A GUIDE TO
SOUND SHIP STRUCTURES

By
AMELIO M. D'ARCANELO
Professor of Naval Architecture and Marine Engineering, University of Michigan

Prepared for the Ship Structure Committee
under the general direction of the Ship
Structure Subcommittee National Academy
of Sciences–National Research Council.

CORNELL MARITIME PRESS, INC.
Cambridge Maryland 1964
# Contents

## Section  

### I. Stresses and Strains on Ships  

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>1-1</td>
</tr>
<tr>
<td>Tension and Compression Stresses</td>
<td>1-1</td>
</tr>
<tr>
<td>Tension and Compression Strains (Illus.)</td>
<td>1-2</td>
</tr>
<tr>
<td>Body of Uniform Weight and Cross Section Floating in Still Water</td>
<td>1-2</td>
</tr>
<tr>
<td>Local Variations of Weight and Buoyancy in a Ship in Still Water, Shear and Bending (Illus.)</td>
<td>1-2</td>
</tr>
<tr>
<td>Ship's Hogging and Sagging Conditions</td>
<td>1-4</td>
</tr>
<tr>
<td>Longitudinal Shear (Illus.)</td>
<td>1-5</td>
</tr>
<tr>
<td>Longitudinal Stress Distribution (Illus.)</td>
<td>1-5</td>
</tr>
<tr>
<td>Geometric Properties of a Structural Member (Illus.)</td>
<td>1-7</td>
</tr>
<tr>
<td>The Ship as a Box Girder (Illus.)</td>
<td>1-15</td>
</tr>
<tr>
<td>Hull Girder Components (Illus.)</td>
<td>1-18</td>
</tr>
<tr>
<td>Localized Stresses of Significance (Illus.)</td>
<td>1-20</td>
</tr>
<tr>
<td>Locations of Significant Shear</td>
<td>1-23</td>
</tr>
<tr>
<td>Stress Concentration (Illus.)</td>
<td>1-23</td>
</tr>
<tr>
<td>Brittle Fracture (Illus.)</td>
<td>1-27</td>
</tr>
<tr>
<td>Fatigue Fracture (Illus.)</td>
<td>1-35</td>
</tr>
<tr>
<td>Summary</td>
<td>1-37</td>
</tr>
</tbody>
</table>

### II. Minor Openings in Ship Steel Structures  

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Introduction</td>
<td>2-1</td>
</tr>
<tr>
<td>Opening Control</td>
<td>2-1</td>
</tr>
<tr>
<td>Opening Location and Workmanship (Illus.)</td>
<td>2-2</td>
</tr>
<tr>
<td>Geometric Ratios in Openings (Illus.)</td>
<td>2-10</td>
</tr>
<tr>
<td>Stress Concentration Factor in Openings (Illus. and Tables)</td>
<td>2-10</td>
</tr>
<tr>
<td>Reinforcement of Openings (Illus. and Table)</td>
<td>2-23</td>
</tr>
<tr>
<td>Reinforcement of Openings in the Strength Envelope (Illus.)</td>
<td>2-27</td>
</tr>
<tr>
<td>Section</td>
<td>Page</td>
</tr>
<tr>
<td>------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Reinforcement of Openings in Beams, Girders, Longitudinals, and Stiffeners (Illus.)</td>
<td>2-31</td>
</tr>
<tr>
<td>Miscellaneous Minor Openings and Cuts in Ship's Structures (Illus.)</td>
<td>2-33</td>
</tr>
<tr>
<td>Summary (Illus. and Tables)</td>
<td>2-37</td>
</tr>
<tr>
<td>III. Major Openings in Ship Steel Structures</td>
<td>3-1</td>
</tr>
<tr>
<td>Introduction</td>
<td>3-1</td>
</tr>
<tr>
<td>Welded Hatch Corner Design</td>
<td>3-1</td>
</tr>
<tr>
<td>Unsatisfactory Welded Hatch Corner Details (Illus.)</td>
<td>3-2</td>
</tr>
<tr>
<td>Modifications of the “Liberty” Ship Original Hatch Corner Design</td>
<td>3-5</td>
</tr>
<tr>
<td>Improved Welded Hatch Corner Details (Illus. and Table)</td>
<td>3-6</td>
</tr>
<tr>
<td>Other Large Openings (Illus.)</td>
<td>3-15</td>
</tr>
<tr>
<td>Summary</td>
<td>3-17</td>
</tr>
<tr>
<td>IV. Welding Joint Details</td>
<td>4-1</td>
</tr>
<tr>
<td>Introduction</td>
<td>4-1</td>
</tr>
<tr>
<td>Standard Welding Symbols (Illus.)</td>
<td>4-1</td>
</tr>
<tr>
<td>Types of Manual Arc Welded Joints (Illus. and Tables)</td>
<td>4-4</td>
</tr>
<tr>
<td>Automatic Welding (Illus.)</td>
<td>4-35</td>
</tr>
<tr>
<td>Defects in Welded Joints</td>
<td>4-41</td>
</tr>
<tr>
<td>Dimensional Defects (Illus. and Table)</td>
<td>4-41</td>
</tr>
<tr>
<td>Lessening Distortion (Illus. and Tables)</td>
<td>4-46</td>
</tr>
<tr>
<td>Soundness Defects (Illus.)</td>
<td>4-51</td>
</tr>
<tr>
<td>Cracking in Welded Joints (Illus.)</td>
<td>4-66</td>
</tr>
<tr>
<td>Heat-Affected Zones and Preheat (Illus.)</td>
<td>4-72</td>
</tr>
<tr>
<td>Summary</td>
<td>4-74</td>
</tr>
<tr>
<td>V. Welding Sequence</td>
<td>5-1</td>
</tr>
<tr>
<td>Introduction</td>
<td>5-1</td>
</tr>
<tr>
<td>Sequence in Welded Joints (Illus.)</td>
<td>5-1</td>
</tr>
<tr>
<td>Basic Principles in Plated Structures (Illus.)</td>
<td>5-6</td>
</tr>
<tr>
<td>Sequence in Plates with Attachments (Illus.)</td>
<td>5-7</td>
</tr>
</tbody>
</table>
CONTENTS

