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Research paper

Reinforcement solution of damaged load-bearing frame structure in a coal power plant for additional loads

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Abstract: Significant subsoil deformation and additional loads from the new denitrification unit caused a major problem with the load-bearing capacity of the coal power plant. It was necessary to perform an advanced assessment of the technical condition of the structure. Laser scanning (LiDAR) were used to obtain detailed data upon structure. Based on the analysis of the point cloud, the location of the column axes was determined, which allowed to determine the global and local displacements of the structure. Spatial models of the structure were created. Non-linear analyses of the structure were carried out using two types of models: 1) global beam-shell 3D models of the boiler room used to calculate the magnitude of internal forces and deformations of the structure; 2) local beam-shell detailed models of selected structural elements. Based on the results of the calculations, necessary reinforcement of the structure was designed and successfully implemented. Advanced analysis of the structure using laser scanning, subsoil monitoring and complex numerical models made it possible to perform only local reinforcements of the entire complex structure.

Keywords: steel superstructure, subsoil settlement, coal plant, laser scanning, LiDAR, TLS

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1. Introduction

The diagnostics of civil engineering structures older than 50 years is a very complex task. The existing technical documentation of the building, including floor plans, structural schemes etc. may be incomplete. The old steel power plant buildings have been recognized as complex multifloor frame structures. The inventory of this type of buildings is a very difficult task. In addition, old structures were usually rebuilt and strengthened in subsequent years of operation. When strengthening, proven and appropriate technical solutions were not always used. Deformations and local damages of the structure can lead to a decrease in load capacity. The deformations can be caused by overloading of the structure due to design or execution errors [1–3]. Other causes may be improper operation of the building or an emergency situation e.g., vehicle impact, unforeseen weather conditions, etc. [4–7]. In addition to factors related to the aboveground part of the structure, ground settlement [8–11] or ground surface uplift [12] can also be an important cause of structural deformation. The latter can be particularly dangerous in the case of adverse kinematic effects, which can specifically affect the structure.

The traditional measuring method including visual inspection, measuring by measure tapes or laser rangefinders are not fully reliable [13, 14]. In addition, the use of tapes or rangefinders for multifloored frame structure need to use additional equipment such as scaffoldings, ladders etc. For some structure this method is not enough to collect needed data for structure dimensions and technology [15]. To collect the data of the damaged structural elements, including cracks, deformation of steel component, buckled columns etc. is almost impossible by traditional method [11].

The precise 3D scanning systems can be a solution for collecting the needed data. Currently the technology named LiDAR / TLS (LiDAR – Light Detection and Ranging, TLS – Terrestrial Laser Scanning) becomes very popular in civil engineering [14, 16–19]. The high precision of existing LiDAR systems helps to create detailed 3D model of structure [20]. In additional LiDAR was successfully used for analysis of structure deformation and identification of damages. The reference LiDAR scan is best way to control whole building behavior and damages during lifetime. Song et al., 2018 [21] show example of this technique in case study of existing two-story reinforced concrete building. Based on LiDAR, the Authors updated the FEM model of structure. Cha et al. 2019 [22] used the LiDAR detection system for evaluate the shape deformation for maintenance of bridge structures. The results proves that quality and precision of LiDAR scan are in line with deflection measured by LVDT sensors.

Nevertheless, for historic building the reference scan do not exist. In this case it is possible to use LiDAR as surveying method as well. Nowak et al., 2020 [14] used the LiDAR system to evaluate the historic building in Karlino. The authors do not have access to historical data or any reference scan. The scan helps to find the structural damages. In addition, based on point cloud, authors design the structural reinforcement. Stałowska et al. 2022 [23] examined the historical building walls by TLS technique. The results proves that TLS technique can be successfully used for identification of cracks on masonry walls. The authors present that even cracks below 1 mm can be identified. Nevertheless, the scanner must be placed close to the wall. Wierzbicki et al. 2020 [11] examined the torsional buckling of existing steel column by LiDAR method. Point cloud help authors to collect the data upon twisted column. Based on received results, FEM model was updated, and torsional buckling problem was solved. In addition, authors prove that is possible to check the thickness of steel member based on LiDAR. To sum up to LiDAR technique could be helpful in new designed building (the reference scan is recommended) and in historical building as well. The presented above research proves that precision of scanning is enough for engineering purposes.

The structure presented and analysed in this paper is a damaged building of a coal power plant that needs to be repaired and modernized. The main purpose of those modifications is to adapt combustion installations to national environmental requirements. These modernizations often introduce new loads on the existing, already extensively serviced power plant buildings.

The problem described in the paper appeared during works on preparing project documentation of the SCR (Selective Catalytic Reduction) system reactor support structure. Construction of the SCR system was associated with the introduction of new horizontal forces acting on the support structure of the boiler room. As part of the analysis of the impact on the existing structure, the designer determined that the structure was overloaded due to uneven ground settlement and that it had already been previously partially reinforced. This situation required detailed analysis and reinforcement design.

The analysed object is a steel frame structure of a coal power plant boiler room, built in the 1970s. The analysis covered the area of four blocks numbered 5 to 8. Two of them are presented in Fig. 1 and Fig. 2. The structure of the boiler room consists of four separated sections with dimensions of 72 × 36 m. This multi-storey frame structure has rigid floor plates with a column grid of 12 × 9 m. In each separated part there are two boilers suspended from a grate supported on the tops of the columns. Fig. 1 and Fig. 2 shows the static diagram of the structure. Fig. 3 shows photos of the structure.

