SSC-361

HULL STRAPPING OF SHIPS

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SHIP STRUCTURE COMMITTEE

1990

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Ship Structure Committee

An Interagency Advisory Committee
Dedicated to the Improvement of Marine Structures

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HULL STRAPPING OF SHIPS

It is sometimes necessary during the service life of a vessel to increase the strength of the hull girder structure. Primary reasons for requiring added strength include changes in service or operating conditions, a need to modify the hull girder stress distribution, or a desire to lengthen the vessel. A common method to increase the strength of the hull girder is to strap the vessel with doubling plates.

This report contains classification society recommendations and guidelines for the design and installation of hull straps. A cost-effective methodology was developed to provide guidance for future strapping projects. Detailed information on strapping practices for several ship types and an analysis of data obtained from vessel surveys and inspections are included.

J. D. SIPES
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

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16. Abstract

A survey was conducted of U.S. and worldwide shipowners, ship operators, shipyards, and major international classification societies by means of a survey questionnaire and follow-up correspondence. Detailed information was requested and obtained for fourteen ship classes which have had hull strappings installed to strengthen the hull girder due to lengthening. Data was collected on the location and extent, the geometry and dimensions and the method of attachment of strapping plates to the hull as well as end tapering details and faying surface tightness provisions. In addition, in-service performance data were obtained for past strappings from the U.S. Coast Guard inspection database.

The results were sorted, reviewed and analyzed with regard to the successfulness of the strapping designs and a practical and cost effective strapping design methodology wasdeveloped to provide guidance to designers in preparing future hull strapping designs.

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Lengthening	New Midbody	
Jumboizing	Hull Scantlings	

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METRIC CONVERSION FACTORS

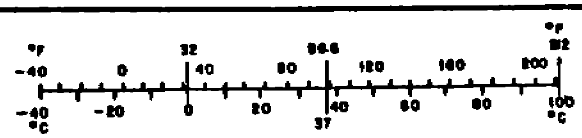
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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APPENDIX

TERMINOLOGY & ABBREVIATIONS

In this report, the words "strap" and "doubler" are used interchangeably to convey the concept of an additional plate of given thickness and width attached to the deck, side shell, or bottom plating of a ship's hull.

The word "strapping" is used for the purpose of referring to the overall hull strengthening and stiffening approach which may consist of one or more doublers installed at various locations on the hull.

"Split Strap" means two or more narrow doublers installed in parallel, and sometimes joined together by welding, instead of a single but wider doubler plate in order to avoid plug welding.

All other terms used in the report are defined and described where they appear in the text.

The few abbreviations used are described below:

ABS: American Bureau of Shipping
ASTM: American Society for Testing Materials
BV: Bureau Veritas
DnV: Det norske Veritas
GL: Germanischer Lloyd
IACS: International Association of Classification Societies
LRS: Lloyd's Register of Shipping
NK: Nippon Kaiji Kyokai

1.0 INTRODUCTION

1.1 Background

During the service lifetime of a ship, it may be necessary to increase the strength and stiffness of the hull girder structure for a number of reasons. One of the most common methods of accomplishing this purpose is "strapping." As the name implies, strapping involves the attachment to the main hull plating of long and continuous widths of plates that essentially "strap" the existing plating and thereby provide additional material to increase the hull girder section modules and, therefore, the strength and stiffness of the hull.

The reasons for strapping may fall into one or more of the following categories:

1. To improve continuity of structure and to prevent recurrence of persistent failures such as cracks, severe buckling, extensive distortion of plates and stiffeners, etc.;

2. To enable the ship to withstand more severe service requirements than that for which it was originally built;

3. To increase the cargo and/or passenger carrying capacity of the ship by "jumboizing", i.e. increasing the vessel's size by lengthening, deepening, widening, or by a combination thereof.

Examples of hull strapping done specifically for Category 1 purposes are very rare in the present day shipbuilding and ship repair activities. However, doublers have been installed on early all-welded steel ships to prevent brittle fracture. Serious fractures had occurred in hundreds of steel all-welded ships built during and after World War II. Breaking in two of several T-2 tankers and Liberty ships was deemed to be due to occurrences of brittle fracture. In efforts to remedy these failures, some design changes were made including the addition of riveted crack arresters (straps) at various locations.

Category 2 strappings have been accomplished with the purpose of changing a vessel's service from limited inland waterways or lakes operation to full open ocean service as well as for converting, for example, a dry cargo or container carrying vessel to an oil/bulk/ore or products carrier. Applications of this category usually involved the installation of one or more hull doublers of required length in order to increase the structural strength of the hull girder to withstand the additional imposed wave bending moments or cargo loads and to provide reinforcement needed due to modifications to existing structure to accommodate the new cargo.

The most common type of strapping is the one mentioned in Category 3 which is employed in conjunction with jumboizing of a vessel and insertion of a new midbody. The new midbody is usually constructed to the original scantlings, inserted between the fore and aft bodies of the existing ship, and the three parts joined together and strapped by continuous doublers extending over both the original and new sections along a specifically determined fraction of the ship's length.

It has been reported in the technical literature that among the many conversions involving jumboizing of ships, some applications had encountered problems with strappings. The problems were related to the method of attachment, tapering of the width and thickness, and the longitudinal extent of doublers. The physical damages observed were usually in the form of cracks, corrosion of the faying surfaces, and propagation of cracks due to lack of shear transfer capability.

The objective of this Ship Structure Committee Project is to survey past strapping designs and to develop a practical and cost effective design approach for strapping of commercial ship hulls by benefitting from the results of this survey.

1.2 <u>Scope Of Study</u>

The scope of work for this project was established by the Ship Structure Committee as follows:

"Develop a rational method of strapping existing hulls and midbodies to ensure adequate strength and stiffness through proper location and attachment of added straps. The method developed shall be applicable to all commercial ships."

The requirements were further described to include the following:

- o "Survey of the past designs for both successful and unsuccessful strapping of hulls including type of vessel, service experience, and pertinent features. The scope of this effort shall include all commercial and naval ships, both foreign and domestic, which have been strapped."

- o "Development, through theoretical considerations, of a practical and cost effective design approach to strapping of ship hulls which, as a minimum, shall address:

  - location and extent of straps
  - size of straps
  - method of attachment, end taper, and
  - faying surface tightness and treatment.

The design method developed shall be reported in a format that can be directly converted into an ASTM practice or guidelines."

This report presents the results of the investigation and surveys of past strapping designs, analyses of the data obtained from surveys, and the detailed strapping design methodology developed on the basis of these findings.

It should be pointed out that the Project Technical Committee for this study had recognized during the project kick-off meeting the difficulty and very time consuming nature of compiling past strapping design data for "all commercial and naval ships, both foreign and domestic, which have been strapped." Consequently, as instructed by the committee, surveys were limited to domestic and foreign tankers, bulk carriers, Ro-Ro ships, and container and combination carriers of approximately 5000 gross tons or larger. Also included was the data provided by the U. S. Navy for one vessel which was strapped.

2.0 SURVEYS OF PAST STRAPPING DESIGNS

Extensive written and verbal communications were initiated by MR&S in order to collect as much information as possible on past strapping designs and service performance.

All probable sources of such information were contacted within a period of approximately six (6) months. Included were the following types of organizations/institutions:

- U.S. based shipowners/operators
- Foreign shipowners/operators
- U.S. shipyards
- U. S. Coast Guard
- Foreign classification societies
- American Bureau of Shipping
- Naval Sea Systems Command
- Military Sealift Command

As a first step in the effort for collecting data on past hull strappings of ships, the six major classification societies were contacted and listings were requested of the names of ships which were jumboized since 1960. It was found that a total of 1551 ships had been jumboized under classification of these six societies. However, whether any or all of these ships had been strapped during jumboizing conversions could not be readily determined without conducting an extensive search of the societies' records for each ship. Furthermore, the class societies required authorization from the owners of the ships in question before such data could be released to the project investigators.

To reduce the amount of correspondence which would have been necessary if the owners of all ships were to be contacted, the lists of each classification society were subjected to a preliminary screening to eliminate all but the following four types of ships of 5,000 gross tons or larger capacity:

- Oil Tankers
- Bulk Carriers
- Roll-on/Roll-off Ships
- Container Ships

Table 1 lists, for each of the six major classification societies, the total number of all ships jumboized (i.e. lengthened, widened, deepened, or any combination of these) since 1960. In addition, Table 1 lists the number of ships remaining after the initial screening which, as can be seen, reduced the number to a total of 110 vessels.

Letters with attached questionnaires were then sent to the owners of these 110 ships. A sample questionnaire is shown in Table 2. The owners were requested to fill out one questionnaire for each ship class that utilized hull strapping in the jumboizing conversion and to make available to the project investigators drawings of the strapping details. If this proved to be difficult or impossible, the shipowners were requested to authorize the cognizant classification society to release the pertinent strapping data to the project investigators.

Table 3 shows the number of shipowners, U.S. based and foreign, to whom questionnaires were sent or from whom data were requested. The number of responses received are also shown; however, not all of these responses contained sufficient information for the purposes of this study.

As indicated in Table 3, a total of 87 shipowners were contacted for data on the 110 ships. Responses were received from only 28 of the addressees and only 11 of the responses contained sufficiently detailed strapping data suitable for use in this study.

A total of 11 shipyards in the United States which are known to have used hull strapping in the past were also contacted and data on these strappings requested. Seven shipyards responded; five yards stated that they either had not used strapping or that the data on past strapping were not available. Only two yards made data available in the form of filled out questionnaires and drawings or sketches of strapping details.

After all of the detailed strapping data obtained were reviewed and sorted, it was found that a total of 14 different ship classes could be included in the analysis of past strapping designs. In most of these cases, several ships of the same class had been strapped in accordance with the strapping designs shown for that class. Table 4 lists the 14 ship classes by type, flag of registry, classification society, year strapped, and the country where strapping was done. The names of ships, shipowners, or shipyards where strapping was accomplished have purposely not been included in order to insure the anonymity promised in the request for information.

TABLE 1

SHIPS JUMBOIZED BY CLASSIFICATION SOCIETIES		
CLASSIFICATION SOCIETY	TOTAL NUMBER OF JUMBOIZED SHIPS	NUMBER OF SHIPS AFTER INITIAL SCREENING
American Bureau of Shipping	197	34
Bureau Veritas (BV)	573	27
Det norske Veritas (DnV)	397	6
Germanischer Lloyd (GL)	99	7
LLoyds Register of Shipping (LR)	171	16
Nippon Kaiji Kyokai (NK)	114	20
TOTAL	1551	110

TABLE 2

QUESTIONNAIRE FOR HULL STRAPPING DATA

1. **Responding Organization** Name: Address: Type of Business:	
2. **Particulars of Original Vessel** Name: Flag: Owner: Type Service: Year Built: Shipyard Built: Classed By:	
3. **Principal Dimensions** Length OA Length BP Beam Depth Draft Displacement Block Coeff.	Before Strapping	After Strapping

TABLE 2

Questionnaire For Hull Strapping Data .....cont'd

4. **Strapping Design Data** Reason(s) for Strapping Strapping Design Prepared By: Strapping Design Approved: By Owner By Classification Society Section Modulus Before Strapping Section Modulus After Strapping Class Designation of Material Used in Straps: (e.g. AH32, Grade D, etc.) Original Hull Material	
5. **Strapping Design Details** (Please provide detailed drawing(s) or answer following questions): Size & Number of Straps: Location of Straps on Hull Longitudinal Extent Method of Attachment to Hull Details of Tapered Ends Faying Surface Treatment	
6. **Strapping Installation** Date Conversion (or Strapping) Accomplished Work Accomplished at Shipyard: Survey and Classification By	

TABLE 2

Questionnaire For Hull Strapping Data .....cont'd

7. <u>Performance Data</u> Was Design Successful? Any Structural or Other Noteworthy Problems Experienced in Service If Yes, please describe:	
8. <u>Comments</u> Please provide any thoughts or comments with regard to hull strapping design, construction, and/or inspection:	

TABLE 3

RESPONSES FROM SHIPOWNERS

Base or Country	Number of Shipowners Contacted	Number of Ships Jumboized	Number of Shipowners Responding	Number of Responses with Strapped Ships
USA	37	46	21	7
JAPAN	13	16	0	0
SWEDEN	6	6	1	1
NORWAY	2	2	1	1
DENMARK	1	1	1	1
UNITED KINGDOM	5	9	1	1
MALAYSIA	3	3	0	0
HONG KONG	3	8	0	0
WEST GERMANY	2	2	1	0
CANADA	2	2	0	0
BRAZIL	2	2	0	0
S. KOREA	2	2	0	0
TAIWAN	2	3	1	0
ITALY	1	1	0	0
BELGIUM	1	1	0	0
SPAIN	1	1	0	0
AUSTRALIA	1	2	0	0
CHILE	1	1	0	0
ISRAEL	1	1	0	0
SINGAPORE	1	1	1	0
TOTAL	87	110	28	11

TABLE 4

CLASSES OF SHIPS FOR WHICH

STRAPPING DETAILS WERE RECEIVED

SHIP	TYPE	CLASSED BY	FLAG OF REGISTRY	YEAR STRAPPED	WHERE STRAPPED
A	Bulk Carrier	ABS	US	75	US
B	Tanker	ABS	US	84	US
C	Containership	ABS	US	85	Japan
D	Containership	ABS	US	72	US
E	Containership	LR	US	81	Japan
F	Containership	ABS	US	88	W.Germany
G	Ro/Ro	ABS	US	82	US
H	Bulk Carrier	ABS	US	73	US
J	Containership	ABS	US	72	US
K	Containership	GL	US	84	W.Germany
L	Navy Escort	-	US	83	US
M	Multi-purpose	ABS	US	84	US
N	Containership	LR	NOR	84	S.Korea
P	Containership	LR	DAN	84	S.Korea

3.0 ANALYSIS OF DETAILED STRAPPING DATA OBTAINED FROM SURVEYS

3.1 Types of Data Received

For the 14 classes of ships shown in Table 4, data varying in type and detail were received from either the shipowners, the shipyards, or the classification societies. Table 5 lists the types of information received for each class of ship. As indicated, the data ranged from completely filled out questionnaires with drawings providing sufficient details on strappings to incompletely filled out questionnaires with a drawing or sketch containing insufficient strapping details. For the latter cases, more information was requested, verbally or when necessary in writing, from owners or classification societies, and sufficient data were thus received for inclusion of these cases into the study.

For some ship classes, the owners themselves provided detailed drawings and responses to the questionnaire. For some other ships, the owners stated it would be difficult for them to complete the necessary data and they therefore authorized the cognizant classification society to release strapping information on their ships to the project investigators.

For a few of the ship classes shown in Tables 4 and 5, data were received directly from the shipyards where the actual strappings were accomplished.

Very few of the responders gave or were able to provide data with regard to the actual in-service performance of the ships with strappings in general or of the strappings themselves in particular. Furthermore, the little information provided by some shipowners was not relevant as far as structural integrity of the plate straps were concerned but was related to corrosion occurrence. This latter information was included in the analyses for Table 6.

For more factual information on in-service performance of strappings, recent literature on the subject was surveyed and a request was made to the USCG that the database for service inspection records of U.S. flag merchant ships be searched for such information. The results are presented in Section 3.4.

3.2 Sorting Of Data

The responses received from all sources for each class of ship were carefully reviewed and sorted into the following categories:

General Information: Ship type, year built, etc.

Strapping Arrangement: Locations and sizes of straps.

TABLE 5

TYPES OF STRAPPING DATA RECEIVED FOR EACH CLASS

SHIP	TYPE OF SHIP	TYPE				
		Q1	Q2	DWG1	DWG2	NAR.
A	Bulk Carrier	X		X		
B	Tanker		X	X		
C	Containership	X			X	X
D	Containership		X		X	X
E	Containership		X	X		
F	Containership		X	X		
G	Ro/Ro	X		X		
H	Bulk Carrier		X	X		
J	Containership			X		
K	Containership			X		X
L	Navy Escort	X			X	
M	Multi-purpose			X		
N	Containership	X				X
P	Containership	X				

Legend For Data Types:

Q1: Completely and Properly Filled Out Questionnaire
Q2: Incomplete Questionnaire
DWG 1: Drawing with Sufficient Strapping Details
DWG 2: Drawing or Sketch with Insufficient Details
NAR: Additional Information Thru Verbal and/or Written Communication.

Strapping Details:	Longitudinal extent, materials, welds, tapering, chamfering, etc.
Service Performance:	(if any data were made available).

The resulting matrix type tabulation which summarizes all data obtained for ships A through P is given in Table 6.

3.3 Analysis And Synopsis

The detailed strapping approaches used on each ship class were analyzed with the objective of identifying important differences between various designs. The following specific strapping characteristics and/or details were considered:

- o Location(s) of doubler plate(s), i.e. plate straps, on the ship's hull.
- o Scantlings and the longitudinal extent of doubler plates.
- o Method of joining parallel strips of doublers to each other.
- o Tapering of plate strap scantlings.
- o Edge preparation of doubler plates.
- o Faying surface treatment.

The descriptions and comparisons for each of these characteristics/details are given below.

3.3.1 Location of Straps on Ship's Hull

On most of the ships shown in Table 6, strapping plates were installed on the deck and/or the bottom shell plating. Table 7 summarizes the strap locations for ships A through P. As indicated continuous hatch side girders and/or longitudinal box girders on container ships were also used as preferred locations for placing doublers. On one of the ships, doublers were installed on the innerbottom plating; and on another, longitudinal girders were added at the bottom in lieu of plate strapping.

In general, deck and bottom shell doublers were placed such that these were "backed-up" by longitudinal bulkheads or girders in order to reduce any "shear-lag" effects.

TABLE 6

ANALYSIS OF DATA FROM PAST STRAPPING DESIGNS

SHIP	A	B	C
Year Built:	1952	1984	1980
Type, Original:	Bulk Carrier	Tanker	Containership
Type, Converted:	Self-Unloader	Tanker	Containership
Year/Country:	75/U.S.A.	84/U.S.A.	85/Japan
Classification:	ABS	ABS	ABS
New Midbody:	120 FT	144 FT	100 FT
L/D Original:	9.0	10.2	12.9
L/D Converted:	10.7	12.6	14.8
General Description of Strapping:	Strapping on Deck; Add'l girder at bottom in lieu of of strapping	Strapping on Dk only Design changed to jumbo before construction started	Strapping on Deck, Sheer Strake & Bottom Shell
Strapping Details:	Deck Straps	Deck Straps	Deck Straps, each side
Extent	2/3 L + 75'	0.6 L	0.55L (From E.R. Bhd to Fwd End of Wide Hatches)
Size each side	1 X 70.5" X 2" (Split to 3 X 23.5" Strips)	2 X 84" X 0.75" 1 X 103" X 0.75"	3 X 24" X 2.6"
Material	Gr C Normalized	AH 32	Grade E
Base	1.35" Dk	0.63/0.59 AH32 Dk	1.7" Grade E Dk
Middle Attachment	1/2" X 3/8" Root Groove W.	1-1/2" X 3" Slot W	None
Side Weld	1/2" Fillet	3/8" Fillet	3/4" Fillet
End Weld	1/2" Fillet	3/8" Fillet	1" Fillet
Butt Weld	25 X 3/8 Root Gap With Shim	45 X 0 Root Gap Without shim	40° X 1/4" Root Gap Without Shim
Thickness Tapering	To 1.5"/1.125" Fwd. 2/3 L	None	To 1.5" at ends in steps outside 0.4L
Width Tapering	From 23.5" to 6" R	From full width to 24" in 18 FT	From 24" to 6" R
Side Chamfer	None	3:1 to 1/2"	1/16"
End Chamfer	30 to 5/8"	3:1 to 1/2"	3:1 to 1" at ends and sides
Remarks	No Structural Problems In Service		

TABLE 6

ANALYSIS OF DATA FROM PAST STRAPPING DESIGNS

SHIP	C (contd)	C (contd)	D
Year Built: Type, Original: Type, Converted: Year/Country: Classification: New Midbody: L/D Original: L/D Converted:			1967 General Cargo Containership 72/U.S.A. ABS 90' 12.0 14.0
General Description of Strapping			Long '1 BHD installed to form Box Girder at Top. Existing bottom connected to heavy insert in new midbody by strapping
Strapping Details:	Bottom Straps	Sheer Strake Straps	Bottom Straps
Extent	(Each Side) 0.5L	(Each Side) 0.55L	0.4 L
Size each side	10 X 18" X 1.3"	1 X 19" X 2.6"	1 X 84" X 0.75"
Material	Grade D	Grade E	ASTM A441
Base	7/8" Gr. B Shell	1.7" Grade E (Sheer Strake)	ASTM A441 5/8" shell
Middle Attachment	None	None	(Slot Weld)
Side Weld	7/16" Fillet	3/4" Fillet	( ) Fillet
End Weld	5/8" Fillet	1" Fillet	( ) Fillet
Butt Weld	40° X 1/4" Root Gap w/o Shim	40° X 1/4" Root Gap w/o Shim	N/A
Thickness Tapering	To 3/4" at about 5' from ends	To 1.5" at ends in steps outside 0.4L	None
Width Tapering	From 18" to 4" R	From 19" to 5" R	N/A
Side Chamfer	1/16"	1/16"	N/A
End Chamfer	3:1 to 7/8" at edges of 1.3" doubler, no chamfers in 3/4" end doubler.	3:1 to 1" at ends and sides	
Remarks			Fillet and Slot Welding details not available

TABLE 6

ANALYSIS OF DATA FROM PAST STRAPPING DESIGNS

SHIP	E	E (contd)	F
Year Built: Type Original: Type, Converted: Year/Country: Classification: New Midbody: L/D Original: L/D Converted:	1981 Containership Containership 1981/Japan LR 96 FT 11.4 12.9		1987 Containership Same (Design Proposal) 1988/W. Germany ABS 87 FT 11.0 12.3
General Description of Strapping	Hatchside Box Girder w/straps and strapping on bottom shell installed		Hatchside Box Girder installed w/straps
Strapping Details:	Straps on Box	Bottom Straps	Straps on Box
Extent	N/A	N/A	1/3L in way of new midbody
Size, each side	2 X 14" X 1.57" 1 X 17.7" X 1.57"	2 X 21" X 1.5"	2 X 17.7" X 2.76"
Material	DH	Gr. D	EH
Base	1.57" DH	3/4" Shell, Gr. B	2.2" EH Box Side Pl.
Middle Attachment	None	None	None
Side Weld	1/2" Fillet (Bevel)	1/2" Fillet (Bevel)	5/8" Fillet
End Weld	Same	Same	5/8" Fillet
Butt Weld	N/A	N/A	N/A
Thickness Tapering	N/A	N/A	None
Width Tapering	N/A	N/A	15 both side to 1" R tip end
Side Chamfer	25 to 1"	25 to 1"	None
End Chamfer	N/A	N/A	15 to 5/8"
Remarks	Welding details not available.	Welding details not available	

