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# CONCRETE BRIDGE DETERIORATION CAUSED BY DE-ICING SALTS IN HIGH TRAFFIC VOLUME ROAD ENVIRONMENT IN LATVIA

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**Abstract.** Design for durability of road infrastructures is becoming increasingly important in view of its large impact on economics. Reinforcement corrosion is the most common cause of concrete deterioration of bridge structures in Latvia. The ingress of chlorides is often considered to be the major threat to durability of concrete structures. During the winter season de-icing salts are spread out on roads to avoid formation of ice and ensure the anti-sliding properties of the road surface. The melting water mixes with de-icing salt are splashed and sprayed on reinforced concrete pier structures by passing vehicles. Absorbed water with chloride ions initiates and accelerates the reinforcement corrosion process. This paper highlights the results of investing accumulation of chlorides in reinforced concrete bridge piers located near high traffic volume roads in Latvia. The chloride contents were determined on different surfaces of reinforced concrete piers. Environmental conditions were analysed and prediction of remaining service life for chloride induced reinforcement corrosion was performed.

**Keywords:** concrete bridges, service life, de-icing salts, chloride profiles, corrosion damage, road environment.

## 1. Introduction

Roads with high traffic volume require special care to maintain safe driving conditions during winter. During winter road maintenance regulations require the use of enormous amounts of de-icing salt. To prevent sliding of vehicles tires, the road authority has used the preventive method – spreading de-icing salts before ice build-up on the road surface during winter maintenance. To improve driving conditions during heavy snowfalls, de-icing salts are also used for fighting snow. This means that bridge structures located beside roadways with high traffic volume are highly exposed to intense chloride ingress. Due to reinforcement corrosion caused by chlorides, the service life of numerous bridge structures is reduced to 40 years or less, though *Eurocode: Basis of Structural Design* defines the bridge service life of 100 years. However, some of the bridges are 100 and more years old and still in service (Fischer 2014; Gode 2010; Malerba 2014). Since bridges are one of the largest community investments and because maintenance and repair costs will increase considerably, it is important to improve the durability of reinforced bridge structures by better understanding the processes and sequences of chloride induced deteriorations.

This paper describes the results of investigation performed on three reinforced concrete bridges near high volume traffic streets in Riga city and on the bridge located on Riga's bypass.

## 2. Background

The service life of concrete structures greatly depends on the durability of the materials used and the aggressiveness of the surrounding environment. Many authors have devoted their articles for modelling of deteriorations mechanisms and service life of concrete structures (Bastidas-Arteaga 2013; Demis 2014; Gao 2013; Gode 2007, 2012; Gołaski 2012). Most deterioration mechanisms of concrete structures are modelled in a two-phase model with initiation and propagation phases (Rostam 2003; Wang 2014). Chloride ingress is a part of the initiation phase while the reinforcement corrosion is part of the propagation phase.

The chloride penetration into the concrete cover layer is modelled by the second Fick's law. A possible chloride profile (chloride ion concentration at different depths in the concrete cover) is shown in Fig. 1. The chloride ion profile shows two different parts. The first part in depth $\Delta x$ shows the decrease of chloride content close to surface where the chloride ions are partly washed out by rain water during the summer period. This part forms the convection zone. The second part corresponds to Fick's law of diffusion (the diffusion zone).


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Residual service life calculations are performed by using an empirical model developed by *fib Model Code for Service Life Design* which matches to Fick's law of diffusion and is easily used for calculations:

$$C(x,t) = C_i + (C_s - C_i)erf\left(1 - \frac{x}{2\sqrt{tD_{app}}}\right), \quad (1)$$

where $C(x, t)$ – chloride amount in concrete depth $x$ (concrete surface, if $x$ = 0 mm) and time $t$, mass balance – %; $C_i$ – initial chloride concentration in concrete, mass balance – %; $C_s$ – surface chloride concentration, mass balance – %; $x$ depth in concrete cover, mm; $erf$ – function: $erf(z) = \frac{2}{\sqrt{\pi}}\int_0^z e^{-y^2}dy$; $t$ – concrete structure age, years; $D_{app}$ – apparent diffusion coefficient, $mm^2$/year.

