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Contributions to the Theory and Practice of Rehabilitation During Exploitation of Reinforced Concrete Structures. Part I- Analysis and Applications

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Abstract

In the paper are analyzed defining aspects of the elaboration and composition of rehabilitation during exploitation systems for linear structural elements, respectively for planar elements. Are defined principles of conformation and applicability of these systems, also detailed constructive solutions that enable the materialization of these principles in the practice of rehabilitation during exploitation. Constructive solutions for consolidation of linear elements are presented exemplified at the consolidation of a reinforced concrete simply supported beam, at a roof caisson, at a slab with metal beams and at a reinforced concrete continuous trestle. Constructive solutions in the case of planar structures: rigid passive systems are presented (consolidation of the slab normal to its plane) and flexible passive systems (consolidation in slab plane).

Rezumat

În lucrare sunt analizate aspecte definitorii ale modului de alcătuire a sistemelor de reabilitare sub exploatare ale elementelor structurale liniare , respectiv de suprafaţă. Sunt definite principiile de conformare şi aplicabilitate a acestor sisteme, precum şi soluţii constructive de detaliu ce permit materializarea acestor principii în practica reabilitării sub exploatare. Soluţiile constructive pentru consolidarea elementelor liniare sunt prezentate exemplificativ la consolidarea unei grinzi de beton armat simplu rezemate, la un cheson de acoperiş, la un planşeu cu grinzi metalice si la o estacadă continuă de beton armat. Soluţiile constructive în cazul structurilor plane : sunt prezentate sisteme rigide pasive (consolidarea plăcii normal pe planul ei) şi sisteme flexibile pasive (consolidarea plăcii în planul ei).

Keywords: consolidation during exploitation solutions, load bearing capacity, linear structure consolidation, consolidated planar structure, active consolidation system, passive consolidation system.

Introduction

The process of consolidation of the structures requires a complex analysis of the causes that have caused, or contributed to the production of structural deficiencies and also identifying physical and mechanical characteristics of structural elements, with the aim of the design of a consolidation

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solution to ensure after the intervention, the initial design parameters or even better ones. Restrictions concerning the interruption of the production process during the period of carrying out the load bearing structure consolidation, due to the considerable financial losses which would be caused, require the adoption of consolidation solutions applicable without affecting the production process that is taking place in that industrial building.

The restoration process by local or global rehabilitation of the construction involves restoring:

- physical properties of the constitutive materials (integrity of masses, resistance to fatigue)
- mechanical properties (resistance, rigidity and ductility). [1]

Generally, the reduction of physical properties leads to solutions of rehabilitation which restore the load bearing capacity with or without the change of the static scheme, while, reduced mechanical properties lead to solutions that modify the initial static scheme restoring or even improvingg the dynamic behavior of the damaged structure. Next, are analyzed defining aspects of elaboration of rehabilitation during exploitation of linear structural elements, respectively, planar.

1. Consolidation solutions for linear structures

Consolidation systems for linear structures are made up of bar type elements (made of laminated profiles) which, after connecting with the consolidated structure (by means of specially designed metal parts), play a role of the taking over the tensile stresses resulting from the working together of the concrete structure and the consolidation system. According to the mode of working can be distinguished:

- active systems;
- passive systems.

1.1 Active Systems

The primary element of an active system is a high strength steel bar with which initial efforts are introduced into the reinforced concrete that is consolidated. Done by external prestressing, the system is effective for the rehabilitation or the increase of bearing capacity of a linear structural element. Use of prestressing for solving situations of insufficient bending resistance, for reinforced concrete or prestressed concrete elements, shall be applied to the concrete elements without degradation or to concrete elements having physical deficiencies (cracked, corroded, etc.).

Technologically, achieving an external prestressing requires:

- the choice of external prestressing reinforcemen layout (rectilinear or polygonal);
- the choice of prestressing effort transmission system.

Strengthening of reinforced concrete beam through active polygonal system is shown schematically in Fig. 1. It is emphasized the effect of efforts from the tie-rod on the reinforced concrete. The system offers the advantage of transforming the bent reinforced concrete element into an element subjected to eccentric compression. In addition the active polygonal system also ensures an increase in shear strength. From technological point of view, execution during exploitation of such a system has the great advantage of execution speed, the process being carried out dry and with a high degree of prefabrication.

