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CALCULATION OF ICE ABRASION FOR THE LIGHTHOUSES INSTALLED IN THE GULF OF BOTHNIA

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ABSTRACT

Presently the most perspective hydrocarbons fields in terms of pre-explored reserves and exploitability can be listed as: deposits in the Barents Sea; deposits in the Kara Sea and Sakhalin offshore deposits in the Sea of Okhotsk (Piltun-Astohskoye, Lunskoye, Arkutun-Dagi, Chaivo etc.). Applicable construction methods and technical solutions for oil platforms are determined by ice regime in those areas. Operational use of GBS in ice-covered shelf seas within areas of intensive ice drifting appears to face a number of problems. One of those problems is ice abrasion that results in reinforcement exposure, accelerated seawater corrosion, and decrease of concrete thickness and durability. Due to dynamic ice effect, concrete surface contacting with ice is permanently abraded with consequent endurance cracks resulting in frequently accelerated concrete corrosion. This reduces concrete density and increases porosity which respectively causes lower freeze-thaw cycles resistance. Maximum abrasion depth shall be defined in order to determine protective layer thickness of GBS. Hence, the intensity of structure's material abrasion due to drifting ice has become the topical issue of the day.

INTRODUCTION

Presently, the most perspective hydrocarbons fields in terms of pre-explored reserves and exploitability can be listed as: deposits in the Barents Sea (Shtockmanskoye, Ludlovskoye, Prirazlomnoye and Varandeyskoye); deposits in the Kara Sea (Rusanovskoye and Leningradskoye) and Sakhalin offshore deposits in the Sea of Okhotsk (Piltun-Astohskoye, Lunskoye, Arkutun-Dagi, Chaivo etc.). Applicable construction methods and technical solutions for oil & gas producing structures and transport facilities are determined by ice regime in those areas.

Operational use of Concrete Gravity Base Substructures in ice-covered shelf seas within areas of intensive ice drifting appears to face a number of problems. One of those problems is abrasion-caused wear-out of concrete facilities that results in reinforcement exposure, accelerated seawater corrosion, and decrease of concrete thickness and structure's durability.

Due to dynamic ice effect, concrete surface contacting with the ice is permanently abraded with consequent endurance cracks resulting in frequently accelerated concrete corrosion. This reduces concrete density and increases voidage that respectively causes lower freeze-thaw cycles resistance. Maximum abrasion depth shall be defined in order to secure safety of Concrete Gravity Base Substructures (CGBS) throughout the operational period. Hence, the intensity of structure's material abrasion due to drifting ice formations has become the topical issue of the day.

No substantiated theory for calculation of ice abrasion intensity is currently available; therefore, requirements for concrete in terms of usage in ice-covered sea environments are missing. Thus, at present the platforms have been fitted with special-purpose ice protection steel belts in the ice load area. Their main function is to protect the concrete against ice abrasion effect.

It should be noted that steel ice protection belts cannot always endure ice effects given the intensive dynamics of ice fields, which induces maximum inconstancy of its morphometric parameters (thickness, compaction, ice field dimensions, etc.) and strength properties. Therefore, ice protection belt installed at "Molikpaq" platform offshore Sakhalin was affected by drifting ice field (see Figure 1). Approval of engineering solutions relevant to design of ice protection elements is a formidable challenge as no substantiated theory for calculation of ice abrasion depth is available so far. Thus, design of ice protection elements for offshore ice-resistant platforms is significantly important.

Results of long-term surveys of ice cover effects on offshore structures suggest the problem of ice/concrete abrasion to be best divided into two main parts: the problem of effects caused by ice and the problem of material resistance to abrasive effect caused by ice cover (Figure 2).

Virtually, on the one hand, abrasion intensity depends on the contact pressure and on the abrasion path length, while, on the other hand, it is as well determined by abrasion resistance properties of structure material.

