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EXISTING CONCRETE SILOS – LESSONS FROM INSPECTION, DIAGNOSIS, REHABILITATION AND STRENGTHENING

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Abstract: The paper presents the behavior of some prestressed soya bean silos and of two other reinforced concrete grain silos, in service for more than 25-30 and 40 years respectively. All of these silos have suffered multiple durability deteriorations for which an in-depth inspection was performed. Studies focused on diagnosis and level of deteriorations, on rehabilitation and strengthening and even replacement of prestressing system. A decision as to level of intervention took into account the estimated remaining service life of each silo. The paper deals with the practical application of repair and strengthening methods and it also recommends inspection intervals.

Keywords: concrete silos, inspection, diagnosis, rehabilitation, strengthening.

1. INTRODUCTION

The first part of the paper presents two cases of soya beans coupled silos of seven hexagonal cells each made of prestressed concrete and the second part presents two cases of grain silos made of reinforced concrete and having cylindrical cells.

An in-depth inspection was performed for each silo, followed by a diagnosis of deteriorations identified and recommendations for rehabilitation and strengthening.

The practical application is presented with the focus on repair and strengthening methods and recommendations are made as to inspection intervals.

2. FIRST PART - COUPLED SILOS OF HEXAGONAL CELLS

The two coupled soya beans silos from the oil factories in Buzau and Urziceni consist of seven hexagonal cells each (figure 1). The side of each hexagonal cell is 3.75 m and about 32 m in height. Figure 2 presents a horizontal cross section.

Fig.1 View of coupled silos

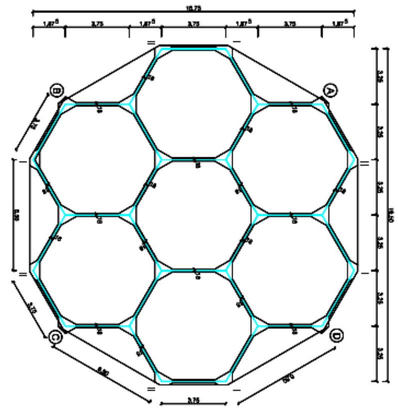

Fig.2 Cross section of hexagonal silo

The structure was achieved in 70s, by slip form method of concrete walls with the planned C16/20 class concrete. The prestressing operation provided strands of 12 mm dia., of two half ring anchored alternatively on concrete blocs. Their protection was provided by coatings for strands (multiple layers) and by concreting for anchorages.

2.1 Inspection

After 25-30 years of service some broken strands were noticed and an in-depth inspection was necessary using climbing platforms for access to the wall at different heights.

The in-depth inspection covered the concrete itself and the prestressing system, including vertical bearing concrete ribs and blocs, strands and anchorages.

The results of inspection on the silos made after about 25-30 years of service showed that the prestressing system presented significant deteriorations due to the corrosion of strands and anchorages, which were similar in all four hexagonal cells batteries.

The next figures show various zones of intensive corrosion on the strands bearing support – fig. 5, at the strands exit from blocs – fig.4, the anchorages in blocs after removing the concrete protection – fig. 3, 6, 7, and 8.

Fig. 3 Blocs examination

Fig. 4 Strands exit from blocs

Fig.5 Strands on the bearing zone



Fig.6 No sensible anchors Fig.7, 8 Anchorages with sensibility to corrosion (hardened only)

Behavior differences can be observed between the anchorages no sensible to corrosion – fig.6 and the anchorages more sensible to corrosion like in hardened steel only – fig. 7, 8.

It was also found that it was impossible to provide a trust protection by coating on more than 1 km of strands for one hexagonal silo.

2.2 Diagnosis

The hexagonal silos showed a significant deterioration of the prestressing system due to the corrosion of strands in local zones and of anchorages, main causes[3], [4] of which are:

- defective protection of strand at the exit from blocs and on the bearing zone; impossible application of coating behind the strands which practically remain uncoating;
- low quality, noncompact concrete for anchorages protection;
- use of hardened steel anchorages with a high corrosion sensitivity.

Many of strands and / or anchorages shoued an in-depth deterioration, that can strongly affect the safety of the prestressing system and of silo itself, as well as the safety in service. This led to the decision to replace the prestressing system so as to conserve the initial design service life.

2.3 Substitute prestressing system

The substitute prestressing system consisted in strands provided in polypropylene tubes filled with protection stable grease. The anchors leaned on additional bearing steel blocs – fig.9 and were protected by sleeve nut filled with grease – fig.10.

