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# Deformability of bends continuous three-span preliminary self-stressed steel concrete slabs

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Continuous steel reinforced concrete structures with the use of monolithic reinforced concrete slab as a compressed part of the section and steel profile part as stretched are widely used in civil building. However, the continuous monolithic reinforced concrete slab is uneven due strength to the different values of the support and span moments of the extreme and middle spans. The conducted experimental researches confirm expediency of the development of a two-stage method of manufacturing (concreting) of continuous multi-span monolithic reinforced concrete slab on fixed formwork (the first stage - concreting of the middle span; the second stage - concreting of the extreme spans) in order to balance the level of deflections in all spans slab. The proposed method allows to effectively use the load-bearing capacity of the continuous slab's reinforcement with the same support installation step of the steel reinforced concrete floor.

**Keywords:** civil building, experimental research, steel concrete continuous slab, two-stage method of concreting.

# Деформативність згинаних нерозрізних трипролітних самонапружених сталезалізобетонних плит

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Багатопрогінні згинані сталезалізобетонні конструкції із застосуванням монолітної залізобетонної плити у якості стиснутої частини перерізу та сталевої профільної частини у якості розтягнутої добре зарекомендували себе за рахунок високої технологічності влаштування та значної експлуатаційної несучої здатності як в цивільному, так і в промисловому будівництві. Проте нерозрізна монолітна залізобетонна плита, що влаштована по сталевих балках розміщених з однаковим кроком, під дією експлуатаційного навантаження при однаковому армуванні крайніх і середніх прольотів має не однаковий рівень напружень за рахунок різних значень опорних та прольотних моментів крайніх і середніх прольотів. Зменшення крайніх прольотів шляхом змінного кроку встановлення сталевих балок є незручним із технологічної точки зору, так як вимагає додаткових індивідуальних конструктивних рішень влаштування нерегулярних опор під ці балки. Для врівноваження рівня використання несучої здатності монолітної плити нерозрізних багатопрогінних сталебетонних плит запропонована двоетапна методика їх виготовлення (бетонування). Суть цієї методики бетонування полягає у створенні попередніх самонапружень (напружень, протилежних тим, що виникатимуть у процесі експлуатації) структурних частин конструкції виключно від їх власної ваги та технології виготовлення без застосування інших заходів попереднього напруження (механічного, електротермічного чи електротермомеханічного). Під час першої черги виготовлення плити виконується бетонування середнього прольоту в ході якого від власної ваги бетону створюються попередні самонапруження сталевої частини перерізу крайніх прольотів (вигин вверх сталевої частини протилежно експлуатаційному). Після набору бетоном першої черги бетонування міцності, виконується друга черга бетонуванні крайніх прольотів в ході чого створюються попередні самонапруження бетонної частини перерізу виготовленого за першим етапом середнього прольоту (вигин вверх бетонної частини). Проведені експериментальні дослідження двох зразків нерозрізних трипрогінних сталебетонних плит, виготовлених за запропонованою двоетапною методикою, підтвердили, що за рахунок змінної в процесі виготовлення жорсткості перерізів середнього та крайніх прольотів плити можливо врівноважувати рівень одночасного вичерпування несучої здатності плити у всіх прольотах

**Ключові слова:** двоетапний метод бетонування, експериментальні дослідження, сталебетонна нерозрізна плита, цивільне будівництво

## Introduction

Bent steel reinforced concrete structures consist of steel load-bearing beams, which work mainly in tension, and a concrete shelf, which works in compression and at the same time performs the functions of a rigid disk and a solid plate. These constructions are widely used in civil and industrial buildings [1]. To increase the size of the spans and reduce the cross section of the floor slabs, the latter performs a continuous static-indeterminate multi-run scheme. Also to reduce the cross-sectional height of the steel beam, it is combined for joint work with the concrete shelf with the help of special design solutions. Combining steel and concrete cross-sectional parts of the structure into joint work increases the overall load-bearing capacity and reliability of the structure [2-3].

Thanks to a specially structure or technology for the manufacture of bent steel reinforced concrete structures, scientists achieve in them the redistribution of stresses between their structural parts and the self-stress of individual elements from their own weight or mounting technology [4]. Thus, preliminary self-stresses are created, opposite to those that arise during the operation of structural parts of steel reinforced concrete structures.

