4. METHODOLOGY

4.1 Evaluation of global ice forces

In principle, the evaluation of global and local ice forces utilizes similar mechanisms for acquisition of data and transformation of measured quantities to ice forces, viz. basically the spring mechanism. In the case of local ice forces, it is the elastic strain in the panel supports that is measured and transformed into reaction forces on the basis of calibrated constitutive relationships between the measured strain and the corresponding stresses. In the case of global ice force evaluation, the entire lighthouse structure serves as an elastic obstacle, the deflection of which is measured and transformed into global ice forces also on the basis of constitutive relationships and, in respect of dynamic response, also on the basis of relationships between measured response motion characteristics and the masses, eigenfrequencies and damping properties of the structure. All these relationships have been quantified on the basis of calibration tests and, in respect of eigenfrequencies and eigenmodes, observations of free vibrations initially generated by ice loads.

Thus, the evaluation of global ice forces comprises the following activities, basically:

* Measurement of the response of the lighthouse structure by means of accelerometers and inclinometers, placed at different levels.

* Mathematical processing of the obtained acceleration records in order to eliminate base line errors and to determine the low-frequency ("static") tilt angle of the structure.

* Transformation of acceleration and inclination response data to global ice forces on the basis of the above constitutive and dynamic transfer functions.

The instrumentation for response measurements is, in principle, the same as described in Chapter 3 for the Phase 1 measurements. More comprehensive descriptions are given in **Appendix 1.** However, since the measurements are now concentrated to Norströmsgrund lighthouse, the instrumentation of this structure has been doubled. The additional instruments are used for the purpose of redundancy in two respects. One is for malfunction of the instruments, the other is for checking of measured quantities by comparing acceleration records at different points. The latter also enables an improved accuracy in determining the modal shapes of the structure.

The locations of the instruments are shown in Figure 4:1.

Also, the procedures for processing the response data are to a large extent the same as those previously developed and applied during

Phase 1. Thus, the procedures briefly described in Chapter 3 and more comprehensively in **Appendix 2** have been applied with some exceptions to Phase 2 as well.

The exceptions are relating to an improved accuracy in the transformation of resonance vibrations to "dynamic" ice forces by accounting for secondary modes of vibration as well as the fundamental cantilever mode. The latter is doubtless of a predominant importance, since it governs the "self-induced" vibrations and thus the very mechanism of ice-structure interaction, but if the other modes are disregarded in the derivation of the ice force time-history (as in Phase 1), an unnecessary approximation is made.

The confirmation of the phenomenon of self-induced vibration and the fact that the ice force at resonance is composed of component sine loads with frequencies which are multiples of the fundamental frequency, facilities a more accurate derivation of the various sine components of the load and thus of a more accurate shape of the composed load time-history. Furthermore, a selective choice of measurement points makes it possible to improve the accuracy of the FE-model, in respect of the shapes of higher modes of vibration particularly.

For each sine component of the load the following procedure is applied:

* The load component is $F_n = F_{n\,max} \cdot \sin(\omega_n t + \Theta_n)$
* The response at the reference point of the lighthouse is $\ddot{x}_n = \ddot{x}_{n\,max} \cdot \sin(\omega_n t + \varphi_n)$
* $F_{n\,max}/\ddot{x}_{n\,max}$ and $\Theta_n - \varphi_n$

  are determined by means of the FE-model
* The quantities $\ddot{x}_{n\,max}$ and φ_n are determined from each particular sequence of recorded (stationary) accelerations that is to be analysed after disintegration and discretization into individual sine components, corresponding to the frequencies ω_n.

The procedure is demonstrated in **Appendix 4.**

Of course, when comparing this procedure with that of Phase 1, it must be kept in mind that the latter was developed and used not only for sequences of steady-state resonance vibrations but for general derivation of ice force time-histories based on various types of responses. However, one of the conclusions of the previous investigations was, that the stationary resonance conditions are likely to be predominantly decisive to the design of offshore structures susceptible to ice-induced vibrations. Therefore, for practical purposes and for the purpose of developing a generic model for "dynamic" ice load prediction, the present procedure is judged to be preferable, and it is consequently generally adopted in the present phase of the study.

