

**GRAĐEVINSKI FAKULTET  
ZAVOD ZA KONSTRUKCIJE  
KATEDRA ZA MOSTOVE**

# **SPREGNUTI MOSTOVI**

*Predavanja za predmet Mostovi II*



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**SPREGNUTO DJELOVANJE PLOČE KOLNIKA I GLAVNIH NOSAČA**

**OSNOVNE DEFINICIJE:**

**Vrste sprezanja: čelik-beton**

- Kruto sprezanje
- Elastično sprezanje
- Isprekidano sprezanje
- Potpuno i djelomično sprezanje

**Sredstva za sprezanje:**

- Moždanici
- Prionjivost
- Trenje



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### VRSTE SPREZANJA:

- kruto sprezanje – nepopustljivi spoj između ploče i čeličnog nosača
- elastično sprezanje – određeni elastični pomak između ploče i čeličnog nosača
- isprekidano sprezanje – isto kao i elastično ali sa svim vrstama moždanika što kod elastičnog nije moguće. Ploča se izvodi neprekinuto i spreže se samo na pojedinim dionicama
- potpuno ili djelomično sprezanje – nosač je smožden za sva opterećenja ili samo na neka (pokretno i dio stalnog)
- prednapinjanje – kolnička ploča se može prednapeti kabelima ili posebnim slijedom

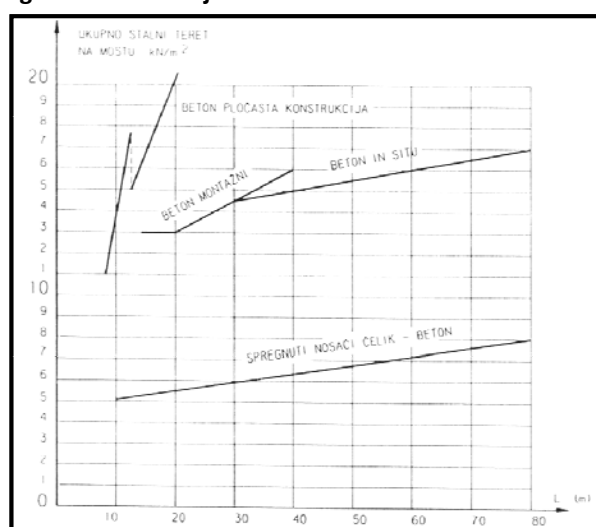


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Stalni teret na mostu po jedinici korisne površine –  
spregnuta konstrukcija lakša 50-60% u odnosu na armiranobetonsku

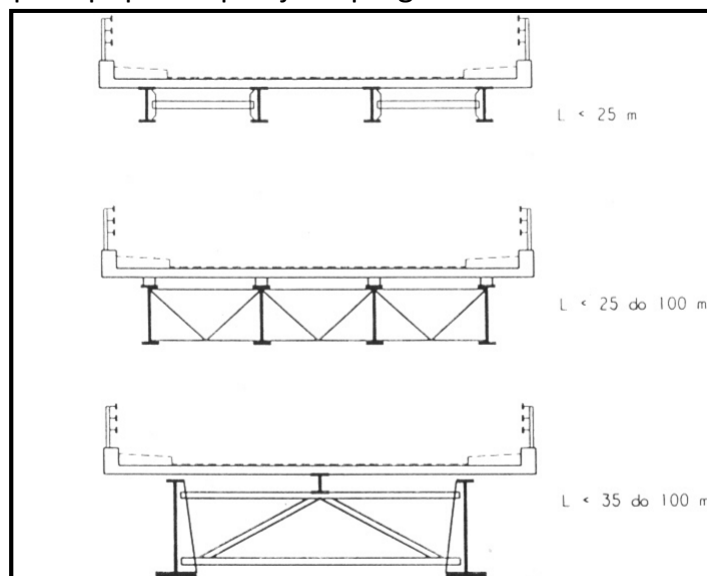


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### Tipični poprečni presjeci spregnutih cestovnih mostova:

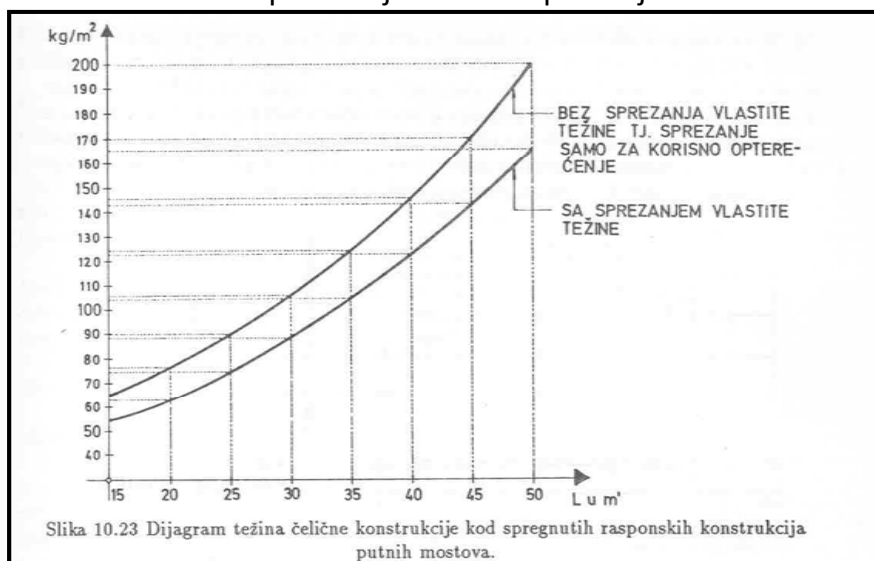


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### Potpuno i djelomično sprežanje:



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**MOŽDANICI:**

- sprezanje se izvodi isključivo moždanicima
- dvije vrste moždanika: (a) - kruti ili nepopustljivi

(a)

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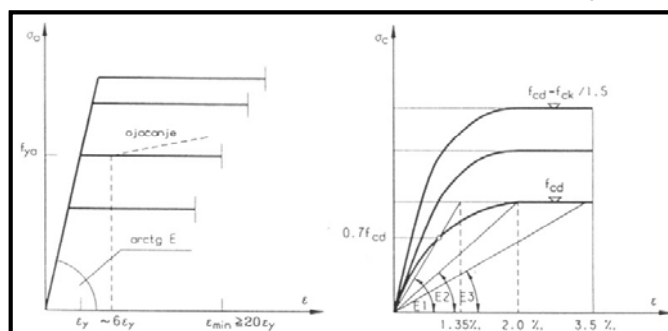
- (b) -vitki ili popustljivi:

- danas se koriste praktično isključivo čepasti moždanici koji omogućuju preraspodjelu sila

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### MEHANIZAM DJELOVANJA SPREGNUTOG NOSAČA:

- u elastičnoj analizi se obično različita svojstva betona i čelika svode na svojstvo čeličnog materijala
- uobičajene pretpostavke:
  - čelik i beton izotropno su elastično-plastični materijali
  - diskontinuirano razmještena spojna sredstva zamjenjuju se kontinuiranom raspodjelom
  - presjeci poslije savijanja ostaju ravni
- radni dijagrami čelika i betona:

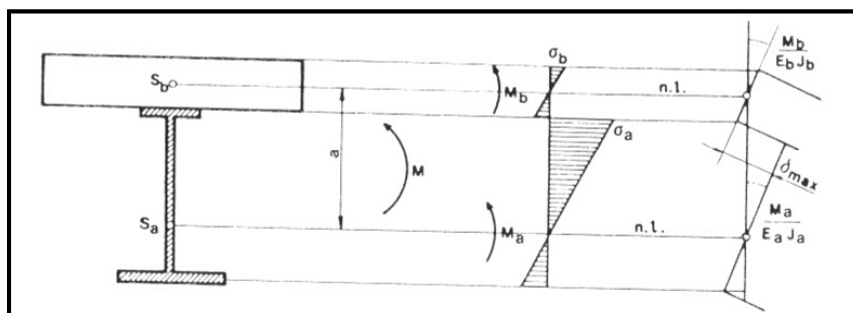


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### NESPREGNUTI PRESJEK:



$$M_a + M_b = M$$

$$\frac{M_a}{E_a I_a} = \frac{M_b}{E_b I_b} = \frac{M}{E_a I_a + E_b I_b}$$

$$M_a = \frac{E_a I_a}{E_a I_a + E_b I_b} \cdot M; \quad M_b = \frac{E_b I_b}{E_a I_a + E_b I_b} \cdot M$$

