https://doi.org/10.29013/AJT-23-1.2-29-37

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EFFECT OF SALT CORROSION ON DECREASING CAPACITY OF ROAD BRIDGE SPAN ELEMENTS

Abstract. The article presents an assessment of the effect of salt corrosion of concrete and reinforcement on the bearing capacity of the superstructure elements. It is shown that the load-bearing capacity of superstructures subject to salt corrosion is almost 2 times less than the load-bearing capacity of superstructures without salt exposure.

Keywords: salt corrosion, span, bearing capacity, salt corrosion effect, reinforcement.

Introduction. Great importance in ensuring high corrosion resistance of reinforced concrete have a density, concrete structure and thickness of the protective layer. The less dense the concrete is and the thinner the layer of the armature, the faster corrosion process starts in more permeable place for moisture and oxygen. An increased permeability of the concrete can be compensated by increasing the thickness of the protective layer. In bridge structures must be provided with a protective layer of concrete with a minimum thickness of 30mm, checking (counting) in the light from the working surface. Reduction of the permeability of concrete is determined by the structure, i.e. the number, size and nature of the structure of the pores of the concrete. To withstand the specified granulometric composition of aggregates used division as coarse aggregate and sand fractions. This ensures a high degree of uniformity of concrete.

Main part. To protect reinforcement from corrosion greatly influenced by the curing mode of the structure. Excessively harsh conditions of curing and drying the concrete to suspend the normal process of hydration of cement, forming a structure with large porosity, which dramatically degrades the protective properties of the concrete. Intensive corrosion of reinforcement causes an additive in concrete chloride salts (calcium or sodium) that is applied to acceleration of concrete hardening.

If there are cracks in the concrete at the steel reinforcement appears galvanic macropore: anodic areas of the reinforcement in the crack area; the cathode – is the place where the strength of adhesion to the concrete is not broken. Due to the small size of the anode sections compared to the small cathodes and the electrical resistance of moist concrete, the corrosive vapor is very intense. Corrosion of reinforcement at cracks this results in high speed [1].

The most common fracture that can occur during corrosion of reinforcement in concrete is the gradual reduction of the working section due to the transition of the outer layers of metal in the corrosion products. Due to the fact that the iron in the electrochemical process of corrosion can only be dissolved at the anodes of corrosion couples would be uneven reduction of cross section. But the character of corrosion damage can be different: from an almost uniform reduction of the cross section over the entire surface to pronounced ulcerative lesions [2].

Local ulcerative lesions of the valves present a much greater danger to reinforced concrete structures than uniform corrosion for two main reasons. First, in pitting corrosion, the local reduction of cross section the reinforcement is corroding much quicker than in uniform. Secondly, the dangerous degree of damage of the structure can occur without visible external signs in the form of cracking and breaking off of the protective layer (which are usually observed at relatively uniform General corrosion), because of a small area of ulcerative lesions of corrosion products can exert a pressure sufficient to rupture the protective layer of concrete.

Different types of damage can be observed on the corroded surface at the same time. More often there is a gradual transition of one type to another: spot corrosion to general corrosion, with the development of deep local ulcers later on. Local corrosion, despite the lower weight loss of metal caused by it, is more dangerous than general corrosion, as it leads to a rapid loss of strength of individual sections. Despite the small weight loss of metal, especially sharply reduces the strength of intergranular corrosion, which breaks the bonds between the crystals.

It has been established [1; 2; 3] that defects in the form of reinforcement corrosion are the main focus of cracking.

Typical configurations of corroded reinforcement cross sections are given in (Fig. 1).

In the reinforcement of reinforced concrete spans the most common corrosion development according to the scheme "a".

The process of corrosion in reinforced concrete can occur according to two main schemes [4; 5]:

1) corrosion of the reinforcement begins after the destruction of the concrete in the protective layer (corrosion of concrete), i.e., the cause of damage to the structure is the insufficient resistance of concrete;

2) development of corrosion begins with the reinforcement, when the concrete does not have sufficient protective properties, but it is not destroyed by the environment, which in this case is not aggressive with respect to it. The failure of concrete occurs under the pressure of rust that is growing on the reinforcement, i.e., it is partly mechanical in nature. This type of failure in concrete structures is generally caused by humid air or by periodic damping.

