Sector

RigEdge Validation document

Project topics

Analytical test

Comparison of rig analysis results with a commercial FEM/FEA tools.

Results

The results of the analytical and RigEdge tests are practically identical

<1% differences on more complex rig analysis results when comparing RigEdge results with the one obtained using midasNFX, a commercial FEM/FEA software

Reference:

Malpede, S., D'Angeli, F., Bouzaid, R. (2013), Advanced structural analysis method for aeroelastic simulations of sails, Proceedings of the Third International Conference on Innovation in High Performance Sailing Yachts, Lorient.

Malpede S., Nasato F. (2011), A fully integrated sail-rig analysis method. Trans RINA, Vol. 153, Part B2, International Journal of Small Craft Technology

Midas NFX www.midasnfx.com

WINDFALL – Courtesy Southern Wind / Ph.Rob Kamhoot

Introduction

RigEdge is a user-friendly software application for the design and analysis of sailing rigs, including multi-rig and gaff rig.

The main features are:

- **DESIGN**
  - HULL [mono/multi-hulls or import feature from *.step (CATIA®) and *.3dm files] and DECK LAYOUT
  - RIG: spars, standing and running rigging
    - Spars and rigging material properties can be either conventional or user-defined: the material library includes also the automatic calculation of the composite material properties by setting the plies properties. Material can be imported from csv files.
  - SAILS: code0, headsails, mainsails, gaff
    - A library of sail design is available
- **CALCULATE**
  - Tuning loads (by setting forces/displacements on shrouds, diagonals, stays and boundary conditions at mast step and collar)
  - Sailing loads (via aerodynamic and structural analysis of sails in user-defined upwind sailing and trimming conditions)
  - Dynamic loads (by setting vertical acceleration, angular accelerations or angle and period of the vessel oscillation)
  - Buckling
- **AVAILABLE RESULTS (AT A GLANCE)**
  - mast bend and luff sag
  - spars internal forces (axial force, shear and moment) and local equivalent stress (absolute/relative to the breaking tension)
  - shrouds, diagonal and stays tensions and stress (absolute/relative to the breaking tension)
  - rigging and spars weights and relative geometrical data (length, vertical centre of gravity and roll static moment)
- **ADDITIONAL OUTPUTS**
  - Spars, rig, sailplan and deformed configuration are available as 3 dimensional dxf or step file for CATIA®
  - Results are available as graphical plots, text file and csv

The finite element model of the rig is based on 3D beam-column theory in order to account for stress stiffening and softening in the presence of axial load. Beam-column equations, with bending about two axes and torsion, are employed to generate the element stiffness and solved with the finite difference method in order to generate the various stiffness contributions of each finite element. Rigging is modelled using cable elements, while sails are modelled using membrane elements. The structural equilibrium of the rig is evaluated under the used defined forces (sailing, tuning and dynamic impact) taking into account the geometrical non linearity. Materials are considered to work within the linear region of the stress-strain function. A more detailed explanation about the methods and validation can be found in [a] and [b].

ANALITICAL TESTS

Table 1

ANALYTICAL test 1	Case 1	Case 2	**Analytical BUCKLING**
model	Circular hollow beam	Custom hollow beam	Custom hollow beam
Section	Round 125x125mm	A, Ix, Iy, J determined	A, Ix, Iy, J determined
Beam Length	1 m	1 m	10 m
Material	Aluminium	Aluminium	E = 100GPa, ρ = 1000 kg/m3
Thickness	1mm	-	
Constraints 1st end	Fixed	Fixed	Pinned
Constraints 2nd end	Free	Free	Pinned
Load	2nd end: 10000 N	2nd end: 100000 N in X	2nd end: 10000 N in -Z
Theory	Displ. 63.6 mm	Displ. 23.8 mm	Euler Buckling Load = 9870 N
RigEdge result	Displ. 63.4 mm	Disp. 23.8 mm	Buckling Load = 9871 N
Difference (%)	**0.3 %**	**0 %**	0.01 %

