THE SOCIETY OF NAVAL ARCHITECTS AND MARINE ENGINEERS
74 Trinity Place, New York, N.Y., 10006
Paper to be presented at the Ship Structure Symposium
Washington, D.C., October 6-8, 1975

Classification Society Experiences in Today's Ships

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ABSTRACT

The traditional approach of the Classification Society in establishing its Rules has been to draw heavily on years of satisfactory experience of similar vessels in service. However, in the last 20 years the evolution of very large sophisticated and highly specialized ships has outpaced the accumulation of service experience. This paper reviews approaches taken by ABS in reviewing the structural adequacy of today's large, sophisticated vessels. Design considerations are discussed, such as the use of finite element analyses and the attention that must be given to local details. The materials of today's ships are considered in the light of their special properties, such as high strength, toughness, cryogenic, antifouling, etc. Other topics include welding, non-destructive testing, and the role of the modern classification society in accommodating the needs of the international maritime community.

INTRODUCTION

Until the early 1960s ships were designed to meet the operating requirements of the first and last mile of the voyage where port facilities imposed draft or physical dimension limits on the vessel. With the development of deep water cargo handling facilities together with the closing of the Suez Canal, these restrictions were modified or removed leading to revolutionary increases in the dimensions of ships. And so we have seen the rapid evolution of supertankers, VLCCs and ULCCs. While the increase in the size of bulk carriers and OBOs has not been as dramatic as that for tankers, due to shore side handling capability, these too have also reached a new generation in terms of size.

Apart from size, a number of other significant developments and changes have occurred in naval architecture over the past two decades which have added efficiency and effectiveness in ocean commerce. While these advances have proven most beneficial, their developments presented a measure of difficulty for the classification society.

As you may know, classification rules, the standards for designing and constructing vessels, have been traditionally based upon years of satisfactory service experience. But, in the last two decades the pace of maritime developments was such that the accumulation of experience was not always possible. This, then, brought a burden to the American Bureau of Shipping - to set standards and review designs for vessels for which there was limited experience. To properly serve the marine industry ABS cannot ask an owner to wait several years while his novel design is researched; a classification society must be able to act with reasonable promptness in reviewing all designs for their adequacy.

The Rules are developed, refined, and updated through a Committee structure composed of internationally eminent specialists in the marine and related fields. These Bureau committees, 43 in all, give the Bureau close contact with interests in various geographical regions with various technological and scientific disciplines. In addition the Bureau is involved in the activities of many technical organizations and societies and participates in and receives the benefits of their research programs. Without these committees, the Bureau would be a much less efficient organization as these committees are a valuable source of information and experience. The particular importance that the Bureau places in the research programs of the Ship Structure Committee and the Society of Naval Architecture and Marine Engineering is evidenced by its active participation in these organizations.

Fortunately the American Bureau of Shipping was able to turn to the recently matured computered sciences for assistance. Sound engineering analysis through computer techniques could be effectively used to complement the "Rules" where experience is lacking.

In fact, without the aid of the computer it is doubtful that the new generation of ships operating today would have been as feasible. The classical methods and tools available to the naval architect 20 years ago would not have sufficed for reviewing, for instance, the scantlings of the modern day VLCC.

DAISY SYSTEM

At the outset of computer applications, ABS used a number of general engineering computer programs such as STRUDL and STRESS, but it was felt that these general engineering programs did not permit a ship to be modeled in a manner to realistically represent the structure or they had other inherent limitations which would give questionable results. While ABS did use these programs with success for a period of time, we were simultaneously concentrating efforts on the development of a computer system specifically for evaluation of a ship's structure and its components. The result of our effort is the DAISY System, developed in cooperation with the University of Arizona and the Chevron Shipping Company. This system is a two and three dimensional finite element program with the necessary preprocessing and postprocessing programs to analyze a complete ship, a section of which represents two or more tanks, or a single two dimensional member such as a web frame or bulkhead web.

Much has been previously written and discussed of DAISY so I will refrain from doing so here other than to direct your attention to those papers cited in the reference 1, 2, 3, 4 and 5. We feel that DAISY is the most comprehensive finite element system of computer programs for analyzing marine structures that is available to the industry. Of course, DAISY System is being continually refined to accommodate the advancements and needs of the industry.

The Bureau has been asked on many occasions to publish the allowable "apparent stresses" for use with a computer analysis but it is impossible to set the allowable "apparent stresses" without full knowledge of the design loads, modeling techniques, method of analysis, assumptions, etc., but in Reference 6 we have indicated allowable "apparent stresses" when using the design conditions indicated in our Rules and using a comprehensive three dimensional finite element analysis such as DAISY. The intent of this paper is to discuss a classification society's experiences both from its technical review and service records with the purpose of possibly preventing some of the past oversights in tomorrow's ships.

Just to digress for a moment, unless one has had the opportunity to visit a VLCC or ULCC it is hard to appreciate the magnitude of the structure involved. It may be helpful to realize that the area of a bottom longitudinal on a VLCC may be more than 20 percent greater than the area of a bottom transverse of a longitudinally framed T2 tanker. This figure for a ULCC could be upward of 30 percent. The center vertical keel of a VLCC may be 7-1/2 meters in depth or the height of a three story building. Also, the bottom transverse on a ULCC may be 2-1/2 times the depth of the center vertical keel of a T2 tanker.

A person once asked what is the most inefficient piece of equipment on a VLCC and the reply was the cargo pumps, which have twice the H.P. of the main engines on a T2 tanker; and they are used only 8-10 days a year. These comparisons should not be part of a technical paper, however I feel that a person discussing today's ships should have some feel of the magnitude of the structures involved.

LOCAL STIFFENING

Design review procedures which 20 years ago were adequate for the vessels of that time may require a more thorough engineering analysis as new areas of consideration for larger vessels becomes increasingly important.

Our experience has shown that while overall longitudinal strength of today's vessels is adequate, some local problems have occurred due to the inability of a panel to take compressive or shear loads, the failure of the supporting members, or details. Compressive and shear loads are more critical than tension loads as they may result in local failure due to buckling whereas tension loads will be redistributed when plastic deformation occurs.

