

# Rehabilitation and Reinforcement of Ferroconcrete Walls with Reinforced Pilasters

Michal Novotný<sup>1</sup>, Jan Všecká<sup>1</sup>

<sup>1</sup> Vysoké učení technické v Brně, Fakulta stavební, Ústav technologie, mechanizace a řízení staveb, Veverí 331/95, Brno, 60200, Czech republic

novotny.m1@fce.vutbr.cz

**Abstract.** The article is focused on renovation, rehabilitation and reinforcement of high ferroconcrete walls. It tries to point out the experience of experts in solving problems with high ferroconcrete walls. During a revitalization of buildings of a military accommodation facility in Brno with basement and connecting corridors of an average height of 25 m, degradation of concrete, locally missing reinforcement and poor-quality concrete mixtures, the strength class of which varied between C8/10–C10/12, were found in these corridors. Along the height of the pilasters, the structure also showed the signs of torsion and it was assessed the structure also needs to be strengthened/reinforced besides the rehabilitation. The reinforcement structure had to be built from the very foundation of the building, it is linked to the existing wall and has three cascade levels. For the first two parts, a construction pit has been created with a Berliner wall, and these parts reach below the modified terrain, are reinforced with concrete reinforcement according to the structural project, concreted with cast concrete, and the foundation is reinforced with deep-based construction. The second and the third parts of the cascade stretch from the modified terrain between the pilasters to the top and they are made with a two-stage shotcrete technique, the first one has inbuilt concrete reinforcement with welded wire mesh and the second one composite mesh anchored by helical reinforcement without static effect. In terms of the damage of the structure, carbon fibre wrapping technique or grouting of the existing ferroconcrete structure was also used in the affected areas. The article also includes photo documentation of the repairs and structural damage prior to them.

## 1. Introduction

The article was based on construction changes to the buildings of the Military Accommodation Facility in Brno. The project addresses the rehabilitation of the supporting structures of the connecting corridors in the building of VUZ Brno in Chodská street between the halls of residence buildings A1–A4 and B1–B2. The existing complex of six buildings has 6 to 9 floors (1B + 6–9F), the buildings are interconnected by a corridor on all floors. Interconnection of individual buildings is solved by a straight staircase or a lift shaft, because the neighbouring buildings are offset by one half of the floor height.



## 2. Structural system of the buildings

The structure of the connecting corridors, as well as the whole building, was designed as a monolithic ferroconcrete structure. Among other things, the corridors also function as a longitudinal reinforcement for adjacent buildings built as a framework system. Individual buildings are designed in a modular grid of 6.0 m in both transverse and longitudinal directions. They have three modules in the transverse direction and six modules in the longitudinal direction. Prefabricated ceiling panels are laid on cross girders. The foundation of the building is done via transverse and longitudinal girders in combination with the base slab. It is a variant of interconnection of the base slab and the grid foundation made up of wall footing. The connecting corridors that are currently rehabilitated consist of wall columns, or pilasters, connecting a monolithic wall. The vertical walls between the pilasters have a thickness of 0.4 m and a width of 3.8 m. The cross-section of the columns is 0.5 x 0.7 m. The perimeter walls and columns of the corridors are reinforced on each floor of the adjacent building by transverse girders of 0.5 x 0.7 m.



**Figure 1.** Damaged structure of connecting bridge with detail of reinforced concrete structure (damaged) [1].

## 3. Failure description

In the case of structures, structural damage is evident at first sight. The visual aspect shows high degradation of the structure's surfaces. The defects and failures are mainly formed by fallen concrete covering layer of the reinforcement and the associated and increased corrosion of the main bearing reinforcement and stirrups, which are often even non-functional due to the damage. In many places, the surface layer has not yet fallen, but it is evident from the cracks that moisture and the environment reach the very reinforcement. During the construction and technical survey, samples (core drilling, hacking off, collection of fallen parts) were taken for laboratory tests. It was also possible to apply non-destructive methods to analyze the state of the structure - for example, georadar or ultrasound-based detectors.



