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Anti-Seismic Bracing in a Hollow-Core Slab of Formwork-Free Shaping for The Possibility of Creating a Rigid Disk in a Building Floor Slab

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Abstract. Building codes and regulations for construction in seismic regions of many countries (including Uzbekistan) require that the floors slabs and elements of a building should possess resistance to seismic impacts, have such functions that not only distribute seismic load between the supporting elements of the building (walls, crossbars and frame columns), but also ensure the spatial operation of the building as a result of reliable bracing of these elements. Therefore, floor slabs made of reinforced concrete prefabricated elements must present rigid horizontal diaphragms (disks) that uniformly distribute seismic loads between load-bearing structures. To fulfill the above requirements, the building standards of Uzbekistan KMK 2.01.03-96 "Construction in seismic areas" oblige designers to provide the strength and rigidity of floors slabs of buildings (structures) by installation the anti-seismic bracings in inter-slab joints between the side surfaces of adjacent slabs; between the end supporting sections of slabs and the frame elements or the anti-seismic belts of stone buildings. The same standards require the presence of free lengths of reinforcement bars or concrete inserts at the ends of slabs for connecting floor slabs with each other and with an anti-seismic belt (or a framing beam); these requirements apply to the production of floor slabs using the aggregate-flow technology. An installation of bracing elements for hollow-core slabs of formwork-free shaping with adjacent structures is not provided since the slabs of a set length are fabricated on a production line by cutting a molded monolithic tape on the line. In this regard, hollow-core slabs of formwork-free shaping must have anti-seismic joint units that provide the bearing capacity of building structures of various systems at the stages of their life cycle. Typical solutions of such units for hollow-core slabs of formwork-free shaping have not been developed. An anchor node with a unit in the void at the end section of the slab has been developed for the anti-seismic bracing of a hollow-core floor slab of formwork-free shaping with adjacent building structures (through a seismic belt or a framing beam).

For anti-seismic bracing in inter-slab joints between the lateral surfaces of adjacent floor slabs, a constructive solution is proposed for the cross section of a hollow-core slab of formwork-free shaping with a widened lower flange relative to the upper flange to install a reinforced concrete framing beam in the inter-slab joints. This creates a rigid disk in the building floors. Tests for pulling out anchor rods from nodes arranged in voids at the end sections of a hollow-core slab of formwork-free shaping assessed the strength and serviceability of the proposed antiseismic coupling units.

The pulling out of the anchor rods in all tested units occurred before the loss of cohesive strength in the contact zone "concrete of the body of anchor unit - concrete of the slab". The use of hollow-core slabs of formwork-free shaping with a widened lower flange relative to the upper flange greatly simplifies the installation of reinforced concrete framing beams in the inter-slab joints of buildings. A useful model was patented in the Intellectual Property Agency of the Republic of Uzbekistan; a constructive solution was proposed for a hollow-core slab of formwork-free shaping with a widened lower flange relative to the upper flange, application number FAP20180174 with priority date 11/08/2018. The proposed solutions for the anti-seismic ties of a hollow-core slab of formwork-free shaping with a building structure meet the requirements of the building codes of Uzbekistan KMK 2.01.03-96 "Construction in seismic areas" for transforming a floor slab made from prefabricated plates into a continuous beam slab to create a rigid horizontal diaphragm. The arrangement of the proposed anti-seismic connecting units in a hollow-core slab of formwork-free shaping does not change the manufacturing technology of this type of slabs, and allows the creation of a wide range of products for buildings and structures with various architectural, planning and structural solutions that increase the possibilities of housing, civil and industrial construction in seismic areas.

Keywords: hollow-core slab, formwork-free shaping, anti-seismic bracing, anchor unit, tests, widening of the lower flange of the slab.

