

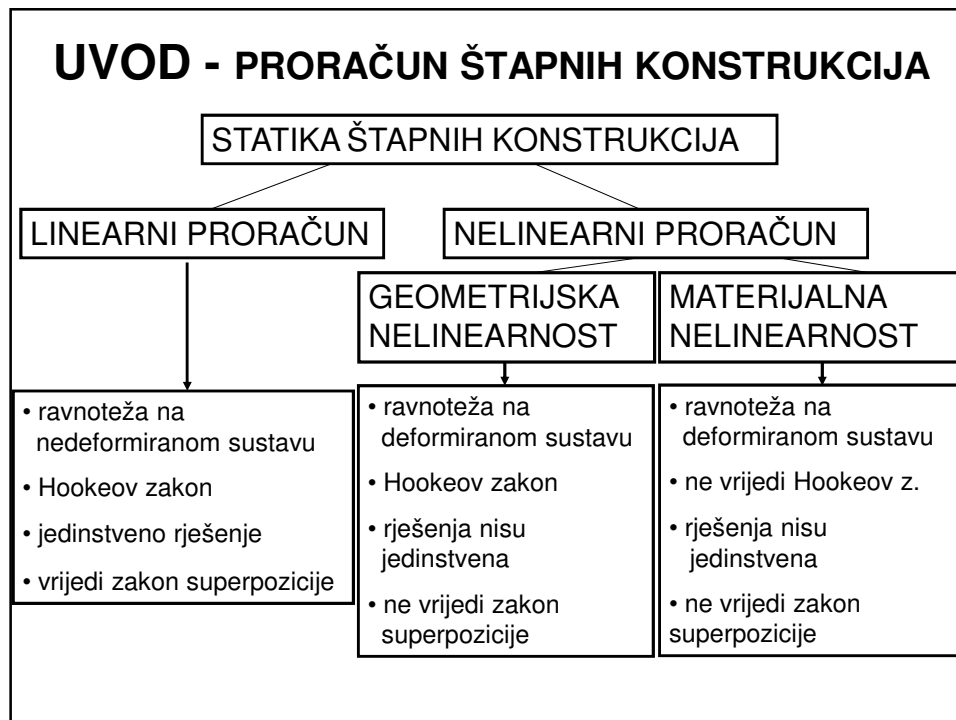
SVEUČILIŠTE U ZAGREBU  
 GRAĐEVINSKI FAKULTET  
 ZAVOD ZA TEHNIČKU MEHANIKU

# NELINEARNA STATIKA ŠTAPNIH KONSTRUKCIJA

Uvod u nelinearni proračun konstrukcija  
 GEOMETRIJSKA NELINEARNOST

## UVOD- PRORAČUN ŠTAPNIH KONSTRUKCIJA

- sustav diferencijalnih jednadžbi koje opisuju ponašanje konstrukcije pod djelovanjem vanjskih utjecaja
  - **DIF.JED. RAVNOTEŽE** – veza vanjskih djelovanja i unutarnjih sila
  - **DIF.JED. KOMPATIBILNOSTI** – veza pomaka i deformacija
  - **DIF.JED. MATERIJALA** – veza naprezanja i deformacija
- LINEARNI PRORAČUN - pretpostavke
  - pomaci mali; uvjeti ravnoteže na nedeformiranom sustavu
  - veza deformacija i pomaka – linearna dif.jed. I reda
  - veza deformacije i naprezanja linearna – Hookeov zakon
- TEORIJA I REDA – geometrijska i materijalna linearnost
- TEORIJA II REDA – geometrijska nelinearnost i materijalna linearnost
- TEORIJA III REDA – geometrijska nelinearnost i materijalna nelinearnost



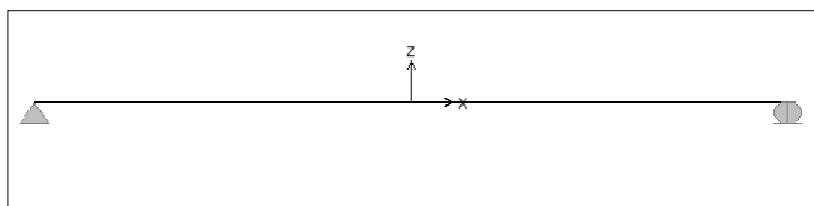
## UVOD- PRORAČUN ŠTAPNIH KONSTRUKCIJA

- GEOMETRIJSKA KRUTOST
  - štap opterećen vlačnom silom → povećanje krutosti
  - štap opterećen tlačnom silom → smanjenje krutosti
  - geometrijska krutost - funkcija opterećenja, dužine štapa
$$\{F\} = [k_e + k_g] \times \{u\}$$
  - problem izvijanja - za vrlo veliku tlačnu silu ukupna matrica krutosti može postati singularna

## UVOD- PRORAČUN ŠTAPNIH KONSTRUKCIJA

- P- $\Delta$  POSTUPAK ZA ZGRADE
  - uzima se u obzir **geometrijska krutost** i na taj način se uključuju **sekundarni efekti** u proračun konstrukcije
  - zgrade - poprečno opterećenje  $\rightarrow$  pomaci katova
    - vertikalna opt.  $\times$  pomaci  $\rightarrow$  dodatni momenti
- $\rightarrow$  **UTJECAJ VERTIKALNOG OPTEREĆENJA NA POPREČNU KRUTOST ZGRADE**
- **DINAMIČKA ANALIZA - produljenje vlastitih perioda**
- dobro koncipirane zgrade s povoljnim omjerom odnosa krutost/težina za svaki kat - pomaci i un. sile se razlikuju za manje od 10% (linearni i nelinearni proračun)
- ako je težina konstrukcije velika u odnosu na poprečnu krutost, P- $\Delta$  ima velik utjecaj (>25%)

## PRIMJER 1. – PROSTA GREDA



RASPON	$l=10$ m	
PRESJEK	$b/h=20/40$ cm	$I=1,067 \times 10^{-4}$ m <sup>4</sup>
MATERIJAL	beton C35/45	$E=3 \times 10^7$ kN/m <sup>2</sup>
OPTEREĆENJE	$q=10$ kN/m <sup>2</sup>	poprečno opterećenje
	$H_{ij}=1000$ kN	tlačna sila
	$H_{vi}=1000$ kN	vlačna sila

### POPREČNI PRESJEK

#### Rectangular Section

Section Name: G20\*40

Section Notes: Modify/Show Notes...

Properties: Section Properties...

