

CALCULUS OF SHAFT LINE FROM SHIPS USING FEM METHOD

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Abstract: This paper will present the calculus of the shaft line from a ship. This calculus consists in the determination of the reactions in the shaft line bearings. Using an educational version of the STAAD software, a static analysis of naval shaft line is performed. After the calculus of the reactions in shaft bearings, the diagram of shear forces and the diagram of bending moments will be determined. The values performed will be compared with the recommendations of the Rules for Classifications and Construction of Ships.

Keywords: fem method, intermediate shaft, propeller shaft, shaft liner, coupling connection, bearing, reaction, weight propeller, weight coupling

1. INTRODUCTION

The main steps in calculus of the reactions performed by FEM method are the following:

- a) Material selections;
- b) Dimensioning of the intermediate shaft;
- c) Dimensioning of the propeller shaft;
- d) Dimensioning of the coupling flanges;
- e) Dimensioning of the shaft line bearings;
- f) Performed of the shaft line scheme;
- g) Estimated of the propeller weight;
- h) Estimated of the couplings shaft line weight;
- i) Approximation of the propeller hub with three cylinders and calculus of the weight force and this point of the application;
- j) Determinations of the coordinates system using in FEM structure calculus;
- k) Determination of coordinates of the structure nodes;
- l) Determination of the structures beams;
- m) The property of the structure beams;
- n) Introduction of the forces in the shaft line scheme;
- o) Static analysis of the shaft line structure;
- p) Interpretation of the results after FEM calculus.

The steps a) – e) were presented in [1].

Calculus will be performed for a cargo ship equipped with an engine with the main characteristics:

- power $P=6000$ kW (MCR regime);
- shaft speed $n=157 \frac{\text{rot}}{\text{min}}$.

The performed of the shaft line scheme is shown in Fig. 1.

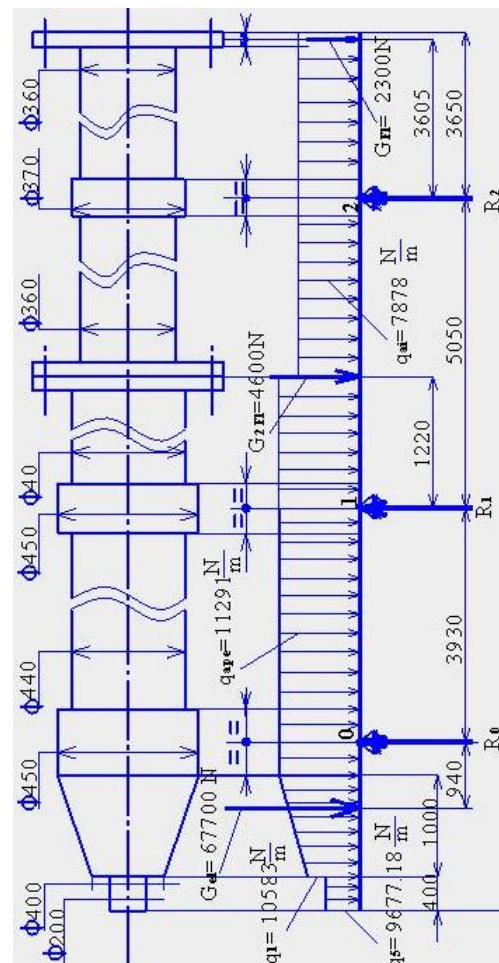


Fig. 1. The scheme for reactions calculus.

2. ESTIMATION OF THE PROPELLER WEIGHT

The propeller weight will be taken into consideration in water and his application point is considered in weight centre of the trapeze (Fig. 2).