The case presented in paper described fallowing topics: 1) Collection the topology and structural sizes data from complex multifloored structures; 2) Analysis the global deformation of structures based on LiDAR and FE modelling; 3) selection the best modelling solution for

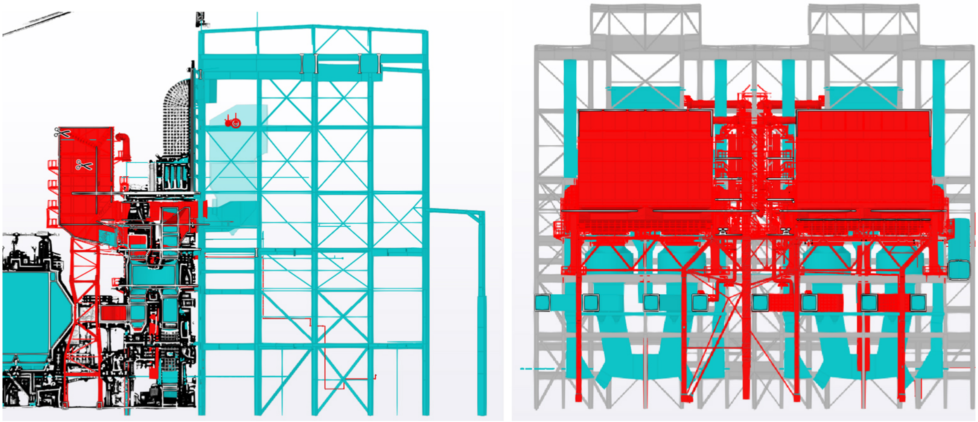
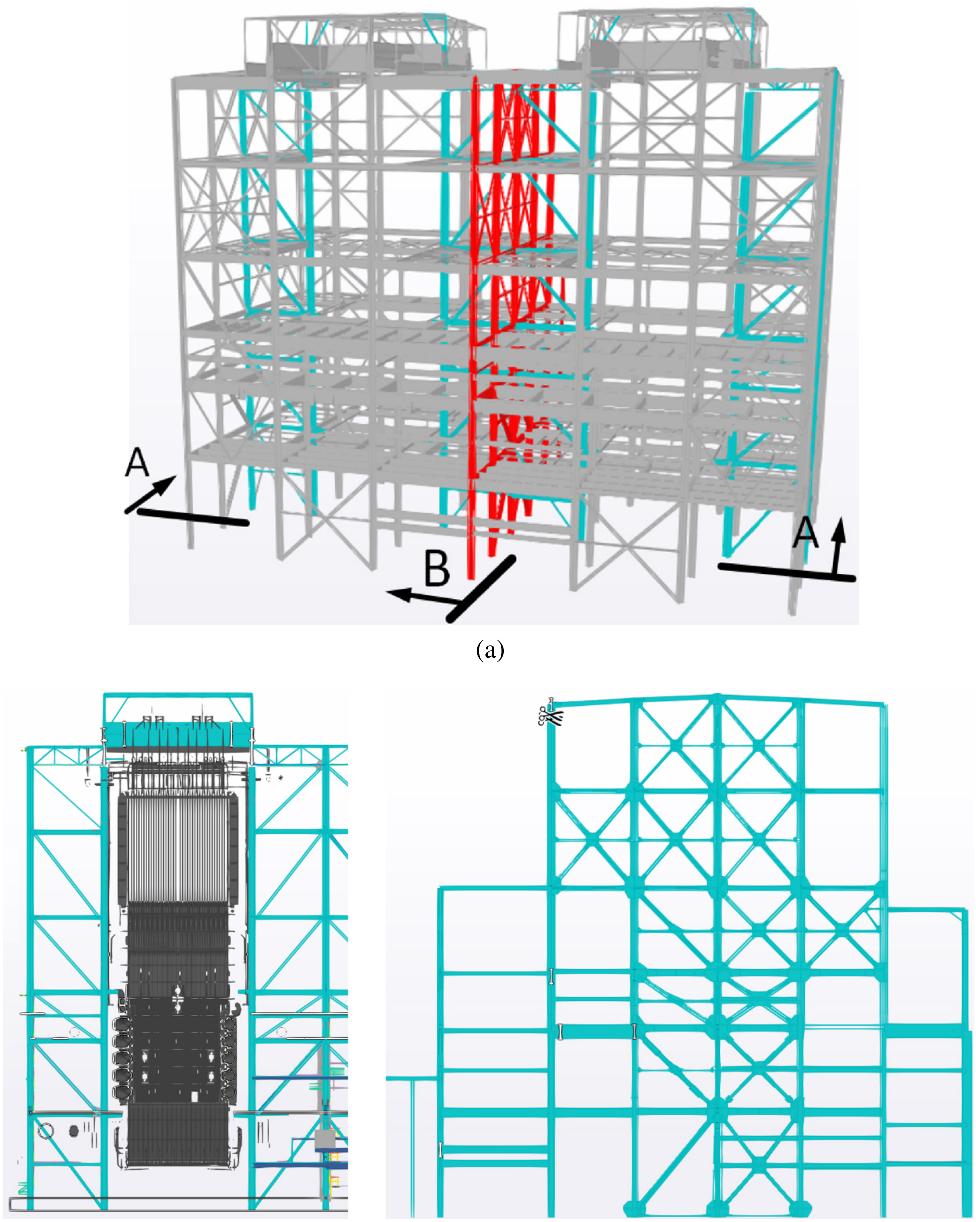


Fig. 1. View on blocks 5–6. Red colour marks newly designed installations and structures

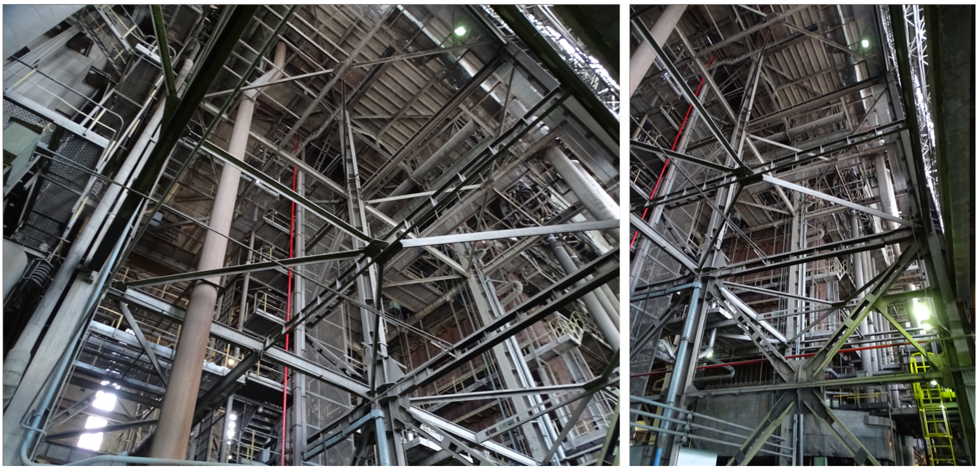


(a)

(b)

(c)

Fig. 2. Construction of boiler room section with a boiler hanging at +60 m: a) View on a segment of blocks 5–6 (elements visible in the cross-section are marked in colour), b) Cross-section A–A, c) cross-section B–B



(a) (b)

Fig. 3. Photos of steel structure at +25.5 m: a) Horizontal bracing on level 34.0, b) Vertical bracing in axes 12

structures damaged by soil settlement and additional SCR load. Analyses were performed using geodetic data from settlement monitoring and laser scanning of the entire structure (LiDAR). Based on the measurements, numerical models were created and calibrated, the state of the object was determined, and the strengthening solution was proposed. The presented analysis, especially selection of modelling method and use of LiDAR scan as calibration of FE model are unique approach for analysis of this type of structure. Final reinforcement solution was design and made based on mentioned analysis and meet safety and economic criteria.