**Figure 2.** Exposed reinforcement imperfections in the structure - various incorrect positions, missing reinforcement, reinforcement degradation.

The complete list of used instruments and methods is not available to the author of the article, it is more or less the "secret" of the author of the exploratory and static part of the documentation Ing. Jan Perla. However, it is possible to find a description of the various methods either in the literature or scholarly articles, for example here - in the article "Identification of the position of concrete reinforcement" [2, 3].

The results corresponded to the observed state, the cylindrical strength of the concrete mixture varied from 6.7–17.5 MPa, being 8.4–21.9 MPa after conversion to cubic strength. Existing concrete therefore corresponds to concrete of class C10/12. Further, after mechanical cleaning and blasting of the structure, more problems with the structure were discovered. First, locally missing reinforcement in the form of bearing horizontal reinforcement in the wall area between the pilasters was found. Subsequently, missing or very unevenly/poorly placed stirrups were also found in the pilaster structure.

These places – both the missing bearing reinforcement and the stirrups – were often at the points of the dummy joint, i.e. at the point of reinforcement contact, where the transfer of forces from one reinforcement to another must work properly. Another found defect, which contributes to the structure degradation, was the technological indiscipline in concreting and laying of concrete, which resulted in separation of the concrete additive and binder, where only a ballast bed was often found above the dummy joint, with a small amount or completely missing binder. The condition of the structure is very poor and due to the long-term durability, safety and functionality of the structure, it is necessary to properly rehabilitate and reinforce the structure.

#### **4. Proposed measure – repairs and reinforcement of reinforcing walls**

The method of securing individual connecting corridors will be very similar – only the missing reinforcement which will be subsequently replaced locally by carbon wrapping with reinforced metal flanges and its extent/amount are assessed, and the technological indiscipline in the form of ballast beds is repaired by grouting. For each wall, a construction pit has first been done due to the depth of the foundation and the building having basement, where the securing must have been connected to the existing foundations. In the construction pit, the existing foundation structure has been reinforced and the deep foundation for the newly formed reinforcement of the connecting corridor structure done by performing piling work with inserted rolled profiles. The last structural part of the new reinforcement system will be the reinforcement of the front walls between the pilasters in the form of reinforcement and meshes [4-6].

#### **5. Proposed repair work**

Depending on the extent of the damage and its location, the project has specified a repair procedure. This procedure can be divided into two basic areas. These are:

- A) Construction of the “foundation pit” and reinforcement of the foundation structures
- B) Reinforcement of the front wall between the pilasters

Let us now say something closer to these two types of construction.

##### ***A) Construction of the “foundation pit” and reinforcement of the foundation structures***

The excavation was secured by means of the so-called Berliner wall, with the construction timber put between HEB 120 beams with strutting in connection to the existing building construction. The size of the pit was made as small as possible, but with regard to the extent of the work performed. The depth of the support is individual in connection with the variable height of the existing or modified terrain. The drilling of piles with inserted HEB 120 beams is done with the HVS 246 rig with tools according to the current geology at the place of the borehole (spiral, hammer, ripping lip, roller, casing etc.). Riders, which are slender elements that transfer the load to the depth of the foundation soil, has been done in connection with the existing foundation.

Riders realization – HEB reinforcement is inserted into the borehole with a diameter of 220 mm and the borehole is filled from the bottom with a grouting needle with activated cement suspension IM30 with a pressure of up to 0.6 MPa – up to the height specified by the project. This is followed by gradual excavation and installation of wooden support between the steel beams. Together with the earthworks, strutting against the existing building according to the PD is done immediately with timbers of 140 x 140 mm.