Table 2

ANALYTICAL test 2	Case 3	Case 4	Case 5
model	Custom hollow beam	Custom hollow beam	Custom hollow beam
Section	A, Ix, Iy, J determined	A, Ix, Iy, J determined	A, Ix, Iy, J determined
Beam Length	1 m	1 m	1 m
Material	Aluminium	Carbon - Epoxy	Carbon - Epoxy
Thickness	-	-	-
Constraints 1st end	Fixed	Fixed	Fixed
Constraints 2nd end	Free	Free	Free
Load	2nd end: 100000 N in Y	2nd end: 1000000 N in X	2nd end: 1000000 N in Y
Theory	Displ. 47.6 mm	Displ. 98.8 mm	Displ. 164.6 mm
RigEdge result	Displ. 47.5 mm	Displ. 98.0 mm	Displ. 161.1 mm
Difference (%)	0.2 %	0.8 %	2.1 %

Table 3

ANALYTICAL test 3	Case 6	Case 7	Case 8
model	Circular hollow beam	Elliptical hollow beam	Elliptical hollow beam
Section	Round 125x125mm	Ellipse 300x150mm	Ellipse 300x150mm
Beam Length	1 m	1 m	1 m
Material	Carbon - Epoxy	Carbon - Epoxy	Carbon - Epoxy
Thickness	1mm	1mm	1mm
Constraints 1st end	Fixed	Fixed	Fixed
Constraints 2nd end	Free	Free	Free
Load	2nd end: 10000 N in X	2nd end: 10000 N in X	2nd end: 10000 N in Y
Theory	Displ. 39.0 mm	Displ. 4.5 mm	Displ. 12.8 mm
RigEdge result	Displ. 39.0 mm	Displ. 4.5 mm	Displ. 12.8 mm
Difference (%)	0 %	0 %	0 %

Table 4

ANALYTICAL test 4	Case 9	Case 10	Case 11
model	Square hollow beam	Rectangular hollow beam	Rectangular hollow beam
Section	Square 125x125mm	Rectangle 300x150mm	Rectangle 300x150mm
Beam Length	1 m	1 m	1 m
Material	Carbon - Epoxy	Carbon - Epoxy	Carbon - Epoxy
Thickness	1mm	1mm	1mm
Constraints 1st end	Fixed	Fixed	Fixed
Constraints 2nd end	Free	Free	Free
Load	2nd end: 10000 N in X	2nd end: 100000 N in X	2nd end: 100000 N in Y
Theory	Displ. 23.0 mm	Displ. 26.3 mm	Displ. 75.6 mm
RigEdge result	Displ. 23.0 mm	Displ. 26.3 mm	Displ. 75.3 mm
Difference (%)	0 %	0 %	0.4 %

Table 5

ANALYTICAL test 5	**Case 13**	**Case 14**	**Case 16**
model	Custom hollow beam	Custom hollow beam	Custom hollow beam
Section	A, Ix, Iy, J determined	A, Ix, Iy, J determined	A, Ix, Iy, J determined
Beam Length	10 m	10 m	10 m
Material	E = 100GPa, ρ = 1000 kg/m3	E = 100GPa, ρ = 1000 kg/m3	E = 100GPa, ρ = 1000 kg/m3
Thickness	-	-	-
Constraints 1st end	Fixed	Pinned	Fixed
Constraints 2nd end	Free	Pinned	Free
Load	57.3 deg/s2 acc in the XZ plane	57.3 deg/s2 acc in the XZ plane	2nd end: 10000 N in -Z
Theory	Displ. 91.7 mm	Displ. 6.5 mm at 51.9% L	Euler Buckling Load = 2467 N
RigEdge result	Displ. 92.9 mm	Displ. 6.5 mm at 52.4% L	Buckling Load = 2470 N
Difference (%)	1.3 %	0 %; 0.5 %	0.1 %

Comparison of rig analysis results with a commercial FEM/FEA tools.

Table 6: SIMPLE beam/cable STRUCTURES (compression, tension and shear forces are in N, displacements are in mm, moments in Nm.