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I. INTRODUCTION

In recent years, many enterprises in Uzbekistan manufacturing prefabricated reinforced concrete structures have been modernized using the equipment for the technology of formwork-free continuous shaping (imported from Italy, Spain, Germany, Russia) of prestressed structures on 12 long-length production lines up to 120 m long [1]. All of these production lines are designed to produce hollow-core concrete floor slabs reinforced with prestressed wire reinforcement.

Such slabs, when compared with the ones made by the aggregate-flow technology, are effective due to two times less consumption of reinforcing steel and three times less metal consumption of molding equipment, reducing the labor-output ratio of slab manufacturing to 50% [2].

The advantages of such structures are: cost-effectiveness, guaranteed quality, reduced weight, effective span to height ratio, leading to a decrease in level height, the versatility of their use in frame, large-panel, precast-monolithic, brick and small-block housing construction [2, 4, 5]. The production of hollow-core slabs of formwork-free shaping was designed for the use in construction in seismically inactive areas.

The Innovation Center at the Tashkent Institute of Architecture and Civil Engineering is conducting research on the introduction of hollow-core floor slabs for the construction in seismic areas. The results of these studies are presented in [1].

In [5], structural features of earthquake-resistant residential and civil buildings are formulated as follows: any structural system of an earthquake-resistant building is characterized both by the properties of the structural system and by anti-seismic measures. Therefore, a direct connection of this point with the standard requirements of Uzbekistan KMK 2.01.03-96 “Construction in seismic areas” is admitted: sections of structural elements and their joints are designed taking into account the calculation results for seismic effects, and structural measures provided for by the standards are designed regardless of calculation results for seismic effects. Based on this, to increase the resistance to seismic impacts, it is necessary to ensure the seismic loads distribution on all elements, creating conditions for the building to work as a single spatial system [6]. Therefore, floor slabs and ceilings within the building bay must be rigid and strong in horizontal and vertical planes.

The design of an anchor unit is proposed and considered in [7, 8] for the connection of such a slab with other structures when erecting a building floor; the unit is arranged in a void on the end section of a slab and designed to sustain the calculated seismic effects of an intensity no less than 7 points. The features of the anchor unit are as follows:

- a steel baffle is welded to the end of an anchor rod with a diameter of 8 mm, embedded in a concrete plug body in a void at the end of the slab, to strengthen the anchoring;
- the end of the free part of the anchor rod (free length) for bracing the slab with adjacent structure in the building floor is made without bending;
- concrete of class B20 is used for the anchor unit.

One of the factors for creating a rigid horizontal diaphragm (disk) in the floor slab (I. Introduction) from prefabricated reinforced concrete slabs is the formation of a framing beam of monolithic reinforced concrete with the required section width in inter-slab joints between the side surfaces of adjacent slabs, for the possibility to install a reinforcing spatial frame in the joint to ensure the strength and rigidity of the framing beam. The framing beam is connected on supports with an anti-seismic belt or the framing beams in other direction.

In this regard, according to the standard requirements of KMK 2.01.03-96 (I. Introduction), prefabricated reinforced concrete ceiling and floor slabs of the building are laid with a spacing of at least 120 mm in inter-slab joints between the side surfaces of adjacent slabs for the possibility of installing a spatial reinforcing element of a framing beam. To install the framing beams in the joints between the spaced slabs, a formwork was installed and fixed at the bottom of adjacent slabs in the section of the inter-slab joints for the possibility of assembling a reinforced concrete framing beam. Installation of a framing beam from monolithic reinforced concrete in an inter-slab joint is complicated when the floor slabs are spaced. Studies concerning the installation of reinforced concrete framing beams in inter-slab joints of floor slabs based on simplified technology (without spacing the prefabricated plates to a predetermined space when installing the floor slabs) were not found.

