Classification of Dredgers – Technical & Regulatory Developments

G. de Jong (Product Manager, Bureau Veritas)

The dredging industry has developed itself from a locally oriented activity to maintain navigable waterways into a global industry involved in maintenance dredging, land reclamation, coastal and port construction, as well as offshore construction by making use of evermore sophisticated and powerful ships. The vessels are extremely specialised and require special attention for design, construction and operation. Therefore, dedicated rules and regulations for dredgers are necessary to ensure adequate safety standards. As the leading classification society for dredgers Bureau Veritas has deep knowledge of and long term experience with dredgers. This paper discusses the key technical issues for the different types of dredgers in use today and provides a comprehensive overview of the applicable statutory regulations and classification rules. In addition, the latest technical advances of the dredging industry and the associated regulatory developments are outlined.

KEY WORDS
Dredging, dredger, classification, rules & regulations, stability, freeboard, structural strength, fatigue, class notations

INTRODUCTION
Dredging has always been a special activity within the maritime industry, making use of dedicated vessels on which specialised technology has been installed. Different types of dredging vessels (dredgers) have been developed for the varying dredging activities. The oldest dredging activities involving ships are peat extraction and maintenance dredging. Maintenance dredging is dredging in order to maintain channels and waterways navigable or to deepen them for the passage of ships with greater draught. This is particularly necessary in coastal areas with large tidal activity and in rivers which are threatened to become silted with sedimented sand and mud (effectively reducing the water depth over time). The Lowlands (Netherlands and Flanders) are a good example of such area. During the Middle Ages peat was extracted by applying dredging poles (or dredge hauls) over the aft of small boats to manually dredge the bottom of peat-moor waterways. The peat was used as a fuel for households and workshops. The same technique was also used to maintain waterways at navigable depth. Waterways with strong currents were dredged using a krabbelaar, a flat bottomed vessel equipped with sails, which was used to drag a plough over the sea or river bottom while drifting along with the current. The loosened sand and mud were consequently carried away by the current. In 1575 Joost Janszoon Bilhamer introduced the moddermolen, an early type of bucket dredger that mechanically collects sediment by circulating a line of buckets which are attached to a wheel or chain. The introduction of the bucket dredger was an important step forward in productivity and efficiency of dredging and marked the start of land reclamation dredging, as the dredged material could be pumped (through vacuum suction) into the ship’s cargo hold in order to off-load at a designated location by means of dumping through the bottom doors (by gravity) or by pumping it overboard with a powerful pump. TSHDs were used as early as 1868 for the construction of the Nieuwe Waterweg, which created a direct link between Rotterdam and the North Sea. The second new type of dredger was the cutter suction dredger (CSD), which uses a cutter head to effectively cut the material to be dredged, which may be consist of both sand as well as hard materials such as rocks which cannot be dredged using a TSHD. The vacuum aft of the cutter head (created by the centrifugal pump) enables the dredged material to be sucked into the dredging line in order to off-load it into hopper barges or split hopper barges, which can dump their cargo by splitting their port side (PS) and starboard (SB) halves along a longitudinal axis (both sides are connected by hinges and controlled by hydraulic cylinders). CSDs are equipped with a retractable spud pole (at the opposite end of the vessel), which enables the cutter head to swing from one side to the other by making use of anchors on long booms. Normally the spud pole is located in a spud carrier which is riding longitudinally through the CSD. This enables the ship to slowly advance while dredging. Stationary CSDs were already used for the maintenance of the Suez Canal in the first decade of the twentieth century. The first electrically driven self-propelled cutter suction dredger was built in 1956 for a Dutch dredging company. Other types of dredgers include the backhoe dredger (sometimes called dipper dredger), which is basically an excavator installed on a pontoon (using spud poles to maintain position), and the water injection dredger, which injects water into the seabed under low pressure to loosen the sediment for being taken away by the current (similar to the krabbelaaar). Both types are mainly used for shallow waters. In more recent years new dredging activities, relating to port construction, coastal engineering and offshore subsea construction (related oil & gas production and

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1 In Dutch: baggerbeugel

2 Designed by Pieter Caland on the basis of observation of similar vessels abroad.
transportation) have been developed. This has lead to the introduction of stone dumping vessels.

As dredging was historically a local activity on inland waterways and coastal waters, statutory regulations relating to design, construction and operation of dredgers were issued by local authorities or, at best, national authorities. Usually such regulations were based on local experience and circumstances. The only generic system of requirements, based on more general principles and global experience, were the rules and regulations of classification societies. Historically Bureau Veritas has been actively involved with the dredging industry, not in the least because the classification society was founded in 1828 in the city of Antwerp, at the time part of the Kingdom of the United Netherlands where a thriving dredging industry existed. A dedicated chapter with technical requirements for dredgers can be found as far back as the 1909 edition of the Bureau Veritas rules & regulations for the classification of steel and iron ships. The rules have been evolving ever since, along with the increasing operational experience and the introduction of new types of dredging vessels, construction materials and methods, as well as powering technology.

In the 1950s dredgers, in particular TSHDs, evolved into seagoing ships engaged in international voyages. Consequently the vessels needed to comply with international regulations, in particular the International Convention on Load Lines (1930, 1966), the International Convention for Safety of Life At Sea (SOLAS, 1914, 1929, 1948, 1960, 1974) and the International Convention for the Prevention of Pollution of the Sea by Oil (OILPOL, 1954), now replaced by the International Convention for the Prevention of Pollution from Ships (MARPOL, 1973). Typical requirements include freeboard and reserve buoyancy, weathertight integrity and intact stability, watertight integrity and damage stability as well as pollution prevention. In some aspects the design of dredgers, in particular hopper dredgers, is quite different from cargo ships and consequently not compatible with the international requirements which have primarily been drafted for cargo ships. Typical issues to be addressed are the absence of hatch covers on the hopper well(s), the working freeboard (dredging operations can only be undertaken in the shallow waters of coastal regions), the application of bottom openings for dumping the cargo and the physical properties of the cargo (dredged material is a mixture of sand and water and shows behaviour as both liquid and dry bulk cargo).

The 1990s marked the start of the era of scale enlargement of hopper dredgers, which provided the dredging companies with important economy of scale advantages as well as increased productivity needed for the new land reclamation projects (e.g. in Singapore). In addition, the increased ship length made it possible to install longer suction tubes, which facilitate mining of sand at greater water depth (using on or more submersible dredge pumps). The Pearl River, delivered in 1994 by IHC Dredgers (Kinderdijk, Netherlands) was the first hopper dredger with a hopper capacity of over 15,000 m³. In 1997 Verolme (Heusden, Netherlands) delivered the WD Fairway, the first so called “jumbo hopper” (hopper capacity 23,350 m³). The next step forward was the first “post-Panamax” hopper dredger Vasco da Gamma (hopper capacity 33,000 m³), delivered in 2000 by Krupp (Emden, Germany). In the first decade of the twenty-first century the existing hopper dredgers WD Fairway (2005) and HAM 318 (2008) were lengthened in order to achieve hopper capacities of 35,500 m³ and 37,500 m³, respectively. Fig. 1 shows the TSHD Queen of the Netherlands, the sistership of the WD Fairway which was lengthened in 2009. Finally, in 2009 Constructiones Navales del Norte (Sestao, Spain) delivered the 46,000 m³ hopper dredger Cristóbal Colón, the largest hopper dredger built to date. She was followed by her sister Leiv Eiriksson in 2010. One of the key technical issues related to scale enlargement is the ship structural assessment, both in relation to the strength capacity (yielding, buckling) as well as fatigue of structural details. This has lead to the introduction of 3D Finite Element Analysis (FEA) and advanced fatigue assessment for hopper dredgers being used for the design verification by class. In addition, dynamic position is making its entry into the market. The aim is to increase precision and reduce manoeuvring time.

Another important development initiated during the last decade of the twentieth century is the optimisation of the hull shape of hopper dredgers, for example through the application of extremely wide bulbous bows, in order to improve trim control and maximise payload while at the same time minimising the operating draught (better performance in shallow water).

On the regulatory side the publication of the Guidelines for the Construction and Operation of Dredgers Assigned Reduced Freeboards (DR-67), published by IMO in 2001 under Circular Letter No. 2285 marked a breakthrough (IMO, 2001). The
guidelines are the outcome of a joint Working Group consisting of interested parties from Belgium, France, Germany, the Netherlands and the United Kingdom and contain the first multinational agreed technical requirements for the design of hopper dredgers, including Load Line Marks and freeboard, the hopper arrangement, intact and damage stability, construction and equipment (dumping system, dredge valves, etc.). Making use of its technical expertise and extensive in-service experience, Bureau Veritas has actively contributed to the conception of the guidelines and has incorporated the requirements into the rules and regulations for ship for dredging activity (Bureau Veritas, 2000). In 2010 the guidelines have been updated and published as Guidelines for the Assignment of Reduced Freeboards for Dredgers (DR-68), mainly to take into account the latest amendments to the SOLAS Convention.

Apart from hopper dredgers also cutter suction dredgers have gone through a process of enlargement, in particular by increasing the effective cutter power. Before the start of the twenty-first century the cutter power was typically below 4,000 kW. The JFJ de Nul, built in 2003 by IHC Dredgers was the first of a new generation of self-propelled “mega-cutters”, with an effective cutter power of about 7,600 kW. Fig. 2 shows another new generation self propelled cutter dredger d’Artagnan, with an installed power of 27,240 kW. One of the key technical issues related to such large installed power is the control of noise and vibrations.

The renewed interest for cutter suction dredgers, fuelled by new capital dredging projects, such as the extension of the Panama Canal and the building and expansion of port facilities, has also created fresh demand for extension and renewal of the fleet of split hopper barges, which are used to remove the dredged materials. Due to their design specific technical challenges need to be considered, in particular the global strength of the half hulls and the design of the strength of hinges and cylinders when operating in a seaway. The maximum hopper capacity of split hopper barges in service is about 3,700 m³, which corresponds to about 6,300 dwt, see Fig. 3.

During the past few years backhoe dredgers have also gone through a process of scale enlargement by increasing the excavator size and power as well as the grab. Today’s most powerful backhoes use grabs of up to 40 m³ and can work in water depths of up to 26 m, see Fig. 4.

