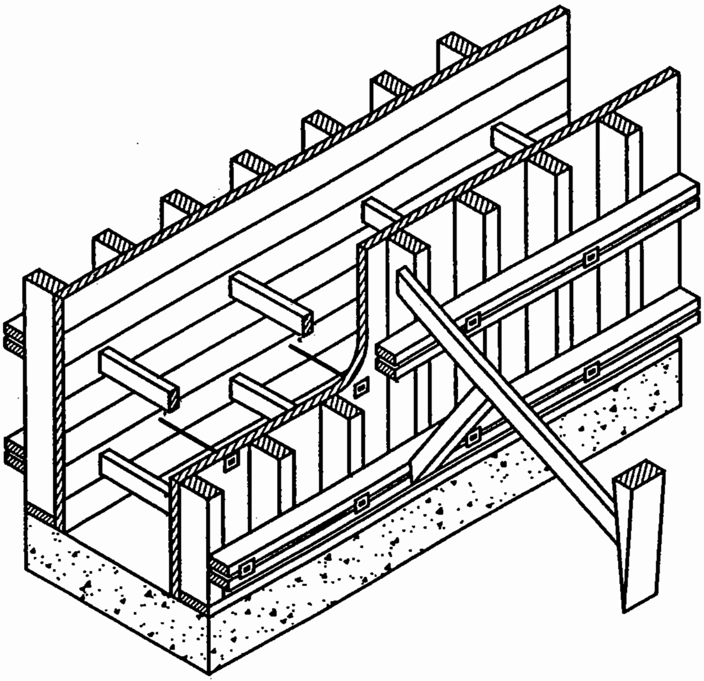
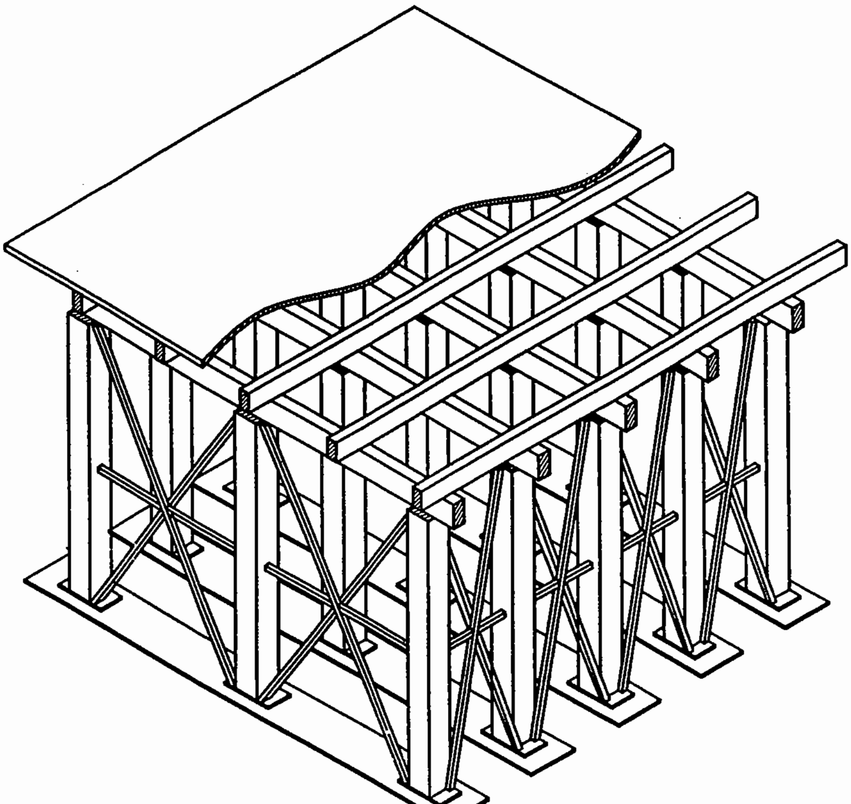
ملزم شدات
رابعه انشاءات
٤



Construction Techniques (III)

Structural Department



4th year Civil

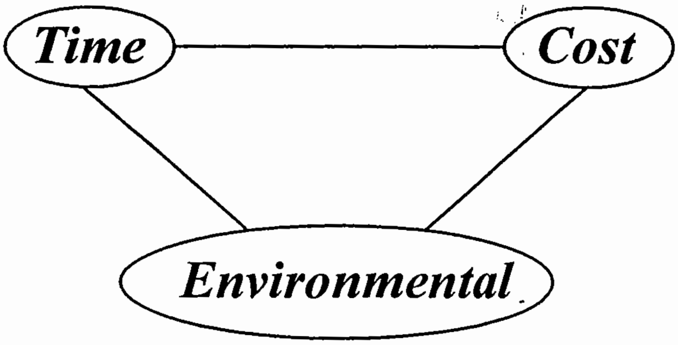
Bridge Construction

Main rule for the choice of the construction method:

The bridge should be constructed and / or erected with the most reasonable method to minimize direct and indirect costs of construction within required period of construction. The duration of construction is important factor that should be optimized.

Criteria of choice:

1- *Economic facilities* — التوفير فى تكاليف الإنشاء
2- *Construction schedule* — الاهتمام بالجدول الزمنى ومدة التنفيذ
3- *Environmental aspects* — الاهتمام بمدى تأثير عملية التنفيذ على البيئة المحيطة



The choice of the most suitable method of bridge construction:

1- ***Max. span of the bridge and the total length.***
2- ***The degree of occupation under the bridge.***
3- ***The type of the bridge deck, e.g. concrete, steel, composite deck***
4- ***The height of the bridge deck over the ground.***
5- ***The condition of the traffic and public situation in the surrounding region.***

Explain the main aspects for construction of bridge:

- ***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 end bridge negatively.*
i.e. Construction should not govern the design of bridge different structural elements.

يتم اختيار طريقة تنفيذ مناسبة حتى لا تزيد الاجهادات الواقعة على المنشأ عن الاجهادات التصميمية.

- ***Economically:*** *The bridge should be constructed and / or erected with the most reasonable method to minimize the direct and the indirect costs of construction within required time as the duration of construction is important factor that should be optimized.*

يجب التنفيذ بأقل تكاليف وفى أسرع وقت ممكن.

- ***Environmentally:*** *The bridge construction shouldn't have a negative influnce on the surrounding environment of the site during construction.*

يجب ألا تكن طريقة التنفيذ لها تأثير سلبى على البيئة المحيطة.

- ***Aesthetically:*** *For long period construction, the influnce of bridge construction on the overall view in the surrounding region should be considered.*

يجب ألا تؤثر طريقة التنفيذ على المنظر العام المحيط بالمشروع.

Designer main target and tasks:

1- ***Choose the most reasonable method for construction.***

اختيار أفضل أنظمة الإنشاء .

2- ***Divide the construction method into stages.***

تقسيم طريقة التنفيذ إلى مراحل .

3- ***Design each stage of construction stages and check stresses in both formwork and in constructed elements at every stage.***

يتم تقسيم المراحل المختلفة مع التأكد من عدم زيادة الإجهادات عن المسموح بها فى كلا من المنشأ المنفذ أو المنشأ الحامل أثناء التنفيذ.

4- ***Design the temporary elements if needed.***

تصميم العناصر المؤقتة أثناء التنفيذ عند الحاجة إليها.

5- ***Determine the required equipment and devices for the construction method.***

تحديد الأدوات والمعدات المطلوبة أثناء التنفيذ.

6- ***Follow the progress of the construction.***

متابعة مراحل التنفيذ المختلفة.

Different methods of construction:

1- ***Cast in-situ technique on fixed or movable shuttering supported on the ground.***

- ***Fixed shuttering over the whole length***
- ***Fixed shuttering supported on temporary columns***
- ***Movable shuttering on movable columns***

2- ***Precast technique.***

- ***Pre-cast beams and Cast in-situ slabs***
- ***Pre-cast beams and Pre-slabs***
- ***Pre-cast beams and Pre-cast slabs***
- ***Hybrid pre-cast technique***
- ***Pre-cast segmental bridge***

3- ***Deck push system for pre-cast concrete decks, steel decks and composite decks.***

4- ***Launching method using launching beams.***

- ***Launching system with launching girder under the deck***
- ***Launching system with launching girder over the deck***
- ***Launching system for construction of pre-cast girders***

5- ***Classic cantilever method.***

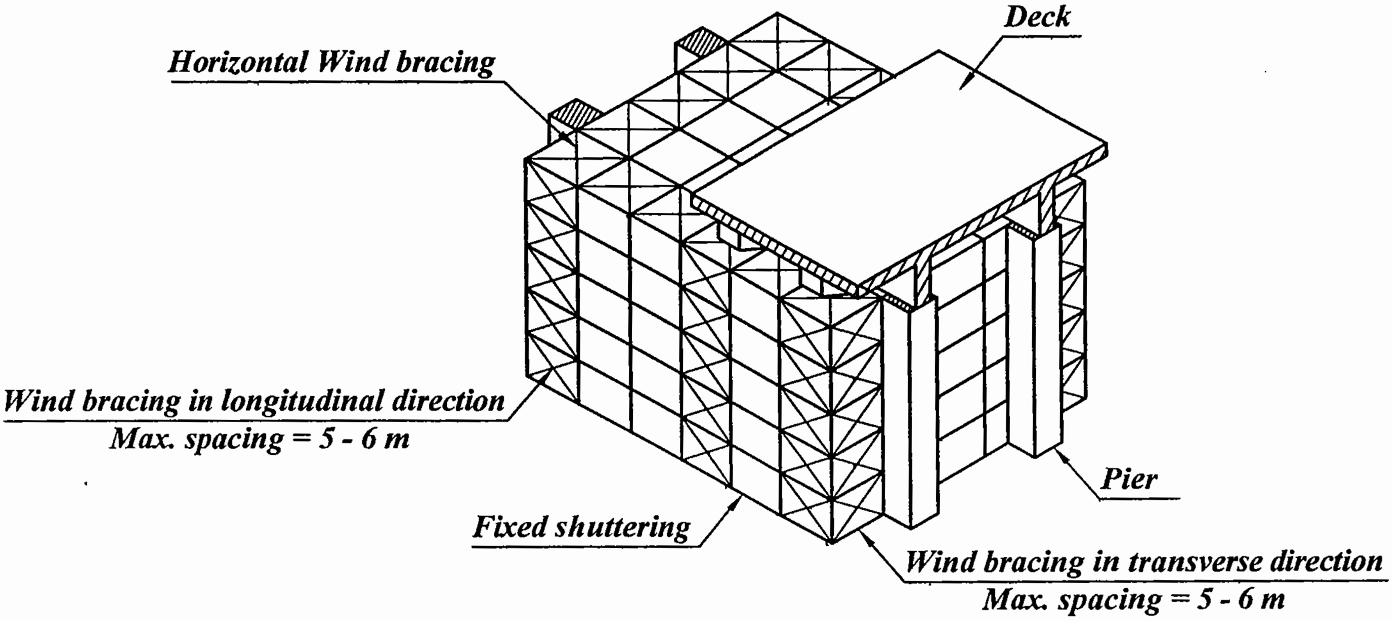
- ***Classic free cantilever method***
- ***Classic free cantilever method with additional launching beams***

1- Cast in-Situ Technique:

A- Fixed shuttering over the whole length

هى عبارة عن شدة خشبية أو معدنية توضع أسفل الكوبرى حتى نتمكن من تنفيذ ال **Deck** . وفى هذا النوع من الشدات تكون جميع أحمال الكوبرى منقولة إلى الشدة فقط أى أنه فى حالة تنفيذ أى عمود من أعمدة الكوبرى لا تنتقل اليه أى أحمال من ال **Deck** إلا بعد إزالة الشدة.

This system is suitable for small spans up to 30 .0 m

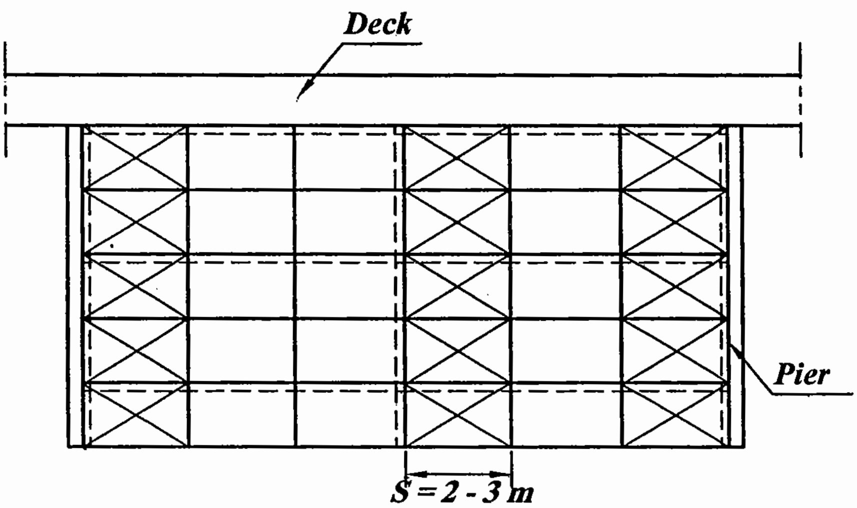


Vertical loads:

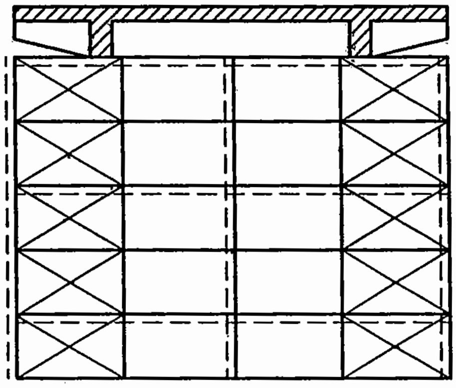
Vertical loads due to D.L., L.L., etc. will be carried by the verticals then load transfer to the ground through the P.C. foundation.

Horizontal loads:

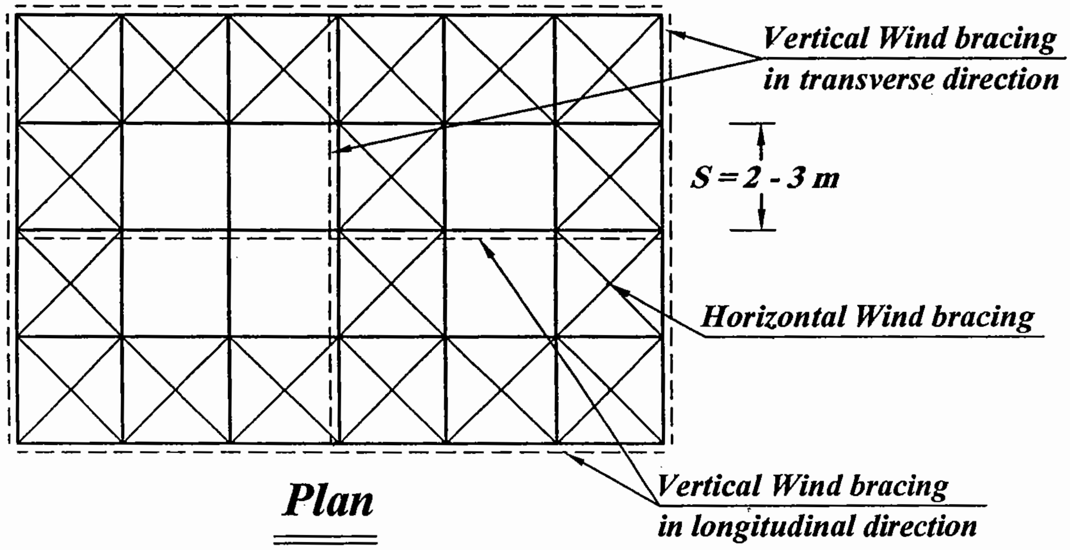
Hz. loads due to wind mainly will be carried by the diagonal members then loads transfer to verticals then to the ground.



Elevation (Longitudinal bracing)



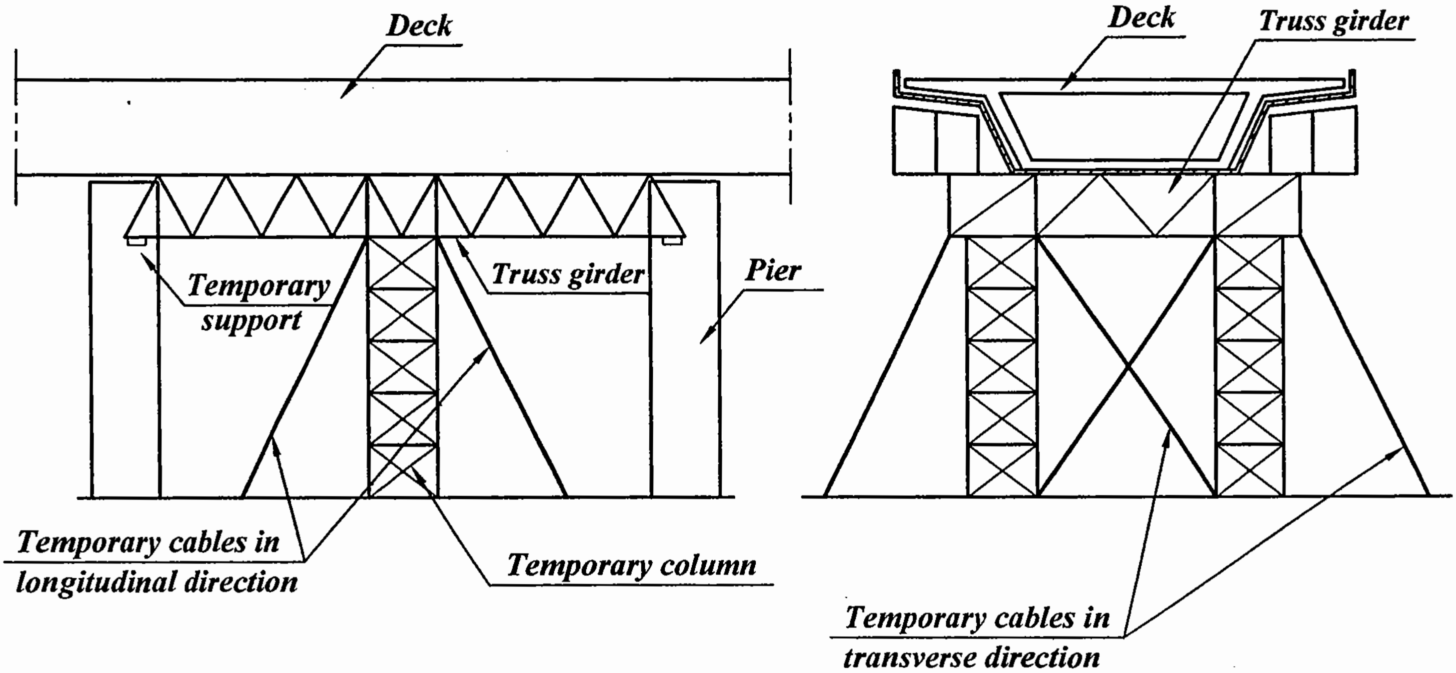
(Transverse bracing)



Plan

B- Fixed shuttering supported on temporary columns

هى عبارة عن شدة غالبا تكون معدنية ***Space truss*** وتكون مرتكزة على أعمدة الكوبرى فقط وفى حالة أن المسافة بين الاعمدة تكون كبيرة يمكن استخدام ***Temporary column*** عبارة عن ***Space truss*** . فى هذا النوع من الشدات لا تيم تنفيذ ***Deck*** إلا بعد إكتساب أعمدة الكوبرى مقاومتها القصوى حتى تستطيع حمل الشدة وتنفيذ ***Deck***



Vertical loads:

Vertical loads due to D.L., L.L., etc. will be carried by the piers and the temporary columns then transfered to the ground.

