Paper No 3.1: Classification Societies' Viewpoint

By
Philip G. Rynn – American Bureau of Shipping

ABSTRACT

In 1990 the United States passed the Oil Pollution Act of 1990 and IMO followed with MARPOL Regulation 13 F in 1992. These regulations require oil tankers to have double hull or an alternative measure to protect the marine environment. The Tanker Structure Cooperative Forum (TSCF) published ***GUIDELINES FOR THE INSPECTION AND MAINTENANCE OF DOUBLE HULL TANKER STRUCTURES*** in 1995. The publication is based on information available to the members of the forum at that time. Experience gained since then through a better understanding of the failure mechanisms of yielding, buckling, fatigue and corrosion of double hull tankers structure will be discussed. The Classification Societies have developed guidance for the evaluation of these failure mechanisms. The structural arrangements of AFRAMAX, SUEZMAX and VLCC tankers will be covered to indicate the TSCF guidance provided and found in current designs. TSCF included in the above manual, guidance on details from known service experience. Additional concerns found during the operation of recent double hull tankers needs to be included in the experience base of tanker service. In general, experience has been good but there have been some minor areas where, either guidance found in the work of the TSCF has not been followed, or the investigative tools have not been available for the designer.

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Introduction

In 1990 the United States passed the Oil Pollution Act which was responsible for the revision of the configuration of tankers. Although the industry used double hull tankers to some extent, the majority of the tankers employed for movement of oil worldwide were of the single hull configuration. Industry, especially the Tanker Structure Cooperative Forum (TSCF), reacted to this significant change. The resulting work of TSCF, as documented in GUIDELINES FOR THE INSPECTION AND MAINTENANCE OF DOUBLE HULL TANKER STRUCTURES, was published in 1995 by Witherby and provided the marine industry with a good reference document on the desired characteristics of a double hull. It also highlighted the areas of the double hull that should be examined in greater detail during design to minimize problems with the structure while in service.

The first element of design to be considered is the arrangement of the structure and TSCF selected the typical arrangements being used for single hulls. The minimum distance between the double hull space had been defined by regulations made in the United States by the Oil Pollution Act of 1990 (OPA-90) as implemented by the United States Coast Guard and at IMO by passage of MARPOL Regulation 13 F. The distance between double side and double bottom is based on deadweight of the vessel. The minimum space for the separation of the inner skin is 2 meters for all vessels above 40,000 DWT. The formulation for the separation distance is:

1- Side clearance 0.5 + DWT/ 20,000, or 2 m,

2- Bottom clearance B/ 15, or 2 m.

The size of vessel that will be covered in this paper is a tanker of 40,000 DWT or more. Typical tanker sizes are:

1- Product tanker – about 40,000 DWT
2- Aframax tanker – about 80,000 DWT
3- Suezmax tanker – about 135,000 DWT
4- VLCC tanker – about 250,000 DWT

All of these would have a minimum space of 2 meters separating the inner and outer hulls of the double hull tanker.

Arrangements

In addition to the clearance between the inner and outer hull being a minimum of 2 meters by OPA-90 and MARPOL Regulation 13 F, cargo tanks must not exceed the size and capacity required by Regulation 24 of MARPOL.

The length of each cargo tank shall not exceed 10 meters or one of the following values, whichever is greater:

a) where no longitudinal bulkhead is provided inside the cargo tanks: $(0.5\ b_i / B + 0.1)\ L$, but not to exceed 0.2L,

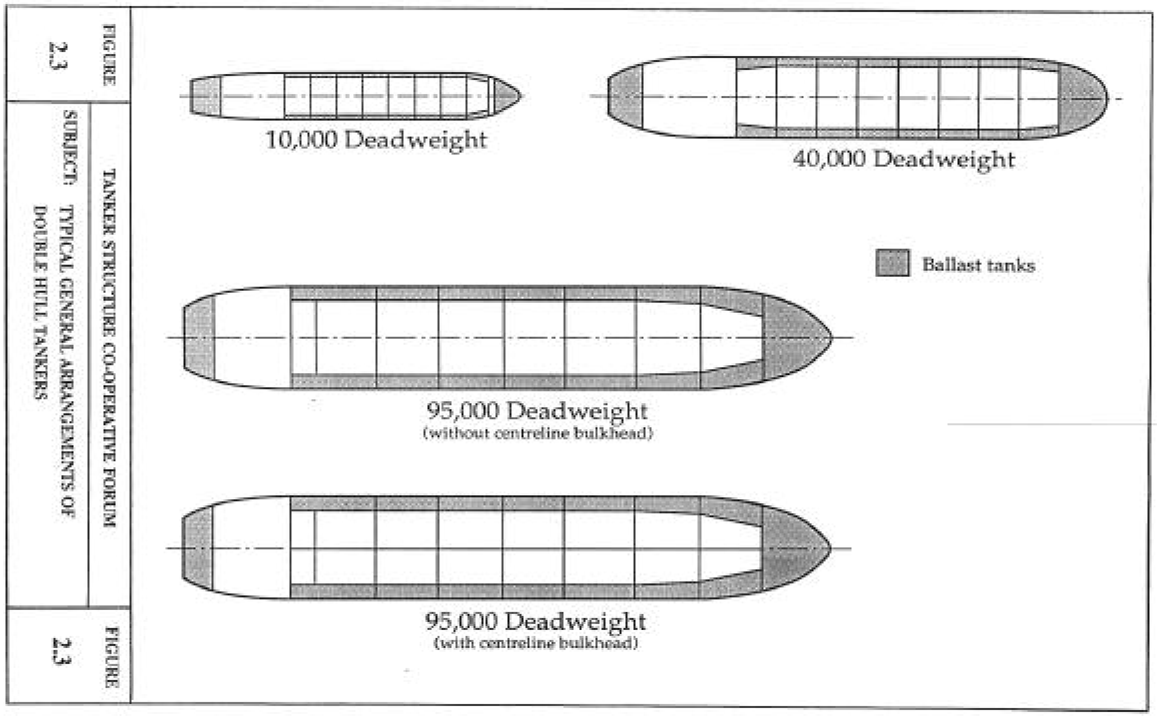
b) where a centerline longitudinal bulkhead is provided inside the cargo tanks: $(0.25\ b_i / B + 0.15)\ L$,

c) where two or more longitudinal bulkheads are provided inside the cargo tanks: (i) for wing tanks: 0.2 L, (ii) for center tanks: (1) if b_i / B is equal to or greater than one fifth: 0.2 L, (2) if b_i / B is less than one fifth: - where no centerline bulkhead is provided: (0.5 b_i / B + 0.1) L, - where a centerline longitudinal bulkhead is provided: (0.25 b_i / B + 0.15) L. L is length between perpendiculars, B is beam of vessel and b_I is breadth of wing tank.

