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# Inżynieria Bezpieczeństwa Obiektów Antropogenicznych

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## STRESS-STRAIN STATE OF THE FLEXIBLE ELEMENT WITH COMPOSITE UNREMOVABLE FORMWORK

*Stan naprężenia-odkształcenia elementu elastycznego z nieusuwalnym  
szalunkiem kompozytowym*

**Shalobyta N.N.**(Assoc. Prof.,PhD., Eng.,  
Brest State Technical University)

**Shalobyta T.P.**(Assoc. Prof.,PhD., Eng.,  
Brest State Technical University)

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### Abstract

The article deals with the work under load of a bent reinforced concrete girder element with a fixed formwork made of cement-bonded particleboard reinforced with. The main strength and deformation parameters of a multi component structure are determined, the main pre-purpose of which is to use overlap for monolithic structures with the inclusion of non-removable formwork of cement-bonded wood board in collaboration.

**Key words:** stress-strain state, flexible element with composite unremovable formwork, monolithic constructions, slab elements, void-former, moment, deflection.

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### Streszczenie

Artykuł dotyczy pracy wygiętego elementu dźwigara żelbetowego z szalunkiem stałym wykonanym z płyty cementowo-drzazgowej zbrojonej pod obciążeniem. W ramach badań określono główne parametry wytrzymałościowe i deformacyjne konstrukcji wieloskładnikowej, której głównym celem wstępnym jest zastosowanie zakładki dla konstrukcji monolitycznych z włączeniem we współpracy nieusuwalnego szalunku z płyt cementowo-drewnianych.

**Słowa kluczowe:** stan naprężenie-odkształcenie, element elastyczny z nieusuwalnym szalunkiem kompozytowym, konstrukcje monolityczne, elementy stropowe, void-former, moment, ugięcie

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### 1. Introduction

Monolithic constructions of effective constructive forms the introduction of which would, undoubtedly, reduce the cost-price of newly erected and reconstructed projects are fairly rarely come across in modern production. One of the reasons for such a state of things is connected with insufficiently developed theory of calculating and constructing of suchlike constructions. While erecting monolithic systems is practically ubiquitously employed a removable or mobile formwork which is placed on the construction site and dismantled after monolithic concrete gains the required strength. Modern technologies presuppose the application of the unremovable or left formwork which is preserved as a construction element after concrete pouring.

One of the perspective variants of the unremovable or left formwork is the gaining popularity in Europe «VST-systems» of the Austrian firm VST BUILDING TECHNOLOGIES AG [1] at the basis of the technology of which is the use, as formwork elements, of sheets of cement strand boards. Cement strand boards (CSB) is a constructive sheet material possessing a number of peculiarities of its main components – cement and wood: high durability, moisture-resistance, hard combustibility, bio-resistance, absence of toxicity, easiness of processing. They

are non-inflammable, atmosphere-resistant, not subject to the influence of insects and fungi, glued well with wood, polymers and metals, comparatively easily yielded to sawing, milling and drilling [3]. For the Republic of Belarus the CSB technology is relatively new because it gives a possibility to lower the construction cost-price, reduce its time and improve the quality of buildings.

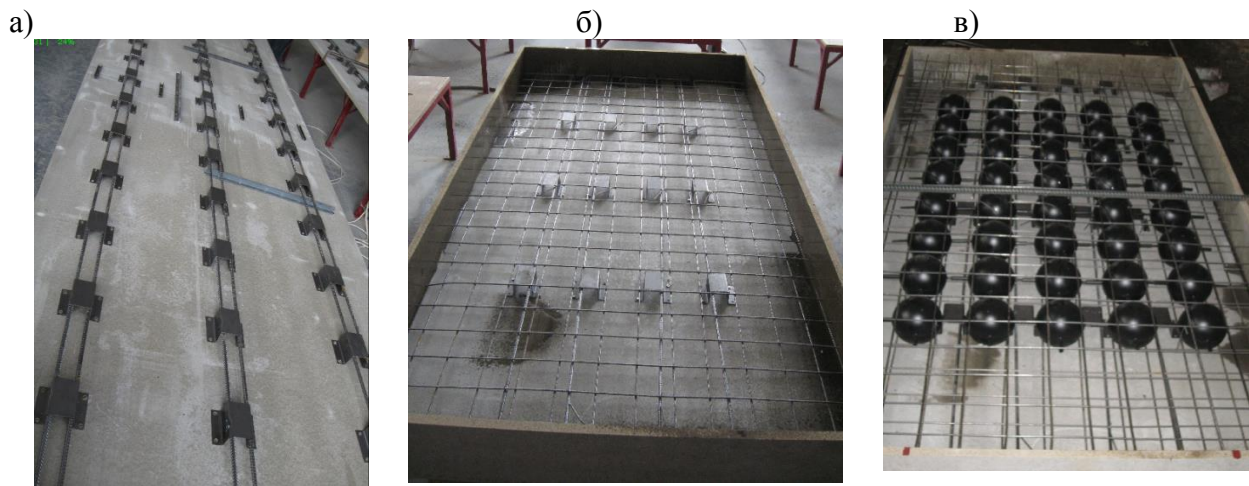
The patented system [1] is the system of unremovable formwork which consists of cement strand boards, 24 mm thick, which are joined in a factory or construction conditions into a prefabricated reinforced elements. For joining the formwork elements are used patented armature units consisting of steel cap-profiles which are located at a definite spacing and welded reinforcement bars with diameter of not less than 10 mm. Subsequently the armature units are secured on the unremovable CSB formwork with the help of steel screws. From now onwards, from separate elements the walls and floor slabs on the construction site are erected, reinforced and then poured with concrete mix, for all that a cement strand board is a unremovable formwork[1].



