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Shear Stops Forces Distribution Analysis in Combined Floors of Multi-Storey Buildings

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Shear stops forces distribution analysis in combined floors of multi-storey buildings

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Abstract. Combined flooring is the most frequent and affordable floor disks constructive solution in steel frame buildings. Vertical load is the main load perceived by the overlap. The horizontal loads become necessary to take into account with the store's number increasing and depending on the construction area. Flexible anchors combine the work of profiled sheet (fixed formwork) and floor beams. The problem is that according to Russian standards the studs setting is governed mainly by design requirements. However, flexible anchors calculation for horizontal load showed that their forces exceed maximum permissible, so the structure cans failure.

The forces in the studs change depending on the floor slabs supporting design solution and the aspect ratio. The correction factor derived in the article allows take into account the real efforts distribution in shear stud without losses in calculation accuracy in buildings and structures design.

This issue's study will clarify the combined overlap's calculating methods and will allow using the material in the most rational way.

Keywords: combined ceilings, flexible connections, shear studs, horizontal load, shear stresses, shear rigidity.

1 Introduction

Currently, steel frames multi-story civil buildings are becoming more widespread. Steel frames may include combined beamed ceilings using profiled flooring as a fixed formwork. Calculations of combined ceilings are quite detailed and widely disclosed in the existing domestic and foreign regulatory framework. At the same time, verification calculations are mainly focused on ensuring adhesion between the worked as reinforcement profiled flooring and concrete. There is the intention that combined overlap failures after the adhesion loss from vertical loads. In foreign practice, there is also a section for calculating combined floors taking into account the horizontal loads effect on the building frame. Such loads can be attributed mainly to wind and seismic. In domestic design practice, additional shear forces in studs from horizontal loads are not taken into account in any way. Nevertheless, with a certain loads combination, the shear forces in the studs from vertical loads can be supplemented by the shear forces from horizontal loads. The latter largely depend on the buildings configuration and its features design. Therefore, in some cases, horizontal loads can have a decisive effect on the studs bearing capacity and the structure as a whole.

Two basic regulatory documents are used to calculate combined ceilings in Russia: CS 266.1325800-2016 “Steel-reinforced concrete structures. Design Rules”and Eurocode 4“ Design of steel-reinforced concrete structures ”(EN 1994-1-1-2009). When performing calculations, it is allowed to use the internal standards of manufacturing companies to facilitate and accelerate the design process. In addition, there are extensive studies on this topic developed by a group of scientists led by E. Ayrumyan. [3-5], as well as a large number of refinements and valuable for checking the accuracy of computer calculations of field experiments are given in the works of Zamaliev F.S. [6-9].

When calculating according to the Eurocode, most designers have a lot of questions regarding the necessary calculations and materials characteristics determination to the article by V. Almazov is devoted. and Harutyunyan S.N. [10]. Therefore, part of the calculations is performed on the Johnson Guide translation [11]. However, all the works mentioned above did not address the floor rigidity estimating issue during temperature exposure. This factor becomes important in unheated buildings or in buildings with large spans, this issue was considered in the article [12]. The flexible anchors nature work question, depending on floor slab geometry and its support method, is raised only in foreign sources [13-14].

Therefore, the need of steel-reinforced concrete flooring using corrugated sheets shear rigidity taking into account arises and this article covers the question.

2 Methods

2.1 Object of research

The aim of the study was to determine the horizontal loads proportion in the flexible anchors load-bearing capacity in combined floors using profiled flooring. In this connection, steel-reinforced concrete ceilings’ world design experience articles were reviewed [16, 17]. An article written by a group of scientists led by Koliou [18] was particularly interest. In the article examined buildings with compliant ceilings and rigid walls. This paper describes the characteristics affect to ductility compliance degree. Precisely flexible anchors and their flexible work was interest, so articles [13-15] were helpful in the single shear studs and their groups work under various conditions of fastening and the studs’ themselves geometry. However, in the aforementioned articles there were no clear instructions on the shear studs behaviour under dynamic and cyclic loads, which tighten the requirements for ceilings’ joints reliability. In this connection, an article [19] was found, which describes the shear studs behaviour under cyclic loads. Interest in this work was caused by a detailed description of the test results, as well as the availability of recommendations for the design of flexible anchors in the presence of dynamics.