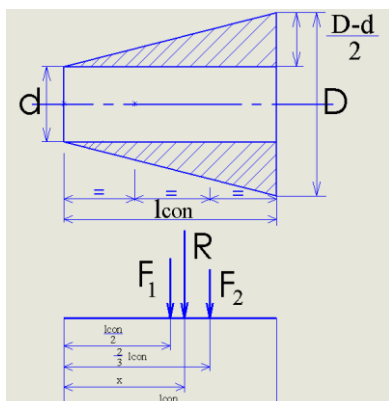


Fig. 2. The application point of the propeller weight

The propeller weight in water is given by:

$$G_{el} = G_{el}^{air} \frac{\rho_{bronze} - \rho_{water}}{\rho_{bronze}}, [N] \quad (1)$$

Where: G_{el}^{air} , [N] - propeller weight in air; ρ_{bronze} = 8600 kg/m³ - bronze density; ρ_{water} = 1025 kg/m³ - water density.

$$G_{el}^{air} = M_{el} \cdot g, [N] \quad (2)$$

where M_{el} , [kg] is the propeller mass and $g = 9.81$ m/s² is the gravitational acceleration.

$$G_{el}^{air} = M_{el} \cdot g = 7845 \text{ kg} \cdot 9.81 \frac{\text{m}}{\text{s}^2} = 76960 \text{ N} \quad (3)$$

$$G_{el} = 76960 \frac{8600 - 1025}{1025} = 67700 \text{ N} \quad (4)$$

For application point of propeller weight we must write the equality:

$$R \cdot x = F_1 \cdot \frac{l_{con}}{2} + F_2 \cdot \frac{2 \cdot l_{con}}{3} \quad (5)$$

where F_1 is the area of the rectangle with the dimensions d , l_{con} and F_2 is the area of the both triangle with the high l_{con} and base $\frac{D-d}{2}$.

$$F_1 = d \cdot l_{con} \quad (6)$$

$$F_2 = 2 \cdot \left(\frac{1}{2} \cdot \frac{D-d}{2} \cdot l_{con} \right) \quad (7)$$

$$R = \frac{(D-d) l_{con}}{2} \quad (8)$$

$$x = \frac{2D \cdot l_{con} + d \cdot l_{con}}{3(d+D)} = \frac{2 \cdot 450 \cdot 1000 + 400 \cdot 1000}{3(400 + 450)} = 509.80 \quad (9)$$

3. ESTIMATION OF THE COUPLINGS SHAFT LINE WEIGHT

It must determinate the weight of the next couplings:

- between intermediate shaft ant engine;
- between propeller shaft and intermediate shaft.

The propeller weight of coupling shaft is given by formula:

$$\begin{aligned} G_{F1} &= V_{F1} \cdot \rho \cdot g + z \cdot (G_p + G_s) = \\ &= \frac{\pi}{4} (D_{ext}^2 - d^2 - 12 \cdot d_s^2) s_{F1} \cdot \rho \cdot g + \\ &+ z \cdot (G_p + G_s) = \\ &= \frac{\pi}{4} (0.700^2 - 0.360^2) \cdot 0.090 \cdot 7850 \cdot 9.81 + 250 = 2211.81 \end{aligned} \quad (10)$$

The dimensions which are used in equation (10) are given in [1].

4. APPROXIMATION OF THE PROPELLER HUB WITH THREE CYLINDERS

The propeller hub will be approximated by three cylinders, like in Figure 3 and Figure 4.

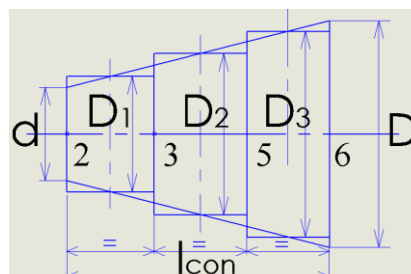


Fig. 3. Approximate of the hub propeller

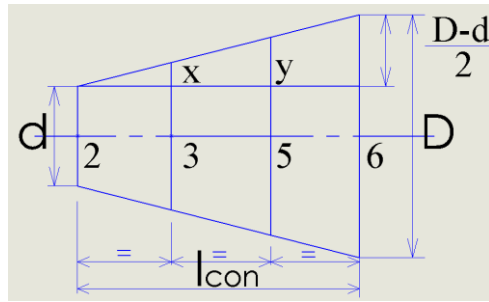


Fig. 4. The scheme for calculus of three diameters

$$\frac{x}{\frac{1}{3}l_{con}} = \frac{y}{\frac{2}{3}l_{con}} = \frac{D-d}{2} \tag{11}$$