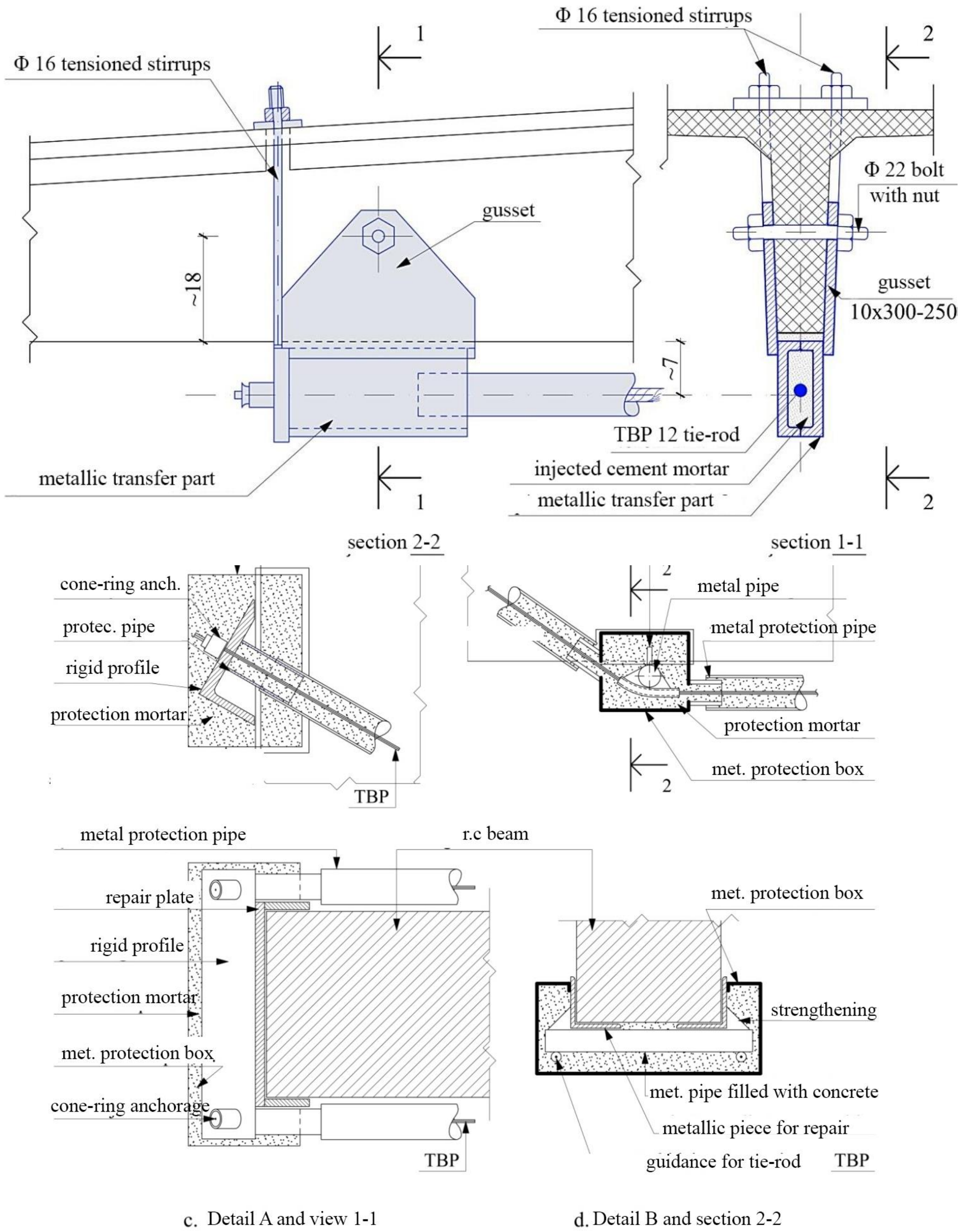


Figure 1. Active polygonal system:a) reinforced concrete beam with post tensioned tie-rod;
b) explanatory details of anchoring and deviation of acive polygonal post-tensioned tie-rod;
(c) post-tensioned polygonal tie-rod deflector
Figure 2. Linear element consolidation (reinforced concrete caisson) with active rectilinear tie-rod system

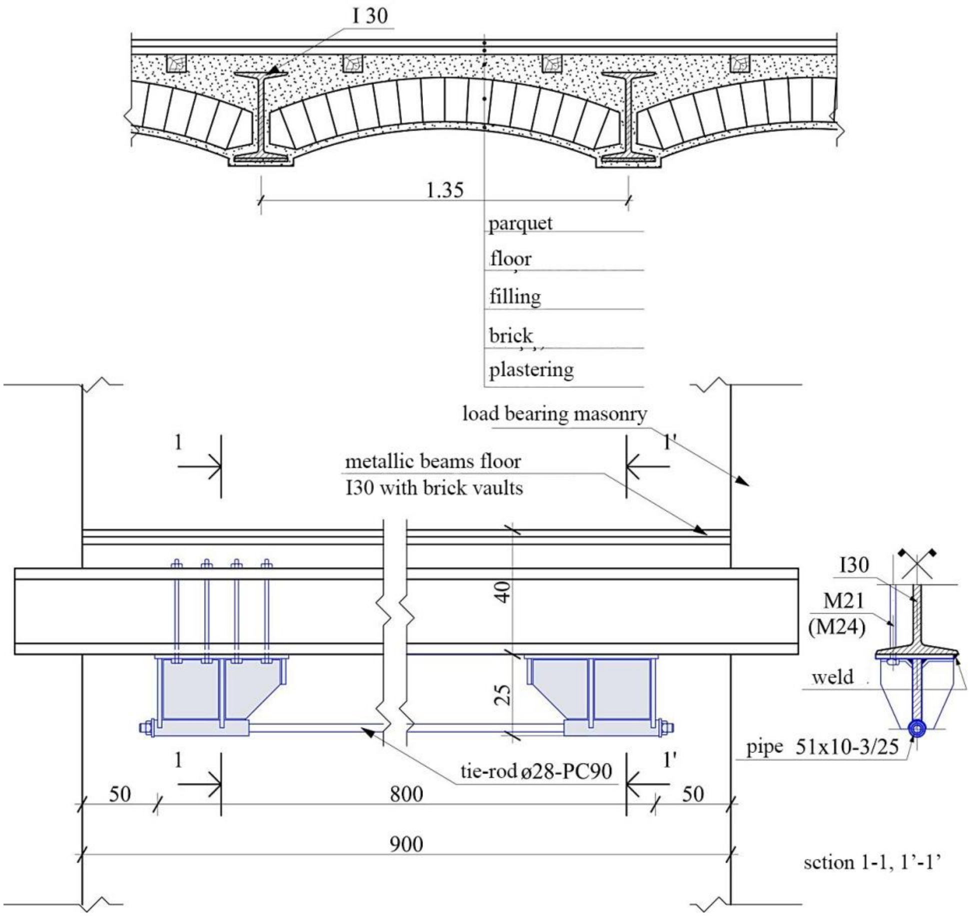


Figure 3. Beam type linear element consolidation with active tie-rod system

Consolidation solution with rectilinear active system is shown in Fig. 2. The transfer is solved with gusset plate and tensioned stirrup. The solution provides a good transfer control of the pretensioning force. In comparison with the polygonal system, which is done with two tensioning bars arranged symmetrically in relation to the vertical axis of the reinforced concrete element, the rectilinear prestressing system presented uses a single tensioning bar which implies a high accuracy in positioning relative to the element of reinforced concrete. It is necessary to check lateral stability. The rectilinear system does not provide an increase in shear strength.

In Fig. 3 are presented variants of metal beams consolidation with rectilinear active system with specific details for the transfer device. [2]

1.2 Passive Systems

Passive systems start working when is modified the deformation state (and implicitly the state of efforts) of consolidated elements compared with the situation which exists when the system is fitted. Their effect upon the element can be assimilated with the introduction of elastic supplementary supports, in the beam field, and with the emergence of horizontal compression forces that have to be compensated on its height.

Efficiency of the system is given by the elements in tension deformability (in the elastic stage). Dimensioning of elements with tensile stresses is done, as a result, by means of trials, until they reach the desired effectiveness i.e. the necessary load-bearing capacity of the ensemble, which is similar to the reduction of the stresses in the consolidated element.

Passive systems can be used both for restoring load bearing capacity of damaged elements as well as for the purpose of increasing it over the designed one.

