FULL-SCALE MEASUREMENTS

A contribution to safer shipping
INTRODUCTION

Ship design and construction is subject to change, mainly driven by economic needs, safety- and ecology-related requirements as well as technological developments. Recently, in particular, size and capacity of container ships have increased rapidly to meet the unceasing growth of marine container transport needs. Currently, container ships able to carry more than 18,000 TEU are being built. Although design experience is limited for such ships, design rules and guidelines are needed to ensure adequate structural safety, and the necessary software must be established in order to aid the designer in specifying wave-induced hull girder loads and assessing the ship structure.

Full-scale measurements are an important source of information for validating design rules and guidelines as well as formulating rule approaches and formulas. In particular, data from full-scale measurements can be employed for the validation of design assumptions, design loads, and of calculation tools. Furthermore, data can be acquired that cannot be generated by computations because the respective methods or tools are not yet or far enough developed, or the required effort for such computations would be excessive. An example of the latter are long-term, high-frequency hull girder loads which are important for the fatigue strength of the hull girder.

Several full-scale measurements have been performed by DNV GL Maritime Technology in the past. Between 1989 and 1991, measurements on four container ships and one tanker were performed. Strains of the primary hull structure as well as transversal and vertical accelerations were measured. A further large, full-scale measurement was performed on a 64,000 DWT bulk carrier between 1995 and 1999. Here the focus was on the measurement of side shell and bottom pressures and strains of side shell frames. More recently, full-scale measurements have been performed on three container ships of different sizes and operated on different routes. These measurements were started in 2007, 2010 and 2013, and all measurements are still running.

In addition to full-scale measurements, several ships, in particular container ships, have been equipped with shipboard routing assistance systems. These systems monitor, among others, the wave environment, ship’s loading condition, and navigational data. The stored data can then be evaluated in order to generate statistical data of these quantities, among others.

This document gives an overview of recent full-scale measurement campaigns performed by DNV GL Maritime Technology and describes evaluations of measured data that were carried out in the past, namely evaluations of operational and navigational data, evaluations with respect to high-frequency hull girder response and to route-specific container stowage.
Full-scale measurement campaigns are currently being conducted onboard a Panamax and two post-Panamax container ships. Table 1 lists the main particulars of these ships.

Operating worldwide, the trade route of the 4,600 TEU Panamax ship extends from Europe to North America and continues through the Panama Canal to East Asia. The trade route of the 8,400 TEU post-Panamax ship runs from North America via Europe and the Suez Canal to East Asia and from there over the North Pacific to the North American west coast. The 14,000 TEU post-Panamax ship trades between Europe and East Asia via the Suez Canal and the Indian Ocean. During these measurement campaigns, only the Panamax and the 8,400 TEU post-Panamax container ships acquired data under conditions representing severe seaways, as their trade route spans the North Atlantic and the North Pacific. The 14,000 TEU container ship sails only under conditions representing relatively mild seaways, as it omits the Atlantic and Pacific Oceans.

The purpose of the campaigns is to consolidate current design rules and guidelines as well as to contribute to future rule development. The measurement campaign on the 4,600 TEU ship comprises the most comprehensive measurement equipment. The focus of this campaign was on the measurement of global hull girder strains, strains at hatch corners, loads on side shell longitudinals (pressures and strains) as well as global accelerations. The measurement campaign on the 14,000 TEU ship was performed within a Joint Development Project with a major Korean shipyard. The sensors and cables were installed by the shipyard, and the data processing and storage units were provided by DNV GL. Here the focus was on the measurement of global hull girder strains, strains at hatch corners, global accelerations as well as slamming pressures. Furthermore, for this campaign the separation of strains due to low-frequency wave loads and high-frequency hull girder vibrations was of special interest.

The most recent measurement campaign for the 8,400 TEU ship was triggered by the need to receive more data on the effect of high-frequency hull girder vibrations on fatigue strength for a medium-sized container ship operating worldwide. Also, for the validation of load assumption made for route-specific container stowage, data on accelerations for such a vessel is needed. Thus, the focus of this campaign was on the measurement of global hull girder strains and global accelerations.