The scope of this paper is to make the reader familiar with dredging activities, the different types of dredgers in use and their characteristic technical issues, as well as to provide an overview of the applicable requirements from the viewpoint of classification rules and statutory regulations. Following the above described introduction into dredging, dredgers and the historical development of technology and technical requirements, the remainder of this paper will address the applicable rules & regulations, considering the key technical features for each of the stipulated dredger types, and present the latest technical and regulatory developments.

**RULES & REGULATIONS**

As other seagoing ships, dredgers are subject to compliance with a large number of general and dedicated regulations. The key international regulations and guidelines applicable to dredgers are listed in Table 1.

The Guidelines for the Assignment of Reduced Freeboards for Dredgers (DR-68) are dealing with some of the main technical and regulatory issues of hopper dredgers. The first point is those hopper dredgers have historically been working (dredging) at a
draught higher than the maximum summer load line in accordance with the ICLL, see Fig. 5. In other words, hopper dredgers are operating at a reduced freeboard. Although reduced freeboards are covered by Regulation 27 paragraph 7, 8 and 9 of the ICLL, the associated (deterministic) damage stability requirements are not normally applied to dredgers. In addition, the dredging freeboard is usually less than the minimum freeboard as per Regulation 27. Consequently, it is concluded that hopper dredgers generally do not comply with the provisions of Article 12(1) of the ICLL, stating that [...] the appropriate loads lines on the sides of the ship corresponding to the season of the year and the zone or area in which the ship may be shall not be submerged at any time when the ship puts to sea, during the voyage or on arrival. This can be both technically and historically justified by considering that dredging operations are normally undertaken in coastal areas due to the restricted operating depth of suction tube. In such areas, which are often sheltered, extreme sea conditions are unlikely to occur. Moreover, dredging operations in a seaway are restricted by the capacity of the heave compensation system installed to prevent damages to suction tube and ship due to large motions. A generally accepted practical upper working limit is about 3 m significant wave height. Consequently the probability that a hopper dredger will encounter extreme seas while operating at the dredging draught is limited. But even if this would happen, hopper dredgers are in a position to mitigate safety risks by opening their bottom doors and releasing (part of) their cargo into the sea by gravity. In this way a hopper dredger can quickly increase the freeboard to a value consistent with the summer load line as per ICLL Regulation 40. As the emergency dumping of the cargo works by gravity, it can also be done in the case of a dead ship by simply releasing the bottom doors. In addition to the above explanation, DR-68 contains specific technical requirements which are to be complied with in order to grant the reduced freeboard, as described later in this section.

Table 1. Key international regulations and guidelines applicable to dredgers

<table>
<thead>
<tr>
<th>Regulations and Guidelines</th>
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<tr>
<td>International Safety Of Life At Sea (SOLAS) Convention, 1974 (self propelled ships ≥ 500 gt)</td>
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<tr>
<td>International Convention on Load Lines (ICLL), 1966 (L ≥ 24 m)</td>
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<tr>
<td>International Convention for the Prevention of Pollution from Ships (MARPOL), 1973</td>
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<tr>
<td>Guidelines for the Assignment of Reduced Freeboards for Dredgers (DR-68), 2010</td>
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<tr>
<td>Developed by DR-67 Joint Working Group, 3 February 2010</td>
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<tr>
<td>Code of Safety for Special Purpose Ships (SPS Code), 2008</td>
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<tr>
<td>IMO Res. MSC.266(84), adopted 13 May 2008</td>
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<td>Previously IMO Res. A.534(13), adopted 17 November 1983</td>
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<tr>
<td>Ballast Water Management Convention, 2004 (not yet in force, pending ratification)</td>
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<td>Maritime Labour Convention, 2006 (not yet in force, pending ratification)</td>
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<tr>
<td>Standards of Training, Certification &amp; Watchkeeping (STCW), 2005</td>
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The second point is that hopper dredgers generally have no hatch covers on the hopper well, which apparently contradicts with Regulation 14 paragraph 1 of the ICLL requiring that the construction and means for securing the weathertightness of cargo and other hatchways [...] shall be at least equivalent to the requirements of Regulations 15 and 16 [of the ICLL]. Regulation 15 covers the requirements for hatchways closed by portable covers and secured weathertight by tarpaulins and battening devices, while Regulation 16 contains requirements for hatchways closed by weathertight covers of steel or other equivalent material fitted with gaskets and clamping devices. Hopper dredgers are generally exempted from the fitting of hatch covers on the hopper wells because sufficient structural strength and stability are to be demonstrated for all possible loading and operational conditions, taking also into account effects of water ingress into the hopper well(s). Again DR-68 provides the technical requirements for accepting such exemption.

Both mentioned exemptions are to be effectuated through an International Load Line Exemption Certificate, as regulated by DR-68 (see Sec 9) and Article 6(2) of the ICLL (see Annex 2 to DR-68 for the relevant form).

Seagoing hopper dredgers engaged on international voyages are generally compliant with international regulations as well as the rules and regulations of a classification society. In this paper the classification rules of Bureau Veritas, the leading classification society for dredgers, are used as a reference. These rules contain very specific technical requirements which have been drafted on the basis of in-service experience as well as research projects executed in cooperation with the dredging industry.

The following two subsections address DR-68 and Bureau Veritas rules and regulations for ships for dredging activity in detail.
DR-68

The preamble of the Guidelines for the Assignment of Reduced Freeboards for Dredgers (DR-68) starts with a brief description of the activities in which dredgers are involved (DR-67 Joint Working Group, 2010):

- clearance or maintenance duties in ports, docks and navigation channels;
- reclamation of land and beach replenishment;
- recovery of materials for the building and civil engineering industries.

As also described in the introduction to this paper, DR-68 acknowledges that dredgers historically the dredging trade did not usually cross national boundaries, hence the existence of a variety of national standards. As the trade developed and became international an international load line assignment in accordance with the provisions of the ICLL became a requirement. Acknowledging that dredgers may be designed to load cargo resulting in a deeper draught than allowed by the ship’s freeboard assignment, the purpose of the guidelines is to establish criteria by which a dredger (and similar vessels) may be issued an ICLL Exemption certificate allowing it to conduct operations at a reduced freeboard (that is, submergence of load line marks). To this end DR-68 provides design and equipment requirements in order to ensure that the dredger has the ability to quickly dump its cargo, also in the event of loss of primary power, which results in an immediate increase of sufficient buoyancy and freeboard to comply with operation at the dredger’s normal ICLL freeboard. The “Joint Working Group on dredgers operating at Reduced Freeboard” represented classification societies, the dredging industry, the shipbuilding industry and regulatory bodies from Belgium, France, Germany, the Netherlands, the United States of America and the United Kingdom. The resulting harmonised standard for construction and operation of dredgers has been developed on the basis of overall safety equivalence to the ICLL, 1966, as modified by the Protocol of 1988 thereto and amended by Resolution MSC.143 (77).

DR-68 specifies design criteria, operation and survey standards and operational safety measures for dredgers permitting safe operation at freeboards less than the minimum freeboards prescribed by the ICLL. The guidelines apply to (self-propelled) dredgers of 500 gt and above, as measured in accordance with the International Tonnage Convention (ITC), 1969, the keels of which are laid, or which are at a similar stage of construction, on or after 1 January 2010. The guidelines may also be applied to existing dredgers and dredgers of less than 500 gt which are subject to the requirements of the ICLL. In addition, the guidelines may be applied to similar vessels, such as hopper barges and stone dumping vessels, if they are capable of discharging their cargo in accordance with the requirements of the guidelines (Sec 7.1). Unmanned or non-self propelled vessels are considered as well (Sec 13). The main topics addressed by the guidelines are related to load lines & freeboard, construction, intact & damage stability, equipment, information to the master, certificates, exemptions & equivalents, surveys and special considerations.

Load Lines & Freeboard

Dredgers with a reduced freeboard are provided with a special load line mark, as shown in Fig. 6.

Fig. 6. Example of (double) load line mark for dredger with reduced freeboard

The reduced freeboard may be assigned for the loading, carrying or discharging of dredgings and is equal to the summer freeboard calculated for a type B ship in accordance with Regulation 40 of the ICLL, reduced by 2/3 of the resulting summer freeboard to be calculated without Regulation 39 (bow height and reserve buoyancy) being taken into account. The resulting summer freeboard as for a type B vessel without any reduction or addition is to be used for calculating the dredger freeboard. The minimum bow height at the dredger load line is the bow height provided by Regulation 39(1) of the ICLL, reduced by the reduction calculated for the dredger freeboard. No requirement for reserve buoyancy applies at the dredger freeboard. The dredger freeboard in fresh water is obtained by deducting the D/40T centimetres from the minimum dredger freeboard in salt water, with D representing the displacement in salt water (in tonnes) and T the tonnes per centimetre immersion in salt water at the dredger freeboard.

Other requirements include the prohibition of fitting bulwarks along the ships’ side abreast of any open hopper and the fitting of a safe access from the fore end to the aft end of the dredger (crew protection). If the access is above the freeboard deck, it shall be as high above the freeboard deck as the difference between the summer freeboard and the dredger freeboard.

Any open hopper and means of overflow of process water are to be arranged as follows:

(a) over the spill-out edge of the hopper coaming; or
(b) trough overflow ducts or spillways in the hopper walls; or
(c) through adjustable overflows.

The overflow arrangements (b) and (c) are to have an area, in m², at least equal to the greater of 0.7Lₙ/1000 or Q/3, where Lₙ is the maximum length of the hopper, in m, and Q is the total maximum water capacity of the suction dredge pumps, in m³/s.
Most modern hopper dredgers are equipped with an adjustable overflow to enhance operational flexibility and efficiency.

The guidelines also provide requirements for a suitable hopper geometry as follows, considering the height of the spill-out edge of the hopper above the dredger load line or freeing ports for an open hopper, or alternatively, a closed hopper. The spill-out edge of the hopper is to be located above the minimum bow height at all points. Subject to suitable hopper arrangement the content of the hopper is assumed to be cargo up to lower edge of the overflow arrangement or, in the case of high density cargoes, the cargo plus a layer of sea water on top of the cargo up to the spill-out edge of the hopper. In other cases the layer of sea water is assumed to extend to the spill-out edge of the hopper.

