

MATEMATIČKI MODEL BRODSKE KONSTRUKCIJE S PRIMJENOM U HIDROELASTIČNOJ ANALIZI

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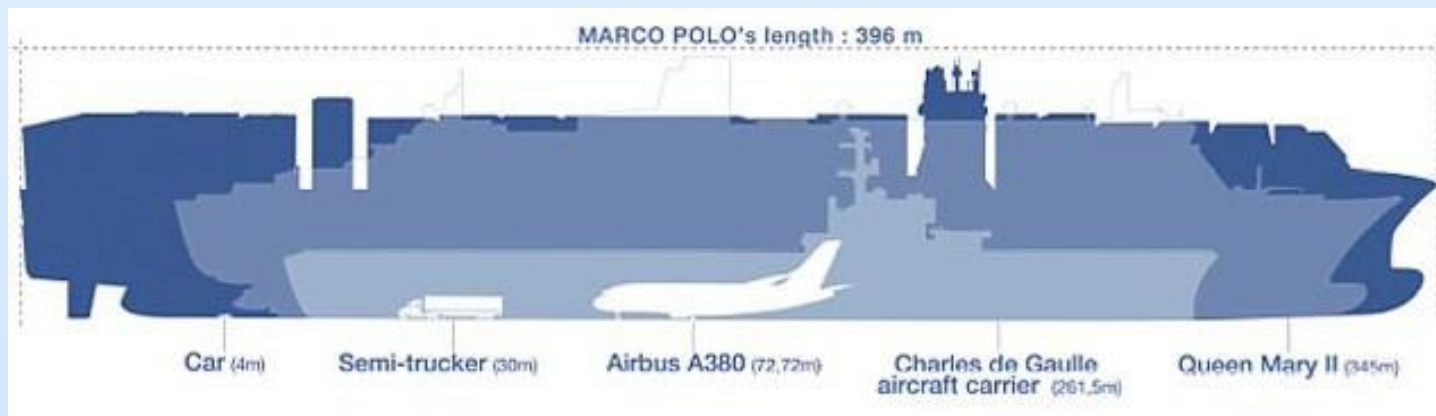
HAZU, Zagreb, 30. svibnja 2014.

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3. Doprinos poprečnih pregrada krutosti broorskog trupa
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1. Uvod

- Projekt MZOŠ “Opterećenje i odziv brodskih konstrukcija”
- EU FP7 projekt “Tools for Ultra Large Container Ships” (TULCS)
- Ekspanzija trgovinske razmjene u kombinaciji s prednostima prijevoza robe kontejnerima uvjetovala je gradnju velikih kontejnerskih brodova
- Kontejnerski transport (jednostavnost, brzina, sigurnost, niski jedinični troškovi, usklađenost s drugim oblicima transporta)
- Suvremeni kontejnerski brodovi:
 - izvan iskustvenih baza na kojima se temelje pravila klasifikacijskih društava
 - provedba izravnih proračuna opterećenja i odziva
 - snižena krutost, visoke susretne frekvencije (veće brzine)
 - prirodne frekvencije mogu upasti u područje frekvencija valne uzbude (više nije moguće zanemariti interakciju fluid-struktura)
 - prve prirodne frekvencije pripadaju spregnutim horizontalnim i torzijskim vibracijama
- **Cilj istraživanja** – povećanje točnosti numeričkog modela za hidroelastičnu analizu velikih kontejnerskih brodova (povećanjem točnosti grednog strukturnog modela)



2. Utjecaj smicanja na uvijanje brodskog trupa

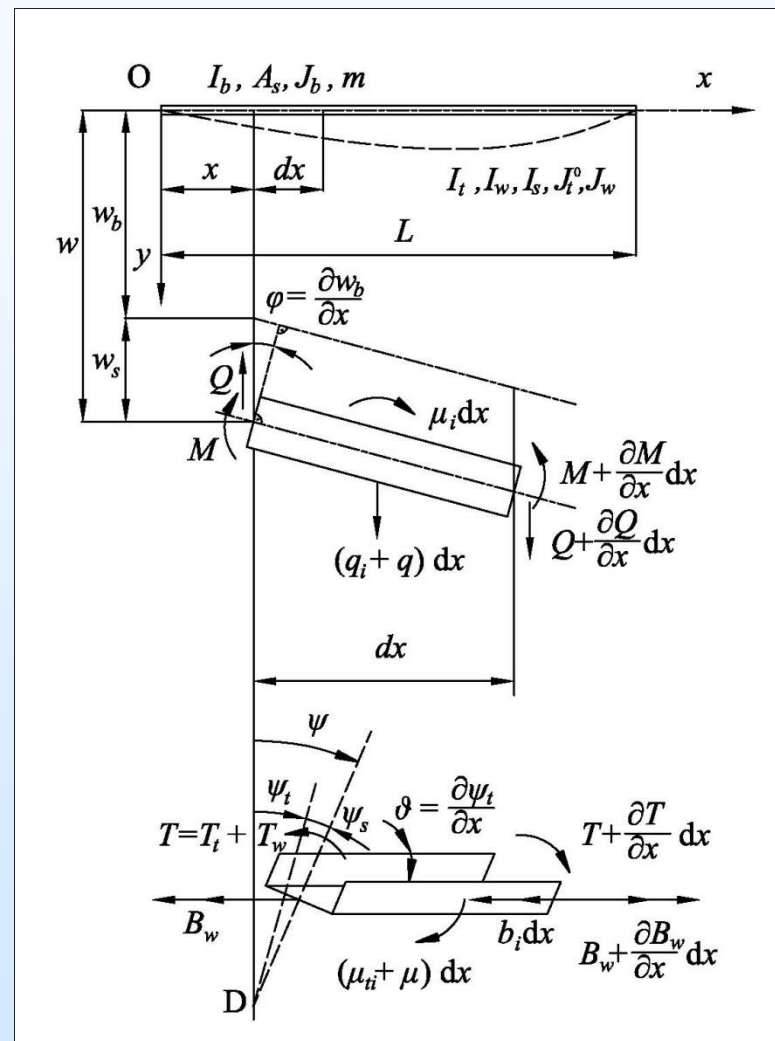
- U literaturi je prepoznata analogija između utjecaja smicanja na savijanje i utjecaja smicanja na torziju (Pavazza, 1991., 1993., 2005.)

$$W = w_b + w_s, \quad w_s = -\frac{EI_b}{GA_s} \frac{\partial^2 w_b}{\partial x^2}$$

$$\psi = \psi_t + \psi_s, \quad \psi_s = -\frac{EI_w}{GI_s} \frac{\partial^2 \psi_t}{\partial x^2}$$

Ref. (FEM formulacija)

Senjanović, Tomašević, Vladimir: An advanced theory of thin-walled girders with application to ship vibrations, *Marine Structures*, 2009.



Savijanje i uvijanje grede

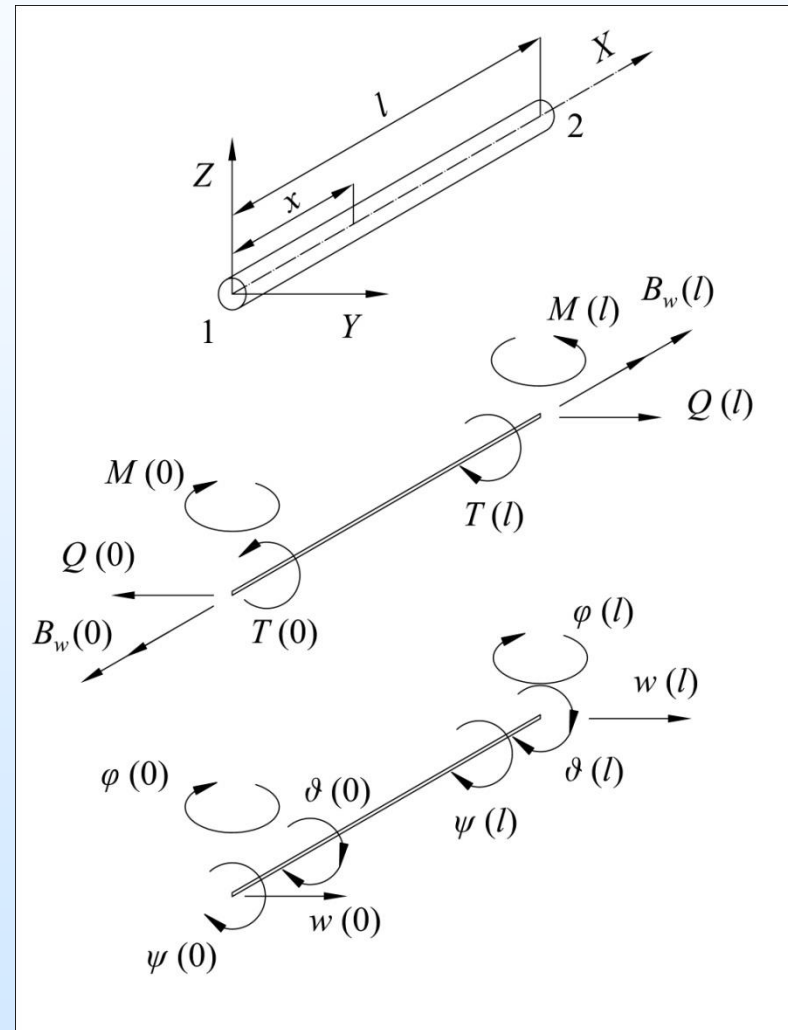
$$\mathbf{f}^e = \mathbf{k}^e \boldsymbol{\delta}^e + \mathbf{m}^e \ddot{\boldsymbol{\delta}}^e$$

$$\mathbf{f}^e = \begin{Bmatrix} \mathbf{P} \\ \mathbf{R} \end{Bmatrix}, \quad \boldsymbol{\delta}^e = \begin{Bmatrix} \mathbf{U} \\ \mathbf{V} \end{Bmatrix}$$

$$\mathbf{k}^e = \begin{bmatrix} \mathbf{k}_{bs} & 0 \\ 0 & \mathbf{k}_{ws} + \mathbf{k}_t \end{bmatrix}, \quad \mathbf{m}^e = \begin{bmatrix} \mathbf{m}_{sb} & \mathbf{m}_{st} \\ \mathbf{m}_{ts} & \mathbf{m}_{tw} \end{bmatrix}$$

$$\mathbf{P} = \begin{Bmatrix} -Q(0) \\ M(0) \\ Q(l) \\ -M(l) \end{Bmatrix}, \quad \mathbf{R} = \begin{Bmatrix} -T(0) \\ -B_w(0) \\ T(l) \\ B_w(l) \end{Bmatrix}$$

$$\mathbf{U} = \begin{Bmatrix} w(0) \\ \varphi(0) \\ w(l) \\ \varphi(l) \end{Bmatrix}, \quad \mathbf{V} = \begin{Bmatrix} \psi(0) \\ \vartheta(0) \\ \psi(l) \\ \vartheta(l) \end{Bmatrix}$$



Gredni konačni element

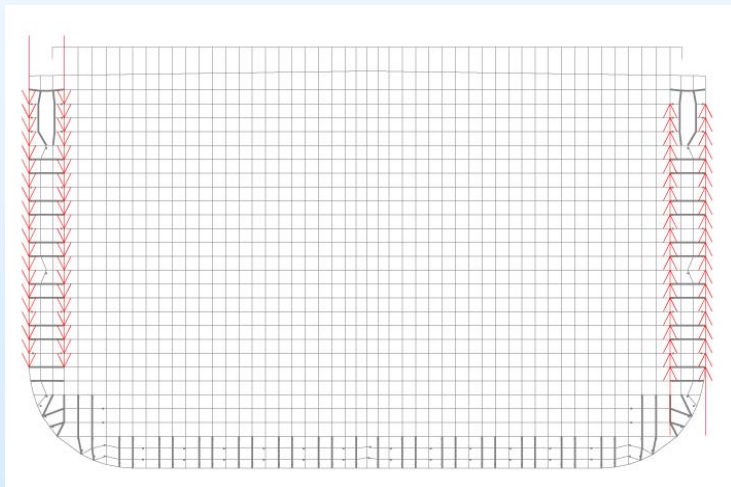
$$k_{bs} = \frac{2EI_b}{(1+12\beta)l^3} \begin{bmatrix} 6 & 3l & -6 & 3l \\ 2(1+3\beta)l^2 & -3l & (1-6\beta)l^2 & \\ 6 & -3l & & \\ \text{Sym.} & & 2(1+3\beta)l^2 & \end{bmatrix}$$

$$[k]_{ws} = \frac{2EI_w}{(1+12\gamma)l^3} \begin{bmatrix} 6 & 3l & -6 & 3l \\ 2(1+3\gamma)l^2 & -3l & (1-6\gamma)l^2 & \\ 6 & -3l & & \\ \text{Sym.} & & 2(1+3\gamma)l^2 & \end{bmatrix}$$