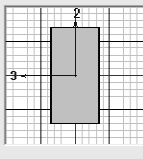
Property Modifiers: Ee: Modifiers...

Material: + BETON

Dimension is:

Depth (t3): 0.4

Width (t2): 0.2



Display Color:

Concrete Reinforcement...

Buttons: CK, Cancel

#### Frame Property/Stiffness Modification Factors

Property/Stiffness Modifiers for Analysis:

Cross-section (axial) Area: 1

Shear Area in 2 direction: 0

Shear Area in 3 direction: 1

Torsional Constant: 1

Moment of inertia about 2 axis: 1

Moment of inertia about 3 axis: 1

Mass: 1

Weight: 1

Buttons: OK, Cancel

### LOAD CASE

#### Opterećenje uzdužnom tlačnom silom

#### Load Case Data - Nonlinear Static

Load Case Name: FD\_TL

Notes: Modify/Show...

Load Case Type: Static

Initial Conditions:  Zero Initial Conditions - Start from Unstressed State

Analysis Type:  Nonlinear

Geometric Nonlinearity Parameters:  F Delta

Loads Applied:

Load Type	Load Name	Scale Factor
Load Pattern	TLAANA	1
Load Pattern	TLBPAS	1

Buttons: Add, Modify, Delete

Other Parameters: Full Load, Results Saved: Final State Only, Nonlinear Parameters: Default

Buttons: OK, Cancel

#### Load Case Data - Nonlinear Static

Load Case Name: NENL\_TL

Notes: Modify/Show...

Load Case Type: Static

Initial Conditions:  Zero Initial Conditions - Start from Unstressed State

Analysis Type:  Nonlinear

Geometric Nonlinearity Parameters:  F Delta plus Large Displacements

Loads Applied:

Load Type	Load Name	Scale Factor
Load Pattern	DET-PPRA	1
Load Pattern	DET-PPAS	1

Buttons: Add, Modify, Delete

Other Parameters: Full Load, Results Saved: Final State Only, Nonlinear Parameters: Default

Buttons: OK, Cancel

**LOAD CASE**

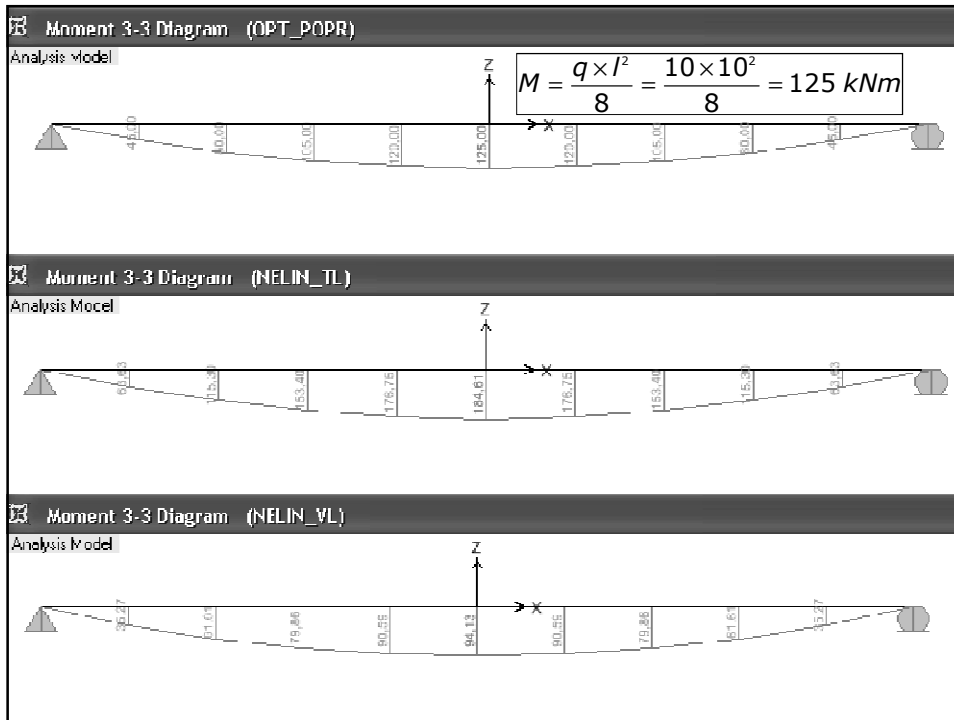
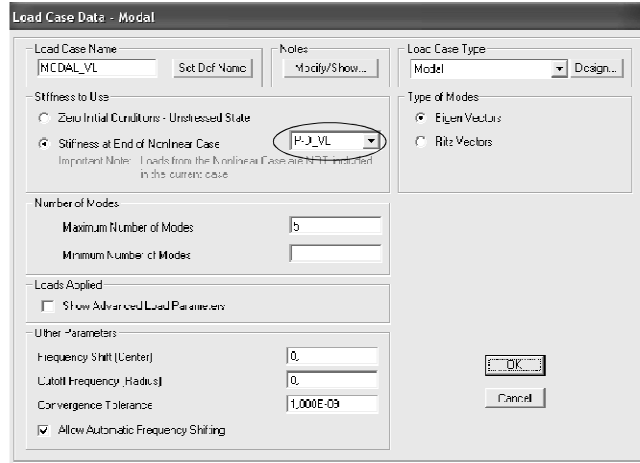
**Modal – za proračun vlastitih oblika**