The purpose of the study is the development of constructive solutions of anti-seismic bracings and their arrangement in a hollow-core slab of formwork-free shaping, which allows creating a solid and rigid disk in the floor and ceiling slabs of a multi-storey building (structure), distributing the load from seismic effect to other load-bearing units of the building. To achieve the goal of the work, the following tasks were solved:

- development of the unit constructive solution and its arrangement at the end section of the slab for the possibility of bracing the slab with the building structures in floor and ceiling elements;
- simplification of the anti-seismic bracing installation in the inter-slab joints between the lateral surfaces of adjacent slabs to provide the necessary rigidity of floor slabs.

II. METHODOLOGY

To connect the slab with the frame element or the anti-seismic belt of the building, an anchor unit is proposed, arranged in a void on the end section of the slab, under calculated intensity of seismic impact of 8 points (Fig. 1).

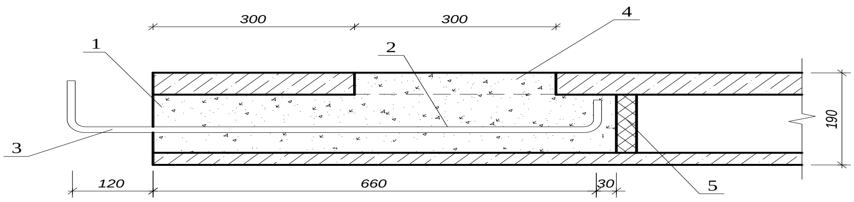

Fig. 1. Installation of the anchor unit on the end section of the floor slab for anti-seismic bracing with the building structures: 1 - monolithic concrete (class B30) (concrete plug); 2 - part of the anchor rod embedded in a concrete plug; 3 - free part of the anchor rod (free length); 4 - a groove on the upper flange of the slab through which the body of the anchor unit is concreted; 5 - foam plug, to prevent concrete mix flowing into the slab voids

According to the standards requirements of Uzbekistan for construction in seismic areas (I. Introduction), in order to increase the resistance of structural elements to seismic impact, it is necessary to create the possibility of developing permissible inelastic strains. Therefore, in the proposed anchor unit, hot-rolled reinforcement of periodic profile of class A400 of steel grade 35 GS with rod diameter 12 mm was adopted, percentage elongation at tear was 14%. A part of the rod with the flanging of the end section is embedded (anchored) in a concrete plug located in the void on the end section of the slab. The free part of the anchor rod also with the flanging at the end (free length), is designed to connect the plate with an adjacent structure. For an example Figure 2 shows the developed connection unit of a hollow-core slab of formwork-free shaping with an anti-seismic belt of a building with load-bearing walls made of masonry using the free lengths of the anchor rod unit, shown in Fig. 1. Anchor units with free lengths are arranged in the 2nd and 7th voids at the end sections of the slab. The installation of anchor units in the slab is performed at a special site after removing the slab from the production line.

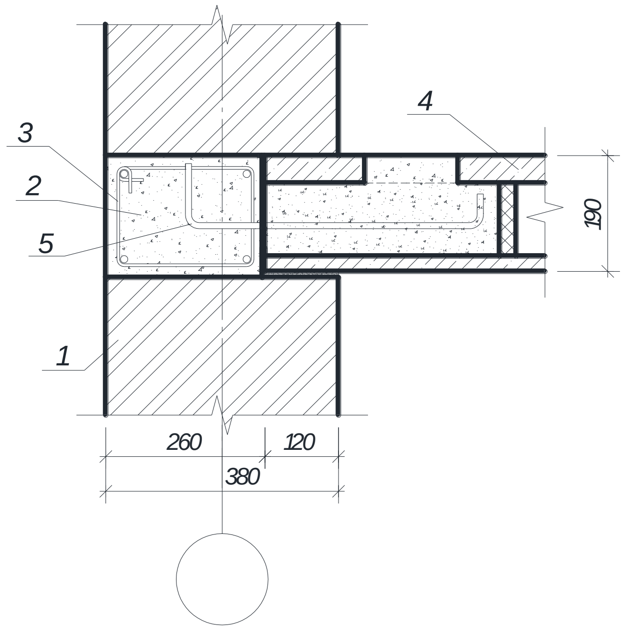

Fig. 2. Floor slab and anti-seismic belt bracing unit of the building with load-bearing walls made of brickwork. 1 - brick wall; 2 - anti-seismic belt of monolithic reinforced concrete; 3 - reinforcing frame of anti-seismic belt; 4 - slab; 5 – free lengths of an anchor rod embedded in a concrete plug located in the slab void