Figure 1. Collapse of ice protection belt at "Molikpaq" platform (Vershinin at al. 2006)

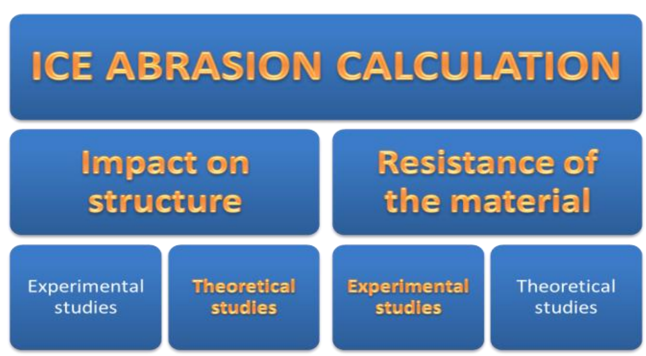


Figure 2. Conceptual model of ice abrasion

Hence, ice abrasion study is complex, incorporating both experimental and theoretical parts.

THEORETICAL STUDY

In order to accomplish the theoretical part of study, within the period of 1985 to 2009 A.T. Bekker, T.E. et al. have developed a probabilistic simulation model of various ice loads formation and their effects on offshore engineering structures. The model served as basis for ICESTRIN ("ICE STRucture INteraction") calculation software (A.T. Bekker, T.E. Uvarova, S.D. Kim, 1998, 2001, 2003, 2004). The model is based on numerical simulation of the function of ice regime parameters distribution as well as on simulation of all probable situations featuring random combination of initial parameters values. Ice loads, contact pressure, abrasion path length and other parameters are calculated for each design situation in real-time mode. The procedure of evaluation enables to calculate ice floe abrasion effect upon structure considering the ice load from all drifting directions and including sea level fluctuations that allows for obtaining the overall pattern of abrasion depth over the whole surface in plane and through the whole height of contact area. (Bekker A.T., Uvarova T.E. at al. 2008, 2007, 2003, 2001)

General procedure for ice abrasion depth calculation

Initial data for the calculation shall be as follows: Parameters of structure (length d, support shape m) and properties of ice cover.

1. Ice regime shall be modeled by exhaustive search of initial parameters: h – ice cover thickness, D – diameter of ice bodies, N – ice compaction, T – ice temperature, V – ice drift velocity, Z – sea level fluctuation, to cover all design situations, i.e. all possible combinations of parameters.

As k-th combination of parameters, particular design ice regime shall be modeled with the following parameters: h_k, D_k, N_k, T_k, V_k,, Z_k. Besides, occurrence probabilities shall be determined respectively: $P(V_k)$, $P(D_k)$, $P(h_k)$, $P(T_k)$, $P(N_k)$, $P(Z_k)$.

2. The lifetime of k-th combination of parameters for t_k ice regime is determined considering random combination of initial parameters combination:

3. At each i-th phase of the simulation calculation, the process of mechanical interaction between ice fields and offshore engineering structures is modeled assuming structure's thickness h_k, ice fields dimensions D_k, ice concentration N_k, ice temperature T_k, drift speed V_k and sea level fluctuations Z_k. The analyzed process duration is t_k. Modeling the mechanical interaction process allows for obtaining ice load value F_i and the length of ice sheet offset caused by interaction with structure X_i – interaction path length.

4. Structure's material abrasion process is modeled basing on the obtained data. As a result, the contact pressure of ice sheet within the contact zone $\sigma_{v,i}$ are calculated, as well as abrasion path length $l_{v,i}$ and material abrasion depth S_i in any point of the contact zone subject to sea level fluctuations.

5. The process continues unless exhaustive search of situations, i.e. ice regime parameters combinations. Characteristics of abrasion process throughout the entire ice formation period shall result as follows:

- abrasion process histogram, i.e. dependence $\bar{S} = f(\sum \sigma \cdot l)$;
- abrasion intensity histogram $S = f(\sum \sigma)$;
- overall abrasion depth as per levels $\bar{S} = f(Z)$;

Thus, concrete abrasion depth within altering water level can be calculated using the obtained empirical dependences and the suggested algorithm. Figure 3 shows ice abrasion calculation scheme.