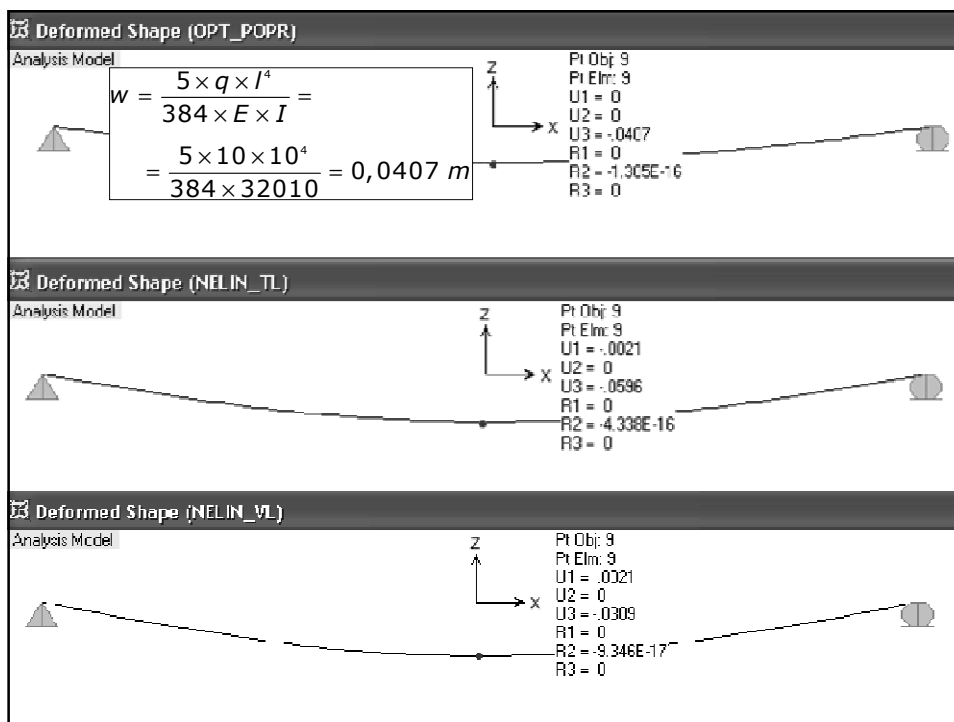
**LOAD CASE**

**Opterećenje uzdužnom vlačnom silom**

**LOAD CASE**

**Opterećenje uzdužnom vlačnom silom**





## PRIMJER 1. – PROSTA GREDA

Usporedba momenata i progiba – LINEARNI vs. NELINEARNI PRORAČUN

	TIR	TIIR - TLAČNA SILA	TIIR - VLAČNA SILA
MOMENT U POLJU [kNm]	125	185	94
PROGIB [m]	0,041	0,06	0,031

povećanje momenata i progiba  
u odnosu na one  
dobivene lin.proračunom  
za cca. 50%

smanjenje momenata i progiba  
u odnosu na one  
dobivene lin.proračunom  
za cca. 25%

$$\Delta M = \frac{M_{II,H}}{M_I} = \frac{185}{125} = 1,48$$

$$\Delta M = \frac{M_{II,V}}{M_I} = \frac{94}{125} = 0,75$$

# PRIMJER 1. – PROSTA GREDA

Usporedba perioda oscilacija – LINEARNI vs. NELINEARNI PRORAČUN

LINEARNI PRORAČUN

Output Case Text	Step Type Text	Step Num Unitless	Period Sec	Frequency Cyc/Sec
MODAL	Mode	1	3.15000	6.400
MODAL	Mode	2	0.036072	25.633
MODAL	Mode	3	0.017348	57.643
MODAL	Mode	4	0.011332	88.247
MODAL	Mode	5	0.006752	148.24

$$T = 2\pi\sqrt{\frac{m}{k}}$$

NELINEARNI PRORAČUN S TLAČNOM SILOM

Output Case Text	Step Type Text	Step Num Unitless	Period Sec	Frequency Cyc/Sec
MODAL_TL	Mode	1	0.188747	5.2961
MODAL_TL	Mode	2	0.040554	24.558
MODAL_TL	Mode	3	0.02351	53.621
MODAL_TL	Mode	4	0.014332	69.247
MODAL_TL	Mode	5	0.009374	107.28

→ "OMEKŠANJE" KONSTRUKCIJE

NELINEARNI PRORAČUN S VLAČNOM SILOM

Output Case Text	Step Type Text	Step Num Unitless	Period Sec	Frequency Cyc/Sec
MODAL_VL	Mode	1	0.135301	7.354
MODAL_VL	Mode	2	0.037854	26.438
MODAL_VL	Mode	3	0.017051	58.647
MODAL_VL	Mode	4	0.011332	88.247
MODAL_VL	Mode	5	0.006681	149.79

→ "OČVRŠČENJE" KONSTRUKCIJE

# PRIMJER 1. – PROSTA GREDA

STABILNOST – problem tlačne sile

Load Case Data - Duckling

Load Case Name: STABILNOST    Notes:    Lead Case Type: Buckling

Stiffness to Use:

- Zero Initial Conditions - Unstressed State
- Stiffness at End of Nonlinear Case

Loads Applied:

Load Type	Load Name	Scale Factor
Load Pattern	TLACNA	1

Other Parameters:

Number of Buckling Modes: 6

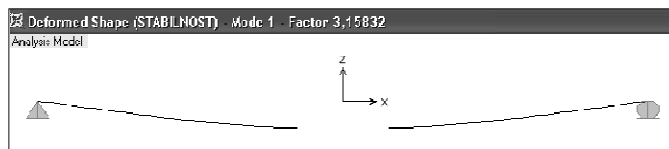
Eigenvalue Convergence Tolerance: 1.00E-09

Buttons: OK, Cancel



## PRIMJER 1. – PROSTA GREDA

STABILNOST – problem tlačne sile

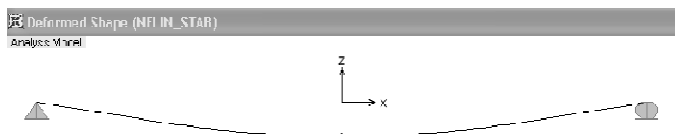


$$P_{cr} = \frac{\pi^2 EI}{l^2} = \frac{3,14^2 \times 32010}{10^2} = 3156,06 \text{ kN}$$

$$P \geq P_{cr} \rightarrow \text{izvijanje štapa}$$

## PRIMJER 1. – PROSTA GREDA

STABILNOST – problem tlačne sile za  $P=3160 \text{ kN}$

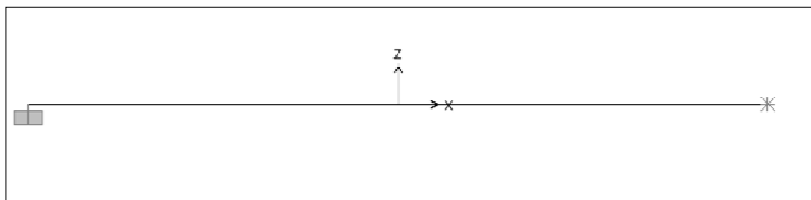
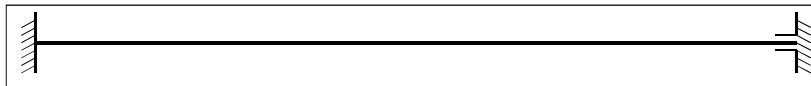


