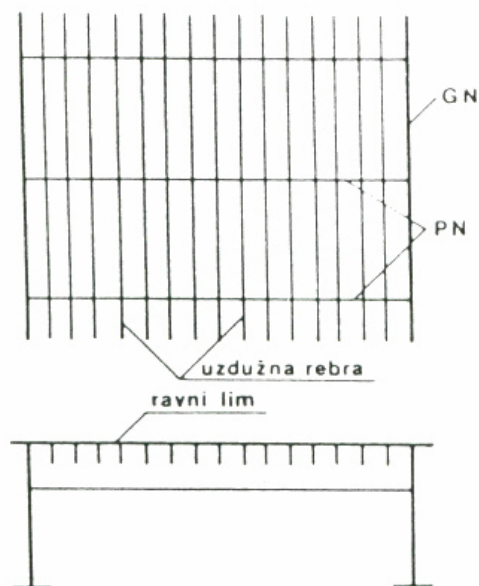
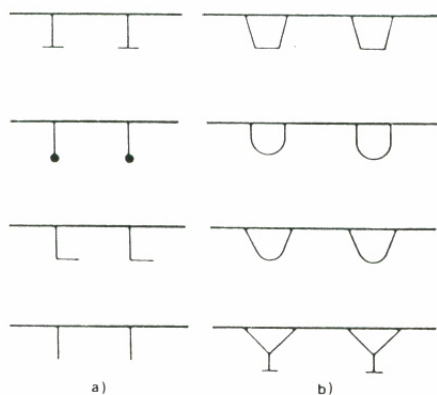


ČELIČNE ORTOTROPNE PLOČE

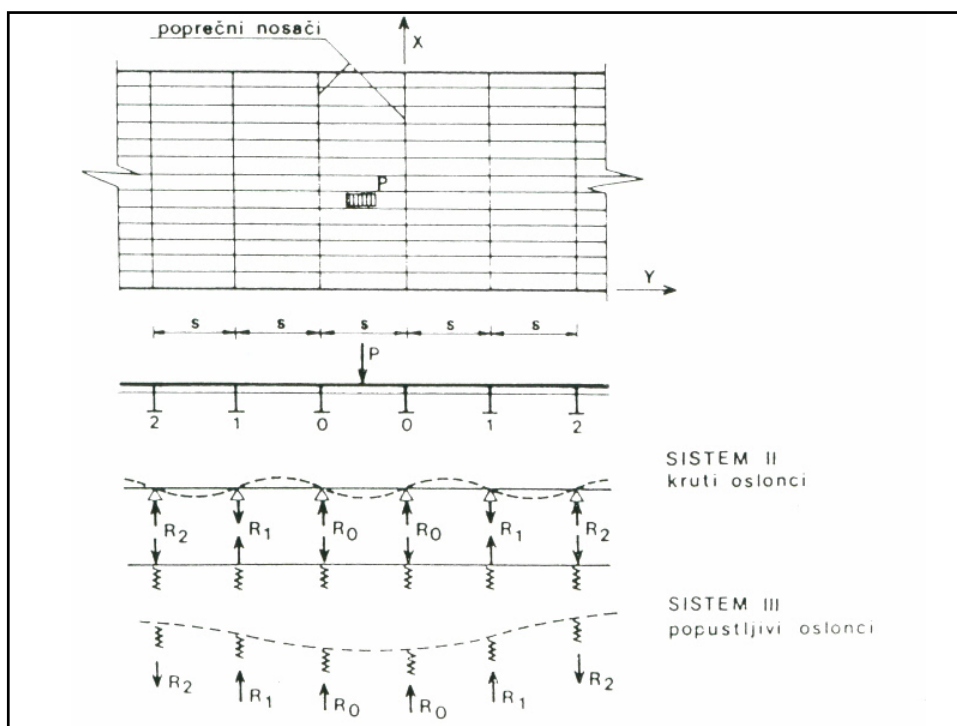
Elementi



Uzdužna rebra



<u>PREDNOSTI</u>	<u>MANE</u>
a) jednostavnost pristupačnost variranje visine	rasprostiranje koncentriranog opt. razmak poprečnih nosača zavarivanje veća težina
b) rasprostiranje opt. tanji elementi razmak PN zavarivanje	komplikacije oko izvedbe



ANALIZA: SISTEM I – izotropna ploča
 SISTEM II – ortotropna ploča
 SISTEM III – ortotropna ploča – roštilj
 SISTEM IV – spregnuto s glavnim nosačima

SUPERPOZICIJA:
 LIM (I), II, III, IV
 UZDUŽNA REBRA II, III, IV
 POPREČNI NOSAČI II, III
 GLAVNI NOSAČI IV

NOSIVI SISTEM I – IZOTROPNA PLOČA

- minimalna debljina lima = 12 mm
- razmak između uzdužnih rebara = 300 mm
- minimalna debljina lima može se odrediti i iz empirijskog obrasca:

$$t \geq 0,072 \cdot a \cdot \sqrt[3]{p}$$

NOSIVI SISTEM II

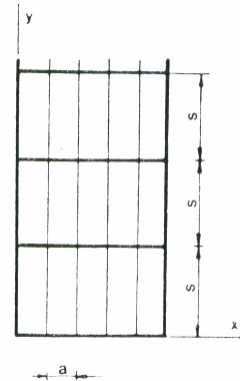
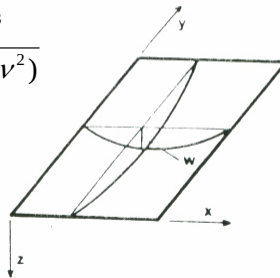
- savijanje ortotropne ploče prema Huberovoj diferencijalnoj jednačbi