De-icing salt impact on concrete bridges in a road environment has been widely investigated in Sweden (Munch-Petersen 1997; Lindvall 2007) where the climate is similar to Latvia. The obtained results allowed making these conclusions:

– each bridge must be treated separately, because of the large chloride profile scatter;

– the chloride distribution greatly varies not only in-between different structures, but within one structure and even within one surface of the structure;

– overall chloride profiles correspond very well to the previously described theoretical model;

– convection zone depth varies greatly between profiles and varies from 10 mm to 25 mm;

– chloride penetration is larger for surfaces close to the roadway (0–0.5 m) and oriented towards the traffic (the splash exposure);

– traffic speed does not have a significant influence on structures close to the roadway (splash zone), traffic speed might be important for structures that are located further away from the road (spray exposure);

– large chloride penetration to columns has been observed at heights of 0–0 m above the ground level (the splash exposure);

– chloride profiles for surfaces that are exposed to de-icing salt exposure depend on whether the surface is protected from direct rain or not. Surfaces that are unprotected from direct rain are more likely to have a longer service life than surfaces that are protected from rain;

– diffusion coefficient values greatly depend on moisture levels of concrete cover.

Reinforcement corrosion caused by de-icing salt is also a major and common type of concrete bridge deterioration in other countries of the Baltic region (Kamaitis 2009).

## 3. Description of road environment

Latvia is located in a temperate climate zone that is determined by the solar radiation and atmosphere circulation in the Northern part of Atlantic. From the end of September until the end of April it is possible that the temperature drops below 0 °C (Fig. 2). The dangerous slippery driving conditions appear when simultaneously the temperature is below 0 °C and there is a precipitation. De-icing salts on roads are also spread for fighting snow, even though a temperature is above 0 °C.

To determine the residual service life of concrete structures exposed to de-icing salts on roads, it is of great interest to know what amounts of chlorides from de-icing agents get on the surface of structures (Strauss 2013; Tang 2013). There are several research studies featuring models (Tan 2013) that determine the amount of chlorides in an environment around roads. The transport mechanism of chlorides from the road where de-icing agents are spread to concrete surfaces of the bridges is very complex, because it depends on changing weather, application method, traffic volume and speed, structure position and shape.

## 4. Description of the investigated bridge structures

### 4.1. Bridge piers of approach ramps to the Salu Bridge

Three approach ramp piers of complex of the Salu Bridge over the river Daugava in Riga have been investigated in this study. All three approach ramps have a similar structure and cross the same road not far from the city centre. Investigated approach ramps were built in 1976 and are

