2.3 WP3000 Ship Design

2.3.1 Introduction

The aim of this work package was to demonstrate the possibility of improving the definition of loads in the design rules from the better knowledge of sea states provided by satellite observation. Three main domains where such improvement may be expected have been considered; each was addressed by an individual sub work package. The first, WP3100 —*Checking Design Criteria* - deals with long term behaviour of the ship structure on an actual trading route (Rotterdam to Trieste). The second, WP3200 — *Fail Safe Calculations* - addresses a fail safe requirement. As an example, a gas carrier in normal condition should not experience any cracks in the ship s structure. Nevertheless, if for any reason some cracks should occur, of a sufficient size to be clearly identifiable, it should be possible to demonstrate that the ship can continue and safely reach a harbour where it can be repaired. Satellite altimeter data for the Rotterdam to Boston route were used for this study. The final case, addressed by WP3300 —*Satellite information for High Speed Craft Trials* - investigates the possibility of using satellite data to speed up the procedure of post voyage or vessel trials analysis. This could be achieved by providing, in near real-time, measurements of the actual sea states corresponding to the stress responses recorded on board the vessel. This would allow a sea state by sea state calibration of loads rather than an averaged life calibration of loads.

2.3.2 WP3100 Checking Design Criteria for Long Term Loads

In this task we examined how it is possible to improve damage prediction from satellite data. In particular we were interested in the route from Rotterdam to Trieste, Figure 2.1. Satellite altimeter significant wave height and wave period data from TOPEX (1992-1999) were employed in this study.

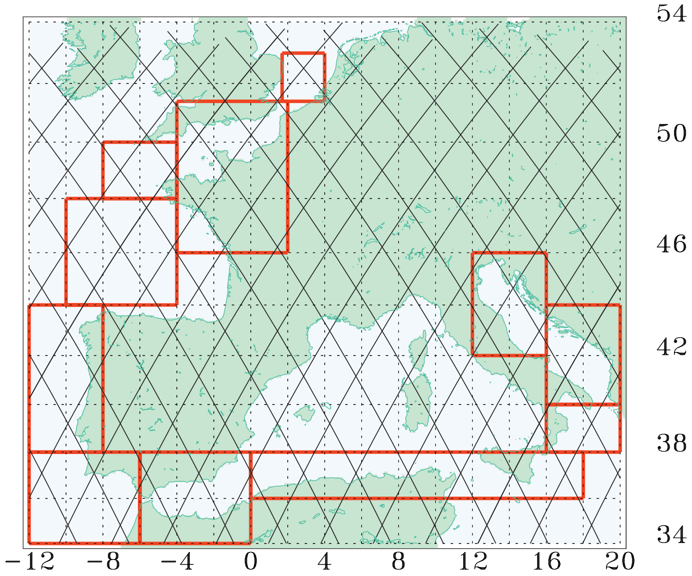

Figure 2.1 Areas (red boxes) selected for satellite data extraction along the Rotterdam to Trieste Route. The diagonal black lines indicate the location of TOPEX altimeter data. Each track is repeated once every ten days.

Damage prediction is currently carried out by classification societies using one of two approaches: rules calculations or direct approach calculations . The first technique (rules calculation) does not lend itself easily to modification in order to include new types of data. This is because the procedures are rigidly defined, and rely a great deal on learnt design experience. Also the loading cases in these procedures are too simplified to easily make use of data from satellite observation. However, and in contrast, the direct calculation procedure is better suited to modification. A standard procedure under this method would involve the following steps:

- A mission profile is determined for the ship, defining the expected life of the ship in a given area with a given heading, speed and loading.
- Area specific scatter diagrams are created. They provide the frequency of sea states expected to be encountered by the ship as defined by Hs (significant wave height) Tma (mean wave period), and heading.
- A shape of the wave spectrum is assumed. Generally for North Atlantic Ocean a Pierson Moskowitz, (Pierson and Moskowitz, 1964) is assumed.
- The damage corresponding to each short term interval is calculated, and then accumulated over the full life of the ship.

This procedure (see figure 2.2) is able to take into account information which can update and improve the determination of sea states, including (if available) data on wave energy distribution versus the frequency and the heading. Thus the direct calculations approach has been selected for use in COMKISS.

However, available satellite data do not directly match the input requirements for these procedures. Thus, in order to make progress, it was first necessary to identify and develop suitable statistical theory, and to establish databases of appropriate derived parameters. Sections 2.3.5 (*Development of a Theoretical Basis*) and 2.3.6 (*Statistical Analysis of Satellite Data*) provide brief descriptions of this work. Readers are referred to the original reports for more detail (Baxenavi et al., 2000a and 2000b).

