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# Reconstruction of Reinforced Concrete Walls of Cylindrical Silos

Reconstruction de parois en béton armé de silos cylindriques

Rekonstruktion der zylindrischen Stahlbetonsilowänden

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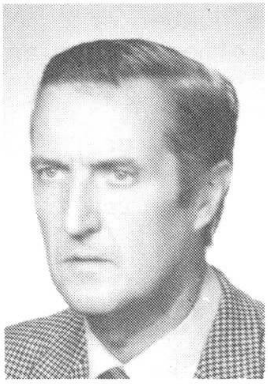

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## SUMMARY

Walls of reinforced concrete silos long in service can become damaged due to various external and/or internal influences. Repairs of such walls require exact appraisals and individual methods. Two examples of large cylindrical silos are presented.

## RÉSUMÉ

Les parois des silos en béton armé en exploitation depuis longtemps, sont souvent endommagés par différentes influences extérieures et intérieures. La réparation des parois exige une évaluation précise et un choix de méthodes individuelles. Deux exemples de réparation de grands silos cylindriques sont présentés.

## ZUSAMMENFASSUNG

Bei lange benutzten Stahlbetonsilowänden erfolgt die grösste Beschädigung infolge verschiedener äusserer oder innerer Einwirkungen. Die Reparatur dieser Wände erfordert eine genaue Bewertung und individuelle Methodenauslese. Es werden zwei Beispiele von Reparaturen grosser zylindrischer Silowände vorgestellt.

## 1. INTRODUCTION

In the past decades the development of reinforced-concrete shell structures was a reason of designers' proud in many countries. The Sydney Opera and many other projects, particularly domes, were the symbols of structural concrete possibilities. Similarly in industrial structures, like containers of many kinds, high chimneys of large diameter, silos and cooling towers, the use of concrete was very common.
Looking for the current economical efficiency designers used very thin shells with minimum cover. Sometimes, the proper execution of those structures was really difficult or even impossible.
Nowadays, after twenty or thirty years of continuous exploitation, the serious problems with safety of the structures have appeared.
For instance, in Poland we experienced a lot of troubles with structures which have been built in sixties or seventies. One 100m high cooling tower collapsed, and few similar had to be demolished. Several high chimneys had to be replaced by new projects, tens of reservoirs were demolished and the large number of containers and silos should be reconstructed. Presently, like in other countries the problems of durability of structures and the necessity of extending lifespan of many of them are treated as more important than erection of new structures. The reasons of damages are very typical sometimes, while in other cases are of quite specific nature.
Two examples of destruction and reconstruction of large silos are presented to illustrate such different situations.

## 2. EXTERNAL DAMAGE OF SILOS AND REPAIR PROCEDURE

The group of six silos has been built in 1969 to store grain, mainly wheat and rye. The storage station was located at the eastern border of industrial zone and the buildings were attacked by polluted air, mainly by acid rains. The great majority of winds in that area were from west, so the surfaces of concrete in silos walls have been badly damaged, particularly from the west side (Fig.1).

