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Reinforcement of cracked hollow-core slabs during the construction of the building

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Abstract

During the implementation of investment processes with the use of ready-made prefabricated elements, undesirable situations may occur that cause scratches, excessive deflections or damage. This is due to the fact that defects occur during transport, storage or incorrect loading of the elements. The conducted tests and technical assessments often allow the use of built-in elements, however, under the conditions of the need to make their reinforcements. This may be due to the scale of damage or defects made during molding and, as a consequence, the implementation of prefabricated elements with too low load capacity. Taking action each time should allow for the implementation of reinforcements of the elements, limiting the need to dismantle them, which would result in their irretrievable destruction. The implementation of reinforcements allows to reduce the generation of waste from new elements and allows for the proper management of already produced prefabricated elements. Used elements with reinforcements should be subject to technical inspection in the same periods as other structural elements. Proper implementation of repairs allows for the final effect to be similar to the parameters of elements free of technical defects. Due to the existing problem of damage to new elements of prefabricated channel ceilings, solutions have been developed that can be used to reinforce the elements without the need to dismantle them from the places of installation, while reducing the time spent on the process.

Keywords: hollow-core slabs, scratches, cracks, damage, reinforcements.

1 Introduction

Prefabricated hollow-core slabs are commonly used in the construction industry as floor slabs, as their application/use speeds up the construction process. The necessity to make slabs of specific dimensions whose manufacturing process is not preceded by proper computational analysis, may result in faults or building disasters later at the construction stage. This is due to the changes that must be made by manufacturers of prefabricated slabs or panels when adapting their typical production process to new requirements for which they are not adequately prepared especially when the building facility designers fail to provide the slab manufacturer with appropriate calculations and solutions for the reinforcement of elements, confirmed by computations as required by the relevant standards [1, 2]. Often faced with short time limits to produce new elements, manufacturers' mistakes cannot be unavoidable. Commonly, the ordering party requires efficient, timely delivery of ready-made elements at a strictly defined time to the construction site. This obligation significantly shortens the period for a reliable verification of the manufacturing process and selection of optimal reinforcement. Sometimes unconsented /ad hoc/ replacement of

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reinforcement rods in the manufacturing process may take place. This is often due to a lack of proper supervision of the manufacturing process.

The elements delivered to the construction site are subject to verification regarding the declaration of their relevant load capacity. However, very often, there is no real possibility to verify the slabs' load bearing capacity against the actual design requirements by the technical staff on the construction site. Problems with the slabs may appear only after their assembly in ceiling spaces, where the first defect symptoms, usually in the form of scratches will occur. The appearance of scratches on external surfaces usually corresponds to the most strenuous spots/locations/,which facilitates later analyses aimed at determining the causes of damage. Scratches appearing in the ceilings where the individual slabs are joined are caused by a lack of proper filling of the spaces between adjacent elements, for example, with fillet concrete and the use of proper reinforcement. A different situation takes place if scratches occur on the surfaces of the elements themselves. This phenomenon /fact should be carefully analysed to see if the right type of slabs has been used to suit the specific design requirements and actual loads.

The appearance of scratches will usually require taking special measures to prevent further deterioration of the technical condition of the slabs by implementing appropriate reinforcement solutions. The strengthening can be performed on the slabs' upper surface, in the space of free channels or from the outside on the bottom surface [3, 4, 5]. Each of the solutions, if properly designed and documented by meeting the standard conditions, can be applied in such a case. Lack of swift and appropriate actions may lead to emergency states, which will manifest more evidently under excessive loads resulting from exceptional forces acting on the structure [6].

This paper deals with problems resulting from correct assessment of scratches in hollow-core slabs created during the construction of a new building facility. It shows the initiation of defects at an early stage of the building process. The first signs of defects in the form of scratches and cracks occurred at loads corresponding to about 50% of operating loads, which may indicate the occurrence of the phenomenon preceding the inevitable process of destruction.