## Review of the research sources and publications

Preliminary stresses in steel concrete structures can be created by the following measures: use of stress cement for preparation of concrete mortar [5], provision of design measures for additional compaction of fresh concrete mortar (centrifugation in individual tubular concrete elements of spatial steel concrete structures) [6], or for preliminary reinforcement (sprungs) [7-8], changes the free-body diagrams of the transverse frame [9-10], changes in the geometric characteristics of the section or the design scheme of the elements in the manufacturing process, specially developed step-by-step technology for the manufacture of structures [11], etc.

High-tech and high load-bearing capacity are distinguished by reinforced concrete planar structures with the use of profiled decking as a fixed formwork and additional reinforcement of the slab [12-13].

## Definition of unsolved aspects of the problem

Continuous monolithic reinforced concrete slab, arranged on steel beams placed with the same pitch, under the action of operating load with the same reinforcement of the extreme and middle spans has not the same stress level due to different values of reference and span moments of the extreme and middle spans. Reduction of extreme spans by a variable step of installation of steel beams is inconvenient from the technological point of view as it demands additional individual constructive decisions of the device of irregular support under these beams.

## Problem statement

The purpose of this work is to develop and experimental study of a special method of concreting two stages of continuous three-span monolithic slab of reinforced concrete structure, which will create a prestress opposite to that which will occur during operation, structural parts of the structure solely from their own weight and manufacturing technology without other mechanical, electrothermal or electro thermomechanical pre-stressing measures.

## Research methods

A set of complementary methods of theoretical and experimental research was used to solve the defined tasks and achieve the set goal:

– methods of system and comparative analysis in the development of the prototypes design of reinforced concrete slabs;

– experimental methods for studying the stress-strain state and load-bearing capacity in tests of preliminary self-stressed reinforced concrete slabs;

– methods of mathematical statistics in the analysis of the experimental studies results of preliminary self-stressed reinforced concrete slabs.

## Basic material and results

To optimize and balance the level of the load-bearing capacity of the monolithic slab in steel reinforced concrete bent structures, it is proposed to use a two-stage method of installing a monolithic slab in the reinforced concrete floor.

During the first stage of concreting (see fig. 1, a), a monolithic concrete slab is arranged through the span. Usually, first of all, it is necessary to concrete medium spans as during operational loading they have a greater margin of bearing capacity (see fig. 1, c). The grips' width in the monolithic plate arrangement is adjusted according to the location of zero bending moments' points on the diagram of internal forces along the beam's length. It should be noted that the options for concreting grippers allow making these supports at the time of the second stage of concreting more rigid or hinged (so-called "imaginary hinges" are created). At this stage, the steel part of the section (steel beams or profiled sheet) in the concreting areas from the weight of freshly laid mortar bends down and thus causes other parts of the section steel part in the "free" spans to bend up.

After the concrete gains the design strength of the first stage, perform concreting of the floor and other parts. At this stage (see fig. 1, b), the concreting areas are bent downwards due to the weight of freshly laid concrete, thus forcing the sections of the concreting first stage (already reinforced concrete section) to bend upwards. At this stage, the deflections values in adjacent spans can be adjusted by steel and reinforced concrete sections' stiffness, as well as the supports sections' stiffness.

*The expected resource-saving result of the developed monolithic slab installation method*: it is possible to create preliminary stresses opposite to the operating stresses in the steel part of the floor section, located in the spans of the concreting second stage, and the monolithic reinforced concrete slab of the concreting first stage.

