

# Contents

## Part I Torsion Stresses in Ships

<b>1</b>	<b>Torsion Stresses in Ships</b>	<b>3</b>
1.1	Introduction	3
1.2	Torsion Loading of Beam Elements	3
1.2.1	Direct Torsion Loads	3
1.2.2	Induced Torsion Load	3
1.3	Variation of Torque and Angle of Twist along Beam Length	4
1.3.1	Beams Subjected to Concentrated Torques	4
1.3.2	Beams Subjected to Uniformly Distributed Torsion Loading	5
1.4	Torsion of Uniform Thin Walled Sections	6
1.4.1	Pure Torsion of Uniform Open Thin-Walled Girders	6
1.5	Torsion of Uniform Thin-Walled Closed Sections	9
1.6	Basic Equations of Torsion of Thin-Walled Closed Sections	10
1.6.1	Shear Flow and Stress	10
1.6.2	Rate of Twist	11
1.7	Torsion of a Uniform Thin-Walled Tube	12
1.7.1	Angle of Twist	12
1.7.2	Torsion Shear Stress	13
1.8	Comparison between Open and Closed Thin-Walled Sections	16
1.8.1	Circular Section	16
1.8.2	Square Section	18
1.9	Torsion Constant of Uniform Thin-Walled Closed Sections with Attached Open Sections	19

<b>2</b>	<b>Torsion Stresses in Thin-Walled Multi-Cell Box-Girders . . . . .</b>	<b>21</b>
2.1	Torsion of Uniform Thin-Walled Two-Cell Box-Girders . . . . .	21
2.2	The General Case of a Uniform Two-Cell Box Girder. . . . .	26
2.3	Torsion Stresses in a Two Identical Cells Box-Girder . . . . .	29
2.3.1	Shear Flow $q$ . . . . .	29
2.3.2	Shear Stress $\tau$ . . . . .	29
2.3.3	Rate of Twist $\theta$ . . . . .	30
2.4	Torsion of Three-Cell Box-Girder . . . . .	30
2.5	Torsion of Uniform Thin-Walled Multi-Cell Box-Girder . . . . .	33
2.6	Combined Open and Closed Thin-Walled Sections . . . . .	34
2.6.1	Combined Open Section with One Closed Cell . . . . .	34
2.6.2	Combined Open Section with Two Closed Cells . . . . .	35
<b>3</b>	<b>Torsion Warping Deformations and Stresses . . . . .</b>	<b>41</b>
3.1	Torsion of Thin-Walled Variable Section Beams . . . . .	41
3.1.1	Free Warping . . . . .	41
3.1.2	Constrained Warping . . . . .	41
3.1.3	Warping of Thin-Walled Sections . . . . .	43
3.1.4	Flexural Warping Stresses . . . . .	46
3.1.5	Development of the General Equation of Torsion . . . . .	47
3.1.6	Solution of the Torsion Equation. . . . .	54
<b>4</b>	<b>Torsion of Container Ships . . . . .</b>	<b>65</b>
4.1	Torsion Loading on Ships . . . . .	65
4.2	Torsion Loading of Open-Decked Ships. . . . .	66
4.3	Torsion Loading on Catamaran Vessels . . . . .	70
4.4	Warping Deformations and Stresses in the Deck Structure of Container Ships. . . . .	72
4.5	Torsional Deformation of Ship Hull Girder . . . . .	72
4.6	An Approximate Method for Torsion Analysis of Open Deck Vessels . . . . .	74
4.7	Calculation of the Shear and Flexural Warping Stresses . . . . .	75
4.8	Solution of the Torsion Equation . . . . .	75
4.8.1	Boundary Conditions . . . . .	75
4.8.2	Distribution of Torsional Loading . . . . .	76
4.8.3	Solution of the Torsion Equation for Constrained Warping . . . . .	77
4.8.4	Calculation of the Sectorial Properties of Ship Section . . . . .	78

4.9	Total Stress in the Deck Plating of Container Ships due to Hull Girder Bending and Torsional Loading. . . . .	85
4.9.1	Hull Girder Stresses due to Vertical Bending . . . . .	86
4.9.2	Horizontal Hull Girder Bending Stresses . . . . .	87
4.9.3	Local Stresses . . . . .	87
4.9.4	Flexural Warping Stresses . . . . .	88
4.9.5	Total Stress Over the Deck Plating . . . . .	89
<b>5</b>	<b>Sectorial Properties of Thin-Walled Open Sections . . . . .</b>	<b>91</b>
5.1	Introduction . . . . .	91
5.2	Sectorial Properties of Thin-Walled Sections . . . . .	91
5.2.1	Principal Sectorial Properties of Thin-Walled Sections. . . . .	93
5.2.2	Position of the Shear Center . . . . .	94
5.2.3	Sectorial Area Diagram . . . . .	95
5.2.4	Procedure of Calculation . . . . .	96
5.3	Applications to Some Typical Sections . . . . .	96
5.3.1	Sectorial Properties for Thin-Walled Sections Free to Warp . . . . .	96
5.4	Sectorial Properties for a Thin-Walled Section with an Enforced Axis of Rotation . . . . .	101
5.4.1	A thin-Walled T-Section with an Enforced Axis of Rotation . . . . .	101
5.4.2	Enforced Center of Rotation for a Thin-Walled Angle Section. . . . .	102
5.4.3	Enforced Center of Rotation at a Point C on the Opposite Side of a Thin-Walled Asymmetrical Fabricated Section. . . . .	102
<b>6</b>	<b>General solution of the torsion equation . . . . .</b>	<b>105</b>

