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Structural and material assessment of historic reinforced brick masonry elevator for grain – a study case

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Abstract. The grain elevator was erected around 1940 and is situated at the Odra River embankment. It has a rectangular plan with the longer side perpendicular to the former port wharf. The structure of the building is mixed, made of reinforced concrete and brick masonry. The entire facility was founded on a reinforced concrete foundation slab. The ground floor columns, supporting the silos, the walls of the ground floor, the floor above the ground floor with silo drainage funnels, the inter-story ceilings of the technical route, the roof concrete frames and the attic ceiling are made of reinforced concrete. The main part of the structure consists of 74 interlocked grain silos, with a square cross-section. The walls of the silo chambers are brick, reinforced with steel bars in each joint. The article presents the results of diagnostics of the technical condition of the assessed object, including material analyses (concrete, brick, steel), as well as the results of static and strength calculations of the main load-bearing elements of the object conducted in order to verify the possibility of its adaptation to new housing functions.

1 Introduction

The grain elevator under consideration (Fig. 1) was built in the years 1938-39 according to the design made by A. Pötzsch and E. Liehr. It was ordered by the (still existing) company Kampffmeyer Mühlen GmbH established in Potsdam in 1883 [1].

Fig. 1. Current view of the grain elevator.

It has its own quay and a reloading siding, connected to a nearby railway station. It was used to store grain, transport and distribute it to nearby industrial plants, including the brewery [2]. The facility functioned until the beginning of the 20th century (Fig. 2), when it was sold, along with the surrounding area, to a private investor.

Fig. 2. View of the grain elevator in 2006 [4].

The purpose of the conducted assessment of the technical condition of the elevator was to evaluate the possibility of its adaptation to new apartment functions worked out in the architectural design [3].

1.1 Description of the elevator structure

The assessed building is situated at the bank of the Odra river, with its longer side perpendicular to it (Figs 2). The dimensions of the building in the projection are: 57.10 x 25.50 m, and the height is 33.60 m. In the middle of the building's length a transverse dilatation was created by doubling the columns and separating chambers (Figs 3,4), which, however, does not include the foundation slab. From the functional side of the facility, the following technological elements could be distinguished (Fig. 3, 4): the underground part under the

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silos, which was used to unload the silo chambers; 8-storey technical route at the gable wall on the wharf side, with a reinforced concrete staircase and elevator shaft; a set of 74 interlocked chambers of grain silos (12 rows, 6 in a row, plus two silos on the north-west side next to the technical road); attic on the ceiling above the silos, in which there were devices for filling the chambers.