2. Damages and settlement as the reason for structural analysis

The structural analysis was performed not only due to planned works described in Section 1 but also due to numerous existing structural damages. The damage was particularly evident in the cross-braces of the vertical tie systems. The analysis of existing damages allowed to group them into three categories: (i) local loss of stability of members, (ii) global loss of stability of members and (iii) local damages for example rupture of tension members. Examples of damages are presented in Fig. 4.

Complex structures like steel frames supporting a boiler room of a coal power plant exhibit a significant susceptibility to ground settlement. This is due to it being to a high degree statically indeterminate. Additionally, the boilers (weighing about 3600 t each) are suspended on a grate resting on top of the supporting columns at a level of about 60 m. This placement of the main load makes the whole structure very sensitive to second order effects, which in turn depend strongly on the influence of uneven ground settlement. This has been known from the

(a) (b) (c)

Fig. 4. Damages of the steel structure: a) buckling of gusset plate, b) buckling of a bracing member, c) ruptured of bracing at the node

beginning of the power plant operation. Continuous measurements of vertical displacements of supports have been conducted for almost 50 years. During the period unfavourable events have taken place to which we can include various types of damage to benchmarks, irregularity of measurements and changes of surveying companies conducting the measurements. This limits the reliability of measurements. The team analysing current state of the boiler room structure and its settlement had to conduct thorough and detailed interpretation of the obtained results.

The ground settlement propagation is measured in number of days in reference to the initial state, which is described as day zero. Fig. 5 shows the development of the column settlement in selected row F of block 6 over a period of more than 33 years of operation of the facility. It can be clearly seen that after about 32.5 years of operation, there was an unexpected sharp increase in the displacement of the supports. In the period of two months from day 11907 to 11976, the settlement in some places (e.g. column F19) reached 7 cm [24, 25]. The degree of settlement of the subsoil can be described as sudden. It became the cause of numerous damages to the steel supporting structure and building's equipment.

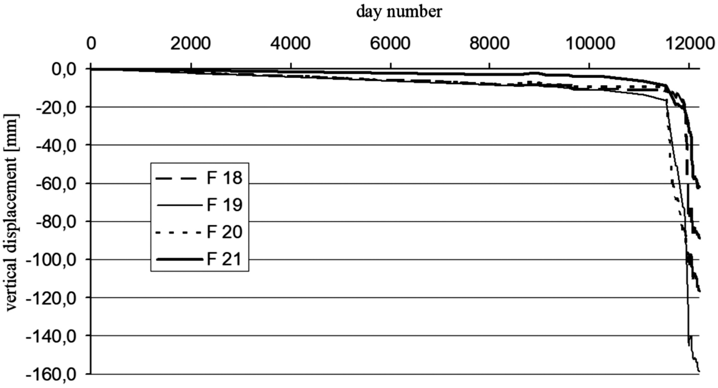


Fig. 5. Vertical displacement of the F row columns in block 6 from day 0 to 12193

The immediate repair works included stabilizing of the ground and temporary shutdown of the block. The results of these actions are presented in Fig. 6. For the same F row columns, the most intensive settlement is shown compared to two periods when the block was out of operation. Apart from the damage to the building, the boiler system, especially technological pipelines, got significantly deformed. The decision to shut down the boiler was necessary for safety reasons and to repair the deformed system. Additionally, coal mills were also shut down. The coal mills are a major source of vibration generated in the ground near the boiler room. The presence of these vibrations can be attributed to the poorly executed stabilization, which was conducted as soon as signs of settlement were discovered. Only the second shutdown of the boiler led to a significant slowdown of the settlement process. The data collected to date indicate that the uneven settlement continues, but with significantly lower rate.

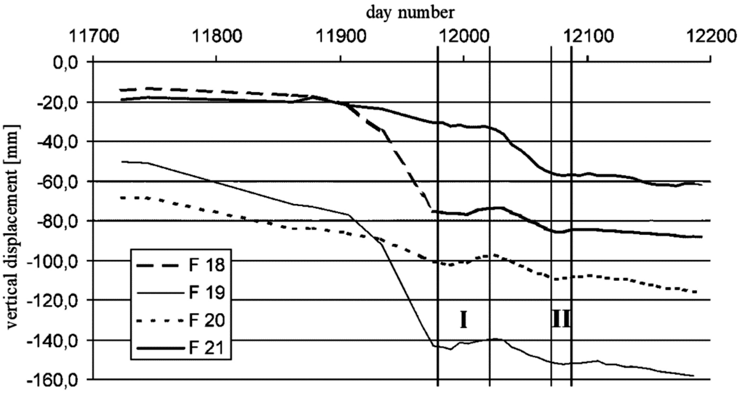


Fig. 6. Vertical displacement of the F row column in block 6 from day 11739 to 12193 with visible effect of the operation stoppage at period I (days 11982–12019) and period II (days 12072–12086)

Soil works were accompanied by intensive analyses of the condition of the loads-bearing structure and designs of reinforcement of the most stressed columns. The steel structure was supposed to be repaired only when the settlement came to a halt, which proved to be a difficult approach. Relatively small effects of overloading due to uneven ground settlement occurred in the steel frame spandrel beams, as the connections between them and columns were not rigid. On the other hand, tie bars showed the highest degree of overload in the linear-elastic analysis. The proposed solution allowed for their partial disengagement from operation due to plasticization or buckling. Places where material rupture occurred were reinforced at their current deformed state.