$$D_x \frac{\partial^4 w}{\partial x^4} + 2H \frac{\partial^4 w}{\partial x^2 \partial y^2} + D_y \frac{\partial^4 w}{\partial y^4} = p(x, y)$$

$$D_x = EI_x = \frac{Et^3}{12(1-\nu^2)}$$

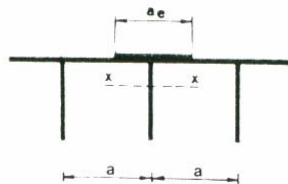
$$D_y = \frac{EI_R}{a} \text{ ili } \frac{EI_R}{a+e}$$

$$H = k \sqrt{D_x D_y}$$



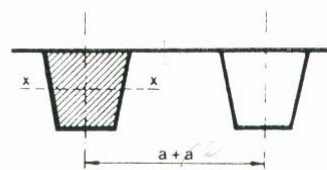
Efektivna torzijska krutost:

$$2H = \mu \cdot \frac{GI_T}{a+e} \quad \mu < 1$$



$$a_e \leq a$$

$$a_e \geq a$$



Rješenje: $w = w_h + w_p$

w_h homogeno -> Fourierov red

w_p partikularno (Fourierov red)

$$w_n = [C_1 sh\alpha_n y + C_2 ch\alpha_n y + C_3 \alpha_n y + C_4] \sin \frac{n\pi x}{b}$$

$$\alpha_n = \frac{n\pi}{b} \sqrt{\frac{2H}{D_y}}$$

$$w' = \frac{\partial w}{\partial y} = \alpha [C_1 ch\alpha y + C_2 sh\alpha y + C_3] \sin \frac{n\pi x}{b}$$

...

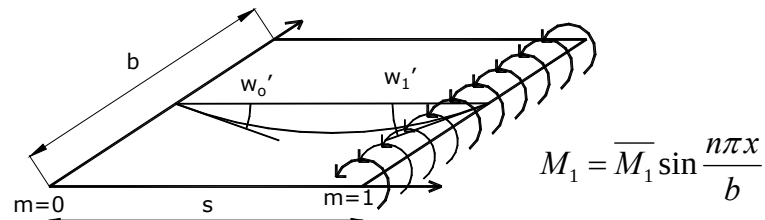
$$w''' = \frac{\partial^4 w}{\partial y^4} = \alpha^4 [C_1 sh\alpha y + C_2 ch\alpha y] \sin \frac{n\pi x}{b}$$

Rubni uvjeti...konstante $C_1, C_2...$
Sve u Fourierovim članovima reda

Partikularni dio – opterećenje, također s Fourierovim redom

w	->	progib
w'	->	zakretanje
w''	->	m_x
w'''	->	Q_x
w^{IV}	->	p

PRIMJER



Rubni uvjeti:

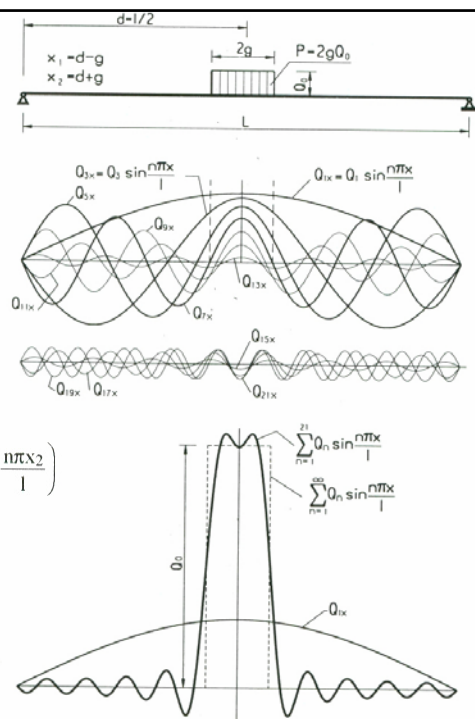
za $y=0$	$w=0$	$M_y=0$
za $y=s$	$w=0$	$M_y=M_1$

$$C_1 = \frac{\overline{M}_1}{D_y} \cdot \frac{1}{\alpha^2 \sinh \alpha s}$$

$$C_2 = C_4 = 0$$

$$C_3 = \frac{\overline{M}_1}{D_y} \cdot \frac{1}{\alpha^3 s}$$

FOURIEROVA ANALIZA OPTEREČENJA



$$Q_n = \frac{2Q_0}{l} \int_{x_1}^{x_2} \sin \frac{n\pi x}{l} dx = \frac{2Q_0}{n\pi} \left(\cos \frac{n\pi x_1}{l} - \cos \frac{n\pi x_2}{l} \right)$$

$$Q_{nx} = Q_n \sin \frac{n\pi x}{l}$$

Pojednostavljenje: Pelikan W. – Esslinger M.