1.2.1. Passive polygonal systems, with horizontal tie-rods

In the case of continuous beams that rest on pillars, the consolidation system can be solved as shown in Fig. 4 and 5. The number of supplementary elastic supports (dit. C, Fig. 6) created in the beam field may be 2 or 4, depending on the beam height which is consolidated and the necessary increase in load bearing capacity. The efficiency of inclined bars decreases with decreasing the angle made with horizontal, which conditions the placing of elastic supports in terms of the number and position.

Vertical component of the efforts in the inclined tie-rods ensures the effect of intermediate elastic support for the consolidated beam.

Horizontal components of the tensions that appear in the tie rods are taken over and balanced, in the field, by horizontal tie-rods, and in supports through intermediate support devices disposed at the top (Fig. 6, dit. A and B). Differences that may arise in the case of different loads in the fields (different loads, different openings) are transmitted through the system to end support devices, where, overlapping horizontal components from marginal fields are transferred to the consolidated element. The consolidated element is transformed into a continuous element on fixed supports (resting on the pillars) and elastic supports (due to the consolidation system) subjected to bending (from external forces) and compression (transmitted from end support devices). In the case of trestles the supporting device is limited in height to the height of a cross member, constituting also the support for the rail.

Connecting inclined tie-rods with the horizontal ones and with the support devices is done with hinge type connection, which provides an easy adaptability of the system to actual geometry of the element to be consolidated. The length of the thread at the ends is determined considering probable dimensional deviations of the consolidated element.

Mounting the support device on the superior face of the element, shall be made on the concrete cleaned of parts that may have been damaged, by means of an epoxy mortar.

The working of the system is done by tightening the nuts on the ends of the tilted tie-rods using a torque wrench. An more efficient start of working of the system can be achieved, in case of the existence of a mobile load on the consolidated element (bridge cranes, wheel carts, etc.), by loading neighboring fields of the field in which are tightened tie-rod nuts. The components of the consolidated system shall be crafted in specialized workshops, with a thorough inspection of the quality of joints. Dimensions and low weight of these elements ensure easy handling and mounting.

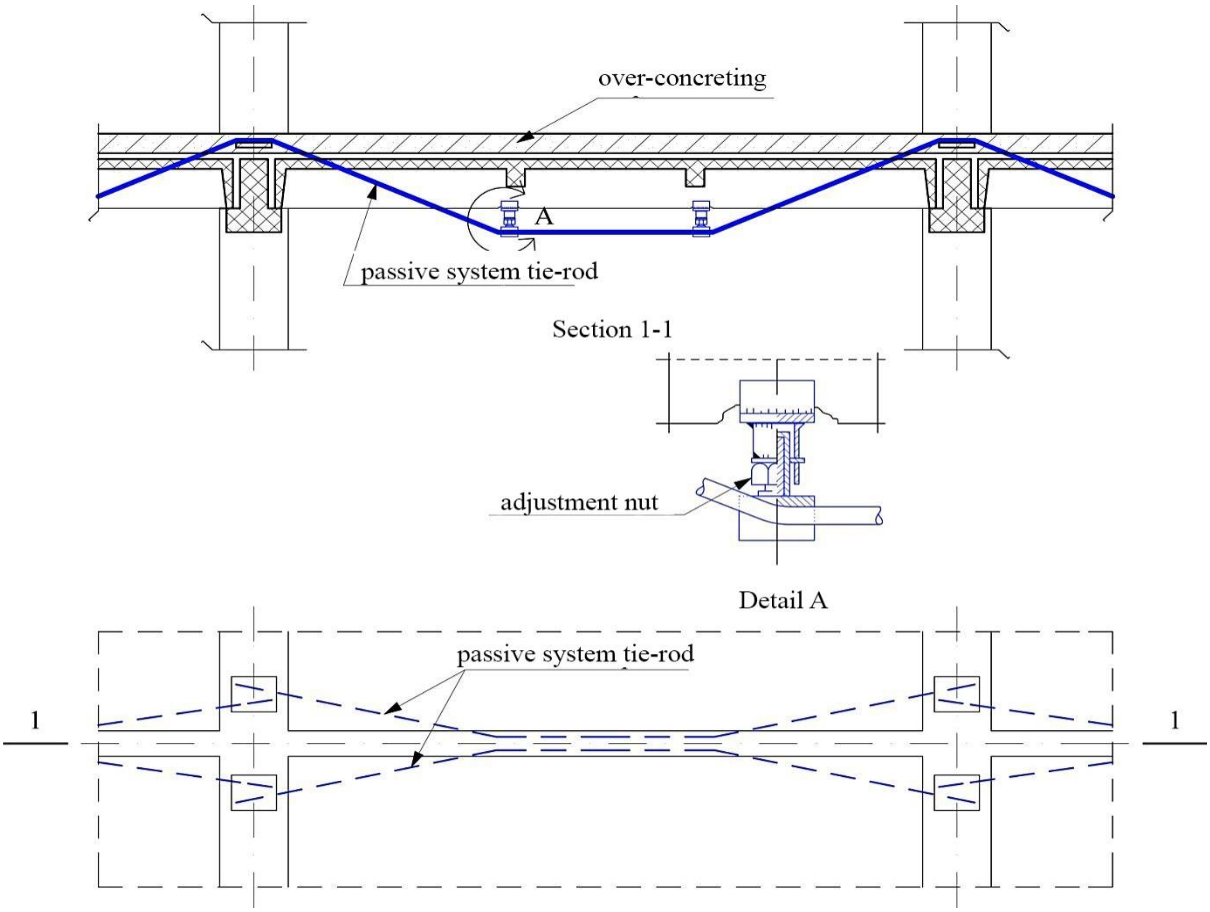


Figure 4.Consolidating with passive polygonal tie-rods. Variant

Operations to be carried out on-the-spot consist mostly in operations of assembly and do not pose significant difficulties from a technological point of view. The system of consolidation remains visible and shall be protected by painting. Here below are presented some images with linear concrete elements, reinforced with polygonal passive system – Photo 1 and 2.

1.2.2. Passive polygonal systems, with braces

For this consolidation system (Fig. 7) horizontal components of tension in tie-rods are taken by compressed bars and transmitted to pillars. The system is composed of ensembles arranged independently of each other, on the beam supports (pillars).

Theory of cutting and fitting is similar to the one shown in the previous point. The system is used with good results for inclinations of tie-rods from vertical up to 45 °.It is realized with a lower metal consumption than previous version, but the processing off horizontal components of tension in the tie rods is done by transfer of compression forces to the concrete pillars.