The formation of cracks in concrete is accompanied by its disengagement from tensile work in the zone of influence of the crack. In this zone, the stresses in the reinforcement are higher than in the neighboring areas where some of the tensile forces are taken up by the concrete. Macro-stresses can also occur in the crack area due to the difference in stresses. They increase the corrosion of the reinforcement. The deepest affection of the reinforcement is observed at the place where it intersects the crack. Less deep ulcers spread on both sides of the crack at a distance of no more than 5–10 mm. Further, as you move away from the crack, the corrosion fades sharply and appears in the form of plaque.

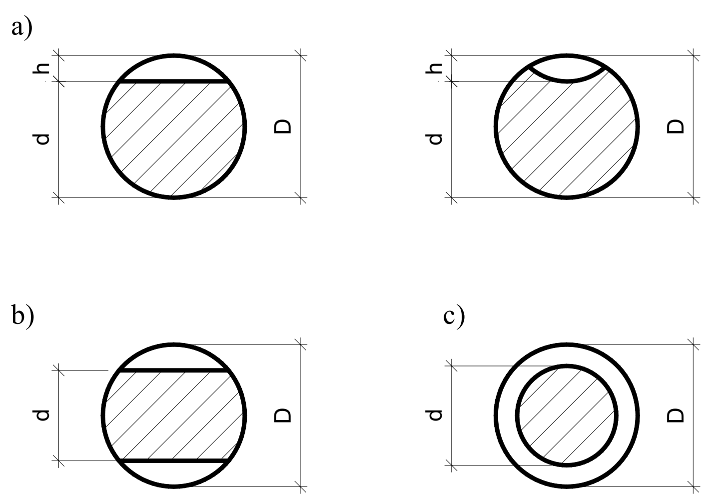
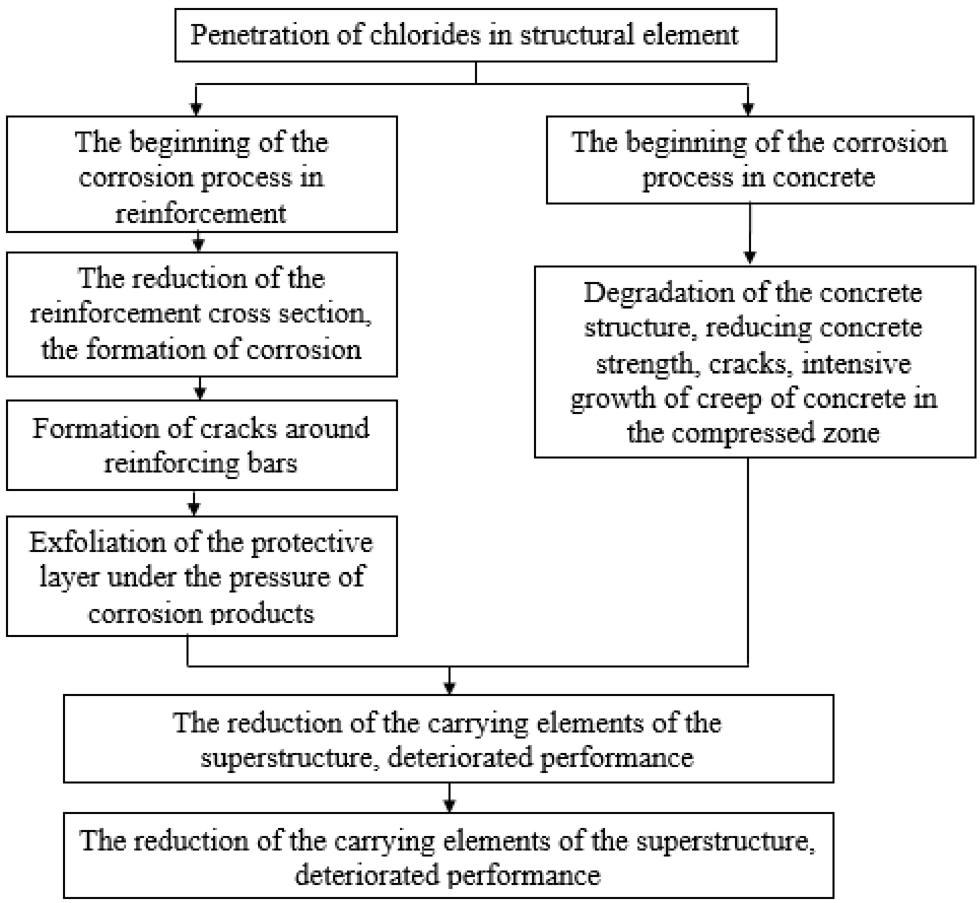