The assessment of the state of structural overloading and necessary reinforcements were made based on the non-linear analyses related to the current state of subsoil settlement. To obtain clear information on the state of subsoil deformation, contour plans were created based on geodetic measurements (with inclusion of more detailed analysis of noticed inconsistencies). Additionally vertical displacements of columns in selected rows and numerically determined gradients of analysed deflection lines were used. Dozens of contour plans were obtained for different time periods, which made it possible to show development of the settlement as a continuous process. There were no qualitative changes in the pattern of vertical movements and the location of the area of the greatest settlement remained practically unchanged. Individual irregularities were eliminated by detailed analyses of the data causing them. The obtained final image of the vertical displacements of the subsoil for the studied period was based on a sizeable initial data. The data was not corrected to preserve the continuity of the settlement process, which allowed to acquire a reliable state of the construction. Fig. 7 shows an example of a contour plan for the day 16652 (more than 45 years of the power plant operation), whereas Fig. 8 presents a visualization of the structure deformation due to settlement.

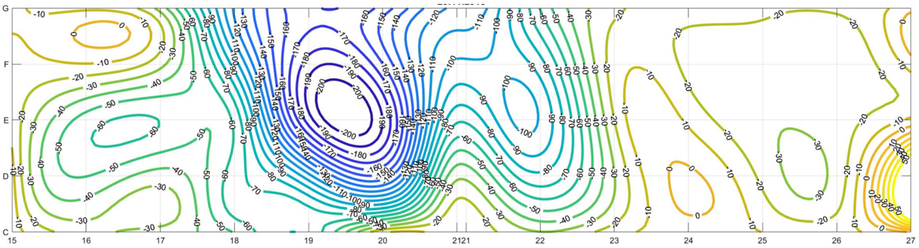


Fig. 7. Contour map of subsoil settlement

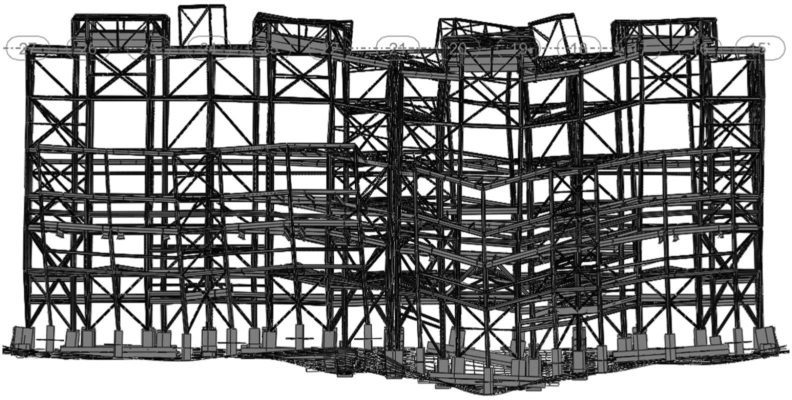


Fig. 8. Deformation of the structure caused by the settlement

3. Laser scanning (lidar) as a tool in design

Laser scanning of structures is an engineering method that allows the measurement of even very complex building structures. It allows the determination of detailed dimensions of a structure or its parts [26], its imperfections [27] or its global deformation state [14, 19].

Laser scanning (LiDAR) was used to obtain a detailed model of the structure and its global deformation state. Laser scanning of the structure was performed using a Leica ScanStation P40 laser scanner unit. The accuracy of a single distance measurement is 1.5 mm + 10 ppm (Parts Per Million, [6–10]), while the angular accuracy is 8″ horizontally and 8″ vertically.

The scanning speed is up to 1,000,000 points per second. The scanner and laser plummet are equipped with a class 1 laser according to IEC 60825:2014. The random survey points were also checked by traditional surveying methods.

The point cloud obtained during scanning (about 460 GB compressed) provided detailed morphology of the structure, the dimensions of the cross-sections of the members, and showed a detailed model of existing damages. Fig. 9 shows a comparison of the actual bar with its representation in the point cloud. Such detailed data allowed to build a reliable computational model of the structure, which is described in Section 4.

(a) (b)

Fig. 9. Comparison of a real-life photo of damaged member with a model from point cloud data: a) photo of a local buckling, b) laser scanning model

Except of detailed geometric data, laser scanning was used to determine the global deformation state of the structure. Based on the analysis of point cloud data, the shape of the column axes was determined showing the displacement of the structure from loads and settlements acting during the operation of the power plant. The obtained data from laser scanning were compared with the results of numerical analyses (see Fig. 10).

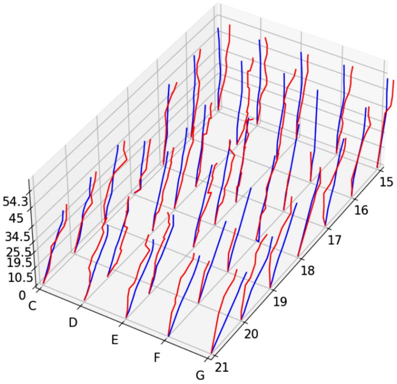
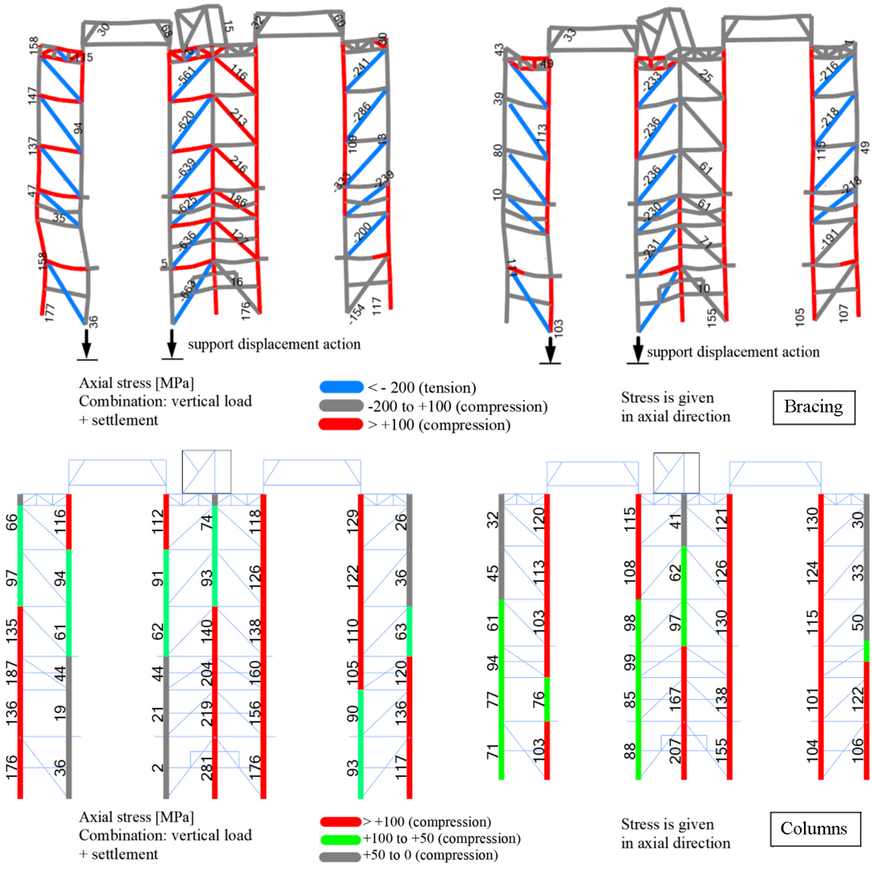


