جامعة عين شمس

كلية الهندسة

قسم الهندسة الإنشائية

# مساعدات التصميم

مادة

# طرق تشييد المنشآت الخرسانية

# (هدن ٤٦٢)

# TYPES OF FORMWORK

- Permanent versus temporary
  - Galvanized metal deck forms
  - Precast concrete deck forms
- Material utilized
  - Wooden
  - Metal
  - Plastics

# TYPES OF FORMWORK

- Formwork versus falsework
  - Formwork: everything from sheathing ألواح التطبيق to supporting elements, hardware and bracing
  - Falsework: temporary structure to support work in the process of construction (usually for heavy construction as bridges)

# LOADS

- Horizontal
  - Wind, earthquake
  - Not less than 2% vertical loads
  - Not less than 0.20 ton/m

# LOADS

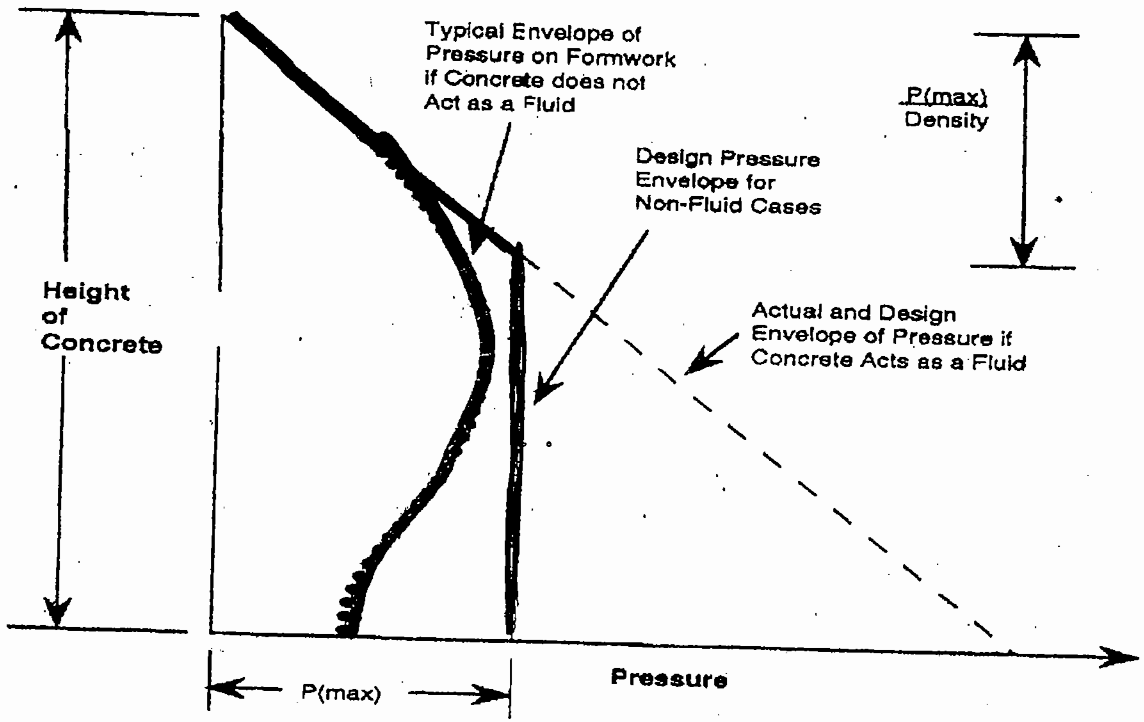
- Vertical
  - Own weight of formwork
  - Weight of reinforcement
  - Weight of fresh concrete
  - Weight of casting labor and equipment
    - Up to 500 kg/m2 when using concrete pumps
  - Parts of higher floors

# LOADS

- ACI Committee 347
  - $P = w * h$
    - P lateral pressure
    - w unit weight of concrete
    - h depth of plastic concrete

# LOADS

- Lateral concrete pressure



# LOADS

- For concrete with OPC, no admixtures, slump < 10 cm, and normal internal vibration

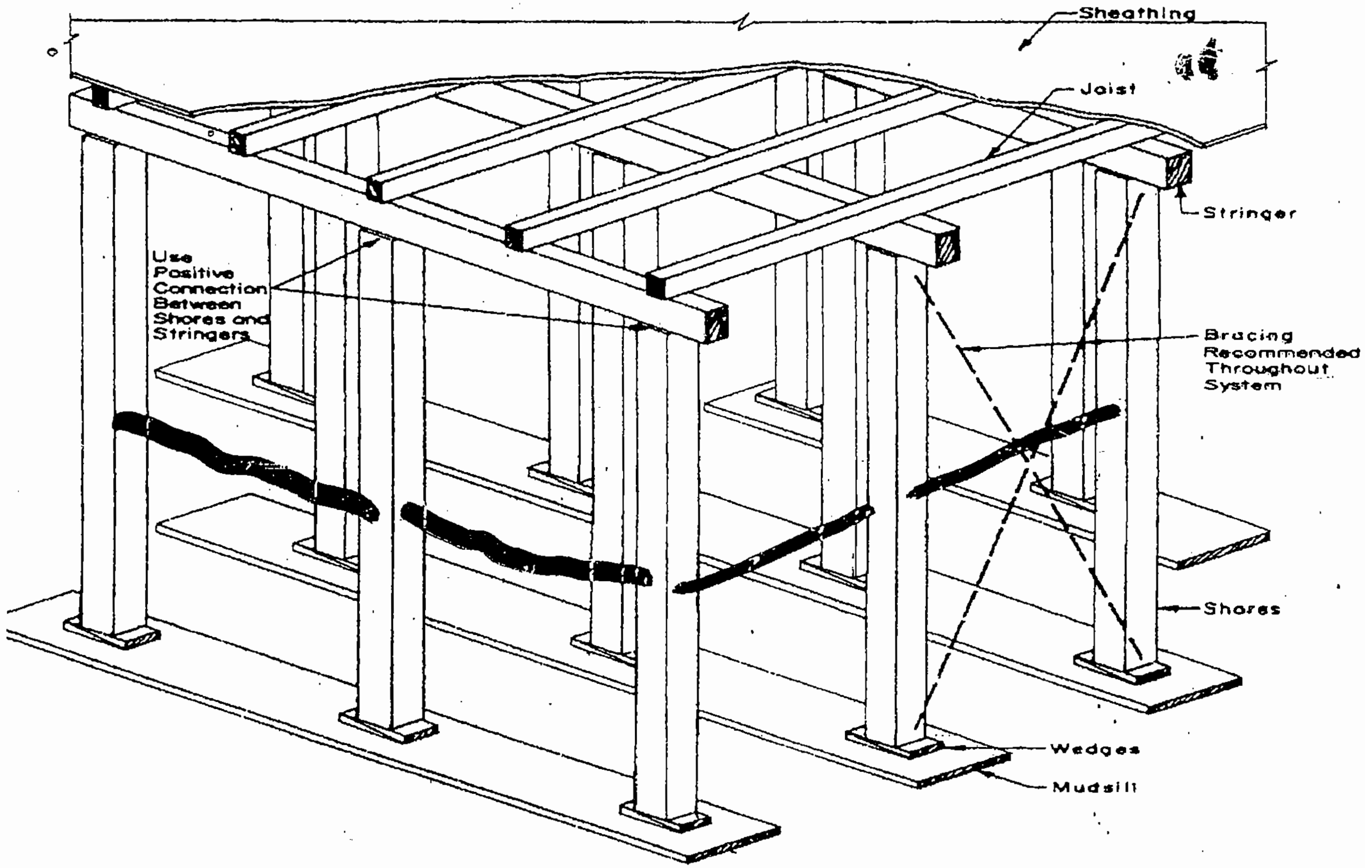
$$\mathbf{2.5\ t/m^2 < P < Pmax < 10t/m^2}$$

  - For **R < 2.00 m/hr**
    - $Pmax = 0.754 + 149.40R/(32+1.8\ T)$
  - For **R < 3.00 m/hr**
    - $Pmax = 0.754+46.48R/(32+1.8T)+218.3/(32+1.8T)$

# DESIGN CRITERIA

- Working stress design
  - Bending
  - Shear
- Deflection limitations
  - $\delta$ < Span / (240 to 360)

# WOODEN FORMWORK



# الشدات التقليدية

- **السقف باستخدام الكمرة والعمود**

فرشات

قوائم ( عروق قطاع ٣ * ٣ الي ٤*٤)

تعريق ألواح خشب ٥×٢ بوصة

تطريح ألواح خشب ٥×٢ مع تقوية جوانب الكمر

تطبيق لتزانة

## Example:

يتم إنشاء بلاطات مسطحة بتخانة ٢٠ سم بحيث يكون منسوب الإنشاء أعلى من منسوب السطح العلوي للبلاطة السفلية بمقدار ٣ متر. يرغب المقاول في استخدام العدة المتاحة له والمتكونة من أخشاب بالمقاسات التالية 4"x4" ، 2"x6" ، 2"x4" ، 1"x4" ، وتتطلب مواصفات المشروع عدم زيادة الهبوط عن $\frac{\text{البحر}}{٣٦٠}$ أو ٠٫٥ سم أيهما أقل. حدد الأبعاد بين العناصر المختلفة للشدة

## Solution

Sheathing التطبيق

نستخدم ألواح ٢٫٥ × ١٠ سم (١ بوصة × ٤ بوصة) الألواح المتاحة بطول أكبر من ٣ متر وبالتالي يكون عدد بحورها فوق الـ Joists (التطريح) أكبر من ٣ (يراعى أن بحور التطبيق دائما في حدود أقل من متر) وبحساب بحر الألواح

Loads :

Dead load of slab $= 0.2 \times 2.5 = 0.5\ t/m^2$ *

o.w. of shuttering $= 30 - 60\ Kg/m^2$

L.L. $= 200\ Kg/m^2$

* IF pump is used multiply by an impact factor

$I = 1.1 \longrightarrow 1.20$

$w = 0.5 + 0.2 + 0.04 \quad 74\ /m$

### Bending Requirements

$$M_{max} = \frac{w L^2}{10} = \qquad m\,t/m'$$

$$Z = \frac{bt^2}{6} = 1.04 \times 10^{-4} \; m^3$$

($b = 100$ cm & $t = 2.50$ cm)

$$f = \frac{M}{Z} = \frac{0.074\, L^2}{1.04 \times 10^{-4}} = 800 \; t/m^2$$

$$\underline{\underline{L = 1.06 \; m}}$$

## Shear Requirement

$$V \simeq 0.6\, wL = 0.74 \times 0.6 \times L = 0.44\, L \quad t/m$$

$f_{shear} = 7 - 12$ kg/cm$^2$ taken $= 9$ kg/cm$^2$

$$f = \frac{3}{2}\frac{V}{A} \Rightarrow 90 = \frac{3}{2}\,\frac{0.44\, L}{0.025 \times 1}$$

$$\underline{\underline{L = 3.41 \; m}}$$ not governing

## Deflection Requirement

$$\Delta_{max} = \frac{1}{145}\,\frac{wL^4}{EI}$$

$E = 90 \; t/cm^2$ $\qquad I = \frac{bt^3}{12} = 1.3 \times 10^{-6} \, m^4$

$$\Delta_{max} = \frac{1}{145}\,\frac{\times 0.74\, L^4}{90 \times 10^4 \times 1.3 \times 10^{-6}} = \frac{4.36\, L^4}{1000} \; m$$

$$\frac{4.36\, L^4}{1000} = 0.0015 \longrightarrow L = \underline{0.76\, m}$$

$$\frac{4.36\, L^4}{1000} = \frac{L}{360} \longrightarrow L = 0.86\, m$$

(?) الخطوة السابقة حددت أبعد أقصى مسافة بين ألواح التطبيق هي ٧٦سم

فمثلاً لو كان طول ألواح التزانة المتاح = ٤٫٠٠ متر يكون عدد

الباكيات = $\frac{400}{76}$ ويؤخذ = 5.00 وتكون بحور الباكيات الداخلية

70 cm ، والخارجية = 60 cm .

لتحديد بحر ألواح التطبيق (المسافة بين ألواح التعريش)

## Stringer spacing (Joist span):

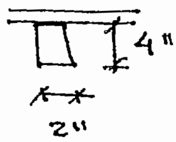
## Load on Joists

$$\omega = 0.74 \times \underset{\text{max length}}{0.76} = 0.56 \ t/m'$$

try stringers $2'' \times 4''$ (5 x 10)

$$\text{Area} = 5 \times 10 = 50 \ cm^2$$

$$I = \frac{5(10)^3}{12} = 416.7 \ cm^4$$



## Flexural (Bending) Requirement

$$M = \frac{\omega L^2}{10} = \frac{0.56}{10} L^2 \quad mt$$

$$f = \frac{M}{I} y \Rightarrow 800 = \frac{0.56 L^2}{10 \times 416.7 \times 10^{-8}} \times 0.05$$

$$L = \underline{\underline{1.09 \ m}}$$

## Shear Requirement

$$V \cong 0.6 \, \omega L = 0.6 \times 0.56 \ L = 0.34 \ L \quad t$$

$\Rightarrow \quad \underline{\underline{L = 0.88 \ m}}$

## Deflection Requirement

$$\Delta_{max} = \frac{1}{145} \frac{wL^4}{EI}$$

$E = 90 \ t/cm^2 \qquad I = 416.7 \times 10^{-8} \ m^4$

$$\Delta_{max} = \frac{1}{145} \frac{0.56 \ L^4}{90 \times 10^4 \times 416.7 \times 10^{-8}} = 1.03 \times 10^{-3} L^4 \ m$$

$$1.03 \times 10^{-3} L^4 = 0.0015 \longrightarrow \underline{\underline{L = 1.09 \ m}}$$

or

$$1.03 \times 10^{-3} L^4 = \frac{L}{360} \longrightarrow \underline{\underline{L = 1.39 \ m}}$$

$\therefore \quad L_{max} = 88 \ cm$

لتحديد المسافه بين القوائم (البحر للألواح التعريض)

## Shore spacing ( Stringer Span):

### Load on stringers

رغم أن أحمال الـ Stringer مركزة إلا انه يمكن اعتبارها أحمال موزعة للتبسيط.

$$w = \frac{0.56 \times 0.88}{0.76} = 0.65 \ t/m'$$

$$\text{or} = \overset{w_s}{0.74} \times \overset{\text{spacing}}{0.88} = 0.65 \ t/m'$$

try Stringer $2'' \times 4''$ $(5 \times 10)$ (9)

$$Area = 5 \times 10 = 50\ cm^2 = 0.005\ m^2$$

$$I = \frac{5(10)^3}{12} = 416.7\ cm^4 = 416.7 \times 10^{-8}\ m^4$$

Flexural (Bending) Requirements

$$M = \frac{\omega L^2}{10} = \frac{0.65}{10} L^2 = 0.065 L^2 \quad mt$$

$$f = \frac{0.065 L^2}{416.7 \times 10^{-8}} \times 0.05 = 800 \quad t/m^2$$

$$\therefore \underline{\underline{L = 1.01 \quad m}}$$

Shear Requirements

$$V \simeq 0.6\ \omega L = 0.6 \times 0.65\ L = 0.39 L \quad t$$

$$f = \frac{3}{2} \frac{V}{A} = \frac{3}{2} \frac{0.39 L}{0.005} = 90 \Longrightarrow \underline{\underline{L = 0.76\ m}}$$