Section

Welding Sequence in Subassemblies ........................................... 5-11
Overall Welding Sequence (Illus.) ........................................... 5-12
Sequence in the Vicinity of Riveting (Illus.) ................................. 5-18
Sequence in Repair Work (Illus.) ............................................. 5-30
Fairing Tolerances ..................................................................... 5-32
Summary .................................................................................... 5-32

VI. Various Details in Ship Steel Structures .................................. 6-1

Introduction .................................................................................. 6-1
Longitudinals at Intersections (Illus.) ......................................... 6-2
Bracket Connections (Illus.) .......................................................... 6-14
Troublesome Intersections (Illus.) .................................................. 6-23
Various Critical Vessel Details (Illus.) .......................................... 6-25
General Details (Illus.) ................................................................. 6-40
Summary ...................................................................................... 6-47

VII. Miscellaneous Structural Data ................................................. 7-1

Tables:

- Squares, cubes, square roots, cube roots, circumferences and areas of circles ....................................................... 7-3
- Fractions and decimal equivalents ........................................... 7-7
- Conversion of inches into decimals of a foot .......................... 7-8
- Weight and gage of steel plates .............................................. 7-10
- Weight of steel plates and corresponding rivet diameters ....... 7-10
- Weight of steel angles in pounds per lineal foot ..................... 7-13
- Weight of steel channels cut to angles ................................... 7-14
- Weight of steel I-beams cut to T-beams ................................. 7-15
- Approximate weights of electrode and weld metal in fillet welds ........................................................................... 7-17
- Approximate weights of electrode and weld metal in square-groove butt joints with reinforcement ................................. 7-18
- Approximate weights of electrode and weld metal in V-groove butt joints with reinforcement .................................. 7-18
- Approximate weights of electrode and weld metal in double-V groove with reinforcement ......................................... 7-19
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riveting size and countersink standards</td>
<td>7-20</td>
</tr>
<tr>
<td>Length of cone head-countersunk point rivets for various grips</td>
<td>7-21</td>
</tr>
<tr>
<td>Length of cone head-cone point rivets for various grips</td>
<td>7-23</td>
</tr>
<tr>
<td>Length of countersunk head-countersunk point rivets for various grips</td>
<td>7-25</td>
</tr>
<tr>
<td>Rivet proportions</td>
<td>7-27</td>
</tr>
<tr>
<td>Weld Stress Formulas (Illus.)</td>
<td>7-29</td>
</tr>
<tr>
<td>Common Riveting Symbols and Abbreviations</td>
<td>7-31</td>
</tr>
<tr>
<td>Common Abbreviations on Ship's Structural Drawings</td>
<td>7-32</td>
</tr>
<tr>
<td>References</td>
<td>7-37</td>
</tr>
<tr>
<td>Index</td>
<td></td>
</tr>
</tbody>
</table>
Index

