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Diagnosis, Repair, Strengthening and Monitoring of a Postindustrial Heritage Site: Flyover of the Odra Cement Factory

Diagnoza, naprawa, wzmocnienie i monitoring poprzemysłowego zabytku – estakady Cementowni „Odra"

Keywords: historical structure, reinforced concrete, diagnosis, strengthening, flyover

Słowa kluczowe: obiekt zabytkowy, żelbet, diagnoza, wzmocnienie, estakada przenośnikowa

Introduction

Postindustrial heritage from the nineteenth century and first half of the twentieth century, like buildings and architectural complexes from other eras, requires protection, revaluation, or revitalization. In the case of disused complexes, this also entails adaptation and an idea for a new form of use that would allow these complexes to survive [Kulikov et al. 2019, pp. 140–146; Ivashko, 2019, pp. 113–117].

One example of industrial heritage, valuable in terms of historical substance and place-based tradition, is the Odra Cement Factory in Opole, a complex that was established at the beginning of the twentieth century and still functions today.

The detailed subject of the study was the fully operational gallery structure (flyover) of a stone conveyor belt, built around 1910 (Fig. 1). The flyover is a listed structure and is under statutory conservation. The flyover structure is a two-span, reinforced-concrete, three-dimensional truss with rigid nodes. As part of an investigation that had been ongoing since 2007 (Fig. 2, 4), an assessment was made of the technical condition of the structure, which was highly damaged on its underside (gaps in the reinforcement lagging, as well as advanced corrosion of the lower reinforcement inserts). The static and strength analysis of the above-mentioned structure allowed a program of repair work to be prepared to allow its continued safe operation. For a period of about fourteen years, the limestone conveyor belt flyover structure

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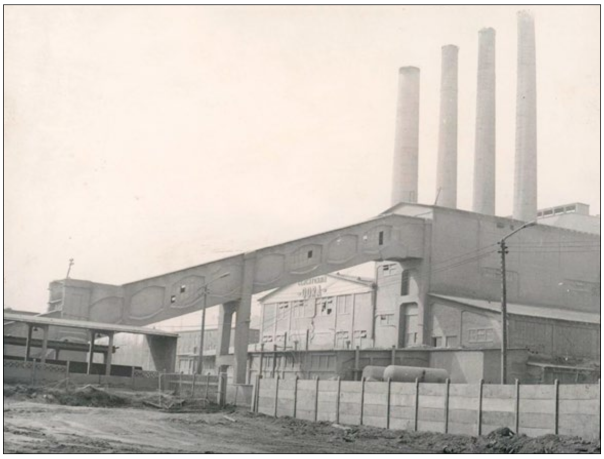

Fig. 1. View of the reinforced concrete flyover in the 1960s; photo [in:] Archive of the Odra Cement Factory, s.v.

Ryc. 1. Widok żelbetowej estakady z lat sześćdziesiątych XX w.; zdjęcie [w:] archiwum Cementowni "Odra", s.v.

Fig. 2. View of the reinforced concrete flyover, 2007; photo by D. Bajno

Ryc. 2. Widok żelbetowej estakady, 2007; zdj. D. Bajno

Fig. 3. View of the reinforced concrete flyover, 2022; photo by Ł. Bednarz

Ryc. 3. Widok żelbetowej estakady, 2007; zdj. Ł. Bednarz

Fig. 4. Interior reinforced concrete flyover, 2008; photo by D. Bajno

Ryc. 4. Wnętrze żelbetowej estakady, 2008; zdj. D. Bajno

was monitored, which is a spatial two-span reinforced concrete truss (Fig. 3). Inside this structure is a conveyor belt that transports the raw material for cement production from the excavation level above one of Opole's streets, which is heavily trafficked. Its destination is the mills of the aforementioned cement factory. The building is covered by a flat roof with a slope of approximately 21° and is finished with corrugated galvanized steel sheets. As mentioned above, the flyover structure was constructed using wet technology, in the form of a three-dimensional reinforced concrete skeleton topped with a massive reinforced concrete floor, with the vertical spaces between the columns filled with solid ceramic brick, approximately 12 cm thick, at the bottom, and reinforced transverse concrete bolts, with spacing coinciding with the spacing between the longitudinal posts of the trusses. It is a two-span structure with support spacing (reinforced concrete columns) equal to 22 and 17 m. The exterior surfaces of the flyover in 2007 were covered with a layer of bound cement dust, approximately 2 cm thick.

