# DURABILITY OF THE JAPANESE CONCRETE STRUCTURES ON SAKHALIN ISLAND

EVGENY E. SHALYI, SERGEI N. LEONOVICH,
LEV V. KIM, ALEXEY G. DZHOGOLYUK

*Far Eastern Federal University*
*Belorussian National Technical University*
*Sakhalin Energy Investment Co. Ltd.*

**Abstract**. *Concrete under exploitation conditions, are particularly susceptible to environmental aggressive action, which consists of the concrete surface layer neutralization and the compounds formation that affect its properties. The most common operating environment for main part of marine structures design is aggressive chloride environment and carbonation. The inspections of reinforced concrete structures of Vanino-Kholmsk ferry complex including Kholmsk and Korsakov ports have been made. The results were compared with the probabilistic calculations and show good compliance.*

## 1 INTRODUCTION

Sakhalin Island has been a subject of territorial dispute between Russia and Japan for a long time. The southern part of the island (called “karafuto”) belonged to Japan from 1905 after war (Portsmouth peace). The coal, forest and fish were explorated the continuous period and need reliable transportation and infrastructure. The berths, railways and roads were build. This territory became the Russian from 1945. The marine structures are under operation up to date. But severe expernal conditions have caused the deterioration of concrete berths in Sakhalin ports [4]. Warm Tsushima current influence on monsoon climate and cause dozen cyclones per year. The annual air temperature is +3.9°C. The development of Sakhalin offshore, Arctic zone and Northern Sea Route require reconstruction of old facilities. The paper presents the inspection results for reinforced concrete structures of Vanino-Kholmsk ferry complex including Kholmsk and Korsakov ports. The main structures were erected in the period 1907-1935.

According to field inspections, project documentation analysis and tests [5, 6] the technical state was defined as bad with deterioration near 40-75%. For the Sakhalin condition the main source of chloride contamination designs is sea water. The most intensive corrosion processes take place in the area of sea level. Most marine concrete structures have been operated without reconstruction over 30 years. Figure 2 shows their critical state.

The corrosion of reinforcement was the result of chloride penetration [7-9]. The durability and service life must be controlled by limiting the maximum value of water-cement ratio, concrete grade, reinforcement and thickness of the protective layer.

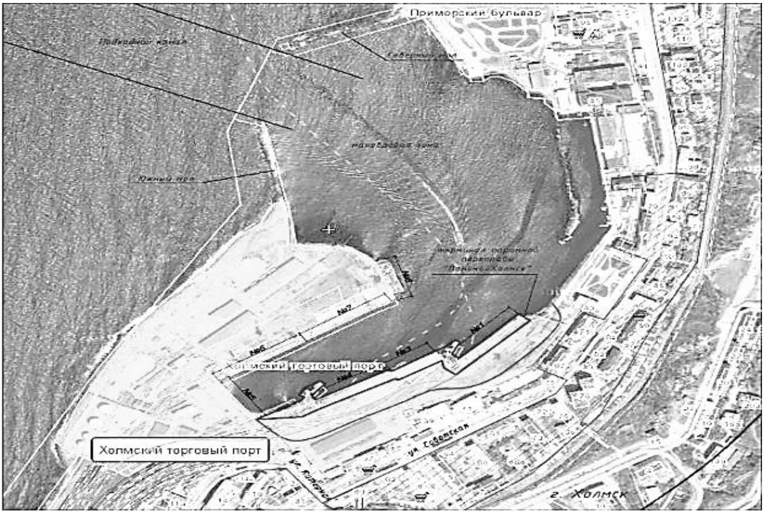

Fig. 1. Situation plan of the Kholmsk port

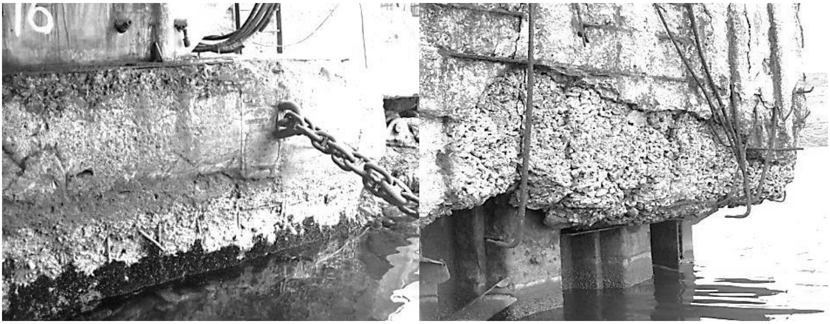

Fig. 2. Quay wall deterioration in a) Kholmsk; b) Korsakov port

## 2 INSPECTION OF VANINO-KHOLMSK FERRY CONCRETE STRUCTURES

Kholmsk is located on the southwest coast of the island and provide for work of "Vanino-Kholmsk" ferry service across the Tatar Strait. Kholmsk commercial marine port was built in 1909-1910 with water depths near berth up to 3 m. The first expansion of the port was carried out in 1921-1927. The first stage of Vanino-Kholmsk ferry complex construction was finished in 1973 and second - in 1987. The last inspection was made in 2010.