Otvorena rebra: $D_x \sim 2H \sim 0$

$$D_y \frac{\partial^4 w}{\partial y^4} = p(x, y) \quad \text{kontinuirana greda}$$

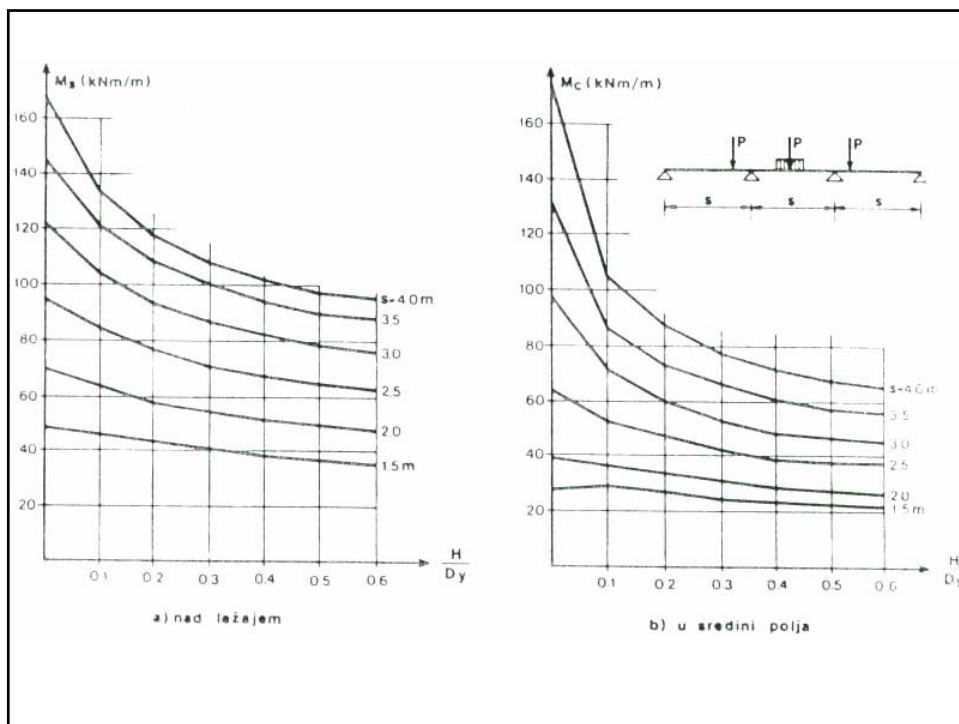
Zatvorena rebra: $D_x \sim 0$

$$2H \frac{\partial^4 w}{\partial x^2 \partial y^2} + D_y \frac{\partial^4 w}{\partial y^4} = p(x, y)$$

$$w = \sum_1^{\infty} w_n$$

$$w_n = (C_{1n} \sinh \alpha_n y + C_{2n} \cosh \alpha_n y + C_{3n} \alpha_n y + C_{4n}) \sin \frac{n\pi x}{b}$$

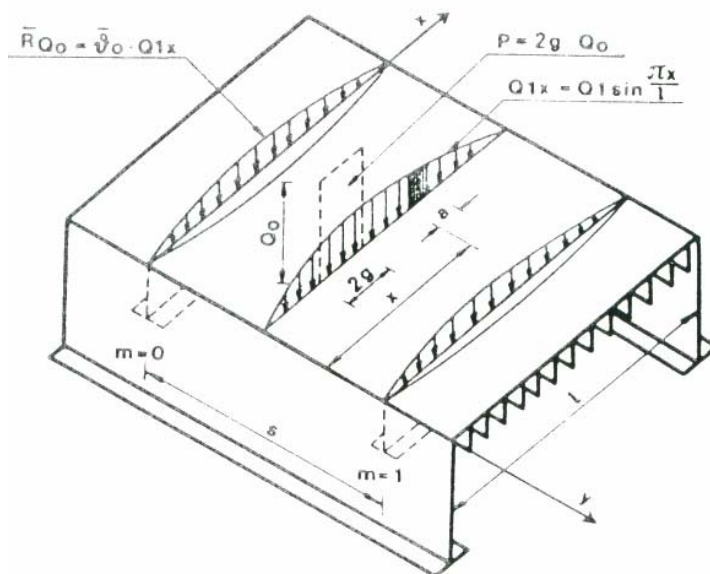
$$\alpha_n = \frac{n\pi}{b} \sqrt{\frac{2H}{D_y}}; C_{1n}, C_{2n}, C_{3n}, C_{4n} = \text{konst.}$$



NOSIVI SISTEM III – ELASTIČNO POPUŠTANJE

$1/R$ – malo, $D_x = H \sim 0$

$$\overline{R_Q} = \delta \cdot C$$



Niz traka Dy zadovoljava ako je $P=f(\sin x)$.

Za n-tu sin-komponentu biti će na 0-tom.

$$\begin{aligned} \left(\bar{R}_{Q0}\right)_n &= \bar{g}_{0n} Q_n \sin \frac{n\pi x}{l} = \delta_n \cdot C_n \\ \delta_n &= \frac{1}{EI_Q} \iiint \bar{R}_{Q0} dx^4 = \frac{\bar{g}_{0n}}{EI_Q} \left(\frac{l}{\pi n}\right)^4 Q_n \sin \frac{n\pi x}{l} \\ \frac{\bar{R}_{Qn}}{\delta_n} &= C_n = \left(\frac{n\pi}{l}\right)^4 EI_Q \\ &\quad \text{za } n=1 \dots C_1 \\ \text{zanemarivo} &< \begin{aligned} &\text{za } n=2 \dots 2^4 \cdot C_1 \\ &\text{za } n=3 \dots 3^4 \cdot C_1 \end{aligned} \\ C &= C_1 = \left(\frac{\pi}{l}\right)^4 EI_Q \end{aligned}$$