Historical background of the facility

The Odra Cement Factory is located in the Zakrzów district of Opole and was built in 1910, at a time when the city belonged to the Prussian part of Silesia.

However, the history of cement industry in Poland began more than fifty years earlier. It began with the construction of the Grodziec Portland Cement Factory near Będzin, which was established on the initiative of nobleman J. Ciechanowski. The plant was opened in 1857 [Hamberg-Federowicz, Paszkowski 2018, p. 80; Ciepiela 2016; Stelmach 1957; Zachuta 2004].

Before the Odra Cement Factory was established in Opole, six cement producing factories were built in the city from the mid to late nineteenth century [Rawska-Skotniczny, Molak 2017, p. 28]. Friedrich Wilhelm Grundmann's cement factory in Szczepanowice was the first to start its operations, followed by the opening of further cement factories, including in Nowa Wieś H. Pringsheim, Groszowice [Długosz, 2017, p. 27], H. Wattenberger's, and Zakrzów (later the

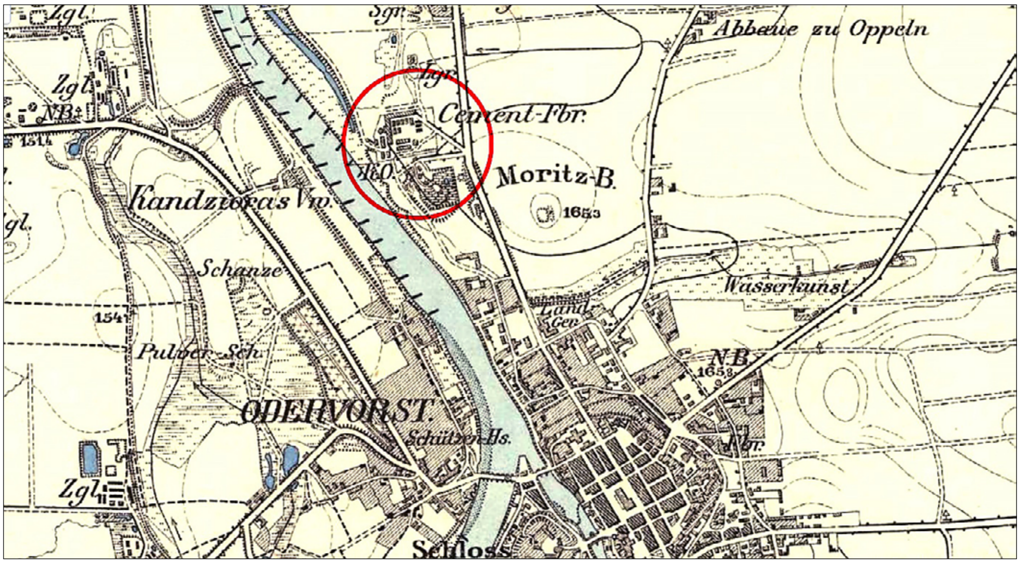

Fig. 5. Location of the Zakrzów Cement Factory marked on a map of Prussia from 1877; source: maps.arcanum.com (accessed 5 VI 2022)

Ryc. 5. Lokalizacja Cementowni Zakrzów oznaczona na mapie prus z 1877 r.; źródło: maps.arcanum.com, dostęp: 05.VI.2022

Opole-Port cement works and then Odra plant were established here).

It should be mentioned that the town of Opole and the surrounding area have always been rich in limestone, the main ingredient in cements. This was the reason for the location of a total of nine cement works here, which undoubtedly had a major impact on the development of the city at the end of the nineteenth and beginning of the twentieth century [*Opole. Dzieje i tradycja* 2011; Adamska 2016, pp. 577–580].

In 1872 [Oleśków, Żymła 2011, pp. 191–202], north of the historical center of Opole, in the area of the village of Zakrzów, the first cement factory was built on this site, which occupied an area of 80 ha (Fig. 5). Its owner was a private investor. Sixteen years later, the plant was renamed to Upper Silesian Portland Cement Factory and expanded in size. It was divided into three plants, operating on the basis of three shaft furnaces of the Dietsch type [Oleśków, Żymła 2011, p. 192]. They produced a total of about 240 t of cement daily [*Cementownia Odra 1911–2011* 2011, p. 12].

Then, in 1911, the Opole-Port Cement Factory was established on this site. The beginning of its operation is also symbolically taken to be the beginning of the Odra factory.