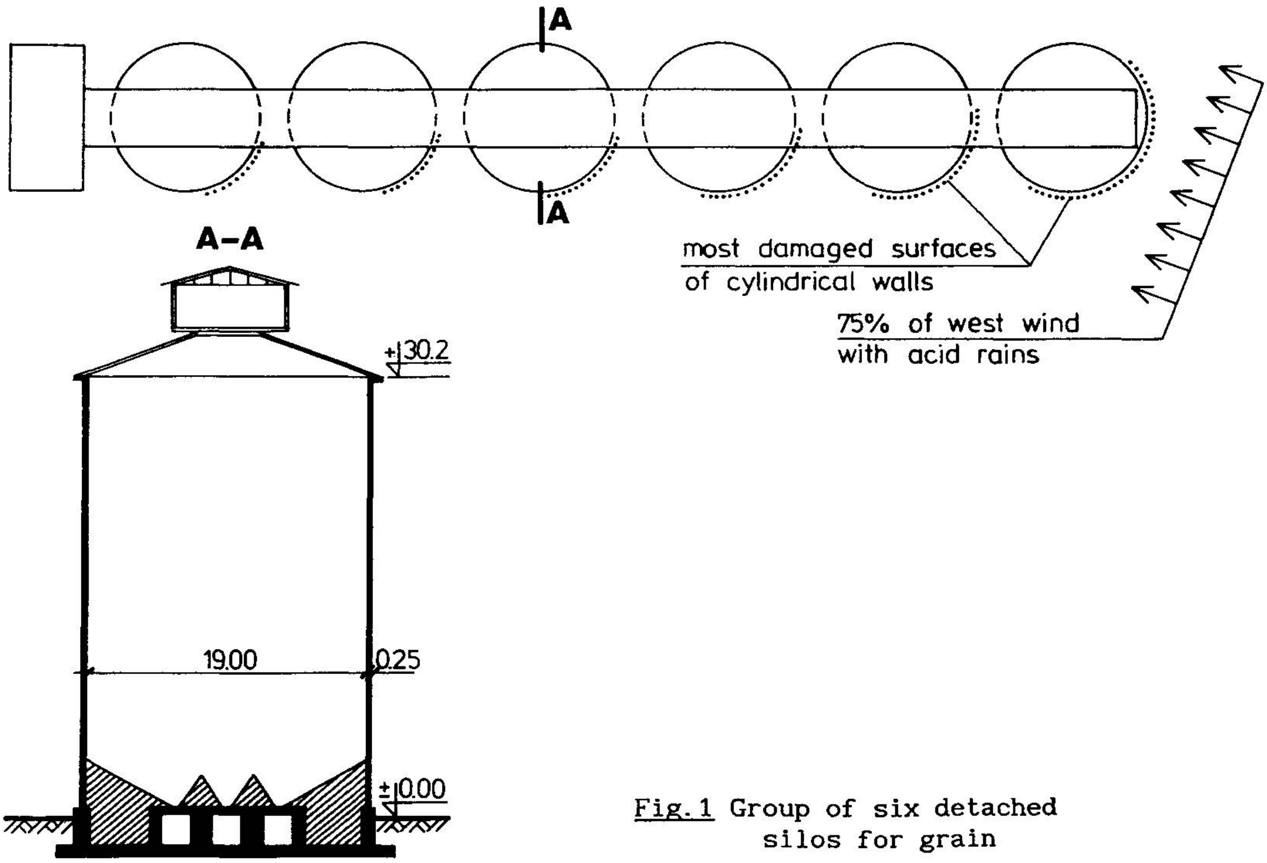
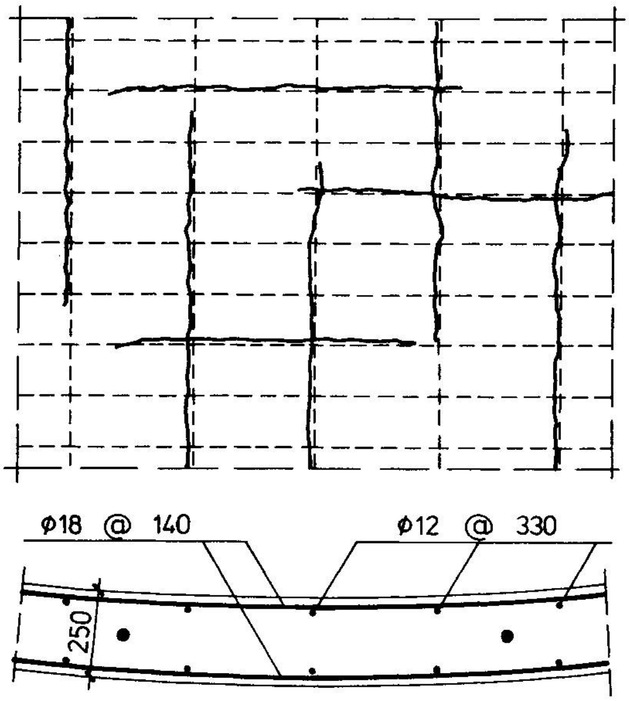



Fig. 1 Group of six detached silos for grain




The corrosive environment in combination with porous concrete surfaces and poor cover caused on more than 1/3 of the external surface area advanced damages with corrosion of reinforcement and serious cracking of concrete along the bars (Fig.2).
Some parts of reinforcement were uncovered at all.
The tests of concrete samples (drilled cores throughout walls) indicated that the strength of concrete was quite sufficient but advanced processes of carbonation were measured to the depth from 60 to 100mm (Fig.3a).