TABLE 6

ANALYSIS OF DATA FROM PAST STRAPPING DESIGNS

SHIP	G	H	H
Year Built:	1973	1958	
Type Original:	Ro/Ro	Great Lakes Bulk	
Type, Converted:	Ro/Ro Containership	Same	
Year/Country:	82/U.S.A.	73/U.S.A.	
Classification:	ABS	ABS	
New Midbody:	126.5 FT	96 FT	
L/D Original:	10.7	N/A	
L/D Converted:	12.8	N/A	
General Description of Strapping	New Box Girder for new container Holds. Strapping on Inner Bottom	Strapping on Deck and Bottom Shell	
Strapping Detail:	I.B. Straps	DK Straps	Bottom Shell Straps
Extent	0.4 L	2/3 L	2/3 L
Size, each side	1 X 66" X 1.25" 1 X 31" X 1.25"	1 X 75" X 1.75" (Split to 3 X 25" Strips)	3 X 18" X 1.5"
Material	Gr. B	Gr. D	Gr. D
Base	N/A	N/A	N/A
Middle Attachment	1-1/2" X 3" Slot Weld	1/2" X 1/2" Root Groove W.	None
Side Weld	( ) Fillet	1/2" Fillet	7/16" Fillet
End Weld	( ) Fillet	1/2" Fillet	7/16" Fillet
Butt Weld	N/A	25 X 3/8" Root Gap w/shim	25 X 3/8" Root Gap w/shim
Thickness Tapering	None	Yes, beyond 2/3 L	Yes, beyond 2/3 L
Width Tapering	Yes	To 6" R Tip in 3 Ft	To 4-1/2" R Tip in 3 FT
Side Chamfer	N/A	Ground Smooth	Ground Smooth
End Chamfer	N/A	30 to 5/8"	30 to 5/8"
Remarks	Welding sizes not available		

TABLE 6

ANALYSIS OF DATA FROM PAST STRAPPING DESIGNS

SHIP	J		K	
Year Built:				
Type Original:	General Cargo		Containership	
Type, Converted:	Container/Gen. Cargo		Containership	
Year/Country:	72/U.S.A.		84/W. Germany	
Classification:	ABS		GL	
New Midbody:	97.5 FT		99 FT	
L/D Original:	11.3		10.6	
L/D Converted:	13.7		12.7	
General Description of Strapping:	Add Longl BHD installed to form Box Girder in way of new container holds; strapping installed on Deck and sheer strake		Strapping installed on Hatch Side Coaming and bottom shell	
<u>Strapping Detail</u>	<u>Deck Strap</u>	<u>Side Strap</u>	<u>Hatch Side Straps</u>	<u>Bottom Strap</u>
Extent	0.5L	0.4L	N/A	0.4L
Size, each side	1X30"X1.2"/1.38"* (Split to 2X15" Strips)	1X30"X1" (Split to 2X15" Strips)	1X35.4"X1.26"	3X55"X0.75"
Material	Gr. B	Gr. B	Gr. D	Gr. B
Base	1/1/8" Gr. B	3/4" Gr. B	1/2" Gr. B	Gr. B
Middle Attachment	Full Groove W.	Full Groove W	None	None
Side Weld	5/8"/7/8" Fillet	5/8" Fillet	1/4" Fillet	1/4" Fillet
End Weld	Same	Same	3/8" Fillet	3/8" Fillet
Butt Weld	30 X3/8" Root Gap w/o Shim	30 X 3/8" Root Gap w/o Shim	N/A	N/A
Thickness Tapering	None	None	None	None
Width Tapering	N/A	To 9" end width in last 10 FT	N/A	To 24" in last 2 frame space
Side Chamfer	1.5" to 3/4"/1"	None	None	None
End Chamfer	N/A	None	N/A	None
<u>Remarks</u>	*Deck straps moved outboard in way of deckhouse and thickness increased from 1.2" to 1.38" for compensation.			

TABLE 6

ANALYSIS OF DATA FROM PAST STRAPPING DESIGNS

SHIP	L	L (contd)	M
Year Built:	1977		
Type Original:	Navy Escort		Multi-Purpose
Type, Converted:	Navy Escort		Multi-Purpose
Year/Country:	83/U.S.A.		84/U.S.A.
Classification:	-		ABS
New Midbody:	0		126 FT
L/D Original:	13.6		9.4
L/D Converted:	-		11.3
General Description of Strapping	Strapping installed on Bottom and Sheer Strake to increase payload/draft		Strapping Installed on Deck to suit new length and loading condition
Strapping Details:	Side Strap	Bottom Strap	Deck Straps
Extent	N/A	N/A	Varies
Size each side	1 X 18" X 3/4" (split to 2 X 9")	1 X 18" X 3/4" (Split to 2 X 9")	P/S 2 X (3 X 24") X 1" S 1 X (7 X 24") X 1" P 1 X (4 X 24") X 1" (all split to 24" strips)
Material	HY 80	M.S.	
Base	HY 80	M.S.	
Middle Attachment	Full Groove W.	Full Groove W.	1/2" X 3/8" Root Groove W.
Side Weld	5/8" Fillet	5/8" Fillet	7/16" Fillet
End Weld	5/8" Fillet	5/8" Fillet	7/16" Fillet
Butt Weld	Single 45 Bevel w/ 1/4" Root Gap w/o shim	Single 45 Bevel w/ 1/4" Root Gap w/o shim	30 X 3/8" Root Gap w/o shim
Thickness Tapering	None	None	None
Width Tapering	To 6" width in last 24"	To 6" width in last 24"	Yes
Side Chamfer	1/8" X 1/8"	1/8" X 1/8"	None
End Chamfer	Same	Same	None
Remarks			

TABLE 6

ANALYSIS OF DATA FROM PAST STRAPPING DESIGNS

SHIP	N	N (contd)	N (contd)
Year Built: Type Original: Type, Converted: Year/Country: Classification: New Midbody: L/D Original: L/D Converted:	1972 Containership Containership 1984/S. Korea LR 52.4 FT 10.8 11.5		
General Description of Strapping	Strapping on Coaming, Deck and Bottom		
Strapping Details:	Coaming Straps	Deck Straps	Bottom Straps
Extent Size each side	0.41L 1 @ 29.52"X1.77"	0.48L 2 @ 29.52"X1.77"	0.43L 2 @21.65"X1.26"
Material Base	GR E MS Coaming	Gr E MS Dk	GR D MS Bott
Middle Attachment	None	None	None
Side Weld End Weld Butt Weld	( ) Fillet ( ) Fillet N/A	( ) Fillet ( ) Fillet N/A	( ) Fillet ( ) Fillet N/A
Thickness Tapering	N/A	N/A	N/A
Width Tapering	Ratio abt. 3:1 Abt 50% of Width @ Ends	Ratio abt. 3:1 Abt. 50% of Width @ Ends	Ratio abt. 3:1 Abt. 50% of width @ Ends
Side Chamfer	N/A	N/A	N/A
End Chamfer	N/A	N/A	N/A
Remarks	No structural problems while in service. Welding sizes not available.	Welding sizes not available.	Welding sizes not available.

TABLE 6

ANALYSIS OF DATA FROM PAST STRAPPING DESIGNS

SHIP	P	P (contd)	
Year Built: Type Original: Type, Converted: Year/Country: Classification: New Midbody: L/D Original: L/D Converted:	1972 Containership Containership 1984/S. Korea LR 49.4 FT 10.8 11.4		
General Description of Strapping	Strapping on Deck and Bottom Shell		
<u>Strapping Details</u>	<u>Deck Straps</u>	<u>Bottom Shell Straps</u>	
Extent Size, each side	Midship to 0.24L Fwd 3 @ 26.38"X1.77" P/S	0.49L 4 @ 24.61" X 1.00"	
Material Base	GR E/EH36 MS EH36	GR D MS	
Middle Attachment	None	None	
Side Weld End Weld Butt Weld	( ) Fillet ( ) Fillet N/A	( ) Fillet ( ) Fillet N/A	
Thickness Tapering	Ratio Abt. 3:1	Ratio Abt. 3:1	
Width Tapering	Ratio Abt. 2:1 Abt 10% of Width @ Ends	Ratio Abt. 2:1 10% of Width @ Ends	
Side Chamfer	N/A	N/A	
End Chamfer	N/A	N/A	
<u>Remarks</u>	No structural problems reported in service. Welding sizes not available.		

TABLE 7

LOCATION OF PLATE STRAPS ON HULL

	LOCATION				
SHIP	@ DECK	@ BOTTOM SHELL	@ SIDE SHELL	@ HATCH SIDE GIRDERS	REMARKS
A	X				Also additional Girders @ Bottom
B	X				
C	X	X	X		
D		X		X	Long'l bhd to form box girder @ top
E		X		X	Straps on New Box Girder
F				X	Straps on Box Girder
G		X (Strap on Innerbottom)		X	New Box Girder
H	X	X			
J	X			X (Sheer Strake)	Long'l bhd to form New Box Girder
K		X		X	Strap on Coaming
L		X		X (Sheer Strake)	
M	X				
N	X	X			
P	X	X			

3.3.2 Scantlings and Longitudinal Extent of Straps

The size and the extent of doubler plates installed is dictated by the strength requirements for the vessel for its new service. For ships A-P, a review of data included in Table 6 reveals that:

- Plate doubler thicknesses ranging from 3/4" to 2.76" have been used.
- Widths of doublers range from a minimum of 9" to a maximum of 103".
- The longitudinal extent of most plate straps was found to be the middle 40% of the ship's length; however, on some ships the lengths of straps extended well beyond the midships 4/10 length to 6/10 and even to 2/3 of the length.

3.3.3 Materials Used in Strapping

The survey results indicate that in general the strapping materials are chosen to be compatible with the ship's hull plating to which they are attached and to comply with classification society requirements.

Obviously, where doubler plates are attached to higher strength steels, the doublers should have at least the same strength properties. Minimum notch toughness properties (i.e, steel grades) specified in the various classification society rules for hull structure in general should at least be met. These minimum requirements are functions of plate thickness and location on the vessel, with higher grades required for thicker material in more critical locations (e.g. sheer and stringer plates, bilge strakes).

Since it is likely that doublers will be thick and located in the more highly stressed regions of the vessel, consideration should be given to the consequences of fatigue cracks propagating into or through doublers installed as strapping. Such considerations may lead to improving the notch toughness (steel grade) of such doublers over and above those required for new construction where doublers are normally not contemplated in the design.

3.3.4 Method of Attachment to Hull

On all of the lengthened ships for which data were obtained, plate straps were attached to the hull plating by welding; riveting or bolting is no longer used.

Various methods of attachment were observed and welding characteristics were broken down into the following categories:

- o Welding of straps at sides only.
- o Welding of straps at sides and in slots.
- o Welding of adjacent strips of doublers.
- o Welding reinforcement at ends.

3.3.4.1 Welding of Straps at Sides Only

In many cases, plate doublers of varying widths were attached to the main hull plating by welding only the two sides and the ends of the doublers. Figure 1 shows the typical arrangement of and welding details for this method of attachment and lists the ships for which such attachments were used. Doublers ranging in width from 14" to 55" were attached to the deck or bottom shell plating in this manner. Even for the 55" wide doubler on Ship K, this type of welding was used with no plug welding or splitting of the doubler's width.

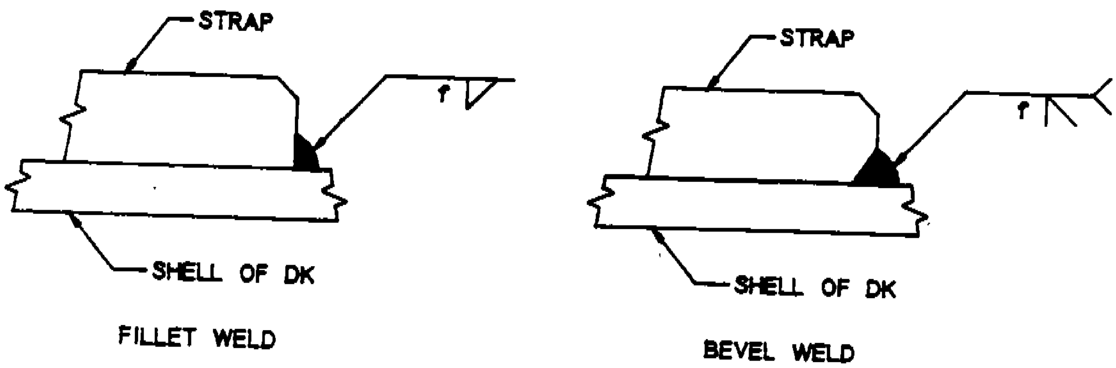
It should be noted that Ship K is a containership recently (1984) lengthened in an overseas shipyard.

The weld connections most commonly used were fillet welds, however on one ship a bevel type weld connection was used as shown in Figure 1. The size of welds ranged from 1/4" fillet for the thinnest doubler on Ship K to 3/4" on the 2.6" doubler of Ship C.

3.3.4.2 Welding at Sides and Slots

Slot welding is normally employed when the doubler plate is very wide. No written rule has been found as to what would be a maximum width for a doubler to be approved for installation without plug welding. A common "rule of thumb" cited was that for doublers wider than 24" or maximum 30", some means of ensuring a tight fitting of doubler and main hull plate should be employed.

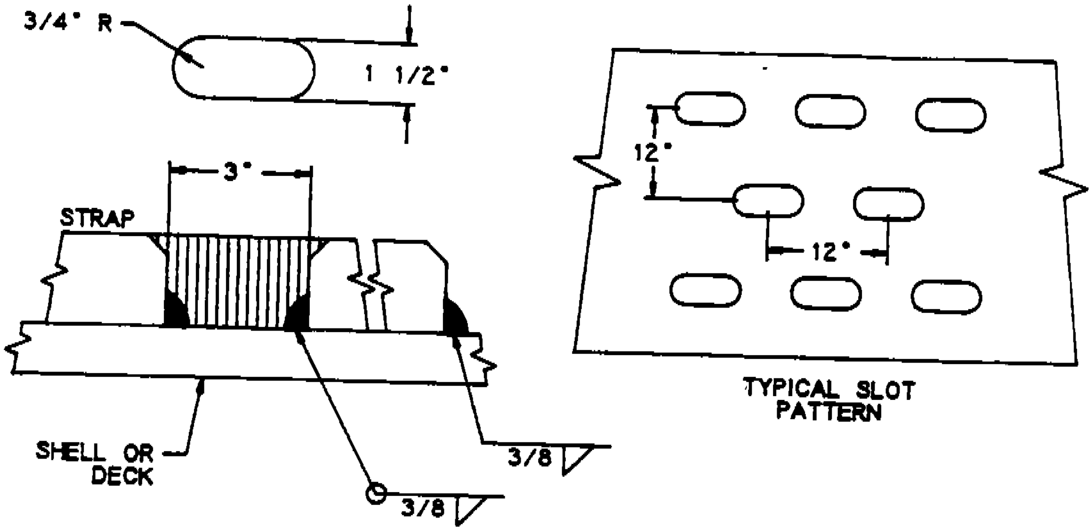
Slot welding has been used on a number of hull strappings to ensure tightness as shown in Figure 2. As many rows of slots as dictated by the width of the doubler were fitted at 12" centers with slots cut lengthwise. The elliptical inner peripheries of the slots were properly welded. The thickness of the doubler plate is governed by the ease of welding the slot; if the thickness is greater than 1-1/2" welding the inside of slots, as indicated in Figure 2, will prove to be difficult. The maximum thickness of doubler on which slot welding was employed was found to be 1-1/4" on the innerbottom strapping of ship G.



SAMPLE APPLICATIONS

SHIP	LOCATION	STRAP WIDTH	STRAP THICK	f	WELD TYPE
C	DECK	24"	2.6"	3/4"	FILLET
	BOT SHELL	18"	1.3"	7/16"	FILLET
E	BOX GIRD	14"	1.57"	1/2"	BEVEL
	BOT SHELL	21"	1.5"	1/2"	BEVEL
F	BOX GIRD	18"	2.75"	5/8"	FILLET
H	BOT SHELL	18"	1.5"	7/16"	FILLET
K	BOT SHELL	55"	0.75"	1/4"	FILLET
	COAMING	35"	1.26"	1/4"	FILLET
N	COAMING	30"	1.77"	N/A	FILLET
	DECK	30"	1.77"		FILLET
	BOT SHELL	22"	1.26"		FILLET
P	DECK	26"	1.77"	N/A	FILLET
	BOT SHELL	25"	1.0"		FILLET

FIGURE 1: STRAP WELDED AT SIDE ONLY



DETAILS

- SLOTS CUT LENGTHWISE
- STRAP EDGES 3/8" FILLET WELDED
- 3/8" FILLET WELD AROUND SLOT HOLE
- SLOT SPACING APPROX. 12 IN.

SAMPLE APPLICATIONS

SHIP	LOCATION	STRAP WIDTH	STRAP THICK	NO. SLOT ROWS
B	DECK	7'-0"	3/4"	6
		8'-7"	3/4"	8
G	INNER BOT	5'-6"	1 1/4"	4
		2'-7"	1 1/4"	2
	BOT SHELL	3'-8 1/2"	1"	3
D	BOT SHELL	7'-0"	3/4"	N/A

FIGURE 2: SLOT WELDING

Cutting and the subsequent welding of slots are labor intensive operations. Controlling the quality of production is also difficult. It is also necessary to blast and adequately coat the slots on doubler plates after welding of the inside periphery in order to prevent corrosion due to collection of water. In one case, Ship B, slot holes were filled with an epoxy compound to prevent collection of water. However, this proved to be unsuccessful; over time the epoxy pulled away from the sides of the slot allowing water to seep in and corrosion to start. The epoxy filling had to be finally removed and slot holes blasted and recoated.

3.3.4.3 Welding Adjacent Strips of Doublers

On two ships, two or more strips of narrow doublers were installed side by side on the deck or bottom and/or on the sheer strake; the strips were joined together by full depth groove welding and the sides fillet welded to the hull plating as shown in Figure 3.

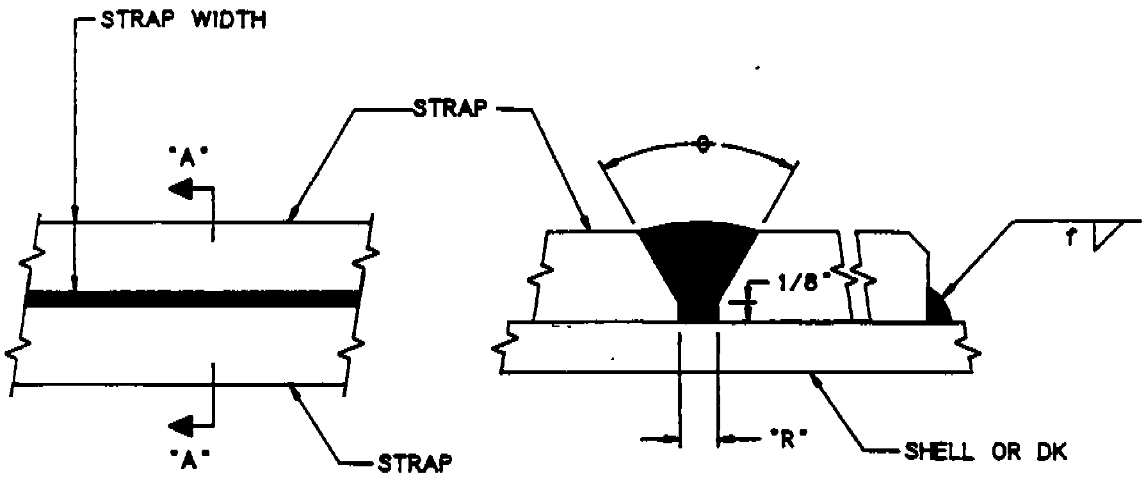
The use of multiple strips of doublers rather than a single wide doubler, obviously, will eliminate the need for slot welding. In Ships J and L, Figure 3, the strips were only 15" and 9" wide and they were welded to each other by a groove welding of depth equal to the doubler's thickness.

With the full depth groove welding, the complete total area of the doubler strips including the width of the welded groove counts as effective contributors to the new hull section modules.

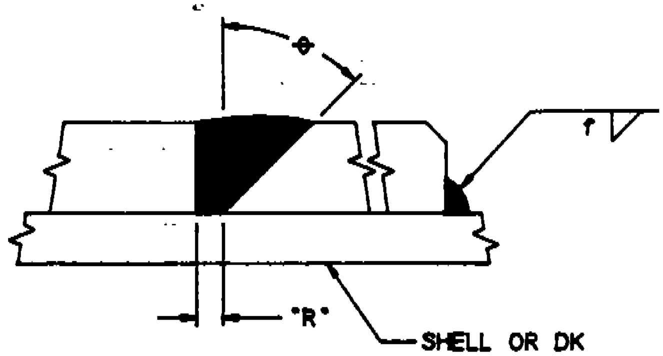
However, in the case of the full depth groove welding, built-in stresses will be created and these must be taken into consideration in specifying weld details for varying thicknesses of doubler strips. This means that the doubler thickness with which full depth groove welding can be employed is limited.

On three other ship classes, the individual strips were wider, approximately 24", and they were joined together by a partially welded groove type connection as seen in Figure 4. With the partial groove welding, there is no limitation to the thickness of doubler plates.

The grooves on the doubler strips installed on decks, whether full depth or partial have been welded using submerged arc welding techniques.



