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Design analysis of strengthening a damaged supporting structure in a swimming pool building

Leopold Kruszka[1], Ryszard Chmielewski[2]

Faculty of Civil Engineering and Geodesy, Military University of Technology, Warsaw, Poland

E-mail: [1]leopold.kruszka@wat.edu.pl (corresponding author)

Abstract. The issue of strengthening the supporting structure of the swimming pool building, with a special attention on damaged reinforced concrete pillars in the sub-pool, is presented. The technical condition of those pillars in the basement of the swimming pool was defined as the risk of structural collapse. Numerous cracks and the occurrence of deformation of reinforcing bars were noticed. Three columns were damaged in basement rooms. First of all, the cause of damage was determined. The actual load carrying capacity of the built pillars was checked. To this aim, the geometry of the columns was checked first and the actual strength class of built-in concrete. It was found that all columns were made of concrete of the same strength class and good homogeneity of concrete, but this concrete did not meet the standard requirements as a construction material for reinforced concrete structures. The new supporting structure was designed in the form of four-leg cross-sections made of an isosceles angle profile. Due to structural damage, an additional safety factor was adopted, increasing the total load per pillar by 50%. This approach took into account the possible redistribution of loads in the building structure that occurred as a result of damages.

Keywords: strengthening of supporting structure, reinforced concrete pillar.

Introduction

The most common cause of construction failure in Poland are chance events that occur in nature and around human activity. The second cause in terms of occurrence are maintenance errors. Building failures that are a consequence of faulty performance are on the third place and are relatively rare: 4.1% in 2017, 5.05% in 2014–2017. The main reason behind these errors is non-conformity with technological requirements: 76.9% in 2017, 64.8% in 2014–2017. The presented case of the newly built swimming pool building is not a case of construction disaster but is an example of a construction disaster risk brought by non-compliance with the performance technology.

The emergence of damage to the pillars of the load bearing structure was sudden, nevertheless a building manager responded to it in a correct way by performing a protective structure in emergency mode. Reinforced concrete pillar in a basement underneath the swimming pool was subject to damage. The ceiling substring that leaned on the pillar was made of steel rolled beams.

The following diagnostic methodology was adopted (Chmielewski & Kruszka, 2005–2017, 2015; Kruszka, 2018):

- technical inspection of damaged construction elements of the building,
- structural and geometric inventory,
- analysis of load per single construction element,
- selection of the extent and technology of necessary repair works.

Currently, many technologies to strengthen reinforced concrete structures are available. The mentioned technologies are mainly based on the use of high strength materials and reinforcement strengthening with carbon fiber tapes (Kruszka, 2018; Brühwiler & Denarié, 2013; Radziszewska-Zielina, Kania, & Śladowski, 2018; Ebead & El-Sherif, 2019; Rius, Cladera, Ribas, & Mas, 2019; Oleszek & Radomski, 2016). While designing the reinforcement of the damaged structure of reinforced concrete pillars, the aim was to ensure compability of both the supporting structure and a damaged building structure.

Description of the building structure

The building of the indoor swimming pool and a gym for corrective exercise is located in a primary school – see Figure 1. The mentioned building was built as a light-frame construction. The roof of the building is made of purlins CN 180 made of St3SX steel supported by prestressed concrete beams of the span of 18.0 m. The roof structure is made of steel fold sheet TR40 that is 0.75 mm thick and based on steel roof purlins. The steel roof sheets carry the insulation of styrofoam panels and a shingle roof cover. Intermediate floors are made of hollow flooring slabs, type II, reinforced concrete elements of the roof were poured of B12 (C12/15) concrete and reinforced with class A III steel.

Figure 1. Building of the indoor pool

Interior and exterior walls at the level of the first floor are made of solid ceramic class 7.5 brick on cement and lime mortar of class 3. Interior and exterior basements walls are made of solid ceramic class 10 brick on cement and lime mortar of class 5. Basement walls were additionally overburdened with ground pressure therefore they were strengthened with ring-beams and columns made of B15 (C12/15) concrete reinforced with class A III steel. Steel ceiling substrings are made of two connected rolled I-sections NP 260 or NP 220 from St3SX steel. I-sections are connected by welding top and bottom belts with 10 cm joints every 10.5 m. The damaged pillars that are identified at the 5.4 position in the project documentation have a square cross-section 25×25 cm and are reinforced with four steel A III bars with a diameter of 14 mm. The building has a swimming pool (Figure 2), whose pool basin is a separate supporting structure.