The Opole-Port Cement Factory was a modern plant at the time. It worked using the so-called wet method and was equipped with the latest generation of equipment. It consisted of, among others: three rotary kilns, whose daily output was 250 t of cement, one mill for grinding raw material and four more mills for cement, which were then collected in silos with a capacity of 21,000 t [Oleśków, Żymła 2011, p. 193; *Cementownia Odra 1911–2011* 2011, pp. 12–13].

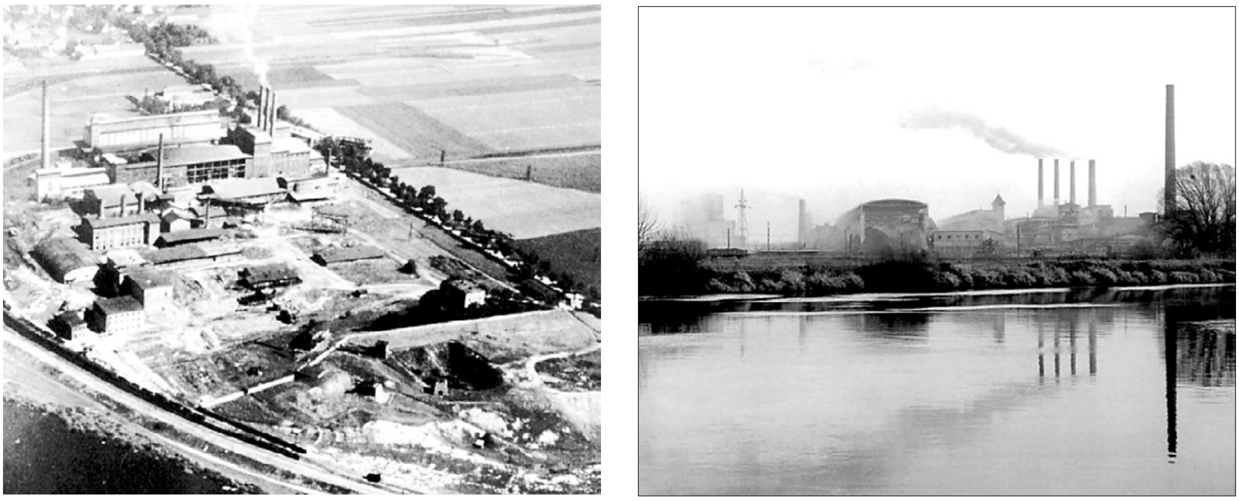

Fig. 6. Aerial view of the cement works in the first half of the twentieth century; by F. Kremer, photo [in:] Archives of the Odra Cement Factory, s.v.

Ryc. 6. Widok cementowni z lotu ptaka z okresu pierwszej połowy XX w.; K. Fremer, zdj. [w:] archiwum Cementowni „Odra", s.v.

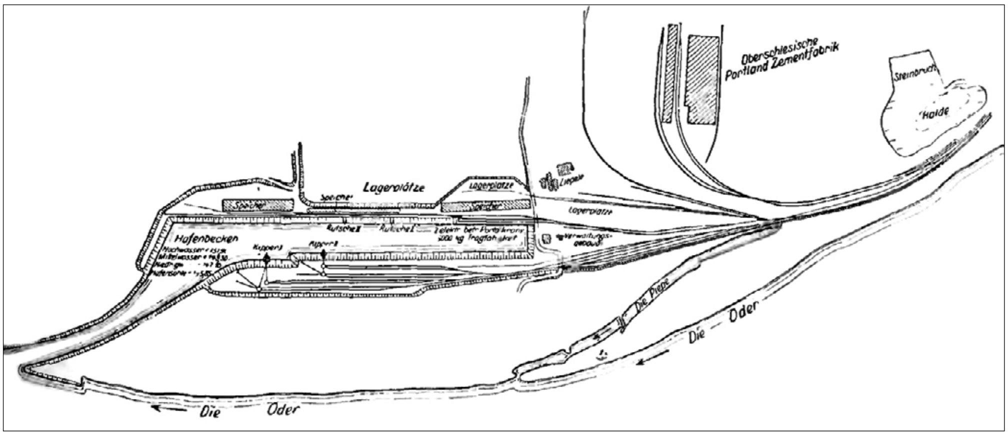

Fig. 7. Map of the port in Opole and the cement factory in 1920–1925; source: K. Mauer, H. Kaimnsky, Deutschlands Städtebau – Oppeln, Berlin 1926