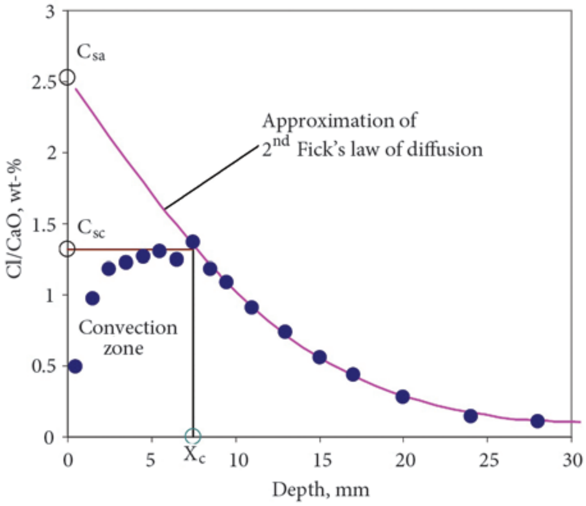


**Fig. 1.** Chloride profile in the concrete cover (Nilsson 2000)

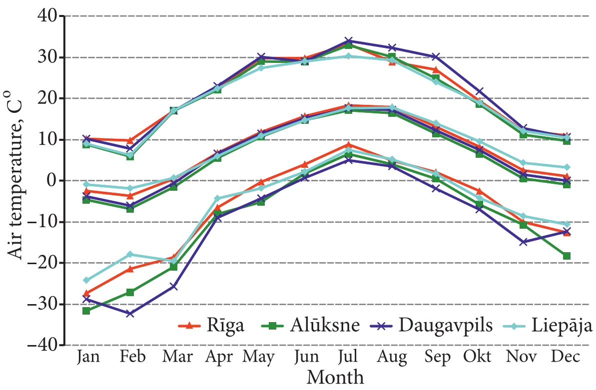


**Fig. 2.** Monthly values for the max, min and average air temperatures in Riga and other major cities in Latvia

numbered as No. 8, No. 5 and No. 7 (Fig. 3). The piers are built in cast-in-place concrete (M300 with $f_c$ = 125 kg/cm$^2$, and frost resistance 200 cycles ($M_{p3}$200) according to structural codes at the time). The design concrete cover depth according to the former Soviet codes was 30 mm for the main reinforcement. Piers are of rectangular shape with width 80 cm, length at the top 360 cm, at foundations 260–295 cm.


**Fig. 3.** The right-side approach ramps complex of the Salu Bridge over the Daugava River

**Fig. 4.** Bridge over Bieķengrāvis

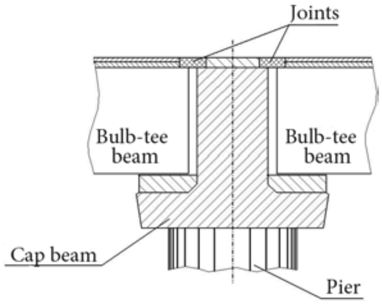


**Fig. 5.** Support structure of the bridge

**Fig. 6.** Bridge over the railroad ("Gaisa tilts") in Riga

**Fig. 7.** Bridge over the Daugava River near the hydro power plant

Piers are located very close to the highway at different angles against the road axis.

The highway beside the bridge piers has three lanes in each direction. The road surface has almost 4% inclination to the outside. Speed limit is 70 km/h and there is a high traffic volume over 20 000 vehicles per day (vpd). The bridge piers and other bridge structures are exposed directly to water containing chlorides that is splashed and sprayed by traffic for almost a half of the year.

### 4.2. Bridge over Bieķengravis

The bridge over Bieķengrāvis is situated on the left side of the river Daugava in the municipality of Riga and is part of the Salu Bridge complex (Fig. 4). Bridge has six traffic lanes, speed limit of 70 km/h and traffic volume of over 60 000 vpd. The bridge consists of 15 simply-based prestressed girder (bulb-tee beam) spans (concrete class M450) and is 384.7 m in length. This bridge was constructed in 1973.

The bridge above each pier has two joints, which are the weak point of these type structures (Fig. 5). Leaking joints may cause reinforcement corrosion damage to cap beam and tail-end parts of the prestressed bulb-tee beams.

### 4.3. Bridge over the railroad – "Gaisa tilts"

This bridge is situated in municipality of Riga, where continuation of highway A2 enters the city centre. The bridge has only two lanes of traffic and two tram lines, which are used as a third traffic lane during rush hours. The speed limit is 30 km/h and traffic volume is over 35 000 vpd. The bridge consists of three simple beam spans which overpasses five railroad tracks (Fig. 6). The superstructure and the middle span piers were built in 1963, whereas the masonry stone abutments were built in 1906. The side spans have 13.24 m long reinforced concrete T-beams (concrete class M300); the middle span has 16.76 m prestressed concrete beams (concrete class M400). The waterproof membrane beneath tram lines has been deteriorated and beams (especially side span beams) are exposed to moisture and de-icing salts.

### 4.4. Bridge over the Daugava on bypass – highway A5

This bridge is situated on the Riga bypass highway A5 (Fig. 7). The bridge is located beside a hydro power plant "Rīgas HES" and has two lanes of traffic with of over 10 000 vpd. The bridge was built in 1973. The superstructure of the investigated bridge consists of six 24 m long spans; each span has six prestressed concrete bulb-tee beams of 450 kg/cm$^2$ compressive strength at 28 days (concrete class M400). Above each pier there is one expansion joint.