SECTION "A-A"
SHIP J

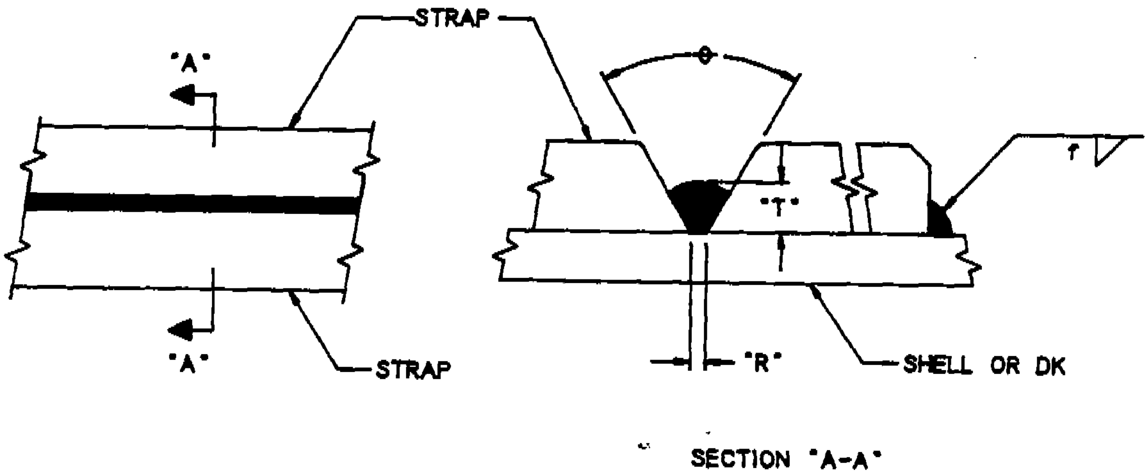


SECTION "A-A"
SHIP L

SAMPLE APPLICATIONS

SHIP	LOCATION	STRAP WIDTH	STRAP THICK	θ	R	f
J	DECK	15"	1.38"	30°	3/8"	7/8"
	SHEER STRAKE	15"	1.0"	30°	3/8"	5/8"
L	SHEER STRAKE	9"	3/4"	45°	1/4"	5/8"
	BOT SHELL	9"	3/4"	45°	1/4"	5/8"

FIGURE 3: JOINING STRIPS OF DOUBLERS WITH FULL DEPTH GROOVE WELDING



SAMPLE APPLICATIONS

SHIP	STRAP WIDTH	STRAP THICK	θ	R	T	f
A	23.5"	2"	25°	1/2"	1/2"	1/2"
H	25"	1 3/4"	25°	1/2"	1/2"	1/2"
M	24"	1"	30°	3/8"	1/2"	7/16"

(NOTE: ALL STRAPS WERE LOCATED ON DECK)

FIGURE 4: STRIPS OF DOUBLERS WITH PARTIAL GROOVE WELDING

3.3.4.4 Reinforcing of End Welds

On a number of ship classes, the size of fillet welds on the fore and aft ends of long doubler plates were increased to provide reinforcement. Figure 5 shows a typical welding reinforcement and the weld sizes at the ends and the middle. The lengths at ends where welding was reinforced are also provided in the tabulation for these applications.

3.3.5 Butt Welding of Strap Plates

Figures 6, 7, and 8 show the strap plate butt welding details found on most ships for various applications. The most typical butt joint detail for application with uniform hull plating thicknesses is the one given in Figure 6. As can be seen from the tabulation, on some of the ships a steel backing bar was fitted between the hull plating and the strap plate. In all cases, the existing hull plating butt welds were ground flush in way of the strap installation. The butt joint shape is a vee with varying root openings and bevel angles. Strap plate butts were arranged so that they are away from the hull erection butts. The distance between existing hull butts and strap plate butts varied between a minimum of 6" on Ship L to about 18" on Ship B.

On two of the ships, the hull plating thickness in way of the doubler straps was tapered and a special butt joint detail, shown in Figure 7, was used in this case. The end of the doubler plate to be butted to the other was ground to match the taper of the thicker hull plating, and a slanted vee-weld was applied at the butt. The existing hull butt weld in way of the doubler plate was ground smooth prior to installation of the strapping plates.

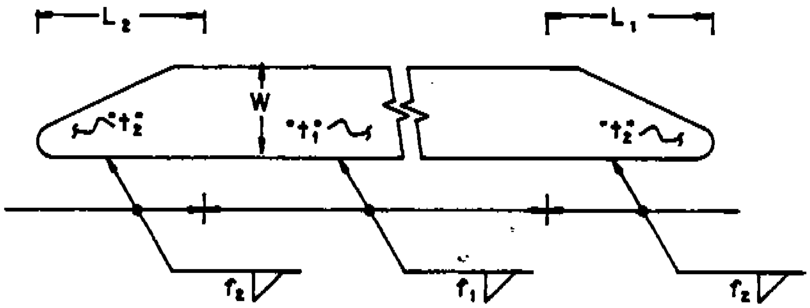
Instances of a plate doubler butt welded to a heavy insert plate, either on a new midbody or in way of specific structure such as a door, have been found on Ships D and J. On Ship D, 3/4" thick doubler plates were installed on the forward and after ends of the existing ship's 5/8" thick bottom shell plating and were butt welded to the 1-3/8" thick insert plate on the new midbody as shown in Figure 8.

In the actual installation, the bottom shell plating was first butt welded to the insert plate and then back gouged and chipped to sound metal prior to butt welding the strap to the insert plate.

On Ship D, the insert plate on the midbody was installed in lieu of strapping because of the savings it provided in drydocking time as well as in the bottom strapping cost.

Additionally, as seen in the sketch at the top of Figure 8, the existing hull erection butt would have been covered up by the doubler if strapping were used instead of an insert.

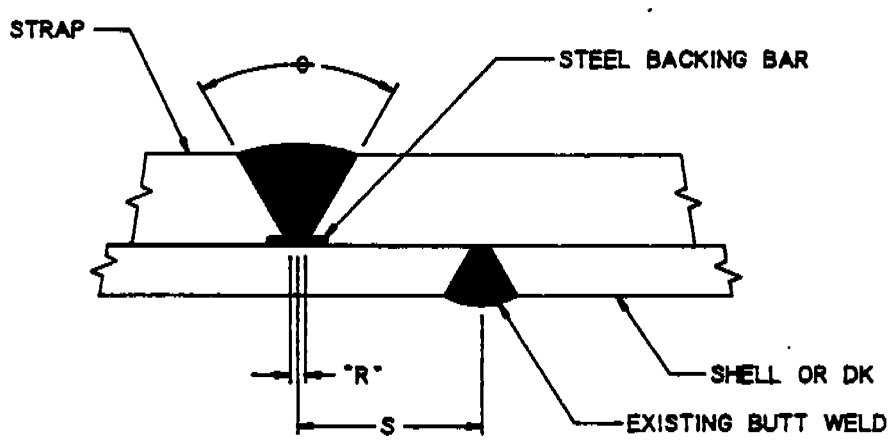
A different type of strap butt welding was found on Ship J. The doubler plate had to pass through a heavy insert plate in way



SAMPLE APPLICATIONS

SHIP	LOCATION	f_1	f_2	W	t_1	t_2	L_1	L_2
C	DECK	3/4"	1"	24"	2.60"	1.50"	9.8'	9.8'
	BOT. SHELL	7/16"	5/8"	18"	1.30"	.79"	9.8'	9.8'
K	BOT. SHELL	1/4"	13/32"	55.1"	.79"	.79"	17.1'	17.7'

FIGURE 5: WELD REINFORCEMENT AT ENDS



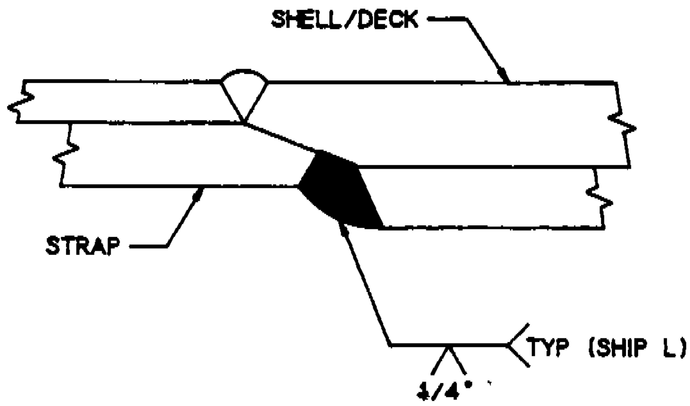
DETAILS

- EXISTING HULL PLATING BUTT WELD GROUND FLUSH IN WAY OF STRAP
- IN SOME CASES A STEEL BACKING BAR WAS INSTALLED BETWEEN STRAP AND DECK

SAMPLE APPLICATIONS

SHIP	LOCATION	STRAP THICK	θ	R	S(MIN)	BACKING BAR
A	DECK	2"	25°	3/8"	—	YES
B	DECK	3/4"	25°	0"	18"	NO
C	DECK	2.6"	40°	1/4"	12"	NO
	BOT SHELL	1.3"	40°	1/4"	12"	NO
H	DECK	1 3/4"	25°	3/8"	—	YES
	BOT SHELL	1 1/2"	25°	3/8"		YES
J	DECK	1.38"	30°	3/8"	—	NO
	SHEER STRAKE	1.00"	30°	3/8"	—	NO
L	SHEER STRAKE	3/4"	45°	1/4"	6"	NO
	BOT SHELL	3/4"	45°	1/4"	6"	NO
M	DECK	1"	30°	3/8"	12"	NO

FIGURE 6: TYPICAL BUTT JOINT FOR STRAPS



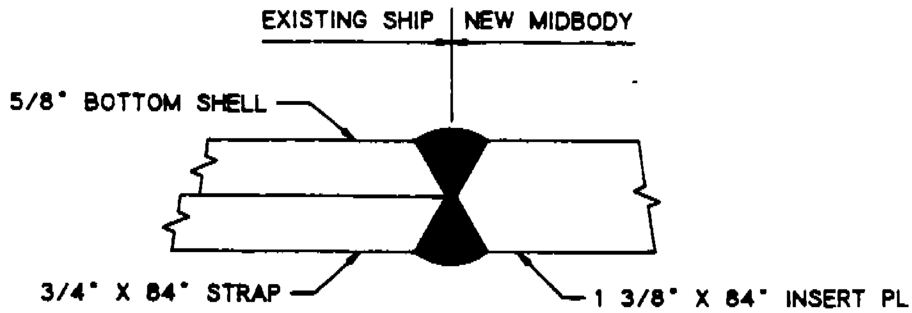
DETAILS

- GRIND STRAP TO SUIT THE CONTOUR OF EXISTING SHELL PLATE TAPER
- GRIND EXISTING BUTT WELD SMOOTH IN WAY OF STRAP

APPLICATION

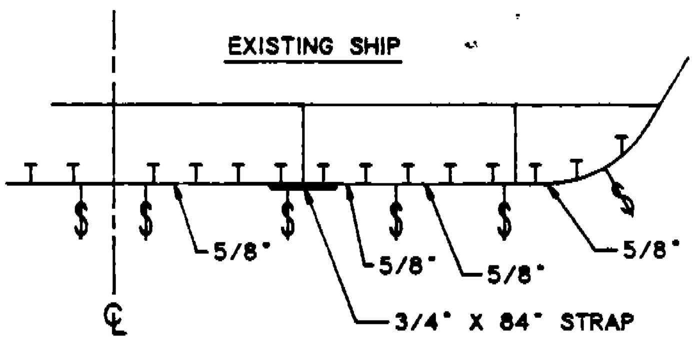
SHIP	LOCATION
C	DECK
L	SIDE SHELL

FIGURE 7: STRAP BUTT JOINT IN WAY OF VARYING HULL PLATING THICKNESS



SAMPLE APPLICATION: SHIP D

- STRAP WIDTH MATCHES THE WIDTH OF HEAVY INSERT PLATE
- SHELL - INSERT BUTT JOINT WELDED FIRST
- SHELL BUTT WELD BACK GOUGED AND CHIPPED TO SOUND METAL



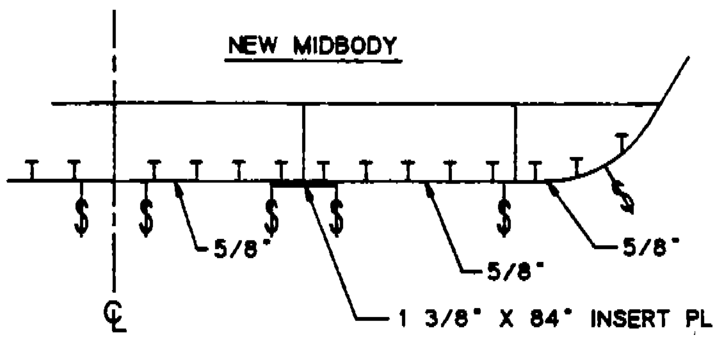


FIGURE 8: BUTT WELDING OF STRAP TO HEAVY INSERT PLATE ON NEW MIDBODY

of a side door as shown in Figure 9. In this case, the thickness of the insert plate on the reinforced side door was greater than the combined thickness of the shell plate and doubler plate. Furthermore, the insert plate was wider than the doubler plate. Consequently, the butt joint detail shown in Figure 9 was employed and the width of strap on the transition doubler plate was increased gradually to match the width of the insert plate. To ensure tightness, slot holes were cut on the tapered transition doubler which was then plug welded to the shell plating.

Again, the shell to insert butt was welded first and then back - gouged and chipped to sound metal prior to butt welding the doubler to the insert plate.

3.3.6 Tapering of Strap Scantlings

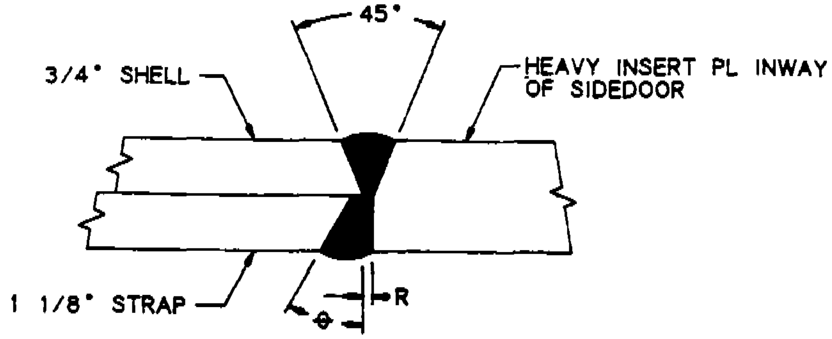
The scantlings of the plate strappings, i.e. their widths and thicknesses, were unchanged on all ships throughout a certain percentage of the midship length. This range varied between 4/10 of the ship's length to about 2/3 as dictated by and determined in accordance with the rules for hull girder strength of the classification society under whose approval and inspection the lengthening (or jumboizing) was accomplished.

On most of the ships for which detailed strapping data were obtained, both width and thickness tapering as well as chamfering of the edges and ends of plate strappings beyond the specified midship length were found to have been employed.

3.3.6.1 Thickness Tapering

In cases where the extent of strapping continues, by necessity such as with deck strappings or hatchside strappings on containerships, beyond the minimum required midship length of 4/10L, 2/3L etc., the thickness of the doubler plate can be, and has been, tapered at the ends.

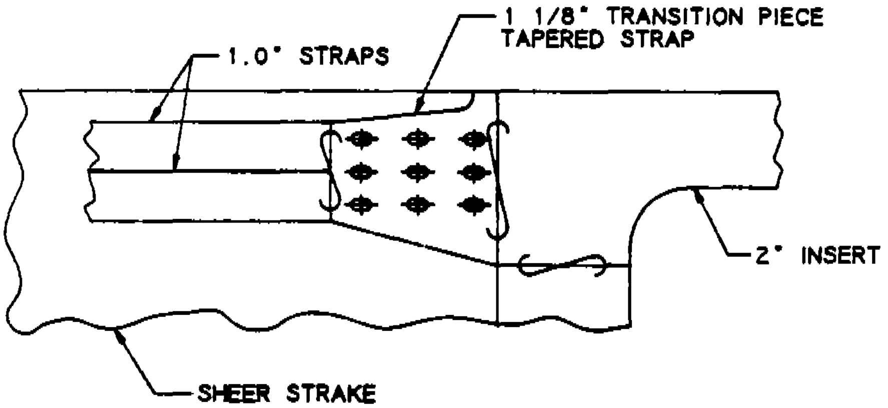
The thickness tapering details used on some of the ships are shown in Figure 10. As seen, the tapering has been accomplished either in two steps as in Figure 10.A, or in one step as in Figure 10.B. The latter figure shows a minor tapering where the difference between the two thicknesses is 1/8" or less. In this case, the thinner plate is joined with the thicker plate simply by butt welding. If the thickness difference is large, the end of the thicker plate is ground in a smooth slope down to the thickness of the thinner plate and then welded on to it.



NOTE: EXISTING SHELL-INSERT WELD BACK-GOUGED AND CHIPPED TO SOUND METAL PRIOR TO WELDING DOUBLER

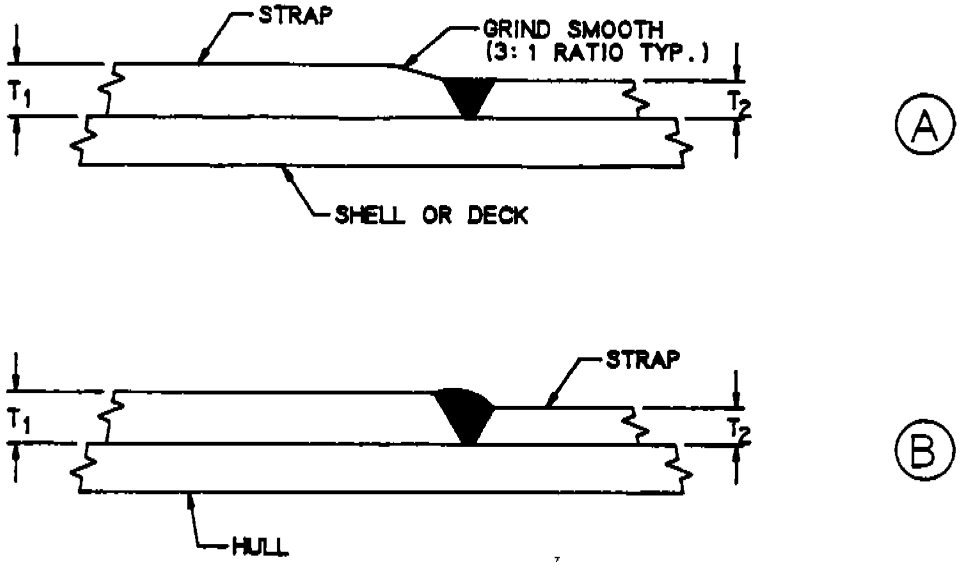
SAMPLE APPLICATIONS

SHIP	LOCATION	θ	R	STRAP THICK	INSERT PL THICK
J	SHEER STRAKE	30°	3/8"	3/4"	2"



NOTE: THE WIDTH OF STRAPS WERE INCREASED GRADUALLY TO SUIT THE WIDTH OF THE INSERT PLATE AND SLOT WELDING WAS USED

FIGURE 9: BUTT WELDING OF STRAP TO HEAVY INSERT PLATE ON EXISTING STRUCTURE



$T_1 - T_2 \leq 1/8"$

SAMPLE APPLICATIONS

SHIP	LOCATION	T_1	T_2	EXTENT
A	DECK	2"	1 1/2"/1 1/8"*	FWD OF 2/3 L
C	DECK	2.6"	2"	BOTH ENDS BEYOND 0.4L
H	DECK	1 3/4"	1 3/8"/1"*	BOTH ENDS BEYOND 2/3L
	BOT SHELL	1 1/2"	1 1/8"	BOTH ENDS BEYOND 2/3L

* THICKNESS TAPERING ACCOMPLISHED IN 2 STEPS

FIGURE 10: THICKNESS TAPERING

3.3.6.2 Width Tapering

To provide for longitudinal continuity as well as for streamlining the ends of strapping, the width is usually tapered beyond the required midship length even without any thickness tapering. As indicated in Figure 11, width tapering may be applied on only one side of the doubler plate or on both sides. In either case, the corner(s) of the plate where the tapering begins are ground smooth. The extreme end of the plate strap may be left as a square nose with rounded corners or as a round nose with a full radius. As listed under "Sample Applications" in Figure 11, both terminations have been used on many ships with one-sided as well as two-sided tapers. No rules were found which govern the taper angle, end width, or the nose radii of such tapered ends.

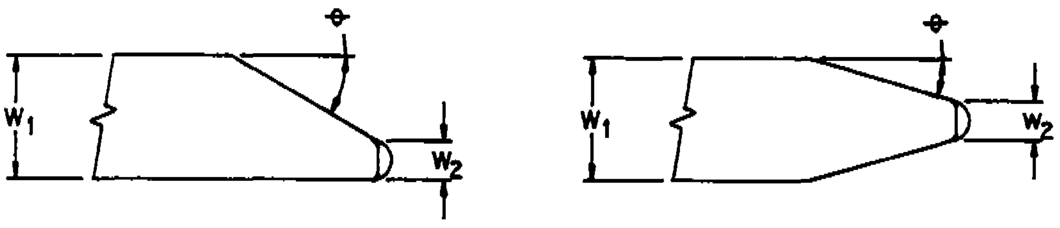
3.3.6.3 Chamfering

Both the ends and the edges of the plate straps may be chamfered to improve continuity at the termination and to reduce the risk of tripping by personnel. Figures 12 and 13 give the details of "end" and "edge" chamfering applications, respectively, for the ship classes studied in this investigation.

3.3.7 Edge Preparation

In the general notes of the detailed strapping drawings for most ships, instructions consisting of one or more of the following were found:

- o Any rough cutting or minor notches on the plating to be ground smooth and plating to be faired prior to installation.
- o Deeper notches to be veed-out, welded, and ground smooth.
- o Edges of plating to be kept clean, free from moisture/grease/loose mill scale/excessive rust or paint in order to obtain sound welding.
- o Corners of all free edges to be dressed smooth and chamfered from about 1/16" X 1/16" to about 1/8" X 1/8" by grinding in order to minimize notch effects.
- o Larger chamfers to be provided on deck strappings for stress streamlining and to reduce traffic/tripping hazards, and on bottom strappings to reduce resistance to flow.



SINGLE SIDED TAPER TWO SIDED TAPER

DETAILS

- CORNERS TO BE GROUND OFF AT BEGINNING OF TAPER
- ENDS MAY BE TERMINATED WITH A FULL RADIUS TIP OR SQUARE CUT WITH RADIUS CORNERS

SAMPLE APPLICATIONS

SHIP	LOCATION	θ	W_1	W_2	W_2/W_1	TIP FINISH	TYPE
A	DECK	21°	23.5"	6"	0.26	FULL RADIUS	1-SIDE
B	DECK	15°	84"	24"	0.28	RAD CORNERS	1-SIDE
C	DECK	10°	24"	12"	0.50	RAD CORNERS	1-SIDE
	BOT SHELL	10°	18"	8"	0.44	RAD CORNERS	1-SIDE
F	BOX GIRDER	15°	17.7"	2"	0.11	FULL RADIUS	2-SIDE
H	DECK	27°	25"	6"	0.24	FULL RADIUS	1-SIDE
	BOT SHELL	18°	18"	4 1/2"	0.25	FULL RADIUS	1-SIDE
J	SHEER STRAKE	6°	30"	9"	0.30	RAD CORNERS	1-SIDE
K	BOT SHELL	12°	55"	24"	0.43	RAD CORNERS	2-SIDE
L	SHEER STRAKE	14°	18"	6"	0.33	RAD CORNERS	2-SIDE
	BOT STRAP	14°	18"	6"	0.33	RAD CORNERS	2-SIDE

FIGURE 11: WIDTH TAPERING

APPENDIX A

AMERICAN BUREAU OF SHIPPING

NOTES ON VESSEL LENGTHENING

AND STRAPPING

FAX NOS.:
201-368-0255
201-368-1986

ABS GROUP
45 EISENHOWER DRIVE
PARAMUS, NEW JERSEY
PHONE: 201-368-9100

DATE: 12 MAR 90

BRANCH CODE: 452

COPIES TO:
M. ROSENBLATT & SON, INC.
350 BROADWAY
NEW YORK, NEW YORK
ATTN: MR. N. BASAR
FAX NO.: (212) 334-0837

TO: U.S. COAST GUARD
GROTON, CT

ATTN: DR. STEVE ALLEN

FAX NO.: (203) 441-2792

FROM: ABS WHQ - SHIP STRUCTURES/STATUTES DEPT.