<table>
<thead>
<tr>
<th>TABLE 1 – PRINCIPAL PARTICULARS OF THE THREE CONTAINER SHIPS</th>
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<tbody>
<tr>
<td><strong>Panamax</strong></td>
</tr>
<tr>
<td>Container capacity</td>
</tr>
<tr>
<td>Length b. p.</td>
</tr>
<tr>
<td>Breadth</td>
</tr>
<tr>
<td>Operated route</td>
</tr>
<tr>
<td>Measurement started</td>
</tr>
</tbody>
</table>
On all ships listed in Table 1, decentralised data acquisition characterises the layout of the measurement systems. Data acquisition units gather data measured by close-by sensors. These units process part of the data, which is then transmitted to the central unit of the measurement system, located in the deckhouse area or the engine room. Each measurement has a different scope, and different types of sensors are installed on the ships. In Figure 1, sensor locations and types are displayed for all three container ships.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Sensor type</th>
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<tbody>
<tr>
<td></td>
<td>Central unit</td>
</tr>
<tr>
<td></td>
<td>Strain gage at primary hull structure</td>
</tr>
<tr>
<td></td>
<td>Strain gage at hatch corners</td>
</tr>
<tr>
<td></td>
<td>Strain gage at side longitudinals</td>
</tr>
<tr>
<td></td>
<td>Accelerometer for global accelerations</td>
</tr>
<tr>
<td></td>
<td>Accelerometer for local accelerations</td>
</tr>
<tr>
<td></td>
<td>Pressure gage</td>
</tr>
<tr>
<td></td>
<td>Wave sensor</td>
</tr>
</tbody>
</table>

Figure 1 – Sensor locations onboard the container ships
Measurement of strains

To monitor global loads, strain gages were attached to primary structural members of the hull girder, typically at three ship stations, shown as orange rectangles in Figure 1. The long side of the rectangle indicates the direction in which the strain is recorded. To distinguish between stress components caused by different kinds of global loads, strain gages were arranged on the 4,600 and 14,000 TEU ships to enable the decomposition of stresses caused by vertical bending, horizontal bending, and torsion (see Figure 2). Strain gages were attached close to or at the edges of structural members, allowing the use of unidirectional strain gages. The location of these strain gages was chosen to minimise the influence of local loads.

Besides global strength aspects, selected local load effects are monitored. The low torsional stiffness of container ships leads to large hatch opening deflections in oblique seas or due to roll motion, inducing high cyclic loads in the hatch corners. Thus, on the 4,600 and 14,000 TEU ships, local stresses at hatch corners of the upper deck are measured by strain gages distributed along the hatch corner radius. In Figure 1, locations at which strain gages were applied to hatch corners are indicated by green rectangles. A typical arrangement of three strain gages at hatch corners is shown in Figure 3. As the sensors on the 8,400 TEU container ship were installed on the ship in service during a voyage, no strain gages could be equipped to the hatch corners; instead, strain gages were attached to transverse bulkheads that are mainly loaded by torsional deflections of the hull girder.

Also, side shell longitudinals in way of the waterline are prone to fatigue. Reasons are fluctuating side shell pressures due to waves and roll motion of the ship as well as dynamic hull girder stresses. Therefore, on the 4,600 TEU container ship, two side shell longitudinals in the midship area are monitored by strain gages. The measurement is carried out close to a ship station equipped for the measurement of global loads. The strain gages were attached at two side shell longitudinals in a wing water ballast tank, about 3 m and 5 m below the design waterline. In Figure 1, the approximate locations of the sensors are shown as blue rectangles. A typical arrangement with three sensors is illustrated in Figure 4. The sensor arrangement as shown in Figure 4 allows decomposing stresses from lateral loads, global loads, and relative displacement of web frames.
Measurement of motions and accelerations
On all ships, motions were monitored by a gyroscope located in the deckhouse area, recording vertical and horizontal accelerations, roll and pitch angles as well as the yaw rate.

To monitor accelerations at different ship stations, accelerometers were equipped as designated by yellow stars in Figure 1. Typically, these accelerometers were installed symmetrically about a vertical plane at center line. Vertical and transverse accelerations were recorded.

Measurement of vibration of local structures was carried out on the 4,600 TEU container ship at different locations in the engine room as designated by magenta-coloured stars in Figure 1. To assess the strength of the excitation source, vibration accelerations at the main engine foundation were also monitored.

