Addressing Military Survivability and Safety Aspects in Classification of Naval Design

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ABSTRACT

It has become standard operating procedure for Classification Societies to provide services for naval ship designs around the world. This paper will briefly discuss the factors leading to this eventuality and describe some of the military survivability aspects of naval design currently being addressed by societies. Using the ABS International Naval Ship Guide (INSG) notations and NATO standard ANEP 77 as examples, the paper will describe some aspects of survivability that classification now addresses. Topics will include:

NATO ANEP 77: The Naval Ship Code is intended to address naval surface ship safety. It is a goal-based standard using IMO conventions and other sources as introduced through the International Naval Safety Association (INSA).

Hull Girder Ultimate Strength Assessment: Discusses the critical failure modes of all hull girder structural elements. All relevant failure modes for individual structural elements, such as plate buckling, torsional stiffener buckling, stiffener web buckling, lateral or global stiffener buckling, and their interactions are considered in identifying the weakest inter-frame failure mode.

Ballistic and Fragmentary Protection: From basic to enhanced levels of protection, this notation addresses ship arrangement details aimed at concealing crew and mission critical assets to protect from attack. Methods to slow ballistic projectiles and protect from structural penetration are used for higher notation levels.

Air Blast: Addresses the calculation of air blast loads and methodology for analyzing structure, using explosive amount and distance from blast to determine protection level desired.

Underwater Shock: Describes the assessment of a structure to withstand an underwater explosion.

Underway Replenishment: Addresses the general guidance to identify the fitness of principal equipment and the completeness of a ship's operational manual in order to perform Underway Replenishment safely.

Redundancy: Notations addressing redundancy arrangements, indicating a vessel is fitted with multiple propulsors and steering systems such that fire or flood in one space will not affect other propulsion systems.

Finally, the paper will consider evolving technologies being considered for naval designs that will need to be addressed by class societies in the future.

KEY WORDS:
Classification societies; naval classification; military notations; standards.

NOMENCLATURE:

ABS: American Bureau of Shipping

Other Classification Societies:

BV - Bureau Veritas

DNV GL - Det Norske Veritas Germanisher Lloyd

IRS - Indian Register of Shipping

LR - Lloyd's Register

PRS - Polish Register of Shipping

RINA - Registro Italiano Navale

ANEP: Allied Naval Engineering Publication

ARI: Acquisition Reform Initiatives

ASTM: American Society for Testing and Materials

CLF: Combat Logistics Force (US Navy)

ConOpS: Concept of Operations Statement

IMO SOLAS: Safety of Life at Sea

INSG: ABS International Naval Ship Guide

IT: Informational Technology

LOP: level of protection

LOS: line of sight

MVR: ABS Marine Vessel Rules

NATO: North Atlantic Treaty Organization

NSC: Naval Ship Code

OT: Operational Technology

RO: Recognized Organization

SDOF: single degree of freedom

UNREP: Underway Replenishment

FACTORS LEADING TO NAVAL CLASSIFICATION

"Change is with us. Change in what we do, how we do it, and sometimes it's even where we do it. It's inevitable that there will be change in how we procure our equipment for the future. The only message I'd like to give industry is that we're not afraid to adopt new ideas or new ways of doing business, or to seek the authority to reach out just a little bit further than we have in the past. It will be a lot better if we figure that out together, as the customer and the supplier." – ADM Boorda

As the Cold War ended, Navies around the world began seeking new ways to continue building ships within ever tightening budgets. For example, in the United States, the US Government initiated Acquisition Reform Initiatives (ARI) in the 1990s and through to the early 21st century. Working with industry, they succeeded in transforming longstanding military acquisition practices into a more commercially relevant acquisition process. The American classification society American Bureau of Shipping (ABS) participated with the US Navy in converting many of their older military documents into commercial standards, as well as incorporating their design practices into rules and guides for their use. The American Society of Testing Materials (ASTM) Committee F25 on Shipbuilding also served as a conduit for converting obsolete military documents into relevant commercial performance standards with military unique aspects where needed.

As ASTM F25 was one of the preeminent standard bodies geared specifically towards US shipbuilding, it was the natural choice as one of the first organizations to gain increased government participation. The committee became an excellent forum for reviewing and comparing of military standards to existing industry standards. As government representatives became more familiar with the commercial counterparts to many military documents, they realized that they could perhaps be made suitable for naval applications with some changes. These changes were added as annexes to the standards known as "Supplementary Requirements" and can be found as part of many ASTM standards in Volume 01.07.