Distinctive features of the proposed anchor unit (see Fig. 1) from the unit given in [8] are:

- a steel baffle is welded to the end of the anchor rod, with a diameter of 8 mm embedded into concrete plug body in the void, to strengthen the anchoring;
- the end of the free part of the anchor rod is without flanging;
- concrete of class B20 is used for the anchor unit.

The tensile forces occurring in anchor rods due to calculated seismic effects with an intensity of 8 points were determined using the results of studies given in [7, 8, 9].

Under the action of horizontal forces arising from seismic loads acting on the building, tensile forces arise between the precast floor slabs. These forces can be perceived by reinforced concrete framing beams arranged in the side inter-slab joints to transform it into a continuous beam slab [2].

To simplify the technology for the construction of a reinforced concrete framing beam in inter-slab floor joints, a configuration of a prestressed hollow-core slab made using the production line technology of formwork-free shaping with widened lower flange by 11.64% compared to the upper flange was proposed (Fig. 3).

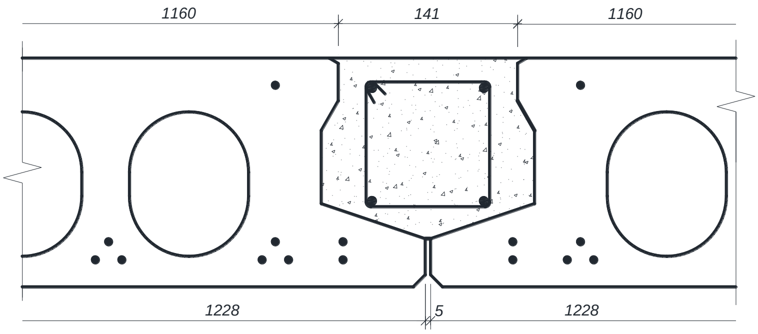

Fig. 3. Installation of reinforced concrete framing beam in inter-slab floor joints with the use of hollow-core slabs of formwork-free shaping with widened lower flange compared to the upper flan

III. RESULTS AND THEIR DISCUSSION

The tensile force arising in the anchor rod of one unit (see Fig. 1) due to calculated seismic impact with an intensity of 8 points, is 30.95 kN. With this force, the diameter of the anchor rod Ø12A400 with the standard value of the yield strength equal to 390 MPa is selected (the forces at the standard values of the yield strength and ultimate tensile strength are 44.11 kN and 63.34 kN, respectively).

The embedment length of the anchor rod 12A400 into concrete plug of the slab voids is calculated according to the standards STO 36554501-048-2016 "Anchoring in concrete. Design Rules. NIIZHB-OJSC "Research Center" "Construction". The embedment length of the anchor rod into the concrete plug is taken with account for plastic nature of the anchor unit damage as a result of the anchor rod reaching the yield strength without its slipping in concrete plug.

Tests of the proposed anchor units embedded into a hollow-core slab of formwork-free shaping were carried out in accordance with the methodology of the standards STO 44416204-09-2010 "Anchor fastenings. Method of determining the bearing capacity of anchors according to the results of field tests. NIIZHB - OJSC "Research Center" Construction", Moscow. The strength and serviceability of the anchor units arranged in the 2nd and 7th voids of the slab (6.2 m long designed for a unified load of 800 kgf/m^2) were assessed in accordance with the diagram shown in Fig. 1.