A recent review of the service records of 266 vessels over 700 feet in length built since 1960 indicated that several vessels have experienced local deformation. The failure can be traced to the two following areas:

a - instability of the panels in compression or shear
b - inadequate attachment between the web frames and the longitudinals

Large panels of web frames on tankers which have inadequate stiffening have experienced some local deformation. Where the web frames are stiffened at alternate longitudinals the critical buckling strength of the panel can be increased by a factor of about 4 by fitting stiffeners at every longitudinal. When stiffeners are fitted at every

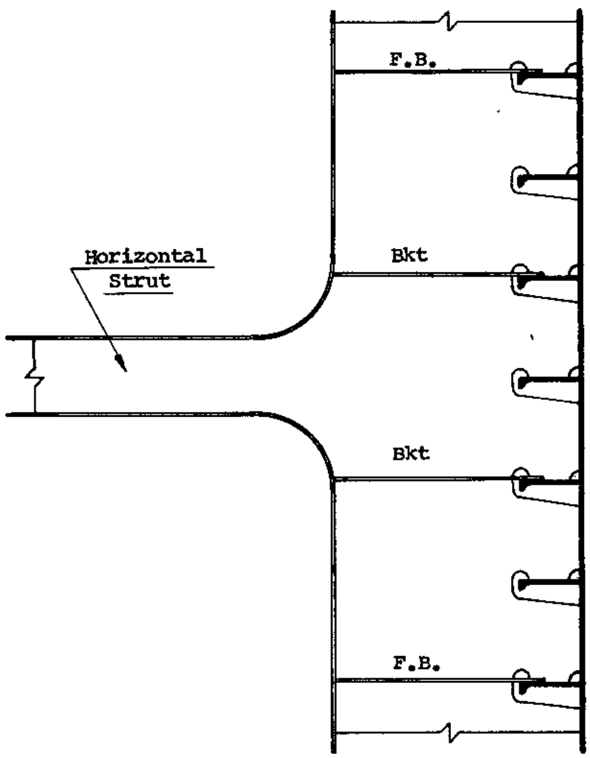


Figure 1

Typical intersection of
web frame and horizontal strut

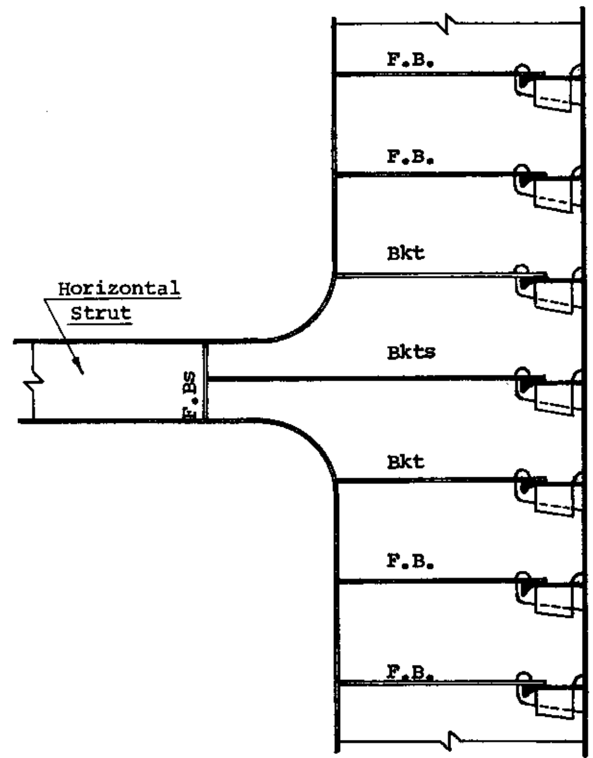


Figure 1a

Typical reinforcement of
web frame and horizontal strut

longitudinal, the aspect ratio of the panel may be critical and it may also be necessary to stiffen the panel to reduce the aspect ratio when the panel depth divided by thickness (d/t) of the web is greater than 200. This additional stiffener should be fitted parallel to the face plate of the web at approximately 1/4 the depth of the web from the face plate to give proper support for compressive loads. Attention should also be given to the inertia of the stiffeners so that they will not fail before the critical buckling stress of the panel is reached.

Figure 1 shows the detail of the attachment at the ends of the horizontal struts and in retrospect it can be clearly seen that there was inadequate stiffening of the webs to transmit the compressive loads in the struts. The deficiency can be easily corrected in the designs for future construction but structural modifications to existing vessels becomes a more difficult problem. Indicated in Figure 1a is a system of reinforcing which has proven satisfactory on a number of vessels.

Our analysis of some of the failures in way of the cut-outs in the web frames for the longitudinals has shown that good judgement should be used in the design of this important detail. A three dimensional finite element analysis of the whole ship or a section of the cargo tanks will not indicate problems in design of details. Extensive detailed finite element analyses have been made of the structure in way of the cut-outs in some instances but this is not the normal routine in plan approval.

In Figure 2 is shown a typical cutout in a web frame for the longitudinals. In those vessels which encountered cracks approximately 75 percent were found in locations G and H. Some cracks were also noted at locations D, E and F. Almost invariably cracks at D, E and F occurred when G and H type cracks were present. One of the conclusions drawn from this investigation was that the initial failure was at the lower end of the stiffener on the web at the attachment to the longitudinal and it appeared that G and H type cracks

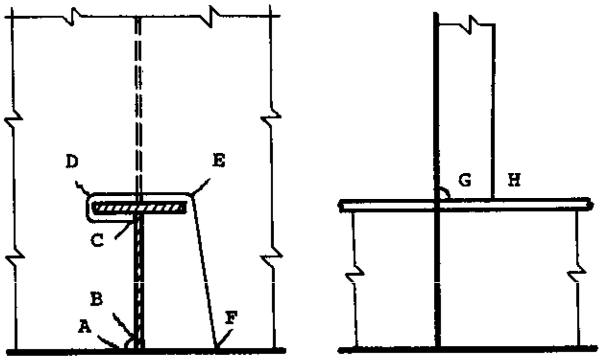


Figure 2

Typical cut-out
for built-up longitudinal

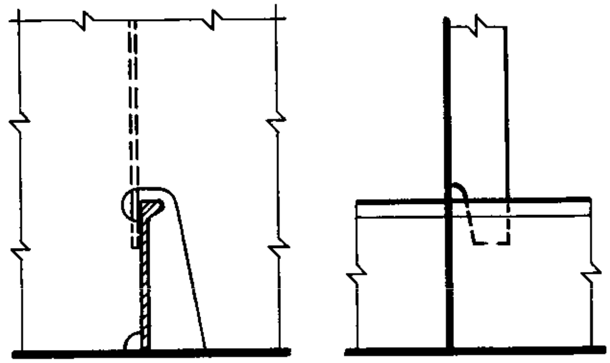


Figure 3

Typical cut-out for
bulb plate longitudinal

occurred first and then type D and E developed. Types A, B and C were found on occasions where other cracks were present but only rarely did they occur by themselves.

Shown in Figure 3 is the typical type of cut-out where the longitudinal was a rolled angle or bulb profile. With this type of construction where the web stiffener is lapped on the longitudinal there had been a failure of the G and H type in way of the cut-out only on rare occasions, as this detail permits a greater amount of welding.