The next step was the selection of a model in order to see the phenomena described in the aforementioned articles; therefore, typical options for civil buildings presented on design organizations sites, as well as buildings already commissioned, were studied. Among all the frames examined the parking project presented on the website of the Steel Construction Development Association aroused the interest. This building was built in 2014-2015 in Moscow on the 22, Mitiska str. The parking is designed for 1370 cars, 3 blocks 5.7 and 12.6 meter span consists, the buildings total length is 137.8 m.

This building aroused interest in the floor beams location installed in only one direction. They did not form a single contour, as can be seen from Fig. 1. Along the building at floors level there are square box-section rods, forming a single contour, together with floor beams at floor disks level.

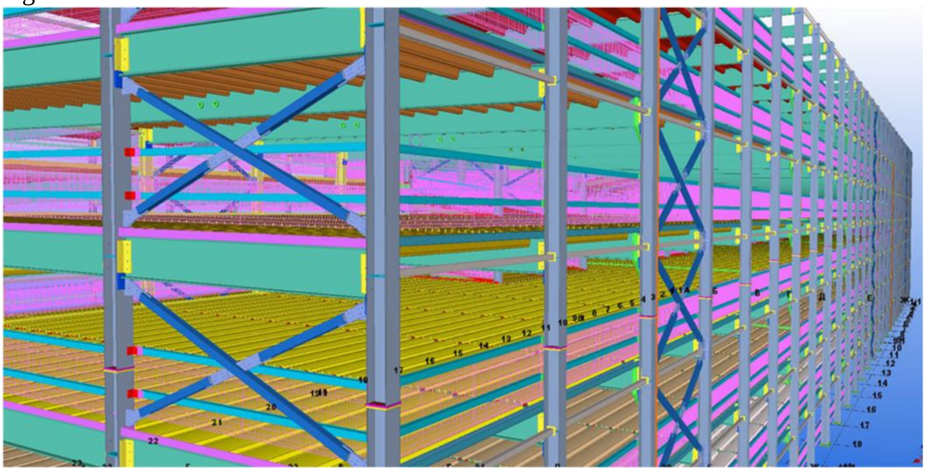

Fig.1. Steel frame constructions view of the parking in 22, Mitiska str., Moskow

2.2 Numerical studies

Before creating your own model, we studied steel-reinforced concrete structures designing nuances, their calculation and the features of setting the design scheme in software systems. Combined ceilings are more often used therefore studied in States namely the Steel Deck Institute by the specialists' team led by Luttrell that why his such ceilings design guidance was considered [20]. Among the works of domestic scientists, Tusnin V.S. [21], Tamrazyana A.G. and Filimonova E.A. [22] articles were considered. They studied sidelabs' constructions possible solutions and determine the floor slabs nature shear work.

Thus, a sample was simulated in the PC ANSYS programme complex (Fig. 2).The elements' characteristics were selected for modelling a plate's part sample with real dimensions. In this sample, all structural elements were defined by volumetric elements: concrete of class B25, shear stud "Nelson" S-245-J2-G3+C450, profiled flooring according to STO 57398459-18-2006, I-section flooring beam No. 60B2 according to GOST R 57837-2017. A 50kN load was applied. It was considered that the floor beams were rigidly fixed to the frame structures.

The next stage considered the same model, but the beam and profiled flooring elements were modelled by plates. The studs were completely removed from the model. Their presence was taken into account by changing the adhesion concrete and profiled sheet characteristics. The article by Yuhong Ling et al. [23] provides recommendations and examples of various methods for modelling shear studs, where one of the points was proposed to change the adhesion concrete and profiled flooring characteristics. In fig. 3 shows a simplified model with the volume elements by replacement plates.