Fig. 9 Additional bearing steel blocs

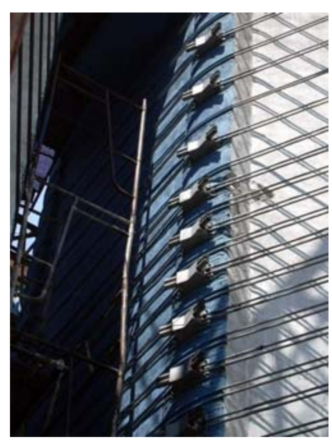

Fig.10 Anchorage protection in sleeve nut

The in-depth inspection was performed in two cases after 3 or 5 years intervals from the replacement of prestressing, providing access along height of the wall. The inspection results showed a good behavior of the system – see fig. 11, 12, including anchorages leaning on bearing steel blocs and protected by sleeve nuts filled with grease.

An exception was found in a few local zones of tube hose connectors where a short movement of tube appeared due to temperature variation. The tube hose connectors were repaired.

It was recommended to carry on surveys, such as in-depth inspection, at 3 to 5 years intervals after the application of a substitute prestressing system.

Fig. 11 Actual view of strands in tube and anchorage sleeve nuts

Fig.12 Grease state of anchorage after removing sleeve nut

3. SECOND PART - REINFORCED CONCRETE CYLINDRICAL CELLS SILOS

The first grain silo from Urziceni storage base built 25 years before the inspection is composed of three batteries of 12 cylindrical cells, one cell of 7 m in diameter and 36 m in high, with the wall thickness of 18 cm. The slip form method of construction was used .

Multiple deteriorations, especially noted in one battery, mainly affected the concrete cells wall, having an advanced state of cracking and numerous deficiencies, such as lack of compactness, due to the slip form method of concrete walls construction.

Fig.13 Urziceni silo

Fig. 14 External cell surface before inspection

The second silo from Dragos Voda storage base, built 40 years before the inspection is composed of 6 cylindrical cells, one cell having a diameter of 7.30 m and 20 m high, with a wall thickness of 15 cm. Two stellate cells are formed between the cylindrical cell walls.

Fig.15 Dragos Voda silo

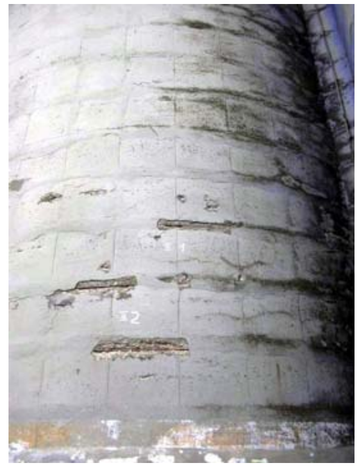

Fig.16 Deteriorations on external cell surface

The main deteriorations of this silo were observed to concrete and reinforcement on external cells surface only.

3.1 Urziceni cylindrical cells silo

Inspection: An in-depth inspection was performed using climbing platforms for access to both sides of wall, including internal one and was made including hammering the concrete and removing the detachable or broken layer of cement mortar and detecting the entire zone of damaged concrete.

Fig.17 Deep deteriorations in concrete

Fig.18 Detached bars cover, cavities

The examination started from the signs of visible deteriorations, which consisted in developed cracks of more than 0.3-0.5 mm, detached or broken cement mortar and even deep deteriorations of concrete.

The inspection showed deep deteriorations in concrete, multiple local small deteriorations, such as cavities, holes (some of them pierced), detached bars cover, inconsistent concrete, unfilled holes provided for slip form supporting bars – Fig.17, 18, 19, 20, 21.



Fig.19 Hole, view from outside Fig.20 Hole, view from inside Fig.21 Deep damages in concrete

Diagnosis of deteriorations: The slip form casting of the planned C16/20 class concrete in cells wall was unfortunately defective and the main concreting deficiencies were:

- portions of concrete cast-in place after setting strength started;
- local cavities or casting interruptions;
- segregation areas (lack of compactness), impurities.

These deficiencies were the main cause of the further deteriorations, such as:

- friable / expelled concrete, concrete settling; cracks, deformations;
- buckling of reinforcing vertical bars (sometimes placed outside of horizontal ones);
- reinforcement corrosion (not active).

Alternative repair / strengthening solutions: The defects and deteriorations may further adversely affect the structure function and its strength and stability [7] .