The general conclusion based on our service experience was that failure resulted from:

1 - a lack of efficient welding attachment between the longitudinal and the web stiffener (Figure 2)

2 - high stresses in the welding attachments

It can be seen from Figures 2 and 3 that the load in the longitudinal is transmitted to the web frame through the welded attachment of the web of the longitudinal to the web frame and into the stiffener on the web frame. For the sake of comparison, this load in a bottom longitudinal in an empty tank on a T2 tanker at summer draft would be approximately 27 tons. On a VLCC it could be 145 tons. An assumption that a detail which has proven satisfactory on smaller ships such as T2 tankers would be adequate through direct extrapolation and need no further investigation on today's VLCCs and ULCCs is shown to be a completely false assumption when the magnitude of the load is realized.

To reduce the general stress levels filler plates should be fitted as shown in Figure 4. In addition, by attaching the web with a filler plate to the longitudinal the critical buckling strength of that portion of the web is increased substantially. Figure 4 also indicates an acceptable method of reinforcement of existing web stiffeners to provide additional welded attachment between the stiffener and the longitudinal.

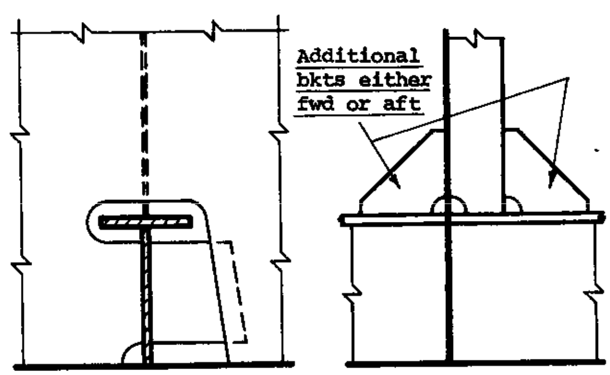


Figure 4

Typical reinforcement of
cut-out for built-up longitudinal

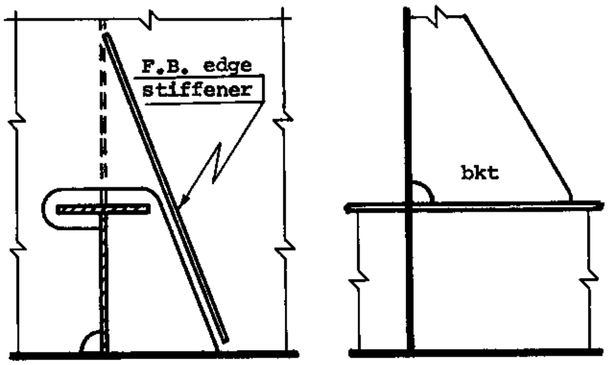


Figure 5

Reinforcement without filler plate

Where the fitting of the filler plate is not practical because of the required flow area to the cargo pump suction, an arrangement similar to that shown in Figure 5 wherein large brackets are fitted as stiffeners to the webs has proven satisfactory. In addition, depending upon the size of the ship, it may be necessary to fit stiffeners along the edge of the cut-out to improve the critical buckling strength of the lower part of the web frame.

Depending upon the size of the ship it may be necessary to add filler plates in way of cut-outs for the side and longitudinal bulkhead stiffeners for at least 3/4 of the depth of the vessel.

The problems as described above in way of cut-outs were found to have a higher frequency of occurrence midway between transverse bulkheads and in way of the cut-outs on the side web frame midway between horizontal struts, bottom or deck transverses. This leads one to the conclusion that the general stress level will have some marked influence on the incident of failure.

On the modern tanker the structure in the permanent (segregated) ballast tanks is subjected to severe loadings in both the loaded and ballasted conditions, and the structure in these ballast tanks has experienced a higher frequency of localized problem areas. This is further complicated by an accelerated corrosion rate caused by the normal occurrence of vibrations in the loaded condition. This points to the need for providing some method or methods to reduce the corrosion in these permanent (segregated) ballast tanks and it is felt in some circles that a system of corrosion control or an increased thickness of the structure in these ballast tanks should be a condition of classification.

Brackets which on yesterday's smaller ships were treated as miscellaneous members, on today's larger ships the brackets may have a leg length of 2 to 3 meters or even larger. With this increased size, there has been considerable effort by the Bureau and others, using a fine mesh finite element analysis, to determine the apparent stresses for the various configurations. Our results indicate that the brackets provided in today's ships, if properly designed, can provide satisfactory service which is confirmed from our service records. The proper design would include the size and method of stiffeners, size and ending of face plates and may also require chocks and anti-tripping brackets.

On today's VLCCs, ULCCs and other large ships a two and three dimension finite element analysis is necessary to properly judge the adequacy of the structure, but equally important is the attention to detail and good engineering judgement. To illustrate this point, on one of the earlier VLCCs, a web buckled during tank testing and the subsequent investigation found that the failure was due to the shipyard's inadvertent omission of some required stiffening of the bulkhead web. The web was repaired as original, the required stiffeners fitted and the vessel has been in service for about eight years with satisfactory service.

With the ever increasing day rate of today's ships, some of which may have a dollar value in six figures on a 125,000 cubic meter LNG carrier, an oversight in the design of details requiring corrective repairs may be very costly.

STEEL FOR HULL APPLICATION

Material requirements for ABS classed vessels are specified in published Bureau rules. These specifications are intended to provide grades of steel at given strength levels which will have the necessary toughness for various applications. This gradation of toughness is obtained by specifying appropriate requirements for control of chemical composition, process of manufacture, melting practice and in some cases verification by Charpy V notch testing. Specifications for ABS ordinary and higher strength steels are shown on Tables I and II.

The application for each steel is indicated in various sections of the Rules to assure that the quality of each steel is suitable for the steel thickness, ship size, and application involved. For example, Grade A steel, which represents the least toughness category may be used up to 51mm (2") thickness

