Introduction to
STEEL SHIPBUILDING

"Almost ready for trials."

Introduction to
STEEL SHIPBUILDING

BY

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INTRODUCTION TO
STEEL SHIPBUILDING

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Respectfully dedicated to

G. GUY VIA

SUPERVISOR OF TRAINING

NEWPORT NEWS SHIPBUILDING AND DRY DOCK COMPANY

WHOSE INTEREST IN THE YOUNG
SHIPBUILDER MADE THIS BOOK
POSSIBLE

PREFACE

This introduction to steel shipbuilding was written as a textbook for the shipbuilding classes at the Apprentice School of the Newport News Shipbuilding and Dry Dock Company. The course in shipbuilding at the Apprentice School is designed to give the student an understanding of the ship's hull as a whole and to enable him to understand the relationship of the many shipyard trades to the finished ship.

The style of the text is one that may be understood easily by a student with a high-school education or the equivalent. The mathematical treatment has been reduced to simple arithmetic, except in Chap. XVI, where trigonometry is used to explain stability. Sufficient trigonometry is presented, however, at the beginning of this chapter to enable the student who has never studied trigonometry to follow the reasoning. No attempt is made to treat every topic in the chapter outline in an exhaustive manner, since this would require thousands of pages and defeat the purpose of the text. However, each topic is developed to a degree sufficient to explain its relationship to the general subject of shipbuilding. As an illustration of this simplification, the subject of strength of materials is treated in the short span of 23 pages. The drawings used throughout the text have been simplified to bare outline sketches. Teaching experience has shown that even the simplest drawings may appear complicated and confusing to the student. Therefore, numerous details have been omitted to allow the important parts to stand out clearly.

Owing to the present war effort, which has brought thousands of new and untrained workers into the shipbuilding industry, G. Guy Via, Supervisor of Training, Newport News Shipbuilding and Dry Dock Company, suggested that the author make this book available to the general public. It is hoped that it will serve as a guide in leading the "trainee" through the confusing learning period and enable him to acquire sufficient background to advance into the higher branches of shipbuilding.

ELIJAH BAKER III.

NEWPORT NEWS, VA.,
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TO THE STUDENT

Although this textbook is written mainly for the apprentice shipbuilder, it is of such a nature that it can be understood readily by those who have other major interests but who also have a desire to learn about ships. It is intended for no particular shipyard trade. Rather, its purpose is to give the apprentices of all trades a *basic understanding of the product they are helping to create.*

Full recognition is taken of the fact that shipbuilding is made up of many trades and that the products of these trades, properly placed in their relation to one another, make up the floating structure known as a ship.

A possible criticism is that the discussion of the ship fitter's art is too extensive. The ship fitter puts the ship together, and its construction is discussed at some length, *but only to give all trades an insight into the make-up of the completed ship.*

Any knowledge that will help the apprentice shipbuilder understand the reasoning behind the construction of the finished product is considered desirable, regardless of the trade he may be mastering.

In order to accomplish our objective, many factors have had to be considered, *viz.:*

1. The new student will probably know nothing about shipbuilding.
2. The new student will have only a high-school knowledge of mathematics, and therefore a complete mathematical treatment of certain phases of our subject is not desirable.
3. The text should be practical rather than theoretical. Enough theory must be presented, however, to explain the practical applications and prevent the course from becoming one of the "dictionary-memory" type.
4. The text should begin in a simple manner and increase in difficulty as it progresses.
5. The content of the course should cover, not only the regular "practical shipbuilding" subjects, but other subjects, such as launching and stability, that will be of interest and use to the student in his later work.

6. The text must be teachable and interesting. These two qualities are correlated and as a consequence are treated together. An effort is made to treat the subject as if it were alive and growing. In many cases, reference has been made to past practice, but only that present practice may better be explained.

7. Riveted as well as welded construction must be considered because riveting as a method of fastening steel together has by no means died out completely. Furthermore, riveted ships already built will be plying the seas for a number of years, and these must be repaired and serviced.

With due consideration of the above factors, the text is arranged in the following manner:

A list of definitions of shipbuilding terms is presented first. These definitions are intended to acquaint the student with general shipyard words and to act as an introduction to the shipbuilder's "language." No attempt is made to cover the terms that will be used in normal shop practice. The student will acquire the language of his shop as he acquires skill in his trade.

A list of symbols and abbreviations used in the text follows.

Chapter I is the key chapter. It explains strength of materials in a manner sufficient for an understanding of the chapters that follow. Little can be accomplished without a thorough knowledge of this chapter. Furthermore, every trade in a shipyard uses the principles of strength of materials discussed here. Chapter I is therefore of particular importance and should be thoroughly mastered by the student.

Chapters II and III discuss the materials used and the methods of joining them.

Chapters IV to XII describe the parts of a ship by groups and discuss and explain their purpose, using the principles set forth in Chap. I.

Chapters XIII to XVIII border on the field of naval architecture but treat these naval architectural subjects from the viewpoint of the man in the yard rather than from the viewpoint of the technician.

Chapter XIX describes the trials that a ship must successfully pass and tells how these trials are conducted.

There are numerous textbooks on naval architecture, marine engineering, ship fitting, strength of materials, mechanics, etc., that will elaborate on the subjects introduced and correlated in this book. As the student increases in knowledge, it is hoped that he will be inspired to continue his studies in the higher branches of shipbuilding. In order to aid the student in choosing worth-while books, a list of advanced books with a brief description of their content is given at the end of the volume.

"The Shipbuilder" by John Ruskin (1819–1900) may serve as an inspirational message to the young shipbuilder.

> Take it all in all, a ship of the line is the most honorable thing that man, as a gregarious animal, has ever produced. Into that he has put as much of his human patience, common sense, forethought, experimental philosophy, self-control, habits of order and obedience, thoroughly wrought handiwork, defiance of brute elements, careless courage, careful patriotism, and calm expectation of the judgment of God, as can be put into a space 300 feet long and 40 feet broad.

SHIPBUILDING DEFINITIONS

1. **Access hole.** Opening in any part of ship's plating used as a passageway while ship is under construction.

✓ 2. **Accommodation ladder.** A portable set of steps suspended over the ship's side for the accommodation of people boarding from small boats.

✓ 3. **Aft.** Toward, at, or near the stern. (Adverb.)

4. **After.** Toward, at, or near the stern. (Adjective.)

5. **Afterpeak.** The compartment in the narrow part of the stern, aft of the last watertight bulkhead.

6. **Afterpeak bulkhead.** Watertight bulkhead farthest aft.

7. **After perpendicular.** A line perpendicular to the base line, intersecting the after edge of the sternpost at the designed water line.

8. **Air port.** A circular window with hinged glass in the ship's side or deckhouse, for light or ventilation; also called *porthole*.

9. **Amidships.** In the vicinity of the middle portion of a ship, as distinguished from the ends.

10. **Angle clip.** A short piece of angle bar used for attachment.

11. **Anneal.** To relieve locked-up stresses by heating and gradual cooling.

12. **Aperture.** The space provided between rudderpost and propeller post for the propeller.

13. **Assemble.** To put together sections of the ship's structure on the skids, in advance of erection on the ways.

14. **Athwartship.** Across the ship, at right angles to the fore-and-aft center line of a vessel.

15. **Auxiliaries.** Various winches, pumps, motors, and other small engines required on a ship.

16. **Backing angle.** A short piece of angle for reinforcing the butt joint or splice of two angles, placed behind the angles joined.

17. **Ballast.** Any weight or weights (usually sea water) used to keep the ship from becoming top-heavy or to increase its draught or trim.

18. **Ballast tank.** Watertight compartment to hold water ballast.

19. **Beam.** An athwartship horizontal member supporting a deck or flat. Also, the extreme width of the ship.

20. **Beam knee.** End of steel deck beam that is split, having one portion turned down and a piece of plate fitted between the split portions, forming a bracket for riveted connection to side frame.

21. **Below.** Below a deck or decks (corresponding to "downstairs").

22. **Bending rolls.** A machine in which power-driven steel rollers are used to give cylindrical curvature to plates.

23. **Bending slab.** Heavy cast-iron perforated slabs arranged to form a large floor on which frames, etc., are bent, after heating in a furnace.

24. **Berth.** A place where a ship is docked or tied up; a place to sleep; a bunk.

25. **Between decks.** The space between any two continuous decks; also called *'tween decks.*

26. **Bevel.** The angle between the flanges of a frame or other member. (Greater than right angle, open bevel; less, closed bevel.)

27. **Bilge.** Curved section between the bottom and the side of a ship; the recess into which all water drains.

28. **Bilge keel.** A fin fitted on the bottom of a ship at the turn of the bilge to reduce rolling. It commonly consists of a plate running fore and aft and attached to the shell plating by welding or by angle bars. It materially helps in steadying a ship and does not add much to the resistance to propulsion.

29. **Bilge pump.** Pump for removing bilge water.

30. **Bilge strake.** Course of plates at the bilge.

31. **Bilge water.** Water collecting in the bottom of a ship owing to leaks, sweat, etc.

32. **Binnacle.** A stand or box for holding and illuminating a compass so that it may be conveniently observed by the steersman.

33. **Bitt.** Tie post for making lines fast on deck.

34. **Bitumastic.** An elastic bituminous cement used in place of paint to protect steel.

35. **Boat deck.** Deck on which lifeboats are kept.

36. **Boiler chock.** Stay brace to prevent fore-and-aft movement of boilers; also called *ramming chock.*

37. **Boiler saddle.** Support for boilers.

38. **Booby hatch.** Watertight covering over an opening on deck of a ship for a stairway or ladder.

39. **Boom.** A long, round, heavy spar pivoted at one end, ordinarily used for hoisting cargo, etc.

40. **Bosom piece.** A short piece of angle riveted inside a butt joint of two angles; butt strap for angle bars; splice piece.

41. **Boss.** The curved swelling portion of the ship's hull around the propeller shaft.

42. **Boss frame.** Hull frame that is bent for clearing propeller-shaft tube.

43. **Boss plate.** Shell plate covering curved portion of hull where propeller shaft passes outboard.

44. **Bow.** The forward end of a ship.

45. **Bracket.** A triangular plate used to connect rigidly two or more parts, such as deck beam to frame or frame to margin plate.

46. **Braze.** To join certain metals by the use of a hard solder.

47. **Breasthook.** A flanged plate bracket joining port and starboard side stringers at their forward end.

48. **Bridge.** Platform extending athwartship at pilothouse; also, an amidships superstructure.

49. **Bridge deck.** Deck at top of bridge superstructure.
50. **Building slip.** Place where the ship is built before launching.
51. **Bulb angle.** Angle shape reinforced at one toe.
52. **Bulb plate.** Narrow plate reinforced on one edge.
53. **Bulb tee.** T bar with toe of web reinforced.
54. **Bulkhead.** A vertical steel partition corresponding to the wall of a room, extending either athwartship or fore and aft.
55. **Bulwark.** The strake of shell plating above a weather deck. It helps to keep the deck dry and also serves as a guard against losing deck cargo or men overboard.
56. **Bunker.** A compartment used for the stowage of coal or other fuel.
57. **Buoyancy.** Ability to float; upward force of water pressure. It is equal to the weight of the displaced liquid.
58. **Buoyancy, reserve.** The additional buoyancy that would result if that part of the vessel's hull which is above the load water line were immersed.
59. **Butt.** The joint formed when two parts are placed edge to edge; the end joint between two plates.
60. **Buttock.** The intersection of a fore-and-aft vertical plane with the molded form of the ship.
61. **Butt strap.** A strip or strap that overlaps both pieces, serving as a connecting strap between the butted ends of plating.
62. **Camber.** The rise or crown of a deck, athwartship.
63. **Cant frame.** A frame not square to the center line, usually at the counter of the vessel.
64. **Capstan.** A revolving device with axis vertical, used for heaving in mooring lines.
65. **Cargo.** The freight carried by a ship.
66. **Cargo batten.** Strip of wood used to keep cargo away from steel hull.
67. **Cargo boom.** Heavy boom used in loading cargo.
68. **Cargo hatch.** Large opening in a deck to permit loading of cargo into holds.
69. **Cargo port.** Opening in a ship's side for loading and unloading cargo.
70. **Carling.** Fore-and-aft member at side of hatch, extending across ends of beams where cut to form hatch.
71. **Casing.** Bulkheads enclosing portion of vessel, such as engine or boiler casing. Also, covering for parts of machinery, such as engine-cylinder casing.
72. **Casting.** A part made by pouring molten metal into a mold and allowing it to cool.
73. **Caulk (calk).** To make a joint watertight.
74. **Center line.** The fore-and-aft middle line of the ship, from stem to stern.
75. **Chafing plate.** Bent plate for minimizing chafing of ropes, as at hatches.
76. **Chain locker.** Compartment in forward lower portion of ship in which anchor chain is stowed.

77. **Chain pipe.** Pipe for passage of chain from windlass to chain locker.
78. **Charthouse.** Small room adjacent to steering wheel for charts and navigational instruments.
79. **Chock.** A heavy fitting through which ropes or hawsers may be led. Saddle or seat of wood or metal.
80. **Chock, roller.** A chock with a sheave to prevent chafing of rope.
81. **Classification society.** An institution that supervises the construction of vessels under established rules, tests all materials for hulls, machinery, and boilers, proof-tests all anchors and chains, and issues a certificate of classification.
82. **Cleat.** A fitting having two arms or horns around which ropes may be made fast. A clip on the frames of a ship to hold the cargo battens in place.
83. **Coaming.** The vertical boundary of a hatch or skylight.
84. **Cofferdam.** Narrow empty space between two oiltight bulkheads to prevent leakage of oil into compartments adjoining oil tanks.
85. **Collision bulkhead.** First watertight bulkhead from bow of ship.
86. **Companion way.** An access hatchway in a deck, with a ladder leading below, generally for the crew's use.
87. **Compartment.** A subdivision of space or room in a ship.
88. **Compass.** A device for indicating the magnetic north, by means of a magnetized bar or needle, or the true north, through the action of a gyroscope.
89. **Compression.** Stress caused by pushing.
90. **Counter.** Overhang of stern of a ship.
91. **Countersink.** The taper of a rivet hole for a flush rivet.
92. **Cowl.** Hood-shaped top of ventilator pipe.
93. **Cradle.** A form on which furnaced plates are shaped. The support in which a ship lies during launching, called *launching cradle*.
94. **Crow's-nest.** An elevated lookout station on a ship, usually attached to forward side of foremast.
95. **Davit.** A crane arm for handling anchors, lifeboats, stores, etc.
96. **Dead flat.** The portion of a ship's form or structure that has the same transverse shape as the midship section.
97. **Dead rise.** Rise or slant up athwartship of the bottom of a ship from the keel to the bilge.
98. **Deadweight.** The total weight of cargo, fuel, water, stores, passengers and crew, and their effects, that a ship can carry.
99. **Deck.** The deck on a ship, corresponding to the floor in a building.
100. **Deck beam.** Athwartship support of deck.
101. **Deck, bulkhead.** The uppermost continuous deck to which all the main transverse watertight bulkheads are carried. This deck should be watertight in order to prevent any compartment that is open to the sea from flooding the one adjacent to it.
102. **Deckhouse.** Shelter built on deck, not extending to the sides.
103. **Deck, main.** The principal deck, usually that immediately below weather deck.

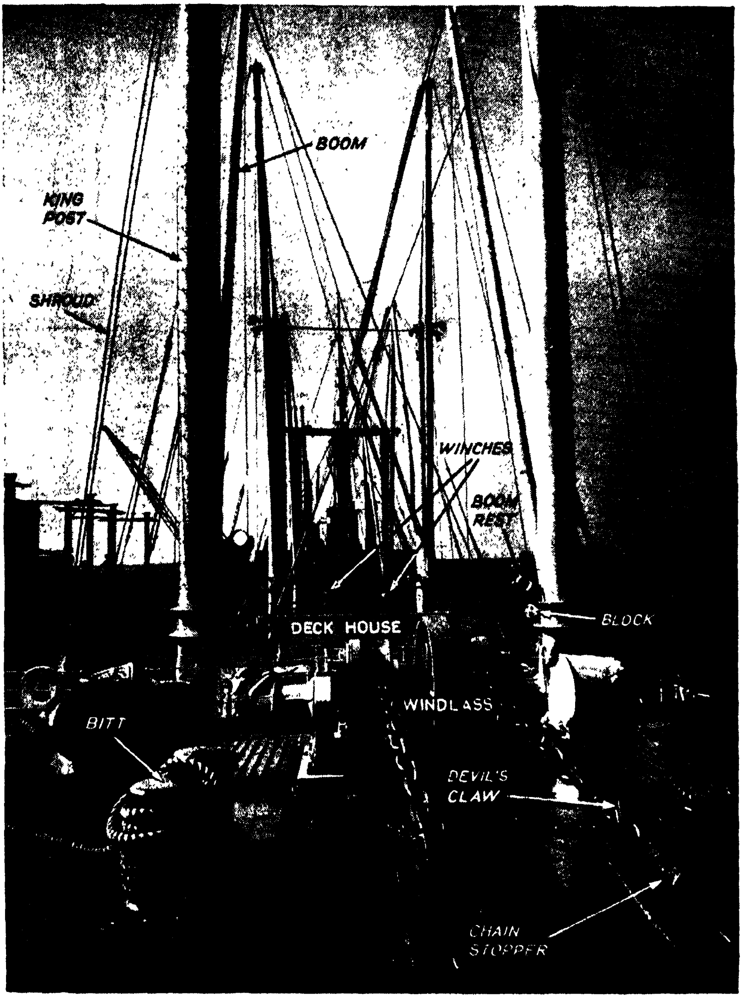

FIG. 2.—Standing on the forecastle deck and looking aft on a C-2 cargo vessel. This is the same ship shown in Fig. 1.

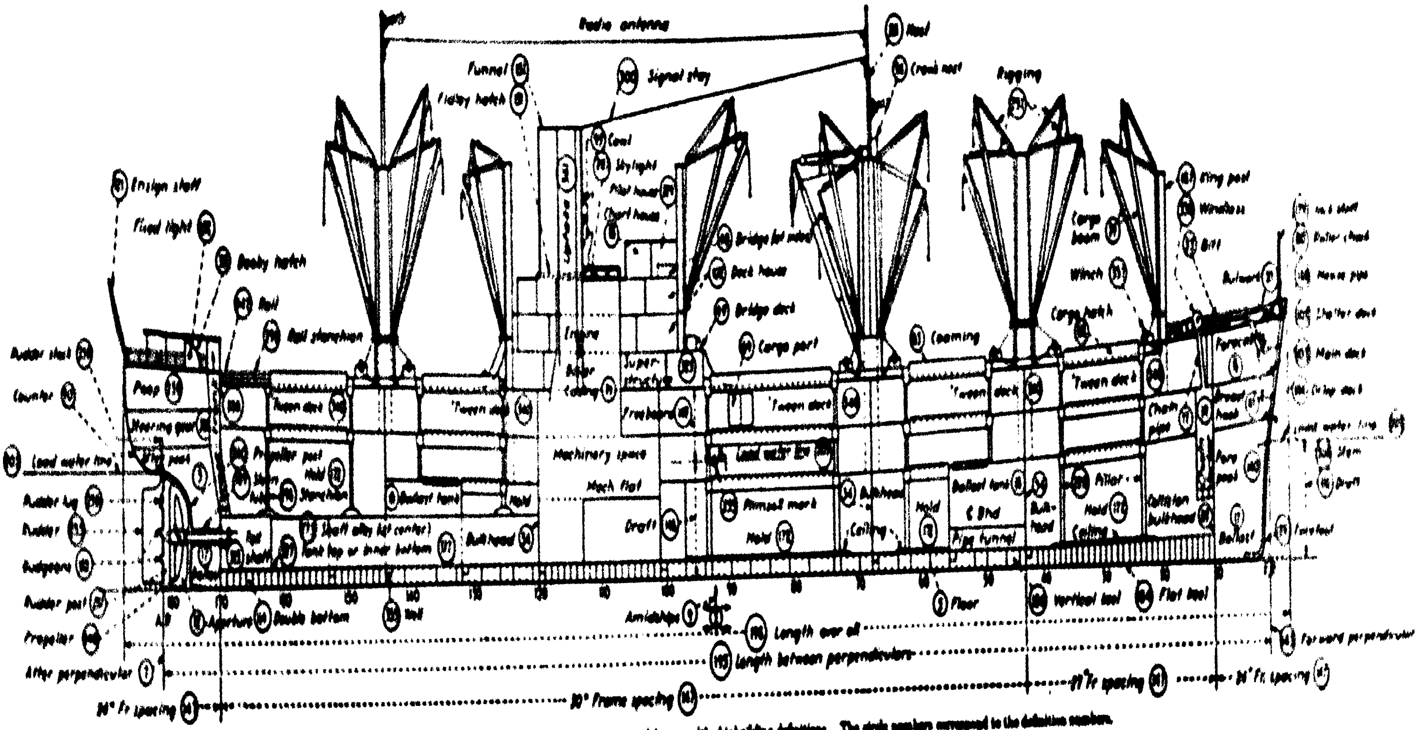

Fig. 1.—Inboard profile of a Maritime Commission C-2 cargo vessel for use with shipbuilding definitions. The circle numbers correspond to the definition numbers.

104. **Deck, orlop.** A partial deck in hold.

105. **Deck, shelter.** Full deck, lightly constructed, above regular weather deck, forming complete superstructure, nominally not closed in, but actually available for cargo.

106. **Deck stringer.** The strake of plating that runs along the outer edge of a deck.

107. **Deck, weather.** Full deck with no overhead protection, watertight.

108. **Deflection.** The amount of bending.

109. **Derrick.** A device for hoisting heavy weights, cargo, etc.

110. **Die.** A tool, having several cutting edges, used for cutting threads. In drop-forging work, a template tool used to stamp out a piece of work in one operation.

111. **Displacement.** The total weight of the ship when afloat, including everything on board, equals weight of water displaced. Displacement may be expressed either in cubic feet or long tons. A cubic foot of sea water weighs 64 lb., and one of fresh water 62.5 lb.; consequently, one long ton is equal to 35 cu. ft. of sea water or 35.9 cu. ft. of fresh water. One long ton equals 2,240 lb.

112. **Docking keel.** Keel on each side, and in plane of regular keel, used to distribute the weight in dry dock in the case of large ships. (Seldom used except on largest naval ships.)

113. **Dog.** A small bent metal fitting used to hold doors, hatch covers, manhole covers, etc., closed. A bent bar of round iron used for holding shapes on bending slab.

114. **Double bottom.** Compartments at bottom of ship between inner and outer bottoms, used for ballast tanks, oil, water, fuel, etc.

115. **Doubling plate.** A plate fitted outside or inside of and faying against another to give extra strength or stiffness.

116. **Draught.** The vertical distance of the lowest point of the ship below the surface of the water when she is afloat.

117. **Draught marks.** The numbers painted at the bow and stern of a vessel to indicate how much water she draws. These marks are 6 in. high and spaced 12 in. apart vertically.

118. **Driftpin.** A small tapered tool driven through rivet holes and used to draw adjoining plates or bars into alignment with each other.

119. **Drop strake.** A strake that is terminated before it reaches the bow or stern. The number of strakes dropped depends on the reduction of girth between the midship section and the ends.

120. **Dry dock.** A dock in which a ship's hull may be kept out of water during construction or repair. Three types are used: (1) the graving dock, a basin excavated near a waterway, with a gate to exclude the water after pumping out; (2) the floating dock, a hollow structure of wood or steel, which is sunk to receive the ship to be docked and is pumped out to lift it from the water; (3) the marine railway, a cradle of wood or steel on which the ship may be hauled out of water along inclined tracks leading up the bank of a waterway.

121. **Ensign staff.** A flagstaff at stern of vessel from which the national ensign may be flown.

122. **Erect.** To hoist into place and bolt up on the ways fabricated and assembled parts of a ship's hull, preparatory to riveting or welding.

123. **Even keel.** A ship is said to be on an even keel when the keel is level or parallel to the surface of the water and the hull is not listed or tipped sideways.

124. **Expansion trunk.** Upper portion of tank on an oil tanker, used to allow for the expansion of oil when temperature rises.

125. **Fabricate.** To process hull material in the shops prior to assembly or erection. In hull work fabrication consists in shearing, shaping, punching, drilling, countersinking, scarfing, rabbeting, beveling, etc.

126. **Fair (fair up).** To correct or fair up a ship's lines on mold-loft floor; to assemble the parts of a ship so that they will be fair, *i.e.*, without kinks, bumps, or waves; to bring the rivet holes into alignment.

127. **Fantail.** Fan-shaped plate on center line of ship on overhanging stern. Plates forming overhang at stern.

128. **Fathom.** A measure of length, equivalent to 6 linear feet, used for depths of water and lengths of rope or chain.

129. **Faying surface.** The surface between two adjoining parts.

130. **Fender.** Heavy strip of wood or steel attached to the side of the vessel, running fore and aft, above the water line, for the purpose of preventing rubbing or chafing of the hull.

131. **Fiddley hatch.** Hatch around smokestack and uptake, for ventilation of boiler room.

132. **Fixed light.** Circular window with fixed glass in side of ship, door, skylight cover, etc.

133. **Flagstaff.** A light spar or pole from which a flag may be displayed.

134. **Flange.** Portion of a plate or shape at or nearly at right angles to main portion; to flange is to bend over to form such an angle.

135. **Floor.** A plate placed vertically in the bottom of a ship, usually on every frame and running athwartship from bilge to bilge.

136. **Floor plate.** Vertical plate in bottom (see Floor).

137. **Fore and aft.** In line with the length of the ship; longitudinally.

138. **Forecastle.** The forward upper portion of the hull, usually used for the crew's quarters.

139. **Forefoot.** The part of the stem that curves aft to meet the keel.

140. **Forepeak.** A large compartment, or tank, at the bow in the lower part of the ship.

141. **Forging.** A piece of metal hammered, bent, or pressed to shape while white-hot.

142. **Forward.** Near, at, or toward the bow of the ship.

143. **Forward perpendicular.** A line perpendicular to the base line, intersecting the forward edge of the stem at the designed water line.

144. **Foundations, main.** Supports for boilers and engines.

145. **Foundations, auxiliary.** Supports for small machinery such as winches and also for condensers, heaters, etc.

146. **Frame.** One of the ribs forming the skeleton of a ship.

147. **Frame spacing.** The fore-and-aft distance between heel and heel of adjacent transverse frames along the center line.

148. **Frame, web.** Heavy side or continuous frame, made with web plate between its members.
149. **Freeboard.** The distance from the water line to the top of the weather deck at side.
150. **Freeing port.** A large opening in the bulwark just above the deck, so that when seas break over the deck the ship can clear itself of the sea water quickly. Rods or bars are generally fitted across freeing ports to prevent men being washed overboard through these openings.
151. **Funnel.** Smokestack of a vessel.
152. **Furnace.** Heater or large forge for heating plates or shapes for bending. To furnace is to bend by heating in furnace.
153. **Galley.** A cookroom or kitchen on a ship.
154. **Galvanizing.** Coating metal parts with zinc for protection from rust.
155. **Gangway.** A passageway, a ladder, or other means of boarding a ship.
156. **Gasket.** Flexible material used to pack joints in machinery, piping, doors, hatches, etc., to prevent leakage of liquids or gases.
157. **Girder.** A continuous member running in a fore-and-aft direction under the deck for the purpose of supporting the deck beams and deck. The girder is generally supported by widely spaced pillars.
158. **Girth.** Distance around a vessel's frame from gunwale to gunwale.
159. **Grating.** A structure built out of wooden strips or metal bars, to form a walkway above a deck or opening without interference with light, drainage, or ventilation.
160. **Gross tonnage.** A figure obtained by dividing the total volume of the ship, in cubic feet, by 100, after the omission of all spaces exempted from measurement by law.
161. **Ground ways.** Timbers fixed to the ground, under the hull on each side of the keel, on which ship slides during launching.
162. **Gudgeons.** Bosses on sternpost drilled for pins (pintles) for rudder to swing on.
163. **Gunwale.** Junction of deck and shell at top of sheer strake.
164. **Gunwale bar.** Angle bar that connects deck stringer plate and shell plates at weather deck.
165. **Gusset plate.** Triangular plate that connects members or braces.
166. **Hatch.** Opening in deck for passage of cargo, etc.
167. **Hatch beam.** Portable beam across the hatch to support covers; also, strong beam at ends of hatch.
168. **Hawsepipe.** Casting extending through deck and side of ship for passage of anchor chain, and for stowage of anchor in most cases.
169. **Heeling.** Tipping of a vessel to one side; also called *listing*.
170. **Helm.** A term used to designate the rudder's position as controlled by the tiller, wheel, or steering gear. To *port the helm* means to put the tiller to port, the vessel's head and the rudder both turning the opposite way, or to starboard.
171. **Hogging.** Straining of the ship that tends to make the bow and stern lower than the middle portion.
172. **Hold.** The spaces below deck allotted for the stowage of cargo.

173. **Hold beams.** Beams in a hold, similar to deck beams, but having no plating or planking on them.
174. **Horseshoe plate.** Small horseshoe-shaped plate around rudderstock on shell of ship, for the purpose of preventing water backing up into the rudder trunk.
175. **Hull.** The body of a ship, including shell plating, framing, decks, and bulkheads.
176. **Inboard.** Inside the ship, toward the center line.
177. **Inner bottom.** Plating forming the upper boundary of the double bottom. Also called *tank top*.
178. **Intercostal.** Made in separate parts, between frames, beams, etc.; the opposite of "continuous."
179. **Jack Staff.** A flagpole at bow of vessel, from which the union jack may be displayed.
180. **Joggle.** To offset a plate or shape to save the use of liners.
181. **Keel.** The principal fore-and-aft member of a ship's frame, which runs along the bottom and connects the stem and stern and to which is attached the frames of the ship. The backbone of the ship's frame.
182. **Keel, bar.** A keel that protrudes through the bottom.
183. **Keelblocks.** Heavy blocks on which ship rests during construction.
184. **Keel, flat.** A fore-and-aft row of flat plates end to end on the center line, running along the bottom of the ship from stem to stern, the forward and after plates being dished up into a U shape to fit the stem and stern castings.
185. **Keelson, side.** Fore-and-aft member placed on each side of, and similarly to, the center vertical keel.
186. **Keel, vertical.** Vertical plate on center line, used as reinforcement for longitudinal flat keel; sometimes called *center keelson*.
187. **King post.** A stub mast, outboard from center line, to carry cargo booms; also called *Samson post*.
188. **Knot.** A speed measurement of 1 nautical mile per hr., a nautical mile being about 1⅐ land miles (6,080 ft. or 1/60 deg. at the equator).
189. **Knuckle.** A sharp bend in a plate or shape.
190. **Knuckle plate.** A plate bent to form a knuckle.
191. **Ladder.** Inclined steps aboard ship, taking the place of stairs.
192. **Lap.** A joint in which one part overlaps the other, the use of a butt strap being thus avoided.
193. **Launching.** The operation of placing the hull in the water by allowing it to slide down the launching ways. During launching the weight of the hull is borne by the cradle and sliding ways, which are temporarily attached to the hull and slide with it down the ground ways.
194. **Laying off.** Marking plates, shapes, etc., for fabrication.
195. **Length between perpendiculars.** The length of a ship measured from the forward perpendicular to the after perpendicular.
196. **Length over all.** The length of a ship measured from the forwardmost point of the stem to the aftermost point of the stern.

197. **Lift.** To "lift" a template is to make it from measurements taken from the job.

198. **Lightening hole.** A large hole cut in a structural member to reduce its weight.

199. **Limber hole.** A hole of a few inches diameter cut in a floor plate to allow water to drain through it near the bottom.

200. **Liner.** A flat or tapered strip placed under a plate or shape to bring it in line with another part that it overlaps; a filler.

201. **Lines.** The plans of a ship that show its form.

202. **Listing.** See Heeling.

203. **Load water line.** Line of surface of water on a ship when loaded to maximum allowance in salt water in the summertime.

204. **Longitudinal.** A fore-and-aft structural member running parallel or nearly parallel to the center vertical keel, along the inner bottom, shell, or deck.

205. **Main deck.** See Deck, main.

206. **Manhole.** A round or oval-shaped hole cut in a ship's divisional plating, large enough for a man to pass through.

207. **Manifold.** A box casting containing several valves, to which pipe lines are led from various compartments and pumps on a ship, so as to allow any tank to be connected to one or more pumps.

208. **Margin angle.** Angle bar connecting margin plate to shell.

209. **Margin bracket.** A bracket connecting the frame to the margin plates.

210. **Margin plate.** Any one of the outer row of plates of the inner bottom, connecting with the shell plating at the bilge.

211. **Mast.** A large long spar, placed nearly vertical on the center line of a ship.

212. **Mess room.** Dining room for crew.

213. **Midship.** Center of ship, located at the mid-point between the forward and after perpendiculars.

214. **Midship section.** A plan showing a cross section of the ship through the middle, or amidships. This plan shows sizes of frames, beams, brackets, etc., and thicknesses of plating.

215. **Mold loft.** Usually the second floor of a building with a large smooth floor for laying down the lines of a vessel to actual size and making templates from them for the structural work entering into a hull.

216. **Mooring.** Securing a ship in position by several lines or cables so that she cannot move or swing.

217. **Mooring ring.** A round or oval casting inserted in the bulwark plating of a ship, through which the mooring lines, or hawsers, are passed.

218. **Mold.** A light pattern of a part of a ship. Usually made of thin wood or paper. Also called a *template.*

219. **Net tonnage.** A figure obtained by making deduction from the gross tonnage for space not available for carrying cargo or passengers.

220. **Oiltight.** Riveted, caulked, or welded to prevent oil leakage.

221. **Outboard.** Away from the center line, toward the side of a ship.

222. **Overboard.** Outside, over the side of a ship, in the water.
223. **Overhang.** Portion of the hull over and unsupported by the water.
224. **Oxter plate.** A bent shell plate that fits around upper part of sternpost; also called *tuck plate.*
225. **Packing.** Material put between plates or shapes to make them watertight. Wooden blocks and wedges supporting ship on sliding ways.
226. **Panting.** The in-and-out vibrations of the frames and shell plating due to variation of wave pressure. Most noticeable in the bow and stern.
227. **Peak.** The space at the extreme lower bow or stern.
228. **Pillar.** Vertical member or column giving support to a deck girder. Also called *stanchion.*
229. **Pilothouse.** Deckhouse containing steering wheel, compass, charts, etc., used for navigation of a ship; generally placed forward, near navigating bridge.
230. **Pintles.** The pins or bolts that hinge the rudder to the gudgeons on the sternpost.
231. **Planking.** Wood covering for decks, etc.
232. **Platen.** Skids on which structural parts are assembled.
233. **Platform.** A flat deck, without camber or sheer.
234. **Plating.** The plates of a hull, a deck, a bulkhead, etc.
235. **Plimsoll mark.** A mark stenciled in and painted on the side of a vessel, designating the depth to which the ship may be loaded.
236. **Poop.** The after upper portion of the hull, usually containing the steering gear.
237. **Port.** The left-hand side of a ship (looking toward the bow.) An opening in the side of a ship for loading cargo, etc.
238. **Porthole.** A circular opening in the ship's side. See Air port.
239. **Profile.** Side elevation or fore-and-aft centerline section of a ship's form or structure.
240. **Propeller.** A revolving device that drives the ship through the water, consisting of three or four blades, resembling in shape those of an electric fan. Sometimes called a *screw* or *wheel.*
241. **Propeller post.** Forward post of stern frame, through which propeller shaft passes.
242. **Quadrant.** A casting, forging, or built-up frame, on the rudderhead, to which the steering chains are attached.
243. **Quarter deck.** That portion of the weather deck nearest the stern.
244. **Quarters.** Living or sleeping rooms.
245. **Rabbet.** A depression or offset of parallel depth designed to take some other adjoining part, as, for example, the rabbet in the stem to take the shell plating.
246. **Racking.** Straining of a ship that tends to make the decks and bottom no longer square with the sides.
247. **Rail.** The rounded section at the upper edge of the bulwarks, or a horizontal pipe forming part of a railing fitted instead of a bulwark.
248. **Reaming.** Enlarging a rivet hole by means of a revolving, cylindrical, slightly tapered tool with cutting edges running along its sides.

249. Reverse frame. An angle bar or other shape riveted to the inner edge of a transverse frame to reinforce it.

250. Ribband. A fore-and-aft wooden strip or heavy batten used to support the transverse frames temporarily after erection and to keep them in a fair line; also, any similar batten for fairing a ship's structure.

251. Rigging. Ropes, wire ropes, lashings, etc., used to support masts, spars, booms, etc., and also for the handling and placing on board the ship of its cargo.

252. Rivet. A short, round metal connection used to fasten two or more members together by clinching after heating red-hot.

253. Rose box. A galvanized iron box with the sides perforated by small holes, the combined area of which equals at least twice the area of the bilge suction pipe. The object is to collect bilge water for pumping out and to prevent refuse from clogging the pumps.

254. Rough bolt. To bolt a plate or frame to ship until it can be faired for reaming.

255. Rudder. A large heavy fitting hinged to the stern frame and used for steering the ship.

256. Rudder Lug. A projection cast or fitted to the forward edge of the rudder frame for the purpose of taking the pintle.

257. Rudderpost. After post of stern frame to which rudder is hung. Also called *sternpost.*

258. Rudderstock. Shaft of rudder, which extends through counter of ship above main part of rudder.

259. Rudder stop. Lug on stern frame or a stanchion at each side of quadrant, to limit the swing of the rudder.

260. Sagging. Straining of the ship that tends to make the middle portion lower than the bow and stern.

261. Samson post. A heavy vertical post that supports cargo booms; also called *king post.*

262. Scantlings. The dimensions of the frames, girders, plating, etc., that go into a ship's structure. For merchant ships these dimensions are taken from the classification-society rules.

263. Scarf. A connection made between two pieces by tapering their ends so that they will mortise together in a joint of the same breadth and depth as the pieces connected. It is used on bar keels, stem and stern frames, and other parts.

264. Screen bulkhead. A bulkhead, dust-tight but not watertight, usually placed between engine and boiler rooms.

265. Scupper. Drains from weather decks to carry off accumulated sea and rain water.

266. Scupper pipe. Pipe that drains water from scuppers through side of a ship.

267. Scuttle. A small opening, usually circular in shape, and generally fitted in decks to provide access or to serve as a manhole or opening for stowing fuel, water, and small stores.

268. **Scuttlebutt.** A drinking fountain aboard ship. Also the Navy term for rumors aboard ship.
269. **Sea chest.** A casting fitted to shell of a vessel for the purpose of supplying water from the sea to the condenser and pumps.
270. **Seam.** Fore-and-aft joint of shell plating, deck and tank-top plating, or lengthwise side joint of any plating.
271. **Seam strap.** Strap connecting plates to form a flush seam.
272. **Shaft.** Long, round, heavy forging connecting engine and propeller.
273. **Shaft alley (shaft tunnel).** A watertight casing covering propeller shaft, large enough to walk in, extending from engine room to afterpeak bulkhead, to provide access and protection to shaft in way of after cargo holds.
274. **Shape.** Bar of constant cross section throughout its entire length, such as a channel, T bar, or angle bar.
275. **Shear.** A stress that tends to cause the adjacent parts of a body to slide over each other.
276. **Shear line.** Line to shear or cut to.
277. **Shears.** Large machine for cutting plates and shapes.
278. **Sheer.** Fore-and-aft curvature of a deck.
279. **Sheer plan.** Side elevation of ship's form; a profile.
280. **Sheer strake.** Top full course of shell plates at strength deck level.
281. **Shell expansion.** A plan showing details of all plates of the shell.
282. **Shell landings.** Points on the frames showing where the edges of shell plates come.
283. **Shell plating.** The plates forming the outer skin of the hull.
284. **Shelter deck.** See Deck, shelter.
285. **Shore.** A brace or prop.
286. **Skids.** Timbers on which structural parts are assembled.
287. **Skylight.** An opening in a deck to give light and air to the compartment below it, usually fitted with hinged covers having fixed lights in them.
288. **Sliding ways.** See Launching.
289. **Slop chute.** Chute for dumping garbage overboard.
290. **Smokestack.** A metal chimney or passage through which the smoke and gases are led from the boiler uptakes to the open air.
291. **Sounding pipe.** Pipe in oil or water tank used to measure depth of liquid in tank.
292. **Spar.** A long, round, wooden timber used to carry rigging.
293. **Spar deck.** Upper deck.
294. **Split frame.** A channel or Z-bar frame split at the bilge so that one flange may connect to the shell plating and the other to the tank top
295. **Stability.** Tendency of a ship to return to her original position when inclined away from that position.
296. **Stanchion.** A pillar or upright post; a vertical rail post.
297. **Staple angle.** A piece of angle bent in the shape of a staple or other irregular shape.
298. **Stapling.** Collars, forged of angle bars, to fit around continuous members passing through bulkheads, for watertightness; now obsolete.

299. Starboard. Right side of a ship looking forward.

300. Stay. A guy line.

301. Stealer. A plate extending into an adjoining strake in the case of a drop strake. Stealer plates are located in the bow and stern, where the narrowing girth compels a reduction in the number of strakes.

302. Steering gear. Apparatus for controlling the rudder.

303. Steering wheel. Wooden or metal wheel having its spokes extended through the rim for handholds and used to control rudder by rope leads or through steering engine.

304. Stem. Forging or casting forming extreme bow of ship, extending from keel to forecastle deck.

305. Step. To set in place, as applied to a mast.

306. Stern. After end of a ship.

307. Stern frame. Large casting or forging attached to after end of keel to form ship's stern. Includes rudderpost, propeller post, and aperture for propeller.

308. Sternpost. After part of stern frame to which rudder is attached; also called *rudderpost.*

309. Stern tube. Tube through stern through which propeller shaft passes.

310. Stiffener. An angle bar, T bar, channel, built-up section, etc., used to stiffen plating of a bulkhead, etc.

311. Stopwater. Canvas soaked in red lead or other material, fitted between two metal parts to make a watertight joint.

312. Storm valve. A check valve in a pipe opening above water line on a ship.

313. Stow. To put away.

314. Stowage. Everything for support and fastening of articles to be stowed, as anchor or boat stowage.

315. Strain. Alteration in shape or dimensions resulting from stress.

316. Strake. A course or row of shell or other plating.

317. Stress. Force per unit area.

318. Stringer. A fore-and-aft member used to give longitudinal strength to shell plating. According to location stringers are called *hold stringers*, *bilge stringers*, *side stringers*, etc.

319. Stringer plate. Deck plate at outboard edge of deck, connected to the shell of a ship by welding or with an angle; also, web of built-up side stringers.

320. Strongback. Portable supporting girders for hatch covers; a rig used in straightening bent plates; a bar for locking cargo ports.

321. Strum box. The enlarged terminal on the suction end of a pipe and forming a strainer that prevents the entrance of material likely to choke the pipe.

322. Strut. Outboard support for propeller tail shaft, used on ships with more than one propeller.

323. Superstructure. A structure extending all the way across the ship, built immediately above the uppermost complete deck.

324. Swash plate. Baffle plate in tank to prevent excessive swashing.

325. **Tail shaft.** Short section of propeller shaft extending through stern tube and carrying propeller.

326. **Tank.** Compartment for liquid or gas, either built into ship's structure or independent of it and supported by an auxiliary foundation.

327. **Tank top.** The inner-bottom plating.

328. **Template.** A mold or pattern made to the exact size of a piece of work that is to be laid out or formed and on which such information as the position of rivet holes and size of laps is indicated. Common types are made out of paper or thin boards.

329. **Tension.** Stress caused by pulling.

330. **Thrust bearing.** Bearing on propeller line shaft, which relieves the engine from the driving force of the propeller and transfers this force to the structure of the ship.

331. **Tie plank.** The fastening holding the ship from sliding down the ways; also called *solepiece.*

332. **Tie plate.** A single fore-and-aft course of plating attached to deck beams under wood deck to give extra strength.

333. **Tiller.** Arm attached to rudderhead for operating rudder.

334. **Transom.** The aftermost transverse frame.

335. **Transverse.** Athwartship at right angles to the keel.

336. **Transverse frames.** Athwartship members forming the ship's "ribs."

337. **Trim.** To shift ballast to make a ship change its position in the water. The trim is the excess of draught forward or aft.

338. **Trunk.** Steel casing passing through deck and forming an enclosure for ladders or cargo hatches.

339. **Tumble home.** Slant inboard of a ship's side above the bilge.

340. **'Tween Decks.** The space between any two continuous decks; also called *between decks.*

341. **Uptake.** A sheet-metal conduit connecting the boiler smokebox with the base of the smokestack. It conveys the smoke and hot gases from the boiler to the stack.

342. **Ventilator.** A device for furnishing fresh air to compartments below deck.

343. **Vertical keel.** Row of vertical plates extending along center of flat plate keel. Sometimes called *center keelson.*

344. **Voice tube.** Large speaking tube.

345. **Warping bridge.** Bridge at after end of hull, used while docking a ship; also called *docking bridge.*

346. **Water line.** The line of the water's edge when the ship is afloat; technically, the intersection of any horizontal plane with the molded form of the ship.

347. **Watertight.** So constructed as to prevent the passage of water.

348. **Watertight flat.** Short section of watertight deck, forming a step in a bulkhead or the top of a watertight compartment or water tank.

349. **Waterway.** A narrow passage along the edge of the deck for the drainage of the deck. A gutter.

350. **Ways.** Timbers, etc., on which a ship is built or launched.

351. **Weather deck.** See Deck, weather.
352. **Web.** The vertical portion of a beam, the athwartship portion of a frame, etc.
353. **Web frame.** A built-up member consisting of a web plate, to the edges of which are attached single or double bars if riveted, or a face plate, if welded.
354. **Welding.** Making a joint of two metal parts by fusing the metal in between them or by forging together at welding heat.
355. **Well.** Space in bottom of a ship to which bilge water runs so that it may be pumped out.
356. **Wheel.** Nickname for propeller; steering-gear control.
357. **Winch.** A small hoisting engine.
358. **Windlass.** The machine used to hoist the anchors.
359 **Wind scoop.** A device used to divert air into a compartment of a ship through an air port.

ABBREVIATIONS

A	Area of water plane, or of a stressed section
A.B.S.	American Bureau of Shipping
AP	After perpendicular
B	Breadth or beam of ship, or center of buoyancy with ship erect
B'	Center of buoyancy, ship inclined
BL	Base line
BM	Distance from *B* to *M* (metacentric radius)
B.M.	Bending moment
BP	Between perpendiculars
CB	Center of buoyancy
CF	Center of flotation (*CG* of water plane)
CG	Center of gravity
CL	Center line
CI	Common interval
D	Depth of ship
d	Draught of ship
Δ (delta)	Displacement of ship in tons of 2,240 lb.
FP	Forward perpendicular
F.S.	Factor of safety
G	Center of gravity
GM	Distance from *G* to *M*, or metacentric height
GZ	Righting lever
I	Moment of inertia of ship's water plane.
i	Moment of inertia of free surface within ship
K	Keel, intersection of center line and base line
KB	Distance from *K* to *B*, or *VCB*
KG	Distance from *K* to *G*, or *VCG*
KM	Distance from *K* to *M*
L	Length of ship
LBP	Length between perpendiculars
LOA	Length over all
LWL	Length on water line or load water line.
LCB	Longitudinal center of buoyancy
LCF	Longitudinal center of flotation (*LCG* of water plane)
LGM	Longitudinal *GM*, or longitudinal metacentric height
LI	Longitudinal interval
M	Metacenter
NA	Neutral axis
SM	Simpson's multipliers
S_s	Average shear stress

T_s	Average tensile stress
V	Volume of ship's displacement, or ship's speed in knots
v	Volume of tank
VCB	Vertical center of buoyancy
VCG	Vertical center of gravity
W	Weight
WL	Water line

INTRODUCTION TO STEEL SHIPBUILDING

CHAPTER I

GENERAL DISCUSSION OF STRENGTH OF MATERIALS

The majority of the steel items that go into the construction of a steel vessel can be divided into four general groups known as *beams*, *plates*, *columns*, and *shafts*. Each group has its own particular function to perform; in addition, it may also function as a part of and in coordination with any of the other three groups.

As an illustration of this coordination of functions, in a longitudinal-strength calculation we consider that the hull of a vessel acts as a gigantic but rather unusual box-type compound beam or girder made up of thousands of smaller parts, all acting as a unit to give strength to the ship as a whole. Basing the hull-girder strength calculation on this assumption, we proceed to support this compound girder first on a standard trochoidal wave[1] with the crests at the ends of the vessel (Fig. 3) and then on the same type of wave with the crest amidships (Fig. 5). Knowing the type of support and the loads that are to be supported, we can calculate the stresses set up within the girder. Our problem then becomes one of constructing the hull girder in such a manner that it has sufficient strength to resist these stresses. Figures 3 and 5 illustrate the type of support, and Figs. 2 and 6 show the probable method of failure that results from overstressing the vessel when it is supported as indicated.

When we have determined the stresses that the vessel and its parts must withstand when acting as a beam, we can determine the scantlings, or sizes, of the various component parts—beams,

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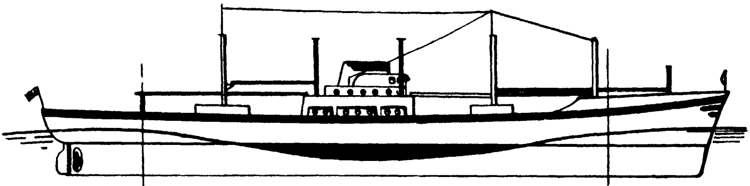
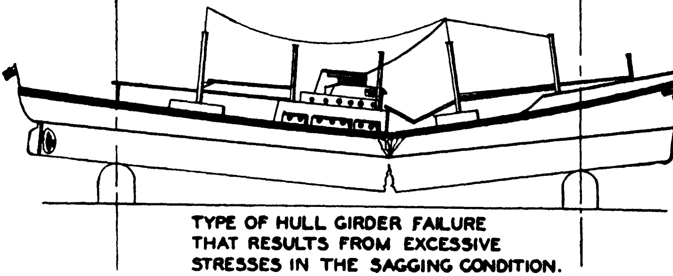
[1] The standard trochoidal wave is one whose length from crest to crest is equal to the length of the ship and whose height is one-twentieth of its length.

plating, pillars, etc.—that make up the vessel. The component parts that act with the hull beam, or girder, also must withstand certain local stresses due to concentrated weights such as masts and turbines. These localized weights are compensated for individually by simply making the affected parts of sufficient scantling, or size, to withstand the heavy loads that will be placed on them.



VESSEL SUPPORTED ON A WAVE WHOSE CRESTS ARE AT BOW AND STERN. THE VESSEL IS SUPPORTED AT THE ENDS AND IS SAID TO BE IN THE "SAGGING CONDITION."

FIG. 3.



TYPE OF HULL GIRDER FAILURE THAT RESULTS FROM EXCESSIVE STRESSES IN THE SAGGING CONDITION.

FIG. 4.

FIGS. 3 and 4.

The erroneous idea should not be conceived from the above that *a ship's hull is only a beam*, for a ship's hull experiences many stresses that a simple beam never encounters. While we can calculate very simply the required size of beam to carry a certain load in a building, it is much more difficult to apply these calculations to a "beam" that is to drive through heavy seas, rapidly accelerating downward as it pitches along a wave slope, only to have its direction changed and be thrown violently upward by the succeeding wave, and at the same time rolling from side to side, receiving terrific blows from the sea, and being stressed further by internal vibration from its own propulsion machinery and propellers.

To understand completely the structural design of a ship subjected to such complex and often unknown forces would require the use of higher mathematics and an extensive study of strength of materials. We cannot hope to cover this broad field in this text. We can, however, study some of the simpler and more apparent aspects of strength of materials and, by using these as a basis, proceed to discuss intelligently the structure of a ship.

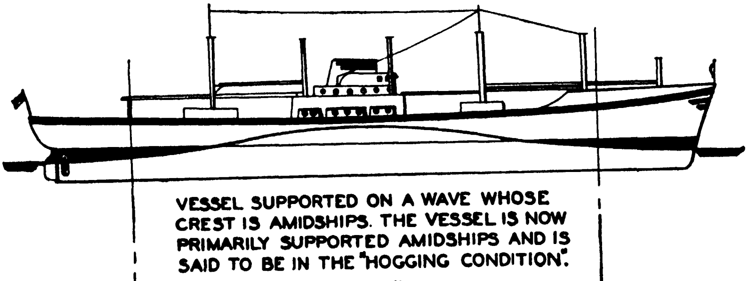


Fig. 5.

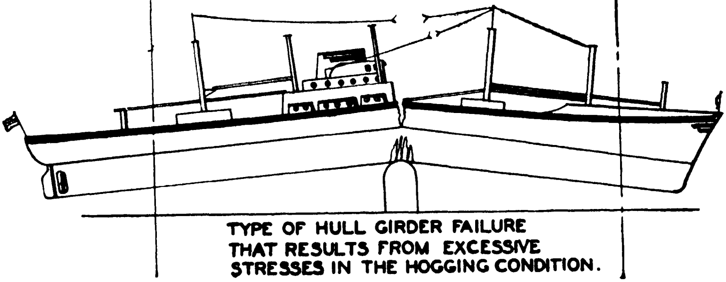


Fig. 6.

Figs. 5 and 6.

Before we can begin our elementary study we must become familiar with a few of the terms used in all structural work. The student is strongly advised to familiarize himself thoroughly with these definitions.

Load is the total force acting on a structure and is usually expressed in pounds or tons.

Stress is the force per unit area and is usually expressed in pounds or tons to the square inch.

Strain is the distortion resulting from stress.

There are three types of simple stress as follows:

1. *Tensile Stress.*—This occurs between two parts of a body when each draws the other toward itself. Tensile stress can perhaps be best illustrated by means of a tie rod subjected to a steady pull. Assume that the tie rod in Fig. 8 is subjected to a pull of P lb. and that its area through section y-y is A sq. in. Then the average tensile stress T_s per square inch would be given by the formula

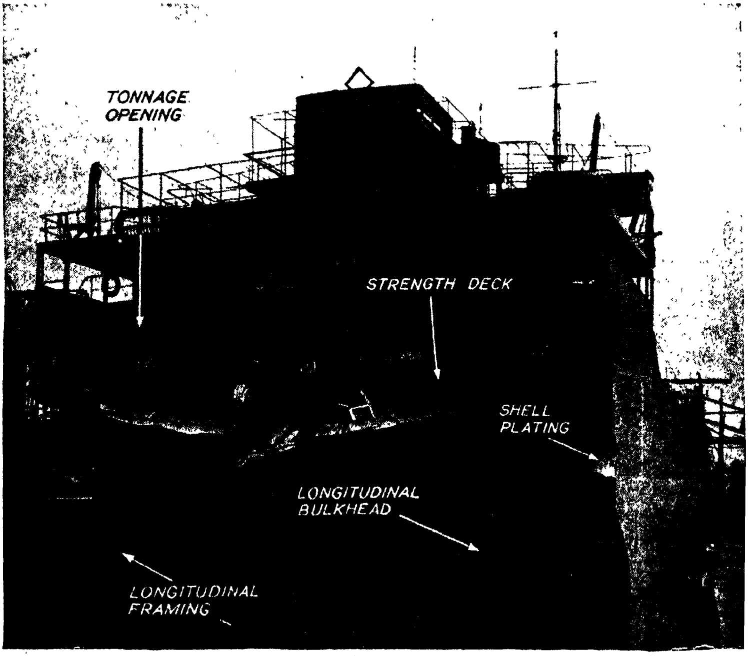


FIG. 7.—Example of a typical hull-girder failure, bow section of the *S. S. Blum.* The break started in the upper deck and worked downward, tearing the shell, the twin bulkheads, and the supporting longitudinal frames and stiffeners. The stern of this vessel was later welded back to the bow, and the vessel again went into service. The bow section shown above is floating freely.

$$T_s = \frac{\text{pull}}{\text{area}} = \frac{P}{A}$$

Using an actual case as an illustration, let us assume that the rod was supporting a load of 20 tons[1] and the area through y-y is

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[1] All shipbuilding tons are tons of 2,240 lb.

4 sq. in. Substituting in the formula,

$$T_s = \frac{P}{A} = \frac{20 \text{ tons}}{4 \text{ sq. in.}} = 5 \text{ tons per sq. in.}$$

2. *Compressive Stress.*—This is the reverse of the above. The same formula holds.

$$\text{Compressive stress} = \frac{\text{compressive load}}{\text{area}}$$

3. *Shearing Stress.*—The tendency of one part of a body to slide over another part is known as *shear*. The magnitude of this tendency to slide at any point is termed the ***shearing stress*** at that point. Consider two pieces of plate tied together with a rivet.

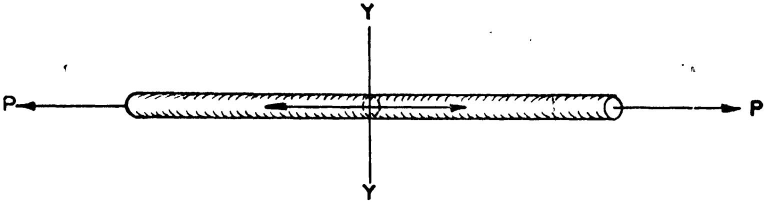

FIG. 8.—Steel tie rod subjected to a steady pull.

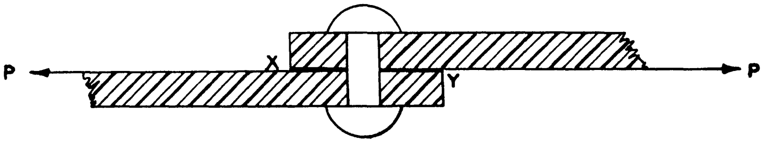

FIG. 9.—A rivet in single shear.

If the total shear across the rivet in Fig. 9 at the line x-y is P tons, then the average shearing stress per square inch would be

$$S_s = \frac{\text{pull}}{\text{area of rivet shank}} = \frac{P}{A}$$

Assume that we have a pull on the plates of 5 tons and that the diameter of the rivet is 1 in. The area of the rivet would be equal to $\pi r^2 = 3.14 \times (0.5 \text{ in.})^2 = 0.785$ sq. in.
Then

$$\text{Shearing stress} = \frac{5 \text{ tons}}{0.785 \text{ sq. in.}} = 6.4 \text{ tons per sq. in.}$$

The ultimate tensile strength of mild steel, which is the principal steel used in shipbuilding, is 28 to 32 tons per sq. in. The ultimate shearing strength is lower, being only about 22 tons per sq. in. No compressive strength is given here, as steel simply flattens out when compressed (at about 18 tons per sq. in.).

The following figures may be taken as averages:

	Tons per sq. in.
Ultimate tension	30
Ultimate shear	22

Such values are based on the assumption that the material is broken. This is really of little value because the ship's structure should be strong enough to remain unbroken and unimpaired in strength after receiving any stresses that it may have to undergo. The following method is employed to determine how much we can stress a material without distorting it permanently.

DETERMINING THE STRENGTH OF STEEL

A small specimen of the material is placed in a testing machine such as that shown in Fig. 10. The specimen is then pulled by the machine, and a conveniently placed dial shows the amount of tensional load in pounds or tons applied at any one time.

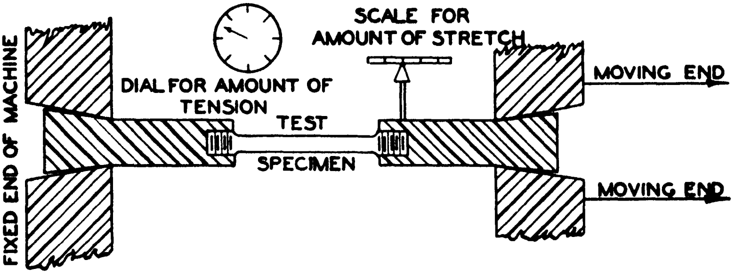

FIG. 10.—Diagrammatic sketch of a test specimen in a testing machine.

If progressive readings are taken of the amount of tension put on the test piece and at the same time measurements are made of the amount of the corresponding stretch or strain, a set of points will be obtained that can be plotted on a sheet of graph paper. If a curve is drawn through these points, it will look somewhat like Fig. 11 and is known as a *stress-strain diagram.*

A study of this curve will answer numerous questions. Note in the drawing that the strain or amount of stretch up to point A is directly proportional to the pull or force applied. This is indicated by the fact that the line is straight between zero and point A. So up to point A we can say that the material follows Hooke's law[1] directly. If the test specimen is stretched or loaded to any point below A, it will contract to its original length when the load is removed. If the specimen is stretched beyond the point A, it will no longer contract to its original length upon removal of the load, and the distortion then becomes a *permanent set*. Loads that do not stretch the material beyond point A, called the *limit of elasticity*, are said to be within the *working range*, for the material is not damaged by the load. All structures are designed so that stresses resulting from the assumed loads are well within this working range. If the material is loaded until it stretches beyond point A, the material will suddenly yield at point B even with little further increase in load and will continue to stretch until it reaches the length indicated by point C, where the yield is overcome owing to some hardening in the metal. If the load is further increased slightly, the metal will stretch out of all proportion to the load applied and will

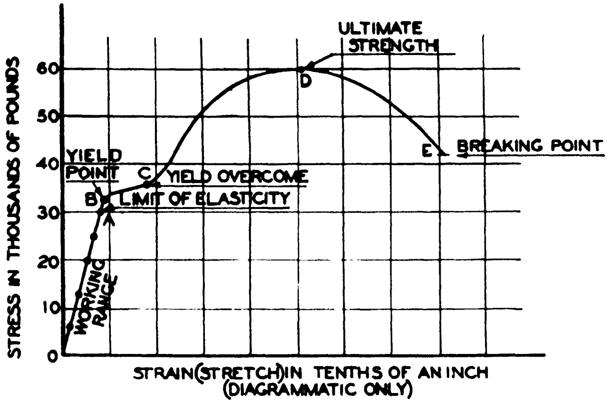

FIG. 11.—A typical stress-strain diagram for mild steel.