These are just two examples of the many ways in which navies throughout the world began working with their national industrial base, and the many classification societies around the world, to transform their acquisition practices from an insular model using government self-certification into a more commercial model using the long established commercial model of ship classification.

The commercial shipping industry has for many years employed the process of ship classification, using the independent third-party certification services of one of the recognized Classification Societies. As noted earlier, many navies (including the US Navy) gained familiarity with that commercial process through the building of many non-combatant auxiliary ships built to commercial standards. In America, the US Navy has participated as part of the ABS Technical Committee for many years, aiding in the development of rules for the design and certification of ships for the combat logistics force (CLF), sealift, and oceanographic service.

What is Classification?

First conducted over 250 years ago, 'Classification' has been performed by classification organizations called societies. The objective of ship classification is to verify the structural strength and integrity of essential parts of the ship's hull and its appendages, and the reliability and function of the propulsion and steering systems, power generation and those other features and auxiliary systems which have been built into the ship in order to maintain essential services on board. Classification societies (or the more common shortened term 'class societies') provide these services through the development of standards called Rules.

These rules form the basis for assessing the design and construction of new vessels and the integrity of existing vessels and marine structures. Implementing the published rules, the classification process typically consists of:

- A technical review of the design plans for a new vessel to verify compliance with the Rules
- Attendance by a class society Surveyor:
    - At the construction shipyard
    - At the relevant production facilities that provide key components for the vessel
    - At sea trials
- When these inspections or surveys are completed, satisfactorily verifying compliance with the rules, the class society issues a certificate of classification.

Once in service, the owner must submit the vessel to periodical onboard class surveys to verify that the ship continues to meet the relevant Rule requirements. An example of the process for American Bureau of Shipping (ABS) is provided below in Figure 1.

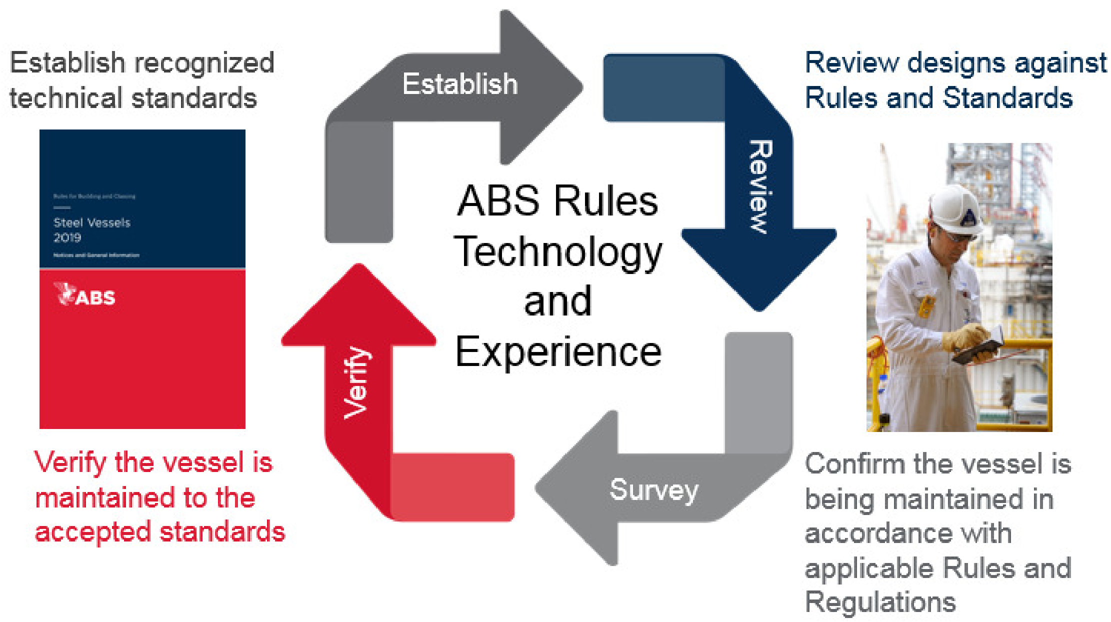


Figure 1: The ABS Classification Model

Use of Naval Classification Increases

As the navies worldwide began to incorporate more commercial processes and standards, they decided to build on their familiarity with class society rules and processes to move towards the next step: rules for combatants. Navies around the world, such as in the United Kingdom, Norway and Germany reached this conclusion, and employed their home class societies. Lloyd’s Register worked with the British Navy and led this effort by publishing their

Naval Ship Rules in 1999. The UK Navy has since applied them to all British naval combatant acquisition programs.