In addition, the location of cargo ports and other similar openings, scuppers, inlets & discharges, as well as side scuttles is to be related to the dredger load line. The minimum coaming height of air pipes and ventilators located on the freeboard deck is to be increased by the difference between the summer freeboard and the freeboard at the dredger load line. Generally, coamings of air pipes and ventilators on board dredgers are to be not lower above the waterline than calculated for the coaming height of air pipes and ventilators on the freeboard deck.

**Construction**

The guidelines require that the structural strength of a dredger operating at the dredging freeboard shall be approved. Depending on the strength capacity operational limitations may be imposed. Different restrictions can be applied at various drafts suitable to the operation of the dredger. In this respect the term approved reverts to compliance with the structural strength standards of a recognised organisation (e.g. a classification society).

**Intact stability**

Specific requirements for both intact and damage stability are provided. For assessing the intact stability particulars, the calculation of the righting lever curves is to taken into account the following points:

(a) the change of trim due to heel (this aspect cannot be ignored for dredgers);
(b) the inflow of sea water or outflow of liquid cargo and sea water over the spill-out edge of open hoppers;
(c) the inflow of sea water through any overflow, spillway or freeing port, either at the lower edge of the opening or at the cargo/sea water interface, whichever is the lower;
(d) the outflow of the cargo only occurs over the spill-out edge of the hopper where this edge has a length of at least 50 per cent of the maximum hopper length at a constant height above the freeboard deck on both sides of the hopper.

The following loading conditions considering the full range of cargo densities are to be taken into account:

1. The dredger loaded to the dredger load line, considering the cargo in liquid state, in the following conditions:
   - the hopper(s) fully loaded with homogenous cargo of density \( \rho_m \), up to the spill-out edge of the hopper, where \( \rho_m \) is given as the mass, in kg, of cargo in the hopper at the dredger load line and \( V_t \), the volume, in \( \text{m}^3 \), of the hopper at the spill-out edge of the hopper, taking into account conditions for stores and fuel equal to 100 per cent and 10 per cent and an intermediate condition if such a condition is more critical;
   - the hopper(s) filled or partly filled with a homogeneous cargo of densities equal to 1000, 1200, 1400, 1600, 1800, 2000 kg/m\(^3\) (when the dredger load line cannot be reached due to the density of the cargo the hopper is to be considered filled up to the spill-out edge of the hopper), taking into account the condition for stores and fuel that is the most critical for density \( \rho_m \) as described under (a);

2. The dredger loaded to the dredger load line, considering the cargo in solid state, in the following conditions:
   - the hopper(s) fully loaded with a homogeneous cargo of density \( \rho_m \) as described for the case of cargo in liquid state above), taking into account conditions for stores and fuel equal to 100 per cent and 10 per cent and an intermediate condition if such a condition is more critical;
   - the hopper(s) filled or partly filled with a homogeneous cargo of densities equal to 1400, 1600, 1800, 2000, 2200 kg/m\(^3\) which are greater than \( \rho_m \), taking into account the condition for stores and fuel that is the most critical for density \( \rho_m \) as described under (a);
   - for dredgers with bottom doors or similar means at port side and starboard side, an additional calculation is to be made for asymmetric discharging, where the dredger is assumed to be loaded with solid cargo of a density equal to 1900 kg/m\(^3\) and, when discharging, 20 per cent of the total hopper load is assumed to be discharged at only one side of the longitudinal centre line of the hopper (horizontally equally distributed at the discharging side), considering the following limiting criteria:
     - the angle of equilibrium should not exceed 25 degrees;
     - the righting lever (GZ) within the 30 degrees range beyond the angle of equilibrium should be at least 0.10 m;
     - the range of (positive) stability should not be less than 30 degrees;

3. The hopper(s) without cargo with the bottom dumping system being open to sea, and with stores and fuel at each of 100 per cent and 10 per cent and an intermediate condition if such condition is more critical, while for split hopper dredgers an additional calculation is to be made in split hull configuration, with stores and fuel at each of 100 per cent and 10 per cent and an intermediate condition if such condition is more critical.
The following intact stability criteria are to be verified for the listed loading conditions (except the asymmetric discharging condition, for which the criteria are provided above):

- The area under the righting lever ($GZ$) curve is to be not less than 0.07 mrad up to an angle of 15 degrees when the maximum righting lever ($GZ_{\text{max}}$) occurs at 15 degrees, and not less than 0.055 mrad up to an angle of 30 degrees when $GZ_{\text{max}}$ occurs at 30 degrees or above;
- Where $GZ_{\text{max}}$ occurs at angles between 15 degrees and 30 degrees, the corresponding area under the righting lever curve is to be not less than $0.055 + 0.001(30 - \theta_{\text{max}})$ mrad, where $\theta_{\text{max}}$, in degrees, is the angle of heel at which the righting lever curve reaches its maximum;
- The area under the righting lever curve between the angles of heel of 30 degrees and 40 degrees, or between 30 degrees and $\theta_{\text{h}}$ if this angle is less than 40 degrees, is to be not less than 0.03 mrad, where $\theta_{\text{h}}$ in degrees, is the angle of heel at which openings in the hull, superstructure or deckhouses which cannot be closed weathertight immerse (small openings through which progressive flooding cannot take place need not be considered as open);
- The righting lever ($GZ$) is to be at least 0.20 m at an angle of heel equal to or greater than 30 degrees;
- The maximum righting lever ($GZ_{\text{max}}$) is to occur at an angle of heel not less than 15 degrees;
- The initial metacentric height ($GM_0$), corrected for the free surface effect of tanks and hopper(s) containing liquids, is to be not less than 0.15 m.

Analysis of the loading conditions and stability criteria learns that DR-68 follows a similar approach to the International Code on Intact Stability, 2008, for supply vessels (see 2008 IS Code, Pt A, Sec 2.4.5), taking into account the specific characteristics of dredgers carrying dredgings in the hopper(s). One of the key points is that the dredgings, often called spoil, are a mixture of substances that are naturally solid and sea water. Whether the spoil “behaves” more as a liquid or as a solid substance (like dry bulk cargo) depends on the quantity of sea water in the mixture and the time the spoil has been carried in the hopper. During dredging process a large amount of water is used as process water to liquefy the spoil and make it easy to pump into the hopper. This process water is then drained from the hopper (through the overflow) in order to maximise the amount of payload (e.g. sand for construction or beach replenishment), creating a more solid type of spoil. In order to be on the safe side the stability requirements cover both extreme cases of liquid and solid cargo, taking into account the rule of thumb (from practical experience) that spoil tends to behave as a liquid if the density is less than 1400 kg/m$^3$. If the spoil has been in the hopper for some time it tends to settle and behave even more like a solid substance. Another important point is that the outflow of spoil into the sea and the inflow of sea water into the hopper are to be taken into account for the calculation of the righting lever curve.

In addition DR-68 requires the application of the weather criterion as per the International Code on Intact Stability, 2008 (see 2008 IS Code, Pt A, Sec 2.3) as follows. First, the dredger is considered as loaded up to the summer load line with the cargo in liquid state and 10 per cent stores and fuel. The hopper(s) are assumed to be filled with a homogeneous cargo up to the spill-out edge of the hopper where the density of such cargo equals or exceeds 1000 kg/m$^3$. Where this condition implies a lighter cargo than 1000 kg/m$^3$ the hopper is considered to be partially filled with a cargo of density equal to 1000 kg/m$^3$. Secondly, the dredger is to comply with the weather criterion at the dredger load line, where a reduced wind pressure equal to $P=270$ Pa may be assumed (instead of 504 Pa for the summer load line).

**Damage stability**

DR-68 requires application of the probabilistic damage stability approach in accordance with the provisions of SOLAS Ch II-1, as amended, but with some modifications in order to taken into account the specificities of dredgers. For dredgers with a subdivision length (Ls) of less than 80 m the Required Subdivision Index (R) is to be calculated using Ls=80 m. It is noted that DR-68 requires damage stability to be calculated for all dredgers irrespective of their length, whereas SOLAS requires compliance with the damage stability requirements for cargo ships with a length (L, as defined as defined in the ICLL) of 80 m and upwards.

For the assessment of the damage stability the following points are to be taken into account for the calculation of the righting lever curves:

- The change of trim due to heel;
- The inflow of sea water or outflow of liquid cargo and sea water over the spill-out edge of open hoppers;
- The inflow of sea water through any overflow, spillway or freeing port, either at the lower edge of the opening or at the cargo/sea water interface, whichever is the lower (adjustable overflows operated from the navigation bridge may be considered to be located at the highest position);
- The outflow of the cargo only occurs over the spill-out edge of the hopper where this edge has a length of at least 50 per cent of the maximum hopper length at a constant height above the freeboard deck on both sides of the hopper;
- The sliding of the cargo surface in the hopper, in transverse and longitudinal direction according to the following shifting law (assuming the cargo surface to be plane):
  - $\theta_0=\theta_0$, for $p \leq 1400$ (liquid cargo);
  - $\theta_0=\theta_0,(2000-p)/600$, for $1400< p < 2000$ (sliding cargo);
  - $\theta_0=0$, for $p \geq 2000$ (solid cargo); where $p$, in kg/m$^2$, is the cargo density, $\theta_0$, in degrees, the shifting angle of the cargo surface, and $\theta_0$, in degrees, the angle of heel or trim, as applicable.
All possible progressive flooding possibilities are to be taken into account in the calculations\(^4\). Internal progressive flooding may occur via:

- pipes and connected valves which are located within the assumed damage, where no valves are fitted outside the damage zone;
- pipes, even if located outside the damage zone, if the considered pipe connects a damaged space to one or more intact spaces, is located below a damage waterline at all points between the connected spaces and has no valves between the connected spaces;
- all internal doors other than remotely operated watertight sliding doors and watertight access doors required to be normally closed at sea.

External progressive flooding may occur via external openings where a damage waterline, taking into account sinkage, heel, and trim, immerses the lower edge of the sill or coaming and where spaces interconnected with those assumed to be damaged.

The attainable subdivision index \(A_{dl}\) is calculated as follows:

\[
A_{dl} = \frac{2200 - 200(i)}{i}, \quad i = [0, 1, 2, 3, \ldots, 6]
\]

\(^4\) Progressive flooding is defined as an additional flooding of spaces interconnected with those assumed to be damaged.