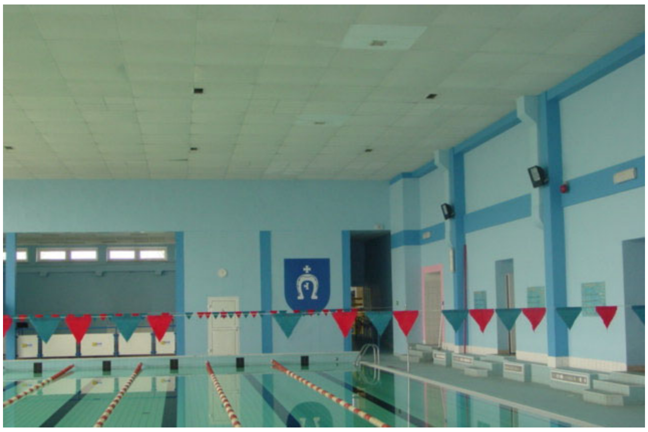

Figure 2. Indoor swimming pool

During on-site inspection that involved visual inspection of all the elements of the construction of the load-bearing structure it was found to be in a good technical condition, apart from the damaged supporting beams in the basement of the building – see Figure 3. The pillars were secured with a temporary steel supporting construction that was ordered by the building manager.

Analysis of causes of the observed abnormalities

The technical condition of the damaged reinforced pillars in the swimming pool basement was described as the risk of the structural collapse. During the on-site inspection, numerous cracks were observed as well as the occurrence of deformations in the form of buckling. Three columns were been damaged in the basement – shortly (about a week) after the appearance of vertical cracks on one of the first pillar (Figure 3a), column no 1), the next two were been damaged (Figure 3a), columns no 2 and no 3). After the first pillar lost its load bearing capacity, the weight was transferred onto two neighbouring pillars that got overloaded as a result. The building manager immediately ordered construction works that involved assembling a temporary steel supporting structure that prevented a building collapse.