Abbreviations on ship's structural drawings, common, 7:32-35
Alignment of structural members, details, 6:45
importance, 6:42
Arithmetic and geometric properties of numbers, 7:3-7
Automatic welding, 4:35
backing welds, 4:39, 41
butt joint illustrations, 4:37-39
details, 4:36
fillet joint, 4:40-41
Bending moment, 1:4
on composite beam, 1:6
relation to bending stress, 1:10, 13
Bending stresses, 1:4
distribution in beam, 1:7-8
equation, 1:9
Biaxial stress, tensile, 1:29-30
Bilge keels, details, 6:26, 27-28
Box girder, 1:16
Bracket connections, chocks, 6:13-14
hard spot, avoidance of, 6:17-23
stresses, full scale tests, 6:14-17
Brittle fracture,
description, 1:27-35
illustration, 1:35
relation to notches, 1:27
under triaxial stress, 1:29-34
Bulkhead, stress at intersections, 1:20, 22
Bulwarks,
detail of recommended types, 6:87
important precautions, 6:32, 37, 39
Buoyancy, description, 1:2
relation to shear and bending, 1:3-4
Butt welded joints,
joining plates of different thicknesses, illustrated, 4:20
nomenclature, illustrated, 4:11-12
plate thicknesses, 4:8, 10
positions, 4:8, 10
special types, illustrated, 4:21
square groove, illustrations, 4:14-15
V-groove, illustrations and typical specifications, 4:16-18
Center of gravity, location of, 1:8-10
Compression strain, definition, 1:2
Compression stress,
definition, 1:1
distribution in beam in bending, 1:7-8
Conversion of inches (in.) into decimals of a foot (ft), 7:8-9
Corner,
rounding of, 1:24-26
stress concentration, 2:14-23
Countersink standards and size of rivets, 7:20
Crack arrestors, 6:18
cargo vessel, 5:20
tanker, 5:19
Cracking,
basic features, 4:66, 71-73
in weld and base metal, illustrated, 4:73
weld congestion and restraints, 6:42-44
weld undercutting, fatigue crack, 6:2
cross section of ship, 1:14, 16-17
Deckhouses, causing structural discontinuities, 1:22-23
detail, 6:30-31
with openings, 2:8-9
Deformation, definition, 1:2
Design,
details for minimizing notches and stress concentrations, 6:46
general rules for structural details, 1:39-40
good practices, 6:1
other larger openings, 3:15-16
welded hatch corners, 3:1-15
Discontinuity, definition, 1:24
Distortions due to welding,
angular, 4:43-44
backstep method, 4:62
excessive number of passes, 4:60
excessive weld reinforcement, 4:58
lessening distortion, 4:46, 64, 66
metal contraction, 4:41
overlap, 4:67
peening, 4:49
planar distortion, 4:48
poor fit-up, 4:59
pre-springing, 4:49, 65
shrinkage, 4:44, 47-48, 52-55
tucking, 4:45, 56
upsetting, 4:41
use of intermittent fillet welds, 4:63
welding sequence, 5:1
Drain holes and clearance cuts,
details, 6:38-42
Ductile fracture, 1:27, 35
Electrode and weld metal approximate weight in various types of joints, 7:17-19
Energy absorption to fracture, 6:3
Fabrication, 
defects due to flame cutting, 2:15 
details, 1:39-40 
general rules for structural details, 
1:39-40 
quality, 1:20 
Fairing tolerances, straightening after 
welding, 5:32 
Fatigue fracture, 
description, 1:35-37 
illustration, 1:36 
Filler welded joints, 
corner, full penetration, 4:26, 29 
face, toe, root, 4:25 
intermittent welds, 4:26, 30, 63 
lap, 4:25-26, 28 
minimum sizes, 4:26 
positions, 4:23 
size and shape, 4:24 
T, 4:22, 24 
typical types, 4:22 
Formulas, weld stress, 7:29-30 
Fracture, 
brITTLE, 1:27-35 
ductile, 1:27, 35 
fatigue, 1:35-37 
shear, 1:32 
Gage and weight of steel plates, 7:10 
Geometric and arithmetic properties of 
numbers, 7:3-7 
Hard spots, 
cause of fatigue failures, 1:37 
definition, 6:1 
in bracket connections, 6:17-23 
intersection of structural members, 
6:23-26 
minimize at longitudinal intersections, 
6:13-14 
Hatch corners, 
American Bureau of Shipping type, 
3:11-12 
importance, 3:1-2 
modified design, 3:6-9 
in "Liberty" ships, 3:2, 4, 11 
in "Victory" ships, 3:10-11 
Kennedy type, 3:14-15 
tests at Univ. of Calif., 3:6 
unsatisfactory designs, 3:2-3 
Hoering, 1:4, 17-18 
Hull girder, 
primary and secondary components, 
1:18-21 
ship cross section, 1:14-17 
I-beam, 
analogy of ship's cross section, 1:15 
effect of flange proportions, 1:15-17 
Length of rivets for various grips, 7:21- 
26 
"Liberty" ship, hatch corner design, 
British Code 1A, 3:6, 9 
modified design, 3:5-6 
original design, 3:2, 4 
U.S.C.G., Code 1, 3:6-7 
Load-bearing intersecting members, 1:20, 
22 
with openings, 2:8-9 
Loading conditions, ship, 1:4 
hogging, 1:4, 17-18 
sagging, 1:4, 17-18 
Longitudinals, connection details, 6:2-14 
butted-through bracket, 6:8 
continuous, 6:9-10 
hard spots, 6:13 
intercostal with collar plate, 6:10 
lapped-through bracket, 6:6 
scalloped ends, lapped and T-welded, 
6:2-3 
T2 tanker design, 6:1 
Longitudinal framing, 
connection of longitudinals to trans­ 
verse bulkheads, 6:2-14 
importance of continuity, 6:2 
secondary notches, 6:2 
Longitudinal stress, 
longitudinal distribution, 1:18 
vertical distribution, 1:6-8, 17 
Manganese, effect on transition tempera­ 
ture of steel, 1:34 
Moment of inertia, 
definition, 1:9 
determination of, 1:9-13 
relation to strength, 1:9, 13 
Multiaxial stress, tensile, 1:27 
Neutral axis, 
definition, 1:7 
location of, 1:7-10 
Notches, 
in plate in tension, 1:27, 29 
secondary, 6:2 
structural, 1:24-26 
Openings, major, 
basic principles, 3:17; see also Hatch 
corners 
machinery casing, corner detail, 3:15- 
16 
Openings, minor, 
advantage of large ones, 2:1 
geometric ratios, 2:10 
in plating, 2:4-7 
intercostal, rules, 2:37 
near stress raisers, 2:8 
orientation, 2:22-23 
proportions, 2:20-22 
reinforcement, 2:23-27 
shear forces, 2:8-8 
stress concentration factors, 2:10-23 
Plastic flow, in brittle fracture, 1:27, 29 
mechanism of, 1:28 
Plug welds, 
illustration, 4:33 
uses and limitations, 4:28, 31 
Proportions of rivets, 7:27-28
INDEX