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[1] Hooke's law states that the stretch of an elastic material up to the elastic limit is directly proportional to the stress; that is, if we double the weight attached to the bottom of a spring, we double the elongation of the spring.

continue to elongate past the ultimate strength at point D and fail at the breaking point E. This operation is known as *testing the material to destruction.*

Curves such as these have been plotted for almost every kind of metal and metallic alloy, and therefore we can easily check the strength of any material with which we may have to work. Good structural design becomes then a matter of keeping the stress resulting from the expected loading well within the working range. An attempt is made to do this by means of a factor of safety.

FACTOR OF SAFETY

In order to keep the expected stresses well within the working range and below the yield point of our material, we use what is commonly called a *factor of safety* (F.S.). When we begin to design a structure, we first attempt to determine as accurately as possible the loads that the structure will have to bear. To make the structure just strong enough to carry this calculated load would be extremely dangerous, for it is entirely possible that, owing to some unforeseen circumstance, the structure will be called on to carry two or three times the load anticipated. Furthermore, the structure may rust and corrode, it may become damaged by impact, the workmanship may be poor, or the material may not be up to its standard strength.

In order to allow for these unknown factors, we usually make the structure four times as strong as it need be; *i.e.*, we use a factor of safety of 4, based on the ultimate strength of the material we are using. It would be more sensible to base our safety factor on the yield point rather than the ultimate strength, for the structure would be completely out of shape by the time the ultimate strength was developed by the material. As the yield point for steel is roughly half the ultimate strength, *we are in reality using only a factor of* 2.

It should be noted here that the tie rod shown in Fig. 8 has a tensile stress of 5 tons per sq. in. On page 6 the ultimate tensile stress for mild steel is given as 30 tons per sq. in. The factor of safety for the tie rod based on the ultimate is then

$$\text{F.S.} = \frac{30 \text{ tons per sq. in.}}{5 \text{ tons per sq. in.}} = 6$$

This is more than ample; the size of the tie rod, therefore, could be reduced.

For the rivet shown in Fig. 9 the shear across the shank of the rivet works out to be 6.4 tons per sq. in. The ultimate for mild steel in shear as given on page 6 is 22 tons per sq. in. Therefore,

$$\text{F.S.} = \frac{22 \text{ tons per sq. in.}}{6.4 \text{ tons per sq. in.}} = 3.44$$

Since this is less than 4, the size of the rivet should be increased.

It is suggested that the student calculate the size of rivet required to give a safety factor of 4 or better in the above case.

STRENGTH OF SHIPS

There are two broad phases of strength. They are *local strength,* relating to the strength of the individual parts of the ship, and the *hull-girder strength* mentioned previously, relating to the strength of the ship as a whole.

In practice, we must make a weight calculation before we can make the hull-girder calculation, and in order to determine the weight we must first determine the scantlings, or sizes, of the individual members that, taken together, make up the vessel.

CLASSIFICATION SOCIETIES

Actually, for merchant vessels of average size, scantlings for most of the parts such as beams, stiffeners, and shell plating are not determined by strength calculations but are regulated by the rules of the classification society that will classify and certify the construction of the vessel.

All maritime nations have their own classification societies that check the strength and seaworthiness of the various merchant ships applying for insurance. This certified inspection protects the insurance company that actually insures the vessel from great losses, thereby reducing the premiums on maritime insurance. Any vessel can be insured even if it is not built to the rules of a classification society, but the insurance rate will be so high that operation of the vessel may become unprofitable. Also, a vessel not classified may have a very low resale value, for the prospective buyer would be taking a large risk in purchasing an unclassified ship.

In the United States this inspection, protective, and classifying agency is the American Bureau of Shipping; in England, Lloyd's Register; in France, Bureau Véritas; in Italy, Registrano Italiano; and in Germany, Germanischer Lloyd.

The rules regulating the construction of ships are fairly fluid; therefore, at intervals a new book of rules is issued. The American Bureau's book of rules costs about $5 and becomes obsolete with the succeeding issue.

These rules apply to most merchant vessels up to 700 ft. in length. However, there are numerous scantlings not covered by the rules that must be calculated individually by using the principles of strength of materials.

NAVAL DESIGN

In the design of naval vessels we have no set of rules as in the design of merchant vessels. This is because of the great and rapid changes that are continually taking place in naval warfare. It would be useless and unprofitable to limit the designers of naval vessels by making them adhere to a detailed set of rules. As a consequence, the warship designer has a more difficult problem than the designer of a merchant vessel, but a more interesting one, for it leaves greater scope for his ideas, inventiveness, and initiative. The size of every part of a naval vessel must be calculated individually; and as the parts are interdependent, due regard must be taken of all surrounding members in order to harmonize the general construction.

Before we can see how the sizes of these parts are calculated, we must discuss some of the principles of strength of materials. Since the bending moment generally determines the size of a beam, we shall consider this first.

BENDING MOMENTS

A moment of a force about any line is the product of the force times the perpendicular distance to that line.

Figure 12 shows a board built into a wall at one end and loaded by a weight, which produces a force acting downward. The wall is the line of support. In *A* the weight is halfway out on the board, and in *B* all the way out, the weight in both cases remaining unchanged.

It will be noted that, when the weight is on the outer end of the board, the board has more deflection than when the weight is halfway out. This is because of the increased bending moment due to the greater distance of the weight from the point of support, or, mathematically,

$$\text{B.M.} = \text{weight} \times \text{distance} = W \times D$$

In *A*

$$\text{B.M.} = 100 \text{ lb.} \times 4 \text{ ft.} = 400 \text{ ft.-lb.}$$

In *B*

$$\text{B.M.} = 100 \text{ lb.} \times 8 \text{ ft.} = 800 \text{ ft.-lb.}$$

At the support, the bending moment (B.M.) illustrated in *B* is twice the bending moment in *A*, and therefore the stress on the board at the support is also twice as great. The bending moment can also be doubled by keeping the distance from the support constant and doubling the weight.

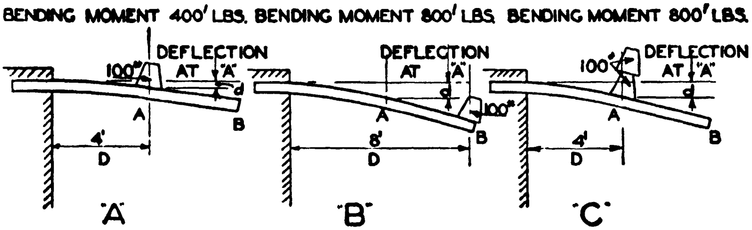

FIG. 12.—Bending moments produced by a concentrated load on a cantilever beam.

In *C* we have placed another 100-lb. weight on top of the original one. The bending moment then becomes

$$\text{B.M.} = 200 \text{ lb.} \times 4 \text{ ft.} = 800 \text{ ft.-lb.}$$

We can say, then, that, if we double the distance from the point of support or if we double the weight keeping the distance constant, we double the bending moment.

This is an important rule and should be noted carefully by the student because the bending moment, rather than the weight supported, determines in large measure the size of the various parts of a vessel.

If we have a clear picture of these simple bending moments in mind, we can proceed with a discussion of beams.

BEAMS OF RECTANGULAR SECTION[1]

Horizontal strength members loaded vertically are usually referred to as *beams*. Such a member is shown in Fig. 13. As this beam is of a homogeneous material and rectangular in shape, it is symmetrical about the line drawn through the beam at mid-depth, designated in the figure as the x-x axis.

In Fig. 14 we have applied a load directly at the center of the beam and the beam has deflected a certain amount, exaggerated in the figure for the sake of clarity. This deflection, or bending, caused the upper surface of the beam to shorten and the lower surface to lengthen. This is quite obvious, because the ends of the beam are no longer parallel to each other but are coincident with the radius of the concentric circle, the arc of which is described by the upper and lower surface of the beam. (Actually, a beam loaded at its center does not assume the shape of the arc of a circle but of a parabola; however, for simplicity the arc shape is assumed.)

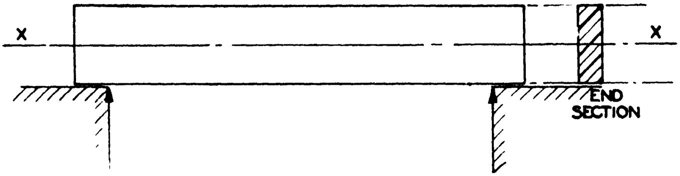

FIG. 13.—Side elevation of a rectangular free-ended beam lying across two supports.

As the upper section of the beam has been shortened, it must have been compressed, or, in technical language, it is *in compression*. The lower section has been lengthened, and we say that it is *in tension*. As compression and tension are opposite forces, there must be a layer within the beam where these forces become zero and change direction. This layer is found to lie along the locus of the center of gravity of the section, which in our case will be along the x-x axis. Note that this refers, not always to the center of the beam, but rather to the *center of gravity* of the beam system.

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[1] All beams discussed in this chapter are considered, for simplicity, to be rectangular in cross section. See any strength-of-materials text for a discussion of beams of other shapes.

This line of zero stress can be understood better if we regard the stresses acting within the beam. Consider the beam shown in Fig. 15 as made up of several superposed unconnected layers. When such a beam is loaded and bends, the ends of the various layers remain parallel to each other, each layer simply slipping upon the other so that the ends are no longer in line. In order

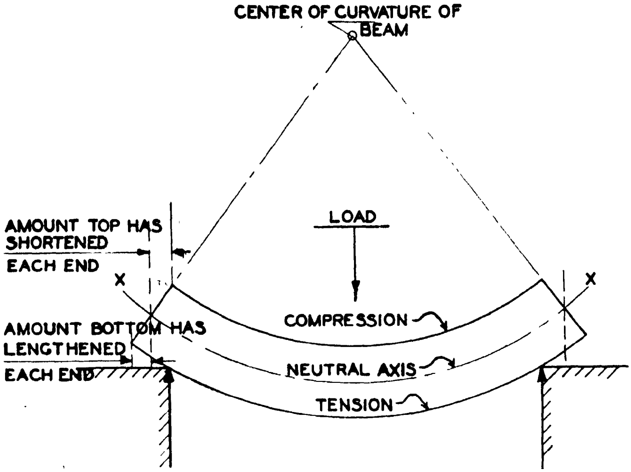


FIG. 14.—Same beam as in Fig. 13 after a load has been applied at center (exaggerrated).

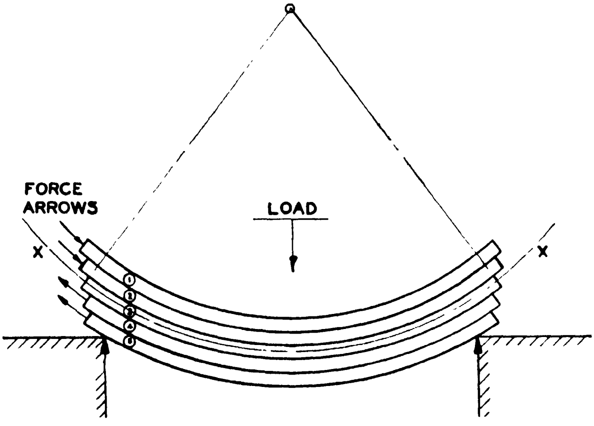


FIG. 15.—This beam is identical with the beam shown in Fig. 14 except that it is made of five layers that are free to slide over each other; however, this beam will support only one-fifth as much weight as the beam shown in Fig. 14.

to create the same internal stress in the beam of Fig. 15 as that created in the beam of Fig. 14, the two upper layers, 1 and 2, would have to be pushed lengthwise and the two lower layers, 4 and 5, pulled lengthwise until they become flush with layer 3. Layer 3 does not require any change. This layer lies along the center of gravity of the beam and is known as the *neutral layer*. A line along the center of this layer is known as the *neutral axis*, since it is neither in tension nor in compression; *i.e.*, it was neither lengthened nor shortened during the process of bending.

If we wished to keep all the layers in line during bending, we should have to apply some external force in line with the ends of the layers or else glue the layers together before bending (the effect would be the same, for the glue would assume the longitudinal stress). The external forces required to shorten the upper layers and to lengthen the lower layers are indicated by arrows in the figure. The direction in which the external force would have to be applied is indicated by the head of the arrow. By glancing at this figure we see that it requires more force to bring layer 1 into line than to bring layer 2 into line. This brings out the important fact that the greater the distance between any particular layer and the neutral axis the greater the stress on that individual layer. It also illustrates how the depth of a solid beam controls its resistance to bending, for the farther the layers from the neutral axis the greater the tension or compression they must assume. Our original beam (Fig. 14) is of one solid section, *i.e.*, the layers cannot slide over one another, and in this case the force bending the beam must be of equal intensity to the tension and compression set up within the beam.

EFFECT OF DEPTH

The strength of a rectangular beam varies as the square of its depth. Let us compare mathematically the strength of a 2 by 4 set on edge and a 2 by 8 set on edge. Using the above rule for rectangular beams, call d_1 the depth of the smaller and d_2 the depth of the larger; then

$$\text{Relative strength} = \left(\frac{d_2}{d_1}\right)^2 = \left(\frac{8}{4}\right)^2 = 4$$

That is, the 2 by 8 will support *four* times as much load as the 2 by 4 rectangular beam. If this reasoning is applied to the five-layered beam shown in Fig. 15, each layer is only $(\frac{1}{5})^2$, or $\frac{1}{25}$, as strong as a solid beam five times the depth of one of the layers, and all layers taken together would be only $\frac{1}{5}$ as strong as a solid beam of the same depth.

All beams, regardless of their shape, may be conceived to be composed of an infinite number of these very thin horizontal layers. When we apply a load to the beam, one surface goes into compression and the other into tension because the infinitely thin layers are restrained from sliding over each other by the web of the beam. This web is the only thing that resists the longitudinal shearing stress set up in the beam. The layer at the center of gravity, or neutral axis of the beam, is, of course, neither in tension nor in compression, but in shear.

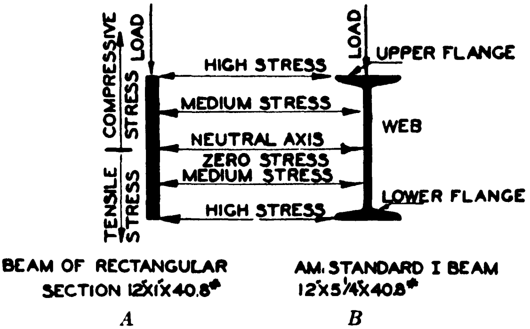


FIG. 16.—Comparison of two beam sections of equal sectional area. Longitudinal shear stress is ignored.

As the tensile and compressive stresses in a beam are very low in the portion along the neutral axis and very high in the portion farthest away from the neutral axis, it is advantageous to move the material from the neutral axis and concentrate it in the flanges. This makes a stronger beam with the same weight or a lighter beam with the same strength. The two beams shown in Fig. 16 have the same depth and same weight; yet beam *B* will carry 84 per cent more load than beam *A*, an effect due entirely to moving the material away from the area of low tensile and compressive stresses (the web) and concentrating this moved material in the area of high stress (the flanges), thus reducing the stress per unit area and strengthening the beam. The flanges also serve to stiffen the beam.

FACTORS AFFECTING THE SIZE OF A BEAM OF RECTANGULAR SECTION

There are four basic factors that affect the size of a beam: (1) the type and amount of load on the beam, (2) the distance between supports, (3) the type and efficiency of end connections, and (4) the number of supports. We shall discuss each of these in order and in a somewhat elementary manner.

1. The Load on a Beam.—Beams are loaded in various ways. We shall consider only two, *viz.*, a concentrated load at center and a uniformly distributed load.

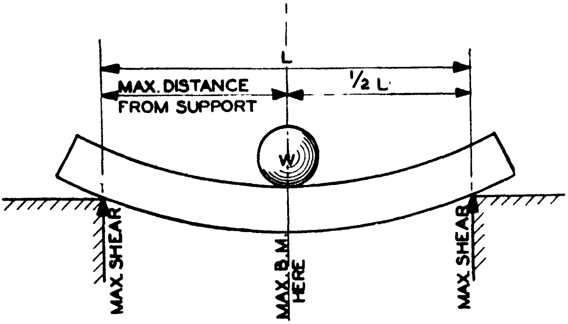


FIG. 17.—A free-ended beam supporting a concentrated load at center.

a. Concentrated Load.—When a beam lying over two supports is loaded as shown in Fig. 17, we say it has a *concentrated load.* The loading shown produces the greatest bending moment at the center of the beam, for the weight is at the maximum distance from the points of support, the bending moment in this case being B.M. $= \frac{WL}{4}$; for example, if the weight is 2 tons and the length 10 ft., we should have

$$\text{B.M.} = \frac{2 \text{ tons} \times 10 \text{ ft.}}{4} = 5 \text{ ft.-tons}$$

b. Uniformly Distributed Load.—A beam with a uniformly distributed load is shown in Fig. 18. This type of loading is uniform along the beam; therefore, certain portions of the load are nearer the points of support than others. These portions, when totaled, produce a smaller bending moment than in the case of the concentrated load. The maximum bending moment for a uniform load is at the center and is given by

$$\text{B.M.} = \frac{WL}{8}$$

where W = total load.
L = distance between supports.

Using the same load and distance between supports as in the previous example, we should obtain

$$\text{B.M.} = \frac{2 \text{ tons} \times 10 \text{ ft.}}{8} = 2.5 \text{ ft.-tons}$$

This is exactly half the bending moment produced by the concentrated load. Other types of loading produce bending moments of different magnitudes.

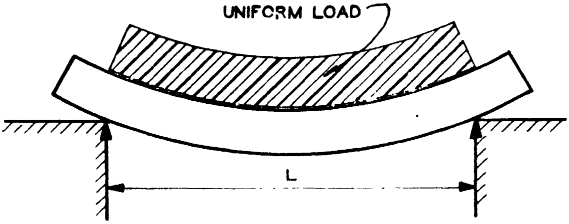


Fig. 18.—A free-ended beam supporting a uniformly distributed load.

The bending, or deflection, of a rectangular beam varies as the bending moment, and the bending moment depends on the load and type of loading. This fact is evident from the formulas above; for when we double the load, we double the bending moment, which also doubles the deflection.

Summarizing, we can say that *in the design of a beam due consideration must be taken of the type as well as the amount of the load.*

2. The Distance between Supports.—The distance between supports is usually referred to as the *span.* The span is one of the factors that govern the strength and the deflection of a beam. It affects the beam in two ways.

a. The deflection of a rectangular free-ended beam varies as the cube of the span. Say that the rectangular beam A (Fig. 19) supports a certain load over a 10-ft. span. On this span the measured deflection is found to be 1 in. How much deflection would the same beam have if the span was increased to 20 ft.?

(Assume no change in load.) Let S_1 = short span; let S_2 = longer span; then

$$\text{Relative deflection} = \left(\frac{S_2}{S_1}\right)^3 = \left(\frac{20\text{ ft.}}{10\text{ ft.}}\right)^3 = 2^3 = 8$$

$$\text{Deflection on the longer span} = 1\text{ in.} \times 8 = 8\text{ in.}$$

b. The strength of a rectangular free-ended beam varies inversely as the span. Beam *B* (Fig. 19) will support only half the load of beam *A*, for the span is twice as great. To illustrate this mathematically, assume that beam *A* will support 10 tons; then

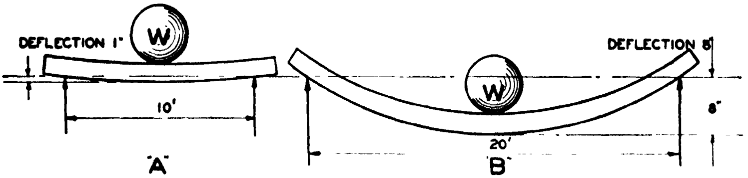


FIG. 19.—The deflection of a rectangular free-ended beam varies as the cube of the span; the strength varies inversely as the span.

$$\text{Relative strength} = \frac{\text{span } A}{\text{span } B} = \frac{10\text{ ft.}}{20\text{ ft.}} = 0.5$$

and the load that beam *B* will support would be

$$10\text{ tons} \times 0.5 = 5\text{ tons}$$

In order to keep our beam sizes and deflections to a minimum, we increase the number of supports, thereby reducing the span.

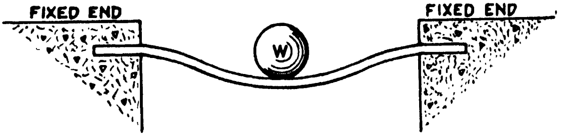


FIG. 20.—A fixed-ended rectangular beam with a concentrated load at center.

3. Fixity of the End Connections.—In our previous discussion we have assumed that the beam simply was lying across two end supports and that the ends were free to take the same curvature as the beam. Now if the ends of the beam are set in concrete, they will be rigidly held. A beam of this type is shown in Fig. 20.

When the ends of a beam are fixed, the conditions heretofore discussed will be considerably altered. It will be noted that while the middle section of the beam is curved like a free-ended beam, the ends built into the concrete have taken an opposite curvature. Fixing the ends of a rectangular beam produces two helpful results.

1. A fixed-ended rectangular beam will support twice as much concentrated load as a free-ended rectangular beam.
2. The deflection of a fixed-ended rectangular beam is only one-fourth as great as the deflection of a free-ended rectangular beam.

As an illustration of the two rules above, compare the relative strength and deflection of beam *B* (Fig. 19) when free-ended and fixed-ended. Let us assume that

Free-ended maximum load = 10 tons
Free-ended maximum deflection = 8 in.

Then from (1) the maximum load with the ends fixed would be

$$2 \times 10 \text{ tons} = 20 \text{ tons}$$

and from (2) the maximum deflection with the ends fixed would be

$$\tfrac{1}{4} \times 8 \text{ in.} = 2 \text{ in.}$$

It is very difficult to get complete fixity in the ends of beams in a ship owing to the flexibility of the structure. However, we can approach a fixity of between 50 and 80 per cent by the use of deep beam brackets and by making the beam continuous over its supports.

Most of the loads on the beams in a ship are uniform, and most of the beams in a ship are partially fixed. Therefore, it is interesting to note that a fixed-ended beam with uniform load distribution has twice the bending moment at the fixed ends that it has at the middle. If it fails, the fracture will take place at the ends. This is the reason why brackets are required at the supports of continuous beams.

4. The Effect of the Number of Supports.—When we have a beam with equal spans and symmetrical loading passing over one or more supports, the beam acts as a fixed-ended beam over the support.

In Fig. 21, span *B* is tending to fix span *A* and span *C*. Therefore, over the supports the beam acts as a partially fixed-ended beam, *and failure would take place at that point.*

The greater the number of supports in a given distance, the shorter the span and, as we have already seen, the smaller the bending moment produced. This would permit a reduction in the size of the beam.

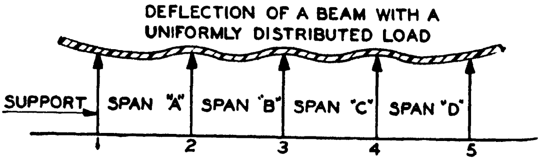


FIG. 21.—A beam with a uniform load lying over five supports.

STEEL SHIPBUILDING PLATES

Flat sheets of steel over $3/16$ in. thick and 48 in. wide or $1/4$ in. thick and 6 in. wide are usually referred to as *plates.* They are used primarily for the sides, bottom, bulkheads, and decks to make a watertight covering or, in the case of lower decks, to make working platforms. When plating is acting to carry a load to its supporting *frames* or *stiffeners* (see Fig. 22), it acts as a series of thin wide beams between the stiffeners. As explained above, the closer the stiffener spacing, the thinner can the plate be made.

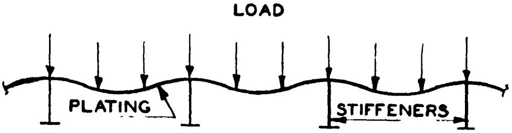


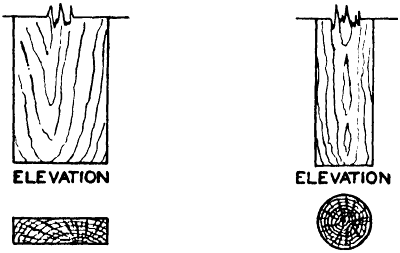
FIG. 22.—Plating acting as a beam.

There is, however, a point at which we must cease adding stiffeners in order to reduce plate thickness, for the saving in plating weight, due to the thinner plate, becomes less than the added weight of the stiffeners. As weight must be kept to a minimum for maximum cargo-carrying ability and speed and as steel is sold by the pound, we must be very careful in our design to see that the ratio of stiffener spacing to plate weight is such that we get the required strength with the least weight.

Shell-, bulkhead-, and deck-plating design are all based partly on the above principles, as we shall see when we discuss them in detail. Steel plates are also used as webs and flanges in built-up beams and columns.

COLUMNS

When two portions of a ship are so loaded that they tend to come together, we usually insert a prop or a strut between them to keep them apart. On a ship, this load ordinarily tends to act vertically, and therefore the prop generally is placed vertically under the load. Such a prop is known among shipbuilders sometimes as a *column* but more often as a *stanchion* or *pillar*.



SECTION THROUGH YARDSTICK
A POOR COLUMN SECTION

SECTION THROUGH DOWEL
A GOOD COLUMN SECTION

FIG. 23.

Just as a beam has the least strength when supported with the thin dimension at right angles to the load, a stanchion likewise is weakest the thin way. As a stanchion is free to bend in any direction, it would naturally bend in its weakest direction. This calls for stanchions to be made from symmetrical sections, the best of which would be circular.

As illustrations of a poor stanchion section and a good one, we can use the typical yardstick and a dowel (Fig. 23), both having the same cross-sectional area. The dowel will support much more weight than the yardstick without collapsing, for it would have no greater tendency to buckle in one direction than in any other direction because it is uniformly strong throughout.

The length-diameter ratio of a ship stanchion is usually small compared with that of an architectural column, and since this ratio is the controlling factor in bending, we very seldom attempt to fix completely the ends of a ship stanchion.

SHAFTS

A shaft subjected to a twisting moment is said to be *in torsion*. This twisting moment is usually called *torque*. A torque will set up a shearing force all along the shaft, as can be illustrated by holding a cigarette firmly at one end and twisting the other.

In addition to torque a shaft also may be subjected to bending moments. This increases the stress considerably; in the case of propeller shafts, great care must be taken to see that they are in nearly perfect alignment, which reduces the bending moment to a minimum.

The torque in a rotating shaft is given by the following formula:

$$\text{Torque (in. ft.-lb.)} = \frac{\text{horsepower} \times 5{,}252}{\text{r.p.m.}}$$

It can be seen from the above formula that the higher the revolutions per minute (r.p.m.) for a given shaft the less the torque; as a result of this, we can use a smaller shaft for the higher r.p.m. This explains why a 5,000-hp. 80 r.p.m. engine will require a shaft of the same size as a 20,000-hp. 320 r.p.m. engine.

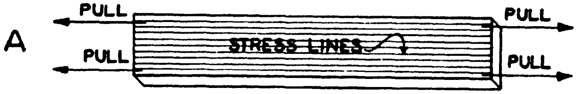
The numerous rotating shafts on a vessel all conform to this same principle.

CONTINUITY OF STRENGTH

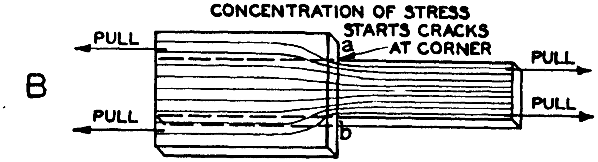
Since the main forces on the hull of a ship generally vary in a gradual and continuous manner, it follows that the change in the hull strength should be gradual and continuous. No part should be oversized for the load it will have to carry; and, of course, none should be undersized. Furthermore, any sudden discontinuity or change of shape will cause a concentration of stress at the point of change that may lead to failure of the structure.

This last phenomenon can be illustrated by the simple sketch in Fig. 24, which shows a piece of steel in tension. The fine lines indicate by their closeness the intensity of the tensile stress in the piece of steel at any one point, due to the tensile force exerted. It will be noted that in *A* the lines are parallel, which indicates that the stress intensity is uniform throughout the plate.

In *B* we have welded on the top of the original plate another similar plate of double the width. It might appear on first thought that we have considerably strengthened the plate. We now reapply the same load. The stress flow is indicated as before by the fine lines. It will be noted that the stress concentration, shown by the closeness of the lines of stress, has increased at the points *a* and *b* owing to these lines' sweeping out from the smaller plate into the larger plate. If of sufficient intensity, this will cause cracks to start at the corners. These cracks will become progressively larger, causing still greater concentration and finally failure of the plate. The extra material that has been added has actually decreased the strength, entirely because of the stress concentration that has taken place at the sharp corners.



LINES OF STRESS PARALLEL THROUGHOUT BAR



LINES OF STRESS SPREAD INTO LARGER PIECE CAUSING A CONCENTRATION AT THE CORNERS.

FIG. 24.—Stress concentration at corners.

In way of hatches, at the ends of decks that are not continuous, at the ends of deckhouses, and at numerous other points in the structure of a vessel, we find sudden changes in area of metal that may impair the continuity of strength. In Chap. XI we shall discuss in greater detail how we attempt to curb the ill effects of these discontinuities.

Problems

1. A steel flat bar 4 by 1 in. is subjected to a pull of 20 tons. Calculate the stress. *Ans.* 5 tons per sq. in.

2. What is the factor of safety in the above problem? *Ans.* 6.

3. A rivet with a cross-sectional area of 2 sq. in. is subjected to a shearing load of 12 tons. Calculate the stress. *Ans.* 6 tons per sq. in.

4. Calculate the factor of safety in Prob. 3. If the factor of safety is less than 4, calculate the area of rivet shank required to give a factor of safety of 4. *Ans.* F.S. = 3.66. Area required = 2.18 sq. in.

5. A 2,000-lb. weight is supported by a cantilever beam fixed in a concrete wall. The distance from the wall to the weight is 13 ft. Calculate the bending moment at the support. *Ans.* 26,000 ft.-lb.

6. If a 2- by 1-in. rectangular beam will barely support 500 lb., how much weight would a similar beam 4 by 1 in. support? Likewise, what would a similar beam 8 by 1 in. support?

Ans. 4-in. beam = 2,000 lb. 8-in. beam = 8,000 lb.

7. A beam lying over two supports has a span of 20 ft. A concentrated load of 3 tons is placed in the center of the beam. Calculate the bending moment produced. *Ans.* 15 ft.-tons.

8. A uniformly distributed load of 5 tons is on a beam freely supported between two supports. The span length is 15 ft. A concentrated load of 3 tons is placed on top of the uniform load at the center of the beam. Calculate the combined bending moment. *Ans.* 20.625 ft.-tons.

9. A beam with a 3-ton load on a span of 10 ft. has a deflection of 2 in. The span is increased to 30 ft. Calculate the deflection. *Ans.* 54 in.

10. A beam on a 20-ft. span will barely carry a load of 20 tons. If the span is reduced to 10 ft., what load will the beam carry? *Ans.* 40 tons.

11. If the beam of Prob. 9 with the 30-ft. span and 54-in. deflection has the ends completely fixed, calculate the resulting deflection.

Ans. 13.5 in.

12. If a free-ended beam will carry a load of 10 tons over a certain span, what load will a similar fixed-ended beam carry? *Ans.* 20 tons.

13. Calculate the twisting moment, or torque, in a shaft produced by (*a*) a 30,000-hp. turbine at 3,000 r.p.m. and (*b*) a 3,000-hp. turbine at 300 r.p.m.

14. What is meant by a hull-girder failure?

15. What is the difference between weight and load?

16. Define unit stress.

17. What is the average working stress for mild steel in tension?

18. Why is a factor of safety used in engineering calculations?

19. Sketch and label a stress-strain diagram.

20. What relation does the yield point bear to the ultimate tensile strength of mild steel?

21. What is the purpose of a classification society?

22. What is a bending moment?

23. Sketch a simply supported free-ended beam lying across two supports. Indicate and label the neutral axis and the extreme fiber.

24. Why is an I beam stronger than a rectangular beam of the same weight and depth?

25. Why does a concentrated load produce a greater bending moment than a uniform load?

26. What is meant by fixity?

27. Why does an I beam make a poor column?

28. Why is strength continuity important in structural design?

CHAPTER II

MATERIALS USED IN SHIPBUILDING

In the past the hull structure of ships has been made of wood, wrought iron, steel, and concrete. Wood was the first shipbuilding material because the supply was abundant and it was easy to work. There is a limit to the size of a ship that can be constructed from wood, chiefly because of our inability to tie the joints together successfully; as a consequence, the maximum length of such ships has been around 300 ft. Wooden vessels in the 200-ft. class have been known to hog, or sag, in a seaway as much as 3 or 4 ft. This caused the seams to work, and dangerous leaks developed as a result. Furthermore, wood is not uniform in strength, is subject to attacks by dry rot, insects, and marine worms (teredos), is combustible, and is heavier than steel of equal strength.

WROUGHT IRON

The first metal to be used in ship construction was wrought iron. The development of the Bessemer and open-hearth (Siemens-Martin) processes of making steel caused the discontinuance of the use of wrought iron, for steel became cheaper and was stronger than wrought iron.

STEEL

Mild steel, the type used to the greatest extent in ships, is practically uniform in strength, can be easily worked into shape, and, since the advent of welding, can be joined together with connections developing the full strength of the steel. The main disadvantage of steel is its lack of resistance to corrosion. Careful painting and maintenance tend to overcome this difficulty to a certain extent. Corrosion-resisting steel (CRS) sometimes is used in parts subjected to excessive corrosive action, but at present its high cost prevents more extensive use.

ARMOR

Heavy armor steel of the Krupp type is made by a special process whereby the face of the plate is made very hard while the inside remains somewhat soft but exceedingly tough. This steel answers the requirements of armor, for the hard face breaks the head and the tough inner portion absorbs the energy of the projectile, thus reducing penetration.

SPECIAL-TREATMENT STEEL

Special-treatment steel (STS) is special-quality nickel-steel alloy. It has excellent ballistic properties and is used for protective decks and light side armor. Shields protecting ships' personnel from shell and bomb splinters are also made of STS.

HIGH-TENSILE STEEL

High-tensile steel (HTS) is now used to a great extent in the main strength members of high-speed warships and large ocean liners. Its increased tensile strength over mild steel is gained by a reduction in carbon and an increase in manganese content. HTS is roughly about 25 per cent stronger in tension than mild steel.

CONCRETE

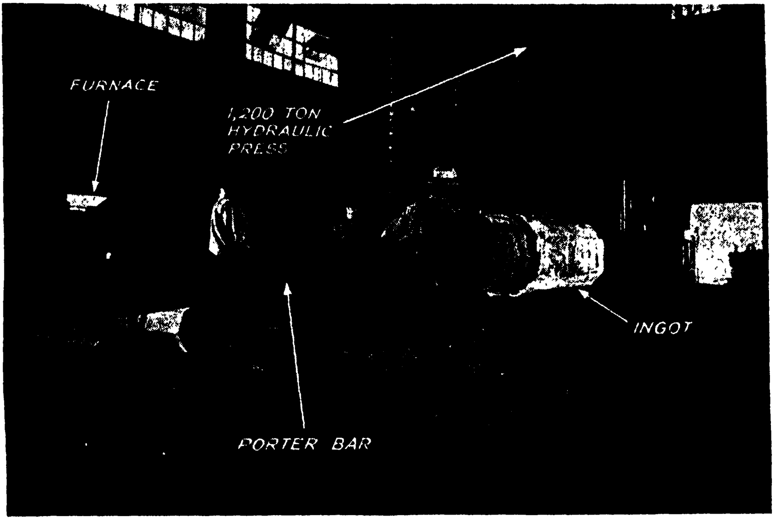
During the First World War, a number of ships were built of reinforced concrete. The tensile strength was provided by steel rods placed within the concrete. These ships were excessively heavy and were easily injured locally. As a consequence, operation of concrete ships was never commercially successful.

OTHER MATERIALS

Other materials used in ship construction, though not to the same extent as steel, include iron, aluminum, copper, zinc, lead, tin, bronze, brass and similar compositions, wood of all kinds, canvas, cork, asbestos, oakum, rubber, tar, paper, glass, leather, various tilings and deck coverings, cements, enamels, and paints. Aluminum alloys deserve special mention, for they may be used in the future for shell plating, beams, frames, and many other parts of a vessel.

FORGINGS

Forgings are made by heating steel to a white heat and then beating it into the required shape by means of a hammer or press (Fig. 25). Having great strength and toughness, forgings are used, in general, where these qualities are required. With the rapid advances made in the techniques of pouring satisfactory steel castings, forgings have been used less and less in shipyards. They are now used principally for rudderstocks, crankshafts, and propeller shafts because, at present, they are cheaper and tougher than castings. Certain smaller fittings are still forged by the drop-forging process, *i.e.*, by a single stroke of a steam hammer and the use of forming dies.



Photograph by Dmitri Kessel.

FIG. 25.—Forging the propeller shaft. A 30,000-lb. ingot under the 1,200-ton hydraulic press. The ingot was heated to white heat in the furnace at left. The operator of the press can be seen at right. The long rod at left, known as a *porter bar*, balances the weight of the ingot. The ingot is rotated by means of the chain which is attached at the center of gravity of the porter bar and ingot.

CASTINGS

In the manufacture of a casting, a wooden pattern is first made to the exact shape and dimensions of the required finished casting, plus a small allowance for shrinkage and machining. This pattern is placed in special damp casting sand, which forms a shell

Fig. 26.—Apprentices making wooden patterns. These wooden patterns will be placed in special casting sand. After the sand has set, the pattern is removed and molten steel is poured into the cavity, thus forming the casting.

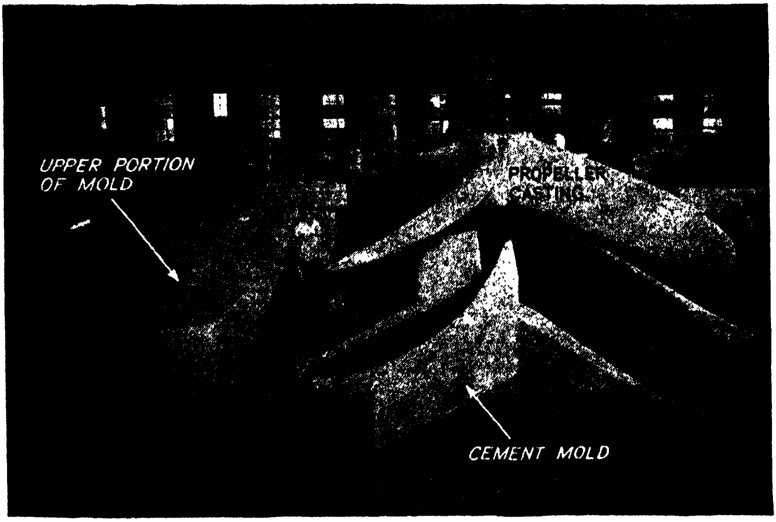


Fig. 27.—A propeller casting. The completed propeller casting is being removed from the cement mold. This casting will now be ground to the finished dimensions.

around it. The pattern is later removed, and molten steel is poured into the hole thus left. Steel castings are quite numerous on a ship and may include the stern frame, stem, stern tubes, rudder frame, propeller struts, spectacle frames, skegs, machinery bedplates, anchors, hawsepipes, chain pipes, pipe flanges, and various small hull fittings. Different grades of steel are used, depending on the class of casting that is required. Many other castings are made of brass or similar compositions.

PLATES

Plates are sheets of steel rolled to a uniform thickness, of ¼ in. or more. Plates less than ¼ in. thick are generally called *sheets*, and their thicknesses are given in gauges. All plate widths are given in inches. The maximum widths for plates to be riveted that can be conveniently handled by most yards are about as follows:

8 to 10.2 lb	75 in. maximum 63 in. preferable
11 to 15.3 lb	87 in. maximum 75 in. preferable
16 to 20.4 lb	96 in. maximum 84 in. preferable
Over 20.4 lb	Up to 110 in.

The last width is the maximum that can be punched in the average shipyard. The width of plates to be welded is not limited by the capacity of yard equipment such as punches and countersinkers.

The inner bottom, bulkheads, deck, shell, trunks, coaming, floors, brackets, girders, built-up sections, and many other structural members are made of plate.

Weights of Plating.—The weight of a cubic foot of steel is approximately 490 lb. A plate 1 in. thick weighs, therefore, 40.8 lb. per sq. ft. (see Fig. 28). Plates are specified by weight per square foot. A 20.4-lb. plate means one ½ in. in thickness, and a 10.2-lb. plate means one ¼ in. in thickness. For convenience, the decimal fraction in the plate weight is usually dropped. Thus, a 20-lb. plate usually refers to one ½ in. thick.

Styles of Plating.—The two principal styles of plate used are *plain plates* for work generally throughout the structure, and *checkered nonskid plates* in the machinery spaces and for some decks and platforms. During fabrication, a plate may be drilled, punched, flanged, sheared, planed, beveled, rolled, furnaced, scarfed, countersunk, knuckled, and joggled (see Shipbuilding Definitions).

Plates fall into three classes in regard to curvature. *Flat plates* form the largest portion of the ship's plating, *i.e.*, plates that have little or no curvature and do not have to be bent. *Rolled plates* are those which have a cylindrical curvature in one direction only and which can be shaped while cold. They are usually found at the turn of the bilge in the middle body. Plates having curvature in two directions are heated and hammered out to the required shape; these are called *furnaced plates.* If the student will take a sheet of paper, which will represent a steel plate, bend it in any direction to a curve, and while holding this first curve bend it at right angles to the first bend, the paper will crumple and become unfair. This effect could not be tolerated in a ship's hull plating and is the reason why some plates have to be furnaced.

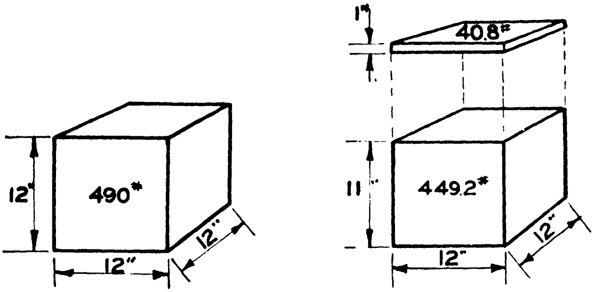


Fig. 28.—One square foot of steel 1 in. thick weighs 40.8 lb.

SHAPES

Rolled bars of constant cross section are called *shapes.* They are usually made of mild steel but may be made of high-tensile steel, aluminum, or almost any other metal that can be passed through the rolls.

1. Plain Angle.—*Plain angles* are used for frames, beams, and hold stringers and, in riveted work, for joining together two pieces of metal that meet approximately at right angles (Fig. 29).

A plain angle and its parts are shown in Fig. 30, sketch 1. Sketch 2 shows a typical riveted attachment of an angle used as a plating stiffener. If the load is as shown, great stress would come on the angle at its toe. As there is very little material in the toe to resist the stresses set up by the load, this stiffening method is very poor. Note also that the position of the neutral axis *NA* is close to the bosom of the angle, which also indicates an increase in the stress at the toe.

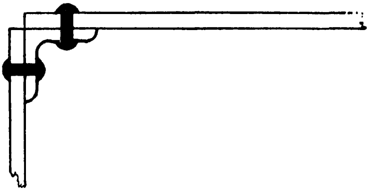
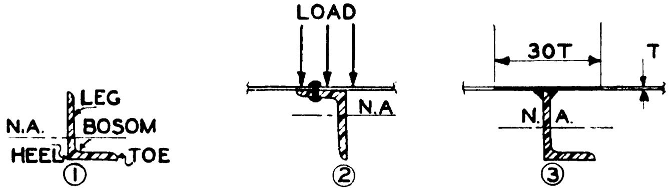


Fig. 29.—Riveted corner attachment

Sketch 3 shows an *inverted angle* welded to the same plating. We usually assume that 30 thicknesses[1] of plating act as a top flange for the angle; and we have then, in effect, a channel section. This gives a fairly symmetrical, or balanced, section that has great strength for its weight. The method of attachment shown in sketch 3 is over three times as strong as that shown in sketch 2. With the welded section we could use an

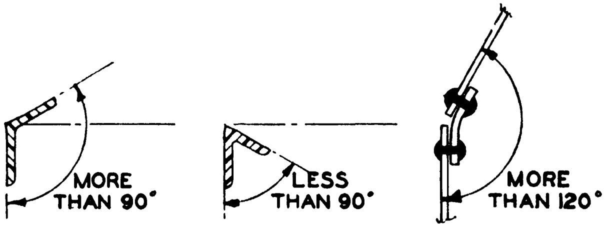


① PLAIN ANGLE

② ANGLE RIVETED TO PLATING

③ ANGLE REVERSED AND WELDED TO PLATING

Fig. 30.



OPEN BEVEL
A

CLOSED BEVEL
B

PLATE ATTACHMENT
C

Fig. 31.

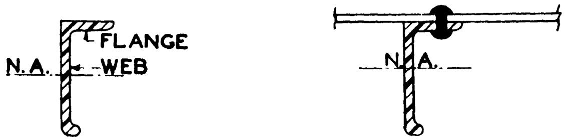
---

[1] This is the United States Navy assumption for sections up to 10 in. depth. Sixty thicknesses are permissible on sections deeper than 10 in. The above assumptions are conservative when compared with actual tests.

angle of roughly half the size and get the same strength. This is one illustration of weight saving due to welding.

When the two legs, or flanges, make an angle that is not 90 deg., the angle bar is said to be *beveled* (Fig. 31). If it is more than 90 deg., it is called an *open bevel;* if less than 90 deg., a *closed bevel.* A shut, or closed, bevel is objectionable in several ways. The beveling work is very difficult; for even when it is done with care, the heel of the bar is seldom in precisely the same plane as the flange, and so when riveted to the shell the contact is imperfect unless the projecting part is removed. Also, as one flange closes over the other, it may be difficult to punch the rivet holes and to hammer up the rivets. It is then obvious why all angles should have an obtuse-angle, or open, bevel. One hundred and twenty degrees is the maximum bevel allowed in an angle. If more is required, a bent plate is used for the attachment (Fig. 31, sketch *C*).

2. Bulb Angle.—The *bulb angle* is simply a development of the plain angle in which a small bulb of material has been added to the toe of the angle at the point of highest stress. This makes the bulb angle considerably stronger than the plain angle when riveted attachments are used (see Fig. 32).



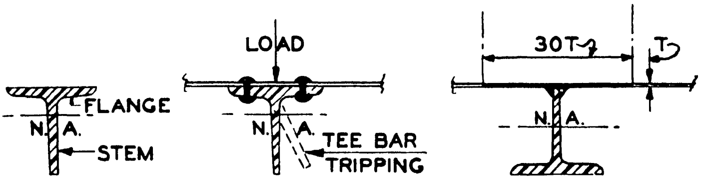
BULB ANGLE

BULB ANGLE SHOWING METHOD OF ATTACHMENT TO PLATING.

FIG. 32.

Bulb angles are used only in riveted construction. They were used for frame bars, stringers, bulkhead stiffeners, deck beams, keelsons, etc., but with the advance of welding in shipbuilding their usefulness is rapidly decreasing.

3. T Bar.—A *T bar* (Fig. 33) may be thought of as an angle one leg of which has been centered on the other. In riveted construction it is used in order to obtain a more symmetrical section and a better connection, for it allows an extra row of rivets to be driven. As a symmetrical section will not fall over or trip as easily as an unsymmetrical one, it is a better section than an angle. It suffers, however, from the same fault as the angle when riveted to plating as a stiffener, *viz.*, lack of material in the outer fibers. When used in welded construction it is inverted and becomes, in combination with 30 thicknesses of plating, a strong and rigid stiffener somewhat akin to an I beam.



TEE BAR

TEE BAR RIVETED TO PLATING.

TEE BAR INVERTED AND WELDED TO PLATING. (SYMMETRICAL SECTION)

Fig. 33.

4. T Bulb Bar.—The *T bulb bar* (Fig. 34) was developed to correct the fault in the T bar, *viz.*, the lack of material in the outer highly stressed fibers. In this case, material was simply added in the form of a bulb at the bottom of the stem.

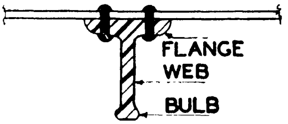


Fig. 34.—T bulb bar

T bulb bars were used primarily for bulkhead stiffeners and deck beams in riveted work, but they are now practically obsolete. They are not used in welded construction.

5. Channel.—A rolled shape having two parallel flanges on the same side of the web and at right angles to it is called a *channel* (Fig. 35). Channels are very useful for side frames, deck beams, bulkhead stiffeners, and pillars; but as they are not truly symmetrical sections, they have a tendency to trip, or fold over, under load. They are used extensively in riveted shipwork, for the upper flange gives a good rivet connection and the lower highly loaded flange has plentiful material concentration.

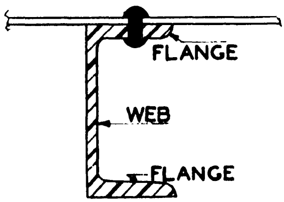
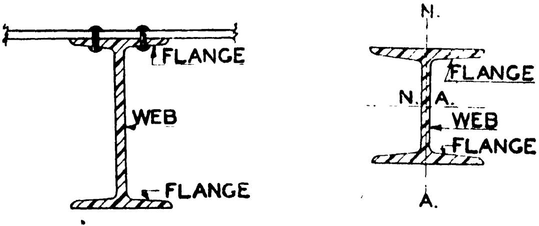


Fig. 35.—Channel.

6. I and H Beams.—A rolled shape having a cross section like the letter I is known as an *I beam* (Fig. 36). An I beam may be considered to be a channel with its web centered. This is a truly symmetrical section and for this reason is excellent for deck beams and girders.

When the flanges of an I beam are as wide as the web, it is called an *H beam* and is used extensively as a column or pillar in way of the engine and boiler spaces. It is not a good section to use as a pillar in the way of cargo holds, for the sharp edges may damage the cargo.

7. Cut Sections.—The use of welding as a connection now permits cutting one flange from a number of shapes previously used intact and thus obtaining lighter sections with no loss in stiffness. This is due to the fact that the plating to which the stiffener is welded acts in place of the removed flange (Fig. 37). It is usual to assume that 30 thicknesses of plating act in conjunction with the attached section.



I beam H beam

Fig. 36.

Assume that we have a 4- by 4- by ½-in. angle welded to a piece of ¼-in. plating (see Fig. 37). The area of a cross section through this angle is 3.75 sq. in.; therefore, the area of the lower flange as welded will be approximately

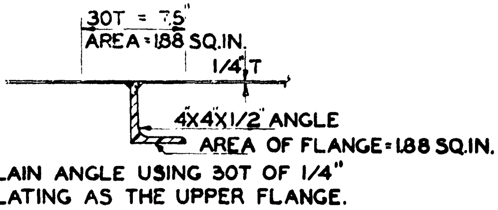


Fig. 37.

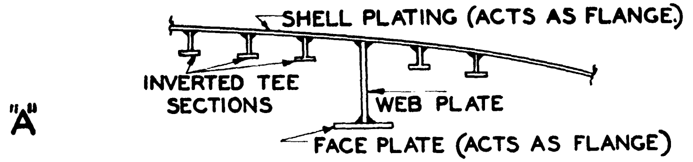
$$\frac{3.75 \text{ sq. in.}}{2} = 1.88 \text{ sq. in.}$$

We may now use any number of thicknesses of plating up to 30 in order to make up enough area to balance the lower flange.

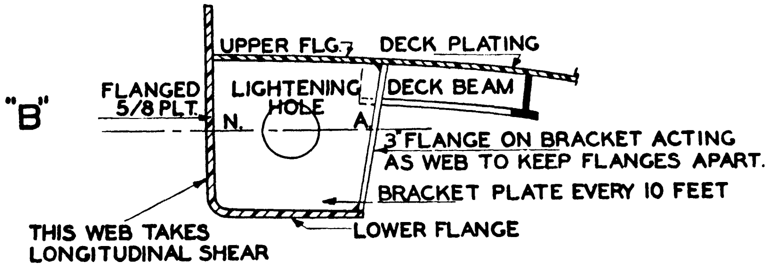
In our case it would take

$$\tfrac{1}{4}\text{-in.}, T \times X = 1.88 \text{ sq. in.}$$
$$X = \frac{1.88}{0.25}$$
$$X = 7.52 \text{ sq. in. required}$$

Thirty thicknesses of ¼-in. plating = 30 × 0.25 = 7.5 in. of plating, and as we are within our 30-thickness limit we can assume that we have a balanced section somewhat similar to a channel but with one flange centered on the web.



SECTION THROUGH SHELL SHOWING INVERTED TEES AND DEEP WEB FRAME



SECTION THROUGH A HATCH GIRDER

FIG. 38.

8. Built-up Sections.—Sections built up entirely of welded plates are now used extensively for both merchant and naval hulls. While they are more expensive than the rolled section, they can be made so that the maximum material will be at the point of greatest expected stresses, thus saving weight. Figure 38 illustrates two of these applications. Many other applications will be noted throughout the text.

Problems

1. Give four reasons why wood makes a poor construction material for large vessels.

2. What is Krupp-type armor?

3. For what purposes is STS used?

4. Why are concrete vessels usually unsuccessful?

5. What parts of a vessel are usually forged?

6. List the three main steps in producing a casting.

7. What is the difference between a steel plate and a piece of sheet metal?

8. Give the thickness in inches of plates listed below:

a. 30 lb.
b. 120 lb.
c. 5 lb.
d. 15 lb.

9. Why is a furnaced plate expensive?

10. Make a simple sketch and label the parts of the six shapes used to the greatest extent in the hull of a ship.

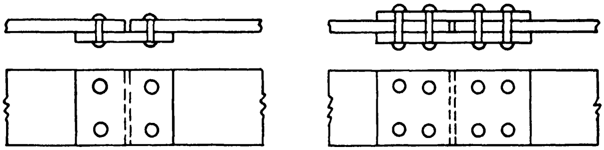
CHAPTER III

RIVETING AND WELDING

RIVETING

Although the joining of steel plates by rivets is gradually giving way to welding, riveting still is important in ship construction.

There are two standard types of riveted joint used in shipbuilding to connect steel plates. They are the *strap joint* (Fig. 39) and the *lap joint* (Fig. 40).

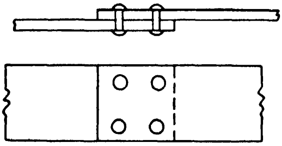


Butt joint with single butt strap

Butt joint with double butt strap

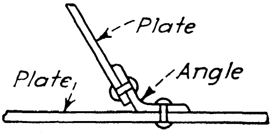
FIG. 39.

When riveted joints occur at the ends of plating, they are called *butts*. When they occur at the sides of the plating, they are called *seams*.



Lap joint

FIG. 40.



Angle connecting two plates

FIG. 41.

Where plates meet at right angles, or nearly so, to each other. they are connected by an angle or some other suitable shape, as in Fig. 41.

Figure 42 shows the connection of a riveted stiffener to a plate. The shape and size of the stiffener will depend upon the strength required.

Riveted joints usually receive all primary stresses: tension, compression, and shear (Fig. 43). Except for a slight secondary bending due to the attachments yielding under load, rivets are not subject to bending.

The amount of compression that a rivet will withstand is usually called its *bearing value*, and so compression on a rivet is usually referred to as *bearing*.

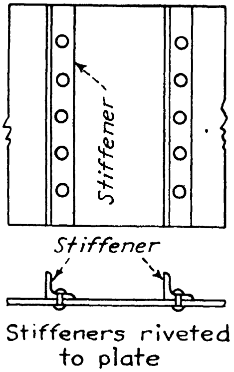


FIG. 42.

There are four methods of failure of a riveted joint (see Fig. 44).

1. *All rivets may be sheared.*
2. *The plate may tear between rivets.*
3. *The rivet may pull through the plate or the rivet may fail in tension.*
4. *Rivets may tear through plate longitudinally, owing either to insufficient bearing area or to insufficient edge distance.*

These modes of failure may be eliminated, in general, by the following methods, each applicable to the correspondingly numbered failure:

1. Increase the size of the rivet or the number of rows of rivets.
2. Increase the distance between rivets.
3. Make the thickness of the plate and the size of the head sufficiently large so that this type of failure will not occur before the rivet fails in shear.

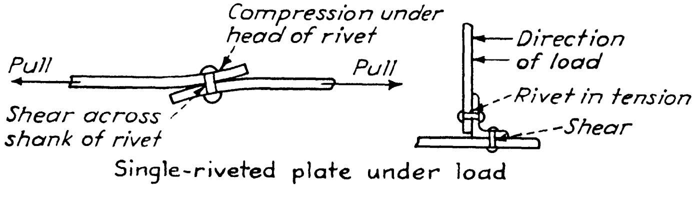


FIG. 43.

4. First, make the plate thick enough in proportion to the rivet diameter to make the bearing value on the rivet equal to the shear on the rivet, and, secondly, make the "edge distance" sufficient. If the distance from the center of the rivet hole to the edge of the plate is made $1\frac{1}{2}$ times the diameter of the rivet, this method of failure will be eliminated.

Fulfilling the above requirements leads us to multiple rows of rivets. Multiple-row joints sometimes fail by combining methods 1 and 2 as in Fig. 45.

In designing a riveted joint each possible method of failure must be calculated. The strength of the weakest divided by the strength of the solid plate is the efficiency of the joint. Maximum efficiency is not desired for riveted joints in shipwork, for the entire ship's plating is weakened to about 85 per cent (7 diameters) by riveting the shell to the frames (Fig. 46).

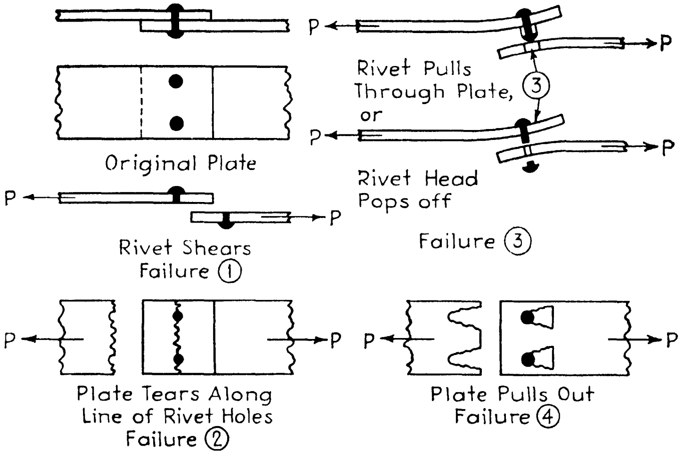


Fig. 44.

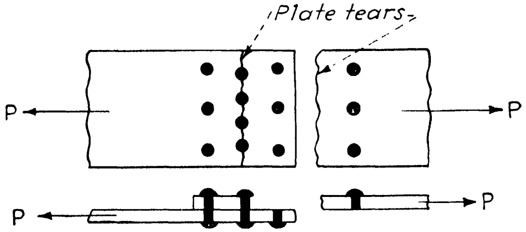


Fig. 45.

In watertight or oiltight work, the rivet spacing is limited to that spacing which will prevent bulging of the caulked edge between the rivets. This rivet spacing is in general $3\frac{1}{2}$ diameters for oiltight work and 4 or $4\frac{1}{2}$ diameters for watertight work.

We cannot obtain absolute tightness by close spacing of rivets. Caulking is usually required, together with close rivet spacing.

If the rivets are spaced too far apart, caulking the seam will cause the plate to distort between the rivets.

The procedure used in edge and butt caulking is shown in Fig. 47. It should be noted that, if the distance between the caulked edge and the first row of rivets is greater than twice the diameter of the rivets, leaks will probably develop, owing to the long span between the caulked edge and the rivets.

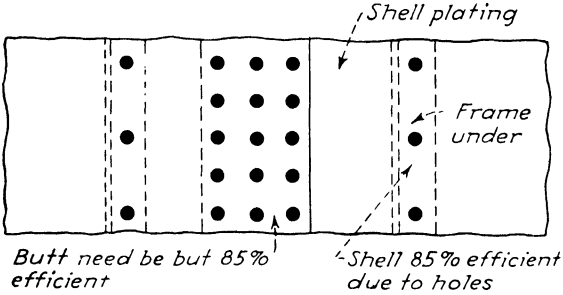


FIG. 46.

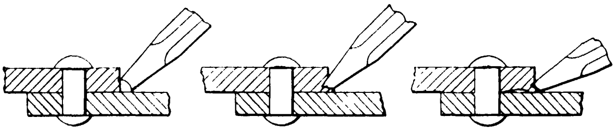
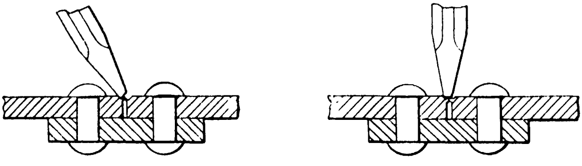

Edge scored

Plate split along score mark

Plate caulked with caulking tool


Plates split along score mark

Plates caulked with caulking tool

FIG. 47.