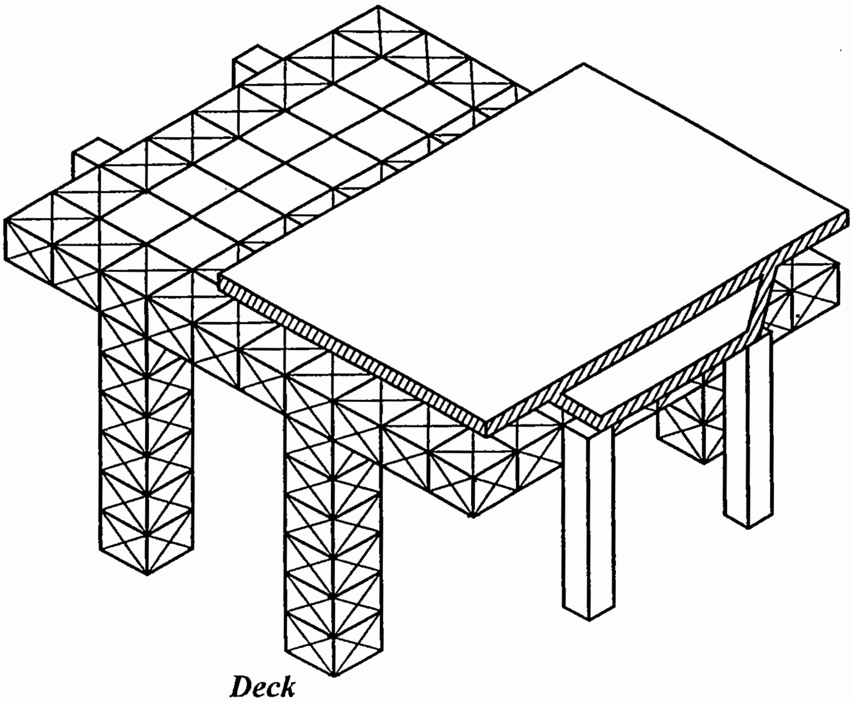
Horizontal loads:

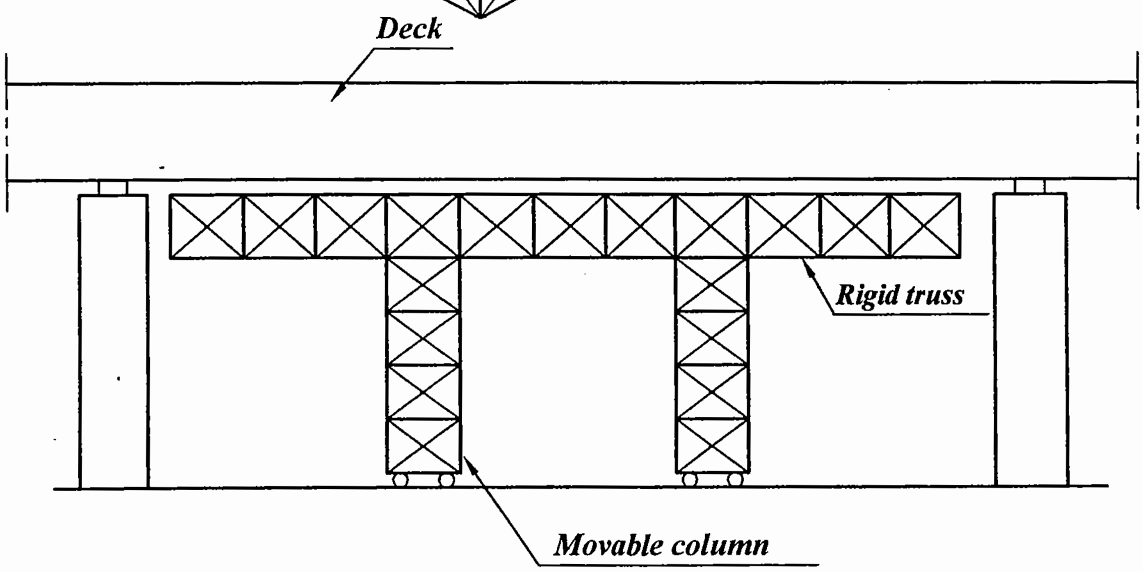
Hz. loads due to wind mainly will be carried by the temporary col. but in most cases the temporary columns can be stabilised by temporary cables to carry the hz. loads in the longitudinal direction and sometimes we can use temporary cables in transverse direction

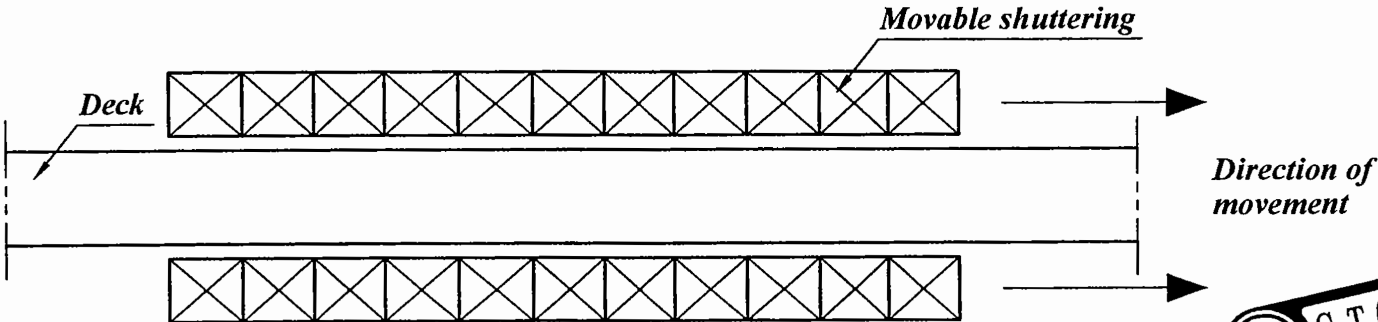
C- Movable shuttering on movable columns

هى عبارة عن شدة معدنية تكون مرتكزة على أعمدة الكوبرى مثل النوع السابق ولكن يكون الـ ***Temporary column*** متحرك مما يسرع عملية إنشاء الكوبرى.

- ***This system is suitable for large spans greater than 30 .0 m***
- ***Short time construction high construction rate***







2- Pre - Cast Technique:

Main advantages of application of pre-cast technique:

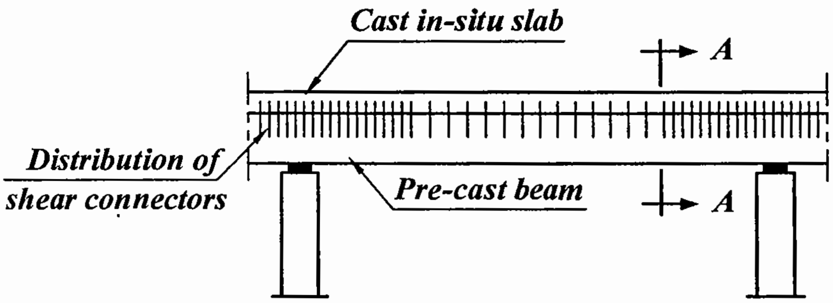
1- Reduction of construction formwork.

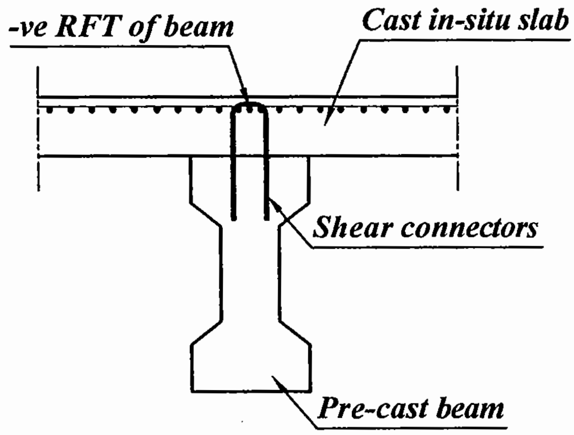
2- Reduction of construction duration.

3- Production of concrete with high quality (high performance i.e. high strength, modulus of elasticity and high durability)

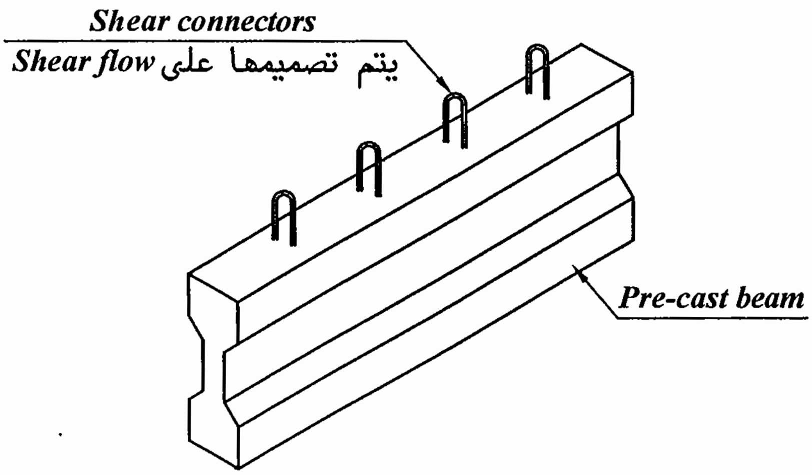
A- Pre-cast beams and Cast in-situ slabs

فى هذه الطريقة تكون الكمرات **Pre-cast** يتم تثبيتها على الأعمدة ثم يتم وضع شدة البلاطة وصب الخرسانة . يتم استخدام **Shear connectors** للربط بين البلاطة والكمرة حتى تنتقل الأحمال من البلاطة إلى الكمرة عن طريق الـ **Shear connectors**



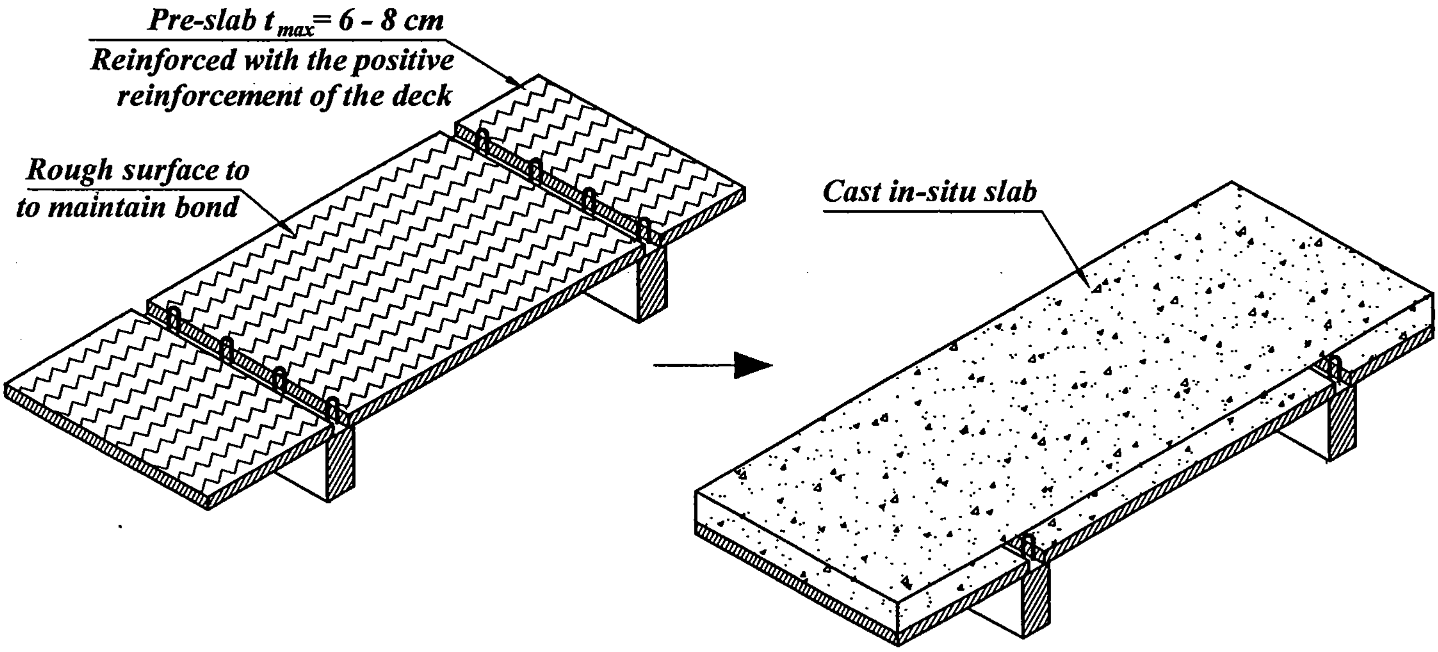


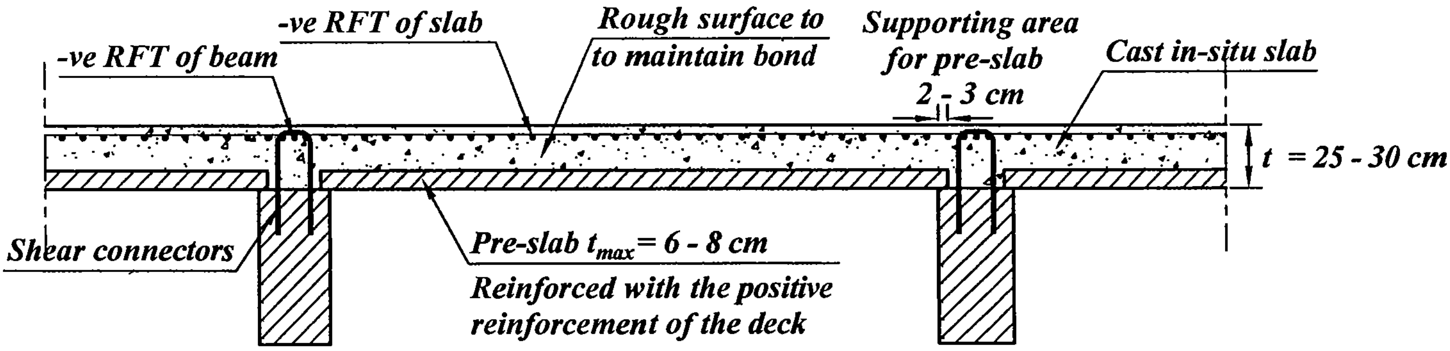
Section A - A



B- Pre-cast beams and Pre-slabs

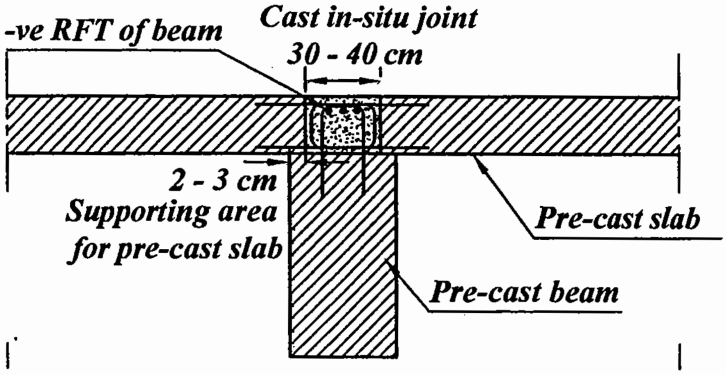
فى هذه الطريقة تكون الكمرات ***Pre-cast*** ويتم تقسيم البلاطة إلى طبقة بسمك ***6 - 8 cm*** تكون ***Pre-cast*** وبها التسليح الـ ***+ve*** للبلاطة وتستخدم هذه الطبقة كشدة لصب باقى البلاطة بالتخانة المطلوبة. ويتم الربط بين البلاطة ***Pre-cast*** والخرسانة المصبوبة فى الموقع عن طريق تخشين السطح.

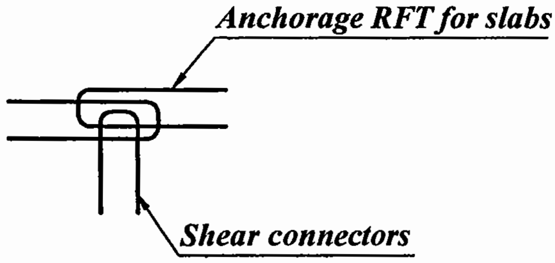


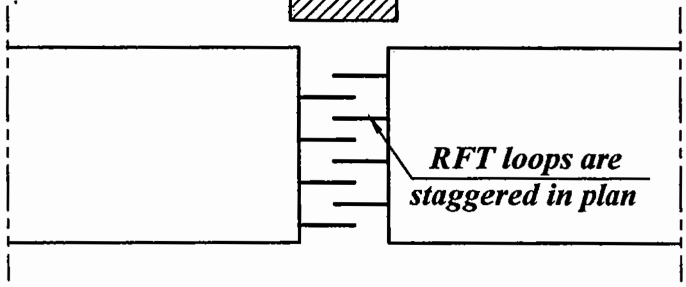


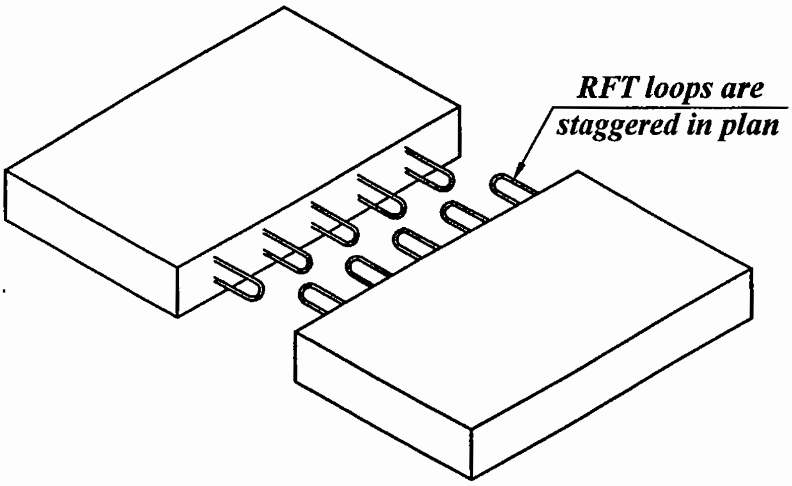
C- Pre-cast beams and Pre-cast slabs

فى هذه الطريقة تكون كلا من الكمرة والبلاطة ***Pre-cast*** ولكن يتم صب الوصلة بينهم فى الموقع ويتم استخدام ***Overlap loop & shear connectors*** وبالتالى يحدث توزيع للأحمال وتنتقل من البلاطة إلى الكمرة