Figure 1. Characteristics of the configuration of corroded reinforcement cross sections. a) unilateral, b) bilateral, c) circular

In Pic. 2 shows a diagram of the mechanism of action of chloride-containing environment to work reinforced concrete superstructures. As seen from Pic.2., ultimately, chloride-containing fluids result in reduced bearing capacity of the spans.

Numerous studies [3; 4; 6; 7] have shown that chloride-containing fluids have a significant influence on the mechanical properties of concrete.

In [6] presents the results of experiments when exposed to liquid chloride-containing environment on reinforced concrete in the compressed zone, in the tensile zone and with the full impact. The test specimens range in age from 28 to 720 days showed that under these conditions there is a reduction of strength and modulus of elasticity of concrete up to 20–25%. Alternate saturation with liquid 1% solution and drying of the concrete intensively increases the drop of the mechanical properties of concrete [3; 4]. The decrease of strength in the loaded element is greater than at idle. The use of waterproofing additives improves resistance of concrete against the influence of chloride salts [8].



Picture 1. The mechanism of action chloride containing environment to work concrete superstructures

Existing ways to combat icing on bridges

Currently, the main means to combat ice on bridges is the use of salts [9].

In the climatic conditions of the Republic of Uzbekistan with sharp fluctuations of night and day temperatures there is an intensive thawing of ice on the bridge after the use of de-icing reagents, and with the existing faults of waterproofing and expansion joints salt water quickly enters the body of concrete (photo 1). A sharp increase in ambient temperature contributes to intensive drying of concrete, and the amount of salt deposited in the body of concrete in natural conditions of the Republic more than in temperate climatic conditions.

Despite repeated bans on the use of salts against ice, operating organizations continue to use various anti-icing salts, motivated by the lack of other methods of control.

Antifreeze and de-icing agents have their pros and cons. In its essence – the name "anti-icing reagent" indicates that the substance reacts with the environment, i.e. the ice cover.

Such a chemical process also depends on a number of factors, both external – natural-temperature and chemical.

a)

b)

Photo 1. Salt water quickly enters the concrete body, in case of existing waterproofing failures and expansion joints: a) overpass on Babur Street (Tashkent); b) overpass on Bunyodkor street (Tashkent)

Deicing reagents can be liquid and solid and have different composition and chemical properties. When a solid anti-ice reagent hits the icy surface of snow or ice, these particles dissolve, forming a brine that has a freezing point below the freezing point of water. It is the solution of the anti-icing reagent, while its concentration is such, that melts the ice and prevents the occurrence of icy formations.

There are the following de – icing reagents:

Calcium chloride is a solid anti-icing agent in granules, packed in 25 kg bags. It is used for sprinkling roads from snow and ice in the winter season.

Ice**melt** is a solid de-icing agent modified calcium chloride. In bags of 25 kg. It is used for processing roads and streets, pedestrian areas and sidewalks in any temperature range up to –20 degrees C.