Many societies have developed Rules to address a range of naval and naval auxiliary vessels, such as ABS, Bureau Veritas (BV), Det Norske Veritas Germanisher Lloyd (DNV GL), Indian Register (IRS), Lloyd's Register (LR), Polish Register (PRS), and Registro Italiano Navale (RINA). At least two dozen navies around the world have applied the process of classification to some degree for either the acquisition or in-service maintenance of their vessels. It has indeed become standard operating procedure for Classification Societies to provide services for naval ship designs around the world.

MILITARY SURVIVABILITY ASPECTS OF NAVAL DESIGN ADDRESSED BY CLASSIFICATION

Survivability is a critical consideration for a vessel. For commercial vessels, this entails the ability to withstand loads due to inclement environments and operate even if critical components or systems fail. Naval vessels have the additional burden of surviving in combat environments. Both offensive and defensive measures can be taken to improve the survivability of the vessel. Survivability for naval vessels is composed of three basic properties:

Susceptibility: This is principally a ship's ability to avoid detection from other offensive ships, which depends greatly on its Signature. Each naval ship has unique signature characteristics in various regions of the electromagnetic spectrum. The spectrums most commonly used for identification and detection purposes are visual, microwave and infrared. Reducing or modifying the various signatures such that they match the operating environment can enhance the survivability of the vessel. Of course, sound and visual identification still remain equally important to signature.

Vulnerability: This is a ship's ability to continue to conduct its mission, either fully or partially, and to protect its crew, after an offensive weapon has struck the ship. The design is to attempt to minimize damage as best as practicable; this can either be done via system redundancies; thwarting the ability of an enemy to successfully acquire targets on the ship (such as through providing protected accesses for crew transit onboard the ship to minimize open air movement); providing means to reduce the energy of the weapon effect; or structure hardening to prevent weapon penetration.

Lethality: This is the ability of a ship to successfully engage an enemy using its offensive weapons or other assets such as aircraft, helicopters or unmanned underwater, surface or aerial vehicles. This third aspect of survivability is typically outside of the scope of the Classification Society, which is principally concerned with hull, mechanical and electrical (HM&E) aspects of the ship design, as well as some non-offensive mission systems.

To better illustrate and describe some aspects of survivability that classification now addresses, the following are examples of military notations addressed in the ABS International Naval Ship Guide (INSG).