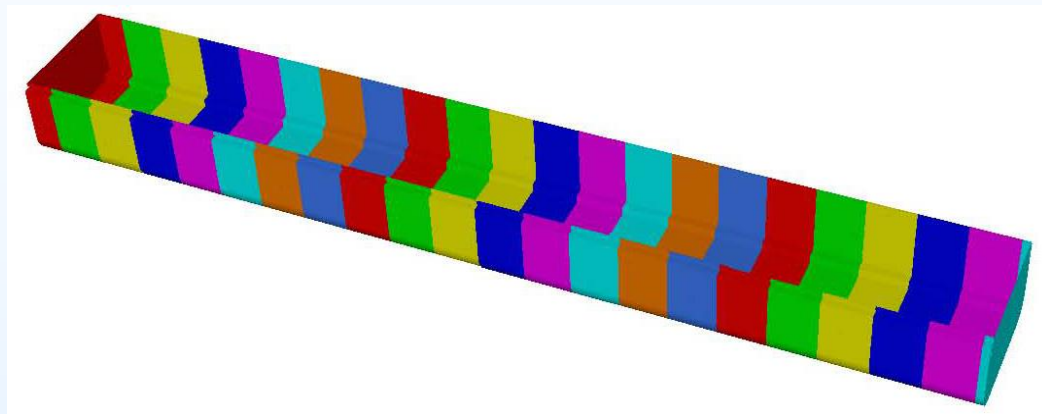
$$[k]_t = \frac{GI_t}{30(1+12\gamma)^2 l} \begin{bmatrix} 36 & 3(1-60\gamma)l & -36 & 3(1-60\gamma)l \\ 4(1+15\gamma+360\gamma^2)l^2 & -3(1-60\gamma)l & -(1+60\gamma-720\gamma^2)l^2 & \\ 36 & -3(1-60\gamma)l & & \\ \text{Sym.} & & 4(1+15\gamma+360\gamma^2)l^2 & \end{bmatrix}$$

$$\beta = \frac{EI_b}{GA_s l^2} \quad \gamma = \frac{EI_w}{GI_s l^2}$$

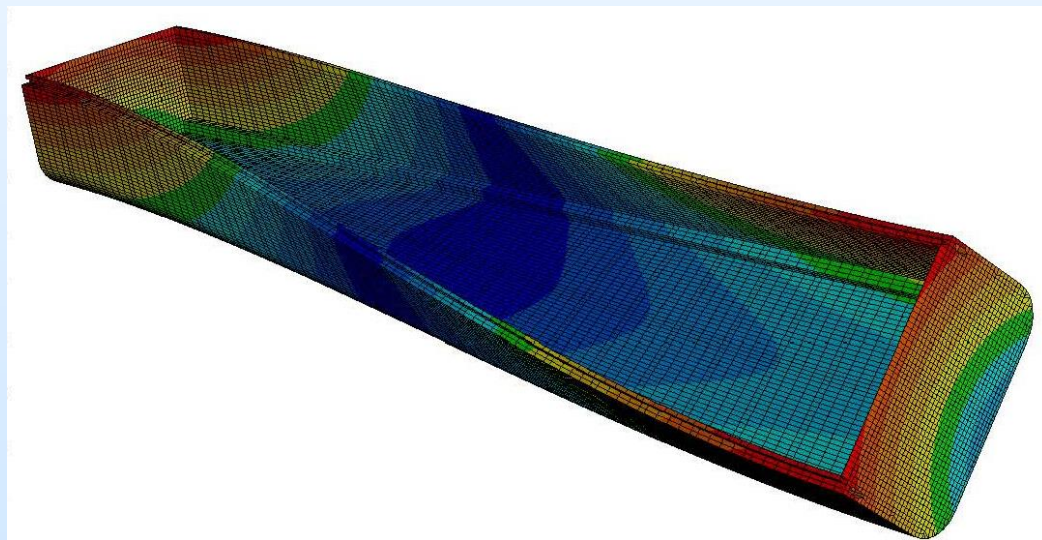
Verifikacija



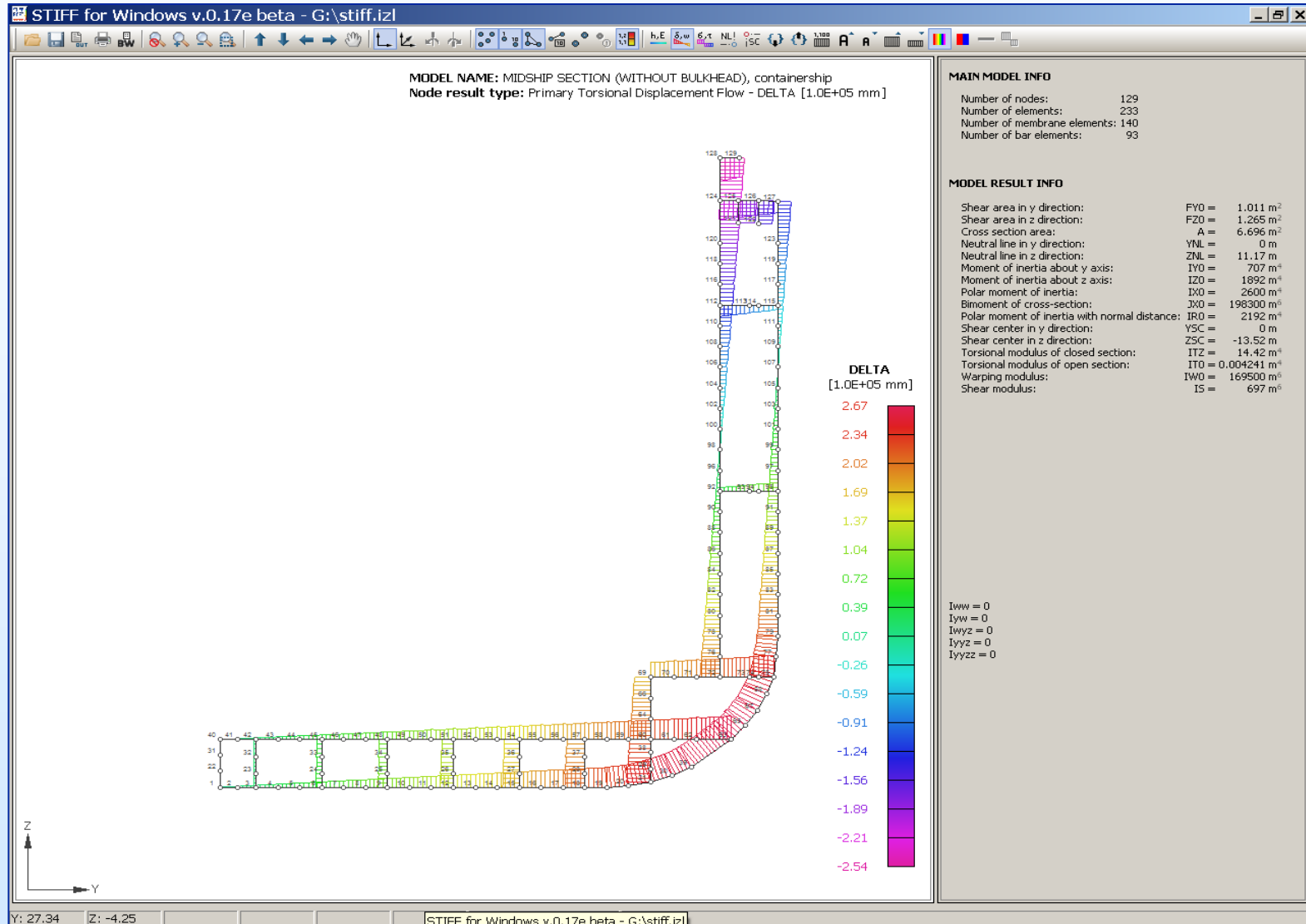
Rubno opterećenje modela



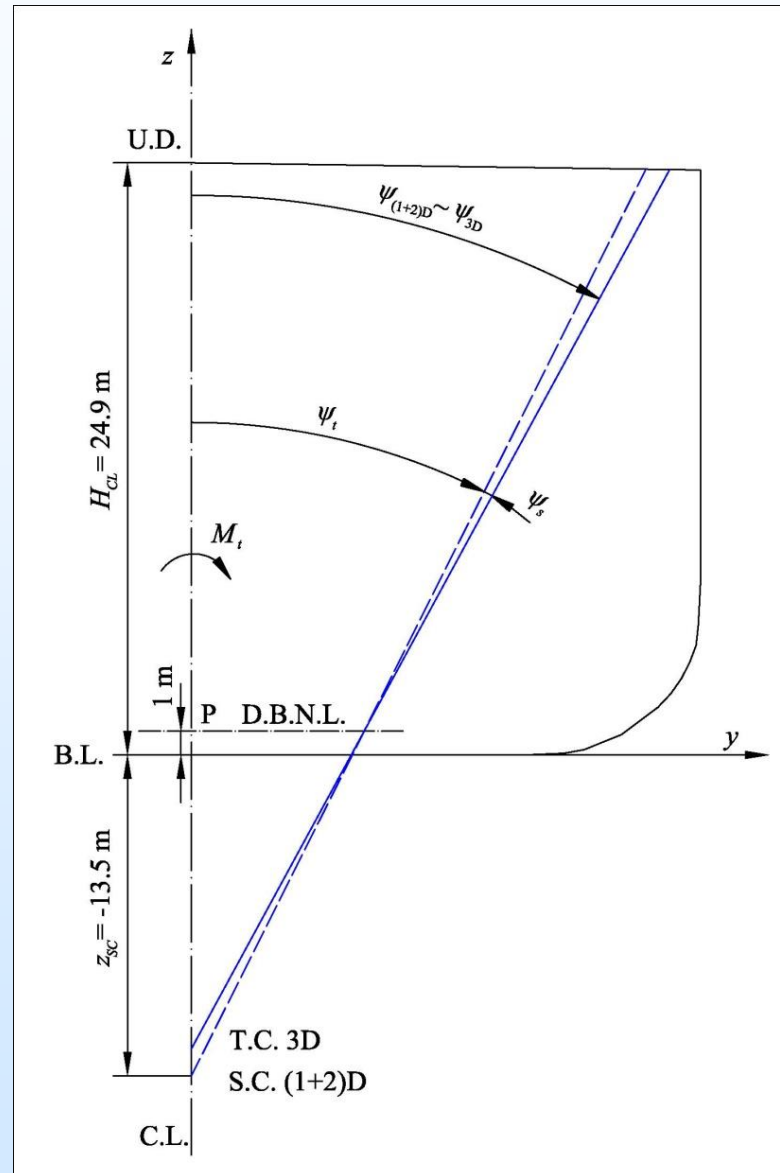
Model superelemenata jednolikog pontona



Deformacija pontona uslijed momenta uvijanja



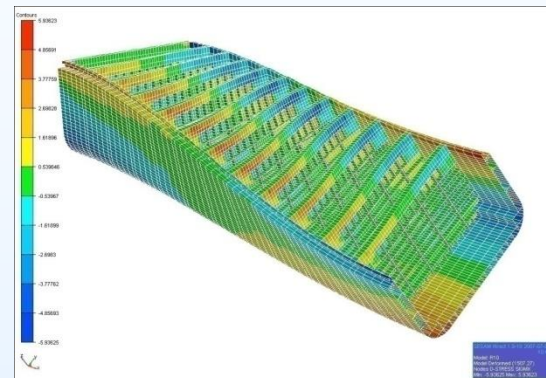
Program STIFF za određivanje parametara krutosti poprečnog presjeka trupa