1.2.3. Passive tie-rods system for rehabilitation of vertical reinforced concrete cantilever at bridge crane trestle

Vertical reinforced concrete cantilevers, from the pillars, that hold the rolling track beams at crane bridge trestle have the role of fixing to horizontal forces the superior flange of the rolling track beam. Cantilever degradation generally occurs at the bottom, in the area of maximum moment.

The consolidation system (Fig. 8) is designed with the idea that we disposition the components only towards the exterior of the trestle, due to the presence of the bridge crane on the inside.

Adaptability to variations of the consolidated ensemble geometry is due to the 3 blocking pipes that can rotate in their supports and 2 inclined tie-rods threaded at one end- see Photo 3.

Resting of the metallic parts on concrete is done through a layer of an epoxy based putty layer. [2]

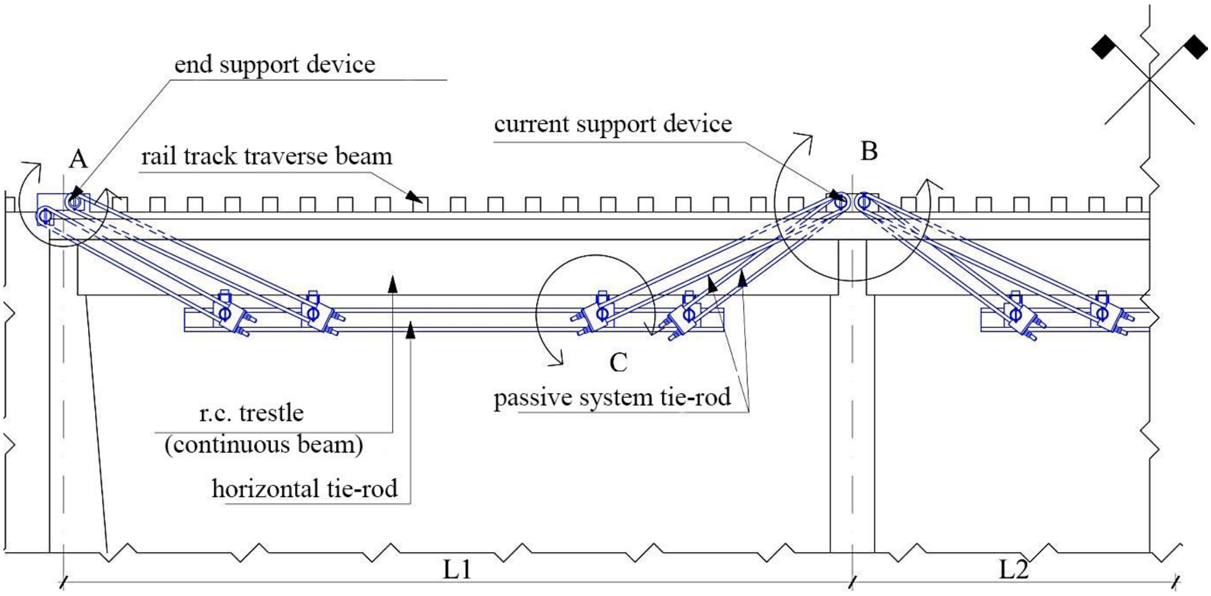


Figure 5. Continuous r.c. beam consolidation (trestle) with polygonal passive system

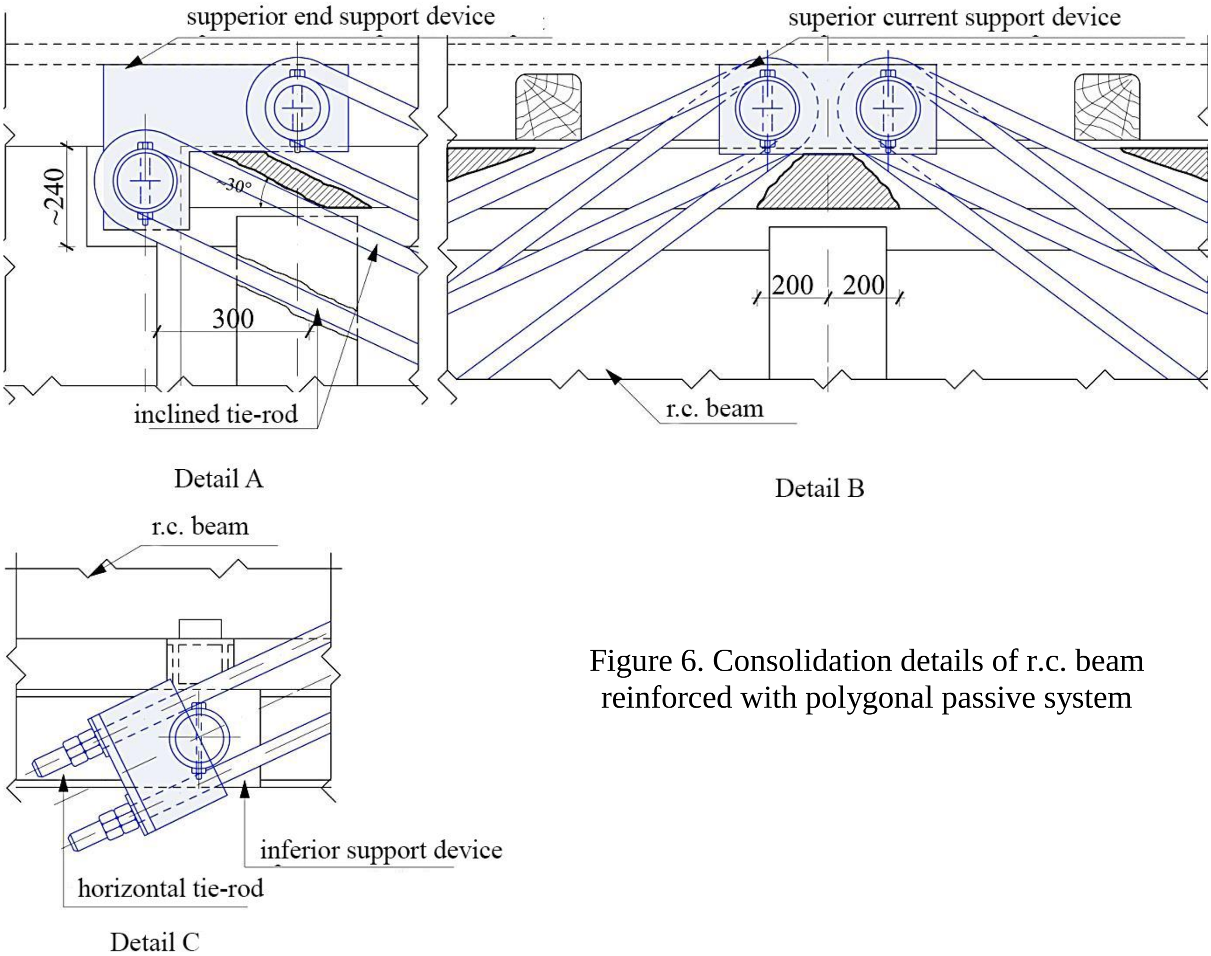


Figure 6. Consolidation details of r.c. beam reinforced with polygonal passive system