In the case that other than steady-state vibration sequences are considered, the method used in the previous studies may be applied. However, the accuracy would be improved if the response of the fundamental mode could be isolated. The quantities $\ddot{x}, \dot{x}$ and x of the isolated first mode should then be introduced into the general equation of motion, the solution of which yields the instantaneous values of the total ice force.

The isolation of individual modal responses from the acceleration records is, however, a complicated procedure, requiring a sharp identification of the various modal shapes, if a high precision called for. This in turn calls for a considerable number of instrument levels. For reasons given above such efforts are not within the frame of the present study. Since the steady-state vibrations are focused at, the more straightforward analysis method with a direct transformation of responses without modal separation is preferred. The particular advantage of this method is that the realism of the derived ice force function can be demonstrated simply by applying the derived ice force time-history as an input to the FE-model and comparing the computed output responses with the instrumental observations.

4.2 Evaluation of local ice forces

As declared in Chapter 2 an important objective of the present study is to sample local ice force data, enabling an evaluation of the ice force distribution not only in time but also in space. Such an evaluation was considered important already during Phase 1, when preparations for local measurements were made which were expected to provide additional bases for prediction of ice forces and for explanation of the mechanisms involved.

The lighthouse Norströmsgrund was provided with arrangements for being lined with ice force sensing panels around the entire circumference. However, due to the considerable costs for manufacturing and installations of the panels, their number had to be restricted at three panels, each with a width of 0,6 m. Thus a maximum of 16 per cent of an exposed half-circle can be expected to be covered by the panels, but the important thing is, that the panels are spaced so that the simultaneous ice force time-histories at the panels can be compared with each other and with the global ice force time-history.

The ice force sensing panel system is described in the next chapter and in **Appendix 5**.

4.3 Uncertainty assessments

The accuracy of the derived global ice load time functions depends, of course, on the accuracy of the simulation of various structural properties in the FE-model. A perfect result requires, that the model shapes and the model eigenfrequencies are perfectly simulated. Since perfection cannot be obtained with reasonable efforts (for example without a large number of measurement points and tests in order to map the exact model shapes) a certain degree of uncertainty must be tolerated. The uncertainty can, however, be limited to a level, where it is practically negligible. The following aspects are important in this respect:

* The model shall be applied merely to conditions of steady-state vibrations.

* Loads and responses shall be disintegrated into their sine components by Fourier processing.

* The eigenfrequencies of the first three modes of the model shall agree well with those of the lighthouse structure. (A frequency range up to about 20 Hz is then covered.)

* Since it is difficult to assess the modal shapes with a good precision based on a few measurement points, it is important to use response values, to which the second and third modes contribute as little as possible. In particular, the second mode should be avoided. Accelerometer are therefore placed closely to the zero deflection point of this mode. The reason for this is, that the frequency of the second mode is fairly close to the frequencies of the 2nd to 3rd sine components of the load. Closely to resonance the amplitudes and phase angles of the structural modes are very sensitive to these frequency relations, the evaluation of which may not be perfectly exact. The accuracy of the quantities used for transformation from response to load components is therefore improved, the more the influences of the 2nd and 3rd modes are avoided. The 3rd mode, however, has little influence even at resonance, since its zero point of deflection is located closely to the ice load.

* The structural damping is, of course, a potential uncertainty factor. Inaccurate modal damping ratios introduced in the model mainly affects load sine components close to resonance. Since resonance effects of the higher structural modes are minimized, as mentioned above, it is only the amplitude of the first mode that is significantly affected. Based on studies of sequences of free vibrations, the damping ratio of the first mode has been estimated at 0.040 ±0.005. The corresponding uncertainty range of the fundamental ice force amplitude is of the order of 10 per cent. Damping effects due to friction between the vibrating structure

and fragmented ice is not likely to affect the above damping value very much. Consequently, such forces, if any, are included in the evaluated global ice force time-history.

* The uncertainties of the quantifications of more high-frequent load components are a little larger due to the abovementioned "disturbances" from the second and third modes of vibration. However, since the fundamental sine component of the load as well as of the response is of a predominant importance as a design prerequisite, the order of ± 10 per cent may be taken as a characterization of the general uncertainty of the dynamic load formulation. The uncertainty of the magnitudes of the "static" load components is somewhat larger.