Fig.2 Cross-section of silo wall and view of external surface with cracks width of 0.3 to 0.5mm along the bars of reinforcement

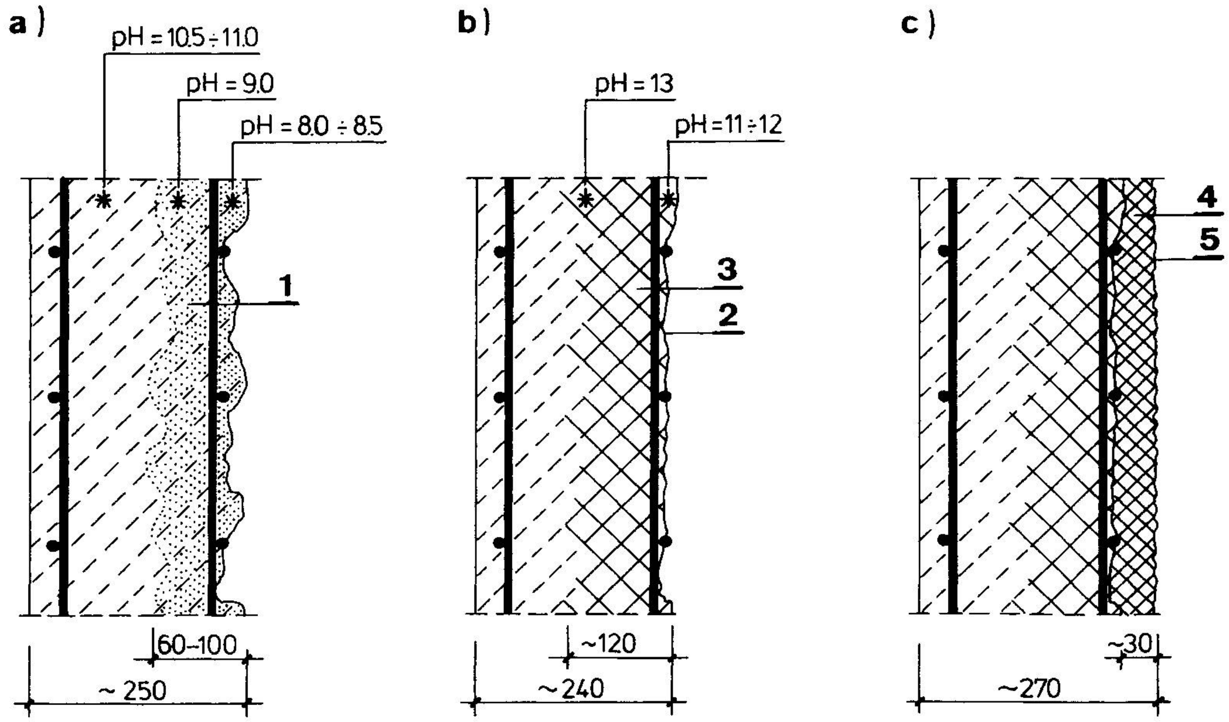



Fig.3 The steps of reconstruction: a) - damaged wall, b) - after sand-blast cleaning and alkalization, c) - after full reconstruction;
1 - zone of carbonized concrete (pH ≤ 9), 2 - sand-blast cleaned concrete surface, 3 - alcalized concrete (pH ≥ 11) and filled cracks, 4 - shotcrete with microsilica admixture, 5 - protection paint with possible air penetration

The reconstruction work has been designed and executed as follows (Fig.3b,c):
- cleaning of concrete surfaces by sand blasting,
- re-alcalization by double or triple impregnation from outside (Consecrate CC)
- local repairs with highly adhesive mix (Sika admixtures),
- single layer of shot crete ~30mm thick, placed by dry method (microsilica additions),
- external protection with air-penetrable painting (Sarsil).

As an interesting idea introduced during reconstruction was the use of silo overloading (by filling over the nominal level with humid, heavy grain) at the impregnation of cracked concrete and at shotcrete placing and hardening. Double benefits were obtained in this way - the increased humidity of concrete, which was important for the effects of both processes and quasi-prestressing of shotcrete layer after unloading.