The other important arrangement is the number of tanks that range from 5 to 9 and can be further subdivided by one or more longitudinal bulkheads. Early designs of Aframax and Suezmax tankers are found with one or no longitudinal bulkheads. Current designs have a longitudinal bulkhead. This is to minimize, and in most cases eliminate, instability found in earlier designs. After a number of instances of lolling during cargo discharge, IMO required new designs to have adequate stability by design to preclude the need for operational measures to prevent lolling.

Arrangements in figure 1 (figures 2.3 and 2.4 of TCSF) show typical designs for Aframax and Suezmax tankers. Some of these designs do not comply with all of the latest requirements from IMO and will have to be modified for future tankers.

Typical information on early double hull designs for the product, Aframax, Suezmax , and VLCC tankers are indicated in Table 1. The separation between the inner and outer hull in general exceed the minimum required by OPA-90 and MARPOL Regulation 13 F. This is either to provide sufficient ballast for the vessel or adequate space for access of ship to inspect the structure. The typical midship section arrangement for a double hull Suezmax tanker is shown in figure 2 (figure 2.7 of TSCF). This arrangement could also be found on early double hull Aframax tanker. The design arrangement for these ships today would have at least a centerline bulkhead.



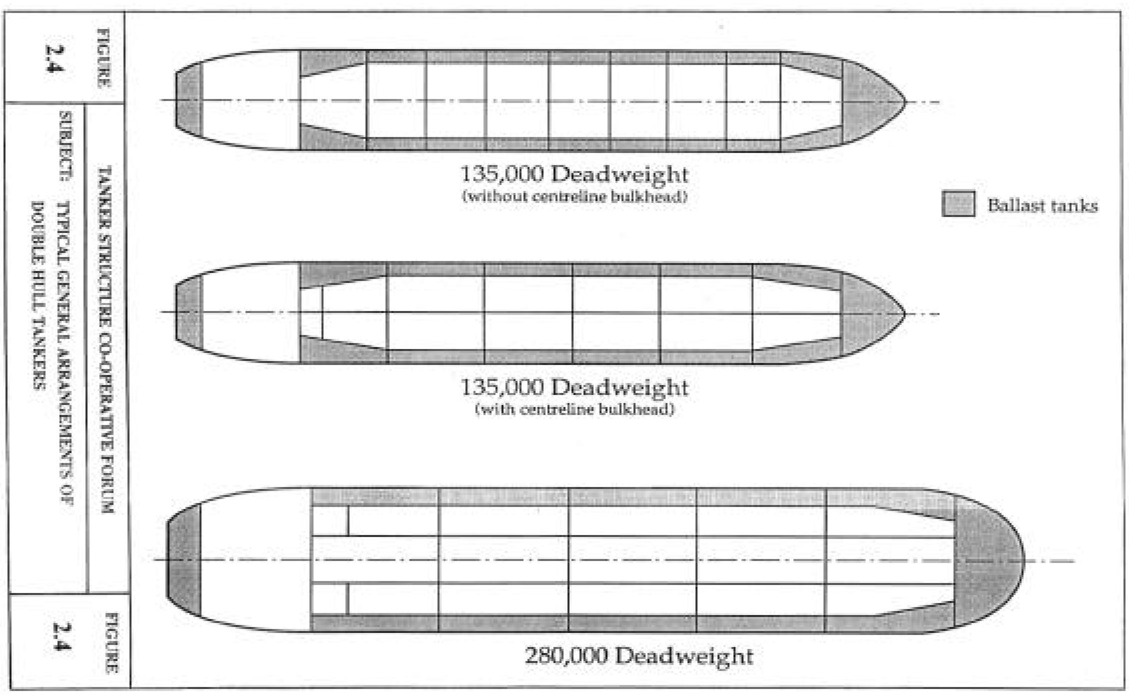


Figure 1 – Typical General Arrangements

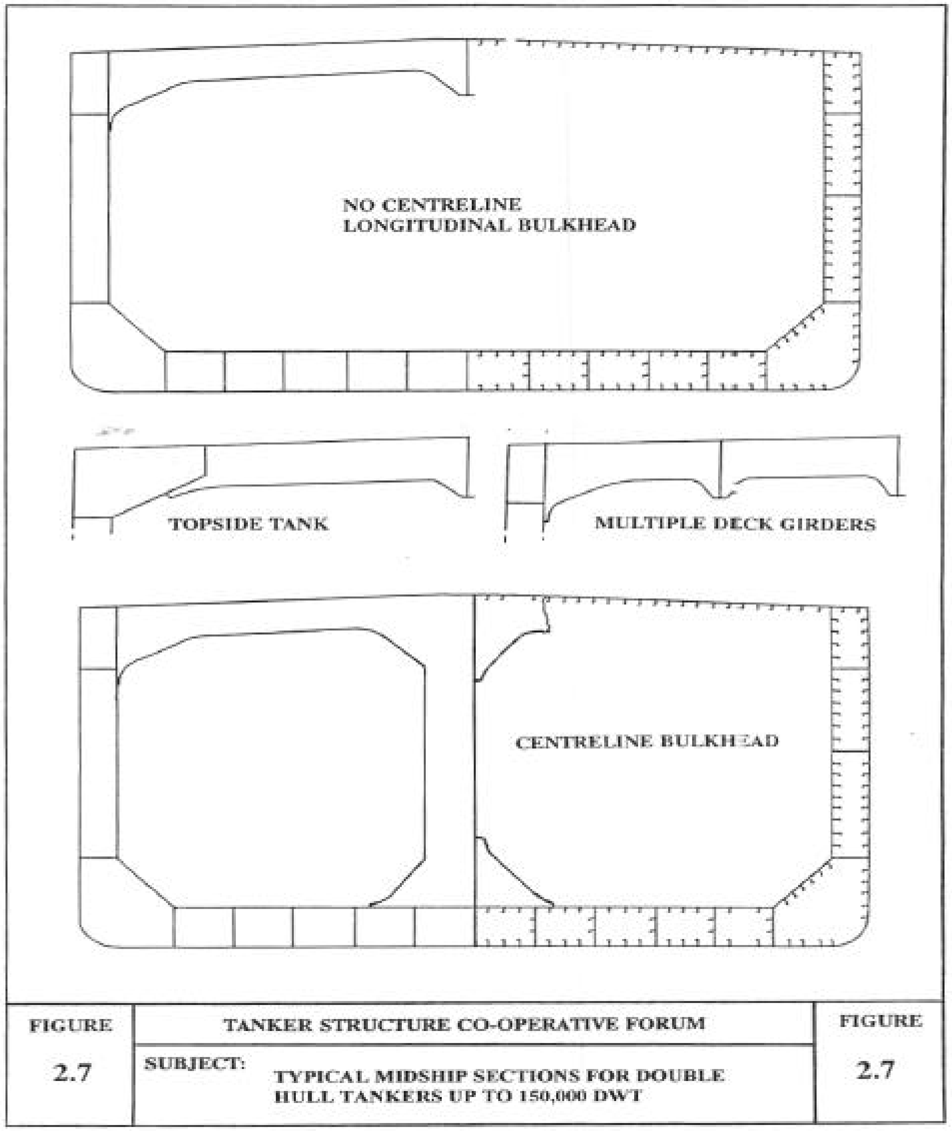


Figure 2 – Typical Midship Sections

TABLE 1- Compliance of TANKER Double Hull Designs

Type	Regulation depth of side	Regulation depth of bottom	Actual depth of side range	Actual depth of bottom range
PRODUCT	2 M	2 M	2 to 2.42 M	2 to 2.18 M