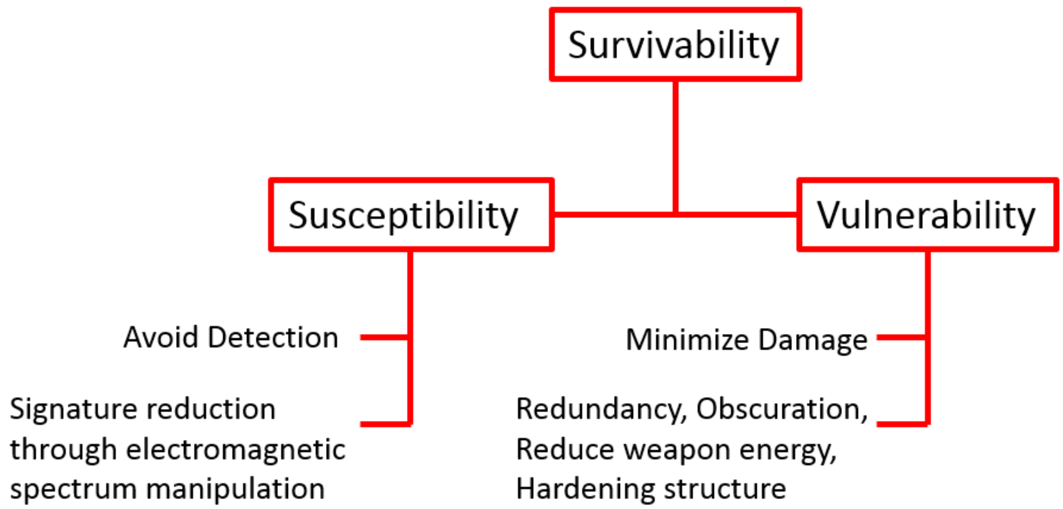


Figure 2: The Survivability Model for Classification

Notations from the ABS International Naval Ship Guide

The ABS Guide for Building and Classing International Naval Ships (INSG) is applicable to non-nuclear, displacement type, monohull surface ships. It addresses hull, mechanical and electrical systems specifically adapted to combatant and non-combatant vessel requirements in areas such as survivability, mission and system requirements and interfaces, and interpretations of statutory requirements. The structure and organization of the INSG is similar to commercial ABS Marine Vessel Rules (MVR), using a proven quality system process. In addition, naval shipbuilding standards from around the world were examined for reference and/or inclusion during development. Key military requirements were adopted to address redundancy and survivability. The INSG is a complete standard for building naval warships, including:

- Mission loads
- Vital space definition
- Damage control
- Fire/flooding requirements
- Revised finite element analysis (FEA) guidance and design pressure requirements
- Battle override features in control and automation

The INSG allows flexibility in tailoring the requirements as needed, typically to become a part of a comprehensive certification matrix. This matrix may include a combination with portions of other Rules (as needed), as well as in conjunction with Naval Administration[1] standards. The matrix is created to best accommodate project support as part of the acquisition process, which in many cases is very complex for a government program. In addition, INSG may

[1] The 'Naval Administration' is the agency within a Government or Nation responsible for the safe operation of government ships. The Naval Administration may be assisted or supported by other government departments, or it may delegate this duty to another agency within the Government.

support Statement of Compliance reviews/surveys, offered as third-party certification by ABS to criteria both originating from ABS Rules as well as other resources (e.g., builder's specifications).

NATO ANEP 77 – Addressing Naval Ship Safety

While it is clear that IMO SOLAS (Safety of Life at Sea, a convention of the International Maritime Organization) is not easily adapted to naval designs – indeed, ships of war are specifically exempted from application to the regulations – safety of life at sea is key for any ship. The Naval Ship Code (NATO Allied Naval Engineering Publication 77, or NSC) is intended to address naval surface ship safety. Using a goal based philosophy for naval ship safety, the Naval Ship Code provides the first high-level comprehensive safety standard for combatant and noncombatant military ships. Put simply, ANEP 77 is a sort of naval version of IMO SOLAS and is being applied to many NATO and non- NATO warships around the world.

ABS INSG offers the **NavalSafe** notation for military ship designs. ABS NavalSafe(x) is an optional notation assigned to the ship once the performance requirements of the defined chapter(s) of the NSC are met and the Naval Ship Safety Certificate is issued. The NSC is based on IMO conventions, resolutions and other sources that are applicable for the majority of naval ships.

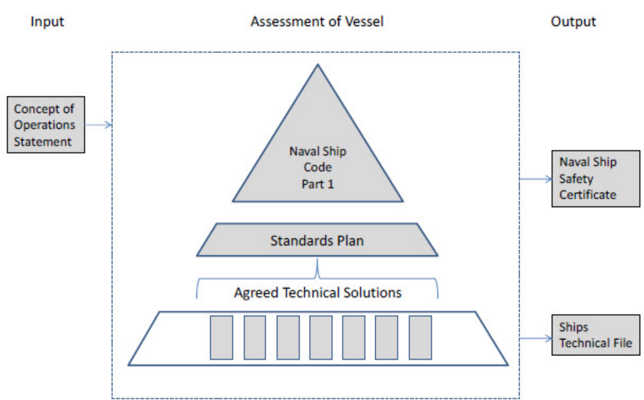


Figure 3 – Naval Safety Ship Certification Process. Source: NATO ANEP 77

The ABS NavalSafe(x) notation determines a minimum level of safety for government combatant and non-combatant vessels. The index 'x' in NavalSafe(x) notation represents: S (Structure), BSC (Buoyancy, Stability and Controllability, ES (Engineering Systems), SS (Seamanship Systems), FS (Fire Safety), EER (Escape, Evacuation and Rescue, C (Communication), N (Navigation), DG (Dangerous Goods), All (if all entries are applicable). The NSC is applicable to all surface craft used for government, non-commercial service, such as navy, coast guard, border patrol, customs etc. It applies principally to conventional powered vessels (non-nuclear) using conventional fuels such as diesel (for example NATO F76 fuel) or intermediate fuel oils.