Deflection Requirements

$$\Delta max = \frac{1}{145} \frac{\omega L^4}{EI}$$

$$= \frac{1}{145} \frac{0.65 L^4}{90 \times 10^4 \times 416.7 \times 10^{-8}} = 1.195 \times 10^{-3} L^4\ m$$

$$1.195 \times 10^{-3} L^4 = 0.0015 \Longrightarrow \underline{\underline{L = 1.06\ m}}$$

or

$$1.195 \times 10^{-3} L^4 = \frac{L}{360} \Longrightarrow L = 1.32\ m$$

Shores $4'' \times 4''$

Load on stringer

$$Load = 0.65 \times 0.7 = 0.46\ t$$

$$\text{Allowable stress} = \begin{cases} \dfrac{0.3E}{(L/d)^2} & \text{to avoid buckling} \\ 0.7 & f_{flexure} \end{cases}$$

$$L/d = \frac{3}{0.1} = 30$$

$$f = \begin{cases} \dfrac{0.3 \times 90 \times 10^4}{30 \times 30} = 300\ t/m^2 \\ 0.7 \times 800 = 560\ t/m^2 \end{cases}$$

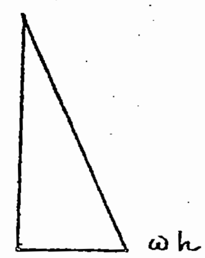
$$f_{actual} = \frac{0.46}{0.1 \times 0.1} = 46\ t/m^2 < 300 \quad ok.$$

## American Concrete Institute

Lateral pressure

$$P = \omega h$$

$$\omega = 2400 \ Kg/m^3$$




For the case of ordinary Portland Cement, no admixtures, slump ≤ 10 cm, Normal internal vibration, the following formulas may be used

**walls**

placement rate < 2m/hr

$$p_{max} = 5.03 \left(150 + 9000 \frac{3.3R}{32+1.8T}\right) \ Kg/m$$

R = rate of placement  T = temp.

placement rate > 2m/hr & < 3m/hr

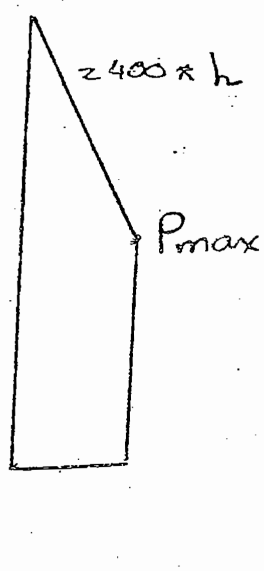
$$P_{max} = 5.03 \left(150 + \frac{43400}{32+1.8T} + \cdot 2800 \frac{3.3R}{32+1.8T}\right) Kg$$

1 **Columns**

$$p = 5.03 \left(150 + 9000 \frac{3.3R}{32+1.8T}\right) \ Kg/m^2$$

tes

) $P = 2400 \ h \leq P_{max}$




$400 < P_{max} < 10000 \ Kg/m^2$

Example ②

مطلوب تصميم شدة لحائط ارتفاعه ٣,٦٠ متر والامكانيات المتاحة هي

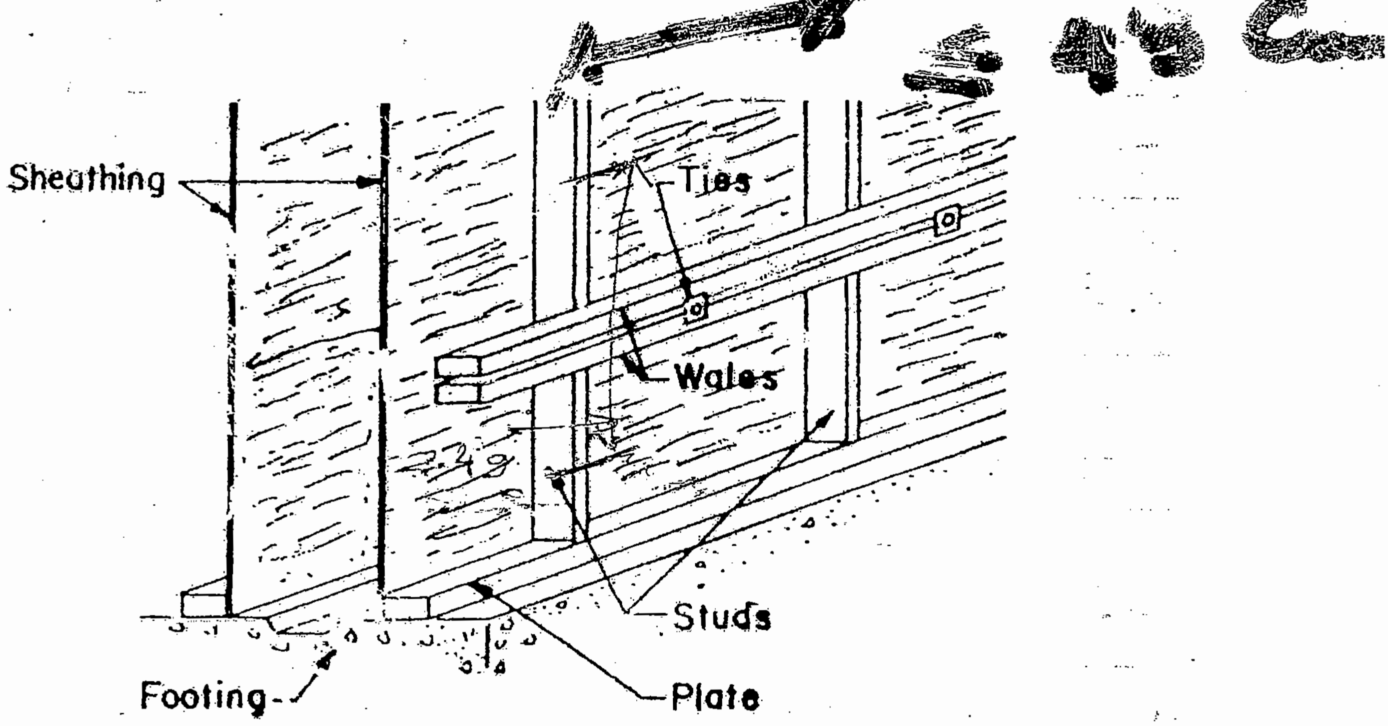
① ألواح تزايله مقاس ٢,٠٠ × ١,٠٠ م × ٣ سم

② ألواح موسكى مقاس ٥,٠٠ × ١,٠٠ سم × ٢ سم ٥ (For Studs )

③ عروف مقاس ١٠,٠٠ × ١٠,٠٠ سم × ٢ سم (For wales)

مواصفات المشروع تتطلب أن يكون أقصى هبوط هو L/240

يتم استخدام أسمنت بورتلاندي عادي بهبوط في حدود ٨ سم ومعدل الصب في حدود امتار/ساعة في درجة حرارة 30°C ولا تستخدم اضافات




$$P_{max} = 5.03\left(150 + 9000 * \frac{3.3R}{32+1.8T}\right)$$

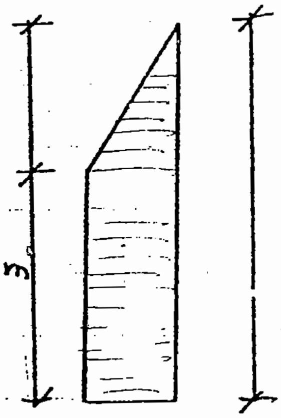
$$= 5.03\left(150 + 9000 * \frac{3.3 \times 1}{32+1.8 \times 30}\right) = 2491\ Kg/m^2$$

$> 2400$ ok.

Concrete lateral pressure

$1.04\,m = \frac{2491}{2400}$

$3.60 - 1.04\,m$



3.60m

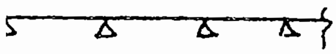
**Allowable stresses**

| | |
|---|---|
| Bending | $70\ kg/cm^2$ |
| shear | $9\ kg/cm^2$ |

**Allowable deflection**

$$\Delta_{all} = L/240 \quad , E = 90\ t/cm^2$$

**Bending, shear, and deflection formulas**



$$M_{max} = \frac{\omega L^2}{10}$$

$$V_{max} = 0.6\ \omega L_{net}$$

$$\Delta_{max} = \frac{1}{145}\ \frac{\omega L^4}{EI}$$

1) **Sheathing design**

Load $/m^2$ = Concrete pressure

$= 2.491\ t/m^2$

Consider a strip of 1m width

$\Rightarrow$ Load $= 2.491\ t/m'$

Section Properties

$A = 0.02 \times 1.00 = 0.02\ m^2/m'$

$I = (0.02)^3 \times 1.0/12 = 6.67 \times 10^{-7}\ m^4/m'$

ding: $\dfrac{2.491\,L^2}{10} = f\,\dfrac{I}{y}$

$= 700 \times \dfrac{6.67\times10^{-7}}{0.01} \Rightarrow \underline{L = 0.43\,m}$

ar: $V = 0.6\,\omega L_{net} = \frac{2}{3}\,q \times A$

$0.6 \times 2.491 \times L_{net} = \frac{2}{3} \times 90 \times 0.02 \rightarrow L_{net} = 0.8\ m$

→ width of stud

$\therefore\ L = 0.8 +$ support width

$= 0.8 + 0.05 = \underline{0.85\,m}$

ection:

$\dfrac{L}{240} = \dfrac{1}{145}\,\dfrac{\omega L^4}{EI}$

$L = \sqrt[3]{\dfrac{145\,EI}{240\,\omega}}$

$= \sqrt[3]{\dfrac{145 \times 90 \times 10^4 \times 6.67\times10^{-7}}{240 \times 2.491}}$

$= \underline{0.52\ m}$

$\therefore\ L_{max} = 0.43\,m$ taken $= 0.40\,m$

$\therefore$ spacing between studs $= 40$ cm

<u>Stud design</u>

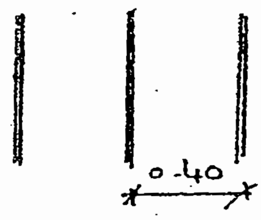
$\omega =$ Load $/m^2 \times$ spacing between studs

$= 2.491 \times 0.4 = 0.996\ t/m'$

Section used $5 \times 10$ cm × cm

Section Properties

$I = 0.05\,(0.1)^3/12 = 4.17\times10^{-6}\,m^4$



$$Area = 0.1 \times 0.05 = 0.005\ m^2$$

Bending:

$$\frac{0.996\ L^2}{10} = 700 \times \frac{4.17 \times 10^{-6}}{0.05} \qquad \underline{L = 0.76\ m}$$

shear :

$$0.6 \times 0.996 \times L_{net} = \frac{2}{3} \times 0.005 \times 90 \qquad L_{net} = 0.5\ m$$

→ width of wale

$$L = L_{net} + \text{width of support}$$
$$= 0.5 + 0.1 \qquad \underline{= 0.60\ m}$$

Deflection :

$$L = \sqrt[3]{\frac{145\ E I'}{240\ \omega}}$$

$$= \sqrt[3]{\frac{145 \times 90 \times 10^4 \times 4.17 \times 10^{-6}}{240 \times 0.996}}$$

$$= \underline{1.31\ m}$$

$$\therefore \quad L_{max} = 0.60\ m$$

∴ spacing between wales = 60 cm

## ) Wale Design

wale loads are concentrated ; however, they may be considered as uniformly distributed.

$$\omega = Load/m^2 \times \text{wale spacing}$$
$$= 2.491 \times 0.6 = 1.50\ t/m'$$

Section Properties 10 x 10

$$I = 0.1\ (0.1)^3/12 = 8.33 \times 10^{-6}\ m^4$$
$$A = 0.01\ m^2$$

ending: $\frac{1.5\ L^2}{10} = 700 \times \frac{8.33\times10^{-6}}{0.05}$ $\underline{L = 0.88\,m}$

hear: $0.6\times1.5\times L_{net} = \frac{2}{3}\times 0.01\times 90$ $L_{net} = 0.66\,m$

$L = L_{net} +$ support width $\rightarrow$ washer of tie

$= 0.66 + 0.05 = \underline{0.71\,m}$

flection: $L = \sqrt[3]{\frac{145\,EI}{240\,\omega}}$

$= \sqrt[3]{\frac{145\times90\times10^{4}\times8.33\times10^{-6}}{240\ \times1.5}}$

$\underline{L = 1.45\,m}$

$\therefore$ $L = 0.70\,m$ (spacing between ties)