Measurement of shell pressures
On the 4,600 and 14,000 TEU container ships, sea pressures at the shell were measured. On the 4,600 TEU ship, the focus was on the measurement of pressures below the design waterline. In total, six pressure gages were mounted in the side shell on portside and starboard side. On the 14,000 TEU ship, the measurement of slamming pressures was focused in the fore- and aftship. Three pressure gages were mounted above the design waterline on portside and one at the centre line close to the bottom line. The locations at which pressure gages were installed on the ships are designated by blue circles in Figure 1.

Measurement of environmental conditions and navigational data
To allow for relating measured wave-induced global and local loads as well as ship motions to environmental conditions, on the 4,600 and 14,000 TEU ships the seaway was measured by a wave sensor as part of the installed shipboard routing assistance system. For this purpose, radar scanners were mounted on the foremast or on top of the deckhouse, respectively, as shown in Figure 1. As input for the assistance system, the ship’s loading condition is traced, namely cargo distribution and masses, tank levels, drafts and metacentric height (GM). Payer and Rathje (2004) give an extensive description of the shipboard routing assistance system. On the 8,400 TEU ship, no wave sensor and shipboard routing assistance system was installed, however, environmental and navigational data was recorded by the ship crew on prepared forms during each watch.

Furthermore, on all ships navigational data is recorded from the ship systems, in particular position, speed and heading.

Data processing and storage
The sample rate for the measured data is typically 50 Hz. For all measured data, statistical evaluations were performed, and maximum, minimum and mean values as well as the standard deviation for 15-minute measurement intervals were stored. For all sensors, time series of 30 minutes in length were stored, triggered by the exceedance of threshold values for selected sensors. Once a time series had been stored, threshold values were increased by a predefined increment. After four days, threshold values were reset to the initial value. On the 8,400 TEU container ship, continuous time series were additionally recorded for some sensors. Furthermore, spectra of the measured responses were stored, yielding information on response ranges and their distribution. These spectra were obtained by applying the rain flow counting method on the continuously measured data for all sensors.

To investigate the effect of whipping and springing on ship response, data measured by strain gages in the upper deck was additionally treated by a low-pass filter. Low-frequency, wave-induced loads were separated from high-frequency hull girder vibrations. On the 14,000 TEU ship, and also for the hatch corners, low-pass filtered strains were recorded. The filter frequencies were chosen with respect to the lowest estimated natural frequencies of the hull girder for the vertical bending and torsional vibration modes. On the 4,600 and 8,400 TEU ships, the filter frequency is about 0.4 Hz. On the 14,000 TEU ships, two low-pass filter frequencies, 0.4 Hz and 0.25 Hz, were chosen to cater for different natural frequencies of the lowest vertical bending and torsional vibration modes. For the low-pass filtered data, statistical data and spectra were also stored on all ships.
EVALUATION OF MEASURED DATA

EVALUATIONS OF OPERATIONAL AND NAVIGATIONAL DATA

The assistance systems installed on some ships trace operational data, namely cargo distribution and masses, tank levels, drafts and metacentric height (GM). Statistics of operational data are valuable information for the rule development. For instance, the probability distribution of the still water bending moment (SWBM) is of interest for fatigue strength. The mean stress of ship structural elements, having an effect on the fatigue damage, mainly depends on the SWBM which is governed by the loading condition of the ship. A realistic estimation of SWBM serves the efficient assessment of fatigue strength.

For five container ships (4,600 TEU, 5,500 TEU, 7,500 TEU, 8,600 TEU and 14,000 TEU) SWBM, drafts and GM values were evaluated. The drafts and GM values were stored by the routing assistance system; however, the SWBM was not stored and thus needed to be calculated by hydrostatic analyses from the recorded cargo load distribution and tank fill levels. For the hydrostatic calculations, models were available for the evaluated ships. A scripted method was developed for the automatic extraction of loading condition data from the records and the generation of load cases for the hydrostatic software.

As the loading condition data is not automatically recorded by the routing assistance system but depends on action by the crew, only data comprising non-constant time intervals between the recorded loading conditions was available. Furthermore, no information was available on whether the ship had been in port or at sea at the time of recording. Thus, a maximum of one recording per day was considered and the validity of a recording was limited to three days, when the interval to the next recording exceeded this limit.