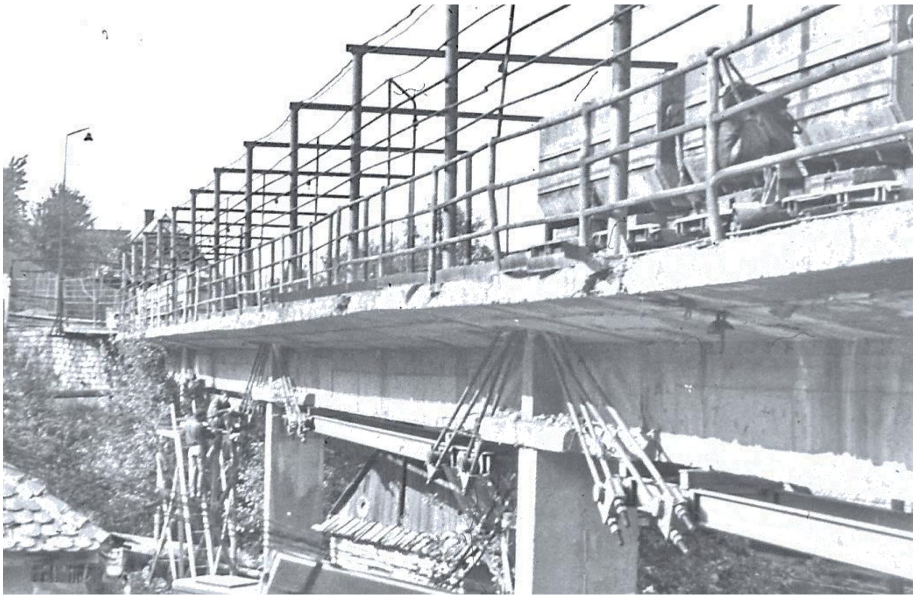
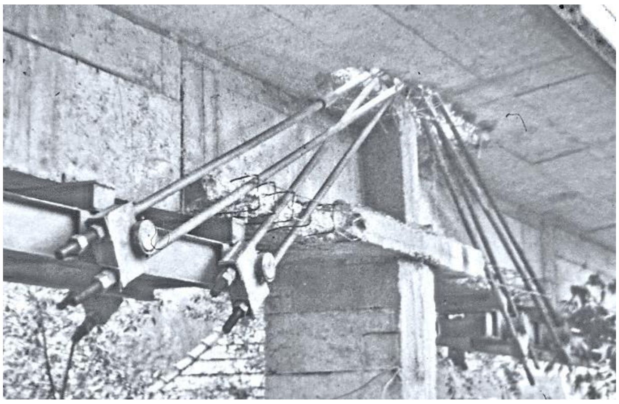
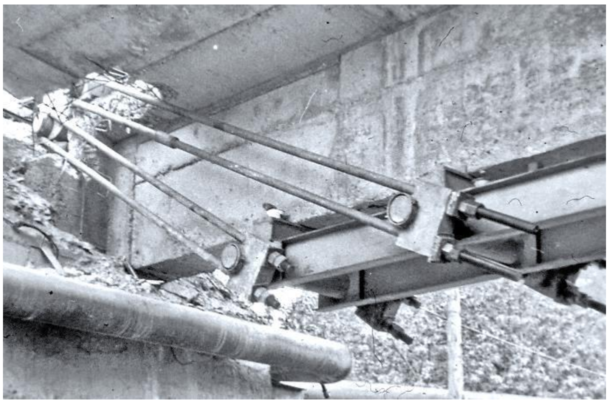
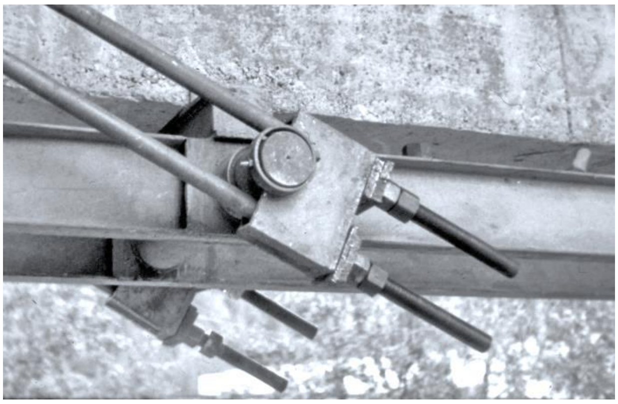


Photo 1.Consolidation during operation of a trestle for wheel carts filled with ore, mining exploitation Balan







(a) (b)
(c) (d)
(e)