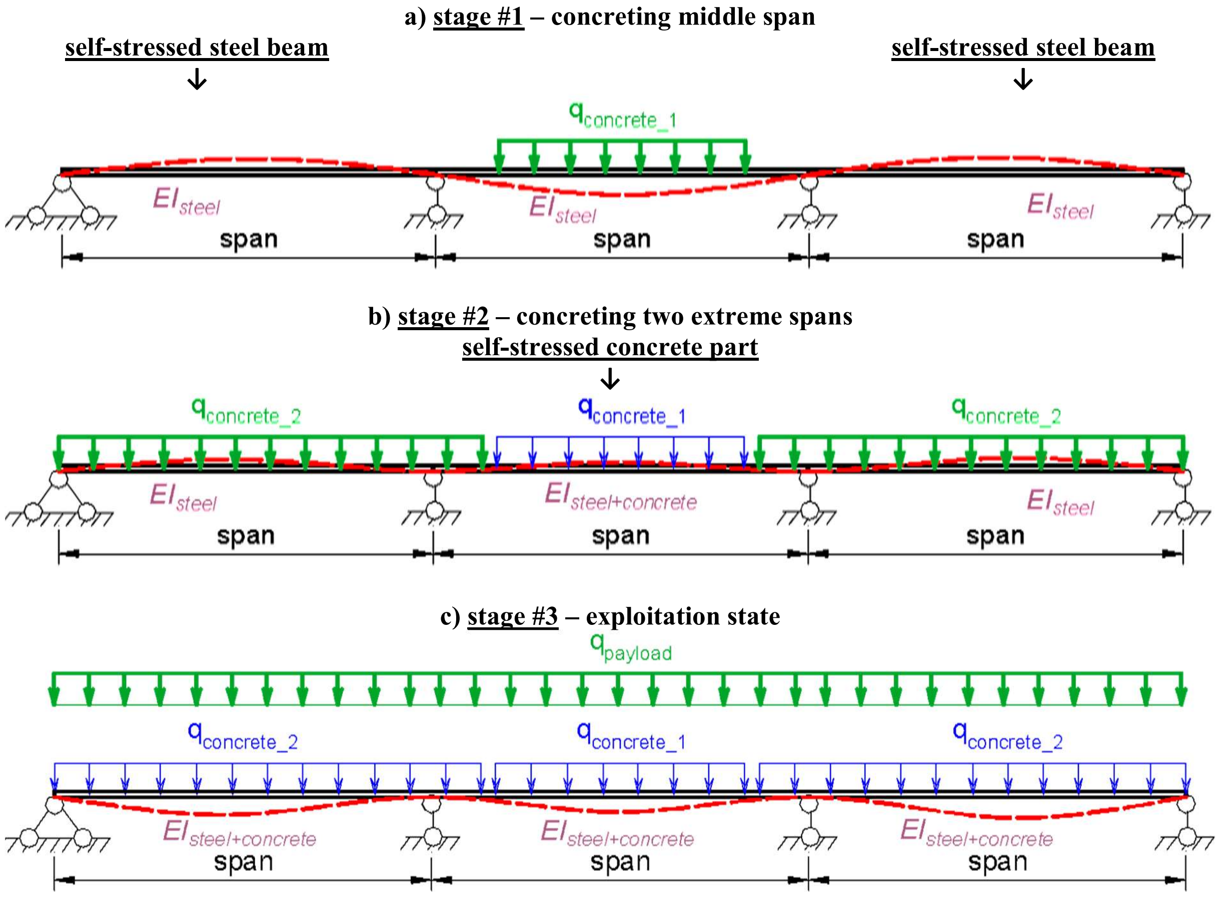


**Figure 1 ─ The stages of the manufacturing preliminary self-stressed steel concrete slab**

For experimental research of the offered technique of the monolithic plate installation, two samples of reinforced concrete continuous slabs were made on non-removable formwork from profiled steel sheeting, arranged according to a three-span scheme. Three spans lengths are equal: 1900-1900-1900 mm. Two test samples were made and tested in two stages. First, the middle span was concreted, and after the concrete strength of this design set, the extreme spans were concreted. The two samples differed in the grippers' width at the two concreting stages, as shown in Fig. 2-3.

The first experimental sample steel reinforced concrete slab is marked 1,7-2,3-1,7 CRCS 0,53×6,0 (see fig 2). For the first sample, the length of the section of the concreting first stage was equal to 2300 mm (see fig 2, b). This length comes out on 1/10 of the span outside the middle supports to the extreme spans. Accordingly, the length of the concreting second stage was 1700 mm (see fig 2, c). For this sample at the time of the concreting second stage, the middle supports were more rigid compared to the stiffness of the span parts of the outer spans' slab. That is the middle supports were relatively rigid.