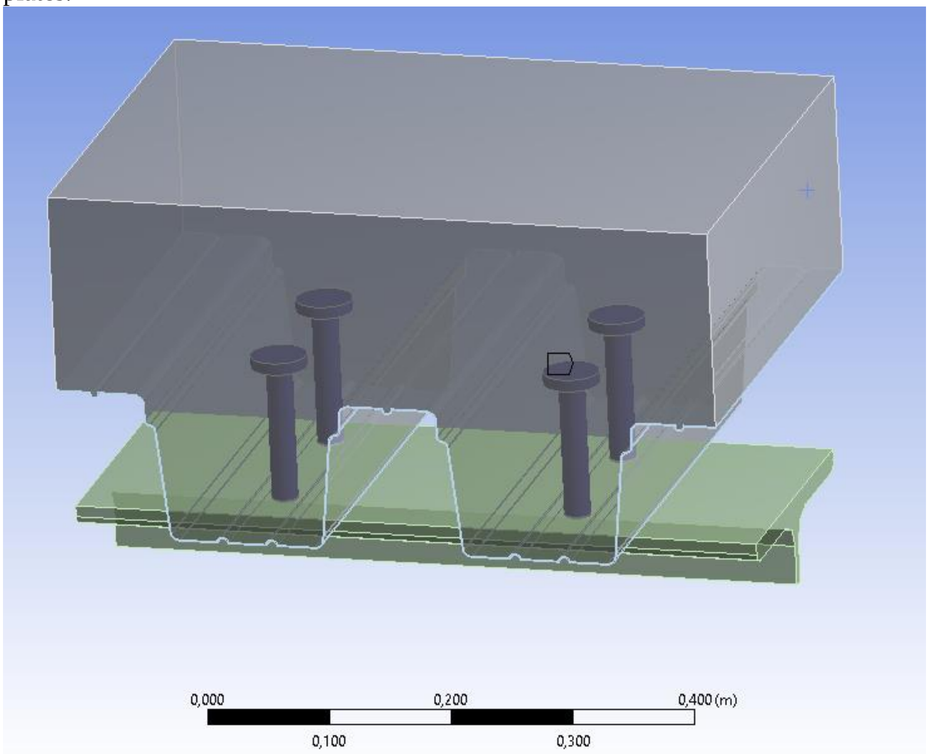

Fig. 2. The slideslab's part model designed by volume elements

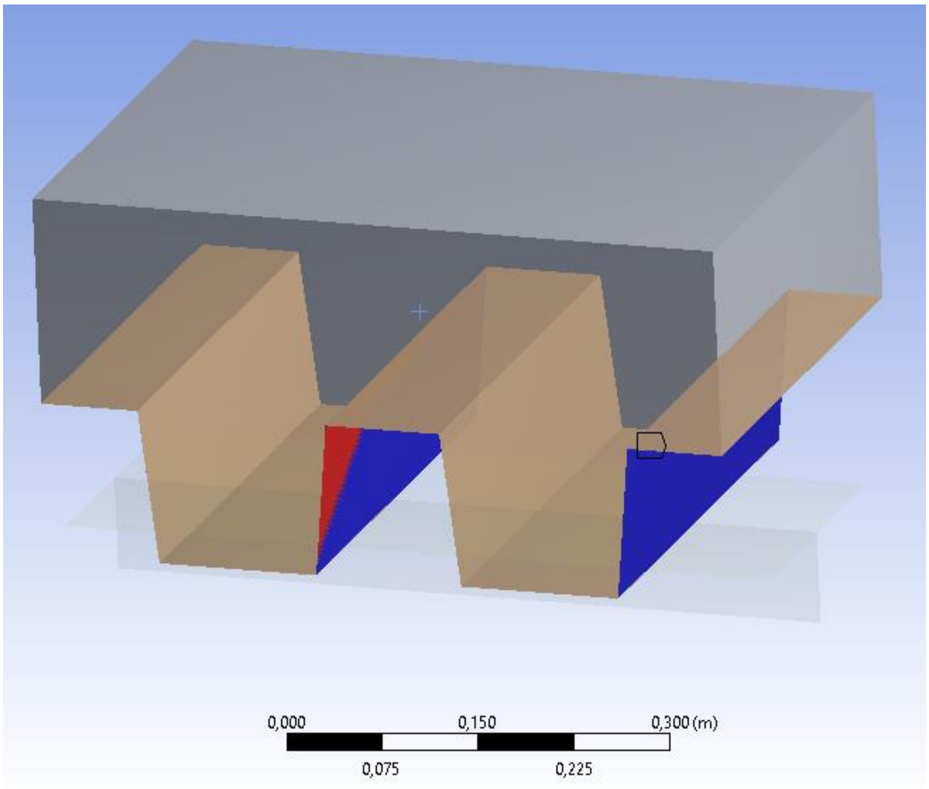

Fig. 3. The slideslab's part model designed by plate and volume elements

Due to changing the Normal Rigidity factor in the sample with plates obtained similar deformations with the volume elements sample. The coefficient taking into account the contact area was changed from 1 (contact over the whole profiled sheet and floor beam surface) to 0.0034 (the area equivalents to studs area on the floor beam).