## <u>Tie Design</u>

Tension = $\omega\times$ wale span $\times$ stud span

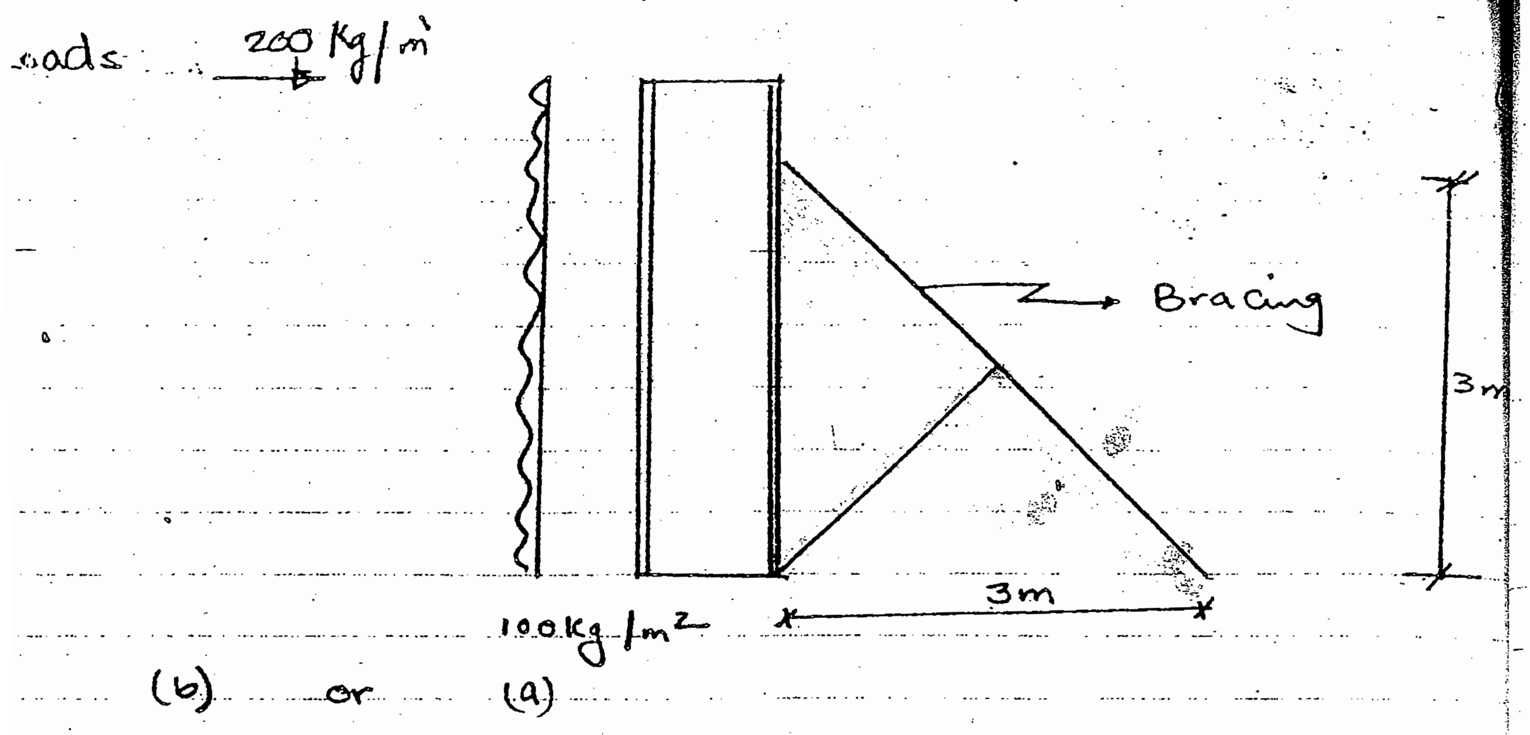
$= 2.491\times0.7\times0.6 = 1.05$ t

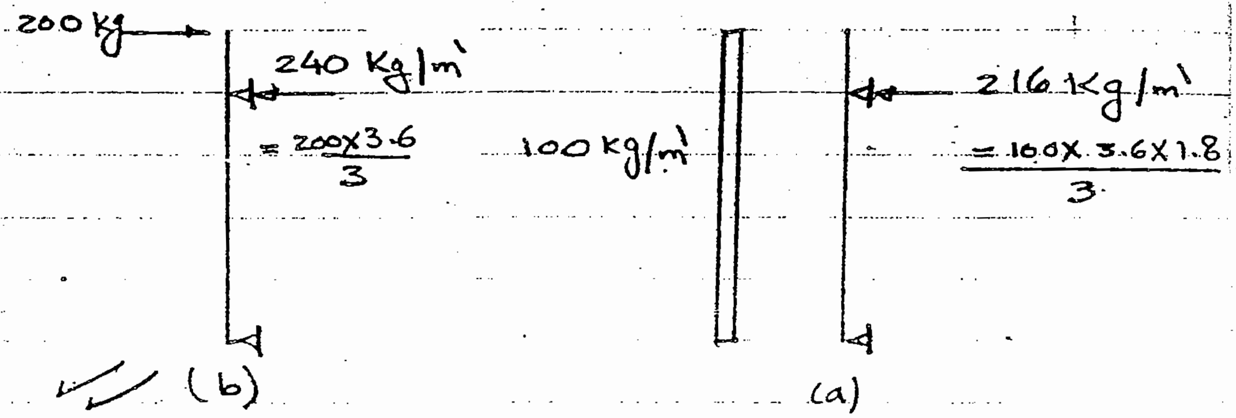
$\therefore$ Select a tie with a capacity of at least = 1.10 ton

## <u>Bracing Design</u>

Bracing shall be designed to withstand the following forces as minimum

* wind load = $100\ kg/m^2$
* Top horizontal load = $200\ kg/m'$




strip 1m

Case (b) produced greater effect

Choose braces of 10 X 5 Cm (10 Cm inside page)

buckling in plan $L_{buckling} = 3\sqrt{2}/2 = 2.12\ m$

outside plan $L_{buckling} = 3\sqrt{2} = 4.24\ m$

$\left(\frac{L}{d}\right)_{\text{in plan}} = \frac{2.12}{0.05} = 42.4$

$\left(\frac{L}{d}\right)_{\text{out-side plan}} = \frac{4.24}{0.1} = 42.4$

determine maximum spacing between braces

$$f = \frac{0.3E}{(l/d)^2} \leq 400\ t/m^2$$

$$= \frac{0.3 \times 90 \times 10^4}{(42.4)^2} = 150\ t/m^2$$

Force in the diagonal $= 240\sqrt{2}$ kg/m'

$\therefore$ Force in bracing $= 339$ kg/m' $*$ Spacing (m)

$= 0.34$ t/m' $*$ spacing

$$f = \frac{\text{Force}}{\text{Area}} = \frac{0.34 * \text{spacing}}{0.1 \times 0.05}$$

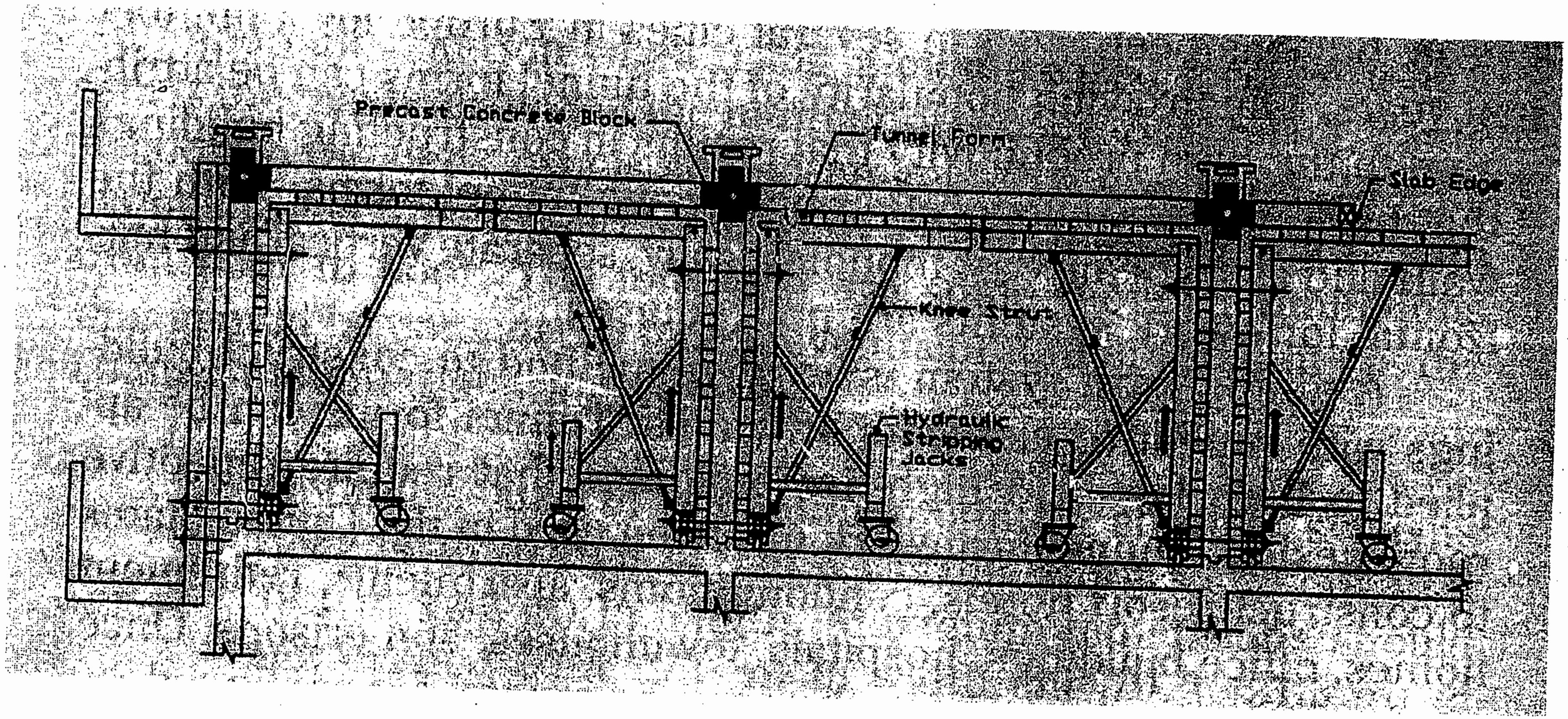
$$\therefore \text{max spacing} = \frac{150 \times 0.1 \times 0.05}{0.34}$$

$$= 2.20\ m$$

Choose spacing $< 2.20$ m

Say spacing $= 1.50$ m

# TUNNEL FORM


Precast Concrete Block
Tunnel Form
Slab Edge
Knee Strut
Hydraulic Stripping Jacks

### 4.3.1 System Description

Tunnel forms come basically in two different shapes: full and half. Full-tunnel systems are all-steel formwork used for rooms that are relatively square in shape. Half tunnel is an L-shaped all-steel formwork system that is set by crane, then another half-tunnel form set separately adjacent to the previous half (Figure 4.9). The two halves are then connected together to form an inverted U-shaped tunnel form. The half-tunnel system allows for greater flexibility in room sizes by simple addition or replacement of center fill panels. Half tunnels are simpler, lighter and faster in use than full tunnels.

The tunnel formwork system consists of:

1. *Deck panel.* The thick steel skin used to form the ceiling and floor of each module
2. *Wall panel.* Also made of a thick steel skin, used to form the walls between two adjacent modules
3. *Waler and waler splices.* Stiffer deck and wall panels to minimize deflection due to concrete lateral pressure
4. *Diagonal strut assembly.* Used to provide additional support for the floor slab and keep walls and floors perpendicular

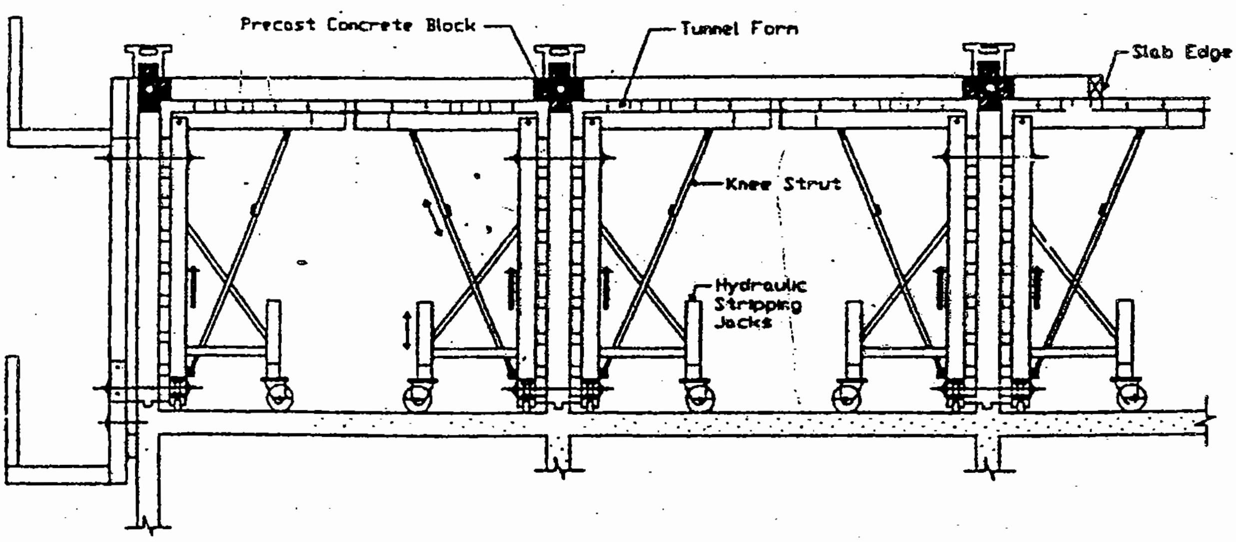



**Figure 4.9** Tunnel formwork system. (Courtesy of Symons Corp.)

# 15: SPECIAL TECHNIQUES IN CONCRETE CONSTRUCTION

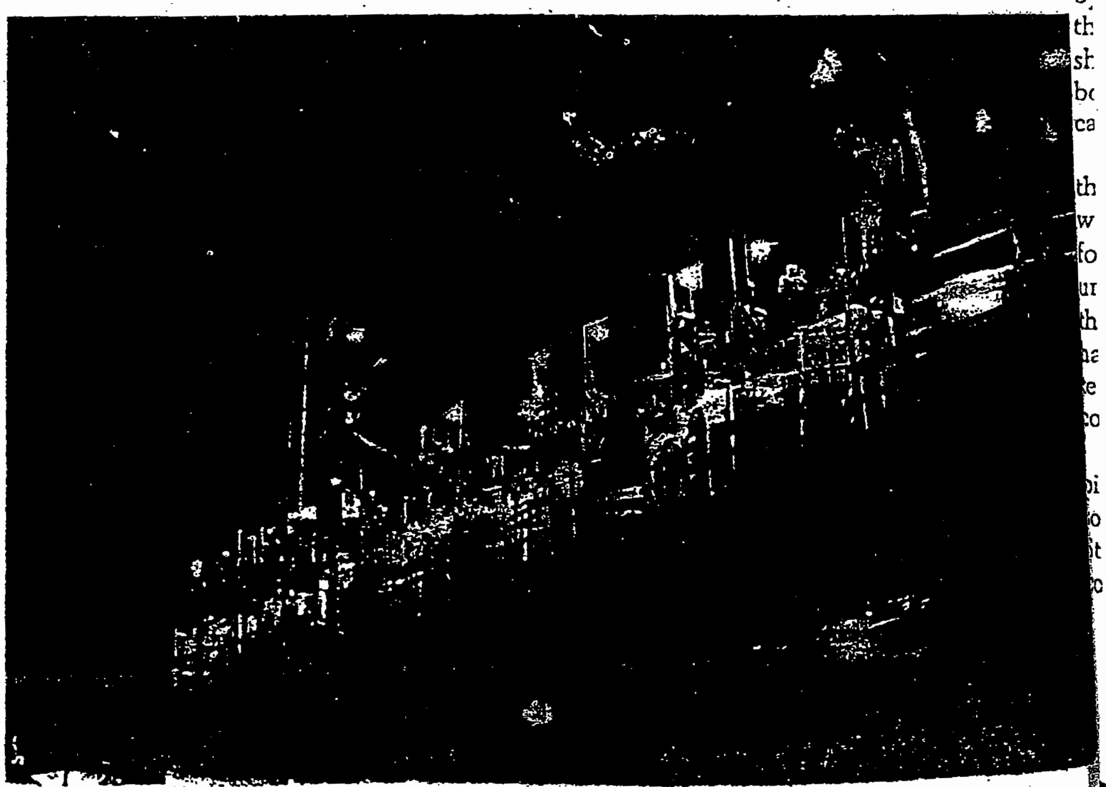
UNUSUAL CONCRETING PRACTICES fre-
ently impose special form requirements; an un-
ual type of form like the slip form may itself make
partures from conventional concreting methods
ical as well as advantageous. For the most part,
ese unusual techniques are handled by specialists.
e discussion of this chapter focuses only on the spe-
l aspects of each type of construction which influ-
ce the formwork needs. No attempt is made to
lly describe the construction methods.* In some of
ese techniques, such as tilt-up work, the forms are
tually eliminated, while in others the form is ex-
mely important. Thus, some of the following sec-
ns are extensive in detail, while others are quite
ef.