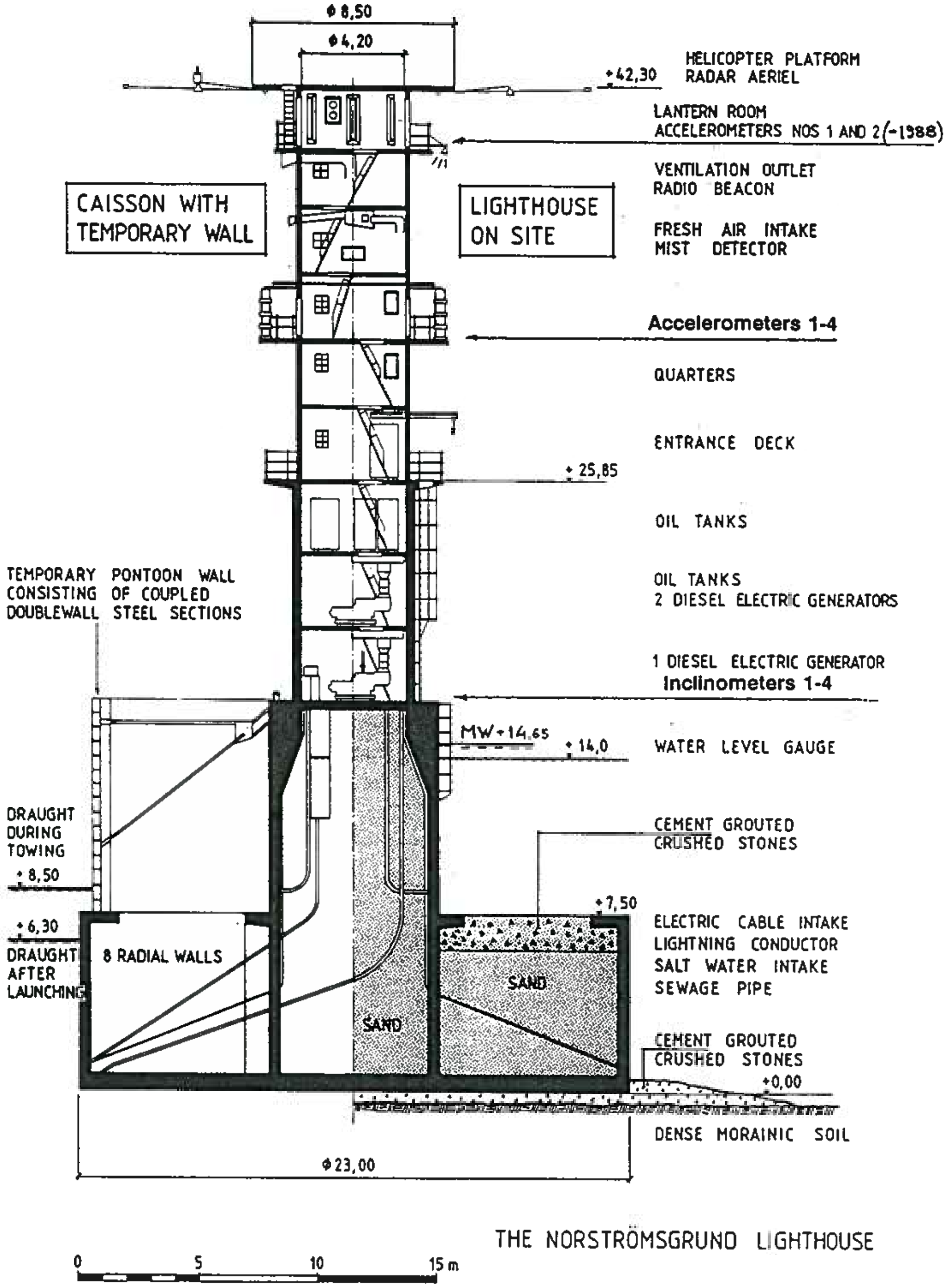

Figure 4:1

The NORSTRÖMSGRUND lighthouse