Kontinuirani nosač na elastičnim osloncima

$$\gamma = \frac{EI_L}{s^3} / C$$

$$\gamma = \frac{EI_R}{a \cdot s^3} \frac{1}{C} \quad \text{odnosno} \quad \gamma = \frac{EI_R}{(a+e)s^3} \frac{1}{C}$$

↓

↓

$$\frac{l^4}{\pi^4} \frac{1}{a} \frac{1}{s^3} \frac{I_R}{I_Q}$$

$$\frac{l^4}{\pi^4} \frac{1}{(a+e)} \frac{1}{s^3} \frac{I_R}{I_Q}$$

γ - veliko -> veliko popuštanje, C-mali, EI_c -veliko

γ - malo, C - veliko -> malo popuštanje

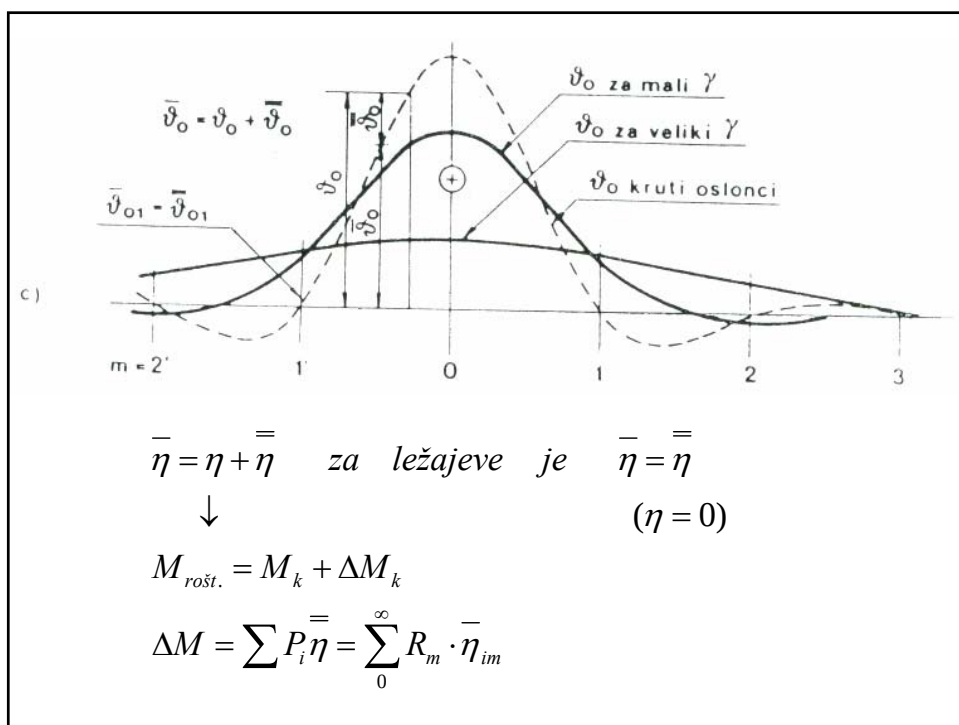
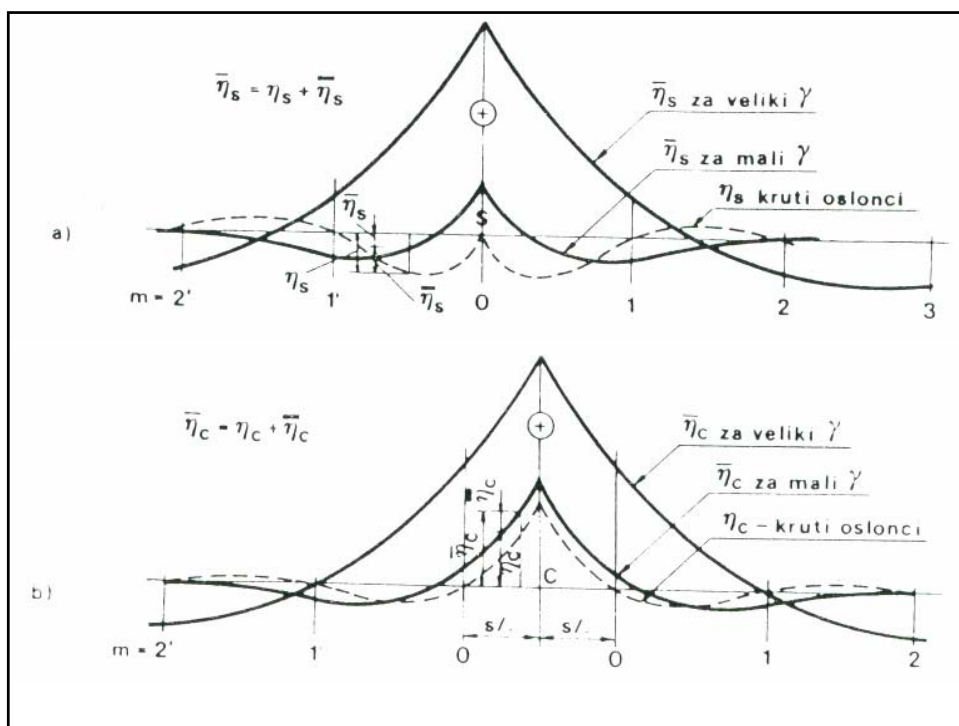
Momenti savijanja ΔM - razlika