Marble chips – fine marble crushed stone with a grain size (fraction) of 2.5–5 mm – tempering form – in bulk and in bags of 50 kg. It is used as an anti-icing agent in winter for sprinkling roads and pedestrian areas.

Granite chips – fine granite crushed stone with a grain size (fraction) of 2–5 mm – release form – in bulk and in bags of 50 kg. It is used as an anti-icing agent for the treatment of roads and pedestrian sidewalks.

Sand-salt (sand-salt mixture) – mixture of sand and technical salt – form of dispensing – loose and in 50 kg bags. It is used for sprinkling roads with ice in winter. It is a mixture of sand and salt in certain proportions, the lower the temperature and the greater the layer of ice, the higher the salt content of the sand-salt mixture. The sand and salt mixture is prepared by mixing in a 30/70 to 50/50 ratio. These products are used on roadways, bridges, and sidewalks. In the process of their application, they primarily prevent ice and also eliminate ice crusts.

Technical salt (sodium chloride) – NaCl – is available both in bulk and in bags. Used in boilers and as an anti-icing agent. It has a wide range of industrial applications. For example, in the oil industry, a salt solution is used to thaw the ground: a salt solution is poured into the cut holes, which penetrates into the soil under pressure and promotes the process of melting.

Rock salt is found in nature in the form of a mineral. Salt is mined and sold from regions rich in this mineral. The salt market is quite extensive, with the bulk of it coming from Belarus, Ukraine, and Central Asia.

On the roads of Uzbekistan, mainly technical salt is used, which is by far the cheapest and most effective remedy against ice.

Under alternating saturation and drying conditions, the concentration of NaCl solution in the pores of the cement stone reaches a maximum.

Such a solution comes into direct contact with the new formations in the fusion zone of their individual crystals. In this case both chemical and adsorptive action of Na+ and Cl ions is possible.

For example, in this case the process of

$$\mathbf{NaCl + Ca(OH)2 \leftrightarrow 2NaOH + CaCl_2,}$$

In recent years, we have surveyed many road bridges on the roads of the Republic of Uzbekistan, built in different years. The main data on these bridges are recorded in Table 1.

Table 1.

No.	Place bridge location	Bridge diagram	Bridge elements	Series No.	Installed damage
1.	M39 1333+14 km road	3 × 16.5	Ribbed span structures	Inv. 56D	Corrosion of concrete due to moisture ingress; destruction of the ends of the extreme beams due to corrosion of concrete;cracks 0.3 mm
			Rigel		concrete corrosion, the surface is covered with a network of cracks
2.	M39 1343+98 km road	1 × 12	Slab span	384/43	Corrosion of concrete due to water ingress; loosely installed on crossbars without supporting parts; incomplete filling of longitudinal joints with concrete
			Rigel		Corrosion of concrete due to water ingress
4.	M39 1357+80 km road	3 × 9	Slab span structures	384/43	Corrosion of concrete due to water ingress; incomplete filling of longitudinal joints with concrete
			Rigel		Poor quality concrete: loose, on coarse gravel
5.	M39 1358+22 km road	9 + 18 + 9	Slab span structures	384/43	Corrosion of concrete due to water ingress corrosion and exposure of reinforcement; insufficient support length;
6.					loosely installed on crossbars without supporting parts; longitudinal seams are not filled with concrete
			Rigel		Corrosion of concrete due to water ingress; insufficient strength of concrete
7.	M39 1360+28 km road	3 × 19.7	Ribbed span structures	Inv. 56D	Corrosion of concrete due to water ingress; cracks up to 0.2 mm
			Rigel		Corrosion of concrete due to water ingress

From the data in table. Figure 1 shows that as a result of long-term operation, numerous damages appeared in the structural elements of road bridges, reducing their carrying capacity and residual life (photo 2–13):

– numerous sections with degradation of the concrete structure as a result of constant ingress of moisture from the surface of the roadway were installed in the spans;

– unacceptable residual deflections were found in slab spans 18.0 m long due to the constant build-up of the asphalt layer on the roadway;

– in the ribbed span structures there are numerous cracks of a power nature. Due to the violation of the waterproofing, water with a salt concentration seeped into the slabs of the beams. One can see the intensive development of salt corrosion of concrete in the cantilever part of the outer beams. The reduction in the cross-sectional area of the working reinforcement due to its corrosion reaches 40%;

– on the surface of the supports through faulty expansion joints, water constantly got from the roadway, as a result of which the concrete of the support bollards in 80% of the bridges has salt corrosion with a loss of strength of up to 50%. The bearing parts are corroded. There is surface corrosion and cracks in the concrete of the support body.