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**SPREGNUTI PRESJEK:**

$$M_a + M_b + N \cdot a = M$$

$$M_a = \frac{E_a I_a}{E_a I_i} \cdot M = \frac{I_a}{I_i} \cdot M$$

$$M_b = \frac{E_b I_b}{E_a I_i} \cdot M = \frac{I_b}{n I_i} \cdot M$$

$$N = \sigma_b \cdot A_b = \frac{S_i}{I_i} \cdot M; \quad n = E_a / E_b$$

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**Posmična sila:**  $T(x) = \frac{dN(x)}{dx}$

za nepustljivo sprezanje vrijedi:  $\frac{dN(x)}{dx} = \frac{S_i}{I_i} \frac{dM(x)}{dx} = \frac{S_i}{I_i} \cdot V(x)$

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za elastično sprezanje vrijedi:  $\frac{d^2 N'}{dx^2} - w^2 N' = -\gamma \cdot M$

**N'** – komponenta sprezanja  
**M** – moment savijanja u presjeku  
**w** i **γ** – parametri presjeka i elastičnih osobina nosača

$$M_a' = \frac{E_a I_a}{E_a I_a + E_b I_b} \cdot (M - N' a); \quad M_b' = \frac{E_b I_b}{E_a I_a + E_b I_b} \cdot (M - N' a)$$

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**UTJECAJ PUZANJA I SKUPLJANJA NA SPREGNUTOM NOSAČU:**

**Preraspodjela naprezanja zbog puzanja:**

Beton – naprezanje pada za  $\Delta\sigma_b$   
 Čelik – gornji pojas – naprezanje raste za  $\Delta\sigma_a$   
 Čelik – donji pojas – naprezanje raste neznatno

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**Geometrijske karakteristike presjeka:**

The diagram illustrates the geometric characteristics of a composite cross-section. It is divided into three main parts: **Geometrijski odnosi** (Geometric relationships), **Raspored opterećenja** (Load distribution), and **Naponi** (Stresses).

**Geometrijski odnosi:** Shows a composite cross-section with a top flange of width  $b_e$  and thickness  $d_b$ , and a bottom flange of thickness  $d_a$ . The total height is  $h_a$ . The centroid of the top flange is at  $S_b$  and the centroid of the bottom flange is at  $S_a$ . The distance between the centroids is  $a$ . The centroid of the composite section is at  $S_i$ . The distances from the centroid of the top flange to the centroid of the composite section is  $z_b$ , and from the centroid of the bottom flange to the centroid of the composite section is  $z_a$ . The distance from the centroid of the composite section to the neutral axis is  $z_i$ .

**Raspored opterećenja:** Shows the distribution of loads. The top flange is subjected to a normal stress  $\sigma_b$  and a bending moment  $M_b$ . The bottom flange is subjected to a normal stress  $\sigma_a$  and a bending moment  $M_a$ . The total bending moment is  $M$ .

**Naponi:** Shows the stress distribution across the cross-section. The stress is linear, with a maximum stress  $\sigma_b$  at the top and a minimum stress  $\sigma_a$  at the bottom. The stress at the neutral axis is zero.

$$A_i = \frac{1}{n} A_b + A_a; \quad a_b = \frac{A_a}{A_i} \cdot a; \quad a_a = \frac{A_b}{n A_i} a, \quad S_i = \frac{A_b}{n} \cdot a_b = \frac{A_a A_b}{n A_i} \cdot a$$

$$J_i = J_a + \frac{1}{n} J_b + \frac{A_b}{n} a_b^2 + A_a^2 = J_a + \frac{1}{n} J_b + \frac{A_b}{n} \left( \frac{A_a}{A_i} \right)^2 a^2 + A_a \left( \frac{A_b}{n A_i} \right)^2 a^2 =$$

$$= J_a + \frac{1}{n} J_b + \frac{A_b A_a}{n A_i} a \left( \frac{A_a}{A_i} a + \frac{A_b}{n A_i} a \right) = J_a + \frac{1}{n} J_b + S_i a$$

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**Moment tromosti možemo napisati i u ovom obliku:**

$$J_i = J_a + \frac{1}{n} J_b + A_i \cdot a_b \cdot a_a$$

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**Raspored sila u presjeku:**

**Vrijede odnosi:**

$$M_b = \frac{J_b}{nJ_i} \cdot M; \quad M_a = \frac{J_a}{J_i} \cdot M; \quad M_{N_a} = -M_{N_b} = \frac{S_i}{J_i} \cdot M$$

$$N_{N_b} = \frac{A_b}{nA_i} \cdot N \quad \text{ i } \quad N_{N_a} = \frac{A_a}{A_i} \cdot N$$

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**Normalna naprezanja:**

$$\sigma_b = -\frac{N_b}{A_b} \mp \frac{M_b}{J_b} \cdot z_b = \dots = -\frac{N}{nA_i} \mp \frac{M}{nJ_i} \cdot z_i$$

$$\sigma_a = \frac{N_a}{A_a} \mp \frac{M_a}{J_a} \cdot z_a = \dots = -\frac{N}{A_i} \mp \frac{M}{J_i} \cdot z_i$$

$$N_b = N_{N_b} + M_{N_b}$$

$$N_a = N_{N_a} + M_{N_a}$$

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$n = n_t$

$n_t \dots$

**Za kratkotrajne utjecaje i opterećenja:**

**Za dugotrajna djelovanja:**

a) kad sprezanje počinje prije 3 mjeseca

$$n_t = n_o (1 + \psi_A \cdot \varphi_t); \quad n_t = n_o (1 + \psi_B \cdot \varphi_t);$$

b) kad sprezanje počinje nakon 3 mjeseca

$$n_t = n_o' (1 + \psi_A \cdot \varphi_p'); \quad n_t = n_o' (1 + \psi_B \cdot \varphi_p');$$

**Za skupljanje i preraspodjelu statički neodređenih veličina od puzanja**

a) kad je sprezanje počelo prije 3 mjeseca

$$n_t = n_o' (1 + \psi_S \cdot \varphi_t);$$

b) kad je sprezanje počelo poslije 3 mjeseca

$$n_t = n_o' (1 + \psi_S \cdot \varphi_p');$$

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### Utjecaj deformacije ploče na spregnutu gredu:

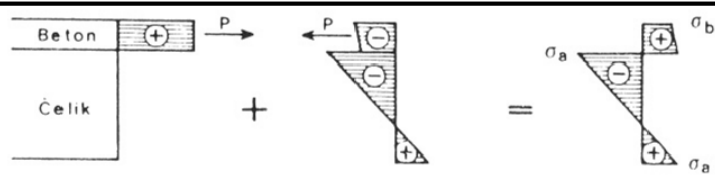
*Slika 8.18. Utjecaj deformiranja ploče na spregnuti nosač: a) slobodna deformacija, b) uvjet kompatibilnosti - snoždenost ploče, c) uvjet ravnoteže, d) kvalitativna slika napona*

$$P = \varepsilon_b \cdot E_b \cdot A_b$$

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(d)

$$\sigma_b = + \frac{P}{A_b} - \frac{P}{nA_i} - \frac{P \cdot a_b}{nJ_i} \cdot z_i = P \left( \frac{1}{A_b} - \frac{1}{nA_i} - \frac{a_b}{nJ_i} \cdot z_i \right) = \varepsilon_b \cdot E_b \cdot \left( 1 - \frac{A_b}{nA_i} - \frac{A_b a_b}{nJ_i} \cdot z_i \right) =$$

$$= \varepsilon_b \cdot E_b \cdot \frac{A_a}{A_i} \left( 1 - \frac{A_a a_a}{J_i} \cdot z_i \cdot \frac{A_i}{A_a} \right) = \varepsilon_b \cdot E_b \cdot \frac{A_a}{A_i} \left( 1 - \frac{A_i a_a}{J_i} \cdot z_i \right) \quad (8.18)$$

**Analogno u čeličnom dijelu nosača:**

$$\sigma_a = - \frac{P}{A_i} \mp \frac{P \cdot a_b}{J_i} \cdot z_i = P \left( - \frac{1}{A_i} \mp \frac{a_b}{J_i} \cdot z_i \right) = \varepsilon_b \cdot E_b \cdot \frac{A_b}{A_i} \left( -1 \mp \frac{a_b A_i}{J_i} \cdot z_i \right)$$