Joint Object	1	2	3
Trans	-0,00658	0,00000	-6104,80
Rot	0,00000	0,00000	0,00000

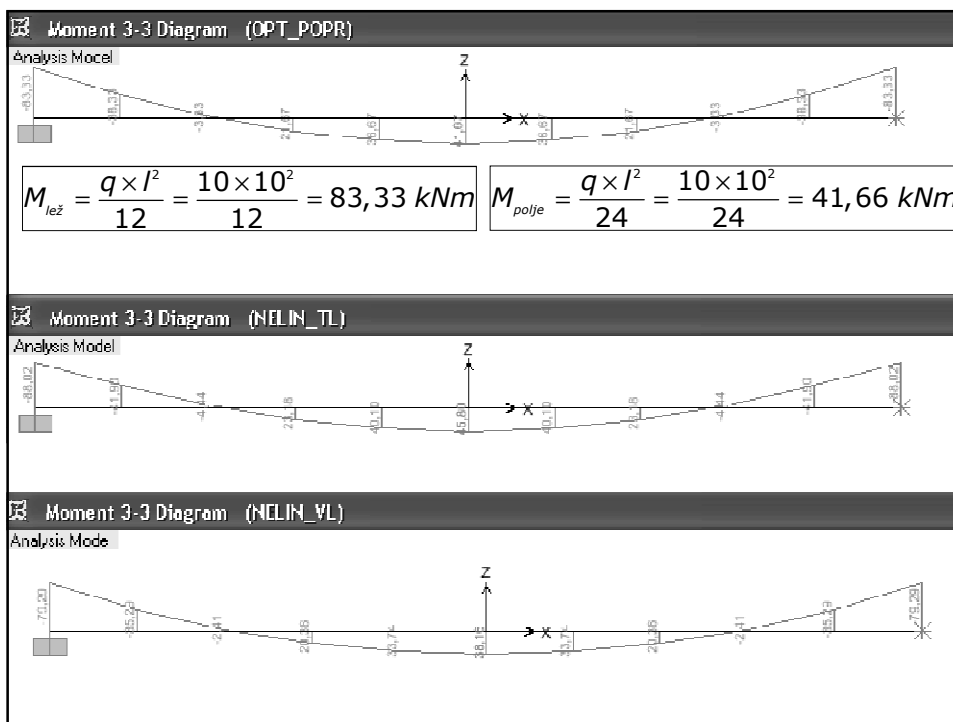


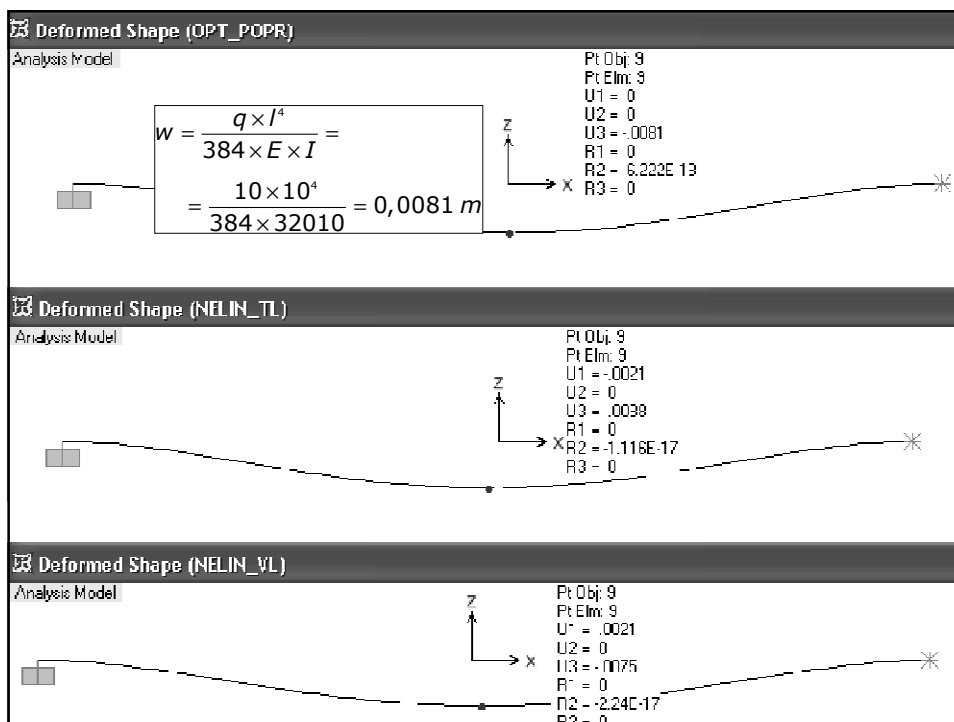
→ NEMOGUĆE!!!!

## PRIMJER 2. – OBOSTRANO UPETI ŠTAP



RASPON	$\ell=10$ m	
PRESJEK	b/h=20/40 cm	$I=1,067 \times 10^{-4}$ m <sup>4</sup>
MATERIJAL	beton C35/45	$E=3 \times 10^7$ kN/m <sup>2</sup>
OPTEREĆENJE	$q=10$ kN/m <sup>2</sup>	poprečno opterećenje
	$H_{ij}=1000$ kN	tlačna sila
	$H_{vi}=1000$ kN	vlačna sila





## PRIMJER 2. – OBOSTRANO UPETI ŠTAP

Usporedba momenata i progiba – LINEARNI vs. NELINEARNI PRORAČUN

	TIR	TIIR - TLAČNA SILA	TIIR - VLAČNA SILA
MOMENT U POLJU [kNm]	42	46	38
MOMENT NA LEŽ. [kNm]	83	88	79
PROGIB [m]	0,0081	0,0088	0,0075

povećanje momenata i progiba  
u odnosu na one  
dobivene lin.proračunom  
za cca. 10%

$$\Delta M = \frac{M_{II,d}}{M_I} = \frac{46}{42} = 1,095$$

smanjenje momenata i progiba  
u odnosu na one  
dobivene lin.proračunom  
za cca. 10%

$$\Delta M = \frac{M_{II,vl}}{M_I} = \frac{38}{42} = 0,905$$

## PRIMJER 2. – OBOSTRANO UPETI ŠTAP

Usporedba perioda oscilacija – LINEARNI vs. NELINEARNI PRORAČUN

LINEARNI  
PRORAČUN

OutputCase Test	StepType Test	StepNum Unitless	Period Sec	Frequency Cyc/Sec
MODAL	Mode	1	0.0688333	14.528
MODAL	Mode	2	0.024379	40.934
MODAL	Mode	3	0.012759	79.377
MODAL	Mode	4	0.011332	89.247
MODAL	Mode	5	0.007749	129.05