Ryc. 7. Mapa portu opolskiego i cementowni w latach 1920-1925; źródło: K. Mauer, H. Kaminsky, Deutschlands Städtebau – Oppeln, Berlin 1926

The period of the First World War somewhat inhibited the development of Opole, as well as construction activity within the city. This had a direct impact on the level of production in the Opole cement plants (including the Opole-Port Cement Factory), which dropped significantly (Fig. 6, 7). This state of affairs continued throughout the war and postwar years [Oleśków, Żymła 2011, pp. 193–194; *Cementownia Odra 1911–2011* 2011, pp. 12–20].

After the First World War, precisely in 1926, the Silesian Portland Industry – Cement Joint Stock Company was established, which included cement plants located in Silesia, including the Opole-Port Cement Factory.

The following years, including the period of the Second World War, were a difficult time for industrial plants, including the Opole-Port Cement Factory, most of whose machinery facilities were taken apart and shipped away, and what was left was devastated. It therefore took some time before the plant became operational again [*Cementownia Odra 1911–2011* 2011, pp. 15–16].

At this point, it should also be mentioned that in 1945, the factory was placed under state administration and taken over by the Alliance of the Polish Republic's Cement Factories. Two years later, it was decided to rebuild the ruined plant (Fig. 8). This lasted until 1951. The rebuilt factory began operating under a new name: Odra Cement Factory [Oleśków, Żymła 2011, p. 194].

Structural assessment of the flyover

The technical condition of the lower chords of the trusses had to be considered poor and in parts completely bad. They contained numerous indented cavities and cracks, while the reinforcing bars were deeply corroded and were exposed due to missing lagging (some of the stirrups no longer existed). The large disproportion between the longitudinal reinforcement inserts and the stirrups (ø25/ø30 versus ø5/ø4 mm) was of particular concern during the survey. Damage to the concrete and corrosion of the bars (Fig. 9) was caused by very intensive fluctuations in moisture and temperature with large amplitudes and values (day, night, summer–winter), lack of insulation, and the loss of plaster also contributed to this.

Fig. 8. Reconstruction of the cement factory after the Second World War; photo [in:] Archives of the Odra Cement Factory, s.v.

Ryc. 8. Odbudowa cementowni po II Wojnie Światowej; zdj. [w:] archiwum Cementowni „Odra", s.v.

No traces of salt crystallization were found on the surfaces of the chipped concrete, but very numerous spalling and losses of both small particles and larger pieces of concrete were visible here. Some of the bars formed bundles of reinforcement with no spacing; i.e., they were interlocked in groups without proper covering, which would not be acceptable today. A serious threat to the entire structure of the building was posed by the lack of stirrups, damaged by corrosion. Even visually (without taking measurements), the excessive deflection of the west span of the flyover was already evident.

The entire reinforced concrete structure of the flyover had to be repaired and reinforced. The concrete in

Fig. 9. View of the damage; photos by D. Bajno, Ł. Bednarz
Ryc. 9. Widok uszkodzeń; zdj. D. Bajno, Ł. Bednarz

the reinforced concrete elements did not have a uniform structure and uniform strength. Non-destructive tests of the concrete class in the lower chords (apart from areas of corrosion) showed that it was of a high class of C20/25 (the flyover structure was built around 1910). These elements had to be urgently repaired in terms of bar cover and filling the cavities between the reinforcing bars with a material compatible with concrete and steel.

In general, the condition of the flyover structure was found to vary. The lower chords of the side trusses of the flyover, a span located in the fenced area belonging to the Odra Cement Factory, suffered the most damage. Their technical condition was deemed to be in danger of structural failure. Deformations and damage to the reinforced concrete structure are not the result of the overloading of any of its elements. They were caused by the effects of external weather conditions on the structure, which was not sheltered or protected. Previously, no ongoing repairs were carried out here to prevent now intensive penetration damage. Some of the cracks in the supporting elements of the beams were not structural in nature. They occurred in locations that lacked the required stirrup lag. Similarly, the correct thickness of the cover for the reinforcement bars had already been neglected when the flyover reinforced concrete structure was constructed. An additional drawback that affected the current technical condition of the lower chords was and still is the very high compaction at the bottom of the beam of the main reinforcing bars (bars ø20÷ø30). Furthermore, the flyover structure is constantly subjected to dynamic loading due to movement of the conveyor belt. The failure to replace the flyover could lead to the risk of a structural disaster at an unspecified time.