**Fig. 1.** The application of the VST-system of floor slabs

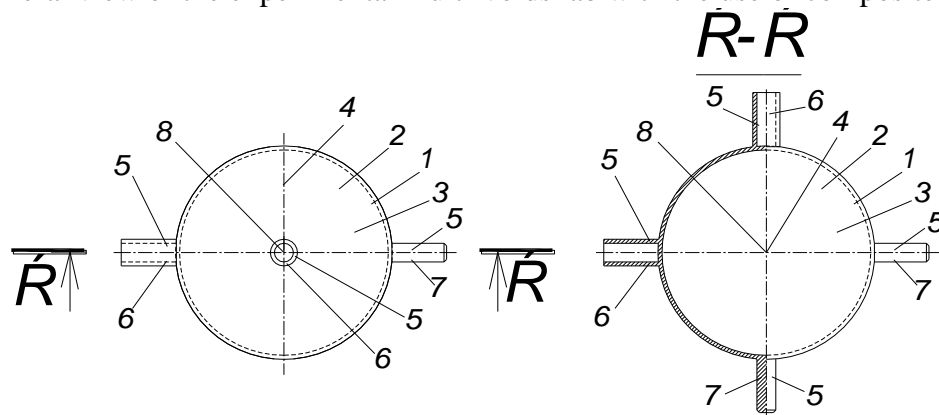
The development of own patent solutions of void-formers for beamless monolithic reinforced concrete floor slabs [12, 13, 14] allowed to introduce them into the construction of VST-system of floor slabs, the main destination of which is in reducing the materials-intensiveness of the construction (Fig. 1.). The void-formers are plastic hollow hermetic bodies of rotation (balls) of special constructive form with detents which are located outside the sphere in octagonal planes that are perpendicular to the rotation axis which goes through the centre of the plane (Fig. 3.). Diametrically opposite pairs of detents are carried into effect in the form of a pintle and a sleeve in such a way that the diameter of the pintle allows to execute its placing inside the sleeve of the near-by located void-former. The detents in length are not less than the thickness of the plate edge, which ensures the required edge resistance while checking the maximum states of the construction bearing capacity from the action of the transverse strength. It should also be pointed out that the presence of detents allows to carry out their convenient fixation to the constructive armature of the unremovable formwork and prevent their surfacing while concrete is being poured in the process of erecting a floor slab.

The advantage of the suggested solution is that there is no necessity of placing and fixing the void-formers by the piece with regard to the armature, which arises in case of void-formers in the form of tubes or light concrete staffers in the form of rectangular prism, which complicates the placement process. In the represented solution, in special workshops or at a construction site the void-formers are joined into units which significantly facilitates their mounting, reduces labour costs on their installation and securing to the elements of unremovable formwork. With all this going on, the units are made of such dimensions which will be able to ensure the possibility of their placement into the formwork.



a) working armature connected with cap-profiles; б) CSB-slab box with working armature and cap-profiles; B) a slab with the unit of void-formers reinforcing mesh

**Fig. 2.** General view of the experimental multi-voids lab with the use of composite formwork



1 – void-former; 2 – rotation body; 3 – ball; 4 – rotation axis; 5 – detents;  
6 – sleeves; 7 – pintles; 8 – rotation body centre

**Fig. 3.** General view of the void-former

The results of the conducted trials [9, 10, 11] showed that there arise a number of questions connected with both taking into account the work of the unremovable CSB-formwork simultaneously with the concrete of the construction and the constructive requirements presented during their designing. Therefore, a significant issue, while designing the given floor slabs, is the development of the methods of their calculation which take into account their real work under weight. This will allow to specify the bearing capacity of the slabs of the class under consideration which will lead to lowering costs while erecting floor slabs.