ORDINARY STRENGTH HULL STRUCTURAL STEEL

GRADES	A	B	D	E	CS	DS
PROCESS OF MANUFACTURE	FOR ALL GRADES: OPEN HEARTH, BASIC OXYGEN, OR ELECTRIC FURNACE					
DEOXIDATION	ANY METHOD EXCEPT RIMMED		SEMI-KILLED OR KILLED	KILLED, FINE GRAIN PRACTICE	KILLED, FINE GRAIN PRACTICE	KILLED, FINE GRAIN PRACTICE
CHEMICAL COMPOSITION (LADLE ANALYSIS)						
CARBON, %	0.23 MAX.	0.21 MAX.	0.21 MAX.	0.18 MAX.	0.16 MAX.	0.16 MAX.
MANGANESE, %	——— *	0.80-1.10	0.70-1.40	0.70-1.50	1.00-1.35	1.00-1.35
PHOSPHORUS, %	0.04 MAX.	0.04 MAX.	0.04 MAX.	0.04 MAX.	0.04 MAX.	0.04 MAX.
SULFUR, %	0.04 MAX.	0.04 MAX.	0.04 MAX.	0.04 MAX.	0.04 MAX.	0.04 MAX.
SILICON, %	———	0.35 MAX.	0.10-0.35	0.10-0.35	0.10-0.35	0.10-0.35
HEAT TREATMENT	———	———	NORMALIZED OVER 35.0 MM (1.375 IN.)	NORMALIZED	NORMALIZED	NORMALIZED OVER 35.0 MM (1.375 IN.)
TENSILE TEST						
TENSILE STRENGTH	FOR ALL GRADES: 41-50 KG/MM^2; 58,000-71,000 PSI					
YIELD POINT, MIN.	FOR ALL GRADES: 24 KG/MM^2; 34,000 PSI					
ELONGATION, MIN.	FOR ALL GRADES: 21% IN 200MM (8 IN.), 24% IN 50MM (2 IN.); 22% IN. $5.65\sqrt{A}$ (A EQUALS AREA OF TEST SPECIMEN)					
IMPACT TEST STANDARD CHARPY V-NOTCH						
TEMPERATURE	———	———	-20C (-4F)	-40C (-40F)	———	———
ENERGY, MIN. AVG.	———	———	2.8 KGM (20 FT. LBS.)	2.8 KGM (20 FT. LBS.)	———	———
NO. OF SPECIMENS	———	———	3 FROM EACH 40 TONS	3 FROM EACH PLATE	———	———

* GRADE A PLATES OVER 12.5MM (0.50 IN.) THE Mn SHALL BE 2.5 x C% (MIN.)

Table I

in low stress areas, but would not be permitted in any thickness for the sheer strake of an ocean going vessel in excess of 137 meters (450') in length. For such service a Grade B would be required up to 16mm (.63"), a Grade D normalized up to 27.5mm (1.08") and a Grade CS, E or DS normalized up to 51mm (2"). The relationship between steel grade and ship application is based primarily on proven service experience under the wide variety of conditions encountered by merchant ships over the past years.

Recent research effort by the Ship Structure Committee has attempted to introduce refinements in criteria for ship steels by proposing toughness criteria based on fracture mechanics concepts employing such tests as the dynamic tear, drop weight or crack opening displacement (COD) tests (7). Using these testing methods and making assumptions as to the magnitude, duration and loading rate of service stresses, service temperature, workmanship quality and other indeterminate factors, some investigators have been led to question the validity of current hull steel specifications which, in some cases, employ a Charpy V notch criteria as one of several means of characterizing the steel.

In this regard no single specimen or test can be expected to incorporate the wide variety of factors which determine an acceptable minimum level of toughness for a particular ship design and service application. The Charpy test as such has proven useful as one of many measures of control to characterize some ship steels which have been repeatedly evaluated by the ultimate test specimen, i.e., full size ships operating under actual service conditions. In this regard it is well to note that the ABS Grade CS steel, which is one of the highest quality ordinary strength grades of ship steels, is not subjected to any impact test, in view of the fact that the specification is sufficient in other respects to assure a steel of the required toughness level.

With respect to the higher strength steels, quenched and tempered steels up to 115,000 psi minimum tensile strength have been successfully used in specialized parts of ship structure and are finding increased use in drilling units. On container vessels for instance, which require large hatch openings leaving a relatively narrow width of effect deck area, these higher strength quenched and tempered steels have been used to advantage in avoiding the use of very thick ordinary strength plating in the construction of the box girders at the upper deck.

Susceptibility to hydrogen crack-

HIGHER STRENGTH HULL STRUCTURAL STEEL

GRADES	AH 32 OR AH36	DH32 OR DH36	EH32 OR EH36
PROCESS OF MANUFACTURE	FOR ALL GRADES: OPEN HEARTH, BASIC OXYGEN, OR ELECTRIC FURNACE		
DEOXIDATION	SEMI-KILLED OR KILLED	KILLED, FINE GRAIN PRACTICE	KILLED, FINE GRAIN PRACTICE
CHEMICAL COMPOSITION (LADLE ANALYSIS)	FOR ALL GRADES:		
CARBON %	0.18 MAX.		
MANGANESE %	0.90-1.60		
PHOSPHORUS %	0.04 MAX.		
SULFUR %	0.04 MAX.		
SILICON %	0.10-0.50 {AH TO 12.5 MM (0.50 IN.) MAY BE SEMI-KILLED IN WHICH CASE 0.10% MIN. Si DOES NOT APPLY		
NICKEL %	0.40 MAX.		
CHROMIUM %	0.25 MAX.		
MOLYBDENUM %	0.08 MAX.		
COPPER %	0.35 MAX.		
ALUMINUM % (ACID SOLUBLE)	0.06 MAX.		
COLUMBIUM % (NIOBIUM)	0.05 MAX.		
VANADIUM	0.10 MAX.		
HEAT TREATMENT	NORMALIZING REQ'D. OVER 12.5 MM (0.50 IN.) IF Nb TREATED	NORMALIZING REQ'D. OVER 25.5 MM (1.0 IN.) IF AL TREATED OVER 12.5 MM (0.50 IN.) IF Nb TREATED OVER 19.0 MM (0.75 IN.) IF V TREATED	NORMALIZED
TENSILE TEST			
TENSILE STRENGTH	FOR 32 GRADE: 48-60 KG/MM² (68,000-85,000 PSI) FOR 36 GRADE: 50-63 KG/MM² (71,000-90,000 PSI)		
YIELD POINT, MIN.	FOR 32 GRADE: 32 KG/MM² (45,500 PSI) FOR 36 GRADE: 36 KG/MM (51,000 PSI)		
ELONGATION, MIN.	FOR ALL GRADES: 19% IN 200 MM (8 IN.); 22% IN 50 MM (2 IN) 20% IN $5.65\sqrt{A}$ (A EQUALS AREA OF TEST SPECIMEN)		
IMPACT TEST STANDARD CHARPY V-NOTCH			
TEMPERATURE	———	-20C (-4F)	-40C (-40F)
ENERGY, MIN. AVG.	———	3.5 KGM (25 FT. LBS.)	3.5 KGM (25 FT. LBS.)
NO. OF SPECIMENS	———	3 FROM EACH 40 TONS	3 FROM EACH PLATE

Table II

ing and magnitude of residual stresses resulting from welding tends to increase directly with increasing yield strength. Fabrication procedures and filler metals should take these factors into account. When appropriate low hydrogen welding techniques are used and weld residual stresses are minimized, shipbuilding experience with steels up to 100,000 yield strength, such as ASTM A514 or A517, have been successfully used. Difficulties, when encountered, are usually associated with the initial use of these materials, when the fabricator has failed to recognize the necessity of maintaining required low hydrogen welding techniques and associated good welding practice.