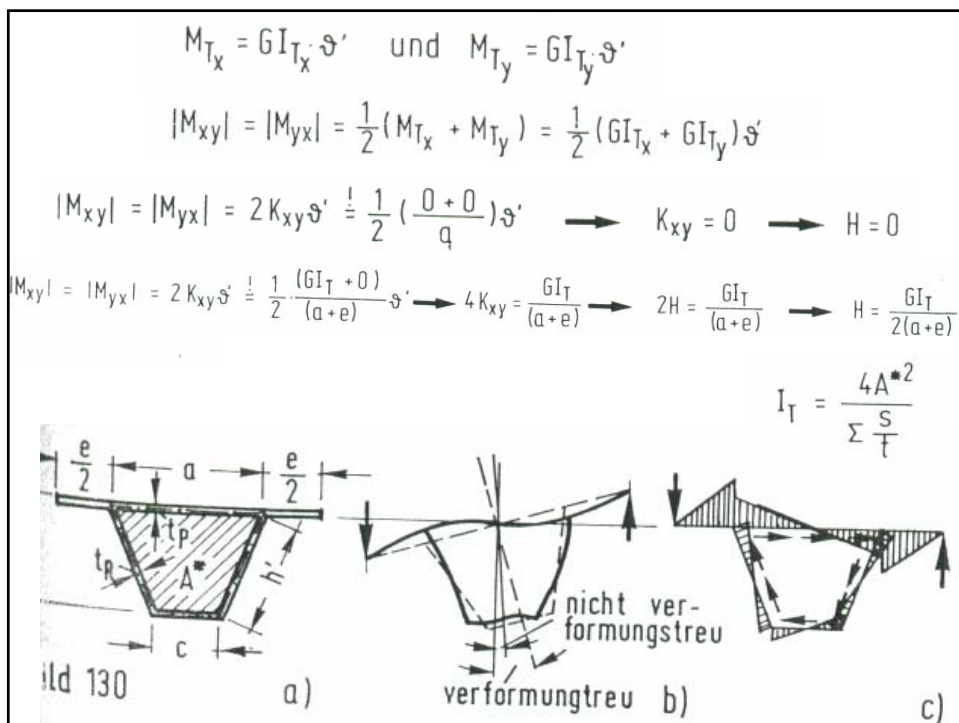
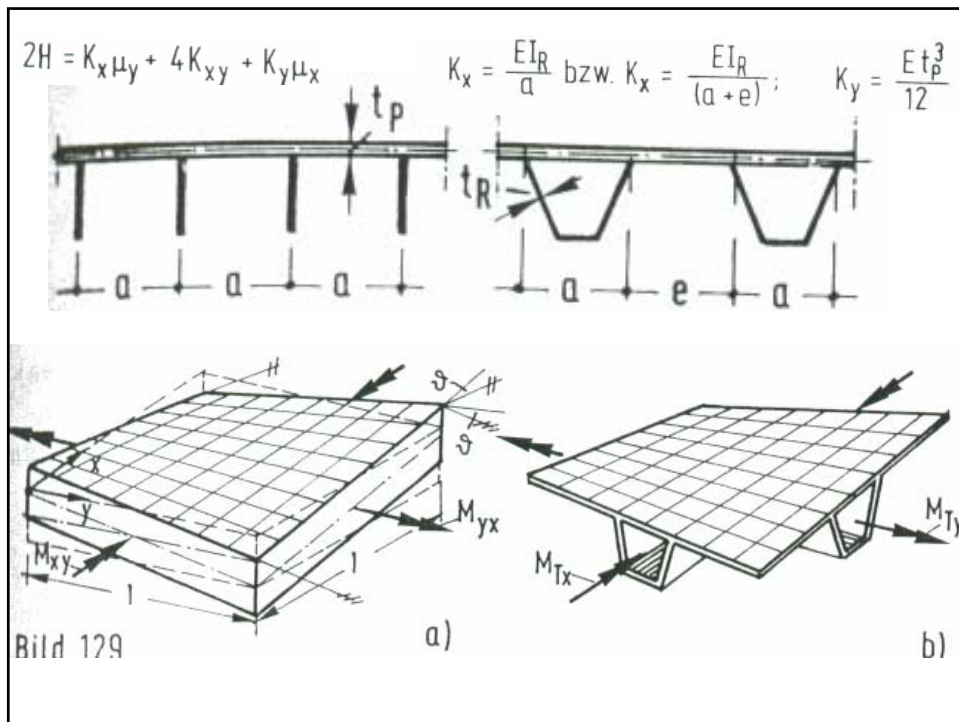
$$\Delta M = P \cdot \bar{\eta} = \sum R_m \cdot \bar{\eta}_m$$

↓

↓

razlika $\eta_s - \bar{\eta}_s$ elastično popustljivi nosač

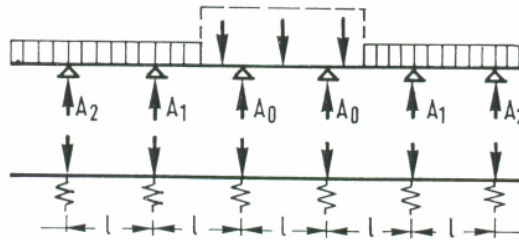




$$H = \mu \cdot \frac{GI_T}{2(a+e)}$$

$$\frac{1}{\mu} = 1 + \frac{GI_T}{EI_P} \cdot \frac{a^3}{12(a+e)^2} \left\{ \left(\frac{\pi}{0,81 \cdot l} \right)^2 \left[\left(\frac{e}{a} \right)^3 + \left[\frac{e-c}{a+c} + \lambda \right]^2 + \frac{\lambda^2}{\kappa} \left(\frac{c}{a} \right)^3 + \frac{24}{\kappa} \left(\frac{h'}{a} \right) (f_1^2 + f_1 f_2 + \frac{f_2^2}{3}) \right] \right\}; \quad EI_P = \frac{E t_p^3}{10,92}$$