*ny excellent books and articles are available to those interested in reading ull construction story. A few of these are listed at the end of the chapter.

## Slip Forms

Slip form construction, also frequently referred to as sliding form construction, is similar to an extrusion process. Plastic concrete is placed or pumped into the forms, and the forms act as continuously moving dies to shape the concrete. The rate of movement of the forms is regulated so that the forms leave the concrete after it is strong enough to retain its shape while supporting its own weight. Although uninterrupted slides are desirable, particularly in vertical work, it is possible to stop and later resume the sliding operation with resulting joints no different from those between lifts of fixed-form construction.

Slip form construction is normally used for vertical structures such as silos, storage bins, bridge piers,



Around-the-clock operation
cl in slip form work requires
uate lighting for night work.
chute from hopper on hoist
r for depositing concrete to be
d in the moving forms.

# Form Stripping

When the forms have reached the top of the slide and jacking is finished, the weight of the forms is generally transferred from the jack rods to the finished wall. This is usually done by bolts or bearers inserted through holes left in the walls below the wales. The location of these holes must be carefully planned for the particular method of supporting the forms. When the weight of the forms has thus been taken off the jacks, the yokes, jacks, and jack rods may be removed if they are needed elsewhere on the job, before the roof slab is concreted.

The working deck frequently serves as the form for casting the roof slab. If the yokes have been left in position, small boxes are set around the vertical ...nbers of the yokes so they will not be keyed into the concrete of the roof slab. After the yokes have been removed, the boxes are stripped and the holes illed with concrete.

Unless stripping is properly organized it may prove o l very expensive. The removal of the outside orms presents no great difficulties or special features, ut it is usual to leave holes in certain planned posiions in the roof slab in order to facilitate the suspenion of a stripping scaffold inside the structure. The ost of labor in stripping and the value of the used aterial should be carefully investigated before it is ecided to drop and waste any sections.

# Vinter Concreting

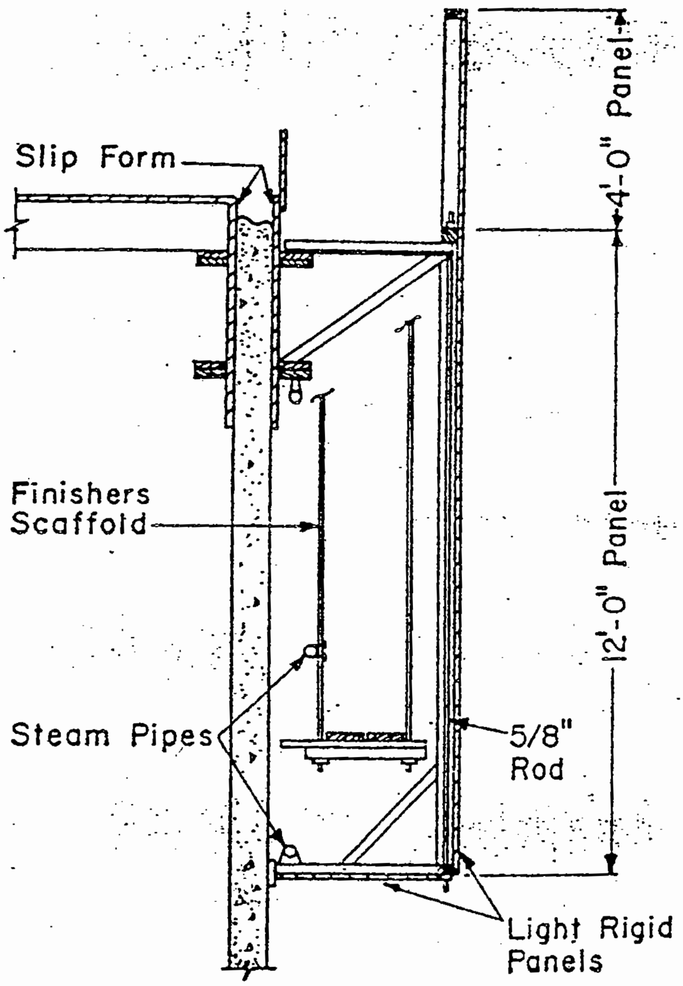
The rate of slide is an important factor in winter ncreting. Since the setting time of the cement is ...eased at low temperatures, the concrete must ... in the forms longer. This can be accomplished reducing the rate of slide or increasing the depth of e forms. To protect the concrete from the cold, a ield of lightweight rigid panels (plywood, hardard insulating board, etc.) attached to the forms a i constructed (Figure 15-15).

In addition to providing protection for the concrete, shield also gives the finishers shelter from winter nds. The shield should be attached directly to the ms rather than to the finishers' scaffold to prevent necessary vibration of the scaffold which may make finishers' work hazardous. Tarpaulin enclosures e been used satisfactorily on many jobs, but they d to flap in the wind and mar the finish of the crete.

Ieat may be applied to the fresh concrete by steam es attached to the finishers' scaffold using a steam rce at the base of the slide within the structure. m is recommended because it will not dry the crete. The warm, moist air inside the structure provides excellent curing conditions. Every effort should be made to equalize the temperatures on the inside and outside faces of green walls to prevent temperature cracks.

# Horizontal Slip Forms

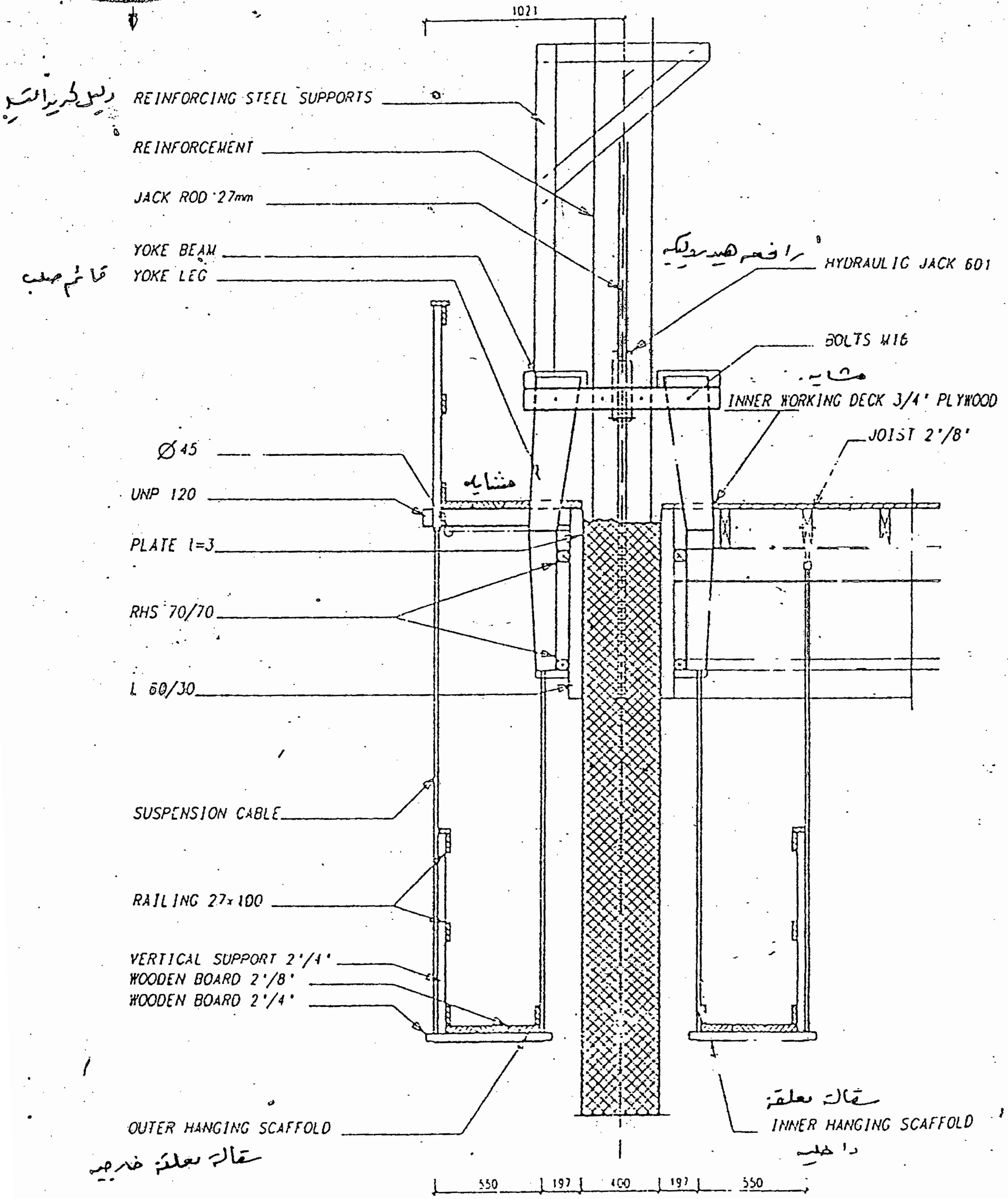
Since most horizontal slip forming is against a fixed form support such as rock or earth, the operation is essentially a consolidating-screeding-finishing operation. The slip form machine usually moves on rails or a shaped berm. The intake of the machine is a trough designed to distribute concrete uniformly to all parts of the form. The concrete is consolidated by a vibrating tube parallel to and a few inches ahead of the leading edge of the form. The fresh concrete can also be consolidated by hand vibrators. Monolithic cast-in-place pipe is also produced by horizontal slip form methods.




**15-15** Simplified drawing of rigid enclosure with steam pipes for winter slip form work. Finishers' scaffold within the enclosure may be supported either from yokes (not shown) or wales.

4

BYGGING INTERCONTINENTAL




SLIPFORM SECTION

شكل (١)

# 2. Design Concept for Construction

## 2.1 General

To construct a bridge, the following aspects should be considered,

**Technically,** the construction should be completed safely without any over-stressing and/or without any additional high residual stresses of the bridge elements, which could affect the design of the end bridge negatively., i.e. the construction should not govern the design of the bridge different structural elements. Moreover the temporary structural elements, used in the construction should be fulfil the requirement of safety and stability during the construction and meanwhile the shuttering should be also dis-erected and transported from the site safely.

**Economically,** the bridge should be constructed and/or erected with the most reasonable method to minimise the direct an the indirect cost of the construction within the required period of construction. The duration of the construction is as an important factor, which should be also optimised.

**Environmentally,** the bridge construction should not have a negative influence on the surrounding environment of the site during the construction, e.g. on the surrounding place, socially, etc.

**Aesthetically,** For long period construction, the influence bridge construction on the overall view in the surrounding region should be considered.

### 2.2 Task of the designer

Considering the mentioned aspects, the task of the bridge designer for construction can be summarised in the following items:

1. Introduce the most reasonable construction method for the bridge taking into consideration the mentioned aspects after studying the boundary conditions of the bridge, e.g. the design conditions, the site and the surrounding area, the traffic conditions and from the bridge site, the climatic conditions during the constructions and others.

2. Make a full design for the different construction stages, i.e. estimation of the internal forces within the bridge elements during the different stages of the construction, to be sure that the construction does not govern the bridge design. In cases if the internal forces in the brige elements are higher than those of the design, some temporary, or aids elements should be adopted to reduce them to be lower than the design values.

3. Design of the temporary elements should be carried out.

4. Introduction of the required equipments and devices for the construction and their technical characteristics, e.g. the capacity for the lifting cranes, capacity and the properties of the transportation equipments.

5. The designer should also follow the progress of the construction to deliver the required recommendations on sites in time due to any changes in the construction planes or the arising unexpected factors, which influence the bridge construction.

Therefore, it is reasonable to tender the bridge project as a design and build tender. However the coupling between the designer and the construction firm, is best way to arrive at the most suitable construction technique for a proper project.

### 2.3 Technical design

Having a decision for a bridge construction method and procedure, the designer should carry a static analysis for each important stage, by which there is a major change in structural system. The designer should be aware with the following main items,

- Loads
- Supporting systems, statical systems and load distribution
- Stiffening methods and temporary structures
- Considerations for the design

These items will be handled in the next taking into consideration the different method of construction.

### 2.3.1 Loads

The following loads are major loads during the bridge construction:

1) Dead Loads: D. L. of Shuttering + D. L. of Bridge + Additional Ballast loads
2) Live Loads: Movable Loads during construction: $P=100\ kg/m^2$
3) Wind Loads: Wind load in transverse and longitudinal directions

    Wind load = wind load on shuttering + wind load on bridge
    $W = C.\ q.\ A_{shut} + C.\ q\ .\ A_{bridge}$
    C: Drag factor (depending on the form of the section)
    q: wind intensity = v/1600 ($kN/m^2$)
    v = design wind speed in m/sec (v= 20-35 m/s)
    $A_{shut}$ = Area of shuttering = 30 - 50 % of the area of shuttering
    $A_{bridge}$ = Area of bridge deck = L . t (t = tot. thickness of deck)

    The designer should consider the wind loads in both transverse and longitudinal direction, therefore bracing elements should be arranged to carry these loads in both directions.

4) Differential Settlement of the soil:
    The settlement of the shuttering can be assumed to equal $\delta = 0.5$- 1.0 cm.
5) Thermal effects:
    Uniform temperature $\Delta t$ = +/- 20 K.
6) Special loads
    Special loads e.g. earthquake loads, snow should be considered, in areas where such natural loads extremely take place.

However, during the construction, the natural loads, e.g. snow, wind and seismic loads could be drastic reduced due to the fact, that the supporting shuttering is a temporary structure. This reduction factors, depend on the period of the bridge construction. For very short construction periods, such loads could be ignored.

### 2.3.2 Load distribution:

**- Vertical loads**
Vertical loads, due to D.L., L.L, etc. will be carried by the verticals, which transfer the load into the ground through the p.c. foundation

**- Horizontal loads, e.g. wind loads**
Horizontal loads, due to wind mainly, are to carried by the diagonal members, which transfer their coupling forces into the verticals and then into the ground. In the following some different systems of wind bracing are illustrated.

### 2.3.3 Design of the structural elements of shuttering

The design of the structural elements of the shuttering, for both wooden and metalic shuttering follow the following procedures:

1) Check of stresses for design loads according to design code. (Buckling of the elements is to be taken into consideration)

2) Design of the joints of the shuttering taking into consideration the max. internal forces at these joints, to guarantee the load distribution between the different elements.

3) Check of the deflection of the shuttering under design loads to guarant the arrival at the required geometry of the bridge deck, piers, etc.