Subsequently, the deep foundation for the newly formed structure linked with the existing structure will be done to reinforce the connecting corridor. Due to its weight, this will be supported by four new micropiles. Like the rider, the micropile is a slender element that transfers the load to the depth of the foundation base. With regard to space, the micropiles will be done by the LUMESA folding drilling rig. Due to the expanded existing foundation, a diamond pre-drilling will be done first in order to ensure as little damage to the existing structure as possible. A deep borehole with a diameter of up to 156 mm follows, immediately provided with a 76/10 mm diameter steel pipe with a smooth and sleeve part for grouting. Afterwards, the borehole is filled with activated cement suspension with a grouting needle from the bottom up to the mouth of the borehole. After the grout sets and starts to harden, grouting is carried out by means of a depth obturator at individual levels at a distance of 0.5 m by pressure up to 4.5 MPa. The micropile roots are finished in this construction and made in solid to solid powdery/sandy soil.





**Figure 3.** Two views of the reinforcement of the foundation structures before the concrete mixture was poured.

This new monolithic structure is placed on an expanded original foundation and linked to the foundations via bolts both horizontally and vertically and also supported on the micropiles. The reinforcement is cascading – the first cascade is 1500 mm high and 700 mm wide, with length always between the wall pillars. The second part of the cascade with a height of -200 mm below the modified terrain and a width of 300 mm is next; the reinforcement of the front wall continues. Standard concrete reinforcement of various diameters according to the PD, with proper interconnection of all parts of the structure from the back to the face, is used for the reinforcement. Vertical bars for reinforcing the wall above the terrain are raised from the second part of the cascade. R10 anchors in the new structure space, bonded in the connecting corridor openings with a two-component chemical adhesive, are used for linking the new and the original parts. The structure of the new part is designed from cast concrete of class C30/37 – XC2 into one-sided formwork.

### ***B) Reinforcement of the front wall between the pilasters***

After completing the previous steps, the construction pit is filled to the level of new wall reinforcement at the base. Compaction with plate compactors / rammers is a matter of course. For further work, it is necessary to erect a stable tubular scaffolding at the connecting corridor structure – this type, in combination with the system type, is probably the most variable. For further work, it is necessary to have appropriate work surfaces along the entire height of the connecting corridors. The scaffolding is used to bush hammer the surface of the structure as a basic step for the subsequent better surface blasting. The surface must therefore be thoroughly cleaned of incoherent parts of concrete, plaster, paint and completely roughened before the rehabilitation is started. These properties are achieved in the structure by a high-pressure water jet with a pressure of 2000–2500 bar. The blasting must be monitored at all times and the pressure must be regulated with regard to the quality of the existing concrete. After

blasting, the exposed reinforcement is rehabilitated. It is properly cleaned and chemically treated against corrosion. In case of high corrosion, any reinforcement loss is checked, and it is subsequently passivated (protected) by prescribed materials. At this moment, the entire structure is being checked, the technical condition is generally assessed with respect to all damage – i.e. imperfections, ballast beds and missing reinforcement. There is grouting of the ballast beds with the EBL machine with pressures of up to 1.3 MPa using packers with finely ground Portland microcement.

In the case of missing reinforcement, namely horizontal or vertical bearing reinforcement or stirrups on pillars, the wrapping must be carried out due to the transfer of stress from one reinforcement to another, and no less important is a deviation in case of the vertical reinforcement, where the reinforcement is exposed to horizontal alternating effects of tension and stress load due to wind. The wrapping consists in bonding the composite reinforcement made of carbon fabric and linked from the back to the face using strips and M10 threaded rods provided with washers and nuts. In the upper part, or more precisely above the terrain up to the vent gaps at the roof of the connecting corridor, it is a linked structure reinforcing the existing wall between the pillars with a final thickness of 140 mm made by the application of shotcrete of strength class C30/37. The total thickness consists of two technological spraying steps. The first one is the concrete reinforcement connected to the reinforcement from the foundations with proper lap joint according to the PD. The reinforcement is generally supplemented with KH30 welded wire mesh made of 6 mm wire and 100 x 100 mm meshes. Laying of the mesh is prescribed by the PD and it is necessary to lap joint by at least 2 meshes when connecting.