Rat holes, importance, details, 6:40-42
Reinforcement of openings,
doubler plate, 2:23-25, 27-30
face bar, 2:23-27
in beams and stiffeners, 2:31-32
percentage, 2:25-26

Rivet,
length of, for various grips, 7:21-26
proportions, 7:27-28

Riveting,
size and countersink standards, 7:20
symbols and abbreviations, common, 7:31

Riveting combined with welding, 5:18-29, 31
oil-stop, 5:28-29
transition from welded seam to riveted
seam, 5:27
using permanent steel shim, 5:25
using temporary copper shim, 5:24

Sagging, 1:4, 17-18
Scantlings, midships, 1:18
Secondary notch, definition and relation
to crack arrestor protection, 6:2

Section modulus,
calculation of, 1:11-12
definition, 1:9
relation to bending stress, 1:9, 13-14
with hatch openings in deck, 2:4

Shapes, steel, used for stiffeners, weights
of, 7:13-16

Shear forces, vertical,
definition, 1:3
load-bearing intersecting members,
1:20, 22-23
on openings, 2:6-8
significant in hull, 2:6-8

Shear fracture, 1:82

Shear strake,
cut causing crack in "Liberty" ship,
6:31, 33
welded attachment causing failure,
strength-deck scuppers detail, 6:31, 34
6:31, 36