While it is apparent that reductions in weight and thickness can be derived from the use of steels of higher strength than an ordinary strength ship steel, in some cases hull girder inertia or buckling criteria can limit the amount of thickness reduction. In addition, in design calculations, credit is only given for a portion of the higher yield strength of the steel; for such a design a "Q" factor as defined in Section 6 of the Bureau Rules may be used to indicate the reduction in section modulus of the deck and bottom.

The practice for design of fixed offshore platforms and mobile drilling units is somewhat different from the engineering concepts applied to ship structures in that design practices are derived from civil engineering concepts. Civil engineering codes are such that their formulae give full credit to the increased yield strength of the material. However, the design loads used with these methods are considered to have a lesser probability of occurrence than those used in the ship structure.

In addition, design of drilling units has led to the increased use of product forms not commonly used in shipbuilding. For example, centrifugal castings, sand castings and tubular products have been used to make up the leg sections of self elevating drilling units.

ABS has had a continuing program to accumulate data relative to the Charpy V, dynamic tear and drop weight characteristic of ship steels. However, in our opinion, investigations as to the adequacy of ABS Rule steels for the particular thickness and service application for which they are used under Rule requirements should have a low priority in view of their proven service experience. If current Rule steels were to prove inadequate for a particular application, a simple upgrading of steel requirements is readily accomplished, using currently specified steel requirements. For example, if service experience were to indicate inadequate material toughness for a particular application or design in which Grade B material was used, corrective action would be to substitute a material with a higher notch toughness such as DS, CS, or E. The primary value in conducting Charpy V, dynamic tear, or drop weight tests is to provide a basis for establishing fracture criteria for new steels, such as high strengths, or low temperature steels which are being introduced into shipbuilding, with which extensive service experience has not been acquired.

The Bureau is currently in the process of developing a toughness criteria for materials for submersibles and decompression chambers which will be of increasing importance in future exploitation of the ocean floor. The criteria, when developed, will take into account the input of the Bureau's Special Committee in Submersible Vessels, governmental regulatory bodies and engineering groups. However, one of the principal considerations in formulating these toughness criteria will be the service experience with the materials that have been used in existing submersibles and decompression chambers.

MATERIAL FOR LOW TEMPERATURE APPLICATIONS

Materials for low temperature applications are currently covered by Bureau Rules and successfully used down to service temperatures of -196 C (-320F). In general, carbon steels are used down to -57 C (-70 F) (for LPG), nickel alloy steel to -79 C (-110 F) and 9% nickel, stainless steel, 36% nickel alloy, and aluminum have been used down to -162 C (-260 F) (LNG temperature), stainless steels are used down to -196 C (-320 F). The Bureau is also familiar with the 5% nickel alloy steel (ASTM, A645) which was developed for cryogenics service but we have had no service experience with this material.

A material application area still under study in LNG ships relates to the structural steels used in the inner hull and contiguous structure which are subjected to temperatures down to approximately -50 F. While materials are readily available to meet the 20 ft. lbs Charpy V at 5 C (10 F) below service temperature required in this application a related requirement is that the heat affected zone (HAZ) of the material also meet this requirement. Since the degree of reduction of Charpy V properties in the HAZ can vary with shipyard welding practice, the problem of establishing the margin of safety to take into account such degradation is still unresolved. Considerations have been given to modifying material requirements to increase the toughness characteristics of the material sufficiently so that the HAZ of the welded material will always meet the specified requirements even when welded with high production rate, high heat input welded processes; another approach is to modify the material toughness requirement slightly but restrict heat input of welding process to keep loss of toughness in the HAZ to a minimum. A third approach is to modify the method of evaluation of the HAZ by the use of the drop weight instead of the Charpy criteria. This approach appears justifiable on the basis that HAZ Charpy specimens from a beveled joint contain varying amounts of weld HAZ, base metal, and the proportions of these areas in a Charpy specimen have great influence on the Charpy value obtained. The problem is currently being reviewed by the various Bureau committees, regulatory bodies and International Association of Classification Societies.

LAMELLAR TEARING

With certain design details, the through thickness properties of a material must be taken into consideration. Some steels have shown separation along planes of weakness parallel to the plate surface, when the steel is loaded perpendicular to the plate surface; such loading is initially imposed during construction by residual welding stresses of a heavy fillet or cruciform filled weld. The problem has sometimes been observed in marine structures when a heavy deck plate was joined to a sheer strake by a full penetration weld shown on Figure 6.

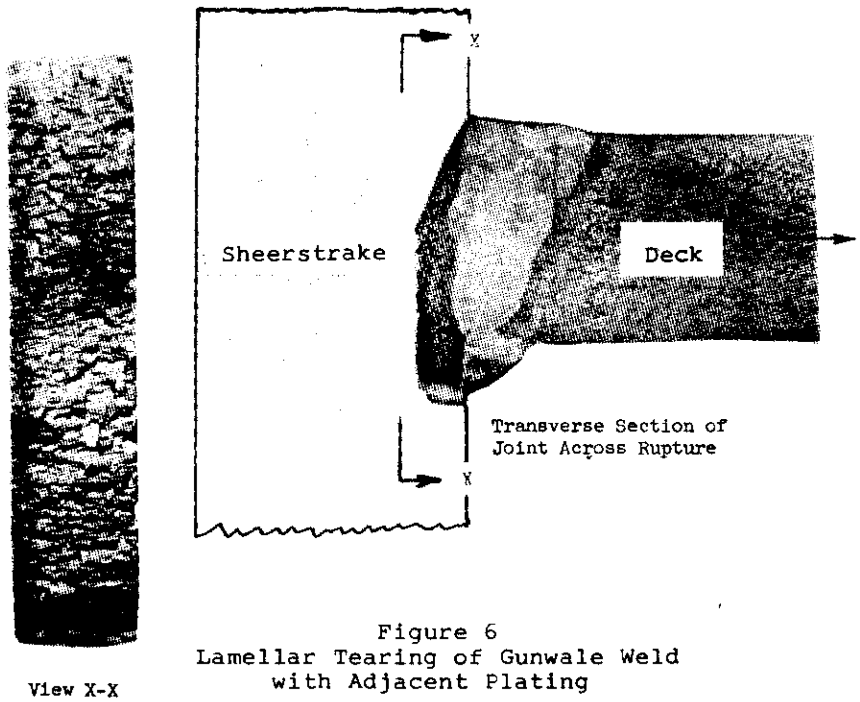


Figure 6
Lamellar Tearing of Gunwale Weld
with Adjacent Plating

The problem may frequently be rectified by redesign of double fillet welds of the type shown in Figure 7.