The first spraying layer is interconnected with the existing wall via R10 reinforcement anchors bonded with a two-component chemical adhesive and bound to the KH30 mesh. The reinforcement is further reinforced by closing edge profiles lining both sides of the columns and linked to these pillars by a flat plate bonded with a two-component adhesive. The first spraying layer is done in height with a bagged mixture by a dry shotcrete technique. The technique uses the SSB 05 machine and an air high-pressure compressor with a supply of water to the spraying nozzle. The application of the mixture is carried out with a spray gun from a distance of 0.6–1.5 m from the substrate by a slight circular spiral movement so as to create a uniform layer of concrete. The water coefficient is considered in the range of 0.4–0.6, and this ratio and the entire spraying quality are influenced by the worker's experience. This is the reason for mixing the water into the dry mixture in the gun at the nozzle by the movement of the valve by the worker – it is therefore necessary to allocate the most experienced team members for this work. The amount of fallen material in bagged (very dry and fine) mixtures is up to 20%. The fallen material must not be used again.

The second layer is a surface layer. It is reinforced with composite mesh of basalt reinforcement with fibre diameter of 3 mm and meshes of 100 x 100 mm. Thanks to its technological base, the material is non-corroding, the anchoring of the mesh is done using cold-drawn helical stainless-steel reinforcement. The composite is, with a sufficient protection, linked to these helical anchors with a diameter of 4.5 mm, which are bonded in the structure with a two-component chemical adhesive. The composite reinforcement serves as a reinforcement layer for shotcrete, which is intended as shrinkage prevention, however, it does not serve for static effect of the linked structure. The final bearing layer of the linked structure follows, which is, due to the application of further technological steps of the façade, adjusted to prescribed shapes by tearing.





**Figure 4.** On the left already complete reinforcement of the foundation before the wall reinforcement, on the right a realization scaffold for the installation of wall reinforcement - KARI and polymer networks.



**Figure 5.** Anchor reinforcement and KARI nets between pilasters ready to apply shotcrete.



**Figure 6.** Left - made polymer mesh anchored by helical reinforcement before application of sprayed concrete, right - made wrapping and reinforcement of the structure by steel profiles and carbon slats

## 6. Conclusion

Concrete structures are very demanding not only for the design but also in terms of the execution phase. We must not forget about the possible emerging risks during the implementation work – it is difficult to determine which activity is less or more important. Every designer must look at the work with the utmost caution and humility, the client must not save at the expense of the work in case of complex structures, but must cooperate with the designer within the framework of the designer's supervision, who personally overlooks the work. When making any concrete structures, it is necessary to strictly observe the PD, technological discipline and check the supplied materials to minimize future defects, concrete degradation, durability and safety of the whole structure.

## References

- [1] J. Všecká, Author's photo archive, 2019.
- [2] M. Ďubek, M. Bederka, and M. Grinč. "Identification of the position reinforcement embedded in concrete," *Buildustry*, number 4/2017, pp. 28-31, 2017.
- [3] M. Ďubek, P. Makýš, S. Ďuběk, and M. Petro. "The Evaluation of the Content of Fibers in Steel Fiber Reinforced Structures and Image Analysis," *Journal of civil engineering and management*, number 24, pp. 183-192, 2018.
- [4] R. Drochytka, J. Dohnálek, J. Bydžovský, V. Pumpr, A. Dufka, and P. Dohnálek, *Technical conditions for rehabilitation of concrete structures*, 2012.
- [5] ČSN 73 1201. *Design of concrete structures of buildings*, Prague, The Institute of Technical Standardization, Metrology and State Testing, 2010.
- [6] ČSN EN 1990. *Eurocode: Basis of structural design*. Prague, The Institute of Technical Standardization, Metrology and State Testing, 2004.