The NSC requires that a Concept of Operations Statement (or ConOpS) be developed to compare the applicability of the criteria and standards chosen. Once this is determined, the Code can provide a path for a ship to be certified by a Naval Administration, along with recognized organizations (RO) such as classification societies, to establish that a vessel is safe to operate in accordance with the ConOpS provided (within the limits of those aspects addressed by the Code), as well as within the safety policies, and safety organization, of the government organization in which it will operate.

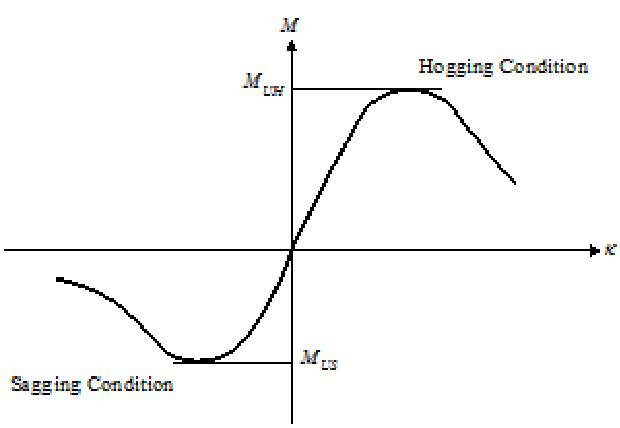
While the goal based nature of the Code allows the Naval Administration and ROs to consider alternatives to the typical safety requirements applied to commercial ships, it is important to emphasize two limitations: (1) It is not intended to be viewed as a complete and entire safety management system for a ship or fleet; and (2) While fully intended to apply to operating conditions and foreseeable damage scenarios applicable to peacetime and maritime security (as determined in the ConOpS), the Code is NOT intended to apply to combat operations, or its associated threat conditions; these are outside of the scope of the Code, and intended to be addressed separately by the appropriate departments within an Administration.

IMO SOLAS requirements may be applied as a solution option for a particular safety aspect of the design; arrangements other than that proscribed in IMO SOLAS may be evaluated using the Naval Ship Code.

Hull Girder Ultimate Strength

When hull girder structural members are compressed beyond their limit it reduces their load carrying capacity. It is therefore important to identify the weakest inter-frame failure mode by investigating all relevant failure modes for individual structural elements, such as plate buckling, torsional stiffener buckling, stiffener web buckling, lateral or global stiffener buckling and their interactions.

In addition to simple longitudinal strength calculations (where the calculated elastic stresses in the deck or bottom shell members are evaluated against prescribed allowable stresses), some navies seek this Ultimate Hull Girder Strength Assessment (**UHS**) notation because the ultimate hull girder strength analysis takes into account elasto-plastic properties of the material, nonlinear geometric behavior of the elements, and their buckling and post-buckling strength, in order to more accurately estimate the strength reserves of the ship's cross section, providing a rigorous, first-principles based alternative evaluation of the actual hull strength. This is particularly relevant for unconventional and highly optimized naval vessel designs. However, it should be stressed that the UHS notation applies to the intact strength of the vessel, it alone is not suitable for evaluation in a damaged condition to mitigate military damage.



The hull girder ultimate strength is represented by hull girder ultimate bending capacity M_U (M_{UH} or M_{US}) (Figure 4) which is defined as the peak value of the curve with vertical bending moment M versus the curvature κ of the ship cross section.

Figure 4: Vertical Bending Moment M versus Curvature κ

Ballistic and Fragmentary Protection

From basic to enhanced levels of protection, this notation addresses ship arrangement details aimed at concealing crew and mission critical assets to protect from attack. Methods to slow ballistic projectiles and protect from structural penetration are used for higher notation levels. ABS uses the notations **BFP1, BFP2** and **BFP3** as optional notations that indicate the level of ballistic and fragment hazard protection. Ballistic and fragment hazards can be mitigated by various methods, which will determine the level of protection (LOP) the ships can attain. Selection of the desired LOP for ballistic and fragment hazard protective barriers should be based on the mission requirements, anticipated threats and results of vulnerability assessments, which should account for ship resiliency under combat conditions. The primary objective of ballistic and fragmentary protection is to provide technical guidance for achieving an LOP for naval ships against direct fire weapons by reducing the line of sight (LOS) and hardening the exposed surfaces. Hardened exposed surfaces may include both transparent (e.g., glazed) and opaque (e.g., steel, aluminum, composite, etc.) barriers comprised of single- or multi-layer construction.