The structure could continue to operate safely, provided adequate protection and strengthening was carried out. The following section discusses how to reinforce the reinforced concrete structure of the flyover. The first thing to do was fill the gaps in the concrete. As the cross section of the lower reinforcement had been reduced by corrosion, it was absolutely necessary to reinforce the structure of the lower flange. No provision was made to expand the reinforcement by adding additional bars due to the large concrete voids and the heterogeneity of the concrete, as well as the considerable compaction of the concrete. Another reason for not reinforcing the structure with additional bars was the lack of data on the grade and properties of the steel from which the bars in the load-bearing sections of the damaged structure were made, i.e., their brittleness, load-bearing capacity, and weldability. Based on our own investigation and an analysis of the literature, it was assumed that reinforcement inserts were made of a type of steel (iron sinker) commonly used at the time, with an ultimate tensile strength of 3,700 kg/cm^2 (370 MPa) to 5,800 kg/cm^2 (580 MPa) and a modulus of elasticity of $E = 2{,}100{,}000$ kg/cm^2 [*Podręcznik inżynierski w zakresie inżynierji lądowej i wodnej* 1932; *Der Eisenbetonbau von A. Toensmann Zivil-Ingenieur* 1910]. The hardness of the steel was measured using an Equotip Live tester by Proceq. The substrate was prepared (cleaned of impurities) before the test. During the test, Leeb scale hardness and tensile strength R_m were determined. Then the steel grade was assigned. This steel could be considered equivalent to St3S steel according to standards [PN-88/H-84020; PN-EN 10025-1:2007] with $R_m = 360 \div 490$ MPa or the S235 used today.

The lack of reinforcement cover and the lack of anchorage of the hooks of the main bars, their proximity to each other, and the lack of stirrups were lost due to corrosion. In the early days of reinforced concrete structures, they were "oversized." As part of the work carried out (more than fifteen years ago), the concrete was tested in compression using a Schmidt N-type sclerometer. The non-destructive testing method using, among other things, the above-mentioned sclerometer allows the strength of concrete to be estimated with appropriate correlation but cannot be regarded as an alternative for determining the compressive strength of concrete. Therefore, the above-mentioned standard [*PN-EN 12504-2:2021-12 Badania betonu w konstrukcjach – Część 2: Badanie nieniszczące – Oznaczanie liczby odbicia*] and the standard regression curve [*Instrukcja ITB nr 210 Metoda sklerometryczna do badań wytrzymałości betonu w konstrukcji 1977*] cannot be used authoritatively in assessing the strength of concrete without appropriate scaling on samples (min. 9) taken from the structure and tested on a testing machine, and such samples were not available in the case under consideration. It was not possible to take samples for laboratory tests here due to the considerable loss of crumbling concrete. It was not decided to take samples from elements outside the range of these defects because these would have been tests that would interfere with the adjacent structure and involved dynamic activities.

In the first three decades of the twentieth century (in design studies at the time), low-grade concretes with kb = 30, 35, 45, 50 kg/cm^2 (currently they should be referred to as B3÷B5) were commonly used in concrete and concrete structures reinforced with iron (steel) inserts [*Der Eisenbetonbau von A. Toensmann Zivil-Ingenieur* 1910; Czapliński 2009]. In fact, non-destructive concrete tests, taking into account the results of laboratory tests of samples taken from undamaged areas, showed that its class was of the order of C20/25 (former designation B25).

