9. AN IMPROVED MODEL FOR CHARACTERIZATION OF ICE FORCES ON OFFSHORE STRUCTURES

9.1 The generalized dynamic ice force function

Based on the results of the analysis described in Section 6 the previously suggested generalized ice force formula can now be adjusted, Thus, the improved accuracy of the process for transformation of response data is taken advantage of, resulting in a reduced uncertainty as regards the amplitudes of the dynamic components as well as the shape of the ice force time function.

Basically, the global ice force is still expressed by means of one "static" and a number of "dynamic" components:

$$F = F_o + \Sigma F_{n\,max} \cdot \sin(n\omega_1 t + \theta_n)$$

As in the previous studies the amplitudes of the sine components can be normalized to the "static" or mean load which can then in turn be related to ice strength characteristics etc. The adjusted amplitude ratios and phase angles are:

n	$F_{n\,max}/F_o$	θ_n (rad)
1	0.23	0.55
2	0.16	0,65
3	0.09	2.38
4	(0.05)	4.26
5	(0.05)	2.84

For most purposes it is likely to be sufficient to use only the three sine components n = 1-3. The resulting generalized ice force time-history is displayed in Figure 9:1. However, in the case that structures and equipment are sensitive to resonance at higher frequencies, load components with frequencies higher than 3 times the fundamental frequency should also be included as indicated in Chapter 6, in which case the increasing uncertainty as regards the amplitude values should be observed and accounted for by correspondingly increased safety factors.