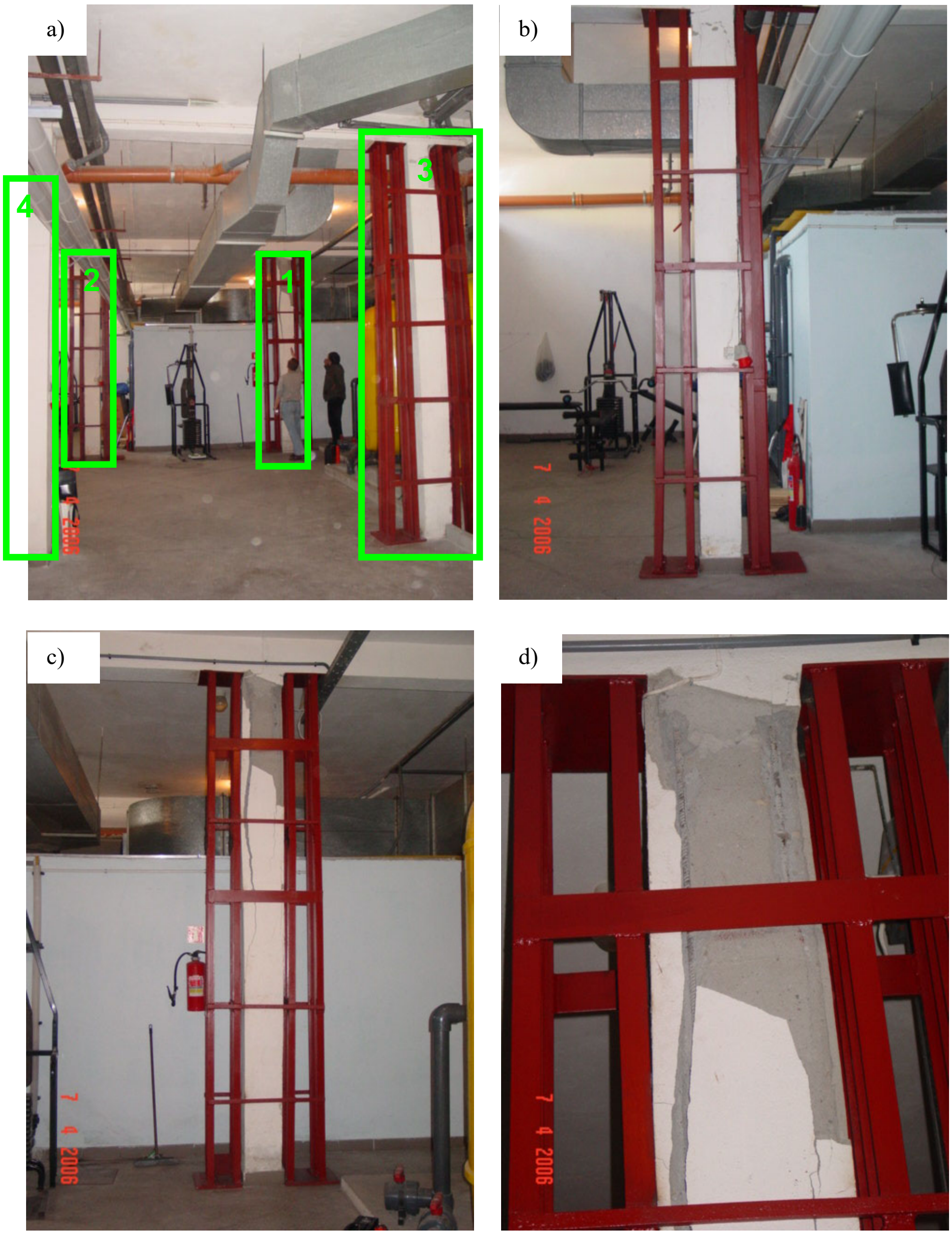

Figure 3. Overall views of the damaged reinforced concrete pillars in the basement.
Damaged pillars are marked with numbers 1, 2, 3

The assessment of the concrete grade in the damaged pillars was conducted with a use of the Schmidt hammer type *N* following the ITB Technical Recommendation no 210. The assessment was carried on side surfaces of all the pillars in the sub-basin basement (position 5.4 in the design documentation). It was concluded that all the pillars were made of the same class concrete with a good material uniformity (ν_R = 11%). The average number of hammer reflections was L = 22. Due to the lack of possibility to drill opencast works on the pillars, it was not possible to verify the hypothetical curve for the material of the columns. Concrete class is determined by the strength of the mortar in a form of so called "composite matrix". Concrete in the damaged pillars was assessed in air-dried state. With a use of hypothetical curve from ITB Technical Recommendation no 210:

$$f_{cm} = 0.04094L^2 - 0.91425L + 7.4\,. \quad (1)$$

The strength of the concrete was estimated at 7.1 MPa. Its homogeneity was good. Using own formula that was developed for concrete in the 1980's:

$$f_{cm} = 0.076L^2 - 2.3L + 25.7\,. \quad (2)$$

The strength was estimated at 10.6 MPa. The average concrete strength in the damaged pillars was concluded as corresponding with class B10 (C8/10 according to PN-EN 206-1:2002 (Polski Komitet Normalizacyny, 2002)). This concrete did not meet the standard requirements of construction material for use in reinforced concrete constructions. The calculation tests of the strength of the pillars, taking into account the incorrect class of the concrete material, were performed. The total design load per the damaged pillar was estimated as 450.86 kN.

Calculation tests of the strength of the pillars taking into account the incorrect class of the concrete material were performed. The total design load per a damaged pillar was estimated as 450.86 kN. According to Figure 4 the following geometrical and material data for a damaged reinforced concrete pillar were accepted:

A_{core} = 441 cm^2 (cross-sectional area of the concrete), A_{s1} = 0.28 cm^2 (cross-sectional area of the tirrup), A_{s2} = 6.16 cm^2 (cross-sectional area of the primary reinforcement), α_{cc} = 0.85 (safety factor), f_{yd} = 350 MPa (design strength of the steel of the primary reinforcement), f_{yd}* = 190 MPa (design strength of the steel of the stirrup).
For concrete strength class B15 (C10/15) that according to the design project should be used, the design shear strength is f_{cd} = 8 MPa.