The hydrostatic calculations yielded the vertical still water shear force and bending moment distribution over ship length. Figure 5 shows an example distribution of sectional loads for a container ship. The results from the hydrostatic calculations were compared to results available from the loading computer. An example for the comparison of the forward draft is shown in Figure 6, which illustrates that the calculated and recorded values match well in most cases. It can also be seen that the recordings are partly fragmentary.
Results for the SWBM were related to the maximum permissible values according to the Stability Booklet yielding percentage values. Figure 7 shows a histogram of SWBM amidships for the 4,600 TEU container ship. It can be seen that the ship was always operated in a still water hogging condition, which is typical for container ships, with a mean SWBM of about 65% of the permissible value. In the better part of the operation time, the SWBM was between 45% and 85% of the permissible SWBM, and extreme SWBM values were found to occur most unlikely.

Correlations of different loading condition parameters were also evaluated; see Figure 8 for the relation of GM to the mean draft of the 4,600 TEU container ship. The graph shows that the loading condition most often results in a metacentric height in the range of 0.5 m and 1.0 m, whereby 0.5 m is the minimum allowable GM value for this ship. Furthermore, a trend towards higher GM values for lower drafts can be recognised, in particular for drafts of less than 80% of the scantling draft.

Besides the operational data, navigational data is recorded from the ship systems. The gathered data of ship position allows route profiles for the ship to be derived, and statistics of the recorded ship speed provide information on average and most frequently travelled speeds. Figure 9 shows the distribution of ship speed for the 4,600 TEU container ship. The ship speed distribution depends on the operation of the ship, which is mainly governed by economic aspects, e.g. fuel efficiency or time schedules; however, it is also be influenced by the wave environment, which may lead to voluntary and involuntary speed loss. For the 4,600 TEU container ship, as depicted in Figure 9, the better part of the travelled speeds ranges from 17 to 23 kn, about 70% to 90% of the design speed.

Based on route profiles, statistics on the route-specific wave environment can be generated. Figure 10 illustrates routes travelled by the 4,600 TEU container ship plotted based on recorded position data. Typically, wave statistics are available for specified sea areas or can be generated by meteorological service providers for individual sea areas. The wave data may come from observations of ship crews, buoy measurements or satellite measurements, among others. In Figure 11, sea areas are shown that were crossed by the 4,600 TEU ship on the routes illustrated in Figure 10. Figure 11 also gives the average fractions of time that the ship stayed in these sea areas. The remaining fraction of time is considered as time in port or in sheltered areas characterised by a very low or zero ship speed.
Among others, for the sea areas shown in Figure 11, statistical wave data was provided by British Marine Technology (BMT, 1986), based on observations of ship crews. From the wave data and the fraction of time the ship stayed in the travelled sea areas, route-specific wave statistics were composed for the world-wide route travelled by the 4,600 TEU ship and the Europe – East Asia route travelled by the 14,000 TEU ship. Figure 12 shows the wave data composed for the worldwide trade of the 4,600 TEU ship compared to that for the North Atlantic according to IACS (2001). The so derived wave data can be employed for seakeeping computations for the specific trade.

Figure 10 – Routes travelled by the 4,600 TEU container ship

Figure 11 – Time fractions [%] in different sea areas crossed by the 4,600 TEU container ship

Figure 12 – Wave data composed for a worldwide trade (left) and for the North Atlantic (right)
All currently performed full-scale measurements include monitoring of unfiltered and low-pass filtered stresses at main hull girder structures and on one ship also at some hatch corners. As explained, this serves to evaluate the effects of high-frequency hull girder loads which are characterised by hull girder vibrations of different modes and frequencies depending on the ship properties and the kind of excitation.

Two basic phenomena can be observed, namely whipping and springing. Whipping is induced by wave impacts on the hull (bow flare, stern and bottom slamming), leading to transient, decaying hull girder vibrations which typically occur in moderate or harsh seaways. Springing is caused by periodic wave trains which excite resonant hull girder vibrations. Springing occurs in low to moderate seaways in which the ratio of wave encounter frequency and the excited hull girder vibration frequency, or its inverse, is a whole-number ratio.