## 5. Field survey and collection of samples

### 5.1. Bridge piers of approach ramps to the Salu Bridge

Core drilling was performed, and core samples were obtained from different pier surfaces and positions.

Approach ramp No. 8 pier is on the outside of highway with the widest surface facing towards traffic at a 31 degree

**Fig. 8.** Reinforcement corrosion cracks at the pier corner

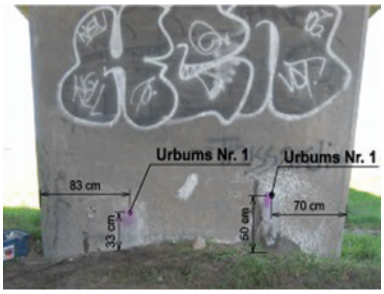


**Fig. 9.** Core sampling from the ramp No. 8 pier


**Fig. 10.** Ramp No. 5 pier and sampling location

angle. Reinforcement corrosion cracks were detected at the corner closest to the road (Fig. 8). Core drilling was performed at 83 cm away from the corner and 33 cm above the ground surface. A second core sample was taken from another side of this surface (Fig. 9).

The pier of approach ramp No. 5 is positioned close to the highway with the shortest surface facing towards traffic at 55 degree angle. This pier also had cracks in the nearest corner to the highway (Fig. 10). One sample was taken from the surface facing traffic and three samples from the wide surface facing away from traffic. Sample No. P5-4 was taken for a pressure test of the concrete.

The pier of the approach ramp No. 7 is positioned similarly to the pier of ramp No. 5. The shortest surface faces towards traffic at a 64 degree angle. Two core samples were taken as follows: one from the surface facing toward traffic and one facing away from traffic.

The samples were cut at 10–15 mm intervals and the pieces were examined for chloride content in compliance to *LVS EN 196-2:2013 Method of Testing Cement. Chemical Analysis of Cement*. The amounts of chlorides in the concrete samples, are presented in the chloride profile shown in Fig. 11 (one point describes chloride concentration in one piece of concrete).

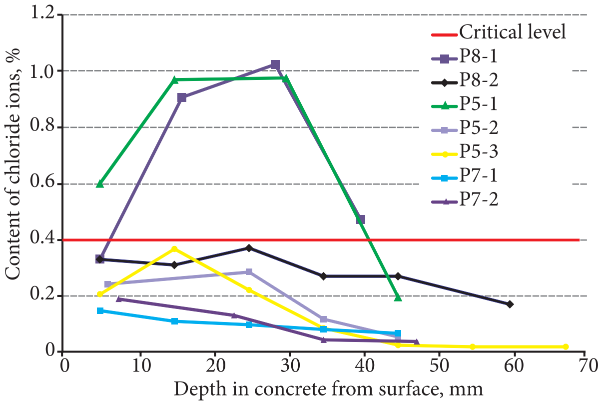


**Fig. 11.** Chlorides in cement paste of bridge piers

**Fig. 12.** Core sample from the web of the beam near leaking expansion joint

### 5.2. Bridge over Bieķengrāvis

For the bridge over Bieķengrāvis we investigated corrosion initiated by de-icing salts that reach structure surfaces through leaking expansion joints. The core samples (Fig. 12) were obtained from the web of the beam near the tail end of it (sample P2 and P3) and from the cap beam side surface bellow the leaching joint (sample P1). The chloride profiles from obtained samples are shown in Fig. 13. The investigated web part of the beam did not have significant moisture signs. It was technically impossible to take the sample at very tail end of the beam, which might have a higher moisture exposure. The investigated cap beam surface that is located below expansion joint has been exposed to moisture and de-icing salts.