$$D_1 = \frac{d + d + 2x}{2} = d + x = d + \frac{D-d}{6} = 400 + \frac{450 - 400}{6} = 408.3 \tag{12}$$

$$D_2 = \frac{D_1 + d + 2y}{2} = \frac{D_1 + d + 2 \cdot \frac{2}{3}l_{con}}{2} = \frac{3D_1 + 2D + d}{6} = \frac{3 \cdot 408.3 + 2 \cdot 450 + 400}{6} = 420.8 \tag{13}$$

$$D_3 = \frac{D_2 + D}{2} = \frac{420.8 + 450}{2} = 435.4 \tag{14}$$

5. DETERMINATION OF THE COORDINATES SYSTEM USING IN FEM STRUCTURE CALCULUS

The coordinates system using in FEM structure calculus is a Cartesian coordinate system xOy. The origin of the coordinate system O will be considered in the aft end of the propeller shaft line. The axis Ox will be considered on the length of the shaft line. The axis Oy will be considered parallel with the support of forces that acting on the shaft line. The axis Oz will be considered perpendicular on the plane xOy.

6. DETERMINATION OF COORDINATES OF THE STRUCTURE NODES

Computing structure using in FEM analysis is shown in Figure 5.

The computing structure consists of a structure with 17 nodes and 16 beams. The coordinates of the structure nodes are given in Figure 6.

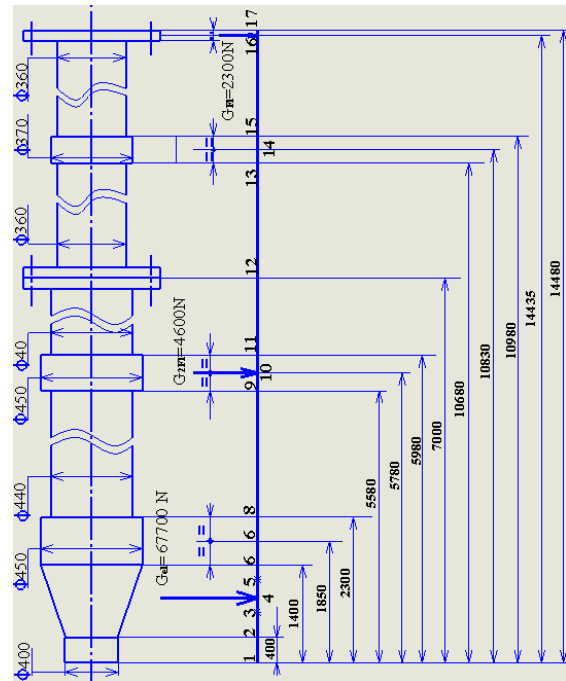


Fig. 5. The computing structure of the shaft line

Node	X m	Y m	Z m
1	0.000	0.000	0.000
2	0.400	0.000	0.000
3	0.733	0.000	0.000
4	0.910	0.000	0.000
5	1.067	0.000	0.000
6	1.400	0.000	0.000
7	1.850	0.000	0.000
8	2.300	0.000	0.000
9	5.580	0.000	0.000
10	5.780	0.000	0.000
11	5.980	0.000	0.000
12	7.000	0.000	0.000
13	10.680	0.000	0.000
14	10.830	0.000	0.000
15	10.980	0.000	0.000
16	14.435	0.000	0.000
17	14.480	0.000	0.000

Fig. 6. The coordinates of the structure nodes.