In addition to the design of the shuttering, a check for the different structural elements of the bridge, e.g. deck, piers, etc.., should be carried out, to ensure that the internal forces in these structural elements during the construction are smaller than those for the bridge under service state (end design).

# 3. Construction of Concrete Bridges using Cast in-Situ Technique

## 3.1. General

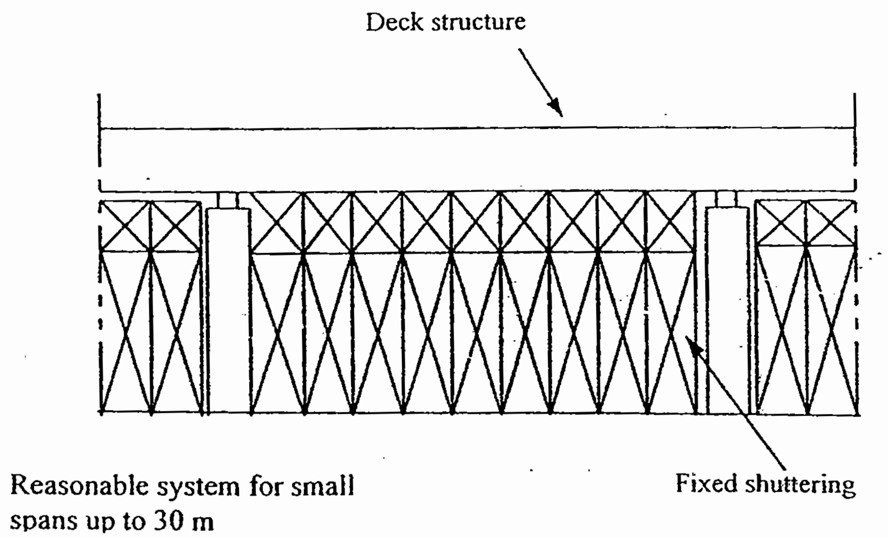
The history of the construction of concrete bridges shows that the most used techniques in the frist half of the last century was the traditional application of the fixed wooden shuttering formworks over the whole bridge length.With the increase of the span and/or due to the fact the area under the bridge is not accessible, e.g traffic flow, water channels, deep vally, the application of a temporary steel girders, which are supported on piers and/or temporary supported were developed. The movable shuttering of the last kind, is the advanced application in order to reduce the construction and the erection duration.

## 3.2. Types and Methodology

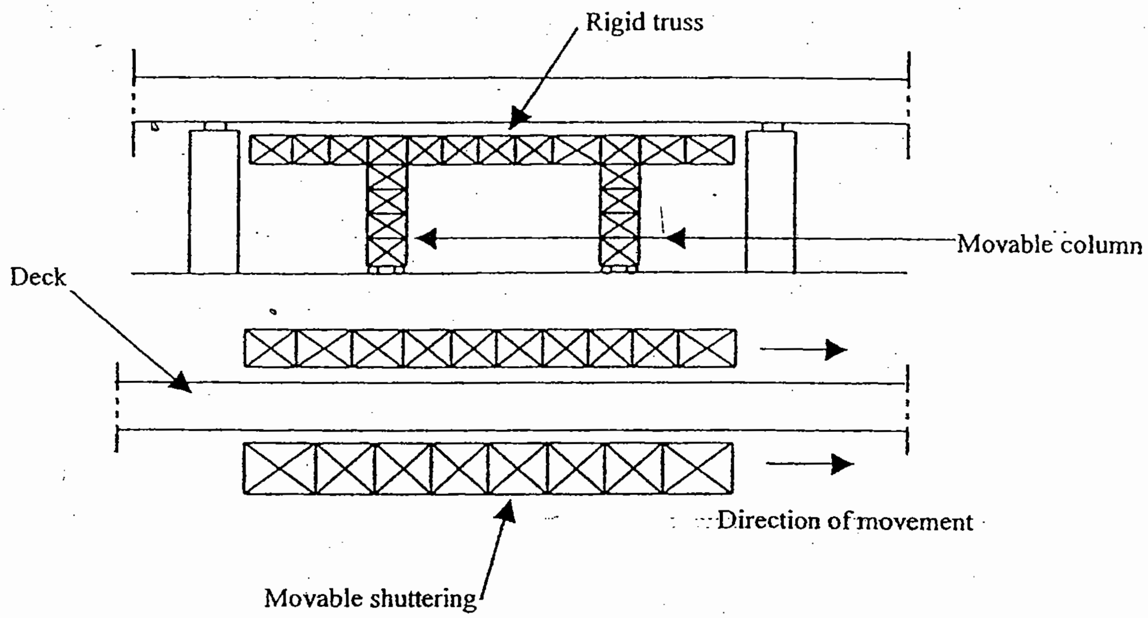
The applcation of the cast-in-situe concrete has used the following construction techniques :

1) Fixed shuttering over the whole length
2) Fixed shuttering supported on temporary columns
3) Movable shuttering (on movable. columns)

**Fixed shuttering over the whole length**



## Shuttering supported on girders (fixed or movable shuttering)




- For bigger spans than 30 m is much more economical
- Short time construction (high construction rate)

## 3.3. Fixed shuttering over the whole length

### 3.3.1. Methodology and Recommendations

Load distribution and method of the analysis:

**Vertical loads**

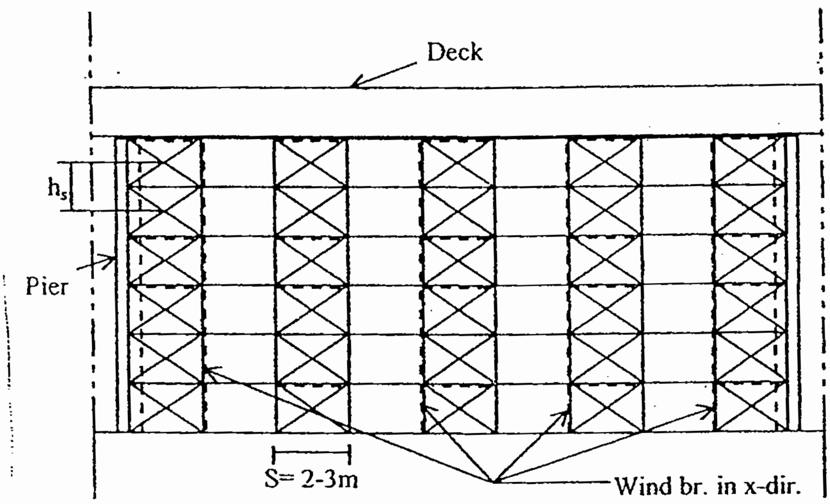
- Vertical loads, due to D.L., L.L, etc. will be carried by the verticals, which transfer the load into the ground through the p.c. foundation.

**Horizontal loads**

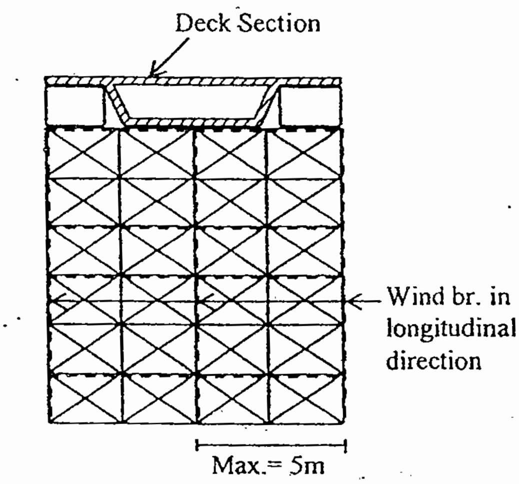
- Horizontal loads, due to wind mainly, are to be carried by the diagonal members, which transfer their coupling forces into the verticals and then into the ground. In the following some different systems of wind bracing are illustrated.

Calculation of the internal forces in the different elements can be carried out using the exact solution for the used space truss (e.g. using a computer model) or using the simplified method.

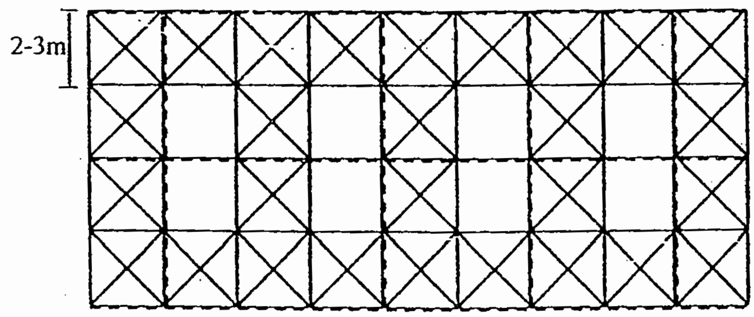
**Alternative 1: (Wooden Shuttering)**




Elevation




Transverse direction




Plan

**Alternative 2:** See design of metal shuttering,(coming further in this section)

### 3.3.2. Load distribution using the simplified method.

**1) Verticals**

Design force $P_{t l V}$

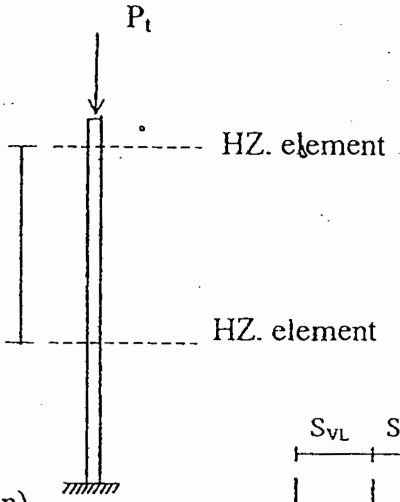
$$P_t = P_{D.L} + P_{L.L} + P_{wind}$$

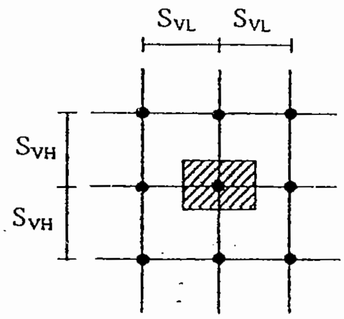
$$P_{D.L} + P_{L.L} = A_V \times w$$

$$A_V = S_{VL} \times S_{VH}$$

$$W = g + p$$

$g$ = Own weight of bridge deck /m$^2$
$p$ = Live load /m$^2$ (during construction)



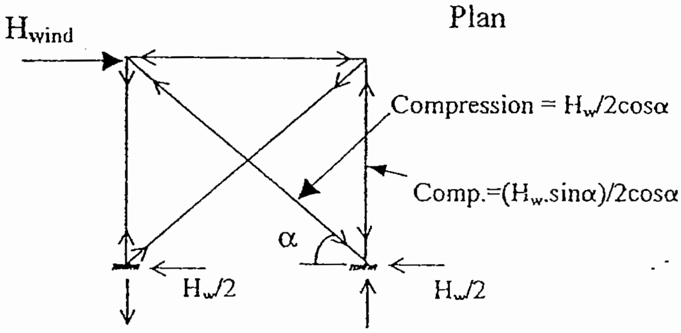



Plan

For a vertical member connected to a diagonal member additional component of the normal force in the diagonal due to wind load should be added.

$$P_{wind} = H_w/(2 \times \tan\alpha)$$

Forces in the verticals
$P_{tlv} = w \times A_V + P_{wind}$
(Compression member)



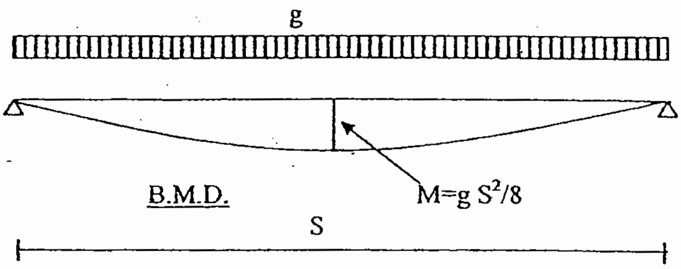

Design of section

$$A_{req} = P_{tlv}/f_{all}$$

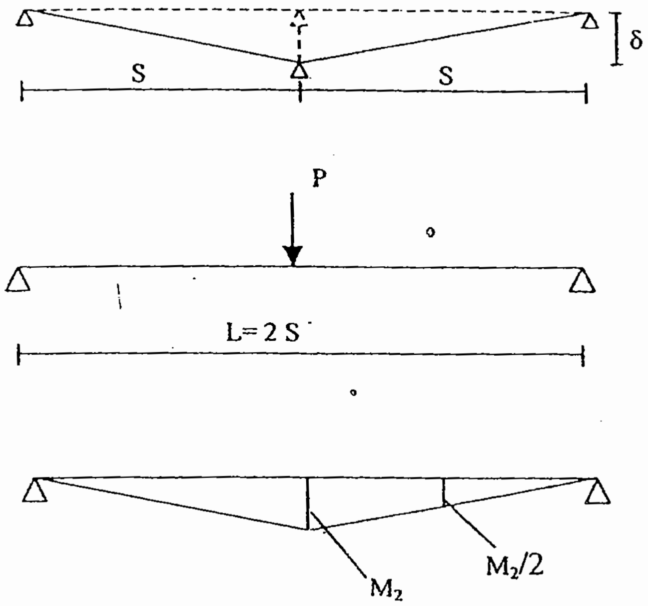
**2) Horizontal members**

Horizontal members are to be designed for the following load cases:

1) D.L of member $M_1$



2) Settlement of the verticals




$\delta = 5$ mm

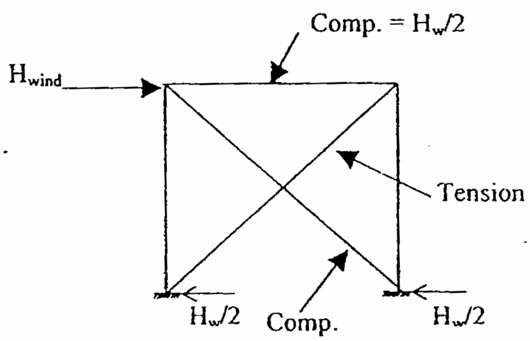
$\delta = PL^3/(48EI)$

$P_{eq} = 48\ \delta\ EI/(8S^3) = 6\ \delta\ E\ I/S^3$

$M_2 = P_{eq} \times (2S)/4$ & $Q = P_{eq}/2$

3) Thermal effect (could be neglected)

4) Horizontal component of wind load




Summary

- B.M.: $M = \text{max. of} \left.\begin{matrix} (M_1+M_2/2) \\ M_1 \\ M_2 \end{matrix}\right]$ choose the bigger