Figure 13 depicts typical sample time series for a whipping and a springing event, with stresses obtained from strain measurements amidships below the upper deck. Shown are the unfiltered signals together with their high- and low-frequency parts. The high-frequency part of the whipping event shows the characteristic transient hull girder vibration caused by a single slam at the ship’s bow. After its initiation, damping caused the vibration to decay. The high-frequency part of the springing event reveals the characteristic harmonic hull girder vibration. The stress amplitude spectrum in Figure 14 is typical in that it reveals two peaks at different frequencies. The first peak (at 0.1 Hz) originated from the wave-frequency response, the second peak (at 0.6 Hz) primarily from the two-node vertical hull girder bending vibration mode.
For the 4,600 TEU container ship in Figure 15, spectra for the unfiltered and low-pass (LP) filtered stress are plotted as a normalised stress range versus the cumulative frequency for a strain gage located under the upper deck close to amidships. These stress range spectra display the influence of high-frequency loads on long-term stresses, in that high-frequency loads increased the stress ranges as well as the number of load cycles. Stress ranges of low probability of occurrence increased more than stress ranges of higher probability of occurrence because whipping was more pronounced in the less probable, severe seaways. However, the smaller stress ranges occurring between about $10^4$ to $10^6$ cycles contributed most to fatigue damage, designated as “fatigue strength regime” in Figure 15.

To quantify the effect of high-frequency loads on the life to failure of typical ship structural details, fatigue damage was determined from the measured spectra of low-pass filtered and unfiltered stresses. As a measure of fatigue damage, the cumulative damage ratio, $D$, was calculated according to the Palmgren-Miner linear cumulative fatigue damage hypothesis. For the stress range spectra shown in Figure 15, Figure 16 plots the cumulative frequency against the associated distribution of fatigue damage, here expressed as damage ratios $D_i$ for the blocked spectra. As can be seen and mentioned above, load cycles in the range of $10^4$ to $10^6$ caused the major part of fatigue damage, in other words load cycles outside this interval barely contributed to total fatigue damage.

The ratio of cumulative damage for the unfiltered response and low-pass filtered response reflects the increase of fatigue damage caused by the high-frequency part, here referred to as HF factor. Table 2 lists the resulting HF factors for the 4,600 TEU ship based on strains measured from gages located below the upper deck.

Full-scale measurements onboard the 14,000 TEU ship revealed the predominant influence of the vertical hull girder bending vibration modes. This became evident by comparing stress range spectra from different strain gages attached to a hatch corner in the upper deck close to amidships. Figure 17 compares unfiltered and low-pass filtered, normalised stress spectra based on strain measurements.
from gages located at the inner and outer radius of this hatch corner. The outer strain gage (designated by the colour blue) measured considerably greater increases of stress ranges due to high-frequency loads than the inner strain gage (designated by the colour red). The inner gage mainly measured strains caused by torsional loads, the outer gage mainly strains caused by vertical bending. Thus, it was concluded that the influence of torsional vibration was small compared to the influence of vertical hull girder bending vibration.

Based on the findings described above, DNV GL issued guidelines for fatigue assessment of high-frequency hull girder response of container ships that came into force in 2013 (GL, 2013a). The guidelines comprise a semi-empirical approach that relies on results from full-scale measurements and on state-of-the-art seakeeping computations. It is further based on damage data collected from the fleet of container ships classed by DNV GL. As the method utilises high-frequency loads extracted from the full-scale measurements, it comprises all kinds of hull girder vibrations, including whipping and springing.

A question which is often raised with respect to hull girder vibrations is whether the fatigue resistance of welded ship structural details is affected by the superposition of high- and low-frequency loads and if the usual fatigue assessment would cover this. To investigate this topic, Hamburg University of Technology performed fatigue tests in cooperation with DNV GL using load histories, measured on the 4,600 TEU container ship. Refer to Kahl et al. (2014) and Fricke and Paetzold (2012).

A 30-minute time series as shown in Figure 19 and the low-pass filtered time series were applied to welded specimens as shown in Figure 18. Figure 20 shows an enlarged part of the stress history shown in Figure 19 together with the low-pass filtered signal, and Figure 21 illustrates the cumulative distributions of the stress range for both stress histories. It can clearly be seen that the stress ranges are enlarged by the vibration (by up to 30%) and that the total number of stress cycles is considerably increased, in this case by a factor of 2.9.
Diagrams in Figure 22 show the results of the fatigue tests in terms of fatigue lives (number of cycles to failure) with the measured stress history (left) and the low-pass filtered 30-minute stress history (right). The tests were performed on different load levels, which are indicated by the maximum stress range in the time series as given on the ordinate of the diagrams. The results are shown in relation to the fatigue life predictions for damage sums $D = 1$ and $D = 0.5$. It can be seen that the relation between the fatigue lives from the tests and the life predictions is similar for the measured and low-pass filtered 30-minute stress histories. Thus, the standard methods for fatigue life prediction are working well for both stress histories with and without superimposed high-frequency loads.

