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# Service Life of Two 100 Year Old Concrete Bridges in Latvia

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***Abstract.*** **The earliest reinforced concrete bridges built in Latvia over river Salaca and Gauja were built in 1908 and 1909. 100 years later both are still in service and require only certain maintenance. Bridges were built with intuition of parameters that produces good quality: concrete mix design, choice of shape and installation within formwork. After 100 years in service, both bridge deteriorations could have been avoided, for example, foundation protection for bridge over Salaca and expansion joints for both bridges. The concrete has been vulnerable to carbonation; during the 100 years of exposition the carbonation has reached 40 mm and the main reinforcement. Within this research performed carbonation calculation results show that the inverse effective carbonation resistance of concrete on site is $\mu=31.45\cdot10^{-11}$,$\sigma=5.32\cdot10^{-11}(m^5/(s\cdot kgCO_2))$.For concrete directly exposed to the wetting the weather function value is $\mu=3.24$, $\sigma=0.74$. The calculation of carbonation process was modelled by using DuraCrete carbonation model and MonteCarlo simulations at full probabilistic level.**

***Key words:*** **concrete, bridge, service life, durability, carbonation**

## INTRODUCTION

The earliest reinforced concrete bridges built in Latvia are now 100 years old. The bridges over river Salaca and Gauja were built in 1908 and 1909 and both have very similar structure. Both are still in service and require only certain maintenance.

Bridge assessment showed that after 100 years in service bridges are in good technical condition, although they do require some repairs for increasing service life for more than 100 years. Bridges were built with intuition of parameters that produces good quality: concrete mix design, choice of shape and installation within formwork. The careful designing and construction has led to great performance.

Service life issues of reinforced concrete bridges are recently becoming more concerning in Latvia and other countries in northern Europe. The very short service life of bridges build 30–40 years ago has demanded to analyze and restudy the durability concept of concrete bridges. Euro codes define a service life of 100 years for infrastructure buildings like bridges. Reinforcement corrosion caused by carbonation has been one of the major reasons for short service life of concrete bridges in Latvia [1]. In neighboring countries a lot of research has been devoted to service life problems of infrastructure buildings [2], [3] and environmental actions on concrete exposed in road environment [4]. The great durability performance of many reinforced concrete bridges which were built in the early years of 20th century has also demanded to restudy the current bridge durability concept [5], [6].


Fig.1. The bridge over Salaca river, built in 1908


Fig.2. The bridge over Gauja river near city of Strenci, built in 1909

## BRIEF HISTORY OF THE TWO OLDEST BRIDGES IN LATVIA

Bridge over river Salaca near city Salacgriva is currently the oldest reinforced concrete bridge in Latvia (fig.1). The bridge was built without a contract and was financed by knighthood of Vidzeme in 1908.

At the time most of the concrete structures were build by French and German companies which did not want to share with their designing and building secrets [7]. The bridge has five spans and consist two continuous (17.90m + 17.90m) two span beams at sides and one span beam in the middle (18.15m). The cross sections of the both bridges are the same – there are four monolithic beams (fig.3). The beam height at piers is 2.04m, in the middle of span – 1.44m. In 1944 the both end spans were blown up. After the WWII the spans were repaired in timber, but in 1962 both spans and side piers were renovated in the original concrete design [7]. In the 1992 the bridge load test showed very good results. In 2007 the bridge surface was repaired with shotcrete. The bridge over river Gauja at city Strenci was built in the same way as the bridge over Salaca (fig.2.). Bridge was completed in 1909. Initially it was a four span bridge the same design as bridge over Salaca, consisted of two continuous two span beams. In 1919 during the war time, the first span was blown up. It was repaired in 1921, the design project of repair can be found in archives [8]. In 1929 flooding of river Gauja and ice forging destroyed the bank at the side of Strenci city [7]. During the depression years additional two spans were built in welded steel beam and timber deck design. The timber deck since then has been rebuilt couple times. This is the current state of the bridge.