- N.F.: $N = H_w/2$

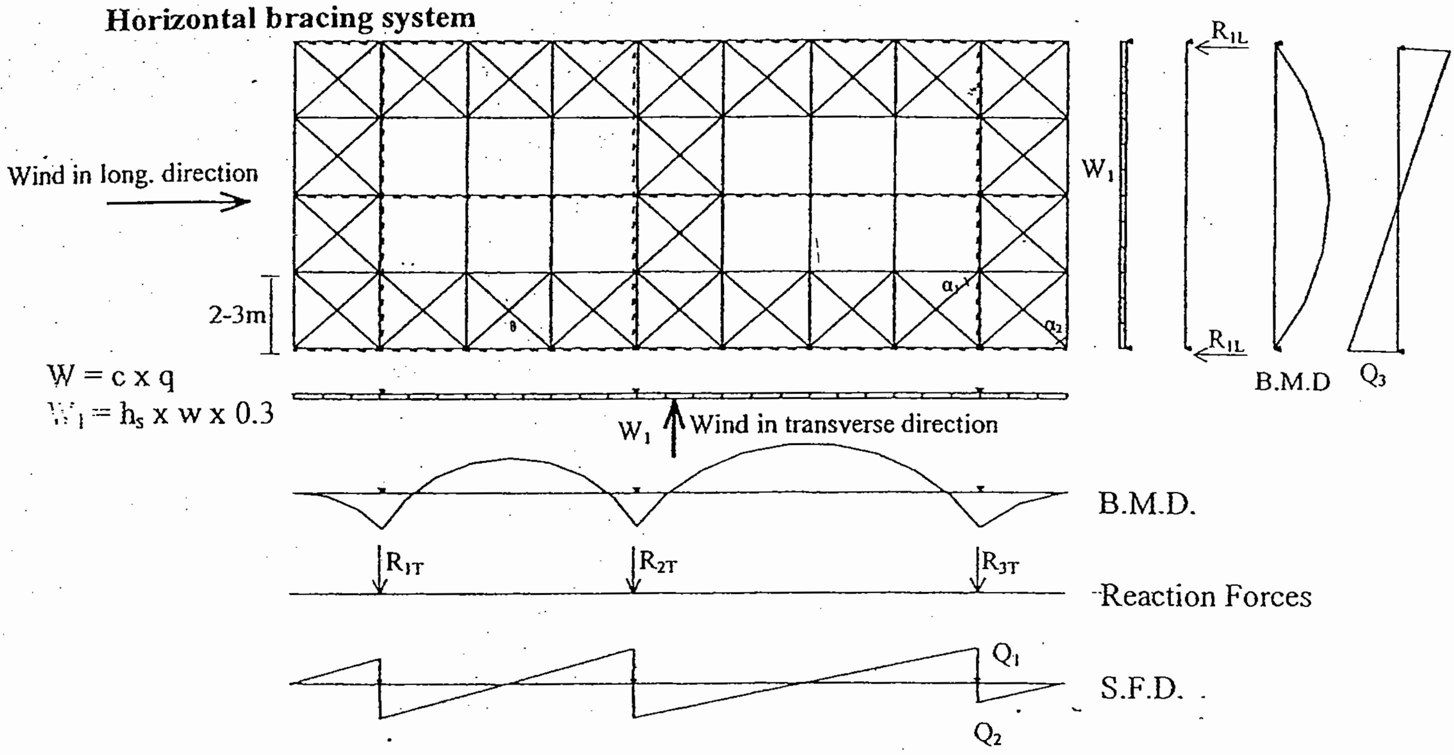
- S.F.: $Q = P_{eq}/2 + gs/2$

Design procedure:

- Assume section
- Check of normal stresses
- Check of shear stresses

### 3) Design of wind bracing

**Horizontal bracing system**

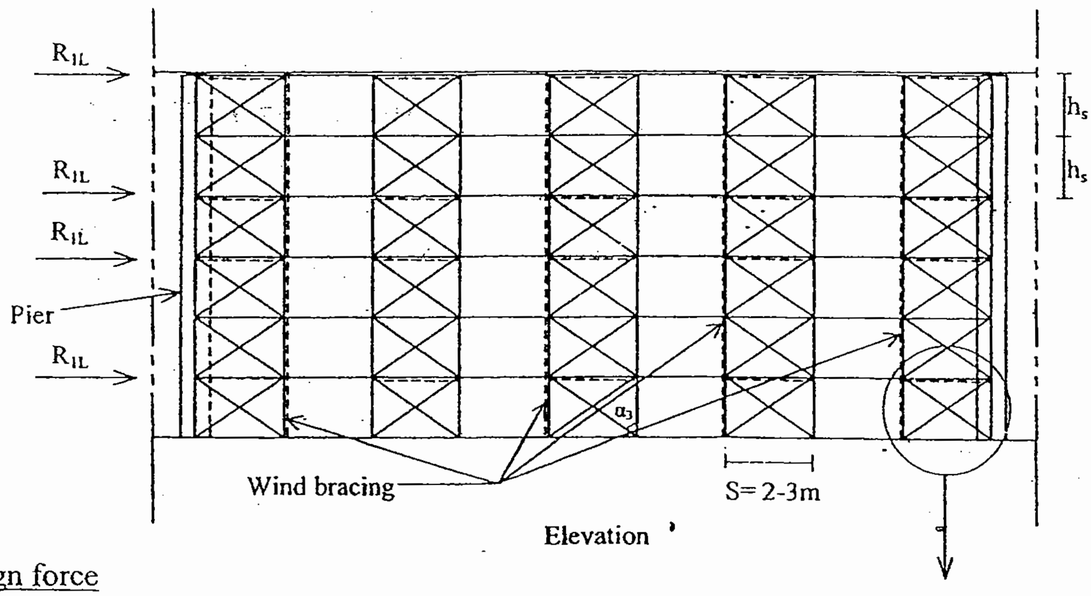



$W = c \times q$
$W_1 = h_s \times w \times 0.3$

Wind in transverse direction

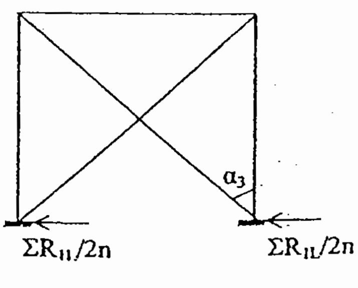
Max. force in the diagonal $F_{Dmax} = Q_1/(2 \times \sin\alpha_2)$
or
$F_{Dmax} = Q_2/(2 \times \sin\alpha_2)$

- Vertical bracing system in longitudinal direction



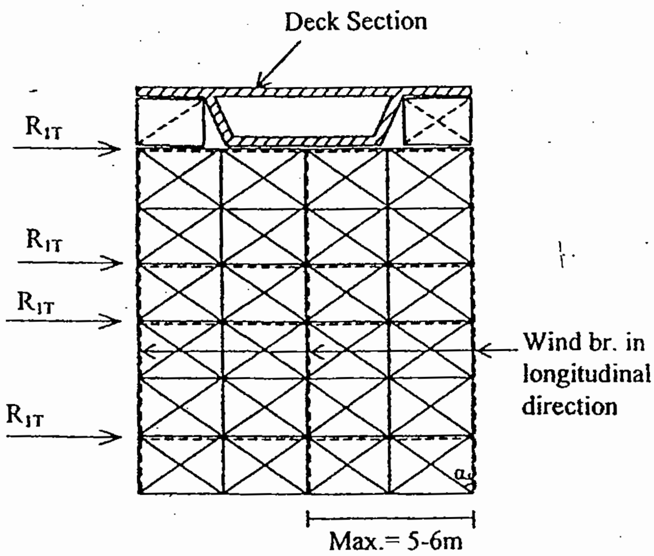

Design force

$F_{diagonal\,2} = + \text{ or } - \Sigma R_{1L}/(2n \sin\alpha_3)$
Where n = no. of braced panels

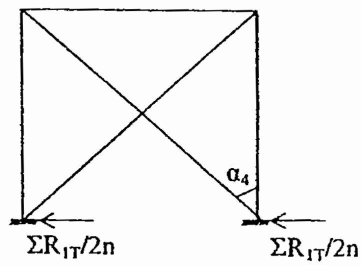



Design
Check of stresses as compression and tension members

- Vertical bracing of the shuttering in transverse direction




Transverse direction




Design force

$F_{diagonal\,3} = \Sigma R_{1T} / (2n \sin\alpha 4)$
n= no. of braced panels

Design
Check of stresses as tension and compression members

### 3.3.3 Design of wooden shuttering

The following recommendations are to be considered:

- The form-work is to be supported on three dimensional space truss, in which the spacing of the vertical ranges between 2-3 m.
- The horizontal members are to be arranged with a spacing of max. 2m to prevent the buckling of the verticals and to carry the horizontal loads due to wind .
- The diagonal wind bracing members are to be arranged with max.spacing between the braced panel of max. 5m in all three directions of the space truss.
- The dimensioning of the wooden shuttering will be designed using the check of stress according to the elastic theory.

**Check of the stresses in the different elements :**

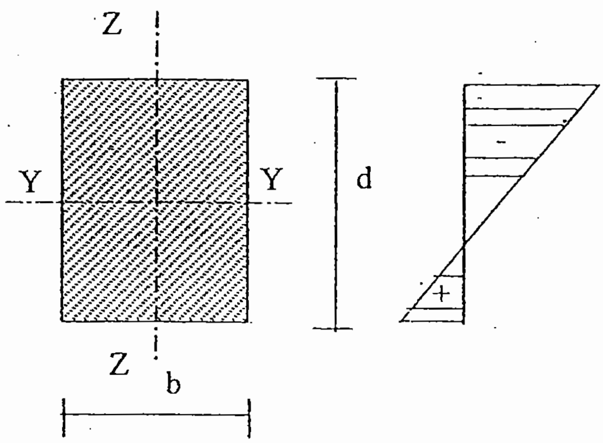
**Check of normal stress:**

The normal stresses at the critical section of the different elements are to be calculated using the Hook's law as follows:

$$\sigma = N/A + My.z/Iy + Mz.y/Iz < \sigma_{all}$$

where,

N, My, Mz: Internal forces
A, Iy, Iz: net sectional properties
$\sigma_{all}$: allowable normal stress
(See the next table)

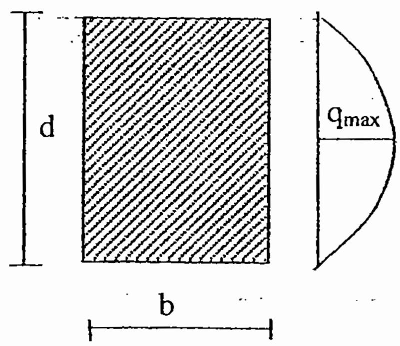



**Check of shear stress:**

The shear stresses at the critical section of he different elements are to be calculated according to the following equation:

$$q = (5/6) * Q/bd < q_{all}$$

Q : max. shear force
d, b : dimension of the section
$q_{all}$ : allowable shear stress
(See the next table)



## Design data for wooden sections:

Wood belongs to light weight material, the designer can consider the following specific weight of wood $\gamma = 350\text{-}500\ Kg/m^3$

The wood is a hetrogeneous ortho-tropic material, by which its characteristics depends on the direction of fibers.The following table summerises the mechanical properties for different classes of wood (in $Kg/cm^2$)

| Property | Parallel to fiber | | | | | Perpendicular to fiber | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 5 |
| **Bending strength $f_{bin,k}$** | 400 | 450 | 510 | 580 | 660 | 380 | 330 | 270 | 180 | 110 |
| **Tensile strength $f_{t,k}$** | 290 | 360 | 360 | 430 | 360 | 310 | 290 | 240 | 200 | 240 |
| **Compression strength $f_{c,k}$** | 210 | 260 | 260 | 310 | 260 | 220 | 210 | 170 | 140 | 170 |
| **Shear strength $f_{s,k}$** | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 |
| **Modulas of elasticity E(x100)** | 440 | 550 | 550 | 660 | 550 | 470 | 440 | 365 | 300 | 370 |
| **Shear mod. of rigidity G (x100)** | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 | 70 |

Material factor of safety of wood for the design in SLS $= \gamma_m$

$\gamma_m = 2.5$
$f_{all} = f_k / \gamma_m$

$f_k$ : Characteristic strength of the material according to the previous table
$\gamma_m$: Factor of safety of material

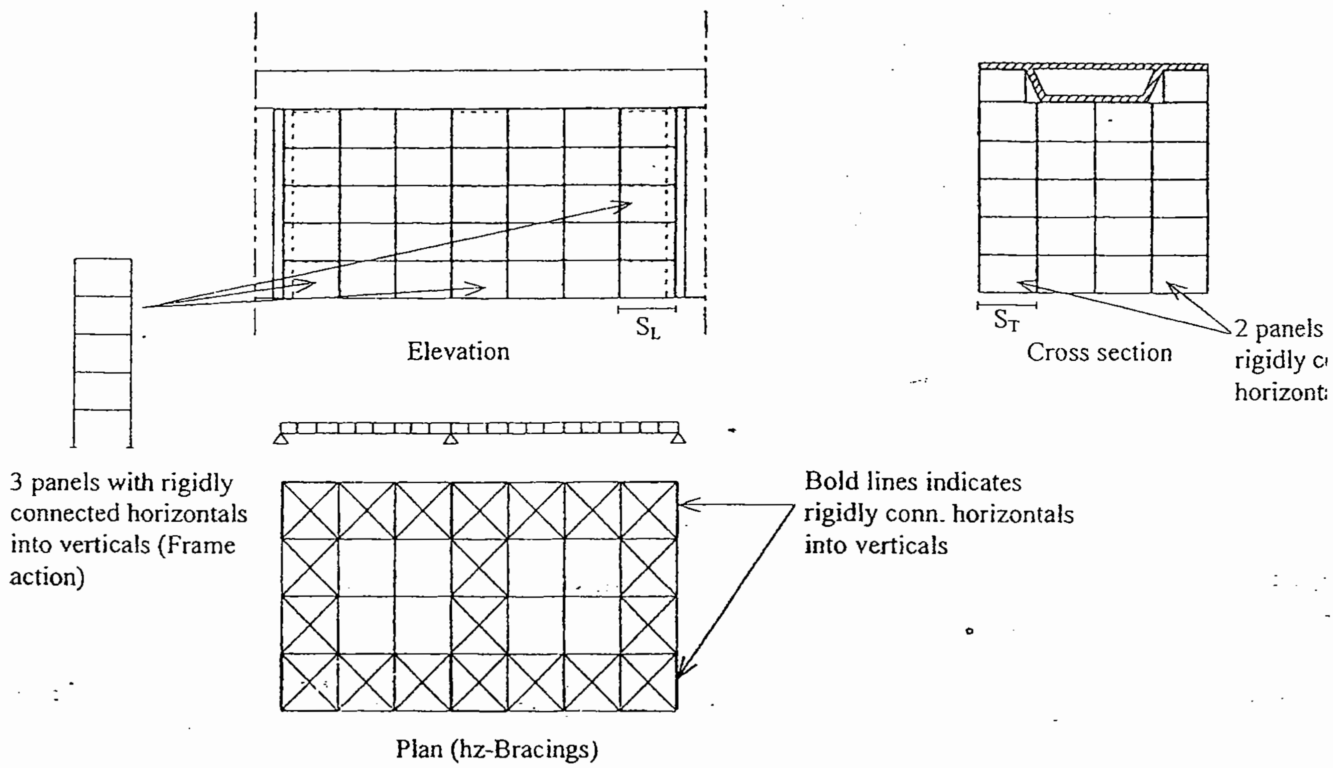
## 3.3.4 Design of metalic shuttering

As for wooden shuttering, the same recommendations can be also applied for the metal shuttering. However the dimensions of the different structural elements of the metal shuttering is smaller. The metal shuttering produces much less deformations during the construction and much more durable than the wooden shuttering. However for the design of metal shuttering the following could be added:

- At base of the verticals, the verticals should be supported on small footings
- The temperature effects produces higher forces than wooden shuttering, therefore this influence should be in some cases considered.
- For forms with rigid connections between the different elements, the produced bending stresses should be taken into consideration, especially, for cases of the differential movements due to soil deformations, or thermal effects.