The second experimental sample steel reinforced concrete slab is marked 2,1-1,5-2,1 CRCS 0,53×6,0 (see fig 3). For the second sample, the length of the section of the concreting first stage was equal to 1500 mm (see fig 3, b). This length comes in on 1/10 of the span to the middle span. Accordingly, the length of the concreting second stage was 2100 mm (see fig 3, c). For this sample at the time of the concreting second stage, the middle supports had the same stiffness as the stiffness of the span parts of the outer spans' plate. That is a "nominal hinge" was artificially created on the middle supports.

The overall size of the samples in the plan was 6,0×0,53 m. The external fixed formwork was profiled steel sheeting type K35-0,5 (here 35 is the height of the profiled steel sheeting in mm; 0.5 is the thickness of this profiled steel sheeting in mm). The height of the concrete shelf above the upper corrugation of the profiled flooring was 35 mm. Thus, the total height of plates was equal to 70 mm.

Reinforcement of the monolithic slab is made of rods with a diameter of 4 mm in the stretched zone of concrete in each wave of the profiled flooring (see Fig. 4, a). The yield strength of this rods steel equals 1300 MPa. For joint work of the profiled steel sheeting and a concrete slab used vertical anchors with a diameter of 4 mm and a length of 60 mm (see Fig. 3, a-b), installed in each wave of the profiled steel sheeting with a step of 100… 200 mm (see Fig. 4, b). The top of the adjacent waves' anchors was connected in the transverse direction by rods with a diameter of 4 mm and length of 500 mm.

**First experimental sample 1,7-2,3-1,7 CRCS 0,53×6,0**

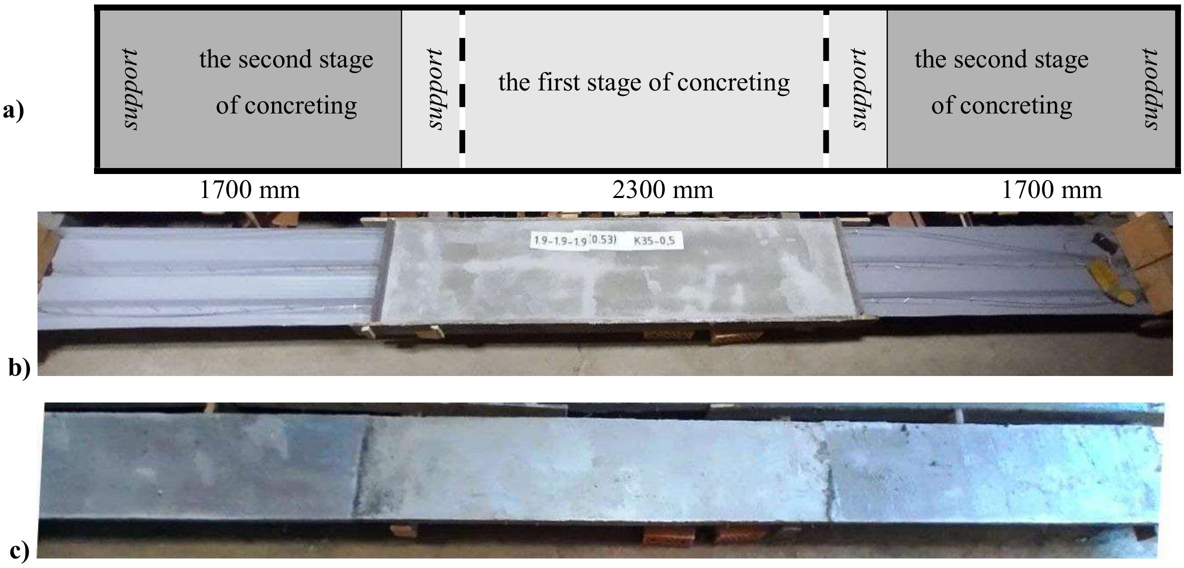


**Figure 2 – First experimental sample of steel reinforced concrete three-span continuous slab on a non-removable formwork from a profiled steel sheeting:**
a) scheme of grippers concreting samples; b) view of the sample after the first stage of concreting; c) view of the sample after the second stage of concreting