WELDING

Welding is the art of uniting two pieces of metal, at or near the melting point, without using another metal having a lower melting point to make the joint. Soldering and brazing differ from welding in that they make the joint with a softer metal. A soldered or brazed joint has a strength no greater than that of the softer metal employed, but a properly designed and executed weld will equal or surpass in strength the metals joined.

If the union is made by heating the metal to or above the melting point, it is called a *fusion weld.* If the union is made by heating the metal to just below the melting point and applying pressure, it is called a *pressure weld.*

Forge Welding.—The forge welding of iron and steel by hammering the parts together after heating them to a plastic condition in a blacksmith's forge has been practiced in shipyards for many years as a means of making joints in forging. The use of welding to replace riveting as a connection between the members of a ship's structure is comparatively recent, and this sort of welding is the subject of this chapter.

Ship Welding.—The welding of hulls on the shipways has been made possible by the development of welding processes for uniting metals through the application of fusing heat without compression, or hammering, and of appliances for doing this welding while the parts to be connected are in place on the structure. All these processes involve *fusion welding.*

The welding of a light structure is also done in the shipyard shops by machines using a combination of pressure with less than fusion heat. This is known as *resistance welding.*

Fusion Welding.—The method of fusion welding consists essentially in depositing molten metal in a joint at a heat that is sufficiently high to fuse together the deposited metal and the adjoining pieces.

We can generate this necessary heat in any one of the following three ways.

1. By the use of an electric arc, known as *arc welding.*
2. By *gas combustion,* such as is used in oxyacetylene welding.
3. By a chemical reaction, such as *Thermit welding.*

1. Arc Welding.—Arc welding may be subdivided into two types, *metallic arc welding* and *carbon arc welding.*

a. Metallic Arc Welding.—In metallic arc welding a metallic electrode is used to strike an arc at the joint to be welded in order to provide heat for welding. To do this the operator brings the end of the electrode in contact with the metal to be welded. The electrode is then withdrawn about $\frac{1}{8}$ in. Electrons (negative electric charges) will flow across this $\frac{1}{8}$-in. space and bombard the base metal. Owing to this bombardment the temperature of the base metal in way of the arc rises to about 2300°C. (4172°F.), and a crater is formed in the base metal. The electrode melts, and particles of the electrode are projected along the electron stream into the crater. This is finally filled, and the weld is thus formed. Metallic arc welding is done with either a bare metal electrode or a covered one.

Experience has shown that some refractory oxides, such as titanium and calcium oxide, will increase the electron-emission rate. Therefore, these or similar oxides are used as fluxes to coat covered electrodes.

If bare electrodes (uncovered) are used, the metallic particles on their way from the electrode to the base metal are exposed to the atmosphere. This exposure is undesirable in that the weld metal is both oxidized and nitrogenized. Oxygen converts the carbon, silicon, and manganese in the weld metal into oxides, which float to the surface as slag, thus changing the properties of the weld metal. The nitrogen is absorbed in the weld metal, making the weld brittle.

The use of covered electrodes reduces the oxidation of the alloying elements as well as the absorption of nitrogen. These results are made possible partly by the action of the flux on the electrode, but primarily by the air-excluding action of the gaseous envelope created by the burning of the electrode covering. Welds produced by covered electrodes are better in tension and have greater resistance to impact than those produced by the uncovered type.

b. Carbon Arc Welding.—In carbon arc welding, an arc is struck with a carbon electrode, and the end of a rod of metal is placed in the arc to supply the material for the weld. Carbon arc welding is used principally in the brazing of cast iron. The disadvantages of this method of connection are overcome by the use of a brazing metal of which the tensile strength equals or exceeds the low tensile strength of the iron casting. Further strength is secured from the carbonizing effect of the arc, from which carbon is absorbed by the cast-iron base metal, thus increasing its tensile strength.

2. Gas Welding.—Gas welding is the art of welding by means of a torch. In this method, heat for welding is provided by a torch through which streams of gas and oxygen are united, producing a flame of high temperature. This flame is directed at the joint to be welded, and the end of a metal rod is placed in the flame to supply material for the weld. The gases most commonly combined with oxygen in gas welding are acetylene and propane.

3. Thermit Welding.—Thermit welding is the process of welding by means of a chemical heat produced by the combination of the elements making up what is known as *Thermit.* This is a mixture of finely divided aluminum with an oxide of iron and chromide. On being heated by a priming of magnesium powder, the aluminum combines violently with the oxygen of the metallic oxide, producing a fluid slag and great heat. Thermit welding is essentially a casting process, as a fire-clay mold must be built around the joint to confine the molten metal. The excess is chipped off after the weld has cooled.

Thermit welding is chiefly used to repair large hull forgings or castings without their removal from the ship and is usually performed while the ship is in dry dock. The phenomenon on which the process is based is also responsible for the development of the incendiary bombs used in the Second World War.

Resistance Welding.—In resistance welding the pieces to be joined are clamped together and an electric current is passed through the joint until the heat produced by the resistance of the metal makes it plastic at the weld. Pressure is then applied to bring the surfaces to be united into close contact and also to exclude air so as to prevent oxidation. This method is used principally for joining sheet metal in the shops. Resistance welding may be subdivided into three main types, *butt, spot,* and *seam.* In resistance butt welding, the pieces are brought together edgewise. In resistance spot welding, the material is overlapped and the welding is done in spots made in an intermittent line down the middle of the lap. In resistance seam welding, the material is also overlapped, but the spots are so close together that actually they form a continuous line.

TYPES OF WELDS

There are two basic fusion welds, of which all other such welds are simply a variation. These basic welds are the *fillet* and the *butt* and are shown in Fig. 48.

DESIGN OF A WELDED JOINT

The design of a weld is based on the assumption of a uniform direct stress across the throat. This assumption is not correct, for the stress distribution is very uncertain; the throat is not always perpendicular to the direct stress, penetration increases the actual width of the throat, and there are locked-up stresses[1] in the weld. The above effects are ignored in the design and are taken care of by using suitable working stresses obtained experimentally.

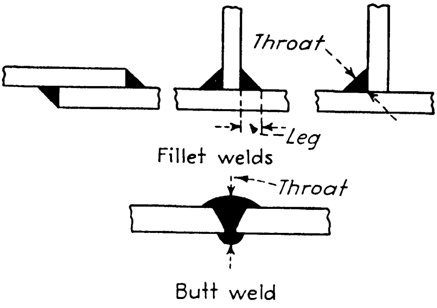


FIG. 48.

Design stresses for welds (merchant-ship practice) are as follows:

	Lb. per sq. inch
Shear	7,950
Tension	15,000
Compression	15,000

Problem: To illustrate the design of a weld, assume that we have a ½-in. weld all along both sides of the flat bar shown in Fig. 49. How much would the bar have to be overlapped to support a straight pull of 40,000 lb. on the bar?

Solution: The ratio of the throat width to the leg of a right-angled isosceles triangle is 0.707, and so our throat width will be

$$0.707 \times 0.5 \text{ in.} = 0.3535 \text{ in.}$$

The area required will be

$$\frac{\text{Total load to be supported}}{\text{Allowable stress per sq. in.}} = \frac{40{,}000 \text{ lb.}}{7{,}950 \text{ lb. per sq. in.}} = 5.03 \text{ sq. in.}$$

The length of weld required to give 5.03 sq. in. of weld metal would be

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[1] These locked-up stresses are due to the shrinkage that takes place during the cooling period of the weld metal. If a proper welding sequence is not used, these locked-up stresses may become great enough to break the weld or tear the plate. Also, weather and poor welding technique are factors tending to produce locked-up stresses.

$$\frac{\text{Sq. in. required}}{\text{Throat width}} = \frac{5.03 \text{ sq. in.}}{0.3535 \text{ in.}} = 14.22 \text{ in.}$$

The overlap required would be half the above as we are welding on both sides. Therefore,

$$\frac{14.22}{2} = 7.11 \text{ in. overlap required}$$

Attachments 100 per cent efficient are impossible with riveted connections, but in welding 100 per cent attachments are easy to obtain.

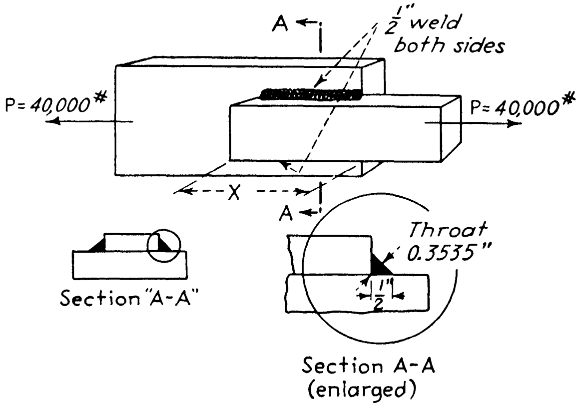

FIG. 49.

There is much more to learn about riveting and welding. The serious student is referred to Rossell's "Riveting and Arc Welding"[1] for a further discussion.

Problems

1. Sketch a plate that has failed by a combination of tearing through the center row of rivet holes and shearing the outer row of rivets.
2. What is the difference between a seam lap and a butt lap?
3. To what type of stresses are riveted joints subjected?
4. How can you eliminate failure of a joint due to the rivets' shearing?
5. What is the difference between oiltight and watertight rivet spacing?
6. Explain the action of the refractory oxide used as the covering of a welding rod.
7. Differentiate between forge and fusion welding.
8. Give a brief description of carbon arc welding.
9. How is a Thermit weld made?
10. Calculate the strength in tension of a ½-in. butt weld 10 in. long. *Ans.* 75,000 lb.

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[1] Simmons-Boardman Publishing Corporation, New York.

CHAPTER IV

KEELS

In the past a vessel's keel was thought of as the "backbone" of the hull. It is still a member of importance, for it ties the transverse bottom members together and distributes the imposed loads fairly evenly over a large area. Some of the newer, larger vessels have dispensed with the traditional keel. Eliminating the keel increases the difficulties of dry docking, for special blocks must be placed to support the vessel; therefore, this practice is not recommended. In twin-bulkhead tankers (Fig. 119) the keel could be dispensed with if it were not for the difficulty of dry docking. Most merchant vessels are dry-docked with the keel resting directly on the keelblocks and carrying most of the weight of the vessel, the bilge blocks bearing only a small proportion. As the keel assembly is usually a massive structure, it absorbs a large proportion of the stresses produced by hull-girder action when the vessel is in a seaway.

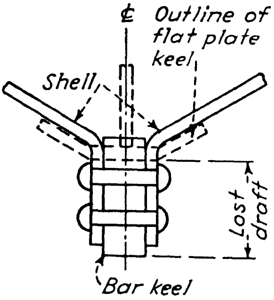


FIG. 50.

BAR KEEL

The *hanging keel*, or bar keel, was used to a great extent in former days (Fig. 50). Its stiffness protected the shell plating somewhat if the vessel grounded on a hard or stony bottom. It also reduced the rolling of the vessel when in a seaway by acting similarly to a bilge keel. Its chief disadvantage was that it increased the draught of the vessel without increasing the displacement. This is an important consideration, for some vessels are designed for trades in which the draught is at a premium.

TONS PER INCH

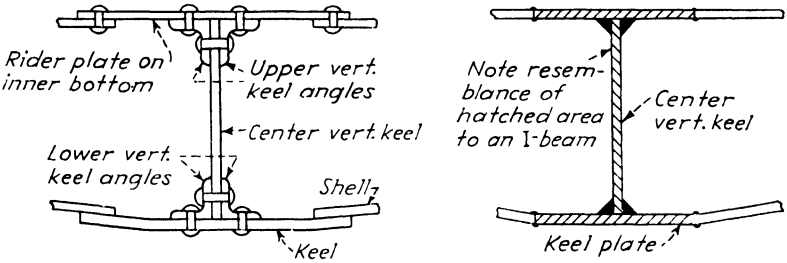
The average 400-ft. cargo vessel has a *tons per inch of immersion* of about 50; *i.e.*, the vessel will sink 1 in. for every 50 tons added to its load. If a ship had to cross a bar at the mouth of a certain harbor and the increase in draught due to the bar keel was 8 in., then the loss in cargo that could be carried (assuming that the vessel without the bar keel could just skim over the bar) would be

$$8 \text{ in.} \times 50 \text{ tons per in.} = 400 \text{ tons}$$

which would be a considerable loss from the owner's point of view. This type of keel is almost obsolete, but it still may be found in yachts and smaller boats, for which increased draught is not objectionable.

FLAT-PLATE KEEL

In order to reduce the draught the *flat-plate keel* was adopted. The flat-plate keel is in reality just one of the shell plates increased in thickness to withstand docking and grounding loads. The flat plate extends from the stem to the stern frame. If riveted, it is usually lapped over the garboard (adjoining) strake. If welded, the seam is simply butted directly to the garboard strake (Fig. 51).



Flat plate keel with riveted attachments

Welded flat plate keel

FIG. 51.

The flat-plate keel itself bears only a comparatively small portion of the total keel stresses. However, in conjunction with the center vertical keel and the rider plate it forms a rigid and powerful I beam.

Figure 51 shows both the riveted and the welded type of flat-plate keel assembly. If riveted, the flat keel plate is attached to the center vertical keel by the lower vertical-keel angles, and the center vertical keel is attached to the rider plate by the upper vertical-keel angles. This assembly is rigid, massive, and strong.

If of welded construction, the angles and laps are omitted, with a corresponding saving in weight.

Before the advent of welding, either the keel was made intercostal and the floors continuous, as in small single-bottom ships, or the keel was continuous and the floors were cut at the keel and riveted to it by angle clips. The severance of the floors in way of the vertical keel reduced the strength of the bottom of the hull so that the thickness of the vertical keel was increased to compensate for this weakness.

As the longitudinal bending moment is greatest amidships, the keel scantlings are greatest in way of this maximum moment. They may be decreased toward the ends of the ship because of the decreasing bending moment. The transverse bulkheads assist in supporting the keel and bottom as shown in Fig. 52.

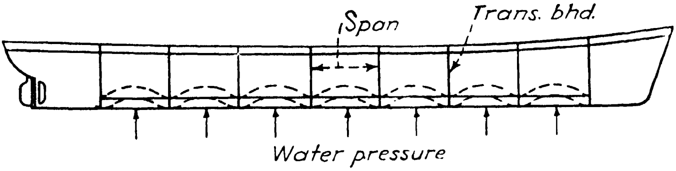


FIG. 52.

These supports transform the keel from a long flexible girder to a series of rigid girders of short span.

Special care should be taken in designing the riveted connections of the floors to the center vertical keel. The size of the angle clips should be consistent with the size of the plates connected and a sufficient number of rivets used to give a good strong attachment. If the stresses are excessive, two angles should be used. The use of two angles, properly designed, will nearly double the strength of the joint.

In double bottoms of the cellular type the keel always runs continuously. The floors are connected through the reverse frames to the tank-top plating and through the frames to the bottom shell. When thus connected the entire structure forms a double bottom composed of numerous rectangular compartments bounded by the floors, longitudinals, and keel. The boxlike girders formed by this cellular construction gives great strength and rigidity to the vessel's bottom.

If the cellular double bottom is all welded, the above remarks relating to the continuous keel do not apply, for all connections are 100 per cent effective and the keel may be either continuous or discontinuous and still develop 100 per cent of the plate strength. Subassembling large sections of the double bottom has been made possible by the use of welding. This subassembly work is usually done with the assembly inverted, which eliminates the difficult overhead welding of the floor tops to the tank-top

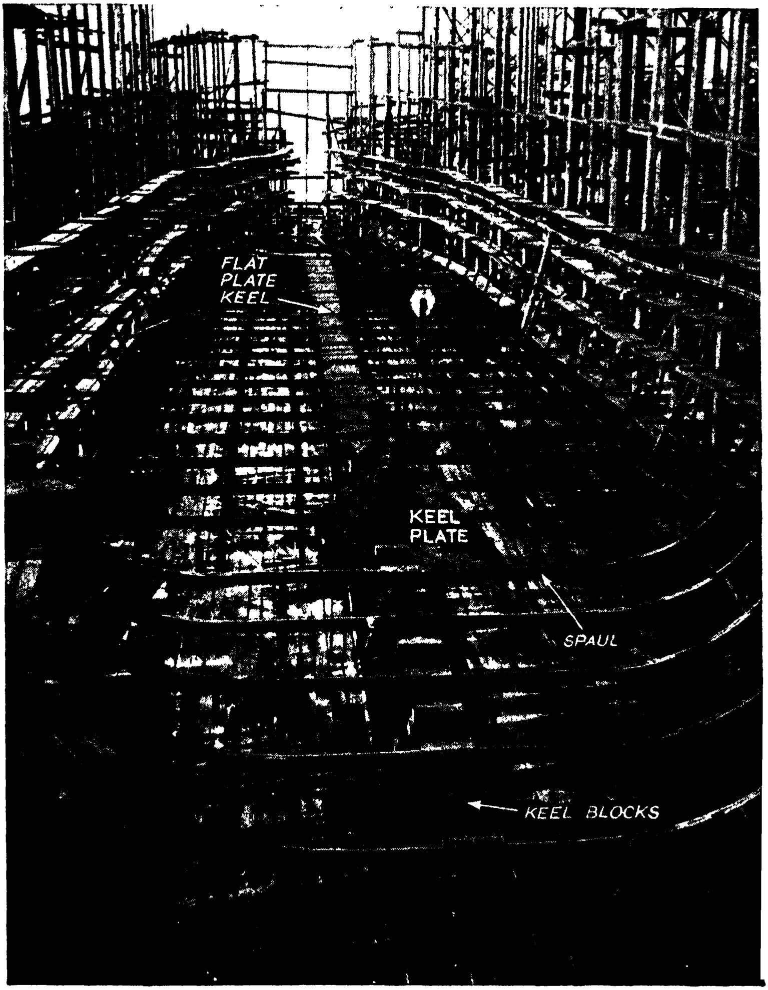


FIG. 53.—Laying the keel. The flat plate keel is being laid along the top of the keelblocks and over the spauls. The spauls support the shell plating until the frames can be put in place and attached to the shell.

plating. The entire cellular assembly thus formed is then turned over and placed in the vessel. Much time is saved and better workmanship is obtained by this procedure.

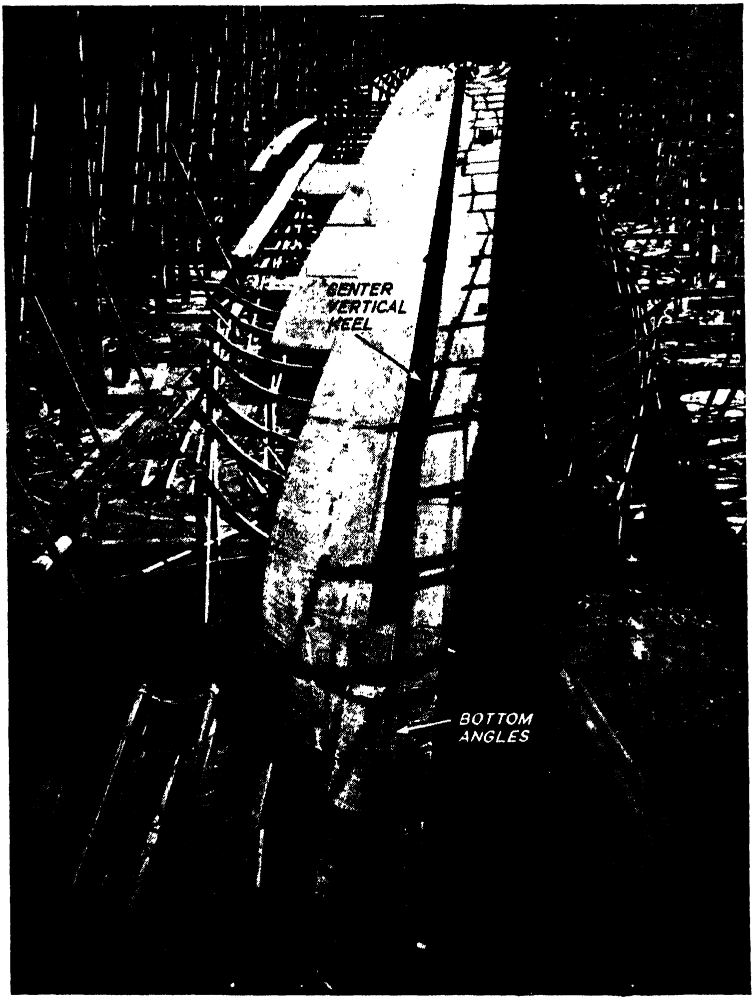


FIG. 54.—Center vertical keel. The flat plate keel has been laid and the center vertical keel is being fitted in place and attached by angle clips.

Attached to the underside of the flat-plate keel on many vessels is a rubbing strip, consisting of a flat bar about 3 in. thick and 6 in. wide, whose purpose is to protect the flat-plate keel from being damaged if the boat should run aground. It also protects the keel plate during dry docking, but it damages the dry dock's keelblocks considerably.

BILGE KEEL

Bilge keels are fitted to most large ships to reduce the rolling of the vessel when in a seaway. They are finlike pieces of steel plate fitted to the vessel in the vicinity of the turn of the bilge. They are fitted only in the midship length of the vessel, for this is the portion subjected to the greatest action of the water when the vessel is rolling. Bilge keels reduce violent rolling but have no effect on the vessel's stability.

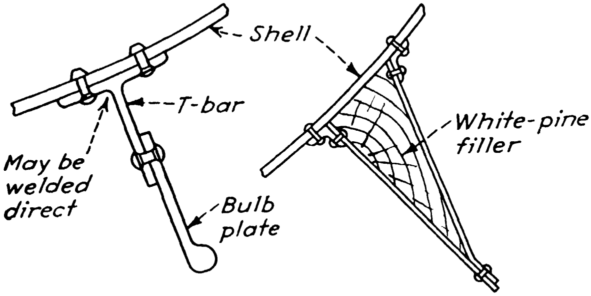


Fig. 55.—Two types of bilge keels.

Bilge keels commonly consist of two general types, the flat-plate type and the filled double-plate type. The flat-plate type, shown in Fig. 55, usually consists of a T bar riveted to the shell, with a bulb plate, or other extender, riveted to the outboard edge of the T. It is now common practice to weld a steel plate directly to the shell. The filled double-plate type is used on the larger vessels. It consists of two plates either attached to the shell by angle bars or welded directly to the shell. Balsa or some other easily worked wood is used as a filler to give rigidity to the plates. Pitch is usually gunned into the bilge keel to fill up any empty space where water might collect and corrode the inside of the bilge keel. This precaution is necessary, for the inside of the bilge keel is inaccessible after it is in place on the ship.

PRESSURE ON THE BOTTOM OF A VESSEL, DUE TO DRY DOCKING

When a ship is completely water-borne, the upward pressure from the supporting water is distributed fairly evenly over the watertight envelop or hull of the ship. When a vessel is dry-docked, however, the situation changes radically, for the total weight of the vessel may have to be borne by small portions of the ship's bottom.

The keel takes most of this load. Bilge blocks, which are pulled under the bilges in order to keep the vessel upright when the water is pumped out of the dock, take but a fraction of the total load. War vessels usually have great masses of concentrated weights, such as armor and turrets, which are well distributed as regards support when the ship is afloat but which would become dangerously concentrated on a few bulkheads and bottom longitudinals if it were attempted to dry-dock them in the same manner as merchant vessels. In order to distribute this weight concentration more evenly over the bottom and thus prevent bottom damage, docking keels, paralleling the center vertical keel, used to be (and in some cases still are) fitted in most large warships. Figure 56 shows a typical docking keel.

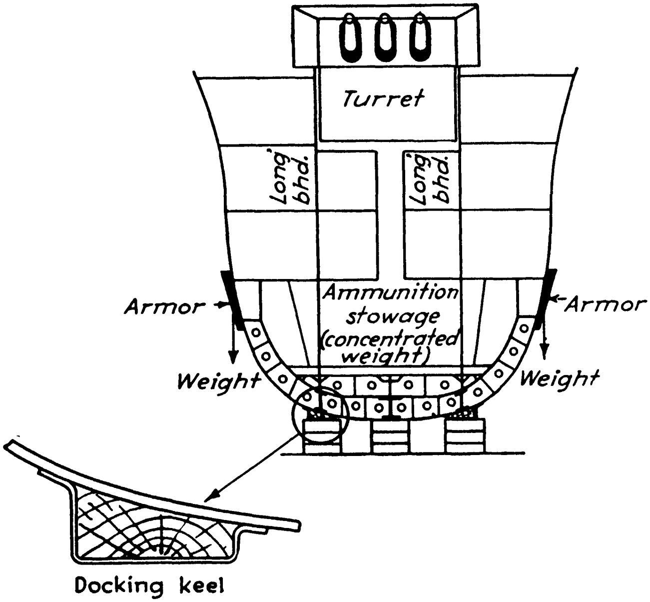


FIG. 56.

At present, before dry docking some naval vessels we build a cradle in the bottom of the dry dock, so arranged that the longitudinal and transverse bulkheads acting with the keel bear on it and assume the support of the weights above them.

Problems

1. What is the disadvantage of the bar keel?

2. Sketch and label a riveted-keel assembly.

3. Does a bilge keel increase the stability of a ship?

4. What is the purpose of the rubbing strip?

5. Why are cradles built to dry-dock a naval vessel when this is not required for a merchant vessel?

6. What is the main objection to deleting the keel of a twin-bulkhead tanker?

CHAPTER V

FLOORS AND DOUBLE BOTTOMS

In the design of a ship the bottom structure is of great importance, for it acts as the lower flange of the box girder formed by the hull. In conjunction with the keel the bottom must resist the longitudinal stresses produced by the uneven support of the hull girder by the crests and hollows of actual waves at sea. Like the keel itself, the entire bottom must be stiff enough to withstand the concentrated pressures due to docking and grounding and strong enough to support the weight of the cargo.

The additional strength and stiffness thus required are obtained by deepening the transverse framing across the bottom of the hull to form what are known as *floors*. A ship's floors, therefore, are not horizontal as in a building but are vertical transverse structures extending across the ship, from bilge to bilge, and usually placed on every frame.

FLOORS

The floors in a single-bottom ship are generally of plate, tapering in width from the center line out to the bilge, around which they are usually carried. If riveted, the floor plate is fitted between the frame and reverse frame, with its lower edge connected to the bottom shell plating by the frame bar and its upper edge stiffened by the reverse frame, which is extended along it for that purpose. In welded construction, the frame is omitted in way of the floor, and the reverse frame may be replaced by a flange or faceplate.

Most of the floors in a double-bottom ship are of plate, but intermediate floors under the holds may be of open construction so as to reduce weight. These open floors are built up out of structural shapes, forming frame and reverse frame, which are connected by a flanged plate bracket at each end of the floor and by angle struts and stiffeners in between. The plate floors are called *solid floors*, to distinguish them from those of open type.

About one-quarter of the weight of a solid floor is saved by replacing it with an open floor.

As in all structural design, the effectiveness of the structure (in this case the floors) depends upon its being held up to its work by auxiliary structural members. The auxiliary structure consists of widely spaced longitudinal girders (usually called *bottom longitudinals*) that keep the floors from tripping, or folding over, in a fore-and-aft direction. In a single-bottom ship the girders include a center keelson and one or more side keelsons on each side, consisting of rider bars of angle or channel along the top of the floors, riveted to intercostal plates clipped to the floors and

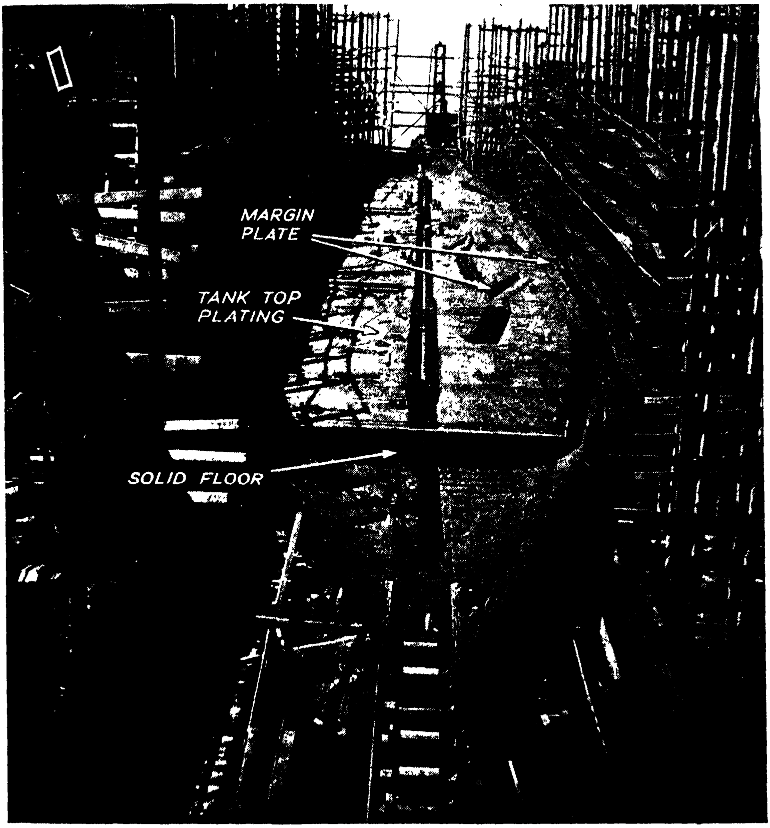


Fig. 57.—The double bottom partially completed. Note how the spauls support the shell plates.

shell. In a double-bottom ship, the center vertical keel is supplemented by similar full-depth side longitudinal girders.

In small vessels, the floors may be short enough to be fitted in one piece, with the vertical keel intercostal, but in most ships the floors are cut at the center line and fitted in two pieces. In large double-bottom ships it is the usual practice to stop the floors at the continuous vertical keel, to which they are connected by angle clips if riveted or directly connected if welded. The side longitudinal girders are usually fitted intercostally between solid plate floors but are not cut at open floors.

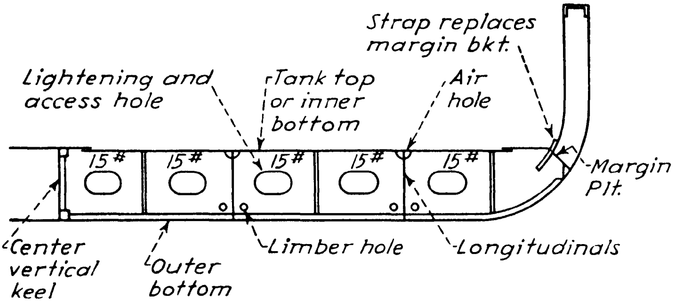


FIG. 58A.—Solid floor as used on C-3 type vessels.

To avoid buckling of the floor plates between the auxiliary longitudinal girders, the former must be made of sufficient depth and thickness. Much weight is saved by cutting lightening holes along the neutral axis of nonwatertight solid floors. These holes are indispensable for access in the construction and maintenance of the double bottom. Their size must be limited, or they will reduce the stiffness of the bottom. A thick floor plate, however,

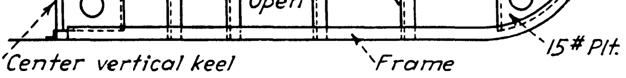


FIG. 58B.—Open floor.

lightened properly, is stiffer and more durable against rust than a thinner plate without any lightening holes.

Extra strength and rigidity in the ship's bottom are required under the machinery space because of the concentrated loads found there. This is further necessary on account of the heavy stress and vibration set up by the engines and the increased liability to corrosion due to the heat and moisture in these compartments. The thickness of the floors is therefore increased throughout the machinery space, and open floors are not permitted.

DOUBLE BOTTOMS

From the earliest times, it has been recognized that an empty ship, riding high out of water with its center of gravity well above the water line, is top-heavy and unstable and therefore liable to capsize in a storm. It has also been found that a vessel in a light condition is difficult to steer and is likely to be driven off its course in rough weather. For these reasons, it has always been the practice to bring an unloaded ship farther down into the water by placing some heavy material, known as *ballast*, in the bottom of its hold.

For many years this ballast consisted of dirt, sand, gravel, or stone, taken from the shores of the harbor where the ship unloaded its cargo. This practice involved a serious delay at both ends of the route, for the ballast could not be put in until after the cargo had been completely taken out and had to be removed before a return cargo could be put in. It was also undesirable from the standpoint of expense, for wages had to be paid for handling ballast and no freight was paid for carrying it.

About 1885 the carriage of water ballast in iron and steel ships was made possible through the introduction of the *McIntyre tank*. This tank was formed in the bottom of the ship by a watertight plate cover built above the floors of a single-bottom ship and supported by fore-and-aft girders riding on the tops of the floors. Into the space thus provided, water ballast could be pumped to give the vessel sufficient draught when light. One of the original McIntyre-type tanks is shown in Fig. 59.

Since this water could be handled by the ship's own pumps and pumped out or in without waiting for the ship to be loaded or unloaded, the delay and expense associated with the use of other types of ballast were obviated by the adoption of water ballast.

The McIntyre tanks, as first constructed, had two disadvantages. (1) The tank top, being raised about 18 in. above the floors on which the cargo had formerly been supported by means of dunnage planks, reduced the ship's cubic capacity for carrying cargo. (2) Although well adapted for carrying ballast, they contributed very little to the longitudinal strength of the hull.

The last-named defect was overcome in later ships by extending the floors up to the tank top and the fore-and-aft girders down to the shell, producing the modern type of cellular double bottom. The additional cubic capacity of the cargo holds required when a double bottom is fitted can be easily provided during the design of a new vessel.

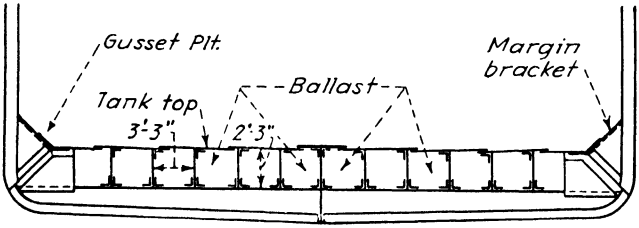


FIG. 59.– The McIntyre system of ballast tank.

It was soon realized that a double bottom possesses a high safety value, in addition to its usefulness for carrying ballast. This safety value lies in the fact that the tank top forms an inner bottom, or second skin, which might save the ship from sinking if it strikes a sunken obstruction or runs aground. Even though the outer bottom is torn open, the watertight inner bottom will limit the flooding to the double-bottom space and protect the cargo from damage by water.

The depth of the double bottom and floors is determined by the depth adopted for the center vertical keel but should be sufficient for ready access to all parts of the double-bottom space so as to allow proper construction and maintenance. In ships carrying heavy bulk cargoes, such as iron ore, the double bottom may be made much deeper than is required for strength and access, in order to raise the center of gravity of the loaded ship so as to produce a more comfortable period of roll (see Chap. XVI, page 181).

A further advantage of the double bottom lies in its availability for carrying fuel oil and water. Thus the cargo space is saved that was once wasted by the large bunkers and tanks formerly required for carrying coal and fresh water.

Figure 60 shows a modern cellular double bottom sketched in isometric projection. The term "cellular" is derived from the fact that the double-bottom space is divided into rectangular cells by the floors and longitudinals. These members act as deep web frames that resist and distribute the upward push of the water on the ship's bottom.

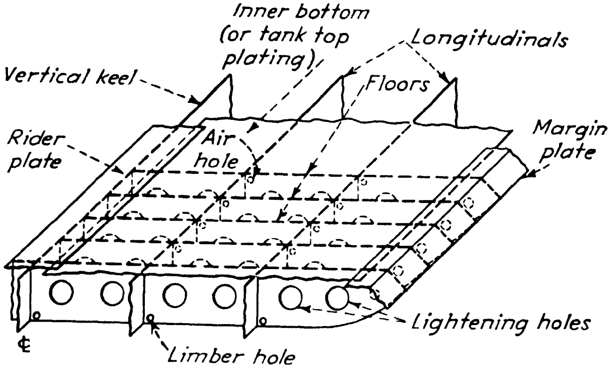


FIG. 60.—Modern cellular double-bottom structure.

INNER-BOTTOM PLATING

The inner bottom is generally fitted in rectangular plates and extends from the centerline strake, called the *tank-top rider plate*, to the outer strake on each side, called the *margin plate*. In riveted construction the inner-bottom plating is usually arranged in fore-and-aft strakes, having their adjacent butts shifted, or placed in different frame spaces, so as to avoid lines of weakness due to the inefficiency of the riveted joints.

In welded work the inner bottom is often plated transversely between the fore-and-aft centerline strake and the margin, and a shift of butts is not necessary, for no line of weakness is produced by the welded connections.

The rider plate is made heavier than the rest of the inner bottom and forms the top flange of the centerline keel girder. The margin plate is usually knuckled down to meet the shell at right angles, unless the depth of the double bottom exceeds the bilge radius, in which case the margin plate is carried straight out without knuckling. The inner-bottom plating is lighter than the bottom shell but is increased in thickness in the engine and boiler rooms to allow for corrosion and the weight of machinery.

The terms "double bottom" and "inner bottom" are not synonymous or interchangeable, for each applies to a different part of the ship's structure. The double bottom is the compartment between the inner and outer bottoms. The inner bottom is merely the plating forming the top of this compartment or tank; it is also called the *tank top*.

Problems

1. What are the requirements of the bottom structure?
2. Sketch a typical open and solid floor.
3. Is it permissible to cut lightening holes in solid floors?
4. What is the purpose of bottom longitudinals?
5. Why are open floors not permitted under machinery spaces?
6. What were the objections to the McIntyre ballast tanks?
7. What is a cellular double bottom?
8. Is it possible for a man to "go down into" the inner bottom?

CHAPTER VI

FRAMES AND FRAMING SYSTEMS

In the transverse system of framing, the principal frames form a transverse belt inside the shell. This transverse belt of frames is further supported by side stringers, bottom longitudinals, and other auxiliary longitudinal framing.

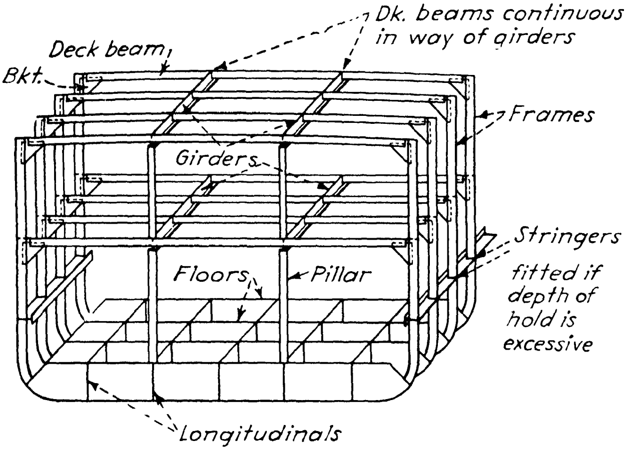


FIG. 61.—Isometric sketch showing transverse framing system.

The longitudinal system of framing differs from the above in that the shell and bottom plating is supported by frames running fore and aft. These longitudinal frames then are reinforced by deep transverse frames spaced at greater intervals than in the regular transverse system.

TRANSVERSE FRAMES

The frame spacing is the distance measured on the center line between the frames. It is usually 2 to 3 ft. on merchant ships and 4 ft. on naval vessels. This spacing is reduced at the bow and stern because the actual span of the shell lying over the frames is greater than is shown by measuring the distance on the center line (Fig. 63). Also, the bow and stern plating is subjected to direct blows from the sea and to panting stresses resulting from the violent pitching of the vessel in a seaway, both of which require additional support behind the shell.

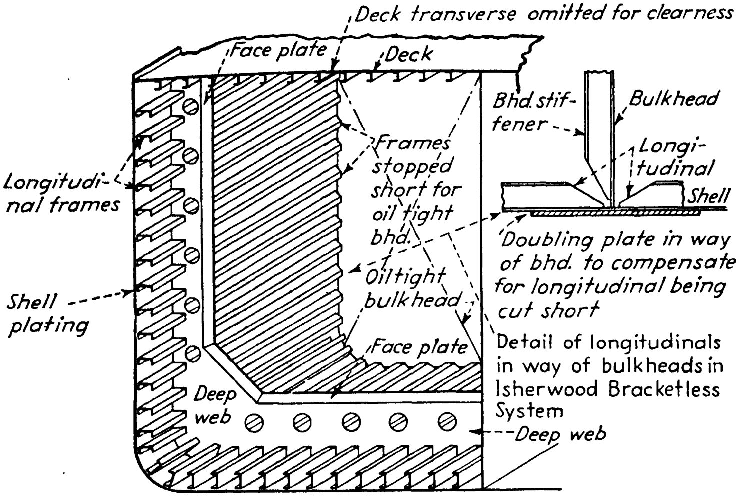


FIG. 62.—Isometric sketch showing the longitudinal bracketless system of framing.

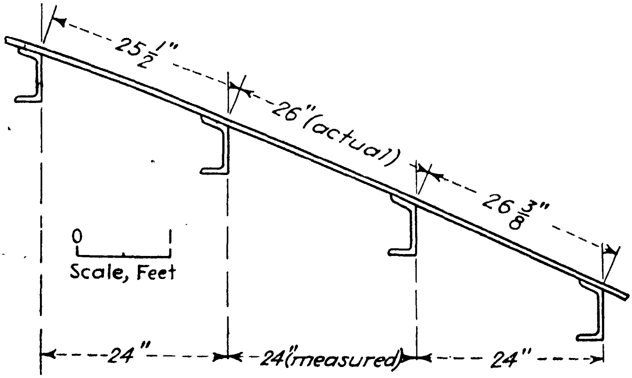


FIG. 63.—Distances measured along the shell are greater than distances measured along the center line.

The marked frame spacing is always 4 ft. in naval vessels. This is a help to the shipbuilder, for he is enabled to locate the distances of any point in a fore-and-aft direction by noting the frame numbers and multiplying by 4. This is not possible in some parts of a merchant vessel, owing to the varying frame spacing. Where extra shell support is needed in a naval vessel,

FIG. 64.—Shell framing. The frames are being erected. Note the shape of the frames lying on the tank-top plating.

half frames are introduced; thus, successive frames would be numbered 21½, 22, 22½ 23, etc.

Of course, the wider the frame spacing, the greater the span of the shell plating. If we increase this span, we must increase the thickness. Also, the larger the vessel, the greater the load on the shell and framing. This requires the fitting of heavier plating and frames on a large vessel than on a small one, and the plating being heavier permits a wider span between shell frames. As an illustration, the American Bureau requires frames spaced 27 in. apart on a ship 400 ft. long and 32 in. on a ship 600 ft. long. (These figures are general and are dependent on the span of the frames and other factors enumerated in the rules.) On an all-welded hull 400 ft. or longer, it probably would be cheaper and better to space the frames 36 in. apart and increase the shell thickness 0.01 in. for each inch by which the frame spacing exceeds the rule spacing. [This would be an addition of 0.01 × (36 − 32 in.) = 0.04 in. for the 600-ft. ship above.] This will add to the weight of the shell but will reduce the number of frames and the amount of welding required.

If the framing is riveted, the forward frames toe aft and the after frames toe forward. This is done to avoid acute angles, or closed bevels, between the flanges of the frame, which would render proper riveting difficult. Consideration of which way to toe the frames is not necessary with welded construction, for the simpler section used for frames usually permits ready accessibility.

LONGITUDINAL FRAMES

In a longitudinally framed ship the principal fore-and-aft frames (Fig. 62) are about 30 in. apart (see Fig. 7). The heavy transverse webs that support these smaller longitudinal frames are placed about 10 to 16 ft. apart, and the span of the longitudinal frames is thus shortened. This lessening of the span gives rigidity to the shell and framing system.

Figure 62 shows a ship of the *Isherwood type,* so called because this type of construction was reintroduced and patented by the British naval architect, Sir Joseph Isherwood. The figure also illustrates the *bracketless system* of construction. In this particular type of longitudinal framing the brackets at the ends of the longitudinal frames are omitted, and the shell is heavied in way of this omission. The majority of tankers are built on the Isherwood or some similar system, for the deep webs required to support the longitudinal frames do not interfere with the carriage of oil as much as they would with the carriage of bulk cargo.

TYPES OF FRAME SECTION

Small vessels, if transversely framed and riveted, sometimes use angle bars for frames. These are beveled and attached to the shell in such a manner that the leg of the angle is at right angles to the center line of the ship. The toe of the angle is parallel to the shell, as shown in Fig. 65. This type of construction is not suitable for large vessels because the neutral axis is close to the shell and there is not much material in the toe of the angle, all of which results in too much flexibility and weakness. For larger riveted vessels the plain angle is sometimes used in combination with a reverse frame, as shown in Fig. 67. The reverse frame adds material to the toe and tends to center the neutral axis. The stiffness is greatly increased by this condition. Channels and bulb angles, when used for frames, will accomplish a similar result with a reduction in the amount of riveting. This was the object in mind when these sections were designed.

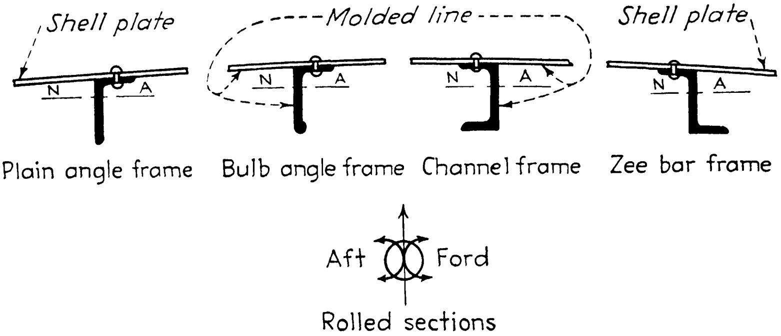


Fig. 65.—Types of frames used in riveted construction.

For riveted work, bulb angles and channels are the usual frame sections (Fig. 65). Channels are used for the main framing, and bulb angles are used in the peak tanks. Depth for depth, the channel is more effective than the bulb angle, and therefore channels are used in way of cargo spaces, for they decrease the cargo capacity less than the bulb angle. The bulb angle is used in the peak tanks because there the frame depth required to make the two sections equal in strength is not a factor. Most foreign shipbuilders prefer bulb angles for the frames of their ships if of riveted construction.

All the above frame types are becoming obsolete owing to the advent of welding. Figure 66 shows some of the welded types now in use. The welded designs are simpler, stronger for their weight, and usually cheaper to construct and fit.

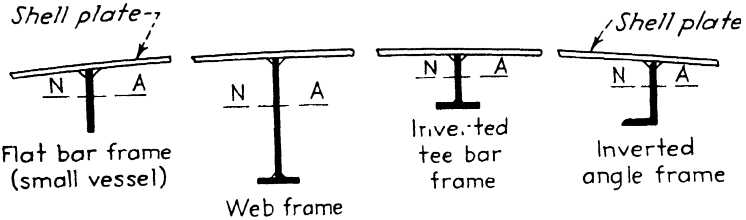


FIG. 66.—Types of frames in welded construction.

WEB FRAMES

Web frames are massive, deep, built-up members fitted into the hull to add strength and rigidity at points of special stress and to support the side stringers, which, in turn, support the transverse frames. The main member is a deep web of plate and usually is lightened by cutting holes along the neutral axis. If riveted, an angle attaches it to the shell, and usually two angles form the inboard flange of the frame. If of welded construction, it is attached directly to the shell by welding, and a flat bar, usually called a *faceplate*, is welded along the inboard edge. Web frames extend from the turn of the bilge to the deck above. They make a belt of great rigidity around the ship in line with their

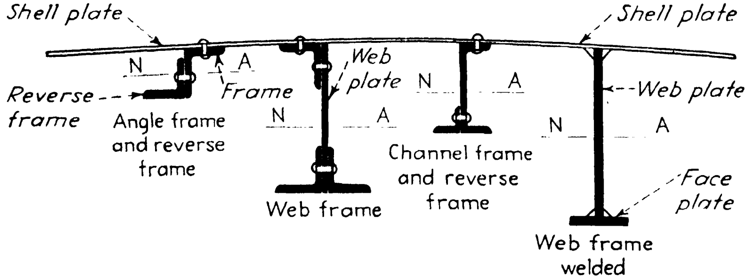


FIG. 67.—Riveted and welded built-up frames.

position. Stringers are fitted behind the web frames and over the smaller transverse frames so that the stiffness furnished by the web may be utilized by the plating.

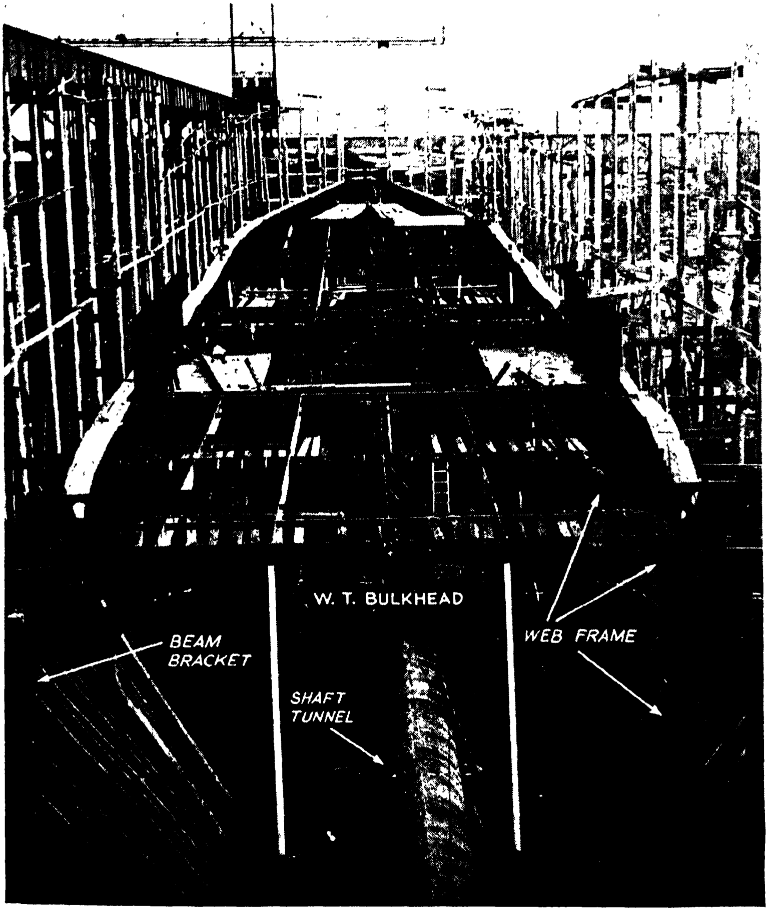


FIG. 68.—Web frames. The shell frames have been put in their proper location. Four of the deep web frames are now in place. This is a picture of a deep hold near the stern, in which many web frames are fitted because of the great span and vibration.

The size of web frames and their spacing are dependent on their span and depth below the lowest deck. Webs were formerly used in conjunction with small transverse frames, about every sixth transverse frame being dropped and a deep web taking its place (Fig. 61). This construction, in combination with a stringer, permitted a reduction in the size of the regular frames. This practice has fallen into disuse.

Sometimes web frames were fitted at the ends of hatchways to take the loads imposed upon the sides of the vessel by the deep hatch end beams. These webs are now eliminated by stiffening the regular frame in way of the hatch end beams.

Web frames are useful in absorbing the vibration resulting from the propellers and engines and are fitted for this purpose around the stern section of high-powered vessels. They are useful also in counteracting panting stresses in the bow sections.

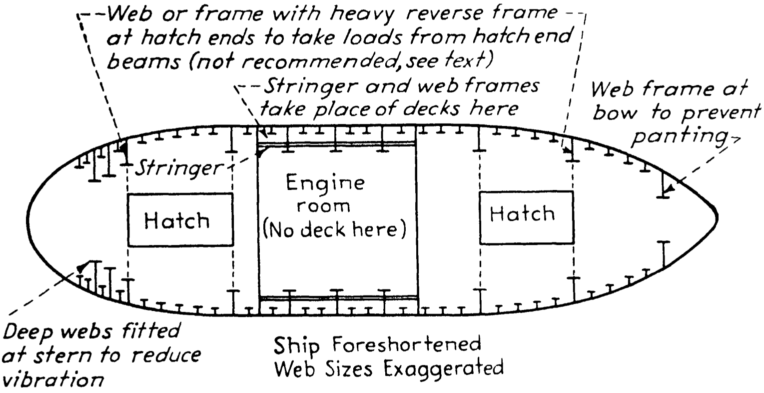


FIG. 69.—Sketch showing location and purpose of deep web frames. Webs at hatch ends are typical only when centerline stanchions are fitted. With two rows of stanchions the webs would be omitted.

Deep webs are fitted in way of the engine and boiler spaces to support the shell. This is usually necessary owing to the fact that the decks do not run through these spaces and the great span calls for extra stiffening. A heavy stringer is run behind the web at deck level to transfer web stiffness to the intermediate frames (Fig. 69).

Problems

1. What is the essential difference between transverse and longitudinal framing?

2. Why are most merchant cargo ships transversely framed and most tankers longitudinally framed?

3. On a naval vessel how far aft of the forward perpendicular is frame 137?

4. Give two reasons for the close spacing of frames in the bow and stern of a transversely framed ship.

5. In a riveted ship in what direction does the toe of the frame point? Why?

6. Give three reasons why deep web frames are used.

7. Where should you expect to find web frames located in the hull of a ship?

CHAPTER VII

SHELL PLATING

The shell plating is the outer watertight covering of the hull. The frames help to stiffen and support this outer covering. When the outer portion of a pipelike structure takes most of the load, it is called a *monocoque* type of structure. The hull plating, which includes the shell plating and the plating of the "strength"[1] deck of a transversely framed merchant ship, takes about 90 per cent of the total stress resulting from hull-girder strains and is almost a true monocoque type. The hull plating of most tankers and naval vessels is supported by longitudinal framing, and this takes some of the load resulting from the longitudinal bending strains, the remainder being taken by the shell.

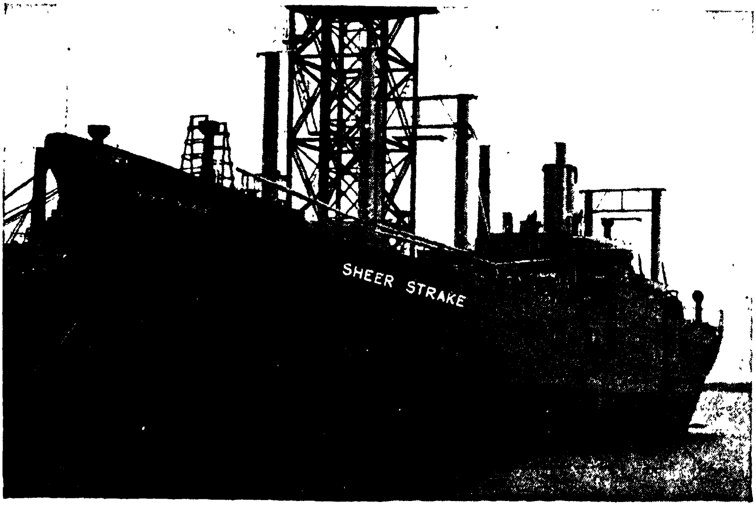


FIG. 70.—Shell plating. The courses, or strakes, may be seen in the above photograph.

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[1] In most merchant vessels, the strength deck is the upper deck. In all cases, it is the deck used as the upper flange of the hull girder in the longitudinal-strength calculation (see *S.S. Blum*, Fig. 7).

As shipbuilding changed from the age of wood to the age of iron, the tendency was to make the plating thick and to space the frames closely together, according to the previous practice in wooden construction. With steel replacing iron, the present tendency is to space the frames farther apart and to accept much thinner shell plating. This change is based on past experience as well as mathematical consideration. As in all engineering practice, past experience is invaluable in new design, and the trial and error method has been the basis of our present practice relating to shell plating.

In general, merchant vessels have shell plating that is much heavier than that used on naval vessels of the same size (except in way of certain armored spaces). This is because the merchant vessel is subjected to rougher treatment and less care than the naval vessel. The merchant cargo vessel may be thought of as a heavy-duty truck specially designed for water usage where repair stations are few and far apart. If the student keeps this idea in mind, he will better understand the reason for the massiveness of some of the parts on the average merchant ship.

The shell is composed of steel plates most of which are rectangular in shape. They are arranged in a longitudinal manner on the ship and, when in place one after the other, are known as a *course*, or *strake*, of plating.

The thickness of these plates varies according to the size of the ship and the location of the plate. It is now common practice to run the plating vertically in way of the anchor so that the anchor will have a smooth surface to slide upon as it comes up to the hawsepipe. The thickness of the shell plating varies between $\frac{1}{4}$ and $1\frac{1}{4}$ in.

TYPES OF SHELL PLATE

In general, there are three types of plate fitted on the hull. They are called, according to their fitted shape, *flat*, *rolled*, or *furnaced plates*. Fortunately, the great majority of plates are flat and do not have to be worked into shape. Rolled plates have cylindrical curvature in one direction only and are usually found at the turn of the bilge amidships. These can be rolled cold by a machine. Furnaced plates have curvature in two directions and must be heated and hammered to shape over a specially prepared and shaped steel form or cradle. They are necessary at some points of the bow and stern; but as they are expensive, they should be avoided whenever possible.

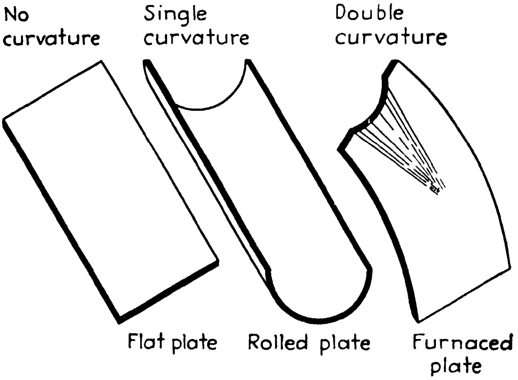


FIG. 71.—Three types of shell plates.

LAYOUT OF THE SHELL STRAKES

Owing to the greater girth (distance around a body) of a ship amidships than at the ends, it is obvious that, if we place sufficient plating amidships and then run the courses parallel to each other, we shall have too much plating at the ends. To obviate this difficulty, certain strakes are dropped as they approach the bow and stern. These *drop strakes* are shown in Fig. 72. The

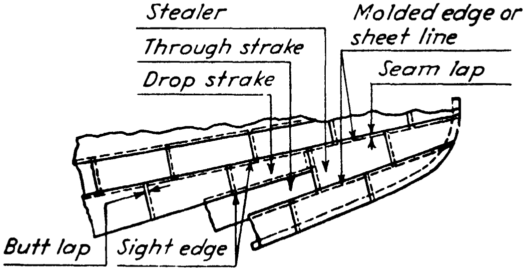


FIG. 72.—Method of deleting excess plating near the bow.

other strakes run through in a continuous line from stem to stern and are known as *through strakes*.

So that the end of the drop strakes may be attached into the through strakes, a plate of about double width is fitted into the through strake below the drop strake, as shown in Fig. 72. This plate is known as a *stealer*.

Other plates with special names are *dished plates*. the *boss plate*, and the *oxter plate*. The boss plate is a furnaced plate fitted at the swelled-out portion in way of the stern frame and is shown in Fig. 73. An oxter plate, the use of which is fast disappearing, is a furnaced plate fitted at the point where the stern frame joins the counter (Fig. 73). Dished plates are U-shaped plates and are usually formed on a flanging machine.

Transverse joints at the plate ends are called *butts*, and the longitudinal joints are called *seams* (Fig. 72). The *sight edge* is the edge of the plating visible from outside the hull. The edge visible from inside is called the *molded edge* or *sheet line*.

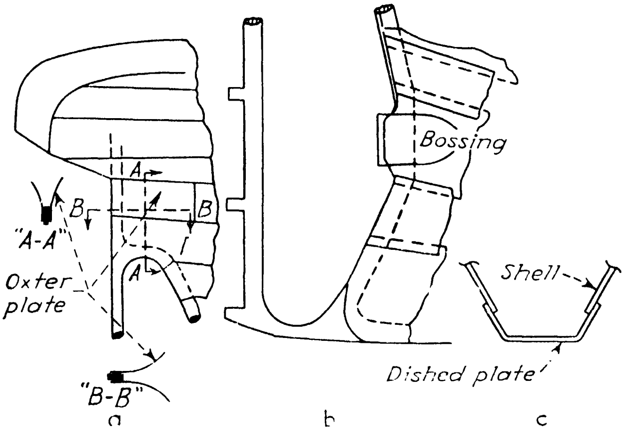


Fig. 73.—Old-type stern assembly showing the oxter plate.

IDENTIFYING THE SHELL STRAKES

There are four strakes of shell plating that have names, but all the strakes except the keel are designated by letters of the alphabet, beginning next to the keel with A. The named strakes are

1. The keel, at the very bottom center.
2. The garboard, at each side of the keel.
3. The bilge strake, at the turn of the bilge.
4. The sheer strake (the upper course of the main hull plating), located just under the sheer line.

The location of these strakes is shown in Fig. 74.

COMPENSATION FOR HOLES CUT IN THE SHELL

There are American Bureau rules that must be complied with in designing merchant ships. These rules specify certain dimensions for the thickness of the shell amidships, at the ends, along the sides at the sheer strake, and under the bottom forward. They also specify that compensation must be made, either by an increase in the thickness of the plate or by a doubler around openings in the side of the ship, for cargo ports, gangways, and coal ports. This requirement for increasing plating thickness at hull discontinuities is due to the stress concentration that takes place at these points (see page 109 for a further discussion of this subject). Doublers are fitted around openings to make up for lost area as well as to alleviate the stress concentration around the opening.