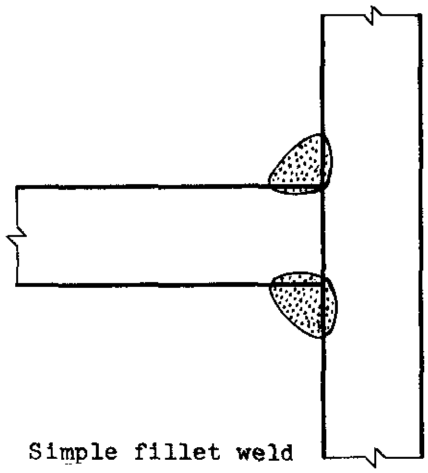
The problem of lamellar tearing in materials with low through thickness properties is of particular concern in the tubular connections of drilling units, where the residual stresses of welding of complex intersecting parts of tubular members induce high tensile stress through the plate thickness (8). As a result, instances of delamination as shown in Figure 8 have been observed in the course of fabrication on several drilling units. Repairs in such instances are difficult and in some cases design changes, to minimize the occurrence of welds which induce such conditions, have been required.

The problem of lamellar tearing due to through thickness weakness is related to lack of ductility rather than lack of strength. The percent reduction in area in a tensile specimen across plate thickness is considered the most reliable indication of the susceptibility of a material to lamellar tearing. Reduction in area values of the order of 15 to 25 percent or more is considered an indication of adequate resistance to lamellar tearing. In addition to minimizing lamellar tearing tendencies by design and welding sequence, materials have been developed which are made with special melting techniques such as magnetic stirring or electroslag remelting which produce materials resistant to lamellar tearing through a reduction of non-metallic inclusions. Other approaches have been to use forgings or castings in selected areas.

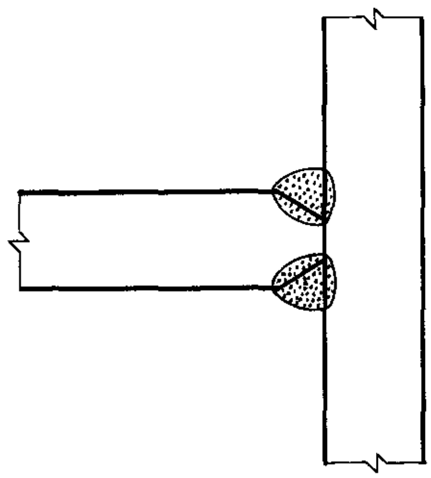
Since through-thickness weakness is attributed to non-metallic inclusions flattened out during the rolling process of plate manufacture, some fabricators have included ultrasonic inspection requirements to cull out laminated plates. While this technique is useful and will detect gross laminations, it is not a completely positive method, since a laminar orientation of constituents of submicroscopic size, such as fine aluminum oxides may not be detected. Since these may be the source of weakness, a more positive approach appears to be through selection of appropriate materials or redesign of the details to avoid or reduce the stress concentrations.

NEW MATERIALS

The search for higher strength to weight and improved corrosion resistant materials is a continuous one. Advances in the technology for application of aluminum alloys in ships is evidenced by the recent 1975 Bureau publication



Simple fillet weld



Partial penetration fillet weld

Figure 7

Sketch showing corrective and partial penetration fillet welds

"Rules for Building and Classing Aluminum Vessels". The Rules parallel the Bureau's rules for steel vessels and are intended to apply to aluminum hulls up to 152 meters (500'). Aluminum is finding extensive use in spherical and prismatic tanks for containment of LNG.

In the area of plastics the Bureau has recently established a special committee of technical experts from industry and government to assist the Bureau in developing standards for the design and construction of reinforced plastic vessels. The proposed standards will be applicable to self-propelled, reinforced plastic vessels up to 200' in length and will include both vessels for ocean service, such as commercial fishing craft, and vessels for limited geographic service, such as recreational

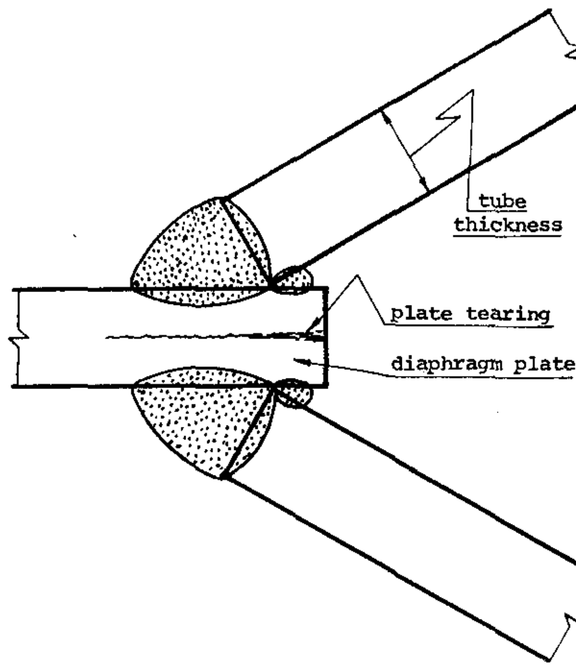


Figure 8

craft. While the great majority of vessels to which the standards will apply are expected to be fiber-glass reinforced plastic (FRP), provisions for using other reinforcing materials such as boron filaments and graphite fibers will be included.

A recent innovation is the use of a solid copper-nickel or a copper-nickel clad steel as hull material. The anti-fouling characteristics of this material has been demonstrated by the 2 years of successful service experience with a 67' copper-nickel hull (1/4" thick) shrimp trawler (9). This ship, which operates in highly fouling waters, after 6 months of continuous service is reported to have shown twice the fuel economy of a steel sister ship at a 7.5 knot speed, about 30 percent lower RPM at 7.5 knots and about 20 percent greater top speed, 9.2 versus 7.5 knots. In addition the lost operational time required for cleaning and scraping the barnacles from steel hulls is eliminated.

For larger ships (as large as 900') the use of copper-nickel clad steel rather than solid copper-nickel is under consideration. In the case of these large ocean going ships, the principal impetus to the use of copper-nickel clad steel hulls is the promise of reduced frictional drag from reduced fouling and roughness. Reference 10 indicates an approximate 10 percent difference in power requirements between "poor" and "best" hull roughness characteristics, and Reference 11 indicates that for a

MECHANICAL PROPERTY REQUIREMENTS
FOR ABS FILLER METAL GRADES

ORDINARY STRENGTH

TENSILE REQUIREMENTS

	Kg/mm^2	psi	$tons/in^2$
TENSILE STRENGTH	41 - 57	58,300 - 81,100	26-36
YIELD POINT (Min.)	31	44,100	19.6
ELONGATION IN 50mm (2 In.) Min.	22.0%	22.0%	22.0%

IMPACT REQUIREMENTS

GRADE	TEST TEMPERATURE		MANUAL & SEMI-AUTOMATIC ENERGY ABSORBED		MACHINE AUTOMATIC ENERGY ABSORBED	
	°C	°F	Kg-m	ft - lb	Kg-m	ft - lb
1	20	68	4.8	35	3.5	25
2	0	32	4.8	35	3.5	25
3	−20	−4	4.8	35	3.5	25
or 3	−10	14	6.2	45	4.5	33