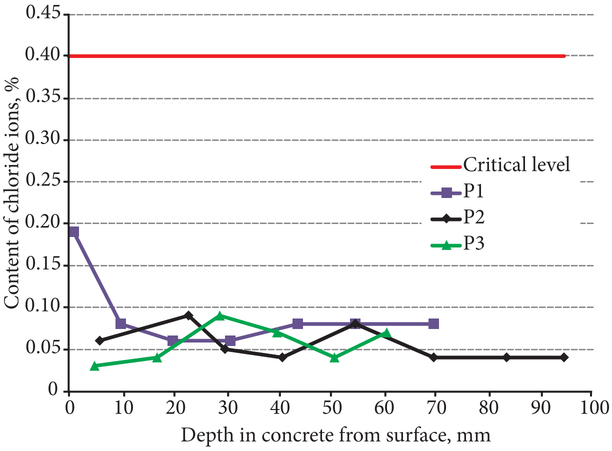


**Fig. 13.** Chloride profiles for the bridge over Bieķengrāvis

### 5.3. Bridge over the railroad – "Gaisa tilts"

The bridge has deteriorated and also has leaking waterproof membrane beneath tram lines (Fig. 14). During inspection it was stated that corrosion of reinforcement bars in the beams is developing, what is causing the concrete cover to crack and delaminate. Two samples for chloride investigation were obtained from the bottom part of the beam near reinforcements. This bridge also has leaking joints that cause chlorides to reach surfaces of the piers

**Fig. 14.** Corrosion of reinforcement

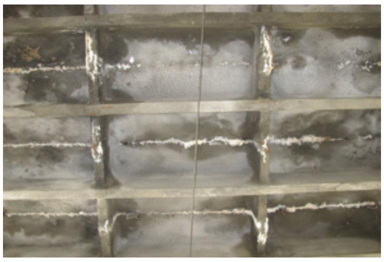

**Fig. 15.** Signs of leaking and deteriorated membrane

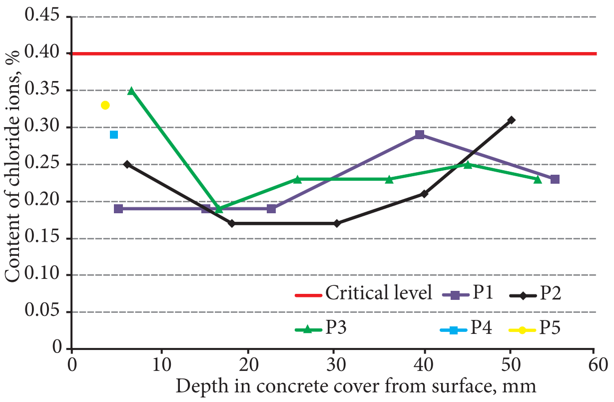


**Fig. 18.** Chloride profiles for bridge over the river Daugava on bypass A5

**Table 1.** The chloride content of the bridge over the railroad ("Gaisa tilts")

| Sample | Position of the sample | $Cl^-$, % |
|---|---|---|
| No. 1 | Span No. 2–3, the bottom facet of the beam at pier No. 3 | 0.41 |
| No. 2 | Span No. 2–3 the bottom facet of the beam at pier No. 3 | 0.53 |
| No. 3 | Pier No. 1, from the bottom part at the depth of reinforcement | 1.03 |

(Fig. 14). During inspection severe corrosion of the bridge piers towards the bottom were noted. The third sample obtained from the bottom part of the pier showed very high chloride content (Table 1). The inspection took place at the end of the summer season where most of the chlorides from the surface were washed out.


**Fig. 16.** Locations of samples P1 and P2 for bridge over the Daugava on bypass A5

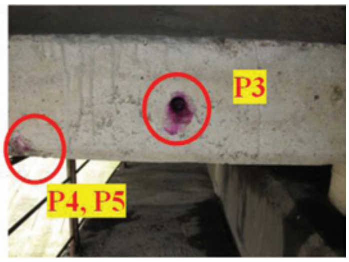


**Fig. 17.** Locations of samples P3, P4 and P5 for bridge over the Daugava on bypass A5

### 5.4. Bridge over the river Daugava on Riga bypass – highway A5

As this bridge has leaking expansion joints, samples P1 and P2 were obtained from the tail end of the beam near a leaking joint where moisture was obvious (Fig. 16) and samples P3, P4, P5 from the position where no moisture or chlorides (signs) were present (Fig. 17). The inspection also took place at the end of the summer season where most of the chlorides from the surface were washed out. The samples were obtained by concrete drilling at different depths from the surface and collecting the concrete powder. The obtained chloride concentrations and chloride profiles are shown in Fig. 18.