General layout of metal shuttering

For example steel St. 37 ($f_y$=2400 Kg/cm$^2$)



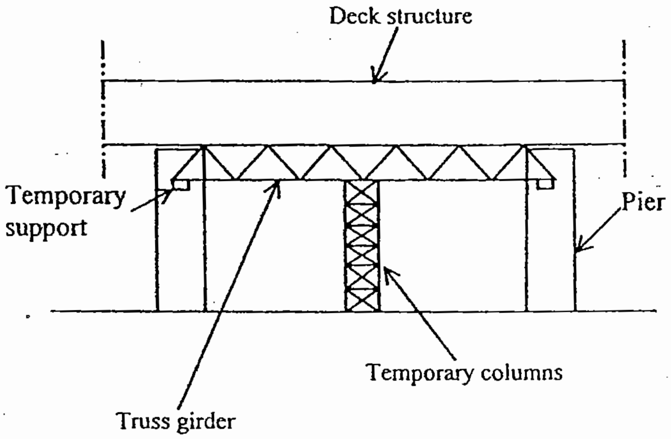

Recommendations

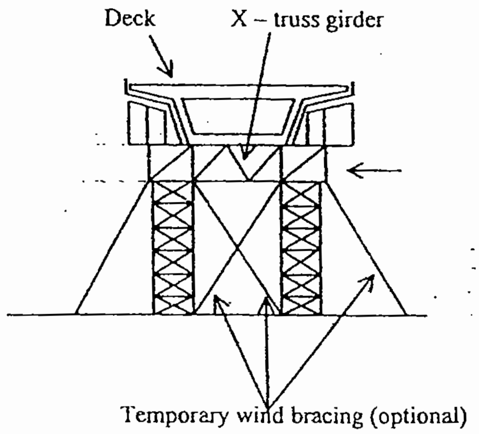
- Sections of verticals are pipe section with $\phi$ 50-80 mm, t= 3-7 mm
- $S_L$ and $S_T$ range between 3-4m.
- Wind load on the horizontal bracing is to be carried as given for the design of wooden shuttering.
- The reaction from the horizontal bracing systems or the vertical system is to be carried by frame action of the panels, in which the horizontals are rigidly connected with the verticals.

## 3.4. Shuttering supported on temporary columns

### 3.4.1. Methodology and recommendations

- The weight of the bridge will be carried during the construction on rigid space truss girders, which are supported on temporary columns and/or the piers of the bridge.
- The given loads in sec. 2.3.1 are the design loads for the shuttering structural elements, i.e. space truss girders and columns
- The vertical and the horizontal loads on the piers and on the temporary columns are to be transferred into the ground. The temporary foundations are to be designed for these loads.
- In most cases, the temporary columns could be stabilised by temporary cables, to carry the horizontal loads due to wind load in longitudinal and in rare cases transverse directions of the bridge.



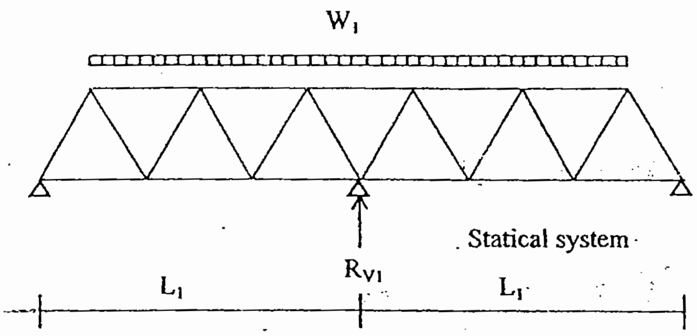




### 3.4.2. Load distribution and statical system:

1) Vertical load on the shuttering truss girder:

Total load: $W = g + p$

n : no. of truss girders
$W_1 = \text{Load/truss} = W/n$
$R_{V1} = 1.2\,(W_1 L_1)$

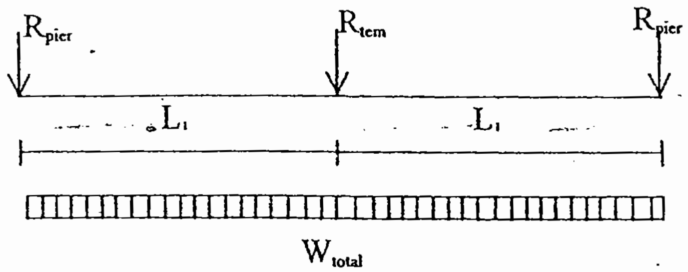



2) Hz-loads on the deck and shuttering truss girder

$W_{total} = W \,.\, d_{deck} + W \,.\, d_{t.g.} \,.\, (0.3)$

$R_{pier} = 0.5\, W_t L_1$

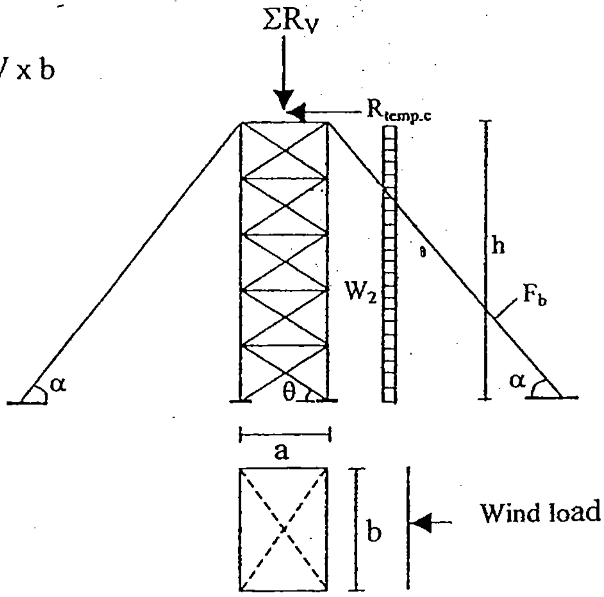
$R_{temp.c} = 1.2\, W_t L_1$



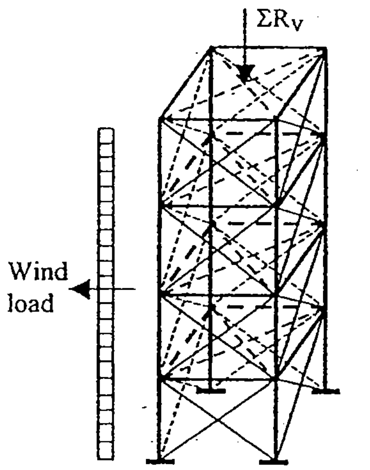
## Loads on temporary columns

Temporary column in Y direction

$W_2 = W \times b$



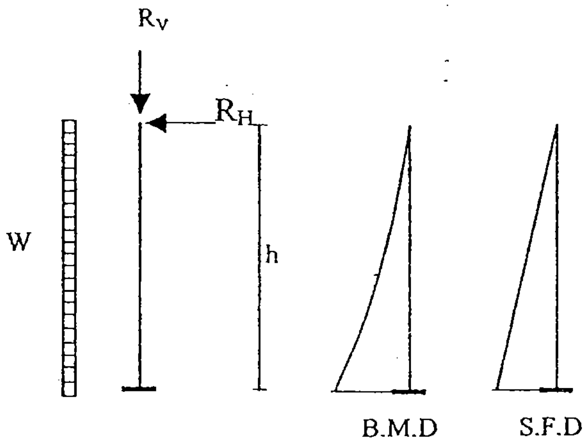

3D-View of the temporary columns




Case 1: Without temporary cables

Statical system as a cantilever system

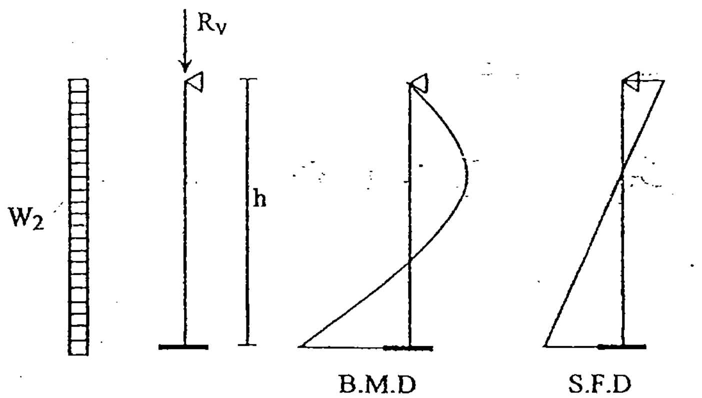
$M = W_2 \,.\, h^2/2$
$N = \Sigma\, R_V$
Force/Vertical $F_V = (N/4) + \text{or} - (M/2a)$
Force/diagonal $F_D = Q_b/(2.\cos\theta)$




Case 2: With temporary bracing

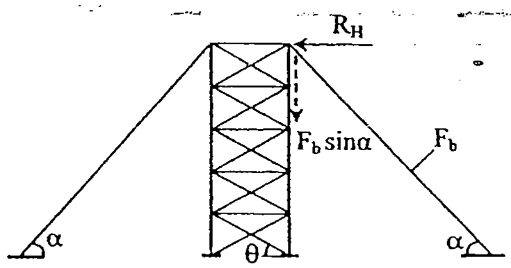
Statical system

$N = \Sigma\, R_V + \Sigma\, F_b \,.\, \sin\alpha$




Loads on the temporary bracing

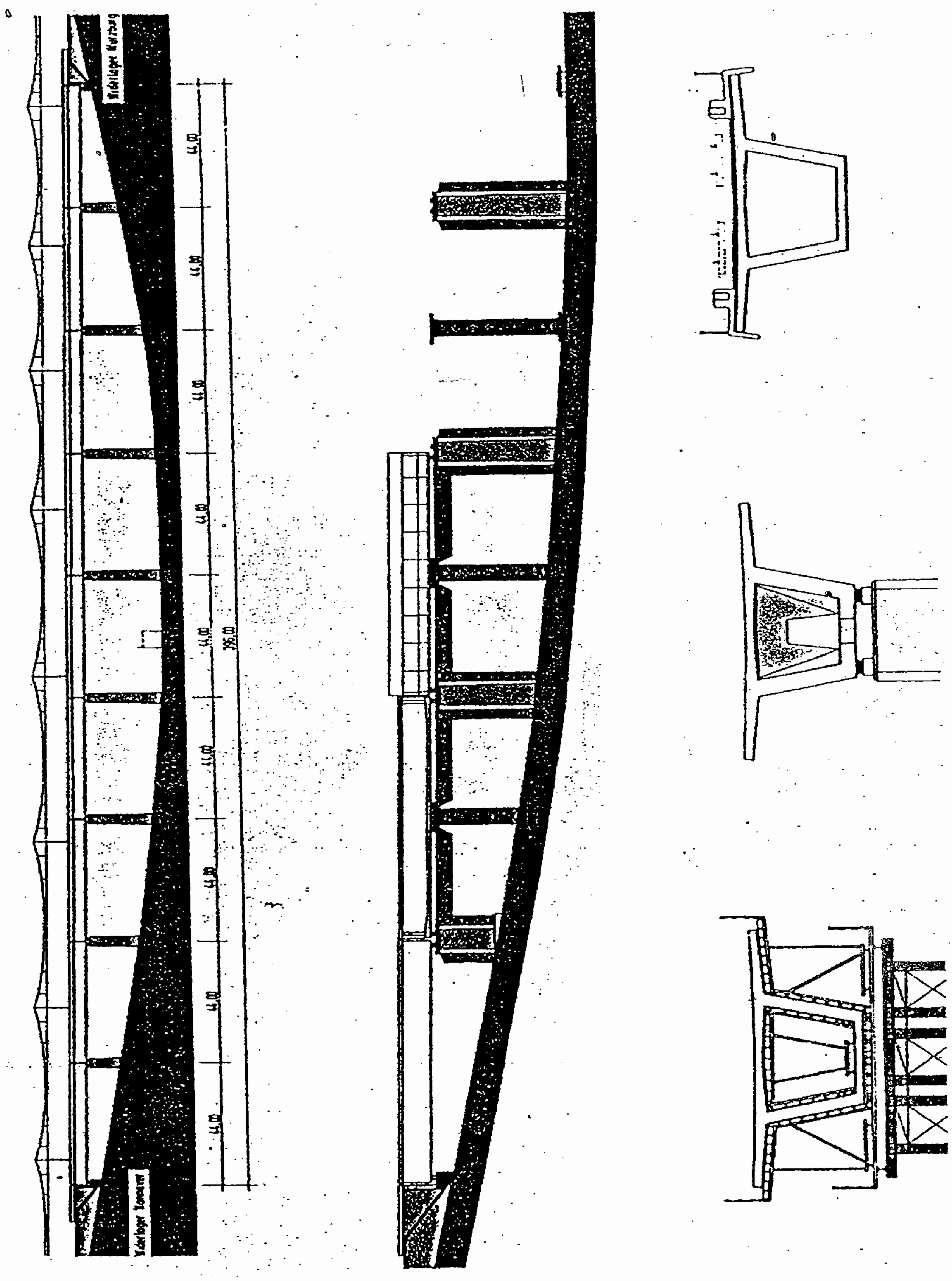
$F_b = R_H/\cos\alpha$ (cables)
$F_b = R_H/2\cos\alpha$ (steel elements)



### 3.4.3. Practical example:

**Hillside Bridge Dittenbrunn**

Single box girders, spans = 44m



## 4. Pre-cast technique

### 4.1. General

The pre-cast technique was applied in the bridge construction in the second half of the last century. The advantages of this construction technique are the reduction of the construction formwork, a reduction of the construction duration and a production of concrete with high quality (high performance concrete, i.e. high strength, modulus of elasticity and high durability). The following techniques were applied for the pre-cast and will be high lighted in this section:

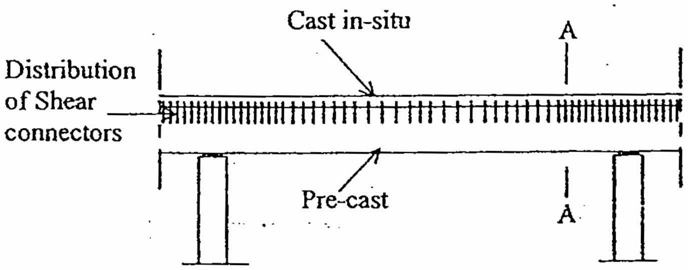
1. Pre-cast techniques for the construction of the deck elements.
2. Pre-slab techniques.
3. Hypride pre-cast techniques.
4. Pre-cast segmental bridge construction technique.

