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Reconstruction of Space Steel Constructions

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Abstract

Reconstruction of some special types of constructions – silos, timber roof structure and a winter stadium are described. The silos are cylindrical with a diameter of 36.0m with a total height of 50.5m. The silo shell is made from steel plates of variable thickness. Capacity of the silo is 60 000t. Gradually, during more than 30 years of operation, local deformations and distinctive 6000mm high cracks in the bottom part of the shells of the silos developed. On the basis of diagnostic inspections and control static calculation a strengthening was proposed. To increase working life of the clinker silos, the shell strengthening over the whole height of the cylindrical body by means of horizontal rings and vertical stiffeners was designed. The total S355 steel consumption for strengthening of one silo shell was 300t. The original roof structure of a winter stadium in Zvolen was made of timber glued beams with span of 55.5m. Some problems occurred during years of serving to its purpose. Diagnostics showed that construction is unsatisfactory for the ultimate and serviceability limit states. Deflection of the roof construction in the year 2005 was more than 500mm. Authors proposed strengthening of the original beams (overall 34pcs) by prestressing.

The original reinforced concrete skeleton of Winter Stadium in Bratislava with plan dimensions of 70.0 x 100.0 m was built in 1943-1952. During extensive modernisation of Stadium, its steel roof structure is also prepared for basic reconstruction.

Keywords: steel structure, reconstruction, silo shell, diagnostic inspections, strengthening, modernization

1. Introduction

Steel load bearing structures must be operated and maintained according to appropriate standards and regulations. The overall technical condition of steel structures is monitored by regularly repeated preventive and detailed inspections. The set of methods for examining technical condition of steel load bearing structures is indicated as assessment. The need to assess steel structures was prompted especially by numerous failures of steel structures, local defects of elements and parts and by requirement of refurbishing load bearing structures after exhausting their physical and moral life.

2. Appraisal of the technical condition of the steel structures of clinker silos

The aim of the appraisal was to determine the cause of a few serious defects and to propose actions in order to assure the working reliability, the safety and to prolong the physical serviceable life of the steel structures of the silos.

The contractor did not have the original complete project documentation and the static calculation of the load-carrying structure of the silos at the disposal.

Detailed diagnostic inspections have been performed in March and May 2006 by workers of the Faculty of Civil Engineering, Slovak University of Technology in Bratislava and were aimed mainly on:

- determination of the real geometrical shape of the shell roof and the foundation structures of the silos,
- determination of the thicknesses of the shell plates, ultrasound measurements,
- determination of material quality, non-destructive tests,
- determination of the technical state of the reinforced concrete structures,
- identification of structural details of the silo's steel structures,
- specification of places of anchorage of the technological equipments producing additional loading,
- assessment of mechanical damage, local and global deformations of the load-carrying parts of the silos.

The steel silo consists of a wall and roof shell and ends with an upper compression ring at the height + 52,50 (fig. 1). The shell is considered as a thin-walled cylindrical shell. It is made of plates with thicknesses 33 – 13mm, welded with vertical and horizontal butt welds. The shell is at the bottom part fixed into the foundation and introduces into it compression, a horizontal force and a moment. Loading of the shell comprises the roof, pressure of the clinker filling, technology on the silo, wind and temperature (clinker filling has 90 ºC).

Figure 1: View of Clinker Silo PC2 with Technology

Extreme stresses resulted from the static solution at the bottom edge in the nearest vicinity of the silo anchorage. The original project assumed that when direct effect of the pressure of the material over a certain height from the anchorage will be prevented, the extreme effects will considerably decrease. For this purpose a reinforced concrete monolithic ring with 40cm width and 100cm height was created in a distance of 50cm from the steel shell, which had to carry the pressure of the material and to prevent the direct influence of the temperature on the bottom ring of the shell. A considerable smoother deformation in the vertical direction should have been the result and so a decrease of the moment influence.
The roof is constructed from profiles connected to the bottom tension ring and to the upper compression ring. Into the compression ring the communication tower is anchored, which exhibits also horizontal forces. The cladding is made from a plate, which was cut in form of a trapezoid, laid and welded to the supporting profiles.
The communication tower is anchored at the ground level into a massive foundation and anchored against horizontal actions at the level + 43.0 into the bottom chord of the silo roof. Acting on the tower is also an additional load from the steep conveyor, which is anchored to a cantilever approximately situated at the level + 35.00.
The gangway, which connects the communication tower with the silo superstructure, is anchored to the tower and to the superstructure and is made from two truss girders with a lower bridge deck and a stiffener at the upper chord. It is a classic conveyor bridge.
The silo superstructure has a relatively complicated structure, because it is placed on the upper circular ring with a diameter of 9.0m and at the same time the axial system of the external load-carrying structure is 9.0m, which results in an inconvenient position of the corner columns. The grid and the floor at level + 52.50 is stiffened in such a way, that this system is able to carry the relatively large actions from the technological equipment.
During operation (more than 30 years) two vertical cracks with a length of ~ 6.0m developed in the bottom part of each silo. Views of the repair of the last crack in the clinker silo are on Fig. 2.