Photo 2. Traces of leaching and corrosion on the surface of beams and cast-in-place concrete

Photo 3. Corrosion of concrete at the ends of the extreme beams

Photo 4. Destruction of the lower part of the beam rib

Photo 5. Corrosion of the concrete crossbar and a network of cracks on it

Photo 6. Traces of leaching and corrosion of concrete on the surface of the beams

Photo 7. Reinforced concrete slabs installed without bearings

Photo 8. Traces of leaching and corrosion on the surface of the beams and abutments of the bridge

Photo 9. The support of the plates on the supports is made on roofing material of various thicknesses

Photo 10. Traces of leaching and corrosion of concrete on the surface of slabs of superstructures

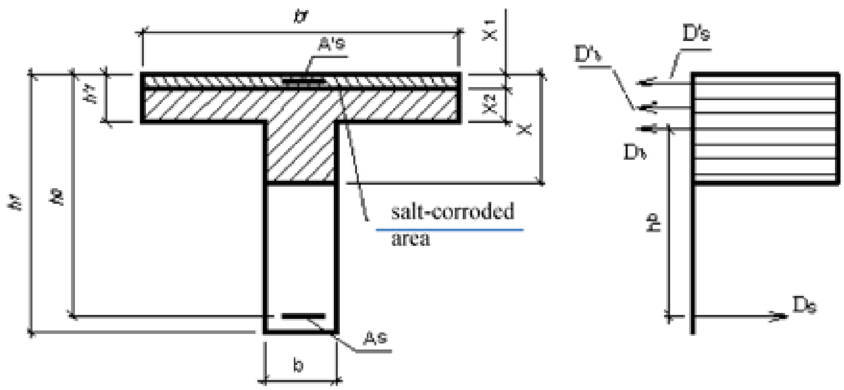
Photo 11. Peeling off the protective layer of concrete and exposing the reinforcement in plate No. 12

Photo 12. The longitudinal seams between the tiles are not filled with concrete

Photo 13. Traces of concrete leaching and corrosion on the surface of beams and supports

In the majority of cases [9; 10; 11; 12] in the main beam is exposed to salt corrosion roadway slab, and the corrosion of concrete in the tension zone at the edge is rare.

Consider the case of salt corrosion and concrete reinforcement in the compressed zone of the main beam (Pic. 2).



Picture 2. Diagram of the main beam

The maximum bending moment M_{cr} for determining carrying capacity, taking into account salt corrosion of concrete and rebar in concrete compressed zone is determined from the equation:

$$D_b'\left(h_0-\frac{x_1}{2}\right)+D_s'\left(h_0-\frac{a_s'}{2}\right)+D_b h_b-M_{cr}=0 \quad (1)$$

Where D_b' и D_b – The resultant force in the compressed zone of the concrete susceptible and not susceptible to salt corrosion; D_s' – The resultant force in compressed reinforcement.

In general, when $x > h_f'$ (1) has the form

$$M_{cr}=R_{b1}b_f x_1\left(h_0-\frac{x_1}{2}\right)+R_b\left(h_f'-x_1\right)b_f\times$$
$$\times\left[h_0-\left(h_f'-x_1\right)\times 0,5\right]+ \quad (2)$$
$$+R_b b\left(x-h_f\right)\left[h_0-\frac{x-h_f}{2}\right]-R_S A_S'\left(h_0-a_s'\right)$$

The height of the compressed zone x defined from the equilibrium equation

$$R_{b1}\times x_1 b_f+R_S A_S'+R_b b_f(h_0-x_1)+$$
$$+R_b b(x-h_f')-R_S A_S=0 \quad (3)$$

here

$$x=\frac{R_S A_S-R_b b h_f'-R_b b_f\left(h_0-x_1\right)-R_S A_S'-R_{b1}b_f x_1}{R_b b} \quad (4)$$

The value of the thickness of the damaged salt corrosion x_1 is determined by concrete test [10].