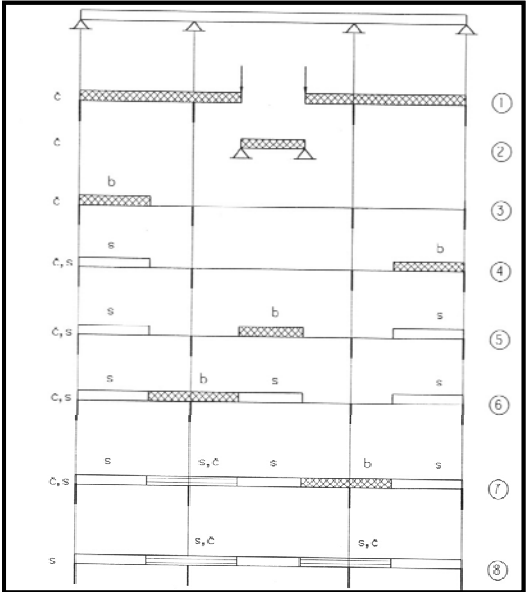
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### NAČINI IZVEDBE:

|                                                           | prosta greda | poduprt nosač | nadvišenje |
|-----------------------------------------------------------|--------------|---------------|------------|
| Momentni dijagram za čelični nosač prije očvršćiv. Betona |              |               |            |
| Uklanjanje pomoćnih Stupova                               |              |               |            |
| Momentni dijagram za spregnuti nosač                      |              |               |            |
| Ukupni moment                                             |              |               |            |
| Rezultirajuća preraspodjela naprezanja                    |              |               |            |

Momenti savijanja i naprezanja od vlastite težine za različite postupke gradnje

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**FAZE POSTUPNOG OPTEREĆENJA:**

č – vl. težina čelika  
 b – opt. svježim betonom  
 s – spregnuti dio nosača  
 s, č – raspucali beton spregnutog nosača

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**STATIČKI SUSTAVI GREDNIH SPREGNUTIH MOSTOVA:**

- **mostovi s jednim rasponom (prosta greda)**
  - statički sistem grede na dva oslonca,
  - rasponi 20-50 m
- **mostovi s više jednakih ili različitih raspona**
  - diskontinuirani statički sistem - rasponi  $n \times (20-50 \text{ m})$
  - kada se očekuje slijeganje
  - maksimalni stupanj sprežanja betona i čelika bez prednapinjanja
  - mogućnost etapne izgradnje
  - prijelazne naprave – trajnosno nepovoljnije rješenje
  - dvostruki broj ležajeva nad stupovima
  - veća potrošnja čelika nego kod kontinuiranih sklopova
- **mostovi s kontinuiranim rasponskim sklopovima**
  - rasponi 20-120 m
  - manje konstruktivne visine
  - velika vlačna naprezanja u betonu nad srednjim osloncima, razmotriti prednapinjanje ili denivelaciju srednjih oslonaca, potrebno odrediti povoljan raspored betoniranja
  - manji broj prijelaznih naprava

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### OSOBITOSTI:

- kolnička ploča debljine 22 do 25 cm – razmak nosača 2,5 do 4 m
- konzole opterećene prometom izvode se bez ojačanja do 1,5 m raspona, a s prometnim opterećenjem do 2,5 m raspona
- ako su razmaci nosača veći (6-7 m) onda se ploče izvode promjenjive debljine (25 cm u polju i do 35 cm nad nosačem)
- manji rasponi - valjani profili
- ako postoje 4 glavna nosača tada na vanjski nosač otpada oko 75% momenata savijanja, a na unutrašnje oko 50%, a raspodjela poprečnih sila je 85% na vanjski nosač i oko 70% na unutrašnje nosače
- do 1,5 m visine treba osigurati funkcionalnost bez ukrućenja osim osim vertikalnih nad ležajevima
- od 1,5 do 2,5 m visine samo vertikalna ukrućenja, a za veće visine i horizontalna
- kod zavarenih nosača najčešće zadovoljava gornji pojas sa  $\frac{1}{2}$  površine donjeg pojasa (osim nad srednjim osloncima kontinuiranih nosača)


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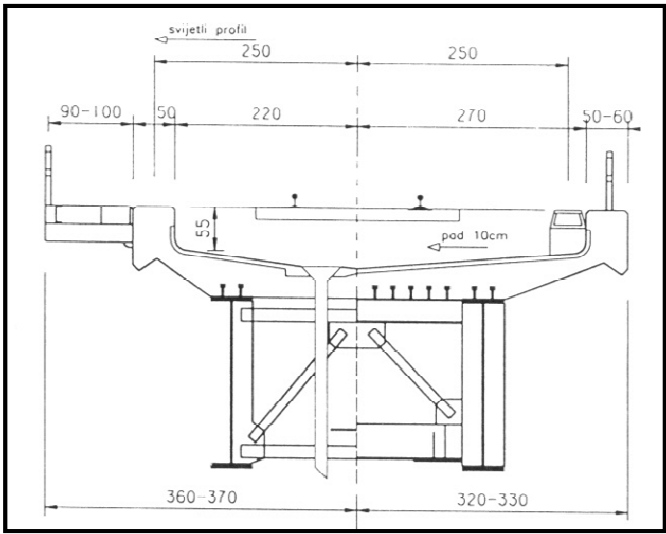
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### PRIMJERI:

#### Tipski željeznički most s kolnikom gore (SBB)



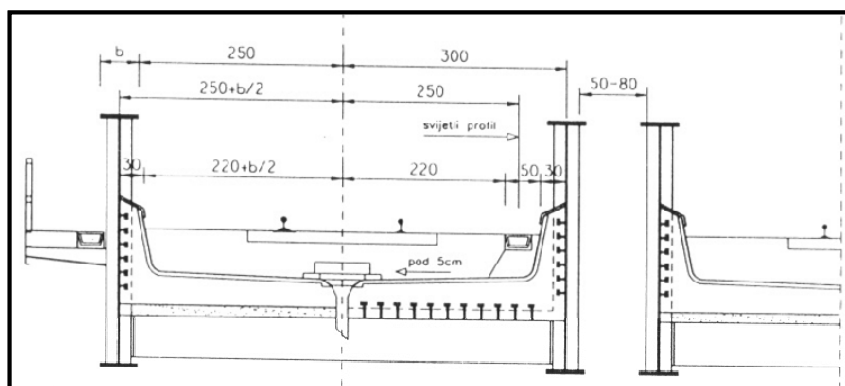

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## PRIMJERI

## Tipski željeznički most s kolnikom dolje (SBB)



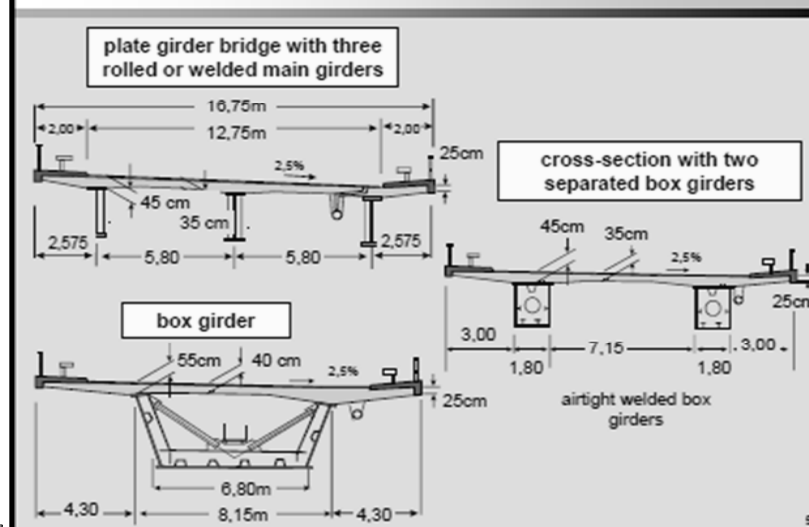
- ploča kolnika spregnuta s poprečnim nosačima
- korito se spreže i s glavnim nosačima na kojima obavlja funkciju stabilizacije