7. DETERMINATIONS OF THE STRUCTURES BEAMS

The beams of the computing structure will be described like in figure 7.

Beam	Node A	Node B	Property Refn.	Material	Beta	Length m
1	1	2	1	STEEL	0.0	400E-3
2	2	3	2	STEEL	0.0	333E-3
3	3	4	3	STEEL	0.0	177E-3
4	4	5	3	STEEL	0.0	157E-3
5	5	6	4	STEEL	0.0	333E-3
6	6	7	5	STEEL	0.0	450E-3
7	7	8	5	STEEL	0.0	450E-3
8	8	9	6	STEEL	0.0	3.280
9	9	10	5	STEEL	0.0	200E-3
10	10	11	5	STEEL	0.0	200E-3
11	11	12	6	STEEL	0.0	1.020
12	12	13	7	STEEL	0.0	3.680
13	13	14	8	STEEL	0.0	150E-3
14	14	15	8	STEEL	0.0	150E-3
15	15	16	7	STEEL	0.0	3.455
16	16	17	7	STEEL	0.0	45E-3

Fig. 7. The description of the computing structure of the shaft line

8. THE PROPERTY OF THE STRUCTURE BEAMS

The beams used in the computing structure will be considered with circular section. These properties are shown in Figure 8.

Ref	Section	Material
1	Cir 0.40	STEEL
2	Cir 0.41	STEEL
3	Cir 0.42	STEEL
4	Cir 0.44	STEEL
5	Cir 0.45	STEEL
6	Cir 0.44	STEEL
7	Cir 0.36	STEEL
8	Cir 0.37	STEEL

Fig. 8. The properties of the computing structure

9. INTRODUCTION OF THE FORCES IN THE SHAFT LINE SCHEME

The next forces are acting in the shaft line scheme:

- the weight of the propeller shaft.
- the weight of the coupling flanges between propeller shaft and intermediate shaft;
- the weight of the intermediate shaft flanges that will be coupled with engine shaft;
- the self-weight of the propeller shaft and the intermediate shaft.

Scheme for the application of forces acting on the shaft line are presented in Figure 9.

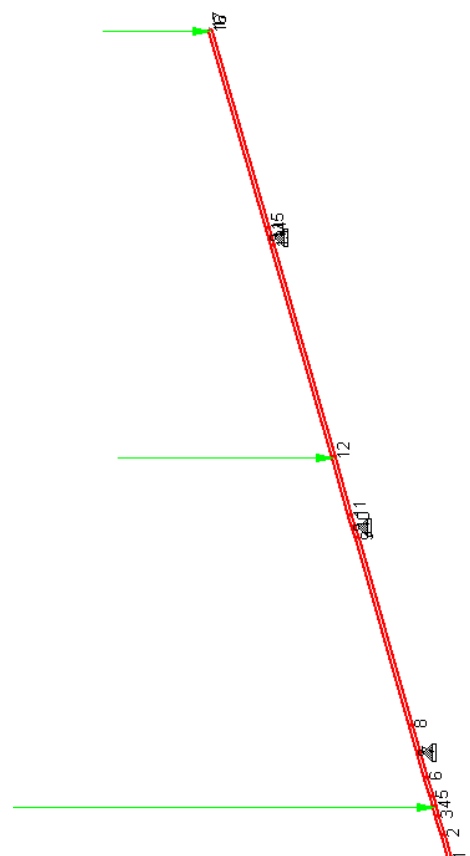
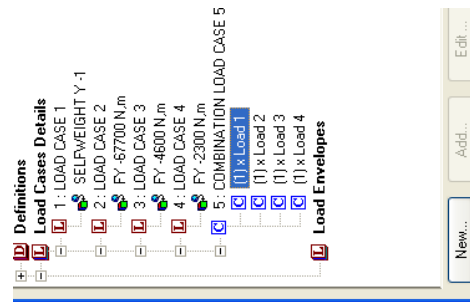


Fig. 9. The scheme of forces

- propeller weight $G_{el} = 67700$ N;
- flange coupling weight between propeller shaft and intermediate shaft $G_{fl} = 4600$ N;
- flange coupling weight between intermediate shaft and engine shaft $G_{fl}' = 2300$ N.