NELINEARNI  
PRORAČUN S  
TLAČNOM  
SILOM

OutputCase Test	StepType Test	StepNum Unitless	Period Sec	Frequency Cyc/Sec
MODAL_TL	Mode	1	0.071644	13.959
MODAL_TL	Mode	2	0.025465	39.289
MODAL_TL	Mode	3	0.013295	77.545
MODAL_TL	Mode	4	0.011355	88.244
MODAL_TL	Mode	5	0.007801	128.19

→ "OMEKŠANJE"  
KONSTRUKCIJE

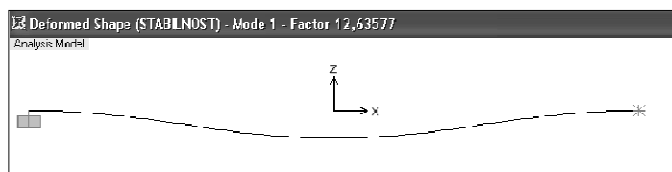
NELINEARNI  
PRORAČUN S  
VLAČNOM  
SILOM

OutputCase Test	StepType Test	StepNum Unitless	Period Sec	Frequency Cyc/Sec
MODAL_VL	Mode	1	0.066337	15.075
MODAL_VL	Mode	2	0.02452	40.783
MODAL_VL	Mode	3	0.012627	79.189
MODAL_VL	Mode	4	0.011332	89.247
MODAL_VL	Mode	5	0.007699	129.91

→ "OČVRŠĆENJE"  
KONSTRUKCIJE

## PRIMJER 2. – OBOSTRANO UPETI ŠTAP

STABILNOST – problem tlačne sile

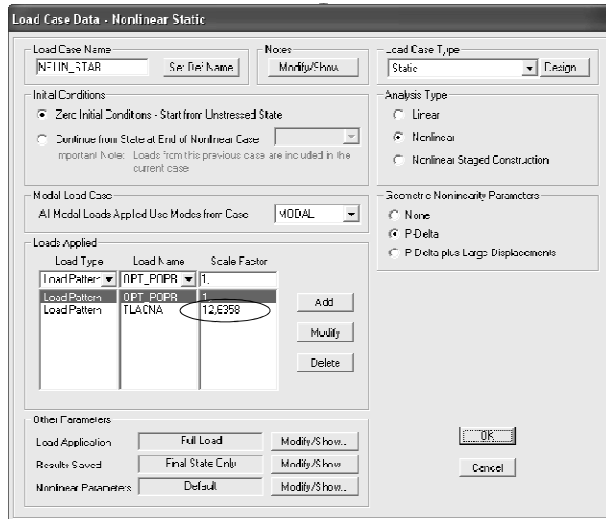


$$P_{cr} = \frac{\pi^2 EI}{(0,5\ell)^2} = \frac{3,14^2 \times 32010}{5^2} = 12624,23 \text{ kN}$$

$$P \geq P_{cr} \rightarrow \text{izvijanje štapa}$$

## PRIMJER 2. – OBOSTRANO UPETI ŠTAP

STABILNOST – problem tlačne sile za  $P=12640$  kN

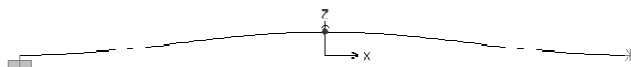


## PRIMJER 2. – OBOSTRANO UPETI ŠTAP

STABILNOST – problem tlačne sile za  $P=12640$  kN

Deformed Shape (NFIIN\_STAB)

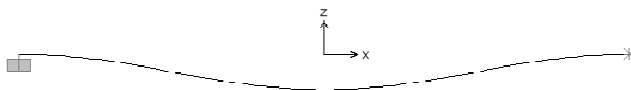
Analysis Model



Joint Object	Joint Element	1	2	3
Trans		-0.02832	0.00000	3796.284
Rot		0.00000	0.00000	0.00000

Deformed Shape (MODAL\_STAB) - Mode 1 - Period -46.48265

Analysis Model



→ NEMOGUĆE!!!!

## PRIMJER 2. – OBOSTRANO UPETI ŠTAP

- AKO POSTOJI POČETNA IMPERFECIJA – npr. 1 cm u sredini nosača

Kako zadati početnu imperfekciju u SAPu?

The diagram illustrates the steps to apply an initial imperfection in SAP. It shows a beam model with a central point load. The 'Modify Undeformed Geometry' dialog box is shown with 'Load Case' set to 'PRISILNIPOMAK' and 'Scale Factor for Displacements' set to '1'. The 'Object Model - Point Information' dialog box is also shown, displaying the coordinates and properties of the point.

## PRIMJER 2. – OBOSTRANO UPETI ŠTAP

- AKO POSTOJI POČETNA IMPERFECIJA – npr. 1 cm u sredini nosača

The analysis results are shown in three panels:

- Deformed Shape (PRISILNIPOMAK):** Analysis Model. Shows the beam with a central point load. The displacement at the center is  $U1 = -0.00006343$ . The rotation at the center is  $U3 = -0.01$ . The reaction at the center is  $R2 = 3.9997$ .
- Moment 3-3 Diagram (NELIN\_TL):** Analysis Model. Shows the moment diagram along the beam. The maximum moment is  $M_{11,H} = 51$ .
- Deformed Shape (NELIN\_TL):** Analysis Model. Shows the beam with a central point load. The displacement at the center is  $U1 = -0.0021$ . The rotation at the center is  $U3 = -0.0096$ . The reaction at the center is  $R2 = 4.231E-18$ .