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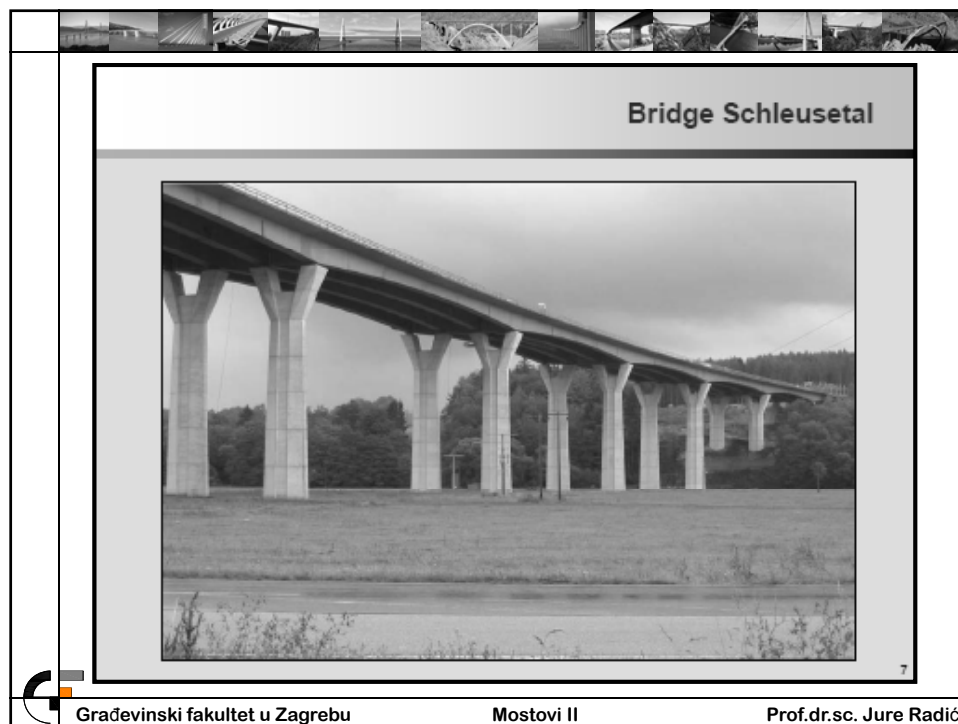
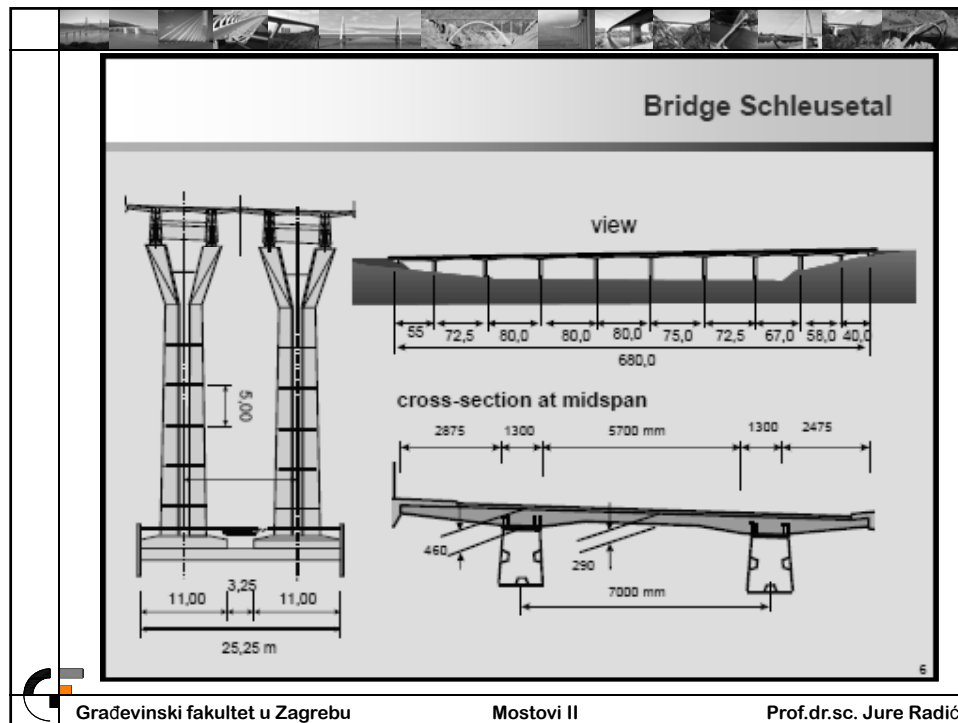
## Typical cross-sections for composite bridges