AFRAMAX	2 M	2 M	2 to 2.28 M	2 to 2.63 M
SUEZMAX	2 M	2 M	2.05 to 2.7 M	2.58 to 2.8 M
VLCC	2 M	2 M	2.4 to 3.6 M	3 to 3.2 M

Design Assessment

During the evolution of Double Hull tankers, designs were analyzed using finite element methods (FEM). The result of this approach enabled the industry to verify the guidance provided by TSCF. The structural understanding of the members of TSCF has been proven through the analyses conducted. The information on problem areas such as provided in figure 3 (figure 3.6 of the TSCF) had been confirmed by industry. The use of the finite element method (FEM) is necessary to verify new designs and provide evidence that the design meets the requirements of the classification society. Results of FEM can also be important in fabrication by identifying high stress locations to the builder, owner and class. The results are used to refine the structural design and construction of the tanker. This information enables the builder to make informed design decisions and to take precautionary measures to prevent any failures at the high stress locations. Some preventative measures used are to increase structural scantlings, improving details, closer alignment of structure, or relocating erection joint in the subassemblies of the fabrication. Of equal importance is the use of the FEM results to guide the operator in identifing areas of high stress. This permits those examining the structure in service to carry out effective close up survey and meet the enhanced survey requirements.

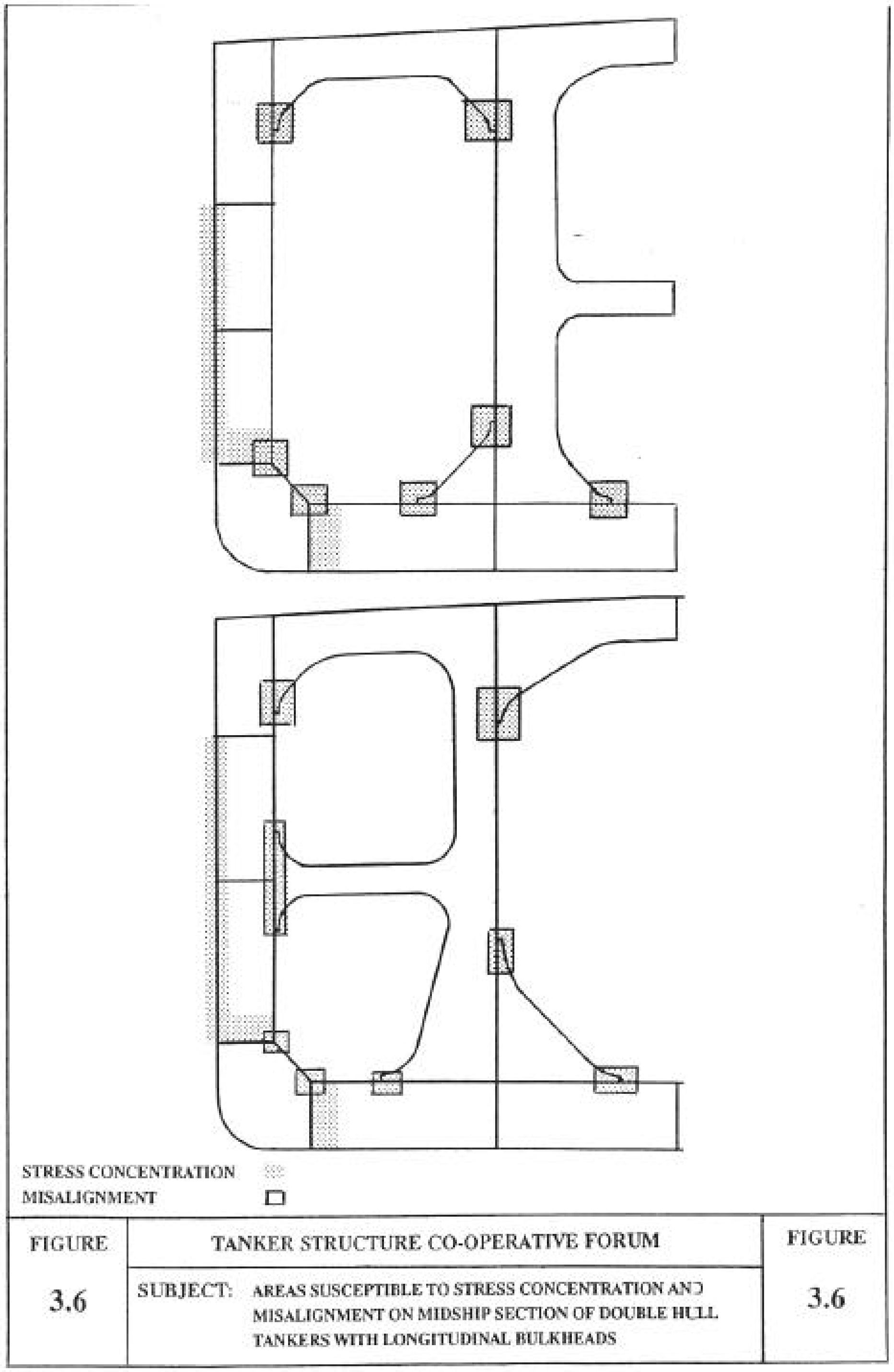


Figure 3 – Stress Concentrations

All members of the TSCF have benefited from exchange of the information contained in the guidance manual and, through publishing the work, it is intended to benefit industry in general as well.