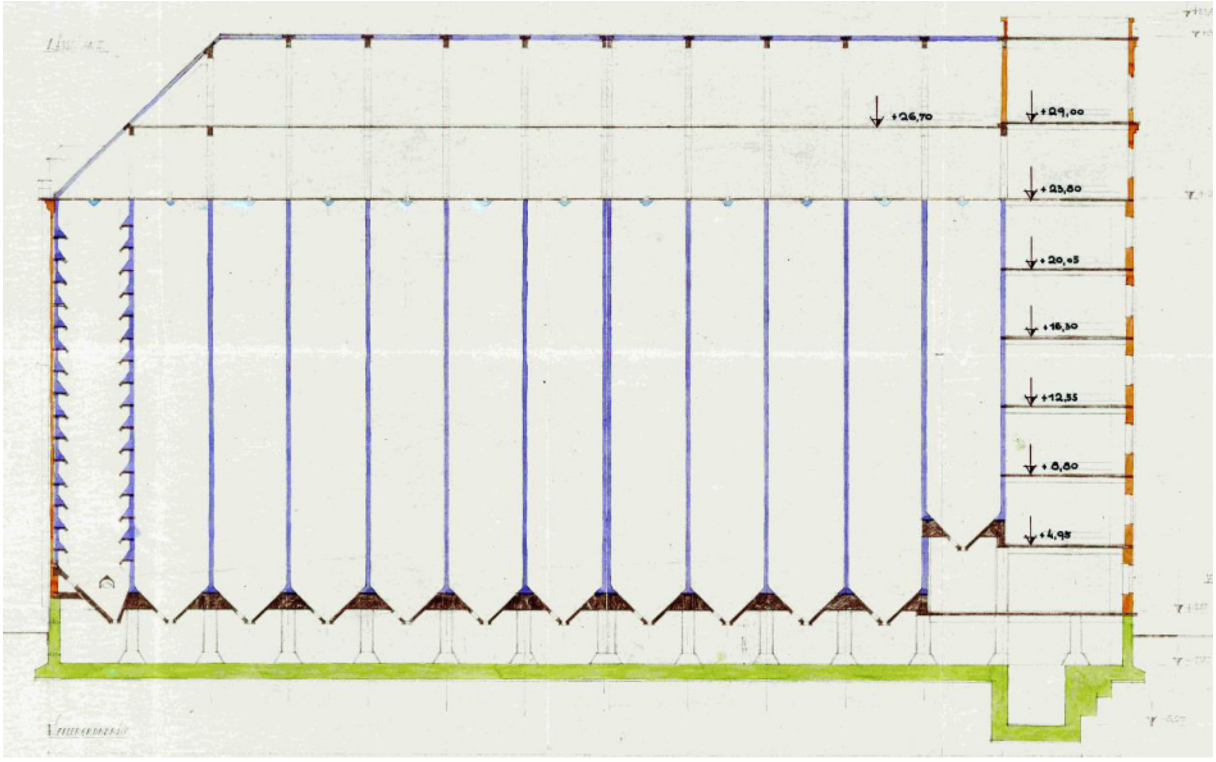

Fig. 3. Vertical cross-section of the grain elevator – archival documentation [5].

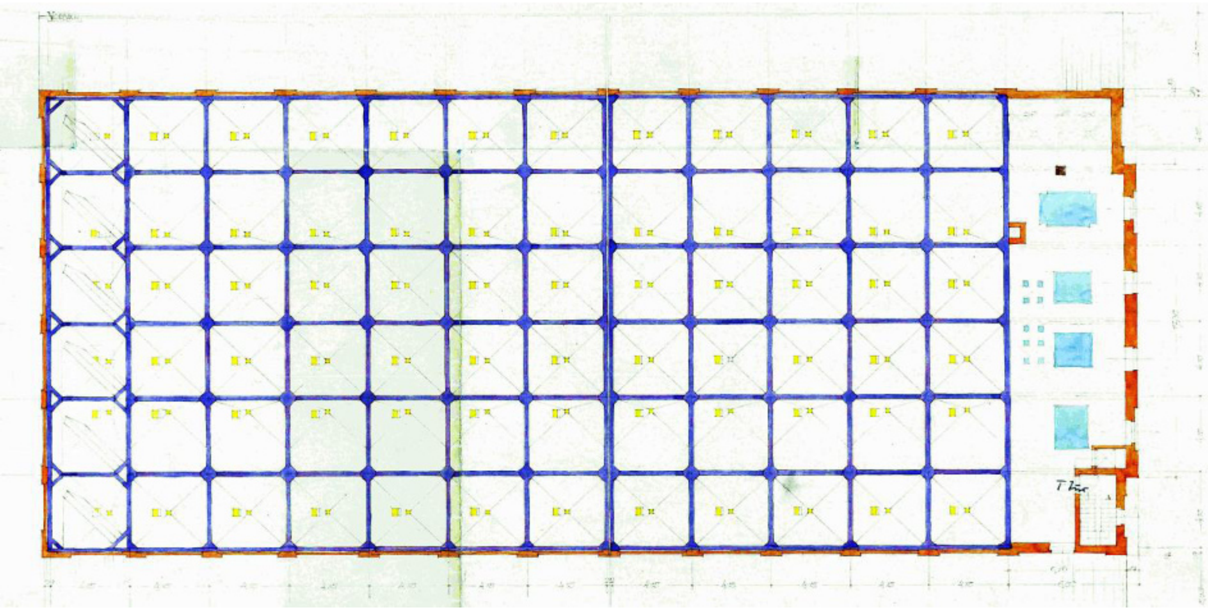

Fig. 4. Horizontal cross-section of the grain elevator – archival documentation [5].