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**Bridge Schleusetal**

transportation of steel girders on site







casting of the concrete deck by moveable formwork

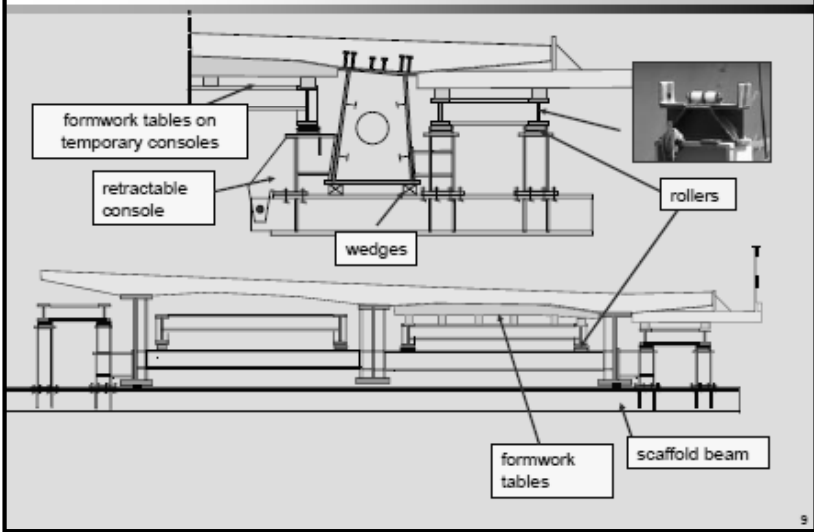
erection of steel girders by cranes



8

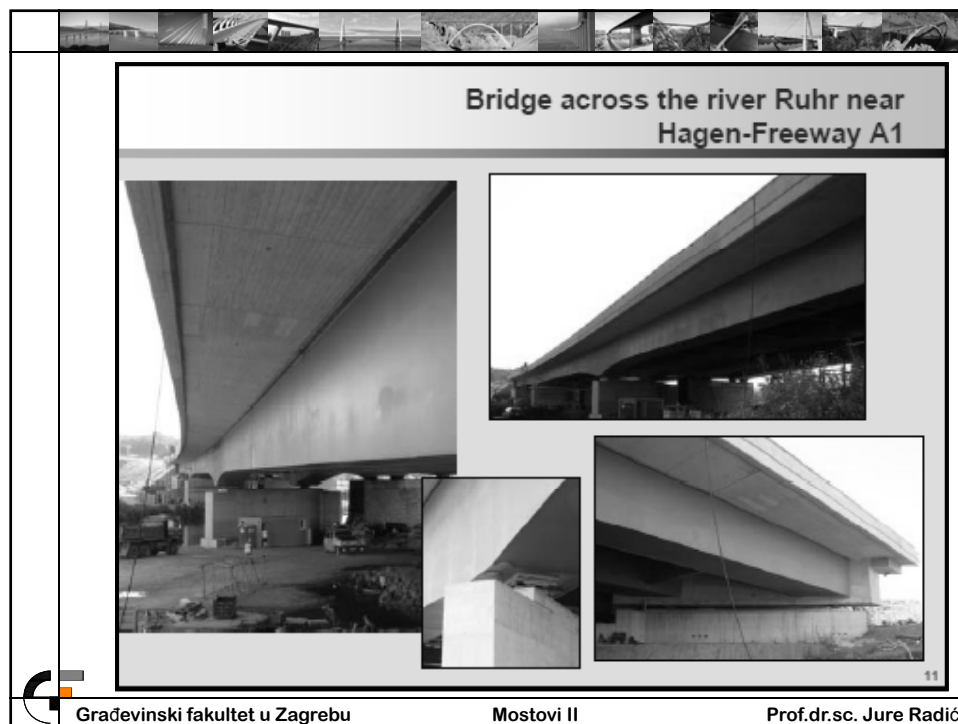
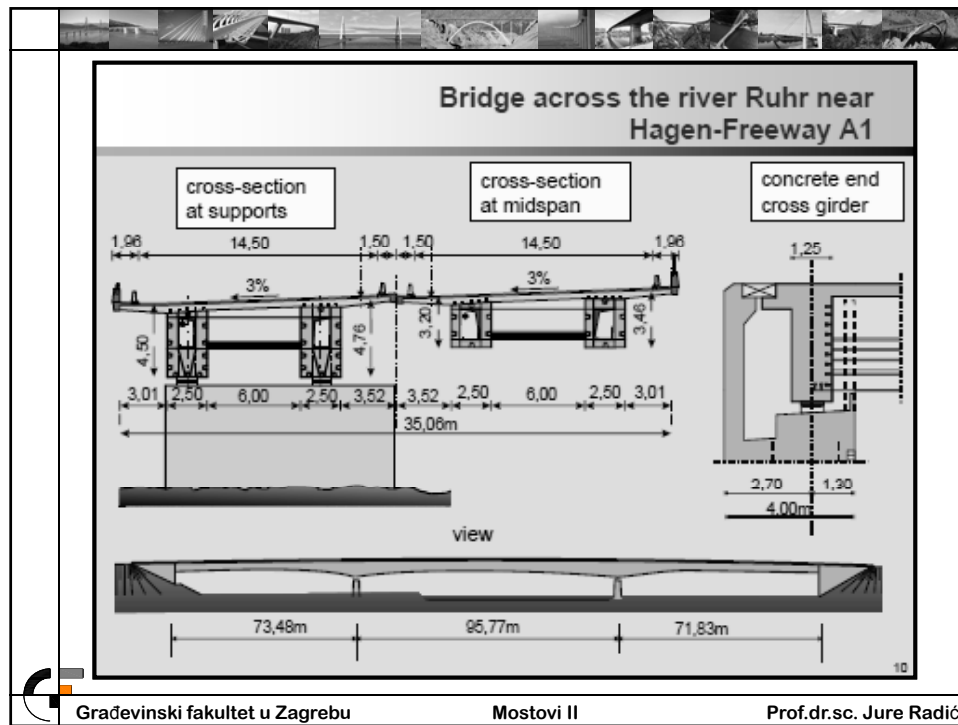
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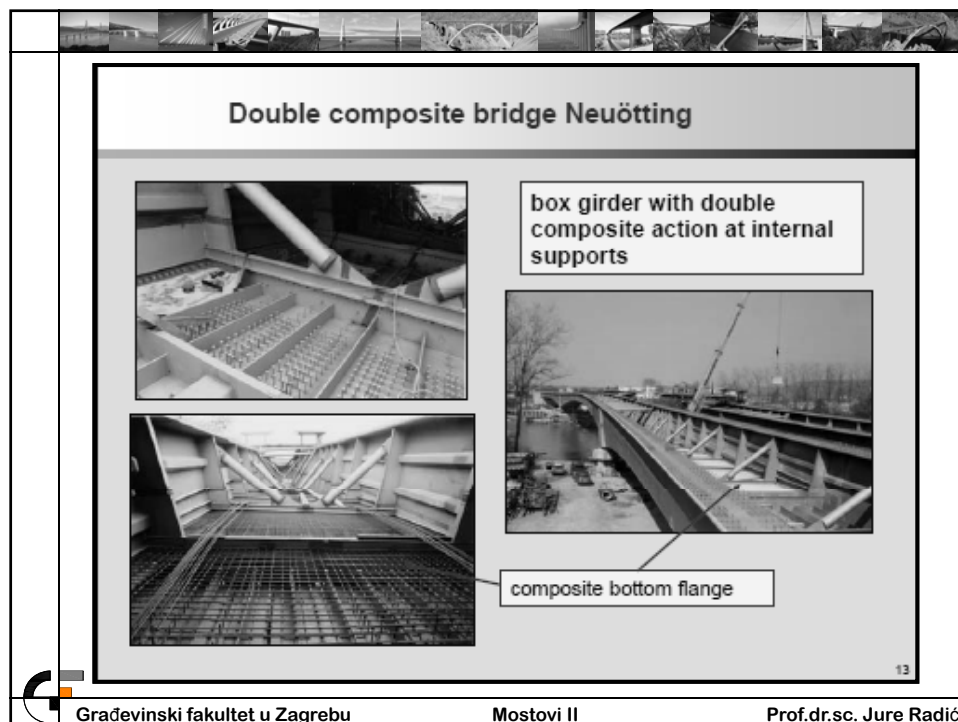
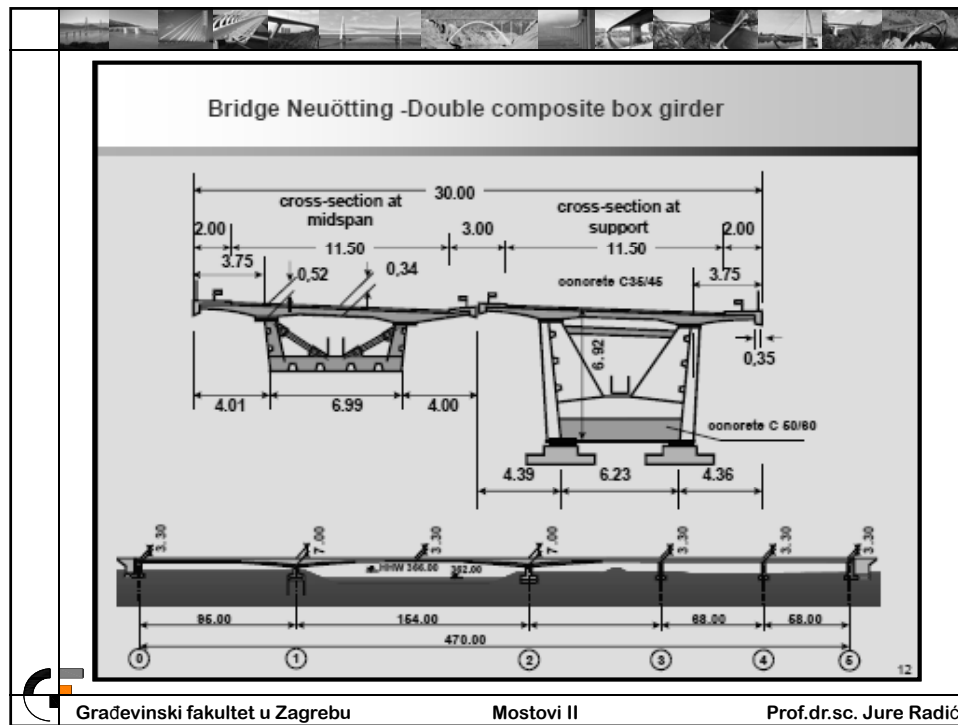
**Examples for formwork systems**



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**Box girders with corrugated webs**