10. THE RESULTS OBTAINED AFTER FEM STATIC ANALYSIS

After FEM static analysis considering the shaft line subjected to combined load (self-weight of shaft line, propeller weight and couplings weight) the following will result:

- reactions in shaft line bearings (Fig. 11).
- bending moment diagram (Fig. 12).
- shear force diagram (Fig. 13).
- displacements and rotations in the nodes computing structure (Fig. 14).
- deformed of the shaft line (Fig. 15).

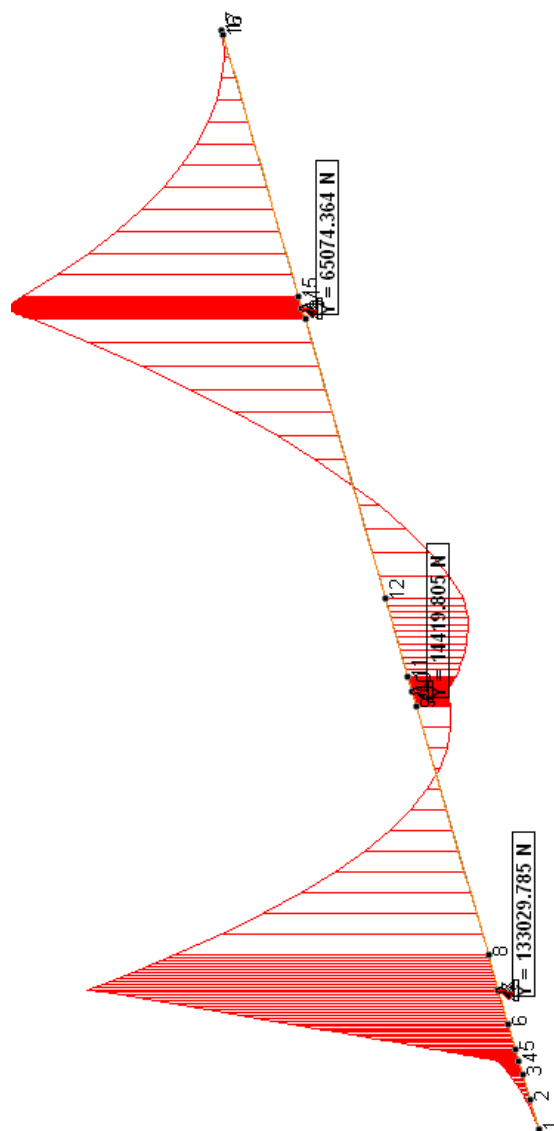


Fig. 10. Bending moment diagram

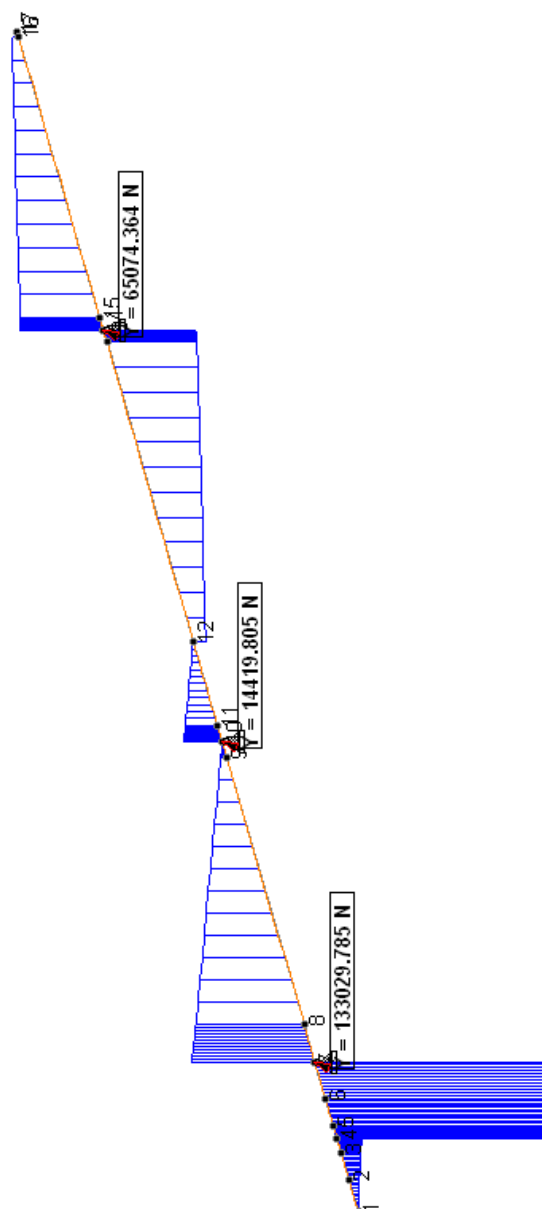


Fig. 11. Shear force diagram

11. INTERPRETATION OF THE RESULTS AFTER FEM CALCULUS

The main rules for classifications and construction for ships stipulate that the reactions in shaft line bearings are positives (orientated in the positive direction of the Oy axis).

The reactions in shaft line bearings obtained are the next values:

- in after stern tube bearing: $Y=133029.785$ N;
- in forward stern tube bearing: $Y=14419.805$ N;
- in intermediate bearing: $Y=65074.364$ N.

Node	L/C	Horizontal		Vertical		Horizontal		Resultant		Rotational		
		X mm	Y mm	Z mm	Z mm	mm	mm	rX rad	rY rad	rZ rad		
1	5 COMBINATI	0.000	-0.519	0.000	0.519	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2	5 COMBINATI	0.000	-0.400	0.000	0.400	0.000	0.000	0.000	0.000	0.000	0.000	0.000