In the case where the zone is condensed in a shelf plate, $x < h_f'$ *u* ltimate bending moment is defined similarly

$$M_{cr}=ax_1^2+cx_1+d \quad (5)$$

$$a=0,5R_{b1}b_f\left(1-\frac{R_{c1}}{R_b}\right) \quad (6)$$

$$c=R_S A_S-R_S A_S' \quad (7)$$

$$d=ch_0-\frac{c^2}{2R_b b_f} \quad (8)$$

In the case where there is corrosion of reinforcement in the compressed zone cross-sectional area A_S' is taken as [12]

$$A_S'=A_{S\phi}'\left(1-4\frac{\delta}{d}\right) \quad (9)$$

where $A_{S\phi}'$ – sectional area of the reinforcement according to project, δ – bar corrosion depth, d – diameter of rebar.

Conclusions

The evaluation of the effect of salt corrosion of concrete and reinforcement on the bearing capacity of the elements of the superstructure. It is shown that the carrying capacity span structures subjected to salt corrosion is almost 2 times less than the carrying capacity span structures without salt exposure.

Thus, the proposed use of dependencies to determine the limit value of bending moments based on corrosion of reinforcement in concrete compressed zone.

References:

1. Mamaev T. L., Guzeev E. A., Piradov K. A. Crack resistance of concrete in conditions of development of processes of sulfate corrosion // Concrete and reinforced concrete.– No. 2(487). 1999.– P. 23–24.
2. Nosarev A. V., Mikhailov G. V., Ruzin Yu. G. On the classification of cracks in reinforced concrete bridge structures by operational characteristics // Tr. / MIIT.– Issue 430.– P. 72–75.
3. Cracks in reinforced concrete and corrosion of reinforcement. Edited by V. M. Moskvin.– M.: Stroyizdat, 1971.– 144 p.
4. Corrosion of concrete and reinforced concrete, methods of their protection. Edited by V. M. Moskvin.– M.: Stroyizdat, 1980.– 536 p.
5. Corrosion, methods of protecting and improving the durability of concrete and reinforced concrete. Ed. Moskvina V. M.– M.: Stroyizdat, 1965.– 176 p.
6. Alekseev S. N. Corrosion and protection of reinforcement in concrete.– M. Stroyizdat, 1968.– 231 p.
7. Artamonov V. S., Molgina G. M. Corrosion protection of transport structures.– M.: transport. 1976.– 192 p.
8. Ganiev I. G., Soatova N. Z. Salt corrosion of concrete in operated reinforced concrete superstructures of road bridges. Problems of strength of materials and structures in transport // Abstracts of the VII International Conference.– St. Petersburg, April 23–24. 2008.– P. 48–50.
9. Mamazhanov R. A practical method for calculating reinforced concrete bridge spans // Transp. page.– No. 3. 1989.– P. 19–20.
10. Saatova N. Z. Influence salt corrosion on the bearing capacity of concrete span11th European Conference on Innovations in Technical and Natural Sciences 02th June, 2016. Austria,– Vienna,– P. 35–39.
11. Soatova N. Z. A practical method for determining the degree of salt corrosion. II Rep. scientific and technical conf. "Problems of introducing innovative ideas, technologies and projects into production", Collection of scientific papers.– Jizzakh, 2010.– P. 188–190.
12. Soatova N. Z. Estimated assessment of the effect of salt corrosion on the work of concrete and reinforcement. "Problems of architecture and construction" SamSACEI.– No. 2. 2010.– P. 24–27.