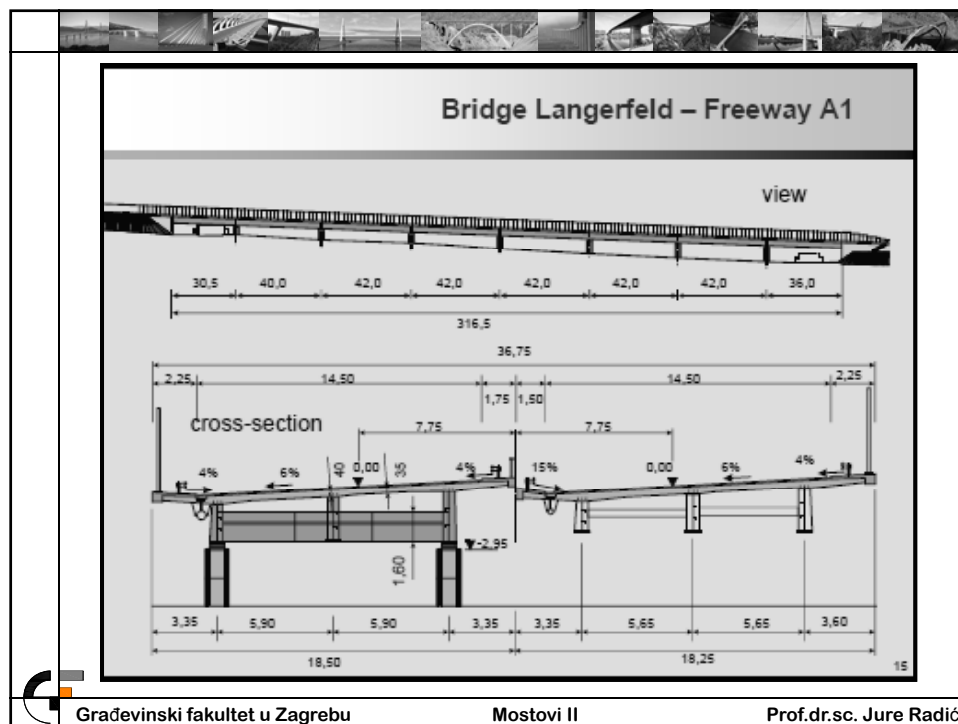
Bridge  
Altwipfergrund

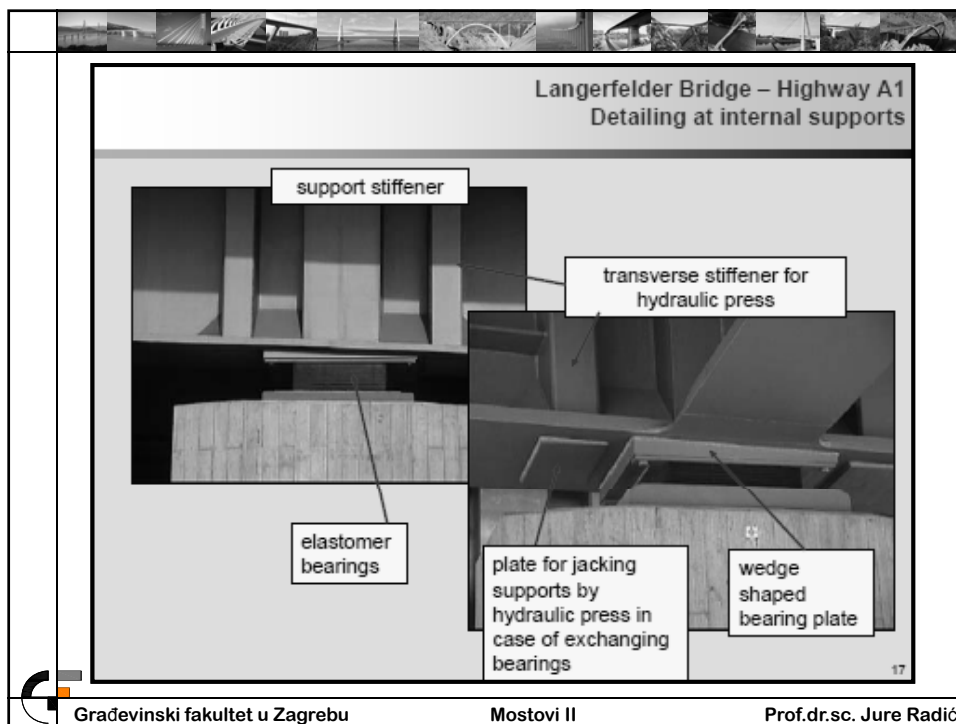
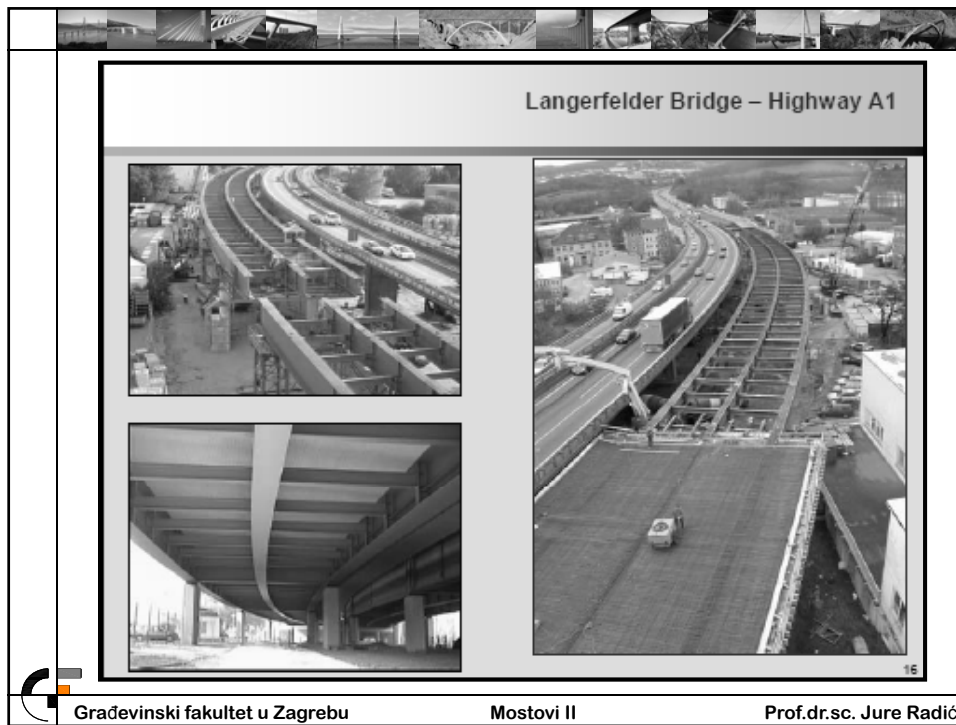




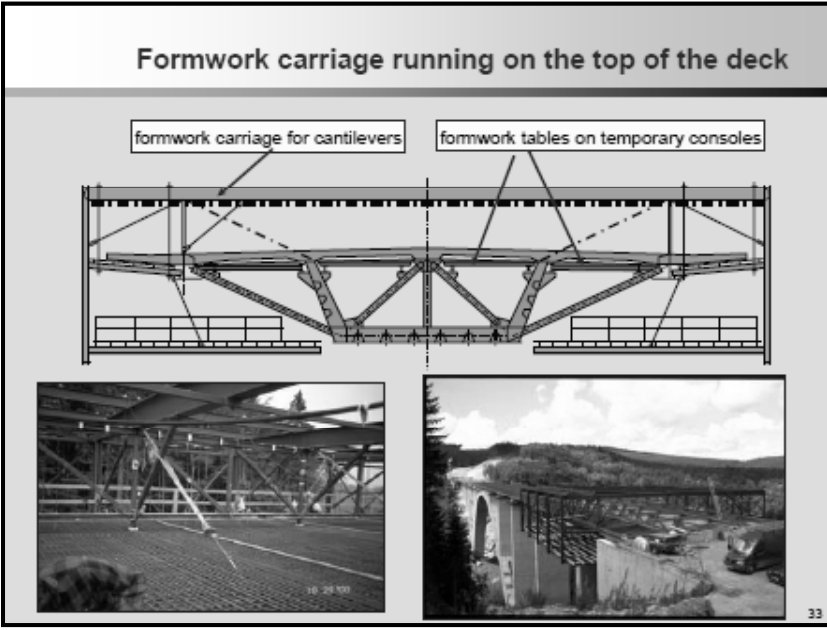
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**Formwork carriage running on the top of the deck**



formwork carriage for cantilevers

formwork tables on temporary consoles

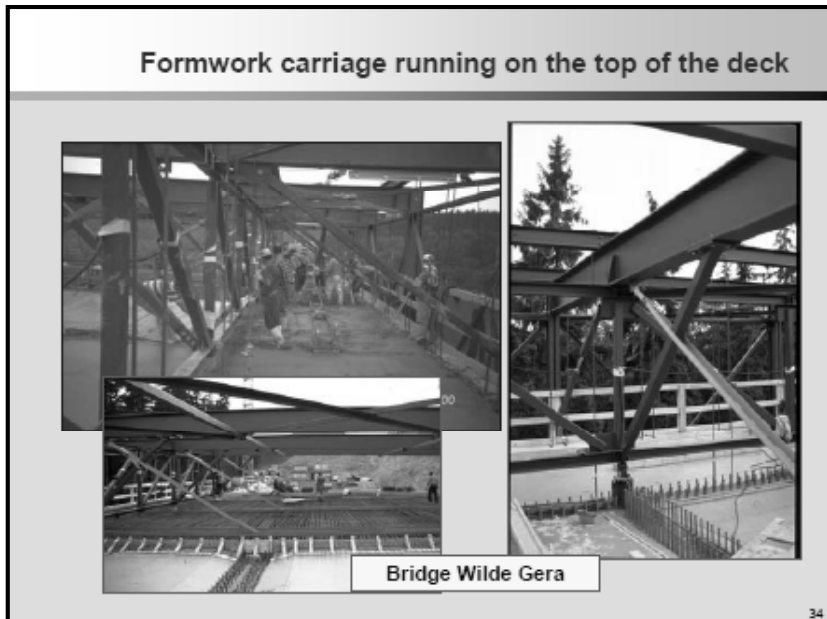
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**Formwork carriage running on the top of the deck**