## 6. Discussion

### 6.1. Bridge piers located near the road

Fig. 14 shows that the amounts of chlorides vary greatly at different depths in concrete and in different places of the structure. In depths under about 15 mm the chloride content is low. This shows that chlorides closer to the surface were washed out. The profiles with the highest chloride concentration (samples P8-1 and P5-1) were found from surfaces facing toward the traffic direction and closer to the corner of the pier.

The profiles (P8-1 and P8-2) from the approach ramp No. 8 piers were obtained from the same surface facing towards traffic. Profile P8-1 shows much greater chloride concentration, because it is much closer to the road. At the reinforcement depth 42 mm the chloride concentration is close to critical value of 0.4%. Since no corrosion was detected, it is assumed that reinforcement corrosion threshold value is at least 0.4% or greater. Both profiles and the fact that there are reinforcement corrosion cracks at the pier corner, which is the closest to highway, show that chloride distribution is greatly influenced by the distance from the road and the angle at which the pier surface is facing traffic.

Profile P5-1 was obtained from approach ramp No. 5 pier's surface facing traffic, and is very similar to P8-1 profile. Other profiles from the surface facing away from the traffic show significantly less chloride concentration. Profile P5-2 which was obtained from the position a little lower than from profile P5-3 shows a bit more chloride concentration. The concrete cover depth of this surface was measured 60 mm.

The profiles P7-1 and P7-2 were obtained from the both piers surfaces of the approach ramp No. 7 facing towards and away from the traffic. Both show low levels of chloride concentration and cracks of reinforcement corrosion close to highway were not assessed. This convinces us that chloride concentration in the road environment is very variable.

### 6.2. Leaking expansion joints

The investigation showed shows that chloride levels are low for the bridge over Bieķengrāvis. The concentration of chlorides in the vertical surface of the cap beam show greater amounts in the top layer, but it is sufficiently low so as not to cause reinforcement corrosion in the foreseeable future. The concrete of the girder and cap beam are of very good quality. The chloride level in the bridge beam close to the leaking joint, but not directly exposed to chlorides, also is very low. The corrosion risk exists only for surfaces with direct chloride exposure, such as horizontal surfaces on the bottom part of the cap beam. Investigation showed that parts below leaking joints at several places have severe reinforcement corrosion.

Chloride profiles for Riga bypass A5 bridge over the Daugava show that in general the chloride concentration level is not high and will not initiate intensive primary reinforcement corrosion. Higher amounts of chlorides are found in depths to 10 mm. At depths of 10–60 mm, the chloride content is more or less constant and is not reducing, which means that the girders have relativity high initial chloride concentration, varying between 0.19% and 0.25%, on average 0.22%. This high chloride concentration did not accumulate during the service life (especially for sample P3), where the girders have not been exposed to intensive and long-term moisture influence.

Chloride profiles for samples P1 and P2 show higher concentration at depths of 40–60 mm because the sample was obtained near the tail end surface of the girder (P1 – 12 cm and P2 – 6.5 cm from the tail end surface). Most likely these chlorides entered the concrete from the tail end surface which is situated right beneath the expansion joint.

Visual inspection detected damage to the tail end surface of the girder, showing that there the chloride concentration is a lot higher and reinforcement corrosion is advancing. Reduced chloride amounts near the surface is likely to be washed out by water containing no chlorides during summer rains.

Taking into account that girders have relativity high initial chloride concentration – on average 0.22%, usually it is about 0.1% (Beck 2012), the additional chlorides needed to initiate corrosion are a lot less. This means that these structures need to avoid being exposed to de-icing salts for longer periods of time. In cases of expansion joint or waterproof membrane damages it would be necessary to stop applying de-icing salts and repair damage to prevent chlorides reaching girder surfaces.