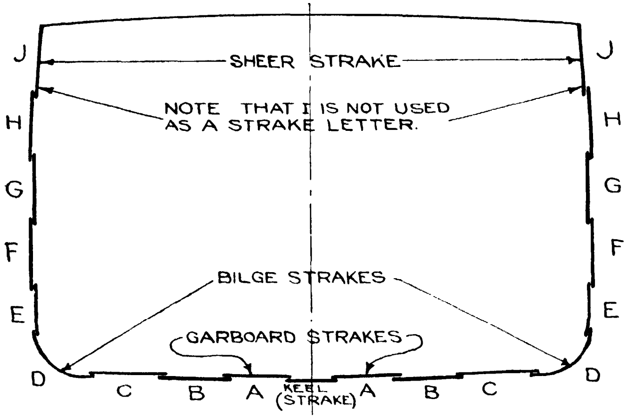


FIG. 74.—Names and letters designating the shell strakes.

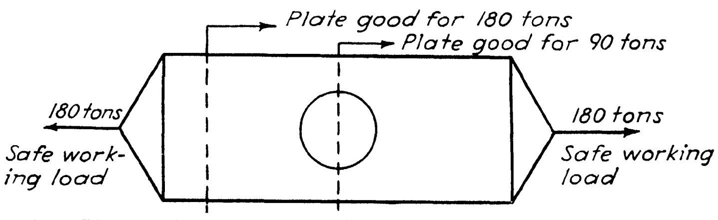


FIG. 75.—Plate cut for air port. No doublers are fitted; 50 per cent of strength is lost.

Consider the flat hull plate shown in Fig. 75. Assume that this plate is ½ in. thick and 4 ft. 0 in. wide. The metal area would be 0.5 in. × 48 in. = 24 sq. in. Assuming the steel to be good for 30 tons per sq. in., the plate would reach its ultimate strength at a load of 24 sq. in. × 30 tons = 720 tons. Using a factor of safety of 4, the "working load" would be

$$\frac{720 \text{ tons}}{4} = 180 \text{ tons}$$

Now, if a 24-in. air port is placed in the center of the plate, half the area of the plate is lost and the plate is good for a working load of 90 tons only. In order to compensate for this loss of strength, we may add a doubling plate (Fig. 76) of say ½ in. thickness and 1 ft. in width on each side of the hole, giving

$$(0.5 \text{ in.} \times 12 \text{ in.}) + (0.5 \text{ in.} \times 12 \text{ in.}) = 12 \text{ sq. in. of metal area,}$$

which would exactly make up the area lost due to the air port and would thus restore the strength of the plate.

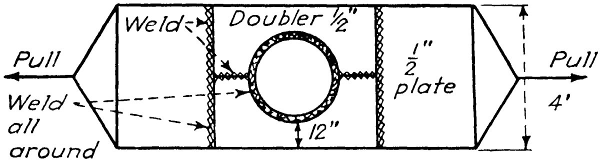


FIG. 76.—Plate cut for air port. Compensating doublers are fitted; no strength is lost.

The American Bureau specifies that any hole cut in the shell of a riveted ship which reduces the effective sectional area of the individual plate by more than 20 per cent must have sufficient compensation by means of doublers or collars to bring the area back to 80 per cent. In an all-welded ship, 100 per cent compensation is demanded by the American Bureau. Each individual hole cut in a naval vessel is considered on its own merits.

The reason only 80 per cent compensation for holes is demanded in a riveted ship is because the holes punched in the plate, to take the riveting of the plate to the frame, have already reduced the strength of the plate about 20 per cent.

Amidships the shell plating is usually of uniform thickness. It may be reduced toward the ends, for the bending moment and the loads are less. This reduction amounts to about 20 per cent.

THE SHEER STRAKE

The sheer strake forms a portion of the upper flange of the hull girder. This calls for a general thickening of this course of plating. If the sheer strake has to be heavied, it is good practice to increase the thickness of one or two strakes below the sheer strake; for it has been found that, although the sheer strake may remain unimpaired owing to its large sectional area, the strakes below show signs of weakness. Some naval vessels and some other vessels of high speed use high-tensile steel (HTS) in the sheer strake to save weight.

There are numerous systems of arranging the seams of shell plating for riveted work. None of these systems is necessary in welded construction, for a welded joint is 100 per cent effective. In general, in riveted work, it is best practice to shift the butts so that there are at least two frame spaces between butts in adjacent strakes and at least five passing strakes between any two butts in the same frame space. If butts are shifted in this way, the shell will have a general effectiveness of about 80 per cent. Figure 77 shows this shift of butts.

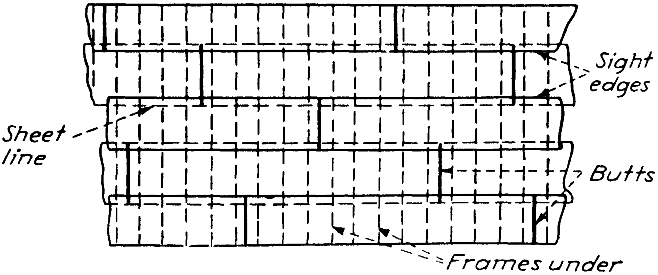
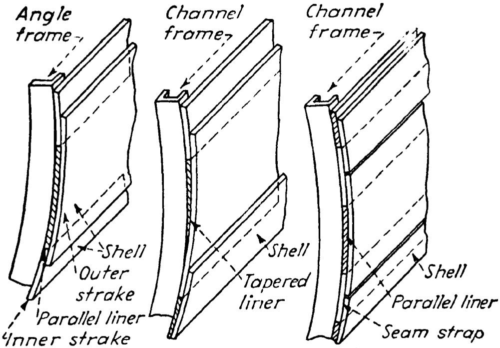


FIG. 77.—Method of shifting the butts of riveted shell plating. A shift is necessary to stagger the line of weakness where the plates are butted. This is not required in a welded shell.

METHODS OF PLATING THE HULL

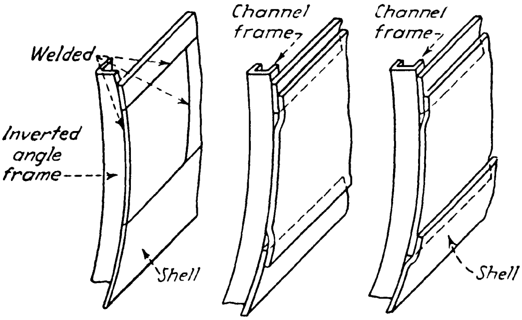
The shell plating may be arranged in any one of several ways. Sometimes a combination of the following ways are used. All methods listed below apply to riveted construction except the one shown in Fig. 78, sketch *D*. It should be noted that these several arrangements were devised in order to get the most satisfactory attachments at the least cost. In a modern yard, riveted shell plating for ships up to 500 ft. long is becoming an oddity. The systems listed below are, however, still in use in some yards, and as there are thousands of ships afloat that have riveted shell plating a discussion of these systems is considered warranted.



In and out
A

Expensive tapered
liner necessary
Clinker - B

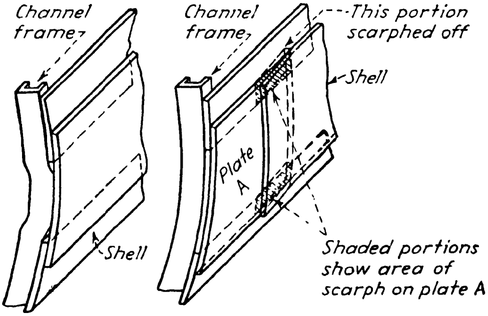
Yacht type
Flush riveted
C



Modern flush
welded
D

European style
joggled in and out
E

Old Type
joggled clinker
F



Usual American
practice, with
Frame joggled
G

A scarphed
Butt joint
H

Fig. 78.—Methods of plating the hull.

1. In-and-out System (Fig. 78, sketch *A*).—This is sometimes known as the *sunken-and-raised system*. In this system the inner plate is against the frame and the outer plate laps over the inner plate and is not joggled, or offset. As a consequence, a space is left between the two plates equal to the thickness of the inner plate. This space is filled by a steel liner with a breadth not less than 3½ times the diameter of the connecting rivets.

2. Clinker System (Fig. 78, sketch *B*).—This system is somewhat similar to the weatherboarding used on a house. It is more expensive than the in-and-out system, for twice as many frame liners are required and each one must be tapered and fitted. Also, the connecting rivets must be of varying length. This system is therefore generally unsatisfactory. Sometimes, if there is an odd number of strakes, one of the strakes is still applied clinker fashion.

3. Flush System (Fig. 78, sketch *C*).—This system is sometimes used on yachts for appearance's sake. Even on yachts it is used only above the water line. It is extremely expensive, for it requires seam straps as well as liners. These seam straps are usually continuous, and the liners are fitted between them. Fitting these curved plates accurately edge to edge requires considerable care and much time. However, this system has not fallen into disuse.

4. Flush Welded (Fig. 78, sketch *D*).—Numerous vessels are being built that have the seams riveted and the butts welded. Many others have plating that has both butts and seams welded and the plating welded directly to the frames. This gives a plating that is flush and obviates liners, seam straps, and joggling. If the shell plating is thin and is welded to the frames, an unsightly ridge is apparent along the line of the frame owing to the welding. Also, difficulty has been experienced with shrinkage of plates welded all around the edge. These two difficulties will perhaps be overcome in the future, and in that case the other systems of plating mentioned here will fall into disuse.

5. Joggled Systems.—The three joggled plating systems listed below are in general use. Joggling relieves us of the necessity of fitting liners, and all the plating is in direct contact with the frames. Either the plating may be joggled on one edge or both edges, or the frame may be joggled. If the plating is joggled, or offset, the longitudinal stiffness of the plate will be increased.

a. Joggled In-and-out System (Fig. 78, sketch *E*).—The inner plate is fitted as in the in-and-out system. The outer plate is joggled on both edges. This joggle, or offset, is, of course, equal to the thickness of the inner plate. This system is very popular in Europe.

b. Joggled Clinker System (Fig. 78, sketch *F*).—In this system only the upper edge of each plate is joggled.

c. Joggled Frame (Fig. 78, sketch *G*).—The joggled frame is the system used extensively in this country for riveted construction. This enables the plates to bear flat on the frame. The joggling is done by machine and is relatively cheap, compared with plate joggling.

Vessels designed to operate in icy seas sometimes have the plating doubled in way of the water line near the bow, for about one-twentieth the length of the ship abaft the stem.

NOTE: The term "doubled" does not necessarily mean that the plating is increased exactly 100 per cent. It means that the plating is thickened, or more material is added, in proportion to the amount of load to be carried or in proportion to the size of hole cut in the plate.

Problems

1. What is a monocoque-type structure?

2. Why is the shell plating of merchant vessels thicker than that usually fitted on naval vessels?

3. Why are drop strakes necessary?

4. What is a stealer plate?

5. Define sight edge, sheet line, and seam.

6. Where is the garboard strake located?

7. In a riveted shell plate 40 in. wide it is desired to cut an 8-in. hole. Would doubling be required?

8. Why is the sheer strake thicker than the strake below?

9. Make a simple sketch of the five methods of plating a riveted ship.

CHAPTER VIII

DECK BEAMS

A deck beam in a vessel has three primary functions, (1) to act as a beam to support vertical deck loads, (2) to act as a tie or as a strut to keep the sides of the ship in place, and (3) to act as a web under the deck plating to prevent plate wrinkling due to the twisting action on the vessel from gunfire or from the ship's sailing at angles to a heavy sea.

BEAM BRACKETS

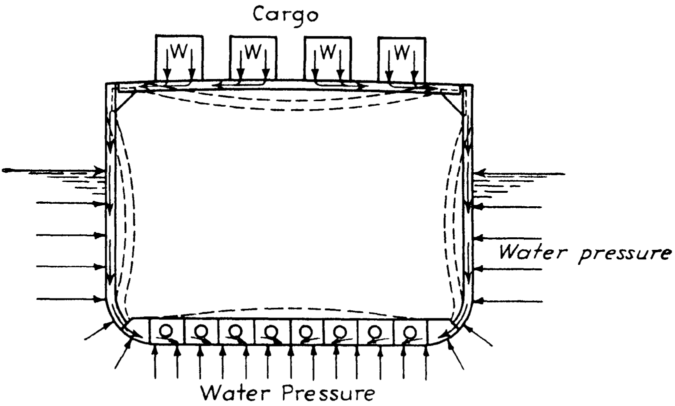
Deck beams run athwartship from side to side of a vessel and are fastened to the frames by beam brackets.

Brackets are fitted to the ends of beams where they connect with the supporting frame. Brackets tend to fix the ends of the beams and are necessary in order that the beam may develop its full strength at the connection. Deck beams are subjected to end-on compressive forces when acting as a strut and to tensional forces when acting as a tie to keep the decks from springing apart when the vessel is in the sagging condition. A bracketed beam also tends to check the racking and the twisting of the hull when the vessel is in a seaway. The usual depth of the beam bracket is 2½ times the depth of the beam. Figure 81 shows a typical welded and riveted beam bracket.

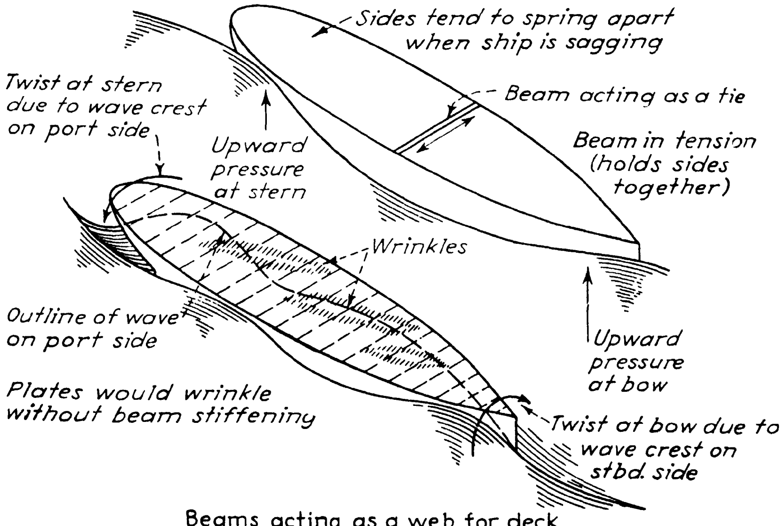
FUNCTION OF A BEAM

It is the function of the beam to take the deck load and transfer it to the frames. The frames in this case act as pillars and carry the load downward, where it is distributed over the bottom by the floors. Water pressure under the bottom of the vessel, transmitted through the floors, frames, and deck beams, supports the load on the deck of the vessel (see Fig. 82).

The beams support the decks or platforms with their permanent or temporary loads. Besides their primary function of supporting a deck or platform, they assist in maintaining the relative positions of the opposite sides when the vessel is subjected to longitudinal bending forces or the forces due to the water pressure upon the immersed surface that tend to crush in the sides of the vessel (see pressure-gradient curve, Fig. 82).



Frame acting as a beam and a strut



Beams acting as a web for deck plating (ship in quartering sea)

FIG. 79.—Some actions of ship's beams and frames.

BEAM SIZES

The tabulation of beam sizes in the A.B.S. rules depends on (1) the length of the beam, (2) the number of pillars, (3) the spacing of the beams, and (4) the loading of the deck and the type of load supported (see page 16 for the reasoning behind this ruling).

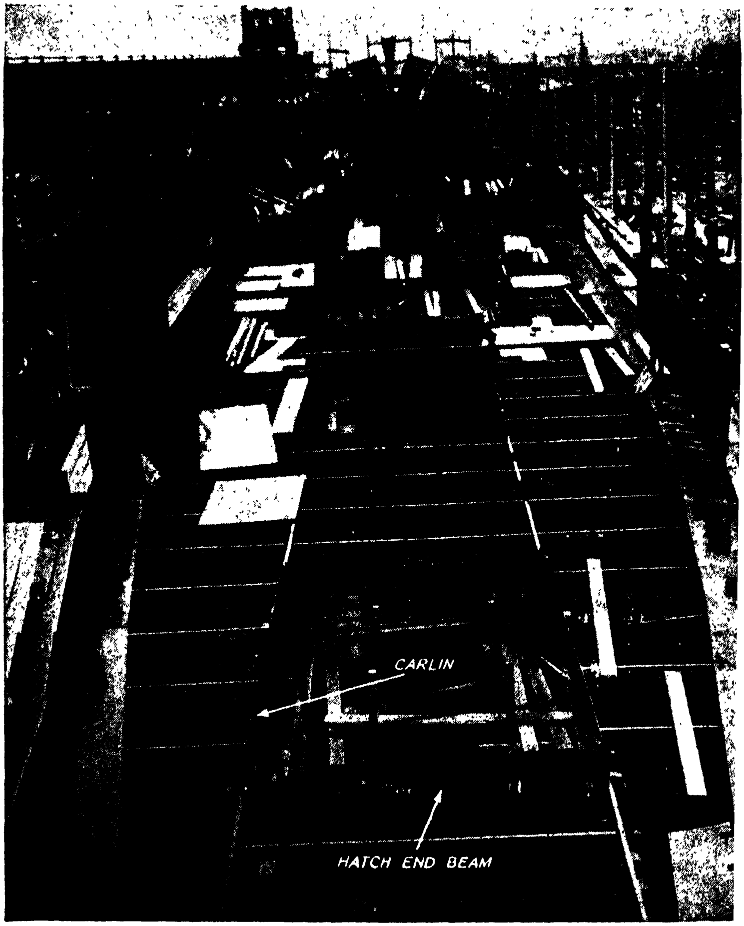
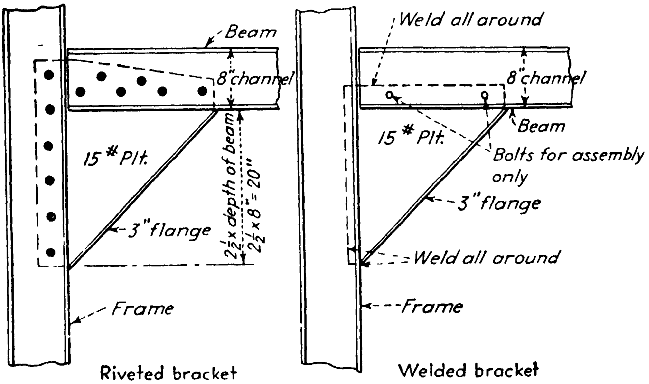


Fig. 80.—Deck beams. This is a photograph of the deck beams in place. Note how the beams are cut in way of the hatch.

SECTIONS USED FOR BEAMS

Deck beams used in riveted construction are bulb angles, bulb tees, or channels. Plain angles are suitable only for very small ships.



Riveted bracket Welded bracket

FIG. 81.—Typical riveted and welded brackets.

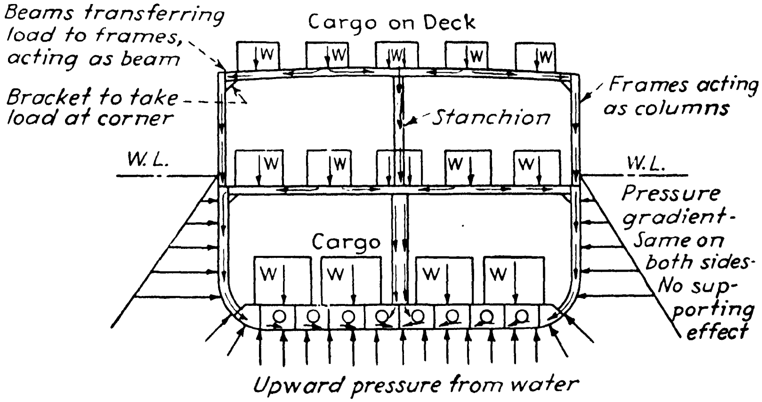


FIG. 82.—Distribution of the loads from the cargo.

If of the welded type, inverted plain angles, inverted T bars, or plates with welded faceplates as the lower flanges make good sections. Large T bars, suitable for welded beams, are now produced by splitting I beams down the center of the web. If the cut is alternately offset in opposite directions at short intervals, two 7-in. T bars, suitable for intermittently welded connections, can be obtained from one 12-in. I beam. This operation is performed by an automatic burning device, which will cut this joggled offset in four to six plates or beams simultaneously.

BEAM SPACING

Beam spacing depends upon the size of the beams, the number of supporting pillars and girders under the beams, the thickness of the deck plating, and the height between decks.

'Tween-deck beams are designed to support a load resulting from an assumed basic cargo of a certain density (weight per cubic foot) completely filling the 'tween-deck space. This explains why the deck height determines, in a manner, the size and spacing of the beams.

Beams are usually fitted on every frame under decks that are unsheathed. It is usually more satisfactory to fit the extra beams than to increase the thickness of the deck plating These extra beams also help prevent buckling of the plating due to compressive loads resulting from hull-girder action. Fitting beams on every frame allows us to decrease the depth of the beams and thus increase the headroom by that amount.

As the weather deck is subjected to excess loads resulting from heavy seas breaking over the vessel, the beams under these decks are made heavier than would be normally required. There are cases on record where the entire forward exposed deck has been "stove in" owing to the weight of water piled on the deck by an excessively large wave.

If a deck beam with a single top flange is used, less riveting is required. The deck plating acting with the beam flange tends to prevent the beam from tripping, or folding over. For welded beams, antitripping brackets are sometimes used to prevent this folding action.

T bars make fair beam sections when riveted, for their symmetry discourages tripping and the double upper flange gives a good connection. They form excellent sections when inverted and welded.

Deck beams, whether fitted on every frame or only on every other frame, are always fitted in line with the side frames. When fitted in this manner they form, in conjunction with the side frames and the double bottom, a continuous belt around the inside of the hull. This ringlike belt enables the relatively thin side, bottom, and deck plating to assume great compressive loads without buckling.

DECK CAMBER AND SHEER

Camber is put in a deck so that water falling on the deck will run down to the scuppers and drain overboard. The beams and plating are arched upward, and this arching is known as *camber*, or *round of beam*. Camber is usually measured in inches per foot of breadth of ship. For example, a deck may have a camber of 12 in. in 50 ft. This means that on a ship 50 ft. wide the deck at center amidships would be 12 in. higher than at the side.

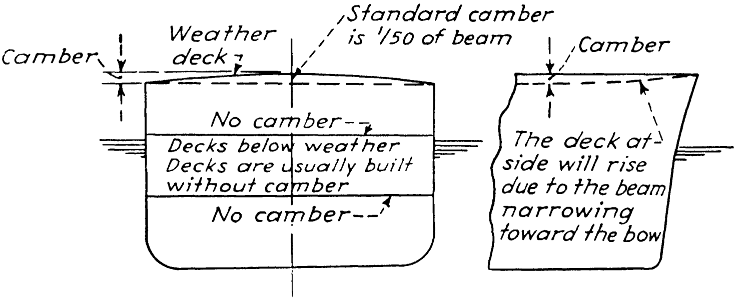


FIG. 83.—Camber.

Camber is measured at the center line of the ship. The amount of camber on a particular ship varies. A ship with much camber in the freeboard deck is permitted by the Freeboard Regulations to load to a greater draught than a vessel with less camber.

The camber of the longest beam in the ship is similar to the camber of the shortest one. To obtain the camber of a beam that is shorter than the longest beam, place the shorter beam on the camber curve of the longest, with their centerline spots coinciding. It will be noted that the ends of the shorter beam will be above the ends of the longer. This will mean that the deck at the side will have to rise to meet the ends of the shorter beams. Thus a cambered deck that is parallel to the base line at the center line will have sheer at the sides (see Fig. 83).

During the First World War the ships built at Hog Island[1] were designed for simplicity of construction with no sheer or camber. Aside from the fact that they looked as if the ends were drooping, they were very serviceable ships. The *S.S. Normandie* (now the *U.S.S. Lafayette*) has decks that are practically flat, but a clever manipulation of the paint line near the deck makes her appear to have a beautiful sheer. Camber does not add to the strength of a deck, for the sides of the ship are too flexible to offer enough support to get the arch effect.

In most ships today the lower two or three decks are flat decks, but the weather deck has sheer. The Freeboard Regulations allow a deeper draught to be assigned to a vessel with sheer than to one without sheer, for the sheer enables the former to ride the waves with a drier deck. Standard sheer is made up of a parabolic curve forward with a height at the bow of 0.2 times the length of the vessel plus 20 in. and a parabolic curve aft with half that height at the stern. Thus a 400-ft. vessel with a 55-ft. beam, if her sheer and camber were standard, would have

$$\text{Sheer} = (0.2L + 20) = (0.2 \times 400 + 20) = 100\text{ in. at bow}$$

$$\frac{100}{2} = 50\text{ in. at stern}$$

$$\text{Camber} = 0.02 \times \text{beam} = 0.02 \times 55\text{ ft.} = 1.1\text{ ft. or }13\tfrac{1}{4}\text{ in. amidships}$$

The above is standard; however almost any sheer or camber may be used by the designer.

Problems

1. Give the three primary functions of a deck.

2. Why are beam brackets necessary?

3. Upon what four factors does the size of a beam depend (based on A.B.S. rules)?

4. What would be standard camber for a boat 75 ft. wide?

5. How much sheer would a ship 800 ft. long have if her sheer were standard?

6. Why are weather-deck beams usually heavier than required to support the normal deck loads?

7. What is the advantage of fitting deck beams on every frame?

8. Is a cambered deck stronger than a flat deck?

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[1] A great shipyard built near Philadelphia in 1917 for the mass production of ships. There were 50 building ways at this one yard.

CHAPTER IX

PILLARS AND GIRDERS

The numerous "posts" fitted throughout a vessel are known to shipbuilders as *pillars*, *stanchions*, or *columns*. They are used to give vertical support to girders, deck beams, and heavy concentrated loads. The pillar assumes the load and transmits it downward toward the bottom of the hull, where it is distributed over a large area.

USE OF PILLARS

When a pillar is placed under a beam or girder, it not only reduces the deflection of the beam but also relieves the beam brackets and the frames at the side of the hull. If the beams had no pillars for support, they would behave as shown in an exaggerated manner in Fig. 84*A*. The load from the cargo is deflecting the beam. This deflection produces a rotation at the top of the frame due to the rigid bracket connection. (NOTE: The actual rigidity of the bracket connection would not be great enough to cause any such rotation as shown in the figure. This exaggeration is considered permissible for educational purposes.) The load would then be taken by the frame down to the turn of the bilge. The upward pressure of the water would cause a

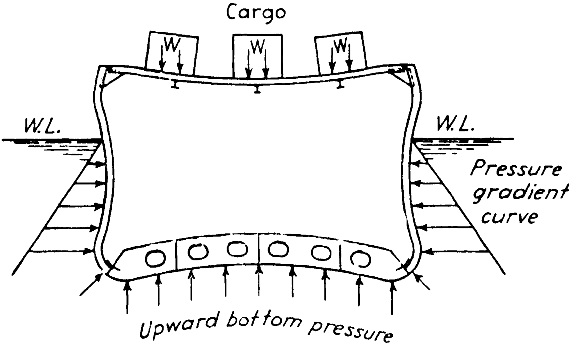


FIG. 84*A*.—Exaggerated shape of an unpillared vessel with a deck load.

deflection in the double bottom that in connection with the load from the frames would cause a depression of the bilges. Figure 84*B* shows a vessel that has been properly pillared. This pillaring has greatly relieved the conditions mentioned above.

Besides acting as compression members keeping the decks apart, pillars also act as tension members tying the decks together. Thus, if a lower 'tween decks is loaded with cargo, the upper 'tween decks is forced, through the tension action of the pillar on the deck, to support a portion of this load. The line of pillars thus forces all decks to act together as a unit.

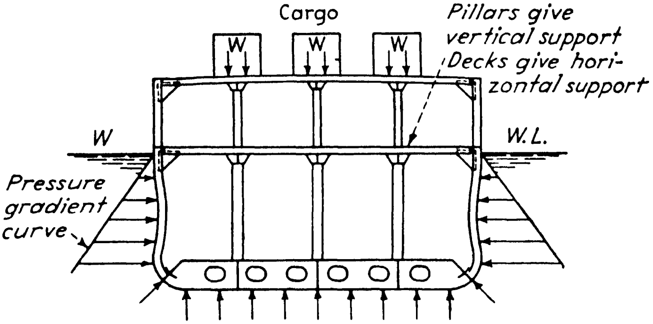


Fig. 84*B*.—Same vessel as in Fig. 84*A*, pillared. Beam-end connections are relieved. Note the effect on the sides of adding a deck.

Pillars should be placed under heavy weights of a permanent nature carried on deck. Under windlasses, cranes, winches, and other hoisting machinery pillars become particularly important, for they force the decks below to assume a part of the straining action resulting from the loads placed on the machinery. The rigidity of this support also reduces the intense vibration accompanying the machinery's operation. Pillars may be used to advantage under the forward part of the weather decks of high-speed vessels to help the beams assume the load thrown upon them by great masses of water coming aboard in a heavy sea.

PARTIAL BULKHEADS

Where the load to be supported is particularly great, partial bulkheads usually take the place of pillars. A partial bulkhead may be thought of as a continuous row of pillars placed so close together that they touch. Partial bulkheads are more efficient supports than pillars but are at times undesirable in that they block access.

ARRANGEMENT OF PILLARS

The naval architect should be careful to place pillars *vertically in line* with each other. If this is not done, bending moments will be induced in the pillars that will greatly reduce their efficiency, and severe vibration may be set up throughout the vessel (see Fig. 85).

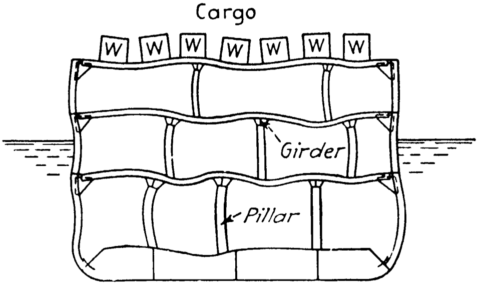


FIG. 85*A*.—Exaggerated effect of having the pillars out of line.

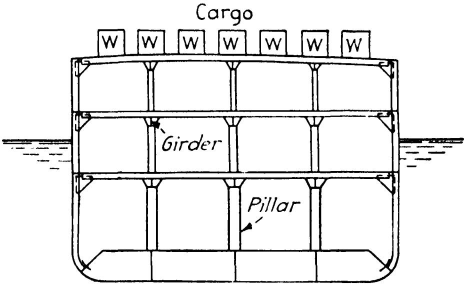


FIG. 85*B*.—Same vessel as in Fig. 85*A*, with the pillars in line.

SIZE OF A PILLAR

The size of a pillar depends upon the *load* it has to support, the *location*, and the *length* of the pillar. Where pillars support, say, only passenger spaces, they may be comparatively small. However, if the location is toward the bottom of the vessel, the pillar must support not only the load from the deck directly above but also the loads brought down by pillars several decks higher.

This calls for heavier pillars in the holds than in the 'tween decks (Fig. 85).

PILLARS IN RELATION TO INTERNAL ARRANGEMENT

Shipyards sometimes receive a set of contract plans, one of which shows an excellent arrangement for cabins, public spaces, etc., while another shows an excellent layout of pillars and girders. When these plans are superposed for a check, it is sometimes found that a pillar will run through a main stairway or down an elevator shaft or even appear in the middle of a bathtub. In any such case, it may be necessary to rearrange the pillar and girder plan or alter the arrangement of the vessel, in order to bring the location of the pillars and girders into agreement with the desired arrangement plan. Had these plans been worked out together properly by the owner's naval architect so as to secure their agreement in the first place, this difficulty would have been avoided, endless correspondence would have been saved, and the ship's owner would have been satisfied instead of being disgruntled because of a comparatively poorly arranged vessel.

TYPES OF PILLARS

Numerous types of pillars are used, some of the most commonly employed being shown in section in Fig. 86. As mentioned in Chap. I, the hollow-pipe or hollow-plate circular-type pillar gives the greatest strength for the least weight. H beams are used to a great extent for engine-room columns primarily because of the ease of attaching the flat sides to the structure above and below. They are usually objectionable as hold pillars owing to their sharp corners, which have a tendency to damage cargo. The octagonal pillar, as shown in Fig. 86, is a cheaper pillar section to produce than the circular-plate pillar. The circular-plate pillar is cheaper than the pipe pillar. The octagonal pillar has therefore become very popular as a pillar section in both merchant and naval work.

OTHER CONSIDERATIONS

Acceleration factors have a great effect on the size of pillar required. As the vessel pitches, rolls, and heaves, the dead loads are forced to move with the vessel. This accelerating and decelerating effect becomes serious near the bow and stern of a vessel; in some cases, the dynamic load will be double the static weight. (That is, a 1,000-lb. weight near the bow may produce a load of 2,000 lb. owing to the rapid deceleration that takes place when the bow of the vessel pitches into a large wave.)

Care should be taken to protect pillars as much as possible from damage by cargo. If a pillar is bent out of the vertical, its strength as a support practically disappears. Pillar connections should be designed to be equal in strength to the unbent column.

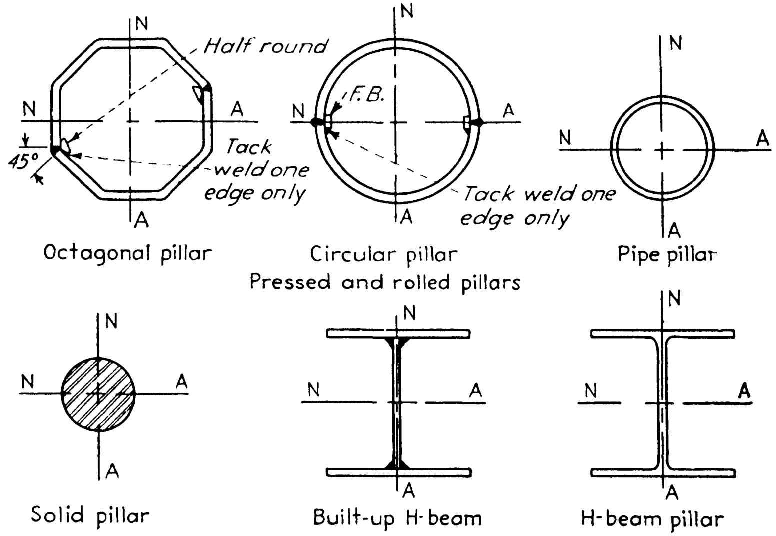


FIG. 86.—Typical pillar sections.

The headplate (top connection) and spring plate (bottom connection) should be designed properly to distribute their loads above and below.

GIRDERS

Girders are heavy fore-and-aft beams placed under the transverse deck beams and along the top of a row of pillars. In newer construction the girders are slotted and the beams pass through the upper portion of the girder as shown in Fig. 87*A*. Without this girder under the beams, the beam over the pillar would be amply supported but the beams in between would have only the negligible support afforded by the deck plating (Fig. 87*B*).

I beams, T bars, channels, and built-up sections are used as girders. Two typical deep built-up girders are shown in Fig. 88. Both are of welded construction.

Pillars and partial bulkheads are excellent structural members, but they are a great hindrance to the stevedore in stowing cargo. They also limit, in some cases, the types of cargo that may be carried. Sometimes pillars are made so that they may be removed during the loading process and then replaced after the cargo is in position.

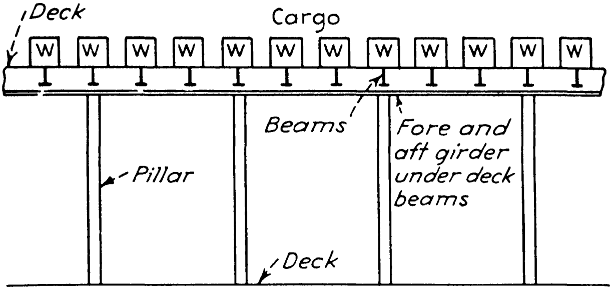


FIG. 87A.—Section through centerline girder under deck beams. This girder reduces the span of the beams passing over it.

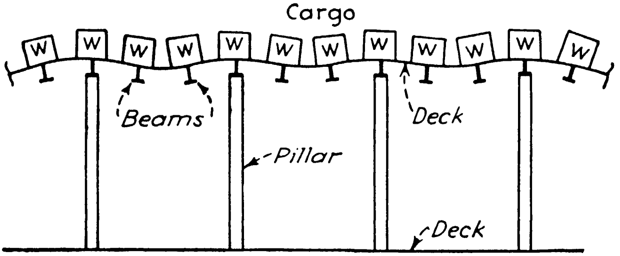
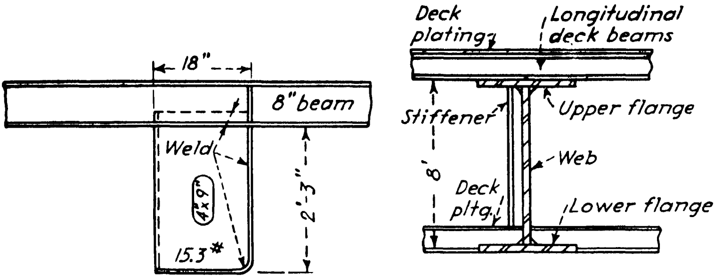


FIG. 87B.—No girder under deck beams. Pillar supports only the beam directly overhead.

The cargo is usually wedged between the pillars, bulkheads, and shell so that it is unable to shift when the vessel is rolling in a seaway.

A good arrangement of pillars lessens their interference with the loading process. Two arrangements are shown in Fig. 89. The upper sketch shows a hold that has a center row of pillars. The line of the center row is shifted to the hatch edge in way of the opening. The lower sketch shows a partial bulkhead fitted on the center line. The hatch is supported in this case by the



"Built up" hatch end beam

Deep "built up" girder

FIG. 88.—Typical deep "built-up" beam and girder.

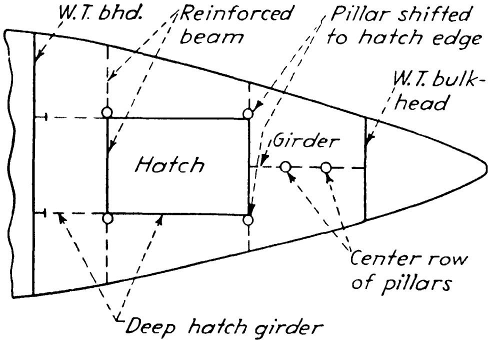


FIG. 89A.—Pillars shifted in way of hatch.

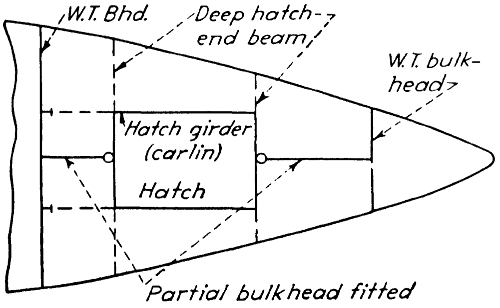


FIG. 89B.—Partial bulkheads and deep-hatch end beams sometimes take the place of pillars.

centerline partial bulkheads and the deep hatch end beams. No hatch corner pillars are fitted. Of course, if the girders are made sufficiently deep and massive, the pillars may be eliminated altogether.

As the beam, or width, of a ship increases, the number of pillars or partial bulkheads fitted must be increased in order to keep down the span of the deck beams and thus reduce their size (see page 17). Care should be taken to work out the proper ratio between the size of pillars, the size of girders, and the size of deck beams required in order to give the lightest and best total structure.

Problems

1. What is a stanchion?

2. Why should pillars always be fitted in a vertical line?

3. Why is a pillar fitted under the windlass?

4. Give the advantage and the disadvantage of fitting a partial bulkhead.

5. Upon what three things does the size of a pillar depend?

6. Sketch three typical pillar sections.

7. How does acceleration affect the size of a pillar?

8. What is the purpose of deck girders?

9. Why should pillars be well protected when cargo is being loaded and unloaded?

CHAPTER X

BULKHEADS AND FLOODING

A ship is divided into compartments and tanks by transverse or longitudinal bulkheads. Bulkheads are important for the following reasons:

1. If watertight, they prevent water from passing from one compartment to the other and in case of a shell puncture may save the ship.
2. They act as fire checks by providing fire-resistant boundaries.
3. After all other means have failed, they permit the flooding of a hold and thus allow the extinguishing of fires.[1]
4. They act as structural diaphragms and resist the transverse deformation of the hull caused by racking stresses.

The numerous rules (American Bureau, Coast Guard, Senate Report 184, Load Line Regulations, International Convention for the Safety of Life at Sea, etc.) relating to bulkhead spacing will undoubtedly seem confusing and conflicting to the student. However, if we space the bulkheads in such a manner that they satisfy the subdivision requirements of the Convention for the Safety of Life at Sea, the other rules will automatically be complied with.

SUBDIVISION RULES RELATING TO BULKHEAD SPACING

It long has been recognized that a ship should be able to suffer a shell puncture and still survive. It has also long been recognized that a vessel primarily carrying passengers should be made relatively safer than a ship primarily carrying cargo. It is possible to make a vessel practically nonsinkable by con-

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[1] Flooding a hold should be done only as a last resort. It will undoubtedly quench the fire, but it also may cause the ship to capsize owing to the attendant loss of stability (see page 182). If there is any doubt as to the ability of a particular ship to remain upright with a certain number of her holds flooded, it is better to let her burn herself out, for an upright ship even though burned out is usually less of a liability than one that is capsized.

structing the compartments within her of such minute size that a great number of holes may be punctured in the side without flooding more than a small space. This minute subdivision is

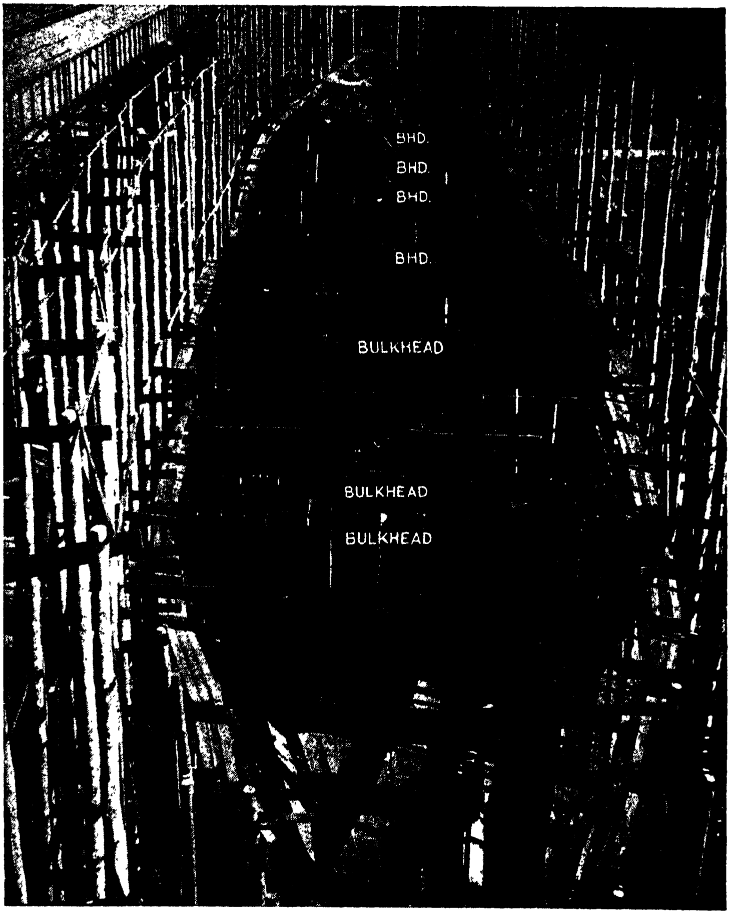

FIG. 90.—Bulkheads. The transverse watertight bulkheads are now in place. The shaft tunnel will run through the arch at the base of the bulkhead in the foreground.

common practice in naval work but is not economically feasible in merchant cargo-ship construction. The owners want the distance between bulkheads to be as great as possible so that the vessel can carry almost any type of cargo. The humanitarians interested in the crew's welfare, the underwriters interested in the ship's safety, and the men responsible for wartime transport service, interested in transporting troops, all want the bulkheads as close as possible to prevent the ship's sinking in case the shell is punctured by collision or war damage.

It would not be good sense, economically, for one nation to set up standards of subdivision that would penalize its own ships. Shortening the holds in a merchant vessel increases her chance for survival if the shell is punctured but also increases the difficulty of loading and decreases the number of types of cargo that can be carried. In order that no nation should be penalized for making its ships safer, the International Conference for the Safety of Life at Sea was called and met in London in 1929. All the principal maritime countries were represented, and they all signed the agreements that were reached at the conference. This convention not only stabilized bulkhead spacing but also was concerned with safety devices such as lifeboats, life rafts, radio, watertight doors, etc.

As we are interested only in bulkheads in this chapter, we shall discuss only the portion of the rules of the convention that relates to bulkheads.

Ocean-going ships were graded at the conference according to their general character, with the pure cargo vessel, carrying only 13 passengers[1] at one end of the scale and a luxury passenger liner like the *S.S. Normandie* (now the *U.S.S. Lafayette*), carrying practically no cargo, at the other end of the scale. The signers of the convention all agreed that the safety of the ship should be commensurate with the nature of the trade in which she engaged. In the discussion below, a one-compartment vessel is one that will remain afloat with one compartment flooded; a two-compartment ship is one that will remain afloat with two adjacent compartments flooded; etc.

The result of this convention, simplified for clarity, is that every ship carrying more than 12 passengers and engaged in international voyages must be at least a one-compartment vessel. As the character of ship approaches that of the luxury liner, *i.e.*, as her length and the number of her passengers increases, the

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[1] Cargo vessels carrying 12 passengers or less do not come under the rules of the convention; however, they must adhere to the Coast Guard regulations.

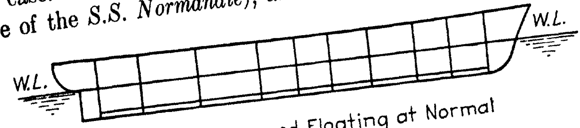
spacing of the main bulkheads in proportion to the length of the ship gradually decreases. As a result, a small vessel, say, 400 ft. long, with relatively few passengers, will be a one-compartment vessel; an intermediate type of ship, 500 or 600 ft. long, with, say, 200 or 300 passengers, will be a two-compartment vessel; and a ship 800 ft. long, with 1,000 passengers or more, may be a three-compartment vessel. The *S.S. America* (now the troop transport *West Point*) is a three-compartment ship.

The manner in which bulkheads act to prevent foundering is illustrated in Fig. 91. These sketches show a two-compartment merchant vessel with holes progressively longer torn in her side. Sketch *A* shows the vessel floating at her normal load water line. In sketch *B* the shell of the vessel has been punctured between bulkheads so that one compartment is flooded. The ship will sink downward and trim forward until the buoyancy lost in way of the flooded space is made up by the buoyancy regained in the process of the ship sinking deeper into the water. When the buoyancy regained by deeper immersion is exactly equal to the buoyancy lost, the vessel will cease to sink and will again be floating in equilibrium.

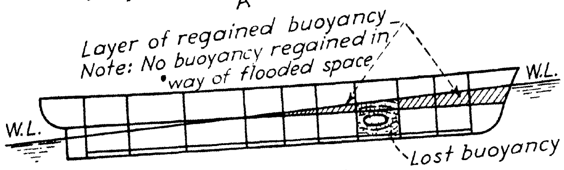
In sketch *C* the damage has extended across a bulkhead, and consequently two compartments have been flooded. The vessel must sink and trim more than in sketch *B* in order to regain the lost buoyancy, for more buoyancy has been lost. As she has sufficient freeboard to make up the lost buoyancy, the ship will still float, but at a deeper water line.

In sketch *D*, two bulkheads have been crossed, and three compartments have been flooded. As before, the ship starts sinking deeper in the water so as to regain the lost buoyancy; but in the process the upper deck goes under the surface of the water, and the water pours into undamaged compartments. The foundering then becomes accelerated and progressive, and the entire ship sinks below the water. The particular vessel shown in the figure cannot remain afloat with more than two compartments flooded and is therefore a two-compartment ship. If her bulkheads had been spaced closer, she might have remained afloat with three compartments flooded; in that case, she would have been a three-compartment vessel.

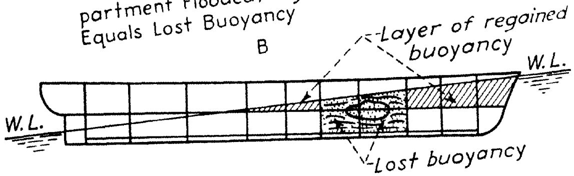
All the above discussion is based on the assumption that the vessel remains upright during the flooding process and simply fills and goes down. We shall see later that this is very seldom the case. Flooding a vessel usually reduces stability (as in the case of the S.S. *Normandie*), and the vessel might capsize with



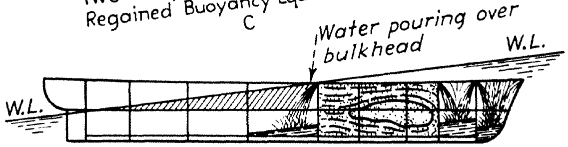
Vessel Undamaged Floating at Normal Designed Load draft
A



Vessel Damaged and One Compartment Flooded, Regained Buoyancy Equals Lost Buoyancy
B



Two Compartments Flooded, Regained Buoyancy Equals Lost Buoyancy
C



Three Compartments Flooded Lost Buoyancy Greater Than Buoyancy Gained by Sinkage and Vessel Foundering by Progressive and Accelerated Flooding
D

Fig. 91.—Effect of size of damage on a two-compartment vessel.

only one compartment filled, even though she would have sufficient buoyancy to float upright with two compartments filled. If this were the case, her two-compartment floodability would be fictitious. The stability of a flooded ship will be discussed in Chap. XVI.

BULKHEADS REQUIRED BY THE AMERICAN BUREAU

Besides the regular intermediate watertight bulkheads required by the convention, there are four bulkheads required by the American Bureau of Shipping as follows:

1. Collision Bulkhead.—This bulkhead is required as a safety provision. Should the ship have the bow broken open by ramming or other means, this bulkhead would serve as an auxiliary bow. Very little change in trim would take place, for little water would enter the ship. If the forepeak tank were already filled with salt water, no excess water would enter. The American Bureau requires that this bulkhead be placed not less than one-twentieth the length of the vessel abaft the stem (measured on the load line).

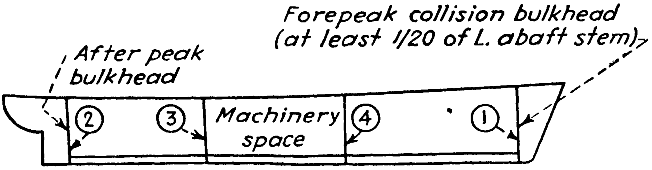


FIG. 92.—Bulkheads required by American Bureau rules.

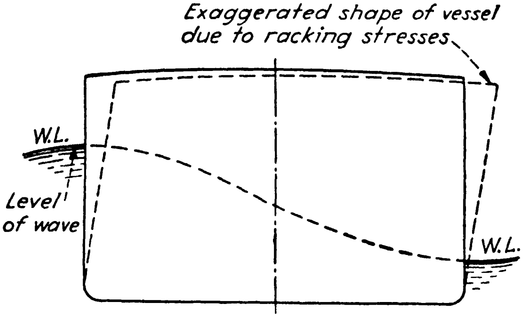


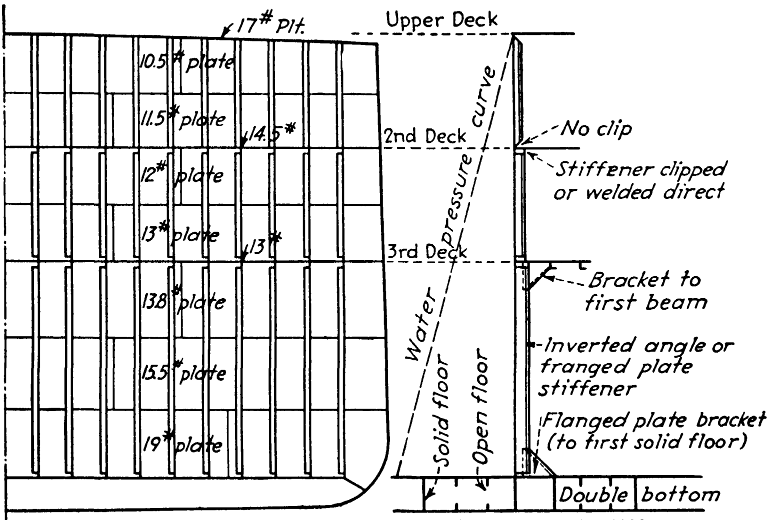
FIG. 93.—Deformation caused by a racking stress. Transverse bulkheads relieve this tendency.

2. Afterpeak Bulkhead.—This bulkhead is required to be fitted in all screw vessels and to be arranged so as to enclose the shaft tubes in a watertight compartment. This is a logical requirement, for a broken tail shaft might allow water to rush into the afterpart of the ship. A watertight afterpeak bulkhead prevents this.

3 and 4. Machinery-space Bulkheads.—Machinery spaces must be enclosed by watertight bulkheads. The American Bureau also has other requirements for bulkhead spacing, but if the subdivision rules are satisfied it will be found that the rules of the bureau also will be satisfied.

BULKHEAD PLATING

Bulkheads usually are plated horizontally. Therefore, the thickness of the plating may be increased gradually toward the bottom of the ship to allow for the increased pressure encountered there (Fig. 94). As the lowest strake of plating has to support the greatest head (pressure) of water, this strake must be the heaviest. The water pressure on a bulkhead at various levels is shown by the water-pressure curve of Fig. 94.



Typical Bulkhead Showing Plating and Stiffeners. (Note horizontal Strakes of Bulkhead Plating)

Section Through Stiffeners

FIG. 94.—Typical merchant-ship watertight-bulkhead construction.

BULKHEAD STIFFENERS

Bulkhead stiffeners usually run vertically since the vertical span (*i.e.*, the distance from deck to deck) is usually less than the horizontal span. As the water pressure and, consequently, the load become less and less as we approach the upper deck, the size of the stiffeners may also become less and less. It will be noted in Fig. 94 that the lower stiffener is bracketed to the tank-top plating and to the underside of the third deck. Between the third and second deck the stiffener is simply clipped to the deck by a riveted angle or is welded directly. The upper stiffener depends solely on the plating for its upper and lower attachment. This system of plating stiffeners and attachments is typical only of merchant work.

Sometimes a combination of vertical and horizontal stiffeners can be used to advantage. Typical riveted bulkhead stiffener sections are T bars, channels, flanged plates, T bulb bars, and bulb angles. Typical welded stiffener sections are inverted tees, inverted angles, and inverted flanged plates.

LONGITUDINAL BULKHEADS

Watertight longitudinal centerline bulkheads are a real source of danger to the normal merchant vessel and as a consequence are no longer fitted unless some method is adopted that will permit any flooding water to pass through the bulkhead and thus equalize the water level on both sides.

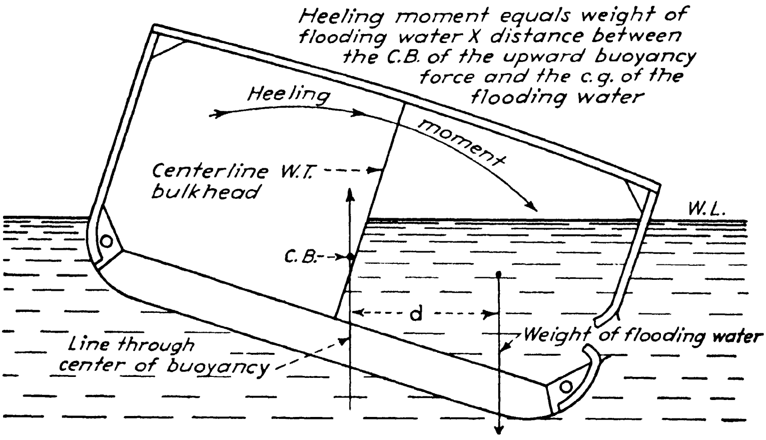


FIG. 95.—Effect of unsymmetrical flooding on the transverse stability of a ship. Equalizing pipes or valves in the centerline bulkhead would alleviate this condition.

The danger of unsymmetrical flooding was brought to the attention of naval architects when the *S.S. Empress of Ireland* capsized, with the loss of 1,000 lives, owing to the flooding of one engine room after she was in a collision. Having one side of a vessel flooded and the other side intact sets up a heeling moment that, if greater than the vessel's righting moment, causes the ship to capsize as shown in Fig. 95. It is common practice to fit transverse bulkheads in way of the boiler spaces of high-powered vessels. This is done in the hope that the vessel will be able to operate in case one of the boiler rooms is flooded. The statements above in regard to longitudinal bulkheads do not apply to naval vessels except in a very restricted way, for their subdivision is so minute that any heeling moments produced by unsymmetrical flooding are relatively small. Also, any heel that is produced may be rapidly corrected in most cases by counterflooding (see page 187).

COFFERDAMS

Cofferdams are usually formed by placing two bulkheads a few feet apart. The purpose of a cofferdam is to prevent leakage of oil from a bunker or cargo tank into an adjoining space where the presence of oil would be dangerous or otherwise undesirable. Cofferdams are commonly fitted between oil tanks and adjacent boiler rooms, pump rooms, water tanks, holds, etc. The principle behind the use of cofferdams is based on the fact that the first of the closely spaced bulkheads, under pressure of the full head of oil in the tank, may happen to spring a leak, but in this case only a small amount of oil will seep through; therefore, little pressure will be experienced by the second cofferdam bulkhead. Also, the space between the cofferdams permits visual inspection of both bulkheads and ready access for quick repair if a leak should occur.

As a well-made welded joint is watertight and oiltight, cofferdams are not required, in so far as watertightness is concerned, in welded ships.

Problems

1. What three functions do bulkheads perform?

2. Why was it necessary for the International Conference for the Safety of Life at Sea to be "international"?

3. What is a two-compartment ship?

4. Why are bulkheads plated more heavily at the bottom than at the top?

5. Why are cofferdams constructed between oil tanks and fresh-water tanks in riveted ships?

6. What ships come under the rules of the International Convention for the Safety of Life at Sea?

7. Who regulates vessels not coming under the convention?

8. What four bulkheads are required by the American Bureau?

CHAPTER XI

DECKS

A ship's deck is a horizontal platform extending across the hull at various heights above the inner bottom. It resembles, structurally, the floor in a house.

Some decks have longitudinal sheer and athwartship camber, while others are entirely flat. A deck is bounded by the shell and connected to the beams and to the trunk and hatch openings.

METHOD OF SUPPORT

The deck plating, or planking, is supported at regular intervals by the deck beams, just as the shell plating is supported by the frames. The beams are supported at their outboard ends by the frames, to which they are attached by beam knees or beam brackets. They are further supported at intermediate points by pillars (stanchions), girders, and bulkheads.

PURPOSE OF DECKS

Decks are useful in several ways, depending on their location in the ship. The upper deck increases the ship's seaworthiness by forming the watertight top of the hull and also contributes strength by acting as the upper flange of the hull girder. The lower decks act as working platforms for the operation of machinery and the loading of cargo and also provide living space for passengers and crew.

An important function of the deck is to serve as a horizontal diaphragm, keeping the ship in shape longitudinally as the bulkheads do transversely. On small vessels, decks may be of wood planking laid over steel beams and tie plates, but on large ships all decks are usually of steel throughout, so as to contribute more strength to the hull structure.

While the upper exposed decks may be covered with wood sheathing either of teak or of pine, the lower decks in living spaces are usually covered with a patented mixture similar to cement, but of more elastic nature, which gives a smooth deck.

Quite often, especially in the newer vessels, they are simply painted. Some of the decks of naval vessels are covered with heavy linoleum. Sheathing a steel deck with wood adds little to its ability to withstand longitudinal stress but stiffens it so as to increase its resistance to heavy seas that may be shipped during stormy weather. Sheathing a steel deck adds to the comfort of passengers by

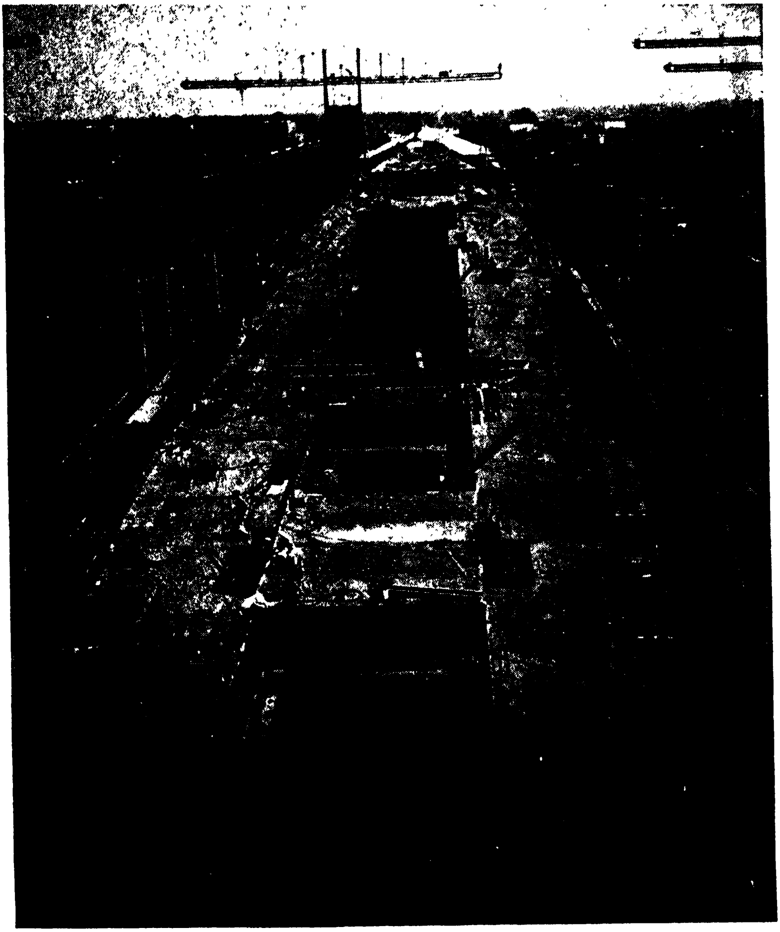


Fig. 96.—Deck plating. Note the heavy stringer plates.