The attained subdivision index \(A_{dl}\) is to be calculated for each of the following cargo densities, assuming the dredger is loaded at dredger load line \(d_L\), with 50 per cent stores and fuel:

(a) design density \(\rho_d\) in kg/m\(^3\), corresponding to the dredger load line, where \(\rho_d\) is calculated as \(M_2/V_2\), with \(M_2\) representing the mass, in kg, of cargo in the hopper at the dredger load line and \(V_2\) the volume, in m\(^3\), of the hopper at the highest overflow position;

(b) each density \(\rho_v\) in kg/m\(^3\), greater than \(\rho_d\) defined by \(\rho_v = 2200 - 200(i)\), with \(i = [0, 1, 2, 3, \ldots, 6]\).

The calculations are to take into account the initial trim at the dredger load line and an assumed permeability of the cargo-filled hopper space of 0 per cent and a permeability of the space above the cargo equal to 100 per cent. The cargo (spoil) is considered not to be porous and any sea water that enters a partially filled hopper due to damage ingres only to the space above the upper surface of the cargo.

The Required Subdivision Index \(R\) and the Attained Subdivision Index \(A\) are to be calculated according to SOLAS Ch II-1, as amended, but taking into account the following formulae (instead of SOLAS Reg II-1/7.1):

- \(A \geq R\), for each cargo density;
- \(A \geq 0.7R\);
- \(A_{dl} \geq 0.7R\), for each cargo density, where \(A = 0.5(A + A_{dl})\), \(A_{dl}\) is the attained subdivision index at light, unloaded draught \(d_l\) and \(A_{dl}\) is the attained subdivision index at loaded dredging draught \(d_L\) and cargo densities defined above.

**Equipment**

Dredgers are to be equipped with a cargo dumping system capable of discharging the cargo by gravity in such a way that the freeboard can be increased from the dredger load line to the summer load line within 8 minutes under normal operation of the dumping system (that is, including application of the jet water system). Means of overflow and spillways are not to be considered as equivalent to a cargo dumping system. Emergency devices, controlled from the navigation bridge, are to be fitted in order to be capable of discharging the cargo in case of failure of the main electric power supply and/or the main hydraulic unit and/or single failure of the normal control systems.

An accurate draught indicator, capable of showing the corresponding position of the dredging draught, as well as to record the draught as function of time, is to be fitted on the navigation bridge.

Dredge valves in piping systems penetrating the shell below the freeboard deck and which are normally open when during dredging operation (cargo loading) are to be provided with emergency closing devices which are operable from the navigation bridge. The closing devices are to be capable of operation in the event of failure of the main electric power supply and/or the main hydraulic unit and/or single failure of the normal control systems.
While operating at the dredger load line in operating areas defined by a limiting significant wave height (see next section), the master is to be provided with meteorological information and a forecast of the relevant seaway condition in terms of significant wave height. Where such information cannot be obtained a wave measuring system (wave radar) is to be used.

**Unmanned or non-self propelled units**

Unmanned and non-self propelled units similar to a dredger either may be assigned the reduced freeboard in accordance with DR-68 or be assigned a freeboard 25 per cent less than those calculated in accordance with the ICLL (see Reg 27(14)).

In accordance with to ICLL Reg 27(14) unmanned units similar to a dredger not required to comply with the minimum bow height requirement. Unmanned units also need not comply with the height requirement of the safe access.

**Classification Rules**

Bureau Veritas Rules for the Classification of Steel Ships contains a special chapter for ships for dredging activity, which is applicable to ships with the following service notations (Bureau Veritas, 2010):

- **dredger**, for ships specially equipped only for dredging activities (excluding carrying dredged material);
- **hopper dredger**, for ships specially equipped for dredging activities and carrying spoils or dredged material;
- **hopper unit**, for ships specially equipped for carrying spoils or dredged material;
- **split hopper unit**, for ships specially equipped for carrying spoils or dredged material and which open longitudinally, around hinges;
- **split hopper dredger**, for ships specially equipped for dredging and for carrying spoils or dredged material and which open longitudinally, around hinges.

Under these service notations trailing suction hopper dredgers (TSHDs) are assigned the service notation **hopper dredger**, cutter suction dredgers (CSDs) the service notation **dredger**. Backhoe dredgers and stone dumping vessels are assigned the service notation **special service**, followed by an **additional service feature** (short description of the function of the vessel). Typical examples are given as follows:

- special service - backhoe dredger;
- special service - side stone dumping vessel;
- special service - fall pipe vessel.

As explained in the introduction of this section, dredgers are likely to operate at sea within specific limits which are related to practical operational issues, such as the water depth and the capacity of the heave compensation system for the suction tube. Within Bureau Veritas rules such dredgers are may be granted an **operating area notation**, which expresses the specified area in which the dredger is likely to operate at sea within specific restrictions which are different from normal navigation conditions.

The following operating area notations may be assigned (Bureau Veritas, 2010):

- dredging within 8 miles from shore;
- dredging within 15 miles from shore or within 20 miles from port;
- dredging over 15 miles from shore.

The operating area of the first two categories may be extended respectively over 8 or 15 miles. In that case, the operating area notation is completed by the maximum significant wave height during service, as follows: **dredging over 8 (or 15) miles from shore with H.S. ≤ ... m**.

For ships being assigned the service notation split hopper unit or split hopper dredger, the operating area notation may be completed by the maximum allowable significant height of waves during the service, being indicated between parenthesis, i.e. (H.S. ≤ ... m).

The associated class requirements for dredgers are provided in Pt D, Ch 13 Ships for Dredging Activity (Bureau Veritas, 2009). These requirements are applicable in addition to the general requirements provided in Pt A, Pt B and Pt C of the rules, as applicable for ships covered by the SOLAS Convention. For ships not covered by the SOLAS Convention the requirements of Pt D, Ch 13 are applicable in addition to Pt A and Pt D, Ch 21, as applicable. This sub-section provides an overview of the requirements of Pt D, Ch 13.

**Stability**

The requirements for intact stability of dredgers are in accordance with DR-68 as well as DR-67, as they are technically equivalent. If the additional class notation **SDS** is assigned, the dredger is to comply with the probabilistic damage stability criteria in accordance with DR-68 when the dredger is assigned a dredging freeboard of less than B/2, where B is the statutory freeboard calculated in accordance with the ICLL, 1966. A freeboard of less than B/3 may not be assigned. In this respect it should be noted that the main technical difference between DR-67 and DR-68 is the incorporation of the latest SOLAS amendments (“SOLAS 2009”) in relation to probabilistic damage stability calculations into DR-68 (expressed in terms of updated SOLAS references).

**Structure Design Principles**

It is noted that, as a consequence of the fact that the structural arrangement of dredgers involves discontinuities, particular care is to be taken to avoid cracks or fractures. The rules provide general structure design principles, considering a large number of dredger related issues, considering:

- structural reinforcement of dredgers working in association with hopper barges;
- flooding prevention due to damage to the shell plating by metal debris on bucket dredgers;
- structural reinforcements at locations where the hull is heavily stressed;
- strengthening of the flat bottom at ends (dredgers are frequently operating in shallow waters and may work while touching the seabed);
- provision for weirs in the hopper spaces to drain off the water-spoil mixture, considering that they prevent the maximum authorised draught from being exceeded during loading, trim and stability are always in accordance with the reviewed loading conditions and that draining off is made without any overflowing on the decks;
- requirement for rounding of the cut-outs in the bottom plating with a radius as large as possible, in particular near the bottom doors (high stress concentrations and risk for occurrence of fatigue cracks);
- structural arrangement of brackets;
- panting structures in split hopper dredgers & units.

More detailed requirements are provided for the longitudinal and transverse members in the area of the hopper wells. Particularly important are the integration into the fore and aft ends of the longitudinal bulkheads of the hopper spaces, the cellular keel (if any), vertical sides of trunks (if any) and double bottom longitudinal girders. Generally extension brackets and aligned longitudinal girders, capable of effectively transmitting the forces associated with the mentioned structural members. In addition, guidance is given for the design of the transverse primary supporting rings within the hopper well area, including requirements for the integration of the cellular keel (if any) and hopper space floors to ensure transverse structural continuity.

Requirements for the structural arrangement near the suction pipe inlets are provided as shown in Fig. 7, addressing structural continuity and reinforcement, as well as stiffening of knuckles and welding. Requirements for structural reinforcements at the location of the drag head are also provided, as well as for the outfitting of the suction pipes for handling and securing.

Fig. 7. Structural arrangement near suction pipes; above transversely frames side; below longitudinally frames side (Bureau Veritas, 2009)

Special attention is paid to structures subjected to heavy wear, such as the longitudinal bulkheads of hopper spaces. Protection by means of chafing plates and structural reinforcement are considered. In practice owners of hopper dredgers frequently specify additional plating thickness (on top of minimum required values by class rules) in order to increase the chafing thickness and therewith extend the lifetime of the plating.

In case grounding is considered for normal operation (e.g. for beach replenishment or “rainbowing” operations) the bottom plating and structure in the flat bottom area are to be reinforced by means of increased plating thickness, additional floors and girders and intercostal stiffeners.

When a dredger is made of several independent members connected by bolting, such as dismountable CSDs, the connection is to be specially considered making use of direct calculations.

**Design Loads**

The design loads for the structural assessment are to be calculated for various load cases as defined in Pt B, Ch 5, Sec 5 (two upright conditions representing head seas and following seas) and two inclined conditions (representing beam seas and quartering seas) for two situations:
- navigation situation;
- dredging situation.

The *navigation situation* considers the dredger operating at the international freeboard (summer load line), taking into account the selected navigation notation, e.g. *unrestricted navigation* or *coastal area*. The *dredging situation* considers the dredger operating at the dredging freeboard (dredger load line), taking into account the selected operating area notation of the dredger as shown in Table 2. The navigation coefficient in dredging situation $n_D$ serves as a multiplator for the wave loads (dynamic hull girder loads and inertia loads) calculated for unrestricted navigation. For dredging within 15 miles from shore (or within 20 miles from port) the reduction in dynamic loads is 33 per cent compared to unrestricted navigation ($n_D=2/3$), while for dredging within 8 miles from shore the corresponding reduction is 67 per cent ($n_D=1/3$). Logically, for dredging over 15 miles from shore no reduction is applied ($n_D=1$), as this resembles the case of unrestricted navigation.