After that, life-size samples were compiled simulating a floor supported part on adjacent floor beams. Earlier, the most common aspect slabs ratios were analysed using completed multi-story building projects examples. Full-size slabs with an aspect ratio of 1:1, 1:2 and 2:3, that is 3x6, 6x6, 6x9, were considered. Sample with 2:3 aspect ratio is demonstrated on the Fig. 4.

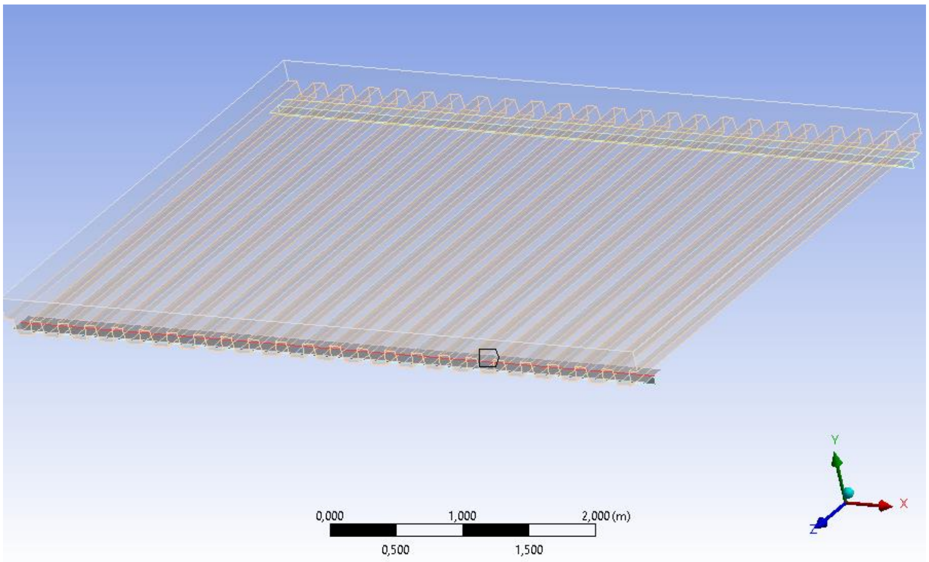

Fig. 4. Full-size sample view (2:3 aspect ratio)

3 Results and discussion

As a numerical experiments result the displacements values in the sideslabs samples with different aspect ratios were obtained. The results are presented in Fig. 5. Knowing the applied load and displacements, we can obtain the rigidity value for plates with different aspect ratios.

However, this characteristic cannot be applied when designing buildings and constructing on the PC Lira-Sapr, and this is the most common program in design organizations. The problem is that a change in the rigidity characteristics will lead to incorrect results when calculated for deformability. Therefore, it was decided to change the Poisson's ratio, which does not affect the accuracy of the calculations.

Structural rigidity is determined by the loads ratio to displacements

$$G' = \frac{F}{\Delta} \tag{1}$$

where G' - shear rigidity,
F - applied load
Δ - the displacement.

In addition, the elastic modulus dependence and Poisson's ratio on rigidity is known from the materials resistance course

$$G = \frac{E}{2(1+\mu)} = \frac{\tau}{\gamma} = \frac{\tau \cdot l}{\Delta} \tag{2}$$

$$G = \frac{G' \cdot l}{t \cdot B} \tag{2'}$$

where E - the concrete elasticity modulus,
τ - tangential stresses,
μ - the Poisson's ratio,
γ - the rotation angle,
B - the disk's width (by corrugated profiled flooring),
L – plate's length (along the corrugation)

By transformations we get the dependence

$$\mu = \frac{E \cdot t \cdot B}{2 \cdot G' \cdot L} - 1 \tag{3}$$

This expression can be converted taking into account the fact that the displacements depend on the aspect ratio. Therefore, shear rigidity for different plate ratios can be reduced to the reference (with a 1:1 aspect ratio) by multiplying by a factor takes into account the plate's length to width ratio. Thus, formula (3) can be transformed to

$$\mu = \frac{E \cdot t}{2 \cdot G'} - 1 \tag{3'}$$

According to the formula (3'), knowing the elastic modulus and the expected load, as well as focusing on the reference samples deformability, we can obtain the reduced Poisson's ratio.

The basic samples deformability depends on the disks size that is celling beam aspect ratio, on the profiled flooring corrugations size and the floor itself height. Here within variations with cell sizes were considered, other aspects were not taken to account. As a result, the dependencies were obtained, which are presented in graph 5.