1. Insulating the space below. Wood decking has a low heat-transmission value.

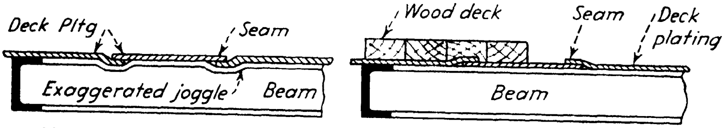
2. Keeping the open deck from becoming so hot that the passengers are unable to walk on it. This is particularly important in the tropics.

3. Preventing sweating underneath the deck. Sweating is due to large and rapid temperature changes. Wood decking resists this tendency.

4. Adding to the appearance of the ship. This is important in passenger vessels only.

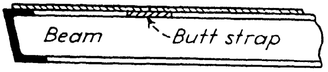
DECK PLATING

The deck plating, like the shell, is usually fitted in wide fore-and-aft strakes, the plates being rectangular in form amidships and tapering at the ends of the vessel to conform to the curvature of the sides. In riveted ships, generally, the deck seams (the longitudinal side joints of the plating) are single-riveted and the deck butts (the transverse end joints) are double-riveted. The connection of the deck plating to the beams is generally single-riveted. In welded construction the weld is carried all around the plate, and in some cases the weld metal is ground flush with the upper surface of the plating.



Flush deck joggled down type

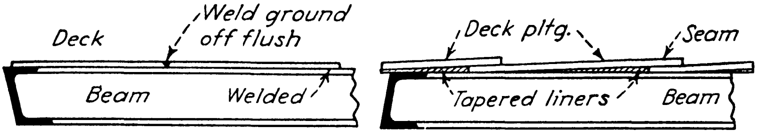
Joggled up type



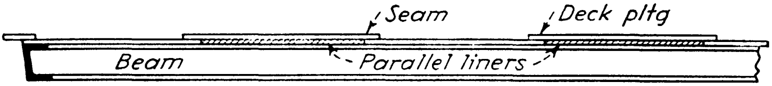
Flush deck with butt strap

Fig. 97.—Types of deck plating.

In riveted construction the different strakes of deck plating may be lapped in either clinker or in-and-out fashion. With a wood deck laid over riveted plating, both of the above arrangements are objectionable, since the planks must be of a varying thickness above the high and low surfaces of the plating and liners have to be fitted under the plating in way of the deck beams. By joggling the laps of the plating, these liners may be eliminated, and if the laps are joggled down and the top flanges of the beams offset to suit a flush surface is obtained. This flush surface allows the wood planking or composition decking to be of uniform thickness. Heavy plating is something made flush on top by the use of riveted butt straps underneath (see Fig. 97). If the decks are welded, all planking can be of the



Flush Welded Deck Clinker Type



In-and-Out

FIG. 98.—Types of deck plating.

same thickness, since the plating is flush. Figures 97 and 98 show examples of the above types of deck plating.

STRINGER PLATE

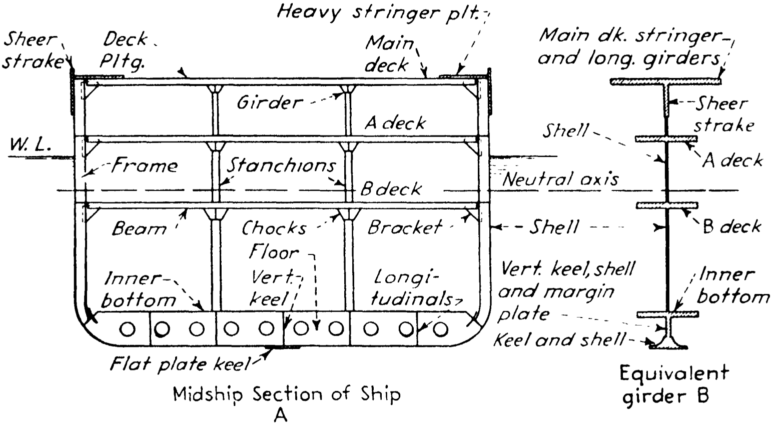
We had previously discussed the fact that in investigating the strength of the ship as a whole, the vessel may be considered to be a gigantic beam supported over a wave crest at its center, in one condition, and between wave crests located at the bow and stern, in another (see Chap. I, page 2, as a memory refresher). Heretofore the student has been asked to assume that this is true. With our knowledge of the action of beams (pages 12 to 20) and strength of materials firmly in mind, let us carefully investigate this assumption.

EQUIVALENT GIRDER

Figure 99 shows a typical midship section and a sketch of a girder equivalent, in the amount of steel contained and its distribution, to the midship section. This girder is called an *equivalent girder*. As a rule, in actual practice, we do not make up an equivalent girder; it is shown here merely as an illustration.

Consider Fig. 99, and think of it as the cross section of a beam. For the upper flange of our beam, we have the deck plating and the longitudinal girders under the deck. The deck plating at the center of the deck is usually cut by the hatches and engine casings. In order to keep a strong continuous uncut row of steel plating in the upper flange, we fit *stringer plates* along both sides of the deck, running from the stem to the stern. This row of plating is heavier than the regular deck plating.

If we calculate the area of the stringer plates, the deck plating inboard of the stringer plates, and the continuous longitudinal girders and bunch them together, we obtain an equivalent upper flange as shown in sketch *B*. If we do the same to *A* and *B* decks, we obtain the two horizontal lines shown as *A* and *B* on the equivalent girder. We now bunch the areas of the tank-top plating, the longitudinals in the double bottom, the center vertical keel, the flat keel plate, and the bottom plating to the turn of the bilge, which gives us the equivalent mass of steel that forms the bottom flange of the girder. If we now calculate the area of both sides of the shell plating from the top of the sheer strake down to the turn of the bilge and combine them, we obtain the web of the girder. The upper and lower flange of the girder, which are the highest stressed portions, will then be made up of the main strength deck and its supporting structure and the keel and its surrounding structure. As the portions of *A* deck and *B* deck are near the neutral axis, they will be stressed very little and



Midship Section of Ship
A

Equivalent girder B

FIG. 99.—A midship section and its equivalent girder.

therefore are not particularly important as strength members (see page 15). This makes it important that the strength deck and the bottom structure be made sufficiently strong to withstand any usual loading without failure.

A striking example of a failure of the upper deck occurred on the *S.S. Majestic* in the summer of 1924 and resulted in such serious damage that she had to be laid up for repairs from December, 1924, to May, 1925. This case illustrates not only the importance of continuity of strength and avoidance of stress concentrations around hatchways and deck openings but also the importance of the upper deck as the top flange of the hull girder (see page 3).

The *S.S. Majestic* was the German-designed and -built *S.S. Imperator*. The vessel was constructed with two outboard uptakes, which pierced the deck somewhat toward the sides. The plating between the uptakes was only ⅝ in. thick, and it was not thought that it would assume any load. The main strength members were the stringer plates, which were 2 in. thick, and the two strakes running inboard of the stringer, which were 1½ in. thick.

It was discovered in the summer of 1924 that the thin ⅝-in. plating between the uptakes had fractured. This received very little attention at the time, for this plating was not designed to take any load. The stringer plates were covered on top with wood decking and below with joiner work; and as it was the rush season, their inspection and repair were deferred until later. The vessel continued her trips until December, at which time she ran into heavy weather. During the storm a loud "cannon-like report" was heard; investigation showed that the deck had cracked all the way across and that the port stringer plate had also parted. The crack ran down the side of the vessel and stopped in a porthole.

The vessel made its way into Southampton, and all trips were canceled. New stringer plates were installed and doubling plates were added around all openings, which compensated somewhat for the stress concentration at the sharp corners. A complete description of this near catastrophe can be found in an article by naval constructor E. Ellsberg in *Marine Engineering*,[1] from which the above was taken.

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[1] August, 1925.

The *S.S. Leviathan* (the former German *S.S. Vaterland*) showed the same defects, and considerable reinforcement was necessary in way of openings in the deck.

These two instances establish two facts, *viz.*, that the strength deck should have sufficient steel to resist the stresses imposed by longitudinal bending and that sufficient steel alone will not be enough to keep the ship from breaking (both ships had sufficient steel area) if we do nothing to relieve the stress concentration in way of deck openings. Therefore all cuts in the main ship structure should be doubled, and, if possible, the corners should be well rounded (see Fig. 76).

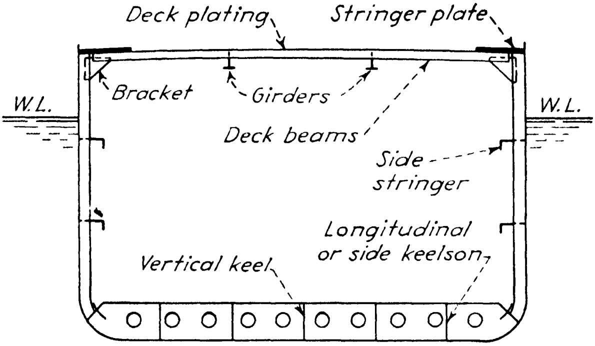


FIG. 100.—The fore and aft girders in a ship.

The stringer plate should not be confused with the side stringers, which are girders. There are three sets of fore-and-aft girders in a ship, *viz.*, longitudinals and keelsons in the double bottom, stringers in the sides along the frames, and girders located under the decks (see Fig. 100). The word "stringer" is sometimes applied to all three groups, but it should be used only for the side girders.

Problems

1. How is the deck plating supported?

2. What is the purpose of wood sheathing?

3. What is the difference in the riveting of a deck seam and a deck butt?

4. Why is the clinker type of deck plating objectionable?

5. What is the purpose of the stringer plate?

6. Sketch a typical equivalent girder, and indicate and label the equivalent parts.

7. Why should the corners of all holes cut into the strength deck be rounded, doubled, or both?

8. Differentiate between side stringer, girder, and longitudinal.

CHAPTER XII

STEM, STERN FRAME, AND RUDDER

The stem, stern frame, and rudder, all being large heavy fittings at the ends of a ship, are usually considered together.

The stem is the main frame connecting the two sides of the shell plating at the bow. It is strongly fastened at the bottom to the forward end of the keel.

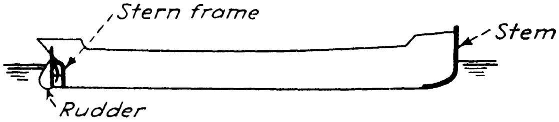


FIG. 101.—Location of the stem, stern frame, and rudder.

The stern frame performs a similar function at the stern. In addition, it furnishes support to the rudder and in single-screw and triple-screw ships to the propeller shaft.

The rudder is important as the means of steering the ship. It is a broad streamline fitting, hinged at its forward edge to the stern frame, and is controlled by a vertical shaft (the rudderstock) attached to it at the top and extending upward into the hull, where it is connected to the steering gear.

Figure 101 shows the location of the three parts mentioned above. Discussing these parts in detail, we shall begin with the stem.

STEM

The stem may be regarded as a more or less vertical extension of the forward end of the keel. Its functions are therefore similar to those of the keel. The stem must give strength and rigidity to the hull structure along the center line of the bow and furnish an effective connection between the two sides of the shell plating. Since the bow is the part of the ship that first encounters the pounding of heavy seas and the impact of obstructions in the ship's course, just as the keel is the first part to meet the bottom in grounding or docking, the strength and massiveness of the stem must be comparable with those of the keel. As in all other parts of the ship's structure, the stem's ability to give strength and rigidity to the entire bow depends largely on the effectiveness of the support given by auxiliary structure within the hull, such as the decks, breasthooks, stringers, and bow framing generally.

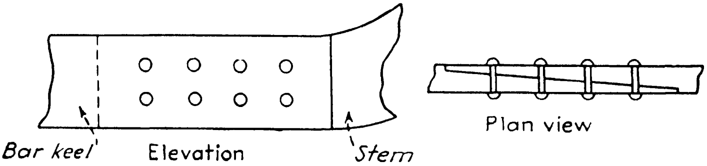


FIG. 102.

One of the simplest types of stem consists of a heavy flat bar of mild steel to which the shell plating is flanged and riveted, as it is to a bar keel. Sometimes the stem bar is a forging, often having its sides rabbeted to receive the shell plating in a flush-riveted joint.

With a flat-plate keel the after end of the stem is gradually reduced in height and increased in width for connection to the

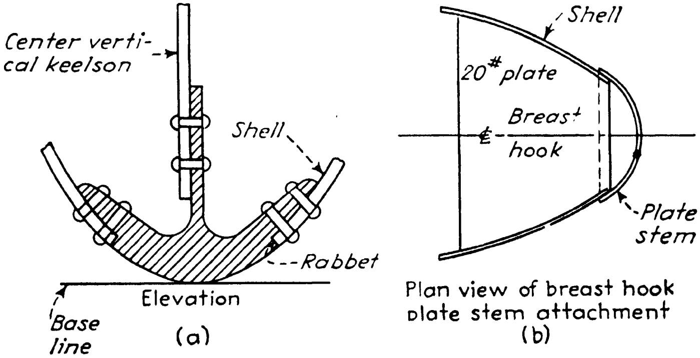


FIG. 103.

forward ends of the flat and vertical keels. With a bar keel the stem is usually a bar of the same cross section as the keel and is joined to it by a scarf joint no thicker than the bars connected, as shown in Fig. 102.

In another design of bar stem the upper part is a forging or rolled flat bar and the lower part is a steel casting, the two sections being scarfed together at a point just above the round of the forefoot. Figure 103 shows the connections of the vertical keel and shell plating to this casting on a riveted ship.

On most of the recent ships a stem built up out of welded plate has been fitted in connection with a casting at the bottom. The stem plate is furnaced to a large radius at the top, becoming narrower toward the bottom, and is reinforced inside by welded-plate chocks to which decks and breasthooks may be attached. A section of this type of stem is also shown in Fig. 103.

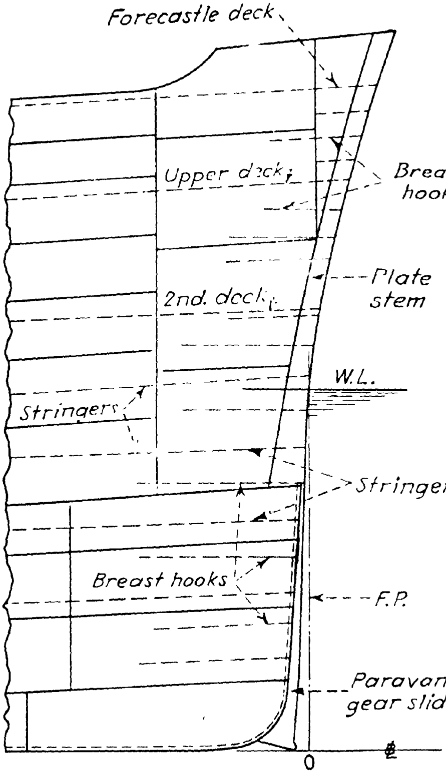


Fig. 104.—A modern semisoft-nosed plated stem.

The Soft-nosed Stem.—The advantage of the use of welded plate instead of a heavy bar is that it forms a "soft-nosed" stem, which is less apt to cause serious damage in collisions than the old-style bar stem. This is due to the fact that a bar stem is relatively sharp and, in case of a collision, would knife through the plating of another vessel. The soft-nosed stem would crumple and offer a broad surface by virtue of which, if it did penetrate the shell of another vessel, the penetration would be kept to a minimum. A combination of soft-nosed vessels and ample subdivision would prevent many sea disasters. It would seem to be the best practice to fit a rigid stem up to a point above the water line and then above this fit a soft-nosed rounded clipper bow, since any damage done by ramming would probably be above the water line of both vessels. Figure 104 shows the plating attachment and structural backing of a modern plated stem.

Bow Types.—There are three types of bows in general use, the plumb-stem bow, the clipper bow, and the raised-forefoot, or spoon, bow.

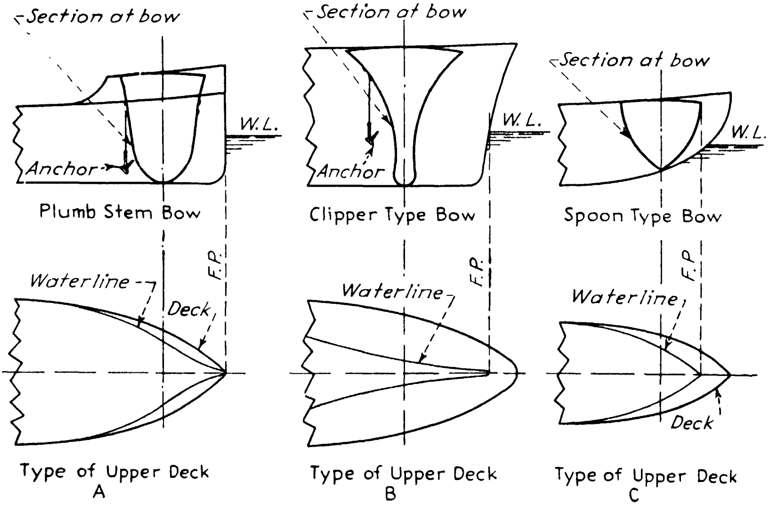


FIG. 105.—Typical bow types.

The *plumb-stem bow* is illustrated by Fig. 105, sketch *A*. This has been the usual merchant bow, but it is generally given a slight forward rake to avoid the appearance of leaning backward. This type usually has very little flare to the sides; as a consequence, the vessel cuts through rather than rides over the waves. Difficulties are encountered with this type of bow when the anchor is raised; for the latter has to slide along the shell plating up to the hawsepipe, and this may cause damage to the shell.

The *clipper-type bow* carries the flare of the sides forward of the forefoot (Fig. 105, sketch *B*), which enables the anchor to come up into the hawsepipes without fouling the shell plating. This also gives a longer and wider forecastle deck; more room is thus provided for deck machinery, and the deck remains drier in rough weather, for the flare throws the water aside. Most aircraft carriers are built with great flare forward; this gives a wider base for supporting the forward end of the flight deck, as shown in Fig. 106.

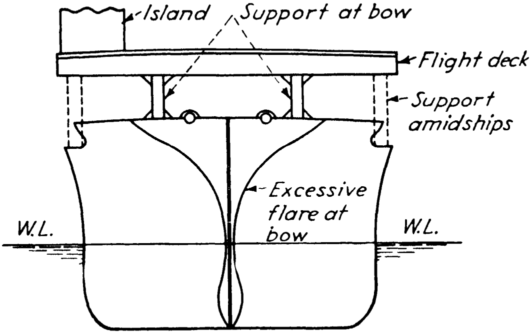


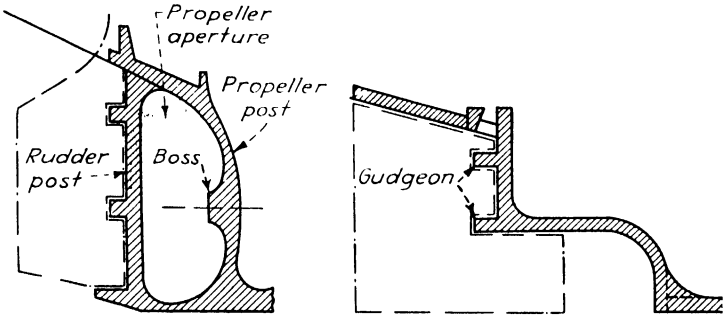
FIG. 106.—Most aircraft carriers have excessive flare forward to take the flight-deck supports.

The *spoon-type bow* (Fig. 105, sketch *C*), is used extensively on sailing yachts and icebreakers and also on a large number of merchant ships. A vessel with this type of bow will rise to the waves, which increases its seaworthiness. When a vessel with a spoon bow is in waves of its own length or longer (which in large vessels is very seldom), model tests have shown that it has less resistance and therefore is easier to drive than the clipper or plumb type.

STERN FRAME

The stern frame is similar to the stem in being a vertical extension of the keel and has the same function of connecting rigidly the two sides of the shell plating. In addition, it must support the rudder and, in single-screw or triple-screw ships, the propeller shaft. In most ships the stern frame must also furnish a solid foundation for the transom frame to which the overhanging stern, or fantail, is attached. For these reasons the design of the stern frame is necessarily more complex than that of the stem.

As shown in Fig. 107, the stern frame on a single-screw ship is composed of two posts called the *rudderpost* and *propeller post*, enclosing a space for the propeller called the *propeller aperture*. The after post is the rudderpost and furnishes support to the rudder by means of projecting lugs called *gudgeons*. These lugs do not take the weight of the rudder but act as bearings for the vertical hinge pins, or pintles, on which the rudder swings. The pintles are bolted into similar projections on the forward edge of the rudder called *rudder lugs*.



Stern Frame for Unbalanced Rudder

Stern Frame for Semi-balanced Rudder

FIG. 107.—Typical stern frames.

The forward post of the single-screw stern frame is the propeller post. It is bossed, or swelled out, to receive the after end of the stern tube, through which the propeller shaft passes out of the hull, and thus supports the propeller itself. The design of a stern frame for a triple-screw ship is generally similar to that for a single-screw vessel, since in both cases one of the screws is on the center line.

In twin- or quadruple-screw ships none of the shafts passes out of the hull on the center line; hence, there is ordinarily no forward post in the stern frame. In such ships the propeller aperture is commonly omitted and the shell plating is carried aft to the rudderpost, which, in this case, is often called the *stern post*. On some large vessels of this type an aperture is sometimes provided forward of the rudder to ensure a better flow of water to the propellers and to obviate vibration set up by the tips of the blades passing too close to the shell plating (Fig. 107). This vibration can usually be reduced by making this tip clearance not less than one-sixth the diameter of the propeller.

On ships having a bar keel the stern frame is commonly forged out of heavy flat bar tapered at the forward end to the same section as the keel, to which it is connected by a scarf joint, as in the case of the stem. When a flat keel is used, the forward end of the stern frame is flattened and widened for connection to the after end of the vertical-keel bars and flat keel and is usually rabbeted to receive the last keel plate. The top of the stern frame is generally extended up into the hull and attached to the transom frame.

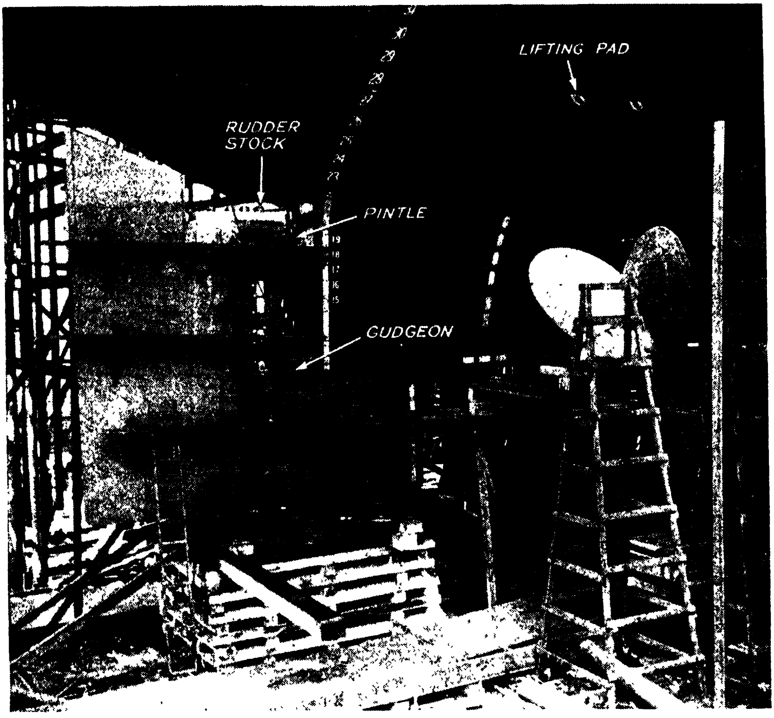
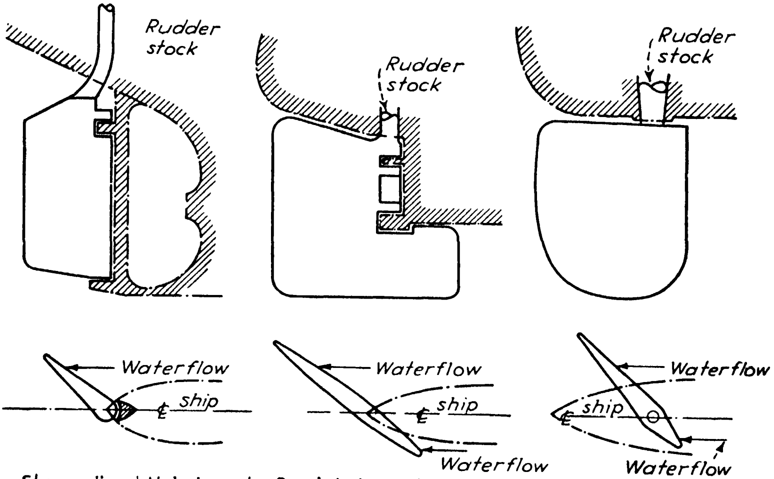


Fig. 108.—Semibalanced partially underhung rudder as fitted on *S.S. America*. This rudder is of hydrofoil shape. The balancing portion forward of the rudder stock is about 25 per cent of the total area. Fairwaters around pintles, gudgeons, and rudder stock are not in place.

RUDDER

In its simplest form a rudder consists of a wide flat blade and a vertical shaft or stock by which this blade is turned so as to steer the ship. The flat-blade rudder is found only on older ships and small boats. The newer type rudders are of streamlined section.

Rudders may be of the semibalanced or unbalanced type. A semibalanced rudder has part of the blade extended forward of the rudderstock, while an unbalanced rudder has all of its effective area aft of the stock. Semibalanced rudders are of several types, the most important of which are shown in Fig. 109.[1]



Streamlined Unbalanced Rudder A

Semi-balanced Rudder B

Spade Rudder C

FIG. 109.—Some typical rudder shapes.

From this figure it is evident that a semibalanced type of rudder requires a smaller steering engine, for the water pressure on the forward edge tends to throw the after edge over. About 25 per cent of the total area of the rudder is placed in the forward balancing section. Semibalanced rudders are in general used on warships and large merchant ships, for they give maximum maneuvering ability without requiring excessively powerful steering gear.

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[1] Quite often the expression "balanced rudder" is used for "semibalanced rudder." The term "semibalanced" is used in this text, for no rudder is "balanced" throughout the entire turning angle.

On most ships the shaft that turns the rudder is made in two sections that are bolted together just below the counter with a scarfed or flanged coupling to facilitate the unshipping of the rudder. The lower section of the shaft to which the blade is attached is called the *main piece;* the upper section, which extends upward into the hull, is called the *rudderstock.* The stock is generally a forging, which is usually cheaper and also superior to present-day castings in its resistance to torsional stress.

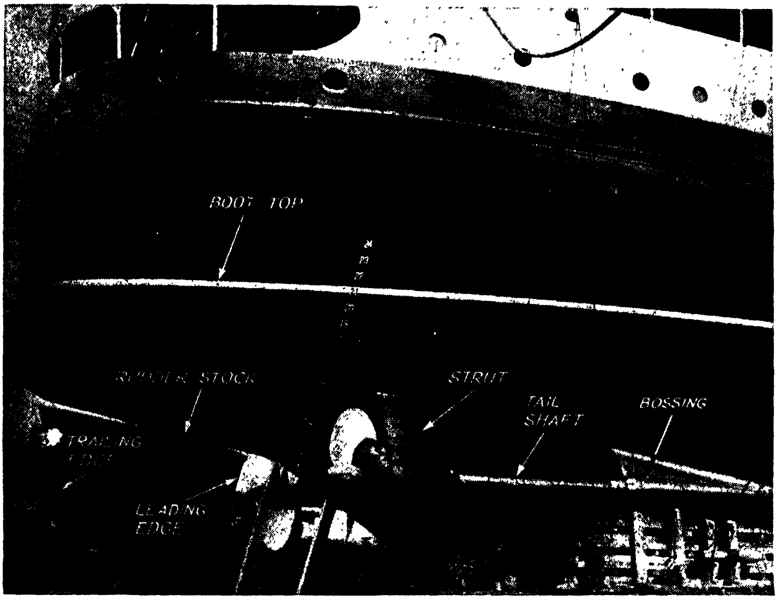


FIG. 110.—Semibalanced spade rudder. Completely underhung semibalanced spade rudder as fitted on the *S.S. Acadia.* The stern is of the cruiser type. The rudder is supported entirely by the rudderstock. No pintles or gudgeons are fitted.

The weight of the rudder is borne by a rudder bearing within the hull, usually placed above the top of the sternpost on the cant floors. The stock is enclosed within a watertight trunk below this point. The inside of the rudder bearing is cylindrical and forms the top bearing for the rudderstock. The upper surface of the bearing is flat or conical and supports a rudder carrier keyed and bolted to the head of the rudderstock. A projecting shoulder is turned on the rudderstock above and below the carrier to keep it from slipping up or down the stock. All rudder-bearing surfaces are lined with nonfriction metal or micarta and thoroughly lubricated.

Single- and Double-plate Rudders.—Rudders are constructed in many different ways according to the type and size of ship and the service for which it is intended. One of the simplest types is the single-plate rudder. This is formed from a heavy steel plate, cut to the designed shape and fastened to the main piece by heavy arms, placed on alternate sides, between which the rudder plate is riveted. The arms may be either steel forgings or castings and are separate pieces shrunk and keyed onto the main piece, which is generally a forging. As a hydrofoil, this type of rudder is very inefficient. Since the stress in a rudder decreases from the top to the bottom and from the stock to the after edge, both the main piece and rudder arms are tapered to a smaller size at the bottom and after end, respectively.

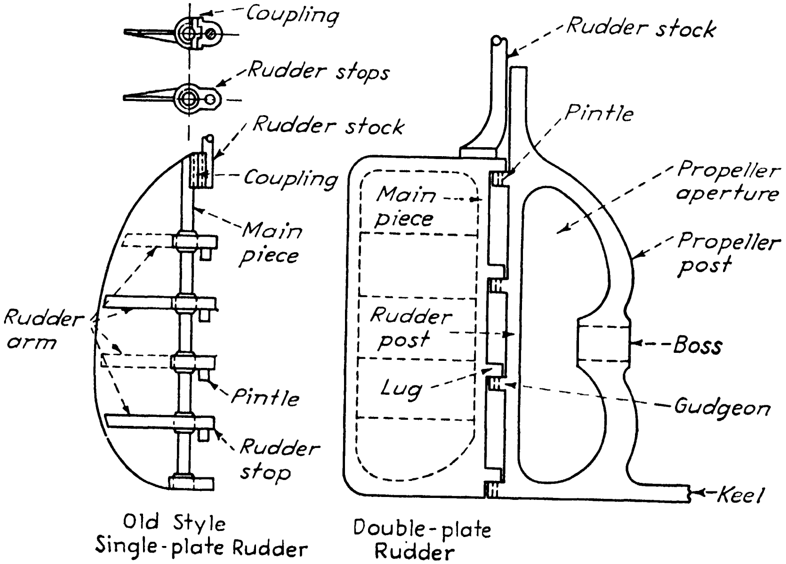


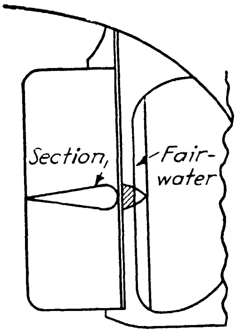
FIG. 111.—Old-style single plate and the modern hydrofoil unbalanced rudder.

The arms are extended forward of the main piece to take the pintles and are therefore spaced to suit the gudgeons on the stern frame. The rudder stock is bolted and keyed to the top of the main piece by means of a flanged coupling placed either vertically or horizontally. A single-plate unbalanced rudder is illustrated in Fig. 111.

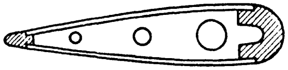
An alternative form of the single-plate rudder has the blade, arms, and main piece combined into a single steel casting. Very large rudders of this type have been successfully installed; but their high cost, excessive weight, liability to warp during production, and poor hydrofoil section have kept them from general use.

Most large modern rudders are of double-plate design, having a central frame on each side of which a plate is riveted or welded. At one time this frame was usually a steel forging or casting made in one piece with the arms and main piece. In later designs the arms have been replaced by stiffening webs of plate. A double-plate rudder of this type is shown in Fig. 111.

Many modern rudders are of completely welded construction, the side plates being welded together or to a heavy forged or cast bar at the outer edges and stiffened internally by welded plate webs. Since the reduction in stress toward the after edge of a rudder makes it possible to taper the blade in thickness, such rudders are of a streamlined hydrofoil form, the leading edge being comparatively wide and rounded and the after, or trailing, edge pulled out to a thin line. Streamlining the rudder has, in some cases, reduced the over-all resistance of a vessel as much as 5 per cent. A welded rudder of this type is shown in Fig. 112.



Profile of Rudder



Section through Rudder

FIG. 112.—Section through a hydrofoil rudder.

In the past the hollow interior of double-plate rudders was filled with some light wood and coated with red lead to prevent corrosion. A more recent practice is to leave the interior hollow and paint it with bituminous enamel. The larger rudders have access manholes in the side plating for inspection and maintenance. This method of construction in some cases gives the rudder enough buoyancy to float itself, thus reducing the load on the rudder bearing.

Goldschmidt Contraguide Rudder.—Another type of rudder, which is being used extensively on the Maritime Commission

C-3 type vessels, is known as the *Goldschmidt contraguide rudder.* This rudder is offset in opposite directions at the level of the propeller hub in such a manner that the propeller blade in passing by the rudder throws its stream of water, or "race," against the offset face of the rudder (see Fig. 114), thus giving a forward thrust, or push, to the ship.

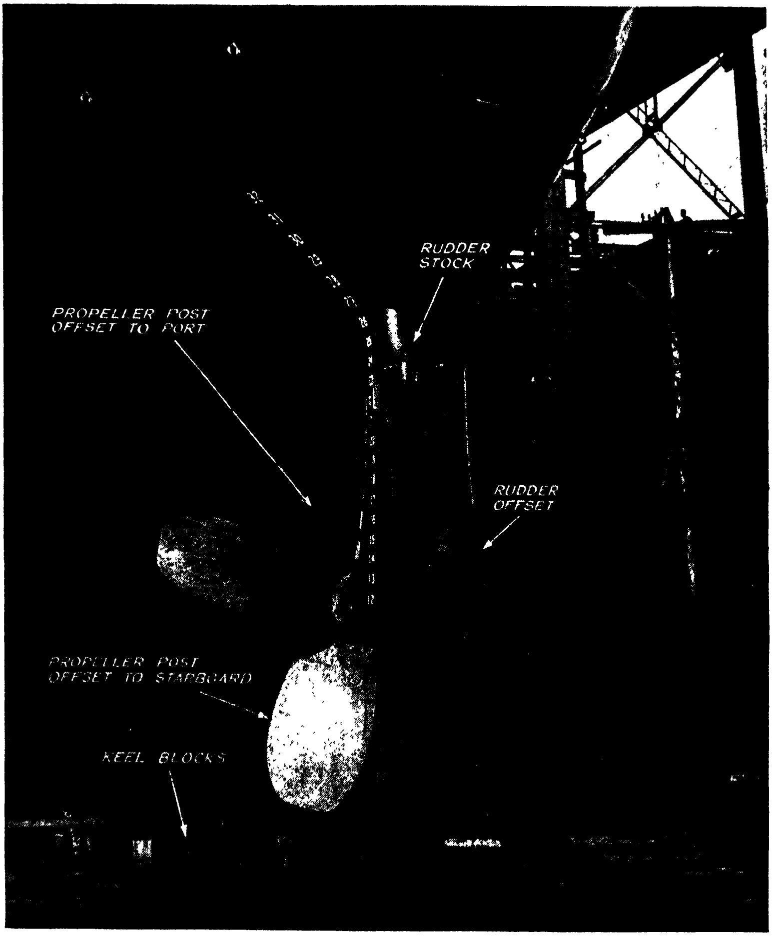


Fig. 113.—The Goldschmidt contraguide rudder. This unbalanced type of hydrofoil offset rudder is extensively used on the Maritime Commission C-2 and C-3 vessels. Notice, also, the offset in the propeller post.

It has been found by experiment that the maximum efficient rudder angle is between 30 and 35 deg. from the center line of the ship. To turn a rudder to a greater angle decreases the speed of the ship but does not decrease the turning radius. As a consequence, rudder stops are placed on the stern frame in such a position that the rudder cannot be turned more than 33 to 35 deg. These stops are usually in the form of projecting lugs on the sides of the rudderpost in line with the uppermost rudder lug, which is enlarged and faced off so as to make the required angle with the rudder stop when the rudder is on the center line. A rudder stop of this type is shown in Fig. 111. On ships having the rudder controlled by a quadrant on the rudderhead, an auxiliary rudder stop is often fitted in the form of a channel stanchion filled with wood, placed so as to act as a quadrant bumper limiting the swing of the rudder to the desired angle on each side of the center line. It is interesting to note here that the turning radius of a ship with the angle of the rudder kept constant is almost the same regardless of the speed; *i.e.*, the vessel will follow about the same path when turning at 10 knots as it does when turning at 20 knots.

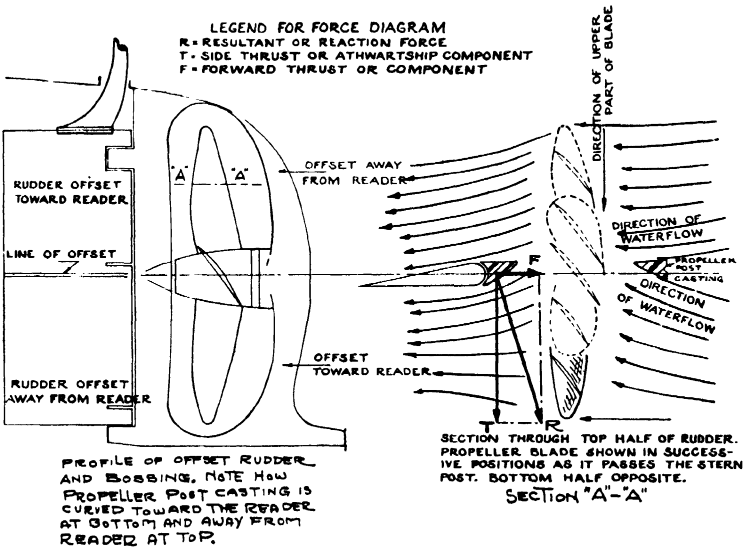
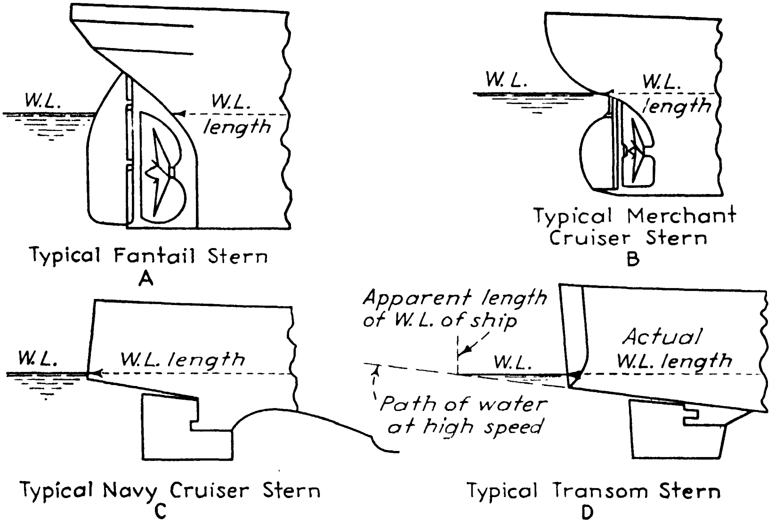


FIG. 114.—Diagrammatic view of the action of a Goldschmidt contraguide patent rudder.

Stern Types.—There are in general four types of sterns that are fitted to normal-type ships, the fantail, the merchant cruiser, the cruiser, and the transom. The *fantail stern* is now practically obsolete but may still be seen on many older vessels. Figure 115, sketch *A*, shows this type of stern. The *merchant-cruiser*, or *bathtub*, stern is at present the most popular stern for merchant vessels. This is primarily because it reduces the resistance of the vessel and makes it easier to drive. In tests carried out at the Newport News Towing Tank on a series of similar ships, it was found that the merchant-cruiser stern reduced the total resistance of the model by about 3 per cent. This reduction is mainly due to the increase in water-line length, which decreases the wavemaking resistance (see Fig. 115, sketch *B*; see Chap. XIV).



Typical Fantail Stern
A

Typical Merchant Cruiser Stern
B

Typical Navy Cruiser Stern
C

Typical Transom Stern
D

FIG. 115.—Typical sterns.

The regular *cruiser stern*, from which the merchant-cruiser stern was developed, is now seen most often on large naval vessels, such as battleships and airplane carriers. Until recently, it was generally used on cruisers; hence its name (see Fig. 115, sketch *C*).

The *transom stern*, familiarly referred to as the *barn-door stern*, is shown in Fig. 115, sketch *D*. This type of stern is now fitted on high-speed vessels in the United States Navy, such as cruisers and destroyers, and on small high-speed pleasure cruisers and runabouts. This type of stern is broad and fairly flat underneath, which is helpful in preventing "squatting" of the hull at high speeds. Resistance is reduced at high speeds about 3 to 5 per cent. This reduction is accomplished by an "apparent" increase in the water-line length of the vessel which is due to the water flowing aft at such a rate that it does not come level with the undisturbed water surface for some distance behind the vessel. This leveling-off distance is the apparent increase in the length of the vessel (see Fig. 115).

Problems

1. What are the functions of the stem?

2. Discuss briefly the advantage of fitting a soft-nosed stem.

3. Sketch a typical riveted flat-bar stem.

4. What are the advantages of the clipper bow?

5. In what length waves is the spoon bow most effective?

6. What is the function of the stern frame?

7. Make a sketch of a single-screw stern frame, and label the parts.

8. Why are semibalanced rudders almost invariably fitted on large vessels?

9. In the normal-form rudder what is the maximum efficient angle?

10. Is the weight of the rudder supported by the pintles?

11. What is the advantage of the double-plate rudder?

12. Why does the merchant-cruiser stern decrease the resistance (total) of a vessel?

13. How does a transom stern increase the apparent length of a vessel?

CHAPTER XIII

TYPES OF SHIPS

Most students are familiar with the automobile family and the work that each member performs. In the table below a comparison is given of the work of the members of the familiar automobile and the not so familiar ship family. In some cases the comparison is not exact but will serve for the purpose of this chapter.

On Land	On the Sea
Tractors	Tugs
Tractor trailer trucks	Tugs with barges
Heavy-duty 10-ton trucks	Full-scantling, maximum-draught freighters
Light-chassis trucks (large vans)	Shelter-deck vessels
Gasoline and oil trucks	Tankers
Coaldealers' trucks	Colliers
Station wagons	Small passenger-cargo vessels
Passenger cars	Yachts
Day buses	Bay steamers, cross-channel steamers, ferries
Transcontinental sleeper buses	Transoceanic liners

This does not begin to cover all types of ships, but it does give us an insight into the purpose of the most usual types. In the above we have entirely ignored the hundreds of specialized ships, such as whalers, cable layers, dredges, etc.

The design of a ship is based on a combination of some or perhaps all of the following considerations:

1. The cargo deadweight (the weight of the cargo to be carried).
2. The number of passengers.
3. The speed at sea.
4. Density of the cargo, *i.e.*, whether it will carry a heavy or a light cargo in relation to the space occupied.
5. Maximum draught. Draught is limited by the depth of some harbors.
6. Type of machinery—steam turbine, turboelectric, Diesel, Diesel-electric, etc.

7. Type of fuel—coal, fuel oil, Diesel oil.
8. Number of crew required.
9. Type of cargo—bales, crates, liquids, grains, etc.
10. Cruising radius required.
11. Safety requirements for the particular trade.
12. Other special requirements.

The determination of the above requirements is based on the owner's past experience, class of business, route of trade, and ability to look into the future, or on an analysis of cost data applied to a series of proposed ships of varying types, length, speed, draught, etc., the type that would return the greatest revenue to the owner being chosen.

A ship must operate at a profit. While the ideal vessel is one that is designed for and operates at its intended "trade," a number of vessels have been designed to operate in several trades and have been highly successful. Hard and fast rules are difficult to make in shipbuilding. Each case must be decided on its own merits.

We shall take up the ship types listed at the beginning of this chapter and briefly discuss their design and purpose.

THE TUG

This is a ship of many uses. The construction is heavy to withstand rough usage over a long period of time. The tug *Dorothy*, built at Newport News in 1891, is still in use in 1943, 52 years later.

Tugs carry no cargo and are in reality floating power plants. They are useful in handling and docking large vessels, towing, fire fighting, and ocean salvage. The harbor tugs are usually small vessels about 70 to 100 ft. in length. They very seldom venture far from their home port. The seagoing tugs, which range up to 200 ft. in length, may be classified into two groups. The first is the ocean towing tug. This tug is ordinarily used for long ocean hauls, perhaps towing dredging or other equipment halfway around the world. The second type is the salvage tug. This type is very fast and powerful. Speed is necessary, for salvage[1] usually goes to the first tug that arrives on the scene of

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[1] "Salvage" is a term used in admiralty law to denote, not only the act of saving life and property from the perils of the sea, but also the amount of money given to the salvor for his risk and work in performing this act.

the disaster. Salvage tugs are usually fitted with fire-fighting, lifesaving, and salvage equipment, in addition to their powerful propulsion engines.

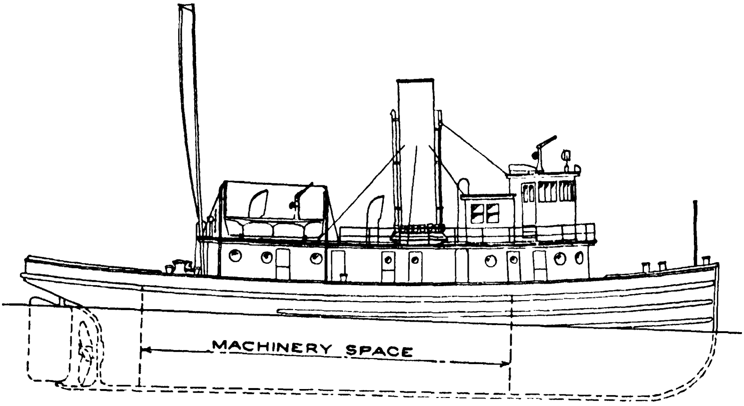

FIG. 116.—Harbor tug *Huntington.*

FULL-SCANTLING MAXIMUM-DRAUGHT FREIGHTERS

Full-scantling vessels are designed to carry heavy, dense cargoes such as heavy freight, ore, and sulphur. The term "full scantling" means that the framing, plating, etc., are heavy and strong and that the vessel is designed to load to the maximum allowable draught based on her length. These vessels may be thought of as the heavy-duty trucks of the sea. The *S.S. Angelina* of the Bull Line is a ship of this type. Figure 117*A* shows a poop, bridge, and forecastle (P. B. and F.), full-scantling vessel.

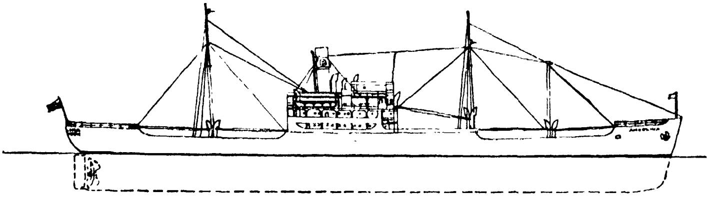

FIG. 117*A*.—*S.S. Angelina.* Full-scantling poop, bridge, and forecastle type.

SHELTER-DECK VESSELS

The other extreme from the full-scantling vessel is the "shelter-decker." This is a type of ship that will give the most space per ton of cargo. If the owner wishes to carry a cargo that occupies much space but has very little weight, such as automobiles or cellulose, he would choose a vessel of this type.

It takes about 220 cu. ft. of automobiles and about 240 cu. ft. of cellulose to make up a ton of cargo. However, 7 cu. ft. of copper slab or 17 cu. ft. of asphalt will weigh a ton. If the automobiles were loaded on the full-scantling ship, the vessel would be full of automobiles long before she was brought down to her maximum allowable draught (Plimsoll mark), which would mean a loss of many tons of cargo. On the other hand, if the shelter-decker were loaded with copper slab, she would be down to her "marks" before the holds were one-third full. This would also mean a loss, for this vessel would travel to her destination two-thirds empty. Loading the copper slab on the full-scantling vessel and the automobiles on the shelter-decker would practically double the amount of cargo transported. Whether to build a shelter-decker or a full scantling or some type in between becomes, then, a question of the cubic feet required for each ton of cargo. The design of both these types is also closely tied up with the American Bureau of Shipping rules (page 9) and the tonnage laws (pages 202 to 206). Figures 117*A* and 117*B* show sketches of a typical full scantling, P. B. and F., and a shelter-decker.

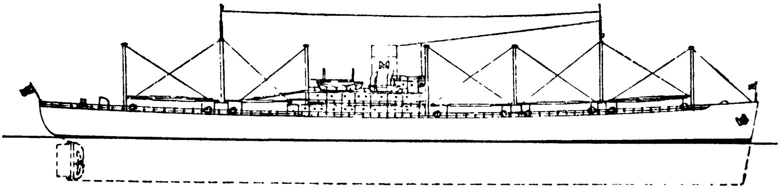

FIG. 117*B*.—*S.S. Hawaiian Planter*, a typical shelter-decker.

TANKERS

Oils, gasoline, molasses, and like liquid bulk cargoes are usually transported by means of a type of ship known as a *tanker*. Most tankers have their machinery located aft and separated from the main tank spaces by means of twin bulkheads forming a narrow empty compartment called a *cofferdam*.

Tankers may be divided into three general classes, ocean-going, coastwise, and river craft. These classes differ very little except in respect to size and service.

Most of the world's modern tankers (about 83 per cent) are propelled by internal-combustion engines. Most American owners, however, still prefer steam propulsion. The steam power plant consumes more fuel than the Diesel, but fuel oil is plentiful and relatively cheap in the United States compared with its abundance and price in foreign countries. Most American designers feel that the steam plant's reliability and freedom from repairs more than make up for the increased cost of fuel. Furthermore, it should be kept in mind that fuel consumption is but one of many factors in the final cost of operation of the propulsion machinery.

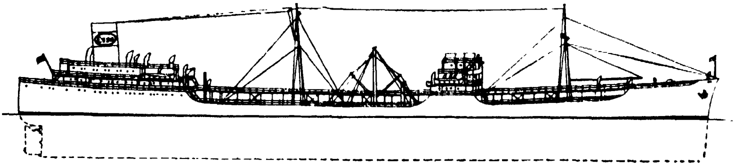

FIG. 118*A*.—*S.S. Esso Richmond*, a 553-ft. high-speed ocean tanker.

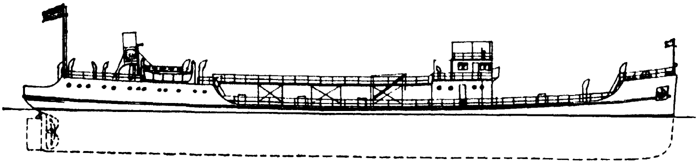

FIG. 118*B*.—*M.S. Esso Delivery No.* 11, a 260-ft. river tanker.

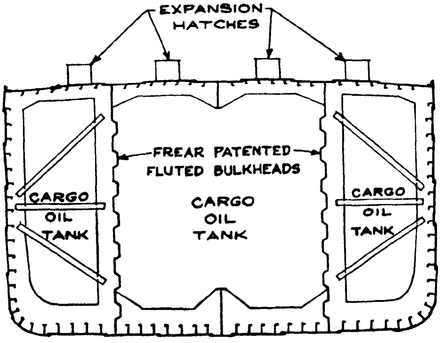

FIG. 119*A*.—Midship section of *S.S. Esso Richmond*, a modern twin-bulkhead type.

Figure 118 shows the *Esso Richmond*, a modern steam-propelled high-speed Standard Oil Tanker, and a smaller river tanker belonging to the same company. It will be noted that no inner-bottom plating is fitted in way of the tank spaces. A tanker does not require a second skin; if the shell is punctured, water would simply flood the tank and, as the tanker is designed to carry liquid cargo, the inflowing water would simply become cargo. A small cargo hold is fitted forward of No. 1 tank to provide space for the carrying of dry cargo and to give excess buoyancy to the bow when all tank spaces are filled.

The sections through the ship in Fig. 119 show the longitudinal framing that is almost universal in tanker construction. As mentioned before, this system gives great longitudinal strength, and the deep webs required do not interfere with the liquid stowage. Sketch *A* shows the modern twin-bulkhead design, and sketch *B* the older centerline-bulkhead summer-tank design.

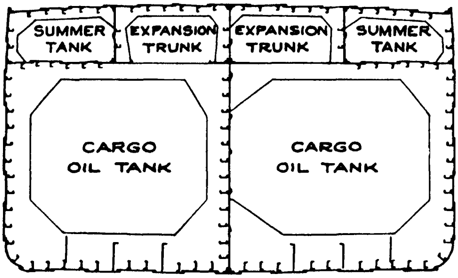

FIG. 119*B*.—Midship section of *S.S. John D. Archbold*, a centerline-bulkhead type.

COLLIER

Colliers are ships specially designed for carrying coal in bulk. There are numerous other ships that are closely akin to the collier. The ore carrier operating on the Great Lakes is an example of one of these. These bulk-carrying ships may be roughly divided into two classes, the "self-unloaders" and those which must rely on shore-based unloading equipment. Modern scientific loading equipment has made it possible to load as much as 12,000 tons of coal aboard a collier in as little as 4 hr. An equal amount of iron ore has been loaded on a lake freighter in 16½ min. and later unloaded in 2½ hr. The self-unloaders can deliver their own cargoes on the dock, 100 ft. from the ship's side, at the rate of 1,000 tons per hr. or more.

The machinery space on these bulk carriers is almost invariably aft to facilitate rapid loading and unloading, for the shaft tunnel necessary with machinery amidships interferes with unloading operations. A typical collier is shown in Fig. 120.

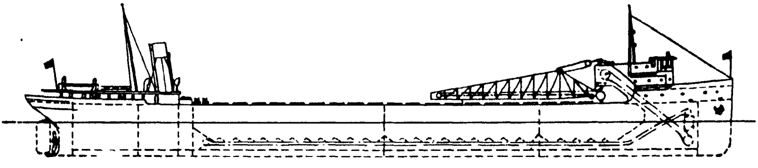

FIG. 120.—*S.S. Huron*, a Great Lakes self-unloading collier.

THE MEDIUM PASSENGER-CARGO VESSEL

A good example of this type of vessel is the *S.S. President Jackson*, a Maritime Commission C-3 design. These vessels are 465 ft. long by 69 ft. 6 in. beam by 42 ft. 6 in. deep, with a 26-ft. 9-in. keel draught, the corresponding displacement at this draught being 16,175 tons, with a deadweight carrying capacity of 9,937 tons. Her gross tonnage is 9,255.86, and her net tonnage is 5,151 (see Chap. XVIII for a discussion of gross and net tonnage).

The *S.S. President Jackson* carries 96 passengers in 38 staterooms. A crew of 122 persons is required for her operation.

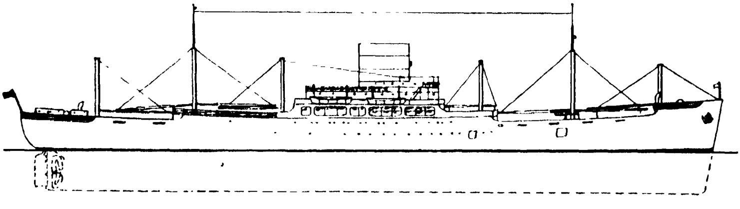

FIG. 121.—*S.S. President Jackson*, a shelter-deck cargo-passenger vessel.

Speaking in general and for ocean voyages only, every 3 passengers require 1 crew member. This does not include deck and engine-room crew. This ship is a good example of a shelter-deck cargo-passenger vessel. A typical C-3 is shown in Fig. 121.

The C-3 type vessel is designed to operate as a "liner"; *i.e.*, she will have a fixed schedule and a fixed course, or "line," of travel. A liner can be thought of as an oceanic ferry shuttling back and forth with predetermined, or fixed, ports of call. The tramp steamer, on the other hand, has been compared to a cruising taxi; *i.e.*, she picks up her cargo where she finds it and goes to any destination. The tramp has no fixed schedule or line of travel.

YACHTS

The yacht is the pleasure car of the sea. Standard-designed factory-type yachts are now built in large quantities. However, many persons prefer to have their yachts custom-designed by one of the numerous yacht architects, while others prefer to design their own. Numerous yachts are built according to rule-of-thumb methods or to no design at all. The results in the last three cases may be good but are more often ludicrous.

A large percentage of the errors in yacht design is due to the fact that the designer ignores the peculiarities of the waters in which the yacht is to operate. As an example of this, a deep-draught sailing yacht that behaves beautifully in the deep water off the coast of Maine will find its ports of call very limited in Chesapeake Bay and if it ventures out of the main channel may find itself hard aground. Likewise, shallow-draught boats designed for bay use are usually at a distinct disadvantage off the coast of Maine. However, excellent compromises suitable for general use are often possible.

BAY, SOUND, AND RIVER VESSELS

These are the vessels that are most familiar to inhabitants on the east or west coast or on the great river systems of the Middle West.

The bay and sound vessels are usually shoal draught (not over 10 to 15 ft.) and fairly fast. Most of them are now screw propelled. While the hull is of steel, the superstructure is usually of wood. Wood superstructures form a distinct fire hazard; no doubt, steel or some other fireproof material will be substituted in the future. If they operate in protected waters, such as Chesapeake Bay, they almost invariably have a midship section shaped as in Fig. 122*B*. This type of section gives a low *GM* when the vessel is upright. This low *GM*, or stability, causes the vessel to have an easy roll. Should the vessel roll to a dangerous angle, the sponsons would become immersed, thus increasing the stability, as explained in Chap. XVI. This type of hull is not suitable for ocean use owing to the large waves encountered.

Most of these vessels carry the passenger's automobile as well as cargo. Some are designed as double-enders and can operate in either direction. If they are double-operating, they will have a propeller and rudder at each end of the vessel. The propellers are usually connected to opposite ends of the same shaft, and both rotate. If of the paddle-wheel type, they have a rudder at each end. Double pilothouses are a feature of this double-ended type of boat, the forward pilothouse controlling the after rudder, and vice versa. On the Hudson River and Great Lakes, some of the steamers are still of the paddle-wheel type and are fast and efficient boats.

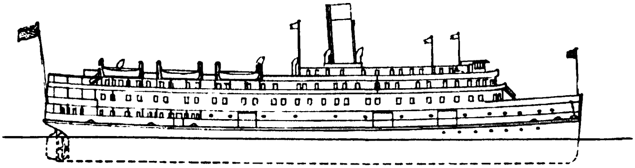

Fig. 122*A*.—*S.S. Yorktown*, a Chesapeake Bay steamer.

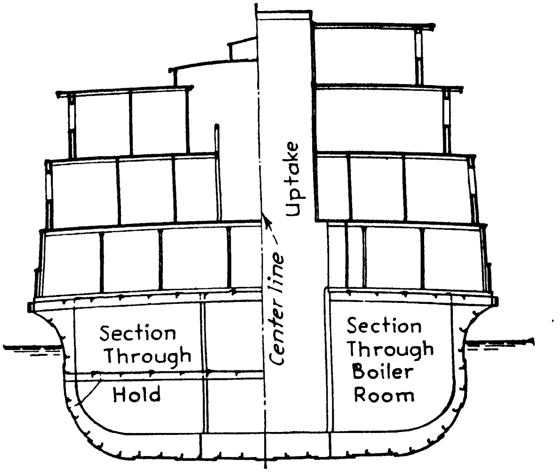

Fig. 122*B*.—Midship section of a Chesapeake Bay steamer.

The Mississippi River boats are usually "side-wheelers" or "stern-wheelers." Some propellers are in use, however, especially on the towboats. These vessels must of necessity be of very shallow draught, which accounts for the stern-wheel propulsion. They usually load and unload by coming right up to the river bank and putting over a gangway. At times the vessel is moored to a tree. The newer boats are usually loaded and unloaded at special docks. Their draught very seldom exceeds 6 to 8 ft., for the limiting draught from Pittsburgh to the Gulf of Mexico is about 9 ft. Figure 123 shows a typical old-style Mississippi River packet. Note the steel rods that support the ends.