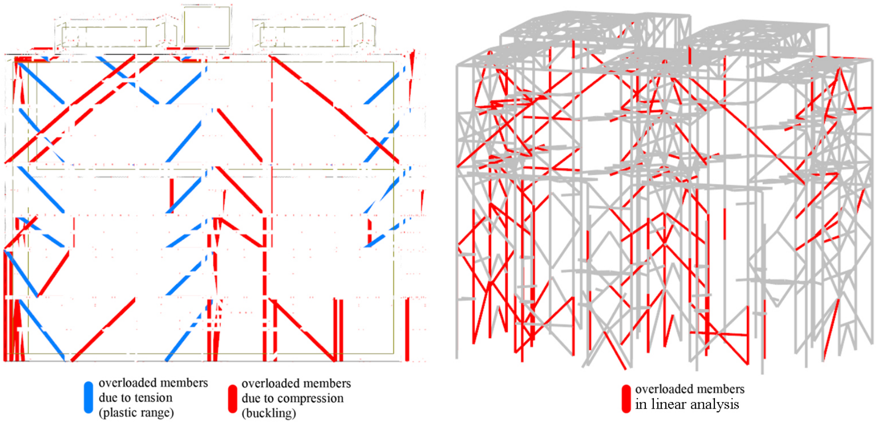
Fig. 10. Comparison of global state of deformation of columns in the area of blocks 5 and 6 obtained by laser scanning with deformations obtained in numerical way (blue – numerical analysis, red – laser scanning)

4. Calculation model

In statically indeterminate systems, the magnitude of internal forces caused by non-uniform settlement of supports depends on the stiffness of the system. In the analysed structure, the vertical braces have capacities many times lower than columns. Use of the linear analysis would not allow a proper assessment of the structure's strength – the forces transmitted from the braces to the columns (as a result of non-uniform settlement) would many times exceed the load capacities of the brace members. Therefore, it was decided to conduct a non-linear analysis, taking into account geometric and material non-linearities as well as imperfections. The adopted modelling technique made it possible to consider the impact of vertical bracing stiffness degradation on the magnitude of forces in the columns. The degradation of bracing stiffness is caused by buckling of compression members and yielding or rupture of tension members. Fig. 11 shows a comparison of the stresses in the elements for linear and non-linear analysis for a combination of vertical loads and non-uniform settlement of the supports. The



(a) (b)

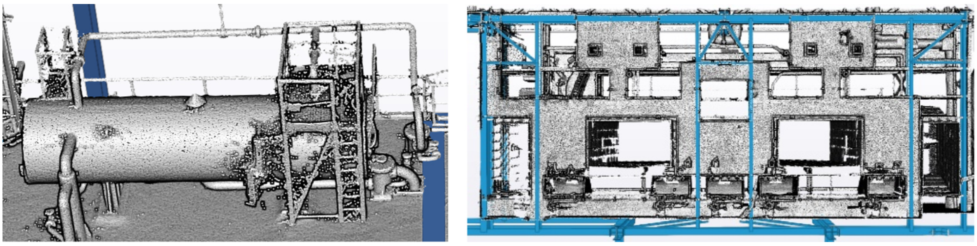


(c) (d)

Fig. 11. Comparison of the linear and non-linear analysis: a) linear analysis, b) non-linear analysis, c) linear analysis – overloaded members, d) Members with exceeded load-bearing capacity

elements which show significant exceedances of the load-bearing capacity conditions in the case of linear analysis are presented. The significant exceedances of load-bearing capacity shown in the linear analysis did not reflect the current state of the structure, which proved that the results should be disregarded for the analysis.

An additional complication was the uncertainty of archival data on process loads: the layout and magnitudes of loads have changed significantly over the 60 years of building operation. Based on the information obtained from the point cloud data (see Fig. 12), the layout of loads acting on the structure was verified and updated, which provided a basis for further analyses, including nonlinear analyses.



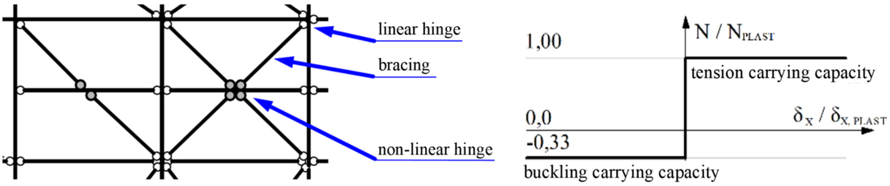
(a) (b)

Fig. 12. Example of loads identification process based on the point cloud data: a) tank – assessment of load, b) floor at +34 m – lack of dead-loads

The non-linear analyses of the structure were performed using two types of computational models: 1) global, beam-shell 3D models of the boiler room used to calculate the magnitude of internal forces and deformations of the structure and 2) local, detailed beam-shell models of selected structural members.

Global models were developed using beam elements to represent the steel structure and shell members to represent the reinforced concrete floor slabs. A single model represented the structure of two power blocks of the power plant, physically separated from the rest of the structure by transverse expansion joints. Geometric nonlinearities were considered by applying large deformation analysis in calculations. Imperfections assumed in calculations were modelled as systems of equivalent equal forces according to Eurocode 3 PN-EN 1993-1-1. Bow and sway imperfections of columns were considered.