**Analysis of the experimental research of the slab elements.** The slabs were tested as a beam element according to the classical layout with the deployment of stress on the thirds of the span which gives a possibility to estimate stress-strain state (SSS) of normal sections in the zone of clear bend.

For the investigation of the work of elements with unremovable CSB-formwork were carried out experimental studies on the flexible elements with the dimensions of rectangular cross section (bxh) equal to 1250 x 200 mm, 2500 mm in length. The unremovable CSB-formwork was accepted as 24 mm thick and was placed in the extended zone of the element. The variable parameter in the trials was the percentage of the element reinforcement. The trial programme is given in table 1.

Table 1 – Short trial programme

Series	Prototype designation	Cross-section dimension	Concrete compressive strength	Reinforcement		Reinforcement percentage
				Quantity	$A_{st}, \text{cm}^2$	$\rho_l = A_s / b \cdot d, \%$
I	II-I-1 II-I-2	1250*200	54,9	8Ø8 S500 Ø4 S500spacing100	6,372	0,255
II	II-II-1 II-II-2	1250*200	54,9	8Ø10 S500 Ø5 S500spacing100	8,632	0,345
III	II-III-1 II-III-2	1250*200	58,9	8Ø12 S500 Ø5 S500spacing100	11,402	0,456

Loading of the slabs was carried out with the help of the system of hydraulic jacks set in the power frame. The load was applied in steps by 10 kH (10% of breaking load). There were made about 10 steps in changing the load before the receiving the load at which the destruction occurred. After each step in changing the load there was a pause, up to 5 minutes, till the next increase in the load. While conducting experimental research there were specified the main parameters connected with the section strength, deformativeness, formation and opening of the cracks when. The trial layout and the view of the tested constructions are shown in figures 4 and 5.