Based on the analysis of the archival documentation and the visual inspection, it was found that the structure of the building is mixed, made of reinforced concrete and brick masonry. The outer walls of the building are two-layered, with a load-bearing part with the thickness of 25 cm (also constituting the walls of the silos), an air gap and a veneer thickness 12 cm, fastened to internal walls with reinforcing bars (Fig. 5). From the side of the west, south and east elevations, the outer walls of the building are also the walls of the outer silo chambers.

The whole building is founded on a reinforced concrete foundation slab (Figs 3, 6). The ground floor columns supporting the silos, the ground floor walls, the floor above the ground floor with silo drainage funnels,

Fig. 5. Two-layered walls of the building and silo chambers.

inter-story ceilings of the technical route, as well as the attic ceiling are also made of reinforced concrete (Fig. 7). The structure of the roof is made of a system of reinforced concrete frames (Fig. 8, 9) with inclined transoms, supported in 1/3 and 2/3 of the building width by additional columns, transferring the loads from the roof to the walls of the chambers. The space between these frames is filled with a Klein brick plate to which the roofing elements were attached.

Silos with a square cross-section and external dimensions of 4.15 x 4.15 m, and a height of 22.70 m have an unusual solution for the wall structure in the form of a solid brick wall, reinforced with 12 mm smooth bars in every second joint (Fig. 5, 10).

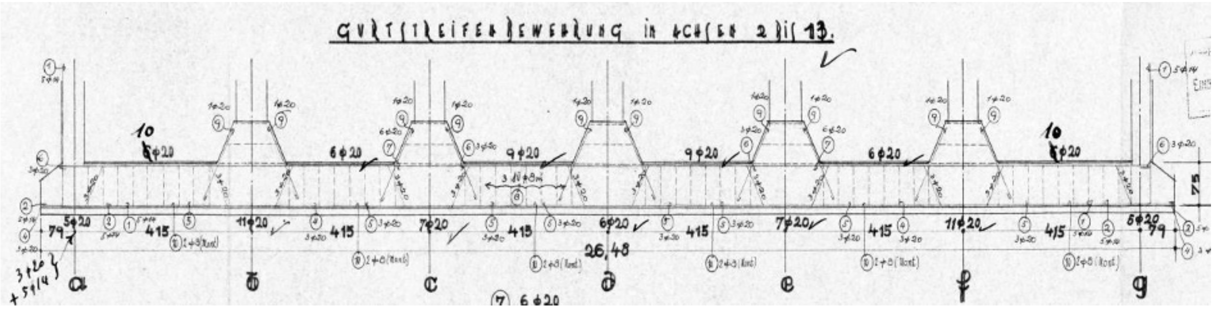

Fig. 6. Archival drawing of the foundation slab [5].

Fig. 7. View of the foundation structure of the elevator.

Fig. 8. View of the frame structure of the roof.

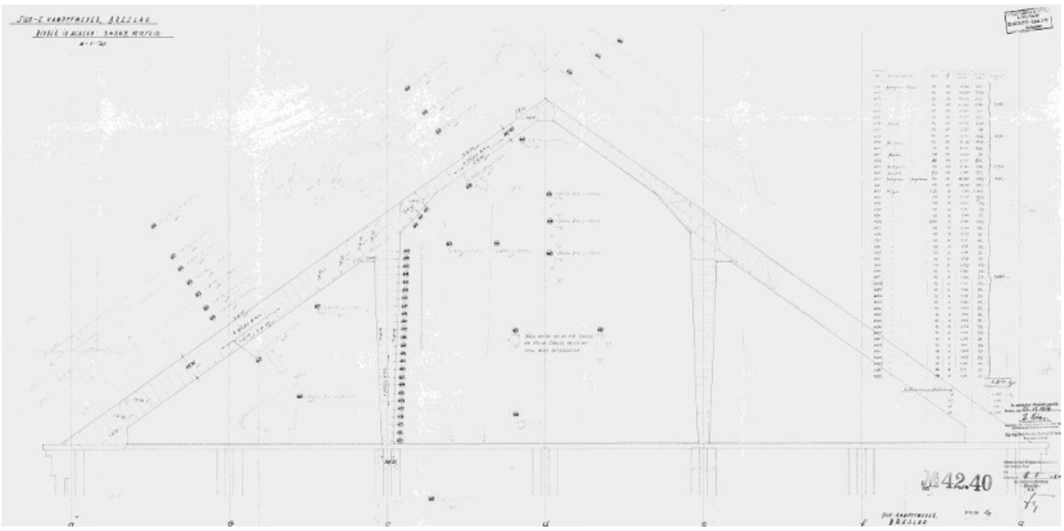

Fig. 9. Archival drawing of RC roof frames [5].

