New Design and Technological Solutions for Ensuring Technological Reliability of Erecting Pre-Cast with Cast-in-Place Slabs in Civil Buildings

New Design and Technological Solutions for Ensuring Technological Reliability of Erecting Pre-Cast with Cast-in-Place Slabs in Civil Buildings

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Abstract. The study of erecting cast-in-place and hybrid pre-cast/cast-in-place civil buildings in the Middle Urals revealed the need to develop new design and technological solutions aimed at ensuring high technological reliability of construction processes being implemented, as well as at enhancing service properties of slabs. Description is made of a set of new design and technological solutions developed with the use of a Russian heuristic formalized structural synthesis method called a Theory of Inventive Problem Solving (hereinafter referred to as TIPS).

1. Introduction

The study of how slab cast over pre-cast joists are erected in civil buildings at the construction sites in Ekaterinburg and other cities of the Middle Urals revealed that the technological reliability of three processes performed with the help of conventional methods and standard outfit [1] is insufficient. The existing low level of technological reliability often leads to functional defects, and, as a consequence, to deterioration of service properties of a slab structure. Thus, new design and technological solutions are necessary for ensuring high level of technological reliability of construction procedures. The development of new technical solutions in construction is related to the solution of a conventional inventive problem, and the correct answer to it depends on many factors. A fair number of inventive techniques with varying degrees of effectiveness [2, 3] have been developed to solve such problems, the theory of inventive problem solving (TIPS) being the best of them [4].

2. TIPS, a heuristic synthesis method, as an effective methodological tool for solving technical problems in construction

A review of a number of literature sources on the theory of inventive problem solving [4, 5, 6] showed the adaptability of this heuristic formalized structural synthesis method not only for solving practical problems in many industries, but also for training technical experts in universities around the world.

The method was developed by Genrikh Saulovich Altshuller, a Russian scientist and inventor. The purpose of this method is to solve an inventive problem by means of consistently revealing system contradictions (administrative, technical and physical ones) and eliminating them using laws, patterns, and trends in the development of technical systems. To resolve the said contradictions, G.S. Altshuller

and other researchers developed other methods based on the assumption that in most cases the contradictions are resolved by similar methods.

The detailed procedure of solving an inventive problem of practically any level of complexity is presented in the respective algorithm for solving inventive problems (hereinafter referred to as ASIP), the latest version of it consisting of about 85 actions (steps).

The main advantage is that it is the most methodically researched heuristic synthesis method based on the fundamental laws of technical systems' development. The TIPS methodical toolkit allows to solve inventive problems of practically any level. Though the method has all the benefits mentioned above, it also has one major drawback – it is rather complicated for practical use because of high requirements to the inventor's education. The ASIP states that an expert, who uses this method effectively, i.e. who is capable of solving complex inventive problems (those of the 3rd and the 4th levels, according to TIPS classification) should possess a university level of knowledge in physics and in that field of technology, to which the inventive task to be solved is related. Using standardized techniques for eliminating technical contradictions will be enough for solving relatively simple problems. The algorithm of using such techniques is so simple that after a short training even schoolchildren of 5th-9th forms can learn how to use it.

The solutions described below are based on the following ASIP principles: revealing administrative contradictions, revealing technical contradictions. The revealed technical contradictions were eliminated using a standard table containing 40 techniques. No determination of physical contradictions was provided for in the development of the solutions described.

3. Design and technological solutions for the arrangement of cast-in-place part of a slab cast over pre-cast joists

3.1. Element for linking the reinforcement bars

The reinforcement bars perpendicular to one another need to be linked in order to arrange the cast-in-place part of a floor slab without welding. The most common way of linking such bars is to tie a place of connection with a thin wire with the help of hand-guided tools. This rather painstaking technique contains a set of technological operations and is not always convenient to use, especially for the lower row of bars in the floor slab. Bar benders often use this technique at the construction site, and the connections thus made are faulty, and thinner than it is required by the design. This leads to the reduction in stiffness of reinforcement cage and, as a consequence, to the reduction of load-bearing capacity of the cast-in-place part of a slab. We used the recommendations listed in [7, 8] to make the patent search of well-known elements for linking the reinforcement bars, and found one constructive solution patented in China [9]. Representing three wire hooks connected with one another, this solution has sufficient technological effectiveness but does not provide for reliable fixing of reinforcement bars due to insufficient length of those parts of the hooks that touch the surface of bars to be connected. We have developed a new deign solution of a linking element to achieve technological and reliable connection.