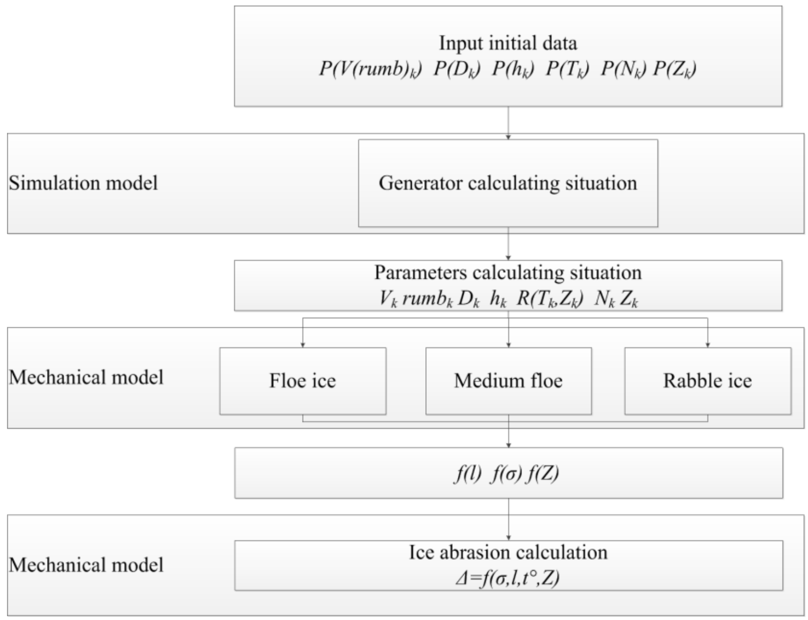


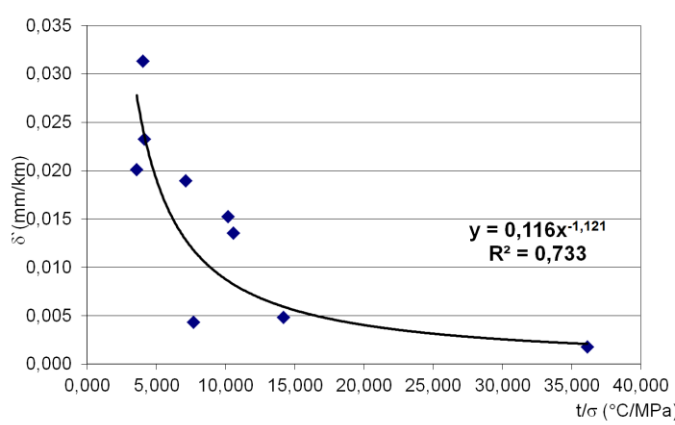
Figure 3. The scheme of calculation of ice abrasion

Theoretical research are supported by field monitoring of concrete abrasion at Raahe, Oulu2, Oulu3 lighthouses in the Gulf of Bothnia as well as experimental data obtained in the course of ice abrasion test of concrete samples taken from the above lighthouses

EXPERIMENTAL STUDY

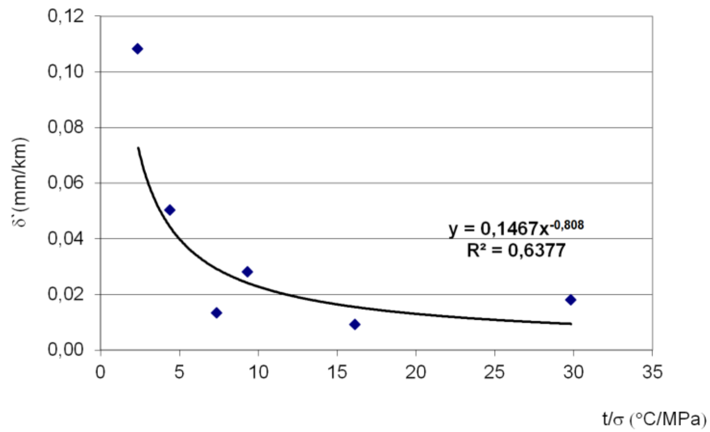
Laboratory tests were performed at custom designed unit at laboratory complex of NPO Hydrotex Ltd. under the guidance of Bekker A.T.