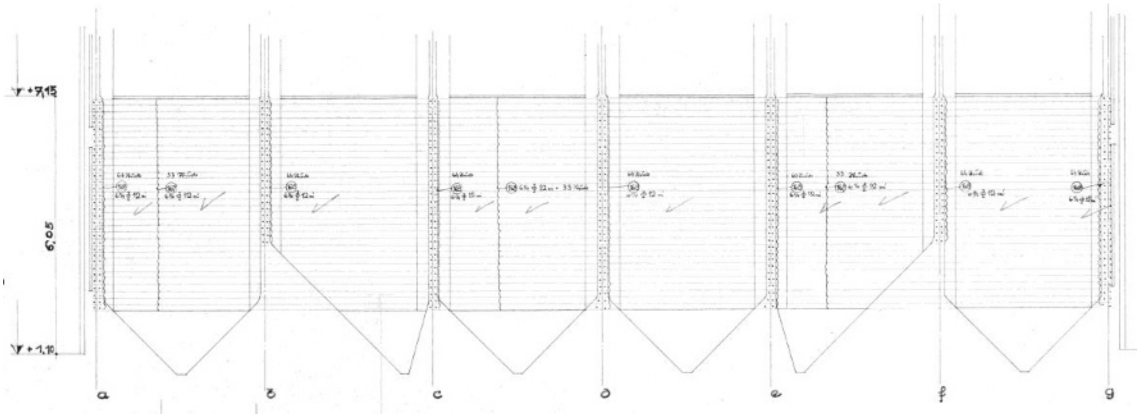

Fig. 10. Archival brick silo chambers design drawing [5].

The walls of the chambers are interconnected (interpenetrate with each other) creating a highly rigid structure. Additionally, all corners of the chambers are stiffened with masonry slants (Fig. 4).

2 Assessment of the technical state of the elevator structural elements

In the procedure of assessing the technical condition of the elevator the following structural analysis and material examinations were made:

- analysis of archival documentation;
- geometrical inventory;
- damage inventory;
- geotechnical examinations;
- concrete, reinforcement steel and masonry strength tests;
- structural modelling, static and strength calculations.

Results of the strength tests were used to define the materials' parameters for structural calculations.

2.1 Structural and damage inventory

The grain elevator has not been in use since 2007 and its building has been left without any protection until the current time. During the assessment, made in 2019, the following most important damages were observed. Simultaneously, the inventory of its most important structural elements was carried out.

2.1.1 Foundation slab

According to the archival documentation as well in made outcrops, the entire building was built on a foundation slab of 75 cm thickness, protruding 0.5 m beyond the face of the external walls (Figs 3, 6, 11). In the drillings made inside the building, the presence of the upper reinforcement of the slab with smooth steel bars was in accordance with the archival documentation - Ø8 mm bars in the span every 14 cm and Ø20 mm between the columns approx. every 20-22 cm. Groundwater appeared in the trench at the foundation level of the building (Fig. 11). There was also no visible damage to the slab or walls above it which would indicate poor operation of the foundations. In connection with the above it was assumed that the building foundations are in good technical condition and would be able to safely transfer the designed loads related to the adaptation of the building for residential purposes.

Fig. 11. View of the foundation slab outcrop.

2.1.2 Ground floor columns and slab

At the ground floor level, on the foundation slab, there are reinforced concrete pillars (Fig. 7) supporting the silo chambers, their discharge hoppers and, at the northern gable wall, the route of technical floors. Most columns measured 75 x 75 cm. At the foundation slab, the columns extend symmetrically to the dimensions of 155 x 155 cm, forming with the foundation slab a kind of inverted mushroom ceiling. The outcrop confirmed compliance of the reinforcement with the archival documentation.