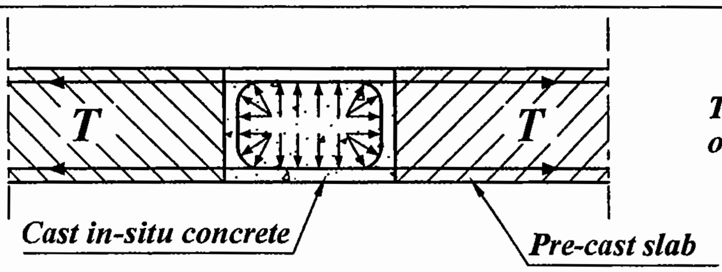


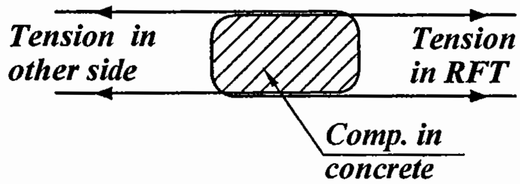






The force movement in RFT between the two pre-cast spans





Tension force in RFT

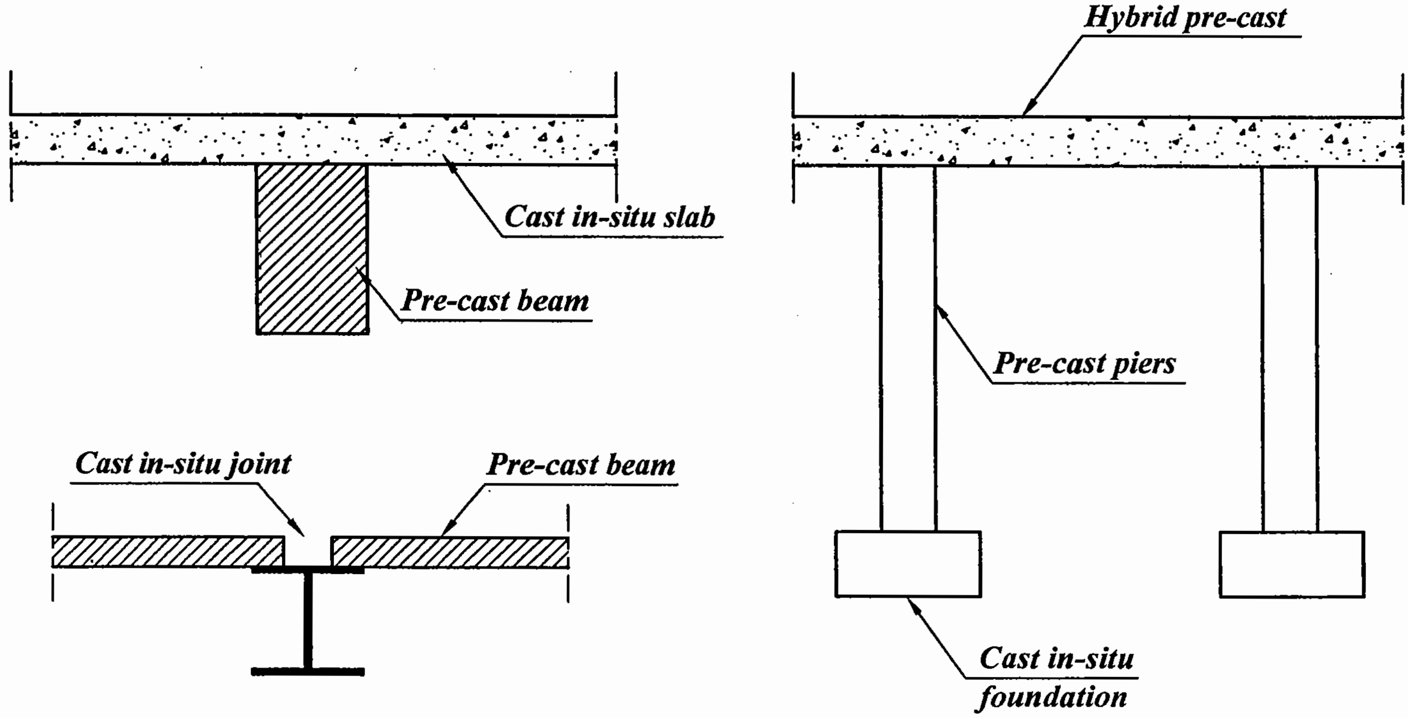
→ *Compression confining concrete*

→ *Tension in RFT on other side*

D- Hybrid pre-cast technique

فى هذه الطريقة يتم استخدام أنواع مختلفة من التنفيذ باستخدام ال **Pre-cast**

- **Pre-cast beams and Cast in-situ slabs**
- **Pre-cast beams and Pre-slabs**
- **Pre-cast beams and Pre-cast slabs**



E- Pre-cast segmental bridge

This system is suitable for spans 50 - 80 m and area under the bridge is not accessible e.g. (water or deep valley)

يتم تنفيذ الكوبرى كما يلى

1- Divide the bridge into segments 5 - 10 m each. Each segment is to be casted in workshop or in site.

يتم تقسيم الكوبرى إلى **segments** ويكون طولها **5 - 10 m** ويتم تنفيذ هذه البلوكات فى الموقع أو إحضارها **Pre-cast**

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

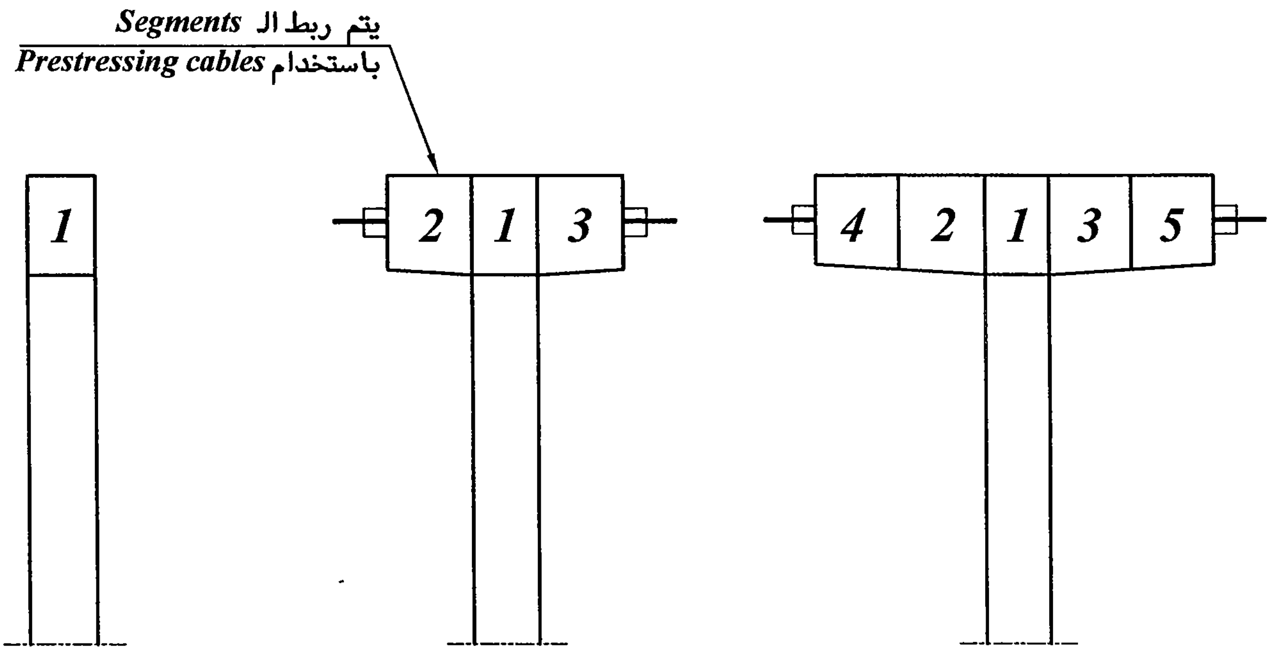
يتم رفع وتركيب البلوكات فى مكانها باستخدام
Launching system or cantilever method

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.***

Prestressing cable يتم الربط بين البلوكات التى تم تركيبها باستخدام

4- ***Progressive erection of the bridge segments lead to a full construction of the bridge spans. At the end the final prestressing cables are to be stressed.***

Prestressing cable بعد ربط جميع البلوكات يتم شد ال

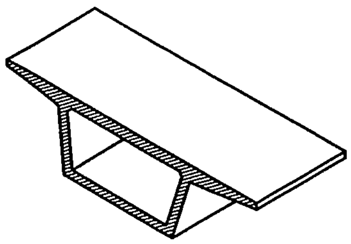


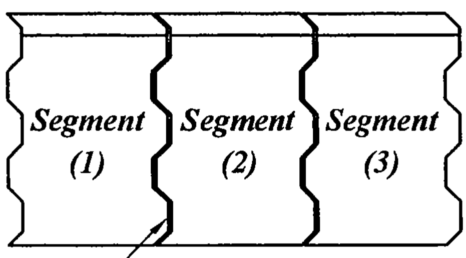
Phase I ***Phase II*** ***Phase III***

NOTES

يتم استخدام ***Pre-cast segmental bridge*** فى الكبارى ذات البحور الكبيرة

Box Section لذلك يكون قطاعها

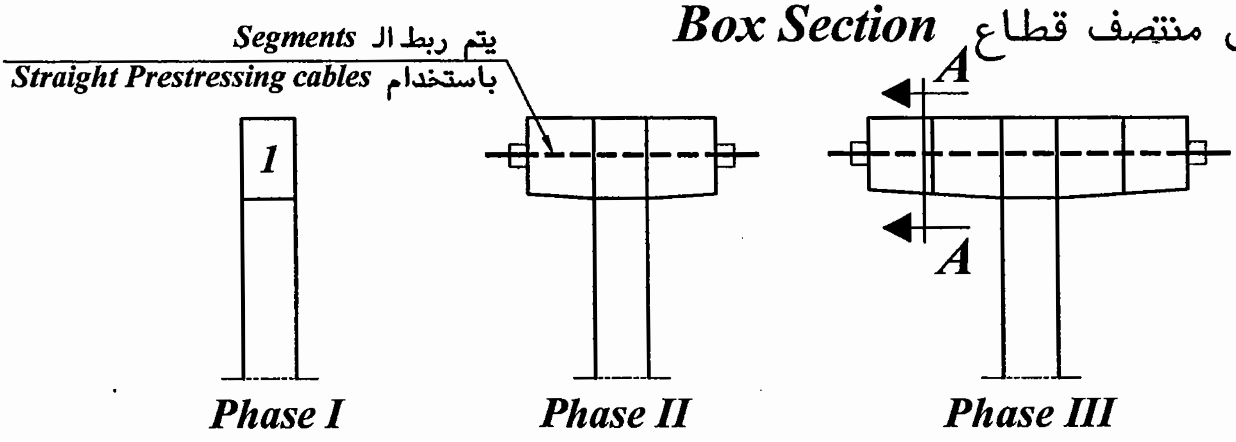


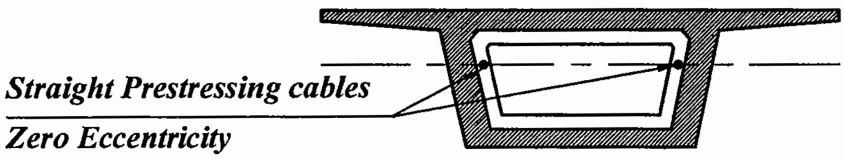


يتم تثبيت ال ***Segments*** مع بعضها عن طريق .

Dry Joints which contains multiple of non-reinforced shear keys.

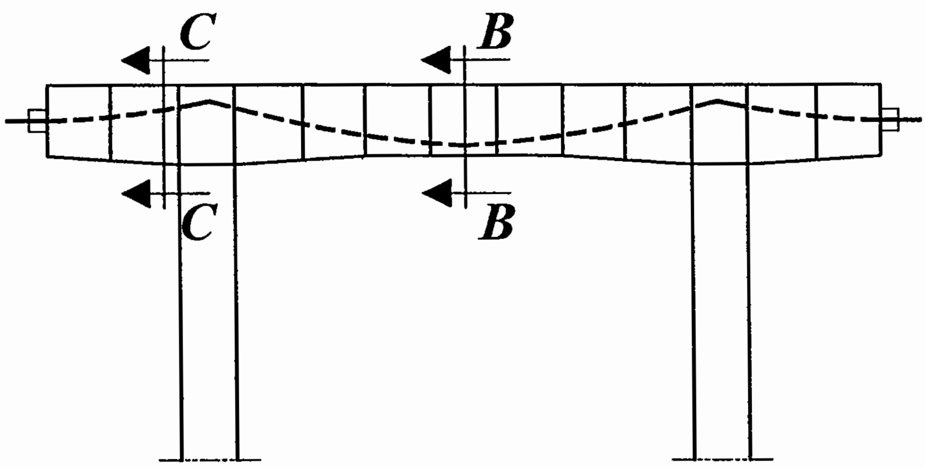
فى المرحلة الاولى اثناء تركيب ال ***segments*** يتم عمل ال ***Prestressing*** مستقيم فى منتصف قطاع ***Box Section***

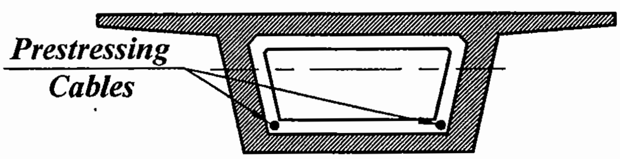




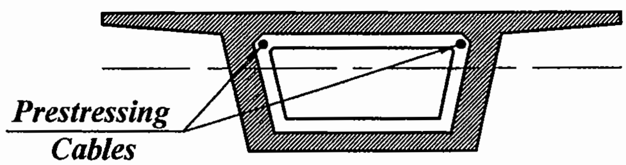
Section (A-A)

فى المرحلة الثانية بعد تركيب ال ***segments*** يتم عمل ال ***Prestressing*** بنفس شكل ال ***Bending Moment***





Section (B-B)



Section (C-C)

يتم تركيب ال ***Prestressing Cables*** دائما داخل قطاع ***Box Section***

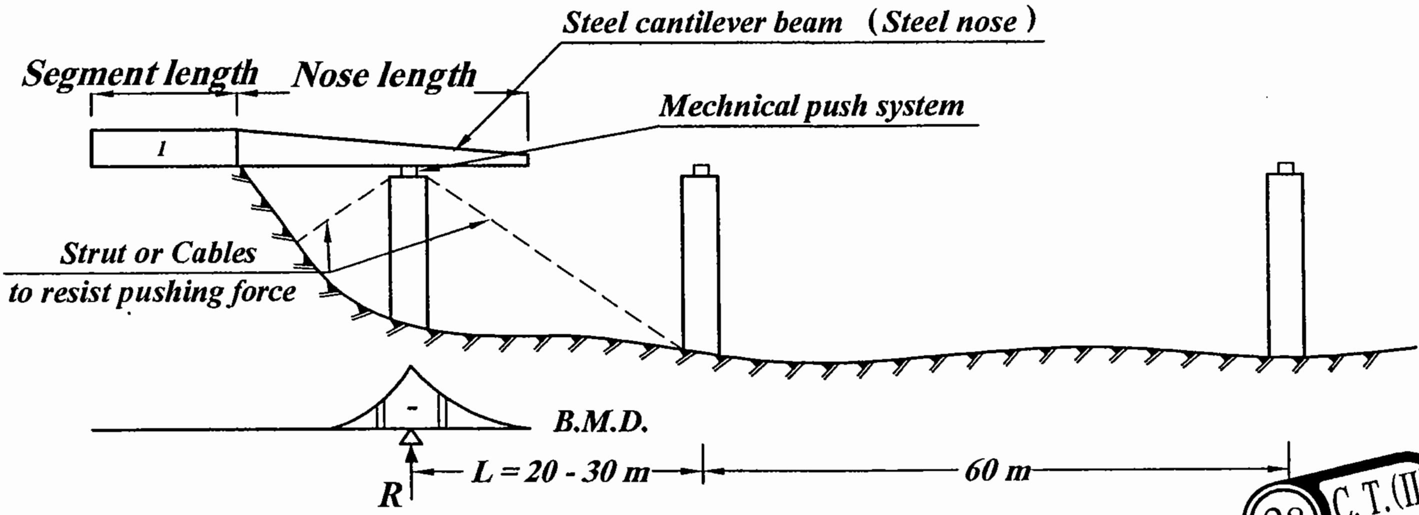
3- Deck Push System:

- ***This system is suitable for spans up to 60 - 70 m.***
- ***Additional temporary columns could be needed during the pushing of the deck.***
- ***This method could be the most economical method for construction of composite sections.***
- ***The deck structures is to be designed for the resulting internal forces (B.M. & S.F.) during the pushing process due to the change of the statical system of the deck.***
- ***The piers and the temporary columns are to be designed for the vertical loads and the resulting horizontal loads due to friction during the movement of the bridge.***

فى هذا النظام الإنشائى يتم صب أجزاء الكوبرى ***Deck*** فى الموقع ثم يتم تحريكها على أعمدة الكوبرى ***Piers*** باستخدام كمرة معدنية ***Steel nose*** يتم ربطها بالكوبرى وبالتالى يتغير النظام الإنشائى للكوبرى من مرحلة لاخرى أثناء التنفيذ .