These laboratory tests resulted in the empirical model of ice abrasion intensity and abrasion intensity / temperature dependence. See Figure.4-6 for the tests results.



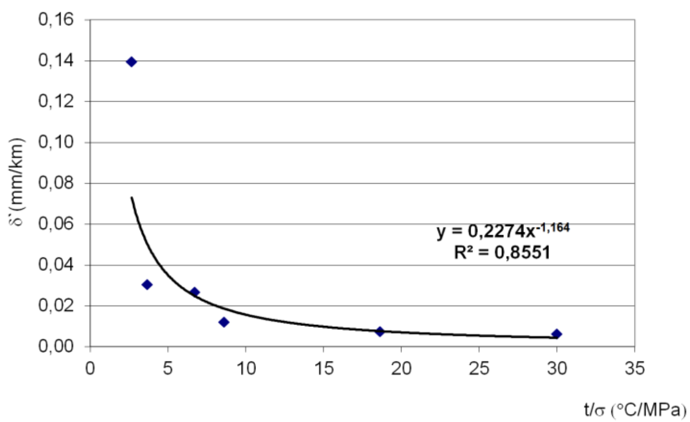
$$\delta'_{aver} = 0{,}116\left(\frac{|t|}{\sigma}\right)^{-1{,}121}$$

Figure 4.Abrasion rate vs pressure and temperature for Raahe lighthouse



$$\delta'_{aver} = 0{,}1467\left(\frac{|t|}{\sigma}\right)^{-0{,}808}$$

Figure 5. Abrasion rate vs pressure and temperature for Oulu2 lighthouse



$$\delta'_{aver} = 0{,}2274\left(\frac{|t|}{\sigma}\right)^{-1{,}164}$$

Figure 6. Abrasion rate vs pressure and temperature for Oulu3 lighthouse

To verify the theoretical model of ice abrasion depth calculation, the ice abrasion depth at lighthouses was estimated with ICESTRIN program.

DESCRIPTION OF STRUCTURE IN THE GULF OF BOTHNIA

For the purposes of laboratory study, three cores were drilled out from Oulu2, Oulu3 and Raahe lighthouses located in the Gulf of Bothnia. The lighthouses are designed as reinforced concrete gravity based structures with foundation diameters about 7.4 m. Lighthouse structural diagram is displayed on Figure 7.