Fig. 12. Example of the ground floor columns' reinforcement corrosion.

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In static calculations it was proved that the columns have sufficient load-bearing capacity to transfer the designed loads. Generally, the technical condition of the columns was assessed as good. No damage was found, except for a few columns at the outside wall where the concrete cover and the reinforcement itself were deeply corroded (Fig. 12).

The ceiling above the ground floor was made in the form of a reinforced concrete slab with a thickness of 90 cm, it rests directly on the pillars of the ground floor and also serves as the bottom of the silos - there are discharge hoppers in it. The technical condition of the ceiling was evaluated as poor. It had cracks in every area of the silo chambers (Fig. 13).

Fig. 13. Cracks in the slab over the ground floor.

2.1.3 Elevator internal walls

The greater part of the building consists of grain silo chambers with internal dimensions 3.90 x 3.90 m. The walls of the chambers are made of 25 cm full brick, reinforced with two Ø12 mm smooth rods every second joint (Fig. 14). The walls of the chambers are interconnected creating a rigid structure. Based on the destructive and sclerometric tests it was found that the chambers were made of a very high quality bricks. The technical condition of the chambers was assessed as good. No damage was found, although most of them were not fully available for direct observation and inside the chambers they may be damage on their surface. The static calculations showed that these walls can be used as load-bearing for the ceilings of residential stories, but with a significant reduction of the designed openings.

Fig. 14. The reinforced brick wall of the silo chamber.

2.1.4 Slab over silo chambers

The attic ceiling covers the entire surface of the building and the silo chambers - their charging and technological openings are located in it (Fig. 15). The ceiling is 12 cm thick and is cross-reinforced at the bottom with Ø10 mm bars every 18 cm, and above the supports (chamber walls) with Ø10 mm bars every 18 cm. No upper reinforcement was found in the open-pits above the chamber walls, while lower reinforcement was found in accordance with the archival documentation. The static calculations showed that despite the lack of support reinforcement, the floor has sufficient load-bearing capacity to transfer the new designed loads. Despite local mechanical damages, its technical condition was assessed as sufficient.

Fig. 15. The attic slab over the silo chambers.

2.1.5 Roof frames

The main structural element of the roof are RC frames, spaced every 4.15 m, i.e., in the spacing of the silo walls. A hollow brick Klein-type plate with a total thickness of 15 cm was made between the frames. Depending on their location, the elements of the roof frames have different dimensions. In typical frames, the lower transoms have the dimensions of 25 x 65 cm, the upper transoms 25 x 35 cm, the posts widen upwards and have the dimensions at the bottom 25x30 cm and at the top 25x70 cm. In the outcrops (Fig. 16) it was found that the bottom transoms have bottom reinforcement of 7Ø18 mm, columns of 4Ø18 mm plus 2 additional bars Ø7 mm in the wider part of the column, stirrups Ø8 mm every 25 cm.

Fig. 16. Local destruction of the roof frames reinforcement.

The reinforced concrete frames of the roof were in a satisfactory technical condition, although most of them have cracks, and several have suffered from significant local loss of the cover and corrosion of the reinforcement (Fig. 16).

2.2 Geotechnical examinations

The oldest drilled soil layers were the glacial sediments of the South Polish Glaciation, developed as clays. Those layers have not been drilled to their final depths. Above them there are Holocene alluvials in the form of medium and coarse sands, gravels, moderately compacted. From the level of the terrain, an uncontrolled mixture of sand, brick fragments, concrete and hummus was detected. Underground water has been drilled in all holes, at the level of the foundation slab of the building. In connection with this, in case of conducting works below the water table, there may occur a groundwater inflow to the excavations.

2.3 Concrete and reinforcement strength tests

In order to determine the strength of concrete and reinforcing steel, several concrete probes were drilled out and a some reinforcing bars were cut from the construction.

In the case of concrete elements, 3 boreholes with a diameter of Ø100mm were taken from the structure and destructive tests were performed with them. For the concrete sample from the foundation slab, the strength corresponded to concrete of C35/C45 class, for the column sample the strength was obtained as for concrete C16/C20, and for the sample from the floor ceiling as for concrete C20/C25. At the same time there were made in many places additional sclerometric measurements. Basing on the standard calibration procedure they showed that the reinforced concrete elements of the building, apart from the foundation slab, were made of C20/C25 class concrete, locally the roof structure was made of C25/C30 concrete, and the foundation slab was made of C30/C37 concrete. Finally, as average values, C30/C37 concrete for the foundation slab was adopted for the calculations, and C20/C25 concrete for the remaining elements.