Bridge Wilde Gera

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**Formwork underneath the concrete deck**

formwork carriage for outer cantilevers      formwork tables on temporary consoles

Bridge Albrechtsgraben

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**Formwork underneath the concrete deck  
(system Kirchner)**

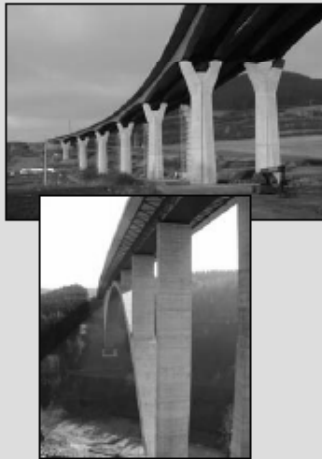
Bridge Schwarza

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### Exchange of concrete decks



Normally it is a general requirement in Germany to have separate bridges for each traffic direction in order to be able to divert the full traffic on the remaining bridge in case of major maintenance work on the other. The concrete deck is the most vulnerable part of a bridge section. With regard to the expected intensive increase of road traffic and local wheel loads in future, the concrete deck must be regarded as a wearing part in contrast to the steel structure with implication of different lifetimes of the concrete deck and the steel structure.

In case of one main composite box girder for both traffic directions the flow of traffic has to be maintained in both directions just on one half of the bridge during a future replacement of the bridge deck. For this procedure the bridge deck will be partially cut out with high-pressure water method and will be replaced by a new bridge deck. During this procedure significant additional stresses result in the superstructure, which have to be considered during design and construction.

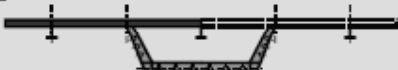
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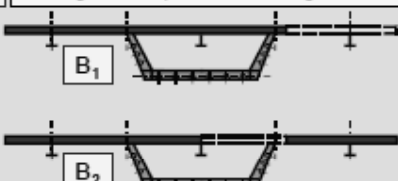


### Different possibilities for the exchange of the concrete slab

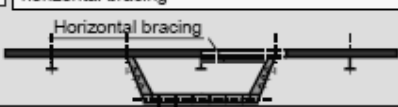
**A** exchange of one half of the deck



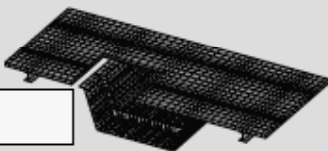
**B** exchange over a quarter of the bridge in two steps



**C** exchange of one half of the deck with additional horizontal bracing

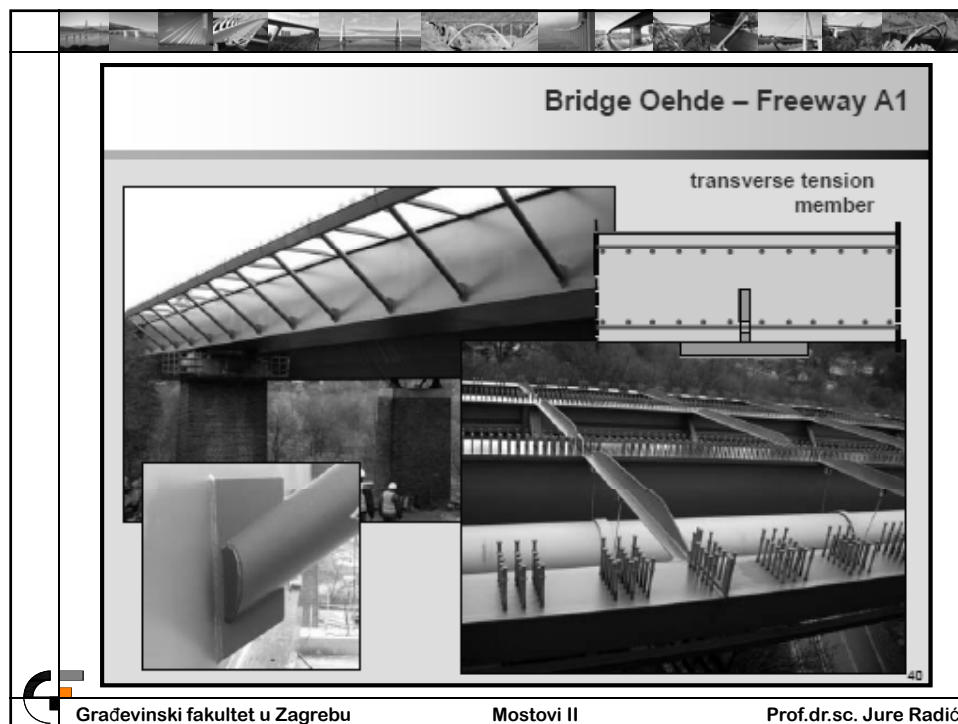
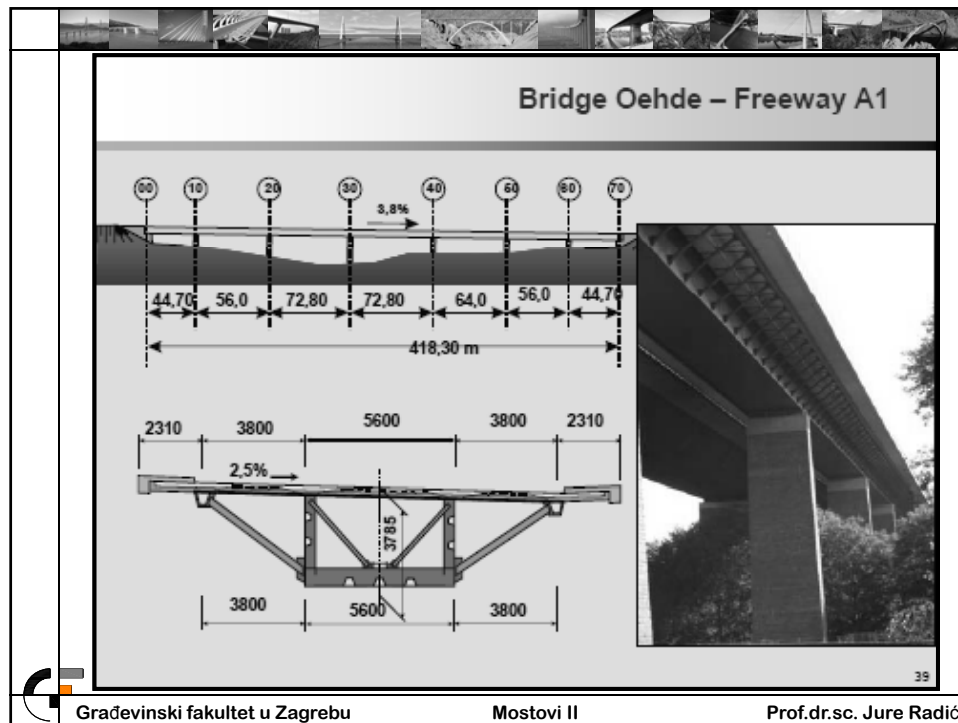


The width of the span is the most important factor for choosing the different methods. Method A can only be used for spans up to 50 m. Methods B or C are possible for the exchange of the concrete deck of bridges with larger spans of up to 100 m.