Due to the extent of the numerical calculations, the number of elements in which material nonlinearities were considered was limited to the vertical braces of the boiler room and included as nonlinear characteristics of the bracing hinges (Fig. 13). A rigid-plastic material model was used for the nonlinear joints, illustrating the tensile and compressive capacity of the members, including loss of stability (Fig. 13b). The buckling resistance model presented in Fig. 13b is a simplified model, however, due to the computational complexity, it was decided to adopt a simplification, which results in lower stiffness of the joints than in reality.



(a) (b)

Fig. 13. Calculation model of bracing with nonlinearities at joint at one end: a) scheme with location of hinges, b) characteristics of non-linear hinge

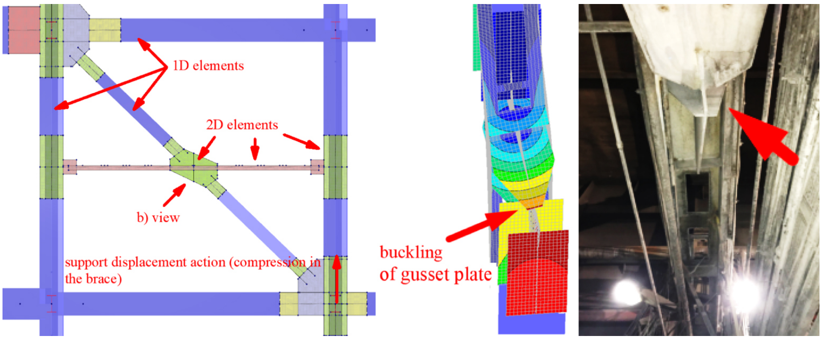
Local models were developed as beam-shell, representing separated structural elements of the boiler room. They were used in analyses of complex failure mechanisms of single members, impossible to evaluate using simple 1D elements. The most important of the local models were:

A) models of isolated vertical braces to determine critical forces in bracing members and connections, also used to produce nonlinear joint characteristics in global models. It was necessary to use shell models to represent the stiffness of the bracing connections;

B) Shell models to determine the true stiffness and bending capacity of the beam to column connections and main column bases. The results obtained were input into the global model in the form of elastic-plastic hinges (Fig. 14 and Fig. 15);

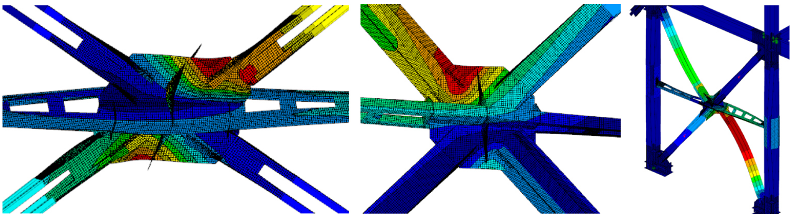
C) models of isolated columns for evaluating torsional buckling resistance and for final determination of the stress state of column sections.

Due to the local concentration of stresses in the area of the connection between the columns and the beams, it was necessary to estimate the size of the plastic reserve. The results obtained from the calculations were used to evaluate the strength of the columns and to analyse the global stability of the structure. Analysis of columns, due to the type of analysis (non-linear analysis, taking into account geometric and material non-linearities as well as imperfections – see Fig. 16 and Wierzbicki et al., 2020 [11]), was reduced to the verification of the strength of successive sections. The assessment of global stability consisted in demonstrating that, under conditions of normal wind action, in superposition with non-uniform settlement, in each series



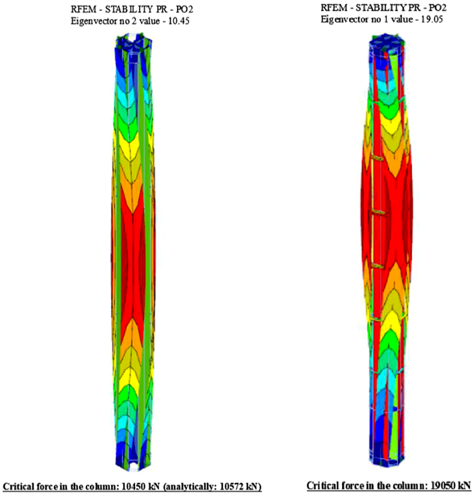
(a) (b) (c)

Fig. 14. Part of vertical bracing calculation model – type 1: a) calculation model, b) buckling in num. model, c) buckled member in reality



(a) (b) (c)

Fig. 15. Buckling of different bracing types: a) type 1, b) type 2, c) type 3



(a) (b)

Fig. 16. Buckling analysis of columns with a flanged cross cross-section: a) without horizontal stiffeners, b) with horizontal stiffeners

of bracings at successive levels of the building, at least one element operates in the elastic range. This approach was intended to ensure the invariability of the non-tilting scheme of the structure. Changing to a tilted scheme would result in a significant increase in bending moments in the columns. Based on the analysis, a reinforcement design was developed.

5. Reinforcement solution

Numerous analyses of both local and global models allowed to propose following repair solutions:

- ruptured bracing connection should be strengthened;
- struts that exhibited buckling should be reinforced or replaced;
- struts that is likely to buckle and whose location means that there is no substitute system capable of supporting the horizontal load must be reinforced. If there are several bracings in the same axis at the same level, the limit state of the bracing system determines the qualification for strengthening. Some members are allowed to buckle if the global stability of the structure is maintained;
- in the bracing of horizontal planes, connections and some members must be reinforced so that the global stability of the structure is maintained;
- overloaded columns should be strengthened by increasing the cross section.

The total mass of reinforcements per one segment (two blocks) was about 25 t, and the mass of the framework reinforced structure was about 2600 t. In some cases unusual solutions were used, such as the example of the brace reinforcement, which buckled but at the same time provided support for active electrical installations (Fig. 17 and Fig. 18). A point cloud data was used to diagnose potential collisions with installations, thus reducing the number of in-situ inspections.