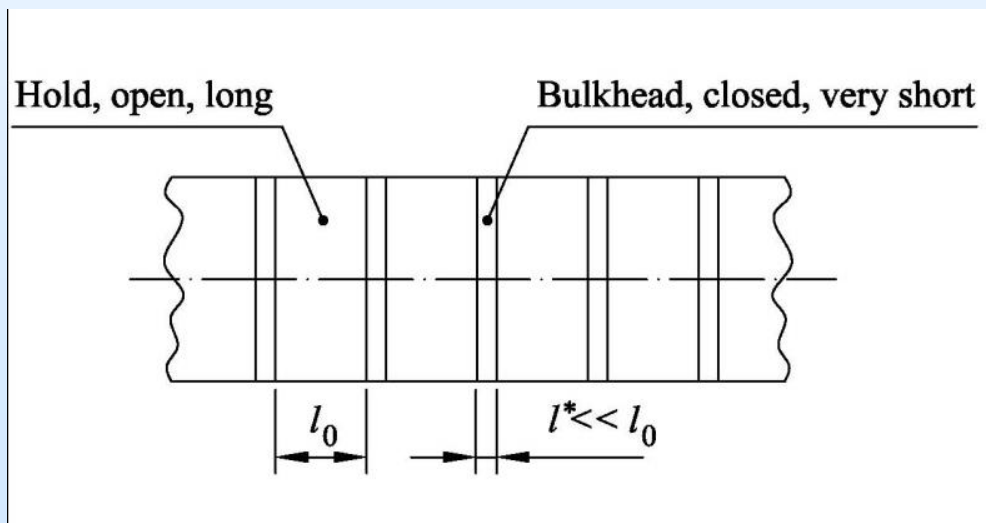
Kut uvijanja na kraju pontona

3. Doprinos poprečnih pregrada krutosti broskog trupa

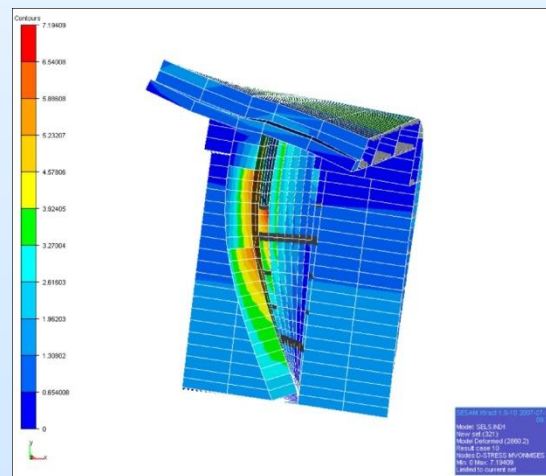
- Teorija uvijanja tankostijenih nosača + teorija savijanja ortotropne ploče (Szilard, 2004.)
- Korekcija modula torzije otvorenog dijela trupa



3D FEM model trupa pontona s pregradama

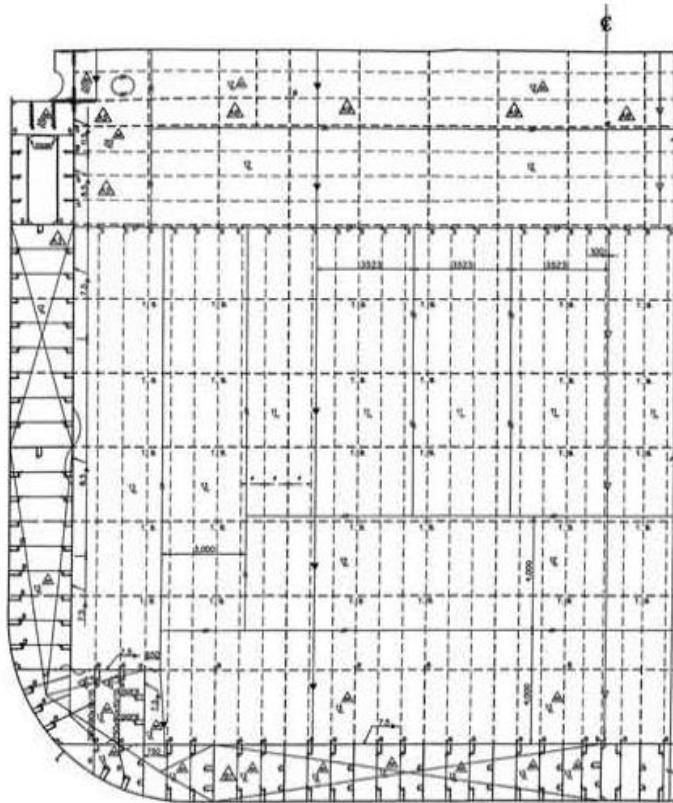


Skica skladišta kontejnerskog broda

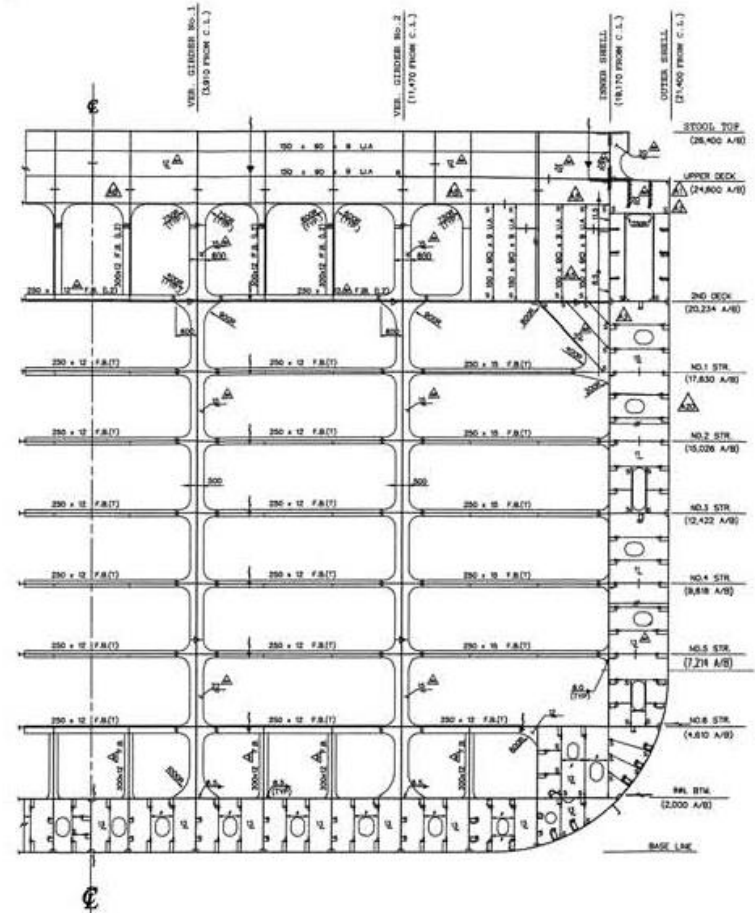


Deformacija pregrade, 3D FEM model

a)



b)



Poprečne pregrade kontejnerskog broda, a) vodonepropusna, b) propusna

Pomaci pregrade:

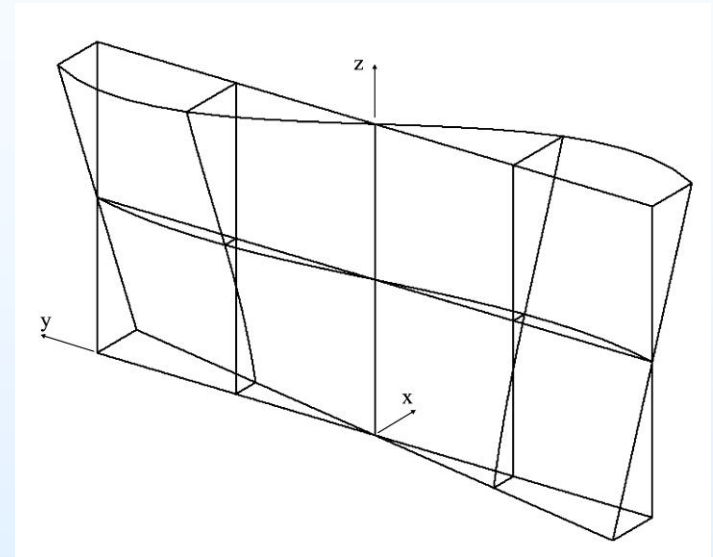
$$u(y, z) = -y \left\{ (z - d) + \left[1 - \left(\frac{y}{b} \right)^2 \right] \frac{z^2}{H} \left(2 - \frac{z}{H} \right) \right\} \psi'$$

Energija deformacije stool-a:

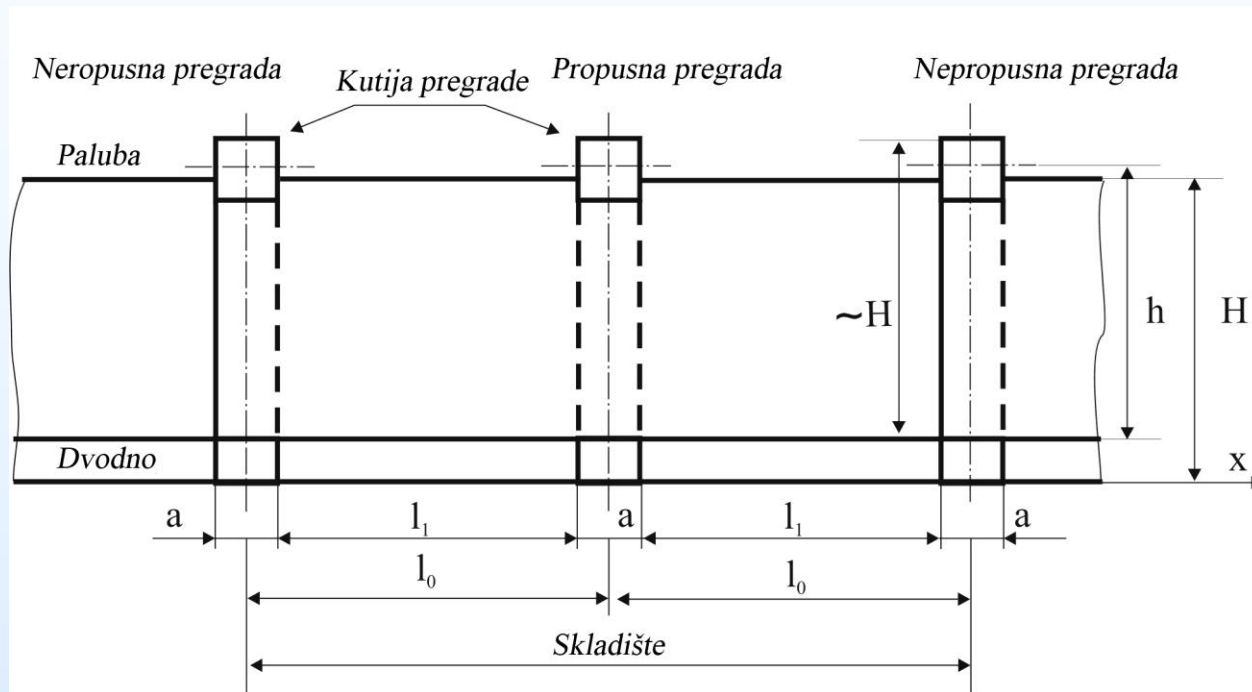
$$U_s = \left[\frac{12h^2 I_{sb}}{b} + 72(1+\nu) \frac{h^2}{b^3} \frac{I_{sb}^2}{A_s} + \frac{9b I_{st}}{10(1+\nu)} \right] E \psi'^2$$

Energija deformacije pregrade:

$$U_g = \frac{1}{1-\nu^2} \left[\frac{116H^3}{35b} i_y + \frac{32b^3}{105H} i_z + \frac{8Hb}{75} \nu (i_y + i_z) + \frac{143Hb}{75} (1-\nu) i_t \right] E \psi'^2$$