Design Details

Detail design is important and classification societies have in fact required closer attention by requesting fatigue assessment of details. Two areas typically requiring this level of examination are:

1-connection of longitudinal to floors and webs,

2-intersection of inner bottom plate to the sloped inner skin (hopper connection)

These details have been identified as possible locations of failure in service. Either a larger connection area is recommended for the longitudinal, or closer alignment is required for the hopper connection to minimize the unavoidable stress concentration. Both are identified in the Double Hull Guidance Manual as shown in figures 4 (figure 23 of the TSCF) and 5 (figure 1 of the TSCF). Also shown is the relative stress level in these connections determined using available FEM capabilities figures 4.1 and 5.1. This information is also amplified by the TSCF - Group No. O; details are contained in the GUIDANCE MANUAL FOR TANKER STRUCTURES published in 1997. Figure 6 (figure D of the TSCF) and 7 (figure E of the TSCF) are samples of the details shown in this group.

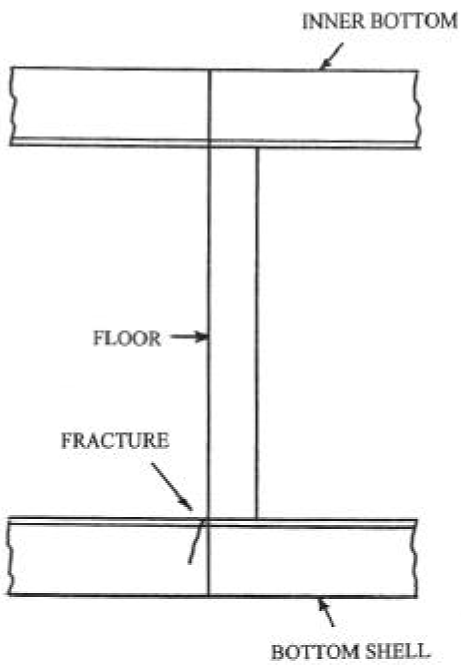
When the above design guidance is followed the structural performance will be improved. Information in the Guidance Manual from TSCF is not always applied in the designs of tankers. The GUIDANCE MANUAL and GUIDELINES FOR THE INSPECTION AND

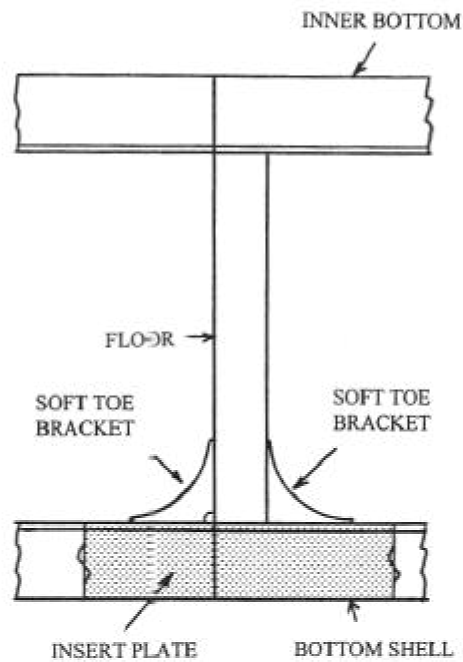
MAINTENANCE OF DOUBLE HULL TANKER STRUCTURES IN 1995 are excellent references for the designer, shipyard and owner in selecting details for the double hull tanker. Unfortunately this guidance is not used in all instances since some areas of structure, indicated as having a design weakness from past experience, have still been used and failures have been reported. An example is the use of lapped connections. The industry has been aware that lapped connections can result in fatigue cracks that, if not discovered early, can result in failure of both the inner and outer hull. Breach of the inner hull can cause difficult clean up. When this breach also is accompanied by outer hull failure pollution can also occur. The use of lapped connections of longitudinal to floor and other structure should be avoided and, in fact, even better connection details are necessary at some locations. This is illustrated by figure 4 (figure 23 of the TSCF). It should be further noted that neither the original, nor the repair, has a lap in the connection. This has been omitted intentionally as a lap in this structural connection has lower fatigue performance than a butt.

Another location indicated as being critical by TSCF is the connection of the inner bottom to the sloped plate of the inner hull. Although there are other connection methods that can be used for this connection, the most common is illustrated in figure 5 (figure 1 of the manual). Even with the alignment shown, fatigue performance can be lower than desired. Class societies have been examining this detail closely and in some designs additional methods have been necessary to ensure adequate fatigue life for the detail. A typical investigation of this detail is illustrated in figure 5.1.