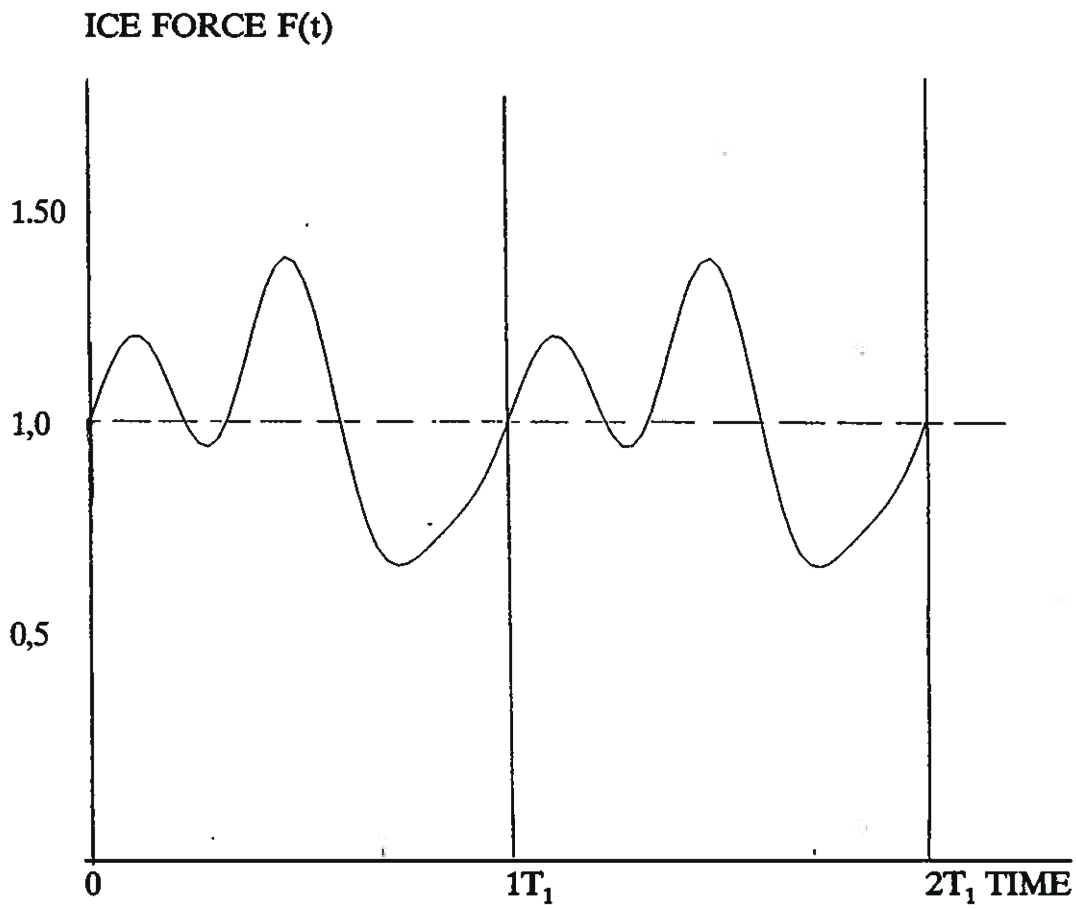

Figure 9:1

Generalized ice force time-history normalized to unit static ice force F_o = 1. T_1 is the predominant period of the natural vibrations of the structure with respect to displacement at the ice level. Fourier components n = 1, 2 and 3 are included

9.2 Calculated response of the Norströmsgrund lighthouse to the generalized dynamic ice load

The acceleration response of the Norströmsgrund lighthouse model at the accelerometer level (node 14) to the derived dynamic ice force (n = 1-3) was calculated in order to demonstrate the suggested response calculation procedure and also to check the appropriateness of the procedure for deriving the ice load by going backwards from load to response.

Thus, the dynamic load time-history shown in Figure 6:9 (n = 1-3) was applied as a load input to the FE model, the acceleration response of which was computed in accordance with the SOLVIA code. The computed acceleration time-history of node 14 is displayed in Figure 9:2. This time-history may be compared with the recorded accelerogram displayed in Figure 6:4. The values of the calculated acceleration amplitudes stabilize at about 0.22 g which is well in agreement with the average of the measured acceleration amplitudes. As expected, there are some peaks, even up to 0.27 g, in the record. Allowance for such occasional effects can be made within the frame of the safety-factoring of the design load.