Both bridges despite some deteriorations, damages and modifications still show great performance although were build in times when engineers compared to today's engineers had less information available of concrete and did not have sophisticated codes. It shows that building a bridge with great care and intuition of parameters that make concrete strength and durability is possible to achieve the service life of more than 100 years.

## Assessment Of Technical Condition Of The Bridges

### *Bridge footings and scouring of river course*

Underwater inspection showed considerable erosion of the earth below the water line due to insufficient protection against erosion. At some places the original underwater ground level has been eroded down to the same level as the bottom of the base of foundation. Comparatively deep scoured areas in concrete footings were found on the sides faced towards the river flow. Maximum damage reached depths of 1.3 m (fig.4).

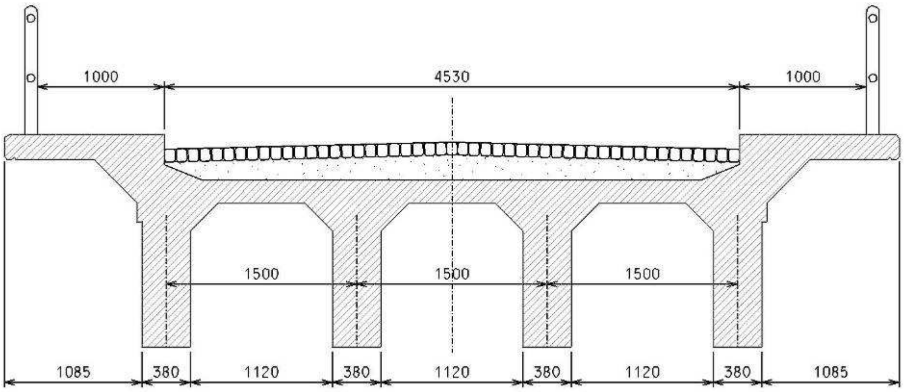


Fig.3. The cross section of the bridge over river Gauja

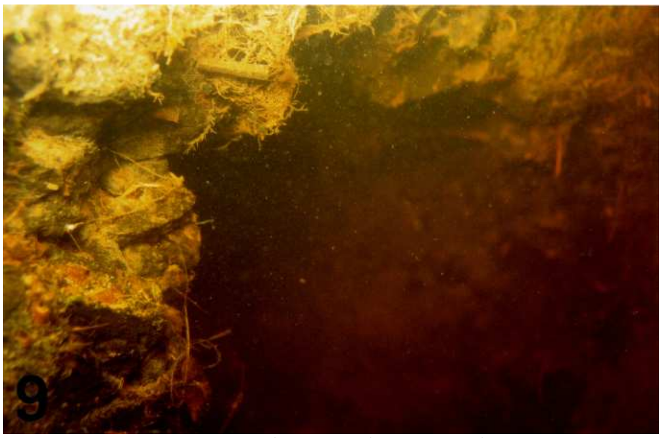


Fig.4. The scouring damage of concrete foundation of the bridge over river Salaca

It can be assumed that the ground erosion and concrete footing scouring was progressing 100 years. Any kind of deformation of the superstructure due to settlement or movement was not detected. It is necessary to repair the damage and build footing protection. The damage of footing might affect carrying capacity. Erosion is caused by heavy particles suspended in water flowing across concrete surfaces of bridge footing. Between piers Nr.1 and Nr.2 there are considerable alluviums which reduce the cross-section of river bed and thus the stream flow at piers Nr.3-5 is accelerated to form scouring of the ground and eventually the The bridge over river Salaca did not have any kind of pier footing protection. scouring of concrete footings appears (fig.5).