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**Bridge Oehde – Freeway A1**

concrete deck with partially prefabricated concrete elements

launching of the bridge with partially prefabricated concrete elements

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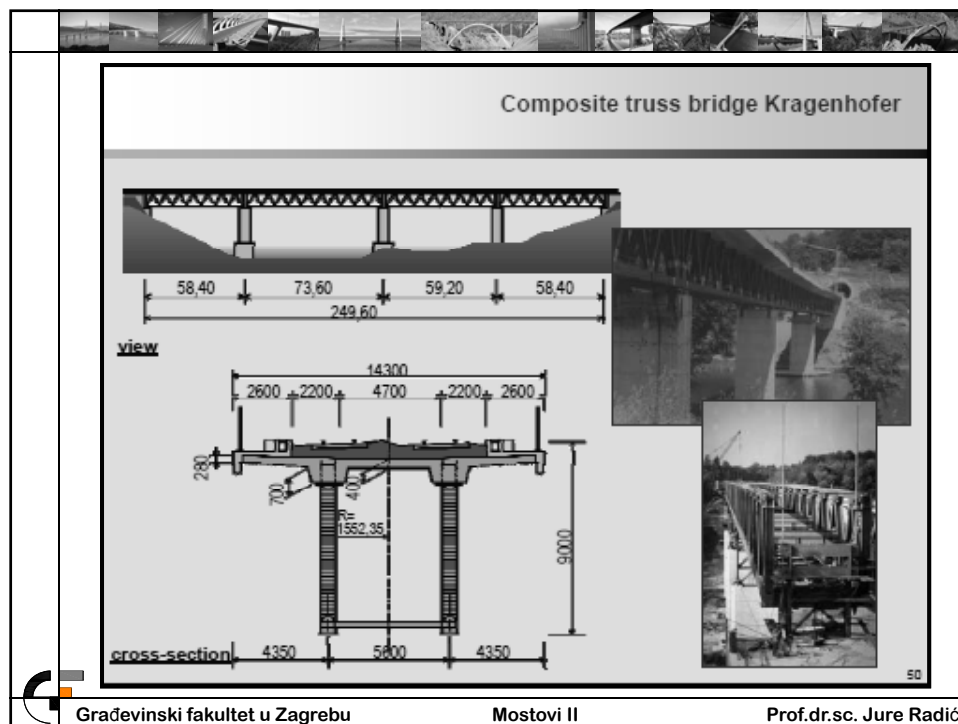
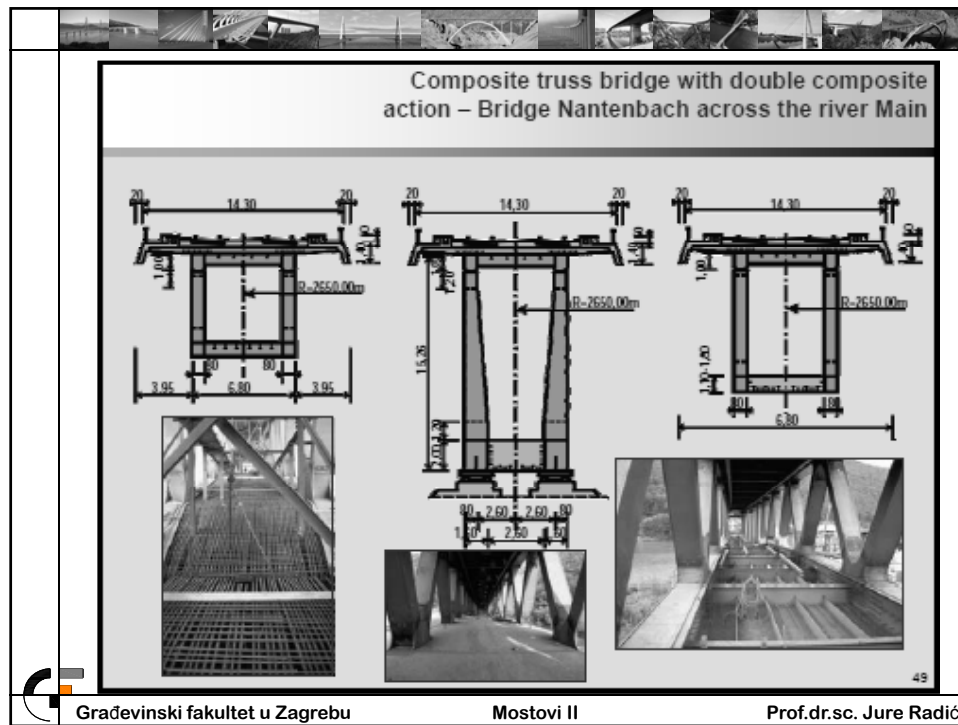
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**Composite truss bridge with double composite action – Bridge Nantenbach across the river Main**

view

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Composite bridges for small and medium spans



Bridge Oberhartmannsreuth

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Composite bridges with rolled sections for small and medium spans



**Advantages**

- short construction time
- simple erection method because of no steelwork on site.
- steelwork only in the shop
- small total depth of the composite section
- concrete slab without any pre-stressing

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### Longitudinal reinforcement at internal supports

- The longitudinal reinforcement at internal supports should be placed over a length not smaller than  $L = 0,15 L_{St}$ , where  $L_{St}$  is larger span length adjacent to the support considered.
- at the end of the steel girder the number of shear connectors should be increased due to local introduction of the tensile force in the reinforcement in the composite section.
- In case of sagging bending moments at internal supports due to temperature effects, traffic loads and settlements of supports for the tensile forces in the bottom flange a connection by steel plates or studs in combination with loops is required.

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### Detailing of transverse supporting beams in concrete

$b_{min} = 80 \text{ cm}$  (indirect support)  
 $b_{min} = 60 \text{ cm}$  (direct support)

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### Detailing of partially prefabricated concrete elements

the depth of the concrete above the prefabricated elements  $h_0$  should be not less than 20 cm within the traffic lanes. In other regions  $h_0$  should not be less than 15 cm.

Elastomeric support strips with a thickness of 2 cm and a width of 3 cm. The minimum value of pressing should be 3-5 mm and the maximum value should not exceed 10 mm.

$\geq C_{nom} = 4,5\text{cm}$

mortar

seal

shear reinforcement

$h_c$

4,0

2,5

1,0

21

$\geq 3\text{cm}$

$\geq 2,5\text{ cm}$

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### Casting of concrete

in case of smaller span length the transverse supporting beams and the concrete slab should be casted in one operation.

in case of larger span length or for bridges with a big total length at first the midspan regions and subsequently the internal supports and the transverse supporting beams should be casted.

casting of mid-span regions

casting of supporting beams and the slab at internal support

0,15 L

L

L

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**VFT-Bridges with welded or rolled I-sections**

in situ concrete slab

precast concrete flange

steel girder

steel girder in the shop

installation by crane

transport on site

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**VFT-Filler beams**

3200

640

rolled section

shear connection

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VFT-Filler beams

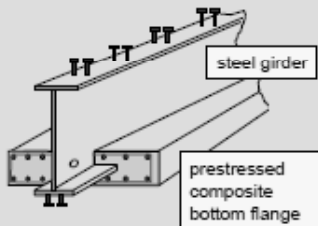





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Preflex - Beams



The Preflex-Beam is a girder with a pre-stressed composite bottom flange where the pre-stressing is applied by elastic bending of the steel girder.

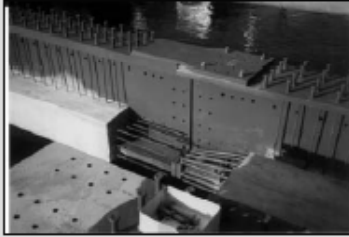
The pre-stress causes a higher bending resistance and a high flexural stiffness. Therefore the deflections under serviceability conditions very small. This type of beam is often used for railway and road bridges where the available construction depth is highly restricted. Ratios of span to structural depth up to 45 are possible for road bridges.




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**Composite bridge with Preflex-Girders**

**Hermann-Lieberum Bridge in Leipzig**

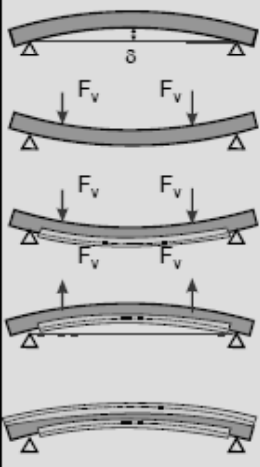
continuous beam, span 33 m and  
construction depth 130 cm



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**Preflex Girders – pre-stressing of the concrete bottom flange**



campered steel girder

pre-stressing forces  $F_v$   
applied to the steel  
girder (elastic bending)

casting of the concrete  
bottom flange

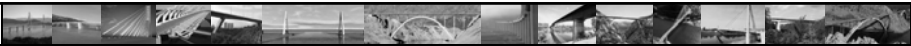
removing of the  
prestressing force  $F_v$   
after hardening of  
concrete causes  
compressive stresses  
in the concrete bottom  
flange

casting of the concrete  
top flange on site




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## NAČINI MONTAŽE ČELIČNIH KONSTRUKCIJA ČELIČNIH I SPREGNUTIH MOSTOVA:

- montaža navlačenjem s čela
- montaža auto-dizalicama ili dizalicama sa vagona ili plovila
- montaža kabel-kranom
- montaža postupkom slobodne konzolne gradnje
- montaža postupkom bočnog prevlačenja
- montaža kombiniranim i specifičnim načinima



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