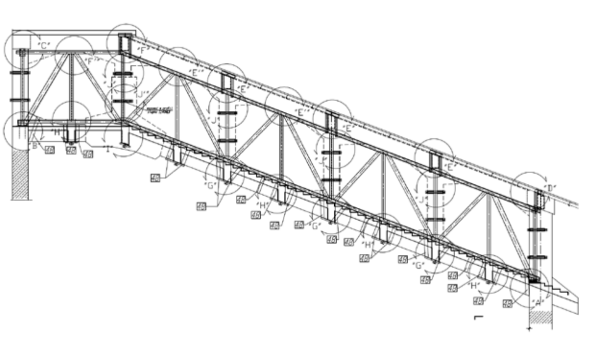

Fig. 10. The repair solution; by D. Bajno

Ryc. 10. Rozwiązanie naprawcze; opr. D. Bajno

Proposed repairs and reinforcement

The repair design [Bajno 2007] for the flyover proposed reinforcing the existing historical structure with a lightweight steel structure that does not obstruct the original (Fig. 10). The functional requirements for this facility have not changed since its inception in 1910, and were therefore taken into account in the development of the reinforcement of its structure. The calculations considered the current quantities and weights of the excavated material transported in the adoption of quasi-static loads. For this reason, the reinforcement method presented was adopted with the aim of leaving the original as authentic as possible. The introduction of the additional structure allowed the bending moments in the individual chord bays of the truss to be significantly reduced, while the increased magnitudes of the compressive and tensile forces were transmitted through the horizontal steel sections. Due to the considerable values of these forces, 18 G2 steel was used in the proposed solution. Until the structure was repaired, the building had to be taken out of service and traffic had to be restricted in the immediate vicinity of the building.

The reinforcement described above used two new internal steel lattice trusses to reinforce the historical reinforced concrete structure; the combined solution was based on two internal steel lattice trusses. The trusses were connected to each other in the upper and lower nodes by transverse steel beams. Thus connected, the structure already formed a spatially rigid system, which was practically entirely "introduced" into the interior of the flyover.

The proposed solution did not constitute a reinforcement of the flyover as a whole. Its role was to supplement the loss of load-bearing capacity in the most weakened sections of the lower chords of the existing flyover. The loss of load-bearing capacity in these elements was estimated to be around 20% based on tests and verification calculations. The solution required ongoing adjustments during the work directly on the structure, which involved adapting the dimensions given on the drawings to the actual dimensions. Particular attention was paid to the proper corrosion protection of the existing structural elements and to the new reinforcing (steel) elements.

Due to the possibility of dislocation of the upper chord members (I140HEB), it was necessary to rein-

Fig. 11. View of reinforcements; photo by Ł. Bednarz
Ryc. 11. Widok wzmocnienia, zdj. Ł. Bednarz

force it with elements (clamps or glued connectors) to prevent it from losing stability, at distances of no more than 1 m, and this also applied to the transverse roof and floor ribs. Some of these showed cracks transverse to the beam direction, including where the stirrup lagging was missing. Therefore, it was recommended that these elements be reinforced in the tension and shear zones with C-FRP carbon fiber strips. The use of fiber-based composite materials in the form of meshes, for example, carbon C-FRCM, tightened with mineral mortars, would also need to be considered at this time [Bednarz 2021, pp. 22–24] in accordance with conservation doctrines and ICOMOS/ISCARSAH recommendations [*ICOMOS/ISCARSAH Recommendations for the analysis, conservation and structural restoration of architectural heritage* 2019].

Finally, the repair works included the reprofiling of damaged concrete, preceded by the cleaning and preservation of existing original bars. Due to the lack of stirrups, a substitute for them was used. The main reinforcement is a spatial internal steel truss that does not disturb the authenticity of the building.

Additional steel suspension and support beams (I140HEB) were also used and attached to reinforced concrete ribs, at intervals of approximately 1 m. The visible reinforcement in the still functioning flyover is shown in Fig. 11. The choice of colors of the reinforcing elements depended on the owner of the building and was agreed with the conservation services. The authors of the expert report indicated that the original color should be preserved.

Proposal for structural monitoring

More than fourteen years of observation of the reinforced concrete structure of the flyover, which has been strengthened and protected against external environmental influences, have allowed conclusions to be drawn that summarize the effectiveness of the methods used. Measurements of deformation, evaluation of the condition of the welded and bolted joints in the strengthening structures, as well as cyclic visual inspections of the historical repaired surfaces (with concrete re-filing, cladding, and lining) have demonstrated the high effectiveness of the diagnoses made and repair methods implemented. The limestone overpass structure is still used without additional treatments. Only maintenance activities are carried out here and the statutory deadlines for regular periodic inspections are observed in accordance with Article 62 of the Building Act [Ustawa z dnia 7 lipca 1994 r. – Prawo budowlane].