The following equations are shown:

$$\Delta M = \frac{M_{11,H,imp}}{M_{11,H}} = \frac{51}{46} = 1,11$$

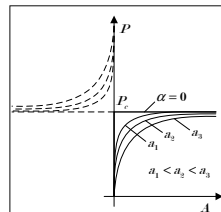
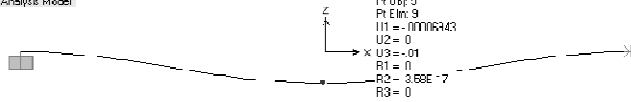
$$\Delta M = \frac{M_{11,H,imp}}{M_I} = \frac{51}{42} = 1,21$$

## PRIMJER 2. – OBOSTRANO UPETI ŠTAP

- AKO POSTOJI POČETNA IMPERFEKCIJA – npr. 1 cm u sredini nosača

### Deformed Shape (PRISILNPOMAK)

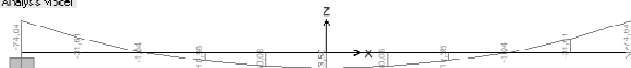
Analysis Model



Ovisnost kritične sile o početnoj imperfekciji za elastični štap

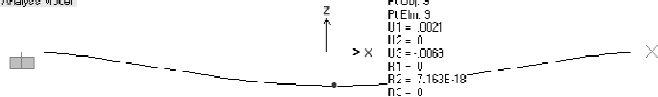
### Moment 3-3 Diagram (NELIN\_VL)

Analysis Model



### Deformed Shape (NELIN\_VL)

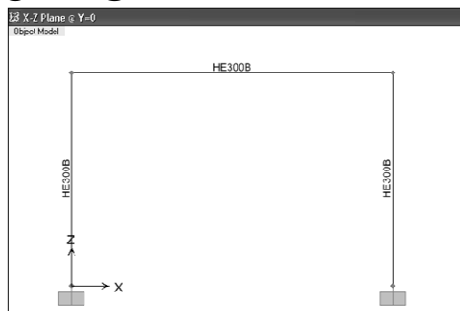
Analysis Model



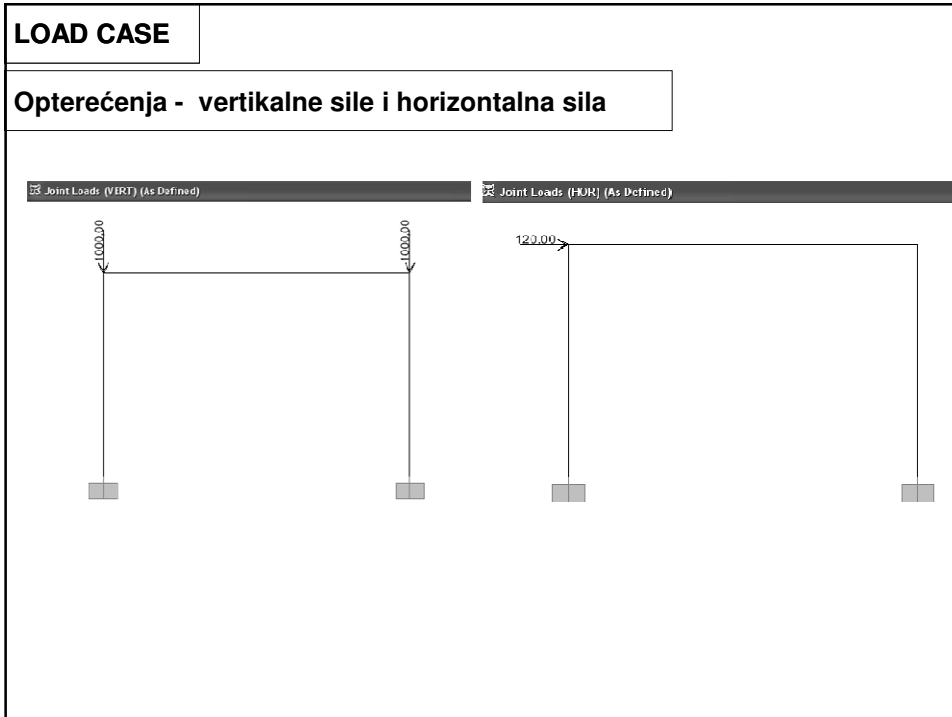
$$\Delta M = \frac{M_{H,VL,imp}}{M_{H,VL}} = \frac{33}{38} \approx 0,9$$

$$\Delta M = \frac{M_{H,VL,imp}}{M_i} = \frac{33}{42} \approx 0,8$$

## PRIMJER 3. – OKVIR



RASPON PREČKE	$\ell=6$ m	
VISINA STUPA	$\ell=4$ m	
PRESJEK	HEB300	$I=2,517 \times 10^{-4} \text{ m}^4$
MATERIJAL	ČELIK S235	$E=2 \times 10^8 \text{ kN/m}^2$
OPTEREĆENJE	$V=1000$ kN	vertikalna sila
	$H=120$ kN	horizontalna sila



### LOAD CASE

#### Opterećenje uzdužnom tlačnom silom

**Load Case Data - Nonlinear Static**

Load Case Name: PC

Load Case Type: Static

Initial Conditions:  Zero Initial Conditions - Start from Unstressed State

Analysis Type:  Nonlinear

Modal Load Case: All Modal Loads Applied Use Modes from Case: MODAL

Load Type	Load Name	Scale Factor
Load Pattern	VERT	1
Load Pattern	RELE	1

Other Parameters: Load Application: Full Load

**Load Case Data - Nonlinear Static**

Load Case Name: NELN

Load Case Type: Static

Initial Conditions:  Continue from State at End of Nonlinear Case: PD

Analysis Type:  Nonlinear

Modal Load Case: All Modal Loads Applied Use Modes from Case: MODAL

Load Type	Load Name	Scale Factor
Load Pattern	HOR	1

Other Parameters: Load Application: Full Load



LOAD CASE

**Load Case Data - Linear Static**

Load Case Name: [LUN]    Notes: [Modify/Show...]

Load Case Type: [Static]    Design...

Stiffness to Use:

Zero Initial Conditions - Unrestrained State

Stiffness at End of Nonlinear Case

Important Note: Loads from the Nonlinear Case are NOT included in the current case.

Loads Applied:

Load Pattern	Load Name	Scale Factor
Load Pattern	HOR	1.
Load Pattern	VEFT	1.

Add    Modify    Delete

OK    Cancel

**Load Case Data - Nonlinear Static**

Load Case Name: [NEUN]    Notes: [Modify/Show...]

Load Case Type: [Static]    Design...

Initial Conditions:

Zero Initial Conditions - Start from Unrestrained State

Continue from State of End of Nonlinear Case    [P-D]

Important Note: Loads from this previous case are included in the current case.

Modal Load Case:

All Modal Loads Applied Use Modes from Case: [MODAL]

Loads Applied:

Load Pattern	Load Name	Scale Factor
Load Pattern	HOR	1.
Load Pattern	VEFT	1.

Add    Modify    Delete

Other Parameters:

Load Application: [Full Load]    Modify/Show...

Results Saved: [Final State Only]    Modify/Show...

Nonlinear Parameters: [Default]    Modify/Show...

OK    Cancel

LOAD CASE

**Modal – za proračun vlastitih oblika**

**Load Case Data - Modal**

Load Case Name: [MODAL\_N]    Notes: [Modify/Show...]