The element for linking reinforcement bars, perpendicular to one another, is made of spring steel wire and consists of three hooks. Two lower hooks (the second and the third ones) lie in mutually parallel planes and are symmetrical with respect to the upper hook (the first one) located in the plane formed by arc-shaped curves. To link the reinforcement bars, the upper bar is passed through the upper hook, while the lower hooks are put on on the lower bar. Thus, the process of linking the bars involves just two simple technological operations. The shape of the plane, where the upper hook is situated, allows to not only increase the length of those parts of the first hook that touch the upper bar, but also to increase the length of those parts of the lower hooks that are in contact with the upper part of the lower bar. Figure 1 below presents the prototype and the developed design solution of the element in schematic drawings of parts of the hooks touching the bars.

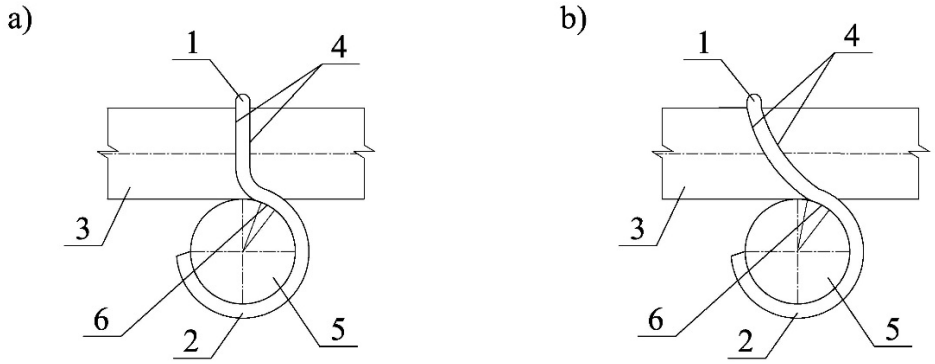

Figure 1. Schematic drawing of parts of the element's hooks for linking the reinforcement bars: a) for the prototype (patent CN No 102691381); b) for the developed solution; 1 – the first hook; 2 – the second hook (the third hook); 3 – upper bar; 4 – fixing length of the upper bar; 5 – lower bar; 6 – fixing length of the upper part of the lower bar.

An application was made on the basis of the developed solution, and a Russian Federation utility model patent RU No 180555 was obtained.

3.2. Method of shaping the edges of a slab's cast-in-place part and a device for its implementation

We also revealed another process with low technological reliability – a process of shaping the edges of a slab's cast-in-place part.

Nowadays the technology of shaping the edges of the slab's cast-in-place part implies the installation of standard end beams on the standard or non-removable formwork of a slab, these elements being fastened against displacement during concrete casting with AV standard brackets (for PERI formwork) or universal fireproof concrete shut-off valves (for DOKA formwork) etc. End beams and brackets are dismantled after concrete casting is completed. The described method implies shaping the inner surface of multiple-use removable end beams by the edge of the cast-in-place part of the slab. This method has low technological reliability because the installation of an end beam is highly painstaking, and because the dismantling has to be performed with high technical discipline, (which requires high quality of works). Our study has shown that both the quality of edge surface of the slab's cast-in-place part, and its service properties largely depend on the wear and tear of end beams, and the weaker is the technical discipline during their dismantling, the more intensive is their wear and tear. Besides, in this method end beams do not allow to obtain a decorative surface of the edge without carrying out additional site works.

We have developed a new method of shaping the edge of the slab's cast-in-place part, and a design element for carrying out this process, which not only ensures the increased technological reliability of shaping the edge, but also allows to obtain the decorative surface of it without any additional works performed at the construction site.

The method involves the following sequence of technological operations. In accordance with the regulations, provision is made for the arrangement of the inverted-U-shaped reinforcement bars (stirrups) on the end sections of the cast-in-place slab located along its edge. These bars are fastened to the main reinforcement (reinforcement cage) of the slab. Next, tying rods oriented along the slab's edges are fastened to the vertical part of the stirrups. Before that the tying rods are passed through the loop outlets of the developed design element (Fig. 2a). The factory-made pre-cast design elements (Fig. 2b, Fig. 2c) are installed along the slab edge on its removable or non-removable formwork. The concrete casting of the slab's cast-in-place part is carried out after installing the said design elements.

The design element for implementing the proposed technique is made in the form of a pre-cast thin-walled reinforced concrete panel and contains loop outlets located on the inner side of it. The inner side of the panel is rough for its adhesion with the concrete of the slab's cast-in-place part, whereas its external side is smooth.

In order to obtain the decorative edge surface of the slab's cast-in-place part, the external side of the panel can be made with brickwork rustication or in the colours of the façade.