In this same category we might place the swift channel steamers plying between England and the Continent. These are like the bay and sound steamers in that they are high speed (18 knots or more) for their size, and their runs are comparatively short. Most of the bay, sound, and cross-channel ships have runs that are timed to a train schedule; *i.e.*, they act as a link in a railroad system. They must function in all sorts of weather and run on schedule whether the water is rough or smooth. Some of these ships are propelled by paddle wheels, but the great majority have screw propulsion. Internal-combustion engines are used to a great extent for powering.

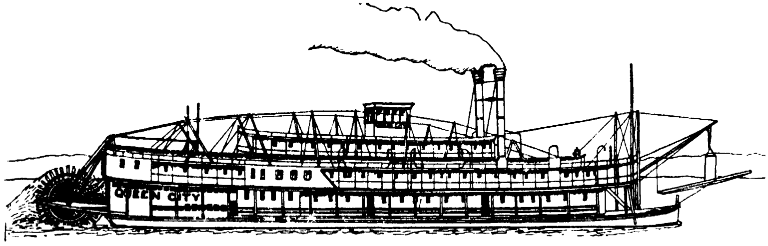

FIG. 123.—The *Queen City*, an old-style Mississippi River steamer.

LARGE TRANSOCEANIC VESSELS

These vessels operate on all the oceans of the world. Some are built primarily for passenger service and are called passenger liners. Others carry passengers and cargo. The number of passengers in relation to the amount of cargo usually determines whether they are called passenger vessels, passenger-cargo vessels, or cargo vessels.

The *S.S. Queen Mary* carries very little cargo and was primarily a passenger vessel. The *S.S. America* has fairly large cargo spaces but is still thought of as a passenger liner.

Between the leviathans, represented by the *S.S. Queen Mary, Queen Elizabeth,* and *Normandie,* and the small vessels plying the coastal waters, there are thousands of types. We have touched on only a few in this chapter. A. C. Hardy's "Ships at Work"[1] is recommended as instructive and entertaining reading for the young shipbuilder.

Another interesting type of ship known as a *weight lifter* is exemplified by the "Bel" ships, so called because the first part of their names always start with "Bel," as the *Belnor*, *Beljeanne*, etc. There is very little difference between a "Bel" ship and a full scantling except that the "Bel" ship has extra-heavy masts, booms, and hoisting machinery. To quote from A. C. Hardy's book mentioned above:

> One of the record cargoes achieved by the Bel fleet was that of the *Belpareil*, a twin-screw ship, which loaded three hopper barges, each weighing no less than 150 tons.
>
> Prior to lifting the barges, two tugs stowed athwartships on the foredeck had already been shipped. In comparison with the barges these seem almost insignificant, but they measured 75 ft. in length and weighed no less than 100 tons apiece.

Problems

1. Name the three types of tug. For what is each used?

2. What is salvage?

3. Tell in a few simple words what the term "full scantling" means.

4. For what types of cargo is a shelter-decker used?

5. What type of propulsion is used in most tankers?

6. Why is double bottom not required in way of the liquid cargo spaces on a tanker?

7. Why is the machinery space on bulk carriers located aft?

8. About how many crew members would be required by an ocean-going passenger liner with a passenger list of 900?

9. Why is the sponson-type hull unsuitable for ocean-going vessels?

10. Where does the term "liner" come from?

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[1] Chemical Publishing Company of New York, Inc.

CHAPTER XIV

LINES AND OFFSETS

The form of any solid body, such as a ship, can be determined by cutting it into sections and then noting its shape as revealed by the outlines of the cut surfaces. Each surface outline, since it lies in one plane, can be measured and then reproduced on a drawing, using the dimensions obtained by measurement.

In the early days of shipbuilding, and even during the clipper-ship era, the naval architect or the builder of a hull would make a small model of a proposed ship and lift lines from this model. The model was usually built of horizontal planks in sandwich fashion. The temporarily attached planks would then be shaped by taking a little off here and there until the experienced hand and eye of the model builder were satisfied that a good, fair form had been obtained. The planks of the model were separated; and measurements, or offsets, were taken from the model at different plank levels. These offsets were used to lay out the frames, planking, etc., of the full-sized ship.

A full-sized ship cannot be sawed apart and measured, but its form can be determined in the same way as that of the model by passing sets of parallel planes through its hull and measuring the outlines of these planes. The plan that defines the form of the ship by the use of such planes is called the *lines plan.*

The lines plan shows the outlines of all the cross-sectional planes and decks required to define the molded surface of the hull. This surface is bounded at the top by the sheer, or fore-and-aft curvature of the decks, and at the ends by the stem and stern profiles. All other lines shown on this plan represent the intersections of three sets of parallel planes with the molded form of the ship, or in other words, the traces of these planes on the molded surface of the hull.[1]

The planes in one of these three sets are horizontal, or parallel

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[1] The Castle Film Co., New York, has issued a film (No. 24), *Preparing and Setting a Keel Block and Bottom Cradle.* This film gives an excellent presentation of a ship's lines and is highly recommended as a teaching aid.

to the base line, and their intersections with the molded form are known as *water lines.* These water-line planes correspond to the upper and lower surfaces of the planks composing the designer's wooden model. In making the model, alternate planks of light and dark wood were often used, or else the wood was put together with dark glue, to show the water-line shapes more distinctly.

The planes in the second set shown on the lines plan are vertical and longitudinal, or parallel to the fore-and-aft center line, and their intersections with the molded hull surface are called *buttock lines.* If the designer's model were built up out of longitudinal planks set on edge instead of being laid flat, the surface of these planks would correspond to the buttock planes.

The planes in the third set are also vertical, but they run transversely, or square to the fore-and-aft center line. Their surface intersections are the frames lines corresponding to the surfaces of the transverse vertical planks, which sometimes were used instead of horizontal planks, in the earliest designer's models mentioned previously.

THE LINES DRAWING

For the purpose of showing the relationship of the three sets of intersection curves to each other, the lines plan is made up of three principal views of the ship's form, known as the *half-breadth plan*, the *profile*, or *sheer plan*, and the *body plan.* These three views show the ship's form as it appears from above, from the side, and from the end, respectively. In each view, the molded surface intersections of one of the three sets of planes, being seen in outline, appear as curves, while the other two sets of planes, being seen edgewise, appear only as straight lines. All three views are laid out from two fore-and-aft reference planes, one horizontal through the base of the molded form and the other vertical and longitudinal through its center. The intersection of the horizontal reference plane with any view is called the *base line* and the similar intersection of the vertical reference plane is called the *center line.* The fact that these lines represent planes viewed edgewise explains why the base line runs longitudinally on the profile and transversely on the body plan, while the center line is vertical on the body plan and horizontal on the half-breadth plan (see Fig. 124).

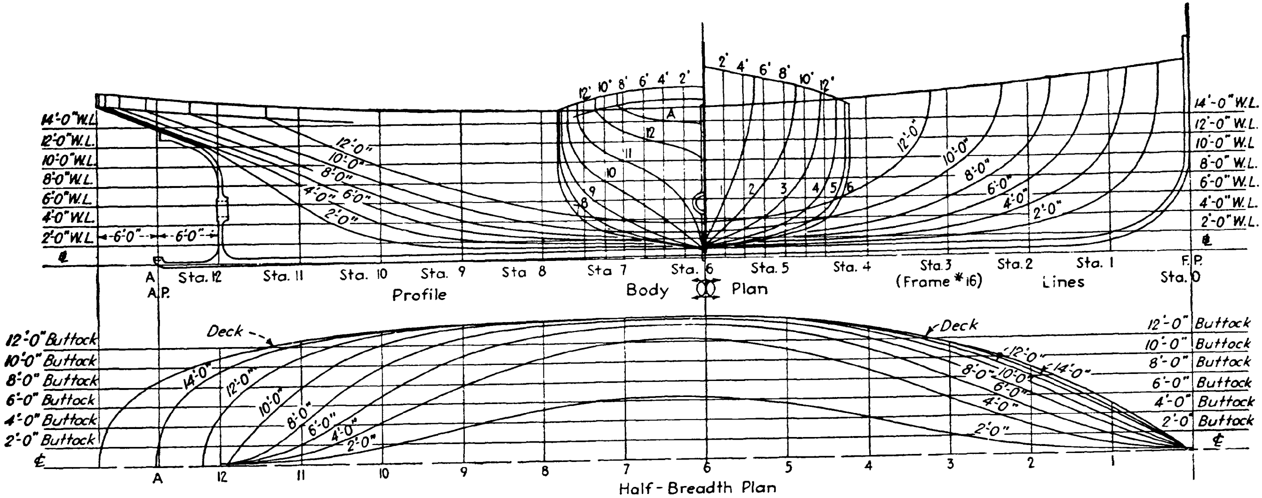

FIG. 124.—Harbor tug *Huntington*, lines plan. Length, 109 ft., 0 in. over-all, 103 ft. 0 in. B.P., beam, 29 ft., 0 in., depth, 14 ft., 6 in.

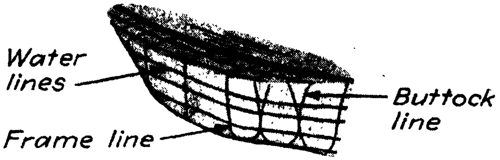

FIG. 124*A*.—The intact model, showing water lines, buttock lines, and frame lines painted on the outside where they intersect the shell.

FIG. 124*B*. FIG. 124*C*.

FIG. 124*B*.—Water planes. Model cut parallel to the base line and lifted vertically to show the shape of the water planes. Outline at shell corresponds to water lines on half-breadth plan.

FIG. 124*C*.—Buttocks. Model cut vertically parallel to the centerline plane and pulled apart laterally to show shape of the buttock planes. Outline at shell corresponds to buttock lines on profile.

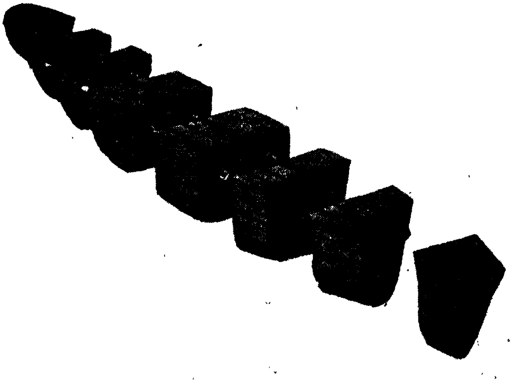

FIG. 124*D*.—Frame lines. Model cut at transverse intervals to show shape of frame lines. Outline at shell corresponds to frame lines as shown in body plan.

Lines model. Note the water lines, buttocks, and frame lines drawn on the intact model. As these lines are in reality planes, they show on all three cuts. A study of the photographs above will aid the reader to visualize Fig. 124.

1. Half-breadth Plan.—The half-breadth plan is usually drawn for the port side only, since both sides of the ship are alike. This plan is made looking down on the ship, showing its hull cut horizontally by the first set of planes, which are parallel to the base. The curved outlines of these planes are the water lines, which reveal the form of the hull at various heights above the base. The half-breadth plan also gives the location and spacing of the frame stations and buttock planes, both appearing edgewise as straight lines. The decks, bulwark rail, and stern knuckle, if any, also appear as curves in this view.

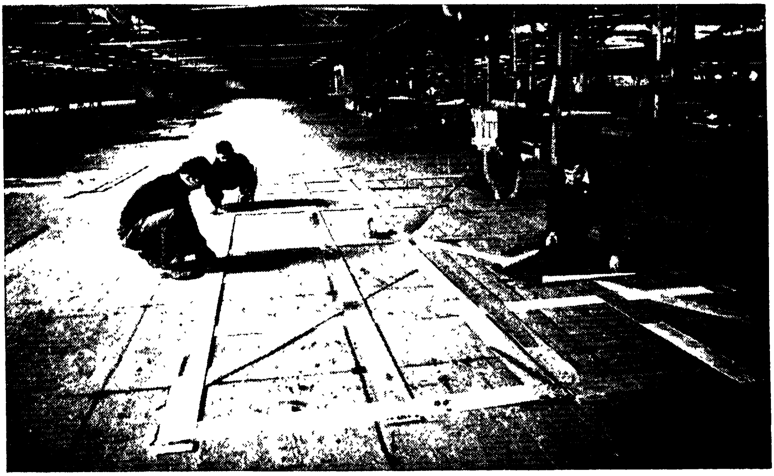

FIG. 125.—View of the mold loft. The mold loft is of sufficient size so that the lines of a ship may be laid down to full scale. The rectangular pieces are templates for shell plates.

2. Profile.—The profile is a longitudinal side elevation, generally drawn with the bow to the right. It shows the contour of stem and stern and the sheer of the decks, rail, and knuckle. Its main purpose is to show the molded form of the ship at the center line and at the longitudinal vertical planes called *buttocks*, parallel to the fore-and-aft center line. It also shows the location of frame stations and water-line planes, which are both seen edgewise as straight lines in this view, while the sheer lines of the decks, rail, and knuckle are curved.

3. Body Plan.—The body plan is an endwise view of the ship's molded form, showing its shape at each transverse frame-station plane, and it also locates the decks, rail, knuckle, longitudinal girders, sheet lines of shell plating, and frame endings. All these lines appear as fair curves in this view, while the water lines and buttock planes are shown as straight lines. The body plan is drawn for one side of the ship only. The sections forward of amidships, making up the *forebody*, are shown to the right of the center line, while the sections aft of amidships, in the *afterbody*, are shown to the left.

Additional planes, known as *diagonals*, are also used to define the longitudinal molded form through the turn of the bilge and just above and below it. These planes run diagonally downward from the center line toward the bilge, more or less normal (perpendicular) to the molded hull surface. They are seen edgewise as straight lines in the body plan, but their true form does not appear in either of the other two views of the lines plan and must be shown in a separate view, often combined with the half-breadth plan.

OFFSETS

The measured dimensions to the outline of the ship's molded form, as revealed by the various planes on the lines plan, are known as *offsets*. This name is derived from the fact that these outlines can be reproduced, either to full size or to any reduced scale, by "setting off" these dimensions from the base line, center line, or any other fixed reference line. When set off vertically above base, an offset is called a *height*. When set off horizontally from the center line, it is a *half breadth* or *half width*.

When three planes intersect each other at right angles, as the various planes on the lines plan do, any point in the line of intersection between two of these planes can be definitely located by a single dimension, measured from the third plane along this intersection line. This principle is followed in measuring the offsets for a ship's molded form, which are generally taken at each frame station, as half widths to each water line or as heights to each buttock line. Since the offset is measured along the intersection of the frame-station plane with the water line or buttock plane for which it is given, *only this one dimension or offset is required to locate each point in the sectional outlines of the molded form.*

Figure 126 shows offsets for points on a frame curve at a water line and buttock. Figure 127 illustrates the fact that, since each point lies in two planes, these offsets determine not only

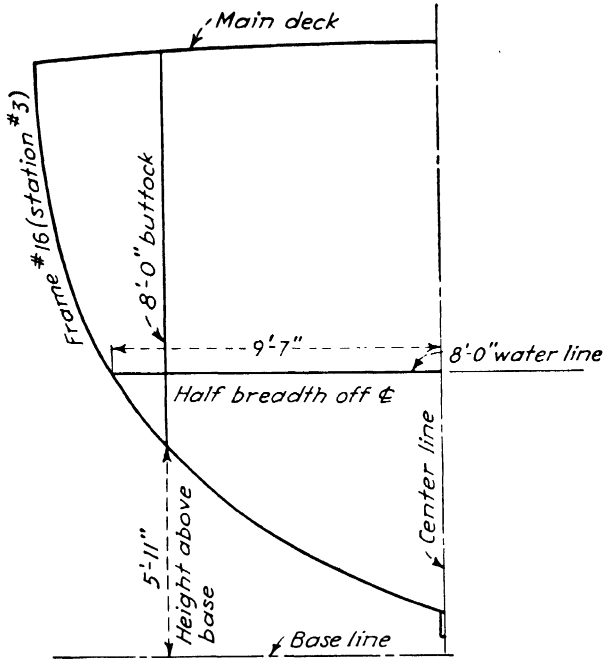

FIG. 126.—Frame offsets for section 3 (frame 16), see Fig. 127.

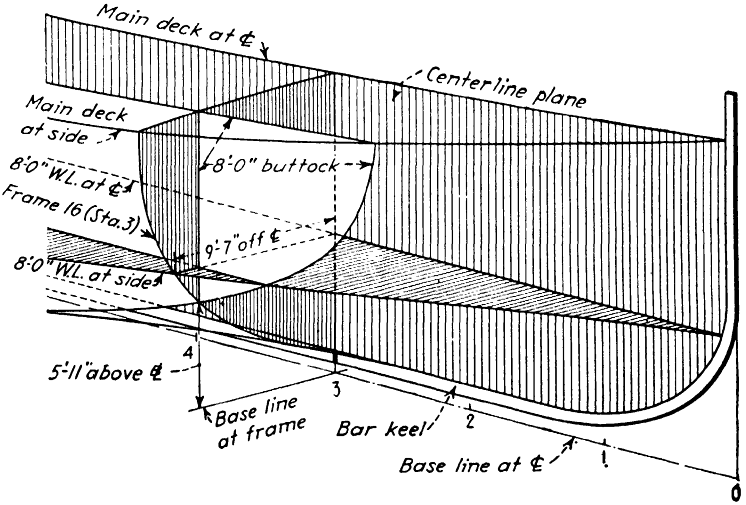

FIG. 127.—Skeleton half model of the tug shown in Fig. 124. The section at frame 16 (station 3) is shown also in Fig. 126.

the half width and height of the frame at a water line and buttock but also the half width and height of the water line and buttock at this frame.

PRELIMINARY LINES

The lines of a new ship as determined by its designer are drawn up to reduced scale (usually about one-fiftieth or one-hundredth of the full size) by the hull technical office of the shipyard hull-design division, as the preliminary lines plan. On this plan, the transverse sections are drawn, not at frames, but at stations equally spaced between the forward and after perpendiculars of the ship. These stations divide the length of the vessel into an even number of intervals, for convenience in calculating the displacement by the rules explained in the next chapter. Another reason why the designer draws the preliminary lines at displacement stations, instead of at frames, is that the frame spacing is usually not determined until long after these lines have been drawn.

From the preliminary lines, offsets are measured with a scale and made up into a table known as the *preliminary offsets*, usually included in the lines plan. Blueprint copies of the preliminary lines and offsets are then sent to the mold loft, where they are used in laying down the lines of the ship to full size, on the mold-loft floor, and in fairing them up. The mold-loft lines are first laid down at displacement stations; but as soon as the frame spacing has been settled, a full-sized transverse section is drawn for every frame, forming the working body plan. From this body plan, molds are made for the fabrication of the steel plates and shapes making up the ship's hull.

FAIRING THE LINES

Fairing the lines of a ship consists of two processes, (1) smoothing out the curves representing sections through the molded form until none of them shows any humps or sudden changes in direction and (2) bringing the intersections of these curves into agreement with each other in all three views of the lines plan. The first object is attained by pinning springy wooden battens in a fair line through the spots determined by the offsets. The second is accomplished by adjusting these battens until the offset to any curve intersection is the same in both the two views in which it is definitely located. In the third view, both the intersecting curves lie in planes seen edgewise as straight lines; hence, the intersection is indefinite and cannot be checked (see intersections *A*, *B*, and *C*, Fig. 124).

As already stated, the lines are laid down in the mold loft to full size, on a scale fifty to one hundred times larger than that of the lines plan. It is therefore easier for the loftsman to notice any *unfairness* or any discrepancies between the same intersections in two different views than it was for the *draftsman* who drew the lines plan. The lines as completed on the mold-loft floor are much more nearly fair than on the preliminary drawing. A set of corrected offsets at frame stations is now scaled by the loftsman from the full-sized lines and returned to the hull drawing room. Here they are made up on tracing-cloth sheets, which are combined to form the book of offsets. Blueprint copies of this

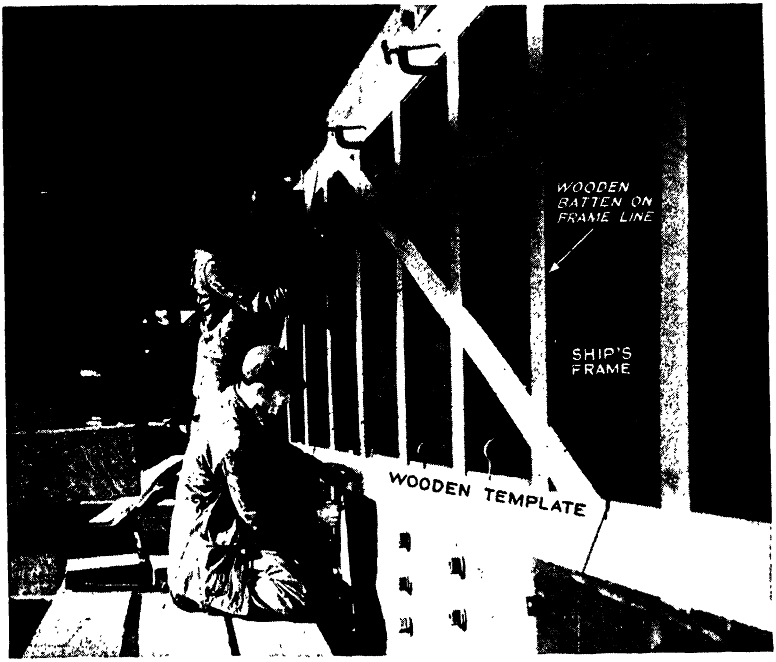

FIG. 128.—Lifting a steel plate. At times it is difficult to pick up accurately the shape of a plate from the mold-loft floor. In such a case, a mold, or template, is made directly from the ship. This is known as lifting a plate. The plate is laid off, cut, and rolled to the shape indicated by the fitted template.

book are then sent to the hull and engine drawing rooms for use in developing the plans for the ship and to various yard departments needing them in their work.

SECTIONAL-AREA CURVE

The lines of a new vessel generally are drawn by its designer in accordance with a predetermined sectional-area curve, based on model-basin results obtained by towing models of previous ships of the same type and proportions as the proposed vessel. The data thus obtained have been studied and analyzed until the best distribution of sectional area for minimum resistance to propulsion has been well established (see Chap. XV, page 161).

The sectional-area curve is drawn on a base line representing, to some convenient scale, the length adopted for the vessel (see Fig. 140). On this base line, ordinates are set up at the same displacement stations to be used in drawing the lines. The length of each ordinate is made to represent, on a suitable scale, the area of a transverse section through the ship's molded form at that station, up to the designed water line and on one side of the fore-and-aft center line. These areas can be summed up by one of the calculating rules described in the next chapter, so as to give the ship's displacement.

Since the form of this sectional-area curve depends on the ship's displacement and length, both these factors in the design must be determined before the curve can be drawn. The displacement can be approximated by the use of a likely ratio of deadweight (carrying capacity) to displacement (total weight of the ship), which should, for example, vary from 0.65 to 0.75 for cargo vessels. The length must be chosen to give suitable relationships *between* displacement, length, and speed. For convenience, those relationships are expressed as dimensionless coefficients, known as the *speed-length ratio* and *displacement-length coefficient.* The speed-length ratio is the ratio of the speed in knots to the square root of the effective length in feet and may be written

$$\text{Speed-length ratio} = \frac{V}{\sqrt{L}}$$

This ratio for normal merchant hulls is seldom greater than 1.0 and usually is about 0.70. At a speed-length ratio of about 1.5 the hull forms a wave crest at the bow and stern and sinks into the trough between. To get a vessel out of this "hole" in the water takes a tremendous expenditure of power. If this expenditure is made and the hull is forced over the bow wave, the phenomenon of "planing" takes place and the hull is no longer of the displacement type. This phenomenon of planing begins at a speed-length ratio of about 2.5 to 3.

Sailing yachts of the displacement type never have the power required to push themselves over their own bow wave; consequently, their maximum speed-length ratio is 1.5.

Below are two problems illustrating the use of the speed-length ratio.

Problem 1: Calculate the maximum top speed of a displacement-type sailboat with a water-line length of 36 ft.

Solution: $\sqrt{36} = 6$, maximum $\dfrac{V}{\sqrt{L}} = 1.5$.

$$V = 1.5 \times \sqrt{L} = 1.5 \times 6 = 9 \text{ knots}$$

Problem 2: If the speed-length ratio of the *Queen Mary* is 1.0 and her length is about 1,000 ft., what is her speed?

Solution: $\dfrac{V}{\sqrt{L}} = 1$, $\sqrt{L} = \sqrt{1{,}000} = 31.8$.

Then,

$$\text{Speed} = 1.0 \times 31.8 = 31.8 \text{ knots}$$

The displacement-length coefficient is the ratio of the displacement in tons of salt water to the cube of the length in hundreds of feet and may be expressed as

$$\text{Displacement-length ratio} = \frac{\text{displacement}}{\left(\dfrac{L}{100}\right)^3}$$

The 100 is used as a divisor to make the coefficient number small. This coefficient is useful in comparing the relative *fatness* of vessels.

FORM COEFFICIENTS

The other dimensions of breadth, draught, and depth, as well as the general character of the lines, are chosen so as to agree with suitable coefficients of fineness, known as the ***block coefficient***, ***prismatic coefficient***, ***maximum-section coefficient***, and ***water-plane*** *coefficient.* The final choice of the breadth is subject to considerations of stability; the draught is usually the maximum available in the harbors on the ship's route; and the depth depends on freeboard and carrying capacity. These coefficients express the fineness of the vessel by giving the ratio of its underwater volume or cross-sectional area to the maximum volume or area allowed by the dimensions. The lower the coefficient, the finer the form.

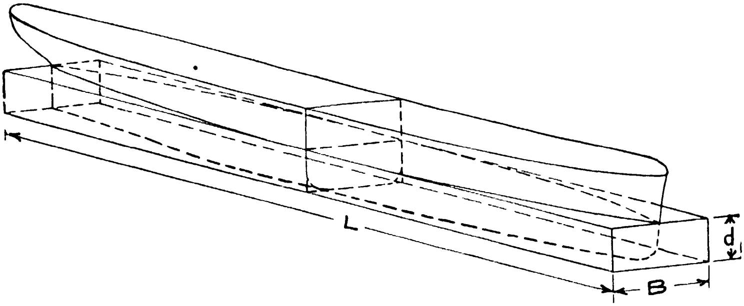

FIG. 129*A*.—The block coefficient.

$$C_B = \frac{\text{volume of displacement}}{\text{volume of block}}$$

Volume of block $= L \times B \times d$

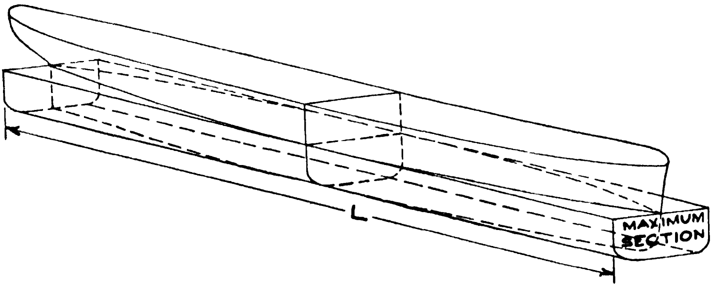

FIG. 129*B*.—The prismatic coefficient.

$$C_P = \frac{\text{volume of displacement}}{\text{volume of prismoid}}$$

Volume of prismoid $= L \times$ maximum section area

The block coefficient is the ratio of the volume of displacement to the volume of the enclosing rectangular block having the same dimensions as the ship's hull. It may be written

$$C_B = \frac{\text{displacement}}{L \times B \times d}$$

where L = length.
B = beam.
d = draught.

The maximum-section coefficient is the ratio of the maximum sectional area to the area of the enclosing rectangle, having as its dimensions the breadth and draught of the ship. This may be written

$$C_M = \frac{\text{maximum sectional area}}{B \times d}$$

The prismatic coefficient is the ratio of the displacement volume to that of a prismoid having the same length and maximum cross-sectional area as the ship. It is equal to the block coefficient times the maximum-section coefficient.

$$C_P = C_B \times C_M$$

The water-plane coefficient is the ratio of the area of the load water plane to the area of the enclosing rectangle. It may be written

$$C_{WP} = \frac{\text{area of water plane}}{L \times B}$$

Figure 129 illustrates the relationship of the underwater form of the ship to the enclosing rectangular or prismatic block, as expressed by the block coefficient and prismatic coefficient. Figure 130 shows graphically the areas whose ratios constitute the maximum-section coefficient and water-plane coefficient. It also shows that the prismatic coefficient represents the ratio of the area under the sectional-area curve to that of the enclosing rectangle, since the height of this curve, by definition, is equal to the maximum-section area and its length is the same as the ship's length.

In using the sectional-area curve as the basis for drawing a ship's lines, the designer must consider the forms found to be best for the frames forward and aft, whether U-shaped or V-shaped, and the most desirable form for the water-line endings, whether full, straight, or hollow. The lines are started by sketching in a freehand body plan, drawn to the correct breadth, draught, and depth and made up of transverse sections having the areas obtained from the sectional-area curve. This sketched body plan will be unfair, and the first line to be faired is the load water line, from which the half breadths for this water line can be corrected on the body-plan sketch and the sections redrawn to suit, without altering their areas. The next line faired will be the bilge diagonal, and the same process will be continued and extended through the other two views on the lines plan until all water lines, buttocks, and sections at stations are fair and in complete agreement. See Fig. 124 and check for any unfairness. The observant student may find several spots that are not quite in agreement.

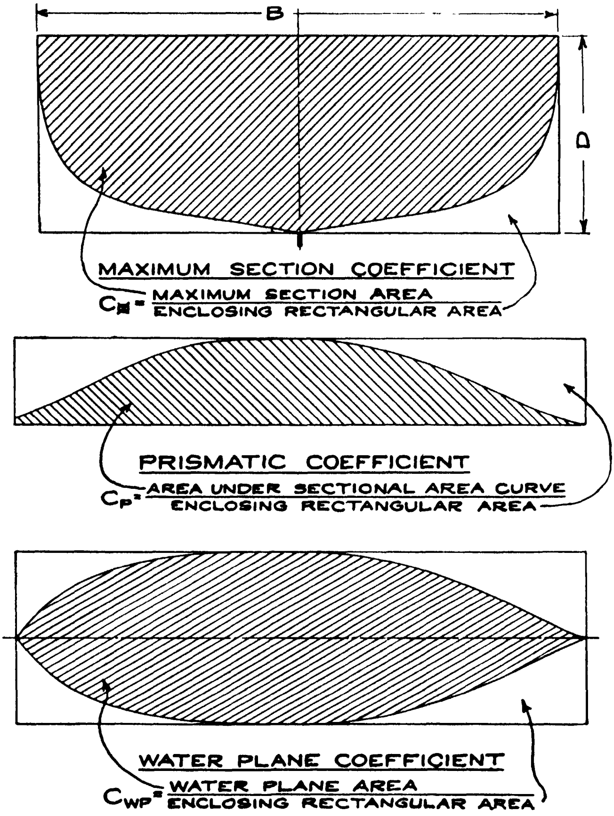

FIG. 130.—Form coefficients.

USE OF THE FORM COEFFICIENTS

The coefficients of fineness (form coefficients) are particularly valuable to the designer, for they are dimensionless; *i.e.*, they will apply to forms of all sizes because they are not in feet, tons, barrels, or other confining units but are merely numbers.

These ratio numbers enable the designer to compare a 400- and a 1,000-ft. ship directly. For example, a 400-ft. ship with a prismatic coefficient of 0.56 and a speed-length ratio of 1.0 would be similar to a 1,000-ft. ship with the same prismatic and speed-length ratio. As these two ships are similar, then the shape of the sectional-area curve will also be similar, regardless of the vast difference in size.

In the same way, the water-plane coefficient gives us an idea of the water-line fineness. A water-plane coefficient of 1.0 would indicate a rectangular barge, and a water-plane coefficient of zero would indicate a straight line with no breadth. In between these two extremes are our ship-shaped forms.

Likewise, the midship-section coefficient tells us the general shape for the midship section. For a further discussion of these coefficients and their relationships, see any standard work on naval architecture.

Problems

1. What is meant by the lines of a ship?
2. Define sheer, water-line plane, buttock.
3. How were the lines of a ship developed about the year 1850?
4. Draw a rough sketch of the three views that delineate the lines drawing.
5. What is a diagonal?
6. Define base line; where is it located?
7. What is an offset? What is its purpose?
8. Why is the preliminary lines plan drawn at equally spaced sections instead of at frame lines?
9. What is the purpose of the sectional-area curve?
10. Name the four coefficients of fineness.

Table of Typical Ships and Their Fineness Coefficients

The ships in this table are arranged in declining order of their speed-length ratios. It will be noted that the tug Huntington is a faster ship for her length than the S.S. AMERICA.

Ship	Type	L'	Knots	$V/\sqrt{L}$	C_B	C_M	C_P	C_{WP}	$\frac{\Delta}{(L/100)^3}$
Nenemoosha	Yacht	121	12	1.09	.464	.760	.611	.677	132
Huntington	Tug	100	10	1.00	.532	.853	.663	.776	489
S.S. Acadia	Pass-Cargo	400	20	1.00	.536	.947	.566	.701	106
S.S. Hawiian Planter	C-3 Cargo	465	18	.835	.670	.982	.682	.790	178
S.S. Esso Richmond	Tanker	547	18	.770	.660	.985	.670	.754	142
S.S. Pres. Jackson	Pass-Cargo	465	16.5	.765	.660	.982	.673	.768	165
S.S. America	Pass-Cargo	686	23	.765	.588	.979	.600	.727	106
S.S. Nightengale	C-2 Cargo	435	15.5	.743	.683	.980	.697	.762	167
S.S. Angelino	Cargo	385	13	.663	.714	.986	.724	.804	185
Liberty Ship (1941)	Cargo	416	11	.540	.748	.988	.761	.848	178
S.S. Clairton (1917)	Cargo	389	10.5	.533	.785	.985	.797	.873	196

CHAPTER XV

WEIGHT AND DISPLACEMENT CALCULATIONS

The area of any regular figure such as a triangle or the volume of any regular figure such as a pyramid can easily be calculated by simple and exact arithmetical means. Thus the area of a triangle is simply

$$\frac{\text{Base}}{2} \times \text{altitude} = \frac{b}{2} \times A = \text{area}$$

and the volume of a pyramid is

$$\frac{1}{3} \text{ area of base} \times \text{altitude} = \frac{B}{3} \times A = \text{volume}$$

We run into difficulty, however, when we attempt to ascertain areas and volumes bounded by curved lines or surfaces. This problem could be most serious for the shipbuilder; for very few of the areas and volumes with which we have to deal in shipbuilding are regular in shape, and as a consequence the simple and exact mathematical formulas are of little value to us. Fortunately, there are several mathematical rules, or "tricks" if you will, that enable us to ascertain by simple arithmetical means the approximate area or volume of almost any figure.

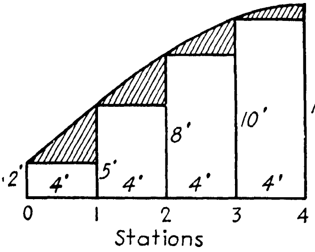

FIG. 131.—The shaded area is lost by using this method.

One method (not particularly accurate and used here merely for illustration) for finding the approximate area of a curved steel plate is to divide the area into small rectangles, find the area of each rectangle, and add these values together to obtain the area of the whole plate. Consider the steel plate shown in Fig. 131. We could measure the length of this plate and then lay off spots

4 ft. apart and measure the width of the plate at each spot, these being designated as stations 0, 1, 2, 3, and 4. Using the ordinate measurements shown in the figure, we should obtain

Station	L, ft.		H, ft.		Area, sq. ft.
0 to 1	2	×	4	=	8
1 to 2	5	×	4	=	20
2 to 3	8	×	4	=	32
3 to 4	10	×	4	=	40

Total of 4 rectangles = 100 sq. ft. = area of plate (nearly)

This answer would not even be close to the correct answer, for we did not obtain in our total the area shown shaded in the figure; and this method, therefore, is of little value. We could obtain a more nearly correct answer by taking measurements halfway between our ordinates and considering the parts so measured as trapezoids rather than rectangles. This is the idea behind the trapezoidal rule.

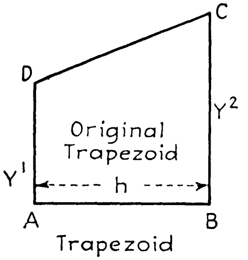

FIG. 132*A*.

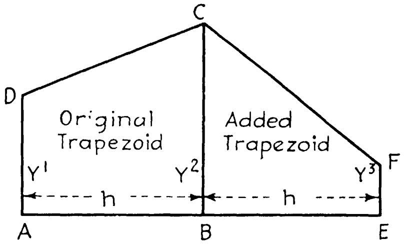

FIG. 132*B*.

THE TRAPEZOIDAL RULE

A trapezoid is a figure formed of four straight lines, two of which are parallel. Consider Fig. 132*A*. If the lengths of the parallel sides *AD* and *BC* are Y_1 and Y_2, respectively, and h is the distance between them, the area of this trapezoid is given by

$$\tfrac{1}{2}(y_1 + y_2)h$$

or one-half the sum of the parallel sides multiplied by the distance between them.

If we now add another trapezoid beside the first one, we should have a figure such as that shown in Fig. 132*B*.

The area of the original trapezoid was given by

$$\text{Area} = \tfrac{1}{2}(y_1 + y_2)h$$

The area of the added trapezoid would be

$$\text{Area} = \tfrac{1}{2}(y_2 + y_3)h$$

The area of the whole figure would be simply an addition of the two areas.

$$\text{Area of both} = \tfrac{1}{2}(y_1 + y_2)h + \tfrac{1}{2}(y_2 + y_3)h$$

Or simplifying and rearranging we should have

$$\text{Area of both} = h(\tfrac{1}{2}y_1 + y_2 + \tfrac{1}{2}y_3)$$

If we then added another trapezoid of the same width, the total area of the three would become

$$\text{Total area} = h(\tfrac{1}{2}y_1 + y_2 + y_3 + \tfrac{1}{2}y_4)$$

This could be continued indefinitely.

We can put this rule into words as follows: To find the area under a curve by the trapezoidal rule, divide the base into *any* number of *equal* parts, and erect perpendiculars from the base to the curve at these points. Then determine the lengths of these perpendiculars, or ordinates, and to half the sum of the first ordinate and the last ordinate add the sum of the intermediate ordinates; multiply this result by the common distance between them (which is h in this case), and the result will be the required area.

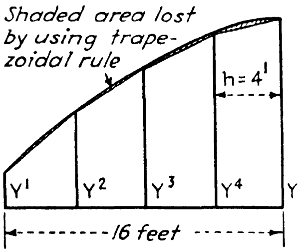

FIG. 133.—The trapezoidal rule applied to a curved plate.

As the curved plate illustrated in Fig. 131 and again in Fig. 133 is very nearly a series of trapezoids, let us solve for the area of this plate using the trapezoidal rule.

Substituting the above measured (page 152) ordinate values in the trapezoidal-rule equation,

$$\left(\frac{y_1 + y_5}{2} + y_2 + y_3 + y_4\right)h = \text{area}$$

we should obtain

$$\left(\frac{2\text{ ft.} + 11\text{ ft.}}{2} + 5\text{ ft.} + 8\text{ ft.} + 10\text{ ft.}\right) \times 4\text{ ft.} = 118\text{ sq. ft.}$$

Comparing this area with the one obtained by adding rectangles (page 153) we can see that our accuracy has increased considerably, for we have added in the triangular-shaped tops of the rectangles, thus obtaining 18 sq. ft. more. However, this is not yet the correct answer, for these top portions are not true triangles inasmuch as one side of the triangle is a curved line.

We can reduce this error by increasing the number of ordinates. It is conceivable that if we used an infinite number of ordinates the answer would be correct.

There is however, another "rule" for finding areas and volumes that is more accurate and that is therefore used to a greater extent than the trapezoidal rule.

SIMPSON'S FIRST RULE

Simpson's rule is of British origin and is extensively used by naval architects of all nations. It is based on the assumption that all curves for which it is to be used are parabolas of the second order, *i.e.*, parabolas whose equation when referred to the coordinate axes is of the form $y = a_0 + a_1x + a_2x^2$, the constants being a_0, a_1, and a_2. This assumption gives excellent results in our work, for most ship curves do approach parabolas of the second order. The answers given by this rule are of course not exact unless the figure we are calculating is bounded by a curve that is a parabola of the second order; however, the answer is sufficiently accurate for all practical purposes.

We shall not attempt to prove this rule mathematically, for the mathematics involved lies beyond the scope of this work. (For a mathematical proof see Attwood and Pengelly's "Theoretical Naval Architecture," Appendix A, page 452.[1]) We can, however, solve some simple regular figures by use of the rule and then solve the same figure by the simple exact formula and compare the answers. This process will illustrate the method and give us more faith in the answers obtained when we apply Simpson's rule to more complicated areas and volumes.

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[1] Longmans, Green and Company, New York.

To make use of Simpson's rule we must divide the length of the figure into any *even* number of intervals that will give us an *odd* number of ordinates. (This differs from the trapezoidal rule, which permits us to use either an even or an odd number of ordinates.) The next step is to multiply the length of each ordinate by a series of numbers known as *Simpson's multipliers.* The sum of the products of this multiplication, called *functions* and designated by *f*, is then multiplied by one-third the common interval (distance between ordinates). The result is the area.

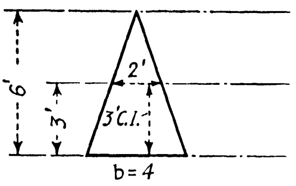
Simpson's multipliers are very simple to remember if we keep their sequence in mind. Set up in tabular form are the multipliers to be used with 3, 5, 7, 9, 11, and 13 ordinates. Of course any *odd* number of ordinates may be used, the correctness of the answer usually increasing with an increase in the number of ordinates. It will be noted that the multipliers always start with 1; the next number is always 4; and they will always end with 4-1. Furthermore it will be noted that we can continue the multipliers indefinitely by simply inserting 2's between consecutive 4's.

NUMBER OF ORDINATES USED AND THE CORRECT MULTIPLIER TO USE WITH ITS CORRESPONDING ORDINATE

Number of ordinates used	Ordinate number												
	1	2	3	4	5	6	7	8	9	10	11	12	13
	Corresponding multiplier												
3	1	4	1										
5	1	4	2	4	1								
7	1	4	2	4	2	4	1						
9	1	4	2	4	2	4	2	4	1				
11	1	4	2	4	2	4	2	4	2	4	1		
13	1	4	2	4	2	4	2	4	2	4	2	4	1

To illustrate the rule and the multipliers, consider the triangle in Fig. 134. As we are using three ordinates, the multipliers will be 1-4-1. As the triangle is 6 ft. high, the common interval between the spaces will be 3 ft.

Multiplying the length of the ordinates by Simpson's multipliers and adding the results gives us a total of 12. Multiplying this sum first by $\frac{1}{3}$ and then by the distance between stations, of the common interval (C.I.), gives us 12 sq. ft. for the area of the triangle. It will be noted in Fig. 134 that the arithmetical formula for the area of a triangle gives the same result.



L	×	S.M.	=	Functions (f)
0'	×	1	=	0
2'	×	4	=	8
4'	×	1	=	4
		Sum of f	=	12

FIG. 134.

By Simpson's rule:

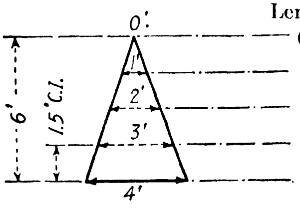
$$\tfrac{1}{3} \times \text{C.I.} \times \text{sum (f)} = \text{area}$$
$$\tfrac{1}{3} \times 3 \text{ ft.} \times 12 = 12 \text{ sq. ft.}$$

By arithmetical methods:

$$\text{Area of triangle} = \frac{b}{2} \times d = \frac{4 \text{ ft.}}{2} \times 6 \text{ ft.} = 12 \text{ sq. ft.}$$

To illustrate how the multipliers can change without changing the answer, we shall recalculate the area of the same triangle, using five instead of three ordinates. (Notice that there must be—and still are in our case—an odd number of ordinates.)

It will be noted in Fig. 135 that although the number of multipliers has increased, the answer remains the same because the common interval decreases with the increase in the number of ordinates used.



Length	×	S.M.	=	Function (f)
0'	×	1	=	0
1'	×	4	=	4
2'	×	2	=	4
3'	×	4	=	12
4'	×	1	=	4
		Sum of f	=	24

FIG. 135.

$$\tfrac{1}{3} \times \text{C.I.} \times \text{sum (f)} = \text{area}$$
$$\tfrac{1}{3} \times 1.5 \text{ ft.} \times 24 = 12 \text{ sq. ft. (as in Fig. 134)}$$

Let us now apply this rule to finding the weight of a steel plate $\frac{1}{2}$ in. thick and of the shape indicated in Fig. 136. It should be noted that this is the same plate shown in Figs. 131 and 133, and therefore the answers should be somewhat alike. The answer given by Simpson's rule will be closer to the correct answer, for reasons heretofore mentioned, than the answers given by the two previous methods.

In working with Simpson's rule it is best to arrange the work in a tabulated form as below.

Station	Widths	Simpson's multiplier	Function
0	2	1	2
1	5	4	20
2	8	2	16
3	10	4	40
4	11	1	11
Sum of functions. .	. .	. .	89

$$\tfrac{1}{3} \times \text{C.I.} \times \text{sum of function} = \text{area}$$

$$\tfrac{1}{3} \times 4 \times 89 = 118.67 \text{ sq. ft. area of plate}$$

Using the trapezoidal rule on this same plate gave us 118 sq. ft. The gain in area of 0.67 sq. ft. is due to the fact that Simpson's rule considered the curve to be a parabola of the second order while the trapezoidal rule considered it to be a straight line between ordinates. Had the curve been bending upward instead of downward, the area given by Simpson's rule would have been less than that given by the trapezoidal rule, but the answer still would have been more accurate.

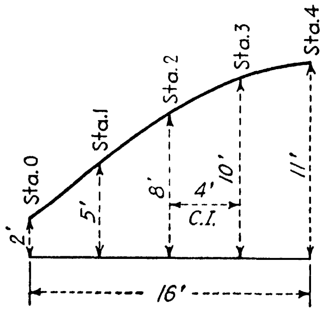


Fig. 136.—Measurements taken on a steel plate at equal intervals. Plate thickness = ½ in.

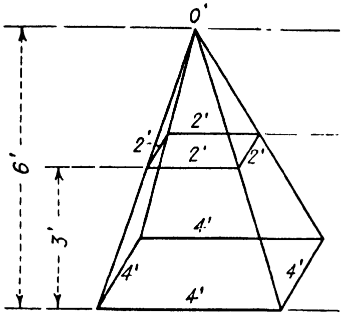
We now have the area of the plate, and we wish to know its weight. A square foot of steel 1 in. thick weighs 40.8 lb. as noted on page 30. As our plate is ½ in. thick, the weight will be 20.4 lb. per sq. ft., and the entire plate will weigh

118.67 sq. ft. × 20.4 lb. per sq. ft. = 2,421 lb. nearly

THE DISPLACEMENT CALCULATION

We have heretofore applied Simpson's rule only to areas. We shall now apply it to determining the volume of a simple geometric figure and then to finding displacement volume, or weight, of a ship.

Consider the pyramid shown in Fig. 137. In this case, instead of multiplying distances directly by Simpson's multipliers, we multiply areas. Distances in feet when multiplied by feet give areas in square feet, and areas in square feet when multiplied by feet give volumes in cubic feet. To clarify this, we shall solve for the areas through the pyramid at stations 0, 1, and 2 and plot the points on a sheet of graph paper, obtaining the curve shown in Fig. 138. After we plot the curve, it will be apparent that we are then simply performing the same operation as when we obtained the area of the steel plate; *i.e.*, we are finding the area under a curve. It should be noted that, in this case, we are finding the area under an area curve, which is already in square feet, and therefore the answer will be a volume, which will be in cubic feet (see Figs. 137 and 138).



Sta.	Area sq. ft.	S.M.	f
0	0	× 1	= 0
1	4	× 4	= 16
2	16	× 1	= 16
		Sum of f	= 32

FIG. 137.

Volume is by Simpson's rule:

$$\tfrac{1}{3} \times \text{C.I.} \times \text{sum of } (f) = \text{volume}$$
$$\tfrac{1}{3} \times 3 \text{ ft.} \times 32 = 32 \text{ cu. ft.}$$

By arithmetical means:

$$\text{Volume of pyramid} = \frac{\text{area of base}}{3} \times \text{altitude} = \frac{16 \text{ sq. ft.}}{3} \times 6 \text{ ft.} = 32 \text{ cu. ft.}$$

In this case Simpson's rule gives the exact answer.

The answers given by Simpson's rule and the arithmetical exact formula are, in this case, identical. It should be borne in mind, however, that Simpson's rule is exact only when the boundary curve is a parabola of the second order.

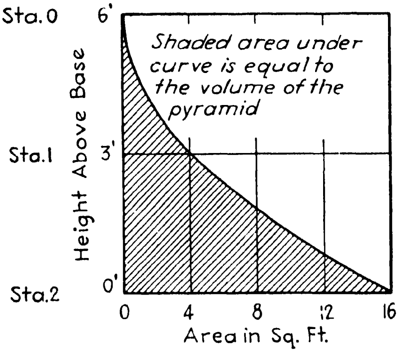


FIG. 138.—Curve of sectional areas for the pyramid shown in Fig. 137.

In Fig. 139 we have an isometric drawing of the profile of a ship. If we obtain the area of each section through the ship up to the water-line plane (this can be done by Simpson's rule, for the areas are bounded by curved lines) and plot these areas at their respective stations on a piece of graph paper, we should obtain the sectional-area curve shown in Fig. 140. We are again simply finding the area under an area curve, and in this case, as previously, we shall obtain a volume.

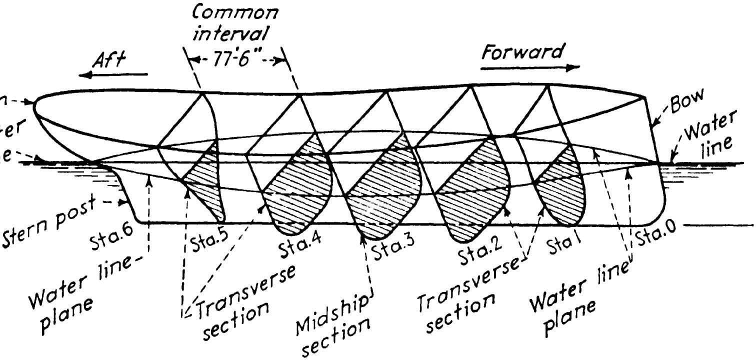


FIG. 139.—Transverse sections below the water line are shown as shaded areas. The area of the shaded portions when plotted as shown in Fig. 140 gives the sectional area curve for the ship.

This curve will give the area up to the water line of any section along the length of the ship. The area under this

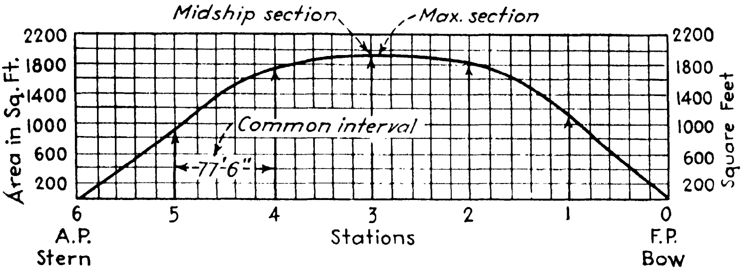


FIG. 140.—Section-area curve. The area of any section through the vessel from the keel to the water line may be read from this curve. The area under this area curve is equal to the volume of water displaced by the ship when floating at the draught for which this curve was plotted. The area under the curve is easily found by the use of Simpson's rule.

curve will be the volume of the ship below the water-line plane. Arranging the work as on page 158 we have the following:

Station	Area	Simpson's multiplier	Functions of the area
0	0	1	0
1	1,041	4	4,164
2	1,801	2	3,602
3	1,859	4	7,436
4	1,751	2	3,502
5	924	4	3,696
6	0	1	0
Sum of f.........	.....	..	22,400

$$\tfrac{1}{3} \times \text{C.I.} \times \text{sum of } f(A) = \text{volume of underwater portion of ship}$$

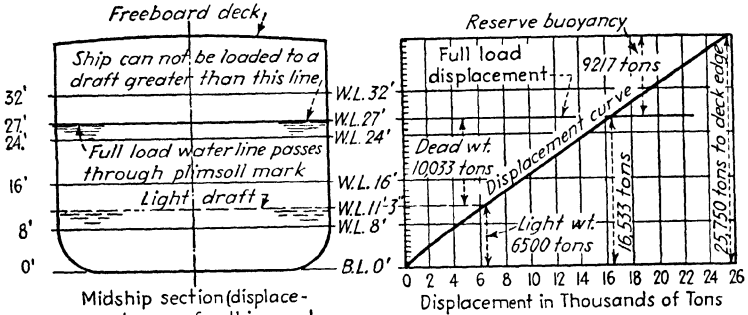
$$\tfrac{1}{3} \times 77.5 \text{ ft.} \times 22{,}400 = 578{,}659 \text{ cu. ft}$$

We remember from our high-school physics that any object floating in water is displacing an amount of water equal to its own weight. One cubic foot of salt water weighs 64 lb. very nearly; therefore, in one ton (2,240 lb.) of salt water we should have $\frac{2{,}240}{64} = 35$ cu. ft.

Our ship is displacing 578,659 cu. ft. of salt water; so the weight of salt water that she is displacing would be $\frac{578{,}659}{35} = 16{,}533$

tons. As the weight of water she displaces is equal to the weight of the ship, the ship must weigh 16,533 tons when fully loaded.

In actual practice, we calculate the displacement of the ship at several water lines and plot the result on a sheet of graph paper (see Fig. 141). We can then read off the displacement at any intermediate water line from the graph. In other words, to determine the weight of a vessel at a particular draught, we read her draught marks and obtain an average of the bow and stern draughts. Then we use this average draught to enter the displacement curve and read the corresponding weight of water she is displacing, which will, of course, equal the weight of the ship.



Midship section (displacement curve for this vessel shown at right)

Displacement curve
The tons of displaced water (weight of vessel) may be read from this curve if the draft is known

FIG. 141.—A typical displacement curve.

Conversely, if we know the weight of a ship before launching, it is a very simple matter to look on the displacement curve and read the corresponding draught. The draught corresponding to the displacement will be the water line at which she will float. (Actually, the displacement curve is calculated with the vessel on an even keel and at zero trim If the vessel is not on an even keel or is out of trim, the displacement will not be exactly the amount read from the curve and will have to be corrected. (To make this correction, which is usually small, see any standard work on naval architecture.)

It will be noted from Fig. 141 that the light draught of the ship is 11 ft. 3 in. and that the corresponding weight is 6,500 tons. This is known as the *light weight* of the vessel, *i.e.*, the weight of the vessel with no fuel, water, passengers, crew, baggage, mail, stores, or cargo aboard. These last items make up the difference in weight between the light weight of the vessel and the total displacement and are called *deadweight items.* The weight of the deadweight items that can be carried is known as the *deadweight carrying capacity* of the ship. The deadweight carrying ability of a ship is vitally important to the owner, for it is from this that he receives his revenue and profits.

Problems

1. Why are the trapezoidal and Simpson's rules of such importance to the shipbuilder?

2. Which of the above rules is most accurate for ship calculations?

3. Using the trapezoidal rule, calculate the area of the following plate. The five ordinates are spaced 4 ft. apart. Ordinate lengths are as follows:

0 = 3 ft., 1 = 4.75 ft., 2 = 6 ft., 3 = 8 ft., 4 = 5 ft.

4. Calculate the area of the plate in Prob. 3, using Simpson's first rule.

5. What would be the weight of the plate in Prob. 3 if it were ¾ in. thick?

6. What is the relation between the displacement of a vessel and its weight?

7. What is meant by the term "deadweight"?

8. How could you determine the water line at which a vessel will float before the vessel is launched?

9. What does the area under an area curve represent?

CHAPTER XVI

STABILITY, TRIM, THE INCLINING EXPERIMENT, AND DAMAGE CONTROL

STABILITY

Stability is the tendency of a ship to return to its original position when inclined from that position by external or other forces.

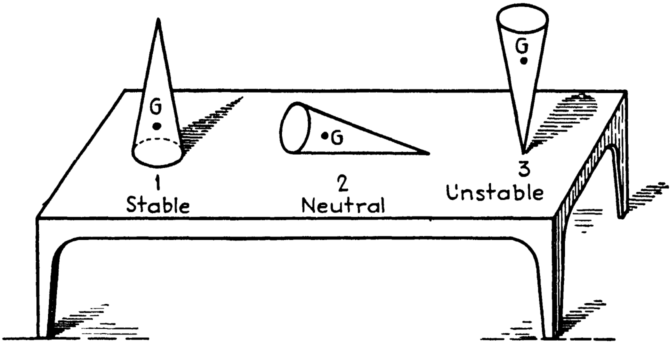


FIG. 142.—The three types of stability.

There are three types of stability. These may be illustrated by discussing the stability of a cone resting on a table. Such a cone is said to be

1. *Stable* when resting on its base. If a force is applied to the cone, tilting it slightly, the center of gravity of the cone is raised relative to the surface of the table. (The center of gravity of any object is a point at which we may consider its entire weight to be concentrated, or the point at which the object would balance.) If the force is removed, the cone will come to rest in its original position.

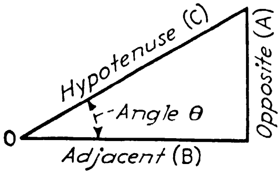
2. *Neutral* when resting on its side. If a force is applied to the cone when resting on its side, the center of gravity is neither raised nor lowered. If the force is removed, the cone will roll until friction overcomes the force applied and it will have no tendency to return to its original position.

3. *Unstable* if balanced on its apex. Even a slight touch will cause a cone in this condition to capsize, owing to a lowering of its center of gravity. The movement of the cone will be out of proportion to the force applied.

A vessel can have neutral stability and remain upright. A vessel with negative stability, or in the unstable condition upright, will not necessarily capsize, for she may become stable when she heels even slightly, as will be discussed later. It should be further noted that a vessel floating bottom side up may be perfectly stable in that condition. In all the following discussion on stability, however, we are referring to the stability of the vessel in the upright or nearly upright condition. The stability that tends to return the vessel to the upright condition when heeled away from that position will be referred to as *positive stability*. It should be noted that off-center weights can cause a vessel to list; therefore, a list to one side or the other does not always indicate negative stability.

SOME ELEMENTARY TRIGONOMETRY

Two expressions, or terms, used in trigonometry, the sine and tangent, are used in investigating the stability of a ship. As some students may not have studied trigonometry, we shall discuss these two terms briefly.



$$\text{Sine} = \frac{\text{Opposite}}{\text{Hypotenuse}} = \frac{A}{C}$$

$$\text{Tan} = \frac{\text{Opposite}}{\text{Adjacent}} = \frac{A}{B}$$

FIG. 143.

Figure 143 shows a right-angle triangle, *i.e.*, a triangle one angle of which is 90 deg.

The sine and the tangent are simply ratios between the sides of the triangle. To illustrate this, consider Fig. 144. If the angle is kept constant and the hypotenuse is made longer by the length xy, then

$$\frac{\text{Hypotenuse}}{\text{Opposite side}} \propto \frac{\text{hypotenuse} + xy}{\text{opposite side} + yw} \qquad (\propto \;=\; \text{proportional to})$$

The proportion between the sides of the triangle has not changed with an increase in the size of the triangle. We can change these proportions, or ratios, only by increasing or decreasing the angle; *i.e.*, the sine and the tangent are a function of the number of degrees in the angle. If we know the sine or the tangent we can find the angle, or if we know the angle we can obtain the sine or the tangent.

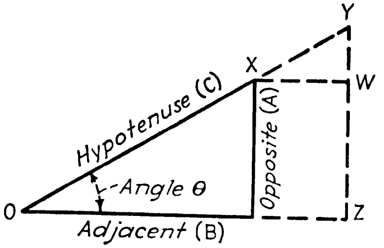


FIG. 144.

Figure 145 shows these relationships worked out for a 30-deg. and a 60-deg. triangle. These values will change with a change in angle. The values for any angle may be obtained from a table of trigonometric functions found in any trigonometry book. If we know the sine or tangent and the length of one side, we can find the length of the other two sides. These relationships are invaluable in stability work, surveying, gunnery, etc. The relationships, or equations, that we shall use are listed below (see Fig. 145).

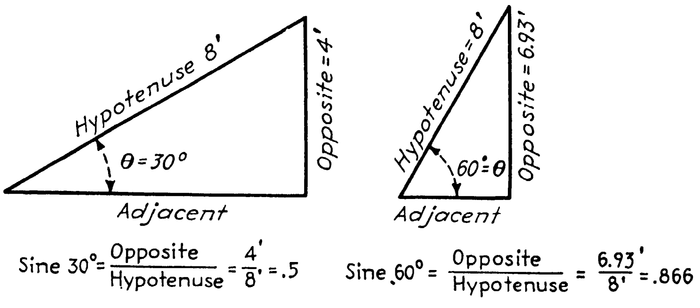


FIG. 145.

$$\sin\theta = \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{A}{C}, \qquad A = C\sin\theta$$

$$C = \frac{A}{\sin \theta}$$

$$\tan \theta = \frac{\text{opposite side}}{\text{adjacent side}} = \frac{A}{B} \qquad A = B \tan \theta$$

$$B = \frac{A}{\tan \theta}$$

Note in the table below that for small angles the values of the sine and tangent are very nearly the same. This is fortunate, for we can use them interchangeably without serious error, up to an angle of about 6 deg.