Fig. 5. Dependence of displacements on the cell size of the beam cell

The displacements obtained in the PC ANSYS are comparable with a similar model simulated in the PC Lira-Sapr. All elements were modelled with the same characteristics as in PC ANSYS. In the second sample, in order to verify the correctness of our assumption, the coefficient obtained by the above formula (3') was introduced in the column for specifying the Poisson coefficient.

In fig. 6 shows the type of sample modelled in the PC Lira-Sapr, in Fig. 7 shows models from different software systems after calculation.

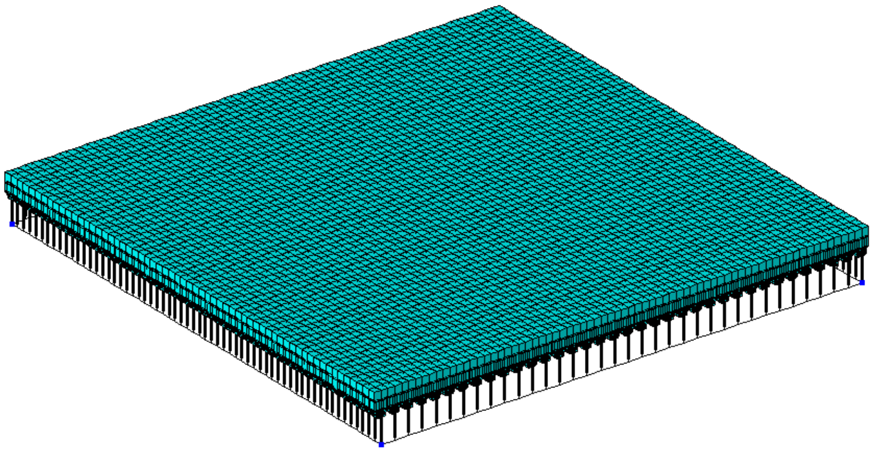

Fig. 6. General view of the sample in the PC Lira-Sapr

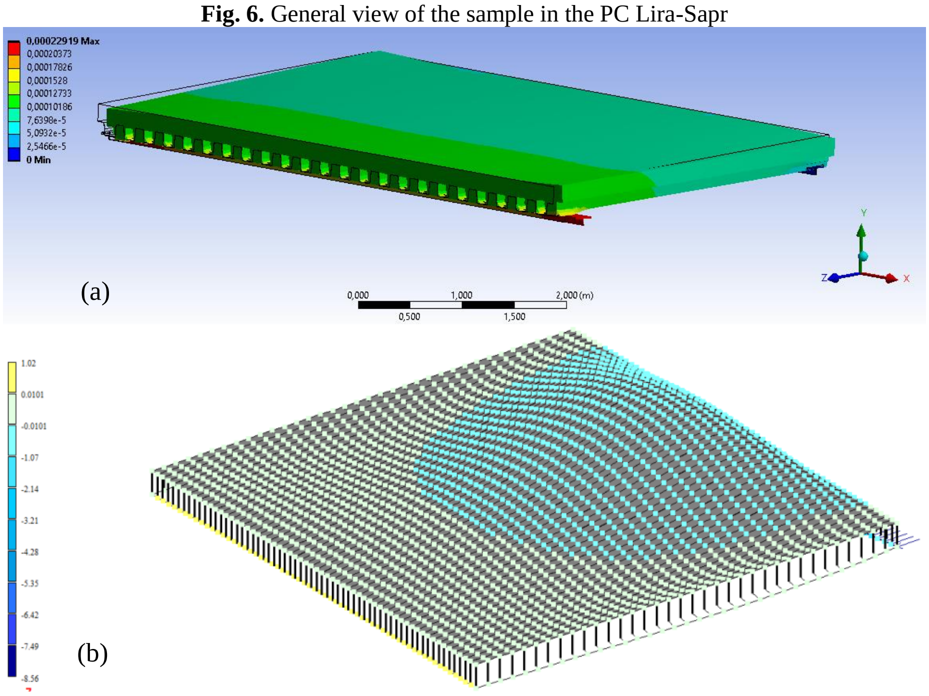

Fig. 7. Movements in samples modelled in different software systems (a) PC ANSYS, (b) PC Lira-Sapr

As can be seen from fig. 7 deformations obtained using the refined Poisson's ratio give a result close to the result obtained in the reference sample from the PC ANSYS.

To compare the correction effectiveness, the same sample was considered, but using the Poisson's ratio for reinforced concrete structures equal to 0.2 (Figs. 8a and 8b).

