehnic Din Iași, Vol. 67 (71), Nr. 1, pp. 17-29. <https://doi.org/10.2478/bipca-2021-0002>
- Sridhar, R. – Prasad, R. (2019) *Uncertainties concerning the free vibration of inhomogeneous orthotropic reinforced concrete plates*. Slovak Journal of Civil Engineering, Vol. 27, No. 3, pp. 44-54. <https://doi.org/10.2478/sjce-2019-0021>
- Storozhenko, L.I. – Gasii, G.M. (2014) *Experimental research of strain-stress state of ferrocement slabs of composite reinforced concrete structure elements*. Metallurgical and Mining Industry, Vol. 6(6), pp. 40-42.
- Sucharda, O. – Konecny, P. (2018) *Recommendation for the modelling of 3D non-linear analysis of RC beam tests*. Computers and Concrete, Vol. 21, № 1, pp. 11-20, <https://doi.org/10.12989/cac.2018.21.1.011>
- Tkachenko, V. – Kwilinski, A. – Klymchuk, M. – Tkachenko, I. (2019) *The economic-mathematical development of buildings construction model optimization on the basis of digital economy*. Management Systems in Production Engineering, Vol. 27, № 2, pp. 119-123. <https://doi.org/10.1515/mspe-2019-0020>
- Vatulia, G.L. – Berestianskaya, S. – Opanasenko, E. – Berestianskaya, A. (2017) *Substantiation of concrete core rational parameters for bending composite structures*. DYN-WIND'2017 – MATEC Web of Conferences, Vol. 107, 00044. <https://doi.org/10.1051/mateconf/201710700044>
- Venglar, M. – Sokol, M. – Aroch, R. (2018) *Ambient vibration measurements of steel truss bridges*. Slovak Journal of Civil Engineering, Vol. 26, No. 4, pp. 234-239. <https://doi.org/10.21595/jme.2018.20419>
- Xiang, L. – Xiaomeng, S. – Hamdy, M. (2022) *Optimization research on prefabricated concrete frame buildings based on the dynamic equation of eccentric structure and horizontal-torsional coupling*. Applied Mathematics and Nonlinear Sciences, Vol. 1, pp. 1-12. <https://doi.org/10.2478/amns.2022.2.0158>
- Zielińska, M. – Grębowski, K. (2015) *Computer-aided construction at designing reinforced concrete columns as per EC*. Int. J. of Applied Mechanics and Engineering, vol. 20, No. 1, pp.183-200. <https://doi.org/10.1515/ijame-2015-0013>