The proposed strengthening method in similar cases was to cast an interior reinforced concrete layer, i.e. a supplementary reinforced concrete cell, but in this case the application of an interior concrete layer to each cell implies a lot of concrete and steel, with high costs.

For the actual state of deteriorations and having in mind the repair / strengthening cost reduction, a restoration of the structural concrete continuity was considered alternatively as a limited repair / strengthening, adequate for an additional shorter service period and lower expenses.

For the structural concrete repair and strengthening, we recommended different procedures, using special reliable chemical products which become available in the country at the time.

So, for filling of all the cavities or holes, the concrete mix of concrete class C20/25 included aggregates of to 3mm or 7mm, an acrylic bonding agent to be applied on old concrete surface and a super plasticizer, so as the concrete vibrating became not needful. Other small deficiencies of the concrete, as well as of the reinforcement concrete cover, were repaired using epoxy bonder or epoxy concrete. The cracks exceeding 0.3 - 0.5 mm were injected using low viscosity epoxy resin.

3.2 Dragos Voda cylindrical cells silo

Inspection: An in-depth inspection was performed using a kind of nacelle crane used for access on electrical poles, removing the detachable cement mortar.

Fig.22 View of outside affected zones

Fig.23 In-deep reinforcement corrosion


Fig. 24, 25 Expelled concrete in zone with reduced concrete cover

The main concrete and reinforcement deteriorations were observed only on the outer side of the cylindrical walls, especially at form panel joints and they consisted in:
- detachments of the reinforcement concrete cover ,where the thickness measured 5-15 mm;
- segregation areas;
- adherent or in-deep corrosion of the reinforcement in this zone;
- concrete deterioration due to freeze-thaw, see Fig.22, 23, 24 and 25.

Diagnosis of deteriorations: After about 40 years in service the Dragos Voda silo showed a good behavior in terms of strength and stability, less in terms of durability.

These deteriorations were caused by the external whether action combined with an insufficient concrete cover of outside layer of the reinforcement and of concrete segregation.

Repair solutions: The repair solutions for durability deteriorations were aimed at ensuring the intended remaining service life of the silo.

An evaluation of the maximum load capacity showed insufficient design reinforcement of the two stellate cells and the need for these cells to be filled up to 50% of capacity.

4. CONCLUSIONS

All silo structures examined have suffered in terms of durability, but no other damages or other deterioration signs from seismic action or differentiated settlements were found.

The hexagonal prestressed concrete silos

The hexagonal prestressed concrete silos suffered, after about 25-30 years of service, from multiple durability deteriorations of prestressing strands and anchorages.

The causes for the corrosion of strands in local zones and of anchorages were the defective strands protection by coating, low quality, non-compact concrete for anchorages protection, use of anchorages with a high corrosion sensitivity.

The decision to replace the prestressing system was taken for the purpose of conserving the intended design service life of the concrete silo.

The chosen substitute prestressing system consisted in strands in polypropylene tube filled with protection stable grease. The anchors leaned on additional bearing steel blocs and were protected by sleeve nuts filled with grease.

The inspection made in two cases after 3-or 5-year intervals as from the replacement of prestressing system showed a good behavior of the system .

It was recommended that surveys, such as in-depth inspections, should further be made at 3-5 year intervals after the substitute prestressing system application.

The cylindrical reinforced concrete silos

In the first case of Urziceni grain silo, the casting in slip form of concrete in a cells wall was unfortunately defective, followed by portions of concrete cast in place after the setting strength started, local cavities or casting interruptions, segregation areas (lack of compactness), impurities, friable / expelled concrete, concrete settling.

The limited strengthening to reestablish the structural concrete continuity appeared to be a more favorable solution and was recommended for a shorter additional service period and lower expenses.

The use of modern chemical products to provide high bond and strength levels between old and new materials and of completion materials offers a reliable rehabilitation solution for a limited strengthening of grain silo cell.

In the second case of the Dragos Voda storage base silo the main concrete and reinforcement deteriorations were located only on the outer side of the cylindrical walls, especially at form panel joints, the main causes being the external whether action along with the insufficient concrete cover of the outside layer of reinforcement and concrete segregation.

For the repair of structural concrete we recommended different procedures using special, reliable chemical products, such as epoxy bonder or epoxy concrete and an outside concrete surface protection by impregnating it with chemical products supplied by SYMONS - DAYTON Corporation USA [6].

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