**Second experimental sample 2,1-1,5-2,1 CRCS 0,53×6,0**

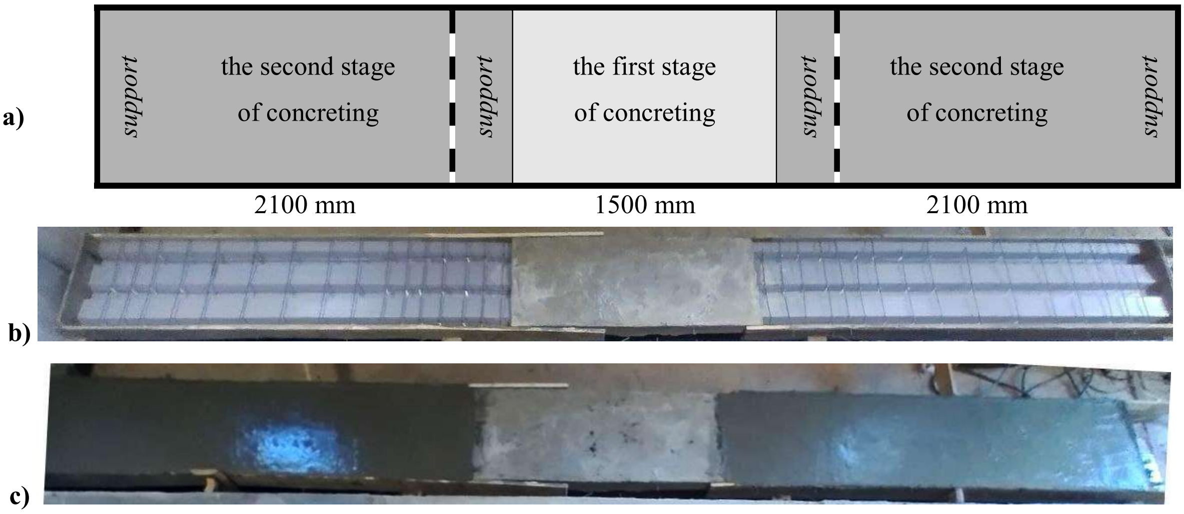


**Figure 3 – First experimental sample of steel reinforced concrete three-span continuous slab on a non-removable formwork from a profiled steel sheeting:**
a) scheme of grippers concreting samples; b) view of the sample after the first stage of concreting; c) view of the sample after the second stage of concreting

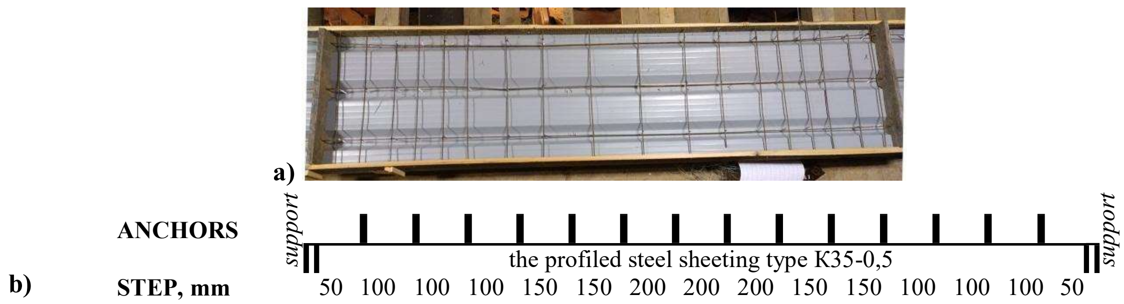


**Figure 4 – Reinforcement of one monolithic slab span:**
a) general view; b) the step of installing anchors in the lower wave of the profiled steel sheeting

Measuring instruments during the research were installed symmetrically, taking into account the possibility of duplication of different instruments readings at characteristic points, in areas with the most expected values of deformation, or areas of possible destruction. When the load reached 80% of the limit, devices that could be damaged were removed from the sample.

To measure the vertical deflections of the profiled steel sheeting during concreting from the own weight of freshly laid concrete mortar and during the experimental load, clock-type indicators IC-10 were used. Division price of indicators IC-10 equal 0.01 mm. Limit of displacement measurements of indicators IC-10 equal 10 mm. Figure 5 shows the layout of the indicators along the length of the samples.