REF. NO. RD-3/PGR/jw

SUBJECT: SR-1327 HULL STRAPPING OF SHIPS

ENCLOSED IS A COPY OF ABS NOTES ON VESSEL LENGTHENING AND STRAPPING TO REINFORCE THE HULL GIRDER.

COPIES WILL ALSO BE SENT BY MAIL.

REGARDS

P. G. RYNN
CHIEF ENGINEER

The following is a general procedure to be followed as a guide for proposed lengthening of existing vessels.

The new section is generally added within the midship 0.4L of the existing vessel. The local scantlings of the new section need not be based on the new length and may be the same as those of the adjacent existing structure. Care should be exercised to repeat the existing structural pattern and to effect good continuity of structure throughout.

Any resulting deficiency in the longitudinal hull girder strength should be compensated with the addition of straps extending for 0.4L and tapered gradually beyond as required by 6.5.2 of the Rules.

If the vessel's longitudinal strength is based on the still water bending moment envelope curve the straps should be developed and extended as required by this curve.

The new materials should meet the latest Rule requirements.

The thickness of the strap should not exceed 1.5 t where t is the thickness of the underlying plate. Straps whose width exceeds 30" (750mm) or 30 times their thickness, whichever is less, should be plug welded to the underlying plate under 30.9.6 of the Rules. Straps should be continuously fillet welded with a throat thickness 0.3 times the strap thickness, increasing to 0.5 times the strap thickness at the ends for a length about 2 times the width of the strap. The gap between straps should be such to allow adequate access for welding the edge fillets, and in general, should not be less than the strap thickness. The strap is to be attached to existing structure only if it is found satisfactory to the attending Surveyor. The structure must be properly prepared and free of distortions to permit proper attachment of the strap.

The lengthening of a vessel is approved subject to the attending Surveyor's verification that the existing structure is found or placed in satisfactory condition and that it has not wasted below the limits permitted for the scantlings required for the new length.

APPENDIX B

BUREAU VERITAS RECOMMENDATIONS

FOR HULL STRAPPING

APPENDIX B-1: EXCERPT FROM BUREAU VERITAS TECHNICAL PAPER 85/10 "CONVERSION OF CARGO SHIPS"

APPENDIX B-2: ANNEX 2 OF BV PAPER 85/10 "RECOMMENDATIONS FOR THE WELDING AND INSPECTION OF DOUBLING PLATES FOR SHELL REINFORCEMENT AFTER LENGTHENING"

It can also check that certain arrangements are in compliance with specific regulations such as :

- Finnish and Swedish ICE class mark,
- application of International Conventions,
- application of the MARPOL Convention,
- arrangements for cattle carriers (according to regulations enacted by the British, Australian or Saudi Arabian Governemnts).

The following describes the various stages of the studies made on the main conversions.

1 - LENGTHENING

1.1 First of all, decide on the new length taking into account the maximum permissible L/C ratio based on the navigation notation :

16.5 for DEEP SEA
18 for COASTAL WATERS
22 for SHELTERED WATERS.

1.2 After that, the new geometrical freeboard will have to be defined.

Note, generally, that the freeboard increases and considering that the draft decreases, it is consequently not necessary to re-examine the structure of the transverse members.

In some cases, if the forecastle length is just 7% of the ship's length, the freeboard can be considerably increased if the forecastle itself is not lengthened. In that case, a correction is to be applied to the basic freeboard compared to height of stem if the conventional forecastle length is insufficient.

The remainder of the verifications consists in :

1.3 Determining the new scantling length.

1.4 Checking location of collision bulkhead.

1.5 Checking shell plating :

- calculate thickness for the new section,
- check thickness of existing plates and determine, if necessary, acceptable reductions for wear limits. Replacement plates must be of the same thickness as that required for the new section.
- define new forward extension of flat bottoms(taking into account, if required, new loading cases),
- analyze the possibilities of maintaining or changing the ICE mark.

1.6 Verification of the overall strength

61. For ships less than 65 m in length after lengthening, the deck sectional area is calculated according to rule formulas.

62. For ships more or equal to 65 m in length after lengthening, the midship section modulus has to be calculated.

This modulus has to be at least equal to the minimum required modulus which can mean limiting the loading cases considered, or be defined according to the loading cases.

In either case, the maximum value of the still water bending moment is determined on the basis of the actual modulus.

63. If the deck sectional area or the modulus is insufficient, the structure is generally strengthened by means of doublers fitted on deck and/or sheerstrake on either side of the ship.

These doublers must cover at least the ship's midship length

Bureau Veritas

and extend beyond the corners of hatches. They are to be welded to structure platings by means of continuous fillet welds.

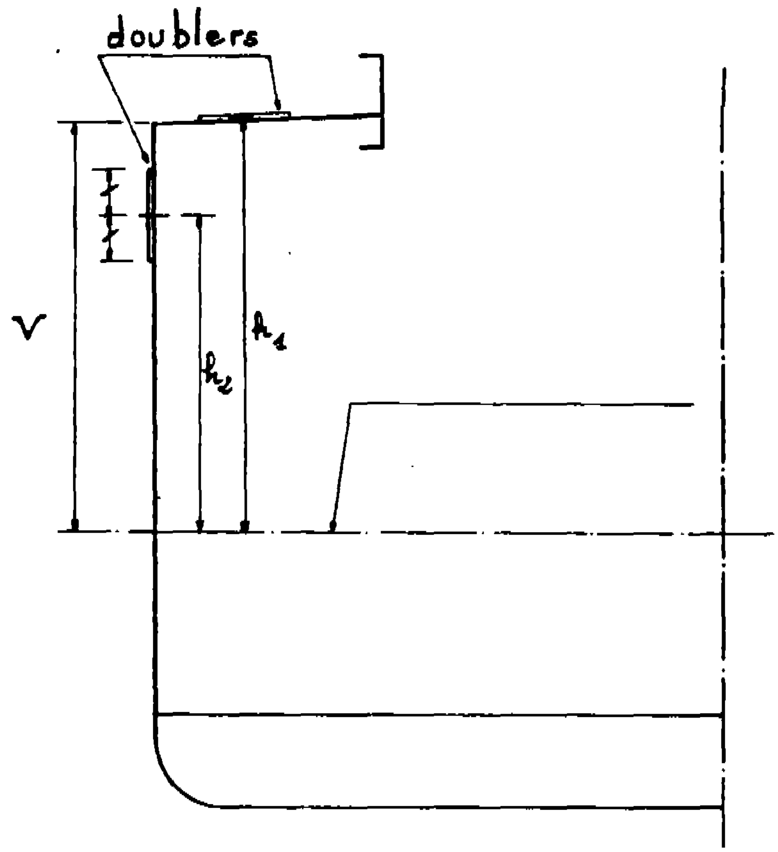
If the modulus has to be calculated to determine doublers, the sectional area is evaluated as follows :

where Wp = minimum deck section modulus

dsp = sectional area required for doublers on either side of ship

difference of Wp = expected Wp - existing W = dWp

$$dWp = 2 \times dsp \times \frac{h}{V}\left(h + \frac{\text{existing W}}{\text{total existing S}}\right)$$



The width of doublers can be reduced at each end. In the midship area, the chosen width must be such that the thickness is compatible with the thickness of the existing plates and avoid using plug weldings in addition to fillet welds to secure doublers to the existing structure.

Generally speaking, the width of a doubling plate will not exceed 0.6 m for an average size ship.

Annex 2 develops the recommendations on welding and the inspection of these doublers.

The longitudinal stiffeners of the new and existing parts are to be checked taking into account the new section modulus.

1.7 Sectional area of discharge ports will have to be increased to take into account the new length of the well.

1.8 Equipment will have to be modified to take into consideration ship's new characteristics.

In some cases, a modification of the anchors and chains leads to very extensive changes on the ship : hawse pipe, windlass or even be impossible when the chain locker is too small.

If the problem can, in certain cases, be solved for chains by providing steel chains of higher strength, the same solution cannot be applied for anchors.

Indeed, the addition of welded flat bars on the anchor shank is not recommended both for metallurgical reasons (welding on moulded steel) and for the use of the anchor which requires that certain proportions between the total weight and weight of anchor head be complied with.

For these particular cases, an allowance can be made depending on the equipment number (NA2) after conversion compared to the value prior to conversion (NA1) :

ANNEX 2

RECOMMENDATIONS
FOR THE WELDING AND INSPECTION OF DOUBLING PLATES
FOR SHELL REINFORCEMENT AFTER LENGTHENING

GENERAL PURPOSE TECHNICAL NOTE ON "METALS - WELDS"

INTRODUCTION

The aim of this technical note is to provide general information on the subject in the form of technical data or recommendations.

We feel that this information can be useful both to our Surveyors and shipyards.

The contents of this technical note must not be considered as rule requirements. Application of such a technical note does not exempt yard or builder from following the normal procedure to obtain prior agreement relative to choice of the quality of the material used, or building methods, or inspection procedures applied by Surveyor in charge of supervising the building.

1) LOCATION

To lengthen a ship, three types of doublers are used to strengthen the hull :

- deck doublers
- sheerstrake doublers
- bottom doublers.

These doublers are interconnected by butt welds (see 4) and attached to shell by fillet welds (see 73).

2) STEEL GRADES OF DOUBLERS

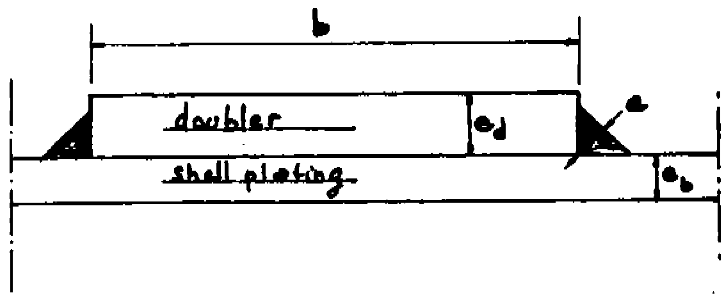
Steel grades must comply with Chapter 3 of Rules for Steel Vessels. If deck is built with high tensile steel, the doublers must be of the same steel with the same mechanical properties.

3) DIMENSIONS OF DOUBLERS

Plug welds used to strengthen connections with shell plating as in the case of very wide doublers, are not recommended (unless special agreement is obtained from Head Office Technical Departments).

To avoid plug welds, narrower and thicker doublers will have to be fitted or doublers are to be divided into 2 or 3 parallel plates, in which case, efficient protection against corrosion must be provided in the groove between doublers.

31 - Thickness of doublers



In the above diagram of a doubler, the following abbreviations are used :

e_b = shell plating thickness

e_d = doubler thickness

b = doubler width

a = fillet weld throat thickness.

It is recommended that the thickness of the doubler be equal or less than twice the thickness of the shell plating and a maximum of 40 mm :

$$e_d \leqslant 2e_b \quad \text{and} \quad e_d \leqslant 40 \text{ mm}$$

32 - Width of doublers (without plug welds)

It is recommended that the width L of the doubler be not more than 40 times its thickness or 800 mm (whichever is the widest).

NOTA : Apart from the dimensions recommended in this technical note, doubling plates of different dimensions can be fitted subject to the approval of the Society's Technical Departments.

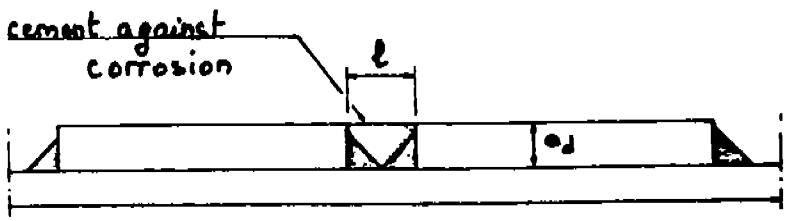
33 - Throat thickness of fillet weld

$$a = 0.5\ e_d \quad \text{(without exceeding } 0.6\ e_b\text{)}$$

The lines of welding will be strengthened up to 0.7 e_d at ends of doublers for a length **l** equal to three times the width of the doubler. The width of doublers is gradually reduced in these areas (see 6 below).

34 - Case of several parallel doublers

To avoid plug welds, it is advisable to reduce the width of the doubler and fit several doubling plates in parallel (see preceding paragraph)



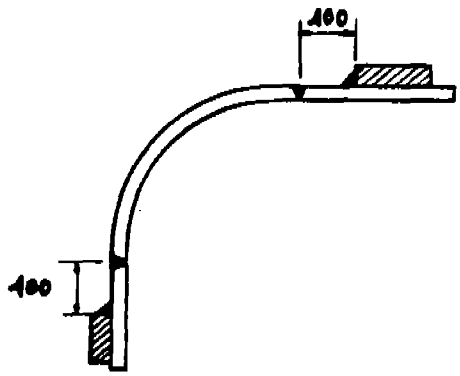
Gap L between doublers must, without being too excessive, be adequate to allow for two filled welds

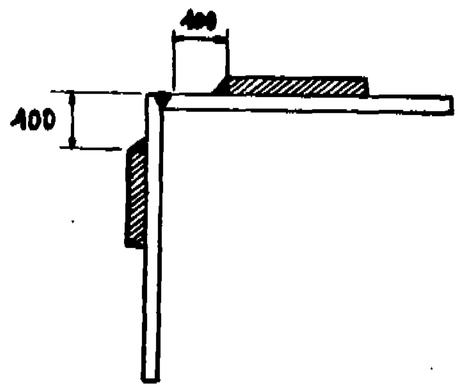
We could recommend $2 e_d \leqslant l \leqslant 3 e_d$

depending on the size of the line of fillet weld and whether it is needed to fill in the gap between the two doublers with a filler (case of deck doublers).

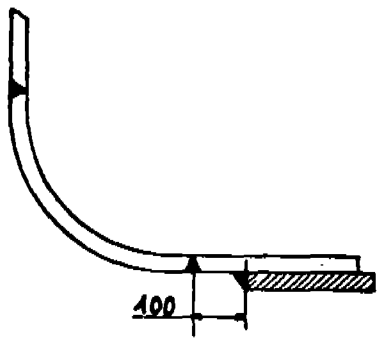
4) LOCATION OF HULL DOUBLERS

41 - Deck and sheerstrake doublers





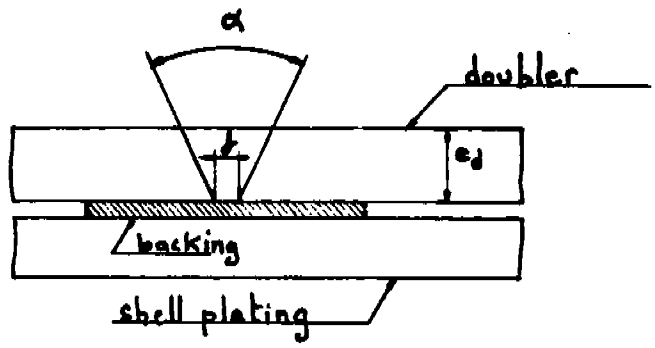
42 - Bottom doublers



No structural members are to be welded to doublers. No openings are to be cut in doublers.

5) BUTT WELDS ON DOUBLERS

These are the most important and most difficult welds to make. They must be made on a backing so as not to be connected to shell and the weld must be a completely continuous penetrating weld.



51 - Welding on backing

- either on temporary backing :
  - copper slat
  - fire-proof ceramic backing
  - glass wool/asbestos ... backing.

- or permanent backing :
  - sheet of 2 mm thick steel.

52 - Preparations prior to butt welding

$e_d \leq$ 25 mm	α = 50°	j = 4 to 6 mm
$e_d >$ 25 mm	α = 45° to 50°	j = 6 to 8 mm

53 - Welding sequence

- runs at root of weld penetration (Ø 3.2 mm electrodes) to obtain a 5 to 6 mm thick deposit,
- grinding of line of welding at the root,
- dye-penetrant test,
- brushing,
- fill in butt welds with Ø 4 or 5 mm electrodes.

54 - Welding precautions

Welding to be made with preheating in the case of high tensile steel (preheating at 80° - 120° C).

Use of well dried low hydrogen content basic electrodes.

Under poor weather conditions (cold, rain, wind) welding is to be done under the local protection of a shelter.

55 - Welding specification - Approval of welding procedures

For all welding operations, the welding procedure is to be approved after tests made according to 3-3 of the Rules for Steel Vessels in agreement with the Surveyor.

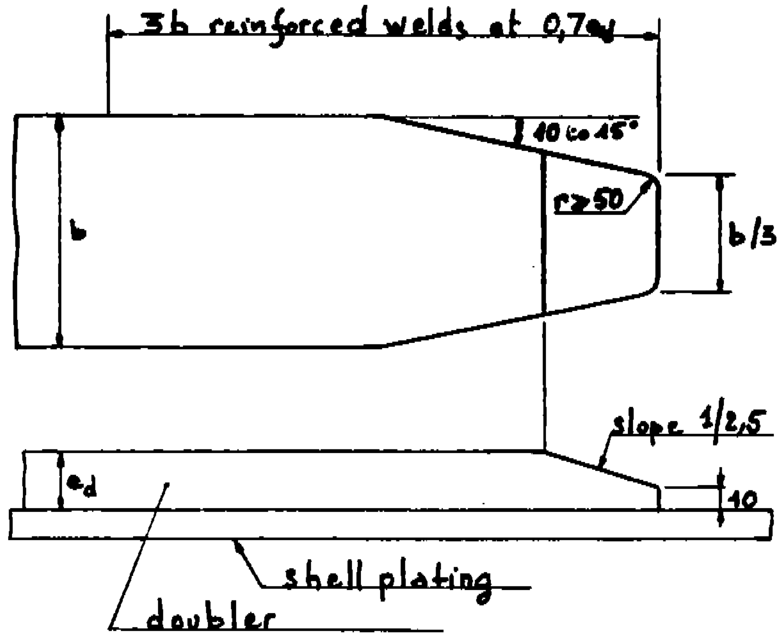
All of the yard's welding procedures relative to doublers are to be indicated in a welding specification approved by the Surveyor.

56 - Inspection of butt welds

. visual inspection at 100%,
. ultra-sonics at 100%,
. dye-penetrant test or magnaflux test at 100%,
. 1 film of X-rays of 10 butt welds at random.

6) ENDS OF DOUBLERS

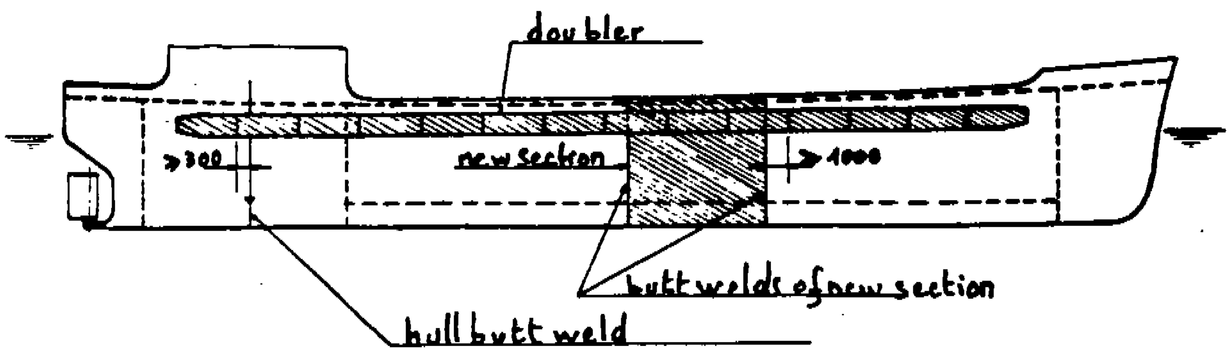
3 line of welding reinforced at 0.7 e_d



7) WELDING SEQUENCE OF DOUBLERS ON SHELL

- butt welds of doublers must be made with a minimum of clamping,
- butt welds of parallel doublers are to be offset as much as possible,
- doubler butt welds must be sufficiently offset compared to butt welds on shell plating and especially the two butt welds connecting the new hull section.

71 - Offsetting doubler butt welds compared to shell butt welds



Distance between doubler butt welds and :

- shell butt welds ≥ 300 mm
- butt welds of new hull section ≥ 1000 mm.

72 - Welding sequence of doublers

1) The normal procedure is :

a) only forward edges are to be welded up to 1 m from butt,

b) butt to be welded,

c) weld edges up to 1 m from the following butt and so on starting from the middle of the ship up to the last doubler butt.

This procedure assumes that the 3 sections of the ship are fitted before positioning of doublers.

2) However, if the doublers are fitted before the three sections of the ship, the procedure is :

It is recommended to gradually proceed with butt welds from one end to the other, once doublers have been positioned and tack welded on shell plating.

Longitudinal fillet welds, if done prior to butt welds,must leave an unwelded length of one metre at either end of the butt welding.

73 - Precautionary welding measures

The precautionary welding measures are as follows :

- welding with preheating for doublers fitted on high tensile steel (preheat and maintain temperature between 80° and 120° C during welding),
- use low hydrogen content basic electrodes, well dried before welding,
- under poor weather conditions (cold, rain, wind, etc...), welding must be done under cover.

8 - INSPECTION OF WELDS

Doubling plates which play an important role in hull lengthening, have to be subjected to thorough inspection, before, during and aft welding. Regarding butt welding of doublers, preparations prior to welding have to be checked (check gap g before welding to make sure of obtaining complete penetration at the root) and inspection is to be carried out after welding as indicated in 56.

A visual inspection together with inspection of throat thickness of welds is to be made for fillet welds connecting doubling plates to shell plating.

Finally, a non destructive test (dye-penetrant or magnetoscopic test) is made at random to check the quality of these fillet welds.