Deformacija pregrade



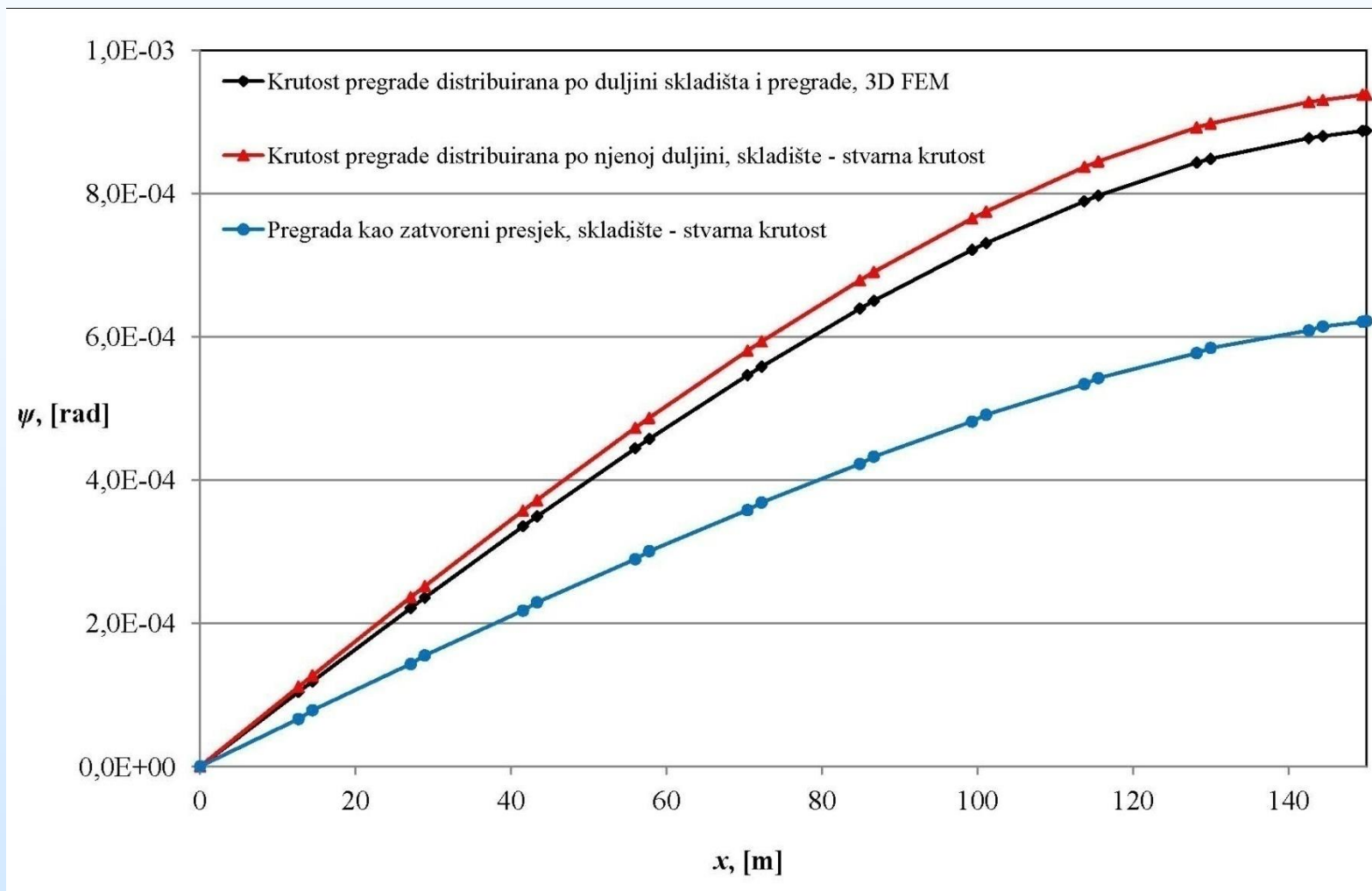
Uzdužni presjek skladišnih prostora

Efektivni parametar krutosti:

$$I_t^* = \left[1 + \frac{a}{l_1} + \frac{4(1+\nu)C}{I_t l_0} \right] I_t, \quad C = \frac{U_g + U_s}{E\psi'^2}$$

Parametri krutosti konačnih elemenata pregrade i skladišta

Način modeliranja	Segment trupa	Parametar krutosti		
		Krutost na uvijanje I_t , m ⁴	Krutost na vitoperenje I_w , m ⁶	Smični modul tromosti I_s , m ⁴
Krutost pregrade distribuirana po njenoj duljini i duljini skladišta	Pregrada	34,42	171400	710,5
	Skladište	34,42	171400	710,5
Krutost pregrade distribuirana samo po njenoj duljini, skladište – stvarni parametri	Pregrada	143,7	171400	710,5
	Skladište	14,45	171400	710,5
Pregrada kao zatvoreni presjek, skladište – stvarni parametri	Pregrada	789,5	38040	217
	Skladište	14,45	171400	710,5



Odziv pontona u ovisnosti o načinu modeliranja poprečnih pregrada

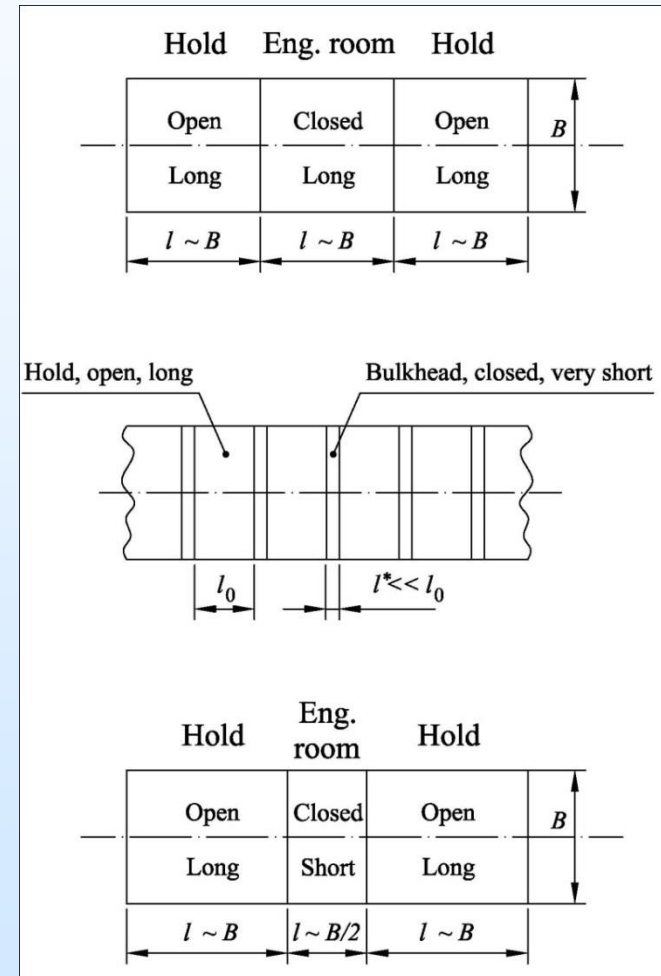
4. Doprinos konstrukcije strojarnice krutosti brodskog trupa

- Strojarnica VLCS je relativno kratka
- Nije efektivna u potpunosti
- Cilj: odrediti efektivne parametre krutosti za primjenu na konačne elemente
- Energetski pristup
- Ideja:

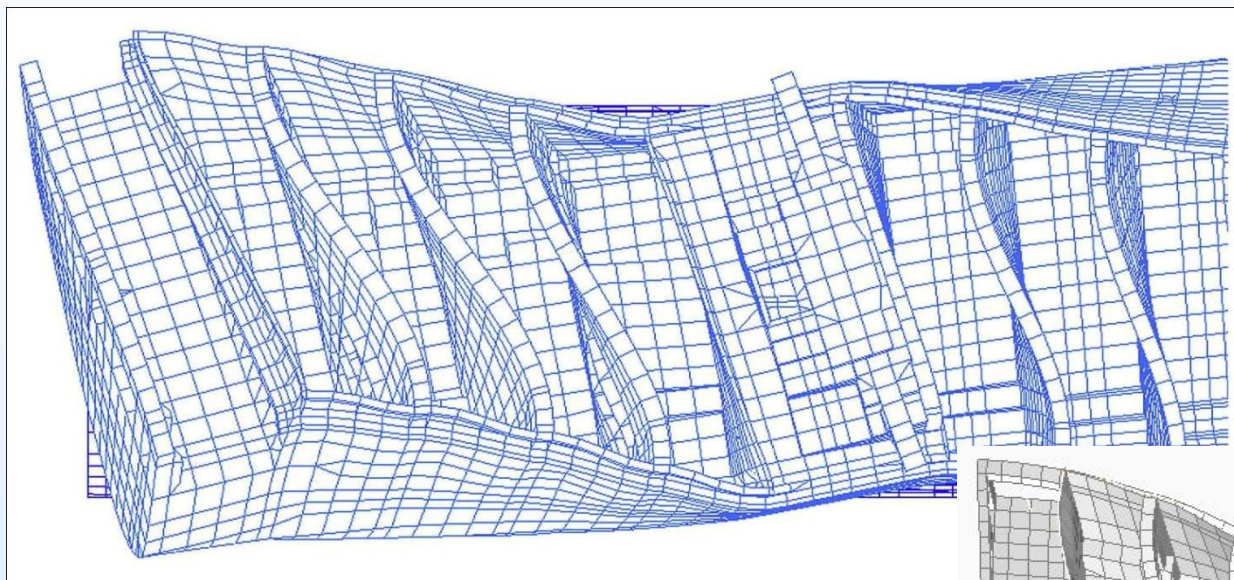
$$\tilde{I}_t = (1 + C) I_t^\circ$$

Ref.

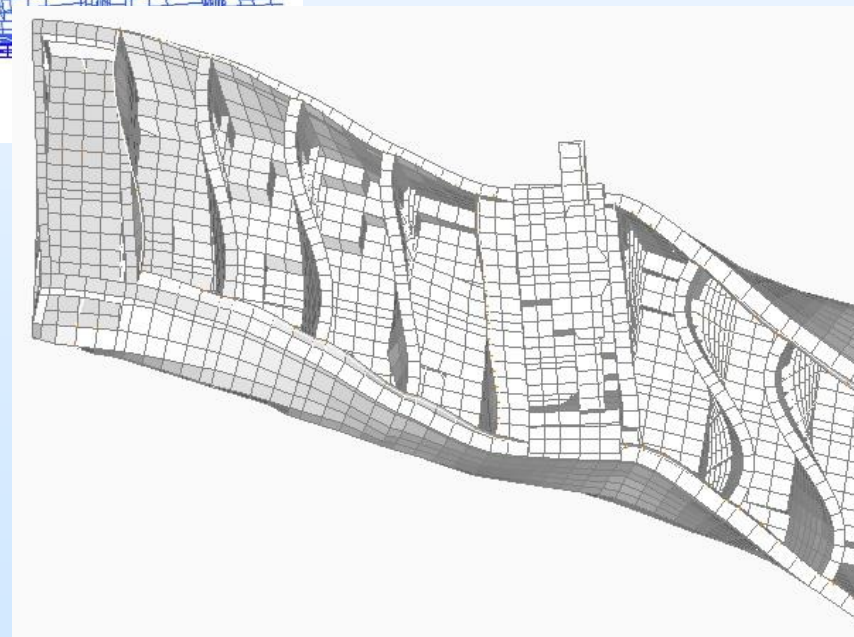
- Senjanović, Vladimir, Tomić: The contribution of the engine room structure to the hull stiffness of large container ships, *International Shipbuilding Progress*, 2010.
- Senjanović, Vladimir, Tomić: Investigation of torsion, warping and distortion of large container ships, *Ocean Systems Engineering*, 2011.