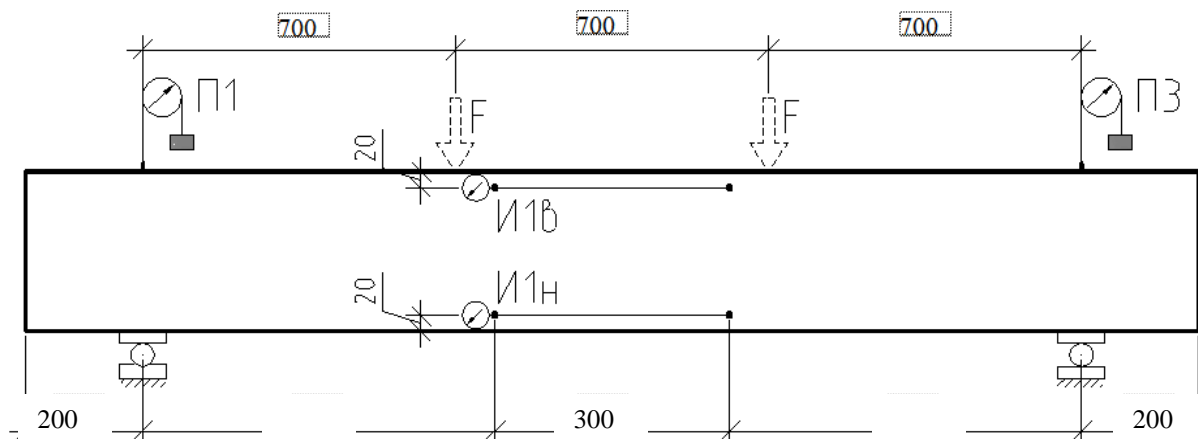


Fig. 4. Layout of slab trial



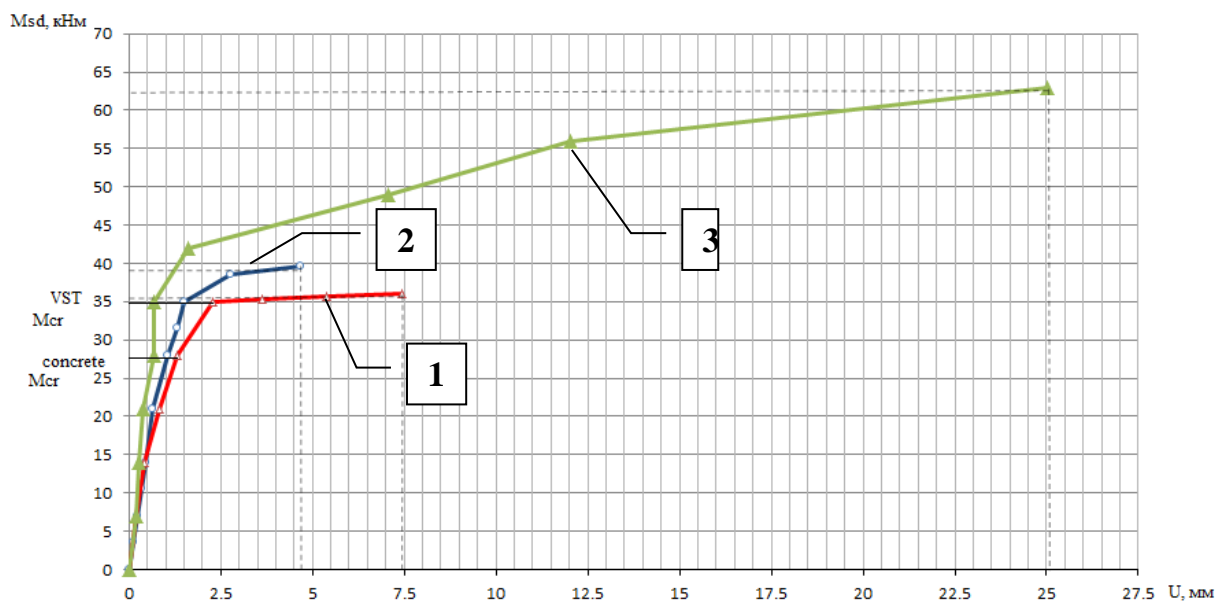
**Fig. 5.** The view of the constructions being tested

As a result of the conducted experimental research of the prototypes was determined that all the tested slabs were broken in the consequence of the exhaustion of the bearing capacity all through the normal sections.



**Fig. 6.** The view of the slabs after destruction

In prototype 1 the slab destruction occurred instantly and in a fragile way in the consequence of CSB break, quick crack opening along the section height and concrete shattering of the compressed zone. The analysis of chart 1 (Fig. 7.) proves the fragile character of the slab destruction. It's apparent that under the load corresponding to the moment of the appearance of a crack in CSB, the stresses in the steel armature reached a flow ability limit in the slab complex construction for which is characteristic a higher resistance to strain of one of the materials. In the case in point, the CSB-sheet located in the slab lower strain zone which has a value of mean resistance to strain when bended  $f_{vst,t} = 14.64 \text{ MPa}$  [5, 6, 7], which several times exceeds the concrete strain resistance  $f_{ctm} = 1.9 \text{ MPa}$ , has apparently received all the acting strain before cracks appear in it, despite the fact that cracks already appeared in the adjoining fibres. Thus by the moment of the crack formation in CSBa strain armature already had tension close to the physical flow ability limit.



1 – plate П-1; 2 – plate П-2; 3 – plate П-3;  
**Fig. 7.** The chart «moment-deflection» for plate samples

The experiment data are proved by the calculation according to which  $M_{cr}^{VST}/M_{Rdu} \approx 0.875$ . On the strength of the conducted experiment it was determined that the accepted, according to the designing norms [4], the steel armature reinforcement percentage for the complex construction concrete equal to 0.255 % does not satisfy not only the bearing capacity requirements but the operating workability requirements, too.

As the analysis of chart 2 (Fig. 7) shows the destruction of prototype 2 occurred as a result of achieving steel armature tension equal to the flowability limit with the subsequent shattering of the compressed zone concrete. For all that, attention should be paid to the fact that despite the nearly 1,5-time increase in the percentage of steel armature reinforcement compared to the first series slab, the destruction of the given slabs occurred under fairly similar values of the maximum bending moments. At the same time it is evident that the relation  $M_{cr}^{VST}/M_{Rdu} \approx 0.95$  indicates that additional increase in the armature area influenced only the general construction deformation but did not exert influence on its bearing capacity.

While analyzing the charts «moment-deflection» for the flexible elements with CSB-formwork for all the examined prototypes was experimentally proved joint work of the unremovable formwork with concrete, and at that, the character of their destruction depended on the reinforcement percentage and mechanical characteristics of the formwork.

## Conclusions

The conducted experimental research allows to make the following conclusions:

1. The carried out experimental research showed that the application of CSB as a unremovable formwork for ferroconcrete constructions is effective but needs further investigation, insomuch as in the practice of designing the systems with unremovable formwork the resistance of the CSB-slab is not considered in joint work with ferroconcrete.
2. One of the detected drawbacks of the flexible elements with CSB-formwork was that immediately after the appearance of a crack in the unremovable formwork there takes place a significant increase in the element deformation on the account of the development of a crack in the body of the ferroconcrete element which leads to the violation of the operating workability requirements in spite of the fulfillment of the bearing capacity requirements.

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