LOCATION :	BOTTOM BALLAST TANK	GROUP
EXAMPLE :	CONNECTION OF LONGITUDINALS TO ORDINARY	NO 4
NO 2	FLOORS	

TYPICAL DAMAGE	PROPOSED REPAIR





FACTORS CONTRIBUTING TO DAMAGE

1. Stress concentration at the connection of bottom longitudinal and stiffener on floor.

FIGURE	TANKER STRUCTURE CO-OPERATIVE FORUM	FIGURE
23	SUBJECT: CATALOGUE OF STRUCTURAL DETAILS	23

Figure 4 – Bottom longitudinal

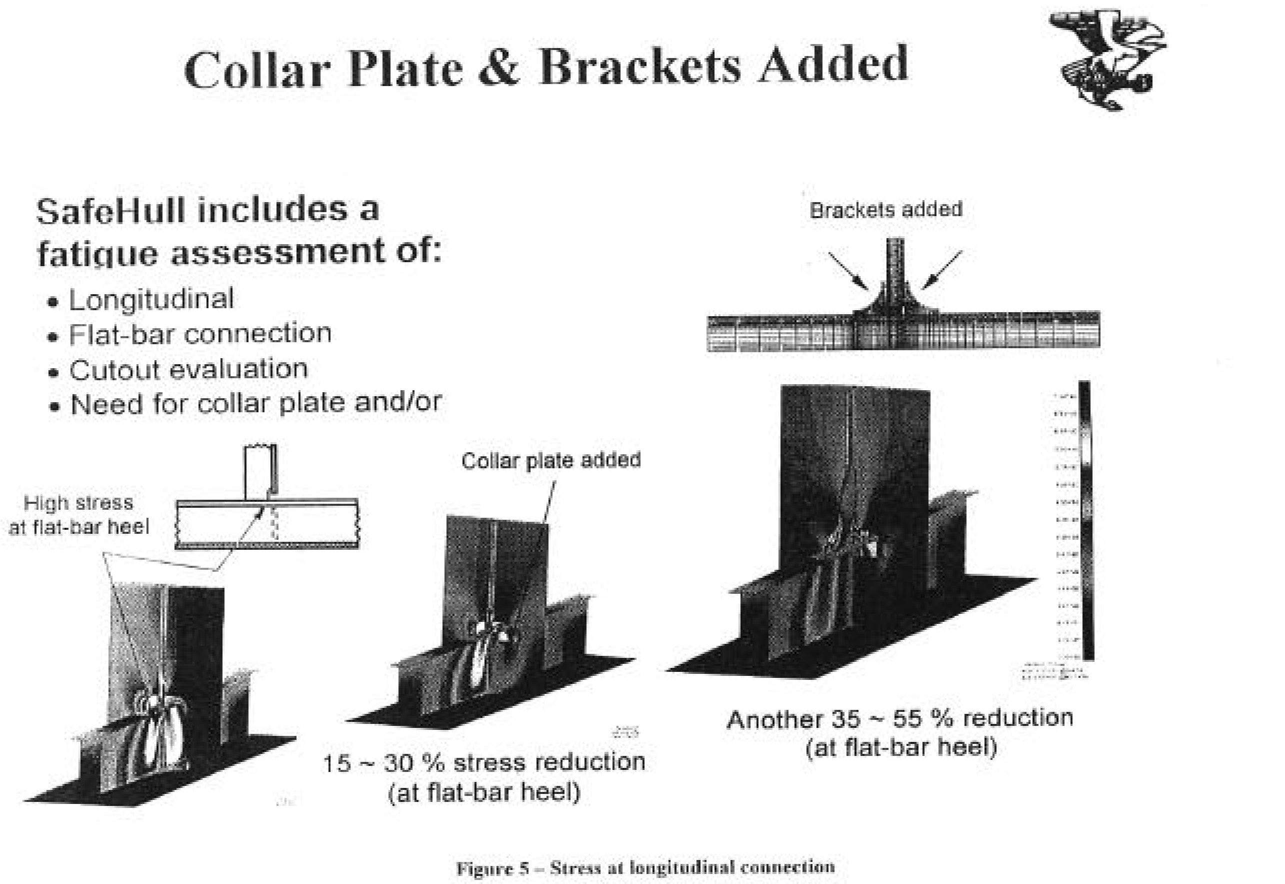
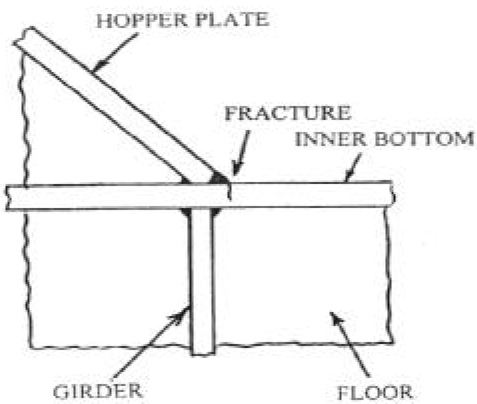


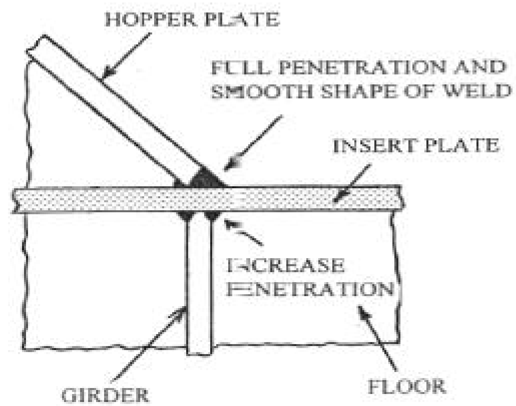
Figure 4.1 – Stress at longitudinal connection

LOCATION : BILGE HOPPER EXAMPLE : CONNECTION OF HOPPER PLATE TO INNER BOTTOM NO 1	GROUP NO 1

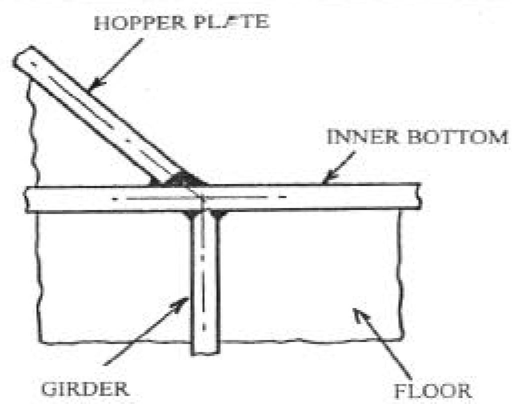
TYPICAL DAMAGE



PROPOSED REPAIR



NEW CONSTRUCTION



Notes: Plate midlines intersect.

FACTORS CONTRIBUTING TO DAMAGE

1. Stress concentration at juncture of hopper plate to inner bottom.
2. Insufficient welding connection.
3. Misalignment between hopper plate, inner bottom and girder.