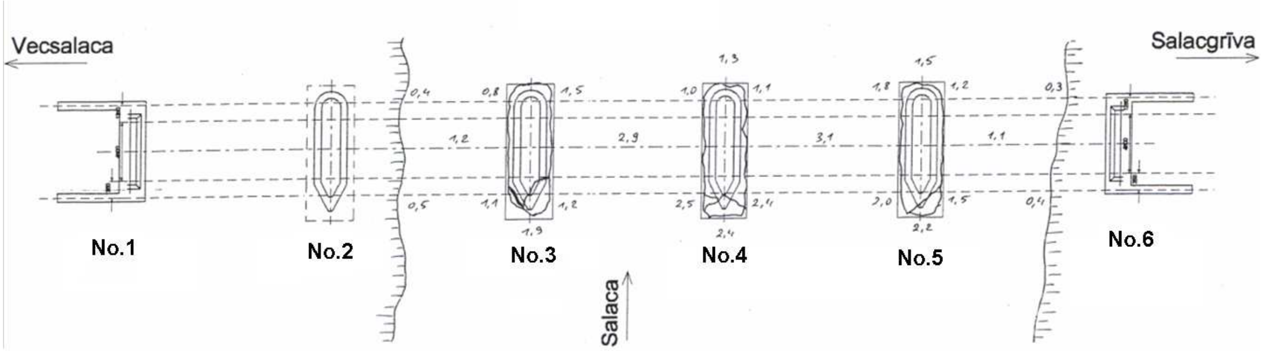


Fig.5. The plan of piers and foundation damage of the bridge over river Salaca

Fig.6. Delimination of shotcrete layer of pier positioned below faulty expansion joint

Fig.7. Repaired pier in 2008

Fig.8. Pier before repair in 1985

### *Bridge piers*

The piers of the bridge over river Gauja have been repaired in 1997. Non sealed expansion joints caused consequential damage to the piers which are positioned below the expansion joints. Delimination of repaired concrete layer (shotcrete layer) was detected to one of the piers (fig.6.). Figures 7 and 8 show that 10 years after repair piers look about the same they were 20 years ago.

### *Bridge beams and slab*

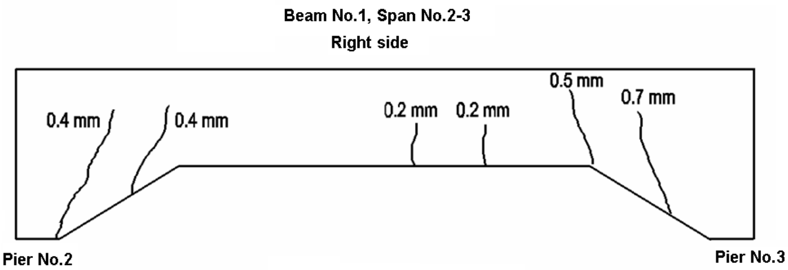
Spalling of small portions of concrete due to corrosion of reinforcing steel and insufficient concrete cover to the underside of beams and slab (fig.9.). Concrete cover measurement results show that it is very variable. At several places the main reinforcement corrosion was detected due to carbonation and longitudinal cracks along the reinforcement.

Shear cracks on beams up to width of 0.7 mm (fig.10). The cause of the shear cracks have been caused by overload of the structure at some point of the time (perhaps during the World War II).

The saturation of chlorides in concrete bridge slab was found low reaching only 0.20% of the weight of the concrete (fig.11). The bridge is not exposed to chlorides or de-icing salts. The average carbonation depth was found about 40 mm (fig.12). Carbonation initiated corrosion was found on the underside of beams and slab with insufficient cover (10 to 30 mm).

Pressure testing of drilled core was performed to determine the strength of the concrete (fig.13). Pressure testing showed good compatibility to jackhammer test performed at different positions of the bridge. The results showed 49.9 N/mm$^2$ compressive strength which applies to the C40/50 concrete.

Fig.9. Spalling of the concrete due to insufficient concrete cover and corrosion of reinforcement