Load Case Type: [Modal]    Design...

Stiffness to Use:

Zero Initial Conditions - Unrestrained State

Stiffness at End of Nonlinear Case    [P-D]

Important Note: Loads from the Nonlinear Case are NOT included in the current case.

Number of Modes:

Maximum Number of Modes: [12]

Minimum Number of Modes: [1]

Loads Applied:

Show & Unmodeled Load Parameters

Other Parameters:

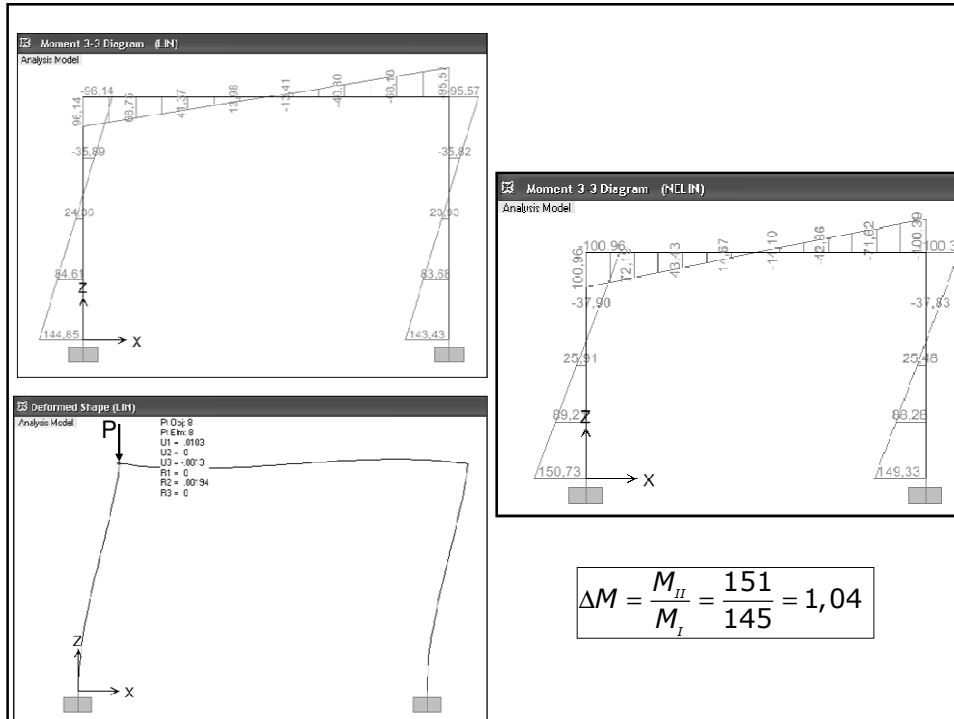
Frequency Shift (Center): [0.]

Cutoff Frequency (Radial): [0.]

Convergence Tolerance: [0.000E 09]

Allow Automatic Frequency Shifting

OK    Cancel



## PRIMJER 3. – OKVIR

Usporedba perioda oscilacija – LINEARNI vs. NELINEARNI PRORAČUN

LINEARNI PRORAČUN

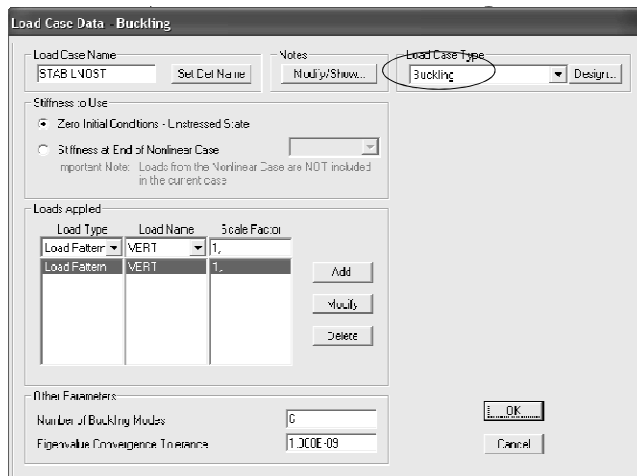
Output Case Text	Step Type Text	Step Num Unitless	Period Sec	Frequency Cycles/sec
NODAL	Mode	1	0.057784	17.306
NODAL	Mode	2	0.022770	43.807
NODAL	Mode	3	0.009197	108.74
NODAL	Mode	4	0.006224	127.08
NODAL	Mode	5	0.006287	159.00
NODAL	Mode	6	0.004157	240
NODAL	Mode	7	0.003508	285.08
NODAL	Mode	8	0.003294	303.62
NODAL	Mode	9	0.002944	339.7
NODAL	Mode	10	0.002050	487.70
NODAL	Mode	11	0.002332	428.7
NODAL	Mode	12	0.001941	515.42

NELINEARNI PRORAČUN

Output Case Text	Step Type Text	Step Num Unitless	Period Sec	Frequency Cycles/sec
MODA_N	Mode	1	0.059206	16.89
MODA_N	Mode	2	0.022831	43.8
MODA_N	Mode	3	0.009235	108.28
MODA_N	Mode	4	0.006262	127.07
MODA_N	Mode	5	0.006299	158.76
MODA_N	Mode	6	0.004167	239.98
MODA_N	Mode	7	0.003508	285.04
MODA_N	Mode	8	0.003299	303.14
MODA_N	Mode	9	0.002944	339.65
MODA_N	Mode	10	0.002055	486.07
MODA_N	Mode	11	0.002332	428.76
MODA_N	Mode	12	0.001941	515.29