Experimental samples loading of reinforced concrete slabs was carried out at the age of concrete for more than 28 days. Prior to the tests, the readiness of the test rig was tested: the correct position of the test structure, test loads of the structure check the correctness of the installation of devices and their ability to measure deformations, ease of loading structures, and ease of reading on measuring instruments, consistency of test crew members.

The loading was performed by artificial small-sized loads – ceramic hollow bricks (see Fig. 6). To determine the weight of the brick, a selective weighing was performed: 5 bricks out of each 50 bricks used (i.e. approximately 1/10 of the total number of bricks used for loading were weighed).

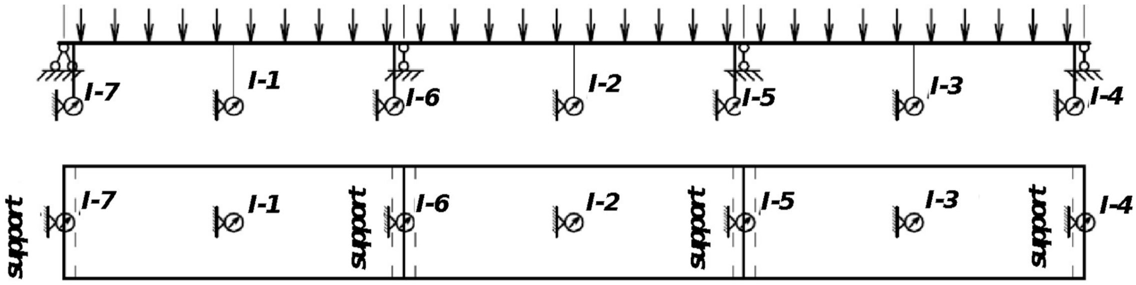


**Figure 5 – Scheme of installation of clock-type indicators IC-10**

**Figure 6 – General view of steel reinforced concrete slab during loading with bricks**

As a result of experimental studies of two samples of steel reinforced concrete slabs, a significant amount of information on their deformability and strength under different schemes of their loading is presented. The following are only the most characteristic results for each sample with a uniform length of loading.

According to the results of previously conducted separate studies of physical and mechanical characteristics of the materials used, it is established that the materials (steel and concrete) adopted for the manufacture of test samples have physical and mechanical properties characteristic of materials used in building design. The variability of concrete strength according to the results of tests of standard cubes, depending on the design class and group of samples was 8.05-21.4%; variability of steel strength was 2.7-4.7%.

Experimental studies of samples of steel reinforced concrete slabs were delayed in time, which is associated with the time of a concrete set of monolithic reinforced concrete slabs of design strength. Manufacturing, namely concreting of samples of reinforced concrete slabs, was performed in two stages (see fig. 2-3). Therefore, the total production time of samples of steel reinforced concrete slabs was about two months. In the manufacturing process at each stage of concreting were measured deflections in the characteristic cross sections of the sample by weight of freshly laid concrete mixture (see Fig. 5). Below is an analysis of the change in deflections along the length of the sample during the two stages of manufacture and the actual payload.

When loading only the profiled steel sheeting type К35-0,5 brick, deflections of the extreme spans of the plate were 3.8 times less than the deflections in the middle span.

For sample №1 with concreted middle supports in the first stage of production, the weight of the concrete mortar of the second stage (concreting of the extreme spans) did not affect the deflections of the middle span (see Fig 7). However, during the payload of this sample, the deflections were leveled in all three spans.

For sample №2 with non-concreted middle supports at the first stage of production, the weight of the concrete solution of the second stage (concreting of the extreme spans) equalized the deflections in all three spans (see Fig. 8). However, during the payload of this sample, the deflections of the extreme spans were 1.75 times greater than the deflections of the middle span.

Figures 7 and 8 show graphs of maximum deflections along the length of samples of steel reinforced concrete slabs at the end of the two stages of concreting and at maximum load with a small load – hollow ceramic brick.

As can be seen from these graphs of deflection changes, the arrangement of concreting of the first stage outside the middle supports allows to regulate the development of deflections in the extreme and middle spans and as a result, balances their values in order to simultaneously exhaust their load-bearing capacity. Due to the two-stage method of manufacturing steel reinforced concrete slabs, it is possible to change the stiffness of the sections in the manufacturing process and thus achieve optimal deflections along the length of the continuous structure.