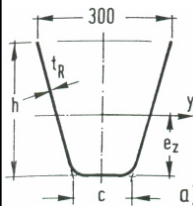
$$\kappa = \left(\frac{t_R}{t_p} \right)^3; \quad \lambda = \frac{(2a+c)(a+e)ch' - \kappa a^3(e-c)}{(a+c)[2h'(a^2+ac+c^2)+c^3+\kappa a^3]}; \quad f_1 = \frac{\lambda}{2} \left(\frac{c}{a} \right); \quad f_2 = \frac{\lambda}{2} \left(\frac{a-c}{a} \right) - \left(\frac{a+e}{a+c} \right) \cdot \frac{c}{2a}$$



$$K_x w'''' = q(x, y)$$

$$K_x w'''' + 2H w'''' = q(x, y)$$

$$w \stackrel{!}{=} \frac{1}{48} \frac{b^3}{E \bar{I}} \rightarrow \bar{I} = \frac{b^3}{48 E w} \quad (\bar{I}_{QTr})$$



Profil	h	t _R	c	G	A	I _y	e _z
2/ 275/6	275	6	135	32,3	41,1	3 168	11,5
2/ 300/6	300		120	34,1	43,4	3 876	13,0
2/ 325/6	325		105	35,8	45,6	4 662	14,5
2/ 350/6	350		90	37,6	47,9	5 529	16,0
		mm		kg/m	cm ²	cm ⁴	cm

Trapezrippenprofile
(Krupp - Profile)
Auszug, geliefert werden
auch die Dicken t_R = 7, 8, 9
und 10 mm

b) Bild 132

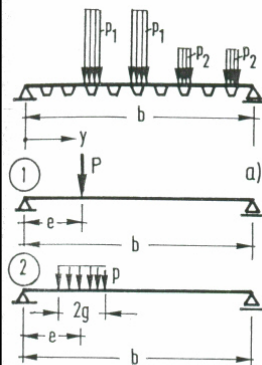


Bild 133

$$w(x, y) = \sum_{n=1}^{\infty} w_n(x) \cdot \sin \frac{n\pi y}{b} \quad q(y) = \sum_{n=1}^{\infty} q_n \cdot \sin \frac{n\pi y}{b}$$

$$① \quad q_n = \frac{2P}{b} \cdot \sin \frac{n\pi e}{b}$$

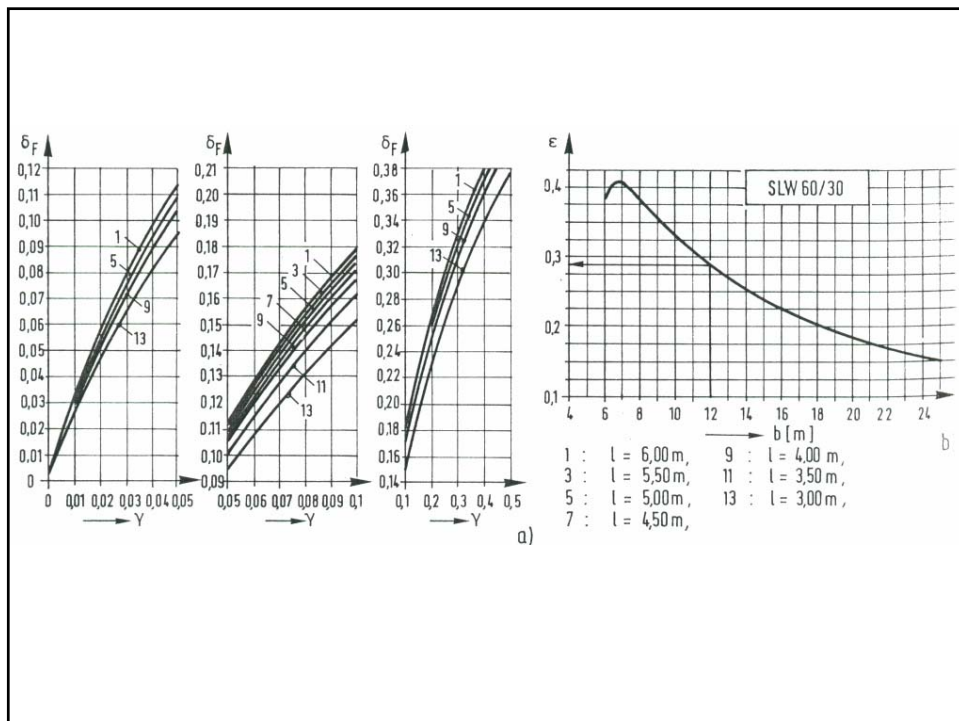
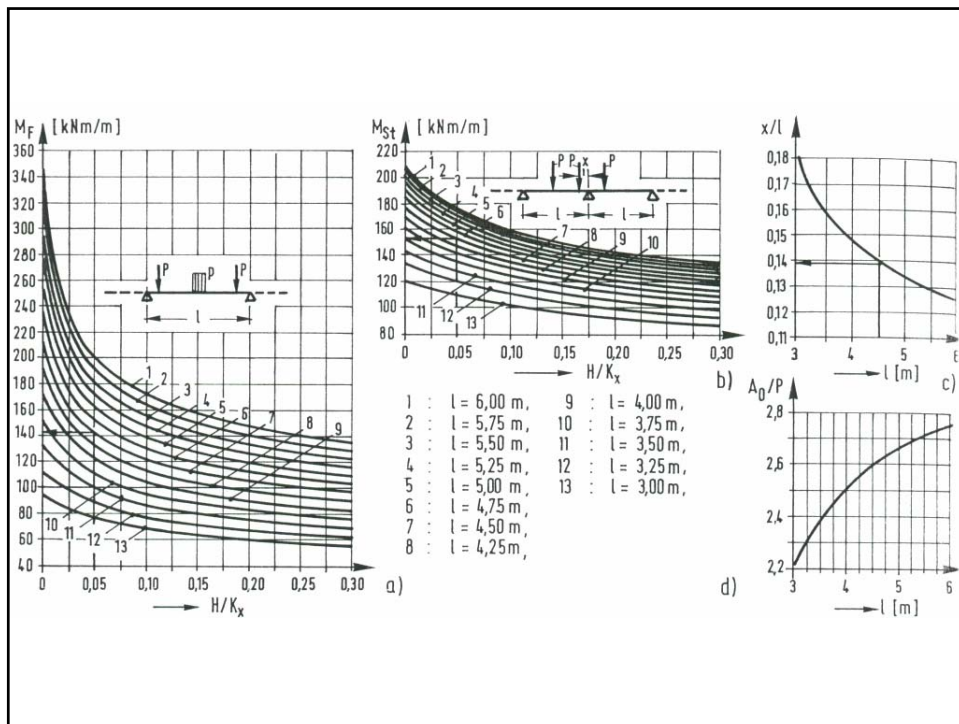
$$② \quad q_n = \frac{4p}{b} \left(\frac{b}{n\pi} \right) \sin \frac{n\pi e}{b} \cdot \sin \frac{n\pi g}{b}$$