Figure 2: View of the Crack in Silo (November 2005)

Detailed diagnostic inspections of structures were performed in March and April 2006. Controlled were the following:

- shell and roof of silos PC1 and PC2, anchorage into the foundations,
- exit from the communication tower,
- connecting gangway from the communication tower,
- superstructure and layout of the technology,
- dump to the small silo.

During the control it was found out that:

- the load-carrying structures are integral and no member was removed by non-professional interference,
- two cracks emerged during operation at the bottom side of the shell of silos PC1 and PC2, which were professionally repaired.

Shell thicknesses of silos PC1 and PC2 were measured by a digital ultrasound thickness meter Digital Wall Thickness Meter DM – 3 with precision of 0.05mm. After measurement we succeeded to obtain the original projected plate thicknesses of the shell and the roof.
The plate width in strip 1 is ~ 2.0m; strips 2 to 16 have a width of 2.5m and strip 17 is ~1.5m wide. The probes at the individual locations were marked. At each probe the thicknesses were measured in 3 places, for verification the mean value from these 3 measurements was taken.
The largest corrosion losses were at the connection of the bottom plate strip of the shell with the base plate (Fig. 3). After cleansing a value $t \doteq$ 30.1mm near the weld was measured at probe S3. Measurements of the roof plate were also carried out. The mean value of the 3 probes was $t \doteq$ 6.2mm.

Figure 3: State of the Shell in Contact with the Base Plate

From the results of the diagnostic inspection follows that:

- the height of the "dead" clinker supplies in silo PC1 reaches up to 13.8m; the dead mass is non-uniformly distributed along the walls with heights of 6.6 to 13.4m.

- the measured, real plate thicknesses mainly in the bottom part of the silo are smaller than the projected ones. During operation a wear of mainly the internal side of the shell occurred and the original thickness is decreased also by corrosion losses. The largest corrosion losses were determined at the connection of the bottom shell plates to the base plate; the real thickness was tp =30.1mm against the original one 33mm. The loss is up to 3mm.
- the strength of the silo shell, determined by a non-destructive method, by a hardness test with a dynamic hardness tester EQUOTIP PICCOLO reaches only 421 ÷ 435MPa against the expected one 520MPa (steel "52"), that is only 81 ÷ 84%. The real mechanical and technological material characteristics of the shell can be determined only by test specimens taken from the silo shell.

During diagnostics a geodetic and photogrammetric spatial survey of the real shape of the clinker silo shells was performed (fig. 4).

- height differences of the bottom steel ring were at silo PC1 -4.0 to 50.0mm; the upper edge of the foundation strip was not horizontal. The ring of silo PC2 was not accessible for control.
- deviations from the theoretical shell diameter r = 18.0m had been found out in various heights. At silo PC1 the maximal deviations were in profile B -57mm (into the silo's interior) and +94mm (out of the silo). In profile F the silo shell was deformed into the silo's interior -76 to -29mm. At silo PC2 the largest deformations were in profile I -50 and +105mm. Because of the magnitude of deformations, it was necessary to make once in a year a control of the geometric shape of the silos (on the set marks) and in the case of an increase of deformations to take adequate action to ensure silo operation.

Static Verification of the Silo
Assessment of actions:

- Calculation of actions from the stored material – according to DIN 1055 (year 1987)
- Temperature actions – according the measured values provided by HOLCIM.
- Non-uniform settlement of foundations – modelling of the non-uniform settlement of foundation structures were done in the „cosine“ shape, where the maximum value of amplitude was determined on the basis of survey as ±10 mm.