The tests of samples taken from the walls after re-alcalization showed the average depth of penetration about 120mm, with effective alkali reaction (pH ≥ 11) - Fig.3b. Final tests of the cores taken out from the repaired walls concerned the bond between old and new concrete. The results were satisfactory - more than half of samples have been broken not in the contact section but through the old concrete.

## 3. DESTRUCTION AND RECONSTRUCTION FROM INSIDE

The second example of silos reconstruction refers to quite different case of damage of structure. The three groups of four cylindrical silos each have been exploited continuously for more than 15 years in the cement plant. The silos were necessary to store cement clinker before grinding (Fig.4).

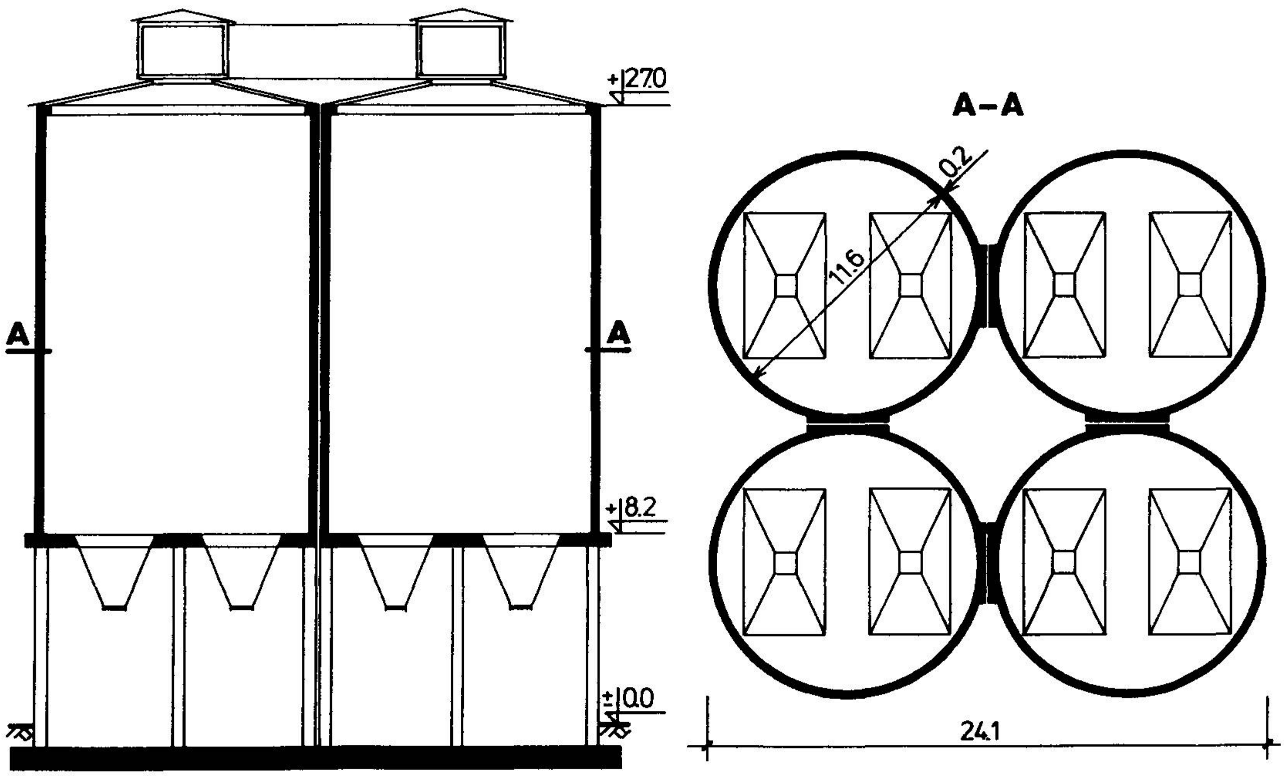



Fig.4 Group of silos in cement plant

The thermal influences were taken into account by designer and over the common bottom-slab the cells were quite independent. During the proper production process the temperature of clinker at loading should not be more than 70°C. Unfortunately, very often the material of 200°C and sometimes even almost 300°C was loaded into the silos, as a result of irregularity of production.
The random thermal actions were not noticed for long time. From outside almost no signals of damage could be observed, particularly in very dusty atmosphere of the cement plant. The local cracks of width up to 0.3mm were not visible without special cleaning of surface.
By accident, during the replacement of steel hoppers in one silo the part of concrete cover from internal surface fell down and uncovered the surface of seriously cracked concrete. The investigations were udertaken and completely destroyed layer of concrete up to the depth of 60 - 100mm from inside was discovered (Fig.5a). In many parts the solids of concrete (like cubes up to 100mm) could be taken away by hand, because, apart from cracking, the bond between concrete and reinforcement was entirely destroyed.

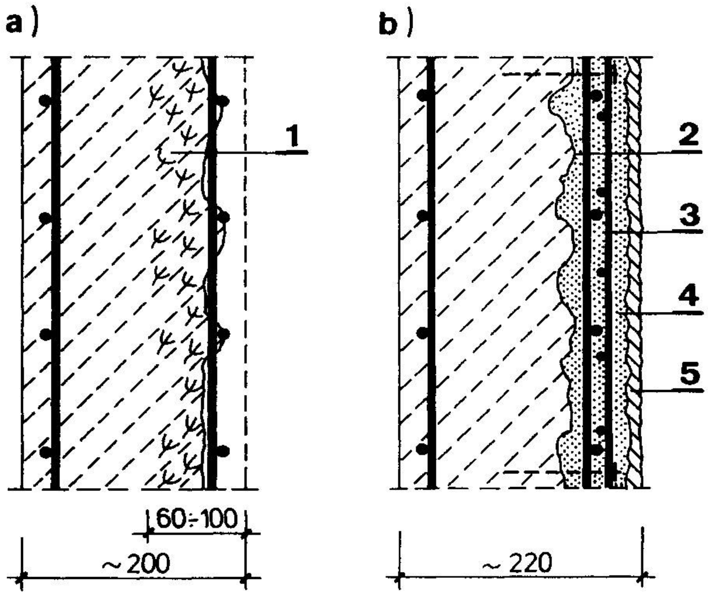



Fig.5 The wall of cement clinker silo:
a) damaged by multiple thermal actions,
b) reconstructed from inside;
1 - zone of highly cracked/crushed concrete,
2 - cleaned surface of slightly cracked concrete and uncovered reinforcement,
