Modern Building Materials, Structures and Techniques
May 16-18, 2001
The 7th International Conference
Faculty of Civil Engineering, Vilnius Gediminas Technical University
Saulėtekio al. 11, LT-2040 Vilnius, Lithuania,
tel.: +370 2 76 35 91, fax.: +370 2 70 04 94,e-mail: sf2001@st.vtu.lt

TECHNOLOGICAL POSSIBILITIES OF REPAIRING CORROSION DAMAGED REINFORCED CONCRETE STRUCTURES

J. Kampioni, G. Słowek
Poznan University of Technology, Poland

1. Introduction

Development of building chemistry influence durability of temporary RC structures significantly. due to mineral and chemical admixtures concrete becomes a material of more and more “perfect” mechanical properties and increased resistance to negative external conditions. Especially chemical admixtures are being constantly improved that provided better material and structural protection of RC structures. Surface protection layers plays an important role. Thanks to them RC structures are practically resistant to environmental factors – both internal and external, that, in general, are called natural and industrial factors. However 30-50 year-old RC structures may cause problems due to advanced concrete and steel corrosion.

Poor quality of concrete and lack of surface protection are the results of not only the contemporary knowledge and technological options. Environmental influence and significance of concrete cover were then underestimated. All the factors and poor erection technologies caused acceleration of corrosion processes. It concerns especially industrial structures suffering structural degradation from aggressive environment. The structures are damaged to the extent that calls for immediate action to restore technical functionality and safety. In such cases repair and strengthening of structural members (or whole structure) aims at restoring initial condition, i.e. reconstruction. It is crucial to eliminate causes of possible further damage or to provide proper protection of repaired structure against harmful environmental factors.

There are few possibilities of repair method and technology. The choice is influenced mainly by enterprise costs that may lead to the method which in not optimal in certain conditions.

2. Chloride corrosion of RC industrial structures

Chlorides are one of chemical factors that are the most harmful for RC structures. Sea water influence on embankments and port structures, influence of road surface de-icing media on viaducts, bridges and tunnels are typical examples of possible chloride corrosion.

Chlorides influence also many industrial structures. RC structures in salt mine and water conditioning building in a boiler station are the examples. In both cases NaCl acts directly on RC structure. The influence is even more dangerous since it takes place in high moisture conditions or under water. Due to diffusion, chlorides penetrate concrete cover, if it is saturated with water. In moist concrete the penetration may take place thanks to adsorption and capillary suction. If chlorides concentration near reinforcing steel reaches critical value, passivation layer on steel may be damaged and relatively fast corrosion starts. Its velocity depends on water saturation of pores. In ambient condition it is influenced by relative moisture content that results in water saturation of pores in concrete. To prolong structural serviceability, the structure must be kept dry.

In terms of concrete chlorides that are salts of weak alkalis (i.e. NH_4Cl, $MgCl_2$) are dangerous. The salts, in the process of hydrolyse, make easily dissolving $CaCl_2$ which causes alkali corrosion. Sufficiently concentrated NaCl, which is the salt of strong alkali, causes also corrosion of lime in cement stone.

3. Examples of industrial structure damage and choice of repair method

3.1. Production building in salt mine

The described structure was erected as cast *in situ* reinforced concrete. It was used in NaCl polluted environment. In spite of that no additional surface protection was applied. Non-destructive tests of concrete strength identify the average strength of 20,2 MPa. However concrete revealed sign of being poorly vibrated which enhances corrosion.

Salt mining and crushing technologies, ball-bearing pulverises produce large quantity of salt dust in moist air, inside buildings. Relative moisture content theoretically should equal about 70%, but practically it reaches 100%. It is better for the staff since dusts of higher moisture content are easier for human being. It should be mentioned that NaCl concentration in the air is obvious immediately after entering the building, giving an impression of "salted" mouth. In the case of adverse weather conditions, the air inside seems to carry salt mist since dry method of mining is used.

Tests of the dust contents revealed: NaCl (96,80%), $CaSO_4$ (2,98%) and H_2O (0,22%). Since the staff tends to exchange the air as much as possible, the moisture content inside and outside may be assumed to be equal.

Due to the harmful conditions the structure experience advanced chloride corrosion. Concrete cover was damaged completely: it was missing or easily removable. In regions of moist floor, gatherings of leached $Ca(OH)_2$ and stalactites of lime salts, especially easily dissolvable lime chloride ($CaCl_2$), what caused porosity increase and strength decrease.

It is obvious that in such conditions revealed reinforcing steel was also corroded. Bars were covere with characteristic flake of corrosion products. Rust make concrete brown in colour. In some cases, due to corrosion, stirrups were missing and part of them had characteristic corrosion pits.

Facing so advanced damage and destruction it was decided to carry out concrete inspection for chlorides content and pH reaction.

Identifying the depth of concrete penetration by chlorides and carbonisation depth was crucial. Cylindrical samples of 50 mm in diameter and 50 mm high were cut out. Each of them was divided into layers (by slicing) of 17 mm thick. So it was possible to identify properties for three layers up to the depth of 51 mm, counting from concrete surface. They were: the external layer (I) – to the depth of 17 mm, middle layer (II) – depth 17 to 34 mm and bottom layer (III) – from 34 to 51 mm towards the member interior.

Test results are given in Table 1.