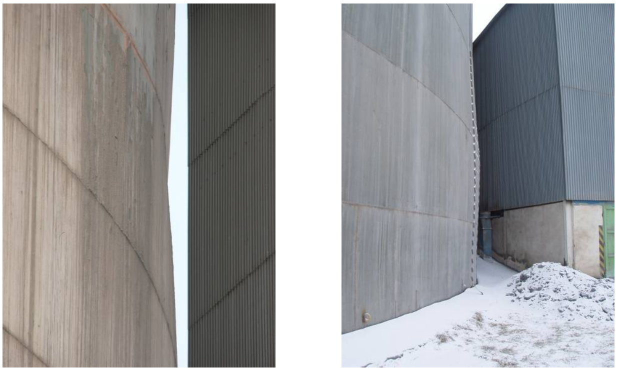

Figure 4: Local Deformation of Silo PC1 Shell

- Other actions – these actions were determined according to STN 73 0035 (1980) – Actions on structures.
- Partial load factors and combination factors – these values were determined according to STN 73 0035 – Actions on structures.

The aim of the calculation was to verify the existing clinker silo structures, to determine possible causes of failures and to propose necessary adaptations of the clinker silo structures. The load-carrying silo structures were checked according to the ultimate and serviceability limit states.

Preliminary static calculation of the original structure was performed on the basis of theory of elasticity in programme MathCad.

Detailed strength calculation was performed with programme IDA NEXIS 32, 3.60.15 from SCIA company. A 3D plate-wall model of the steel structure of the clinker silo shells was used.

The results of the preliminary and the detailed calculation of the original structure agreed very well.

Results of the calculation:

- The stress state of the structure has been evaluated on the basis of equivalent Von Misses stresses. The maximal stresses were calculated for the existing state of the structure and also for the new strengthened structure.
- The control calculation of the original structure of the clinker silo has shown that the maximal equivalent stress in the structure taking into account all actions and their combinations exceeds in some areas of the shell the design strength of the silo material S 355.
- By strengthening of the original clinker silo structure by a system of rings and vertical stiffeners a sufficient decrease of the maximal level of the equivalent stress in the structural shell was achieved. That means that the maximal equivalent stress of the strengthened structure and of its new parts (stiffening members) does not exceed the design strength of the silo material S 355.

Stability Verification of the Silo

The check was performed according the Slovak standard STN 73 1401:1984. Stability of shells is dealt with in Annex VI. There are different cases covered in this Annex.

Unstiffened shell with inner pressure:

- The silo loaded with clinker and non-uniform settlement was up to 2/3 height not satisfactory.

Shell with longitudinal stiffeners (without inner pressure):

- The silo loaded with clinker and non-uniform settlement was in the middle part not satisfactory. This is because the positive influence of the inner pressure was not taken into account (STN does not cover this case). That is why we then took the greater resistance of the stiffened shell without inner pressure or the unstiffened shell with inner pressure (but with stresses on the stiffened shell). The silo was found satisfactory (only in some strips the resistance was exceeded by maximum 5%, which will be offset by the influence of the inner pressure).
- The longitudinal stiffeners are checked for bending and axial compression as beam columns. The bending moment distribution was found on a strut 3D model which took into account the favourable circumferential tension into account by modelling "fictitious" rings that carried tension (i.e. the local bending moments were reduced in comparison with a continuous beam supported by ring stiffeners only). The circumferential tension had also a favourable effect on the buckling lengths. They were also calculated on the same 3D strut model.

Horizontal ring stiffeners:

- The ring stiffeners have to have adequate stiffness to provide support for the curved panels and longitudinal stiffeners as well. The dimensions of the ring stiffeners were calculated according to Buckling of Steel Shells, European Recommendations, ECCS 1998. The stress Sigmax was taken as 1.2-times the design value of buckling compressive stress (of the cylinder stiffened by longitudinal stiffeners, buckling between the ring stiffeners – see the ECCS publication).

Proposal of Silo Shell Strengthening

The steel silo shells will be strengthened by a system of vertical stiffeners and horizontal rings. After strengthening, the cylindrical shell will act as an orthotropic (orthogonal anisotropic) shell (fig. 5).
Horizontal rings are divided in primary and secondary. The primary rings have an angular shape, they are made of web (400.12 - 115768) and flange (250.25 – 115768).
There are five intermediate rings and one upper ring, which will be situated closely bellow the silo roof level.
The secondary rings are from flat steel 250.25 – 113154. The bottom ring is located over the foundation ring, the other 4 secondary rings are always minimally 200mm above the existing horizontal weld. This rule is valid also for the location of the primary horizontal rings.

The vertical stiffeners are from flat steel with variable dimensions. They will be located around the outer silo perimeter (totally 80pcs) in spacing ~ 1514mm. Their minimal distance from the original vertical welds is 150 to 200mm.
The total S355 steel consumption for strengthening of one silo shell is 300 t.
To execute the proposed strengthening of the silo shells it is necessary to work out:

- detailed workshop documentation of the structural strengthening elements,
- precise and complete the welding specifications for strengthening and a
- detailed erection procedure.