FIGURE 1	TANKER STRUCTURE CO-OPERATIVE FORUM SUBJECT: CATALOGUE OF STRUCTURAL DETAILS	FIGURE 1

Figure 5 - Inner Skin and Inner Bottom

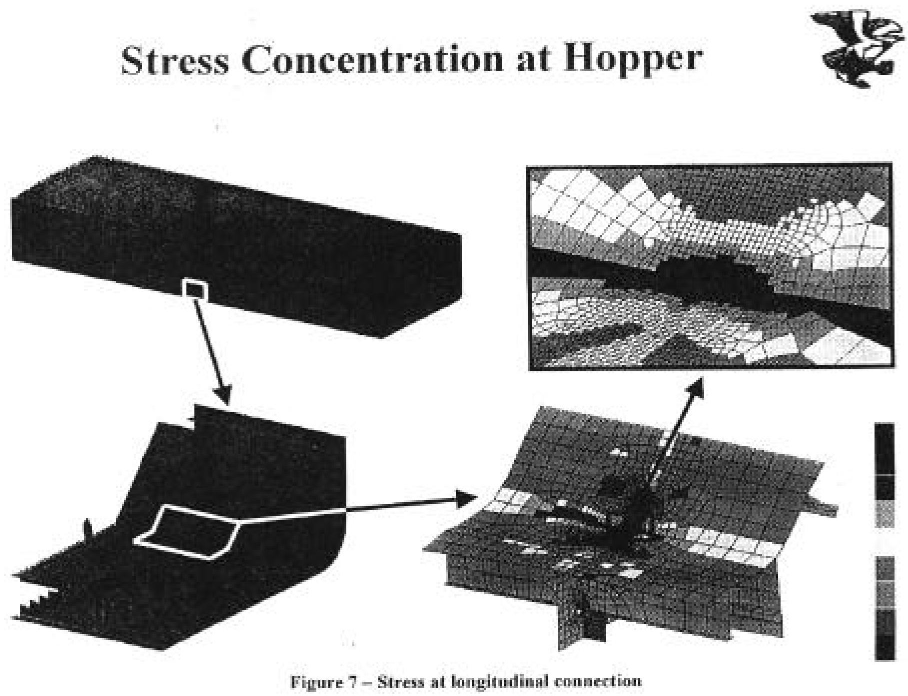
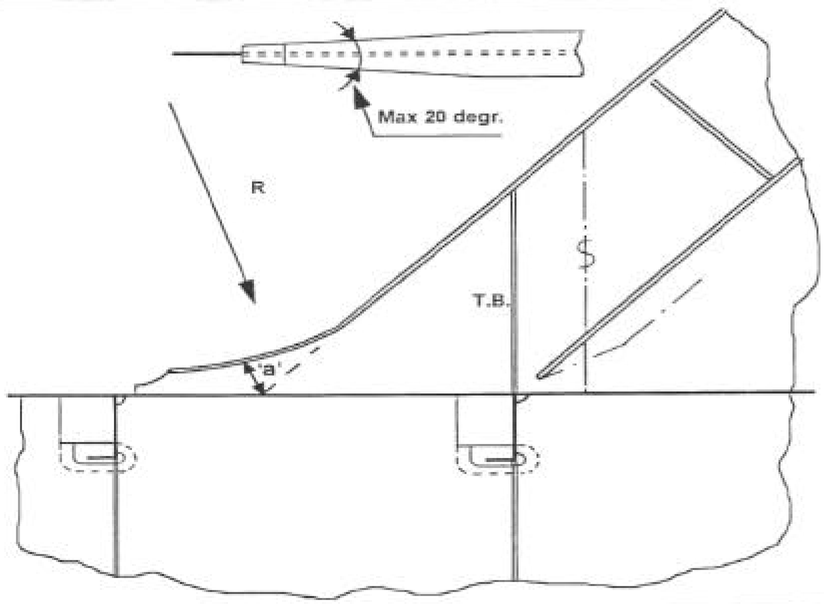


Figure 5.1 – Stress at longitudinal connection

TYPICAL LOCATION: Web Frame connections DETAIL TYPE: Bracket Toe, Symmetrical Flange Plate	GROUP No. 0

RECOMMENDED DESIGN



NOTES:

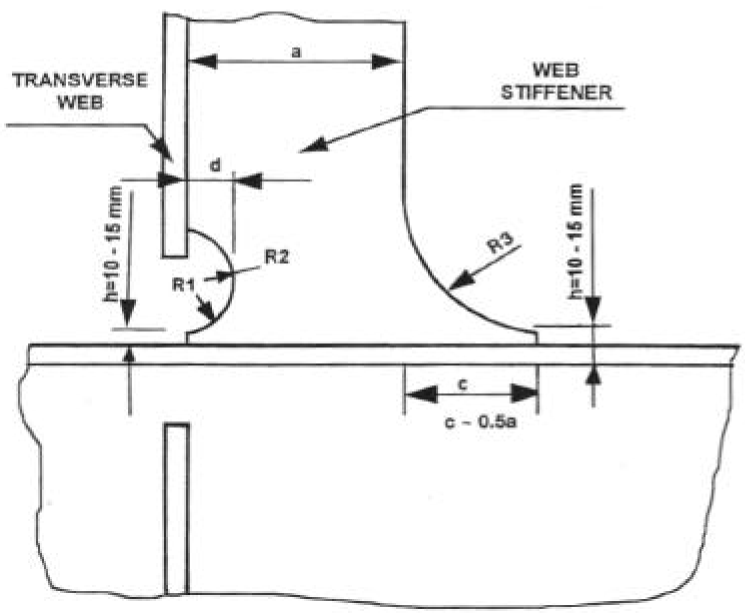
1 - Face plate should be tapered with a total angle of 20 degree or less (i.e. taper 1:3)
2 - Breadth of face plate at tip should be as small as possible (approx. t + 20 mm, t= toe thickness)
3 - Face plate tip should be tapered in thickness down to 10 mm with a max slope of 1:3
4 - Toe of web should be of increased thickness
5 - Toe height should be as small as possible (10 - 15 mm)
6 - Toe cross sectional area, ref. measure 'a' should be approx. 60 % of flange cross sectional area
7 - Welds connecting toe web to plating and to face plate to be full penetration over the length of the snipe or radiused part whichever is greater and grinding flush of toe recommended
8 - Tripping bracket should be fitted as indicated to reduce flexing of the bracket and face plate
9 - Collar plates welded to the platingshould be fitted in way of toe. Tip of toe clear of cut-outs
10- Slope of toe to be max 1:3 at face plate end
11- Correct alignment of bracket with web on the other side is essential

FIGURE E	TANKER STRUCTURE CO-OPERATIVE FORUM SUBJECT: CATALOGUE OF STRUCTURAL DETAILS	FIGURE E

Figure 6- Faceplate Improved Ending

TYPICAL LOCATION: Web Frame / Side Longitudinal DETAIL TYPE: Web Stiffener	GROUP No. 0

RECOMMENDED DESIGN



NOTES:

1 - Toe height as small as possible (h=10 - 15 mm)
2 - For a slope at toe max. 1:3, R1 = 1.5 x d and R3 = 1.5 x c
3 - Depth 'd' of key hole notch as small as possible, max. 30 mm

FIGURE D	TANKER STRUCTURE CO-OPERATIVE FORUM SUBJECT: CATALOGUE OF STRUCTURAL DETAILS	FIGURE D

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Figure 7- Flat Bar Connection Improved Detail

The tapering of the bracket faceplate has also proved to be a source of failure in single hull ships. Guidance on better termination of this faceplate has been provided in the most recent edition of TSCF publication as shown in figure 6.

Another area where problems in service have been encountered is the flat bar stiffener connection to the longitudinal. Guidance on better connection detail has been provided in the most recent TSCF publication as shown in figure 7.

Classification Society Assessment

OPA-90 and IMO MARPOL Regulation 13 F have caused the design of tanker structure to be evaluated by all in the marine industry. The boldest move, and also the correct move, has been taken by ABS in employing first principle methods to assess the needs of the double hull tanker structure. This effort is found in the SafeHull requirements of ABS Rules for tankers. The SafeHull system examines the structure for defined dynamic loads, by prescribed methods, and for identified failure modes.