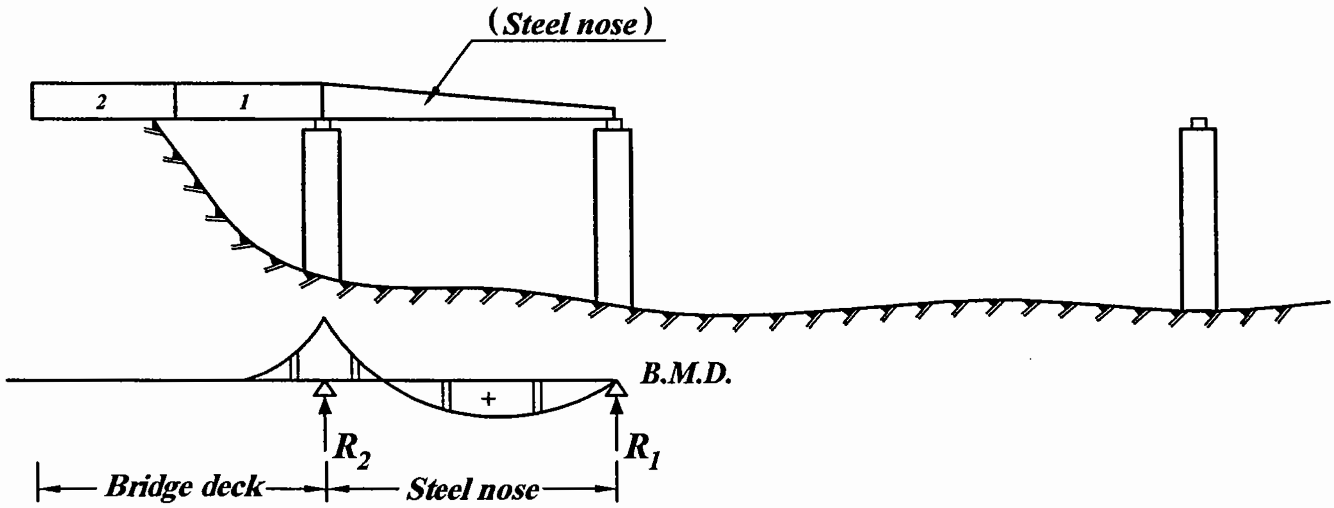
Stage 1:

- ***Supporting of the starting pier and preparation works for casting the first segment***



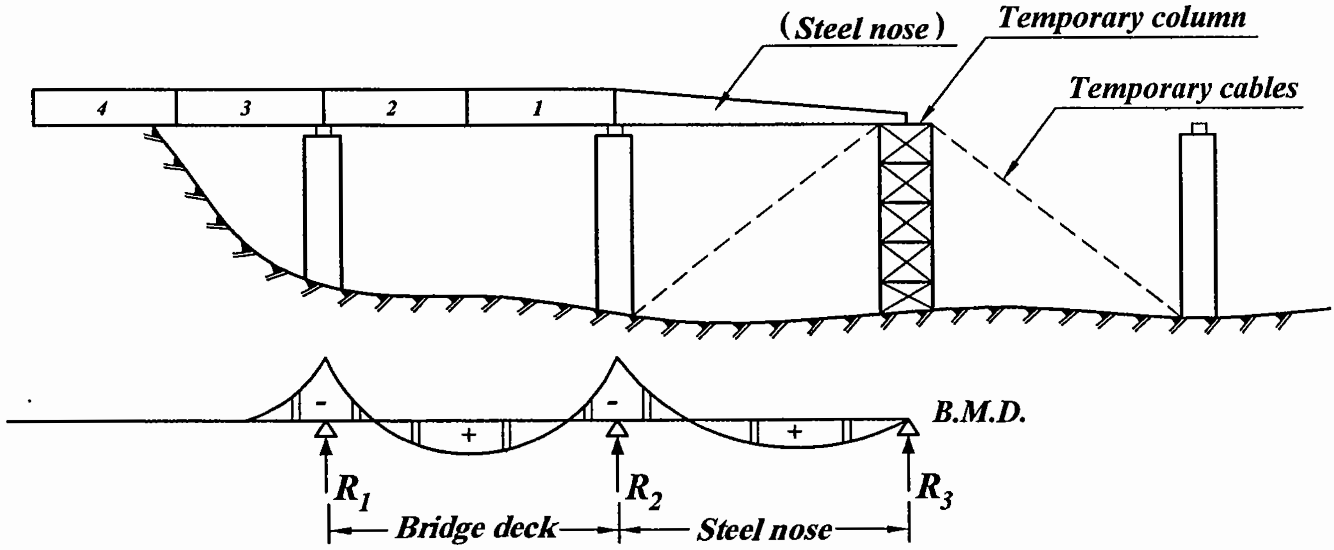
Stage 2:

- ***Pushing of the deck***
- ***Preparation for casting the second segment***



Stage 3:

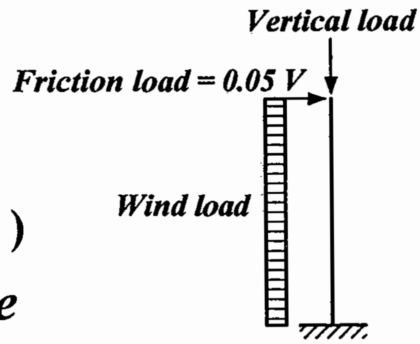
- ***Finishing of the third segment***
- ***Pushing the system to be placed over the temporary column***
- ***Preparation for casting segment 4***



NOTE

يجب أن تكون الوصلة بين أعمدة الكوبرى ***Piers*** و جسم الكوبرى ***Deck*** ***Hinged Connection*** حتى تسمح بتحريك ***Steel nose*** على الأعمدة ***Piers***

Temporary columns:



Temporary columns are to be designed on

- ***Vertical loads** (max. reaction of deck)*
- ***Friction force = 5% of vertical force***
  (to simulate the friction bet. the deck and the bracing)
- ***Wind loads** (carried by temporary cables in transverse and longitudinal direction)*

Statical system of temporary columns

Statical system in case without temporary cables

Statical system in case with temporary cables

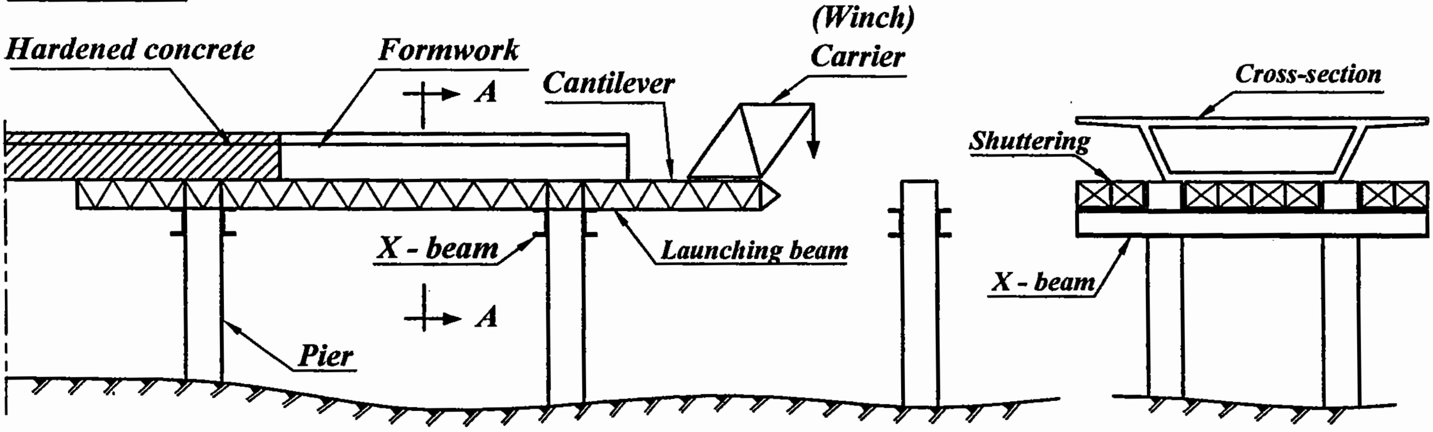
4- Launching System:

- *This system is suitable for spans 30 - 70 m if the area under the deck is not accessible.*
- *Launching beam during construction should be designed to carry all loads of the deck during construction.*
- *Piers are to be designed for the summation of the reaction forces from the deck and launching system.*
- *Wind load on the launching beam in additional to wind load on the deck should be carried by the piers.*
- *For decks with small height and spans up to 40 m and a material delivery over the deck, the cast in-situ technique is reasonable method using launching girder under the deck.*
- *For very high decks over ground > 30 m and spans > 60 m the application of the pre-cast segmental bridge deck with launching girder over the deck is an optimum choice.*

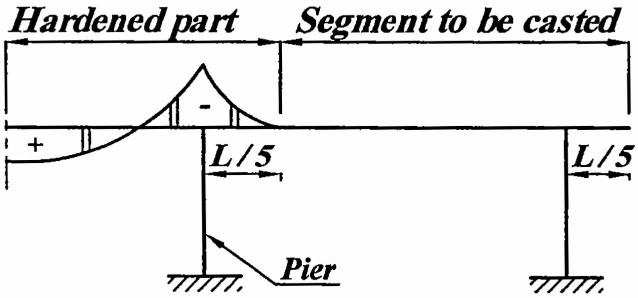
Using launching girder under the deck	*Using launching girder over the deck*
1- Small heights.	*1- Very high decks.*
2- Span up to 40 m.	*2- Span more than 60 m.*
3- Using cast in-situ technique may be better.	*3- Using pre-cast segmental bridge.*
4- Material delivery over the deck.	

A- Launching system with launching girder under deck

Stage 1:

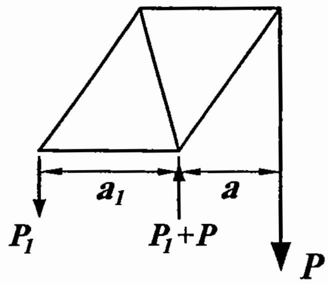


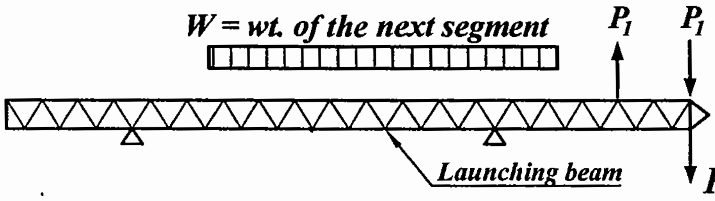
Section A - A



B.M.D. in the deck

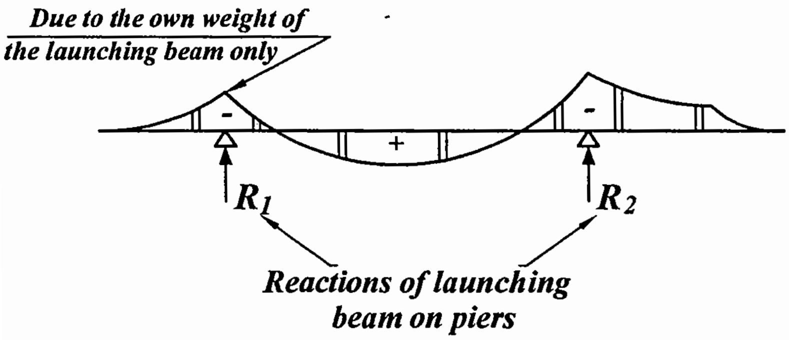
Lifting carriage





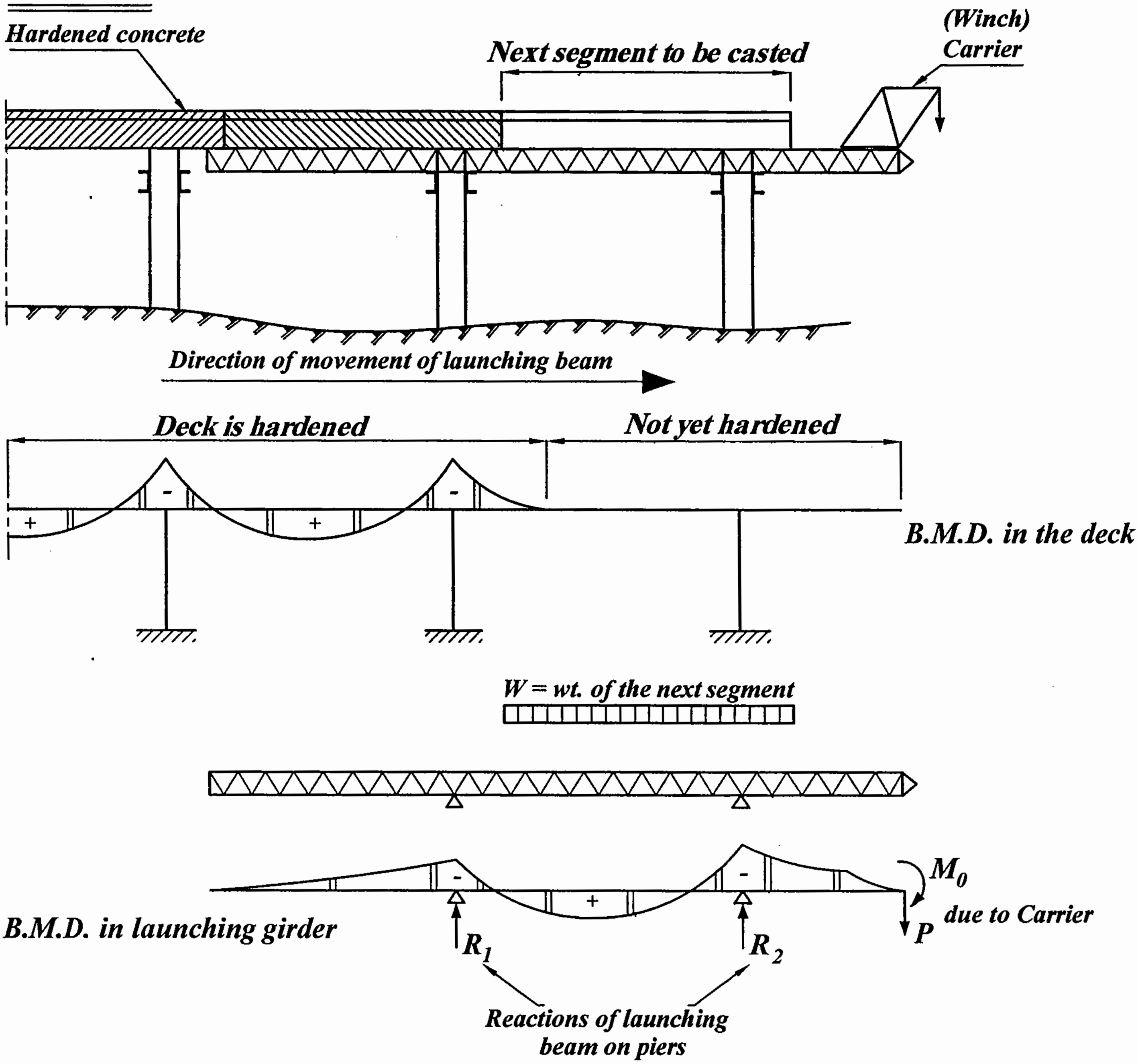
P = wt. of lifted parts

$M = P \times a$
$P_1 = M / a_1$



B.M.D. in launching girder

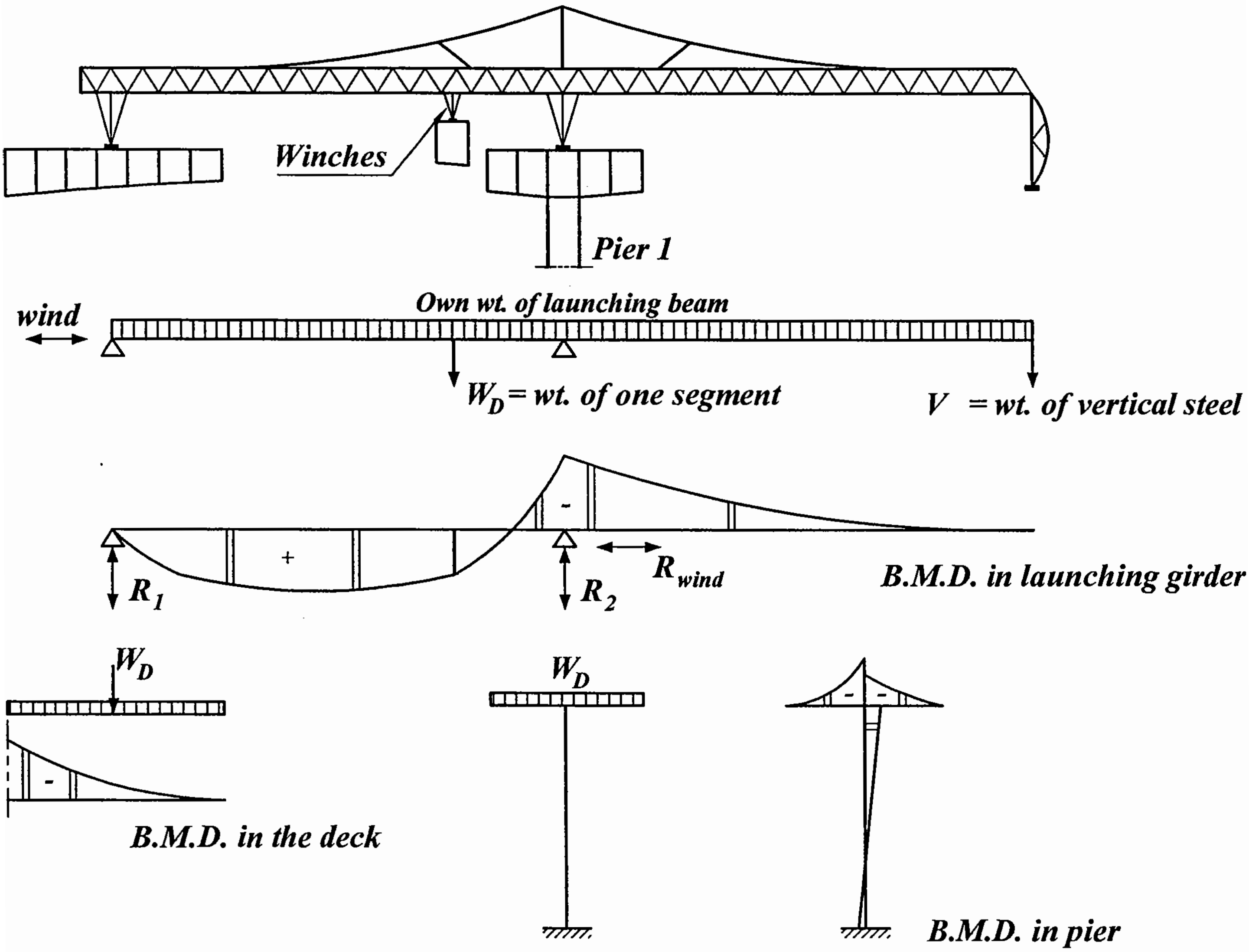
Stage 2:


Hardened concrete
Next segment to be casted
(Winch)
Carrier
Direction of movement of launching beam
Deck is hardened
Not yet hardened
B.M.D. in the deck
W = wt. of the next segment
B.M.D. in launching girder
M_0
P
due to Carrier
R_1
R_2
Reactions of launching
beam on piers

B- Launching system with launching girder over the deck

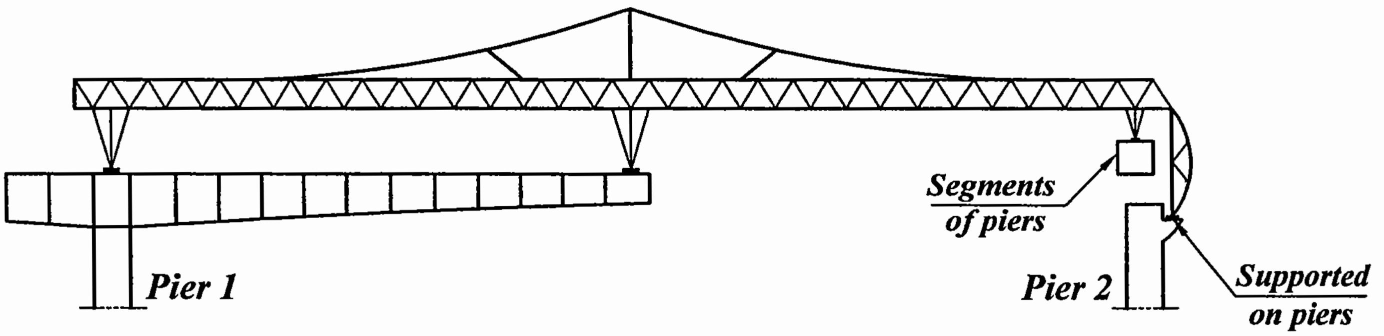
Stage 1:

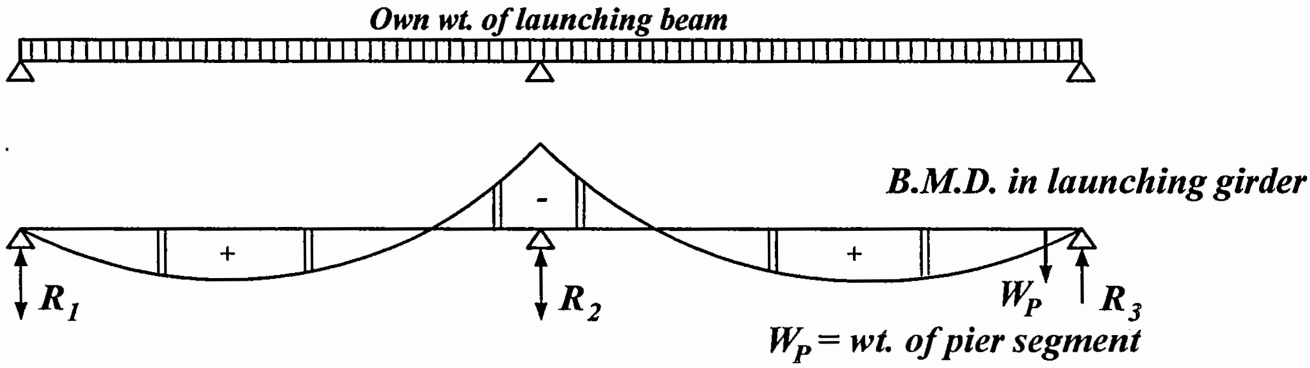
- *The launching girder is supported on bridge piers.*
- *Winches which are mounted on the launching truss girder are used to lift the bridge segments.*
- *The segments are to be fixed into the completed part. Prestressing cables are to be stressed.*