HIGHER STRENGTH

TENSILE REQUIREMENTS

	Kg/mm^2	psi	$tons/in^2$
TENSILE STRENGTH	50 - 67	71,000 - 95,000	32 - 42
YIELD POINT (Min.)	39	55,500	24.8
ELONGATION IN 50mm (2 In.) Min.	20.0%	20.0%	20.0%

IMPACT REQUIREMENTS

GRADE	TEST TEMPERATURE		MANUAL & SEMI-AUTOMATIC ENERGY ABSORBED		MACHINE AUTOMATIC ENERGY ABSORBED	
	°C	°F	Kg-m	ft - lb	Kg-m	ft - lb
H1	20	68	5.5	40	4.1	30
H2	0	32	5.5	40	4.1	30
H3	−20	−4	5.5	40	4.1	30
or H3	−10	14	6.9	50	5.3	38

Table III

32,000 ton tanker speed can be reduced from 16.5 (new ship) to 15 after one year due to fouling and roughness factors.

WELDING

Bureau rules for welding are essentially those of the shipbuilding industry. To assure adequate toughness in weld metals, the Bureau classed filler metals in accordance with the six grades shown in Table III. As indicated therein, each grade is required to meet a toughness criteria which is comparable with a given base plate grade shown in Table IV. The Bureau publishes annually a listing of approved welding electrodes wire-flux and wire gas combinations which indicates the electrode brands throughout the world which have met the above requirements or those of AWS specifications which contain similar requirements.

The problem of preservation of toughness level in the HAZ of low temperature steels was previously noted in the discussion on low temperature materials. For general ship construction, a similar problem exists when high heat input welding processes such as electroslag or electrogas welding are applied to some of the fine grained normalized steels used in critical areas such as the sheer strakes. Current practice in many highly automated shipyards is to apply electrogas and electroslag welding to the side shell; when the welding reaches the sheer strake

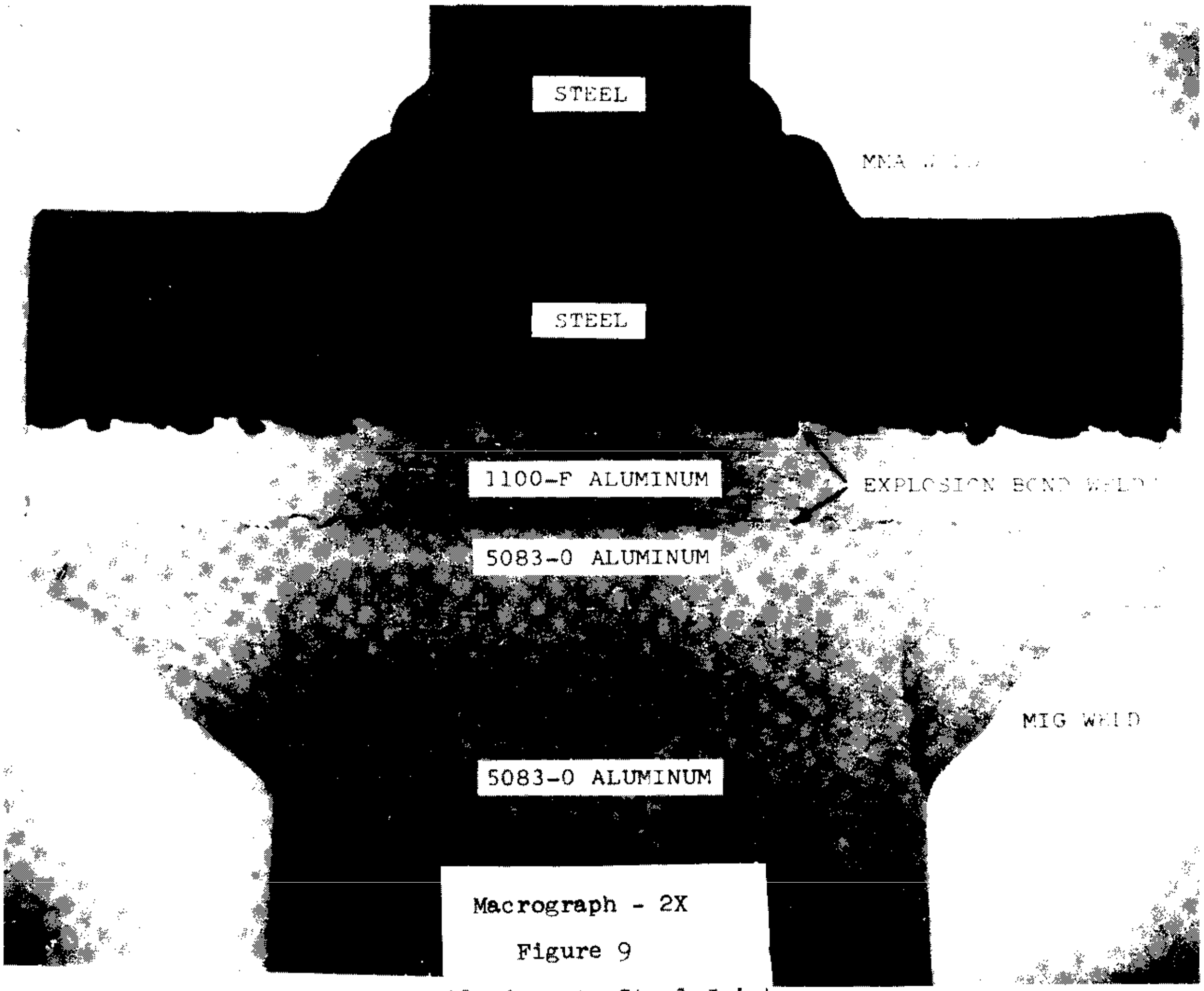
TABLE IV

ABS Filler Metal Grade	Acceptable AWS Classification (1)	Applicable ABS Hull Structural Steel
	Ordinary Strength	
1	AWS A 5.1-69 E6010, E6011, E6027 E7015, E7016, E7018, E7028	Grade A to 12.5 mm (½ in.) incl.
2	AWS A 5.1-69 E6010, E6011, E6027 E7015, E7016, E7018, E7028	Above + Grade A over 12.5 mm (½ in.), B, D, DS
3	AWS A 5.1-69 E6010, E6011, E6027 E7015, E7016, E7018	Above + Grades DN, CS, E
	Higher Strength	
H1	AWS A 5.1-69 E7015, E7016, E7018, E7028 AWS A 5.5-69 E8016-C3, E8018-C3	ABS Grade AH to 12.5 mm (½ in.) inclusive
H2	AWS A 5.1-69 E7015, E7016, E7018, E7028 AWS A 5.5-69 E8016-C3, E8018-C3	Above + AH over 12.5 mm (½ in.), DH
H3	AWS A 5.5-69 E8016-C3, E8018-C3	Above + EH