$$q(x, y) = q(x) \cdot q(y) = q(x) \cdot \sum_{n=1}^{\infty} q_n \cdot \sin \frac{n\pi y}{b}$$

$$\sum_{n=1}^{\infty} [K_x w_n'''' - \left(\frac{n\pi}{b} \right)^2 2H w_n'''] = q(x) \cdot q_n \sin \frac{n\pi y}{b}$$

$$w_n'''' - \left(\frac{n\pi}{b} \right)^2 \frac{2H}{K_x} w_n'' = \frac{q_n}{K_x} q(x)$$

$$w_n(x) = C_{1n} \sinh \alpha_n x + C_{2n} \cosh \alpha_n x + C_{3n} \alpha_n x + C_{4n} + w_{n,part.}(x) \quad \text{mit } \alpha_n = \frac{n\pi}{b} \sqrt{\frac{2H}{K_x}}$$



$$\Delta M_F = \delta \cdot \epsilon \cdot p l$$

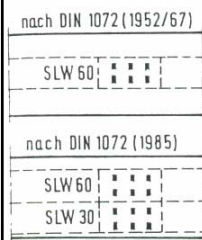
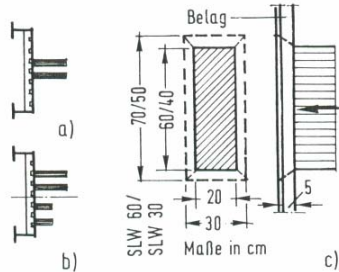


Bild 136



heute maßgebende Lastbelegung. Wird die Belagdicke zu 5cm und die Lastausstrahlung zu 45° angenommen, ergibt sich für den SLW60 eine Radauflastbreite von $60 + 2 \cdot 5 = 70$ cm (Bild 136c).

Beispiel: Gegeben sei:

$$l = 4,50\text{m}; \quad b = 12,00\text{m};$$
$$K_y = 20\,000 \text{ kNm}^2/\text{m},$$
$$H = 1000 \text{ kNm}^2 / \text{m}$$
$$EI_{OTr} = 9,45 \cdot 10^5 \text{ kNm}^2$$

$$\frac{H}{K_x} = \frac{1000}{20000} = 0,05; \quad \gamma = \frac{20000 \cdot 12,0^4}{9,45 \cdot 10^5 \cdot 4,50^3 \cdot \pi^4} = 0,0494$$

Aus Bild 134 folgt:

Bild 134: $M_F = 143 \text{ kNm/m}$; $M_{St} = -148 \text{ kNm/m}$ ($x = 0,139 \cdot 4,5 = 0,63 \text{ m}$)

$$l = 4,5 \text{ m} \rightarrow \varphi = 1,4 - 0,008 \cdot 4,5 = 1,364 \rightarrow p = \frac{1,364 \cdot 100}{0,7} = 194,9 \text{ kN/m}$$