The classification societies, with the introduction of double hull requirements, have assessed the method of providing requirements to the naval architect, shipbuilder, owner, operator and administration. In general this information is contained in the Rules of each society.

The classification societies who are members of the TSCF (ABS, BV, DNV, GL, LR and NK) have also provided computer programs to guide in the design development. The process used by all has FEM as a key element of proving the suitability of the design. The specific area where all societies have a common requirement through International Association of Classification Societies (IACS) is the strength of the Hull Girder. In regard to other elements of structural design all classification societies have similar requirements and methods to determine strength. A brief description of the requirements of ABS and NK follows:

ABS - SafeHull

Assessment of Tanker Structures

Strength Criteria

A fundamental premise of the ABS criteria involves integration of initial minimum requirements with an overall strength assessment requirement. The criteria specify load and the load combinations required to establish minimum values for local initial scantlings, and assessment requirements to ensure compliance with established failure criteria for yielding, buckling, and fatigue.

To establish a threshold for the minimum strength of the hull structure, the criteria are based on a "net scantlings” concept, which is intended to ensure that, with coatings and good maintenance, the strength requirements will be met over the vessel's life.

Load Criteria

The load criteria define realistic representations of the static and dynamic load components, and load combinations required to assess the failure modes, considering:

- global hull-girder loads,
- static and dynamic components of cargo and ballast loads, and
- external hydrostatic and dynamic pressures.

Failure Modes and Strength Assessment

The initial scantlings are considered minimum values, which are verified by finite element stress analyses. The stress analyses explicitly consider yielding, buckling, ultimate strength and fatigue failure modes.

Yielding Strength - Allowable stresses, based on the material yield strength, are used to assess structural members against yielding. In general, total direct stresses and Hencky-Von Mises stresses are considered for stiffener and plate elements, respectively.

Buckling and Ultimate Strength - In assessing the buckling and ultimate strength of plate and stiffened panels, the combined effect of simultaneously acting bi-axial compression, lateral pressure and shear is considered for stiffeners both column and torsional/flexural buckling failure modes.

Fatigue Strength of Structural Details - Fatigue strength analysis is based on the Palmgren-Miner cumulative damage theory, which is applied in conjunction with a specific set of S-N data. The combined long term hull girder and local stress ranges are computed and compared to the permissible stress range for North Atlantic Ocean 20-year service.

Other Design Considerations - Additional design considerations are provided to address overall safety of the hull structure. The identified failure modes encompass a wide spectrum, spanning from global failure to local failures. The following design considerations are part of the criteria:

- hull-girder ultimate strength
- stiffness requirements for main supporting members

- capability of the hull girder to reach its predicted ultimate strength, by requiring that individual plate panels and stiffeners not exceed their ultimate strength.
- assessment of residual hull-girder strength following damage, such as those sustained by collision or grounding.

NK - Data

DATA or Designed by Application of Total Analysis Concept is a class notation assigned by Class NK which certifies that a ship has been designed and constructed according to a high-level computer-based hull strength analysis method. The DATA concept incorporates advanced design technology and consists of several steps. Estimates are first made of the various loads acting on the ship under actual operating conditions based on ship motion and load analysis. These loads are applied in the conduct of extensive FEM in order to evaluate the yielding, buckling and fatigue strength of the ship structural components. The results obtained are used to determine the structural scantlings that will provide sufficient strength for the ship to operate safely.

Use of the DATA-approach results in more precise estimates of external wave loads acting over the entire length of the ship as well as cargo loads, ballast loads, and other related loads, and the effect these loads will have on the various structures of the ship. It also makes it possible to calculate the stresses generated to a greater degree of accuracy through large-scale structural analysis using the estimated loads directly. Based on this, it becomes possible to assign optimum structural scantlings to members.

In the DATA evaluation process, the most severe weather and sea conditions that a ship may encounter while in service, are assumed, and detailed examination is given to hull strength which corresponds to these assumptions. This enables designers and shipbuilders to reduce the possibility of design weaknesses in structural members, including the potential for fatigue failure, thereby obtaining greater reliability with regard to ship safety.

Extensive hull structural data generated during the design process of a DATA designated ship can be used even after the ship enters service. This database can be used in the recalculation of the structural strength of a ship that has been affected by corrosion, wastage or other similar factors. This information can be used to evaluate how much reinforcement or repair is necessary in order to ensure acceptable levels of structural strength. In addition, rational and effective maintenance and spot check planning can be performed, since it is possible to specify high-stress members within the hull structure beforehand from previous calculation data.

Design Improvements

Selecting details known to be underperformers does, at times, result in less expensive construction, but at what cost? The cost is not only to the ship owner who must repair the structure when failure occurs but also to the environment, industry, and the reputation of the shipyard and others involved in the design. Therefore it is necessary for all involved in the design process to be cognizant of details selected and their performance.

Performance can be determined either through resources such as TSCF Double Hull Guidance Manual and SSC 405 –"Fatigue-Resistant Detail Design Guide for Ship Structures," or better still by direct assessment of the detail. Details can be analyzed by FEM to determine the stress distribution and stress range and thus defining the relative performance to resist the failure modes of yielding, buckling and fatigue. Using these approaches the industry can, with well established methods currently available, refine the design to meet the necessary performance required for the ship’s intended service.

In regard to performance of a detail employing fillet welds it is known that such welds incorporate a defect formed by the lack of full penetration. This defect is eliminated when a full penetration weld is provided. Figure 6 “ Faceplate Improved Ending” not only recommends improved geometry to alleviate stress concentration but also recommends full penetration weld over the length of the snipe for the faceplate. This improvement is accomplished not only by modifying geometry to reduce stress, but also by selection of a weld that has improved performance characteristics. Other methods to improve the weld are also possible but these should be used when no other reasonable solution can achieve the required performance of the detail. Some of the weld improvement techniques are:

1- control of weld profile,

2- dressing the weld toe,

3- thermal stress relief, and

5- peen the weld.

The above weld improvement techniques can be used but should not be the first choice, but rather the exception when all other reasonable efforts to improve the detail have been unsuccessful.