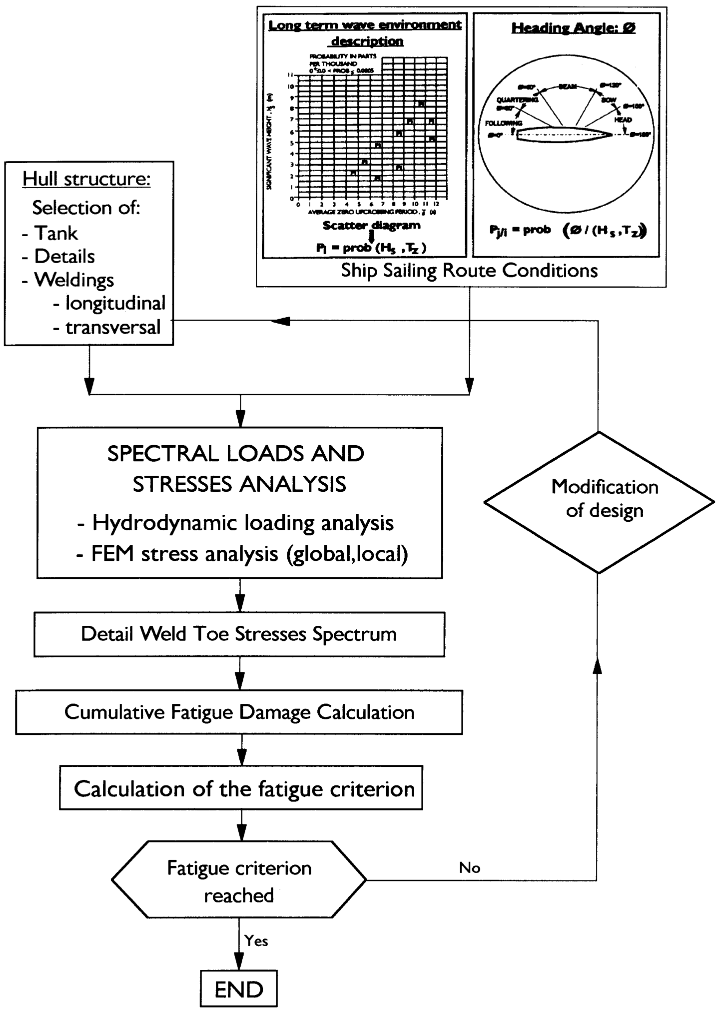

Figure 2.2 Direct Calculation Fatigue Analysis Procedure Flow Chart.

2.3.3 WP 3200 Fail Safe Calculations

Until now there has been no generally accepted methodology to check the safety of a ship with a leakage. The failure mechanism is well known and deals with the mechanics of fracture. i.e. crack propagation until brittle fracture condition is reached. The main problem is to define a realistic loading history corresponding to the period of time between the detection of the leakage and the arrival to a place where the ship may be unloaded and repaired. In this task we planned:

- to define a methodology to obtain a set of typical loading history taking the expected correlation between the successive sea states due to the persistence of storms.
- to ascertain if satellite observations may provide data that fit the above model, and so provide to the designer reliable data to carry out his/her verification check on an actual gas carrier. The designer would apply a fracture mechanics tools currently used in Bureau Veritas to establish the structure strength against crack propagation after a leakage.

Together these stages would also demonstrate the applicability of the methodology. This study required a statistical analysis and processing of satellite data which involved the construction of a time referenced data set. This is described in Section 2.3.6 (*Statistical analysis of satellite data*). TOPEX altimeter significant wave height and wave period data covering the North Atlantic route from Rotterdam to Boston (USA) were used in this study (Figure 2.3)

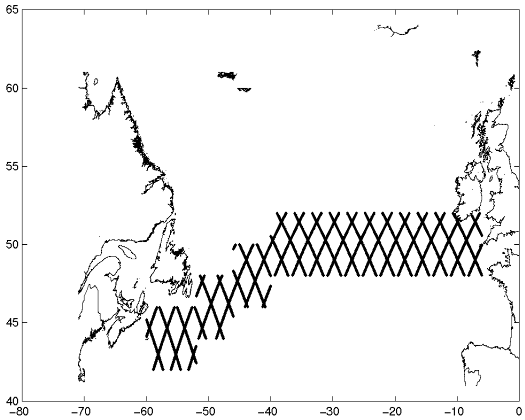

Figure 2.3 Satellite data coverage (from the TOPEX/Poseidon altimeter satellite) over the Rotterdam to Boston (USA) route.