3	5 COMBINATI	0.000	-0.301	0.000	0.301	0.000	0.000	0.000	0.000	0.000	0.000	0.000
4	5 COMBINATI	0.000	-0.249	0.000	0.249	0.000	0.000	0.000	0.000	0.000	0.000	0.000
5	5 COMBINATI	0.000	-0.202	0.000	0.202	0.000	0.000	0.000	0.000	0.000	0.000	0.000
6	5 COMBINATI	0.000	-0.107	0.000	0.107	0.000	0.000	0.000	0.000	0.000	0.000	0.000
7	5 COMBINATI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
8	5 COMBINATI	0.000	0.067	0.000	0.067	0.000	0.000	0.000	0.000	0.000	0.000	0.000
9	5 COMBINATI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
10	5 COMBINATI	0.000	-0.008	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.000	0.000
11	5 COMBINATI	0.000	-0.027	0.000	0.027	0.000	0.000	0.000	0.000	0.000	0.000	0.000
12	5 COMBINATI	0.000	0.036	0.000	0.036	0.000	0.000	0.000	0.000	0.000	0.000	0.000
13	5 COMBINATI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
14	5 COMBINATI	0.000	-0.045	0.000	0.045	0.000	0.000	0.000	0.000	0.000	0.000	0.000
15	5 COMBINATI	0.000	-2.153	0.000	2.153	0.000	0.000	0.000	0.000	0.000	0.000	0.000
16	5 COMBINATI	0.000	-2.185	0.000	2.185	0.000	0.000	0.000	0.000	0.000	0.000	0.000
17	5 COMBINATI	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Fig. 12. Displacements and rotations in the nodes computing structure