Angle, Deg.	$\sin \theta$	$\tan \theta$
2	0.0349	0.0349
6	0.0697	0.0699

EQUILIBRIUM

A vessel to remain at rest and afloat in still water must fulfill two conditions.

1. The weight of the vessel and everything on board must equal the weight of the water displaced by the hull.
2. The center of gravity of the ship and everything on board must be directly in a vertical line with the center of gravity of the displaced water.

DISPLACEMENT

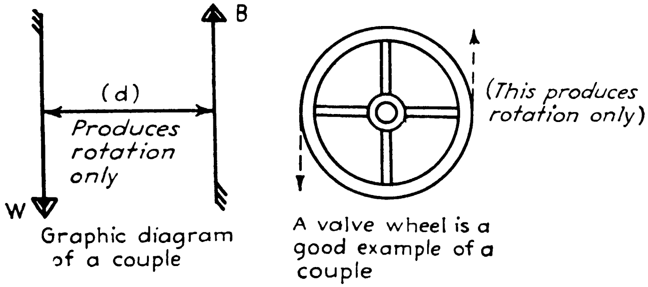
To understand what is meant by displaced water and the center of gravity of the displaced water (center of buoyancy), assume that we have a ship floating in still water and that we are able to freeze the water around the ship and remove the ship from the ice. A hole is left in the ice that is the exact shape of the ship. If we weigh the ship and then pour into the hole a weight of water equal to the weight of the ship, the hole will be filled exactly level with the top of the ice. The weight of this water is equal to the weight of water displaced by the ship, and the center of gravity of the displaced water is known as the *center of buoyancy*.

THE COUPLE

The weight of the vessel acts downward at its center of gravity, and the pressure resulting from the displacement of the water acts upward at the center of buoyancy (center of gravity of the displaced water) to form two equal and opposite forces.

As long as these two forces are equal and in a vertical line, the vessel is in equilibrium. When they move out of a vertical line, a *couple* is formed This couple may be either a righting or an upsetting couple.

Two parallel forces that are opposite in direction and equal in amount and with different lines of action constitute a couple, as *WB* (Fig. 146). The perpendicular distance between them, *d*, is known as the *arm of the couple.* The product of either force (the two forces being equal) times the arm is known as the *moment of the couple* (see page 10 as a memory refresher).



Graphic diagram of a couple

A valve wheel is a good example of a couple

FIG. 146.—The couple.

$$Wd = Bd = \text{moment of couple}$$

From this formula it is obvious that the moment of the couple may be increased by increasing either *B*, and *W*, or *d*.

STATICAL STABILITY

Figure 147 shows a ship on even keel floating in still water. Point *G* is the center of gravity of the ship, and point *B* is the center of buoyancy.

As the center of gravity is over the center of buoyancy and as the weight of the vessel equals the weight of the water displaced by the vessel, the vessel is in equilibrium and at rest.

In Figure 148, the vessel has been heeled to an exaggerated degree by some momentary external force, and the vessel is tending to return to the upright position after this force has been removed. A study of this figure shows why it returns to the upright. The following is an analysis of the righting process:

1. G has not moved. This is to be expected unless some weights in the ship have shifted or fallen overboard.

2. B has moved outboard along the arc of a circle whose center is at the intersection of a vertical line through B and the center line of the vessel. This point of intersection is designated as M. B becomes B' in its new position.

3. M is known as the *metacenter*. The Greek word *meta* means "above"; "metacenter" means "above the center" of buoyancy.

4. The distance from G to M is known as GM, or the *metacentric height*, and is a measure of the vessel's stability in the upright or nearly upright condition.

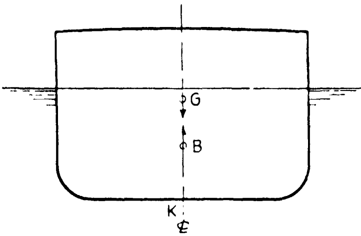


FIG. 147. Ship at rest.

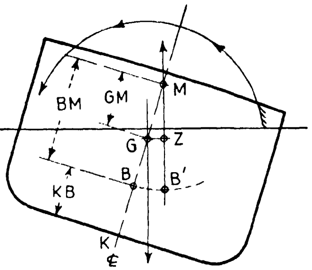


FIG. 148.—The couple (weight × GZ) is tending to right the vessel.

5. The distance from B to M is known as BM. This height is found by the equation $BM = \frac{I}{V}$, which will be discussed more fully on page 178.

6. K denotes the keel, and KB the distance from the keel to the center of buoyancy.

7. A new letter, Z, has been added. This is a point opposite G, and the line GZ is parallel to the water line.

8. A little study will make it evident that G acting downward and B acting upward will form a couple whose arm is GZ. The moment of this couple will depend on the weight of the vessel and the distance GZ.

9. The couple formed is tending to return the vessel to the upright. When the vessel is back in the upright condition, the arm of the couple, GZ, becomes zero, as in Fig. 147, the righting moment becomes zero, and the vessel will remain at rest in that position.

Figure 149 shows sections through four vessels. The first two have the same beam (and the same KM) but different vertical CG's and the last two have the same vertical CG's but different beams.

These sketches illustrate the relation of stability to GM.

1. If M is above G, the ship has positive stability.
2. If M is at G, the ship has neutral stability.
3. If M is below G, the ship has negative stability.

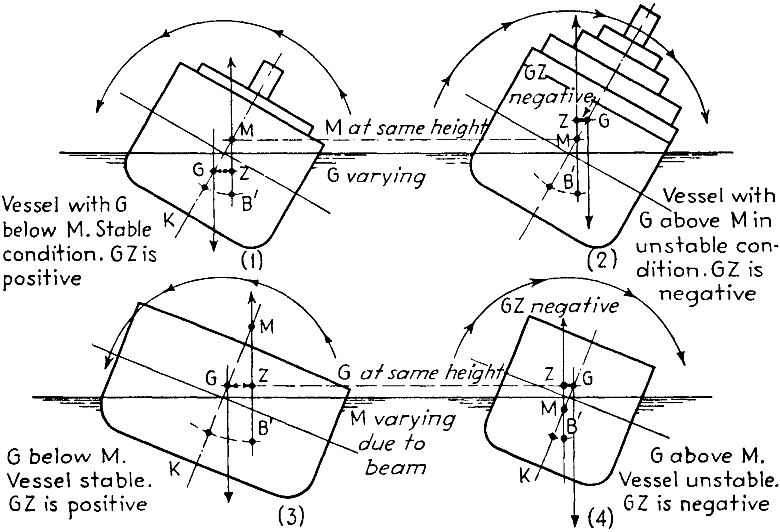


FIG. 149.—The effect of varying the height of G and M.

Figure 150 shows a cross section of a ship to a large scale and illustrates he use of the tangent of the angle of inclination (heel) to obtain GZ, the arm of the couple.

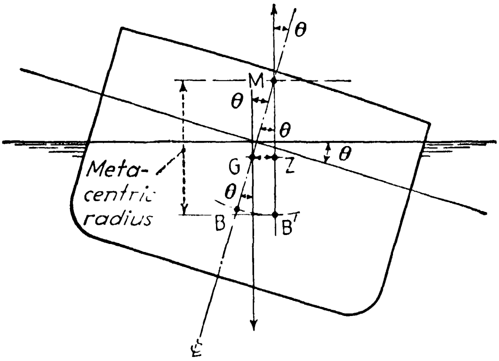
GZ is the opposite side of the triangle of which GM forms the hypotenuse and ZM the adjacent side. If we know the angle of heel, θ, and GM, we can find GZ, which is the righting lever, by the equation

$$GZ = GM \sin \theta$$

Tangent θ is easier to measure on a ship than sin θ; and as the tangent and the sin are very nearly the same at small angles we may substitute tan θ for sin θ and our GZ equation becomes

$$GZ = GM \tan \theta$$

Problem: Assume that the GM of the vessel shown in Fig. 106 was 4 ft. and that she was heeled to an angle of 2 deg. What is the value of GZ?



In triangle GMZ
GM = Hypotenuse; GZ = Opposite; ZM = Adjacent;
θ = Angle of inclination. ∴ $\sin\theta = \frac{GZ}{GM}$
and rearranging $GZ = GM \times \sin\theta$, and for small angles; $GZ = GM \times \tan\theta$ (approx.)

FIG. 150.—The relation of GZ to GM at small angles.

Solution: The value of the tangent of 2 deg. (from page 167) is 0.0349. Substituting in the equation

$$GZ = GM \tan\theta$$

we have

$$GZ = 4 \text{ ft.} \times 0.0349 = 0.1396 \text{ ft.}$$

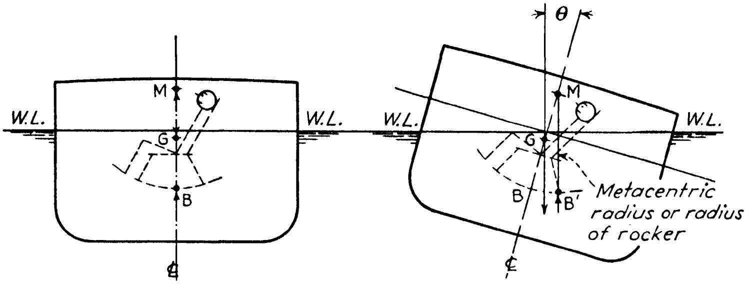
To find the moment tending to right the ship we multiply the arm of the couple, GZ, by the weight of the vessel. Assume this weight to be 10,000 tons, then,

$$\text{Moment of statical stability} = W \times GM \sin\theta = W \times GZ$$
$$= 10{,}000 \text{ tons} \times 0.1396 \text{ ft.} = 1396 \text{ ft.-tons}$$

ROCKING-CHAIR ANALOGY

The rocking-chair analogy is the basis of an interesting experiment relating to the stability of a ship that any student may perform at home.

Figure 151 shows the three points *B*, *G*, and *M* sketched in the section of a ship and also these same three points sketched in corresponding positions on a rocking chair.

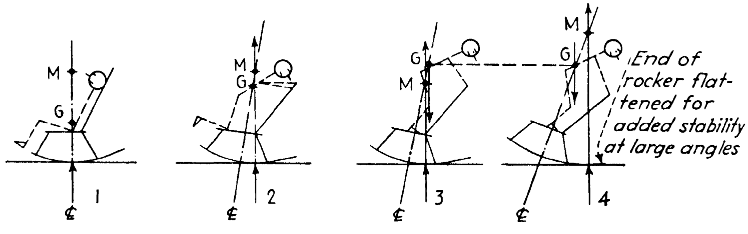


M is at the center of curvature of rocker. B moves along a curve whose center is at M

Ship and chair at a slight angle

FIG. 151.—A rocking chair and occupant superposed on a midship section of a ship to illustrate the similarity between the stability of a ship and a rocking chair.

The center of support for the rocker is on the arc of the circle along which the center of buoyancy moves. The center of this circle is at *M*, which is the center of curvature of the rocker. The center of gravity *G* of the chair includes the person in the chair.



Fast quick roll due to large GM

Slow easy roll due to small GM

Chair capsizing due to G being above M (negative GM)

Flattened end of rocker causes M to rise rapidly and altho G remains the same as in sketch 3, GM becomes positive and averts a catastrophe

FIG. 152.—The rocking-chair analogy. The stability characteristics of a rocker are similar to the stability characteristics of a ship.

If the curvature of the rocker is constant, the height of *M* will remain constant. The height of *G*, which can be easily varied, will change *GM*. We can then note with each change in *GM* the corresponding change in the behavior of the chair (Fig. 152).

1. Sit in the chair in the normal way. The chair will rock back and forth at its normal rate (Fig. 152, sketch 1).

2. Put the knees in the chair and the hands on the back of the chair. This will cause G to rise, making GM smaller. The chair will have a long, easy, slow roll (Fig. 152, sketch 2).

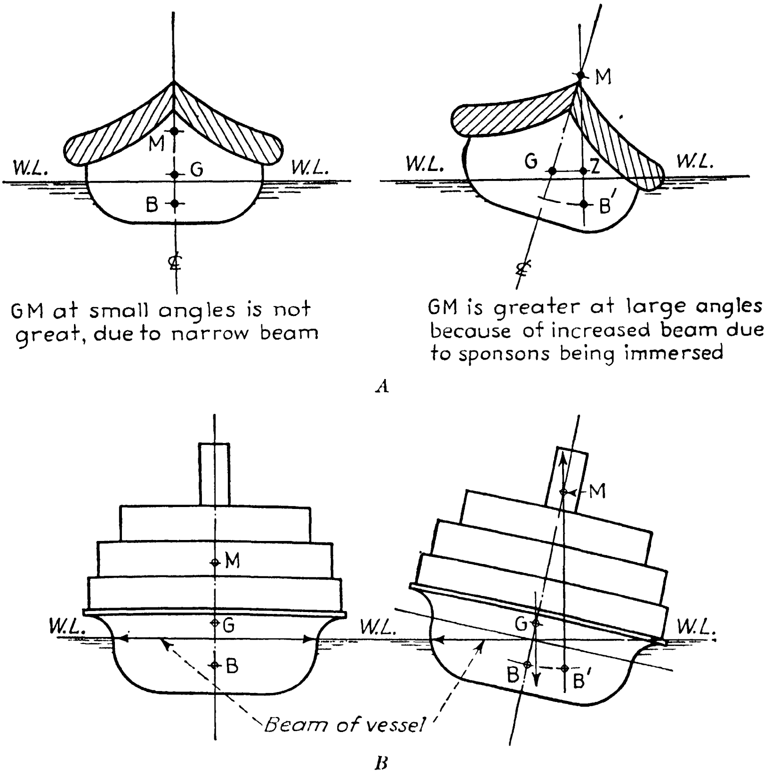


FIG. 153.—*A*, Sponsons on a canoe. *B*, sections through a Bay steamer. If the ship gets dangerously close to capsizing, the sponsons go into the water, increasing the beam of the vessel. This increase in beam raises M and thereby increases GM.

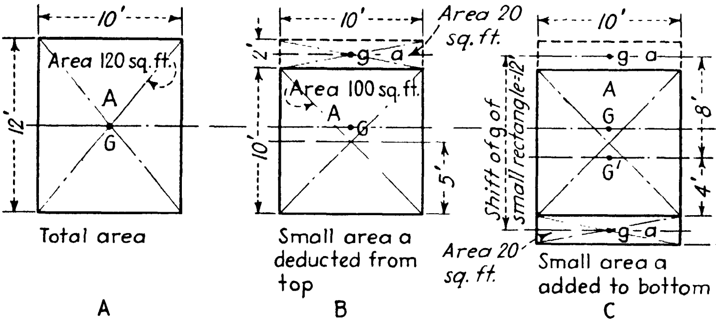
3. Now stand up in the chair, grasp the back of the chair with the hands, and start the chair rocking. G is now above M, and the chair will probably capsize (Fig. 152, sketch 3).

Figure 152, sketch 4, shows why rocking chairs have the rear ends of the rockers flattened. As M is at the center of curvature of the rocker, flattening the curvature causes M to rise, thus increasing the GM should the chair get dangerously close to capsizing. This same effect is produced by the sponsons on pleasure canoes and the wide flare on Chesapeake Bay steamers (Fig. 153).

THE INCLINING EXPERIMENT

To work out stability problems we must find *G*, the center of gravity of the vessel, and *M*, the metacenter.

When a ship is in the design stage the naval architect's staff works out the weights of the individual parts, or groups of parts, of the vessel and the center of gravity of each part. During the design of the *S.S. America* this was done very painstakingly, even the weights and centers of the pillows on the beds and the chairs in the staterooms being carefully estimated and included in the total weight and center of gravity of the whole ship.



Total area
A

Small area a deducted from top
B

Small area a added to bottom
C

FIG. 154.—Effect on center of gravity of shifting a portion of the figure.

When the ship is complete, or nearly so, it is usual to have an inclining experiment (sometimes called erroneously "rolling the ship"), which is a very simple method of locating exactly the vertical center of gravity of the vessel. Quite often the question is asked by men in the yard: How can you obtain the center of gravity of a ship by rolling a weight across the deck? The answer is obtained by simple arithmetic.

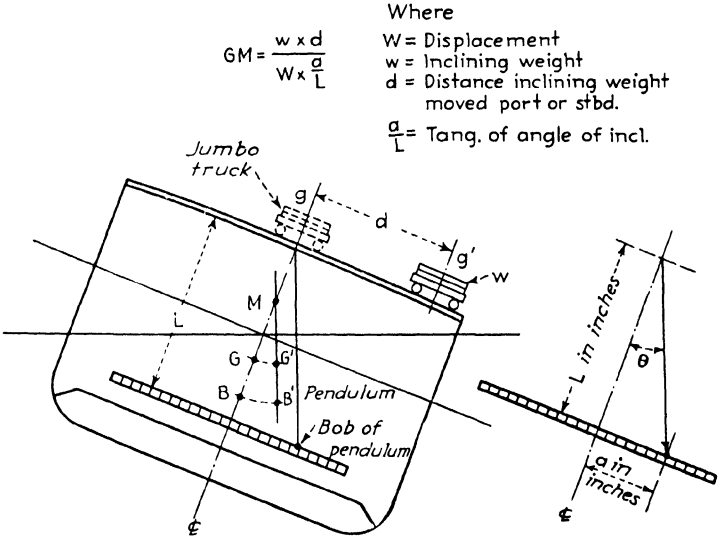
Shift of the C. G. of a Vessel Due to Shift of a Weight Already on Board. Consider the small rectangle in Fig. 154. In Fig. 154, sketch *A*, we have a rectangle 10 by 12 ft. or 120 sq. ft. in area. The center of gravity is, of course, 6 ft. above the base. In Fig. 154, sketch *B*, we have cut 2 ft. from the height of the rectangle, leaving an area of 100 sq. ft. with a center-of-gravity height of 5 ft. above the base. In Fig. 154, sketch *C*, we have added the 2-

by 10-ft. rectangle to the base of the original rectangle, giving us the original area of 120 sq. ft. with a center of gravity 4 ft. above the original base or 6 ft. above the new base. We shall work this mathematically and endeavor to derive an equation for what we have done.

First consider the following areas:

Area of small part = a = 10 ft. × 2 ft. = 20 sq. ft.

Area of original rectangle = A = 10 ft. × 12 ft. = 120 sq. ft.



Vessel Inclined to Small angle (greatly exaggerated in Sketch

Action of Pendulum

Tan $\theta = \frac{a}{L}$

FIG. 155.

It can be seen from Fig. 154, sketch C, that the center of gravity of the original rectangular area has dropped 2 ft. owing to shifting the small area from the top to the bottom. The center of gravity of the small rectangular area was shifted a total of 12 ft. Using the areas obtained above, we can now equate these results.

Original Rectangle		Small Rectangle
Area A × shift of CG (GG')	=	area a × shift of cg (gg')
120 sq. ft. × 2 ft.	=	20 sq. ft. × 12 ft.
240	=	240

or algebraically,

$$A \times GG' = a \times gg'$$

We can substitute weight W for area A and not disturb our equation. We should then have

$$W \times GG' = w \times gg'$$

Rearranging,

$$GG' = \frac{w \times gg'}{W}$$

To perform an inclining experiment we shift a weight, placed on a large jumbo truck, transversely across the deck of the vessel. Unless prevented by external forces the vessel will heel to such an angle that the center of gravity of the weight shifted in combination with that of the vessel will be directly over the center of buoyancy of the ship. Figure 155 shows a ship in this condition. The angle of inclination is small, being about 1 deg. (The angle is greatly exaggerated in the sketch.)

If we call the angle of inclination to the upright θ and GM the metacentric height, then, for small angles where the values of the sine and the tangent are very nearly equal,

$$\tan \theta = \frac{GG'}{GM}$$

or

$$GG' = GM \tan \theta$$

Substituting this value for GG' in the formula from the top of this page we should have

$$GG' = \frac{w \times gg'}{W}$$

$$GM \tan \theta = \frac{w \times gg'}{W}$$

or

$$GM = \frac{w \times gg'}{W \times \tan \theta}$$

W is equal to the weight of the vessel. This can be obtained by reading the draught marks and reading the corresponding displacement from the displacement curve. (Refer to Chap.

XV, page 162, for a memory refresher.) Therefore, W is known. Likewise, w is the inclining weight and truck, which is weighed before being placed on the ship. Therefore, w is known.

gg' is the distance the inclining weight is moved. This can be measured with a tape and so is known.

The only thing we do not know is the angle the ship inclines when the weight is moved. This is usually determined by hanging three pendulums down convenient hatchways and measuring the distance that the plumb bob moves when the weight is shifted. The pendulums should be 20 ft. or longer so that the reading will be reasonably accurate.

If we know the length of the pendulum and the distance it swings, it is easy to obtain the tangent of the angle, for

$$\tan \theta = \frac{\text{distance pendulum swings}}{\text{length of pendulum}} = \frac{a}{L}$$

The tangent can be measured directly from the ship by measuring the pendulum length and the distance it moves. This is the reason why $\tan \theta$ was substituted for $\sin \theta$ in the equation $GZ = GM \sin \theta$.

We can now write our formula in its final form.

$$GM = \frac{w \times d}{W \times \frac{a}{L}}$$

Note that for convenience we have substituted d for gg' and $\frac{a}{L}$ for $\tan \theta$.

To illustrate the above we shall work through the data obtained from the inclining experiment on the *S.S. Coamo,* which was built at Newport News.

INCLINING EXPERIMENT

Name of vessel = *SS. Coamo*
Vessel heading = due east
Wind = E × NE 4 miles
Draught of vessel (mean) = 18 ft. 3 in.
Corresponding salt-water displacement (from curves) = 6,197 tons

Density of James River water (from hydrometer) = 1.01735

$$\text{Correction to salt-water tons} = \frac{1.01735}{1.026} \times 6{,}197$$

$$= 6{,}143 \text{ tons actual}$$

Length of pendulum (middle) = 21 ft. 4¾ in. = 256.75 in.
Distance weight moved = 18.25 ft. from center line to port
Inclining weight including truck = 21.96 tons
Distance (a) middle pendulum moved to port = 7.71 in.

$$\text{Tangent of inclined angle} = \frac{a}{L} = \frac{7.71 \text{ in.}}{256.75 \text{ in.}} = 0.0300$$

$$GM = \frac{w \times d}{W \times \tan\theta} = \frac{21.96 \text{ tons} \times 18.25 \text{ ft.}}{6{,}143 \times 0.030} = 2.17 \text{ ft.}$$

The tabulation above has been considerably shortened and should not be taken as a model. Actually, three pendulums are used, the inclining weight is moved across the deck about nine times, and pendulum readings are taken after each movement. (For a complete description of an inclining experiment see any standard work on naval architecture.)

We have seen how we can find GM. This is not exactly what we were looking for; we wished to find G, the vertical center of gravity of the vessel. Knowing GM, we can find G if we know the height of M.

DETERMINING THE HEIGHT OF THE METACENTER

In order to find M, we must make use of a term not heretofore discussed, *viz.*, the *moment of inertia.* The moment of inertia of a plane area about any axis is the sum of the product of each elementary area times the square of the distance from the inertia axis. To discuss moment of inertia completely would require higher mathematics. Here we shall confine ourselves to a discussion of the moment of inertia of a rectangle. For a rectangle with the axis taken at the center line the equation would be

$$I = \frac{AB^2}{12}$$

where I = moment of inertia.
A = area of rectangle.
B = breadth of rectangle. See Fig. 156.

The moment of inertia I depends on the shape of a figure; therefore, different equations are used for calculating the moment of inertia of each figure. The moment of inertia of the water plane may be found by the proper use of Simpson's rule. We shall discuss only the moment of inertia I of a rectangle about its own center line, for this will amply illustrate the effect of beam on the stability of a ship (Fig. 156).

The equation $BM = \frac{I}{V}$ was given on page 169. BM is the distance from the center of buoyancy to the metacenter; I is the moment of inertia of the water plane; V is the volume of displacement of the vessel in cubic feet (Fig. 157).

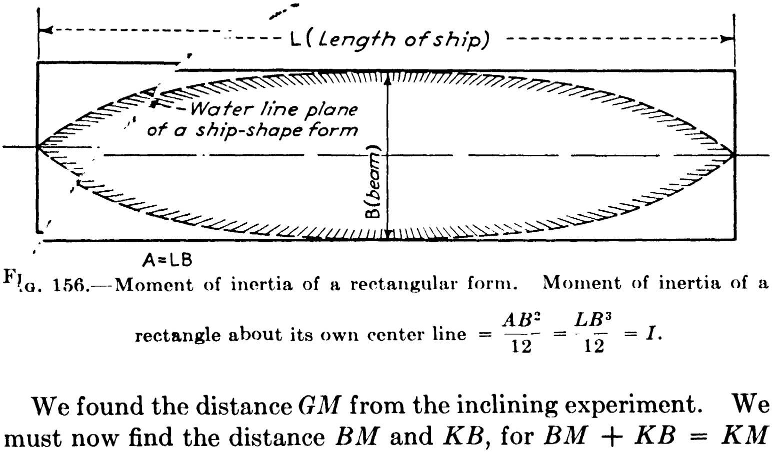


FIG. 156.—Moment of inertia of a rectangular form. Moment of inertia of a rectangle about its own center line $= \frac{AB^2}{12} = \frac{LB^3}{12} = I$.

We found the distance GM from the inclining experiment. We must now find the distance BM and KB, for $BM + KB = KM$ and $KM - GM = VCG$, which is the vertical center of gravity of the ship—exactly what we are looking for.

To illustrate the use of our BM formula we shall find the height of the metacenter of a rectangular barge with a rectangular midship section as in Fig. 158.

Problem: Calculate the height of M in the rectangular figure as sketched. GM is 3 ft. as determined by an inclining experiment. Find the vertical center of gravity.

Solution:

$$I \text{ of rectangle} = \frac{AB^2}{12} = \frac{100 \text{ ft.} \times 24 \text{ ft.} \times (24 \text{ ft.})^2}{12}$$

$$= \frac{2{,}400 \times 576}{12} = 115{,}200 \text{ ft.}^4$$

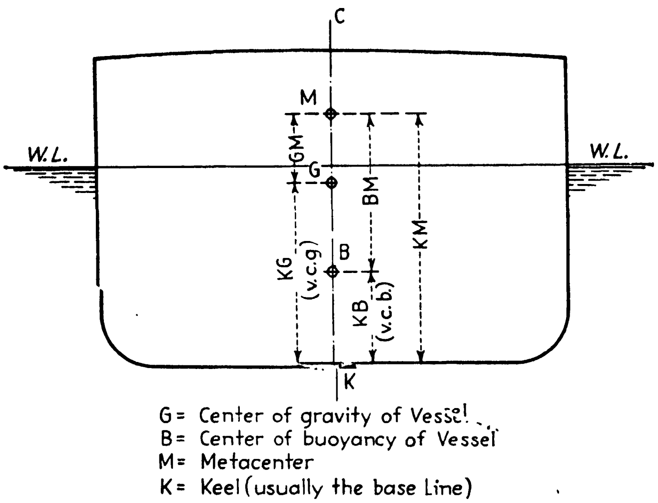


FIG. 157.—The relation between *BM*, *GM*, *KB*, and *KG*.

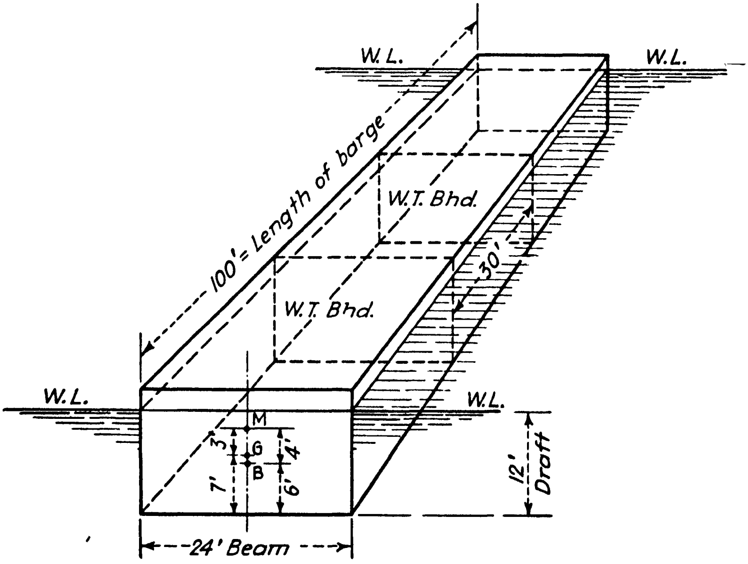


FIG. 158.—A rectangular barge.

Displacement of rectangular barge

$$= L \times b \times d = 100\text{ ft.} \times 24\text{ ft.} \times 12\text{ ft.} = 28{,}800\text{ cu. ft.}$$

$$BM = \frac{I}{V} = \frac{115{,}200\text{ ft.}^4}{28{,}800\text{ cu. ft.}} = 4\text{ ft.}$$

Height of center of buoyancy = ½ draught = 6 ft.

Then

$$\text{Height of } M = BM + KB = 10\text{ ft.} = KM$$

If the *GM* of this barge, as determined by an inclining experiment, was 3 ft., then

$$VCG = KM - GM = 10\text{ ft.} - 3\text{ ft.} = 7\text{ ft. above base line}$$

IMPORTANCE OF *GM*

It is important that we know the center of gravity of a ship, for the behavior of a ship at sea depends upon the value of *GM*. The point *M* changes somewhat as the vessel increases or decreases draught, but the point *G* can be made to vary widely by changing the cargo-weight distribution. A change in either *G* or *M* varies *GM*. The value of *GM* for ordinary merchant ships should be about 5 per cent of the beam. If this value of $0.05B$ is greatly exceeded, the ship will become so stiff that if it is thrown over by a wave it will come back to the upright with a jerk. This jerky motion is very uncomfortable for the passengers and crew and may even endanger the vessel. Ships with small *GM* values usually ride with a long, easy roll; however, low *GM* values may endanger a ship if her shell is punctured, for she may lose stability and capsize owing to the free surface of the flooding water. A happy medium is required in this as well as in other design work.

FREE-SURFACE EFFECT

The surface of a liquid in contact with air, *i.e.*, with a free surface, remains parallel to the surface of the earth when the container is inclined from the vertical. Free-surface effects become particularly important when they occur inside a ship, for they reduce the stability of the vessel.

It can be seen from our now familiar equation

$$BM = \frac{I}{V}$$

that it is the moment of inertia of the water plane that keeps a ship right side up, for BM increases with an increase in I. Furthermore, I depends entirely on the beam of the vessel, because, for a rectangle,

$$I = \frac{AB^2}{12}$$

It will be noted that I increases as the *square* of the beam. Thus a rowboat 6 ft. wide has four times the BM of a similar one only 3 ft. wide. (Note that length is not a factor.)

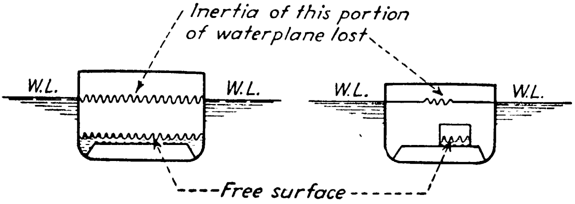


FIG. 159*A*.—Section through a flooded hold and a flooded tank.

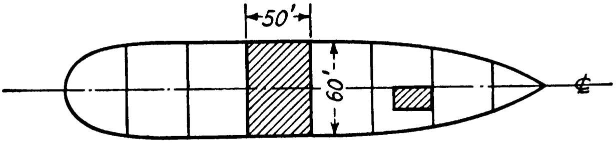


FIG. 159*B*.—Plan view of the flooded hold and the flooded tank.

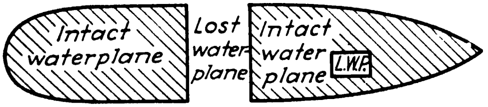


FIG. 159*C*.—The remaining water plane.

The effect of the inertia of the water plane of a vessel is neutralized if an equal free surface exists within the hull. This fact is generally overlooked by the layman and was the cause of the capsizing of the *S.S. Segovia* at Newport News, Va., and more lately the *S.S. Normandie* in New York, N. Y. It will pay every shipbuilder to know something of the effects of free surface within a floating object.

Assume that we have a ship with one hold flooded as indicated in Fig. 159. The free surface in the hold will neutralize an amount of water plane equal to the area of the free surface of the flooded water. Also, the tank (which is shown about one-third full) will neutralize the water plane in way of the tank. This causes a reduction in the metacentric height GM.

As

$$BM = \frac{I}{V}$$

Then

$$\text{Loss in } GM = \frac{i}{V}$$

where

i = moment of inertia of the flooded space.

Our rectangular barge whose VCG was calculated on page 181 had a GM of 3 ft. 0 in. Let us assume that a small amount of water, say ⅛ in. deep, is pumped into a space amidships 30 ft. long, which is shut off by watertight bulkheads. This small amount of water would affect the draught very little, and so the rise in KB could be neglected (see Fig. 157).

The free surface of the flooded area would be as follows:

$$\text{Flooded area} = 30 \text{ ft.} \times 24 \text{ ft.} = 720 \text{ sq. ft.}$$

$$i \text{ (in this case)} = \frac{AB^2}{12} = \frac{720 \times 24^2}{12} = 34{,}560 \text{ ft.}^4$$

$$\text{Loss in } GM = \frac{34{,}560 \text{ ft.}^4}{28{,}800 \text{ cu. ft.}} = 1.2 \text{ ft.}$$

It should be noted that in the above equations no account was taken of the depth of the water in the hold. This is correct, for the volume of water *plays no part* in the stability loss—it is the moment of inertia of the free surface that counts.

As our original GM was 3 ft., the GM remaining would be 3 ft. − 1.2 ft. = 1.8 ft., which would still be sufficient as a safe margin of stability.

However, had the barge been flooded ⅛ in. deep throughout its total length, we should have

$$\text{Flooded area} = 100 \text{ ft.} \times 24 \text{ ft.} = 2{,}400 \text{ sq. ft.}$$

$$I = i = \frac{AB^2}{12} = \frac{2{,}400 \times 24^2}{12} = 115{,}200 \text{ ft.}^4$$

$$\text{Loss in } GM = \frac{115{,}200 \text{ ft.}^4}{28{,}800 \text{ cu. ft.}} = 4.0 \text{ ft.}$$

Our remaining GM after flooding 100 ft. of the 100 ft. total would be

Original GM − GM loss = 3 ft. 0 in. − 4 ft. 0 in. = − 1 ft. 0 in.

The barge would have negative stability and would heel over slightly. This small inclination would cause the free water to run to the low side. The barge would then come to rest at a slight angle, for the area of the free surface would be considerably reduced. Had the flooding water been deeper, capsizing would have been almost certain. For a further discussion see Comstock's *Introduction to Naval Architecture*,[1] Chap. XI.

Had the firemen ceased to increase the number of holds they were flooding the moment they noticed the vessel listing, we should not have had to right the *S.S. Segovia* and *S.S. Normandie* before rebuilding. The effect of free surface on stability will be illustrated conclusively to the student if he steps into a rowboat about half full of water.

LONGITUDINAL TRIM

Using what we learned about transverse stability we can shift to longitudinal stability without changing our reasoning, for the same principles hold.

The change in trim of a ship is the algebraic sum of the draught forward and aft; or, better, it is the difference in the draught-mark readings.

Problem: A ship is on an even keel with a draught of 10 ft. 0 in. A weight already on board is shifted aft so that the draught marks on the extreme bow and stern now read 7 ft. 0 in. forward and 13 ft. 0 in. aft.

Solution: She has risen 10 ft. − 7 ft. = 3 ft. at the bow and sunk 13 ft. − 10 ft. = 3 ft. at the stern, which would give a total of 6 ft. 0 in. trim by the stern. The same result could be obtained by subtracting the readings of the new draught marks; *i.e.*,

13 ft. 0 in. − 7 ft. 0 in. = 6 ft. 0 in. trim by stern

A ship when changing trim very seldom trims about amidships or about the center of buoyancy. A ship *will always trim* about

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[1] Simmons-Boardman Publishing Corporation, New York.

the center of flotation, which is the center of gravity of the water plane of the vessel.

Longitudinal stability is similar to transverse stability. The only difference is that we use the longitudinal *GM* in place of the transverse *GM*. The longitudinal *GM* will be very large compared with the transverse *GM*. Longitudinal *GM* is about $1\frac{1}{4}$ times the length of the ship.

The change of trim in inches resulting from moving a weight already on board would be

$$\text{Change of trim in inches} = \frac{12 \times \text{weight} \times \text{distance moved} \times \text{ship length}}{\text{displacement of ship} \times \text{longitudinal } GM} = \frac{12 \times w \times d \times L}{W \times LGM}$$

It is more convenient for us to work out a *moment to change trim* 1 in. for our vessels than to use the above equation. As a moment is equal to a weight times a distance, it is possible if we know the moment to trim 1 in. to work out the trim resulting from a weight shift aboard a vessel or from adding a weight to a vessel at a certain point.

The moment to change trim 1 in. at load draught is approximately one-tenth the displacement in tons, and the *tons per inch* immersion for a normal-form 400-ft. freighter is approximately 50 (50 tons would cause the freighter to sink 1 in.). It should be borne in mind that these figures are only approximations and that the hull technical division works out the exact values for moment to trim 1 in., tons per inch immersion, etc. The values used here are merely for illustration. For exact values a copy of the displacement and other curves calculated for the particular vessel in question should be consulted.

To illustrate the method of calculating trim and sinkage we shall use the approximations above and work two type problems.

Problem 1: *Trim Resulting from Shifting a Weight Already on Board.* Assume that we have a 400-ft. 8,000-ton-displacement cargo vessel floating at a draught of 19 ft. 0 in. forward and aft and that we are going to move a 35-ton tank from No. 5 hold to No. 1 hold. Calculate the approximate change in trim resulting from this change (see Fig. 160).

Solution: The moment to change trim is approximately one-tenth the displacement; so

$$\frac{1}{10} \times 8{,}000 \text{ tons} = 800 \text{ ft.-tons}$$

The tons per inch immersion is approximately 50. This is not used in Prob. 1, for no weight has been added to the vessel; we are simply shifting a weight already on board. Assuming that the center of flotation of the vessel is amidships (which is not usually true), our trimming moment would be

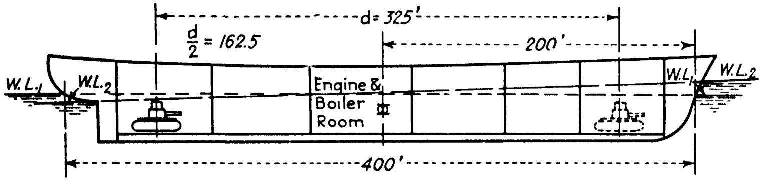

FIG. 160.—Change of trim resulting from moving a weight already on board

$$\text{Trimming moment} = (162.5 \text{ ft.} + 162.5 \text{ ft.}) \times 35 \text{ tons} = 11{,}375 \text{ ft.-tons}$$

$$\text{Trim in inches} = \frac{\text{trimming moment}}{\text{moment to trim 1 in.}} = \frac{11{,}375 \text{ ft.-tons}}{800 \text{ ft.-tons}} = 14.22 \text{ in.}$$

The stern would rise $\frac{14.22}{2} = 7.11$ in. and the bow would immerse the same 7.11 in.

The new draughts would be

Bow = 19 ft. 0 in. + $7\frac{1}{8}$ in. = 19 ft. $7\frac{1}{8}$ in. nearly
Stern = 19 ft. 0 in. − $7\frac{1}{8}$ in. = 18 ft. $4\frac{7}{8}$ in. nearly

Problem 2: Trim Resulting from Adding a Weight to a Vessel. Let us say that we now add two 50-ton landing barges in No. 5 hold. Calculate the new draught.

Solution: We are now adding a weight to the vessel; she will therefore (1) sink a certain amount and (2) change trim.

1. To calculate the sinkage: The tons per inch is approximately 50· therefore,

$$\text{Sinkage} = \frac{\text{weight added}}{\text{tons per in.}} = \frac{100 \text{ tons}}{50 \text{ tons per in.}} = 2 \text{ in.}$$

The draughts, not including trim, will be

$$\text{Bow} = 19 \text{ ft. } 7\tfrac{1}{8} \text{ in.} + 2 \text{ in.} = 19 \text{ ft. } 9\tfrac{1}{8} \text{ in.}$$
$$\text{Stern} = 18 \text{ ft. } 4\tfrac{7}{8} \text{ in.} + 2 \text{ in.} = 18 \text{ ft. } 6\tfrac{7}{8} \text{ in.}$$

2. To calculate the trim: The trimming moment is obtained by multiplying the weight added times the distance from the added weight to the center of flotation.

The center of flotation in our case was assumed to be amidships and the weight added is 100 tons; therefore,

$$\text{Trimming moment} = 162.5 \text{ ft.} \times 100 \text{ tons} = 16{,}250 \text{ ft.-tons}$$

The moment to trim 1 in. is still 800 ft.-tons. Therefore,

$$\text{Trim} = \frac{16{,}250}{800} = 20.31 \text{ in.} = 20\tfrac{3}{8} \text{ in. nearly}$$

The new and final draughts would be

$$\text{Bow} = 19 \text{ ft. } 9\tfrac{1}{8} \text{ in.} - \frac{20\frac{3}{8}}{2} \text{ in.} = 18 \text{ ft. } 11 \text{ in. nearly}$$
$$\text{Stern} = 18 \text{ ft. } 6\tfrac{7}{8} \text{ in.} + \frac{20\frac{3}{8}}{2} \text{ in.} = 19 \text{ ft. } 5 \text{ in. nearly}$$

It should be noted that the above is only an approximation and is used merely as an illustration of the method. With a copy at hand of the displacement and other curves calculated for the particular vessel the calculation can be made exact.

DAMAGE CONTROL

The above method of calculating trim may be used in making the calculations for *flooding-effect diagrams.* These diagrams are made up for every warship and at present for most merchant ships. They furnish trim and heel information in a simple form to the damage-control officer, so that in case a part of the vessel becomes flooded he may quickly bring her back to even keel.

The principle of damage control is a simple one. A vessel afloat is a balanced object. If a vessel's shell is punctured, an amount of water flows in that is proportional to the size of the space that is flooded.[1] We consider this to be an added weight.

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[1] Any cargo stowed in the space will exclude an amount of water equal to the volume of the cargo. If the flooded space is filled with lumber, very little water can flow in. If the space is empty at the time of flooding, a large amount of water will flow in.

The vessel will heel and trim a certain amount depending on the weight added and the distance of the center of gravity from the center of flotation and from the center line.

To return the vessel to an even keel the damage-control officer must adopt one of the following methods:

1. Add a weight that has an equal and opposite heeling and trimming moment.
2. Shift weights already on board that will give equal and opposite heeling and trimming moments.
3. Remove a weight that has the same trimming and heeling moment.

Method 1 is accomplished by flooding tanks that are located on the opposite side of the center line and the center of flotation from the damaged part.

Method 2 is accomplished by pumping liquids from tanks on the damaged side to tanks on the intact side.

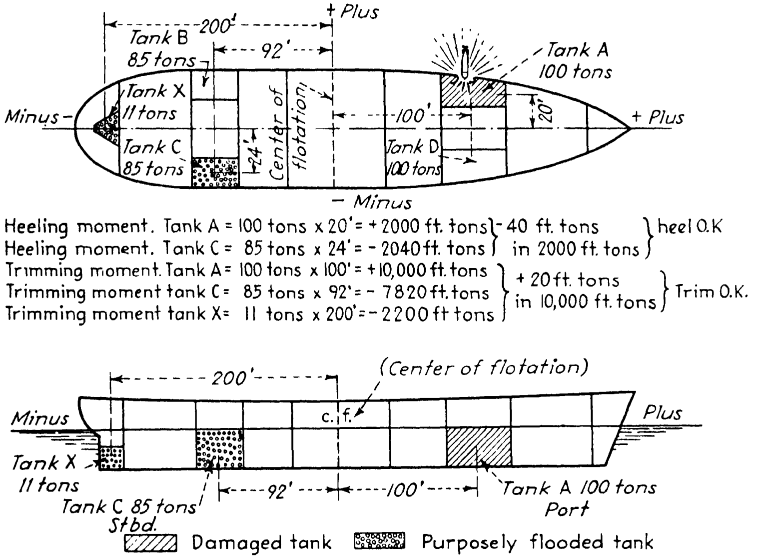
Method 3 is accomplished by emptying tanks on the same side of the center line and center of flotation as the damaged part. This is the most satisfactory procedure.

As an illustration, consider Fig. 161. The vessel shown has just been torpedoed. The vessel's shell has been punctured in way of tank *A*. This tank will flood and the vessel will (1) trim by the bow and (2) heel to port.

The damage-control officer attempts to correct this heel and trim. The heel could be corrected by flooding tank *D*; however, this would increase the trim (for tank *D* is forward of the center of flotation), which may be undesirable.

Tank *A* has a heeling moment of +2,000 ft.-tons and a trimming moment of +10,000 ft.-tons. Figure 142 shows that tank *C* has a negative heeling moment of −2,040 ft.-tons. Filling this tank would correct the heel. Tank *C*, however, has only a negative trimming moment of −7,800 ft.-tons, which would not be sufficient to bring the vessel back to an even keel fore and aft. Tank *X*, the afterpeak tank, holds 11 tons and is 200 ft. aft of the center of flotation. Flooding this tank would give a trimming moment of −2,200 ft.-tons. Tank *X* has no heeling moment, for its center of gravity is on the center line. This trimming moment added to the negative trimming moment produced by flooding tank *C* would bring the vessel back to an even keel fore and aft. The vessel would have increased her draught, however, owing to the addition of 296 tons of water. Even-keel conditions might be obtained by flooding tank *C* and pumping tank *Y*, the forepeak tank, provided that the proper moment is obtained by so doing. Emptying full tanks is usually more desirable than flooding empty ones, for it decreases rather than increases the draught.

Heeling and trimming moments are calculated for every compartment and tank. These moments are placed on a drawing of the vessel in their proper places so that the damage-control officer can ascertain at a glance the trimming and heeling moments resulting from filling or emptying any tank or compartment.



Heeling moment. Tank A = 100 tons x 20' = +2000 ft. tons
Heeling moment. Tank C = 85 tons x 24' = −2040 ft. tons
} −40 ft. tons in 2000 ft. tons } heel O.K

Trimming moment. Tank A = 100 tons x 100' = +10,000 ft. tons
Trimming moment tank C = 85 tons x 92' = −7820 ft. tons
Trimming moment tank X = 11 tons x 200' = −2200 ft tons
} +20 ft. tons in 10,000 ft. tons } Trim O.K.

▨ Damaged tank ▒ Purposely flooded tank

FIG. 161.—Correcting list and trim by counterflooding.

Problems

1. What are the three types of stability?

2. Will a vessel that has negative stability necessarily capsize?

3. What two conditions are necessary for a vessel to float at rest in still water?

4. From your own experience give a simple illustration of a couple.

5. Describe in your own words the relation of *GM* and stability.

6. Make a rough sketch of a midship section slightly heeled, and spot in the points *G*, *M*, *B*, B^1, *Z*, and θ.

7. Try the rocking-chair analogy at home.

8. Why is excessive GM as great a danger in some cases as deficient GM?

9. What is the purpose of the inclining experiment?

10. Tell in your own words the procedure to follow in performing the inclining experiment.

11. About what GM should you expect to find in a normal modern passenger vessel of 90 ft. beam?

12. What caused the capsizing of the *S.S. Normandie?*

13. On a vessel is it always best to put out a fire by pouring water into the holds?

14. Define moment to trim 1 in. and tons per inch immersion.

15. State in your own words the principle of damage control.

CHAPTER XVII

LAUNCHING

The actual launching operation itself is simply a transfer of the vessel from the building stocks into the water. However, the preparations preceding the launching must begin before the keel is laid. We shall discuss these preparations in this chapter.

The preparation of the shipway, or berth, is one of the most important operations in shipbuilding. As the ground under shipways is usually too soft to support the concentrated weight of a large vessel, the ways must be extensively piled. This piling is driven down to a depth of 30 to 50 ft. A pile driven into the soil under the shipways at Newport News will support about 1 ton per foot of driven length. Sometimes under one shipway there are as many as 6,000 piles, averaging about 40 ft. in length. These piles are closely spaced (about 2 ft. 6 in. apart) under the standing and sliding ways because they must take the weight of the vessel and its cradle. As the vessel slides down the ways, these piles are called upon to resist the pivoting load that is thrown upon them at a certain period of the launch.

The keelblocks take the greater part of the weight of a vessel during the construction stages, and the bilge blocks and shores take the remainder.

There are, in general, three types of building stocks, wooden stocks, semisubmerged concrete building ways, and submerged shipways.

WOODEN-STOCK WAYS

Most wooden stocks are constructed of timber uprights set on cross balks in the ground, these latter being supported by piling. The tops of the wooden stocks are set to a grade of about $\frac{9}{16}$ in. per ft. The ends of the stocks extend into the water about 100 ft. in the case of the smaller ones to 250 ft. in the case of the larger.

SEMISUBMERGED WAYS

Semisubmerged building ways are usually constructed entirely of concrete, extensively piled as mentioned before. At their outboard ends they have floating gates, which may be pumped out and removed. With the gates removed the dock is partly

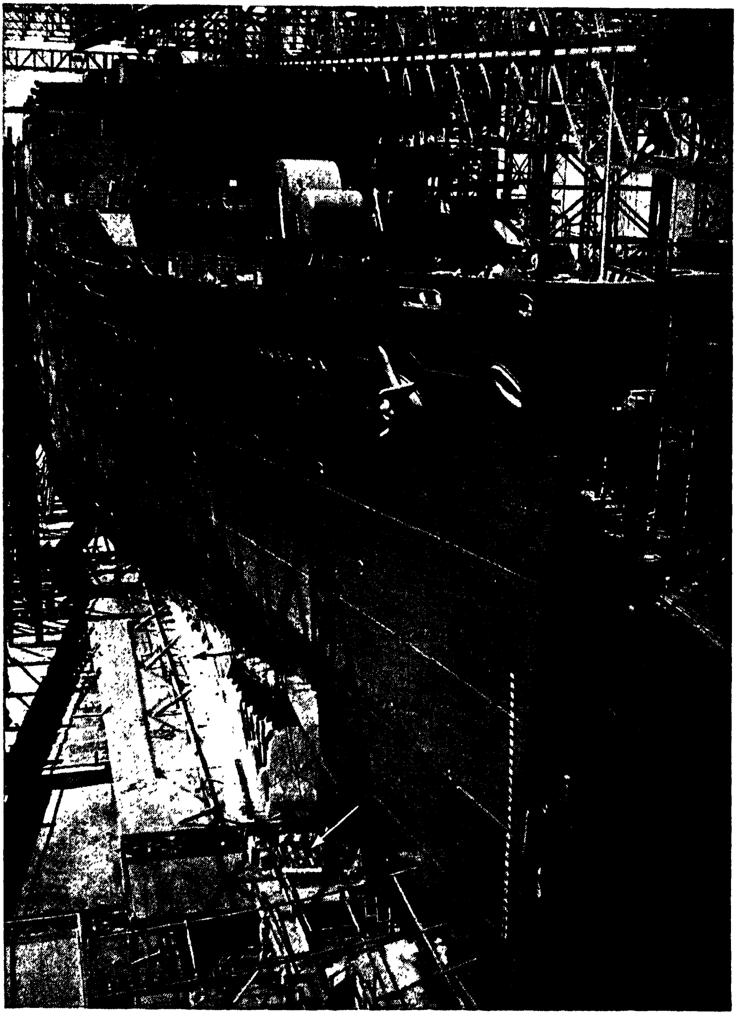


FIG. 162.—Bow view of vessel ready for launching. Note the relation between the size of the fore poppet and the vessel.

flooded and a portion of the ways covered with water. The depth of the water over the sills of semisubmerged ways averages about 20 ft.

SUBMERGED WAYS

Completely submerged ways are sometimes used for the construction of large vessels. They are also valuable as dry docks when not being used for construction.

LAUNCHING TERMS

The following applies only to fore-and-aft launching operations from inclined ways. Figure 164 shows in barest outline a vessel resting in its cradle ready for launching and illustrates some of the terms that will be used in the following section.

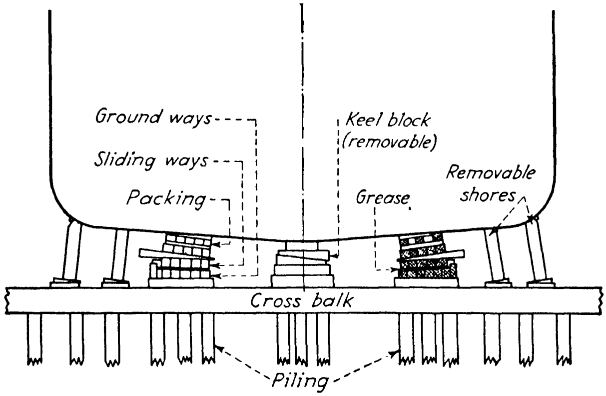


FIG. 163.—Section through ship and ways showing the system of piling and hull support prior to launching.

The *ground ways*, or *standing ways*, are supported by the pile foundations. The top of these ways is coated with launching grease. Launching grease is put on in layers, the total thickness usually being about 1 in. To launch the aircraft carrier *Yorktown*, 43,400 lb. of launching grease was used to coat the two ways.

The *sliding ways* rest on top of the grease that coats the ground ways. When the vessel is released, the sliding ways slide on this grease and carry the vessel into the water.

The *wedges* shown in Fig. 163 extend from the forward end to the after end of the cradle and are driven up hard before the shores and the keelblocks are removed. *They do not lift the vessel* but merely bring the cradle up close to the bottom of the

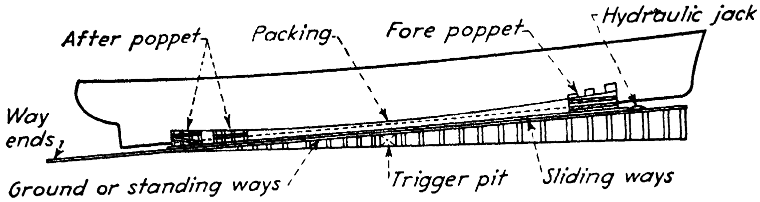


FIG. 164.—Ship poised on ways ready for launching.

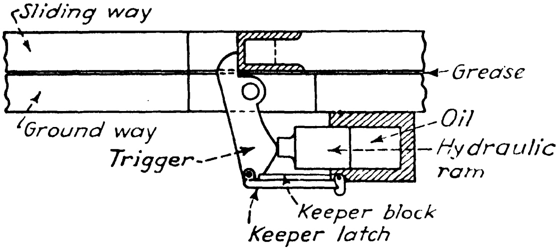


FIG. 165A.—Typical hydraulic trigger arrangement (one trigger is placed in each way). Mechanical triggers with a system of levers replacing the hydraulic ram are also used.

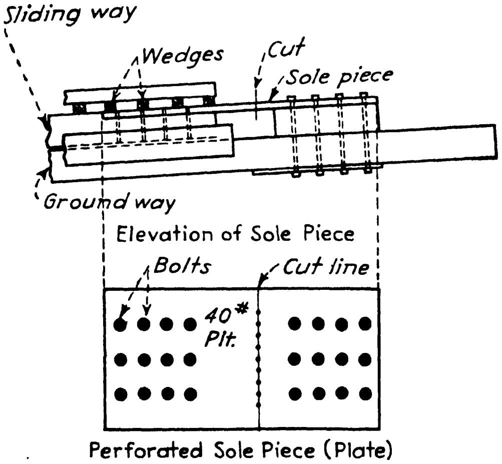


FIG. 165B.—Ship releasing arrangement making use of a sole piece.

ship so as to prevent excessive settling when the shores and keelblocks are removed. (Sometimes in side launching small boats, wedges are used to lift the vessel.)

The *hydraulic triggers*, of which there is one in each standing way, keep the sliding ways from moving until the shores and keelblocks are removed. Sometimes, in launching small vessels, solepieces are used to hold the vessel just before the launch. The type of solepiece shown in Fig. 165 is cut with a burner's torch to release the vessel.

The *fore poppet* (Fig. 166) takes the poppet load that is thrown upon it when the vessel pivots during the launch (see below).

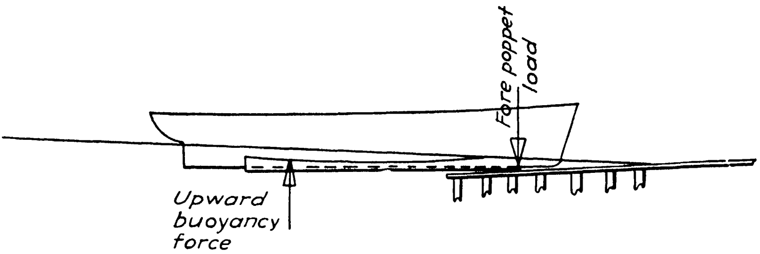


FIG. 166.—Ship pivoting. Load on fore poppet is the difference between the upward buoyancy force and the weight of the vessel.

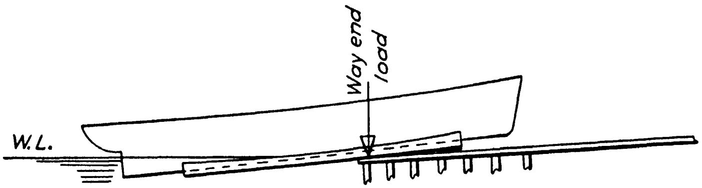


FIG. 167.—Ship tipping over way ends (insufficient buoyancy at stern).

At a certain stage of the launch the *way ends* exert a strong pressure on the ship's bottom (Fig. 167).

THE LAUNCHING PROCESS

Let us assume that we have a hypothetical ship poised on the ways, with all shores and keelblocks removed and held only by the hydraulic triggers. The triggers are released, and the vessel starts down the ways. As long as the cradle is still largely supported by the ways, very little can happen, for the vessel still slides along on most of its original support. However, as shown in Fig. 167, the time arrives when the afterpart of the sliding ways begins to slide out beyond the ground ways. When this happens, the vessel may "tip," which would cause the stern to lower and the bow to rise, thus putting severe pressure on the way ends and the bottom of the vessel. The buoyancy of the stern of the vessel counteracts this tipping tendency.

Finally, the buoyancy of the vessel becomes great enough to lift the stern. Then the afterpart of the cradle lifts from the ways, and the remaining weight of the vessel is thrown on the fore poppet (Fig. 166). This is known as *pivoting*, and the weight thrown on the fore poppet is known as the *poppet pressure.*

After the ship pivots, it continues to enter the water, supported by the buoyancy of the water and by the fore poppet until the latter drops off the standing ways; or if the supporting buoyancy equals the weight of the vessel, it simply floats off with no drop. The vessel is now free of the ways and must have sufficient stability when afloat to remain upright.

FACTORS INFLUENCING THE LAUNCHING

A launching to be successful depends upon the following four factors:

1. *The ship must start.* Starting depends upon the declivity (slope) of the ways, the weight per square foot on the grease, the temperature at the time of the launch, and the type of grease used. The declivity is usually set at $\frac{5}{8}$ in. to the foot; but it may be necessary to increase this for small vessels, for the tendency to slide decreases as the weight per square foot on the grease decreases.

The weight per square foot on the grease can be controlled within limits by decreasing or increasing the width of the sliding ways. For example, suppose we have a vessel 400 ft. long and weighing about 3,230 tons when launched. The length of the sliding ways would be about 350 ft. If the width of each sliding way was, say 2 ft., then we should have an area of

$$350 \text{ ft.} \times 2 \text{ ft.} = 700 \text{ sq. ft. for one way}$$

and both ways would have an area of 1,400 sq. ft. The weight per square foot would be

$$\frac{3{,}260 \text{ tons}}{1{,}400 \text{ sq. ft.}} = 2.33 \text{ tons per sq. ft.}$$

If possible, a width of sliding way is used that will give a pressure per square foot of between 2 and $2\frac{1}{2}$ tons. Above a pressure of 2½ tons per sq. ft. the grease has a tendency to squeeze out and burn. Below a pressure of 2 tons the vessel may not slide down a ⅝ in. per foot slope.

2. *Pressure on the way ends, due to tipping, must not be great enough to buckle the bottom of the ship or to cause damage to the way ends* (Fig. 167). This pressure can at times be reduced to a safe value or to zero by increasing the declivity of the keel or by cambering the ways. Adding ballast forward is of doubtful value. Before the *S.S. America* was launched, the open floors were shored internally so that they might resist an expected high way-end pressure. The amount of way-end pressure would be proportional to the difference between the weight moment tending to cause the vessel to tip and the buoyancy moment tending to lift the stern.