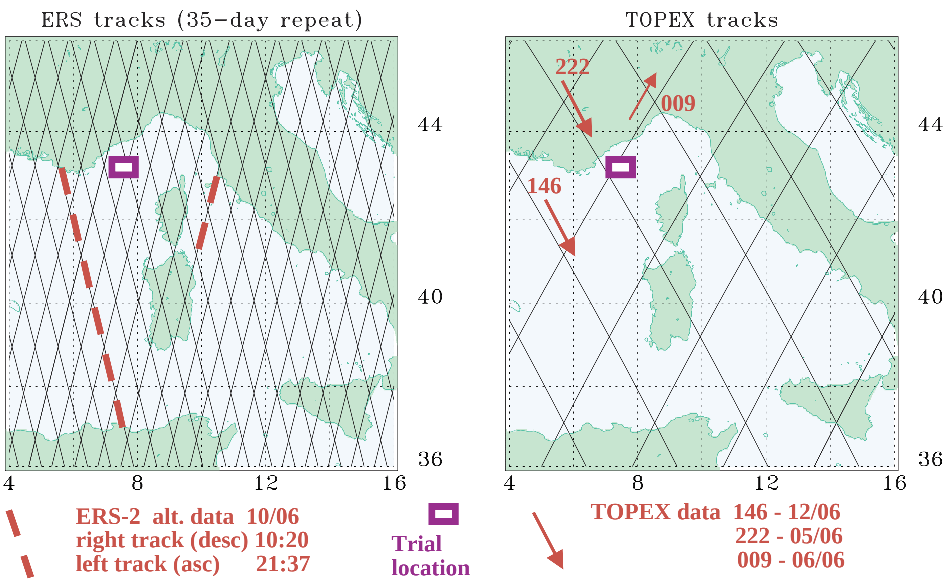

Figure 2.4. Location of Bureau Veritas High Speed Craft trials in the Mediterranean Sea, and of nearest altimeter data (left, ERS-2; right TOPEX) at the time of trials in June 1998.

2.3.4 WP3300 Near Real Time Data

For a new concept of ship such as a HSC, it is important for a designer and a classification society to know if the current design tools remain applicable or if new techniques should be developed to determine the best ship structure. For this task we investigated whether the satellite data could provide the relevant information to enable calibration of the hydrodynamic calculation using actual measured sea states.

HSC on the BV register are monitored and regularly provide the authorities with information concerning the stress history used for ultimate strength and fatigue damage accumulation. The process of rules loads calibration could be improved by the knowledge of actual sea state corresponding to stress and acceleration records. A period from May to August 1999 was selected for this study. The region of interest was a small area to the south of Nice where HSC trials normally take place (Figure 2.4). The aim was to use the available satellite data as input to hydrodynamic calculations and compare the statistics of resulting stresses and accelerations with those derived directly from measurements on the craft.

2.3.5 Development of a Theoretical Basis for Vessel Responses

This section briefly describes a study carried out at the University of L nd to support WP3000. Readers are referred to the full report, Baxenavi et al. (2000a).

The Problem

Let us consider a ship which is undertaking voyages over a certain relatively long period of time. The loads she experiences and consequently her responses to these loads are random and thus are best analysed by reliable statistical methods. Clearly, from the engineering point of view, it is most important to find an accurate approach to study the extreme events occurring during the period under investigation. The principal methodological challenge in this problem is that there are several different sources of random variability. They are directly related to temporal-spatial scale within which one considers the sea surface. Yet, conditions occurring on the sea surface are changing continuously in time and in space, and the randomness is different in different scales and thus different methods should be chosen depending on the scale. If necessary, calculations should be made at different scales, and the separate results then combined together.

Although much of the relevant theory has appeared previously in the literature, this is, as far as we know, the first attempt to establish a consistent methodological framework. We expect that this new framework will prove helpful for future advances in research on these topics.

General Description

We consider the following three different scale threshold levels. First, there is randomness related to short-time variability of the sea surface in time intervals measured in minutes or, at most, a few hours, and in a restricted region in which the weather conditions appear to be the same (Figure 2.5, top left). Another level of variability is due to the change of the sea states, as a consequence of changes of weather conditions occurring within several hours or even several days (Figure 2.5, top right). Local conditions may also be different to those in distant regions of the sea. Finally, there is a stochastic variability of different journeys which are undertaken at different times of year and possibly along different routes (e.g. Figure 2.5 bottom left and bottom right). Of course, these are only few of many possible factors and the complete analysis would be extremely complex, if possible at all. In these notes we focus on these factors which are most important for the statistical properties of extreme waves (or responses). However, the proposed methods can be also applied to studies of arbitrary, not only extreme, waves.