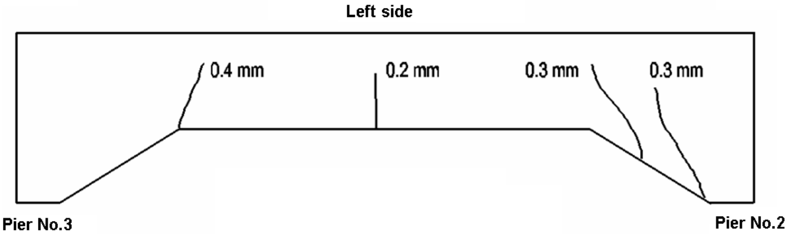


Fig.10. Position and width of shear and flexure cracks on beams

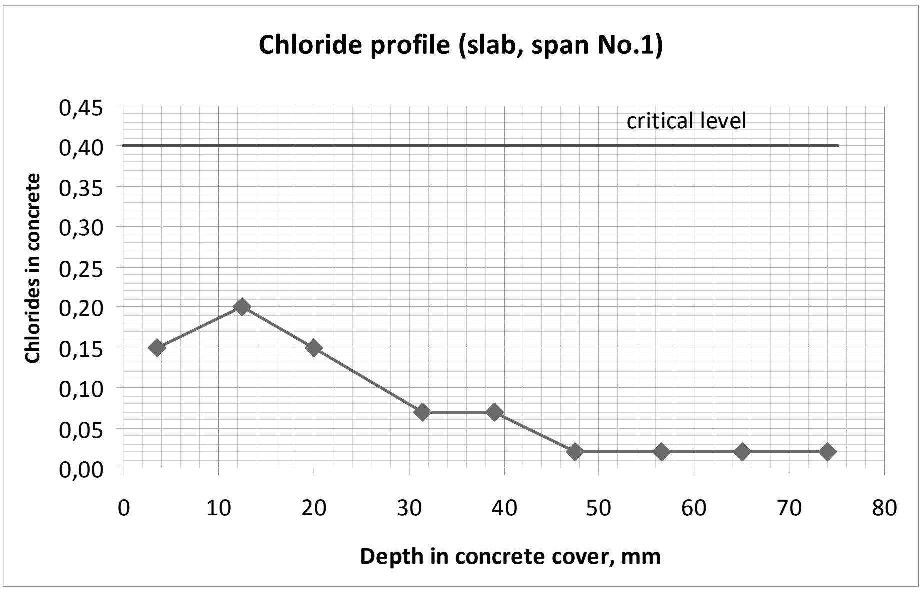


Fig.11. The chloride profile taken from the top surface of the bridge slab

Fig.12. Determination of the depth of carbonation of the concrete

Fig.13. Concrete core drilling

TABLE 1

Calculation of input and output parameters for concrete not exposed to wetting

| Name | Parameter | Source of data | Unit | D-Type | Mean (μ) | StD (σ) |
|---|---|---|---|---|---|---|
| gradient of $CO_2$ concentration | $\Delta C_s$ | [10] | $[kgCO_2/m^3]$ | ND | 0.00082 | 0.0001 |
| carbonation depth | $X_C$ | inspection | [m] | ND | 0.04 | 0.003 |
| time in service | $t$ | inspection | [s] | const | 3153600000<br>(100 years) | - |
| weather function | $W$ | inspection | [-] | const | 1 | - |
| inverse effective carbonation resistance of concrete on site | $R_{Carb}^{-1}$ | calculation (2) | $[m^5/(s\cdot kgCO_2)]$ | ND | $31.45\cdot10^{-11}$ | $5.32\cdot10^{-11}$ |

## CALCULATION OF PARAMETERS OF CARBONATION RESISTANCE OF CONCRETE

The concrete of bridge beams has been vulnerable to carbonation; during the 100 years of exposition the carbonation has reached 40 mm and the main reinforcement. Within this research the calculation of main carbonation parameters for 100 years of exposition to carbonation was performed.

The carbonation process of concrete can be modelled using *DuraCrete* model (equation 1)[9]. The *DuraCrete* carbonation model currently is the most practical and widely used for concrete carbonation prediction. The main factors which influence the depth of carbonation over the time are the amount of $CO_2$ in surrounding environment, the carbonation resistance of the concrete and weather as a function of concrete wetting periods. When concrete is exposed to wetting no $CO_2$ diffusion takes place and thus the rate of carbonation process is reduced significantly.

$$X_c = \sqrt{2 \cdot \Delta C_S \cdot R_{Carb}^{-1}} \cdot \sqrt{t} \cdot W \qquad (1)$$

where

$X_c$ – carbonation depth [mm];

$\Delta C_s$ – gradient of $CO_2$ concentration [$kgCO_2/m^3$];