To determine the strength of the reinforcing steel, 3 samples of reinforcing bars were taken from concrete elements and tested to failure in a tensile testing machine. As a result of the tests, the following yield values were obtained:
R_{sr} = 531 MPa, s = 36 MPa,
R_G = 531-1.64x36 = 472 MPa,
f_{yk} = 0.8x472 = 378 MPa,
f_{yd} = 378/1.15 = 250 MPa,
where: R_{sr} - mean value of strength from *n* samples; s – standard deviation; R_G – guaranteed tensile strength; f_{yk} – characteristic tensile strength; f_{yd} – tensile strength. Finally, the yield limit f_{yd} = 210 MPa for steel was taken for the structural calculations.

2.4 Brick silos walls strength tests

For the testing of structural strength of brick walls, 3 core boreholes of Ø150 diameter were taken from the walls of the silos (Fig. 17) and tested to failure in compression. From the destructive tests the compressive strengths were obtained as follows:
f_{k1} = 13,400 kPa,
f_{k2} = 14,900 kPa,
f_{k3} = 6,000 kPa,
For the mortar, M20, M15 and M10, respectively.
Based on the calculation method as for concrete the following results were obtained:
f_{ksr} = 11,400 kPa; s = 4,800 MPa;
f_{kG} = 11,400-1.64x4,800 = 3,500 MPa;
f_k = 0.8x3,500 = 2,900 kPa,
where: $f_{k1,2,3}$ – results from tests, f_{ksr} – mean value of the measured strength; s – standard deviation; f_{kG} - guaranteed compression strength; f_k – characteristic compression strength.

Fig. 17. Borehole in the masonry silo walls.

Comparatively, the results of sclerometric tests for bricks were made. In those cases rebound numbers obtained were between 42 and 58. Based on the visual inspection and charts from the research literature [6, 7, 8], for all masonry elements, a characteristic value of the strength was assumed as f_k = 5,600 kPa, material coefficient α_m = 0.5, design strength for compression f_d = 5,600x0.5 = 2,800 kPa, the material elastic coefficient a_m = 1,100 (according to the adopted design code PN-67/B-03002).

Finally, these results were applied in structural calculations.

2.5 Structural modelling and calculations

Static and bearing capacity calculations of the selected, building structural elements were conducted basing on the worked out structural and material examinations and using design concepts of building refurbishment [3].

This architectural concept generally assumed the following ideas:
- dividing the entire building into 9 storeys, but at different levels than currently existing in the technical part of the elevator;
- maintaining the number of storeys and ceilings in the technical part in the elevator;

- use of existing reinforced brick silo walls as supporting elements for new slabs, however with many new openings made in them;
- demolition of the central part of the building covering 2 rows of silos – for communication and lightning functions;
- execution of a glass roof over the demolished chambers to illuminate the open space below.

Calculations were conducted to check the possibility of the above mentioned concepts to be applied from the point view of the capacity of the existing structure.

Below only the results of the structural calculations of the roof frames, silos walls and foundation slab are briefly presented and discussed.

2.5.1 Roof RC frames

The static calculations showed that when the existing Klein board would be left between the roof frames, the upper rafters of the frames would not have sufficient load-bearing capacity to transfer the designed loads related to the roof insulation. In the case of dismantling the Klein slab and replacing it with a glass roof cover the frames would have sufficient load capacity.

2.5.2 Silo reinforced brick walls

The load-bearing capacity of the brick walls of the silos was checked for two types of solutions for new ceilings: cross-reinforced ceilings and one-way reinforced ceilings, taking into account designed openings to be made in their walls.

Construction analyzes and strength calculations have shown that in the first case the load-bearing capacity of the walls would be sufficient, and the communication openings could be quite wide, however, it would be extremely difficult to make such ceilings, as they would require undercutting of the walls at large widths.