In the future or if emerging damage is observed, consideration may be given to implementing more accurate monitoring of the structure. Technologies proposed, for example, in selected publications by Ł. Bednarz [Bednarz et al. 2021a, pp. 1–29; Bednarz et al. 2021b, pp. 147–156] or the installation of devices of the rapidly developing IoT (Internet of Things) technology

[Scuro et al. 2018, pp. 4–14; Chanv et al. 2017, pp. 151–157] can be used. This technology is capable of providing continuous wireless monitoring of the condition of a structure, including, for example, displacement, deviation, temperature, humidity, vibration, as well as other parameters necessary for structural diagnostics. This type of monitoring can be done using Wireless Sensor Networks (WSNs) bundled within Low-Power Wide Area Networks (LPWANs), which will support many of the devices envisioned for IoT deployment. Wireless systems are able to acquire the necessary information in the form of data which, when processed and interpreted, will quickly provide reliable information needed for analysis, e.g., numerical analysis using FEA (Finite Element Method), and documentation of the structural state of a facility.

Monitoring systems of this type use wireless sensors of the LoRaWAN protocol (Long Range Wide Area Network) protocol, which was designed from the ground up to optimize LPWANs in terms of battery life, capacity, range, and cost. LoRaWAN uses a star topology in which gateways relay messages between end devices and a central network server. The gateways are connected to the network server through standard IP connections and act as a bridge. Wireless communication allows for a one-step connection between an end device and one or more gateways. Each gateway forwards packets from the end node to the cloud-based network server via some backhaul connection (cellular, Ethernet, satellite, or Wi-Fi).

The use of the proposed technology can provide a solution that allows almost unattended monitoring of structures and can generate reports on these measurements. The automatic analysis and visualization of the measurements taken can help to study the behavior of the structure during changing conditions, and enable direct signaling in cases where boundary values are exceeded. Reading data is possible from a distance and using a phone, tablet, or computer, which is fast, convenient, cheap, and practical.

Due to wireless transmission, data reading takes place continuously, and all values are transmitted and stored on cloud servers with appropriate security measures. The lack of a measurement infrastructure (cabling) is another advantage. The installation of the sensors only involves mounting the measuring devices at the correct points. Sensors are battery-powered and do not significantly interfere with monumental substance.

Conclusions

This article presents an example of the revitalization of a historical reinforced concrete structure, part of a production plant still operating, whose technical condition prevented further safe operation. A method of reinforcing the structure was given, assuming the least possible interference with the historical structure and material. Therefore, the importance of the obligation of periodic inspections of structures, which is imposed on facility managers by the Construction Law [Ustawa z dnia 7 lipca 1994 r. – Prawo budowlane], should be emphasized, as neglecting it may lead to the risk of a building disaster. In the case under analysis, this has become a reality, as it must be assumed that the corroded reinforcement, visible in Fig. 9, would lose its load-bearing capacity as a result of further use.

The example described and analyzed above also fits into the broader, currently very important direction of revitalization and revalorization measures aimed at protecting postindustrial heritage. This heritage is, in fact, an important part of the cultural landscape of Polish cities of the late nineteenth and early twentieth centuries.

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Abstract

This paper presents a wide range of diagnostic tests, repair and reinforcement measures, as well as a proposal to monitor the technical condition of a flyover structure located in the Odra Cement Factory in Opole. The poor technical condition of the structure determined the need to prepare a design aimed at repairing the structure. Design studies were fully used during the execution phase of the work. The purpose of this study is to present the characteristics of a historical postindustrial building in urgent need of revitalization and the assumptions adopted for repair. The reason for engaging in this project was the advanced state of degradation and the danger it posed. The primary objective was to guarantee safety and preserve this structure to the highest possible degree of authenticity. This was to protect this historical structure from failure or demolition and to ensure that it could continue to be used indefinitely.

Streszczenie

Niniejszy artykuł prezentuje szeroki zestaw badań diagnostycznych, działań naprawczych i wzmacniających, a także koncepcję monitorowania stanu technicznego estakady przenośnikowej w Cementowni „Odra" w Opolu. Zły stan techniczny budowli spowodował konieczność przygotowania projektu mającego na celu naprawę konstrukcji. Studia projektowe zostały w pełni wykorzystane w fazie wykonawczej prac. Celem niniejszego opracowania jest przedstawienie charakterystyki zabytkowego obiektu poprzemysłowego, który pilnie potrzebuje rewitalizacji, a także założenia przyjęte w ramach działań naprawczych. Powodem podjęcia się projektu był zaawansowany stan degradacji i zagrożenie, które obiekt stwarzał. Głównym celem było zagwarantowanie bezpieczeństwa i zachowanie jak najwyższego stopnia autentyczności obiektu. Miało to ochronić ten zabytkowy obiekt przed katastrofą budowlaną i rozbiórką oraz zapewnić możliwość jego dalszego, bezterminowego funkcjonowania.