### 6.3. Leaking waterproof membrane

The main reason for corrosion deterioration of the bridge over the railroad "Gaisa tilts" is leaking waterproof membrane and also leaking joints. The leaking membrane is below tram lines, which makes them difficult to repair and it is obvious that they have not been repaired for very long time. The leaking waterproof membrane causes girders to have a high moisture level throughout the year and chloride contained moisture during winter. Corrosion damage usually appears on the bottom part of the beam and is spread within the whole span, which will cause the loss of structural bearing capacity in the middle of the span in the future.

## 7. Remaining service life calculations

Chloride profiles were analysed to determine service life. To perform service life calculations, the theoretical chloride profile line was fitted into the obtained chloride profile from the samples, and by doing so diffusion parameters were calculated. Then the possible future profile was calculated for the target service life of 100 years. The calculation was performed using *fib Model Code for Service Life Design* model as described previously at the deterministic and semi probabilistic level. Surface chloride concentration and diffusion coefficient were considered to be constant throughout the service life.

### 7.1. Bridge piers of approach ramps to the Salu Bridge

The profile P5-3 corresponds closely to the theoretical profile (Fig. 19). The future profile for 100-year service life is calculated by extrapolation. Fig. 19 shows that the critical concentration of chlorides at which it is assumed that corrosion starts has not reached the depth of reinforcement.

Other profiles did not have sufficient points for reliable calculations or the chloride concentration is so low that it does not correspond to the theoretical chloride profile (Table 2). Profiles 8–1 and 5–1 which showed greater

**Table 2.** Results of diffusion coefficient calculations at deterministic level

| Profile | Number of useful points | Time in exposure, years | Surface chloride concentration, % | Diffusion coefficient, $mm^2$/year |
|---|---|---|---|---|
| P8-1 | 2 | 33 | – | – |
| P8-2 | 4 | 33 | 0.526 | 56.285 |
| P5-1 | 2 | 33 | – | – |
| P5-2 | 3 | 33 | – | – |
| P5-3 | 6 | 33 | 0.756 | 7.384 |
| P7-1 | 5 | 33 | 0.141 | 21.135 |
| P7-2 | 4 | 33 | 0.236 | 14.217 |

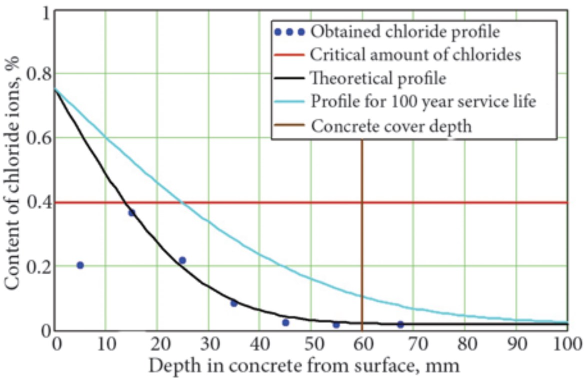


**Fig. 19.** Calculation of chloride profiles (profile P5-3) at deterministic level

chloride concentrations have only 2 useful points for calculations, thus, providing no reliable results.

### 7.2. Bridge over the Daugava on Riga bypass – highway A5

For calculation of chloride ingress parameters and the remaining service life was used methodology from *fib Model Code for Service Life Design*. The calculations are performed at a semi-probabilistic level with reliability index β value of 1.8. In addition, the service life calculations were performed for a case of damaged and leaking waterproof membrane or expansion joints where high concentrations of chlorides reach superstructure surfaces.

The remaining service life was calculated using expression:

$$\frac{\mu_{cover}-\left[2\sqrt{tD_{app}erf\left(1-\sqrt{\dfrac{C_{crit}-C_i}{C_s-C_i}}\right)}\right]}{\sqrt{\sigma_{cover^2}+\left(0.5\left[2\sqrt{tD_{app}erf\left(1-\sqrt{\dfrac{C_{crit}-C_i}{C_s-C_i}}\right)}\right]\right)^2}}=\beta, \qquad (2)$$

where $\mu_{cover}$ – mean value of concrete cover thickness, mm; $\sigma_{cover}$ – standard deviation of concrete cover thickness, mm; $C_{crit}$ – critical chloride concentration, mass balance – %; β – reliability index.