2 Design solutions for floor slabs in the building

Hollow core slabs serve as ceilings in buildings and are adapted to carry permanent and variable loads resulting from the functions of the facilities. As a rule, the same solutions are used in buildings for all ceilings between storeys, which simplifies the ordering process and eliminates assembly errors. The ceilings are supported on the structural walls with a mortar that compensates for the unevenness of the support zones, and the next step is to place the bars between the adjacent elements working for negative support moments. Prior to the process of shaping the rims, fillings are placed in the slab channels to limit the flow of concrete into the deeper parts of the channels. If the crown molding process was carried out correctly, it is possible to use the effect of partial rigid fixing during the panel operation phase. The global effect of the work of prefabricated elements corresponds to the work of a simply supported beam with a width corresponding to the dimensions of the prefabricated element. Placement of the bars between adjacent panels and proper filling of these spaces, forming locks, allows to limit the phenomenon of uneven deflection and the formation of mutual displacements of the panels.

The occurrence of damage to hollow core slabs in newly erected buildings becomes a problem due to the reliable determination of their causes. A typical picture of damage observed in the area of prefabricated hollow-core slabs included their lower surfaces in the form of scratches and cracks. The defects took a course perpendicular or parallel to the length of the boards and may cover only the middle zones of the boards or their entire surface. Examples of damage that properly illustrate the described damage pattern are shown in Fig. 1.

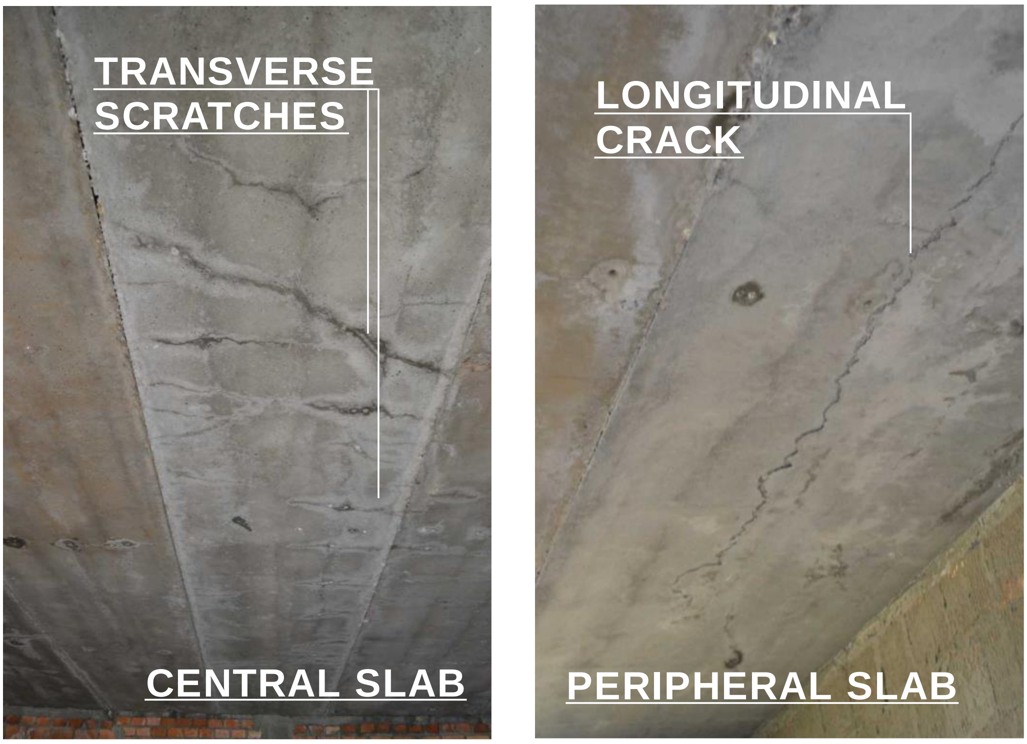

Figure 1. *Examples of defects (cracks and scratches) on the bottom surfaces*

The most common damages are scratches with a course similar to transverse, covering more than a single element. The width of the cracks is varied and it is difficult to clearly indicate their border, however, in most cases it was in the range of 0.1 ÷ 0.3 mm, and in some ceilings it was up to 0.5 mm. Scratches are often clearly visible due to moisture accompanying the penetration of rainwater through the surface of the ceiling. Longitudinal scratches have a different course because they cause a crack which may be accompanied by a shift of adjacent fragments resulting from different permanent deflections.