APPENDIX C

DET NORSKE VERITAS RECOMMENDATIONS

FOR HULL DOUBLERS

DET NORSKE VERITAS

Det norske Veritas Classification A/S
Division Ship and Offshore
ADDRESS: Veritasveien 1, Høvik, Oslo
POSTAL ADDRESS: P.O.Box 300, N-1322 Høvik, Norway
TELEPHONE: +47 2 47 99 00
TELEX: 76 192 verit n
FACSIMILE: +47 2 47 99 11

Det norske Veritas Classification A/S

NEW JERSEY

YOUR REF

OUR REF DSO-233-LLAR/BB

DATE 6th September, 1989

RE: SHIP STRUCTURE COMMITTEE PROJECT SR-1327
"HULL STRAPPING OF SHIPS"

Reference is made to letter dated 18.08.89 from M. Rosenblatt & Son. Inc., a copy of which was received with your fax dated 21.08.89.

Regarding hull strapping in general, we may refer to our approval instructions, a relevant extract of which is enclosed.

In addition to what is stated in the instructions we may add that the workmanship for this type of reinforcements is assumed carried out as for other highly loaded longitudinal material, i.e. any burnercuts etc. and chafing to be dealt with to the attending surveyor's satisfaction, considering the fact that the straps usually are cut from plate material.

Another aspect of reinforcement with straps to be mentioned is the necessary longitudinal extent. When inserting new mid-bodies it is normal practice to increase scantlings in the new parts to comply with requirements to the lengthened ship.

Regardless of this, it is normal practice to keep the straps continuous also in this area. Needless to say, as the length of the new mid-body increases, the question is raised whether to fit strapping in transition areas only, omitting the new mid-body which by theory should be strong enough, disregarding the problems termination of straps within highly loaded midshipareas may cause. Our policy so far has been to require the straps continuous all over, disregarding the "sufficient" strength already present in the new part.

5.4 Welding of Doublers for Longitudinal strength

Doublers are to be welded to the strengthened parts with continuous welding along the edges. For doubler plates with breadths exceeding

$$b = 100 + 30.t \text{ mm, maximum } 850 \text{ mm}$$

where

t = thichkness of doubler,

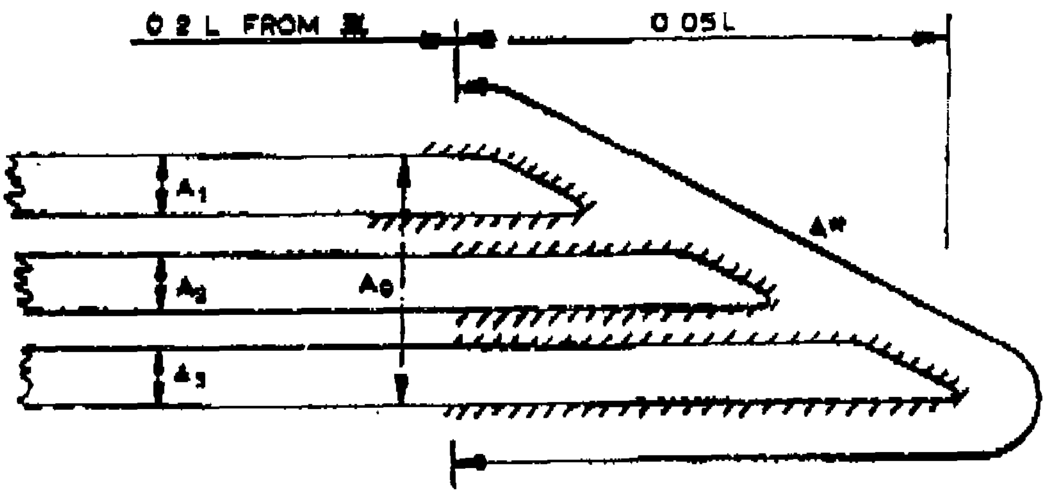
welding through evenly distributed slots will be required. Slots should be oval, measuring from 50 x 15 mm to 75 x 25 mm, and are to be supplied with continuous fillet welds. The slots are to be filled with a bitumastic compound.

The throat thickness of fillet welds should in general be similar to that required for a fillet weld for a longitudinal strength member.

Where double plates are tapered within 0.2 L and 0.25 L, fore and aft of amidships, the weld area surrounding the taper of each doubler should not be less than 1.75 x the doubler area. Where several doublers are terminated in the same region, the sectional area A* of the strengthened part should not be less than

$$A^* > 1.75 \left(\sum_{i=1}^{n} Ai + Ao \right)$$

where A_0 is original shell plate area i.w.o. doublers.



APPENDIX D

CLASSIFICATION SOCIETY TABLES

FOR HULL STEEL GRADES

D-1: Lloyd's Register of Shipping

D-2: Bureau Veritas

D-4: Det norske Veritas

D-5: Germanischer Lloyd

D-6: Nippon Kauiji Kyokai

Structural member	Material class		
	Within 0,4*L* amidships	Between 0,4*L* and 0,6*L* amidships	Outside 0,6*L* amidships
Where *L* > 250 m: Sheerstrake or rounded gunwale; Stringer plate at strength deck	V	III	II
Where *L* ≤ 250 m: Sheerstrake or rounded gunwale; Stringer plate at strength deck	IV	III	II
Bilge strake (*see* Note 4); Deck strake in way of longitudinal bulkhead			
Strength deck plating (*see* Note 5); Bottom plating including keel; Continuous longitudinal members above strength deck; Upper strake of longitudinal bulkhead; Upper strake of topside tank	III	I	I
Deck plating, other than above, exposed to weather; Side plating; Lower strake of longitudinal bulkhead	II	I	I
External plating of rudder horn	–	–	III
Sternframe; Internal components of rudder horn; Rudder; Shaft bracket	–	–	II

NOTES

1. For structural members not listed, class I may generally be applied.
2. Within 0,4*L* amidships, single strakes required to be of class IV, class V or of Grade E are to have breadths not less than 800 + 5*L* mm, but need not be greater than 1800 mm.
3. In ships with breadth exceeding 70 m at least 5 deck strakes including stringer plates are to be of class IV within 0,4*L* amidships.
4. Bilge strakes may be of class III within 0,4*L* amidships in ships with a double bottom over the full breadth and with length less than 150 m.
5. Plating at corners of large hatch openings will be specially considered. Class IV or V to be applied in positions where high local stresses may occur.
6. The material class used for reinforcement and the quality of material (i.e. whether mild or higher tensile steel) used for welded attachments, such as waterway bars and bilge keels, is generally to be similar to that of the hull envelope plating in way. Where attachments are made to rounded gunwale plates, special consideration will be given to the required grade of steel, taking account of the intended structural arrangements and attachment details.
7. The material class for deck plating, sheerstrake and upper strake of longitudinal bulkhead within 0,4*L* amidships is to be maintained at the poop front and at ends of the bridge where fitted.
8. For container ships, the strength deck, sheerstrake and torsion box structure material classes within 0,4*L* amidships are to be maintained in way of the cargo hold region.
9. On tankers having a poop, the quality of strength deck plating in way of the poop front is to be extended forward to cover any pump room openings.
10. Engine seat top plates outside 0,6*L* amidships of thickness greater than 40 mm, may be grade A mild steel. Steel grade requirement for top plates within 0,6*L* amidships will be specially considered.
11. Steel grade is to correspond to the as fitted thickness when this is greater than the Rule requirement.

Steel grades

Thickness, *t* in mm	Class I		Class II		Class III		Class IV		Class V	
	Mild steel	H.T. steel	Mild steel	H.T. steel	Mild steel	H.T. steel	Mild steel	H.T. steel	Mild steel	H.T. steel
$t \le 15$	A	AH	A	AH	A	AH	A	AH	D	DH
$15 < t \le 20$	A	AH	A	AH	A	AH	B	AH	E	DH
$20 < t \le 25$	A	AH	A	AH	B	AH	D	DH	E	EH
$25 < t \le 30$	A	AH	A	AH	D	DH	E	DH	E	EH
$30 < t \le 35$	A	AH	B	AH	D	DH	E	EH	E	EH
$35 < t \le 40$	A	AH	B	AH	D	DH	E	EH	E	EH
$40 < t \le 50$	B	AH	D	DH	E	EH	E	EH	E	EH
$t > 50$	B	AH	D	DH	E	EH	E	EH	E	EH

See NOTES

Midship region (0.4L) (LONGITUDINALS)		
Thickness in mm	$e \leq 30$	$e > 30$
Bottom, deck, side shell and longitudinal bulkheads longitudinals (on 0,1C)	A	B

Clear of the midship region		
Thickness in mm	$e \leq 20$	$e > 20$
Sheerstrake - Stringer plate - Deck plating in way of the superstructure ends	A	D
Plates of corner deck fitted at large hatchways..................	A	D*

* For ships with opened deck and for $e > 30$ mm: grade E.

Midship region (0.4L) (PLATES)					
Thickness in mm	$e \leq 15$	$15 < e \leq 20$	$20 < e \leq 25$	$25 < e \leq 30$	$e > 30$
Bilge - Sheerstrake - Stringer plate	A	B	D	E	E
Side shell	A	A	A	A	B
Deck - Bottom	A	A	B	D	D
Deck strakes in way of the longitudinal bulkheads	A	B	D	E	E
Lower and upper strakes of longitudinal bulkheads	A	A	B	D	D
Corners of large hatchways	A	B	D	D	E
Upper strake of the top side tank (bulk carriers)...	A	A	B	D	D

Midship region (0,4L) (PLATES)				
Thickness in mm	$e \leq 20$	$20 < e \leq 25$	$25 < e \leq 30$	$e > 30$
Bilge - Sheerstrake - Stringer plate	AH	DH	EH	EH
Side shell	AH	AH	AH	DH
Deck - Bottom	AH	AH	DH	DH
Deck strakes in way of the longitudinal bulkheads	AH	DH	EH	EH
Lower and upper strakes of longitudinal bulkheads	AH	AH	DH	DH
Plates of corner deck fitted at large hatchways	AH	DH	DH	EH
Upper strake of the top side tank (bulk carriers)	AH	AH	DH	DH

Midship region (0,4L) (LONGITUDINALS)		
Thickness in mm	$e \leq 35$	$e > 35$
Bottom, deck, side shell and longitudinal bulkheads longitudinals (on 0,1C)	AH	DH

Clear of the midship region		
Thickness in mm	$e \leq 25$	$e > 25$
Sheerstrake - Stringer plate Deck plating in way of the superstructure ends	AH	DH
Plates of corner deck fitted at large hatchways	AH	DH*

* For ships with open deck and for $e > 30$ mm : grade EH.

BUREAU VERITAS - CONT'D

Thickness in mm	Class				
	I	II	III	IV	V
t ≤ 15	A/AH	A/AH	A/AH	A/AH	D/DH
15 < t ≤ 20	A/AH	A/AH	A/AH	B/AH	E/DH
20 < t ≤ 25	A/AH	A/AH	B/AH	D/DH	E/EH
25 < t ≤ 30	A/AH	A/AH	D/DH	E/DH	E/EH
30 < t ≤ 35	A/AH	B/AH	D/DH	E/EH	E/EH
35 < t ≤ 40	A/AH	B/AH	D/DH	E/EH	E/EH
40 < t ≤ 50	B/AH	D/DH	E/EH	E/EH	E/EH

Material classes.

Structural member	Within 0,4 L amidships	Outside 0,4 L amidships
Lower strake in longitudinal bulkhead. Deck plating exposed to weather, in general. Side plating.	II	I
Bottom plating including keel plate. Strength deck plating. 1) Continuous longitudinal members above strength deck. Upper strake in longitudinal bulkhead. Upper strake in top wing tank.	III	I
Sheer strake at strength deck. 2) Stringer plate in strength deck. 2) Deck strake at longitudinal bulkhead. 3) Bilge strake. 4)	IV	III (II outside 0.6 L)

1) Plating at corners of large hatch openings to be specially considered. Class IV or V to be applied in positions where high local stresses may occur. Normally class IV will be required for ordinary dry cargo and bulk carriers, class V for open type bulk carriers and container vessels.
2) To be of class V within 0.4 L amidships in ship with length exceeding 250 m.
3) In ships with breadth exceeding 70 m, at least 3 deck strakes to be class IV.
4) May be of class III in ships with a double bottom over the full breadth and with length less than 150 m.

Application of the material classes.

Structural Member	Material Class	
	Within o,4 L amidships	Outside o,4 L amidships
lower strake of long. bulkheads weather deck plating (general) side shell plating	II	I
bottom plating incl. keel plate strength deck [1]) upper strake of long. bulkheads upper strake of upper wing tank bottoms continuous long. strength members below strength deck	III	I
sheerstrake [4]) continuous long. strength members above strength deck [4]) stringer plate of strength deck [4]) deck strake above long. bulkhead [2]) bilge strake [3])	IV	III (II outside o,6 L amidships)

[1]) Hatch corner plates of large hatchway openings will be specially considered. Class IV or V materials to be used in regions of high local stresses.
[2]) In ships with breadth exceeding 7o m, at least 3 deck strakes to be fitted of the required material class.
[3]) May be of class III material in ships with lengths less than 15o m and with a double bottom over the full breadth.
[4]) In ships exceeding 25o m in length class V materials within o,4 L amidships.

Struotural Member	Material Class
face plates and webs of girder systems	II [1])
rudder body [1]), sole piece, stern frame, propeller brackets	II
top plates of machinery foundations if welded into the inner bottom	II

[1]) Class I material sufficient, where rolled sections are used or the parts are machine cut from normalized plates.

Class \ Thickness t [mm][1])	≤ 15	> 15 ≤ 2o	> 2o ≤ 25	> 25 ≤ 3o	> 3o ≤ 35	> 35 ≤ 4o	> 4o ≤ 5o
I	A/AH	A/AH	A/AH	A/AH	A/AH	A/AH	B/AH
II	A/AH	A/AH	A/AH	A/AH	B/AH	B/AH	D/DH
III	A/AH	A/AH	B/AH	D/DH	D/DH	D/DH	E/EH
IV	A/AH[2])	B/AH[2])	D/DH	E/DH	E/EH	E/EH	E/EH
V	D/DH	E/DH	E/EH	E/EH	E/EH	E/EH	E/EH

[1]) actual thickness of the structural member
[2]) for continuous longitudinal strength members above strength deck within o,4 L amidships: D/DH

Application of Mild Steels for Various Structural Members (to be continued)

Structural member	Application		Thickness of plate: t(mm) $t\leq15$	$15<t\leq20$	$20<t\leq25$	$25<t\leq30$	$30<t\leq40$	$40<t\leq50$
Sheer strake at strength deck	within 0.4L amidship	$L_1\leq250$	*A*	*B*	*D*	*E*		
		$L_1>250$	*D*	*E*				
	within 0.6L amidship excluding the above		*A*		*B*	*D*		*E*
	other than those mentioned above		*A*				*B*	*D*
Side plating within 0.4L amidship	within 0.1D downward from the lower surface of strength deck		*A*		*B*	*D*		*E*
	other than those mentioned above		*A*				*B*	*D*
Bilge strake	within 0.4L amidship	ships of $L_1>150$, having single or double bottom structures	*A*	*B*	*D*	*E*		
		ships of $L_1\leq150$, having double bottom structures	*A*		*B*	*D*		*E*
	within 0.6L amidship excluding the above		*A*		*B*	*D*		*E*
Bottom plating including keel plate	within 0.4L amidship		*A*		*B*	*D*		*E*
Stringer plate in strength deck	within 0.4L amidship	$L_1\leq250$	*A*	*B*	*D*	*E*		
		$L_1>250$	*D*	*E*				
	within 0.6L amidship excluding the above		*A*		*B*	*D*		*E*
	other than those mentioned above		*A*				*B*	*D*
Strength deck strake adjoining to longitudinal bulkhead	within 0.4L amidship		*A*	*B*	*D*	*E*		
	within 0.6L amidship excluding the above		*A*		*B*	*D*		*E*

(to be concluded)

Structural member	Application	Thickness of plate: t (mm)					
		$t \leq 15$	$15 < t \leq 20$	$20 < t \leq 25$	$25 < t \leq 30$	$30 < t \leq 40$	$40 < t \leq 50$
Strength deck at hatch corners	within 0.4L amidship	*A*	*B*	*D*	*E*		
	other than those mentioned above. (in case of large hatch opening, to be in accordance with the requirements given in the above column)	*A*				*B*	*D*
Strength deck	within 0.4L amidship	*A*		*B*	*D*		*E*
Deck plating exposed to weather, in general	within 0.4L amidship	*A*				*B*	*D*
Upper strake in longitudinal bulkhead adjoining to strength deck, within 0.4L amidship.		*A*		*B*	*D*		*E*
Lower strake in longitudinal bulkhead adjoining to bottom plating, within 0.4L amidship.		*A*				*B*	*D*
Upper strake in sloping plate of topside tank adjoining to strength deck, within 0.4L amidship.		*A*		*B*	*D*		*E*
Longitudinal members on strength deck including bracket and face plate of longitudinals, within 0.4L amidship.		*A*		*B*	*D*		*E*
Face plate and web of hatch coaming longitudinally extended on the strength deck over 0.15L within 0.4L amidship.		*A*		*B*	*D*		*E*
Stern frame Rudder horn Shaft bracket		*A*				*B*	*D*
Rudder plate		*A*				*B*	*D*
Other members than those mentioned above		*A*					*B*

Application of High Tensile Steels for Various Structural Members (to be continued)

<table>
<tr><th rowspan="2">Structural member</th><th rowspan="2" colspan="2">Application</th><th colspan="6">Thickness of plate: t(mm)</th></tr>
<tr><th>≤15 t</th><th>≤20 t 15<</th><th>≤25 t 20<</th><th>≤30 t 25<</th><th>≤40 t 30<</th><th>≤50 t 40<</th></tr>
<tr><td rowspan="4">Sheer strake at strength deck</td><td rowspan="2">within 0.4L amidship</td><td>$L_1 \le 250$</td><td>AH</td><td colspan="3">DH</td><td colspan="2">EH</td></tr>
<tr><td>$L_1 > 250$</td><td colspan="2">DH</td><td colspan="4">EH</td></tr>
<tr><td colspan="2">within 0.6L amidship excluding the above</td><td colspan="3">AH</td><td colspan="2">DH</td><td>EH</td></tr>
<tr><td colspan="2">other than those mentioned above</td><td colspan="5">AH</td><td>DH</td></tr>
<tr><td rowspan="2">Side plating within 0.4L amidship</td><td colspan="2">within 0.1D downward from the lower surface of strength deck</td><td colspan="3">AH</td><td colspan="2">DH</td><td>EH</td></tr>
<tr><td colspan="2">other than those mentioned above</td><td colspan="5">AH</td><td>DH</td></tr>
<tr><td rowspan="3">Bilge strake</td><td rowspan="2">within 0.4L amidship</td><td>ships of $L_1 > 150$, having single or double bottom structures</td><td>AH</td><td colspan="3">DH</td><td colspan="2">EH</td></tr>
<tr><td>ships of $L_1 \le 150$, having double bottom structures</td><td colspan="3">AH</td><td colspan="2">DH</td><td>EH</td></tr>
<tr><td colspan="2">within 0.6L amidship excluding the above</td><td colspan="3">AH</td><td colspan="2">DH</td><td>EH</td></tr>
<tr><td>Bottom plating including keel plate</td><td colspan="2">within 0.4L amidship</td><td colspan="3">AH</td><td colspan="2">DH</td><td>EH</td></tr>
<tr><td rowspan="4">Stringer plate in strength deck</td><td rowspan="2">within 0.4L amidship</td><td>$L_1 \le 250$</td><td>AH</td><td colspan="3">DH</td><td colspan="2">EH</td></tr>
<tr><td>$L_1 > 250$</td><td colspan="2">DH</td><td colspan="4">EH</td></tr>
<tr><td colspan="2">within 0.6L amidship excluding the above</td><td colspan="3">AH</td><td colspan="2">DH</td><td>EH</td></tr>
<tr><td colspan="2">other than those mentioned above</td><td colspan="5">AH</td><td>DH</td></tr>
<tr><td rowspan="2">Strength deck strake adjoining to longitudinal bulkhead</td><td colspan="2">within 0.4L amidship</td><td>AH</td><td colspan="3">DH</td><td colspan="2">EH</td></tr>
<tr><td colspan="2">within 0.6L amidship excluding the above</td><td colspan="3">AH</td><td colspan="2">DH</td><td>EH</td></tr>
</table>

(to be concluded)

Structural member	Application	Thickness of plate: t(mm)					
		$t \le 15$	$15 < t \le 20$	$20 < t \le 25$	$25 < t \le 30$	$30 < t \le 40$	$40 < t \le 50$
Strength deck at hatch corners	within 0.4L amidship	AH	DH			EH	
	other than those mentioned above. (in case of large hatch opening, to be in accordance with the requirements given in the above column)	AH					DH
Strength deck	within 0.4L amidship	AH			DH		EH
Deck plating exposed to weather, in general	within 0.4L amidship	AH					DH
Upper strake in longitudinal bulkhead adjoining to strength deck, within 0.4L amidship.		AH			DH		EH
Lower strake in longitudinal bulkhead adjoining to bottom plating, within 0.4L amidship.		AH					DH
Upper strake in sloping plate of topside tank adjoining to strength deck, within 0.4L amidship.		AH			DH		EH
Longitudinal members on strength deck including bracket and face plate of longitudinals, within 0.4L amidship		AH			DH		EH
Face plate and web of hatch coaming longitudinally extended on the strength deck over 0.15L within 0.4L amidship.		AH			DH		EH
Stern frame Rudder horn Shaft bracket		AH					DH
Rudder plate		AH					DH
Other members than those mentioned above		AH					

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SHIP STRUCTURE COMMITTEE PUBLICATIONS

SSC-324 Analytical Techniques for Predicting Grounded Ship Response by J. D. Porricelli and J. H. Boyd, 1984

SSC-325 Correlation of Theoretical and Measured Hydrodynamic Pressures for the SL-7 Containership and the Great Lakes Bulk Carrier S. J. Cort by H. H. Chen, Y. S. Shin & I. S. Aulakh, 1984

SSC-326 Long-Term Corrosion Fatigue of Welded Marine Steels by O. H. Burnside, S. J. Hudak, E. Oelkers, K. B. Chan, and R. J. Dexter, 1984

SSC-327 Investigation of Steels for Improved Weldability in Ship Construction by L. J. Cuddy, J. S. Lally and L. F. Porter 1985

SSC-328 Fracture Control for Fixed Offshore Structures by P. M. Besuner, K. Ortiz, J. M. Thomas and S. D. Adams 1985