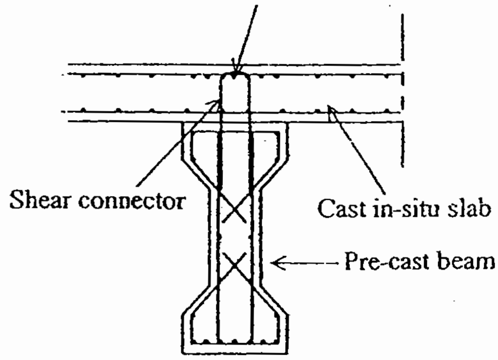
The first technique is to be applied for the construction of decks with slab and girder type. The second-type is to be applied for girder type-concrete decks as for slabs of composite bridges. The hypride pre-cast technique is the most applied, by which some structural elements, such as pier or foundations are to be casted in situ and others are to be constructed using pre-cast technique such as slabs. The modern construction technologies has applied the segmental bridges using the pre-cast techniques, by which the bridge segments are to be lifted, positioned and then the bridge segments are to be tighed together using the prestressed technique. The launching method or the cantilever method are the adopted methods during the erection and the assembely of the pre-cast segments of the bridge deck. The application of the pre-cast technique was adopted not only for the bridge decks but also for the construction of piers, foundation of piers and even for construction of foundation piles.

### 4.2. Different pre-cast techniques

1) Pre-cast beams and cast in-situ slabs

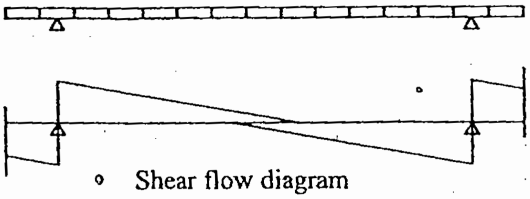
1. Arrangement:



Section A-A

## 2. Design of shear connectors

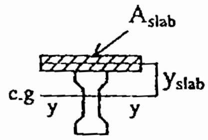


Shear flow diagram

For the design of the shear connectors, between beams and slabs, the shear flow at this gab should be determind, as follows:

Shear flow = $\tau = Q.s/I_y$

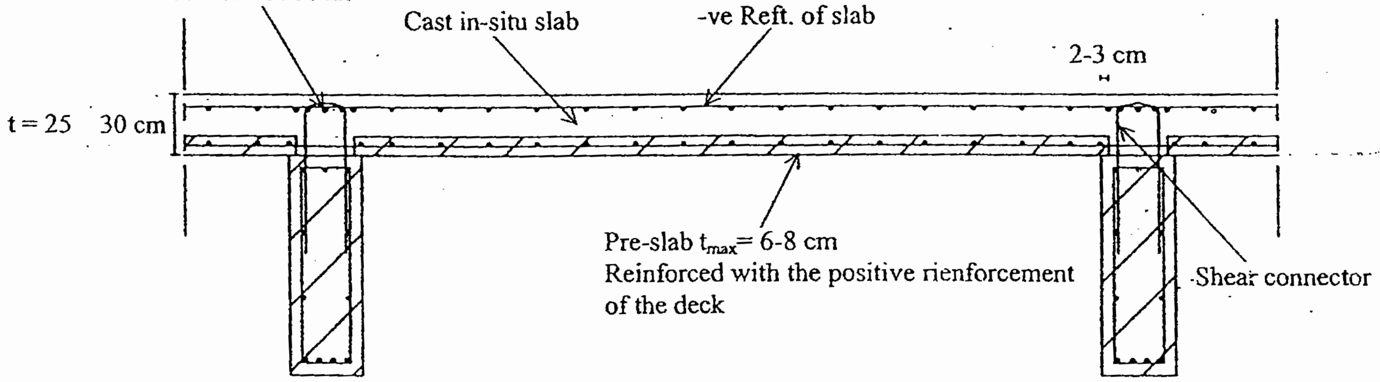
Required reinf. For shear connectors = $\tau/(f_{yk}/\gamma_s)$




$S = A_{slab} \cdot y_{slab}$

$f_{yd} = f_{yk}/\gamma_s$

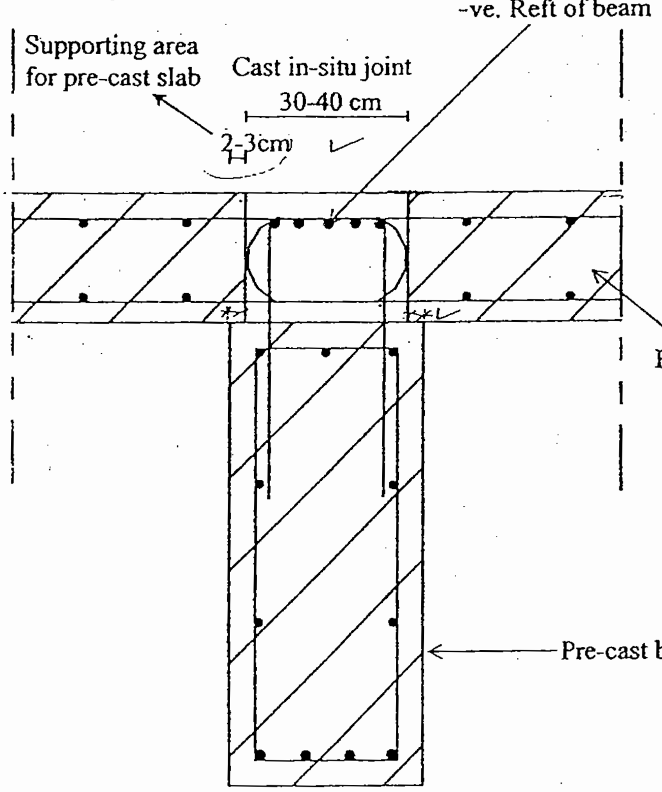
## 2) Pre - cast beams and pre - slabs

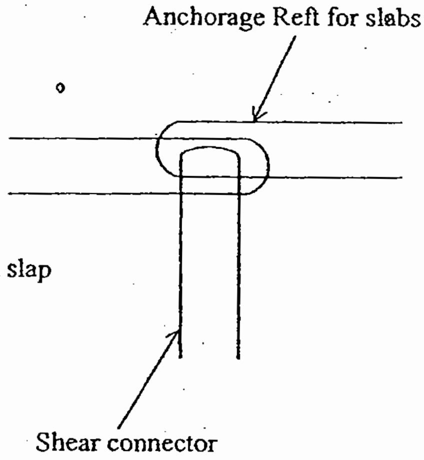



Arrangement of pre-slab technique in bridge

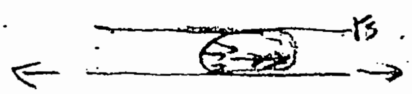
3) Pre-cast beams and pre-cast slabs

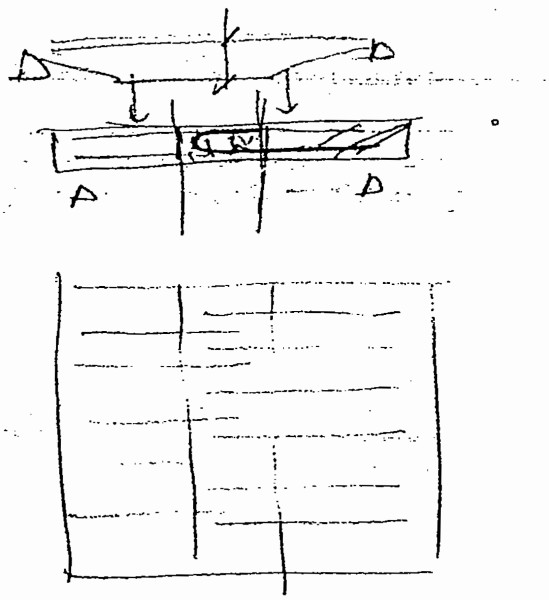
1. Arrangement:




This joint was used frequently in the construction of concrete and composite bridges, e.g. Ting Kau bridge in hong kong. This joint was tested experimentally, the results shows that this joint arrangment is very efficient to carry ve moments under service loads, in addition it guarantees the fatigue requirments of bridges.

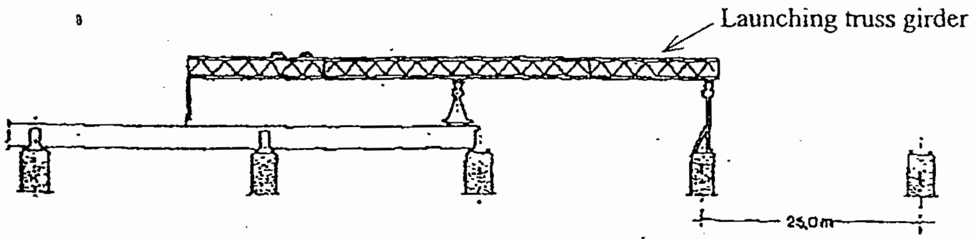




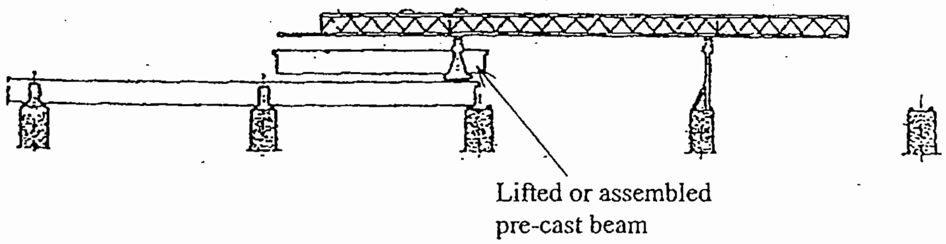
## 4.3. Example for the application of pre-cast technique in bridge construction

The following example shows the application of pre-cast technique for the construction of a bridge using the launching girder above the deck. Mainly, the pre-cast deck will be lifted and placed into its final position using winchs supported on the launching girder. The following figure shows some of the construction stages using this technique.

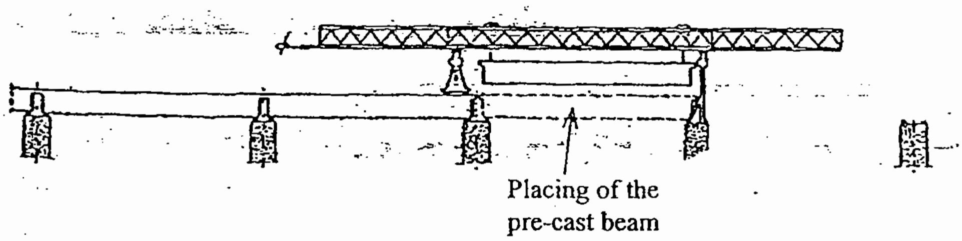
Stage 1: Positioning of the launching girder and its fixation into piers and already erected spans




Stage 2: Delevey of the pre-cast beams to be erected in the next step



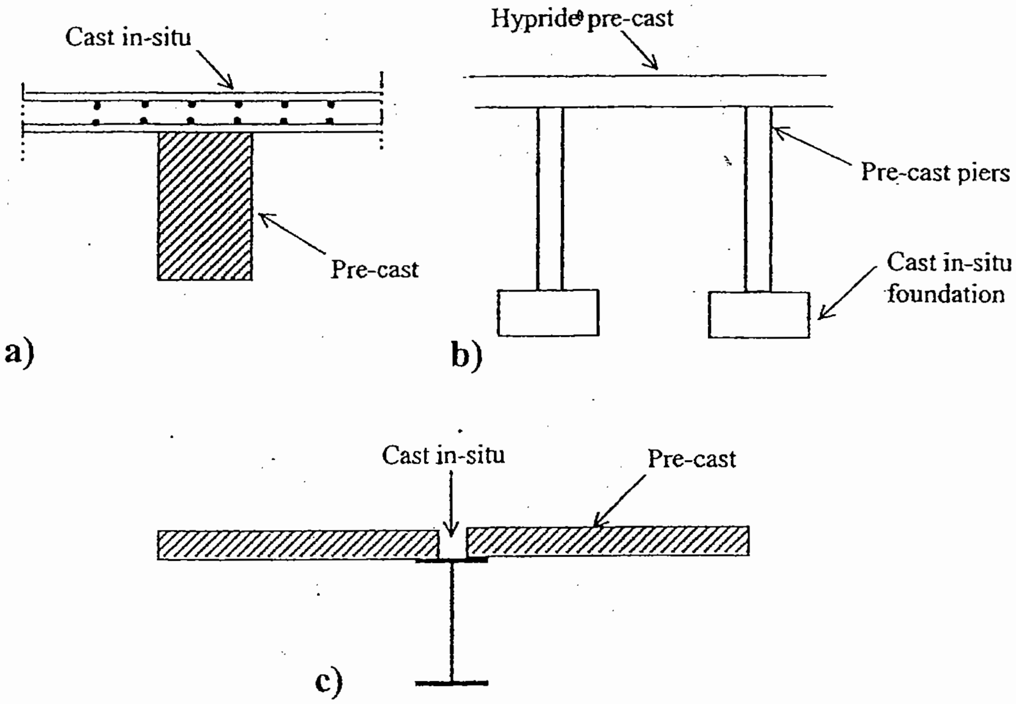

Stage 3: Placing of the next pre-cast beam and casting of the joints in situ.



### 4.4. Hybrid pre-cast technique

In most cases, the application of pre-cast technique is to be combined with cast in-situ procedure to produce what is called hybride construction or hybride pre-cast technique.

The following figures shows examples for a hybride construction technique, in fig. (a) the precast beams are to be combined with cast in-situ slabs, where in (b) the application of the hybrid pre-cast deck with pre-cast columns and cast in-situ foundation. Fig. (c) shows the application of pre-cast slabs for steel composite bridges.




Hybride pre-cast technique

### 4.5. Pre-cast segmental bridges:

The segmental pre-cast technique was frequently used in the last 3 decades, due to the development of the prestressing technique and the mechanical technique for lifting. This solution is powerfull for spans 50-80m, when the area under the bridge is not accessible, e.g. water or deep vally, the follwing procedure is to be applied for the bridge construction.

1. Dividing the bridge into segments, each 5-10m. Each segment is to be casted in work-shop or on site.

2. Using the launching method or the cantilever method the bridge segments are to be lifted and erected into position.

3. The successive erection of the bridge segments is to be carried out mutually with the prestressing of the proper erected segment into the previous erected one.

4. Progressive erection of the bridge segment lead to a full construction of the bridge spans. However, at the end the final prestressing cables are to be stressed.