<table>
<thead>
<tr>
<th>Operating area notation</th>
<th>Coefficient $n_D$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dredging within 15 miles from shore or within 20 miles from port</td>
<td>$2/3$</td>
</tr>
<tr>
<td>Dredging over 15 miles from shore</td>
<td>$1$</td>
</tr>
</tbody>
</table>

The table is particularly interesting, as it also provides means for the practical implementation of an extended operating area notation beyond 8 or 15 miles, respectively, by assigning an associated maximum significant wave height as function of the ships size (length $L$) and selected operating area notation. This enables a dredger to operate outside the designated operating area (based on maximum distance from shore or port) if the weather conditions, in terms of significant wave height, are within the limits specified in the table. Such practice is well founded within the scope of DR-68 (see DR-68, Sec 5 & 7.4).
The limiting ranges for the maximum significant wave heights listed in Table 2 have been drawn up by Bureau Veritas in close cooperation with the Maritime Research Institute Netherlands (MARIN) by making use of the results of calibration calculations for the vertical wave bending moment (the dominant design parameter for the hull girder structure of hopper dredgers) on the basis of long term statistical analysis for representative hopper dredgers. The long term statistical analysis is performed in straightforward fashion (Journée, 2001). First the transfer function of the vertical wave bending moment is calculated by linear seakeeping theory. The response spectrum is then obtained by multiplying the transfer function squared by the incident wave spectrum (irregular seas described by JONSWAP spectrum). Under the realistic assumption of stationary Gaussian incoming waves and a narrow banded response spectrum, the response amplitudes can be considered to follow the Rayleigh distribution. The associated short term probability density function of the response is therefore well known and can be calculated for all wave direction intervals and sea state intervals (making use of the area under the response spectrum). The long term probability density function can then be calculated as the weighted sum of all short term results, taking into account the long term probability of each wave interval and sea state interval by making use of relevant wave scatter diagrams. Evaluation of the long term probability density function then yields the maximum vertical bending moment as function of the probability of exceedance. In order to obtain this curve for a specified maximum significant wave height the wave scatter diagram is stripped of the part considering higher significant wave heights than the specified maximum. By doing this in a systematic way (step by step increase of the maximum significant wave height) the curve of the maximum vertical bending moment as function of the maximum significant wave height associated with the rule value of the vertical wave bending moment due to the difference in hull pressure exerted by the outside sea water and the spoil in the hopper, if any, as shown if Fig. 8. Even in still water and in head or following seas such horizontal bending moment is present and needs to be accounted for.

Making use of the defined navigation coefficients the hull girder loads and local loads can be calculated in a practical manner for both the navigation situation as well as the dredging situation. Specific loading conditions to be taken into account are the following:

- homogeneous loading at maximum dredging draught;
- partial loading conditions;
- any specific non-homogeneous loading condition, in particular where dredgers are fitted with several hopper spaces;
- navigation conditions with hopper space(s) willed with (sea) water up to the load line (“transit condition”);
- working conditions at international freeboard with hopper space(s) filled with spoil;
- ballast navigation conditions, with empty hopper space(s), if applicable.

The hull girder design loads for dredgers, hopper dredgers and hopper units are based on the same formulae as applicable to all ship types (see Pt B, Ch 5 of the rules and IACS UR S7), with the exception that for the dredging situation the dynamic loads are multiplied by the coefficient \( n_p \) to account for the operating area notation (see above). For split hopper dredgers and split hopper units the situation is quite different. This is caused by the fact that the hull girder of a split hopper vessel cannot be regarded as a single beam (like for normal ships). Instead, the two “half hulls” comprising the split hopper vessel need to be considered individually as they experience a horizontal bending moment due to the difference in hull pressure exerted by the outside sea water and the spoil in the hopper, if any, as shown if Fig. 8.

Fig. 8. Forces exerted on half hull of split hopper vessel (Bureau Veritas, 2009)

The vertical bending moment acting on each half hull is obtained by adding half the vertical still water and wave bending moment calculated with the standard rule formulae for the whole ship (applying the coefficient \( n_p \) to account for the operating area notation). The total horizontal bending moment acting on each half hull is obtained in two steps. First, the horizontal still water bending moment is computed by considering the half hull as a beam (simply) supported at the locations of the hinges and twice integrating the distributed load acting along the length of the half hull. The distributed load is obtained as the difference between the horizontally projected load exerted by the outside sea pressure and the internal spoil pressure, as shown in Fig. 4. For the simplified case of a split hopper vessel with two hinges located at the end of the hopper well the maximum horizontal still water bending moment at mid-length would be \( 1/8qf_p^2 \), where \( q \) represents the resulting horizontal distributed load and \( f_p \) the length of the hopper well. The formulae in Bureau Veritas rules also take into account the longitudinal distance between the actual hinges and the hopper well ends, see Fig. 9.
Specific formulae for computing the distributed load (per metre length) are provided for each relevant loading condition:

- maximum loading at dredging draught;
- loading corresponding to international freeboard with well full of spoil;
- service condition with well filled with water up to the waterline;
- service condition with well filled with water up to the lowest weir level.

Secondly, the horizontal wave bending moment acting on each half hull is computed as a function of the associated vertical wave bending moment, taking into account the geometric properties of the split hopper vessel, the associated wave parameter (reference wave height), the coefficient $n_D$ and the considered loading condition. The results of these empirical formulae match with the results of direct calculations in head seas and beam seas (taking into account outflow of spoil over the spillout edge due to roll motions). Finally, the total horizontal bending moment acting on each half hull is obtained by adding the still water and wave components.

For the calculation of the internal pressures acting on the hopper well boundaries the cargo (effectively a mixture of sand and sea water) is considered as a liquid if the cargo density is less than $1.4 \text{ t/m}^3$ and as a sliding dry bulk cargo if the cargo density is equal to $1.4 \text{ t/m}^3$ or above. Consequently, the “apparent cargo density” $\delta_1$, in $\text{t/m}^3$, is computed as follows:

- $\delta_1 = \delta$, for $\delta < 1.4$;
- $\delta_1 = \delta + (1.4 - \delta) \sin^2 \alpha$, for $\delta \geq 1.4$;

where $\delta$ the actual cargo density, in $\text{t/m}^3$ and $\alpha$ is the angle, in degrees, between the horizontal plane and the surface of the hull structure to which the considered calculation point belongs. The calculation of the associated still water and wave pressure is performed on the basis of the apparent cargo density $\delta_1$ by considering hydrostatic analogy. In addition, a minimum pressure for sloshing effects is taken into consideration.

**Hull Girder Strength Assessment for Dredgers, Hopper Dredgers and Hopper Units**

Special care has to taken for the calculation of the midship section modulus of hopper dredgers (and hopper units) with a cellular keel, in particular when the vessel is equipped with a single hopper well as shown in Fig. 10. Due to the arrangement of bottom door openings and hopper floors the integration of the cellular keel into the side boxes may be relatively weak. In such case the cellular keel becomes less effective in contributing to the hull girder strength. This effect can be demonstrated by performing 3D Finite Element Analysis (FEA) with a VeriSTAR HULL Complete Ship Model (CSM) in a seaway, see Fig. 11.

The distribution of the vertical shear force in the hopper floors has been computed and compared to the results of the formulae given in the rules and the results of a beam calculation of the hopper floors and cellular keel (all beams considered clamped at the integration with the hopper walls), as shown in Fig. 12. The calculation of shear force distribution in hopper floors using the formulae given in the rules, a beam model of the hopper floors and cellular keel (Steel) and a 3D finite element calculation on a Complete Ship Model (VeriSTAR)
It is easily seen that the rules calculation yields the highest value shear force, which is in addition considered constant over the hopper length. The rules are clearly on the conservative side, but this is the necessary consequence of applying simplified formulae. A direct calculation with a beam model gives a more realistic distribution of the shear forces. The maximum value is less than obtained from the rules, while the distribution is in line with the expectation that the shear force in the floors will be less at the hopper ends as the cellular keel becomes more effective in transmitting the (net) hopper load to the hopper end bulkheads (short force pathway). The result of the 3D finite element calculation is particularly interesting. The maximum shear force in the midship region is nearly equal to the value obtained from the beam calculation, showing that the beam model is sufficiently accurate to determine the maximum design force. However, the distribution of the shear forces over the hopper length is quite different. Generally the 3D finite element calculation shows high shear forces than the beam model. In the forward half of the hopper this effect is very strong, while it is less pronounced in the aft half. Two important observations can be made from this result. First, the cellular keel is apparently less effective in transmitting the load than assumed on the basis of the beam model. In order to adjust the beam model the fully fixed boundary condition at the ends of the cellular keel needs to be replaced by a spring. In other words, the fixation of the cellular keel into the transverse hopper end bulkheads is not as rigid as assumed in the beam model. Secondly, the force distribution is not symmetrical. This point can only be explained by a difference in fixation of the cellular keel in the aft and fore hopper end bulkheads. Analysis of the structural arrangement near the transverse hopper end bulkheads shows that this is indeed the case. The fixation of the cellular keel into the aft end is much more rigid (due to a continuous tweendeck) than compared to the fore end (only heavy girders).

By considering Hooke’s law it is concluded that the difference in hull girder normal stresses between the cellular keel and side boxes implies a longitudinal strains as well. This in turns leads to the conclusion that the classic assumption that the hull girder can be considered as a single beam with non-deformable cross section no longer holds. And as the longitudinal displacement between the bottom plating of the cellular keel and side boxes is different, the floors are experiencing an enforced deformation as shown in Fig. 15. The existence of this deformation is demonstrated by considering the distribution of secondary bending stresses in the hopper floors (the enforced deformation causes a shear constant force and linearly distributed bending moment in the hopper floor), which is depicted in Fig. 16.