Photo 2 (a-e). Details of the metallic consolidation system

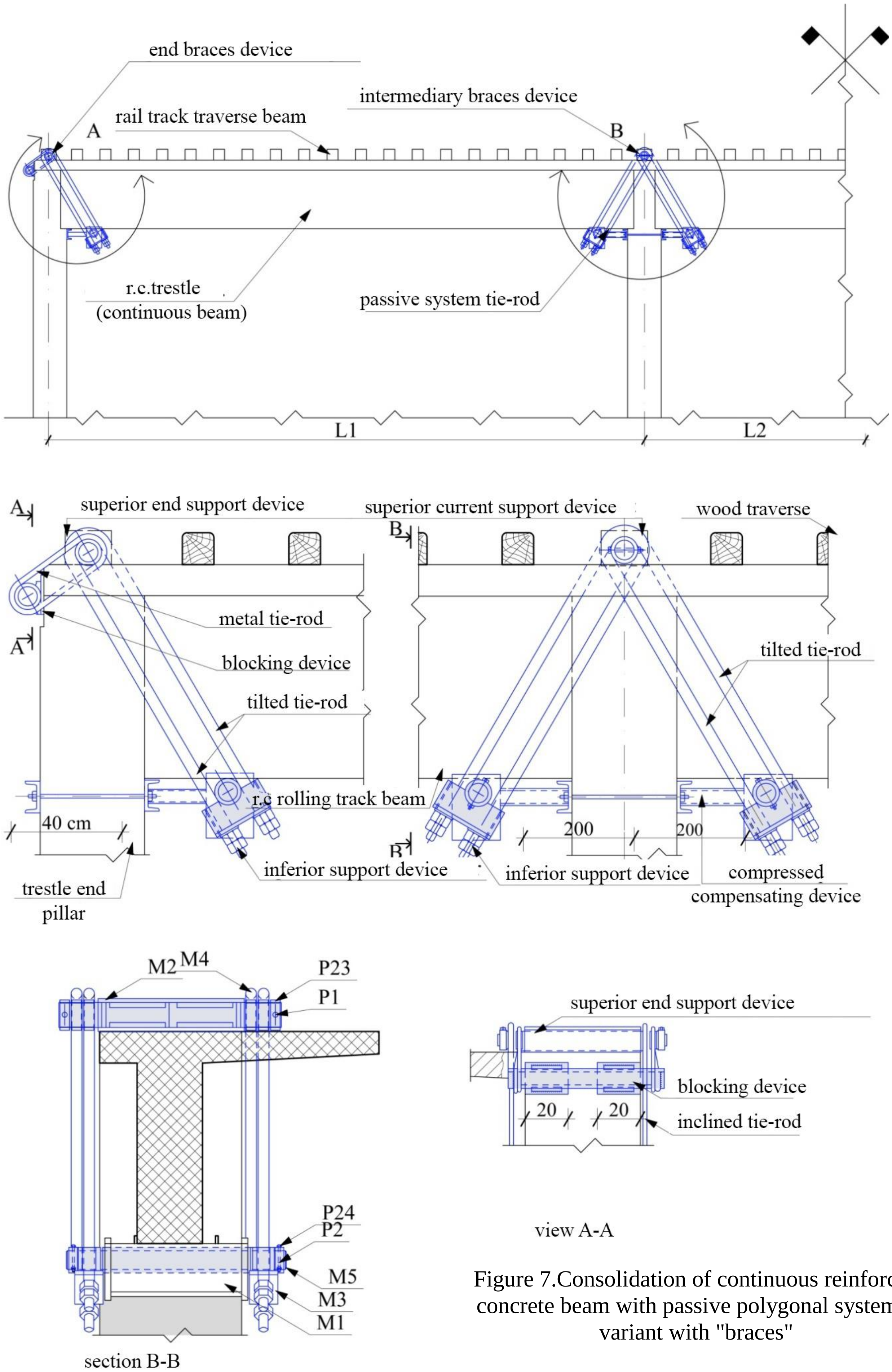


Figure 7.Consolidation of continuous reinforced concrete beam with passive polygonal system – variant with "braces"

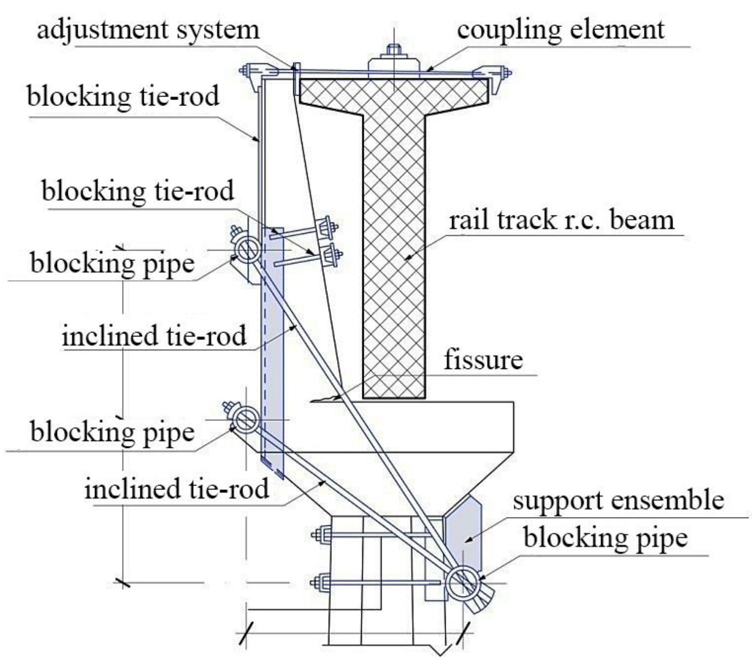


Figure 8. Reinfoced concrete cantilever consolidation for fixing rolling track beam – passive tie-rods system.

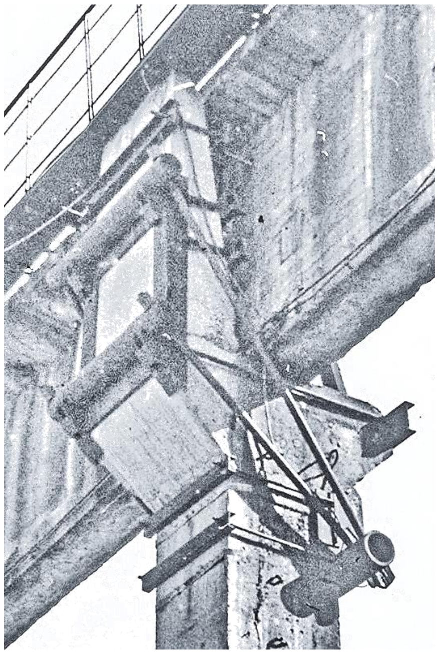


Photo 3. The same as Fig. 8. Consolidation during exploitation of a trestle at CCH Dej

2. Consolidation solutions for plane structures

2.1. Passive rigid systems
2.1.1. Rigid systems in bending are used in the rehabilitation of plane structures in the case of need for increasing load bearing capacity or rigidity normal to their plan. Consolidation solutions of surface elements during exploitation supposes the positioning of additional supports for floor plate, made of metal beams beams resting on the primary beams of the structure or on their own supports.