3 Assessment of the state of panel effort

In order to assess the load-bearing capacity of the slabs, it is necessary to carry out tests and measurements to obtain the necessary technical parameters. The analyzes begin with determining the depth of the slab supports on the structural walls constituting the supports. The depth of the panel supports on the wall should be greater than the minimum value of 50mm, which results from the construction requirements. Prefabricated hollow-core slabs are unidirectional elements, therefore they should have shaped supports on the edges perpendicular to their length. The calculation model is a slab strip corresponding to the width of a single prefabricated element, which, after filling the joints between the slabs, becomes a one-way reinforced ceiling. The nature of the defects is usually related to the shaped schemes of the elements' support. In the conditions of proper implementation of the Variant I backrests, the cracks were located in the central zone, and in the case of an additional support, along the longitudinal edge of Variant II, longitudinal cracks may occur in conditions close to half the width of the element. The global nature of the damage correlated with the boundary conditions is shown in Fig. 2.

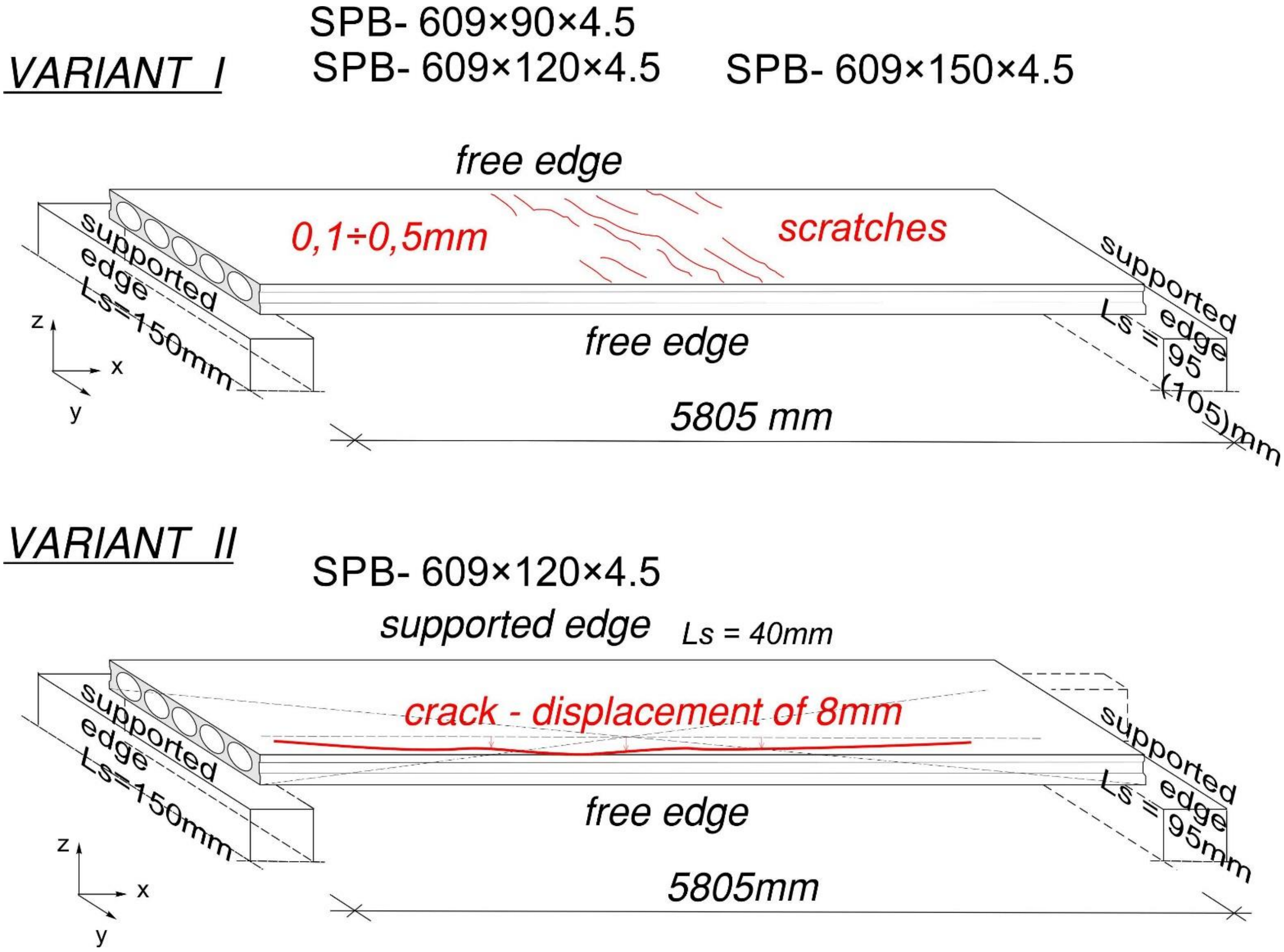

Figure 2. Support model and fault location on external surfaces

In the phase of erecting structures with the use of hollow-core slabs, the load level usually does not exceed half of the total loads for which the slabs were designed. The first obvious cause that can cause the described effect of element damage may be related to the incorrect implementation of their reinforcement. It is then necessary to specify the types and amounts of the main reinforcement used, which is of particular importance in the conditions of embedding elements of non-standard lengths L.

3.1 Conditions of the actual state of exertion