**Part II Shear Loading and Stresses in Ships**

<b>7</b>	<b>Shear Stresses in Thin-Walled Structures . . . . .</b>	<b>111</b>
7.1	Basic Principles . . . . .	111
7.2	Shear Stresses in Beams due to Bending . . . . .	111
7.2.1	Solid Beams . . . . .	111
7.2.2	Average Shear Stress . . . . .	114
7.2.3	Shear Flow and Stress in Thin-Walled Sections . . .	115
7.3	Shear Centre. . . . .	124

7.4	Shear Deflection . . . . .	127
7.4.1	Shear Deformation. . . . .	129
7.5	Shear Lag. . . . .	130
<b>8</b>	<b>Shear Flow and Stresses in Thin-Walled Box-Girders . . . . .</b>	<b>133</b>
8.1	Single Cell Box-Girder . . . . .	133
8.2	Shear Flow in Asymmetrical Closed Box-Girders Subjected to a Vertical Shear Force $F$ . . . . .	135
8.3	Shear Stresses in Thin-Walled Two-Cell Box-Girders . . . . .	142
8.4	Calculation of the Correcting Shear Flow for 3-Cell Box-Girders Subjected to Shear Load . . . . .	146
<b>9</b>	<b>Shear Flow and Stresses in Ships . . . . .</b>	<b>149</b>
9.1	Introduction . . . . .	149
9.2	Procedure of Calculation of Shear Flow Distribution. . . . .	149
9.2.1	Ship Section Idealization . . . . .	149
9.3	Determination of the Effective Thickness. . . . .	157
9.4	Shear Flow Calculation . . . . .	157
9.4.1	Procedure of Calculation of Shear Flow Distribution	158
9.4.2	Shear Flow Distribution over a Ship Section of a Two-deck Cargo Ship . . . . .	160
9.5	Calculation of Shear Stress Distribution. . . . .	161
9.5.1	Equivalent Stress. . . . .	161
9.6	Calculation of Shear Stress Distribution over a Ship Section. . .	162
9.6.1	Calculation of Shear Flow Distribution over a Twin Deck Cargo Ship . . . . .	163
9.7	Shear Flow Distribution over a Catamaran Section . . . . .	164
<b>10</b>	<b>Calculation of Shear Stresses in Tankers Subjected to Longitudinal Vertical Shear Forces. . . . .</b>	<b>167</b>
10.1	Coastal Tankers Having One Longitudinal Bulkhead. . . . .	167
10.2	Calculation of Shear Flow Distribution for Twin Longitudinal Bulkhead Tankers . . . . .	169
10.3	Shear Load Carried by Longitudinal Bulkheads and Side Shell Plating . . . . .	173
10.3.1	Sea-Going Tankers with Two Longitudinal Bulkheads. . . . .	173
10.3.2	Coastal Tankers with One Longitudinal Bulkhead. . .	175
10.4	Shear Flow Distribution Over a Ship Section of an Oil Tanker Experiencing a Local Damage in the Shell Plating or Longitudinal Bulkhead. . . . .	176
10.4.1	Introduction . . . . .	176

10.4.2	Shear Stress Distribution Over a Tanker Section Experiencing a Local Damage. . . . .	177
10.4.3	Scenarios of Assumed Damage Locations on the Tanker Section . . . . .	177
<b>11</b>	<b>Shear Loading and Stresses in Bulk Carriers . . . . .</b>	<b>187</b>
11.1	Introduction . . . . .	187
11.2	Structural Configuration. . . . .	187
11.2.1	Upper and Lower Stools of Transverse Bulkheads . .	188
11.2.2	Double Bottom Structure . . . . .	189
11.3	Hull Girder Loading . . . . .	189
11.4	Longitudinal Vertical Shearing Force . . . . .	190
11.4.1	Stillwater Component (FS) . . . . .	191
11.5	Wave-Induced Component ( <i>FW</i> ) . . . . .	195
11.5.1	The Distribution of the Largest Expected Vertical Wave-Induced Shearing Force. . . . .	197
11.6	Dynamic Component ( <i>FD</i> ) . . . . .	198
11.7	Total Vertical Shearing Force <i>F</i> . . . . .	200
11.8	Approximate Value to the Maximum Vertical Shear Force . .	201
11.9	Variation of Various Shear Stress Components with Time . .	202
11.10	Shear Flow Distribution in Bulk Carriers . . . . .	202
11.10.1	Structure Idealization . . . . .	202
11.10.2	Effective Thickness . . . . .	203
11.10.3	Shear Flow Distribution . . . . .	204
11.10.4	Shear Stress Distribution . . . . .	205
11.10.5	Shear Flow Distribution Over the Hopper Tank . . .	205
11.10.6	Shear Flow Distribution Over the Top Wing Tanks. . .	207

**Part III Programming Implementation**

<b>12</b>	<b>Programming Implementation . . . . .</b>	<b>213</b>
12.1	Introduction . . . . .	213
12.2	Program List. . . . .	214
12.3	Solved Problems . . . . .	258
<b>13</b>	<b>Problems . . . . .</b>	<b>265</b>
	<b>References . . . . .</b>	<b>273</b>
	<b>Index . . . . .</b>	<b>275</b>
	<b>CV of the Author . . . . .</b>	<b>277</b>