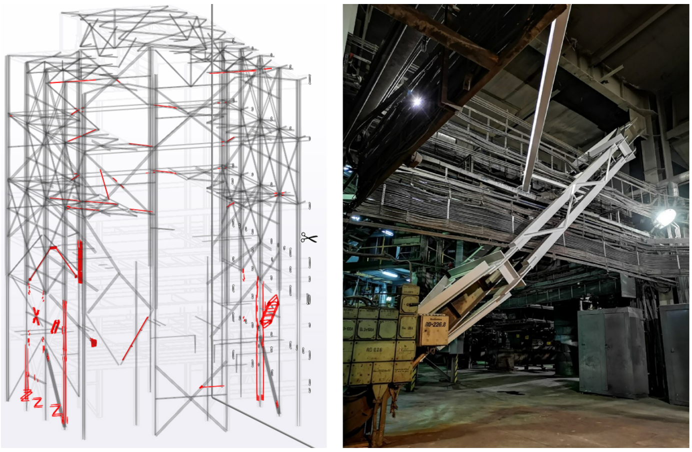
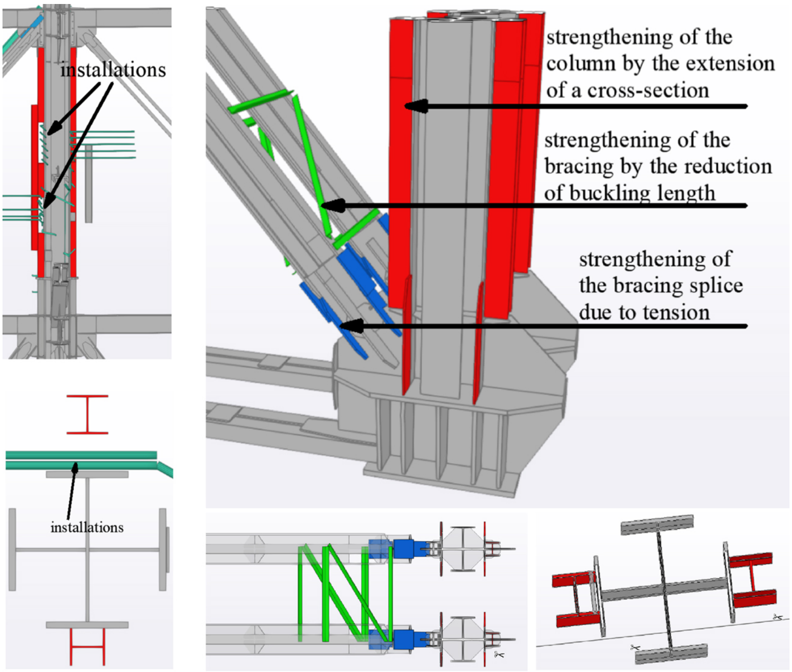

(a) (b)

Fig. 17. Reinforcement of the boiler room structure: a) applied reinforcement – new elements shown in red, b) example of a bracing reinforcement that omits existing electrical wiring



(a) (b)

Fig. 18. Reinforcement of the boiler room structure: a) reinforcement of the column omitting the electrical wiring, b) examples of reinforcement

The applied reinforcement system consisting of local solutions that significantly improve the performance of the structure allowed to restore its safety with minimal interference. This approach required a complex numerical analyses described in the previous sections performed on the basis of detailed data obtained from geodetic monitoring and point cloud.

6. Conclusions

Subsidence of the ground and the need to modernize the power plant resulted in a threat to the load capacity of the steel frame structure of the object. The degree of complexity of the analysed object required the use of advanced measurement and calculation methods. The basic conclusions of this study can be presented as follows:

- application of the linear static analysis method would lead to inadequate assessment of the structure condition (the obtained results of linear analysis showed several times exceeding of the load capacity of bracing members);
- proper calculation results were obtained based on advanced nonlinear models considered geometric and material non-linearities, bow and sway imperfections, nonlinear hinges in damaged members;

- obtained data from laser scanning confirmed the global deformation obtained using nonlinear models of the structure;
- the complexity of the object required the use of advanced measurement techniques in the form of laser scanning (LiDAR) to obtain data concerning the structure and its deformation. Obtaining this data using traditional methods would have been impossible;
- it was necessary to use geodetic monitoring data of the supports in order to correctly assess the stress state of the structure;
- the use of local reinforcements of the structure allowed to restore its correct and safe operation.

Based on complex numerical analyses and using advanced measurement techniques, the existing structure was successfully strengthened and the SCR reactor support structure was designed and installed without compromising its operation and safety.

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Przystosowanie uszkodzonej ramowej konstrukcji nośnej elektrowni węglowej do wprowadzenia dodatkowych obciążeń

Słowa kluczowe: stalowa konstrukcja nośna, osiadanie podłoża, elektrownia węglowa, skanowanie laserowe, LiDAR

Streszczenie:

Przykłady sytuacji mogących zagrozić nośności konstrukcji możemy spotkać w polskich elektrowniach, gdzie prowadzone są prace modernizacyjne, których głównym celem jest dostosowanie instalacji spalania do krajowych i unijnych wymogów środowiskowych. Modernizacje te nierzadko wprowadzają nowe oddziaływania na istniejące, mające długi okres eksploatacji konstrukcje budynków elektrowni. Opisany w referacie problem pojawiłsię w trakcie prac dotyczących opracowania dokumentacji projektowej konstrukcji wsporczej reaktora odazotowania spalin SCR. Wykonanie zabudowy SCR wiązało się z wprowadzeniem nowych siłpoziomych działających na konstrukcję nośną kotłowni.