As a representative technical problem that correctly reflects the described state of damage to the elements, an analysis of boards adapted to carry design loads of 4.5 kN/m^2 with an unusual length of 609cm, which is marked as SPB-609×90×4.5, can be used; SPB-609×120×4.5; SPB-609×150×4.5. It was assumed that the depth of the supports on the wall is greater than the structural requirements and is in the range of Ls = 95÷150mm. If the space between the elements is properly filled with cement mortar, the level of loads at the erection phase of the structure in the implementation conditions without floor layers is 3.5kN/m^2, 2.92kN/m^2, 3.04kN/m^2, respectively, for slabs 90, 120 and 150 cm wide. The load values are in the range of 39.4÷43.8% of the total load values that the boards should carry safely. It was originally assumed that the effect of damage to the elements may be related to the method of their reinforcement in conditions of unusual lengths. It is then important to refer the type of reinforcement used to typical solutions of 600 cm long slabs. If a lower percentage of reinforcement is found, in-depth analyzes are important to determine the actual moment of cracking elements. It was assumed that in the spaces between the panel openings, 2 ribbed bars ϕ8mm made of 34GS steel were used, and one ϕ8mm bar at the edges. Reinforcement area related to typical solutions of 600cm long boards is lower by about 13% compared to the requirements. This fact may be the cause of cracks in the conditions of the target load of the ceiling, and not during the construction process. The analysis based on the provisions of the standard [2] of the span bending moments of the slabs, which are responsible for the nature of damage, in two support schemes showed that for the existing load level, the values of internal moments may cause the first cracks in the scheme according to variant 1. On the other hand, cracks, and even more cracks cannot occur in the conditions of supporting the panel on three edges, variant 2. The results of the analysis are presented in Fig. 3.