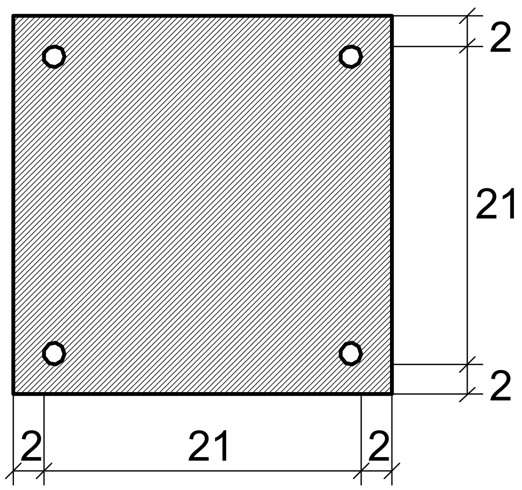

Figure 4. Reinforced concrete pillar cross-section. Dimensions in cm

The pillar design load capacity for a correct class of concrete is:

$$N_{RD} = 0.9 \propto_{cc} f_{cd} A_{core} + f_{yd} A_{s2} + 2.5 f_{yd}^{*} A_{s1} = 498.70 \text{ kN}, \quad (3)$$

where N_{Rd} = 498.79 kN – ultimate limit state (ULS) condition is met.

Taking into account the actual concrete class C8/10 that was found in the damaged pillars as f_{cd} = 5.2 MPa, then beam resistance is: N_{Rd} = 404.33 kN, and the ultimate limit state (ULS) condition is not met.

Discussion and proposal of repair works

The next step was to design a reinforcement for the above supporting structure. This new structure was designed in a form of four-arm equal-angled cross-sections. Due to constructional damage, an additional safety factor was added in order to increase the total load exerted on a single pillar by 50%. This approach enables the redistribution of loads within the building structure that occurred as a result of the damage.

The new construction of the reinforced concrete pillars was designed as a four-arm equal-angled cross-sections of L 80×80×10 mm made of 18G2A steel where f_{yd} = 295 MPa. The load per pillar is equal to Q = 450.86 kN, the additional safety factor (adopted due to the damage) is equal to γ_{dod} = 1.5, therefore the total calculated load imposed per pillar is $Q(r)$ = 676.29 kN.

The load capacity of the steel pillars was checked first, it was assumed that the damaged reinforced concrete pillars do not transmit the load imposed on them. The total load will be carried out by the new supporting steel construction while the reinforced concrete elements will remain as non-structural components. The slenderness of the angled cross-sections was 29.70. Comparative slenderness of the cross-section λ_p is:

$$\lambda_p = 84\sqrt{215 / f_d} = 71.71 . \tag{4}$$

The relative slenderness ratios are:

– for the single L-section:

$$\overline{\lambda_1} = \frac{\lambda_v}{\lambda_p} = \frac{20.747}{71.71} = 0.289,$$

– for whole the multi-constituent profile:

$$\overline{\lambda_p} = \frac{\lambda_m}{\lambda_p} = \frac{20.7}{71.71} = 0.414 ,$$

where: λ_v – substitute slenderness of a single L-section, λ_m –slenderness of a single profile of multi-constituent.

Because λ_p is less than 250, the load bearing capacity of the cross-section N_{Rc} was determined with the formula:

$$N_{Rc} = \psi A f_d , \tag{5}$$

where: ψ – the reduction factor of the design load capacity of the cross-section, equal to min(φ_1, φ_p); A – cross-section area – 60.4 cm^2; φ_1 – buckling coefficient for a single branch constituent: 0.956; φ_p – buckling coefficient of a cross-section: 0.899.

Therefore: N_{Rc} = 0.899·60.4 cm^2·295 MPa, and N_{Rc} = 1602 kN < $Q(r)$ = 676.29 kN.

The calculated condition of the ultimate limit state (ULS) of the pillar was fulfilled.

The further step was to check the load-bearing capacity of pillar battens. The column battens were designed as flat bars of cross-sectional dimension of 6×100 mm and bending strength W = 60 cm^3, cross-section area of A_v = 6 cm^2.