Otvoreni i zatvoreni segmenti trupa

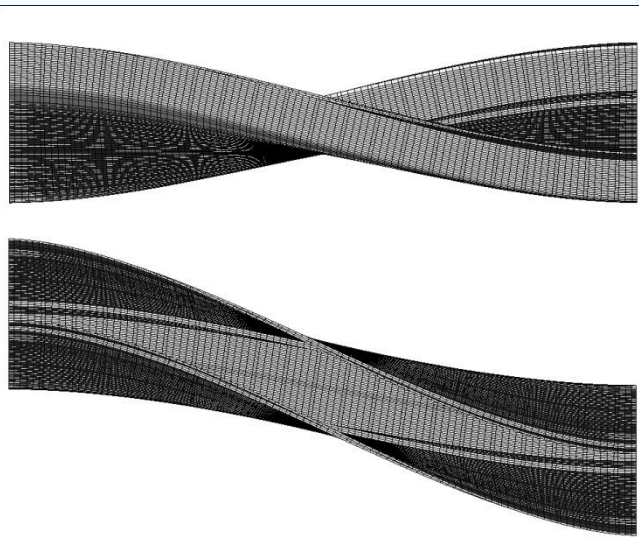


Deformacija krmenog dijela kontejnerskog broda nosivosti 11400 TEU



Deformacija krmenog dijela kontejnerskog broda nosivosti 7800 TEU

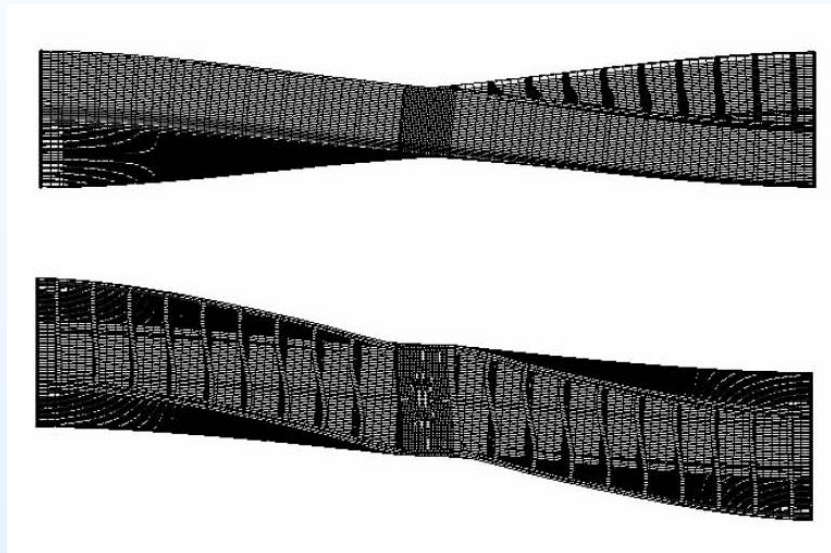
a)



b)



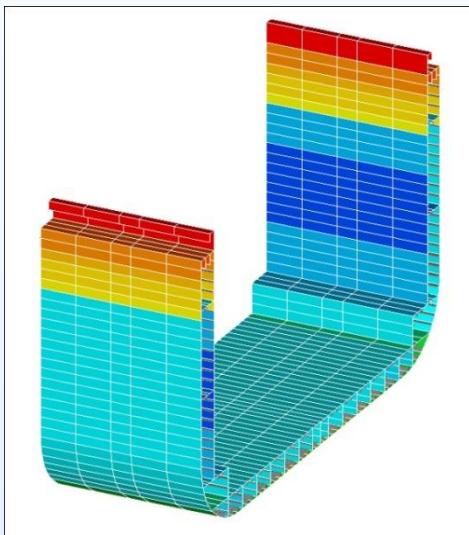
c)



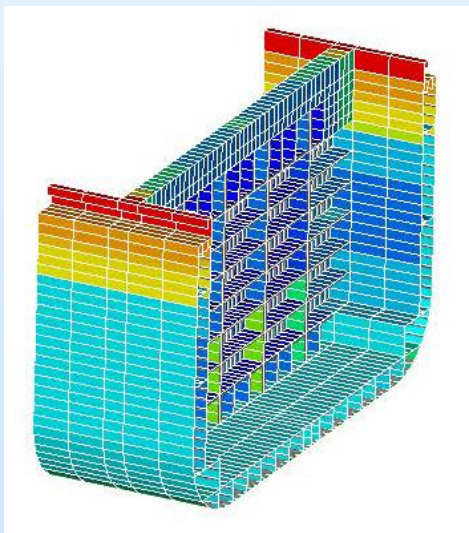
FEM modeli

- a) Jednoliki ponton bez pregrada
- b) Ponton sa strojarnicom bez pregrada
- c) Ponton sa strojarnicom i pregradama

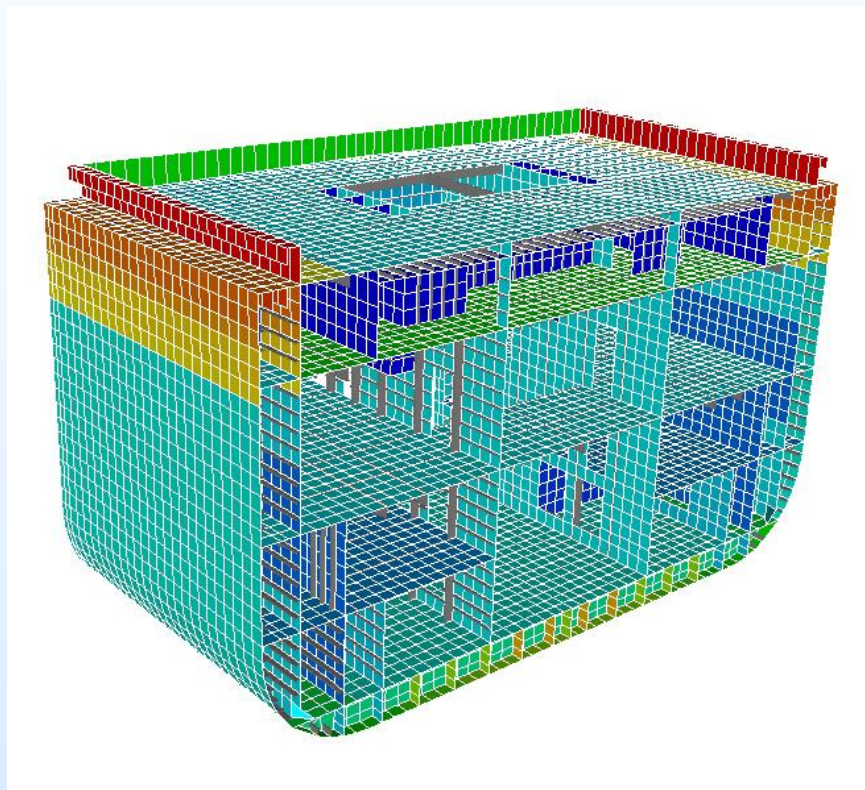
a)



b)

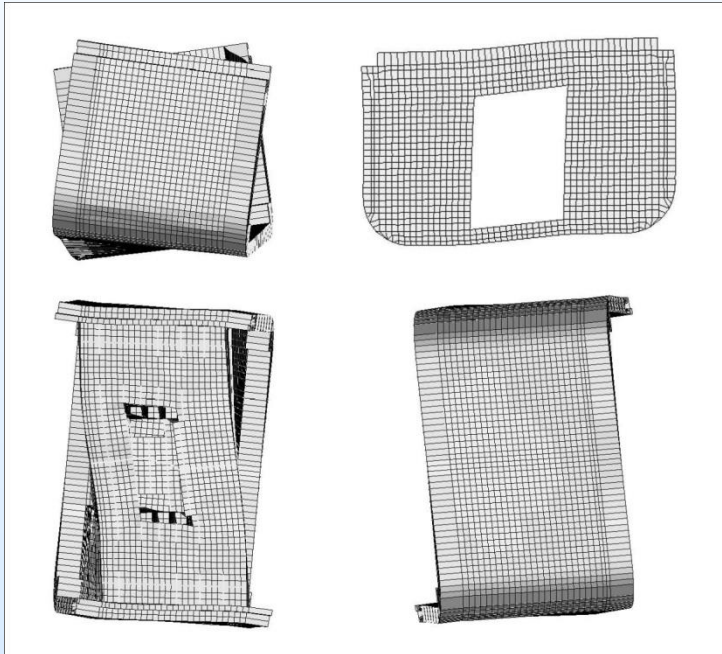


c)

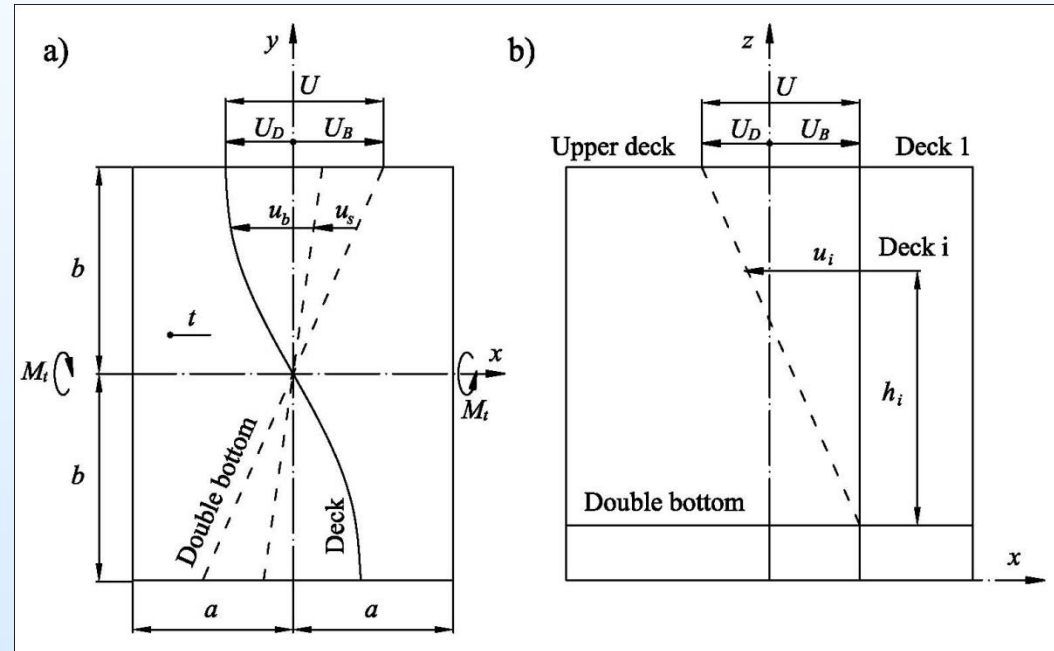


Superelementi:

- a) Otvoreni
- b) Otvoreni s pregradom
- c) Zatvoreni (strojarnica)



Deformacija strojarnice u 3D modelu



Deformacija gornje palube i rotacija dvodna,
a – ptičji pogled, b – bočni pogled

$$U = |U_D| + |U_B| = (|w_D| + |w_B|) \psi'_t$$

$$u_b = \frac{y}{2b} \left[3 - \left(\frac{y}{b} \right)^2 \right] U_b$$

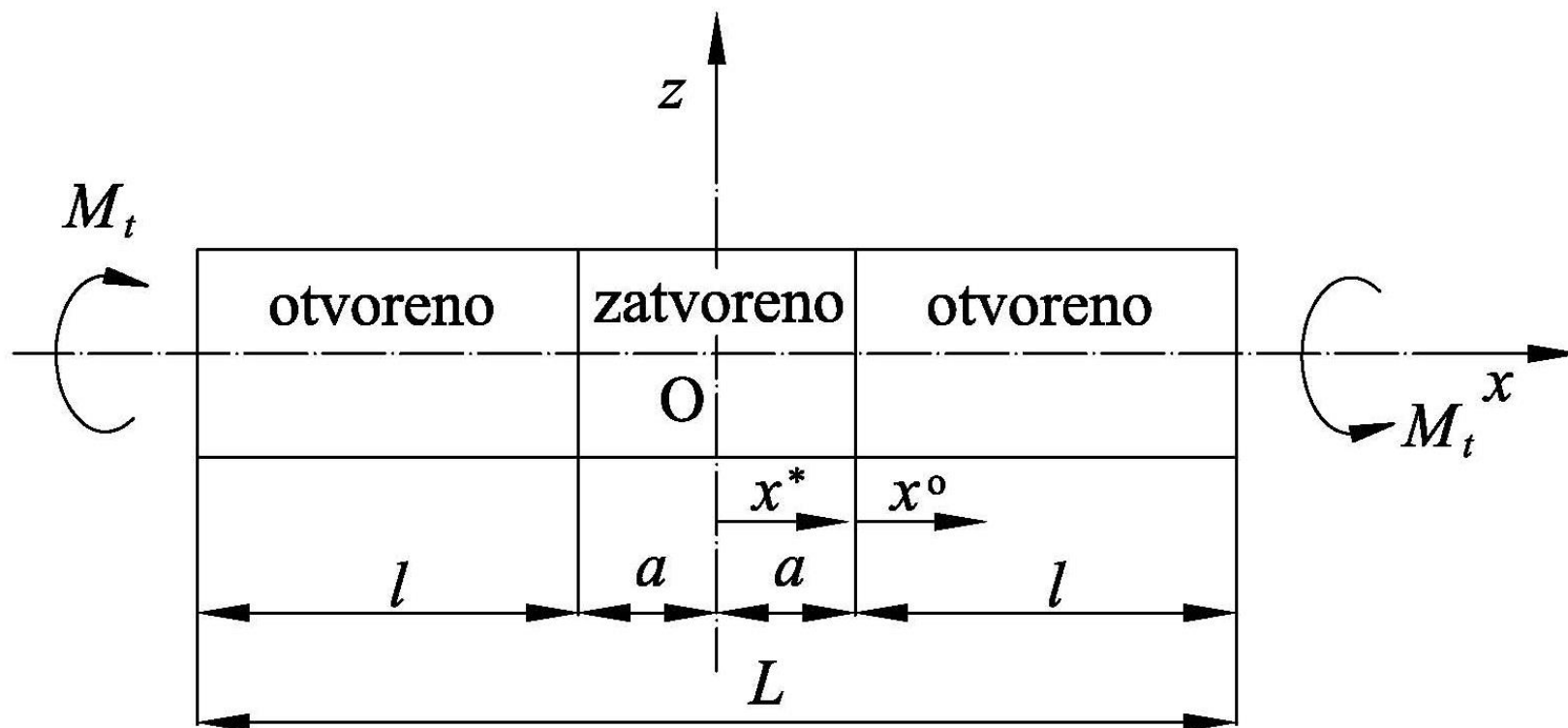
$$u_s = -\frac{EI}{GA} \frac{d^2 u_b}{dy^2} = 2(1+\nu) \left(\frac{a}{b} \right)^2 \frac{y}{b} U_b$$

$$E_1 = \frac{1}{2} EI \int_{-b}^b \left(\frac{d^2 u_b}{dy^2} \right)^2 dy + \frac{1}{2} GA \int_{-b}^b \left(\frac{du_s}{dy} \right)^2 dy$$