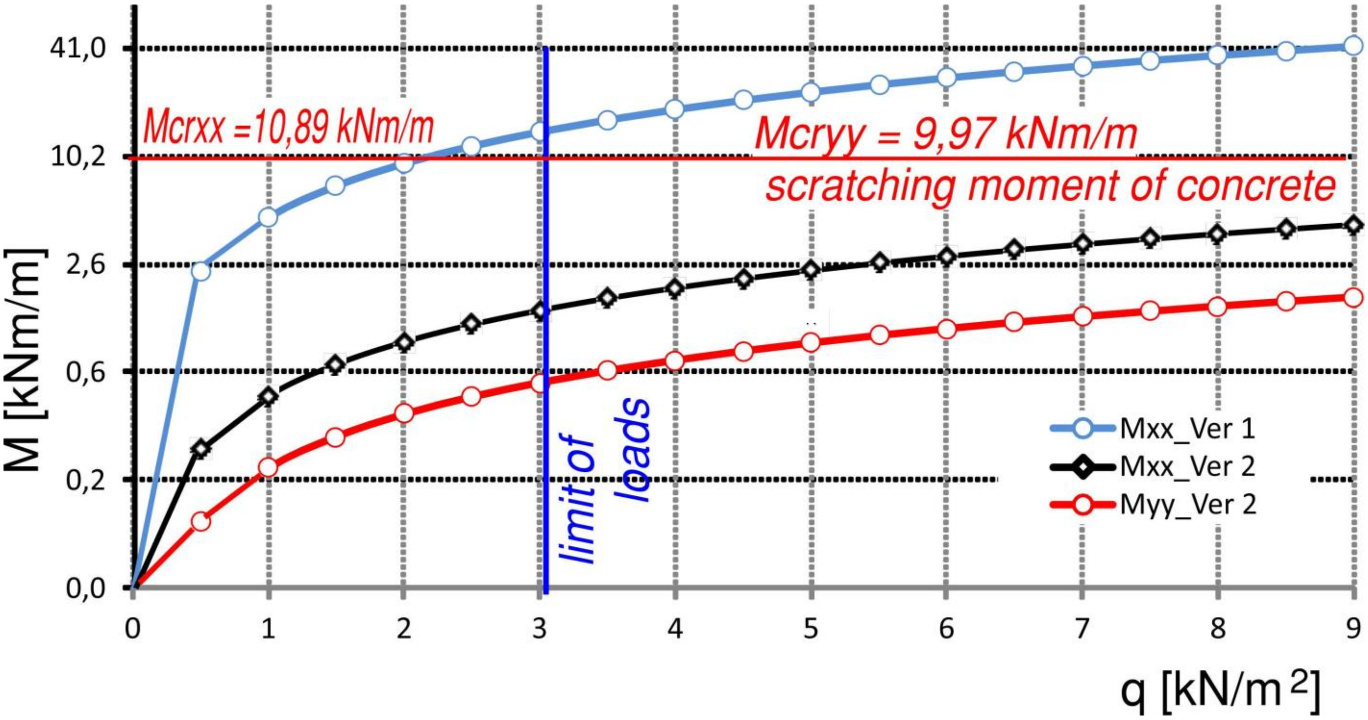

Figure 3. Slabs bending moments in correlation with external load and drawing moment

An extended analysis for variant 1 showed that the crack width should not exceed 0.1mm, regardless of the width of the elements, and the distance between them should be about 300mm. The actual nature of the cracking of the elements and their intensity is different and the performed calculations do not properly explain their causes. Despite the use of an insufficient cross-section of slab reinforcement, the expected damage should be less intense and longitudinal cracking should not occur.

4 Causes of permanent plate damage

The correctness of the production of prefabricated slabs, where the steaming process is used during the formation of elements, which significantly accelerates the maturation of concrete, should also be analyzed. The result of an improperly implemented concrete maturation process in the elements may be the collapse of the upper concrete fragments in the channel zones and the loss of the flat surface of the elements. The process of concrete shrinkage may increase the defects of the elements, causing additional scratches, which may be favored by zones of previously deformed bands above the empty channels. The discussed issues are illustrated in figure 4, where the sunken places above the channels are marked and the shrinkage crack accompanying the board production process is indicated.