Analysis of the efforts in the plane element to be consolidated, necessary for detailing the consolidation solution, shall be made after the adoption of static schemes appropriate for real behavior of the surface element. Final efforts state in the consolidated plate is obtained by overlapping efforts developed under the permanent existing loads before activating the consolidation system, as calculated on the static scheme of the unconsolidated structure, with efforts arising under the action of live loads and dead loads disposed after the activation of the consolidation system, on the static scheme resulting from consolidation.

The analysis assumes the choice of appropriate position and rigidity of elements of the consolidation system, its efficiency and by default the effect on the efforts in consolidated element being determined by them.

A consolidation system with bending rigidity (Fig. 9), used for rehabilitation of plates, may be designed in the form of metal beams which shall be fixed between main beams faces with purlin type support devices Various types of support devices can be developed, their role being to transmit the reaction of metal consolidation beam to the main floor beams. The system must be adaptable to the actual geometry of the structure, keep the efficiency parameters and to ensure control of entry into work after activation.

Fitting technology and activation of the consolidation system is a function of the constructive solution chosen.

For example, for variant shown in Fig. 9, the succession of technological operations used in mounting and activating the system, is as follows:

• are drilled holes in the reinforced concrete plate for the fixing bolts of the consolidation system;

• is placed the metal beam in position (with epoxy mortar between metal and concrete) with the help of bolts that provide the working together of the elements;

• type purlin support devices are mounted, fixing bolts are tightened, resulting in a blockage of the metallic beam on supports, including to the horizontal movement;

• is welded the support apparatus to the metal beam.

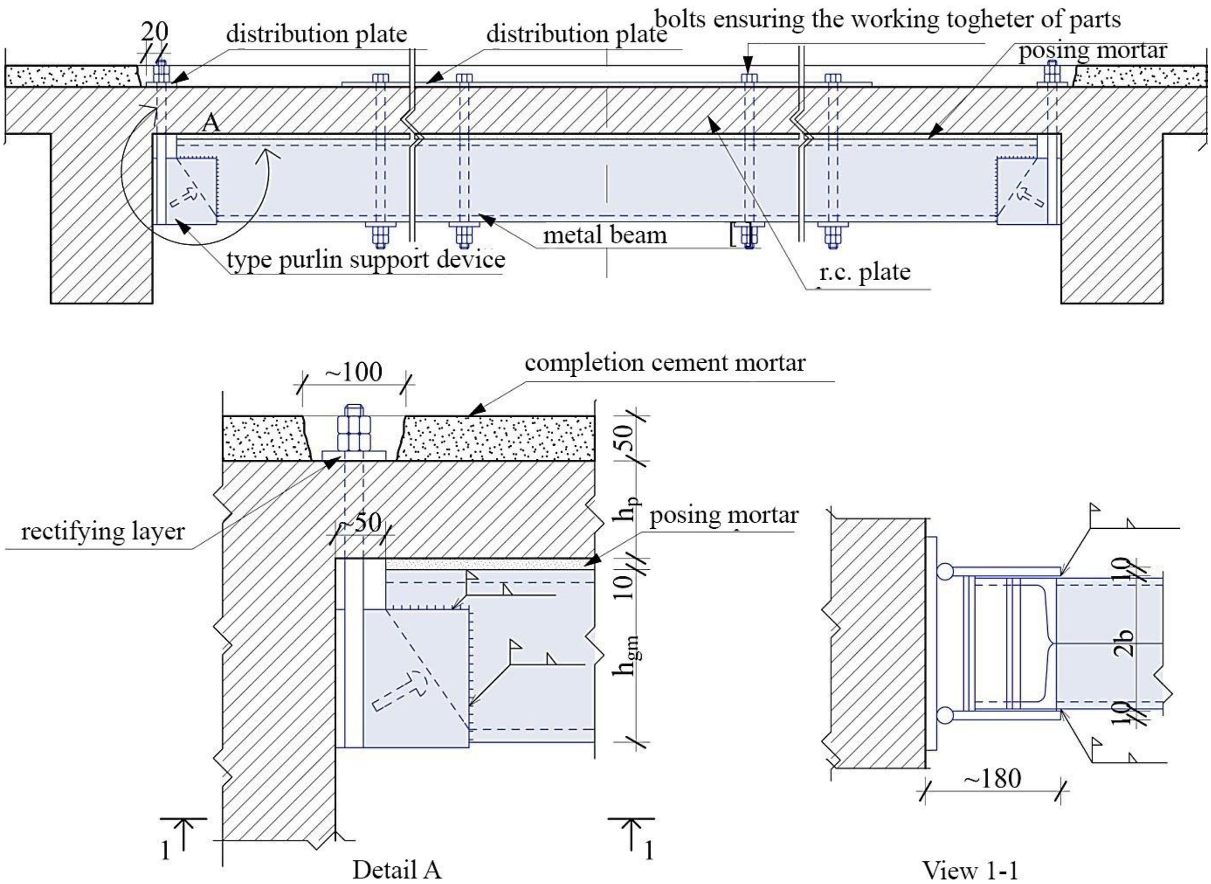


Figure 9. Strengthening of a reinforced concrete slab with rigid system

2.2. Flexible passive systems

Flexible systems are used in the rehabilitation of plane structures when it is needed the increase/recreation of the load bearing capacity or rigidity of the elements in their plan.

Restoring rigid plane effect behavior of the prefabricated floors [4] (see Fig. 10), damaged during seismic action by cracking along joints between prefabricated elements, shall be done by means of horizontal bracing, mounted under the floor, without interrupting current exploitation of the floor.

Braces, from round steel, are anchored in both central core as well as in perimetral, more flexible, structure, forcing them to work together to horizontal forces. The adaptability of the system to the geometry of the building is carried out by attaching the tie-rods with hinged connection at their intersection and by the provision of threaded areas at the ends.

In order to ensure instant entry in work of the elements of consolidation elements it shall be introduced in the bars of the system an initial effort of about 5-10 % of the capable effort.