Applications and Present Methodology

In various practical problems, for example in safety considerations, it is important to determine the probability that the response - for instance the heave amplitude, or the acceleration at a given location of a ship, or the stress in a given member - exceeds some critical level over some time interval (one voyage, the duration of a storm, the lifetime of the vessel).

The conventional method is presently to oversimplify the problem, assuming that the random influencing variables are uncorrelated and of known simple distributions, and/or to use Monte Carlo type simulations of numerous potential histories for the time interval of interest, and accept the statistics of their results as a valid basis for the safety assessment.

New Developments

Satellite measurements provide data at time intervals such that the conventional method of history reconstruction cannot be used with them. Baxenavi et al., (2000a) sets the definitions and theory for methods that rely on parameters that may be estimated from the satellite measurements.

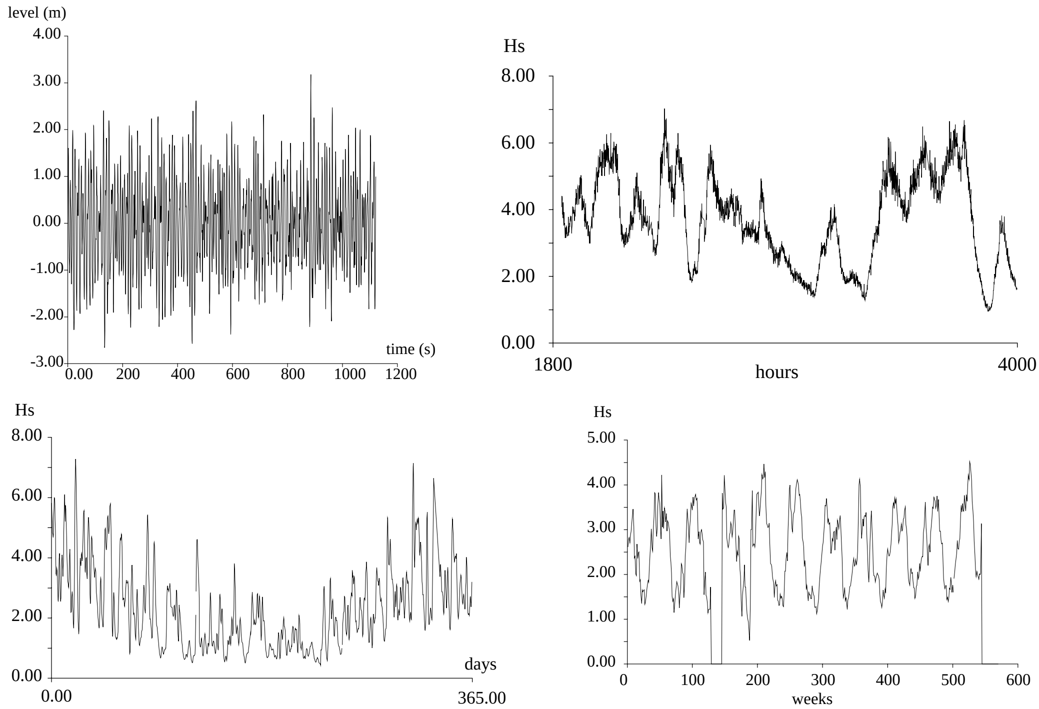

Figure 2.5 Wave height records over different periods. Top left : 17 minute record of a 4 m significant wave height (Hs) sea state. Top right one month record of Hs, Bottom left 1 year record of Hs, bottom right, 11 year record of Hs.

In Baxenavi et al., (2000a) a number concepts are defined and discussed:

Sea state and its duration; Route, as a time-indexed trajectory, and as an unknown variable apart from its end-points; Response Process, on the basis of a conditional Gaussian model.; Periods of stationarity.; Distributions of response and probabilities of exceedances; Crossing intensity and oscillations density functions.; Height of the crest of an oscillation; Distribution of rainflow cycles; Poisson approximation for the number and probability of exceedances; Connection of route segments; Estimation of probabilities.

Conclusions and Recommendations

The conclusions and recommendations coming from this theoretical study are summarised in Box 5.

Box 5: Conclusions and Recommendations from Baxenavi et al., 2000a.