Figure 4. Disadvantages of the process of forming elements, collapse of concrete in the zones of channels and local longitudinal scratches

Defects committed in the technological process additionally weaken the elements, causing a change in the position of the concrete compression zone, which also reduces the load capacity of the elements. The arm of internal forces between the stretched bars of the lower zone and the compressed concrete surface, being reduced due to deformation, causes a drop in the load capacity of the element, which was set at several percent. The identified defects in the process of forming elements also turned out not to be the cause of numerous scratches and cracks observed on the surfaces of the lower plates.

In the analyzed situations, the cause of damage resulted from errors made during the process of erecting the building and storing wall materials directly on the ceilings made of hollow-core slabs. It turned out to be important that after the ceilings were made, the process of continuing construction works on erecting the facilities included the construction of structural walls from small-sized wall elements. If you analyze in detail the process of using materials to make the walls of the next floor, for example from ceramic hollow bricks with dimensions of 188 × 250 × 220 mm, it will turn out in what quantities they should be delivered directly to the place of laying. To make the walls of the next storey, 2.60 m high, more than 5,000 elements should be used in multi-family housing, which are delivered to the construction site in pallets of 112 pieces. Based on the data of the manufacturer of wall elements, it was determined that the weight of a single pallet is 1050 kg. When erecting buildings, in order to speed up the construction process, pallets are usually placed locally on the ceilings, from which the elements are taken directly to build the walls.