W ramach analizy wpływu tego oddziaływania na istniejącą konstrukcję, projektant ustalił, że konstrukcja ta uległa przeciążeniom wskutek nierównomiernego osiadania podłoża i że była ona już częściowo wzmacniana. Sytuacja ta wymagała przeprowadzenia szczegółowych analiz i opracowania projektu wzmocnień. Analizowany i wzmacniany obiekt to stalowa konstrukcja szkieletowa kotłowni elektrowni węglowej, wybudowanej w latach 70. XX wieku. Analiza objęła obszar czterech bloków (fig. 1, fig. 2). Konstrukcja kotłowni składa się z czterech oddylatowanych części o wymiarach 72 × 36 m. Prezentowana konstrukcja to wielokondygnacyjna konstrukcja szkieletowa ze sztywnymi tarczami stropowymi o podstawowym module siatki słupów 12 × 9 m. W każdej oddylatowanej części obiektu znajdują się dwa kotły podwieszone do rusztu opartego na wierzchołkach słupów. Na figurze 1 pokazano schemat statyczny konstrukcji. Genezą przeprowadzenia zaawansowanej oceny technicznej stanu konstrukcji – poza opisaną w punkcie 1 modernizacją – były liczne uszkodzenia konstrukcji. Szczególnie wyraźnie ujawniły się one w krzyżulcach pionowych układów stężających (fig. 4). Analizując zinwentaryzowane w obiekcie uszkodzenia można wyodrębnić uszkodzenia polegające na: 1) lokalnej utracie stateczności ścianek prętów; 2) globalnej utracie stateczności prętów; 3) uszkodzeniach miejscowych polegających np. na zerwaniu prętów rozciąganych. Przykładowe uszkodzenia przedstawiono na figurze 4. Główną przyczyną uszkodzeń były nierównomierne osiadanie konstrukcji. Konstrukcje tak złożone jak stalowy szkielet nośny kotłowni elektrowni węglowej wykazują bardzo wysoki stopień wrażliwości na nierównomierne osiadanie podłoża. Wynika to z wysokiego stopnia statycznej niewyznaczalności oraz dodatkowego czynnika, jakim jest zawieszenie kotłów (o masie ok. 3600 t każdy) na ruszcie opierającym się na wierzchołkach słupów nośnych na poziomie ok. 60 m. Skaning laserowy konstrukcji jest metodą inżynierską, która umożliwia pomiar nawet bardzo skomplikowanych konstrukcji budowlanych [1–13]. Pozwala na określenie szczegółowych wymiarów konstrukcji lub jej części [23], jej imperfekcji [7] czy też jej globalnego stanu deformacji [11, 14]. W celu wykonania szczegółowej inwentaryzacji konstrukcji oraz stanu jej globalnej deformacji wykorzystano metodę skaningu laserowego (LiDAR). Uzyskana podczas skaningu laserowego chmura punktów (w wersji skompresowanej zajmuje około 460 GB) dała informację na temat szczegółowej morfologii konstrukcji, wymiarów przekrojów elementów prętów oraz pozwoliła na szczegółową inwentaryzację uszkodzeń. Poza uzyskaniem szczegółowych danych geometrycznych (fig. 1) skaning laserowy posłużyłdo ustalenia globalnego stanu deformacji konstrukcji. Na podstawie analizy danych z chmury punktów określono kształt t osi słupów obrazujący stan przemieszczeń konstrukcji od obciążeń i osiadań działających w okresie eksploatacji elektrowni. Stworzono kilka modeli obliczeniowych. Analizy prowadzono zarówno w zakresie statyki liniowej jak i nieliniowej uwzględniając nieliniowości geometryczne oraz materiałowe. Podczas analiz uwzględniano przewidziane normami łukowe oraz przechyłowe imperfekcje konstrukcji. Analizy prowadzone z wykorzystaniem modelu zakładającego liniową pracę konstrukcji uniemożliwiły właściwą ocenę stanu wytężenia konstrukcji – siły przekazywane ze stężeń na słupy (w wyniku nierównomiernego osiadania) wielokrotnie przekraczały nośność prętów stężeń. W związku z tym podjęto decyzję o zastosowaniu modelu nieliniowego, uwzględniającego wpływ degradacji sztywności tężników pionowych na wielkości siłw słupach. Degradacja sztywności spowodowana była wyboczeniem prętów ściskanych i uplastycznieniem/zerwaniem stężeń rozciąganych. Analizy nieliniowe przeprowadzono z wykorzystaniem dwóch typów modeli obliczeniowych: 1) globalnych: prętowo – powłokowych modeli 3D budynku kotłowni służących do obliczania wielkości siłwewnętrznych i przemieszczeń konstrukcji. 2) lokalnych: prętowo-powłokowych szczegółowych modeli wybranych elementów konstrukcyjnych. Z uwagi na lokalne spiętrzenia naprężeń w słupach, w obszarze połączeń z ryglami konieczna była ocena wielkości rezerwy plastycznej. Uzyskane wyniki obliczeń posłużyły do oceny wytężenia słupów i analizy stateczności globalnej konstrukcji. Na tej podstawie opracowano projekt wzmocnień. Liczne analizy na modelach globalnych i lokalnych, doprowadziły do wprowadzenia systemu wzmocnień konstrukcji składającego się z lokalnych napraw. System wzmocnień pozwoliłna przywrócenie bezpieczeństwa konstrukcji przy minimalnym nakładzie pracy i niewielkiej ingerencji w istniejącą infrastrukturę. Takie podejście wymagało opisanych w referacie bardzo złożonych analiz numerycznych wykonanych na podstawie szczegółowych danych uzyskanych z monitoringu geodezyjnego oraz chmury punktów. Podstawowe wnioski z niniejszej pracy można przedstawić następująco: 1) zastosowanie liniowej analizy statycznej prowadziło do niewłaściwej oceny stanu technicznego (uzyskane wyniki wykazywały kilkukrotne przekroczenia nośności prętów stężeń); 2) uzyskanie poprawnych wyników obliczeń było możliwe na podstawie zaawansowanych modeli nieliniowych uwzględniających nieliniowości materiałowe, geometryczne, imperfekcje oraz nieliniowe przeguby wprowadzane lokalnie w miejscach istniejących uszkodzeń prętów; 3) stopień skomplikowania obiektu wymagałzastosowania zaawansowanych technik pomiarowych w postaci skaningu laserowego (LiDAR) w celu uzyskania danych dotyczących konstrukcji oraz jej przemieszczeń/deformacji. Uzyskanie tych danych metodami tradycyjnymi byłoby niemożliwe; 4) niezbędne było wykorzystanie danych z monitoringu geodezyjnego podpór, w celu poprawnej oceny wytężenia konstrukcji; 5) zastosowanie lokalnych wzmocnień konstrukcji pozwoliło przywrócić jej poprawną i bezpieczną pracę. Na podstawie złożonych analiz numerycznych i przy wykorzystaniu zaawansowanych technik pomiarowych udało się skutecznie wzmocnić istniejącą konstrukcję oraz zaprojektować i zrealizować konstrukcję wsporczą reaktora SCR w sposób nie pogarszający jej pracy i bezpieczeństwa.

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