3 - additional steel fabrics ø8@100/100mm,
4 - shotcrete with basalt aggregate,
5 - anti-abrasive layer with fibers

Due to dry environment inside the steel bars were relatively in good stage, almost without signs of corrosion, but in many parts the bars were bent by mechanical action of sliding down solids of clinker.
The only problem, but very significant was the long time of process of dehydration of concrete connected with destruction due to local overheating of the wall.
The immediate general repair was necessary with replacing part of existing reinforcement and addition of reinforced shot crete supplementary layer. The shot crete was placed in three steps, 25 - 30mm each. The final layer of shotcrete was of particular recipe, with anti-abrasive components (basalt aggregate, reinforcing fibers and Sikacrete admixture) - Fig.5b.
Obviously, the correct process of production has been ensured parallely by the technological changes.

## 4. CONCLUSIONS

The critical stage of reinforced-concrete or prestressed-concrete structures is usually the result of three groups of reasons:
- design incorrectness, particularly lack of designer's imagination about exposure to severe external environment or influences of internal conditions,
- execution errors, most often connected with quality and casting of concrete or cover size,
- utilization faults, especially lack of periodical control and repair, and deviations from the proper exploitation.

Nowadays, testing methods for diagnosis of structures as well as various methods

for repair, with respect to the required lifespan of structures are commonly available.
Sometimes the specific situations may occur: a building originally planned for 20-25 years has to be used for the next period, e.g. 20 years. The analysis of necessary protection and/or reconstruction should be then especially careful. Taking no account of symptoms of destruction and delay of actions for protection and repair are the approaches which usually lead to either cutting down the structure lifespan or to the costly reconstruction process necessary to extend the safe use of building. Unfortunately, there is the third possibility - the disaster of part or entire structure.