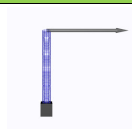
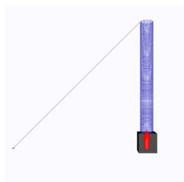
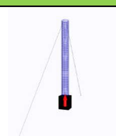
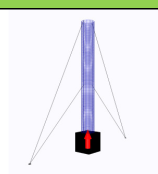
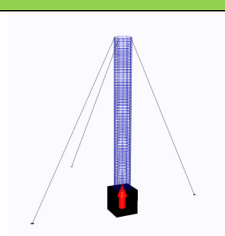
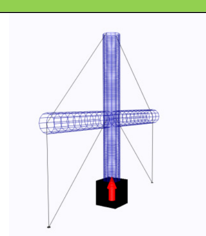
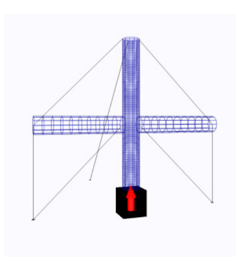
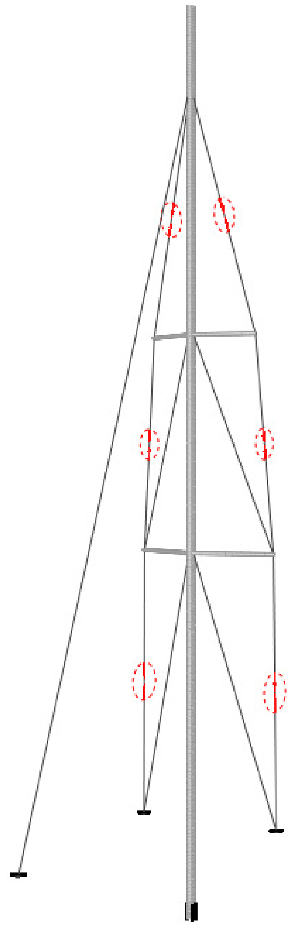
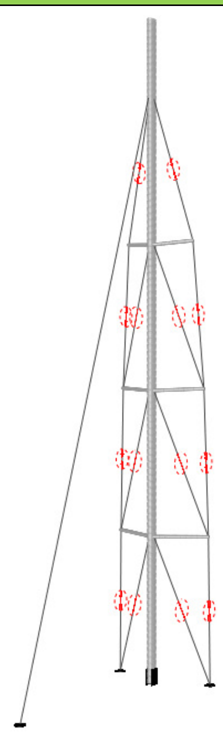
Case	Model preview	Parameter	MIDAS NFX	RigEdge	Difference
case 1		Mast head displacement	5.56	5.5	-1.1%
Self-standing		Mast step compression	-8.8	-7.25	-17.6%
		Mast step shear	10000	10000	0.0%
		Mast step moment	9999.7	9999.8	0.0%
case 2		Tuning displacement	1 cm mast jack		
Forestay		Mast head displacement	12.37	12.4	0.2%
		Forestay tension	17405	17590	1.1%
		Mast step compression	12396	12527	1.1%
		Mast step shear	12218	12343	1.0%
		Mast step moment	12908	13042	1.0%
case 3		Tuning displacement	1cm mast jack		
Shrouds		Mast head displacement	9.81	10	1.9%
		Shroud tension	81064	80990	-0.1%
		Mast step compression	115200	115100	-0.1%
case 3.1		Tuning displacement	1 cm mast jack		
2 shrouds		Mast head displacement	9.4	9	
		V1 tension	124575	124451	-0.1%
		V2 tension	159430	159153	-0.2%
		Mast step compression	450869	450252	-0.1%
case 4		Tuning displacement	1cm mast jack		
Forestay + shrouds		Mast head displacement	12.14	12.1	-0.3%
		Forestay tension	16890	17060	1.0%
		Shroud tension	80856	80780	-0.1%
		Mast step compression	126928	126949	0.0%
		Mast step shear	11161	11262	0.9%
		Mast step moment	12534	12661	1.0%
case 5		Tuning displacement	1 cm mast jack		
Shrouds + spreaders with end release		Mast head displacement	9.53	10	4.9%
		V1 tension	80891	80812	-0.1%
		V2 tension	115228	115114	-0.1%
		D1 tension	160274	160106	-0.1%
		Spreader compression	390604	390205	-0.1%
		Mast step compression	80883	80803	-0.1%
case 6		Tuning displacement	1 cm mast jack		
Forestay + shrouds + spreaders with end release		Mast head displacement	11.8	11.8	0.0%
		Forestay tension	16440	16599	1.0%
		V1 tension	80717	80632	-0.1%
		V2 tension	114980	114863	-0.1%
		D1 tension	160097	159927	-0.1%
		Mast step compression	401705	401407	-0.1%
		Spreader compression	80710	80628	-0.1%
		Mast step shear	10286	10306	0.2%
		Mast step moment	12207	12322	0.9%