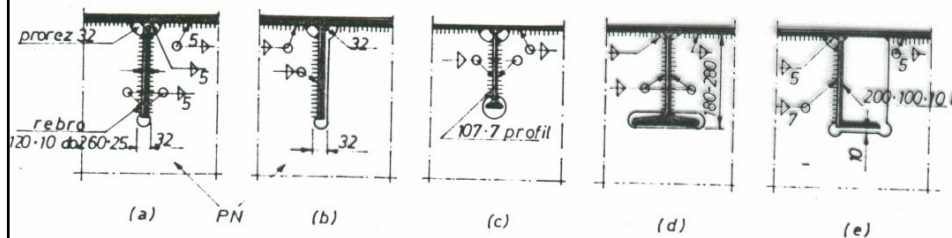
Aus Bild 135 folgt: Bild 135: $\delta = 0,107$; $\epsilon = 0,287$; $\Delta M_F = 0,107 \cdot 0,287 \cdot 194,9 \cdot 4,50 = +27 \text{ kNm/m}$

$$\max M_F = 143 + 27 = \underline{170 \text{ kNm/m}}$$

DETALJI PRIKLJUČAKA UZDUŽNIH REBARA I POPREČNOG NOSAČA

Otvorena rebra:

- a) i b) stabilnost ?
- c) bolje (zabranjeno u UK)
- d) komplicirano
- e) ograničeno



$$\frac{b}{t} \leq 25$$

3,20
3,57
2,753
2,53
2,50
2,50
3,58

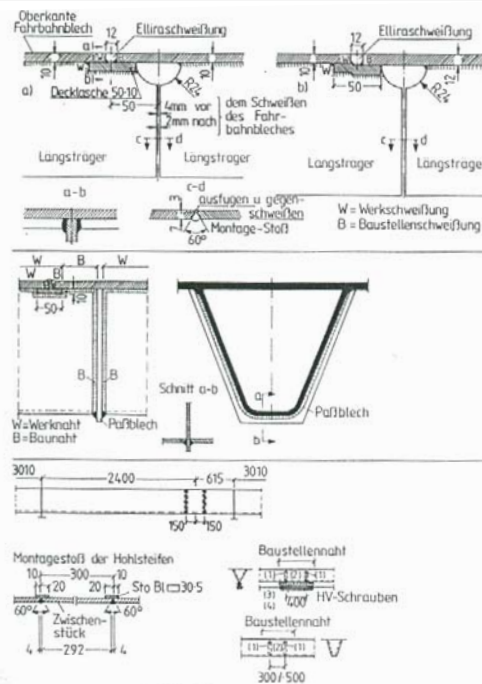
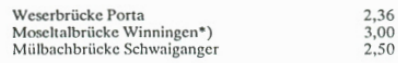
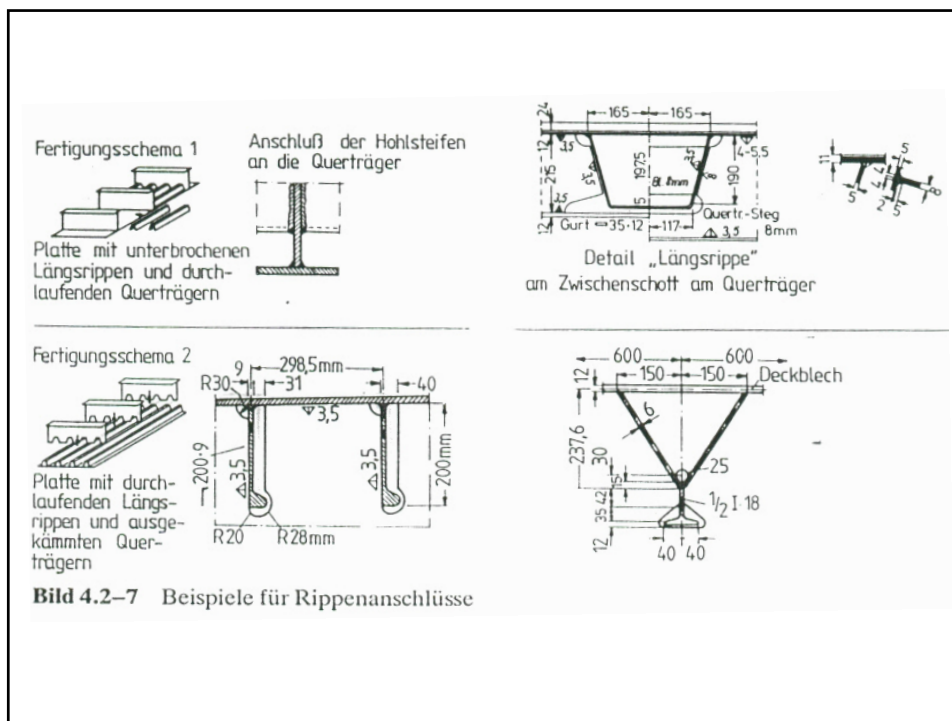


Bild 4.2-6 Beispiele für Rippenstöße



OSOBITOSTI:

- $e/t \leq 25$,
- $t \geq 10 \text{ mm}$, $e/t \leq 40$
- razmak poprečnih nosača 2-3 m – otvorena rebra
- razmak poprečnih nosača 3-5 m – zatvorena rebra
- izolacija bitumen ili umjetna smola na bazi epoksidnih smola
- zaštitni sloj – asfaltni mastiks i lijevani asfalt 35 mm
- habajući sloj – lijevani asfalt (asfalt-beton)
- izolacija na pjeskarenu plohu čistoće SA 2 1/2, danas plamenikom zbog zaštite okoliša
- pukotine uzdužne uglavnom nad hrptovima krutih uzdužnih nosača
- minimalne krutosti u DIN 18809 u ovisnosti o rasponu
- HUBER jednadžba aproksimacije jer pretpostavlja simetriju oko neutralne osi (ravnine) ploče
- klasična teorija – proširenje na ravninski problem (disk) i pločasti dio