Bureau Veritas Rudder Stock Calculations

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Derecktor 44m Gemini Sailing Catamaran

Notes Calculations are for a spade rudder with a hollow carbon post.
See BV guidelines Part B, Chapter 10, Section 2.

Input Values
Calculated Values

Vessel Data				**Notes**		**English Equivalents**	
44.20	m	=	Length over all (L)			145.01	ft
43.20	m	=	Length on water line (Lwl)			141.73	ft
210.0	T	=	Max displacement			462,840	lbs
25.0	kts	=	Max ahead speed (V1)	15.5	= Hull speed (kts)		
12.5	kts	=	Max astern speed (Vad)	Not be less than .5 x V1			
Rudder Data							
2.347	m	=	Depth of blade (L10)			7.70	ft
0.122	m	=	Dist from top of blade to lower bearing (L20)			0.40	ft
0.588	m	=	Distance between bearings (L30)			1.93	ft
2.029	m	=	Distance between top of blade and bottom of post (Lz)			6.66	ft
86%		=	Percentage of post length in blade			2.84	ft
2.169	m^2	=	Rudder area (A)			23.35	ft^2
0.416	m^2	=	Rudder area forward of post CL (Af)			4.48	ft^2
19.2	%	=	Rudder percent balance				
2.540		=	Aspect ratio (λ)				
1.513		=	Shape factor (r1)				
1.200		=	Max ahead lift coeficient (r2) (from table 1)				
0.800		=	Max astern lift coeficient (r2) (from table 1)				
0.800		=	Prop proximity coeficient (r3)	To be .8 when far from prop, 1.15 when behind propeller nozzle, 1.0 when inside propeller jet			
0.384		=	Calculated ahead lift coeficient (c)				
0.256		=	Calculated astern lift coeficient (c)				
0.962	m	=	Average breadth of rudder blade (b)			3.16	ft
0.133	m	=	Rudder torque lever, ahead (r)			0.44	ft
0.450	m	=	Rudder torque lever, astern (r)			1.48	ft
Rudder Forces						**English Equivalents**	
266,642	N	=	Rudder ahead force (Cr)			59,941	lbs
44,440	N	=	Rudder astern force (Cr)			9,990	lbs
35,451	N.m	=	Rudder ahead torque (Mtr)			26,148	ft.lbs
20,017	N.m	=	Rudder astern torque (Mtr)			14,763	ft.lbs
345,434	N.m	=	Max rudder stock bending moment (Mb)			254,779	ft.lbs
587,473	N	=	Max shear force at upper bearing (Q30)			132,064	lbs
266,642	N	=	Max shear force at lower bearing (Q20)			59,941	lbs
587,473	N	=	Max side force at upper bearing (R30)	59,906	kg	132,064	lbs
854,115	N	=	Max side force at lower bearing (R20)	87,095	kg	192,005	lbs
10,454	N.m	=	Bending moment at bottom of post			7,710	ft.lbs
Rudder Post Data			**Upper Bearing**				
20.0	cm	=	Post OD at upper bearing	10	cm rad	7.87	in
18.0	cm	=	Post ID at upper bearing	9	cm rad	7.09	in
2,701.0	cm^4	=	Post inertia at upper bearing (Ixx)	10	mm wall thickness	64.89	in^4
270.1	cm^3	=	Post Section Modulus at upper bearing (Wb)			16.48	in^3
5,402.0	cm^4	=	Post polar inertia at upper bearing (Izz)			129.78	in^4