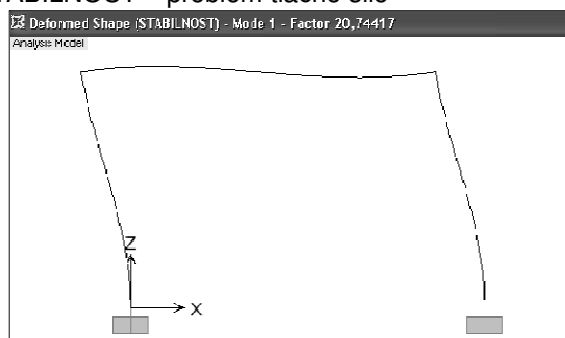
## PRIMJER 3. – OKVIR

STABILNOST – problem tlačne sile



## PRIMJER 3. – OKVIR

STABILNOST – problem tlačne sile



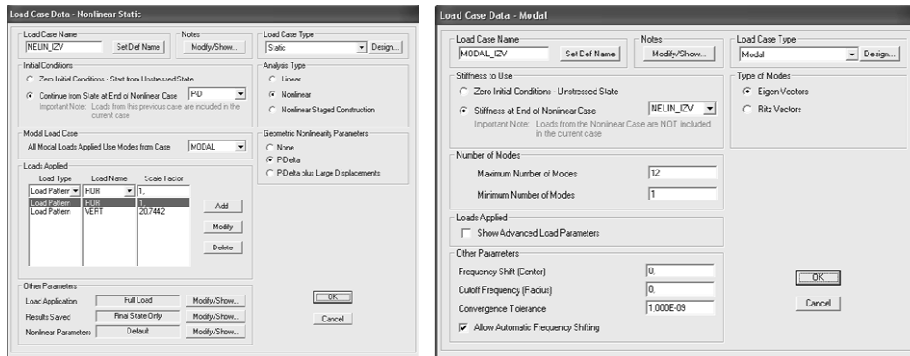
$$P_{cr} = \frac{(kl)^2 EI}{l^2} = \frac{2,57^2 \times 50340}{4^2} = 20780 \text{ kN}$$

$$P \geq P_{cr} \rightarrow \text{izvijanje stupa}$$

## PRIMJER 3. – OKVIR

STABILNOST – problem tlačne sile

za  $P = 20780 \text{ kN}$



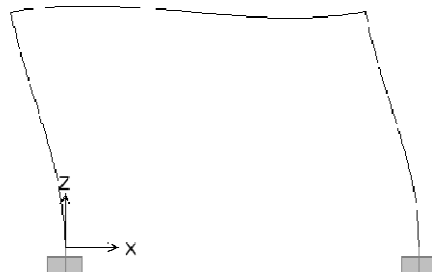
## PRIMJER 3. – OKVIR

STABILNOST – problem tlačne sile

za  $P = 20780 \text{ kN}$

Deformed Shape (MODAL\_I2V) - Mode 1 - Period: 0,26024

Analysis Model



→ NEMOGUĆE!!!!

## PROJEKTIRANJE ČELIČNIH KONSTRUKCIJA

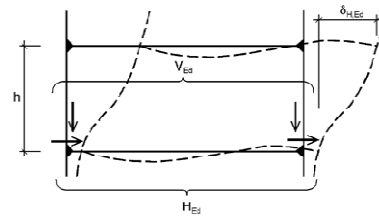
### UČINCI PREMA TEORIJI II REDA

- učinci prema teoriji II reda moraju se uzeti u proračun ako utječu na ukupnu stabilnost građevine ili dostizanje graničnog stanja nosivosti
- granična vrijednost kad se učinci II reda **moгу zanemariti**:

$$\alpha_{cr} = \frac{F_{cr}}{F_{Ed}} \geq 10 \text{ (15)}$$

- pomični okviri:

$$\alpha_{cr} = \left( \frac{H_{Ed}}{V_{Ed}} \right) \left( \frac{h}{\delta_{H,Ed}} \right)$$



- u nedostatku drugih podataka - granična vrijednost svedene vitkosti:

$$\bar{\lambda} \geq 0,3 \sqrt{\frac{A \times f_y}{N_{Ed}}}$$

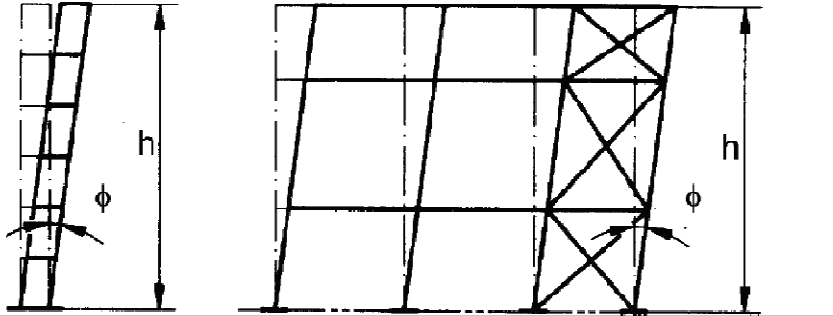
→kad učinci II reda  
**nisu zanemarivi**

## PROJEKTIRANJE ČELIČNIH KONSTRUKCIJA

### STABILNOST OKVIRA

- PREMA TIPU OKVIRA I GLOBALNOJ ANALIZI, UTJECAJI II REDA I IMPERFEKCIJE MOGU SE PRORAČUNATI PREMA SLJEDEĆIM METODAMA:
  - oboje pomoću globalne analize
  - djelomično preko globalne analize i djelomično kroz provjeru stabilnosti pojedinačnih elemenata
  - osnovni slučajevi stabilnosti pojedinačnih elemenata uzimajući u obzir odgovarajuće duljine izvijanja prema globalnom tonu izvijanja konstrukcije
- JEDNOKATNI OKVIRI – povećanje horizontalne sile  $H_{Ed}$  i ekvivalentnih vertikalnih opterećenja  $V_{Ed}$  zbog imperfekcija za faktor

$$\frac{1}{1 - \frac{1}{\alpha_{cr}}}; \quad \alpha_{cr} \geq 3,0$$



**GLOBALNE IMPERFEKCIJE OKVIRA**

- pretpostavljeni oblik globalnih imperfekcija može se dobiti iz **elastičnog moda izvijanja** konstrukcije u promatranoj ravnini
- uzeti u obzir za **najnepovoljnije opterećenje**
- za okvire osjetljive na izvijanje u pomičnom modu, utjecaj imperfekcija uzima se u obzir preko početne hor. imperfekcije

$$\phi = \phi_0 \alpha_n \alpha_m; \quad \phi_0 = 1/200$$

$$\alpha_n = 2 / \sqrt{h}; \quad \frac{2}{3} \leq \alpha_n \leq 1,0$$

*h* – višina konstrukcije

$$\alpha_m = \sqrt{0,5(1 + 1/m)}$$

*m* – broj stupova u redu

## PRIMJER 3. – OKVIR

PROPISI – da li je trebao proračun po teoriji II reda?

$$\alpha_{cr} = \frac{F_{cr}}{F_{Ed}} = \frac{20780}{1000} = 20,8 \geq 10$$

→ nije trebao, povećanje unutarnjih sila je zanemarivo u odnosu na teoriju I reda



$$\Delta M = \frac{M_{II}}{M_I} = \frac{151}{145} = 1,04$$

$$\frac{1}{1 - 1/20,78} = 1,05$$