$R_{Carb}$ – effective carbonation resistance of concrete on site [$m^5/(s \cdot kgCO_2)$];

$t$ – time in service [s];

$W$ – weather function: $W = \left(\frac{t_0}{t}\right)^w$ [-];

$$w = \frac{\left(p_{splash} \cdot ToW\right)^{b_w}}{2};$$

$t_0$ – reference time [s];

$p_{splash}$ – probability of splash (for horizontal surfaces $p_{splash} = 1$) [-];

$ToW$ – time of wetness:

$$ToW = \frac{amount.of.days.with.rain\_h \geq 2.5mm/days}{365};$$

$b_w$ – regression parameter [-].

If concrete is not exposed to wetting at all, the time of wetness equals to zero ($ToW = 0$) and weather function is equal to 1 ($W = 1$). This applies to the inside surfaces of the beams underneath the bridge deck. The effective concrete carbonation resistance was calculated using the equation No.2.

$$R_{Carb} = \frac{2 \cdot \Delta C_S \cdot t}{X_C^2} \qquad (2)$$

The calculation was performed using the *MonteCarlo* simulation method. Results are summarized in table No.1.

For concrete exposed directly to rain, such as a horizontal top surfaces of the bridge deck the carbonation rate is influenced greatly by the time of wetting. The measured carbonation depths for the two different positions showed that the carbonation rate of the concrete exposed to wetting was much smaller. As the concrete is the same for both positions it was assumed that the concrete carbonation resistance is the same, the only different parameters are the carbonation depth.

The calculation parameters and results are shown in table No.2.

and the weather function. Based on the calculation of concrete carbonation resistance for concrete not exposed to wetting it was possible to calculate the value of weather function for concrete exposed to wetting using equation (3).

$$W = \frac{\sqrt{2 \cdot \Delta C_S \cdot R_{Carb}^{-1}} \cdot \sqrt{t}}{X_C} \qquad (3)$$

TABLE 2

Calculation of input and output parameters for concrete exposed to wetting.

| **Name** | **Parameter** | **Source of data** | **Unit** | **D-Type** | **Mean (μ)** | **StD (σ)** |
|---|---|---|---|---|---|---|
| gradient of $CO_2$ concentration | $\Delta C_s$ | [10] | $[kgCO_2/m^3]$ | ND | 0.00082 | 0.0001 |
| carbonation depth | $X_C$ | inspection | [m] | ND | 0.013 | 0.003 |
| time in service | $t$ | inspection | [s] | const | 3153600000<br>(100 years) | - |
| inverse effective carbonation resistance of concrete on site | $R_{Carb}^{-1}$ | calculation<br>(see table No.1) | $[m^5/(s\cdot kgCO_2)]$ | ND | $31.45\cdot10^{-11}$ | $5.32\cdot10^{-11}$ |
| weather function | $W$ | calculation (3) | [-] | ND | 3.24 | 0.74 |

The weather function considers the derivation of the carbonation process of unsheltered structures from the square root of time relation. In this case the concrete carbonation in horizontal surfaces is slowed more than three times. The effective carbonation resistance of concrete on site can be compared to carbonation resistance in accelerated (*ACC*) test.

## CONCLUSIONS

The earliest reinforced concrete bridges built in Latvia are now 100 years old. During this period both bridges received little to almost none maintenance, despite that both bridges still show great performance. That shows us how careful designing and construction can lead to great performances.

After 100 years in service, both bridge deteriorations could have been avoided for example foundation protection for bridge over Salaca and expansion joints for both bridges.

The concrete has been vulnerable to carbonation; during the 100 years of exposition the carbonation has reached 40 mm and the main reinforcement. At downward surfaces, were the concrete cover has been insufficient the reinforcement corrosion is underway.

Within this research performed carbonation calculation results show that the inverse effective carbonation resistance of concrete on site is $\mu=31.45\cdot10^{-11}$, $\sigma=5.32\cdot10^{-11}$ $(m^5/(s\cdot kgCO_2))$. For concrete directly exposed to the wetting the weather function value is $\mu=3.24$, $\sigma=0.74$. The calculated value of the weather function can be used for calculation and prediction of carbonation for concrete exposed to wetting in northern regions of Latvia.