540.2	cm^3	=	Post Polar Modulus at upper bearing (Wtr)			32.96	in^3
			Lower Bearing				
31.9	cm	=	Post length at lower bearing			12.56	in
15.6	cm	=	Post width at lower bearing			6.14	in
2.5	cm	=	Post side wall thickness at lower bearing			0.98	in
1.7	cm	=	Post fore/aft wall thickness at lower bearing			0.67	in
5,882.3	cm^4	=	Post inertia at lower bearing (Ixx)			141.32	in^4
754.1	cm^3	=	Post Section Modulus at lower bearing (Wb)			46.02	in^3
17,129.3	cm^4	=	Post polar inertia at lower bearing (Izz)			411.53	in^4
1,073.9	cm^3	=	Post Polar Modulus at lower bearing (Wtr)			65.54	in^3
7.8	cm	=	Max distance y from N.A. (Vy)			3.07	in
16.0	cm	=	Max distance z from N.A. (Vz)			6.28	in
			Bottom of Post				
11.5	cm	=	Post length at bottom of post			4.53	in
9.2	cm	=	Post width at bottom of post			3.62	in
1.0	cm	=	Post side wall thickness at bottom of post			0.39	in
1.0	cm	=	Post fore/aft wall thickness at bottom of post			0.39	in
340.3	cm^4	=	Post inertia at bottom of post (Ixx)			8.18	in^4
74.0	cm^3	=	Post Section Modulus at bottom of post (Wb)			4.51	in^3
450.7	cm^4	=	Post polar inertia at bottom of post (Izz)			10.83	in^4
78.4	cm^3	=	Post Polar Modulus at bottom of post (Wtr)			4.78	in^3
4.6	cm	=	Max distance y from N.A. (Vy)			1.81	in
5.8	cm	=	Max distance z from N.A. (Vz)			2.26	in
Rudder Post Material Properties							
T300 uni pre-preg		=	Post Material				
2,405	N/mm^2	=	Ultimate Tensile Strength	From Toray test data dated June 10, 2006		348,800	psi
131,138	N/mm^2	=	Tensile Modulus	Toray material P591A-300-305		19.02	Msi
1,475	N/mm^2	=	Ultimate Compressive Strength	Test panels were cured in Autoclave		214,000	psi
112,385	N/mm^2	=	Comressive Modulus			16.30	Msi
51	N/mm^2	=	90 deg. Tensile Strength			7,450	psi
8,274	N/mm^2	=	90 deg. Tensile Modulus			1.20	Msi
1,805	N/mm^2	=	Ultimate Flexural Strength			261,800	psi
113,143	N/mm^2	=	Flexural Modulus			16.41	Msi
88	N/mm^2	=	Laminar Shear Strength			12,830	psi
Rudder Post Laminate Properties							
60%		=	0 deg. fiber percentage				
38%		=	±45 deg. fiber percentage				
2%		=	90 deg. fiber percentage				
1,167	N/mm^2	=	0 deg. Strength	Weighted average of laminate assuming linear		169,209	psi
1,004	N/mm^2	=	±45 deg Strength	reduction of properties when off-axis		145,595	psi
341	N/mm^2	=	90 deg Strength			49,410	psi
Stress In Post			**Upper Bearing**				
65.6	N/mm^2	=	Torsional Stress (τt)			9,518	psi
15.3		=	Fiber tortional safety factor	2.2	= Minimum value		
1,884	kN/m	=	Plain shear load in F/A web (Nxy)	As per 4.3.2(b)		1,079	lbs/in
			Lower Bearing				
458.0	N/mm^2	=	Bending Stress (σb)			66,435	psi
2.5		=	Fiber compressive safety factor	2.2	= Minimum value		
33.0	N/mm^2	=	Torsional Stress (τt)			4,788	psi
1,083	kNm/m	=	Bending moment of side walls (Mx)	As per 4.3.2(a)		20,286	ft.lbs/in
855	kN/m	=	Plain shear load in F/A web (Nxy)	As per 4.3.2(b)		488	lbs/in
			Bottom of Post				

141.3	N/mm^2	=	Bending Stress (σb)			20,496	psi
8.3		=	Fiber compressive safety factor	2.2	= Minimum value		
Rudder Weights			**Post**				
34.0%	%	=	Resin by weight ratio				
1.515E-06	kg/mm^3	=	Density of carbon pre preg				
5,969	mm^2	=	Sectional area thru upper bearing				
340	mm	=	Length of upper bearing				
17,683	mm^2	=	Sectional area thru lower bearing				
335	mm	=	Length of transition from upper to lower bearing		`		
289	mm	=	Length of lower bearing				
3,121	mm^2	=	Sectional area at bottom of post				
2000	mm	=	Length from lower bearing to bottom of post				
2,029,469	mm^3	=	Volume in upper bearing				
3,961,714	mm^3	=	Volume in transition from upper to lower bearing				
5,110,387	mm^3	=	Volume in lower bearing				
20,804,000	mm^3	=	Volume in transition from lower bearing to bottom of post				
31,905,570	mm^3	=	Total volume in post				
48.34	kg	=	Total weight of carbon post				
			Bearing wraps				
3.00	mm	=	Thickness of upper bearing wrap				
0.971	kg	=	Weight of upper bearing wrap				
16.83	kg	=	Weight of upper bearing sleave				
36,434	mm^2	=	Area of lower bearing wrap				
15.95	kg	=	Weight of lower bearing wrap				
29.17	kg	=	Weight of lower bearing sleave				
			Rudder blade				
2.7	mm	=	Blade skin laminate thickness				
11,712,600	mm^3	=	Total volume in blade skin				
17.75	kg	=	Total weight of blade skin				
0.106	m^3	=	Total volume in blade core				
80	kg/m^3	=	Density of blade core				
8.49	kg	=	Total weight of blade core				
			Stub shaft				
3,306,450	mm^3	=	Total volume of stainless steel stub shaft				
7.920E-06	kg/mm^3	=	Density of 316 Stainless Steel				
26.19	kg	=	Total weight of stub shaft				
			Totals				
163.68	kg	=	Total weight of assembled rudder				