Maximal and minimal values of Cl^- content and pH reaction were also given for measurement. The result variation was caused by poor quality of concrete, which was porous locally.

Table 1. Tests of Cl^- content and pH reaction

No.	Concrete layer [mm]	Measured value	Total content [kg/m^3]	pH reaction
1	I (0 ÷ 17)	max:	105,43	12,17
		min:	13,40	10,15
		average:	**35,00**	**11,38**
2	II (17 ÷ 34)	max:	44,27	12,10
		min:	8,16	10,44
		average:	**23,18**	**11,86**
3	III (34 ÷ 51)	max:	19,22	12,12
		min:	12,82	12,07
		average:	**16,75**	**12,10**

Given results of chemical tests and technical condition inspection, the choice of repair method was not easy. Significant scatter of results, large Cl^{-} ions concentration make the repair efficiency dubious. Economical aspect was also important. The structure could not have been shut down – this would mean cease of production and the end of the mine existence.

Finally the case was qualified as special and partial repair was taken up. It was chosen to prolong the structure life without restoring its initial condition. This practice use applied in the USA for road surface on bridges.

During repair the contaminated concrete was partially remove. It slows degradation process but does not protect the reinforcing steel against corrosion. In carbonised and Cl^{-} contaminated concrete, corrosion advance depends on moisture content. Thus the structure under repair should be kept as dry as possible.

That is way it was decided to use surface protection that allows for concrete moisturising and let water to vapour. The surface layer let the vapour from the inside out enabling self-drying of concrete – concrete may "breathe".

The repair was carried out with sprayed concrete. Dry method of application was chosen since it was more suitable for the type of damage (various loss depths) than the wet method.

Prior to the repair loose, carbonised concrete and products of steel corrosion were removed. Concrete was cleaned, uncovered reinforcement sand-blasted and revealed surfaced were water-blasted using 100 bar pressure. Then strengthening reinforcement was installed where initial reinforcing bars were missing or concrete loss was significant.

Dry method concrete spraying was done with fine aggregate with admixture of micro-silica among others.

Surface protection of the repaired structure was applied in two layers using airless method.

3.2. Water conditioning building in boiler station

The structure was erected as cast *in situ* RC frame with RC ribbed floors. Internal and external walls are 0,38 m thick and made of solid ceramic bricks bonded with cement-lime mortar. The thickness qualifies the walls as "load carrying" what was important for the choice of repair method.

In water conditioning building (adjacent to the boiler building) the water is softened and transported to boilers

High moisture content, aggressive environment due to usage of NaCl for water softening caused significant damage, especially of RC columns. RC fool was less damaged thanks tight to surface concrete layer and properly profiled inclinations and outlet channels.

Near walls, in regions hard to access due to location of machines the moisturising and NaCL contamination was more intense. Thus significant damage was done to RC columns of load carrying structural frame.

Structural RC columns that were in direct contact with salt experienced the biggest weakening.

Reinforcing bars in the columns were very corroded, sometimes discontinued. Concrete was cracked, concrete cover missing, steel-to concrete bond non-existent. Columns were in emergency condition - Fig.1.

Accident was avoided thanks to large ribbed floor stiffness (rib spacing was 1,10 m) and taking up some loading by masonry wall between boiler building and water conditioning building.

Fig.1. One of columns in emergency condition

Taking into account all possibilities, traditional repair method was chosen. RC floor had small material losses that did not influence its load carrying capacity. It was proved by appropriate calculations.

Thus the repair concerned restoring concrete cover what was completed manually.

Columns were strengthened by cross-section magnification. Additional strengthening reinforcement and 10 cm layer of B25 concrete was applied. Concrete was placed in stages 1,20 m long in specially designed moveable steel formwork. Afterwards surface protection layer was applied manually on all members.

An important feature of repair, influencing its efficiency was erecting RC pedestals along walls at the level of floor. It was covered with additional moisture-tight isolation to eliminate migration of salt water that would penetrate RC columns.

4. Conclusion

Presented cases of chloride corrosion of RC structures showed that it causes serious damage particularly in environment of elevated moisture content. Chemical tests, identifying degree and depth of contamination enables the choice of the most suitable repair method. In given conditions it may be partial – prolonging structure life without restoring its initial condition. Attention was draw to the fact that using sprayed concrete during repair is not always economically justified in spite of the technology advantages over traditional, manual methods of concrete making up.

The most important factor influencing repair efficiency is the necessity of application of proper surfaces protection layers. It ensures technical effectivity of repaired structures.

5. Acknowledgements

The project's financial backing is provided by the Polish Committee for Science Research work 11-023/2001 DS, 11-045/2001/ BW

Įteikta 2001 02 15

……………………………………………………………………...

Jerzy KAMPIONI, dr. (Dr Sc.), Lecturer in Institute of Structural Engineering Poznan University of Technology. Piotrowo 5, 60-965 Poznan, Poland. Graduate of Faculty of Civil Engineering (1974, civil engineer), PhD (1982).

……………………………………………………………………...

Grzegorz SŁOWEK, dr. (Dr Sc.), Lecturer in Institute of Structural Engineering Poznan University of Technology. Piotrowo 5, 60-965 Poznan, Poland. Graduate of Faculty of Civil Engineering (1969, civil engineer), PhD (1978).