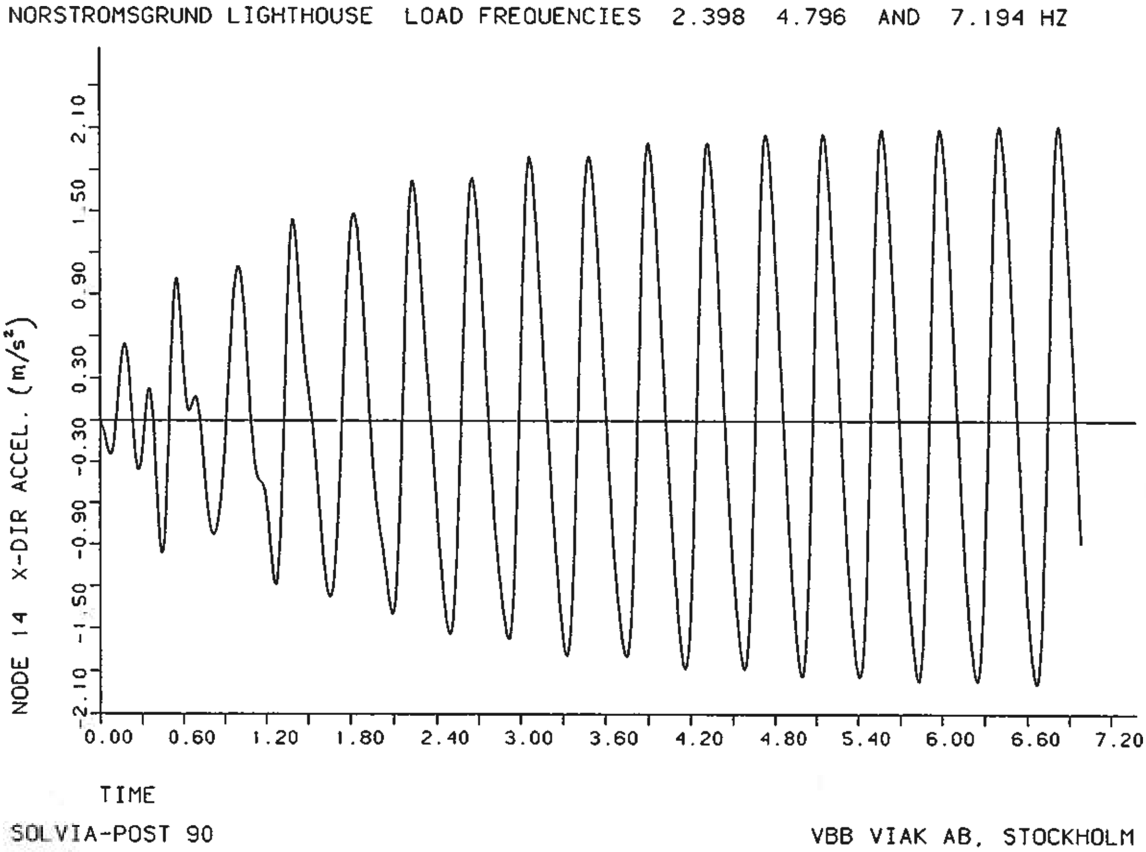

Figure 9:2

Computed acceleration response of the lighthouse model when subjected to the load time-history derived based on the measured response of the lighthouse.

9.3 Quantification of the ice force function based on ice parameters

The anchor parameter for the generalized dynamic ice force function is the "static" ice force component F_0 which is obtained by averageing the fluctuating ice force during a time period of sufficient length not to give rise to any dynamic response of the affected structure.

This average force may also be written as the product between the "effective ice pressure" and the "gross contact area":

$$F_o = p_{eff} \cdot A_g$$

Since the net contact area could hardly be quantified in generalized terms, it is the "effective pressure over the gross area" that has to be related to the specific ice conditions, for which the ice force is to be predicted. Then, by analogy with the definition of the static ice force F_o, the effective ice pressure should be defined as the mean ice pressure over the gross contact area, averaged during a time period of sufficient length to obtain a smooth time-history, not affected by the fluctuations caused by local pressure increase followed by brittle failure. In mathematical terms this component of the pressure may also be expressed by one or several of those low-frequency Fourier-components of the load which have lower frequencies than the components reflecting the fluctuations associated with local ice failures.

This "time-averaged effective ice pressure" can be related to the various ice strength parameters, the size of the contact area, the ice thickness, etc. as described in Chapter 2.

From the observations of ice forces acting on the ice force sensing panels, as summarized in Chapter 8, we can draw the conclusion, that the effective ice pressure, defined as above, will be less sensitive to the geometry of the contact area than peak pressures. By superposition of simultaneous time-histories from two or three panels we can see, that the peak values of the effective pressure vary considerably with the size of the total contact area.

Considering the mechanism of more or less random local failures over the cross contact area, this is what can be expected, but little attention has been paid to this condition when observations and derivations of ice forces have been discussed in literature.

In summary, the work during Phase 2 of the study has resulted in a refined model for characterization of ice force time-histories as well as improved understanding of the coupling between the load characteristics and the failure mechanism of the ice. This has been achieved mainly by an extended analysis of data from Phase 1, since the extreme series of mild winters in Northern Europe has precluded sampling of additional data.

REFERENCES

1. A. Engelbrektson:
   An ice-structure interaction model based on observations in the Gulf of Bothnia.
   Report to POAC 89.

2. E. Wessels, P. Jochmann, L. Hoffmann:
   First results of ice force measurements with TIP-panels at Norströmsgrund lighthouse. Report to POAC 89

3. J. Schwartz, E. Wessels: Ice force measurements with TIP-panels at Norströmsgrund Lighthouse in Winter 1988/89.
   HSVA-Report No. 201/90. March 1990.