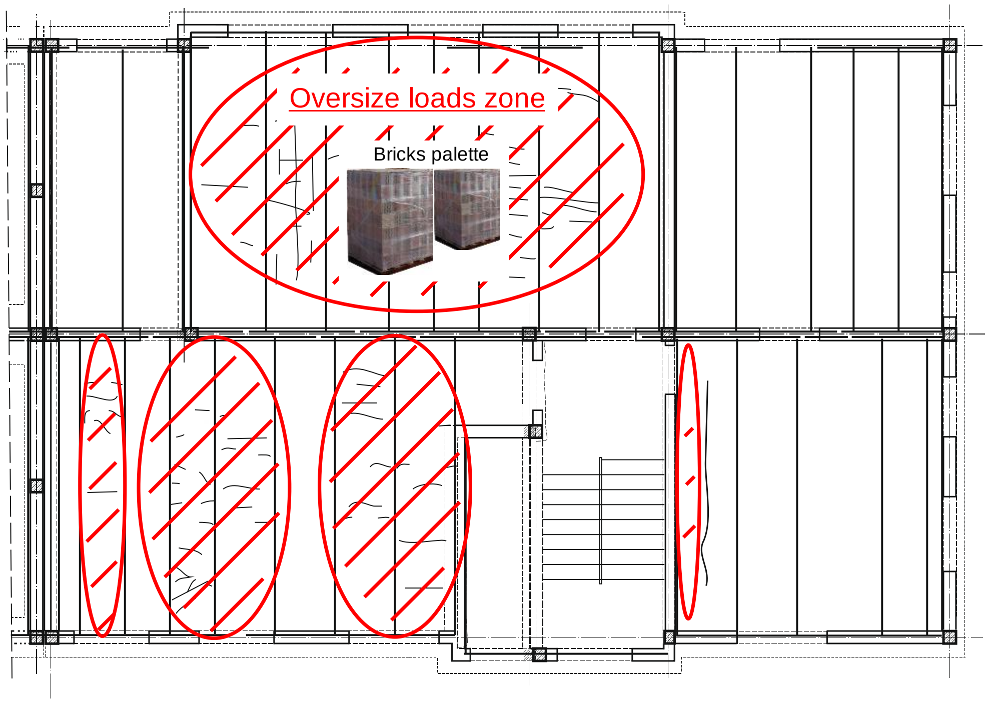

Figure. 5. The zone of presumable collection of blocks for erecting walls

The common image of panel damage during the construction of buildings, which could not have been created for other reasons, indicates that the pallets were placed on the ceilings in zones where scratches and cracks occurred, Fig. 5. The one-time number of pallets stored on the ceilings cannot be clearly determined, therefore a simulation was carried out the effect of a single and two pallets placed on the ceiling. Setting one pallet around the center of the span of the hollow-core slab leads to an increase in the crack spacing to about 0.22mm with the distance between them being about 20cm. For two pallets placed next to each other in the area of the middle of the panel span, the crack spacing would increase to a value of approximately 0.56÷0.61mm, depending on the width of the prefabricated panel. The number of damages occurring in the elements proves that once on the surface of the ceilings material was accumulated in an amount exceeding their load-bearing capacity, which consequently led to their permanent scratching. Calculation simulations in relation to the scale of defects indicate that in most cases, about half of the number of pallets with the material necessary to make the walls was stored on the ceilings at one time. Longitudinal cracks in the slabs resting on three edges were, in turn, caused by placing two pallets directly next to the erected wall. The result was an increase in bending moments in the perpendicular direction My and in the absence of appropriate reinforcement in this direction, both fragments of the slab element disintegrated.

5 The concept of strengthening the hollow core slabs

In order to restore the required operating parameters of the ceilings in the conditions of cracking, a concept of strengthening excessively bent, cracked elements was developed. An important issue turned out to be the restoration of the horizontal plane of the bottom plate in buildings where these surfaces are plastered ceilings, without the use of covers in the form of suspended ceilings. For this purpose, pre-leverage of elements whose deflection measured in