Shear stress, in plastic flow, 1:27-29
maximum, 1:22
significant, 1:23

Ship bottom, 1:14-15
Size and countersink standard of rivets,
7:20

Slag inclusions, 4:55-56, 70

Slot weld,
dimensions, 4:28
illustrations, 4:33-34
uses and limitations, 4:28, 31

Steel, in brittle fracture, 1:27
transition temperature, 1:34

Strain,
compression, 1:2
definition, 1:2
relation to stress, 1:2
tension, 1:2

Strength,
declared, 1:18-19
illustrated, 1:19
longitudinal, 1:9
measure of, 1:9

Strength envelope, described, 1:18
Stress,
at bulkhead intersections, 1:20
bending, description, 1:4
biaxial tensile, see Biaxial stress
caused by deckhouse
compression, definition, 1:1
definition, 1:1
in side shell, 1:17
local, 1:25
localized, 1:20, 22
multiaxial tensile, see Multiaxial
stress, tensile
relation to strain, 1:2
shear, maximum, see Shear stress,
maximum tension, definition, 1:1
uniaxial tensile, 1:27
weld joining, 7:29-30

Stress concentration factor,
circular hole, 2:11-13
definition, 1:25
experimental vs. theoretical determi-
nations, 2:19
in bracket connections, 6:14-17
square hole, 2:14-23

Stringer plate,
deck chock detail, 6:31, 35
Structural discontinuities, definition,
1:22
Structural notches, see Notches, struc-
tural
Superstructures,
causimg structural discontinuities,
1:22-23
end of superstructure detail, 6:32

Tables of,approximate weight of electrode and
31 weld metal in various types of
joints, 7:17-19
arithmetic and geometric properties of
numbers, 7:3-7
common abbreviations on ship's struc-
tural drawings, 7:32-35
common riveting symbols and abbrevi-
at ions, 7:31
conversion of inches (in.) into deci-
mals of a foot (ft), 7:8-9
length of rivets for various grips,
7:21-26
rivet proportions, 7:27-28
riveting size and countersink stand-
ards, 7:20
weight and gage of steel plates, 7:10
weight of steel shapes used for stif-
feners, 7:13-16

Tanker, T2,
attachments of longitudinals to trans-
verse bulkhead, 6:2-3
bracketed connection, hard spot, 6:18
bulkhead intersection, 6:23-24
Tension strain, definition, 1:2
Tension stress, definition, 1:1
distribution in beam in bending, 1:7-8
multiaxial, brittle fracture, 1:27
Transition temperature, 1:34
Triaxial stress, tensile, 1:29-34

Weight, and gage of steel plates, 7:10
of electrode and weld metal in various types of joints, approximate, 7:17-19
of steel shapes used for stiffeners, 7:13-16

Weld joints, automatic welding, 4:35-41
backing straps, data, 4:18
backing weld, 4:13
butt welds, 4:8-19
cracking, 4:66, 73
distortion, 4:41, 43-51
fillet weld, 4:19, 22-27
full penetration, 4:26-27
gas entrapment, 4:56, 71
heat-affected zones, 4:72
incomplete penetration, 4:52-53, 63
lack of fusion, 4:61, 69
overlap, 4:57
penetration, definition, 4:52, 67
plug, 4:28, 31, 33
poor fit-up, 4:59
preheating, 4:74
size reduction, 4:57
slag inclusions, 4:55, 70
slot, 4:28, 31, 33-34
slugging, 4:64
soundness defects, 4:51-72
tucking or corrugating, 4:56
undercut, 4:57
Weld metal and electrode, approximate weight in various types of joints, 7:17-19
Weld stress formulas, 7:29-30
Weld symbols, basic types illustrated, 4:5
definition, 4:4
Welding, advantages in ship construction, 4:1
Welding sequence, block and cascade, 5:4-6
built-up, 5:3, 5
definition, explanations, 5:1
in plated structures, 5:5-7
side shell in panels, 5:10-11
stiffeners in subassemblies, 5:8-10
to prevent ship ends from raising off blocks, 5:13-17
in repair work, 5:30-31
in the vicinity of riveting, 5:18-19
multi-pass welded joints, 5:4-5
overall ship, 5:12-17
symmetrical back-step, 5:2, 4
Welding symbols, sides of joints, arrow-side, other, 4:2-4
standard, definition, 4:1-2
supplementary, 4:8
typical symbols illustrated, 4:6-7
Workmanship, details, good and bad practices, 6:40-48