The input data and calculation results are shown in Table 3 and in Figs 20–21.

**Table 3.** Service life calculation parameters and results

| Parameter | Current chloride exposure | | | Higher chloride exposure | |
|---|---|---|---|---|---|
| Concrete cover, mm | 9 | 20 | 40 | 20 | 40 |
| Time in service, $t$, years | 10 | 10 | 10 | 10 | 10 |
| β | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 |
| $C_{crit}$, % | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| $C_i$, % | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 |
| $D_{app}$, mm$^2$/year | 6.459 | 6.459 | 6.459 | 6.459 | 6.459 |
| $C_s$, % | 0.461 | 0.461 | 0.461 | 1.5 | 1.5 |
| $\mu_{cover}$, mm | 9 | 20 | 40 | 20 | 40 |
| $\sigma_{cover}$, mm | 0.6 | 1.1 | 1.4 | 1.1 | 1.4 |
| Remaining service life, $t_{remaining}$, years | 7 | 76 | 336 | 2 | 48 |

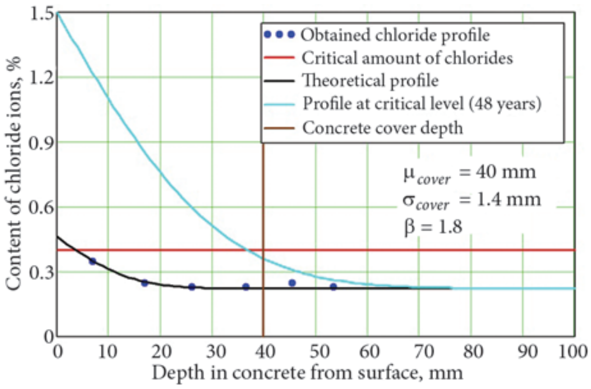


**Fig. 20.** Calculated chloride profile for 40 mm concrete cover in a case of a higher chloride exposure

## 8. Conclusions

1. Chlorides from the de-icing salts spread on roads are very unevenly distributed not only between different surfaces but also within one surface. The chloride profile shapes differentiate from the theoretical profile most likely due to the lack of samples for one profile, but also due to complex exposure conditions which feature constantly changing surface chloride concentrations and moisture levels.

2. The results show that exposure to chlorides is generally highest for surfaces facing towards traffic and that are lower and closer to the road. The position and shape of the bridge piers are important.

3. Corrosion risk exists only for the surfaces with direct chloride exposure. Surfaces located below leaking waterproof membrane and expansion joints are exposed not only to de-icing salts but also to a lot of moisture in summer that reduces the chloride level in top layer of the concrete thus reducing the overall chloride amount in concrete.

4. Some older precast girder bridges might have a higher initial chloride concentration (above 0.20%) that

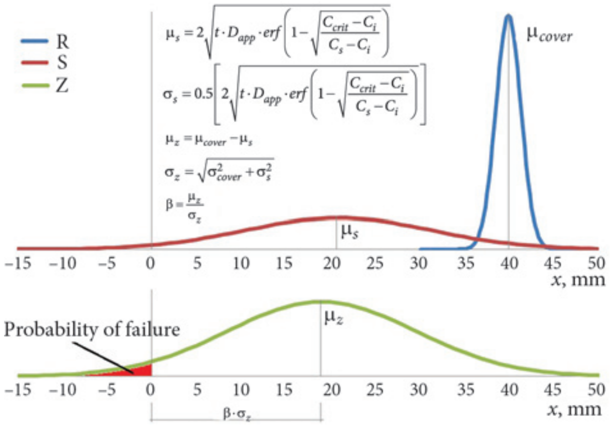


**Fig. 21.** Reliability concept for performed calculations

significantly reduces service life. The secondary reinforcement for structures built during the Soviet times is in danger of having corroding reinforcement even in lower chloride exposures.

5. Severe chloride exposure that occurs on high volume roads for bridges with leaking expansion joints and waterproof membrane significantly reduces service life of bridge structures that are built of good quality concrete and even have a concrete cover of 40 mm.

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