BFP1 notation focuses on obscuration from open view of typical crew activities. An example where BFP1 might be employed regards the configuration of the access to the Bridge. Access doors on either side of a Bridge, that might allow clear visibility to the helm when opened, would allow the possibility of a straight line of sight (LOS) shot by a sniper at the watch officer, navigator or helmsman. Using a small right angle for the door entrance to the Bridge would eliminate this force protection weakness. Higher levels of this notation (BFP2, BFP3) would address items like protective glass around the Bridge, and enhanced protection of bulkheads and decks surrounding ammunition storage and crew gathering areas such as the mess and recreation areas.

Air Blast

ABS notation "**AB (Weight, Range)**" is an optional notation that indicates protection from an air explosion event. Ships complying with these requirements will be eligible for the optional notation AB (Weight, Range), where Weight is the equivalent TNT weight of the explosive material and Range is the safe distance from the source of explosion. Blast curve methodology for a hemispherical surface burst is used to predict the air blast loads acting on exposed surfaces of the ship resulting from open-air (unconfined) bursts of high explosive (HE) at the water surface.

Equivalent single degree of freedom (SDOF) systems is used for structural analysis. SDOF reduces the level of analytical effort and facilitates the use of parametric studies and the development of analysis. As shown in the figures below, the simplest method for solving the structural dynamic equilibrium equation is through a graphical representation solution. A dynamic response chart which provides the solution for a SDOF system having perfect elastic-plastic resistance and a triangular pulse loading is used. Given the applied loading and the basic SDOF system parameters, the ductility demand may be read directly from the response chart.

Analysis curves for hull plate thickness (Figure 5) and longitudinal stiffener (Figure 6) are also provided. These curves encompass all of the engineering steps from blast load determination through the nonlinear dynamic structural analyses and damage state predictions. Knowing the hull plate thickness (t) and longitudinal frame spacing (s) or the longitudinal stiffener particulars: length (L), cross sectional area (A), moment of inertia (I) and plastic modulus (z), an engineer can quickly assess the ability of the reviewed structure to meet the required level of protection.