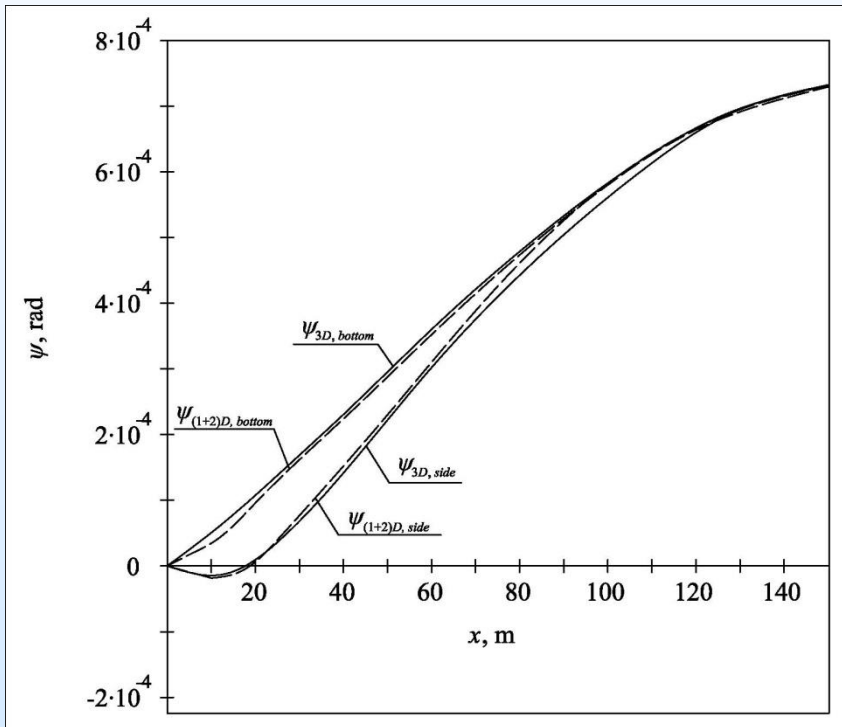
$$\tilde{I}_t = (1+C) I_t^\circ$$

$$C = \frac{\sum E_i}{E_t^\circ} = \frac{4(1+\nu) t_1 \left(\frac{a}{b} \right)^3 (|w_D| + |w_B|)^2 k}{\left[1 + 2(1+\nu) \left(\frac{a}{b} \right)^2 \right] I_t^\circ a},$$

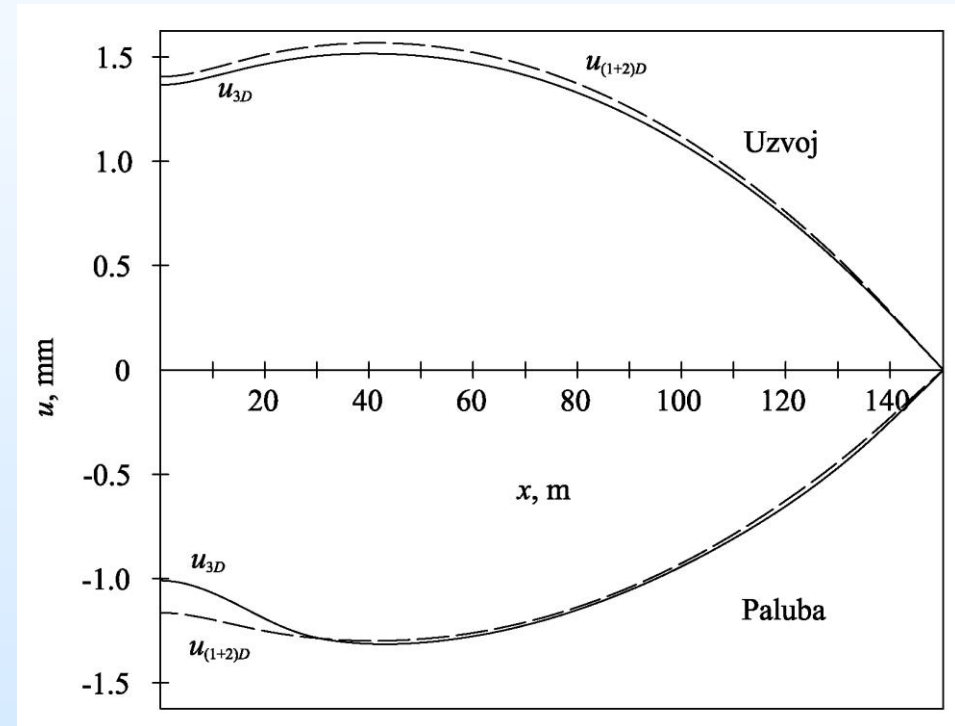
$$k = \sum \frac{V_i}{V_1} \left(\frac{h_i}{h_1} \right)^2$$



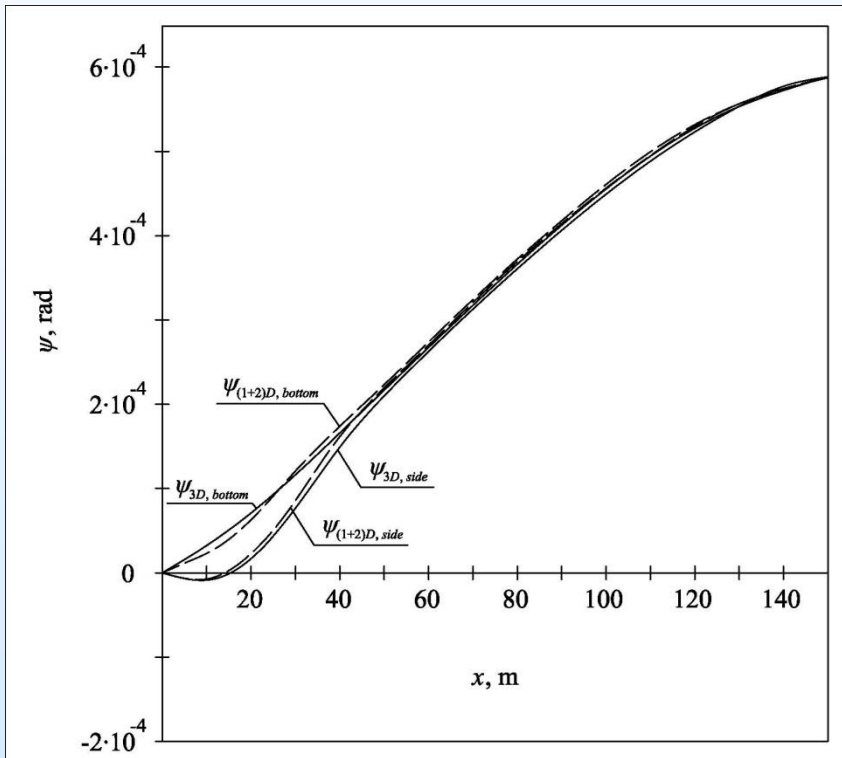
Uvijanje segmentnog nosača



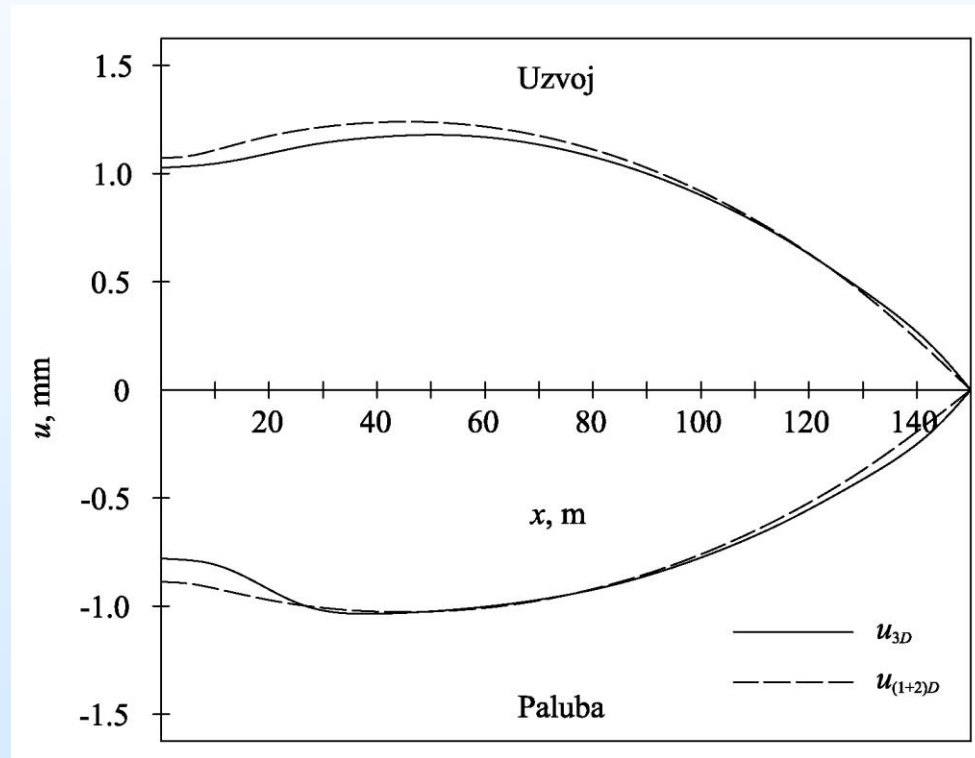
Kutovi uvijanja segmentnog pontona bez pregrada