In accordance with the recommendations listed in [10], Figure 2 presents the graphic explanation of the developed method in isometric views.

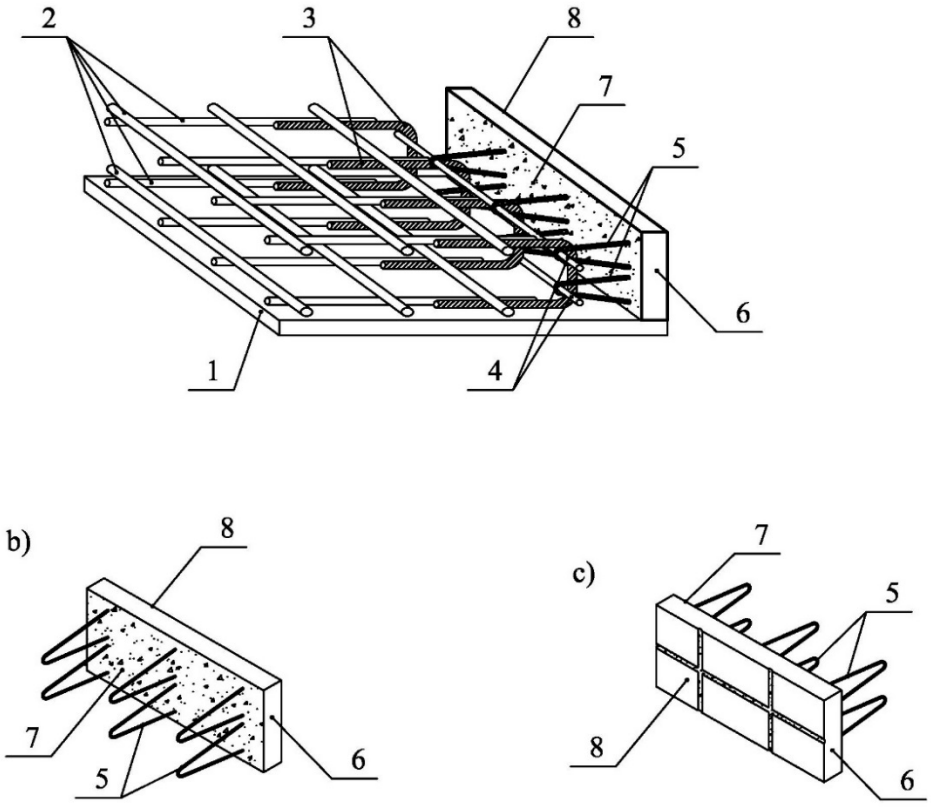

Figure 2. Method of shaping the edges of a slab's cast-in-place part: a) slab fragment before concrete placing; b) design element (inside view); c) design element (outside decorative view); 1 – formwork of a slab's cast-in-place part (removable or non-removable); 2 – reinforcement bars of the end sections of a slab's cast-in-place part; 3 – inverted U-shaped stirrups; 4 – tying rods; 5 – loop outlets of the design element; 7 – inner side of a design element panel; 8 – external side of a design element panel.

An application was made on the basis of the developed solution, and a Russian Federation patent on invention RU No 2658687 was obtained.

4. Technological solution for assembling the pre-cast part of a slab cast over pre-cast joists

The method used for assembling bents for the arrangement of slab cast over pre-cast joists of the building implies the installation of the bent on the mounting tables attached to the built-up columns, and on the intermediate supports in the form of telescopic jack columns of the collapsible forms of the slab. The bent should be subject to height and horizontal alignment by means of assembly tools and then installed on the beam of the slab. In case pre-cast with cast-in-place bents are present in the slab, the cast-in-place part of the bent should also be arranged.

It was established that this method for installing the bent has low technological reliability due to the fact that: height alignment of the bent is very painstaking when using telescopic jack columns of the standard formwork of the slab, particularly in case of uneven or inclined base, on which the jack columns are resting;horizontal alignment of the bent is very painstaking, too, and there is no opportunity for technological and reliable horizontal fixation of the bent when the slabs are installed thereon, and the cast-in-place part of the bent is being arranged.

The latter is a particularly important prerequisite for high-quality erection in case of using a pre-cast bent with the reinforcement bars being pre-stressed and the bent is subject to one-sided loading with pre-cast slabs.

We have developed a new way of erecting a pre-cast part of the bent and an erection device for it. Their application will allow to improve the technological reliability of erection.

The method involves the installation of the bent on mounting tables fastened to the columns. At least two erection devices are installed vertically before installing the bent, and screw-jacks are used to align their vertical position together with the height position of their U-shaped trays, so that the bent should rest on the lower part of these U-shaped trays while being in the design position. After installing the bent on mounting tables and fixtures, it shall be aligned horizontally using the screws located on the U-shaped trays, and fixed until the completion of subsequent works related to installation of slabs on the bent and arrangement of the cast-in-place part thereof.