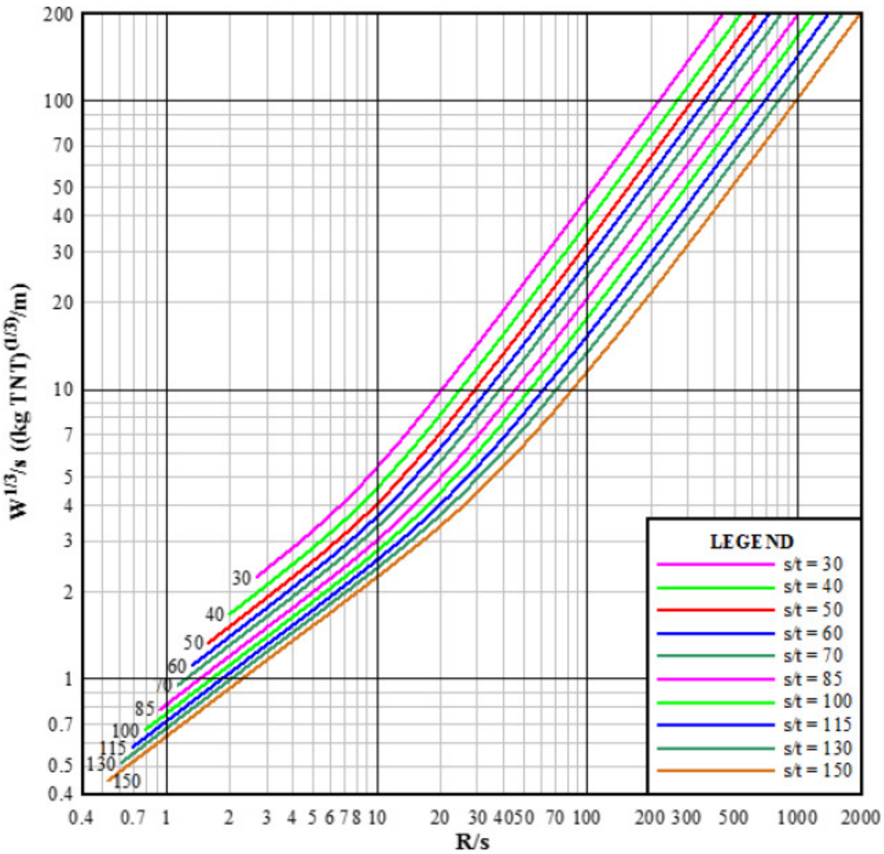


Figure 5: Scaled R-W for Hull Plates

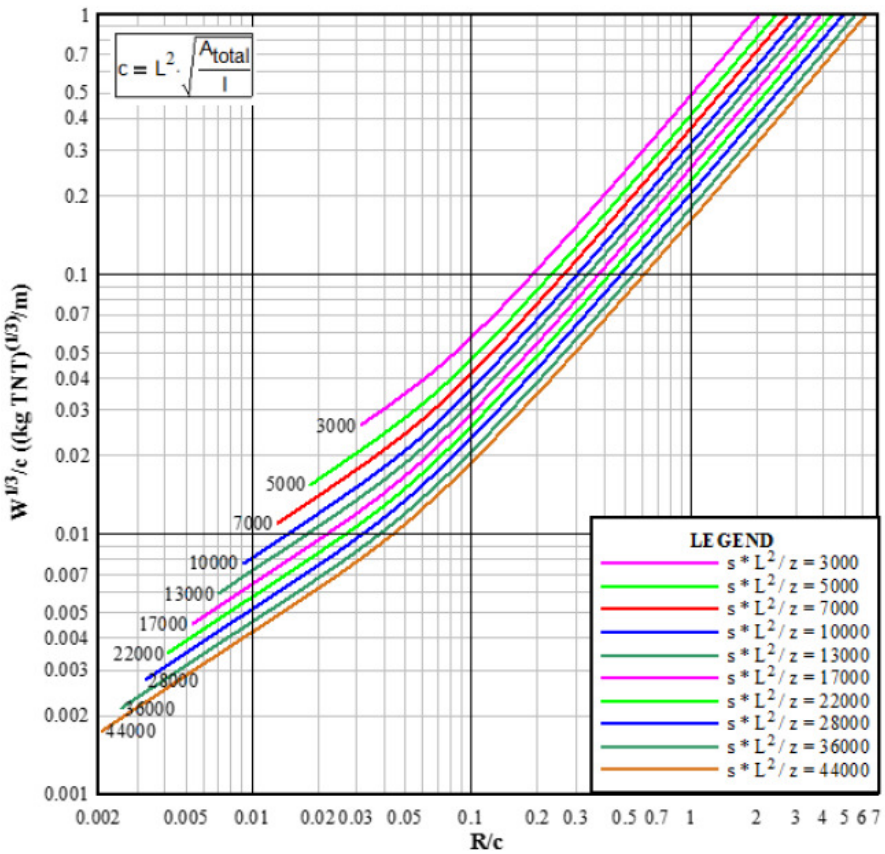


Figure 6: Scaled R-W for Longitudinal Stiffener

Underwater Shock

The ABS shock notation (described as **UNDEX (Weight, Range)**) provides steps needed to protect ship structures from underwater shock. The UNDEX (Weight, Range) notation covers the hull structure below the waterline, and shock effect on the equipment. The Naval Administration is to define the underwater shock threat in the form of charge weight and the expected safe distance from the source of the underwater blast. Shock loading can come from shock waves, gas bubble pulses and bulk cavitation. Only shock waves comprised of direct, surface reflected, and bottom reflected waves are considered.

Equivalent single degree of freedom (SDOF) analysis can be used to design the protective structures subjected to blast loads based on calculated underwater shock loading. Use of equivalent SDOF systems significantly reduces the level of analytical effort, and there are several numerical methods that can be used to solve the dynamic equation using SDOF. In the notation guidance, the linear acceleration method is used. In this method the response is evaluated at successive increments (Δt) of time. At the beginning of each interval, the condition of dynamic equilibrium is established. Then the response for a time increment (Δt) is evaluated approximately on the basis that the spring coefficient in the equation of motion remains constant during the interval Δt. Assessment of supporting members such as girders or transverses can either be done using a series of separate SDOF dynamic analysis for each of the supporting members or by more advanced structural analysis.