> The theoretical statistical bases have been established to allow analysis and estimation of response level exceedance and of rainflow damage accumulation experienced by a vessel.
>
> Baxenavi at el., (2000a) raise many questions. The most important issues are the validation of the assumptions, and the practical estimation of the parameters used in the theoretical formulae. Such practical estimation should not be limited to satellite data, but should of course consider them as one of the potential sources of information.
>
> Safety assessment needs to be understood in a stochastic manner. This is not yet current practice everywhere, but the models presented here are essentially stochastic, and they are a compelling stage in the process, all the more if satellite data are to be used.
>
> Collaborative research actions should be able to shed light on the ways to solve the problem of extracting information on the time-histories of sea state processes from the almost instantaneous space lines of the orbital path.

2.3.6 A Statistical Analysis of Satellite Wave Data in the Mediterranean and the North Atlantic Ocean.

This section presents a summary of a second study carried out at the University of L nd to support WP3000. In this study satellite altimeter significant wave height and wave period data for the Mediterranean Sea (Rotterdam —Trieste) and North Atlantic Ocean (Rotterdam — Boston) were processed to create the data sets that were necessary to address the problem posed by Bureau Veritas. Again, readers are referred to the original report, Baxenavi et al., 2000b.

Statement of the Problem and Approach

This study addressed the design rules in shipbuilding. Conventional strength criteria for ships are based on a description of loads that is independent of actual ship service and corresponds to worst sea conditions expected over a period of 20 years. Knowledge of actual sea conditions would allow the demonstration of the capacity of a ship designed for a specific service.

A second topic is to investigate the possible spatial structure of the wave climate, in particular the dependence structure over extended areas, in order to make possible the estimation of the fail-safe properties of ocean crossings, and in particular to find the distribution of the worst wave conditions over a fixed period of time, typically 10-15 days.

The study was broken into two parts. A Mediterranean and Eastern Atlantic route Trieste-Rotterdam (Figure 2.1) was chosen for the design rules and a Northern Atlantic route Rotterdam-Boston (Figure 2.3) for the fail-safe part.

The two routes are not only different from a meteorological point of view, but they are also monitored by the satellite passages in quite two different ways. Much of the Trieste-Rotterdam route, in particular the Adriatic part near Trieste, lies rather close to the coast, and there are many missing or unreliable data. The Atlantic data are rather more reliable and stable. The parameters for the statistical distributions in the wave characteristics are of course different and vary along the routes, with small and regular variations in the Atlantic, and larger ones in the Mediterranean.

Applications and Present Methodology

Fatigue is one of the most important criteria in the design of ships. Estimation of the fatigue loading can be significantly improved if precise climate information, including seasonal trends, can be made available all along the route. The fail-safe condition would correspond for instance to avoidance of the risk that a crack in a LPG carrier, undetected at the inspection before sailing, would propagate to full ruin during a single, extremely severe, voyage of 10 to 15 days.

The conventional method, fatigue assessment by direct calculation, is based on the partitioning of the oceans in the areas of the Global Waves Statistics atlas (BMT, 1990), and on a combination of the corresponding Hs-Tz scatter diagrams with weights corresponding to the probability of presence of the ship in each area.

Due to the wide geographical extent of the areas, this method does not describe precisely the climate of routes, and the averaging of conditions over areas where strong climate gradients exist may lead to severe over- or under-estimation of the actual fatigue damage.

Moreover, the method is unable to provide any realistic estimation of the probability and the nature of the most severe conditions on a given route.

New Developments

Satellite altimeter measurements of significant wave height, Hs, give an opportunity to refine the estimation of the distribution of sea states, both in space and by season. In this study, TOPEX-Poseidon data provided by the SOS WAVSAT archives were used to this end. Time was separated between summer and winter months, and space in square bins of about 2 by 2 degrees. The following procedure was then applied:

- Reconstruction of missing values in each track
- Fit of a parametric (log-normal) distribution to the observations in each bin.
- Validation of the processing method.
- Parameterisation of the distributions with respect to the position on the route.
- Computation of overall damage distribution for voyages along that route.