Uzdužni pomaci palube i dna segmentnog pontona bez pregrada



Kutovi uvijanja segmentnog pontona s pregradama



Uzdužni pomaci palube i dna segmentnog pontona s pregradama

5. Globalni hidroelastični odziv velikog kontejnerskog broda

Duljina preko svega

$L_{OA} = 363,44 \text{ m}$

Duljina između okomica

$L_{pp} = 348,0 \text{ m}$

Širina

$B = 45,6 \text{ m}$

Visina

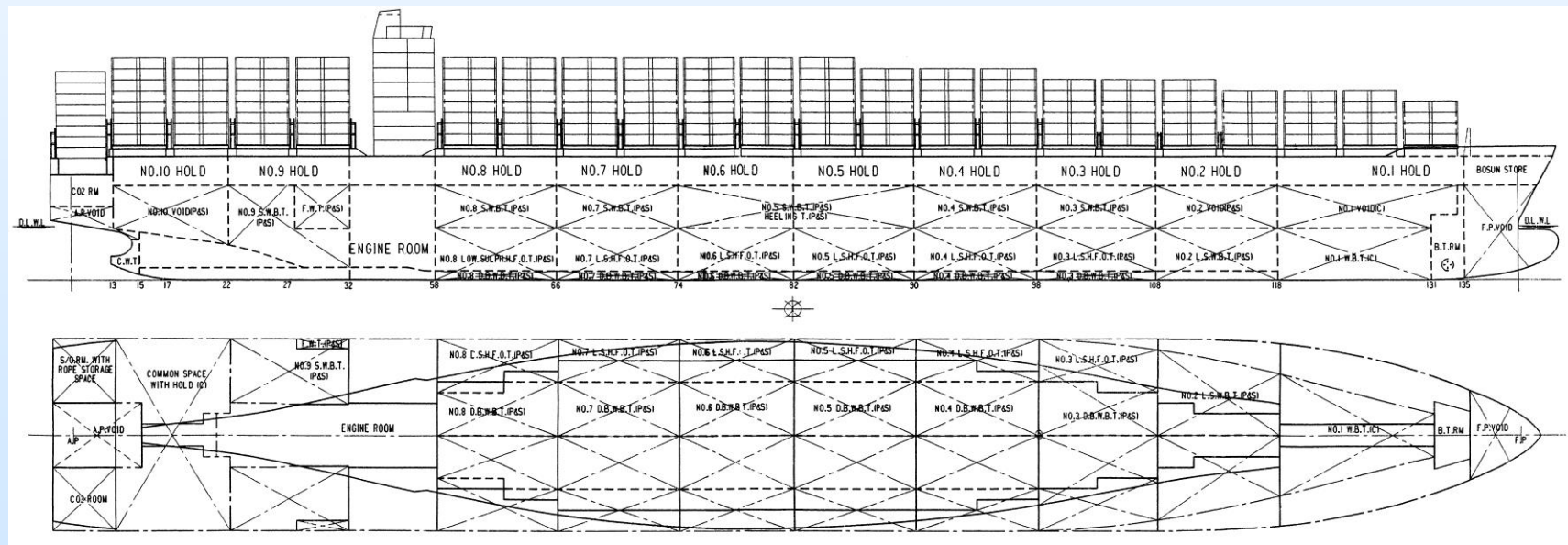
$H = 29,74 \text{ m}$

Gaz

$T = 15,0 \text{ m}$

Brzina

$V = 25,4 \text{ čv}$



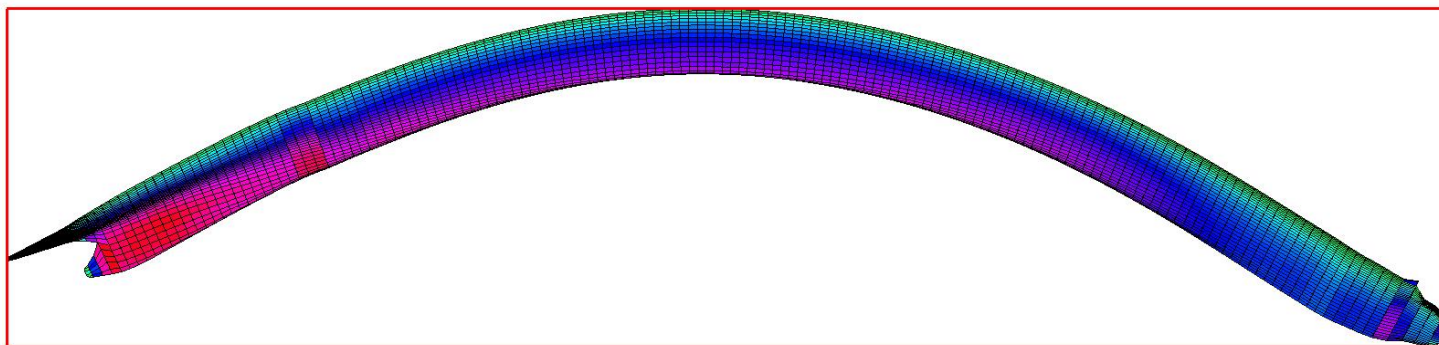
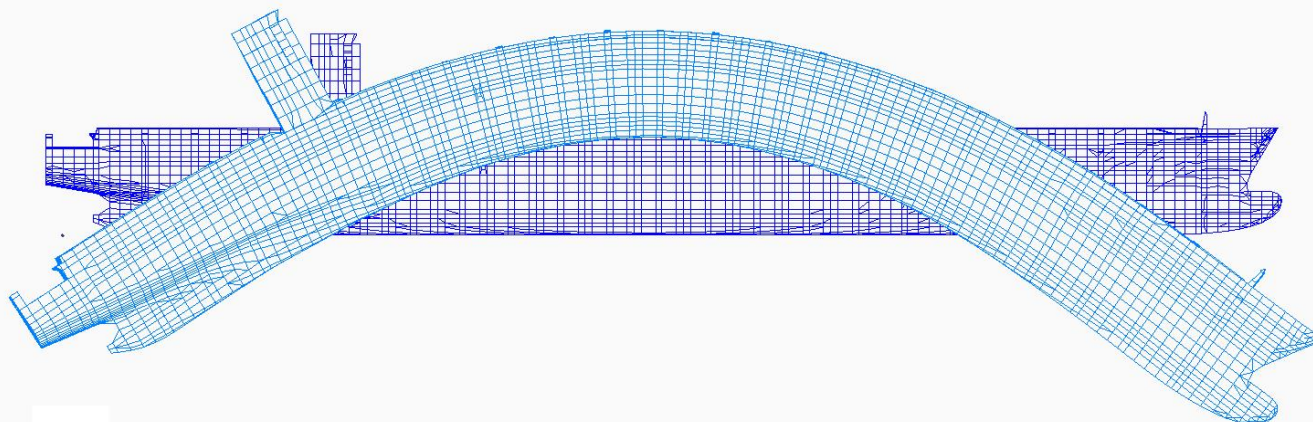
Kontejnerski brod nosivosti 11400 TEU

Suhe prirodne frekvencije vertikalnih vibracija trupa, f_i (Hz)

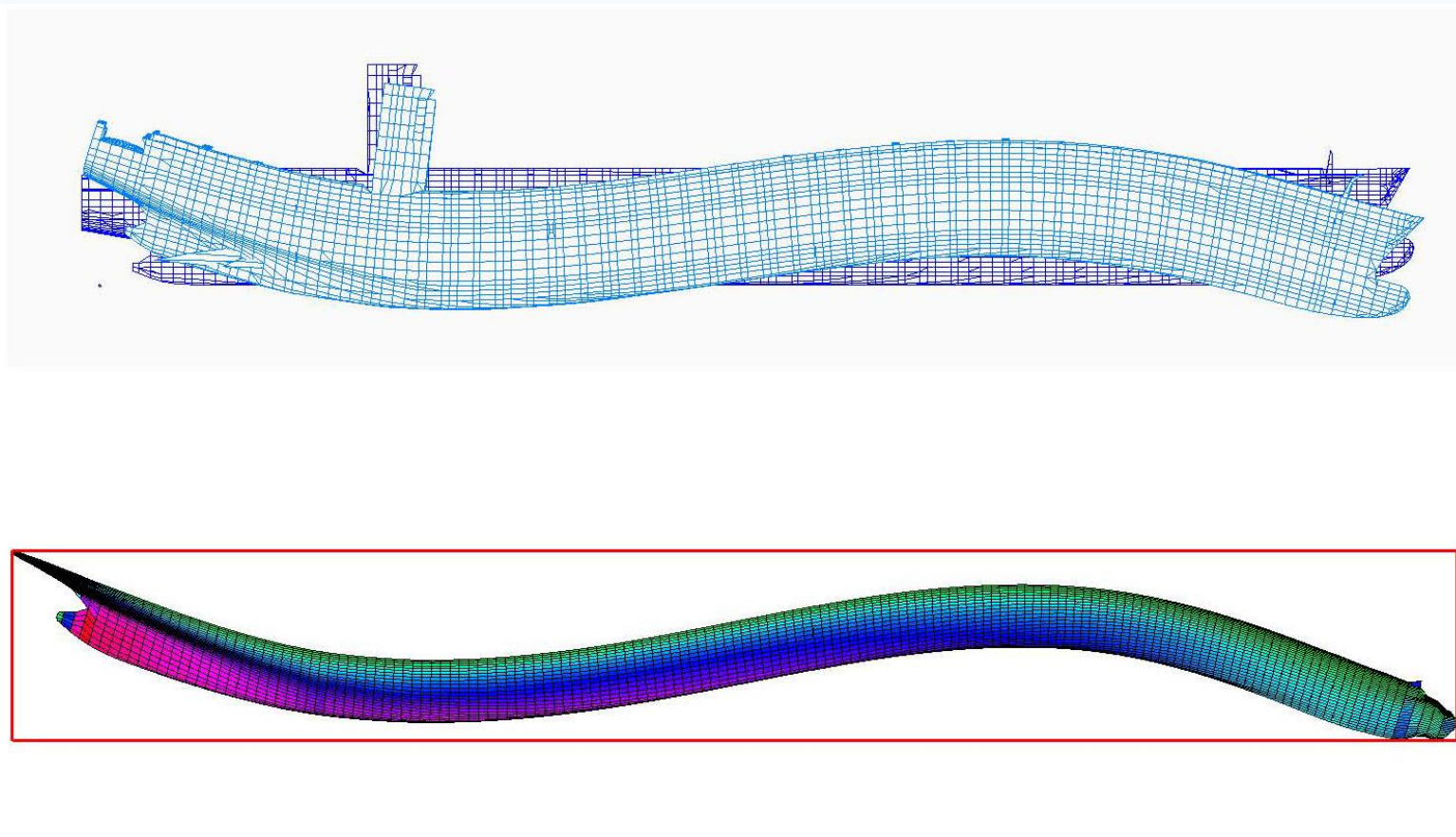
Oblik br.	1D FEM	3D FEM	Razlika, %
1	1,149	1,159	-0,86
2	2,318	2,327	-0,39
3	3,695	3,654	1,12
4	5,457	5,409	0,89
5	6,913	6,605	4,66

Suhe prirodne frekvencije spregnutih vibracija trupa, f_i (Hz)

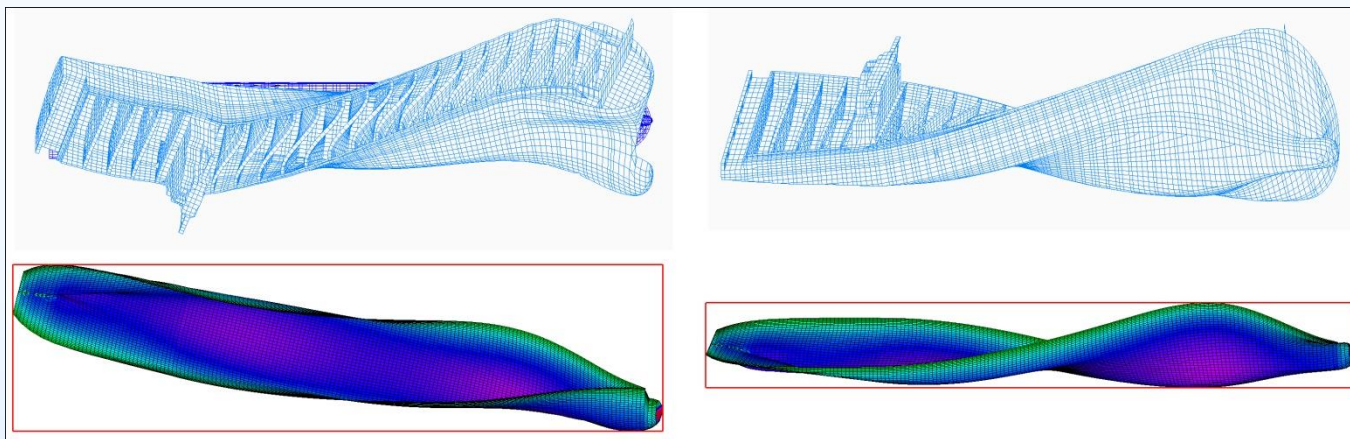
Oblik br.	Spregnuti oblik	1D FEM	3D FEM	Razlika, %
1	T1	0,639	0,638	0,16
2	T2+H1	1,056	1,076	-1,86
3	T3+H2	1,745	1,749	-0,23
4	T4+H3	2,233	2,429	-8,07
5	T2+H5	3,072	2,630	16,81
6	T5+H4	3,350	3,519	-4,80