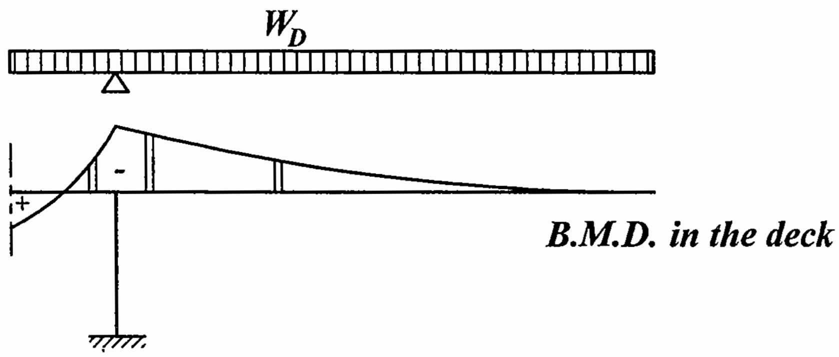


Stage 2:

- *Supporting of the launching girder to the casted part.*
- *Lifting the segments of the pier.*
- *Successive erection of the deck segments.*

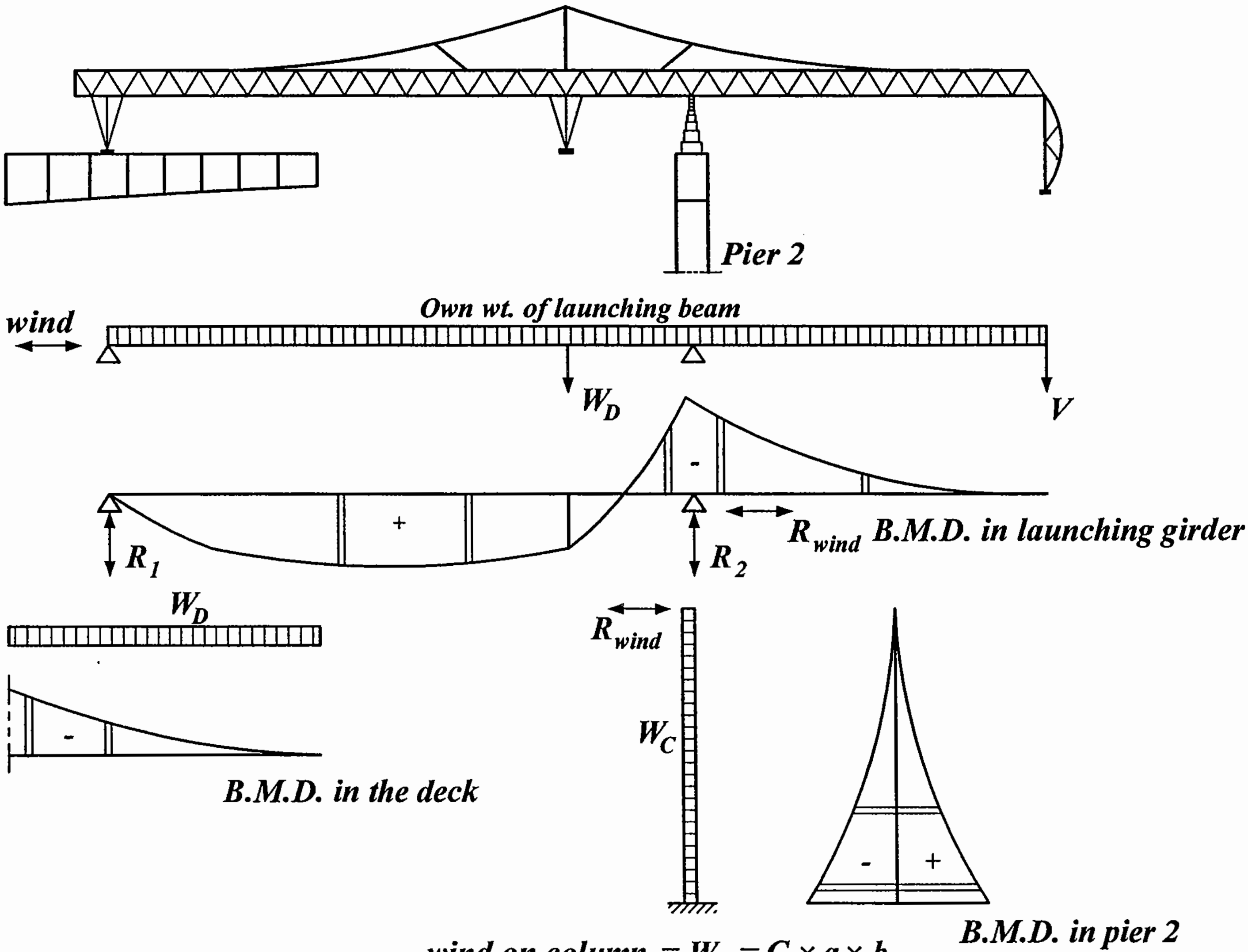






Stage 3:

- ***Propelling of the launching girder to be supported on the deck and pier.***
- ***Successive erection of the deck segments.***

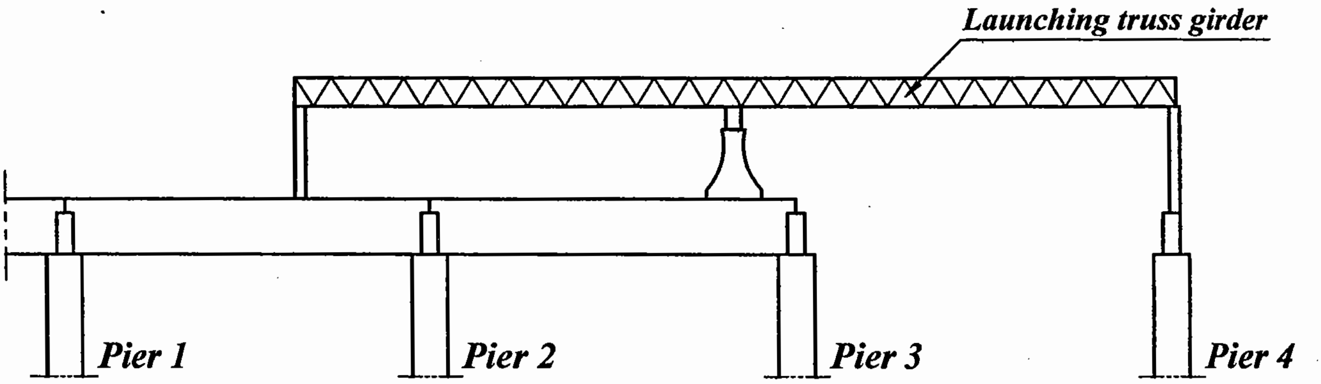


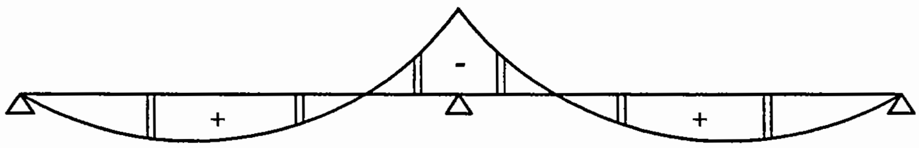
wind on column $= W_C = C \times q \times b_c$

C- Launching system for construction of pre-cast girders

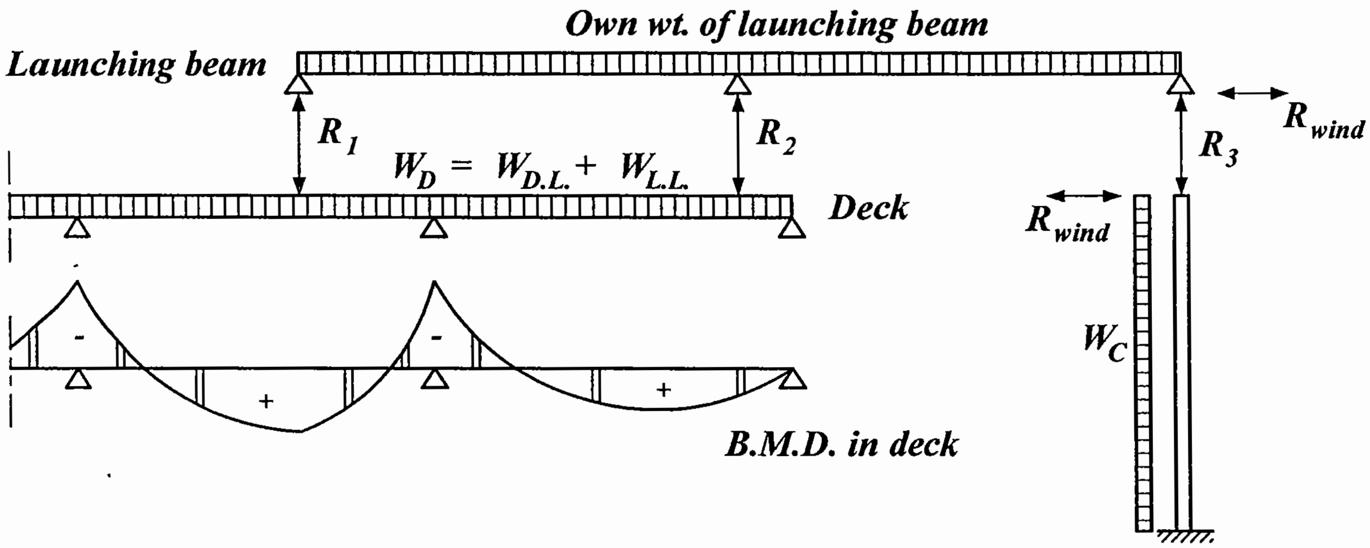
Stage 1:

- Supporting the launching girder over the deck and the pier





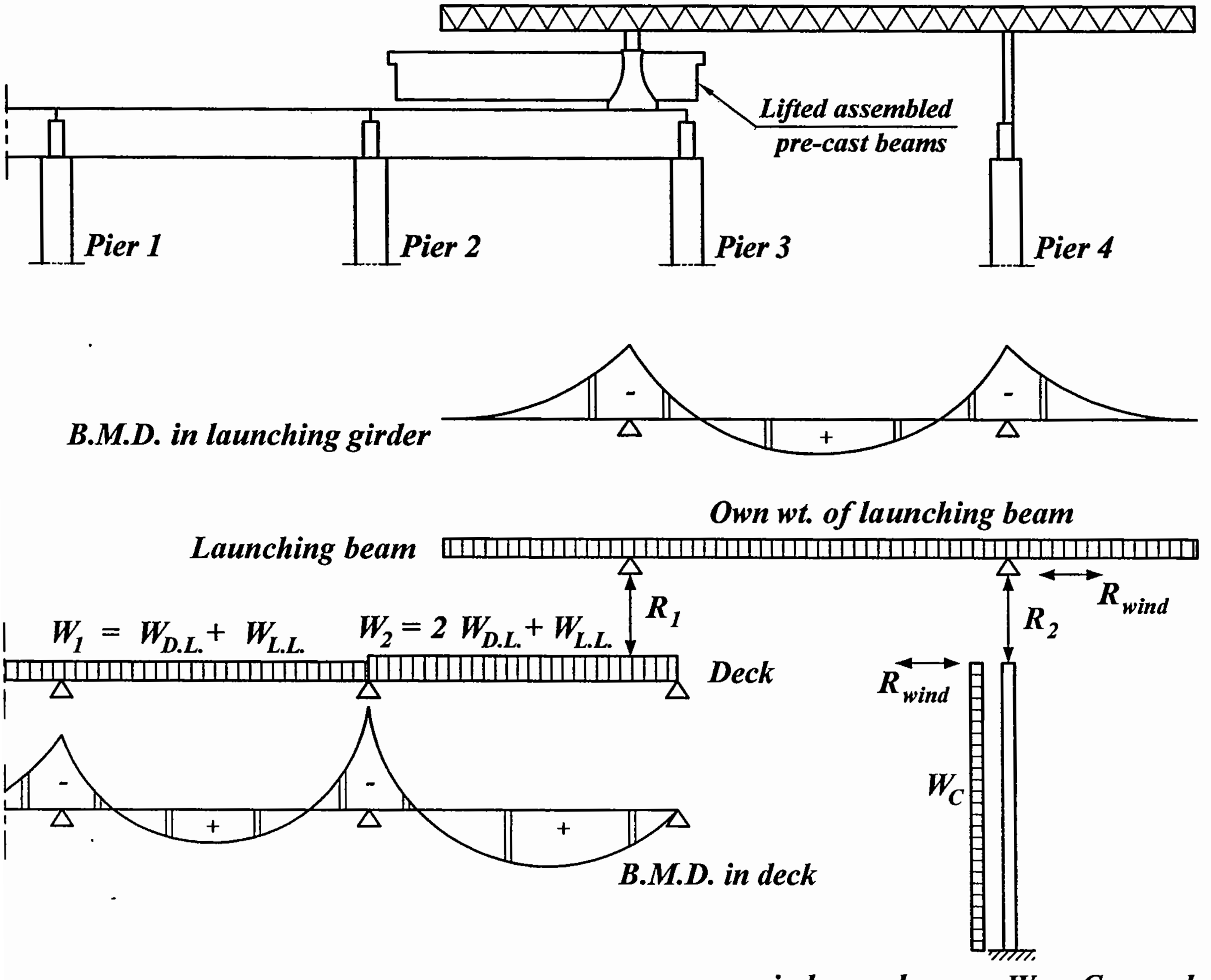
B.M.D. in launching girder



wind on column $= W_C = C \times q \times b_c$

Stage 2:

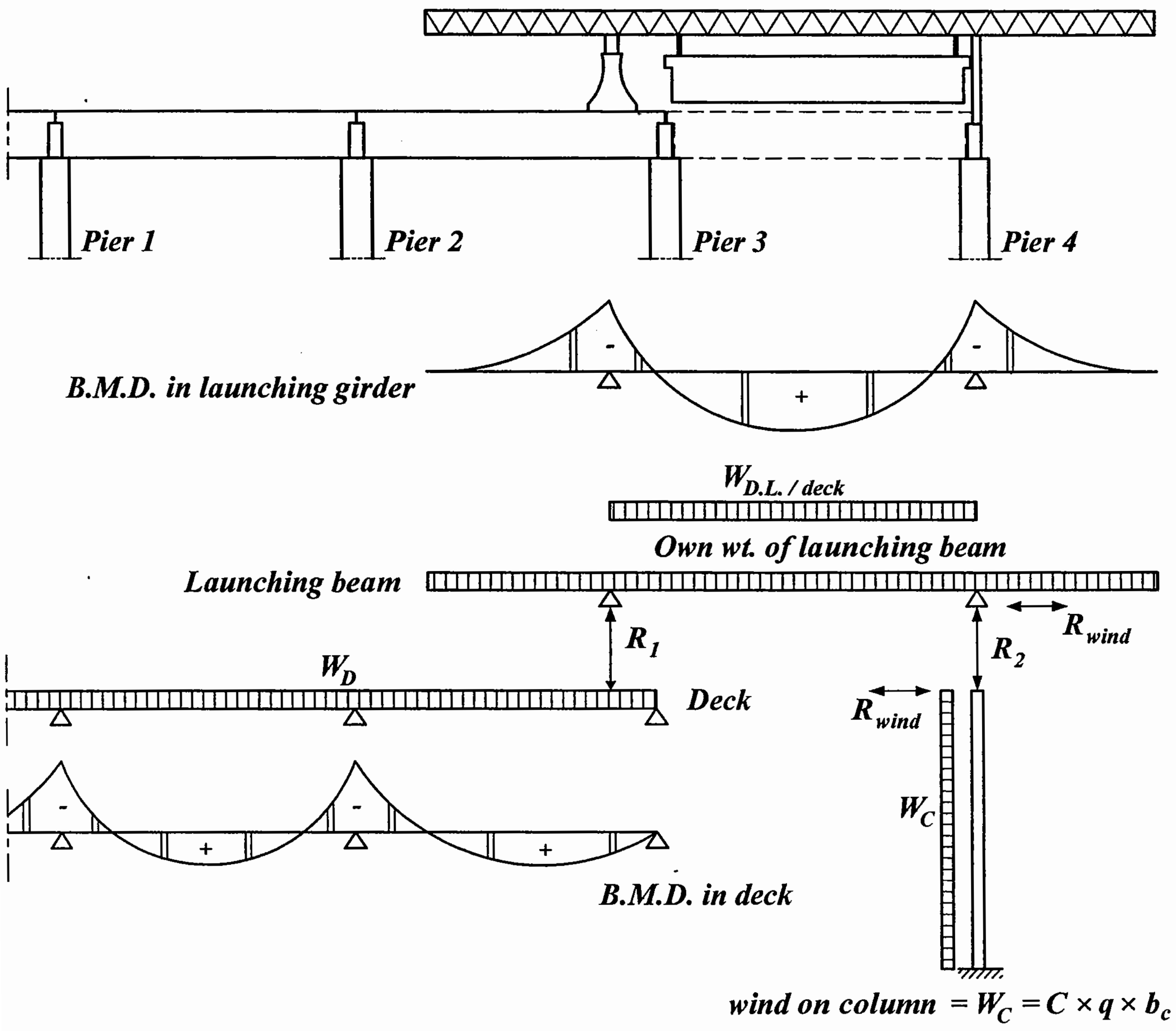
- Lifting of full scale pre-cast beam



wind on column $= W_C = C \times q \times b_c$

Stage 3:

- Placing of the pre-cast beam



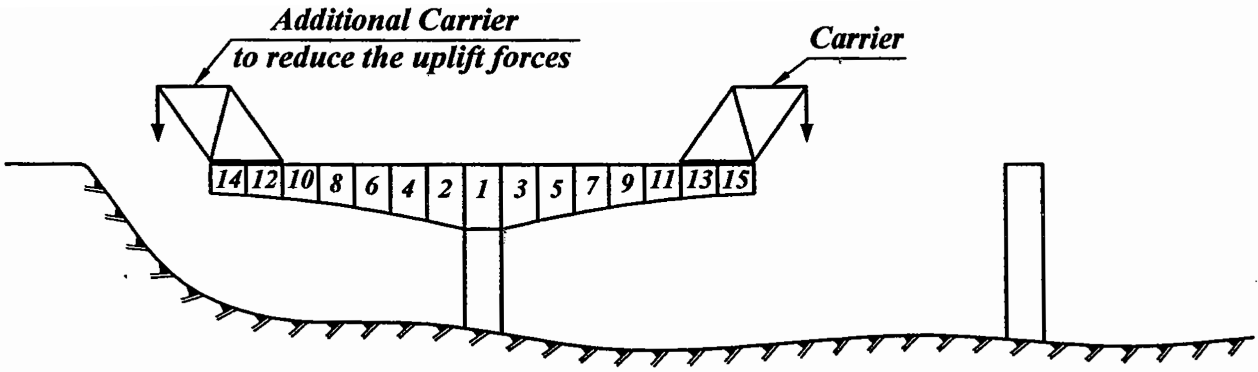
5- Classic cantilever method:

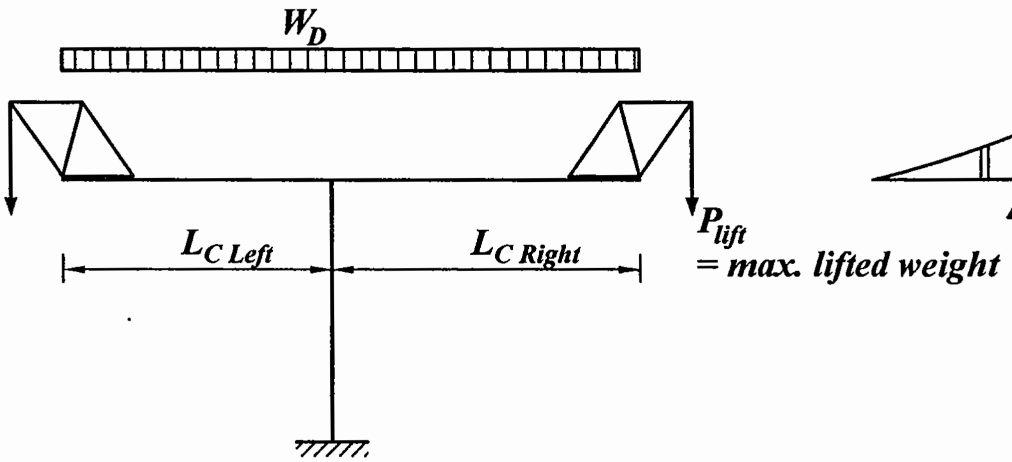
- *This system is suitable for concrete bridges with spans up to 70 - 200 m where the area under the deck is not accessible.*
- *It is used for construction of cable stayed bridge with spans 250 - 1000 m.*
- *It is used for construction of arch bridges over navigational channels or high valleys.*

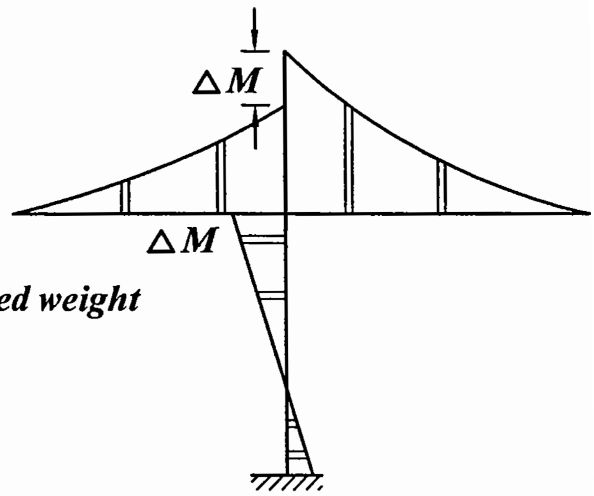
A- Classic free cantilever method

The following rules should be applied:

1. *The joint between deck and pier should be a rigid joint.*
2. *The length of the starting segment is equal or greater than the width of the pier.*
3. *The construction progress should be performed on both sides simultaneously to reduce the transferred bending into erection piers.*
4. *The weight of the winches should be taken into consideration during the erection of the bridge segments. Therefore an additional counter weight can be placed at the other side to reduce the uplift forces which should be carried by the deck.*
5. *The capacity of the lifting carriage depends on the max. weight of the lifted bridge segments.*



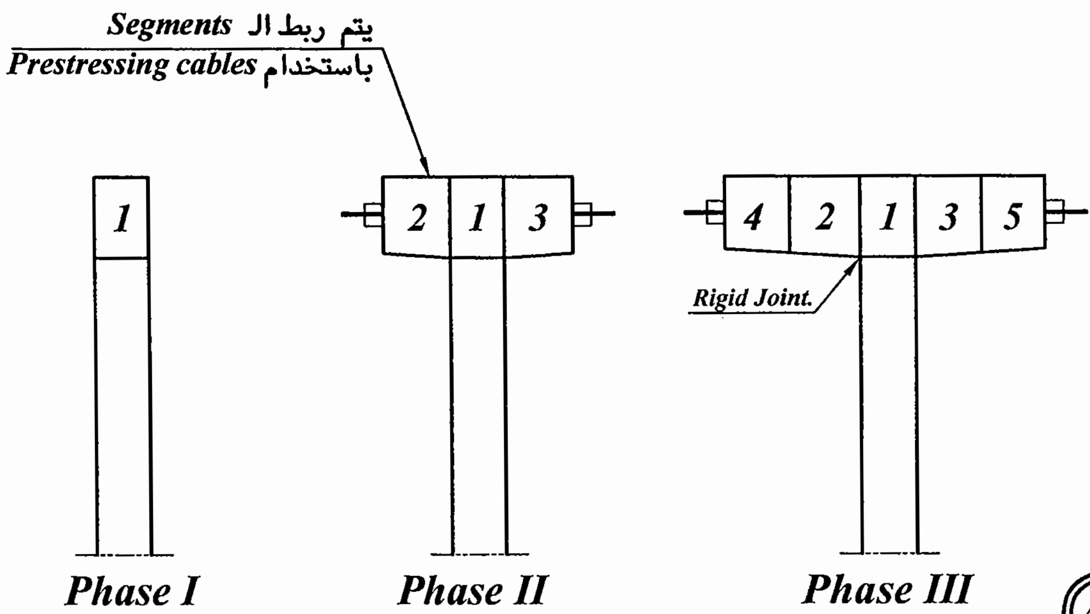




B.M.D. due to vertical loads
for case $L_{C\ Right} > L_{C\ Left}$

NOTE

The joint between deck and pier should be a rigid joint (Fixed Joint).

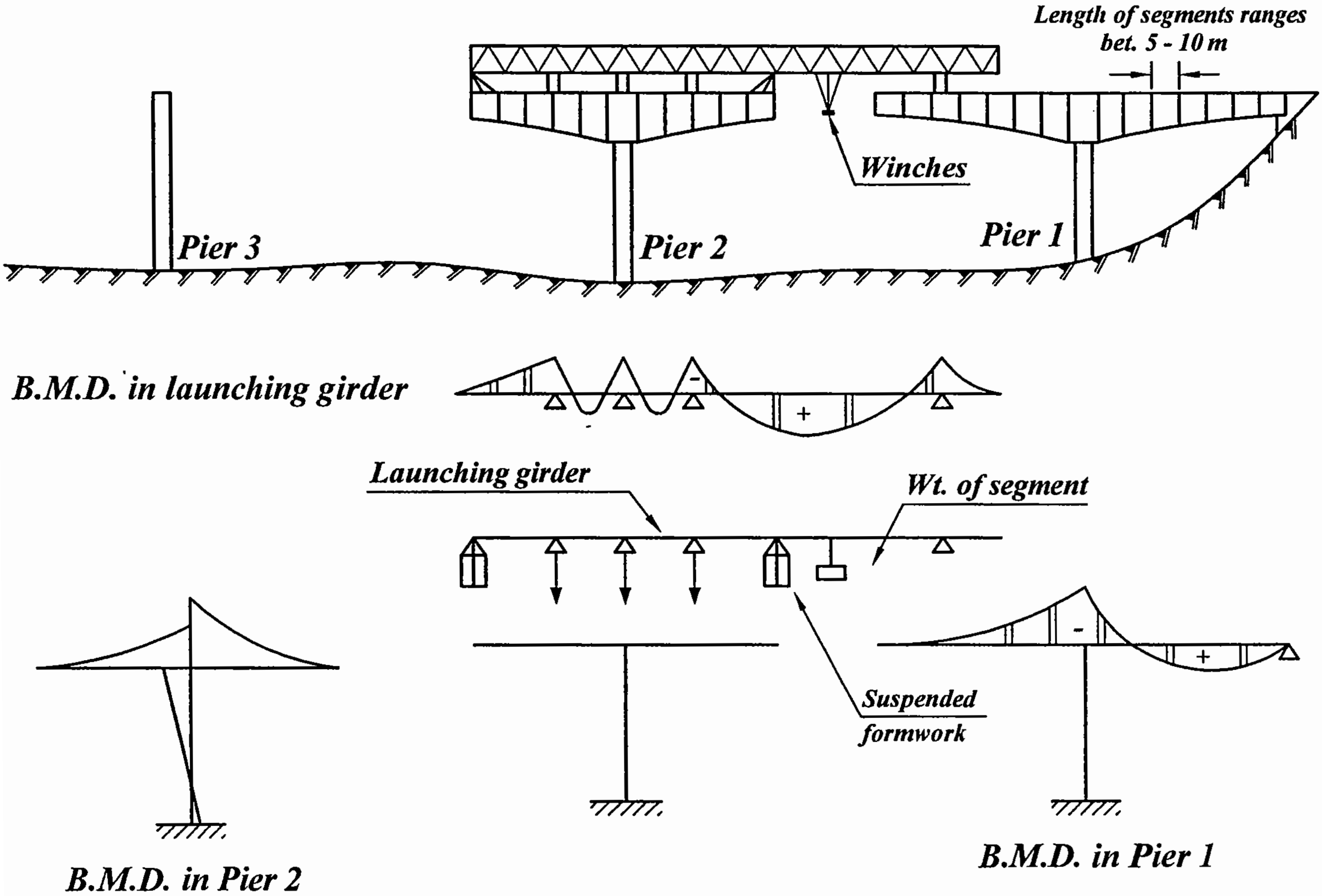


B- Classic free cantilever method with additional launching beam

In this system we use additional launching steel girder over the deck. This girder helps in material transport and segment lifting and in some cases it can be used in supporting the erection carriage of the cantilever method.

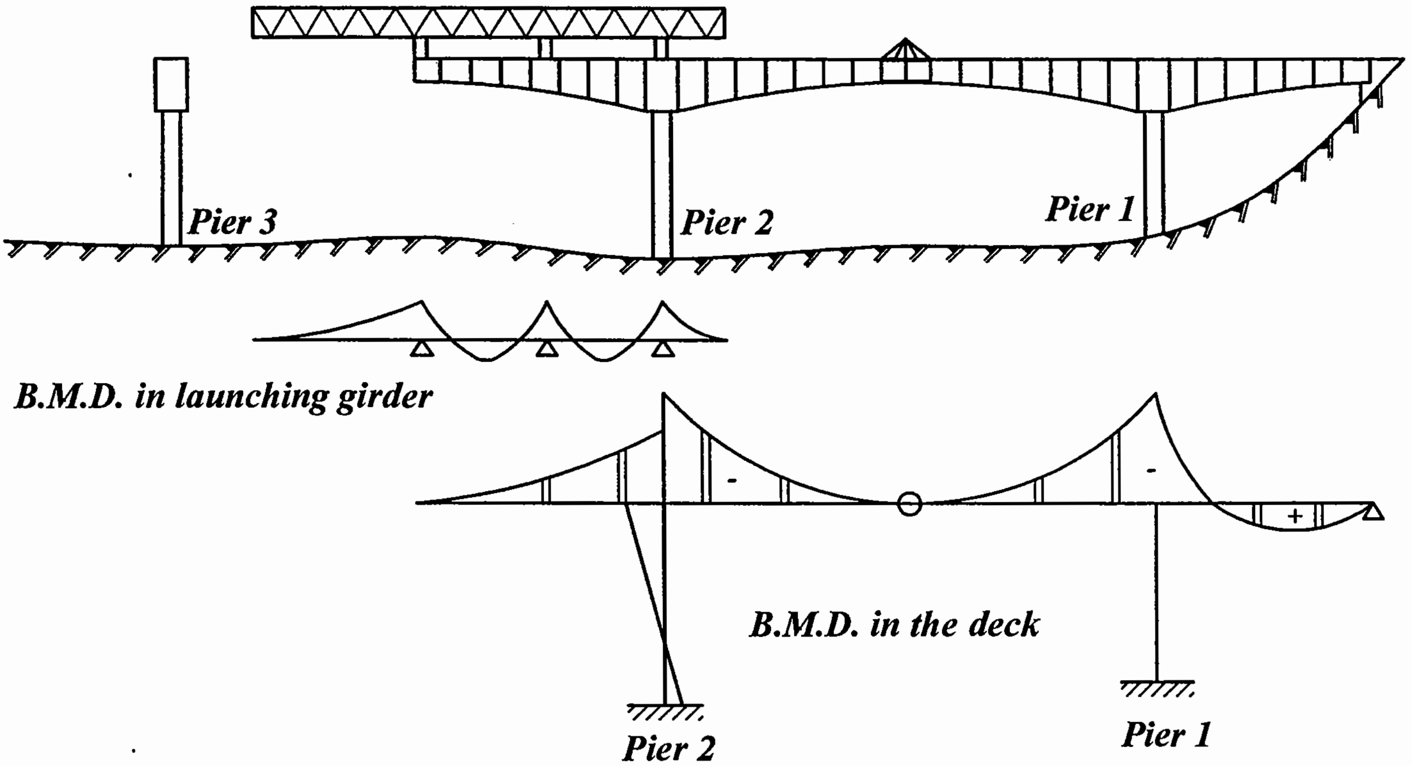
Stage 1:

- ***Cantilevering of bridge deck from pier 1 and pier 2.***
- ***The launching steel beam helps in material lifting and segments lifting.***



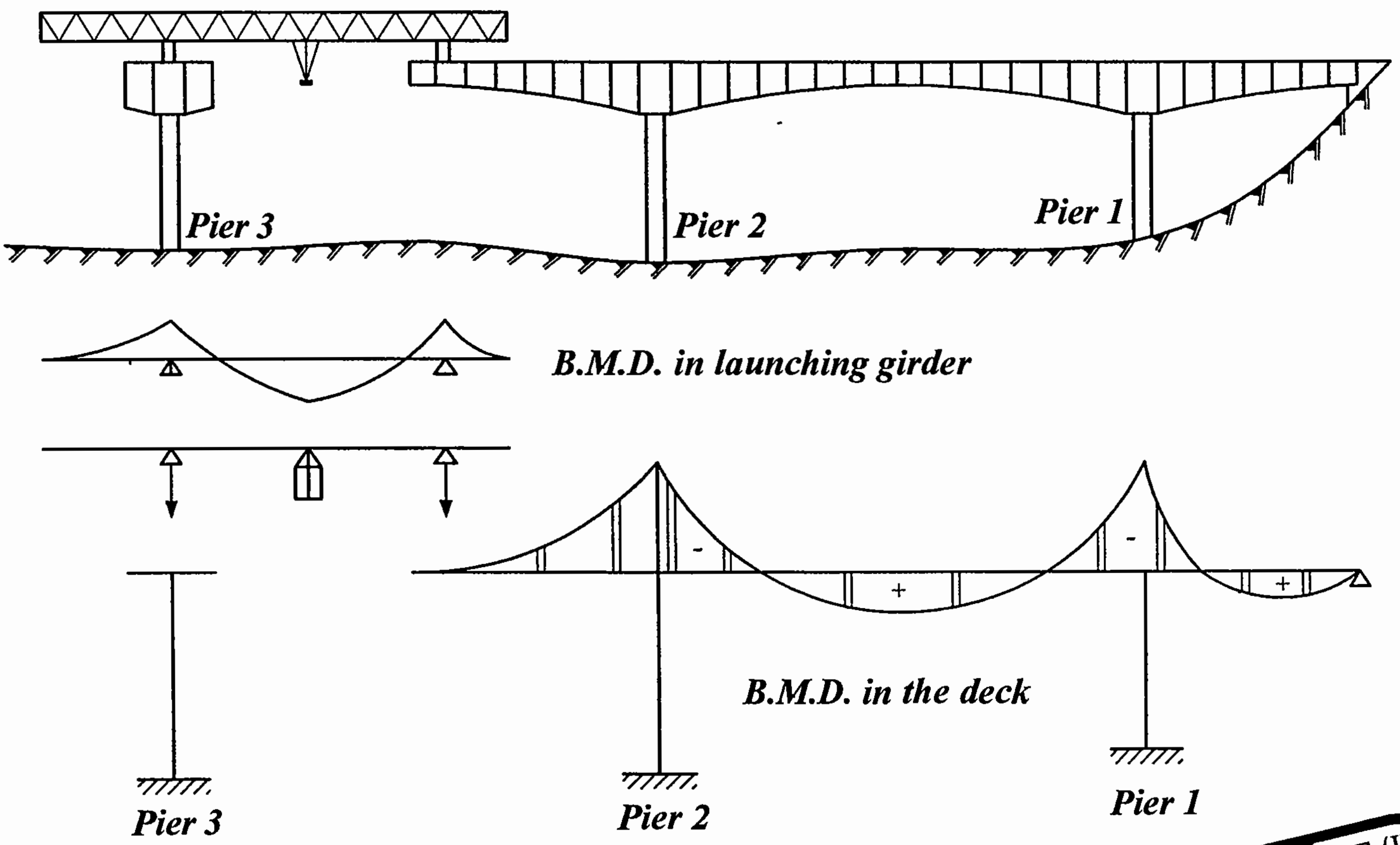
Stage 2:

- Just before closing the first intermediate span of the deck.



Stage 3:

- Cantilevering from pier 2 and pier 3.



Fixed shuttering over the whole length	***Fixed shuttering on temporary col.***	***Movable shuttering on movable columns***
1- Span up to 30 m. *2- Area under bridge is accessible.*	*1- Span up to 60 m.* *2- Area under bridge is accessible.* *3- Temporary columns are used if span greater than 30 m.*	*1- Span more than 30 m.* *2- Area under bridge is accessible.* *3- Short time construction high rate.*

Deck Push System	***Classic Cantilever method***
1- Span up to 60 - 70 m. *2- Temporary columns are used if span greater than 30 m.* *3- More economic for composite sections.*	*1- Span up to 200 m.* *2- For cable stayed bridges.* *3- For arch bridges.* *4- Very high decks.*

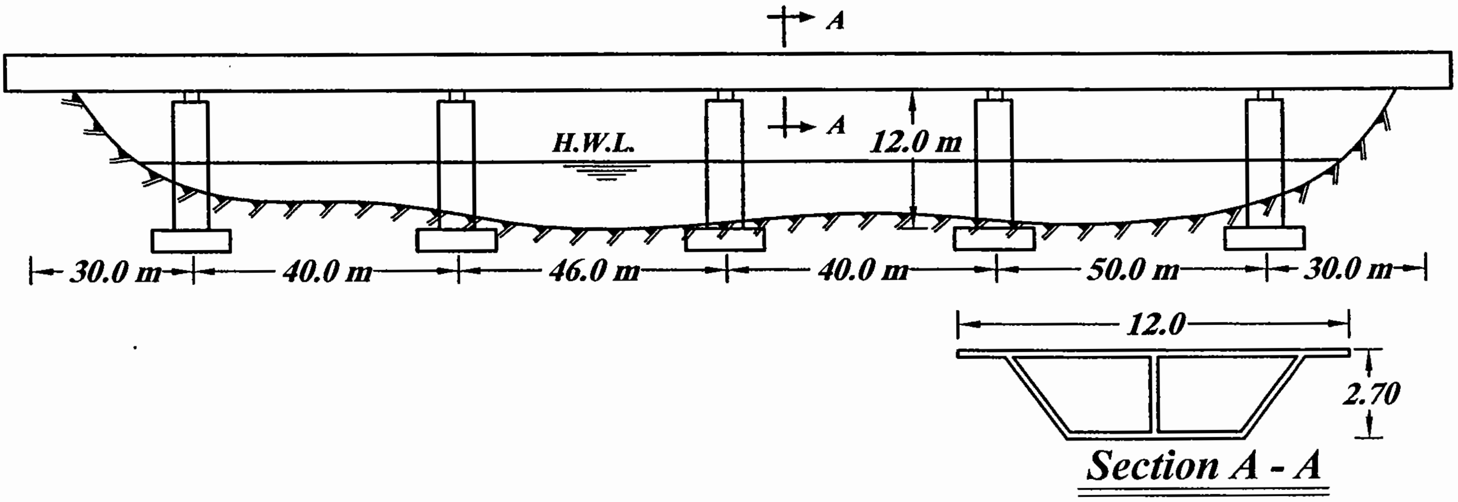
Using launching girder under the deck	***Using launching girder over the deck***
1- Small heights. *2- Span up to 40 m.* *3- Using cast in-situ technique may be better.* *4- Material delivery over the deck.*	*1- Very high decks.* *2- Span more than 60 m.* *3- Using pre-cast segmental bridge.*

Example (1):

For the following bridge systems, choose the most suitable technique for the construction of each bridge deck and explain why. Show some of the construction stages and draw each stage with diagrammatic sketches, the main internal forces (e.g. B.M.D.) in both structural elements of construction equipment and in the bridge deck.