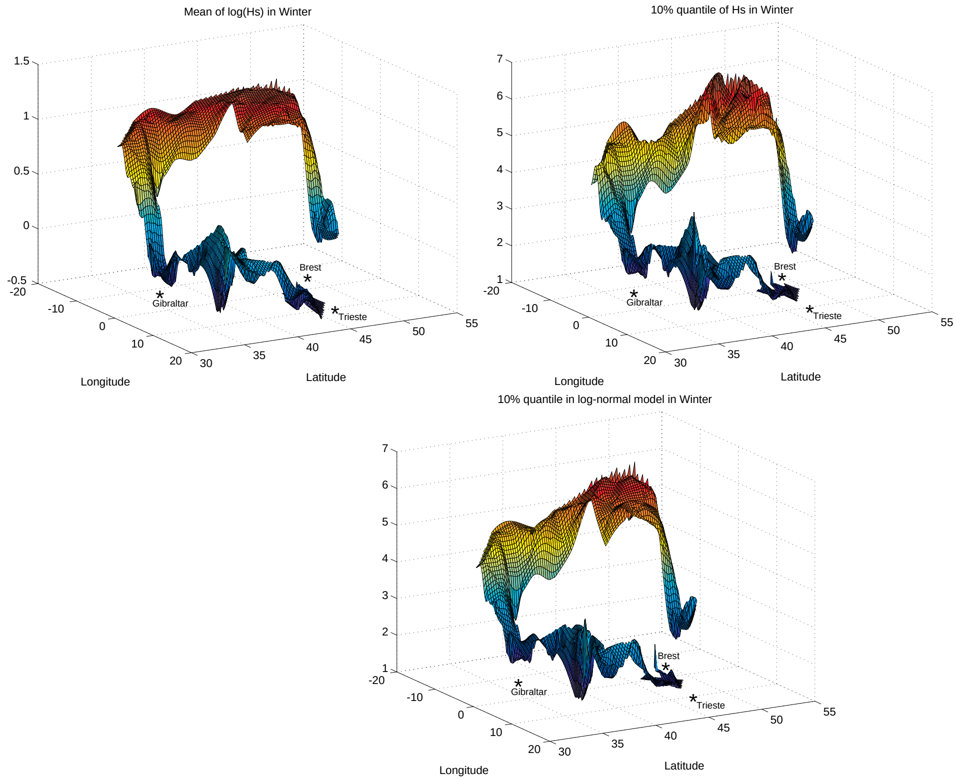

Figure 2.6 Analysis of satellite altimeter significant wave height data along the Rotterdam — Trieste route. Top left — Mean of log(Hs)for winter, Top Right- Estimated 10% Hs quantile for winter, Bottom —10% Hs quantile from a log-normal model generated from reconstructed data.

Figure 2.6 provides representations of (winter) Hs data along the Rotterdam —Trieste route, as derived for this COMKISS study. The top two panels give the mean of log(Hs), and the 10% Hs quantile estimated directly from the satellite data. The bottom panel gives the 10% Hs quantile derived from a log-normal model generated from reconstructed data. The small difference between these latter two figures (not shown here) indicates that the model form is acceptable. In this form, these data are now suitably organised for fatigue calculations.

A different procedure was required for the consideration of the North Atlantic data, because the short term duration and geographical extent of storms was an important factor. Thus the altimeter Hs values were used to generate upcrossing statistics (e.g. the frequency with which a certain significant wave height threshold is crossed in a km). Figure 2.7 presents such data for the central section of the North Atlantic in winter.

Analysis of the Example

This experiment was a good demonstration that the probability density function of Hs and Tz could be modelled along a given route, and the parameters of the model may be estimated from satellite data.

However, for a given voyage, the sea states that are encountered are correlated in a manner that cannot be straightforwardly estimated from satellite measurements. This is the reason for the definition of the problem described in section 2.3.5.

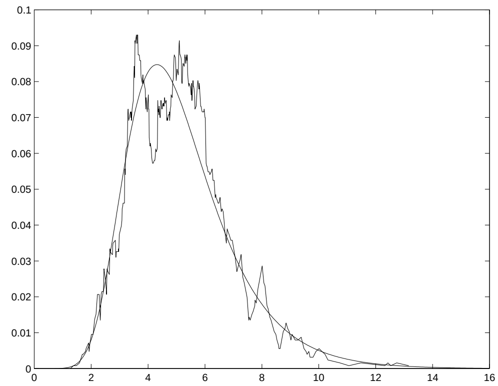

Figure 2.7 Probability of upcrossing a Hs threshold in winter, for the mid section of the Rotterdam — Boston route (North Atlantic). A Gumbel distribution has been fitted.

Conclusion and Recommendations

It is important for the user to recognise that fail safe conditions (and fatigue over a single voyage, for sea-fastening for instance) need to be understood in a stochastic manner. This condition is necessary because satellite data does not directly provide sea state histories that could be used for more deterministic approaches.

Based on this work, it was concluded that it should become possible in the future to consider the correlation of the sea-states that are encountered along a given route in a single voyage. Also, the service providers should soon be able to give directly height-period, or even damage distributions for a simple transfer model, for a given route instead of asking the user to combine local information.