The destruction of steel reinforced concrete slabs occurred suddenly as a result of cracks in the upper zone of concrete on the middle supports, in the area of maximum bending moment in the stretched area in the upper section fibers.

Thus, the used test method and the adopted measuring instruments and schemes of their placement allowed to obtain the necessary objective experimental data on the development of deformations and the nature of the destruction of the studied samples.

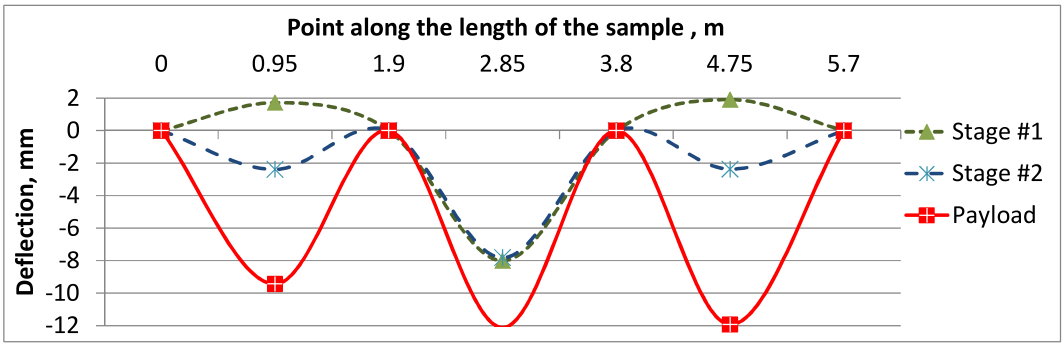


**Figure 7 – Change of deflections along the length of the first sample <u>1,7-2,3-1,7 CRCS 0,53×6,0</u> at the end of two stages of concreting and at maximum payload**

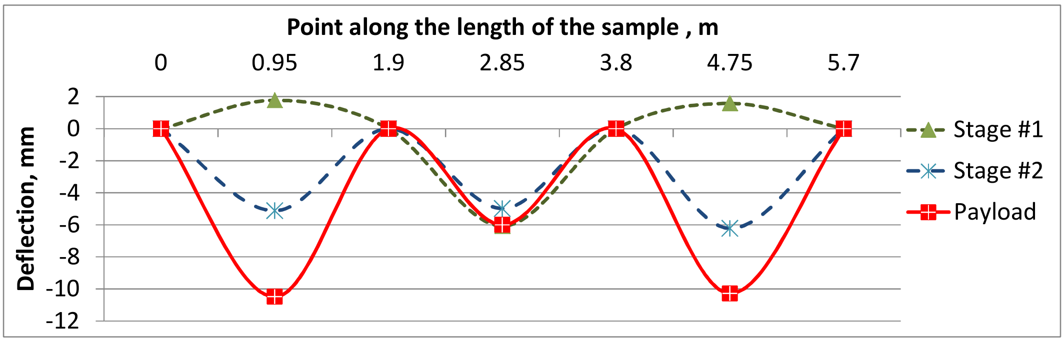


**Figure 8 – Change of deflections along the length of the second sample <u>2,1-1,5-2,1 CRCS 0,53×6,0</u> at the end of two stages of concreting and at maximum payload**

**Conclusions**

According to the results of tests of samples of reinforced concrete slabs to study the effect of the two-stage method of concreting monolithic slabs of reinforced concrete bent structures on the balance of the level of use of its load-bearing capacity, the following is:

– developed a two-stage method of concreting of continuous multi-span monolithic reinforced concrete slab on fixed formwork (the first stage – concreting of middle span; the second stage – concreting of extreme spans) allows to adjust deflections to balance the level of depletion in all bearing capacity of the slab;

– installation of concreting of the first stage (concreting of the middle span of the slab) outside the middle supports, allows to regulate the development of deflections in the extreme and middle spans by changing the stiffness of the cross section on the supports;

– the proposed method of uniform use of the bearing capacity of three spans can reduce deflections or increase the payload by 35%.

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