An erection device has been developed in order to implement the proposed method (Fig. 3). The device consists of two columns linked with one another, an U-shaped tray with side parts equipped with screws able to move horizontally being rigidly fastened to the upper part of the columns. The fixing plate is rigidly fastened to each screw, and the lower part of each column is equipped with a screw jack and a supporting plate.

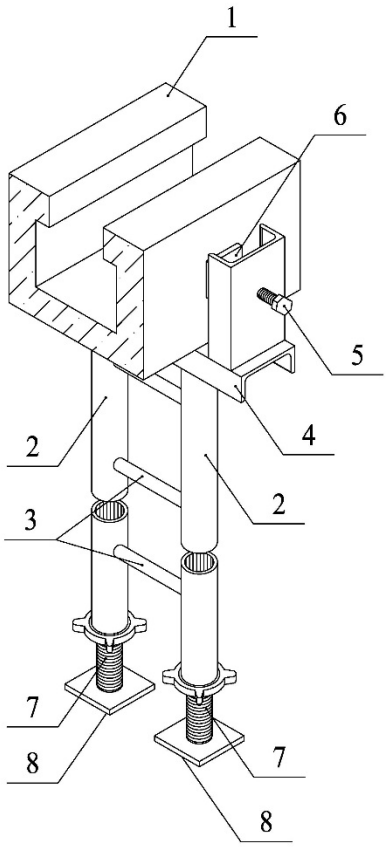

Figure 3. Erection device
1 – pre-cast part of the bent; 2 – column; 3 – link; 4 – U-shaped tray; 5 – screw; 6 – fixing plate; 7 – screw-jack; 8 – supporting plate.

An application for a patent of Russian Federation No. 2018127991, which is currently undergoing expert review, had been drawn up on the basis of the developed solution.

5. Conclusion

The existing level of technological reliability of the erection of slab cast over pre-cast joists does not provide for the required service properties of load-bearing structures of the buildings. The use of modern inventive techniques, in particular, of the theory of inventive problem solving, allows to obtain new patentable design and technological solutions, which, if applied, improve technological reliability of construction operations and reduce the possibility of construction defects. The following things have been developed according to the results of the study: an element for linking the reinforcement bars; a method for shaping the edges of the slab's cast-in-place part and the device for carrying it out; a method for erecting a pre-cast part of the bent and an erection device therefor. The novelty and the industrial applicability of the developed solutions have been confirmed with the Russian patents.

References

[1] Peurifoy R and Oberlender G 2010 *Formwork for Concrete Structures* (New York: McGraw-Hill Education) 544 p ISBN 978-0-07-163917-0
[2] Arciszewski T 2016 *Inventive Engineering: Knowledge and Skills for Creative Engineers* (Boca Raton: CRS Press) 417 p. ISBN 978-1-498-71124-1
[3] Chakrabarti A 2002 *Engineering Design Synthesis: Understanding, Approaches and Tools* (London: Springer) 330 p ISBN 978-1-849-96876-8
[4] Chechurin L 2016 *Research and Practice of the Theory of Inventive Problem Solving (TRIZ): Linking Creativity, Engineering and Innovation* (New York: Springer) 281 p ISBN 978-3-319-31782-3
[5] Hua Z, Yang J and Coulibaly S (2006) Integration TRIZ with Problem-solving Tools: A Literature Review from 1995 to 2006 1 (1-2) *International Journal of Business Innovation and Research* pp 111 – 128
[6] Gadd K 2011 *TRIZ for Engineers: Enabling Inventive Problem Solving* (Chichester: John Wiley & Sons) 504 p ISBN 978-0-470-74188-7
[7] Kennedy J and Watkins W 2012 *How to Invent and Protect Your Invention: A Guide to Patents for Scientists and Engineers* (New Jersey: John Willey & Sons) 226 p ISBN 978-1-118-36937-1
[8] Hitchcock D 2013 *Patent Searching Made Easy: How to do Patent Searches Online and in the Library* (Berkeley: NOLO) 272 p ISBN 978-1-413-31872-2
[9] Yu Jin, Chen Ronglin, Cai Yanyan Patent CN No 102691 A IPC E04C 5/16, 5/18, 5/20 Simple fixing device for staggered tube rod pieces
[10] Pressman D 2015 *How to Make Patent Drawings* (Berkeley: NOLO) 256 p ISBN 978-1-413-32156-2