The strength of concrete, dimensions, moisture and chloride contents in the protective layer were determined. The strength have tested with sclerometer and an ultrasonic device "Pulsar 2.2". The reinforcement diameters were measured with device “IPA-MG4.01”. Penetration of carbon dioxide was defined with phenolphthalein test.

The quay wall No. 4 have supports from prestressed columns with diameter 1600 mm, wall thickness 150 mm and a length 8 m, row longitudinal distance 6 m. The superstructure includes reinforced concrete T-beams with 3 m step. Figure 3 shows the state of the superstructure. The comparison with inspection of 2010 shows the bas state. Table 1 presents the NDT results of concrete.

Fig. 3 The front wall of Kholmsk port berth facilities

Table 1 – The NDT test results of concrete B30 in Kholmsk.

| Name | | Front wall | RC superstructure | Beam | Bridge columns | RC coating |
|---|---|---|---|---|---|---|
| Sclerometer | $R_m$, MPa | 40.0 | 33.7 | 39.5 | 36.2 | 32.6 |
| “Pulsar 2.2” | | 40.4 | 41.9 | 28.1 | 41.7 | 30.8 |
| Decrease of the protective layer | % | 94 | 90 | 78 | 90 | 84 |
| Strength | $R_m$, MPa | 40.2 | 37.8 | 33.8 | 39.0 | 31.7 |
| Measured concrete class | | B30 | B30 | B25 | B30 | B25 |

## 3 PROBABILISTIC CALCULATION OF CARBONATION

The penetration of $CO_2$ was found on a basis of carbonation model DuraCrete [2, 3] which was verified by Gehlen [1]. It’s based on Fick's 1st law (eq. 1) for concrete without cracking. The thickness of the protective layer was compared with the carbonation depth $x_c$ for a certain time $t_p$

$$x_c = \sqrt{2 \cdot k_{RH} \cdot k_c \cdot \left(k_t \cdot R_{ACC,0}^{-1} + \varepsilon_t\right) \cdot C_s} \cdot \sqrt{t_{SL}} \cdot \left(\frac{t_0}{t_{SL}}\right)^{\frac{(p_{SR} \cdot T_{0W})^{b_w}}{2}} . \qquad (1)$$

Table 2 presents probability calculation results. The small difference in the values connected with the combined action on carbonation hydraulic structures, aggression chloride, sulfate corrosion and alternate freezing, thawing.

## 4 CONCLUSION

The results of a comprehensive inspection of the port facilities were used for reconstruction projects in Kholmsk and Korsakov ports. The probabilistic calculations shows good results in comparison with tests. The measures to restore the durability of the concrete elements were recommended.

Table 2 – The speed and depth of carbonation.

| Operation period, years | Penetration depth $x_c$, mm | Penetration speed, $\upsilon_к$, mm/year |
|---|---|---|
| | Korsakov port | |
| 10 | 10.54 | 1.054 |
| 25 | 16.67 | 0.667 |
| 30 | 18.26 | 0.608 |
| 50 | 23.57 | 0.472 |
| 100 | 33.33 | 0.333 |

End of table 1

| | | |
|---|---|---|
| Kholmsk port | | |
| 10 | 11.880 | 1.188 |
| 25 | 18.780 | 0.751 |
| 30 | 20.580 | 0.686 |
| 50 | 26.560 | 0.531 |
| 100 | 37.570 | 0.376 |

## REFERENCES

[1] Andrade C. and Martinez I., “On site techniques for corrosion rate monitoring in real structures”, *Proceedings of the International Conference on Construction and Architecture,* Minsk, Belorussia, 17-26, 2003.

[2] Badaoui A., Badaoui M. and Kharchi F., “Probabilistic Analysis of Reinforced Concrete Carbonation Depth”, *Materials Sciences and Applications*, **4**, 3A, 205-215, 2013.

[3] *Dura Crete: Brite EuRam III Project*, Rept R4-5, BE95-1347, London, 1998.

[4] Bekker A.T., Alexandrov A.V. and Kim L.V., "Quality control of concrete of gravity base structures in project "Sakhalin 2", *Hydroengineering construction*, 10, 25-37, 2008.

[5] Bob C., *Probabilistic assessment of reinforcement corrosion in existing structures*, Concrete in the service Mankind, Concrete repair rehabilitation and protection, E & FN SPON, London, 1996.

[6] Gehlen C., *Probabilistic Lebensdauerberechnung von Stahlbetonbauwerken*, Zuver Lassigkeitsbe trachtungen zur wirksamen Vermeidung von Bewehrungskorrosion, Thesis, RWTH-Aachen, D82, Aachen, 2000.

[7] Kolomiets V.I. and Kim L.V., "Frost resistance and durability of concrete of offshore structures", *Building materials. Technologies of XXI century,* **7**, 37-41, 2007.

[8] Leonovich S. and Cherniakevich O., “Probability model for carbonation of reinforced concrete structures", *Science& Technique*, **5**, 58-64, 2012.

[9] Moskvin V.N., *Corrosion of concrete*, Gosstroyizdat Publ., Moscow, 1952.