It is finally observed that a (complex) combination of high hull girder normal stresses and secondary bending stresses exists near the corners of the bottom door openings. The amplitude of these stresses varies with the wave period, as well as loading and unloading of the hopper. The corners of the bottom door openings represent a significant structural discontinuity, which inevitably causes stress concentrations. Therefore, the corners of the bottom door openings are sensitive to fatigue damage accumulation and need to be designed with great care.
The above described phenomenon has been incorporated in the rules in a simplified manner by reducing the sectional area of the structural elements of the cellular keel (and other structures which can partly withdraw from providing full contribution to the hull girder resistance) in the calculation of the (midship) section modulus. In other words, the cellular keel is given a reduced “effectiveness” in its contribution to the hull girder strength. As a consequence the hull girder normal stresses in the side boxes are increased. The rules provide a reference value of 85 per cent for the effectiveness of the cellular keel. For unusual designs the effectiveness of the cellular keel can be obtained from the results of a finite element analysis of a complete ship model. The complete ship model is required in order to obtain the correct level of fixation of the cellular keel into the fore and aft part, as demonstrated in this above.

The criteria for calculating assessing the hull girder strength are as per normal rules (in accordance with IACS UR S11). Depending on the assigned operating area notation and the difference between the international and the dredging freeboard either the navigation situation of the dredging situation will be determining the required hull girder section modulus. Loaded hopper dredgers and hopper units are, due to their arrangement, always in sagging condition. In empty of ballast condition the bending moment is generally small compared to the loaded situation (slightly sagging, near zero or slightly hogging, as the case may be). Dredgers (CSDs) are normally in hogging condition. As they carry no cargo the deadweight is limited and therefore also the range of applicable still water bending moments.

It is to be noted that the hull girder strength for hopper dredgers and hopper units is not only critical in the midship region, but also near the hopper ends due to the high hull girder shear forces, see Fig. 17. These are a consequence of the general arrangement of hopper vessels, with relatively concentrated heavy cargo in the midship area and buoyancy compartments at the fore and aft ends. In addition to this the transition from the hopper structure into the fore and aft end structures usually contains large structural discontinuities, such as (partial) termination of the longitudinal hopper bulkhead, termination of the trunk or coaming, the presence of large openings in longitudinal bulkheads and/or decks, etc. In particular when the longitudinal hopper bulkhead is not continued into the fore and aft ends, careful checking of the side shell plate against yielding and (shear) buckling is to be performed. An example of the shear stress distribution in the cross section of a hopper dredger just before the forward hopper end bulkhead is shown in Fig. 18. Due to the structural discontinuities the section modulus of the cross section near the hopper end bulkheads may be significantly reduced, so also the hull girder normal stresses need to be verified. An additional complicating factor in this region may be the presence of the suction tube inlet, which causes additional discontinuities in the side shell structure.

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hull girder normal stresses is shifted. The transformation of main axes is shown schematically in Fig. 20.

As the horizontal and vertical hull girder bending moments for split hopper vessels are of the same order of magnitude, the maximum hull girder stress may occur in any of the four following locations:

- hopper coaming top (or maindeck at intersection with hopper well bulkhead if the coaming is not continuous);
- bilge;
- bottom at centre line;
- maindeck at intersection with side shell.

Consequently, the horizontal and vertical bending moments need to be transformed to the new main axes in order to calculate the hull girder normal stresses. The hull girder stress criteria are the same as for dredgers, hopper dredgers and hopper units.

For split hopper vessels not only the stress levels need to be checked, but also the deflections of the half hulls. In the midship area this is required to determine the sealing arrangement at the bottom in order to prevent loss of cargo, while at the ends of the vessel it needs to be verified that the half hulls are not touching each other (which could cause local damage and would change the distribution of the horizontal bending moment).

**Hull Scantlings**

For the strength check of local structural members (plate panels, ordinary stiffeners and primary supporting members) Bureau Veritas applies the net scantling approach. This means that all yielding and buckling checks, as well as (tabular) minimum scantlings are checked against the as-built scantlings minus a specified corrosion addition which depends on the type of compartment(s) in which the considered structural member is located. The corrosion additions are based on statistics obtained from thickness measurements on ships in service and represent the average state of the vessel after a service life of 20 years (considering adequate maintenance in accordance with class requirements). Hopper well structures are exposed to heavy wear and appreciable levels of corrosion due to the nature of the cargo (mixture of sand and sea water) as well as the frequency of loading and discharging (up to four times per day). Therefore, the corrosion addition for structural members in the hopper well is relatively high with 2.0 mm per side (as compared to 1.0 mm for a ballast tank and 0.5 mm for a dry space).

The calculation of the local scantlings follows the same approach as the general requirements of Pt B, considering four load cases (wave conditions which maximise the determining design loads), except that all calculations are carried out for both the navigation situation (international freeboard) as well as the dredging situation (dredging freeboard), duly taking into account the navigation coefficient for dredging \( n_D \) to obtain the corresponding dynamic loads, as described in the subsection Design loads. This means that a large number of scantling calculations are to be made in order to obtain the required scantlings. In order to support designers Bureau Veritas has made its internally developed scantling verification tool MARS, in which the rules for dredgers are fully incorporated, available to ship designers (enabling an efficient design process).
these beams. In general, the forces exerted by the hydraulic cylinders and reaction forces of the bottom doors on the bottom structure need to be included in the assessment of the primary structure of hopper dredgers.

Fig. 22. Zoom on midship area for finite element model shown in Fig. 21.

Fig. 23. Detailed finite element analysis of corner of bottom door opening for a large hopper dredger; left model, right Von Mises stresses

Fig. 24. Detailed finite element analysis of integration of flange of hopper floor into side box structure for a large hopper dredger; left model, right Von Mises stresses

In addition, also hopper end bulkheads are to be considered as critical areas, as they do not only have to withstand the spoil pressure but also transmit the net hopper load (spoil weight minus sea water pressure on the bottom, including dynamic effects) in shear to the side shell. On top of that, for hopper dredgers with cellular keel the hopper end bulkheads also absorb the bending moment exerted by the cellular keel, as described above.

**Particular Structural Issues on Dredgers**

Dredgers are by nature equipped with heavy duty machinery, such as internal combustion engines, generators, pumps, suction tubes and associated gantries, cranes, cylinders for closing the bottom doors of hopper wells, cylinders and hinges in split hopper vessels, cutter ladders and spud carriers in cutter suction dredgers, etc. The supporting structures of all these items need to be carefully designed in order to assure their proper foundation (from the viewpoint of strength as well as stiffness, in particular in relation to vibrations). In this respect, the scantlings of the structure for attachment of the equipment intended for dredging operations (e.g. connection of the suction pipe to the hull, foundation of the suction pipe gantries) are to be based on the service load of such equipment. In determining the above service load, the loads imposed by ship movements are to be taken into account. The rules provide guidance to support the designer in this task, in particular in the assessment of bottom doors and valves. For example, in Fig. 25 the force arrangement of two different types of bottom doors is shown.

Fig. 25. Bottom door force arrangements; left double doors, right bottom valve (Bureau Veritas, 2009)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dredging and navigation with spoil, with sea state limited to $H_{s} = 3, \text{m}$ (1)</td>
<td>$10^{-6}$ for jacks and hinges</td>
</tr>
<tr>
<td>Navigation without spoil, without limitation on sea state (2)</td>
<td>$10^{-7}$ for jacks, $10^{-5}$ for hinges</td>
</tr>
</tbody>
</table>

(1) $H_{s}$ : Significant wave height, in m.  
(2) In sailing condition without spoil, a different probability level may be adopted for the calculation of dynamic forces on the cylinders, subject to the Society's agreement, when a device intended to restore the pressure to the cylinders after opening of the safety valves is fitted (see also [10.3.1]),

Note 1: Different calculation conditions are to be justified by the Designer.

As the two half hulls of split hopper vessels are only connected by the hinges and cylinders a single failure of each of these elements could lead to a catastrophic failure. Therefore the rules require a special assessment of the maximum dynamic loads which can be expected during the ship’s lifetime to ensure that the design is sufficiently robust. In particular, the dynamic force in each hydraulic jack (cylinder) and the horizontal and vertical dynamic forces in each hinge are to be calculated by means of a long term statistical analysis in accordance with the methodology described earlier in the subsection *Design loads* (for the evaluation of the maximum significant wave height associated with the operating area notations), taking into consideration the conditions and probabilities shown in Table 3. An example of a transfer function of the horizontal force at the forward hinge of a split hopper unit is shown in Fig. 26.
The scantlings of the jacks and hinges are to be verified against the calculated forces (static plus dynamic). In addition, requirements apply for the design and construction of the hydraulic jacks. For large split hopper vessels a measuring system of the hydraulic pressure is to be provided for each jack, which (in addition to the indication of the pressure at the bridge and at the dredging room) is to comprise a visual and audible alarm at the same locations, to be activated when a certain limit is exceeded. At least one relieve valve is to be provided to protect each part of the circuit which may be subject to overpressure due to external loads or due to pump action.

Another main point for split hopper vessels is the connection between the ship and superstructure, which remains in the upright position if the half hulls are opened. Both the transverse and the longitudinal direction need to be addressed in order to properly dimension the hinges. The rules provide detailed guidance for the computation of the associated forces and the checking of the scantlings of the hinges. Different types of hinges and bearing systems are considered. Fig 27 shows a schematic overview of the hinge connection in transverse direction, as well as a detail of a hinge with load transfer bearings.

In order to correctly assess the longitudinal strength of large CSDs the additional bending moment during cutter operations needs to be accounted for. This bending moment is caused by the forces exerted on the cutter head, which are balanced by the spud pole which is pushed into the seabed. As the pathway of this force goes all the way through the hull girder and the arm is large (equal to the working depth), this bending moment can reach an appreciable value. As this additional moment only applies in working conditions, which are limited by a practical upper limit in sea conditions, the calculation of the total bending moment can be based on the maximum wave bending moment associated with the worst sea condition during working, taking duly account of the still water bending moment in working condition. The issue of the additional bending moment is illustrated in Fig. 28, where the additional bending moment due to working is computed as $M_{add} = Fd$.

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Dismountable CSDs form a special category of dredgers. Usually they are relatively small vessels intended for dredging operations in, often remote, shallow waters (estuaries, lakes, etc.), see Fig. 29 for an example. As they are dismountable it is easy to transport such dredgers from one working location to the next (on a cargo ship or sometimes even by road). Dismountable CSDs consist of a number of pontoons (e.g. port side, starboard and centre pontoon) which are connected by bolts and/or hooks. Depending on the intended operating area the coupling system can be adjustable (for coastal waters) or non-adjustable (for sheltered waters, lakes and inland waterways). From a design perspective the couplings need to be designed such as to provide sufficient strength to cope with the static and dynamic loads. For transversely coupled pontoons the beam sea condition is the most important, for longitudinally coupled pontoons the head sea condition.