SSC-329 Ice Loads and Ship Response to Ice by J. W. St. John, C. Daley, and H. Blount, 1985

SSC-330 Practical Guide for Shipboard Vibration Control by E. F. Noonan, G. P. Antonides and W. A. Woods, 1985

SSC-331 Design Guide for Ship Structural Details by C. R. Jordan and R. P. Krumpen, Jr., 1985

SSC-332 Guide for Ship Structural Inspections by Nedret S. Basar & Victor W. Jovino, 1985

SSC-333 Advance Methods for Ship Motion and Wave Load Prediction by William J. Walsh, Brian N. Leis, and J. Y. Yung, 1989

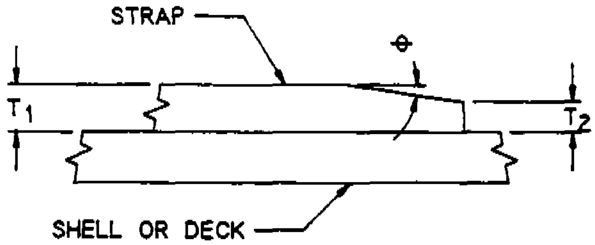
SSC-334 Influence of Weld Porosity on the Integrity of Marine Structures by William J. Walsh , Brian N. Leis, and J. Y. Yung, 1989

SSC-335 Performance of Underwater Weldments by R. J. Dexter, E. B. Norris, W. R. Schick, P. D. Watson, 1986

SSC-336 Liquid Slosh Loading in Slack Ship Tanks; Forces on Internal Structures & Pressures by N. A. Hamlin, 1986

SSC-337 Ship Fracture Mechanisms Investigation (Parts 1 and 2) by Karl A. Stambaugh and William A. Wood, 1987

None Ship Structure Committee Publications - A Special Bibliography, 1983

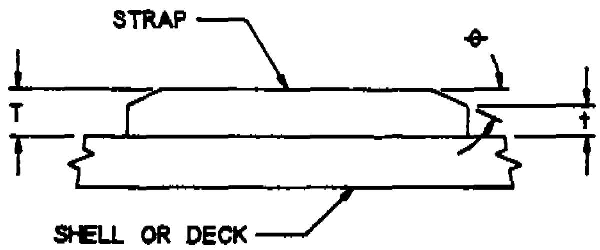


LONGITUDINAL SECTION

SAMPLE APPLICATIONS

SHIP	LOCATION	θ	T_1	T_2
A	DECK	30°	2"	5/8"
C	DECK	18°	2.6"	1"
	BOT SHELL	18°	1.3"	5/8"
F	BOX GIRD	15°	2.75"	5/8"
H	DECK	30°	1.75"	5/8"
	BOT SHELL	30°	1.75"	5/8"
J	DECK	14°	1.38"	1"

FIGURE 12: END CHAMFER



TRANSVERSE SECTION

SAMPLE APPLICATIONS

SHIP	LOCATION	T	θ	t
B	DECK	3/4"	18°	1/2"
C	DECK	2.6"	45°	2.54"
	BOT SHELL	1.3"	45°	1.24"
E	BOX GIRD	1.57"	25°	1"
	BOT SHELL	1.5"	25°	1"
H	DECK	1.75"	NOTE 1	
	BOT SHELL	1.5"	NOTE 1	
J	DECK	1.38"	14°	1"
L	SHEER STRAKE	3/4"	45°	5/8"
	BOT SHELL	3/4"	45°	5/8"

NOTES:

1. EDGE GROUND SMOOTH, NO SPECIAL CHAMFERS SPECIFIED.

FIGURE 13: EDGE CHAMFER

3.3.8 Faying Surface Treatment

No special treatments were specified nor applied on the surfaces of hull and doubler plates facing each other (i.e. the faying surfaces) on any of the ships reviewed other than the general cleanliness note of requiring them to be free of moisture, grease, loose mill scale, excessive rust or paint, etc.

Furthermore, no written standards were found related to the accomplishment of tightly fit strappings. In some applications, requirements were found for hull plating in way of straps to be made even and free of any buckling distortions. Any deformations were required to be corrected/faired prior to installation of straps.

Also, in these as well as in other applications, it was required that the existing hull plating butt welds be ground flush and any weld spatters or burrs on plate edges be completely removed.

3.4 In-Service Performance Of Strappings

All respondents to the survey questionnaire stated that their strapping designs had proven to be successful and that no structural problems were experienced with the straps during the service period. As pointed out against "remarks" in Table 6, at the bottom of each page, one vessel (Ship B) was reported to have had some problems with the epoxy material used to fill the slot welded holes to prevent collection of water. In-service, the epoxy had pulled away from the sides of the slot and allowed corrosion to take place. In order to eliminate the cause of this corrosion, the epoxy had to be removed from the slots and the area had to be blasted and recoated.

On another vessel (Ship E), minor cracks were observed in "slab welding", which we assume occurred in the fillet welds; these were repaired reportedly without further problems.

One respondent, whose response to the questionnaire consisted of only general information and no details, had nevertheless indicated that the strapping was installed on the vessel while afloat at dockside and that this had caused concern with regard to creating built-in stresses with the ship in a hogging condition. However, it was also reported that the design was structurally successful and that no problems were encountered.

In order to obtain more input data on the in-service performance of strappings, it was suggested by the SSC during a project review meeting that the U.S. Coast Guard's inspection report database be searched for relevant information on U. S. flag vessels. A listing of inspections conducted on eleven U.S. flag ships (of the fourteen shown in Table 4) was obtained from the USCG Marine Inspection Office in New York. A number of inspection reports were selected from this listing for each ship based on possible contents with regard to hull structural inspections, and copies of these inspection reports were requested from the responsible local Marine Inspection or Marine Safety offices.

Of the inspection reports received, only those associated with one class of vessel contained pertinent information. These reports indicated that cracks had been found in the butt welds of both deck and bottom doublers after the vessels had been returned to service following lengthening. As a result, an extensive inspection program was initiated to identify defects in the butt welds of all doublers. Where defects were found, these were repaired using procedures approved by the cognizant classification society. Where complete removal of the butt weld was required, a 2 millimeter (1/16") thick steel backing bar (chill strip) was utilized in the repair welding procedure; in the original butt welds a backing bar was not used.

The cause of the cracks was not identified in the inspection reports, nor was it clear whether these defects developed in service or were initial welding imperfections. There is some indication that the initial butt welds were not ultrasonically tested.

In view of this, consideration should be given in the conversion contract as to the degree of inspection of welds in general and butt welds in particular. It is noted that most major classification societies provide recommendations with respect to butt weld inspection.

4.0 STRAPPING DESIGN METHODOLOGY

4.1 General

One of the main objectives of this Ship Structure Committee Project is the development of a rational method for the design of hull strapping of ships. The method, in its broad coverage, should address the following considerations:

- Requirements imposed by the Classification Society rules with respect to the hull girder strength and the effectiveness of structure;
- Structural characteristics of the ship in question before and after strapping;
- Selection and use of proper strapping materials to be compatible with the existing hull materials.

Since the hull girder strength requirements, the overall design approach, and the classification society rules related thereto are well known and understood by the marine community, the project investigators were directed by the SSC to give priority to the collection of data on past strappings and to the discussion of design details for plate doublers used for strapping of ship hulls.

Consequently, only the following specific areas of hull strapping designs have been included in the methodology in greater detail than the aforementioned considerations:

- Locations and sizes of doublers
- Longitudinal extent of doublers
- Structural continuity
- Attachment and welding details
- Fabrication and inspection considerations

Prior to any detailed investigation relative to jumboizing a vessel, those responsible for the technical aspects of the alteration should carefully review the rules of the cognizant classification society, including those for new construction as well as any specific requirements for the class of vessel appropriate for the proposed conversion. In addition, open discussions with the classification society is strongly recommended as early as practicable, in order to resolve potential problems and to obtain a mutual understanding of class criteria for the converted vessel.

A description of what should be covered in jumboizing a vessel is beyond the scope of the present study. However, the scantlings, locations, and extents of strapping may well involve not only considerations of longitudinal strength, but additional considerations which the recommended course of action will (hopefully) reveal.

As an example, the structural configuration and scantlings of the deck, hatch coaming and upper side shell areas of a containership are based on torsional as well as longitudinal strength considerations. In order to accommodate such torsional effects, especially in vessels with large hatch openings, an increase in the scantlings of these components over and above those based solely on longitudinal strength may well be necessary. (Germanischer Lloyd's current Rules, Reference #3, for example, suggests as guidance an increase of 10% over the minimum allowable section modules in approximating scantlings for such new containership construction. Similar increases would probably be appropriate for conversions subject to detailed calculations.) In addition, since the torsional moments of a vessel do not necessarily decrease appreciably over the cargo length, extent of the full midship section modules may have to be carried significantly beyond the midships 0.4L.

As indicated by this example, strapping designs may thus well be affected by considerations over and above those associated solely with longitudinal strength.

It is noted that ABS as well as most other classification societies require an analysis of new containership designs to determine the suitability of the structure for longitudinal and torsional moments. It is reasonable to assume such an analysis will also be required for a conversion or lengthening of a containership.

Additionally, in planning for a jumboizing project in which a new section of midbody (i.e., a "plug") is contemplated, it may be advisable to conduct parametric studies to determine the optimum length of the plug and the associated extent and size of the strapping to be installed, if any.

The detail designs for hull strapping of specific ships will necessarily have to be customized and developed on a case by case basis. What is presented in this section is a method for developing a cost effective approach for the design of hull strapping based on consideration of longitudinal strength for all commercial vessels in association with jumboizing the vessel.

4.2 Review Of Existing Ship's Structural Background

The first step in any strapping design must be a review of the structural background and current condition of the existing ship that is to be strapped.

Background reviews of the existing ship's structure should include:

- o Obtaining all structural scantling and arrangement plans, longitudinal strength calculations, stability booklets, etc.

- o Identification of the existing strength deck and of the materials used for the primary hull structure, i.e. shell and deck plating, bulkheads, longitudinal and transverse frames, and/or box girders, etc.

- o Condition of the existing hull structure as to whether wastage of plating or framing is present, any defects, any permanent deformations, etc.

- o Estimation of the "as-is" hull girder section modules.

- o If feasible and when approved by the Owner, a survey of the structural condition of the ship including gaging of plating and framing thicknesses by ultrasonic equipment, and determination of any repairs to be accomplished during the conversion period but prior to installation of straps.

After this review, the designer will establish the cut lines for the existing ship's forward and aft sections (if this is a lengthening with a new midbody) so that the details of doubler plate and midbody attachment can be developed.

It is noted that in general, classification society approval must be obtained prior to installing straps. In addition, the existing plating or other structure to which straps are to be welded must be satisfactory to the attending class surveyor, and the structure must be properly prepared and free of distortions to permit proper attachment of the straps.

It is further noted that the lengthening of a vessel is usually approved by the classification society subject to the attending Surveyor's verification that the existing structure is found or placed in satisfactory condition, and that it has not wasted below the limits permitted for the scantlings required for the <u>new</u> length.

4.3 <u>Determination Of The Converted (Strapped) Ship's Required Hull Girder Strength</u>

4.3.1 <u>Applicable Classification Society Rules</u>

The major classification societies' "Rules for Construction of Ships," References #1 through #6, are intended to apply to new construction, and therefore do not contain specific requirements with regard to the design and detailing of straps used to reinforce the hull girder. However, during the investigations for this study, some guidelines were received from ABS, BV, and DnV which are specifically directed to the design and detailing of hull strapping of ships. These "strapping specific" notes and guidelines are included in Appendix A for ABS, Appendix B for BV, and Appendix C for DnV.

Where a new section of midbody is to be added within the midship 0.4L of an existing vessel, it is common to increase the scantlings in this new part to comply with the requirements associated with the lengthened vessel. However, the classification society guidelines for ABS, BV and DnV require that strapping be carried continuously throughout at least the midship 0.4L, including any added midbody located within this region. Consequently, it is somewhat redundant to increase the section modules and/or hull girder moment of inertia of such a new midbody section over that of the existing vessel, since the straps required by the classification societies must be sufficient to bring the existing vessel structure up to the required strength.

In Appendix A, which was reproduced from reference 11, ABS indicates that for a new section of midbody located within the midship 0.4L, the local scantlings of the new section need not be based on the new length and may be the same as those of the adjacent existing structure. Care is required to repeat the existing structural pattern and to effect good continuity of the structure throughout. Any resulting deficiency in the longitudinal hull girder strength is to be compensated by the addition of straps extending for 0.4L and tapered gradually beyond as required by Section 6.5.2 of the ABS Rules. For those vessels which are required to have longitudinal strength based on still water bending moment envelope curves, the straps should be developed and extended as required by such a curve for the modified vessel.

In general, the applicable rules for section modules and moment of inertia are those given in the respective classification society rule books. The required values of these properties should reflect the new size and type of vessel after conversion, i.e., after installation of the new midbody. In some cases the requirements may reflect additional factors, such as the torsional consideration previously cited.

A technical paper published by Bureau Veritas (BV) Reference #7, gives a rather thorough description of the approach to different ship conversions including lengthening, widening and deepening of ships and includes, in Annex 2 to the paper, strapping design details that would be acceptable to BV.

An excerpt from Reference #7 that relates directly to the overall strength verification for lengthening and to the determination of doubler scantlings is included in Appendix B-1. Annex 2 of the cited reference which contains recommendations on the welding and inspection of doublers is included in its entirety in Appendix B-2.

Det norske Veritas (DnV) has provided the project investigators with a copy of an extract from their approval instructions with regard to welding of doublers for longitudinal strength. This one-page extract and DnV's letter discussing strapping designs are included in Appendix C.

4.3.2 Computation of Required Section Modulus Based on Longitudinal Strength

Depending on the converted vessel's new type and service, the minimum required rule hull girder section modules and minimum required moment of inertia can be calculated using the guidelines contained in the classification society rules. Most classification societies indicate in their rules that the longitudinal strength formulations contained therein are valid for vessels with length to depth (L/D) ratios not exceeding a designated value. For example, ABS in Reference #1 states this value to be 15; i.e., the equations given in their rules for longitudinal strength requirements can be used for vessels of 200 feet or greater length which are classed for unrestricted ocean service and have L/D ratios of up to 15. Vessels with ratios greater than 15, or which are of a type not covered by the rules, will be subject to special consideration.

Limitations by the major classification societies on dimensional ratios for applicability of equations governing longitudinal strength are compared in Table 8.

The equation for rule minimum section modules is expressed in terms of the ship's length, beam, and block coefficient. It is clear that the vessel's new length, beam (if widened) and hull form must be carefully determined on the basis of vessel owner's requirements and the ship's intended service. The designer may be requested to analyze various alternatives to achieve the desired end result and establish the optimum jumboizing approach in a most cost effective manner.

Table 9 lists the equations to be used for the determination of minimum hull girder section modules amidships as dictated by the major classification societies. As all of the cited classification societies have adopted the same minimum section modules requirements proposed by the International Association of Classification Societies (IACS), all of equations should give the same result in actual application. It is noted that, depending upon the vessel's configuration and service, the section modules may have to be increased to accommodate bending moments higher than those associated with the minimum section modules requirement. Additionally, most classification societies have

TABLE 8

Limitations on Dimensional Ratios for Applicability of Minimum Rule Section Modulus Equations by Major Classification Societies

Classification Society	Dimensional Ratio Limitations
ABS (Per ABS Rules 1989)	L/D (max) = 15 L = Length D = Depth
Germanischer Lloyd	L/D (max) = 16 For Unlimited Range Vessels = 18 For Coastal Vessels = 19 For Shallow Water Vessels
Lloyd's Register	L/B (min) = 5 B/D (max) = 2.5 B = Beam C_B (min) = 0.6 C_B = Block Coefficient
Nippon Kaiji Kyokai	No Stated Limitation
Det Norske Veritas	No Stated Limitation
Bureau Veritas	L/C (max) = 14 For Bulk Carriers C = Depth Note: BV guidelines, Appendix A-1 indicate maximum permissible L/C ratios for vessel lengthenings as follows: L/C = 16.5 for Deep Sea = 18 for Coastal Waters = 22 for Sheltered Waters

TABLE 9

Minimum Section Modulus Requirements by Major Classification Societies

Class Society	Equation	Legend
ABS	$SM = 0.01C_1 L^2B (C_b + 0.70)$	L = Length of Vessel B = Breadth of Vessel C_b = Block Coefficient C_1 = Coefficient varying with vessel length
Germanischer Lloyd	$SM = kCL^2B (C_b + 0.7) (m^3)$	C = Coefficient varying with vessel length k = Material factor (1.0 for mild steel)
Lloyds Register	$SM = fk\ C_1L^2B (C_b + 0.7)10^{-9}(m^3)$	f = Ship Service Factor (1.0 For Unrestricted)
Nippon Kaiji Kyokai	$SM = C_1L^2B (C_B + 0.7)\ cm^3$	
Det Norske Veritas	$SM = a\ C_{wo}\ L^2B (C_B + 0.7)/f_1\ (cm^3)$	C_{wo} = Coeff. varying with vessel length a, f_1 = 1.0 for ships with mild steel construction
Bureau Veritas	$SM = FL^2B (C_B + 0.7) (m^3)$	F = Coefficient varying with vessel length

moment of inertia requirements which must be met by the converted vessel. For shallow vessels and/or those with extensive use of high strength steel, the inertia requirements may be controlling.

The longitudinal strength requirements for the converted vessel are in part governed by the extent of lengthening, deepening, and/or widening desired by the owner for the vessel's new intended service and carrying capacity. The term "jumboizing" may include any one or any combination of these three types of size and capacity increases. As pointed out above, the naval architect may be requested to analyze the possibilities and recommend that optimum jumboizing approach to the owner for the most cost effective option.

Once the jumboizing approach is approved by the owner, then the rule proportions will have to be checked to establish if the classification society longitudinal strength equations may be used. In many cases, the still water bending moments for given loading conditions must be ascertained and the strength requirements determined using basic engineering principles with supporting calculations submitted to the Society.

The supporting calculations needed for special consideration by the classification societies include the estimates of actual loads imposed on the vessel during its intended service. In order to determine these loads, different loading conditions of the vessel will have to be established. For nearly all types of vessels to be jumboized, the full load departure and full load arrival conditions and an interim condition such as ballast arrival (or other applicable condition depending on the type of ship) should be analyzed.

The still water bending moments (SWBM) can be determined through the analysis of the weight, buoyancy, and load curves obtained from the application of data for the various loading conditions of the converted ship. This must be followed by the computation of wave bending moments and shear forces. These can be obtained directly from the applicable rules or from statistical analysis based on ship motion calculations in realistic sea states. Such an analysis could be obtained using the modified "SCORES" program, Reference #9, which provides long term predictions of the vessel's forced responses utilizing wave heights, wave periods, and sea spectra representing a random sea state.

The theoretical governing total hull bending moment is the summation of the still water and wave bending moments. When the total bending moment is divided by the appropriate allowable stress of the hull material, the required section modules will be obtained.

4.3.3 Choice of Strapping Materials

The classification society rules do not contain any specific rules or regulations with regard to the choice of materials to be used in doubler plates for strapping of ship hulls. As a practical matter, however, classification societies will require that doubler materials be compatible with the ship's hull material to which it is attached and meet the notch toughness requirements for the location and thickness contemplated. ABS states, in Appendix A, that "the new materials should meet the latest rule requirements". The French society Bureau Veritas states in Reference #7 (extracts from which are included in Appendix B) that steel grades of doublers "must comply with Chapter 3 of Rules for Steel Vessels. If deck is built with high tensile steel, the doubler must be of the same steel with the same mechanical properties." This is probably the universal approach to the selection of strapping materials. As previously described in Section 3.3.3, consideration of notch toughness requirements for the prevention of brittle fracture may favor going beyond minimum class requirements in selecting steel grades. Notch sensitivity of strapping materials is also an important factor to consider in comparison to the existing material properties in way of the attachment. Depending on the location, type and method of attachment, doublers of increased thicknesses may have to possess a higher level of notch toughness.

Major classification societies specify the physical and chemical properties of steel material to be used in hull construction. Strength characteristics for various grades and classes of steels for hull construction are tabulated in the ABS rules as well as in the rules of other societies. The ABS steel grades are reproduced here (for quick reference) in Table 10; those of other societies can be found in the respective parts of their rules as shown below:

LRS: Section 2.1
GL: Chapter 2, Section 2, Part B
DnV: Section 3.1-2
BV: Section 3-13
NK: Part 6, Sections 1.1.7 and 1.1.11

Copies of these tabulations are included in Appendix D.

4.3.4 Required Cross Sectional Area

Once the strapping material is selected, and the allowable stresses identified, it will be possible to determine the reinforcing required to meet the new section modules. The difference between required section modules for the converted ship (as determined by the classification societies' rule equations or by basic engineering principles) and the "as-is",

TABLE 10: ABS STEELS

Material Class and Grade Requirements

Structural member	Material class[1] Within 0.4L Amidships	Outside 0.4L Amidships
Shell		
Bottom plating including keel plate	III	I
Bilge strake	IV[2,3,4]	III[5,6]
Side plating	II	I
Sheer strake at strength deck[7]	IV[3,4,8]	III[5,6]
Decks		
Strength deck plating[9]	III	I
Stringer plate in strength deck[7]	IV[3,4,8]	III[5,6]
Strength deck plating within line of hatches and exposed to weather, in general	II	I
Strength deck strake on tankers at longitudinal bulkhead[10]	IV[3,4]	III[5,6]
Longitudinal Bulkheads		
Lowest strake in single bottom vessels	II	I
Uppermost strake including that of the top wing tank	III	I
Other Structures in General		
External continuous longitudinal members and bilge keels	III	I
Stern frames, rudder horns, rudders, and shaft brackets	—	I
Strength members not referred to in above categories and above local structures	I	I

Notes

1 Special consideration will be given to vessels in restricted service.
2 May be of class III in vessels with a double bottom over the full breadth and with a length less than 150 m (492 ft).
3 Single strakes required to be of material class IV and V or E are to have breadths not less than 800 + 5L mm (31.5 + 0.06L in.), but need not exceed 1800 mm (71 in.).
4 Below 90 m (295 ft) in length this may be class III
5 May be class II outside 0.6L amidships.
6 Below 90 m (295 ft) in length this may be class I
7 A radius gunwale plate may be considered to meet the requirements for both the stringer plate and the sheerstrake, provided it extends suitable distances inboard and vertically. For formed material see 30.3.7
8 To be class V in vessels with length exceeding 250 m (820) ft).
9 Plating at the corners of large hatch openings are to be specially considered.
10 For tankers having a breadth exceeding 70 m (230 ft) at least the center line and one strake port and starboard at the longitudinal bulkheads are to be class IV.