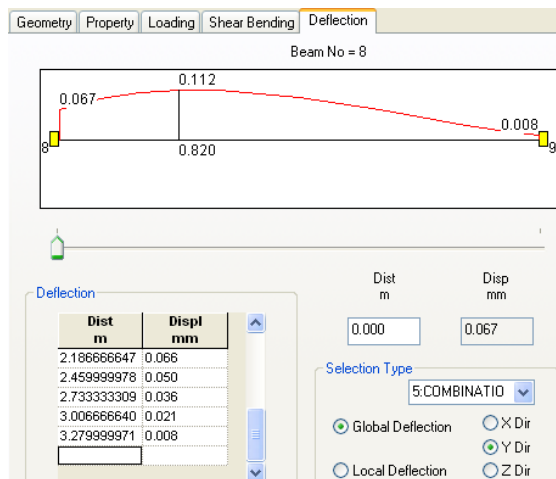


Fig. 13. Deformed shaft line in the stern tube area

12. CONCLUSIONS

In this paper was presented a FEM methodology for calculus of reactions in the shaft line destined for ship propulsion power plants. This calculus is effected by STAAD software (educational version).

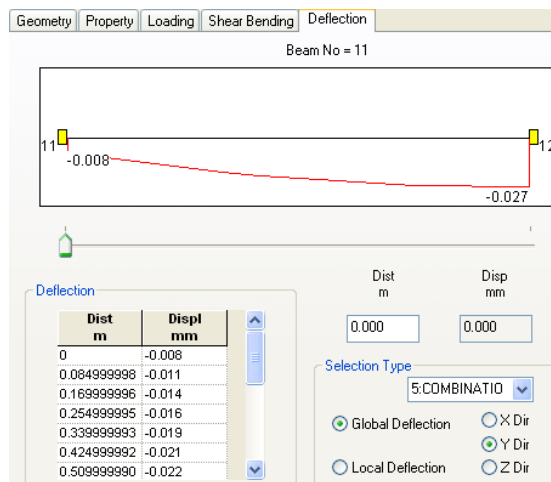


Fig. 14. Deformed shaft line between propeller shaft and intermediate shaft

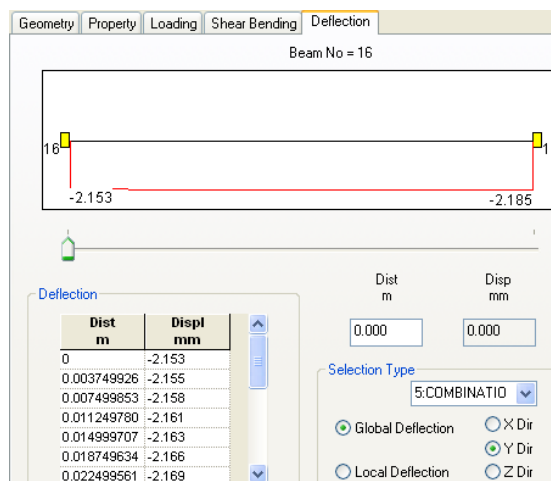


Fig. 15. Deformed shaft line between intermediate shaft and engine shaft

13. REFERENCES

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Rezumat: În această lucrare se prezintă calculul liniei de arbori de pe o navă. Acest calcul constă în determinarea reacțiilor în lagărele din linia de arbori. Folosind o versiune educațională a software-ului STAAD, se efectuează o analiză statică a liniei de arbori navale. După calcularea reacțiilor în lagărele

arborelui, se determină diagrama forțelor de forfecare și diagrama momentelor de încovoiere. Valorile realizate sunt comparate cu recomandările Normelor tehnice privind *clasificarea și construcția navelor* maritime.

Cuvinte cheie: metoda FEM, arbore intermediar, arborele elicei, linia arborelui, racordul de cuplare, rulmentul, reacția, greutatea elicei.