Figure 5: Reconstruction Works on the Clinker Silo

3. Reconstruction of the roof of the ice stadium in Zvolen

Control inspections have been made of the timber roof structure of the ice stadium, which accompanied the data obtained from the client. During the inspection the basic dimensions of the roof structure in transversal and longitudinal direction as well as the dimensions of some selected roof girders were checked.
The main cause of the extensive deformations (the measured value in 2006 was 463.5mm) was an insufficient resistance of bolted connections.
Every original timber glued girder with a total height 2.6m (totally 34 pieces) was strengthened by means of prestressing according to Fig. 6. The assembly of the new steel members of anchor brackets and tie rods was performed from the inside of the building.
The steel truss anchor brackets were manufactured of steel S355. The anchorage trusses were supplied to the site as individual members from rolled U-sections of light weight. The members of the anchor brackets have been connected to the timber girders by means of steel bolts with diameter 24 and 32mm. The field joints of steel members were bolted to gusset plates with M16/10.9 bolts (fig. 7) .

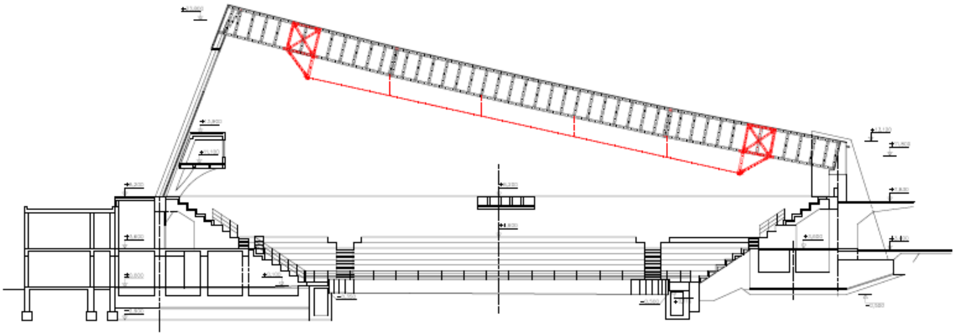

Figure 6: Strengthening of the Timber Girders by Prestressing

4. Modernization of the winter stadium in Bratislava

The winter stadium building in Bratislava was originally built in the years 1943-52. The RC frame has stands that are located around the ice rink with 30*60 meters dimensions. The stands are covered by a RC slab with 16m width, which is propped in the middle of the width by a longitudinal beam in 8m height above the stands. The beam is supported by circular RC columns located at 10m intervals.

In 1959, during the first reconstruction, the ice rink was additionally covered by a steel structure, which was placed on the strengthened columns of the original structure. It consisted of shallow welded steel frames with a 52.8m span.

In 1988, during the second reconstruction, the steel frames were supplemented with a bottom chord and diagonals, due to the load increase by modern technological equipment.

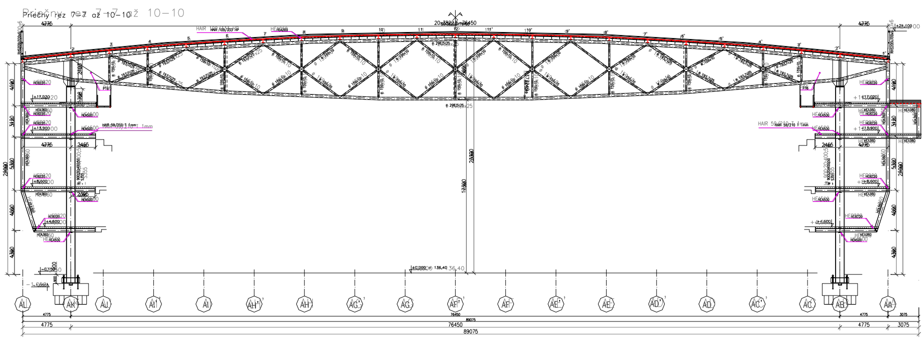

Figure 7: Scheme of the new steel structure

The columns of the original RC structure obstruct the view of the spectators, so the upper RC slab and the supporting columns will be removed. Only the RC structure of the stands will remain. During the third reconstruction, which started already, the steel structure of the roof will be completely dismantled. Due to the increase of the stadium capacity and modernisation of the building the original RC stands will be supplemented by a new steel structure build around them. The span of the main hall is 4.775+74.45+4.775 , the theoretical width is 86m (fig. 7). The main hall plan dimensions are 86*102m. 6m high truss girders with cantilever ends will be placed on the main columns.

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