Longitudinal rigidization of reinforced concrete trestles for a bridge crane can be carried out with the system shown in Fig. 11: a system of crossed tie-rods fixed into the ends of pillars by

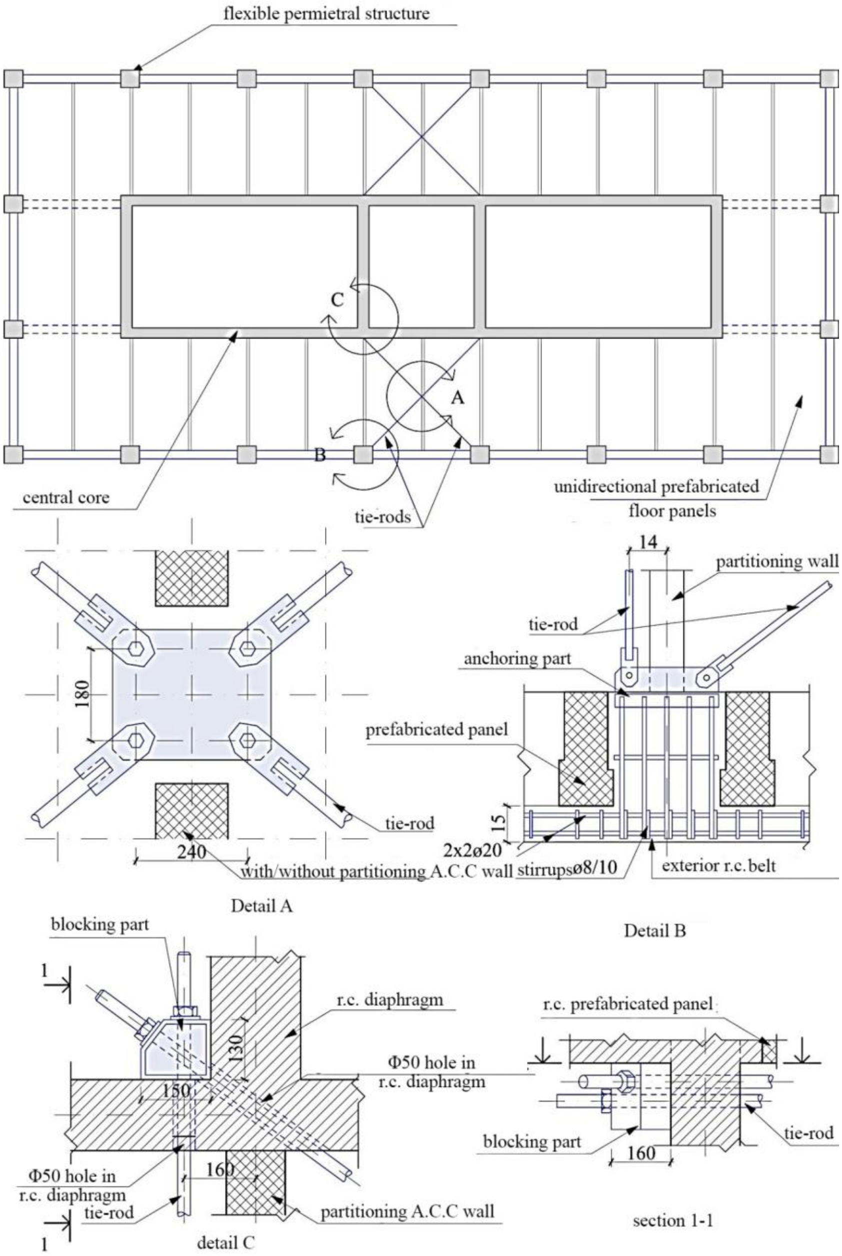


Figure 10. Restoring the rigid plane effect of the floor with passive tie-rods system

means of bolts. Slippage of the fixing device on the pillars is eliminated by stripping off the concrete concrete from the longitudinal reinforcement and welding on to it some fixers or by fixing with chemical anchors.

Sizing the system is done to the longitudinal force coming from the braking of the crane bridge. [2]

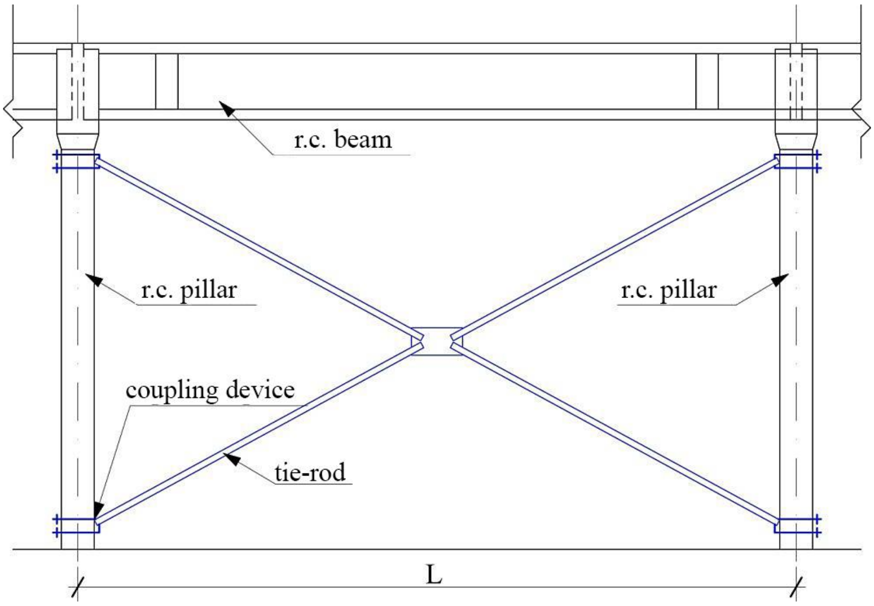


Figure 11. The longitudinal rigidization of a bridge crane trestle with passive tie-rods system

3. Aspects of the schematization for the calculation of the consolidation systems analyzed

For the analysis of the presented consolidation systems have been commented the particularities of the system in question.

In the case of polygonal passive systems used to reinforce linear elements, respectively in the case of passive flexible systems used to strengthen plane structures, the connections between metal sub-assemblies of the system are of hinge type. Connections between lower support devices (elastic supports introduced by the consolidation system) and the element of reinforced concrete are of simple support type, with or without taking into account the friction between metal-concrete. Connections between superior metal supporting devices and the concrete element, arranged at the ends of the element, are hinge type.

Modeling for the calculation of the support devices does not involve a special approach, its formation and the rigidity of constitutive elements permitting their dimensioning on the basis of efforts determined through static equilibrium relations.

4. Conclusions

The constructive solutions presented in this article allow the introduction in structural consolidation practice of the rehabilitation during exploitation concept of linear and plane elements. The solutions are demonstrative for the way in which the requirements of such a consolidation system may be carried out. The common element of the above mentioned solutions represent the geometry's adaptability/flexibility of the consolidation system at element's particularities with the maintainance of its efficiency.

5. References

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