2.5.3 RC foundation slab

Calculations of the foundation slab were performed as for the slab on an elastic foundation (Fig. 18). The arrangement of the soil layers under the slab was adopted in accordance with geotechnical tests, additionally assuming that the groundwater level was stabilized at the foundation level. As the building was used for a long time with high loads and there was a significant consolidation of the soil underneath it, the foundation slab was additionally calculated as for the inverted mushroom ceiling, evenly loaded with ground resistance (Fig. 19).

Independently, from the static models used for the slab, calculations showed that after the building is adapted for residential purposes the foundation slab will be affected by much lower loads than when the building was operated as a grain elevator, and that it has sufficient load-bearing capacity to transfer the designed loads.

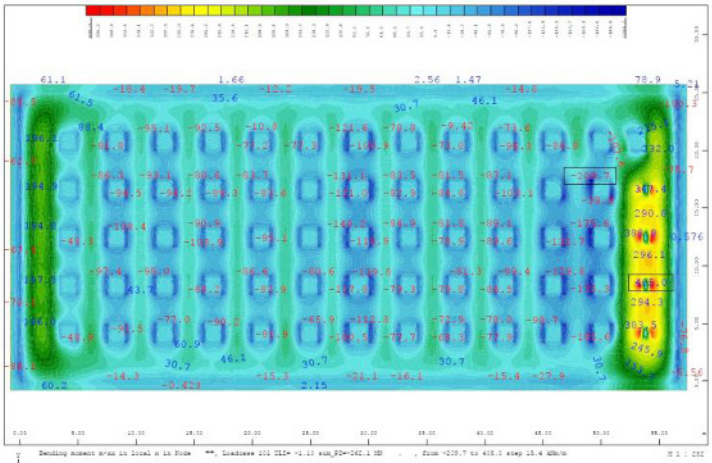

Fig. 18. Bending moments M_{xx} – model of slab on elastic foundation.

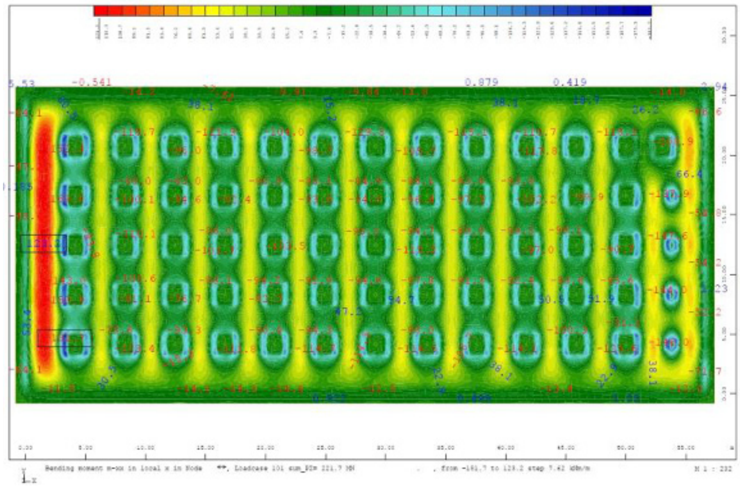

Fig. 19. Bending moments M_{xx} – model of inverted mushroom slab.

3 Final remarks

The article presents the results of the assessment of the technical condition of a reinforced concrete and brick grain elevator, aimed at determining the conditions for its refurbishment and adaptation for residential and utility purposes based on the developed architectural concept.

The assessment of the technical condition included the analysis of archival documentation and its comparison with the existing elevator condition, inventory of damage and specification of the method of their repair, material tests and static and strength analyzes.

It was found that the general technical condition of the building was only sufficient, mainly due to damage to structural elements resulting from long-term operation without appropriate renovation and the lack of protection of the building after its decommissioning.

The performed static and strength calculations of the elements of the elevator structure (with the use of the results of the tests of structural materials) showed that they had load capacities allowing them to transfer the newly designed loads.

However, the proposed construction solutions, although interesting in terms of architecture, would be very difficult to implement due to the specific nature of the elevator and the construction solutions used in it - e.g. the construction of silo chambers in the form of reinforced brick walls, partially intended for demolition, which would significantly affect the stability of the whole elevator structure.

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