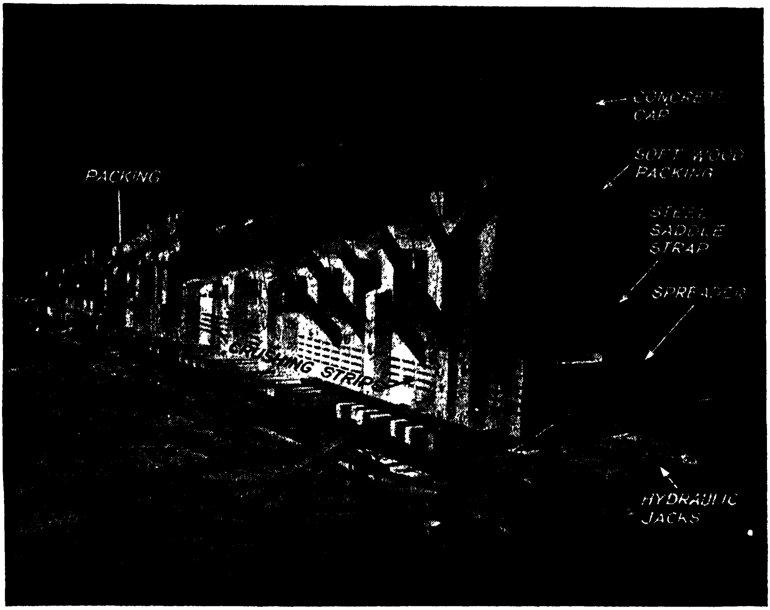


FIG. 168.—A close-up of the fore-poppet structure, *S.S. America.*

3. *The fore poppet must be of sufficient strength to receive the load thrown upon it when the stern lifts and the vessel pivots.* When the *S.S. Normandie* was launched, her pivoting load was 7,000 tons, or 25.3 per cent of her total launching weight (27,666 tons). As 7,000 tons is greater than the light weight of the C-3 type

492-ft. cargo and passenger vessel *S.S. President Jackson*, it is easy to visualize the reason for the massive fore poppets used under some of the larger vessels. As the vessel pivots, the keel lifts, which throws the entire poppet load on the first saddle (Fig. 169). It is structurally undesirable to concentrate this load on such a small area, for to do so would endanger the ship, the fore poppet, and the ways. There are several methods of distributing this pivoting load over a fairly large area.

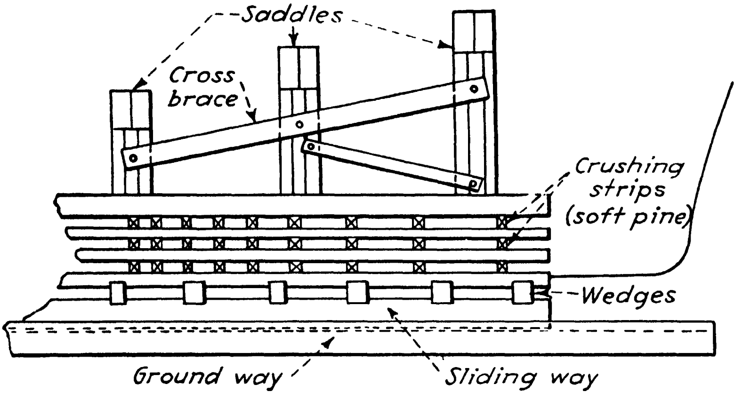


FIG. 169.—Elevation of fore poppet showing crushing strips and wedges. (Note increased spacing of crushing strips forward.)

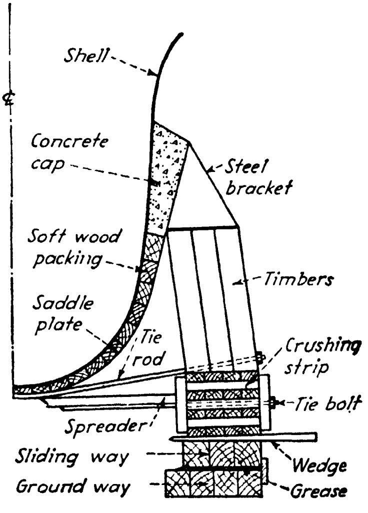


FIG. 170.—Section through a typical fore poppet.

The method used at Newport News and at many other yards was developed by William Gatewood, former naval architect at that yard. Figure 170 shows diagrammatically and in profile the arrangement of this type of fore poppet, by means of a section cut through one of the fore-poppet saddles.

The saddle straps are flat steel U- or V-shaped plates that pass under the hull and are welded at their upper edge to steel brackets. Wood packing is placed between the steel saddle strap and the hull to prevent damage to the hull. On large vessels, concrete is usually poured in at the top to make a strong close fit in way of the poppet-timber bracket (see Fig. 170). The poppet timbers rest on longitudinal beams separated by *crushing strips* about 3 by 3 in. in cross section and made of some soft wood. The crushing strips are spaced farther apart under the forward end of the saddles than under the after end so that when the ship begins to pivot and the load is thrown on the forward saddle the widely spaced crushing strips (being unable to carry as much load as the closely spaced ones) crush downward, throwing a portion of the load on the second saddle, which in turn crushes downward, throwing a portion of the load from the first two saddles on the third. This progressive crushing continues until the pressure is approximately equalized among the saddles. Five rows of crushing strips were used in the fore poppet on the aircraft carrier *Yorktown;* the actual maximum amount of crushing was $6\frac{15}{16}$ in.

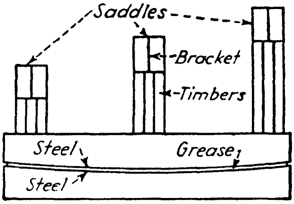


FIG. 171.—Rocker-type fore poppet shod with steel and greased.

Figure 171 shows another method of spreading the poppet load. This fore poppet is known as the *rocker type* and has been used by the New York Shipbuilding Co. It is essentially a circular joint shod with steel and greased.

4. *The ship must not capsize when afloat.* This was discussed in Chap. XVI. The 105-ft. tug *Sommers N. Smith* capsized in the James River during launching in 1896. Her instability was due to the fact that her machinery had not been installed. She was later righted and after her machinery was installed was sufficiently stable. The *S.S. Principessa Jolanda* capsized during the launching at La Spezia, Italy. All that was salvaged was some of the boilers.

Failure of the ship to start or too great a way-end pressure would be serious. A fore-poppet failure or lack of stability after launching would be catastrophic.

LAUNCHING ROUTINE

The actual transfer of the weight of the vessel from the keel-blocks, cribbing, and shores on which the vessel was built to the launching ways takes place the day of the launch.

The following description outlines a typical routine but applies to no particular ship. (1) The grease irons, which are spaced about 20 ft. apart and which keep the load of the sliding ways and packing from bearing on the grease until just before the launch, are removed. (2) The wedges are driven up, which brings the poppets and packing up tight against the shell. (3) The shores are removed from between the ways. (4) The wedges are again driven up. (5) The removal of the keelblocks and the remaining shores can now take place simultaneously. When these are removed, the vessel is resting on the launching cradle and is ready for release.

KEELBLOCKS

A number of ingenious methods have been devised to facilitate the removal of the keelblocks. Under some ships, wedge-shaped filler blocks are placed under the flat top blocks and are removed by knocking out the wedge-shaped filler pieces. As the size of the vessel increases, the difficulty of knocking out the blocks increases. Also, as each keelblock is removed, its load is partly thrown on to the adjacent blocks. In the yard at Newport News collapsible sandboxes (Fig. 172) are usually placed on alternate keelblocks. The top of the sandbox is supported only by the sand contained in the box. Just before the vessel

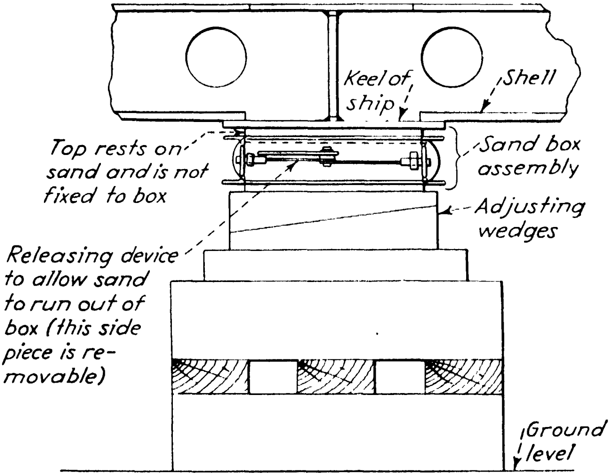


FIG. 172.—Keelblock assembly with a quick-releasing sandbox.

is ready for launching, a releasing lever is pulled and the forward side of the box is removed. The sand then runs out, and the support is thus removed from the top of the box, which in turn drops to the bottom of the sandbox. The blocks are then easily removed, for they have no pressure on them.

A system similar to the above was used at the launch of the *S.S. Normandie* except that salt was used in the boxes instead of sand. Steam forced through the box condensed into water, and the water dissolved the salt. The salt solution ran out of a small hole in the bottom; the support of the keelblocks was thus removed and this load transferred to the cradle. These collapsible blocks are installed about 2 weeks prior to the launching.

Problems

1. Name and describe three types of building ways.
2. Why is extensive piling required under most shipways?
3. What is the difference between a trigger and a solepiece?
4. What are the four critical periods during a launch?
5. Why are ways sometimes cambered?
6. What is meant by tipping? What counteracts tipping?
7. Why are crushing strips used only under the fore poppet?
8. Make a freehand sketch of a section through a fore poppet.
9. Describe in your own words the routine followed in launching a vessel.
10. Describe two ingenious devices developed to facilitate the removal oı the keelblocks.

CHAPTER XVIII

TONNAGE

HISTORY

Even in early Egyptian and Phoenician times it became apparent that length, breadth, and depth did not adequately express the earning capacity of a vessel. Therefore, certain crude devices were used to determine a vessel's carrying capacity, in order to distribute equitably the various harbor dues, etc., among the vessel owners.

Tonnage measurements, as we know them now, began in the thirteenth century. At this time vessels were carrying large amounts of wine. Wine was usually stored and transported in a large cask or barrel known as a *tun*, which meant a measure of capacity. This tun when filled with wine held 250 gal., occupied about 57 cu. ft. of space in the ship, and weighed 2,240 lb. This capacity and weight for the tun were established by law in England in the fifteenth century. At that time the taxes or port dues were paid in actual barrels, or tuns, of wine, so that the payment came to be called *tunnage*, meaning the number of tuns a certain vessel had to pay as fees based upon the number of tuns she could carry. The spelling of the word was later changed and became *tonnage*.

TONNAGE MEASUREMENTS

As the word "tun" meant space occupied (57 cu. ft.) and also weight (2,240 lb.), great confusion existed (and still exists) as to what should be used to express the earning ability of a ship—the space in the vessel suitable for stowage of cargo or the actual weight that could be carried. The idea now is to base tonnage on the earning space in the vessel rather than on the weight the vessel can carry. Therefore, Simpson's rule is used to get the volume of earning space in cubic feet, and this volume is then arbitrarily divided by 100, giving the tonnage of the vessel. This tonnage is *space* tonnage, not weight tonnage.

The actual rules for working out the tonnage are complicated and archaic. They are contained in a booklet entitled "Measurement of Vessels."[1] Tonnage measurements are made by the government while the vessel is under construction in the builder's yard and must be completed before a carpenter's certificate will be issued. Without this certificate the vessel cannot be documented and therefore cannot leave the builder's yard. To calculate the actual tonnage of a vessel the government uses the booklet "Measurement of Vessels."

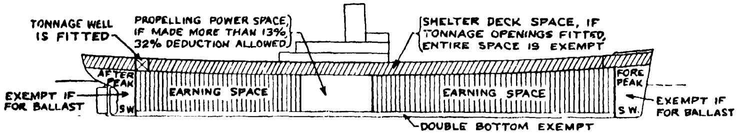


FIG. 173*A*.—Shelter-deck vessel, type *A*, for light bulky cargo. Gives maximum capacity but requires more freeboard than Type *B*. Similar to *S.S. Hawaiian Planter* (Fig. 117*B*).

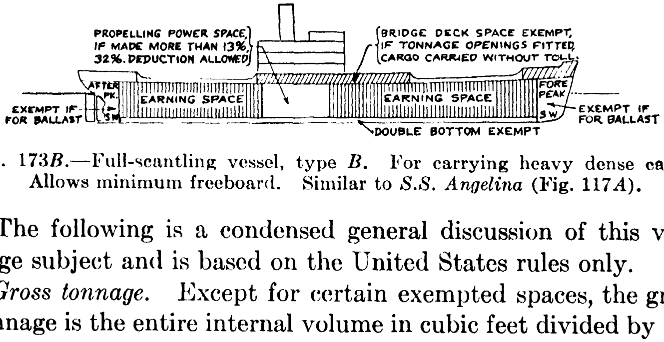


FIG. 173*B*.—Full-scantling vessel, type *B*. For carrying heavy dense cargo. Allows minimum freeboard. Similar to *S.S. Angelina* (Fig. 117*A*).

The following is a condensed general discussion of this very large subject and is based on the United States rules only.

Gross tonnage. Except for certain exempted spaces, the gross tonnage is the entire internal volume in cubic feet divided by 100 (100 cubic feet = 1 ton by law).

Net tonnage is the tonnage that remains after the so-called "nonearning" spaces are deducted from the gross tonnage. It is intended to be a measure of the ship's earning ability. Tolls for canal transit, wharfage, etc., are based on net tonnage. The naval architect therefore tries to make this as small as possible.

Exemptions. Certain spaces are *exempt* from measurement and are *not included* in gross tonnage (see Fig. 173). They are

1. The entire double-bottom space.
2. The fore- and afterpeak space and deep tanks, if fitted to carry water ballast only.

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[1] Government Printing Office, Washington, D.C.

3. Poop, bridge, and forecastle, if fitted with tonnage openings (see Fig. 175 for a sketch of a tonnage opening).

4. An entire shelter deck, if fitted with a small well and suitable tonnage openings (see Fig. 173, type *A*).

5. Passenger spaces on the deck above the uppermost continuous deck (see Fig. 174, types *C* and *D*).

6. Other miscellaneous spaces, such as companions, skylights, wheelhouses, vents, and some water closets.

The tonnage, exclusive of the above-mentioned spaces, is the gross tonnage of the vessel.

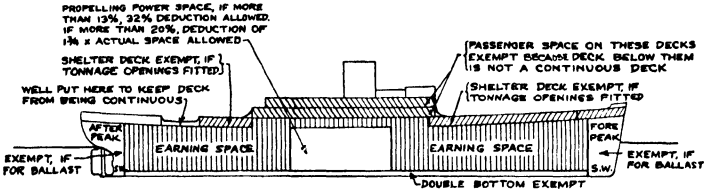

FIG. 174*A*.—Freight and passenger shelter-deck vessel, type *C*. Similar to *S.S. President Jackson* (Fig. 121).

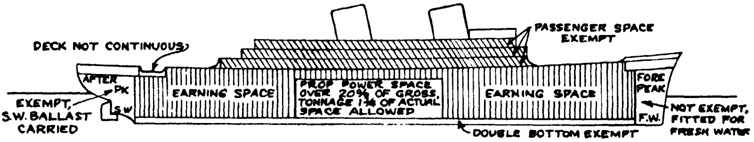

FIG. 174*B*.—High-speed passenger-cargo vessel, type *D*.

Deductions. From the gross tonnage certain spaces may be deducted. These spaces are, in general, crew and working spaces. The machinery space is the principal deduction, which, in general, is as follows (see Fig. 173):

1. If the machinery space is 13 per cent, or less, of the gross tonnage, the deduction shall be 1¾ times the actual space.

2. If the machinery space is over 13 per cent and less than 20 per cent of the gross tonnage, the deduction shall be 32 per cent of gross tonnage.

3. If the machinery space is over 20 per cent of the gross tonnage, the deduction goes back to 1¾ times the actual volume.

It follows from the above that the wise ship designer will make the volume of the machinery space over 13 per cent of the gross tonnage, even though this volume is not required by the machinery, thus obtaining the flat 32 per cent deduction, which would be much greater than 1¾ times the size of the actual space. To illustrate this, let us assume the machinery space to be 12 per cent of the gross; the deduction would be 1¾ × 12 per cent = 21 per cent. But by increasing the size of the space to 13 per cent we would be allowed to deduct 32 per cent of the gross tonnage, a deduction gain of 11 per cent.

In order to get crew and working spaces deducted, the builder must certify that they will be used for crew and working spaces only. Thus we see, above the doors to the crew and working spaces, "Certified 8 seamen," "Certified for galley," etc. "Certified for 8 seamen" does not mean that eight seamen will be crowded into the one stateroom. Accommodation for one seaman by law is equal to 120 cu. ft. of space and at least 16 sq. ft. of deck space. A stateroom with a floor space 9 by 13 ft. with 8 ft. 3 in. deck height would be certified for eight seamen although only three would probably occupy the room.

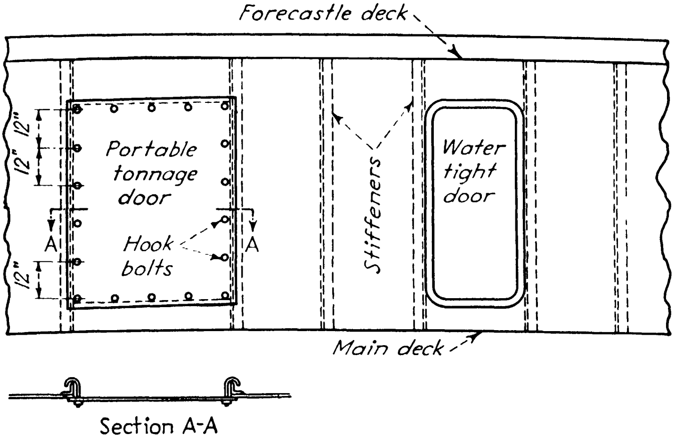

Fig. 175.—Tonnage opening in bulkhead *nominally* nonwatertight (no gasket). Watertight door at right is used for access (see Fig. 7).

Tonnage openings. In order to help the shipowner further, the rules permit the exemption of poops, bridges, forecastles, and even entire shelter-deck spaces, if certain nominally nonwatertight openings are fitted in the enclosing structure (see Fig. 7). These openings may be secured by bolted plates (no gasket allowed) or wooden battens and are known as *tonnage openings.*

Vessels designed to transport light bulky cargoes make use of this device so as to deduct the entire shelter deck (see Fig. 175).

The two major canals, Suez and Panama, have their own rules, which differ in some respects from the above, giving, in general, a greater tonnage than the United States rules discussed here.

Reasons for Tonnage Measurements.—Most fees, tolls, and dues are based upon either gross or net tonnage. Dry docking is based upon gross tonnage and is usually about 10 cents per gross ton per day. Thus the fee for dry docking a 10,000 gross ton ship would be about $1,000 a day.

Harbor dues in foreign ports, foreign and American dockage dues, canal tolls, and sometimes pilotage are based on net tonnage.

Problems

1. What is a tun?

2. A vessel has an internal volume of 200,000 cu. ft., not including exempted spaces. What is her *gross* tonnage?

3. There are 50,000 cu. ft. of space in the above vessel of Prob. 2 that may be deducted under the present laws regulating tonnage. What would be her net tonnage?

4. Who makes the tonnage measurements?

5. What is the purpose of the tonnage opening?

6. Can cargo be carried in spaces fitted with tonnage openings?

7. Make a list of the more important exemptions.

8. What is the principal deduction allowed by law?

9. How are crew and galley spaces exempted from tonnage?

10. Why do we have tonnage measurements?

CHAPTER XIX

TESTING THE SHIP ON TRIALS

Almost every man in the shipyard hopes some day to be aboard during the trial trip of a new ship. This interest is heightened as the worker observes the ship undergoing dock trials a few days prior to the sea trials. This dock trial is held while the ship is tied to the builder's pier for the purpose of making certain that all machinery installations are in an operating condition. It is usually held at about half power, and the main propulsion units and auxiliaries are checked for any defects.

While the sea trial is for most of the personnel both work and pleasure, very few aboard ship actually understand all the purposes of the trial or the interesting things that are going on around them. In this chapter, we shall discuss briefly some of the more outstanding features relating to the specialized equipment required for measurements and to the requirements of trial courses and touch on the standardization runs and tests that are held during the trial. Throughout this chapter the official trip of the passenger liner *S.S. America* as run on the measured mile at Rockland, Me., June, 1940, will be used as an example.

THE PURPOSE OF THE TRIAL TRIP

During the preliminary design stages of a ship the naval architect develops the lines (shape) of the hull that will suit the speed and displacement required. A 20-ft. model is usually made from these lines and is run, self-propelled, in the Taylor Model Basin at Carderock, Md., or some other model basin, to determine the horsepower and revolutions of the propellers required for various speeds. From the results of such tests a calculation is made for the full-sized ship. Figure 176 shows how closely the model basin can predict the actual trial results for a full-sized ship from the results obtained from a 20-ft. model. The curve for the actual ship has not been corrected for the effect of the wind. In fact, some naval architects feel that careful predictions based on model tests are probably more accurate than the horsepower measured on most trial trips.

As the ability of the ship to develop her power and the efficiency of the machinery in developing this power are extremely important, it is usually stipulated in the contract between the builder and the owner that she must develop a certain power and operate at a certain efficiency in developing this power. Another usual stipulation in the contract provides that if the terms of the contract are not met a certain amount will be deducted from the contract price of the vessel. On the other hand, if the guaranteed performance is better than stipulated in the contract, the builder is to receive a bonus. As an illustration, in the contract on the *S.S. America* there was no limitation on the amount the shipyard could be penalized for not meeting the guarantees, but the maximum fuel-economy bonus allowed was to be **$50,000.**

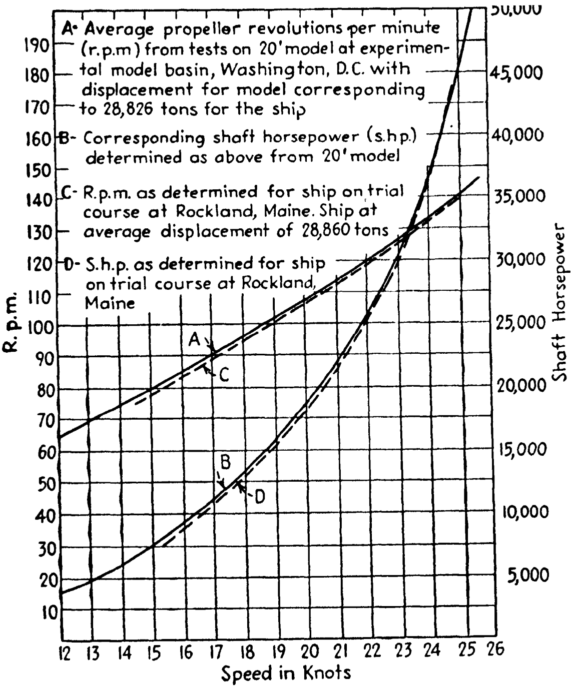

FIG. 176.—Horsepower and r.p.m. curves, *S.S. America.*

To determine the speed of a ship at a particular displacement in the open sea where the economy trials are run, we first must know the r.p.m. of the propellers that will give a certain speed. To determine this relation we run the ship over a measured-mile course at various speeds and record simultaneously the r.p.m., speed, and horsepower. When these three factors have been determined we can plot our results as in Fig. 176 and then proceed to the open sea for the 4-hr. economy runs and other tests.

Besides giving the above information, these trials also give the engineering personnel an opportunity to check their preliminary calculations on the performance of the ship and the machinery in the operating condition and also to gather information that is invaluable when making up future designs. The data thus obtained are studied and analyzed after the trial is completed. Great advances in marine engineering have resulted from the study of such data. Preceding the official trial trip of the ship an unofficial *builder's trial* is run for most large vessels to make sure that all the machinery is in proper working condition. It is of short duration and need not include measured-mile runs.

After the builder's trial has been run, the official trial is conducted. For naval vessels a third trial called the *final-acceptance trial* is run during the 6-month period in which the shipbuilder has to guarantee the performance of the vessel. If the final-acceptance trial is satisfactory, at the end of the 6-month-guarantee period the contract is considered discharged and the builder is paid the contract price in full.

REQUIREMENTS OF A TRIAL COURSE

1. Depth of Water.—If the water in which a ship is operating is shallow in relation to the draught of the ship, the over-all resistance of the ship and the horsepower required to drive the ship at a given speed are ordinarily increased. This phenomenon is due to interference between the bottom of the bay or ocean and the wave system set up by the ship and necessitates that the trial course be laid out in deep water. Admiral Taylor in his "Speed and Power of Ships"[1] gives the following formula as the least depth of water required to overcome this interference:

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[1] U.S. Maritime Commission, Washington, D.C.

$$\text{Least depth} = 10 \times \text{ship's draught in feet} \times \frac{\text{speed in knots}}{\sqrt{\text{length of ship in feet}}}$$

This is another way of saying that the depth required is proportional to the speed-length ratio of the ship if the draught is constant. However, it should be noted here that John P Comstock and C. H. Hancock in a paper (The Effect of Size of Towing Tank on Model Resistance) before the Society of Naval Architects, 1942, pointed out from their experiments that the depth of water required is not proportional to the speed-length ratio $\frac{V}{\sqrt{L}}$ but that for speed-length ratios of less than 1 $\left(\frac{V}{\sqrt{L}} \text{ for } \textit{S.S. America} = 0.89\right)$ the depth of water should be about 75 per cent of the length of the ship. Later in the chapter we shall use both these formulas for calculating the least depth required on our trial course.

2. Closeness to Shore.—The course must be close to some shore line, for it must be possible to sight on fixed markers (beacons) set up on shore. The distance between these markers is accurately surveyed. There are very few places in this country where there is sufficient depth close enough to the shore line to permit the markers to be seen. About 1 mile is the maximum distance for good visibility.

3. Tides and Currents.—Ideally, the course should be free of tides and currents. This, of course, is impossible; but if conditions permit, the course should be such that the tides and currents will be small and will run nearly parallel to it.

4. Direction of the Course.—An east-west course with the range beacons to the north is more desirable than a north-south course. With the latter it is necessary during some part of the day to pick up the markers against the sun.

5. Weather.—The course should be in a locality that is not affected too often by fogs and strong prevailing winds.

6. Sea Protection.—The course should be protected from large waves.

7. Right of Way.—The course should not be located across a much-used trade lane, for traffic might interfere with the trial.

To be able to locate a course to meet all the above requirements would be indeed fortunate. All courses now used are deficient in one or more of these particulars. There are five deepwater courses now in general use for vessels built in the United States. They are

1. Rockland, Me., in Penobscot Bay (see Fig. 177) for surface ships.
2. Provincetown, Mass., for submarines.
3. San Pedro, Calif., for surface ships.
4. San Diego, Calif., for submarines.
5. Guantánamo Bay, off the coast of Cuba, for surface ships.

We shall discuss only one of the above courses, that at Rockland, Me. This is considered by the United States Navy to be the best all-round deepwater course in the country. The most important drawbacks of the Rockland course are the great distance from some of the shipyards, the fog, and the extremely cold weather in winter.

LAYOUT OF THE COURSE

The trial course at Rockland is laid out as shown in Fig. 177 and runs approximately north and south. There are six large can buoys on the course, painted white. The total run between extreme buoys is 7 miles. There are a 3-mile approach at either end for high-speed runs and a 1-mile approach for slow-speed runs. The depth of water on the course averages about 400 ft. Substituting the characteristics of the *S.S. America* in the Taylor formula for minimum depth of water gives

$$\text{Minimum depth} = \frac{10d \times \text{speed}}{\sqrt{L\ \text{ft.}}} = \frac{10 \times 28\ \text{ft.} \times 23\ \text{knots}}{\sqrt{666\ \text{ft.}}} = 250\ \text{ft.}$$

And substituting this in the formula given by Comstock and Hancock,

$$0.75 \times 666\ \text{ft.} = 500\ \text{ft.}$$

The depth of water is ample by Taylor's formula but is not quite sufficient by Comstock and Hancock's.

Traveling south on the course the observers line up the marker beacons, which can be seen in Fig. 177. When the three beacons are in line, the ship is "on the mile" (a nautical mile of 6,080 ft.).

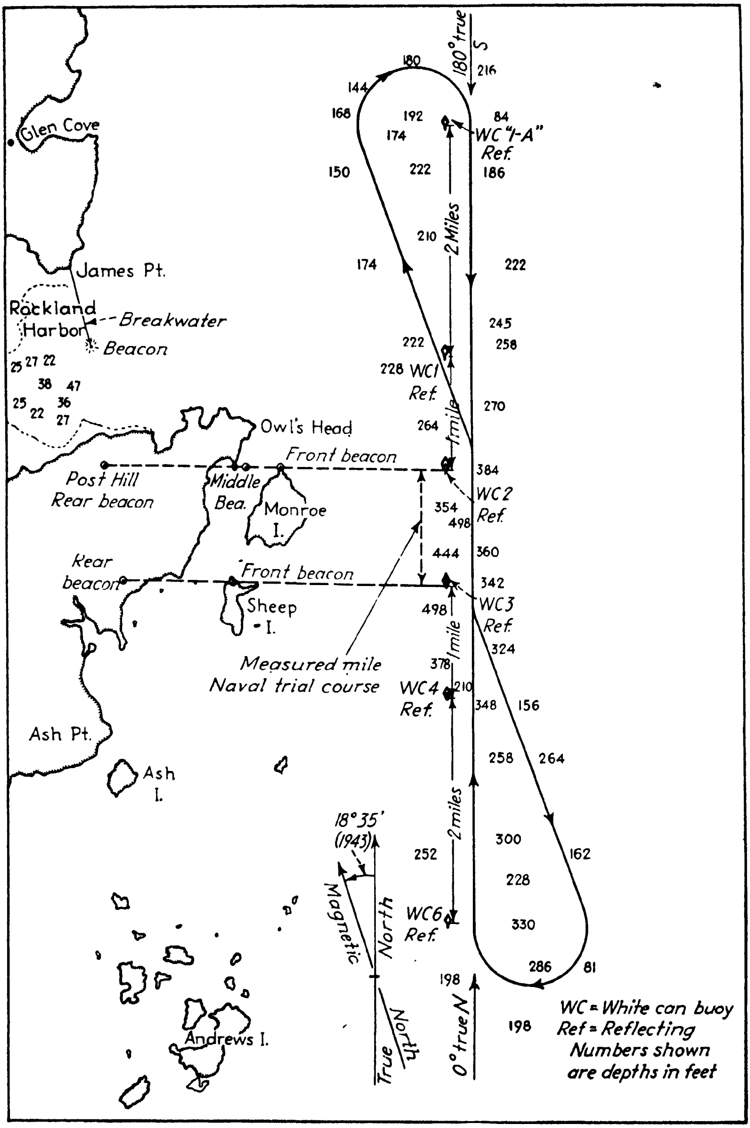


FIG. 177.—The U.S. Navy trial course at Rockland, Me.

When the second set of beacons are lined up, the ship is "off the mile" and after a short run turns as indicated by the arrows and retraces her run. Note that the turn is always made so as to get a long straight approach to allow time for accelerating.

The beacons are constructed on structural steel bases and have a tubular "transit" pole affixed to the top of the structure. For added visibility in light fogs and at night the rear beacons have 500-watt electric reflecting lights affixed to their tops.

The course is in Penobscot Bay; therefore, heavy seas are seldom encountered. The tide over the course sets practically parallel with the course and usually averages less than ½ knot.

THE STANDARDIZATION RUNS

To plot the curves shown in Fig. 176, we must make a series of runs over the measured mile and while the ship is under way measure accurately the revolutions of the propellers, the speed, and the horsepower developed. We usually make three runs over the mile at each speed, one in one direction and two in the other. For the full-power runs the ship usually traverses the mile five times.

TIMING

We cannot use an average of the ship's time over the mile for obtaining the average speed, for the answer might be seriously in error. This may be simply illustrated by the following:

Problem: Assume that a man is rowing in a river that has a downstream current of 2 knots. *He is able to row the boat at the speed of* 4 *knots.* Therefore, going upstream he is able to make a speed over the ground of 2 knots; downstream, a speed of 6 knots.

Solution: The time to row 1 mile upstream would be

$$\frac{1 \text{ mile}}{2 \text{ knots}} = 0.5 \text{ hr. or } 30 \text{ min.}$$

The time to row 1 mile downstream would be

$$\frac{1 \text{ mile}}{6 \text{ knots}} = 0.166 \text{ hr. or } 10 \text{ min.}$$

s a comparison, we average both time and speed and see which correct.

Direction	Time, min.	Speed, knots
Upstream	30	2 *
Downstream	10	6
Total	40	8

The average time of the runs would be;

$$\frac{40 \text{ min.}}{2} = 20 \text{ min. or } 0.33 \text{ hr.}$$

So average knots based on averaging time would be

$$\text{Speed} = \frac{\text{distance}}{\text{time}} = \frac{1 \text{ mile}}{0.33 \text{ hr.}} = 3 \text{ knots}$$

Now, averaging the speeds we should have

$$\frac{8 \text{ knots}}{2} = 4 \text{ knots}$$

which is the actual speed assumed. Averaging the speeds agrees with the original assumption of a rowing speed of 4 knots. Had we averaged time instead of speed we should have obtained 3 knots, which would be in error by

$$4 \text{ knots} - 3 \text{ knots} = 1 \text{ knot}$$

In ship timing the tide and the wind seriously affect the results. The tide is compensated by taking a mean of means of the runs, which is simply an average of more than two runs. The wind effect is calculated later. This mean of means (or averaging of the runs) is not correct unless the trial speeds during each run are very nearly constant both ways. Admiral Taylor in his "Speed and Power of Ships" brings out this fact clearly.

Omitting details, to obtain this mean of means we attach twice as much importance to the second run as we do to the first and third. Giving twice as much weight to the second run as we do to the first and third helps to eliminate the tide effect. To illustrate the above, assume that we make three runs at the following speeds and that the tide is decreasing 0.2 knots each run. Then as shown in the table below we should obtain the correct average speed of 15 knots:

Direction	Speed on mile, knots	First mean, knots	Second mean, knots
Run north	15.5	15.1	15
Run south	14.7	14.9	
Run north	15.1		

If we had added the speeds of the above three runs and then divided the sum by 3, we should have obtained 15.1 knots, which would have been in error by $\frac{1}{10}$ knot.

DISPLACEMENT

As the displacement, or the weight of the ship, has a great effect on the power required, a standard trial displacement is written into the contract. It is very important that the mean trial displacement be reached at the middle of the full-power runs. If the ship falls much below the mean trial displacement (weight), the runs should be voided and run over.

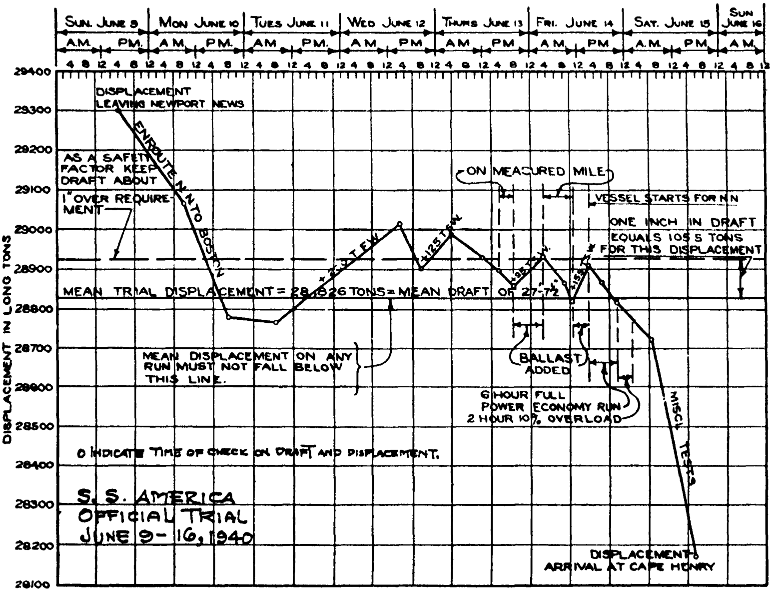
Figure 178 shows a graph of the displacement of the *S.S. America* from the time she left Newport News until she arrived off Cape Henry (Virginia Capes) on her return. It will be noted from the figure that the ship left Newport News at 4:00 P.M., Sunday, June 9, with a displacement of 29,300 tons. At 6:00 P.M. she had passed the Capes.

ADJUSTING THE MAGNETIC COMPASSES (SWINGING SHIP)

As soon as the *S.S. America* was at sea a few miles east of the Virginia Capes, a professional compass adjuster compensated the ship's magnetic compasses. There are usually three magnetic compasses aboard an ocean liner (not including those in the lifeboats): one in the pilothouse, the standard compass on top of the pilothouse, and one at the after steering station. Although gyroscopic compasses are now standard equipment on all large American vessels, magnetic compasses are nevertheless fitted as a precaution in case the gyro compass should fail and also as a check on the latter.

As magnetic compasses are directed by the earth's magnetic field and as the steel in the vessel may deflect that magnetic field locally, it is necessary to correct the compasses to eliminate all, or nearly all, the deviation. (Deviation is the deflection of the compass needle away from the actual magnetic north.)

Because the strength of a magnetic field varies as the square of the distance from the point of affectation, it is possible to use a group of relatively small round bar magnets located in the binnacle below the compass to counteract the ship's local effect on the earth's magnetic field. The two large round iron balls on either side of the compass are also used in this connection.



MEAN TRIAL DISPLACEMENT CURVE

FIG. 178.

The compass adjuster has the ship headed for a short run on such courses as magnetic north, south, east, and west and then northeast and northwest. While at each of these headings, he changes the magnets and iron balls until the deviation is all, or nearly all, eliminated. At the same time an observer uses a pelorus to obtain the exact heading of the vessel from a shadow from the sun and depends upon this for his work. After the deviation has been corrected as much as possible by these means, the ship is again slowly turned through 360 deg. and the remaining uncorrected deviation is recorded every 15 deg. The deviation, after compensation has been completed, is ordinarily not over a degree or two and frequently is zero for most headings. The navigator must take any existing deviation into account in his work at sea; therefore the remaining deviation is marked on a card, and a correction is made for this when the ship is being navigated by magnetic compass.

FURTHER CHECKING

On the trial run of the *S.S. America,* after the compasses were adjusted the ship started for Boston for dry docking and bottom cleaning. On June 10, a preliminary full-power dress-rehearsal run was made en route. This was completed at 4:00 P.M. At 8:00 P.M. that night the ship anchored in Boston Harbor. The displacement at that time was 28,780 tons. This figure was obtained by reading internal-draught gauges, which are affixed forward, amidships, and aft. With the average draught known the displacement is read from the displacement curve. (A small correction must be made for hog, or sag, and for the density of the water. See Chap. XV, page 162, for a memory refresher.) The vessel was placed in dry dock on June 11, at 7:45 A.M., and the crew given shore leave.

At 1:15 P.M. on June 12, the ship was clear of the dry dock and proceeding to Rockland, Me. It will be noted that 230 tons of fresh water had been added at Boston, which increased the displacement to 29,010 tons. This is somewhat above the 28,820 required for trial. At 5:15 P.M. the *S.S. America* had arrived off Monhegan Island, south of Rockland, and was hove to because of fog. The displacement was checked; as it was too low owing to consumption while anchored, 125 tons of salt-water ballast was added. On June 13 at 10:30 A.M. the ship was still anchored off Monhegan Island, owing to the fog.

In order to utilize this time it was decided to hold the *anchor-windlass test.* This test is a working trial of the anchor windlass under specified conditions. It must be held in 30 fathoms or more of water (a fathom is 6 ft.). The windlasses must raise both anchors and their chains simultaneously at the rate of at least 6 fathoms per min.

The anchors are then let go and their braking apparatus must be able to stop the anchor and 30 fathoms of chain within a distance of 2 fathoms. Sometimes brakes fail to hold; therefore, it is best to clear the deck before the test, for the bitter end of the anchor chain may lash out of the chain locker and sweep the deck with great speed and violence.

At 12:16 P.M. the fog had cleared, and the ship proceeded toward Rockland. At 3:36 P.M., June 13, the ship was on the measured mile. At this point we shall consider the apparatus used to determine speed, horsepower, and r.p.m.

TRIAL EQUIPMENT

The United States Navy and the Maritime Commission provide complete sets of special equipment for use aboard ships during trial. This equipment is placed aboard the ship sometime before the trial and is distributed about as shown in Fig. 179. This figure should be consulted during the following discussion.

1. The Smith-Cummings Mechanical Revolution Counter.—The Smith-Cummings revolution counter is attached to each shaft at some point in the shaft alley. An observer stationed at the counter copies the readings on a special data pad and sends them by messenger to the computing room, where they are tabulated. This counter is in reality two counters, one of them running only while on the measured mile and the other running at all other times. When the midship deck observer (see Figs. 179 and 180) clicks the key upon sighting the two beacons in line, he starts one of the counters and stops the other. At the end of the mile he again presses the key, which stops one counter and starts the other. The reading from this counter is used only if the Taylor counter fails.

2. The Taylor Electric Printing Revolution Counter.—One of these Taylor counters is attached to each shaft at a point in the shaft alley. The counting mechanism is operated by a worm drive directly from the shaft. Both the forward and aft observers operate this counter so that two sets of readings are obtained. These are printed on a tape, which is torn off and sent to the computing room.

Both the Taylor and Smith-Cummings counters are started simultaneously with the chronograph, which is located in the computing room.

3. The Chronograph.—This is a special instrument made at the model basin in Washington especially for trial trips. A chronometer is attached to the chronograph that, by means of an electric make-and-break circuit, scratches a ½-sec. broken line on waxed paper fed through the machine. These ½-sec. interval marks make it possible to count the time interval between the marks on the waxed paper made when the deck observers click the contact makers. The anemometer (wind-gauge) readings and revolutions of the shaft are also recorded on this waxed tape, a picture or record of the entire operation being thus created.

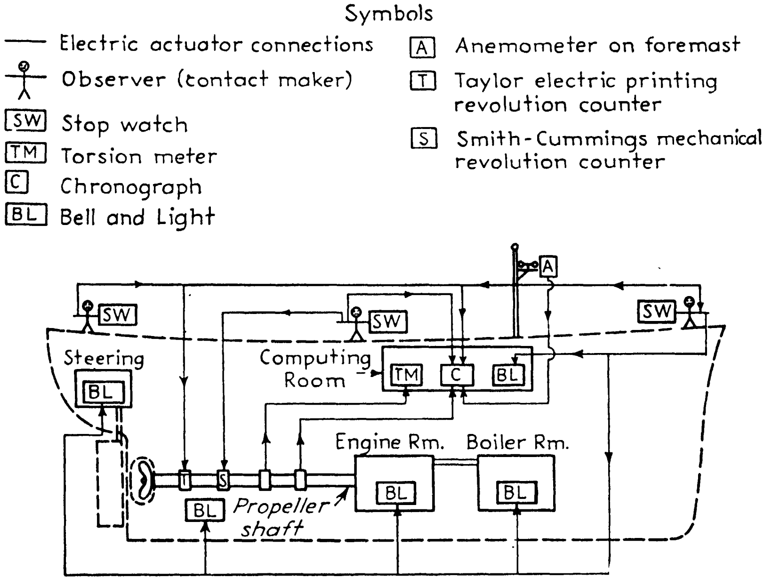


FIG. 179.—Schematic diagram showing arrangement of instruments throughout the ship for making observations on the measured mile, *S.S. America*.

4. The Electric Torsion Meter.—This device is placed on each shaft to record the twist of the shaft in a certain length. As this twist is small, it is magnified mechanically, electrically, or optically. The Ford torsion meters used on the *S.S. America* were of the electric type. This measured twist is proportional to the torque developed.

The shaft horsepower (s.hp.) developed is found by the following formula:

$$\text{s.hp.} = \frac{\text{r.p.m.} \times \text{torsion-meter reading}}{c}$$

c in the formula is obtained by multiplying a rigidity factor for the particular propeller shaft by the torsion-meter factor that is inherent in the instrument used or by calibrating the shafts in the shop before installation by applying a known torque and measuring the twist.

To obtain a zero reading for the torsion meter we allow the propellers to idle. This is done by getting the ship under way at a speed of at least 5 knots and then shutting off the steam. The propeller shafts rapidly slow down until the idling speed of the propeller is reached. From this point on, the propeller revolutions drop very slowly, and the twist in the shaft most nearly approaches zero. In order to obtain a good zero reading we attempt to read the zero for the torsion meter right at the transition point between the rapidly decelerating and the slowly decelerating propeller. The zero reading is noted, and the steam is again allowed to pass into the turbines. Any reading above this zero reading just obtained is proportional to the torque in the shaft.

While the ship is on the measured mile, the torsion meters are read about every 10 sec. The results are averaged and combined with the r.p.m. of the shafts to obtain an average horsepower over the mile.

5. The Contact Makers.—Each of the three deck observers has one contact maker in his hand. This is a squeeze-type electric contact device connected electrically to the chronograph and to one of the counters in the shaft alley. A stop watch is attached at the top of the squeezing device (see observer's right hand, Fig. 180). When the contact is made by any of the observers, it makes a record on the chronograph in the computing room. If actuated at either the forward or after observation post, it starts the Taylor counter in the shaft alley. If actuated at the midship post, it starts the Smith-Cummings counter, also located in the shaft alley. The act of contact making also starts or stops a stop watch attached to the contact-making squeezing device. A record of the elapsed time over the mile as recorded by the stop watch is marked down on a slip of paper and sent to the computing room. The stop-watch timing marked on the paper is not used unless the electric chronograph fails.

6. The Bell-and-light System.—Bells and lights are located about as shown in Fig. 179. The forward-deck observer operates this system and gives a double bell-light warning 30 sec. before the measured mile is reached and a single bell light at the beginning and end of the mile for the information of the engine-room and data-taking personnel.

7. Control Panel.—The electric control panel for controlling the trial equipment is located in the trial-board room.

8. Anemometer.—The anemometer is located on a bracket on the mast or on the signal yard and is electrically connected to the chronograph. The wind speed at each instant is recorded on the waxed tape.

9. Fuel-oil Meters.—Always one and very frequently two fuel-oil meters are connected in series to each fuel-oil line. These meters are accurately calibrated before and after the trial. During the trial, they show the amount of fuel oil used during any interval.

CREW AND SPECIAL PERSONNEL

The crew operating the ship is made up of the personnel of the shipyard that constructed the vessel. Besides the regular operating crew, there are

1. *The management's representative.* He is in charge of the vessel for the shipyard.

2. *The trial board,* in charge of conducting the actual trials. They maintain their own staff of experts, who go from ship to ship conducting trials.

3. *Navigating crew,* consisting of a captain and usually three mates. A captain is chosen who is familiar with the trials of ships and particularly with the trial course chosen.

4. *Representatives of the hull and engine departments.* Usually represented by the naval architect and the chief engineer.

5. *Owner's representatives* (for merchant vessels) *and supervisory prospective crew members.*

6. *Sub-contractor's representatives.* As some of the auxiliary machinery of a vessel is subcontracted, the subcontractors are represented by experts on the various pieces of machinery that they have supplied. They observe the operation of their machines and stand by to give any aid they can should their particular installation give trouble.

7. *Data takers.* These men read the various gauges, thermometers, revolution counters, torsion meters, fuel meters, etc., and serve as contact makers and computers.

The total persons aboard the *S.S. America* numbered 799, very few of whom were not actually engaged in necessary duties.

Usually on the way to the trial course the ship's company and data takers will have several dress rehearsals to familiarize the personnel with their duties. The trial board sometimes goes to the course with the ship but more often boards the vessel just before she goes on the measured mile. The trial board brings its own special instruments, forms, data books, and chronograph.

Just before the trial is about to start, the data takers are called together and given final instructions. Then they proceed to their appointed stations.

ACTIVITY IN THE ENGINE AND BOILER ROOMS

While not directly connected with the timing of the trials the engine- and boiler-room personnel have important functions. Steam pressures and temperatures, fuel-oil pressures and temperatures, bearing temperatures, forced-draught pressures, noise levels, reduction-gear noises, and many other items are all recorded to show that the machinery is meeting the requirements of the specifications. During the economy trials every effort is made to avoid wasteful use of lights, pumps, galley equipment, ventilation, fans, etc., for this adds to the fuel consumption and decreases economy.

THE MEASURED MILE

As previously mentioned, the object of running the measured mile is to ascertain the relationship between r.p.m. and speed as well as the maximum speed obtainable. The trials on the mile are therefore run at progressive speeds. An attempt was made to run the *S.S. America* over the mile at speeds of 10, 15, 18, 21, and 22.5 knots and at full power. To obtain these speeds (which would give a good spread of spots on the r.p.m.-speed curve, Fig. 176) the number of r.p.m. to give the speeds required was estimated in advance from the model-basin curves shown in Fig. 176.

The estimated information on the r.p.m. to give the required progressive speeds is given to the engine-room supervisors. With all observers in place, the ship is ready to enter the measured mile. The forward deck observer has a contact maker, which he presses 30 sec. before the ship enters the mile. This 30-sec. notice is indicated by two bells and lights at the spaces noted in Fig. 179. Also, over the ship's loud-speaker system comes the warning, "We are now coming on the range—we are now coming on the range—we are now on the range." As the ship crosses the line of the markers, the following events take place:

1. The forward observer upon getting the two shore beacons in his line of sight presses the bell-light contact once and also presses the contact maker, thus tripping the Taylor counter in the shaft alley and making a mark on the chronograph tape in the computing room. The stop watch in the contact maker also is started by squeezing the contact maker.
2. A few seconds later, the shore beacons line up with the line of sight of the midship observer (Fig. 180), and he presses the contact maker. This starts the stop watch, starts one of the Smith-Cummings counters and stops the other, and makes a record on the chronograph tape.
3. The shore beacons then come into the line of sight of the aft observer, and he presses the contact maker, which starts a stop watch, again trips the Taylor counter, and makes a record on the chronograph.

At the bell-light signal, flashed by the forward observer, the data takers take readings of oil temperatures, bearing temperatures, etc. At the end of the mile the three observers press their respective contacts as the markers come in line.

Immediately after the ship leaves the mile, the computers in the computing room start to work from the collected data. They must calculate the r.p.m. and shaft horsepower so that they may send these data to the engine room before the ship turns and enters the measured mile again.

It is highly important that any one set of runs over the measured mile be made at a constant speed. This is difficult to do in practice. If the runs are too erratic the result of the means of the runs is doubtful.

Note the precautions taken to prevent the loss of a run over the course.

1. If either the forward or the aft observer fails, the other observer will trip the Taylor counter and mark the tape on the chronograph.

2. The midship observer is independent of both the other observers, for he operates the Smith-Cummings counter and makes his own mark on the chronograph tape.

Photograph by Wythe W. Holt

FIG. 180.—Sighting the beacons on the measured mile. The author as midship deck observer on the official trial of the *S.S. America*. The beacons are located on the shore line, which is barely visible in the background. The stop watch attached to the top of the contact-making device may be seen in the observer's right hand. Pressure on the contact maker starts the stop watch and, through an electrical connection, starts one Smith-Cummings counter in the shaft alley and stops the other and makes a mark on the chronograph tape in the computing room.

3. If all three observers fail to mark the chronograph tape, the timings may be taken from the stop watches.

If the time recorded by the three observers varies 0.3 sec. (naval vessels), the run is usually thrown out.

The Backing Standardization Run.—The ship is usually backed over the measured mile to obtain r.p.m.-speed at about 90 per cent of full-power backing. This is to get r.p.m. for the astern test.

After making all runs at the progressive speeds previously indicated and the backing run, we plot the results of the runs on a curve as shown in Fig. 176 and are ready to proceed to sea for the endurance and economy runs.

Note here from Fig. 178 that the displacement of the vessel has been kept to an average of about 28,870 tons. As the tons per inch immersion of the *S.S. America* at this draught was about 105 tons, she averaged about 27 ft. 8 in. draught, which gave a ½-in. draught to spare.

ENDURANCE AND ECONOMY RUNS

During endurance and economy runs, signals are given from the forward deck observer station every 30 min. so that data takers may take simultaneous readings. Sometimes these signals are only 15 min. apart. The torsion meters are read at more frequent intervals.

Full-power Four-hour Endurance and Economy Run.—This run is made at full power to measure the fuel oil burned per shaft horsepower and to test the reliability of the machinery and boilers. Often no bonus is paid for overpower, but a deduction is usually specified in the contract for underpower. For the *S.S. America* the 8-hr. run described below was substituted for this run.

Eight-hour Endurance and Economy Trial.—As the contract on the *S.S. America* for fuel oil consumed was based on speed and not on horsepower developed, speed was used as a criterion of these runs. (Quite often fuel-oil consumption is based on horsepower developed.) Such endurance and economy trials are held in deep water, and the ship is so ballasted that she reaches her mean trial displacement at the middle of the run. Note from Fig. 178 that the *S.S. America* was within ¼ in. of this required draught. The run consisted of 6 hr. of full power plus a 2-hr. run with boilers at 10 per cent overload. Half of the run was made with the wind and half against the wind so as to minimize the wind effect.

MISCELLANEOUS TESTS

There are several miscellaneous tests that are usually made on the way home.

The log of the *S.S. America* on trial follows:

June 14, 4:15 A.M., start dragging shafts for torsion-meter zeros.
4:28 A.M., finish dragging shafts for torsion-meter zeros.
5:00 A.M., start first 18-knot standardization run.

10:16 A.M., finish last full-power standardization run; proceeding to Newport News.
2:30 P.M., start 6-hr. full-power economy trial.
8:30 P.M., finish above trial.
8:30 P.M., start 2-hr. 10 per cent boiler overload run.
10:30 P.M., finish above run.
June 15, 8:00 A.M., start ahead steering tests.

Steering tests consist of several maneuvers, which were as follows for the *S.S. America:*

1. *Steering-gear and rudder test.* The rudder is put hard over to hard over. This test is a modification of the old figure 8 maneuver. Most landlubbers get quite a thrill from it. The angle of heel is very seldom over 18 deg. but appears to be much greater. During this test it is best to remove dishes, etc., from the tables and to stop galley operations. This test is primarily for the steering gear and rudder.

2. *The Z maneuver.* This is a test of maneuvering ability. The rudder is put over to 20 deg. at full power (also at half power) and held there until the ship is at 20 deg. to its original course. When the angle is reached, the helm is put over 20 deg. to the opposite side and held until the ship is 20 deg. to the other side of her original course. The rudder is then put over to the opposite side and held until the vessel is back on the original course. The total time elapsed between the beginning and the end of the maneuver is indicative of the maneuvering ability of the ship.

3. *Astern steering tests.* The rudder is put hard over to hard over while under full-power astern. The oil pressure in the steering engine should not exceed the design pressure. The time required for hard over to hard over is noted.

4. *Turning diameter.* This is determined by a turning test at normal horsepower. A floating object is thrown overboard, and the turning diameter is observed at intervals through a small range finder as the vessel completes the turn. A small navigational range finder is adequate. From these data the tactical turning diameter is obtained.

5. *Crash backing test.* This consists of a change-over from full power ahead to full power astern. The time required and distance traveled from full power ahead to dead in the water are noted.

Besides the above tests the trial board or owner's representatives check on

1. Unfinished work.
2. Proposed alterations.
3. Rolling period of ship.
4. Auxiliary-machinery operation.
5. Angle of squat at various speeds (for high-speed ships).

The ship is also given a general inspection.

By this time the ship is in sight of her birthplace, and a broom is usually seen tied at her masthead to denote that she has made a clean sweep of all trials. Most of the crew members aboard are only too glad to get home for some much-needed sleep. The ship is tied up to the pier and after a few minor adjustments and changes is ready to be delivered.

Figure 181 shows the *S.S. America* after the trials as she left the yard to go to New York for delivery to her owners, the United States Lines.

Problems

1. What is the purpose of the trial trip?

2. What is meant by swinging the ship?

3. Why is it necessary to run a self-propelled model of a large ship in the model basin before we take the ship to the measured mile?

4. What are some of the usual guarantees that have to be made by a shipbuilder?

5. Where are economy trials run?

6. What is the difference between a builder's trial, an official trial, and a preliminary-acceptance trial?

7. List six requirements of a trial course.

8. Name two trial courses for submarines.

9. Why is it not feasible to average the time over a measured course in order to determine the average speed?

10. How much excess draught is usually allowed as a safety factor on the measured mile and the economy trials?

11. Describe the anchor-windlass test.

12. Who furnishes the trial equipment?

13. How many revolution-counting machines are used on the measured mile?

14. Describe what happens when the midship observer clicks his contact maker.

15. How is the recording done on the chronograph?

16. Why are shafts dragged?

17. Describe what happens as the ship crosses the line of the first beacons.

18. What is the purpose of the economy run?

19. What precautions should be taken during this run?

20. Describe the *Z* maneuver.

21. What is the purpose of the steering test?

22. Describe a crash backing test.
23. What does a broom at the masthead signify?

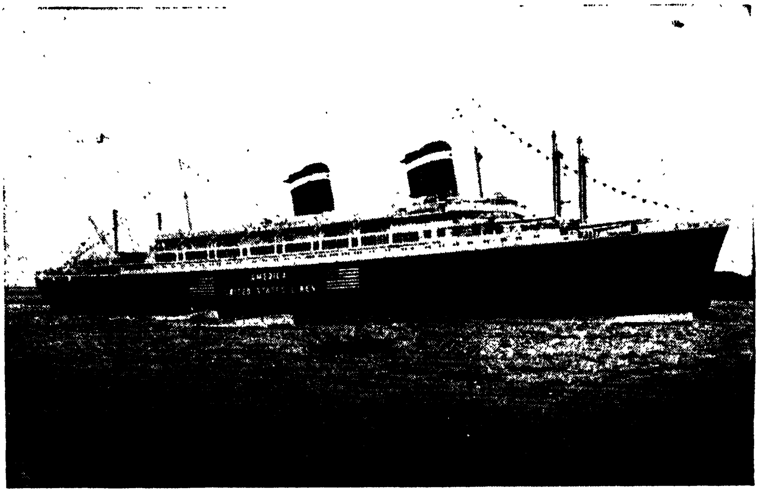


Fig. 181.—The finished job. Leaving her builder's yard for delivery to her owners, the United States Lines.

Bibliography

Taylor, Adm. D. W.: "Speed and Power of Ships," U.S. Maritime Commission, Washington, D.C.

Data on Official Trials *S.S. America*, from files of Engine and Hull Technical Divisions, Newport News Shipbuilding and Dry Dock Company.

BOOKS RECOMMENDED FOR ADVANCED STUDY

The list below by no means covers the advanced field. There are numerous valuable books not listed here. The following texts have been carefully reviewed and are recommended to the ambitious student.

Naval Architecture and Strength of Materials

COMSTOCK, J. P.: "Introduction to Naval Architecture," Simmons-Boardman Publishing Corporation, New York. An excellent text for the beginner in naval architecture whether a high-school graduate or a transfer from some other branch of engineering. Combines the theoretical and the practical considerations of ship design. Very clearly written.

ATTWOOD and PENGELLY: "Theoretical Naval Architecture," Longmans, Green and Company, New York. A standard work on naval architecture. More advanced than Comstock's book above. Well written and up to date. Numerous practical problems add to its value.

TAYLOR, ADM. D. W.: "The Speed and Power of Ships," U.S. Maritime Commission, Washington, D.C. A classical work on speed, power, and propulsion. The curves given in the back of the book are invaluable to the naval architect and marine engineer. Highly recommended.

"Principles of Naval Architecture," 2 vols., Society of Naval Architects and Marine Engineers, New York. Written by a group of experts and edited by Rossell and Chapman. This book is more a reference book than a textbook. Highly technical. No problems. Not recommended for the beginner, but an excellent book for more advanced students.

MURRAY, A. J.: "Strength of Ships," Longmans, Green and Company, New York. Now out of print but still available in some bookstores. The age of the book limits its value, but it is still of considerable use to the student.

LOVETT, W. J.: "Applied Naval Architecture," Longmans, Green and Company, New York. The application of the principles of naval architecture to practical problems. A good text but has not been revised to cover modern practice. Still of value to the student.

HOVGAARD, WILLIAM: "The Structural Design of Warships," United States Naval Institute, Annapolis, Md. An excellent treatise on the design of warships. Revised 1940.

MANNING and SCHUMACHER: "Principles of Warship Construction and Damage Control," United States Naval Institute, Annapolis, Md. A treatise on the fundamental principles of naval architecture and the

control of hull damage. Written for the operating personnel of the United States Navy.

LEIGH and MANGOLD: "Practical Mechanics and Strength of Materials," McGraw-Hill Book Company, Inc., New York. An excellent book for the beginner. Advanced mathematics not required to follow the reasoning.

TIMOSHENKO and MCCULLOUGH: "Elements of Strength of Materials," D. Van Nostrand Company, Inc., New York. More advanced than the preceding text. Well presented. A knowledge of calculus is necessary.

SKENE, N. L.: "Elements of Yacht Design," Kennedy Bros., Inc., New York. A good book for students interested in the design of small boats.

Marine Engineering

"Naval Machinery," United States Naval Institute, Annapolis, Md. Discusses the fundamentals behind the design of the main propelling and auxiliary-machinery units. A good elementary text. Mostly descriptive.

"Marine Engineering," 2 vols., Society of Naval Architects and Marine Engineers, New York. Written by a group of experts. Gives the design principles of marine engines and auxiliaries. Too advanced for the beginner.

OSBOURNE, ALLEN: "Modern Marine Engineer's Manual," 2 vols., Cornell Maritime Press, New York. A good all-round handbook for the operating personnel. Also contains valuable design data.

LABBERTON, J. M.: "Marine Engineering," McGraw-Hill Book Company, Inc., New York. An excellent book for the beginner. Broad coverage of the field, backed up by practical problems.

CHAPMAN, L. B.: "Marine Power Plant," McGraw-Hill Book Company, Inc., New York. Deals primarily with merchant vessels. Good coverage of the engineering developments in foreign ships. Suitable for the beginner.

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