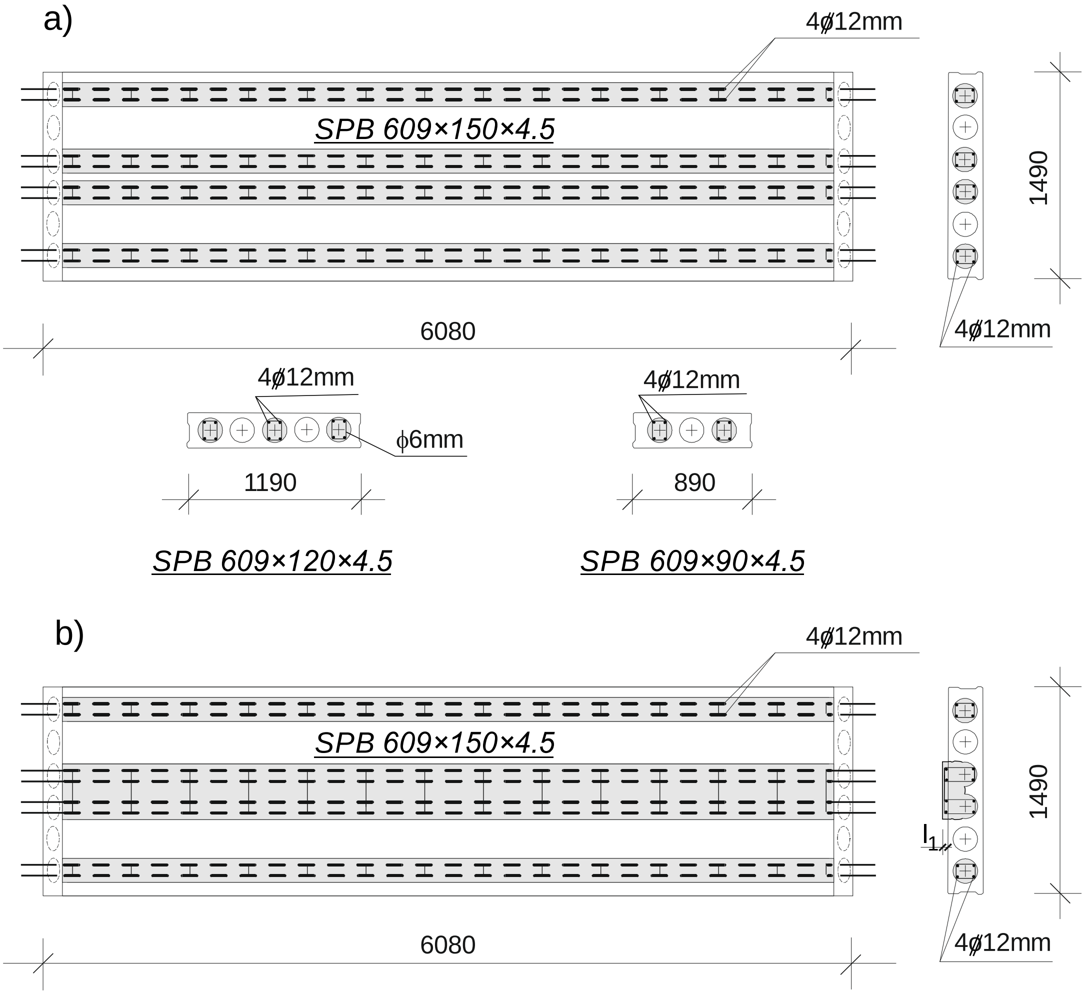

Figure. 6. Reinforcement concept for cracked hollow core slabs.

a) transverse cracks, variant I; b) longitudinal cracks, variant II

the middle of the span exceeded a = 10mm was provided. In the process of restoring the original shape, the use of intermediate supports stabilizing the structure of the slabs in a non-deformed position was provided. After the preliminary works prepared in this way, it was planned to open the channels from the top and make reinforced concrete beams in them with a circular cross-section, Fig. 6a, or similar to a rectangular one, Fig. 6b.

Before implementing the reinforcement, the exposed surfaces should be cleaned of contamination and then moistened with water. Reinforced concrete cores reinforcing the cracked prefabricated slabs were made of concrete class C30/37, reinforced with 4 bars ϕ12mm in the area of each of the circular fields, exposure class XC3 for environmental conditions [2]. The stirrup bars used in the reinforcement process are ϕ8mm in diameter and spaced every 25cm. The dimension of the height of the reinforcement l1 in the event of longitudinal cracks depends on the floor surface finish and should be correlated with the designed layers. In typical solutions, when the insulation is placed on ceilings 5 cm thick, this dimension may correspond to the thickness of the insulation.

6 Summary

The most common cause of damage in erected buildings are human errors related to the lack of technical awareness and negligence, as well as ignorance of the technical staff.

In the examined cases of damage to hollow-core prefabricated slabs, it turned out to be defects made during the erection process by excessive storage of materials in the area of floor slabs. The consequence of overloading the ceilings was the occurrence of scratches and sometimes cracks of reinforced concrete structures. An additional factor that increased the impact was the method of transporting materials and placing them on the slabs made with the use of lifts mounted on wheeled vehicles. There were often dynamic influences in the process of lowering the pallets with brick materials, causing the primary break of cooperation between adjacent slabs. The dynamic impacts accompanying the process of placing pallets on the floor surfaces are difficult to estimate and in each case depend on the operators conducting the unloading process.

Ceilings made of hollow-core slabs cannot be loaded with pallets on which wall materials are placed, because, as it has been shown, they are not adapted to carry such loads. This is due, among others, to the fact that during the assembly of prefabricated hollow-core slabs, no intermediate supports are used and the weight of a full pallet turns out to be greater than the load capacity of a single element.

Accelerating the process of constructing objects by placing wall materials on the surface of prefabricated channel ceilings is a mistake that results in permanent damage to the elements and makes it necessary to strengthen them in conditions of their safe operation. In the event of damage, each time the cost of repairing the elements should be estimated according to the proposed concepts, thus eliminating the disassembly of the prefabricated elements built into the ceiling structure.

Knowledge of the consequences that may occur in the event of a faulty construction process will help to eliminate such problems in the future.

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