Many organizations are examining ways to improve structural design information. The Ship Structure Committee (SSC) is one of these. The SSC is an interagency group established by The United States Congress over 50 years ago also sponsors work on ship structures. A recent SSC Report 405 contains methodology to evaluate the design tradeoffs that must be considered by the designer, builder and operator in selecting details for tanker design. SSC Repot 405 contains useful guidance in selecting details as illustrated by Figure 8. This work is for guidance in selecting details for fatigue resistance. This work has examined details used in ships and provided a method to rank the detail. The example shown is similar the Figure 4 from TSCF. The detail illustrated has three variations and ranks them. Ranking is from 1 to 3 with 1 being the best. The attributes that are considered in the ranking are fatigue performance, ease of inspection, maintenance cost and fabrication cost. Thus the most expensive cost will be a 3 and the least expensive cost a 1. This approach permits a means to measure the overall utility of the detail in question. It is important that the detail finally selected achieve the performance required. Therefore, a detail that ranks top "A" as shown in Figure 8 may in fact not be acceptable as fatigue performance may only be satisfied for the design by detail "C". Thus detail "C" must be used. This is only a sample how information currently available to the marine industry can be used.

Although many of the designs have been assessed to the requirements of classification societies and the societies have adequate tools to evaluate the design, there is still more that can be done. The areas where design improvement can be made are in both the details used and the fabrication tolerances used at shipyards. The improvements of details must be an effort on the part of all involved in the marine industry.

The design as it develops has less and less flexibility in influencing changes which, if considered at an early stage, could easily be accommodated with minimal impact on the overall cost for the ship.

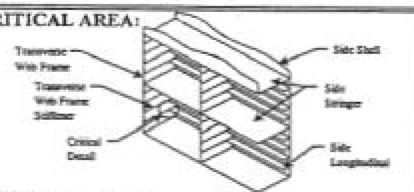
Vessel Type: Double Hull Oil Tankers
Critical Area: Double Side
Critical Detail: Intersection of Side Shell Longitudinal and Transverse Web Frame Stiffener
Detail Description: Asymmetric Longitudinal

Ship Structure Committee
FTL FLEET TECHNOLOGY LTD

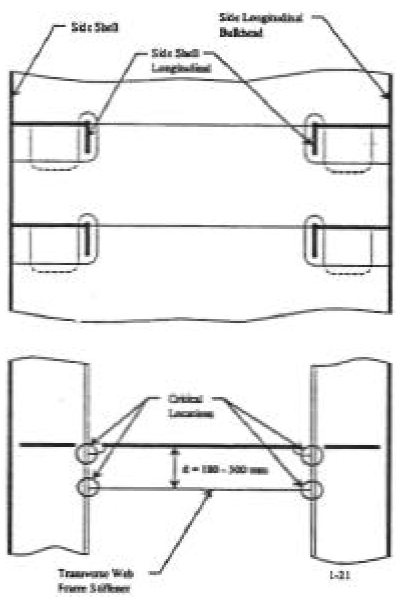
Detail 21

Rev 001-250199

CRITICAL AREA:



CRITICAL DETAIL:

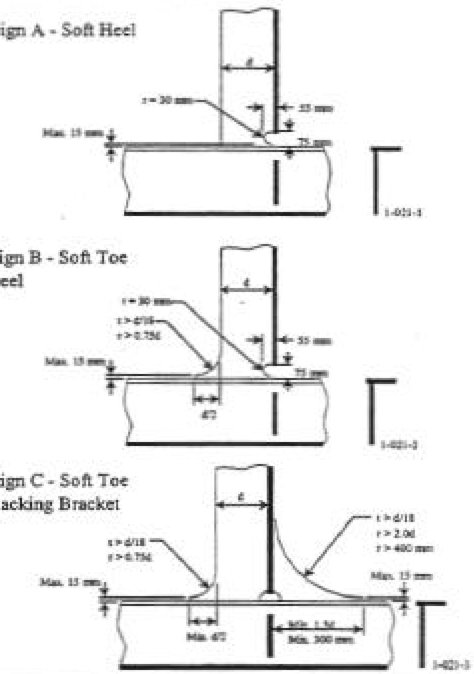


DETAIL DESIGN GOOD PRACTICE:

Detail Design A - Soft Heel

Detail Design B - Soft Toe and Soft Heel

Detail Design C - Soft Toe and Soft Backing Bracket



Detail Attributes	Design Detail Rankings		
	A	B	C
Fatigue Performance	3	2	1
Ease of Inspection	1	1	2
Maintenance Cost	1	2	3
Fabrication Cost	1	2	3

COMMENTS:

- Alignment between the transverse web frame stiffener, the backing bracket and the web of the longitudinal is to be maintained.
- A wrap around weld, free of undercut or notches, around the heel and toe connections of the stiffeners and the backing bracket to the longitudinal face plate.

Figure 8- Typical Connection Details for Longitudinal

An early double hull design being developed had wide spaced floors and only a centerline girder. During the early stages of design development one mention was made of providing more girders. At a later stage after considerable development it was suggested that adding two girders on each side would improve the structure and reduce deflection of the double bottom. Of course the design had developed past the point where this could be considered. However, for a subsequent design at the same shipyard the owner requested what could be done to reduce deflection of the structure. This request, being made at an early stage in the development, could be accommodated, and in fact was, with the result that the structure in this design incorporated significant improvements that otherwise would not have been. The key in the design development setting, is to include as many characteristics desired in the design, before the design cycle reaches a critical stage.

Some areas contained in the TSCF guidance that must influence the design early are:

1- cargo tank arrangement,

2- material for construction,

3- protection of cargo tanks and coating life,

4- fabrication details and operating life,

5- inspection methods to be built in

Using such information during development of a design, will return sound ship building practices to the industry and minimize the experiences of the past where elimination of steel in design has been the goal. The cost of this effort has been fatigue and other structural failures that can be avoided. Avoidance will come with consideration of loads, response and causes of failure as well as diligence in assessing the structure in service. The work of the forum and classification societies has been focused in this direction. The other segments of the marine industry must also work diligently in this direction to restore credibility to the marine industry.

Conclusion

Designs of double hull tankers present to the marine industry both an opportunity and a challenge. The ship builder does have many decisions to make in the construction of the double hull tanker. However, the industry has made more tools available to make informed choices in design and construction. The marine industry must at every level make the right choices to restore public confidence to an industry that has been faced with bad press, bad performance and poor choices in the past. It is necessary for the ship builder, owner, operator, classification society, administration and the mariner to make the right choice in reducing risk in the marine industry. Those of us present are in general responsible for the initial step in the vessel's life. It is our obligation to choose the right material, proper details, and adequate structure for successful operation of the vessel. Each of us should not only look at the cost of the structure, but the consequences of poor structure on the marine industry. Let each of us pledge to take ownership of our responsibility in successful ships for the millennium.