Table 7: RIG STRUCTURES (compression, tension and shear forces are in N, displacements are in mm, moments in Nm.

Case	Model preview	Parameter	MIDAS NFX	RigEdge	Difference
case 7.1		Tuning pretension	V1 tightened 7.5 mm V2 and V3 tightened 5 mm		
2 swept back spreaders fractional rig ***spreaders are FIXED on the mast***		Mast head displacement	3.65	3.67	0.5%
		Mast step compression	37879	37814	-0.2%
		Mast step shear	235	233	-0.9%
		Maximum compression	37880	37814	-0.2%
		Maximum shear	681	677	-0.6%
		Max bending moment	1376	1366	-0.7%
		SP 1 compression	1259	1258	-0.1%
		SP 2 compression	1905	1898	-0.4%
		V1 tension	12153	12121	-0.3%
		V2 tension	10620	10584	-0.3%
		V3 tension	10904	10867	-0.3%
		D1 tension	5053	5055	0.0%
		D2 tension	1565	1571	0.4%
		Forestay	4174	4168	-0.1%
case 7.2		*Tuning pretension*	*V1 tightened 7.5 mm* *V2 and V3 tightened 5 mm*		
2 swept back spreaders fractional rig ***spreaders are FREE TO ROTATE on the horizontal axis***		Mast head displacement	3.66	3.68	0.5%
		Mast step compression	37842	37777	-0.2%
		Mast step shear	225	223	-0.9%
		Maximum compression	37843	37778	-0.2%
		Maximum shear	687	683	-0.6%
		Max bending moment	1367	1356	-0.8%
		SP 1 compression	1291	1290	-0.1%
		SP 2 compression	1912	1906	-0.3%
		V1 tension	12111	12080	-0.3%
		V2 tension	10594	10558	-0.3%
		V3 tension	10927	10891	-0.3%
		D1 tension	5078	5079	0.0%
		D2 tension	1659	1665	0.4%
		Forestay	4172	4166	-0.1%
case 8		**Tuning pretension**	**V1 75000 N pretension** **V2 45000 N pretension** **V3 30000 N pretension** **V4 15000 N pretension** **D1 10000 N precompression** **D2 10000 N precompression** **D3 1000 N precompression**		
3 swept back spreaders fractional rig ***spreaders are FREE TO ROTATE on the horizontal axis***		Mast head displacement	6.41	6.41	0.0%
		Mast step compression	59100	59086	0.0%
		Mast step shear	1110	1111	0.1%
		Maximum compression	59104	59090	0.0%
		Maximum shear	1687	1688	0.1%
		Max bending moment	4664	4671	0.2%
		SP 1 compression	1990	1989	-0.1%
		SP 2 compression	1562	1560	-0.1%
		SP 3 compression	3217	3219	0.1%
		V1 tension	23929	23932	0.0%
		V2 tension	19361	19365	0.0%
		V3 tension	16573	16583	0.1%
		V4 tension	16882	16889	0.0%
		D1 tension	2921	2911	-0.3%
		D2 tension	4864	4859	-0.1%
		D3 tension	2932	2924	-0.3%
		Forestay	6140	6139	0.0%