(1) Equivalent AWS classifications for wire-gas and wire-flux combinations are also permitted.

manual metal arc or metal inert gas arc processes must be used. However, if it can be demonstrated by Charpy testing that adequate toughness will be maintained across the HAZ of the electroslag or electrogas weld the process may be used. Since degradation is more often observed in higher strength steel, such as Grade EH, when using electroslag or electrogas welding process the full economic benefit of these high production rate processes cannot always be achieved. The Bureau recently conducted a cooperative research program with MARAD (12), and administered by the Bethlehem Shipbuilding Company to determine the means to extend the applicability of the electroslag and electrogas process by developing approaches to minimize deleterious effects on HAZ toughness and to develop more realistic methods for evaluation of toughness in the joints. The most noteworthy result of this investigation is the conclusion that the toughness performance of high heat input electrogas or electroslag weldments in Grade CS steel can yield essentially equivalent results to the more commonly used manual metal arc or submerged arc welding process. In addition, the results of this research effort indicate three areas of consideration which should be evaluated; use of faster travel speeds to lower heat input, use of beveled joints, and investigation of candidate steels which would exhibit minimum tendencies for HAZ toughness degradation.

In general the Bureau will approve use for a shipyard of any weld process, automatic or manual, which can be shown



Macrograph - 2X

Figure 9

Aluminum to Steel Joint

by procedure testing to provide weld joints of adequate properties under production conditions. Processes approved by ABS have included a variety of techniques including one sided welding, submerged arc welding, thermal welding, electrogas and electroslag welding, tungsten inert gas and metallic arc inert gas, as well as conventional metallic arc welding. More sophisticated methods such as explosion bonding have also been approved as shown in Figure 9 which is used as a transition joint between an aluminum tank structure and steel in a LNG gas tanker.

NONDESTRUCTIVE TESTING

Bureau requirements for radiographic and ultrasonic inspection of hull welds are found in the 1975 Bureau publication "Nondestructive Test Requirements for Hull Welds". The radiographic standards shown therein were based on standards introduced as guidelines in 1965 and finalized as Bureau Rules in 1971. The two classes of acceptance levels shown therein are based on length of ship and location of welds in the ship regardless of the type of ship. The extent of radiographic inspections used for surface ships are expressed by a formula which takes into account the length, breadth and depth of the ship. These standards have been in use since their inception and have been applied to butt welds in all marine structures classed by the Bureau including offshore drill units, underwater structures, low temperature containment vessels, aluminum structures, etc.

The ultrasonic requirements shown therein represent formal adoption of requirements first issued as provisional requirements in 1972. They were derived from a study by the Bureau of the various ultrasonic techniques used in shipyards throughout the world and have been implemented worldwide with minor modifications since their issuance (13). The ultrasonic specification parallels the radiographic inspection standard with respect to levels of acceptance.

When ultrasonic inspection is to be used as a quality control measure at a shipyard, shipyard capability is first determined with respect to operator training and qualifying practices, reliability and reproducibility of results and the proper application of approved procedures. Where ultrasonic inspection is used as a primary inspection method the Bureau requires that such testing be supplemented initially with a reasonable amount of radiographic inspection to determine that adequate quality control is achieved. In applying either radiographic or ultrasonic inspection, confusion sometimes arises since radiography and ultrasonics have different sensitivities to a given discontinuity; discontinuities which are detected by one inspection technique may not be detected with the other. In general the acceptance standard applicable to the selected primary inspection methods governs, unless discontinuities known to be detrimental are revealed by the secondary inspection method.

The Bureau's radiographic and ultrasonic standards only apply to butt welds. Conventional magnetic particles or dye penetrant methods are used for the inspection of fillet welds. However, in cases where ship builders or designers indicate ultrasonic or radiographic inspection of materials or joints other than butt welds, applicable acceptance standards designated by the designer as specified by the accepted specifications are utilized. Such requirements have occasionally been applied to drillunit construction wherein the fillet welds are primary strength joints and where in some designs there is concern as to delamination of base metal in way of these welds.

IACS

In addition to the Bureau's committees, the Bureau endeavors to extend its contacts to all phases of the marine community by participating in over 90 industrial and governmental committees which have a strong influence on keeping our Rules up-to-date.

IACS, International Association of Classification Societies, the purpose of which is to provide by cooperation and consultation, the aims which its members hold in common and to provide for cooperation and consultation with other national and international organizations was formally organized in 1968. It had its origin in the 1930 Load Line Convention, which urged the classification societies to get together to discuss strength standards as applied to the vessels to which the societies assigned freeboards under that Convention. The societies involved, American Bureau of Shipping, Bureau Veritas, Det norske Veritas, Germanischer Lloyd, Lloyd's Register of Shipping, Nippon Kaiji Kyokai, and Registro Italiano Navale, met several times between 1935 and 1968 to discuss technical matters concerning the Load Line Convention and other matters of common interest.

It became apparent during the 1960s that IMCO was going to be successful as a forum for the development of international maritime regulations at the governmental level, and it seemed desireable for the classification societies as a group to establish liaison with IMCO. That body is permitted to recognize international organizations which have an interest in its proceedings by granting "consultative status" to them. In addition to the seven societies mentioned above, the Register of Shipping of the USSR, and the Polish Register of Shipping have since been admitted as members, and the Yugoslav Register of Shipping has been granted associate membership. Associate membership may be granted to societies which are not large enough to be considered international societies.

There are 14 working parties and correspondence groups within IACS which are working on items common to all classification societies and any resolution will benefit the marine industry. To date some 95 "Unified Rules" have been developed through IACS and most of them have been adopted by all the class societies.

It is unlikely that there will ever be a complete set of unified rules for building and classing vessels. Each society must, after all, answer to its own constituency. However, work is proceeding in many areas, and the differences between the rules of the various societies are gradually being reduced.

CONCLUSION

Yesterday's ship, a general cargo ship with four or five holds with the cargo being handled by the ship's gear, is becoming an obsolete structure as the emphasis is now on reducing the inport costs and turn-around time. Tomorrow's ship will continue this trend and will include concepts which are still being developed.

The marine industry is becoming more complex with the development of more sophisticated structures such as offshore drilling units, submersibles, LPG/LNG vessels, single point mooring and atomic power plants to mention a few, and to provide the necessary expertise, the marine industry will require many of the engineering and technical disciplines not normally employed in today's ships.

ACKNOWLEDGEMENTS

Grateful acknowledgement is made to the various members of the Bureau's staff, especially I.L. Stern, whose contributions of time and material were instrumental in assembling much of the information presented in this paper.

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