Conclusions and recommendations are summarised in Box 6.

Box 6. Conclusions and recommendations from Baxenavi et al., 2000b

Conclusions:

- Joint probability density functions of wave height and period can be accurately estimated on a given route for a given season from satellite data.
- The estimation is robust, and provides a higher resolution than the climatological atlases.
- These pdfs can be transformed to the damage increment distributions that are of primary interest to design and risk assessment.

Recommended research actions:

- Provide a clear statement of the problem for the correlated conditions encountered in a single voyage.

4. Improve the model of the probability density function of the overall fatigue damage cumulated during one voyage along a given route.

2.3.7 WP3000 Results — End User Perspective

WP3100 Checking Design Criteria for Long Term Loads

From the satellite observations it was possible to obtain a useful and accurate description in space of the wave height statistic parameter. Unfortunately, unless design techniques are also altered, this improvement in the description of the wave amplitude cannot on its own provide an immediate improvement in the determination of the ship fatigue damage. This is because the stress equivalent level for fatigue damage estimation depends not only on the wave height, but also on ship (relative) heading, wave period and ship speed. The ship s speed and route are usually well defined and available for this study. However, the wave direction and periods were not available, and are essential for fatigue calculations as presently constructed.

WP3200 Fail Safe Calculations

Establishing a methodology

A storm model has been proposed to describe the sequence of sea states along the route of a ship. This model involves parameters that allow the user to adjust the intensity and the duration of the storm, and, if necessary, can allow an asymmetry between the periods of increasing intensity and decreasing intensity.

Can satellite observation provide adequate data?

The duration of a typical storm may be estimated as between 4 to 8 days. The mean interval of time between two consecutive satellite observations is close to 10 days. So, without recourse to other data sources (e.g. hindcasts), it was not possible to validate the statistical model of storm versus actual sea data.

Application to actual gas carrier

Due to the lack of information on the actual sequence of sea state conditions it has not been possible to determine a set of reference loading history that could be used to determine the worst case that a gas carrier could encounter on a period of 15 days. So, with present data density, satellite data cannot be used to carry out a fatigue calculation to establish fail safe conditions.

WP3300 Near Real Time

Over a 3 month period we have found very few satellite observations which coincided with the dates of sea trials. Only on 4 days during this time did the dates and locations of satellite data correspond to those of the HSC trials carried out in an area of the Mediterranean Sea between Nice and Corsica (Figure 2.4). Due to variability in the local sea conditions it is very difficult to extrapolate the satellite observation from one location to another, and the sea conditions vary quickly from an hour to another. At the end we identified only one case where the satellite track crossed the ship route within one hour. Thus, for similar reasons as before we cannot directly use the satellite observation to determine the stress and acceleration response of the HSC. However, we did have the opportunity to compare the satellite measured Hs with that recorded in the vessel Logbook. It was found that:

- The logbook indicated an Hs between 1.5 m to 2m when the satellite data indicated 1.3 m
- the logbook provides the wave direction whereas the satellite altimeter data do not.
- the logbook provides an estimate of wave period.
- The safnav which recorded the acceleration and stresses corresponding to the bending moment provides an indication of the period of the acceleration and bending moment.

The wave period was estimated from the ship s forward speed and heading. This provided an estimate for Tma in the range 4 to 7 seconds. Unfortunately, this range corresponds to a large variation of response of the ship in pitch acceleration and in bending moment. It was concluded that the calculation used in the dimensioning of the ship structure is probably conservative, as expected, but we were unable to measure the degree of overestimation of the loads on the ship.

2.3.8 WP3000 Potential Benefits

As the situation stands (regarding satellite data availability) no immediate real benefits may be expected from satellite data unless there is a willingness to modify design procedures. If coverage can be improved, i.e. if the ship could obtain continuous information in a localised area which provide an accurate representation of sailing conditions, important benefits may be expected.

WP3100 Checking Design Criteria for Long Term Loads

Two aspects of this procedure may benefit from improved wave data provision. First, more accurate and reliable data could allow more economical designs by decreasing the uncertainty on the design loads. The second aspect has to do with inspection and maintenance planning.

Sea conditions can be quickly varying, particularly in coastal waters, according to the geographic position. A refined description of sea states involving the actual directional spectrum (i.e. wave energy density versus frequency and direction) representative of an area over a few square kilometres may help particularly in checking design rules and tools. This would in turn allow the calibration of the design criteria which were originally based on feedback from on board the vessel. This type of analysis would require a history of sea states in all areas covered by the ship during its lifetime.