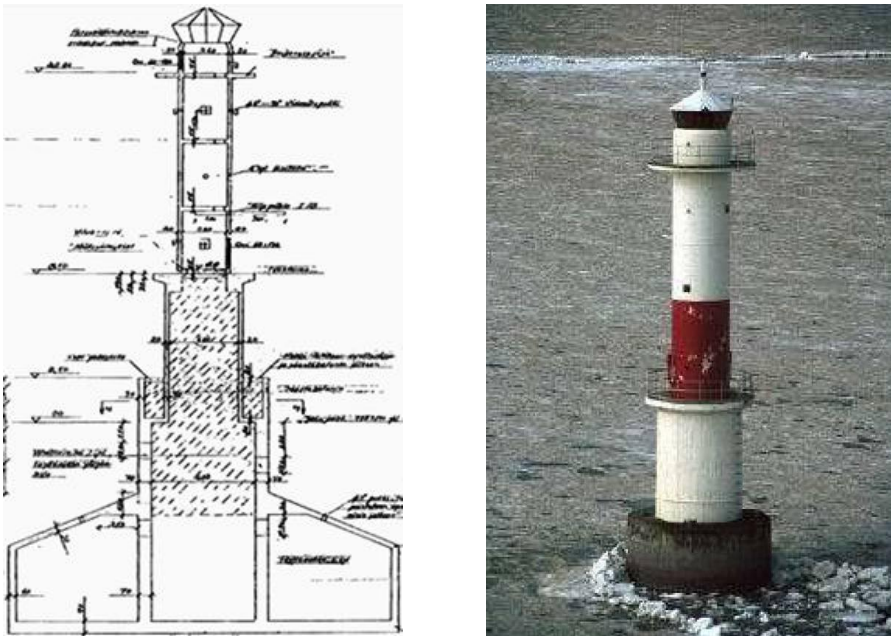


Figure 7. Lighthouse design

DESCRIPTION OF ICE CONDITIONS IN THE GULF OF BOTHNIA

In the southern part of the Gulf of Bothnia the first ice is observed in mid January, in the northern part - in November or early December. Maximum development of ice cover is observed at the end of February and March. In this period the most part of the gulf is covered by stationary ice. The central part of the sea is usually free of ice. Southern part of the gulf is completely free of ice by the first decade of May, northern part – by third decade of May. In case of severe winter ice may stay till July.

The northern Gulf of Bothnia is covered with ice for 160-210 days per year, its middle part – for 185 days. The maximum duration of this period (220-245 days) in the Gulf of Bothnia is observed in the area of lighthouses considered. Average ice thickness is insignificant (0.1–0.3 m), but in severe and extremely severe winters it may exceed 1m. Design parameters of hydrometeorological and ice regimes in Raahe lighthouse area have been provided by “Aker Solutions” and specially processed for further use in ICESTRIN program. Initial data includes histograms of monthly (January-May) distributions of basic design parameters, such as:

- Drifting ice cover compaction;
- Flat ice thickness;
- Ice fields drift velocity;
- Sea level fluctuations.

Histograms of ice drifting speed, ice compaction and ice thickness were built based on statistical analysis of 5-years long field studies (2005-2009) provided by “Aker Solutions”. Statistical distributions as per ice fields dimensions and data on Gulf of Bothnia ice strength are missing, so the no exact initial data on these parameters is available. Sea level distribution histograms are built based on statistical analysis of 20-years field studies (1989-2009) as per hydrometeostations data. Design parameters of hydrometeorological and ice regimes in lighthouses area were obtained based on statistical analysis of 5-year long field studies (throughout 2005 – 2009); sea level distribution histograms are built based on statistical analysis of 20-years field studies (1989-2009) as per hydrometeostations data.

CALCULATION RESULTS

Ice abrasion depth for Raahe lighthouse is determined with special-purpose ICESTRIN program. Empirical ice abrasion model is obtained throughout laboratory ice abrasion tests of concrete specimens drilled out of the lighthouse at elevation of 1.5m above the average sea level.

Figure. 8-9 demonstrates the results of field observations of ice abrasion at Raahe lighthouse and calculation results.

According to calculation results given at Figure 9, ice abrasion depth at elevation -0.168 m is 83cm, while the observed ice abrasion depth at the same elevation is 80 cm.

Therefore, both the estimated and the observed abrasion depths are comparable values; moreover, the estimated form of ice abrasion vertical distribution almost coincides with the observed one. Based on this comparison, a conclusion can be made that accuracy of ice abrasion depth calculation by the developed mathematical model is sufficiently high.