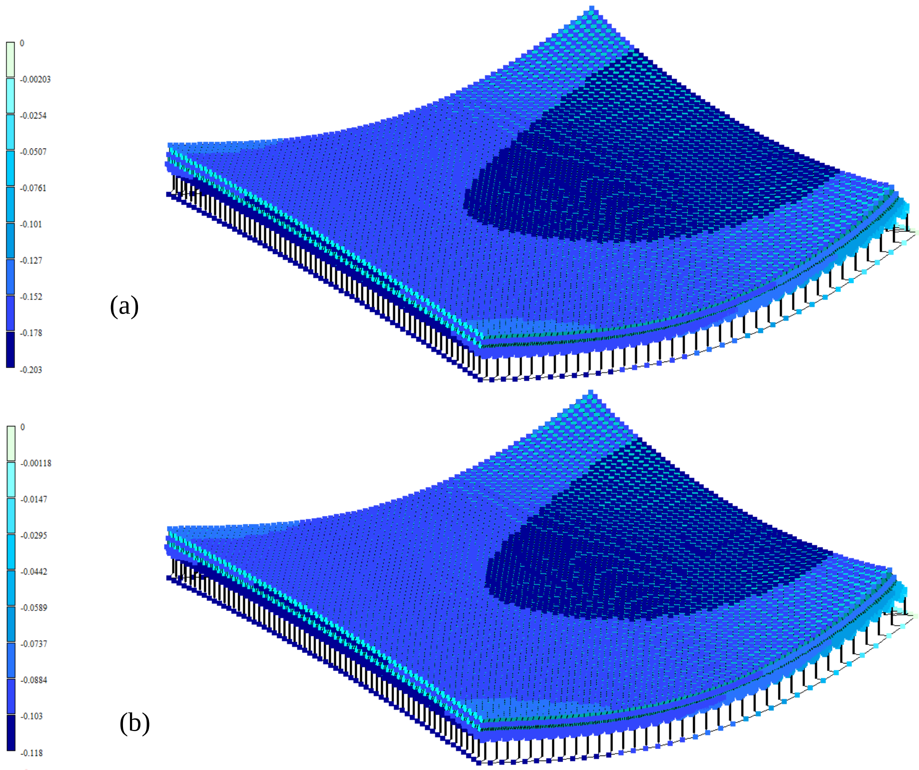

Fig. 8. Displacements comparison in samples: (a) when using the reduced Poisson's ratio, (b) when using the Poisson's ratio for reinforced concrete

Comparing fig. 8a and fig. 8b, we see the displacement values are 32% less. The values obtained for testing for deformability do not correspond to reality.

4 Conclusions

Summarize all the points noted above. When designing steel-reinforced concrete structures using profiled flooring, the Code Specification and the Eurocode are used, and to simplify the design, there are many anchors organizations-manufacturers standards based on Eurocode calculations adjusted for anchor design itself. The domestic regulatory framework considers efforts from shear, however, taking into account horizontal loads and floor disks deformations issue is only passingly mentioned. Therefore, I would like to note the importance of studying the effect of horizontal loads on the operation of flexible anchors.

Abroad, this issue has been studied in sufficient detail, therefore, when determining the bearing capacity in the Eurocode, the overlap disk itself shear rigidity is taken into account, then stud's location, profile type, anchor design, etc.

Flexible anchors nature work issue depending on the overlapping disks geometry and its support method is also raised only in foreign sources. Depending on the aspect ratio, the displacement values in the overlapping disks change. This fact was demonstrated when different sizes full-sized samples displacement values were determined.

When designing steel-reinforced concrete floors using profiled flooring according to domestic standards, the floor disks shear rigidity is not taken into account. Whereupon it was proposed to introduce an updated the Poisson's ratio value, which would make it possible to refine the calculation without losing its accuracy in deformability.

In conclusion, I would like to summary the conclusions made as a floor disks shear rigidity horizontal effect of loads studying result:

1. The regulatory literature study, as well as studs manufacturing organizations' standards showed a shear forces action calculating unified method absence.

2. The sideslabs shear rigidity in buildings steel frames calculations are taken into account only in foreign standards. Despite the Russian scientists' research availability, this fact is not taken into account in the regulatory literature.

3. When calculating not the reinforced concrete actual but its adjusted taking into account the profiled sheet with flooring beams mobility Poisson's ratio value proposed to use.

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