Material Grades

Grade CS may be used in place of Grade E
Grade DS may be used in place of Grade D where Grade D is not required to be normalized

Thickness *mm (in.)*	Material Class				
	I	II	III	IV	V
$t \leq 15$ ($t \leq 0.60$)	A, AH	A, AH	A, AH	A, AH	D, DH
$15 < t \leq 20$ ($0.60 < t \leq 0.79$)	A, AH	A, AH	A, AH	B, AH	D[1], DH
$20 < t \leq 25$ ($0.79 < t \leq 0.98$)	A, AH	A, AH	B, AH	D, DH	E, EH
$25 < t \leq 30$ ($0.98 < t \leq 1.18$)	A, AH	A, AH	D, DH	D[1], DH	E, EH
$30 < t \leq 35$ ($1.18 < t \leq 1.38$)	A, AH	B, AH	D, DH	E, EH	E, EH
$35 < t \leq 40$ ($1.38 < t \leq 1.57$)	A, AH	B, AH	D[1], DH	E, EH	E, EH
$40 < t \leq 51$ ($1.57 < t \leq 2.00$)	B[2], AH	D[1], DH	E, EH	E, EH	E, EH

Notes
1 Grade D of these thicknesses to be normalized.
2 May be grade A for stern frames, rudder horns, rudders, and shaft brackets.

i.e. before conversion, section modules is an indication of the additional strength to be provided by the strapping and the new midbody's increased scantlings, if any. This difference can be determined by computing the required section modules of the new midbody and comparing this against the actual section modules of the fore and aft bodies of the existing ship. If, as is normally the case, the fore and aft body section modules is less than the required SM for the converted ship, strapping or other reinforcing may be necessary to meet the strength requirements, depending upon the required tapering of the section modules along the vessel's length.

Should strapping be the preferred choice to obtain the required structural reinforcement for longitudinal strength, then the amount and type of reinforcement will be determined by first calculating the additional cross sectional area that the strapping should provide. For the determination of sectional area to be provided by strapping, Bureau Veritas recommends, in Appendix B-1, the following equation for deck doublers:

$$dwp = 2(dsp)(h)(h + W/S)/V \qquad (1)$$

where: dwp = Difference between "before" and "after" conversion deck section moduli.

dsp = Additional sectional area required for doublers on either side of ship.

h = Vertical distance from the centerline of deck doubler to the existing neutral axis of the section.

V = Vertical distance from the deck line at side to the existing neutral axis of the section.

W = Existing deck section modules.

S = Total existing midship sectional area.

This equation can be rearranged to give the following for calculation of strapping sectional area.

$$dsp = V(dwp)/[2(h)(h+W/S)] \qquad (2)$$

Equation (1) may also be used for calculating the change in deck section modules attributable to side shell doublers by inserting the applicable h value. The total change assuming both deck and side shell doublers are fitted is then the summation of the two dwp values.

In general, the required sectional area of strapping is a function of the SM before and after strapping, the midship sectional area available, and the distance between the CG of doubler and Yo, the distance from the neutral axis of ship before strapping to the top of strength deck or bottom, whichever is smaller.

4.4 Development Of Strapping Design Details

4.4.1 Overall Design Considerations

After determining the cross sectional area to be provided by the doublers used in strapping the ship's hull, careful consideration should be given to the selection of locations, number, and scantlings of the doublers.

Important considerations in strapping designs include, in addition to the location and scantlings of the doublers, the use of proper attachment methods, suitable taper ratios, measures to avoid stress concentrations and corrosion of the faying surfaces, and most importantly, assuring structural continuity between the new midbody and the existing fore and aft portions of the ship.

All of these factors are discussed further in the following subsections of this report.

4.4.2 Determination of Strap Locations

In determining the locations on the ship where the doublers may be installed, an optimum distribution of the added steel is one of the first and most important considerations. As discussed in Section 3.3.1, on the classes of ships which have been lengthened with strappings in the past, the doubler plates were installed mostly on the strength deck and bottom shell plating. However, as shown in Table 7, some ships had doublers installed on the side shell plating (sheer strake) and this can be done when available clear deck area is limited due to structures or obstructions on the strength deck or when additional strength or stiffness (i.e. moment of inertia) of the ship over and above that provided by deck doublers is required.

The selection of optimum strap locations will be governed by the type of ship to be strapped. For example, for ships with continuous and effective deep hatch coamings and/or hatch side box girders of substantial scantlings, installing the doublers on the coamings or box girders will prove to be more effective than installing them on the decks.

Installing and welding the doublers on bottom plating will require the ship to be drydocked for this purpose, if she is not already in drydock, and in this sense will prove to be more difficult and more expensive. For most types of ships, the neutral axis of the midship section is usually closer to the baseline than it is to the deck at side; consequently, the available section modules at deck is less than that at the bottom. When this is the case for the ship to be strapped, it may be possible to install the doublers on the deck only and in this manner achieve a cost effective strapping design.
It should be noted that precisely this was accomplished on Ships B and M which are discussed in Section 3.0 with strapping details

described in Table 6. Ships A, F and J also had no doublers installed on the bottom shell plating; Ship F had them on the new box girder, Ship J on the deck and the sheer strake, Ship A on the deck with an additional girder installed on the bottom but inside the ship, and Ship G had new box girders installed for new container holds with doublers installed on the innerbottom, all of which made it possible to carry out the strapping without the need for drydocking.

When strapping must be installed on the bottom due to specific section modules requirements or arrangement peculiarities of the ship in question, alternative means may be found to accomplish the same end result in a more cost effective manner especially in cases where a drydock is not available or when the cost of strapping is the most important consideration. The methods used in the above-mentioned Ships G and A are good examples of alternative approaches. On Ship A, as described, a half girder has been added on the bottom in lieu of bottom strapping and on Ship G doublers were placed on the innerbottom plating instead of on the bottom shell plating.

It is clear that a standard strap location applicable to all ships cannot be recommended. The selected location, to reiterate, will be governed by the type, arrangement, and strength requirements of the ship to be strapped. Possible strapping locations are schematically shown in Figure 14 for a tanker which are also applicable for bulk carriers, general cargo ships, and vessels of similar construction. Figure 15 shows appropriate locations for a containership, also applicable to Ro/Ro carriers, combination carriers, etc. For these latter types of ships, deck doublers should be located and arranged in such a manner that they will not only meet the section modules requirements but also provide extra reinforcement for heavy deck loadings, Ro/Ro ramps, and hatch openings.

Annex 2 of the Bureau Veritas Technical Paper, Reference #7, cited in Section 4.3.1, a copy of which is reproduced by BV's permission in Appendix B-2, specifies minimum distances from existing hull butt welds to the side weld of the nearest doubler for deck, sheer strake, and bottom doublers. It also recommends that no structural members be welded to the doublers nor any openings be cut in them. The project investigators concur with these recommendations.

4.4.3 <u>Longitudinal Extent and Scantlings</u>

The strapping should cover at least the midship length according to BV in Appendix B. In nearly all classification society rules, including those of ABS in Appendix A, the midship length is defined as 40% of mid-length and specified as the extent to which the vessel's primary strength capability should continue. The actual longitudinal extent of strapping for any specific ship, however, will obviously depend on its type and configuration in addition to the strength requirements. As an example, if the subject ship is a bulk carrier, a container

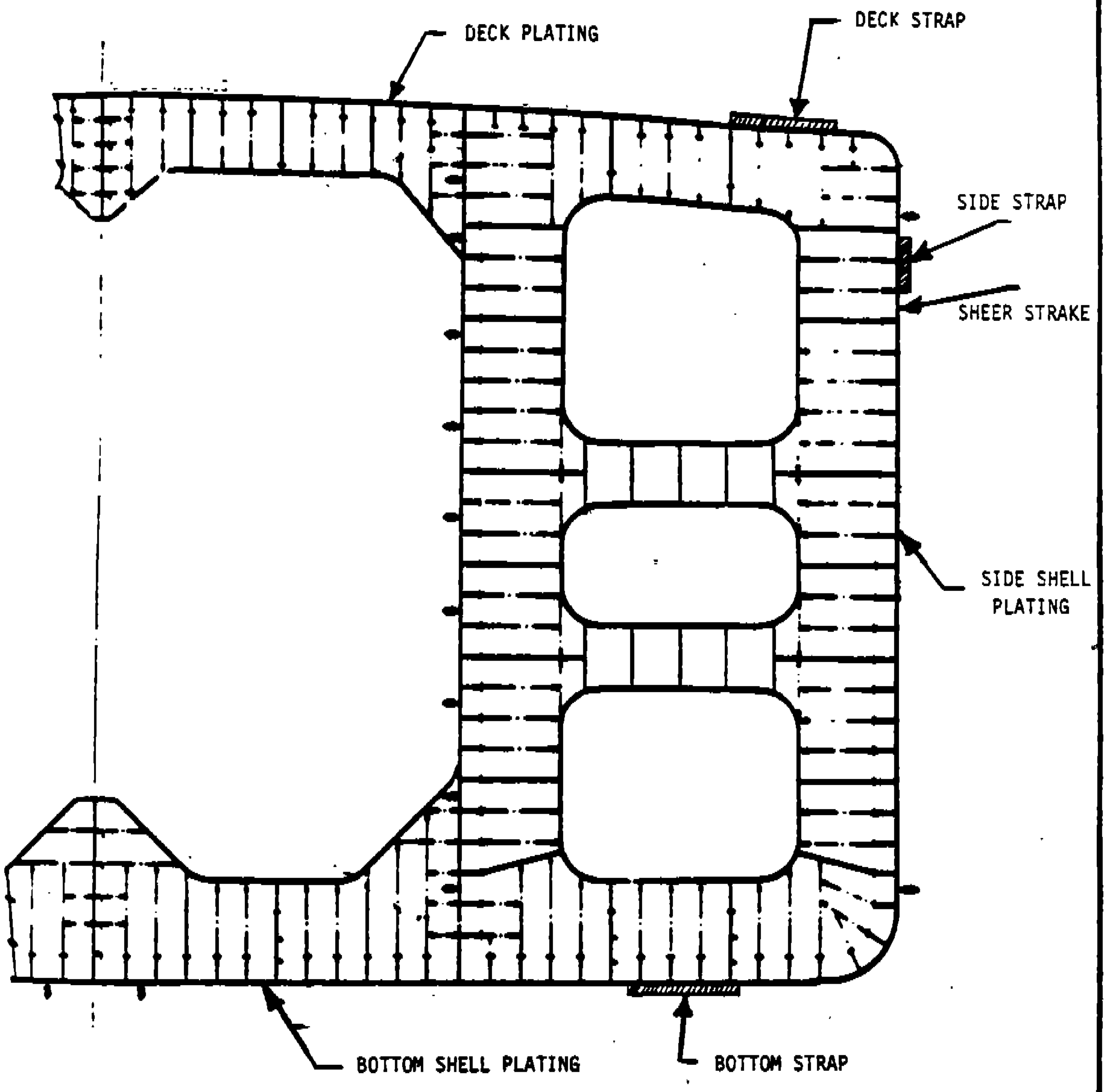


FIG. 14 STRAP LOCATIONS FOR A TYPICAL TANKER

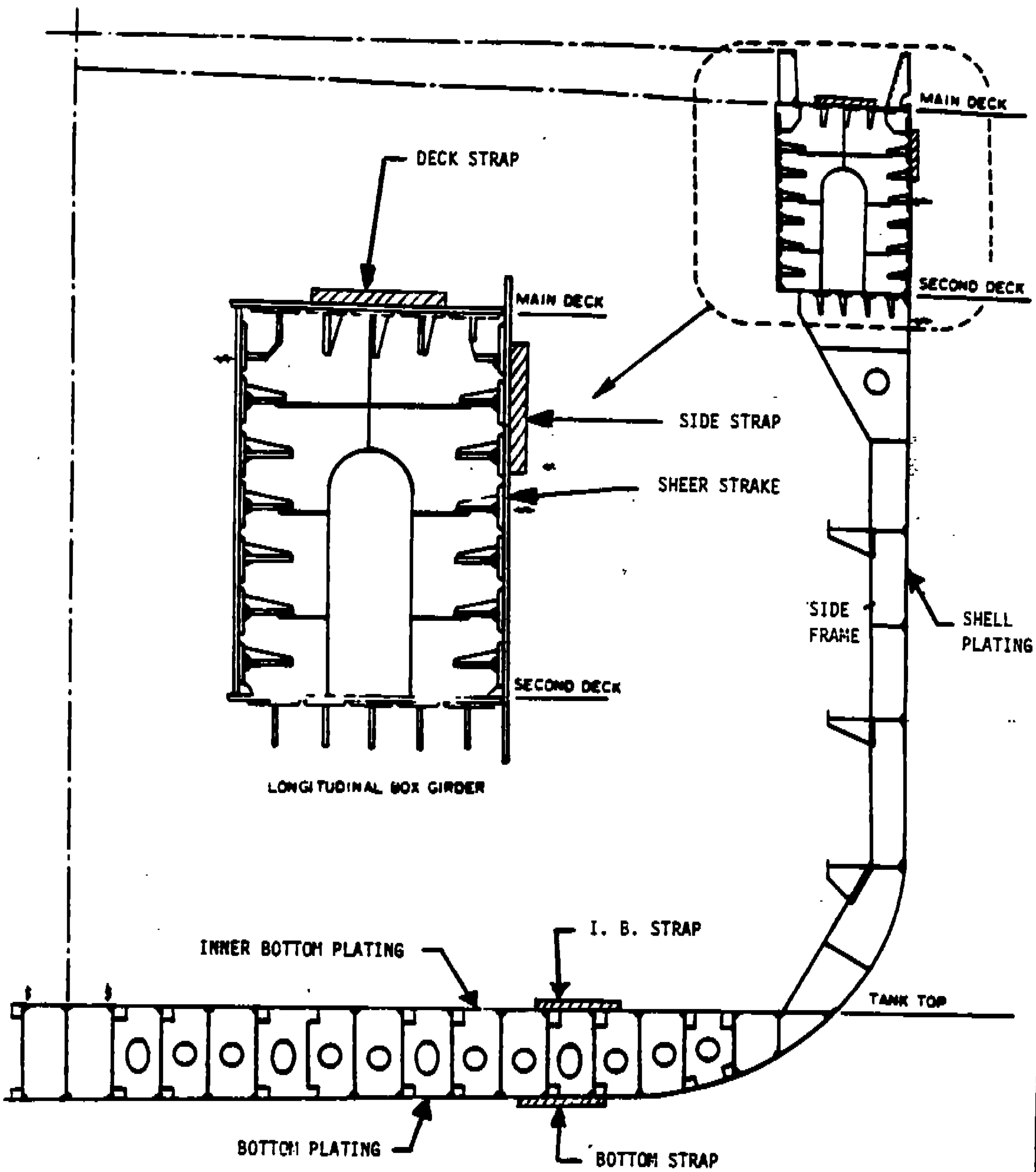


FIG. 15 STRAP LOCATIONS FOR A TYPICAL CONTAINERSHIP

carrier or a similar vessel with hatches along most of its length, any deck doublers to be installed must extend beyond the hatch ends, even if this is not a longitudinal strength requirement, in order to provide structural continuity and/or to reduce torsional and horizontal bending stresses. Examples of this are seen in Ship A in Table 6 where the longitudinal extent is approximately 3/4 L, on Ship H where it is 2/3 L, and in Ship P where it is 1/2 L.

General recommendations from ABS include the following:

1) Strap ends should terminate beyond (i.e. overlap) structural changes in section (such as hatch ends, superstructures and bulkheads) by at least two frame spaces (or say 2 meters)

2) Where possible, straps should be situated over underdeck longitudinal girders or bulkheads.

3) Strap widths should be tapered down at the ends.

The total required sectional area of the strapping determined as described in 4.3.4 may be provided by one or more strips of doublers of appropriate thickness and width. The selected thickness will obviously have to be compatible with the thickness of existing hull plates to which the doublers will be attached. In Appendix A, ABS indicates doubler thicknesses should not exceed 1.5 times the thickness of the underlying plate, while BV in Appendix B-2 recommends that doubler thicknesses should not exceed twice the thickness of the underlying plate or a maximum of 40 millimeters (1.57 inches). From a review of the past strapping designs discussed in Section 3.0, it will be seen that doublers of up to 2.76 inch thickness have actually been used in some strappings - (see Ships A,C F,H,N, and P in Table 6). All of these strapping designs were approved by the cognizant classification societies and, additionally, they have reportedly given successful performance without any structural problems.

Accordingly, it is recommended as a general guideline that doubler thicknesses be selected such that they are not less than the existing plating thickness but also not more than 50% above that thickness. BV's guidance in Appendix B-2 also leaves the possibility of using different doubler thickness open by stating that they can be fitted subject to the society's approval. The thickness selection may also depend on the physical arrangement and the structural configuration of the ship in question.

As discussed earlier, the doublers may have to be installed on the deck only and the ship's deck must have ample space for installing the doublers. If such is the case, it may be more advantageous to install two or more doublers of smaller thickness in parallel rather than one thick doubler to avoid plug welding.

On the other hand, for a different ship type the available deck space may be limited and/or cluttered with obstructions, in which case the best approach may be to install a doubler of greater thickness.

Also affecting the thickness selection will be the choice of the number of doublers to be installed and the width of each doubler. As stated above, if ample deck or bottom space is available, two or more doublers of narrower width and smaller thickness may be used to achieve the same reinforcing as one wide doubler of thicker plate.

Table 6 reveals that the doubler widths used in past strapping designs range from a minimum of 9 inches to a maximum width of 103 inches. However, only four ship classes (Ships B, D, G, and K) had wide doublers (103", 84", 66", and 55" respectively). Of these, Ships B, D, and G had these wide doublers attached to the hull plating by slot welding while Ship K, despite using a wide doubler, did not. As a matter of fact, the project investigators contacted the cognizant classification society on this point, and the explanation provided by them is discussed in Section 4.4.4.2.c "Slot Welds", along with a discussion on assuring the tightness and shear transfer capabilities of doubler plates.

In Appendix B-2, BV states that in order to avoid plug welds, narrower and thicker doublers may be arranged in 2 or 3 parallel strips. Additionally, BV indicates that the widths of doublers for installation without slot welding will normally not exceed 600 millimeters (24") for an average size ship and recommends a maximum width of not more than 40 times the doubler thickness or 800 millimeters (31.5") whichever is the greatest. As indicated in Appendix C, DnV would normally require slot welding for doublers wider than either 850 millimeters (33.5") or 30 times the doubler thickness plus 100 millimeters. ABS guidelines in Appendix A allow doublers without slot welding provided the doubler width is not more than 750 millimeters (30") or more than 30 times the doubler thickness.

It is clear that the designer will have to consider all these possibilities and choices and determine the most suitable locations, numbers, and scantlings (i.e. longitudinal extent, width, and thickness) of doublers to be used in strapping the specific ship's hull.

4.4.4 Attachment and Welding of Doublers

In order to achieve its most important function, i.e, reinforcing and stiffening the converted ship's hull, a doubler should be properly attached to the existing plating. The attachment details that should be carefully developed include:

- Providing tightness of doubler's attachment to existing plating and preventing corrosion.

- Welding sizes and details;
- End reinforcing and chamfering details;
- Thickness and width tapering;
- Fabrication and inspection procedures.

The above details are discussed further in the following subsections.

4.4.4.1 Tightness and Corrosion Prevention

The doubler plates should be fitted as tightly as possible against the base hull plating. This is important both from the standpoint of ensuring effective shear transfer and also for the purpose of preventing corrosion of the faying surfaces.

To provide for proper tightness during the strapping design process, the side and end welding details should be carefully determined as discussed below in Section 4.4.4.2. In any case, the doublers are to be attached to the existing hull plating by continuous fillet welds and separate lengths of doubler plates are to be interconnected by butt welds. The recommended sizes as specifically applicable to doublers, for each type of welding, i.e, fillet and butt, are contained in Appendix B by Bureau Veritas. ABS also has guidelines for sizing fillet welds as contained in Appendix A. These are cited in Section 4.4.4.2a and d. Other major classification societies did not provide such specific guidelines but would require the designs to follow their current welding rules for classification and construction of ships.

From the survey of past strapping designs, it was also not possible to find any written standards for strap-fitting tightness. Other than specifying the appropriate fillet and butt weld sizes, tightness can be obtained by following proper fabrication and inspection procedures, such as preparation of the existing hull plating prior to installing the straps, as discussed in Section 4.4.5.

The tightness of the attachment and the corrosion prevention measures are obviously very closely interrelated: the tighter the attachment of doubler to existing base plates, the less chance of water seeping through and initiating corrosion of the faying surfaces. However, there are other precautionary and preparatory measures, also discussed in 4.4.5, which should not be overlooked.

The practice of coating the faying surfaces to prevent corrosion has most probably been carried over from the strapping of wooden and riveted steel ships. For welded ship construction, coating of faying surfaces is probably not as important nor necessary.

The current trend in most shipyards with regard to the faying surfaces of deck fittings (such as mooring bitts, etc.) and hull doublers is to completely seal off these fittings by welding and leave the faying surfaces completely uncoated. The areas in the vicinity of welds are protected by taping from even the wash primer (the zinc silicates used immediately after sandblasting) in order to assure a sound welding.

One of the members of the review committee for this report, Mr. Edward Moll of Bath Iron Works, recommended (Reference #12) that faying surfaces be treated the same as any other surface exposed to the weather; that is, if the ship exterior surfaces receive a zinc coating system, then the doublers should receive the same treatment except in way of welds, where the areas should be masked prior to blasting and painting to avoid any contamination of the weld-affected areas, or health hazards to production personnel.

As there appears to be no general consensus as to the treatment of faying surfaces, no specific recommendations are made in this report, other than to note that assuring that sound welds are obtained may impact the decision as to faying surface treatment, if any. For example, if slot welding is to be used in installing doublers, accurately masking the base plate in way of all slot welds may not be practicable. Additionally, preheating may be required for doubler installation, especially for doublers of high strength material, and this may affect decisions as to faying surface coating.

In any event, sealing off the faying surfaces by sound continuous edge fillet welding and quality slot welds (if provided) is probably the most effective way of controlling corrosion of the faying surfaces.

With respect to bevel welding of doubler edges, this is not normally used; the extra expense of edge preparation and welding is not generally considered necessary nor economical.