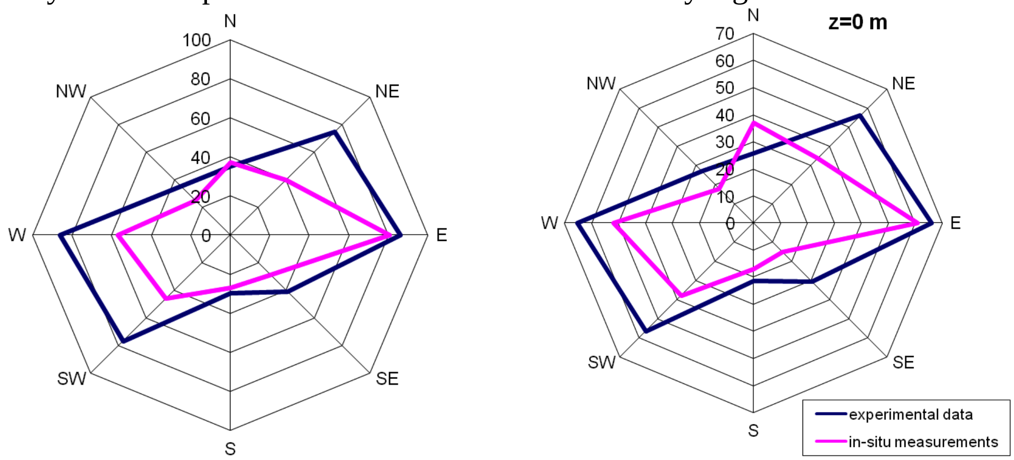


Figure 8. Overlap Raahe abrasion depth and at elevation 0 m

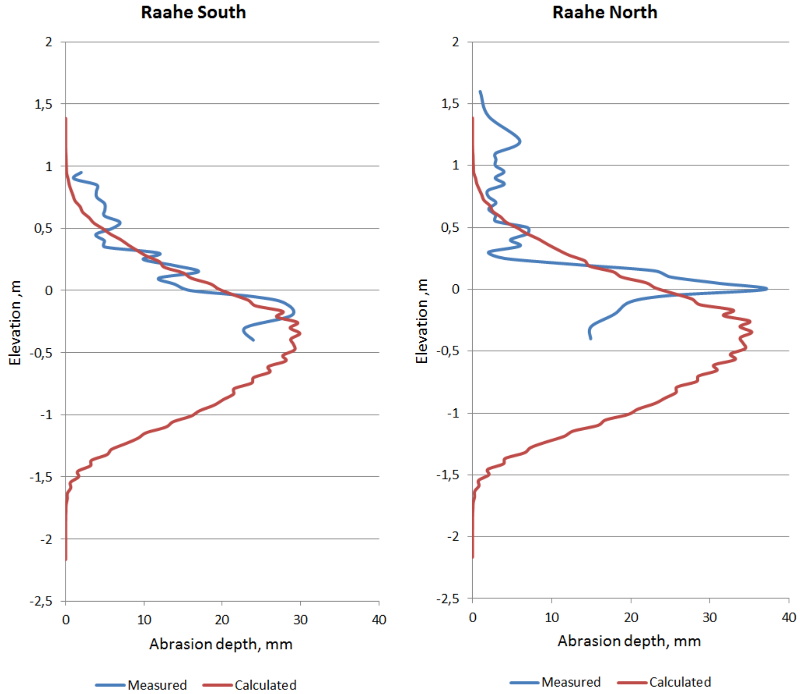


Figure 9. Diagrams of abrasion depth for Raahe lighthouse

CONCLUSIONS

The outcomes from the field observations of ice abrasion depth at the lighthouses upon 44 years of service were compared both by values and by spatial distribution, and such comparison revealed satisfactory compliance with the estimated values. Thus it is proved that the mathematical model is good for calculation of the general effects and for the processes causing concrete ice abrasion, while the empirical models obtained throughout the laboratory ice abrasion tests are satisfactory for description of the lighthouse concrete resistance to ice abrasion, respectively.

The mathematical model is multi-purpose one and it may be applied to various structures and materials. The calculation requires data on the ice regime, on the sea level fluctuations and the empirical model of material resistance to ice abrasion.

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