Pull-out tests of anchor rods embedded in the voids of hollow-core slabs of formwork-free shaping (length 6.2 m, designed for a unified load of 800 kgf/m^2) were conducted. Anchor units are embedded in the 2^{nd} and 7^{th} voids at the end sections of the slab in accordance with the diagram shown in Fig. 1. Concrete strength of the slab and anchor unit (of concrete plug) was determined on the day of testing with a Silver Schmidt sclerometer of the PCN type (shock-pulse method and the ONYX-OS device with an electronic unit (it determines the strength and class of concrete by the shearing method). The strength of concrete slabs was estimated as 29.4 MPa (design class of concrete B30, the required handling strength of at least 70% – 26.9 MPa). The strength of anchor unit concrete is 23.7 MPa (the required handling strength of concrete must be at least 26.9 MPa for concrete class B30). To test the anchor rods for pull-out from the unit located in the void plugs at the end sections of the slab, a TEL-10/10B electric traction winch was used, and a PCE-CS10000N electronic dynamometer was used to measure tensile forces in the winch cable. When creating the forces in the anchor rods which correspond to the standard yield strength of steel, the following was found:

- signs (cracks, concrete spalling around the anchor rod, the rods slipping in concrete plugs) preceding the pull-out of the anchor rods from concrete plugs in the slab voids were not observed;
- slipping of the anchor unit body (concrete plugs) in the slab voids was not registered.

The final test result is the reaching ultimate resistance to pull-out (tear) the anchor rods in the points of free length from all 4 units of the slab (the average value of force at which the tear of anchor rods occurred was 67.2 kN).

Conclusions on tests results of anchor units arranged in the slab voids in accordance with the scheme proposed in Fig. 1 are as follows:

- the destruction of anchor units with reinforcing bars Ø12A400 occurs as a result of tear of these rods;
- cohesive strength in the contact zone "concrete of the anchor unit body - concrete of the slab" is ensured until the anchor rods tear.

The technical result of the proposed cross-sectional configuration of a hollow-core slab of formwork-free shaping with a widened lower flange relative to the upper flange (see Fig. 3) is as follows:

- during the installation of such floor slabs, a space of required width in an inter-slab joint is formed without spacing apart the slabs to a predetermined distance, for the subsequent formation of a framing beam of monolithic reinforced concrete in the inter-slab joint;
- there is no need to install and fasten the formwork to the floor slabs on the section of the inter-slab joints at the bottom of adjacent floor slabs for the possibility of concreting the framing beam in the inter-slab joint of reinforced concrete;
- the ceiling slabs of a building made of monolithic slabs of formwork-free shaping are designed without considering the slabs spacing, in order to create an inter-slab joints of the required width to install the framing beam.

The manufacturing technology of slabs with a widened lower flange is not changed, i.e., it is possible to produce the slabs of formwork-free shaping for the entire product range, traditionally used in construction, with the broadening of the lower flanges relative to the upper ones. A utility model for granting a patent "Hollow-core slab of formwork-free shaping" was submitted to the Agency of intellectual property of the Republic of Uzbekistan; it proposes a slab with a widened lower flange relative to the upper flange, application number is FAP20180174 with priority date 11/08/2019.

IV. CONCLUSIONS

1. The design standards requirements of Uzbekistan for construction in seismic areas do not consider the design features of hollow-core slabs of formwork-free shaping.
2. The use of hollow-core slabs of formwork-free shaping with a widened lower flange relative to the upper flange greatly simplifies the arrangement technology in the inter-slab joints of the building floors and ceilings of reinforced concrete framing beams to transform the floor slab into a continuous beam slab with a rigid horizontal diaphragm.
3. The proposed constructive solutions for the anti-seismic bracing of the floor slab with adjacent load-bearing structures of the building satisfy the standards requirements of Uzbekistan KMK 2.01.03-96 "Construction in seismic areas" to ensure the transfer of seismic loads to all load-bearing elements, creating conditions for the construction to work as a single spatial system.

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