For backhoe dredgers two main points require special consideration. The first point is the integration of the excavator foundation into the main pontoon structure. The shear force and bending moment at this location are high due to the excavator’s own weight. Ensuring sufficient structural continuity is the key point here. In addition, the bottom plating should be carefully checked for buckling due to high compression stresses caused by the bending moment exerted by the excavator. The second point is related to the use of the spuds. Depending on the spud arrangement and lifting system, some backhoe dredgers can use their main pontoon as a semi self-elevating unit (for example during the low tide while working in an area with large tidal changes, see Fig. 30). In that case the spud poles are supporting part of the vessel’s weight. Not only need the strength of the spuds be sufficient to support this additional load, also the main structure if the pontoon needs to be checked, as the bending moment on the pontoon (considered as a beam) is changed. In performing this strength assessment the dynamic effects (wave loads) in the worst anticipated sea condition in which the
pontoon is intended to operate need to be taken into account. Depending on the strength of the pontoon (including buckling resistance) it may be necessary to prescribe a minimum safe operating draught for such backhoe dredgers.

Fig. 29. The IHC Beaver® 50 series of dismountable CSDs was introduced by IHC Merwede in 2009

Fig. 30. Backhoe dredger working a self-floating draught ($T_1$) and partial draught ($T_2$)

**Hull Outfitting & Equipment**

As dredgers, due to the nature of their activity, are frequently involved in long time duration manoeuvring in shallow waters the rules require that the rudder stock diameter is to be increased by 5 per cent relative to the minimum diameter obtained by the rules for cargo ships in order to create additional robustness. In addition, each rudder on a split hopper vessel is to be served by its own steering gear.

A dredger specific formula for the equipment number, \( EN = 1.5 (LBD)^{2/3} \), with \( L \), in m, representing the Rule length, \( B \), in m, the moulded breadth, and \( D \), in m, the depth, respectively. For dredgers of 80 m in length and above the standard equipment tables (see also IACS UR A1). For smaller dredgers the rules provide a specific table on the basis of long term experience. Due to the nature of dredging operation the anchor systems are often used during working, e.g. in the case of stone dumping vessels. In such case, for reasons of practical operations, it is useful to use wire ropes instead of chain cables. Under certain conditions this may be accepted, provided that adequate measures are taken to ensure the effectiveness of the anchoring system, such as increased length of the wire ropes to compensate for the loss of weight compared to chain cables, and equal minimum breaking load as required for chain cables. In addition a short length of chain cable is to be fitted between the wire rope and the anchor, having a length equal to 12.5m or the distance from the anchor in the stowed position to the winch, whichever is the lesser. The application of high holding power (HHP) and very high holding power (VHHP) anchors is permitted.

In some cases the classification society is requested by ship owner to certify the gantry cranes used for lifting and operating the suction tube(s), in particularly on large hopper dredgers, see Figs. 31 and 32. Bureau Veritas assesses such crane on the basis of plan approval and inspections during manufacturing and installation on board, making use of the *Rules for the Classification and the Certification of Cranes onboard Ships and Offshore Units* (Bureau Veritas, 2007).

Fig. 31. Two gantry cranes operating the suction tube on a hopper dredger

Fig. 32. Schematic overview of large gantry crane

**TECHNICAL DEVELOPMENTS IN DREDGING AND ASSOCIATED CLASS RULES**

In this section the latest technical and ongoing regulatory developments are addressed. Five points will be discussed: fatigue assessment of large hopper dredgers, stability of stone dumping vessels, dredgers carrying special personnel, the application of dynamic positioning systems on dredgers and environmental protection.
Fatigue Analysis of Large Hopper Dredgers

In general, classification rules request that for large ships a fatigue analysis is carried out for critical structural details repeatedly exposed to cyclic stresses. For example, the side longitudinals of an oil tanker near the loaded water line are subject to cyclic sea pressure caused by passing waves (causing a relative motion). The connection of the longitudinals with the supporting web frames is sensitive to fatigue damage due to geometrical stress concentrations and welding. With each passing wave the stress at the connection passes through a harmonic stress cycle. If the detail is of poor design and/or workmanship, there is a risk that a fatigue crack will occur after a certain number of stress cycles (or, in other words, passing waves). In order to prevent this, these critical details are subject to fatigue analysis during the design (review) stage.

Following the previous sections in this paper it is clear that, in addition to the side longitudinal, the corners of the bottom door openings of hopper dredgers are sensitive to fatigue damage cracking caused by cyclic loads. Other details exposed to high cyclic stresses, such as the connections of cellular keel structures to transverse bulkheads, expansion joints in discontinuous gantry crane tracks may need to be considered as well. The case of a hopper dredger, however, is slightly more complicated compared to the previous example of an oil tanker due to the simultaneous occurrence of two important types of stress cycles (for details affected by hull girder normal stresses). The first type is, like for the oil tanker, the wave (frequent) stress cycle. The second type is the loading/unloading stress cycle. For most merchant ships the frequency of the loading/unloading cycle is very low compared to the frequency of the passing waves (the loaded condition and ballast condition on an oil tanker remain nearly the same for a large number of days on end). As a consequence the contribution to the fatigue damage caused by the loading/unloading cycles is deemed negligible compared to the fatigue damage accumulation caused by the passing waves. For a hopper dredger working on a land reclamation project, however, it is not uncommon to load and discharge the hopper three or four times per day (depending on the sailing distance between the mining location and the project). On top of that, the difference in hull girder normal stress between the fully loaded condition (maximum sagging) and the unloaded condition (near zero still water bending moment) is relatively large. From experience feedback it is well known that the amount of cycles required to initiate a fatigue crack is exponentially decreasing with the difference between the maximum and minimum stress associated to the cycle, which is usually referred to as the stress range. This phenomenon is generally represented through so called S-N curves, where S, or $\Delta \sigma$, represents the stress range (difference between the maximum and minimum stress) and N the amount of cycles required to initiate a fatigue crack, which is a statistical parameter. Fig. 33 shows a number of standard S-N curves obtained from fatigue experiments for different structural details. Due to the comparatively high frequency of occurrence and large stress range of the loading/unloading cycle of hopper dredgers (considering the exponential nature of the S-N curve as illustrated in Fig. 33), it is clear that the risk of fatigue damage associated with the high stress range due caused by the loading/unloading cycle of hopper dredgers needs to be accounted for to prevent a serious underestimation of the fatigue life of structural details.

With regard to the treatment of the two types of cyclic stresses it is important to note that their distributions are different. The loading/unloading cycle of hopper dredgers shows very little variation (or spreading). A hopper dredger is normally fully loaded on the cargo carrying leg (in order to maximise revenue) and empty on the return leg. In other words, the stress range is nearly constant at the maximum level (considering either the international draught or the dredging draught). For the wave frequent stress range the situation is different, as the stress level depends on the encountered sea states (significant wave height and period). The long term distribution of the wave frequent stress range may be assumed to follow the Weibull distribution (making use of the dynamic loads given by the rules), which enables relatively simple calculation of the fatigue damage by making use of the relevant S-N curves and applying Miner’s rule. For a more precise estimation spectral fatigue analysis can be applied. In that case the long term stress range distribution is obtained from statistical analysis, making use of the short term stress range distributions calculated for all relevant sea states and applicable wave scatter diagrams on the basis of the ship’s operating area (may be either specific or worldwide). The fatigue damage is again determined by the Miner’s rule and appropriate S-N curves.
The last and perhaps most important consideration to be made is that the two types of stress cycles are not independent phenomena. Therefore, the simple idea of calculating the fatigue damage for both phenomena separately and adding the results would still lead to an underestimation of the total fatigue damage accumulation. The reason why can easily be seen from Fig. 34, showing a schematic time history of the stress level in a critical detail covering two loading/unloading cycles. The loading cycle is somewhat simplified as the necessary time to load the hopper is ignored. This is, however, acceptable as it leads to a conservative result. By considering the graph it becomes clear that the maximum wave frequent stress amplitude needs to be added to the stress amplitude resulting from the loading/unloading cycle, effectively increasing the low frequent stress range. This is important, as the amplified stress range will lead to a further reduction in fatigue lifetime. Therefore, this effect also needs to be accounted for in the fatigue analysis.

As indicated above, the magnitude of the amplification is dependent on the sea state. Therefore, the prediction of the fatigue lifetime of a structural detail under combined cyclic loading is relatively complex. Theoretically, the best solution would be to perform Rainflow counting to assess the fatigue damage accumulation (Rainflow counting is a method to break a complex time signal into individual cycles which can be more easily treated by application of Miner’s rule and relevant S-N curves (considering narrow bandwidths of stress ranges). However, this is a complex and time consuming exercise, requiring direct analysis of time histories of stresses in all relevant loading conditions, sea states, speeds and wave headings. Therefore it is preferable to apply a simplified method which can be justified on the basis of the Rainflow counting method. A Bureau Veritas in-house working group is dealing with this problem in order to provide guidance for the design of sensitive structural details.

Apart from the issues raised above it also needs to be considered weather a detail is welded or not. In case of welding near the stress peak (hot-spot) tension will be the dominant stress component due to the residual welding stresses. In the absence of welding near the hot-spot, a part of the stress cycle may be in compression. In such case the fatigue damage is less than the damage considering the full range in tension. For hopper dredgers this effect may be present in non-welded structural details in the deck zone. For the critical corners of the bottom door openings there is no such effect due to the fact that practically the whole stress cycle is in tension.