Underway Replenishment (UNREP)

Replenishment at Sea is crucial for any naval fleet engaged in power projection extending far from its nation's shores, as well as supporting allied navies in extended exercises. The notation **UNREP (Beam, Stern, Vert)** is applicable to both supplying and receiving ships, and covers:

- Ship's maneuvering
- Engagement
- Cargo transferring and its equipment
- Disengagement
- Breakaway

As guidance, the notation does not cover the following, as these items are typically addressed in fleetwide procedures for each navy:

- Cargo loading
- Cargo storing
- Equipment below the cargo hook (ex: personnel cage, cargo container, etc.)

The notation addresses general guidance to identify the fitness of principal equipment and the completeness of operational manuals in order to perform UNREP in a structured manner.

Redundancy

One property of vulnerability resistance addresses redundancy arrangements, indicating a vessel is equipped with propulsion and steering systems designed to provide enhanced reliability and availability through functional redundancy, such that a fire or flood in one space will not affect other propulsion systems. The objective of redundancy is to provide requirements which reduce the risk to personnel, the vessel or other vessels. The requirements for this notation are intended so that, following a single failure, the vessel is capable of either maintaining course and maneuverability at reduced speeds without intervention by other vessels, or maintaining position under adverse weather conditions to avoid uncontrolled drift and navigating back to safe harbor when weather conditions are suitable. In addition, it addresses aspects which would reduce the detrimental effects to the propulsion systems due to a localized fire in the machinery spaces.

Notations offered address multiple propulsion machines (**R1**), multiple propulsors and steering systems (**R2**), multiple propulsion machines in segregated spaces (**R1-S**)**, and** multiple propulsors and steering systems in segregated spaces (**R2-S**). Weather criteria may also be applied resulting in the addition of a plus (**+**) to the above notations. However, it should be stressed that while this notation has applications for military ships, it is intended principally for commercial vessels and is based upon a single failure concept only. Specifically, this concept accepts that failures may occur but that only one such failure is likely at any time. Of course, military ships intended to go in harms way may be expected to sustain more than a single failure point. This is determined based on the ship design's hazard and survivability analysis typically conducted by the Navy.

Evolving Technologies and the Future

Autonomous Operations are becoming more and more pervasive in naval operations, as navies operate successively larger and more operationally capable aerial, surface and undersea vehicles. This will result in additional platform space for air capable operations, control centers, mission space and deployment gear, hull accesses and ramps. On the command and control side, it will push navies to consider further defensive measures to preserve their networks and protect them from cyber-attacks. Cyber protection, both from an operational technology (OT) and informational technology (IT) perspective, has already become one of the preeminent properties for a superior warfighting ship, and this will continue for the foreseeable future. In some cases, class societies (such as ABS) are working with navies to publish guidance to help improve cybersecurity and mitigate related risk, such

"Novel uses for increasingly sophisticated robotics, energy storage, 3-D printing, and networks of low-cost sensors, to name just a few examples, are changing almost every facet of how we work and live." – ADM Richardson

as through the ABS Guide for Cybersecurity Implementation for Government Vessels, Facilities and Assets (Volume 6 of the ABS CyberSafety© series of publications).

For at least the last 60 years, diesel engines, gas turbines and boiler/turbine plants delivered the power necessary - via a shaft and propeller - for ship propulsion for the world maritime industry. While these forms of propulsion, principally using diesel engines, is quite likely to continue into the next few decades, current technological advances offer a number of other options. These options typically center on transitioning from a conventional mechanical propulsion arrangement to a hybrid electric propulsion system. Modern electric propulsion systems may incorporate new technology, such as using fuel cells, as power generation, and batteries (principally lithium ion), super-capacitors and flywheels to provide energy storage to supply and/or supplement the electrical power needs of the vessel. The stored energy aspect augments energy needs to enhance safety in response to emergency scenarios, as well as the high power needs necessary to serve directed energy systems and related weapon technology. Fuel cells have already been used for supplemental electric power generation on naval platforms since the beginning of the 21st century, such as the air-independent propulsion system for the German Navy's Type 212 and 214 submarine classes, among others developed around the world.

SUMMARY

In the US Navy, Chief of Naval Operations Admiral Richardson has frequently stressed the need for experimentation, engineering and prototyping to ready the fleet for the next conflict and yield a relevant navy that is ready to defend the country from attack and protect US interests around the world. His focus on conceptual, geographic and technological agility has reverberated with navies throughout the world who are now considering a number of commercial processes and evolving technologies for naval designs. As a now established trusted partner in naval design and construction worldwide, class societies will continue to innovate and develop to meet the needs of the navies they serve.

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