Satellite data may be in competition with or may complement ship-borne monitoring and measurement recording. With knowledge of actual sea conditions experienced on voyage, a procedure involving hydrodynamic and structural calculations can generate an estimate of accumulated damage. This information, together with information from ship-borne stress transducers, may help the ship owners and classification society to schedule the inspection and/or maintenance of the ship, and establish the risk of delaying a scheduled visit if trading requirements make the disposability of the ship important.

It is clear that this possibility assumes that:

- The ship-owner could have available the wave spectral density versus the frequency and direction in a wavelength range between (at least) 10 m to 1000 m.
- That this spectrum be representative of actual sea conditions and not subjected to the errors that can occur in hindcast model output.

WP3200 Fail Safe Calculations

The project has demonstrated that up until now there has been no objective data to evaluate the worst load history on a ship on a period of time of 15 days .

It is clear that a raw Monte-Carlo process does not describe the actual loading process as it neglects the interactions between consecutive sea states. Also data sets based on historical ship records are not sufficiently reliable to provide anything other than a mean value .

This worst case information is necessary, from a statistical point of view, to allow the continuing operation of certain categories of ship. Also, an observation every 3 hours (full wave spectrum) could drastically improve the design of ship to allow survival after a first failure.

Clearly, an expectation of an accurate, measured, three hourly time series everywhere on any given ship route is unrealistic. Hindcast data provide one solution to this problem. Otherwise, the work of Baxenavi et al., 2000b suggests that the processes are stochastic, and provide a statistical basis for an alternative formulation of the problem.

WP3300 Near Real Time

The High Speed Craft can only operate under a specified limit of wave height. Currently the estimated wave height, which determines whether the craft will set out on its voyage, is based on specific analysis of a forecaster who provides the expected sea state over the next few hours. Due to a lack of direct information of the local conditions, the actual sea states encountered by a High Speed Craft navigating in narrow seas like Mediterranean Sea are rarely known precisely. If knowledge of the actual conditions can be acquired then a more accurate definition of acceptable limits of wave conditions may be derived, and safety factors could be more precisely specified.

This would require a continuous knowledge of the local sea conditions or at least the knowledge of the sea conditions at the time and location where the ship is navigating. If this type of knowledge were available it might be possible to define ship specific allowable sea state conditions, which will depend upon wave height, direction and period, as well as shape and size of ship.

2.3.9 WP3000 End User Recommendations

Satellite wave data, as currently available, require improvements to be useful in ship structure design, as outlined below.

Type of Data

For ship design, a measurement of wave height is not sufficient. Calculation of loads are carried out from an assumed power spectrum of the wave versus frequency and direction. To be really applicable to ship design, satellite data should provide sufficient parameters to allow an estimation of the wave power spectrum over the full range of wave frequencies. There remains a question as to whether SAR wave spectra data are sufficiently accurate for this purpose.

Area described

In coastal navigation or closed seas the sea states depend significantly upon interaction with the nearby land topography. Information averaged over an area is not sufficient as:

- For ultimate strength the designer needs information on the worst sea condition, i.e. to decrease the uncertainty on the scatter of sea states encountered by the ship.
- Fatigue depends on the wave amplitude in a non-linear way. If a mean value is used in calculations, it may lead to an underestimate of the fatigue load on the ship.

- ***Frequency of observations***

To be effective, particularly with regard to the fail safe conditions and the near real-time requirements, data are required with a much higher spatial frequency. Certainly less than one day, and ideally every three hours.

Long term calculation

If ships are designed for world-wide operation, the designer needs only a sufficient number of observation to be representative of a mean operation condition, whilst allowing for an estimate the uncertainty around this mean mission profile . An important question is: Can the satellite observations be competitive with other type of observation for coastal navigation?

Fail safe

To be effective any data source should be able to provide information on the evolution of consecutive sea states. A typical storm duration may be about 4 days, and the typical persistence time of a given sea state may be estimated at around 3 hours. Therefore the designer should have information regarding the worst possible sequence of 3 hourly sea states during 15 days. This analysis is most relevant for deep sea navigation, and so precisely located information is probably not too important, although time regularity is very important.

Near Real Time

To be effective the satellite should be able to provide information at the immediate location and time where the ship may be sailing.

- ***Reliability of data***

The estimation of fatigue strength is very sensitive to the stress amplitude, which in turn depends upon the accuracy of the wave data. Within the COMKISS studies Bureau Veritas found some discrepancies between the satellite measurements and the logbook observations. Without a third reference source, one cannot be certain which data set provides the more accurate estimate of conditions.