![Figure 20](image-url) - Enlarged part of the stress history shown in Figure 19

![Figure 21](image-url) - Cumulative distributions of the stress range of the 30-minute stress history shown in Figure 19 and for the low-pass filtered stress history

![Figure 22](image-url) - Fatigue lives from variable-amplitude tests with measured stress history (left) and low-pass filtered 30-minute stress history (right) and life prediction
New rules that consider route-specific stowage of containers onboard container ships have recently been introduced by DNV GL (GL, 2013b) to contribute to increasing container capacity compared to current standard lashing procedures. The old lashing rules were based on unrestricted service in any sea environment. The new lashing rules, valid since May 2013, consider route-specific lashing, allowing ship operators to carry heavier containers stacked higher on deck and to enable ships to carry more cargo and facilitate more stowage options. For the development of the new rules, systematic long-term seakeeping computations of ship motions and lateral accelerations for route-specific environments were performed (Rathje et al., 2013). These seakeeping computations in route-specific environments utilised wave scatter tables derived from full-scale measurements as described above.

The computed lateral accelerations for route-specific environments were validated by comparison to results from full-scale measurements on the 4,600 TEU and 14,000 TEU container ships. From the measured data, Weibull spectra of transverse accelerations were extrapolated for 20 years of operation to obtain the associated extreme values for both ships (see Figure 23 for an example). From these values, acceleration factors were obtained, showing the relation between the extreme acceleration values and gravity. Table 3 lists the resulting comparable measurement- and rule-based transverse acceleration factors for locations on the upper deck of the container ships as shown in Figure 24. These factors were obtained for the most frequent loading conditions, characterised by a GM equal to 1.0 m and 5.0 m for the Panamax ship and the post-Panamax ship, respectively, and a draft equal to 80% of the scantling draft. The generally favourable agreement validated the new (2013) rules for stowage and lashing of containers.

### Table 3 - Comparable Transverse Acceleration Factors on Upper Deck of Two Container Ships

<table>
<thead>
<tr>
<th>Location</th>
<th>4,600 TEU</th>
<th>14,000 TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement</td>
<td>Aft</td>
<td>0.42</td>
</tr>
<tr>
<td></td>
<td>Fore</td>
<td>0.48</td>
</tr>
<tr>
<td>Rules 2013</td>
<td>Aft</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>Fore</td>
<td>0.49</td>
</tr>
</tbody>
</table>

Figure 23 - Determination of extreme values of transverse accelerations for 20 years from measured data

Figure 24 - Locations for the evaluation of transverse accelerations on the 4,600 TEU (top) and the 14,000 TEU (bottom) container ship
SUMMARY AND PERSPECTIVE

Full-scale measurements are an important source of information for validating design rules and guidelines as well as for formulating rule approaches and formulas. Several full-scale measurements have been performed by DNV GL Maritime Technology in the past, and the three most recent full-scale measurement campaigns on container ships have been described. Evaluations of operational and navigational data as well as evaluations with respect to high-frequency hull girder response and to route-specific container stowage have been illustrated as examples for the exploitation of these measurements. It becomes obvious that full-scale measurements are essential for backing up innovation by validation and for supplying operational data that is needed to make appropriate assumptions for developing rules.

The need for full-scale measurement results will persist; however, in future more and more data may be available from hull monitoring systems, which are becoming more common, in particular on large ships. This trend would give the opportunity to gather data from a large number of ships, from different ship types and for different trades. Up to now, measurements have been installed only on a limited number of ships yielding data only representative for the specific ship type, ship size and operated route. This drawback could be compensated to some extent by the systematic acquisition of data from hull monitoring systems. It has to be considered, however, that those systems will record only specific ship responses.

REFERENCES

Driven by its purpose of safeguarding life, property and the environment, DNV GL enables organisations to advance the safety and sustainability of their business. DNV GL provides classification and technical assurance along with software and independent expert advisory services to the maritime, oil & gas and energy industries.

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