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### Kristaps Gode, Ainārs Paeglītis. Divu 100 gadu vecu dzelzsbetona tiltu kalpošanas laika analīze Latvijā

Vecākie dzelzsbetona tilti Latvijā pašlaik jau ir sasnieguši 100 gadu vecumu. Tilti pār upēm Salacu un Gauju tika uzbūvēti attiecīgi 1908. un 1909. gadā. Abiem tiltiem ir ļoti līdzīga konstrukcija un tie vēl aizvien tiek ekspluatēti. Tiltu inspekcija parādīja, ka pēc 100 gadu ekspluatācijas tilti ir labā tehniskā stāvoklī. Tomēr, lai nodrošinātu par 100 gadiem ilgāku kalpošanas laiku, ir nepieciešami nelieli remontdarbi. Tilti tika būvēti laikā, kad vēl neeksistēja vispārpieņemtas normas un to kvalitāti noteica intuitīvi: optimālu betona sastāvu, formas izvēli un iestrādāšanu veidņos. Pēc 100 gadu ekspluatācijas abiem tiltiem ir bojājumi no, kuriem bija iespējams izvairīties, veicot atbilstošus uzturēšanas darbus, kā, piemēram,izlabojot pamatu konstrukcijas izskalojumus tiltam pār Salacu un deformācijas šuvju bojājumus abiem tiltiem. Betons ir ticis pakļauts betona karbonizācijas iedarbībai, 100 gadu laikā karbonizācija ir sasniegusi 40 mm dziļumu betona aizsargkārtā un nesošajos stiegrojumos. Siju apakšējās virsmās, kur betona aizsargkārta ir nepietiekama, ir sākusies stiegrojuma korozija. Šajā pētījumā veiktie karbonizācijas attīstības aprēķina rezultāti parāda, ka inversā efektīvā betona karbonizācijas pretestība ir $\mu=31.45\cdot10^{11}$, $\sigma=5.32\cdot10^{11}$($m^5/(s\cdot kgCO_2)$). Betonam, kas ir tieši pakļauts ūdens iedarbībai, laika apstākļu funkcijas vērtība ir $\mu=3.24$, $\sigma=0.74$. Karbonizācijas attīstības procesa aprēķinā tika izmantots *DuraCrete* izstrādātais karbonizācijas modelis un veikti aprēķini, pielietojot *MonteCarlo* simulāciju. Aprēķins tika veikts pilnās varbūtības līmenī.

### Кристапс Годе, Айнарс Паэглитис. Время службы двух 100-летних железобетонных мостов в Латвии

Первым Латвийским железобетонным мостам исполнилось 100 лет. Мосты над рекой Salaca и Gauja были построены в 1908 и 1909 годах и оба имеют очень схожую структуру. Проведенное обследование показало, что после 100 лет эксплуатации мосты находятся в хорошем техническом состоянии и требуют небольшого ремонта. Мосты были построены во время, когда не существовало всеобщих правил проектирования и строительства, многие параметры принимали интуитивно: состав бетена и железобетона, выбор формы и установка внутри форма-опалубка. После 100 лет эксплуатации оба моста имеют повреждения, которые можно было избежать при проведении регулярных ремонтных работ. За 100 лет эксплуатации бетонные конструкции подверглись карбонизация. Глубина карбонизации достигла 40 мм. На поверхностях балок, где имеется тонкий слой бетона, началась корозия арматуры. Результаты развития карбонизации, полученые в данном исследовании, показывают, что обратное эффективное сопротивление корбанизации $\mu=31.45\cdot10^{11}$, $\sigma=5.32\cdot10^{11}$ ($m^5/(s\cdot kgCO_2)$). Для бетона, который нарямую подвергся воздействию воды $\mu=3.24$, $\sigma=0.74$. Расчёт развития карбонизации проведен, используя модель карбонизации *DuraCrete* и имитацию *MonteCarlo*.