**Stability of Stone Dumping Vessels**

The design of stone dumping vessels requires some particular attention due to the fact that the cargo is weather exposed and therefore liable to entrap water (either green water or rainwater) during normal operation. If the cargo space is adequately drained (e.g. by freeing ports) there will not be any significant accumulation of trapped water. In reality the cargo, consisting of several types and sizes of stones and rocks as well as sediment (e.g. mud), may (partially) block the means of drainage, effectively causing build up of trapped water. This may have two consequences. First, if the vessel would be operating at the deepest load line without entrapment of water, any trapped water would make the vessel operate at a higher draught line that allowed (ref. ICLL Article 6(2)). Secondly, the trapped water negatively impact the (intact) stability particulars, as it is located at a relatively high position (increasing the ship’s centre of gravity and decreasing the initial metacentric height) and may be associated with an additional free surface moment (relatively free movement of water between the stones decreases the apparent (initial) metacentric height (metacentric height corrected for free surface effects). The obvious solution is to enlarge the drainage openings. This may, however, be practically difficult, as too large openings could lead to the loss of cargo during navigation (in particular in beam and quartering seas). This is specifically the case for side stone dumping vessels which carry the stones on a flat deck, where the shovel (used to push the stones overboard during dumping), side flaps (used to contain the stones during navigation) and transverse cargo space end bulkheads effectively from a recess capable of entrapping water, as shown schematically in Fig. 35. Two extreme types of cargo can be considered: cargo containing large cavities (usually large rocks which are not “sticky”) and cargo containing small cavities (usually small stones containing “sticky” sediment). Large cavities are easily filled with water, but can also easily be drained as the water can flow relatively freely. In this case the water level cannot exceed the top of the flap (in case lower means of drainage are blocked), but free surface effects need to be accounted for. Due to the capillary effect the water trapped inside small cavities cannot easily escape. The cargo can be compared to a dry bulk cargo with high moisture content. Consequently, the entire water level can reach above the upper level of the flap (theoretically the cavities in the entire cargo volume can contain water, but free surface effects are limited. In summary, trapped water in large cavity cargoes can lead to a moderate increase in vertical centre of gravity and free surface effects, while for small cavity cargoes a substantial increase of the vertical centre of gravity of the cargo an be expected. Due consideration is to be paid to the design and maintenance of means of drainage, as well as adequate margin in the stability particulars.

![Fig. 35. Cross section of cargo space of side stone dumping vessel](image-url)
Another issue to be included in the checking of the stability particulars is the case of asymmetrical dumping. That is, all cargo on one side is dumped first and the other half after repositioning the vessel (e.g. for covering a subsea pipeline). Similar provisions as for dredgers with bottom doors at port side and starboard side are applicable, see the section DR-68.

Dredgers Carrying Special Personnel
For ships carrying more than 12 special personnel for particular operational duties in addition to the ship’s crew the Code of Safety for Special Purpose Ships (SPS Code, 2008), is generally applied. Due to their knowledge of ship layout, training in safety procedures and handling of safety equipment special personnel are not considered as passengers. Therefore special purpose ships do not need to fully comply with all SOLAS requirements for passenger ships and consequently the scope of Code is to provide equivalent level of safety compared to SOLAS. The SPS Code may be applied to large dredgers carrying special personnel for operating subsea installation equipment, for example stone dumping vessels.

The technical requirements of the SPS Code cover stability and subdivision, machinery installations (steering gear), electrical installations (emergency source of power, precautions), periodically unattended machinery spaces, fire protection, dangerous goods, life-saving appliances, radio communications, safety of navigation and security. The applicable SOLAS requirements depend on the number of special personnel on board.

The most important change in the 2008 edition of the SPS Code is related to damage stability. The requirements have been updated in accordance with the probabilistic methodology of SOLAS Ch II-1, where the ship is considered as a passenger ship (special personnel are considered as passengers). The required subdivision index R, to be calculated in accordance with SOLAS Reg. II-1/6.2.3, given as:

- R for ships certified to carry 240 persons or more;
- 0.8R for ships certified to carry not more than 60 persons; while linear interpolation between 0.8R and R is to be applied for ships certified for more than 60 but not more than 240 persons.

In accordance with SOLAS requirements calculations also to be performed for intermediate stages of flooding, while the maximum heeling moment due to wind, crowding of passengers or launching of survival crafts is to be included as well. A key point is the double bottom height, as additional deterministic damage stability calculations assuming bottom damages are to be performed if the double bottom height is less than \( h = \frac{B}{20} \text{ m} \), where \( h \) is to be not less than 0.76 m and does not need to be taken as more than 2.0 m. In the formula \( B \), in m, is the ship’s moulded breadth.

In case the number of special personnel is more than 60 persons, but less than 240, the following specific requirements apply:

- SOLAS requirements for passenger ships with less than 36 passengers apply for fire safety (SOLAS Ch II-2);
- The emergency source of power is to be in accordance with SOLAS requirements for passenger ships (SOLAS Ch II-1 Pt D Reg. 42);
- Precautions against shock, fire and other hazards of electrical origin are to be in accordance with SOLAS requirements for passenger ships (SOLAS Ch II-1 Pt D Reg. 45.11);
- Life Saving Appliances are to be in accordance with SOLAS requirements for passenger ships (SOLAS Ch III), with some alternatives and relaxations.

Upon verification of compliance a Special Purpose Ship Safety Certificate is issued by the flag state or the recognised organisation on behalf of the flag state.

Dynamic Positioning
As dredgers are engaged in high precision subsea operations station keeping is a key point, in particular when working in waves or swell. To this end Bureau Veritas proposes the DYNAPOS family of additional class notations, covering the certification of dynamic positioning systems. The following optional additional symbols can be assigned:

- SAM (Semi Automatic Mode; manual intervention);
- AM (Automatic Mode; automatic position keeping);
- AT (Automatic Tracking: unit is maintained along a predetermined path, at a preset speed and with a preset heading which can be different from the course);
- R (Redundancy implies equipment class 2 in accordance with IMO Circ. 645);
- RS (Redundancy is achieved by two systems or alternative means of performing a function physically separated; equipment class 3 in accordance with IMO Circ. 645).

Typical notations are DYNAPOS AM/AT (equivalent to DP1), DYNAPOS AM/AT R (equivalent to DP2) and DYNAPOS AM/AT RS (equivalent to DP3). The requirements are provided in Pt F, Ch 10, Sec 6 of Bureau Veritas Rules for the Classification of Steel Ships (NR 467).

Environmental Protection
Environmental issues are becoming increasingly important in the maritime industry. This is particularly true for dredgers, which are mainly operating in coastal waters and ports where specific requirements apply for pollution prevention and emission control apply (e.g. in the Emission Control Areas). In this respect the additional class notations CLEANSHIP (C), CLEANSHIP and CLEANSHIP SUPER are available in BV rules. Each notation may be completed by the additional symbol AWT if an Advanced Wastewater Treatment installation is installed, as well as an additional number to specify the number of consecutive days the ship is able to operate with the full complement of on-board personnel, including crew and passengers, without the need for discharging any substances into the sea (minimum is 1,
The dredging industry has developed itself from a largely local near land-based activity into a global operation which is of key importance for merchant shipping on keeping the ports accessible, waterways navigable. In addition, dredgers are active in land reclamation projects, coastal and port construction and offshore construction (including subsea activities). Along with the industry the dredging vessels have developed into highly sophisticated ships of dedicated design, depending on the intended activity. The main types of ships for dredging activity are trailing suction hopper dredgers, cutter suction dredgers, backhoe dredgers, split hopper units/dredger, stone/rock dumping vessels and fall pipe vessels.

The very specific designs of dredging vessels have always evolved on the basis of experience feedback and technical innovation (such as the introduction of the centrifugal pump). Applicable regulations were traditionally issued by local authorities and therefore applicable to local circumstances. With the internationalisation of the dredging industry the need emerged for an international set of safety regulations applicable to dredgers, duly taking into account the technical and operational specificities of dredgers.

One of the key points is the apparent conflict with the requirements of the International Convention on Load Lines, 1966, which specifies the maximum operating draught on the basis and requests the fitting of hatch covers. Hopper dredgers, due to their ability to dump their cargo, can operate safely at a reduced freeboard, while hatch covers are generally not necessary as water can effectively be drained from the hopper and the strength and stability take into consideration all possible loading conditions and states of cargo (basically a mixture of water and sand). On the basis of such considerations the international regulations for dredgers operating at reduced freeboard have been developed. The latest revision are the Guidelines for the Assignment of Reduced Freeboards for Dredgers (DR-68), which are applicable to new dredgers with a keel laying date on or after 1 January 2010.

Bureau Veritas, as the leading class society for dredgers, has a long history with the certification of dredgers and has developed specific technical requirements long before the international guidelines were conceived. Making use of the knowledge built up with design verification, newbuilding surveys and in-service inspections Bureau Veritas continues to develop its knowledge base and feed this back into the classification rules. In addition, Bureau Veritas experts are playing a very active role in the drafting of the international guidelines.

A major technical development in regulations applicable to dredgers has been the introduction of the operating areas, which have created the necessary link between the reduced dredging freeboard and the longitudinal strength. Based on technical studies performed by Bureau Veritas the operating areas can be extended on the basis of the maximum significant wave height associated with the operating area notation of the dredger. This has further enhanced the operational flexibility of dredgers.

The paper provides a comprehensive overview of the major technical issues associated with the different types of dredgers and how the related challenges are effectively addressed in the rules. In addition to class requirements Bureau Veritas has also developed design (verification) tools which enable fast efficient compliance verification with the specific class requirements for dredgers.

Finally, a number of recent developments in dredging technology and associated castigation requirements are presented. With the dredging industry pushing its frontiers...
towards higher efficiency, lower environmental impact and the deployment of new and advanced technologies, class societies need to continue to invest in technical research and the development of services to support the dredging industry in achieving these objectives.

REFERENCES

BUREAU VERITAS, “Freeboard of Dredgers and Barges Fitted with Bottom Dump Doors (NR 144 R00 E/F)”, 1971
BUREAU VERITAS, “Rules for the Classification of Steel Ships (NR 472.3 DTM R00 E) - Pt E, Ch 13”, June 2000

DR-67 JOINT WORKING GROUP, “Guidelines for the Assignment of Reduced Freeboards for Dredgers (DR-68)”, 3 February 2010
BUREAU VERITAS, “Rules for the Classification of Steel Ships (NR 467.A1 DT R09 E) - Pt A, Ch 1, Sec 2”, July 2010
BUREAU VERITAS, “Rules for the Classification of Steel Ships (NR 467.D3 DT R04 E) - Pt D, Ch 13”, April 2009