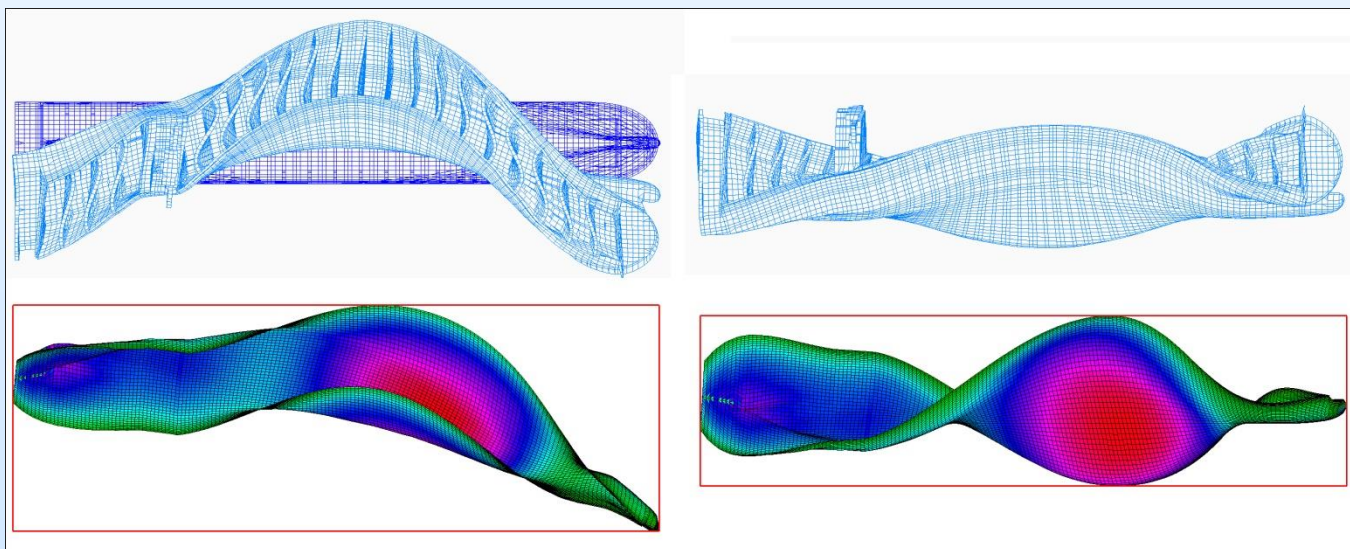
Prvi prirodni oblik vertikalnih vibracija kontejnerskog broda, 3D FEM i 1D FEM



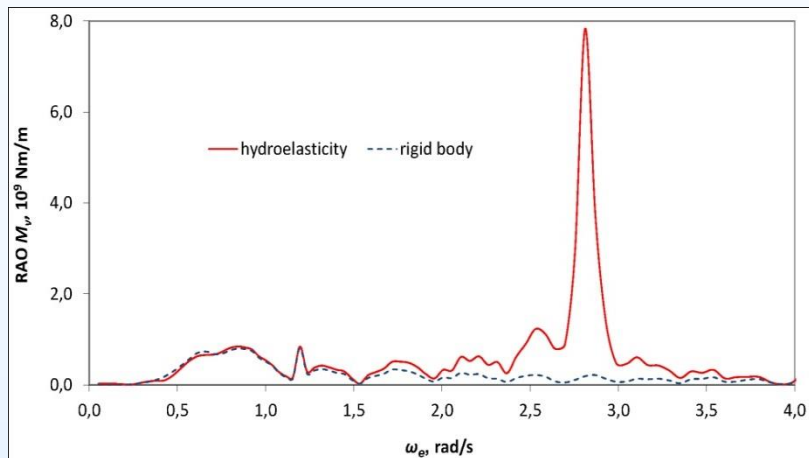
Drugi prirodni oblik vertikalnih vibracija kontejnerskog broda, 3D FEM i 1D FEM



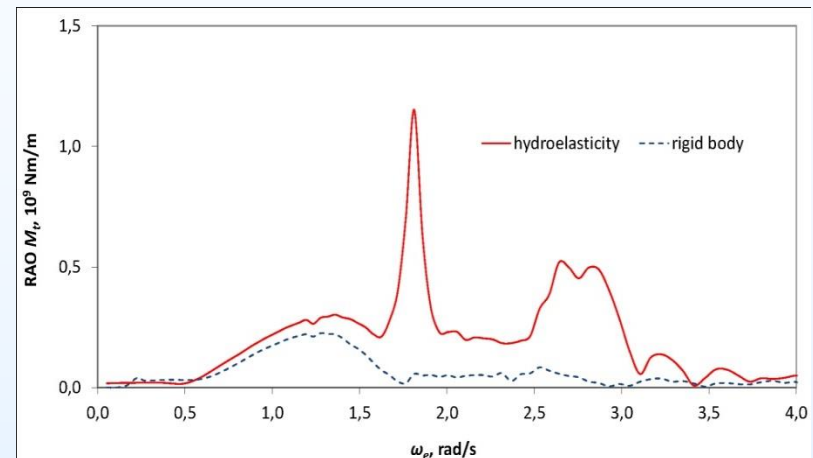
Prvi prirodni oblik spregnutih vibracija kontejnerskog broda, 3D FEM i 1D FEM



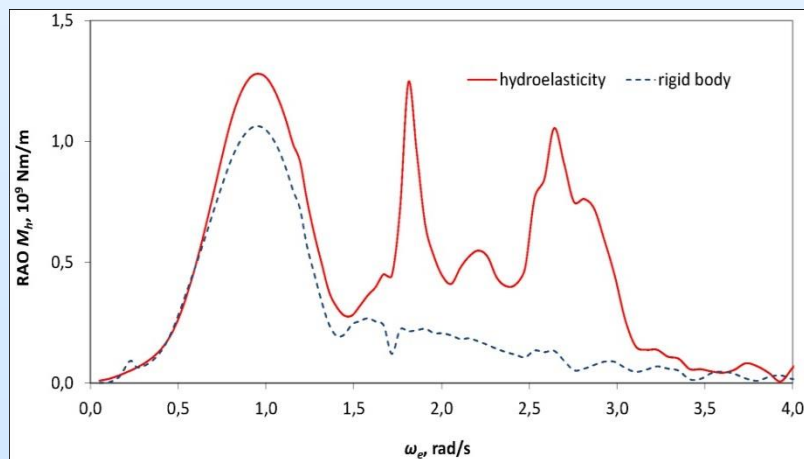
Drugi prirodni oblik spregnutih vibracija kontejnerskog broda, 3D FEM i 1D FEM



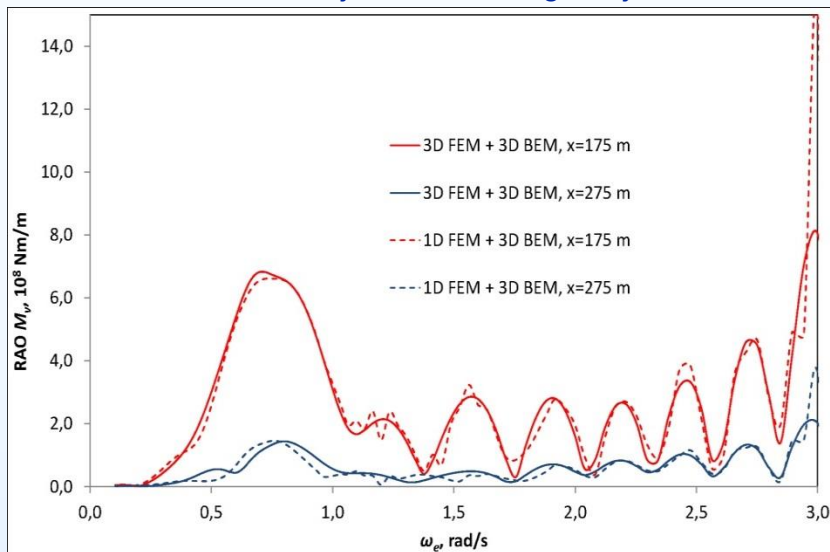
Transfer function of vertical bending moment,
 $\chi=120^\circ$, $V=24.7 \text{ kn}$, $x=175 \text{ m}$ from AP



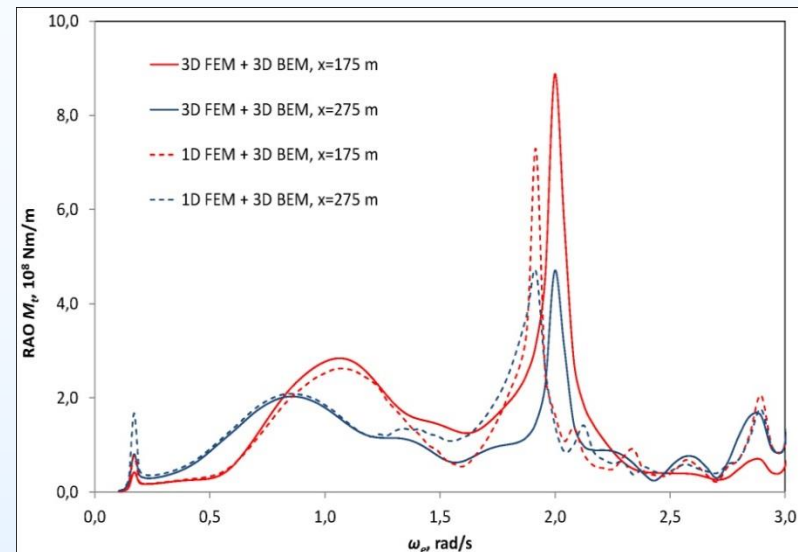
Transfer function of torsional moment, $\chi=120^\circ$,
 $V=24.7 \text{ kn}$, $x=175 \text{ m}$ from AP



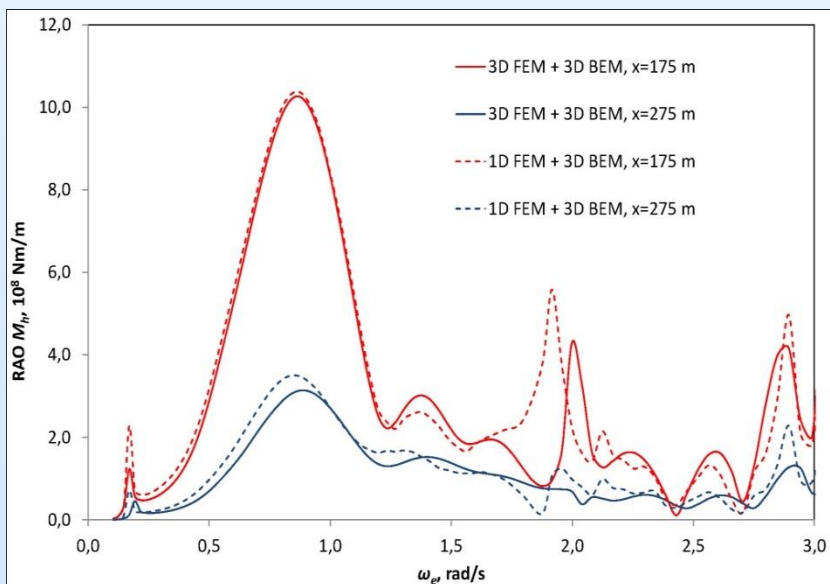
Transfer function of horizontal bending moment,
 $\chi=120^\circ$, $V=24.7 \text{ kn}$, $x=175 \text{ m}$ from AP



Transfer function of vertical bending moment,
 $\chi=120^\circ$, $V=15.75 \text{ kn}$



Transfer function of torsional moment, $\chi=120^\circ$,
 $V=15.75 \text{ kn}$



Transfer function of horizontal bending moment,
 $\chi=120^\circ$, $V=15.75 \text{ kn}$

6. Zaključak

- Hidroelastični model utemeljen na grednom strukturnom modelu predstavlja pouzdan numerički alat za analizu velikih kontejnerskih brodova (frekvencijska domena)
- Valjanost teorijskih razmatranja vezanih za gredni model dokazana usporedbom s rezultatima analiza 3D numeričkih modela
- Strukturni model
 - utjecaj smicanja na savijanje i uvijanje
 - doprinos poprečnih pregrada općoj krutosti trupa
 - model efektivne krutosti strojarnice
- Povećana razina točnosti osnovnog modela
- Gredni model – jasnija fizika ponašanja konstrukcije
- 3D model – nužan za analizu lokalnog odziva konstrukcije