4.4.4.2 Welding Details

a. Fillet Welds

The sides and ends of doublers should, as mentioned above, be attached to the existing hull plating by means of continuous fillet welds. A typical doubler side fillet weld was shown in Figure 1 of Section 3.0 along with sample weld sizes used on some of the ship classes surveyed during this investigation. As seen, the weld sizes ranged from a minimum of 1/4" to a maximum of 3/4". This range can be used as a rule-of-thumb in determining the fillet weld size in conjunction with consideration of the plating (doubler and base hull) thicknesses and corrosion allowances. BV in Appendix B recommends a fillet weld throat thickness (see Figure 16) equal to one half the thickness of doubler plate but not more than 60% of the base plating

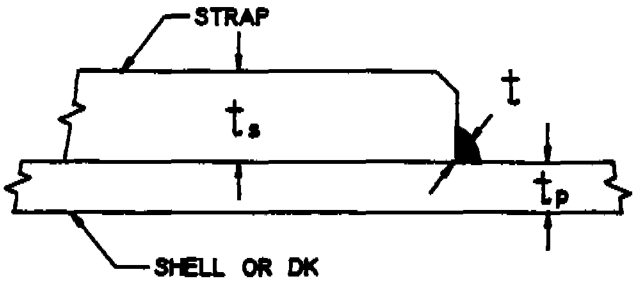


FIGURE: 16

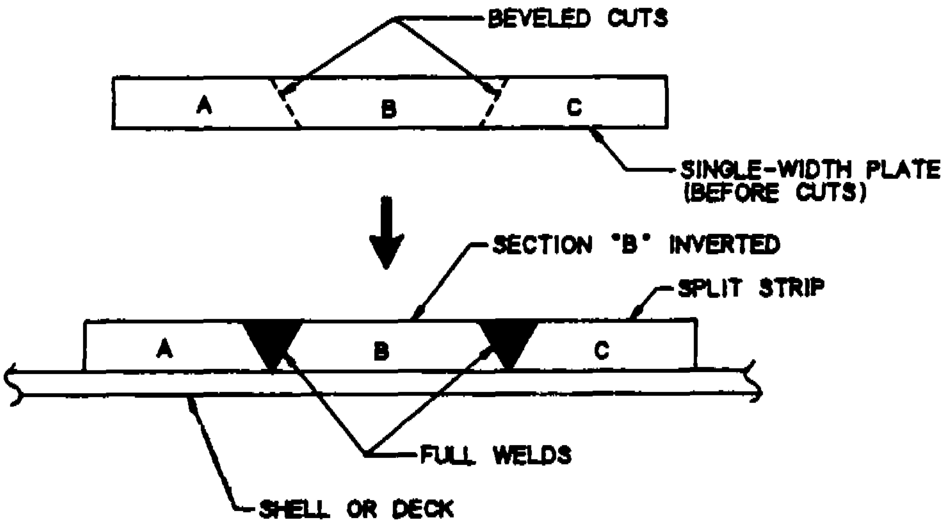


FIGURE: 17

thickness. ABS guidelines, Appendix A, indicate that for continuous fillet welding, the fillet weld should have a throat thickness equal to 3/10 of the strap thickness. Guidance for sizing fillet welds of doublers in general (not specifically for strapping) may also be found in the Rules of other classification societies, as for example in Section 19, Part B.2.4 "Local reinforcements, doubling plates," of the GL Rules, Reference #3.

It is possible to optimize the fillet weld design by reducing the weld sizes at the sides of doubler except at or near the ends since the middle regions of the doubler plates will be subjected to lesser fatigue loading (see discussion on end weld reinforcement in Section 4.4.4.2.d below). Examples of this reduction were found in some recent strappings (Ships C and K in Table 6 of Section 3.0). However, the classification guidelines cited above should still be met.

If the strapping design requires the use of several strips of adjacent doublers arranged in parallel, which may be the best choice to avoid plug welding of a single wide doubler, the gap between the two strips should obviously be at least large enough to allow two fillet welds. In general the gap should not be less than the thickness of the strap (ABS, Appendix A). BV recommends a gap of between two and three times the strap thickness (Appendix B-2).

When it is possible however, it may be advisable to join the two strips together by a fully welded groove as shown in Figure 3 of Section 3.0. In this case, the whole sectional area of the doublers including the fully welded groove will count as effective. The built-in stress due to such full depth groove welding should not be overlooked and proper precautions should be taken to prevent it (see Section 4.4.6.4). For this reason the doubler thicknesses with which full depth groove welding can be utilized are somewhat limited. When two strips of thick doublers are to be joined together, the method shown in Figure 4 of Section 3.0 may be employed where the groove is only partially welded. It is also possible to utilize the total area of the doublers by utilizing and arranging the strips as shown in Figure 17 instead of cutting grooves on each doubler.

For parallel deck doubler strips with gaps between or with partially welded grooves, BV in Appendix B recommends the use of a filler material, such as cement, as protection against corrosion.

b. <u>Butt Welds</u>

Individual lengths of doubler plates, throughout the longitudinal extent of strapping, are joined together at ends by butt welds. The survey of past strapping details showed that some of the doubler butt welds employed a backing bar, as shown in Figure 18, with a completely continuous full penetration weld. This practice is recommended by Bureau Veritas.

Most of the ships surveyed however did not employ backing bars for doubler butt welds. One of them (Ship B) had zero root gap instead of a backing bar. This detail is considered conservative but not reliable with regard to obtaining full strength from the joint.

The BV recommendations for detailing doubler butt welds are contained in Appendix B-2, page 5, and include dimensional guidelines for root gap, bevel angle, and bar sizes, etc. Appropriate bevelling (angle θ) and root opening (R) should be provided to obtain 100% joint efficiency. Bevel angles of 30° to 40° and root openings of 1/4" to 3/8" are common practice.

If the existing shell or deck plating near the ends of the longitudinal extent of doublers is reduced in thickness, as is the case for most applications, a special detail shown in Figure 19 may be employed.

An alternative detail is shown in Figure 20 where an insert plate is extended toward the straps by means of a special transition doubler plate butt welded to the insert and to the straps at its two ends and also slot welded.

Figures 8 and 9 in Section 3.0 demonstrate the details employed in welding doublers to a heavy insert plate in way of a new midbody and in way of a side opening on the existing structure. As noted therein, the combined width of the doubler plate and the existing hull plate should match the width of the insert plate on the new midbody or the side opening.

c. <u>Slot Welds</u>

Slot welding, as discussed in 3.3.4.2 and 4.4.3, should be used with doublers exceeding certain widths and only upon approval of the cognizant classification society. Typical widths beyond which slot welding is mandatory are given in Section 4.4.3. In contrast, Bureau Veritas, in Appendix B, does not recommend the use of slot welds to strengthen the doubler connection to shell plating unless special agreement is obtained from the Head Office. Rather, BV generally limits the doubler plate width as given in Appendix B-2.

During the survey of past strapping designs, three ships were found which had the doublers slot welded to the hull plating. The widths of doubler plates on these ships varied between 66" and 103", and slot welding was necessary to maintain a tight connection. Another ship had a 55" wide doubler installed but had not employed slot welding. As pointed out in Section 4.4.3, the project investigators discussed this point with the cognizant classification society. The explanation given was that the subject strapping design was approved many years ago at which time they had "no special requirements for welding of doubler plates." It was added that nowadays they "require slot welding if the breadth of doubler exceeds 30 times the thickness of doubling plate."

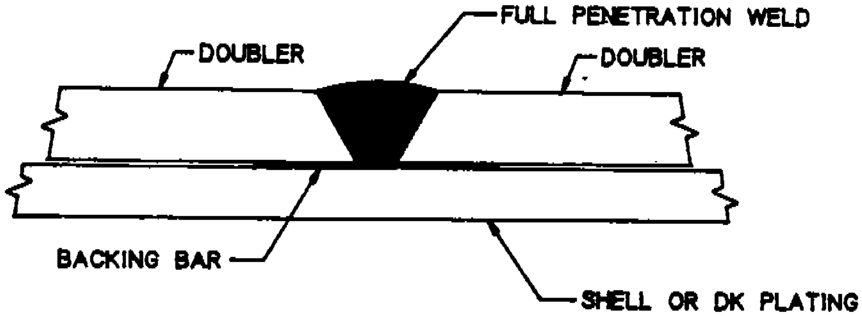


FIGURE 18: DOUBLER BUTT JOINT WITH BACKING BAR

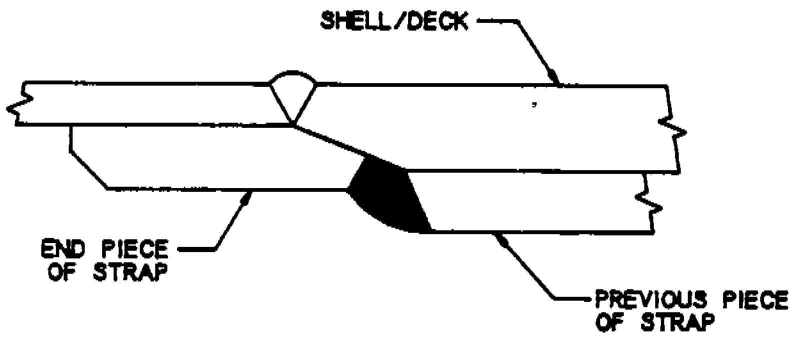


FIGURE 19: STRAP END WELDING

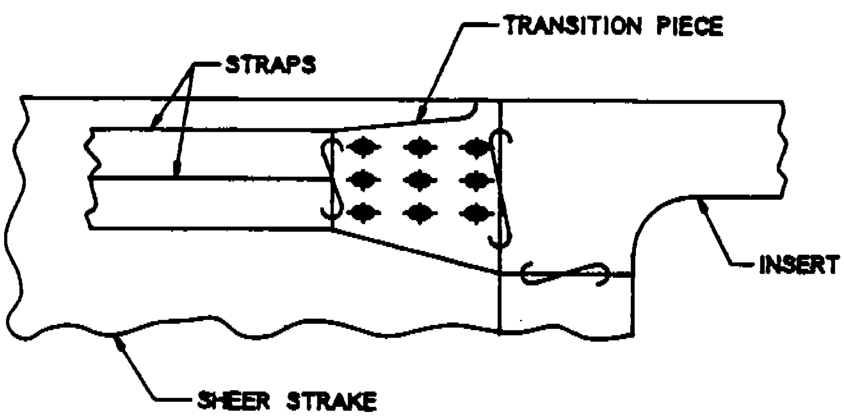


FIGURE 20: ALTERNATIVE DETAIL FOR STRAP JOINED TO INSERT

It is recommended for the purposes of strapping design methodology that wherever possible, narrow doublers not exceeding in width 30 times their thickness be used and slot welding be avoided. When, however, wider doublers must be installed due to arrangement peculiarities and/or non-availability of space for multiple parallel narrower doublers, slot welding may be employed subject to review and approval prior to installation.

Typical slot welding details used in previous strapping projects were discussed in Section 3.3.4.2 and illustrated in Figure 2 thereof and these may be used as guidance in new strapping designs. Slot welding details used for hull strapping are subject to classification society approval. Some further guidance is provided in the Rules of the various societies, References #1 through #6, as for example under Section 30.9.6 "Plug Welds or Slot Welds" of the ABS Rules and Section 19, "Welded Joints", Part B.3.3.11 (Plug Welding) of the GL Rules. DnV, in Appendix B also provides guidance for slot dimensions and welding requirements which are in close agreement with the guidance provided above.

d. <u>End Reinforcing</u>

The extreme ends (fore and aft) of doubler strap plates may be subjected to repeated, high stress fluctuations and reinforcing of the welds at these locations against fatigue failure should be considered. Reference #10 discusses allowable fatigue stress ranges for long cover plates, straps, (as applicable to bridge structures). At or near the strap ends, the allowable fatigue stress range is only about one half of that at the sides of the strap. Table 11, reproduced from Table 1.3.13V of the cited reference, lists the allowable ranges for various stress categories. For the same number of constant stress cycles, it can be seen that the allowable range for stress Category B (corresponding to sides of strap) is nearly twice the allowable range for stress Category E (which corresponds to ends of strap). As far as stress fluctuations are concerned, the bridge structures are similar to ship structures and it becomes obvious that reinforcement of the strap end welds is advisable.

BV provides guidance for the amount and extent of weld reinforcement at ends of doubler plates; and in Appendix B-2, recommends increasing throat thickness from 0.5 times doubler thickness to 0.7 times thickness for a length at ends equal to three times the width of the doubler.

ABS guidelines for fillet welds at the ends of straps are contained in Appendix A, and indicate a throat thickness of 0.5 times plate thickness should be used at the ends over a length of approximately two times the width of the strap.

TABLE II: ALLOWABLE FATIGUE STRESS RANGES

(Reproduced From Reference #10)

Stress Category	Allowable Fatigue Stress Range, S_{Rfat} (ksi) for No. of Constant-Stress Cycles, N				
	150,000	200,000	500,000	2,000,000	> 2,000,000
A	53	48	36	24	24
B	40	36	27	18	16
C	28	26	19	13	10 12[a]
D	24	22	16	10	7
E	19	17	12	8	5
F	14	13	12	9	8

[a] For transverse stiffener welds on webs or flanges.

4.4.4.3 Chamfering

Figures 12 and 13 in Section 3.0 contain illustrations of end and edge chamfer details utilized in some of the past strapping designs. Chamfering serves to improve structural continuity at the termination regions and also reduces the risk of tripping by personnel in the case of deck doublers and the flow resistance in the case of bottom doublers. In general, the corners of all free edges of doubler plates should be dressed smooth and chamfered by grinding to 1/16"X1/16" or 1/8"X1/8" to minimize the notch effect.

4.4.4.4 Tapering

The width and thickness of the doubler plates used in strapping ships' hulls remain constant throughout the minimum midship length as required by the classification societies. As discussed in Section 4.4.3, the minimum midship length is usually 40% of the ship's rule length. However, the longitudinal extent of strapping may have to go beyond this length, depending on the type of ship and the specific application, in order to maintain structural continuity and to reduce horizontal and torsional bending stresses.

Width tapering and chamfering are usually employed together without thickness tapering. On the other hand, in cases where strapping is required to continue extensively beyond the midship length (such as the deck or hatch side girder doublers on containerships), thickness tapering may be considered.

It was stated in Section 3.5.6.2 that no rules were found governing the details of width tapering for hull strapping. This is true; however, one classification society, DnV, has provided guidance on this subject (it was stated by other classification societies that no special guidance notes were publicly available for such details but that the details would be subject to their revew and approval). DnV's recommendations on tapering can be found in Appendix C.

The recommendations for new strapping designs is to utilize width and thickness tapering in conjunction with chamfering and end reinforcing of appropriate extent and size as customized to the specific application.

4.4.4.5 Fabrication and Inspection

During preparations for and actual installation of strapping, the precautions summarized below are recommended.

a. Preparation and Precautions

- The existing hull and/or the new midbody plating to be strapped should be flat, fair, and well supported by existing longitudinal structural members.

- If the plating is buckled or otherwise unfair, any fairing or repairs to the existing plating should be accomplished prior to installation of doublers.

- Existing hull or new midbody erection butts must be ground flush; undercuts, if any exist, should be repaired; weld spatters and burrs at ends should be removed.

- Faying surfaces should be clean, free of moisture and any foreign materials such as grease, mill-scale, paint or rust. An ordinary thickness of primer coating or a thin linseed oil coating may be allowed, upon approval by the classification society, provided it is demonstrated that their use will have no adverse effect on the production of satisfactory welds.

b. Welding Precautions and Sequence

- A welding specification should be prepared detailing the welding procedure on the basis of cognizant classification society's rules.

- Preheating and temperature maintenance requirements for welding high strength steels in accordance with the rules must be observed (see Appendix B-2 for further details).

- A proper welding sequence for installing doublers should be established in accordance with the rules of the cognizant classification society. A sample welding sequence, recommended by BV, is given in Appendix B-2.

- In installing doublers in way of hull erection joints, a short section of the doubler (about 3 ft. in length) may be left unwelded until after completing, testing, and flush grinding the hull joint.

c. Inspection

In order to obtain the strengthening and stiffening expected to be provided by strapping, all doubler plates must be thoroughly inspected prior to, during, and after welding as well as during periodic classification society underwater hull surveys and all drydocking surveys for in-service performance follow-up.

During fabrication and welding stages, the cognizant class society surveyors will normally conduct inspections to ensure compliance with their rules. Separate detailed inspection requirements for doublers are not available from all societies. The general fabrication and welding inspection requirements for hull structure are normally used and these are incorporated into the building yard's own "Quality Assurance Program" if and as dictated by the Owner's conversion specifications. An inspection procedure specifically for doubler welds is contained in BV's Annex-2 to Reference #7 which is reproduced in Appendix B-2 of this report. As will be seen, it contains guidance on the extent of visual inspections; ultrasonic, dye-penetrant, and magnaflux testing; and radiography.

In determining the inspection procedure to be followed, it is noted that the inspection standards to be utilized may be based, at least in part, on considerations of fatigue strength and fracture mechanics. In particular, allowable limits on welding flaw sizes to insure adequate fatigue life can be assessed using fracture mechanics analyses. Such limits can then be used in developing inspection standards.

4.5 Cost Effectiveness Of Strapping Designs

In various preceding sections of this report, the importance of a most cost effective strapping design without sacrificing strength and structural continuity was touched upon.

Listed below are some measures and/or considerations recommended for accomplishing this purpose:

- If the ship in question is to be jumboized, first conduct an analysis of possible alternatives (such as adding a new midbody and strapping, constructing a new forebody, etc.) to determine the most suitable and economical jumboizing approach to obtain the same end result.

- Should strapping of the existing hull and the new midbody be the selected approach, carefully determine the optimum locations of doublers through consideration of:

  - Ease of construction (e.g., minimum of obstructions on the existing ship's deck, ample support for doublers from existing longitudinal structural members, minimum amount of removal and reinstallation, etc.).

- If drydocking the vessel is not required for other reasons, elimination, if possible, of the need for drydocking the vessel for strapping purposes by installing doublers on the deck only or on the innerbottom or other such location allowing work to be accomplished while the vessel remains afloat.

- Utilization of the additional strength provided by the deck doublers also in providing extra reinforcement for heavy deck loadings, ramps, hatches, etc. if such exist on the ship, provided allowable stress levels are not exceeded.

o Extend the doublers sufficiently beyond the rule required midship length to obtain good structural continuity and to avoid costly additions/reinforcements in later stages of the strapping installation.

o Select the optimum and most economical numbers and widths of doublers to be installed keeping in mind the fact that the more the number of doublers the greater the cost of welding operations. If the required reinforcement can be provided installing only one doubler plate of reasonable width and thickness, select this option and determine the best location for it.

o In determining the thickness of doublers to be installed, use the following criteria:

  - Assure compatibility with existing hull plating thickness (see Section 4.3.3).

  - Avoid using, if possible, very thick doublers requiring multiple passes since welding of thick plates is more labor intensive than welding thinner plates.

  - If the required reinforcement can only be obtained by installing a thick doubler of maximum allowable width, conduct a trade-off study and try installing two parallel doublers of smaller thickness and narrower width. Include in this analysis the consideration of the extra length of welding required for the two straps versus the extra amount of welding passes needed for the single thick doubler.

  - In any case, avoid plug welding (which is a costly affair) by using narrower doublers unless absolutely dictated by the particular configuration of the ship and the complexity of obstructions on the deck.

5.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

A thorough review of the past strapping designs for fourteen classes of ships was conducted. The data for strapping details of these ships were obtained from various sources including shipowners, shipyards, and classification societies.

The collected data consisted of filled out questionnaires (prepared specifically for purposes of this project), drawings of ships detailing the strapping design, and some overall comments on the subject. The data were sorted and analyzed with the objective of benefitting from successful past experience and avoiding unsuccessful designs in any new strapping application.

It was found that sufficient information had been gathered to enable an analysis of the past designs but practically no information had been provided with regard to the in-service performance of hull strappings. Upon suggestions by the Project Technical Committee, a request was made to the U.S. Coast Guard Marine Inspection and Marine Safety Offices throughout the U.S. to provide relevant inspection results for the ships surveyed. Responses received indicate that no specific strapping inspections were conducted on the ships in question with the exception of one vessel class. For this class, some defective strap butt welds were found as described in Section 3.4.

On the basis of the information obtained, it was not possible to judge if any of the past strapping designs was unsuccessful. Responders, in filling out the special questionnaire, all stated that their designs were successful and that no specific structural problems were experienced during in-service performance of the doublers.

However, variations in the design details were encountered in some applications and it was possible to adopt one design detail against another less desirable application to include in the recommended strapping design methodology.

The design methodology that was developed on this basis is presented in detail in Section 4.0 of this report. A summary of the most important factors which must be taken into consideration during the strapping design development for new applications, is presented below:

- The number of doublers to be installed should be established on the basis of available space (on the deck, side shell, or the bottom shell of the ship to be strapped) and the extent of strengthening needed to meet the required midship section modules and moment of inertia.

- The most suitable locations on the ship's hull should be selected for installation of doublers to provide ease of construction while assuring effective structural continuity.

- Care must be taken to ensure that the doublers are amply supported by existing longitudinal structural members.

- Scantlings of doublers (i.e, the width, thickness, and longitudinal extent) should be determined with a view toward reducing costs without sacrificing strength.

- Strapping materials should be selected such that they are compatible with the ship's underlying hull plating to which they will be attached; notch toughness should be considered in selecting steel grades.

- Appropriate design details should be provided for the installation, attachment, and inspection of doublers. Most suitable details for the specific type and configuration of the ship to be strapped should be utilized.

- Design details should establish the width and thickness tapering of doubler plates at ends, chamfering of the edges and ends, weld reinforcing at ends, spacing and joining details for two or more parallel strips of doublers (if employed), butt welding of individual lengths of doublers, and slot welding (if employed with approval of the cognizant classification society).

- Specific instructions with regard to fabrication procedures and precautions peculiar to doubler installation (such as faying surface preparations and treatment, etc.) should be provided.

- Welding specifications and a proper welding sequence to assure sound connections and to avoid built-in stress concentrations should be developed in agreement with the building yard's standard practices.

- Special quality control requirements with regard to the inspection and testing of doubler installations should be developed and incorporated into the building yard's "Quality Assurance Program."

In order to make sure that experience from past strapping designs are fed back to the designers, it is highly desirable to have one central authority collect all inspection results for ships with strappings in a separate data base. The USCG inspection database currently contains some data for U.S. flag merchant ships. It is recommended that specific instructions be added for the USCG inspectors to at least visually examine hull strapping, if present, on every occasion even if it does not seem necessary. If the visual examination reveals any defects, then appropriate additional inspections such as ultrasonic, magnaflux, or dye-penetrant testing should be requested. The results of doubler inspections should be recorded in a separate data file for easy retrieval. This will make it possible to maintain a running record for the in-service performance of doublers so that the more successful applications may be identified and utilized in future hull strapping of ships.

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