The lateral force in batten plates V_Q is:

$$V_Q = \frac{0.012 Q^{(r)} l_1}{2a} ,$$

where: a – column spacing: 213.2 mm; l_1 – calculated branch length between the batten axes,

$$V_Q = \frac{0.012 \cdot 676.29 \text{ kN} \cdot 500 \text{ mm}}{2 \cdot 213.2 \text{ mm}} = 9.52 \text{ kN} .$$

The bending moment in batten plates is:

$$M_Q = \frac{0.012 Q(r) l_1}{4} ;$$

$$M_Q = \frac{0.012 \cdot 676.29 \text{ kN} \cdot 500 \text{ mm}}{4} = 1.01 \text{ kNm} .$$

The designed bearing load capacity is calculated:

$$M_{R,V} = M_R \left(1 - \left(\frac{V_Q}{V_R} \right)^2 \right) , \tag{6}$$

where: M_R – the calculated load-bearing capacity of the cross section with one-way banding; V_R – the calculated shearing load-bearing capacity of the cross section.

$$M_R = W \cdot f_d = 60 \text{ cm}^3 \cdot 295 \text{ MPa} = 1.77 \text{ kNm};$$

$$V_R = 0.58 \cdot A_v \cdot f_d = 0.58 \cdot 6 \text{ cm}^2 \cdot 295 \text{ MPa} = 102.66 \text{ kN},$$

hence:

$$M_{R,V} = 1.77\ \text{kNm}\left(1-\left(\frac{9.52\ \text{kN}}{102.66\ \text{kN}}\right)^2\right) = 1.755\ \text{kNm}$$

$M_{R,V} > M_Q$ the condition of the load-bearing capacity of the batten plates was been fulfilled.

The last of the designed elements were the column baseplates. The total design load carried by the pillars onto the spread foundation is 676.29 kN. The total computed strength of the B15 concrete in terms of pressure is equal to 8 MPa, the floor concrete was crosschecked with the sclerometric method.

The required baseplate surface area F_b is:

$$F_b = \frac{676.29\ \text{kN}}{8\ \text{MPa}} = 845.36\ \text{cm}^2 .$$

A 42×42 cm bottom sheet with a 22×22 cm opening and a total surface of 1280 cm^2 was been adopted. It is always very important to pay special attention to establishing if the correct technology used for construction works after a reported risk of structural collapse. Construction works should be carried in such a way that when the damaged construction elements are reinforced, they should not be further damaged as a result of the work.

In the case of the damaged load-bearing pillars of the swimming pool building it was recommended to do the following steps:

- preparatory work (gathering construction materials, equipment and devices),
- moving the support structure 0.5 m away from each side of the damaged columns,
- taking off damaged wall plasters and cracked concrete from the damaged pillars,
- making holes in the basement floor to the upper surface of footings and removal of the plaster of the ceiling substrings in order to directly base the steel beams, the minimum dimensions of the holes in the flooring are 60×60 cm,
- hacking off the coating of the reinforcement bars at the top and bottom part of the reinforced concrete columns for plates at the middle and base of the column,
- the assembly of steel elements for reinforcing the concrete pillars in previously prepared places,
- filling of the spaces between the steel elements of the reinforcement of the construction and the damaged reinforced concrete ceiling using non-shrinking repair cement mortar,
- corrosion protection of the built-in steel elements,
- plastering of the pillars – plaster on the Rabitz steel mesh,
- filling in the floor around the reinforced pillars.

The construction work should be carried out sequentially for each pillar. The removal of the existing steel supporting the structures can only be done after all four damaged pillars are reinforced.

Conclusions

The technical condition of the load-bearing structure of the building is described as good, apart from the damaged reinforced concrete pillars in the basement of this building. The mentioned pillars are currently supported by the temporary protective structure. Because of the quick reaction of the building manager and user of the facility, the construction of the steel supporting structure of the damaged pillars and steel substrings have caused that the damage in this part of the basement did not spread onto the remaining elements of the load-bearing structure of the described building. The cause of the damage to three reinforced concrete load-bearing pillars in the swimming pool basement was an incorrect structural concrete whose strength class was established as C8/10. The fourth reinforced concrete pillar that was not damaged has also been made of insufficient C8/10 concrete class. Due to the damage to the reinforced concrete pillars in the basement of the building, the securing renovation work required a construction permit. The mentioned permit was obtained on the basis of the design project developed by the authors of this paper (Chmielewski & Kruszka, 2006). The construction works were carried under the constant supervision of the authors. The temporary steel protective structures raised in order to strengthen the damaged pillars were removed only after the planned reinforcement of all the pillars in the basement was completed. The normal use of the building facilities resumed after the planned construction works were completed and handed over. Currently, few years after the renovation work was finished, the building is fully functioning without any limitations.

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