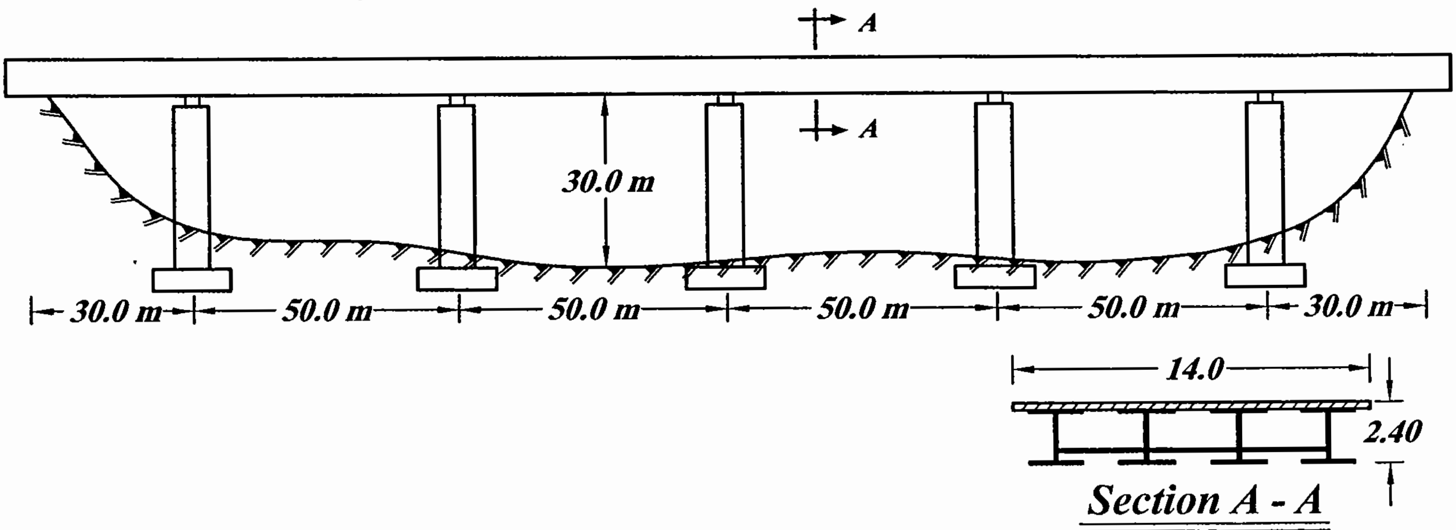
Bridge 1:

Pre-stressed Concrete Bridge with a box section
(The area under the deck is not accessible)



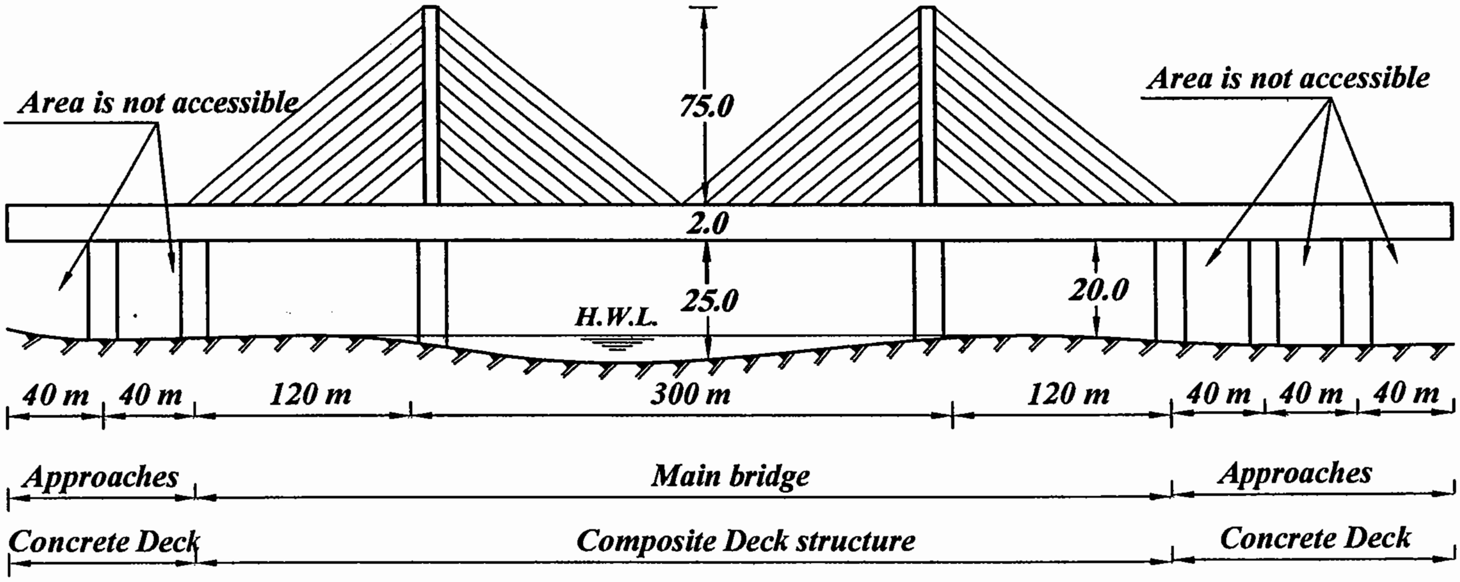
Bridge 2:

Composite Bridge Deck
(Only temporary columns are allowed)



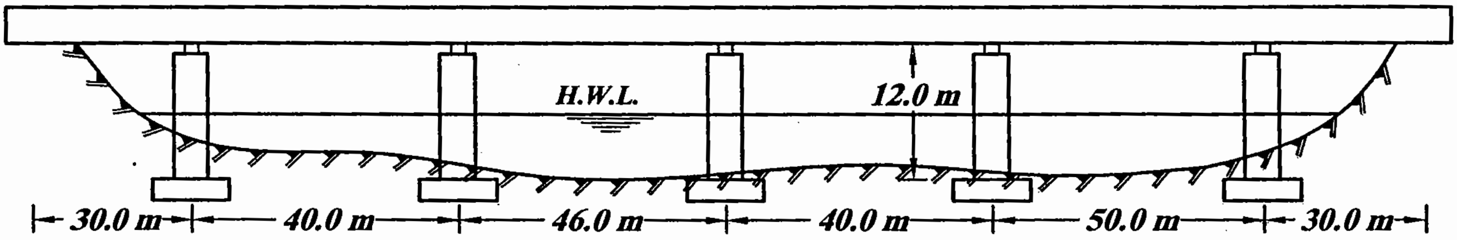
Bridge 3: Cable Stayed Bridge with approaches

Note: Differentiate between the consruction technique in main and approach spans



Bridge 1: Pre-stressed Concrete Bridge with a box section

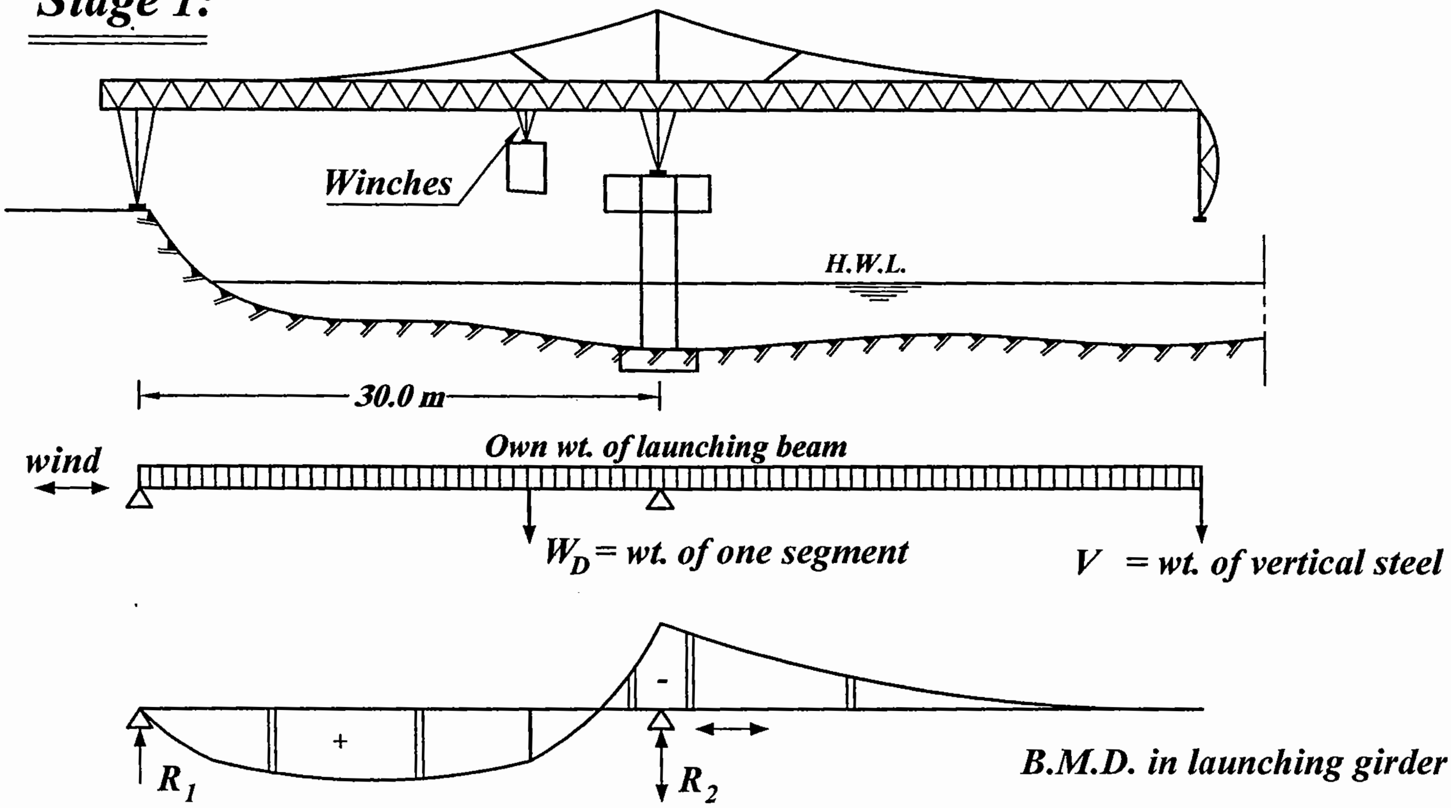
(The area under the deck is not accessible)

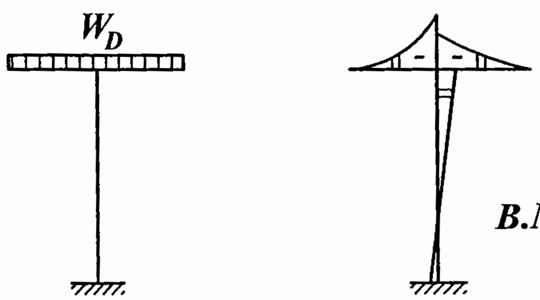


→ ***Using Segmental precast units erected using launching girder over the deck***

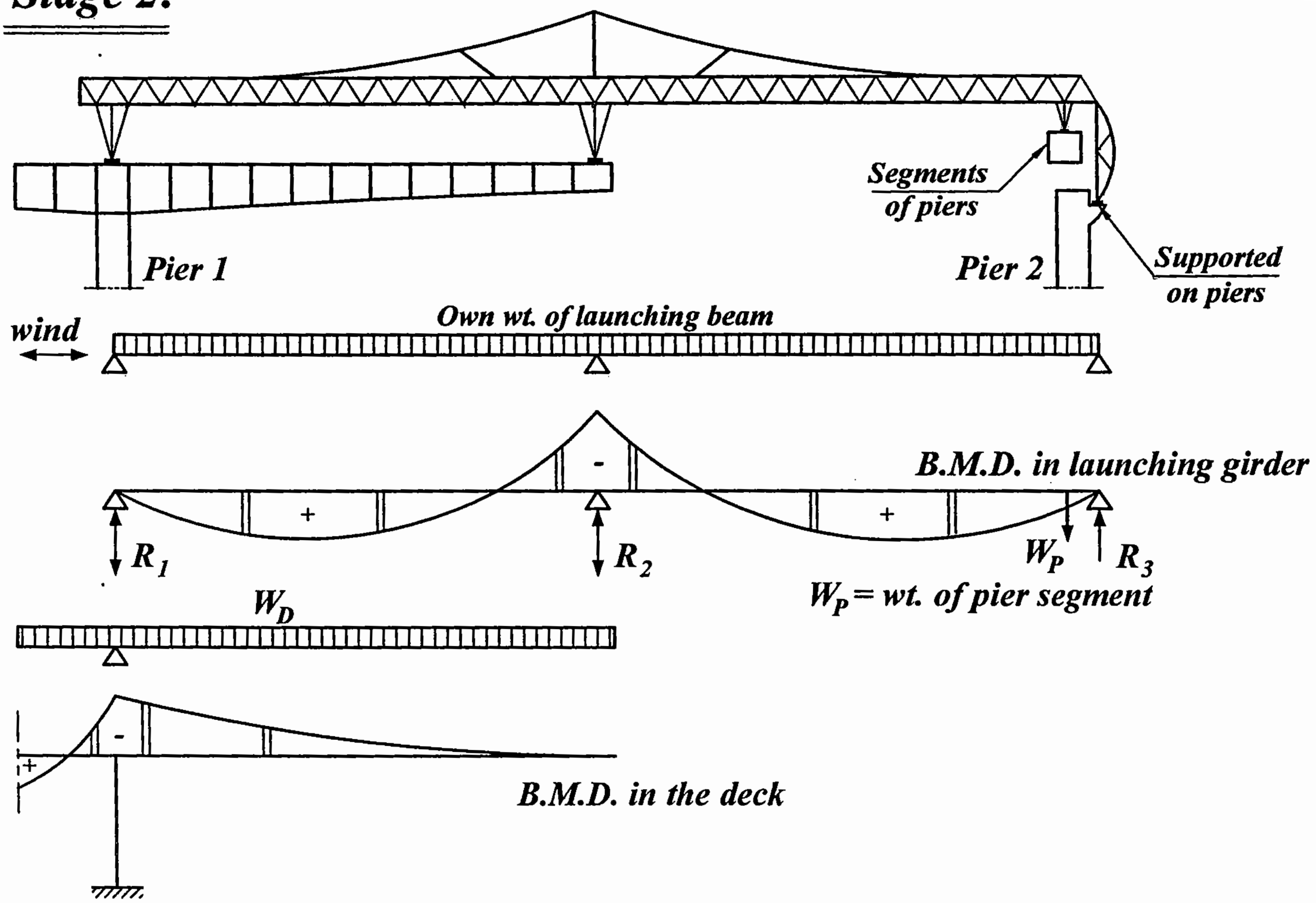
As the area under the deck isn't accessible and the cross section of the bridge using prestressed concrete enables the usage of precast segments. We erect this segments using the launching girder over the deck. As the span is less than 70 m we can use this construction technique.

Stage 1:

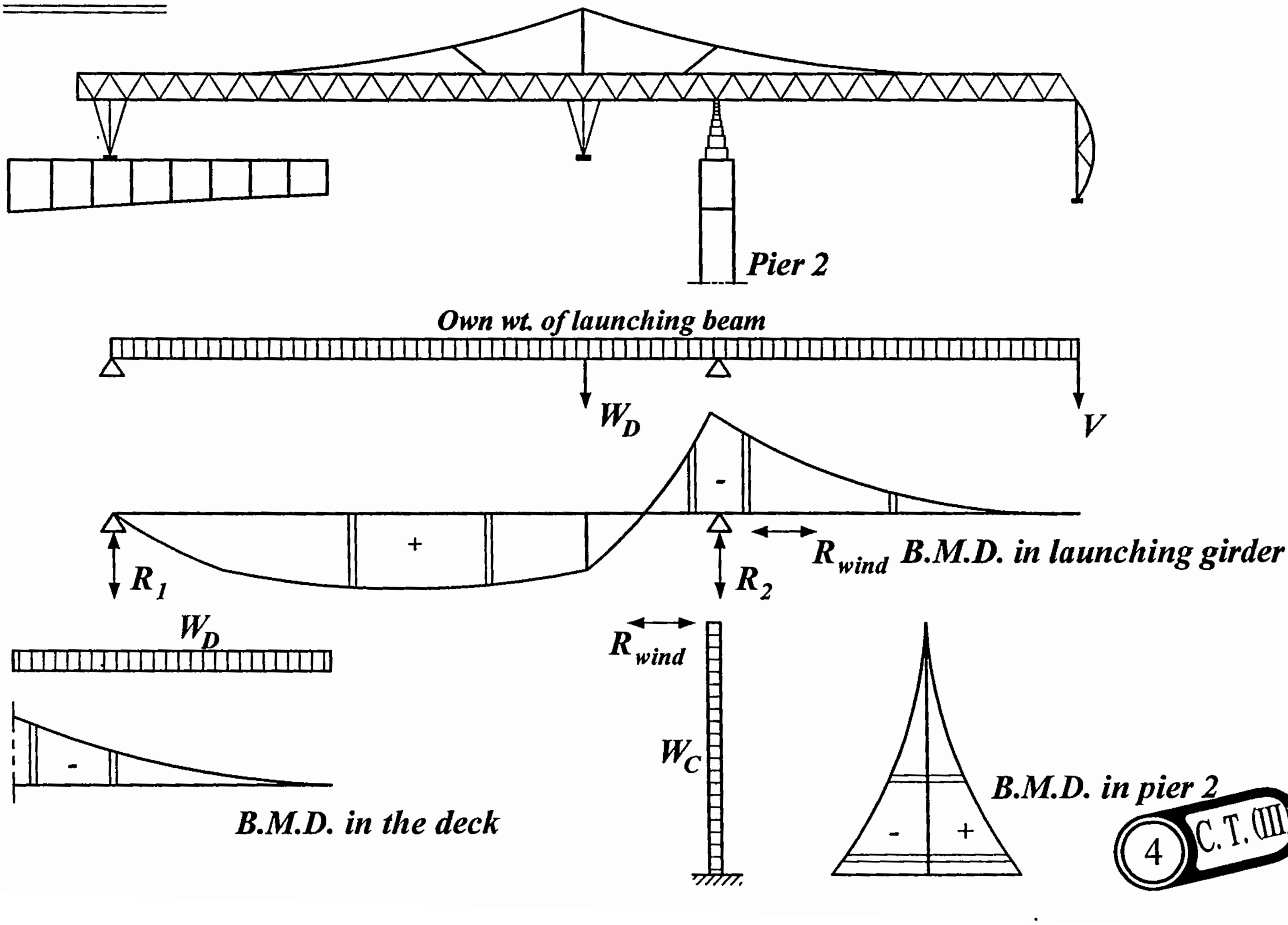




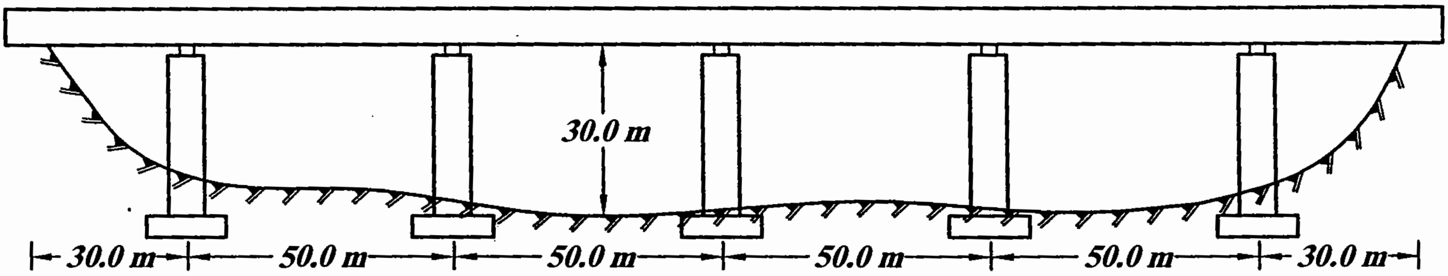
Stage 2:



Stage 3:



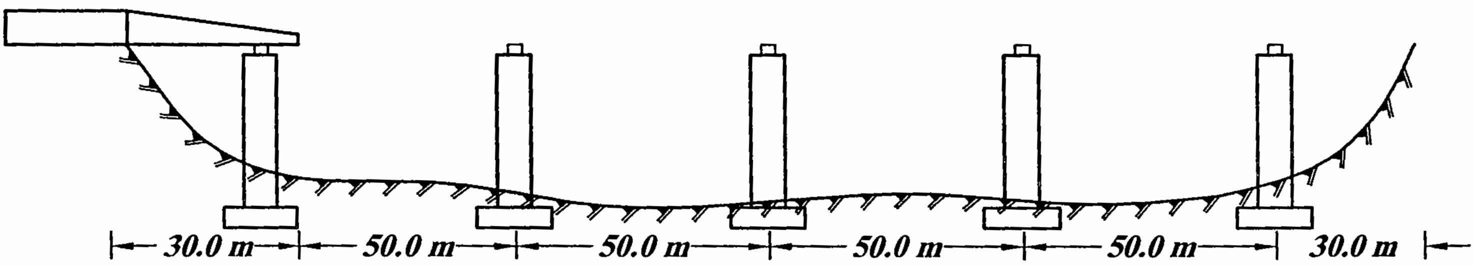
Bridge 2: Composite Bridge Deck
(Only temporary columns are allowed)



→ Using Deck Push system

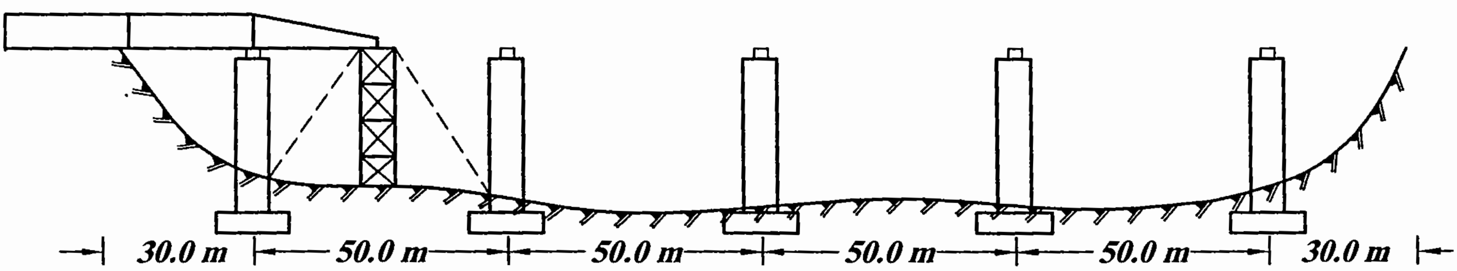
As this method is much more economical method for composite sections with big heights over the ground. It will be more economical to use shorter steel nose as temporary columns are allowed. In this system we will push the still section and then concrete slab will be casted in-situ.

Stage 1:



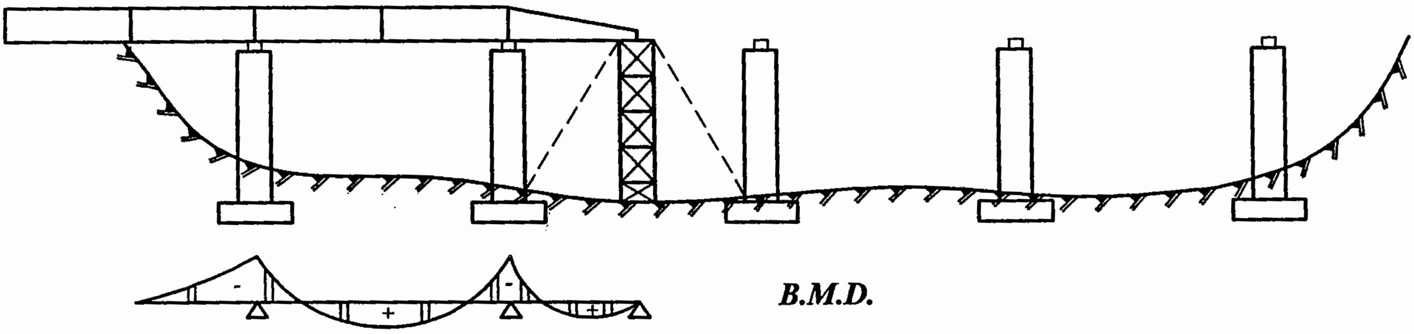
B.M.D.

Stage 2:

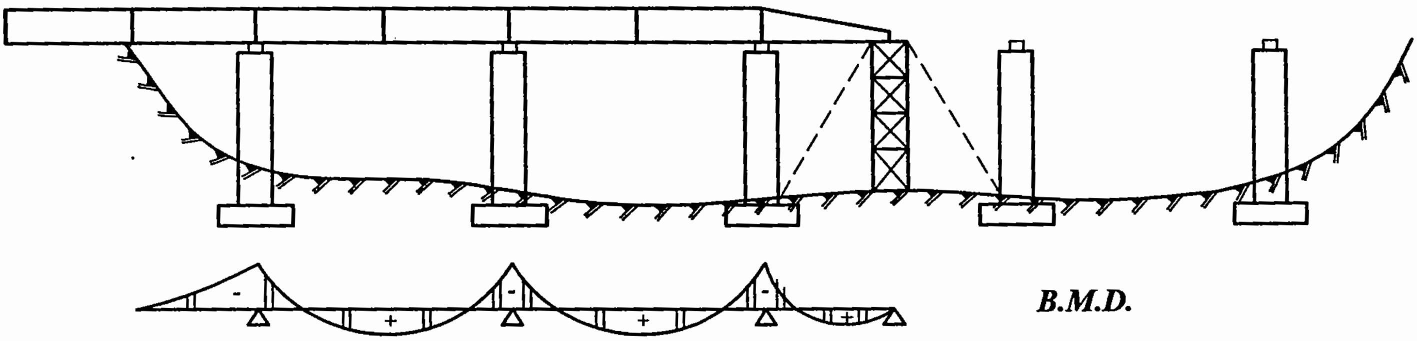


B.M.D.

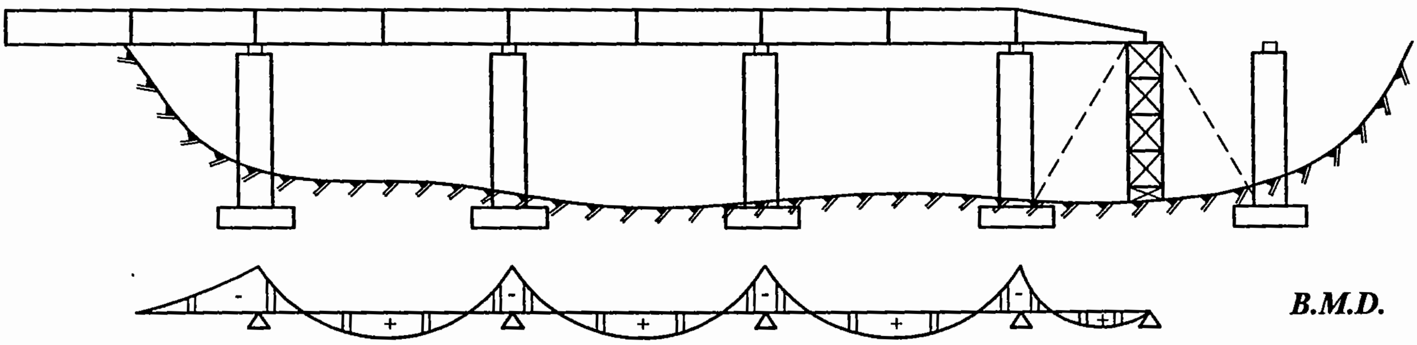
Stage 3:



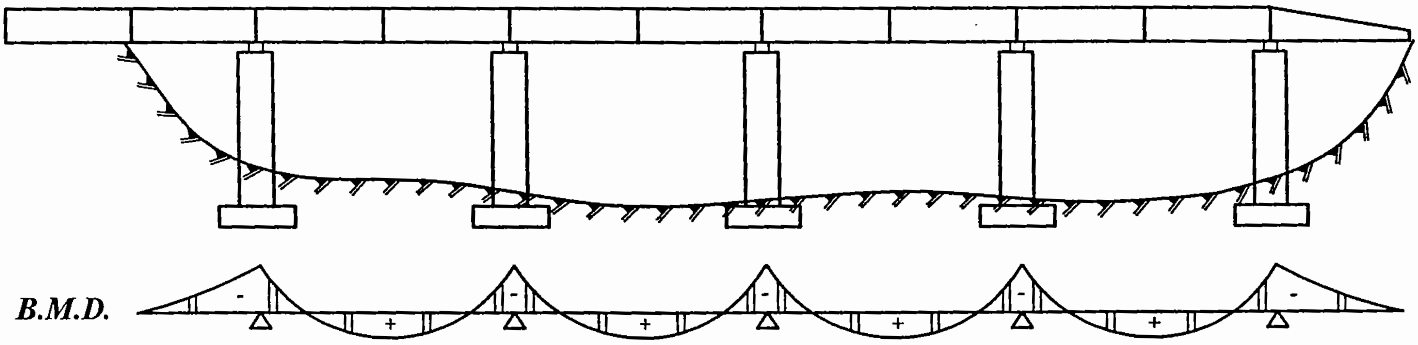
Stage 4:



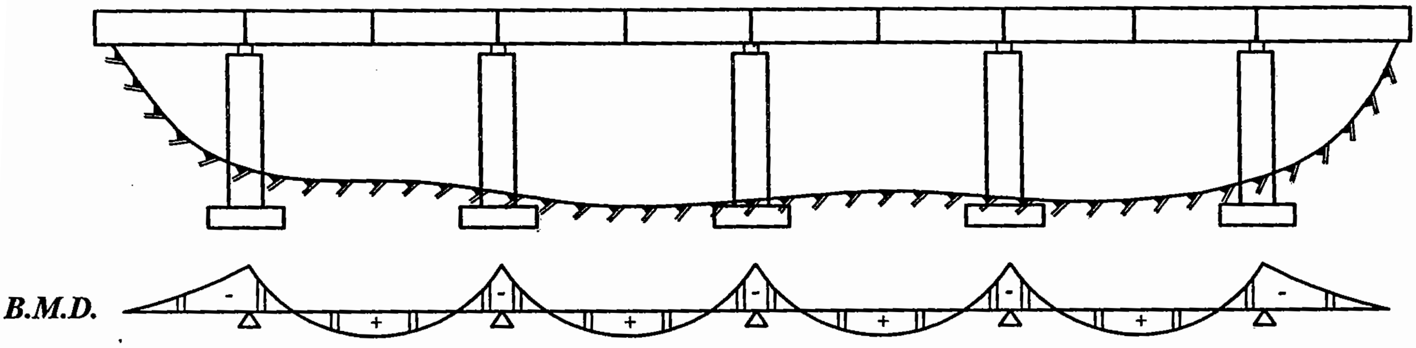
Stage 5:



Stage 6:



Stage 7:

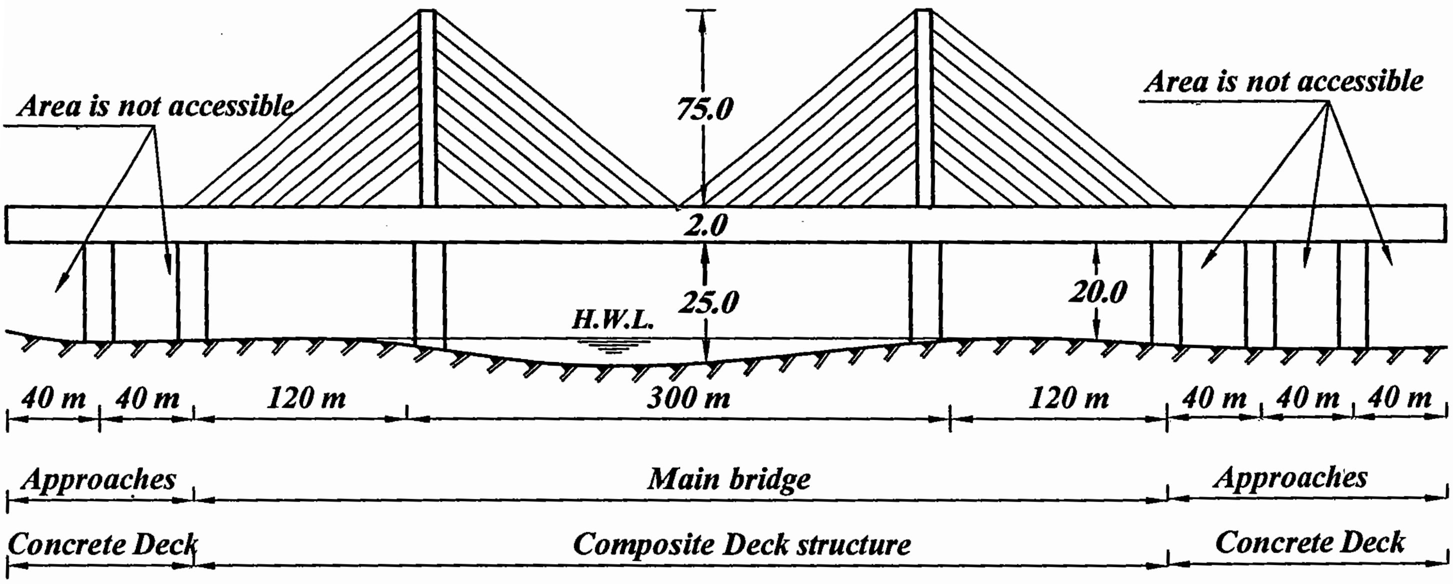


NOTE

لا يشترط رسم جميع المراحل ولكن يتم رسم مرحلتين أو ثلاثة مراحل فقط

Bridge 3: *Cable Stayed Bridge with approaches*

Note: Differentiate between the consruction technique in main and approach spans



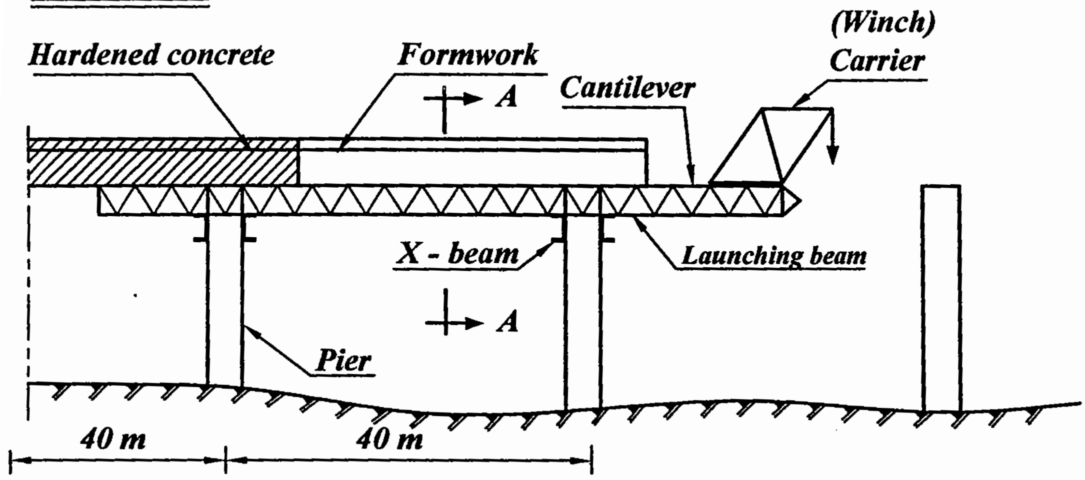
→ ***For approaches: Using Cast in-situ launching under the deck***
For Main bridge: Using Classic cantilever method.

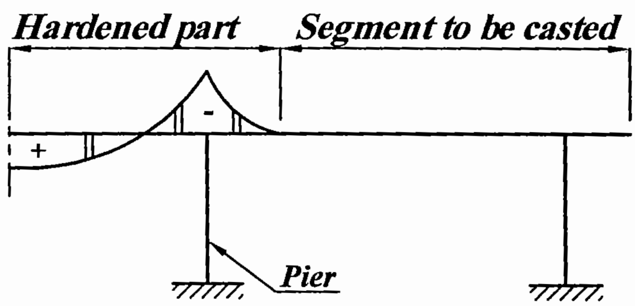
For approaches as area is not accessible and span = 40 m and small height, that is why using launching under the deck is the best system

For main bridge as it is cable stayed bridge, cantilever method is the required technique.

For approaches

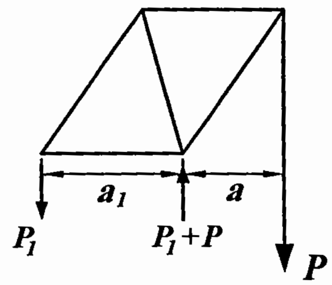
Stage 1:

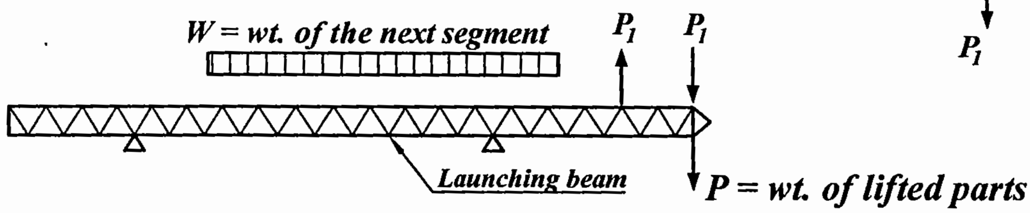




B.M.D. in the deck

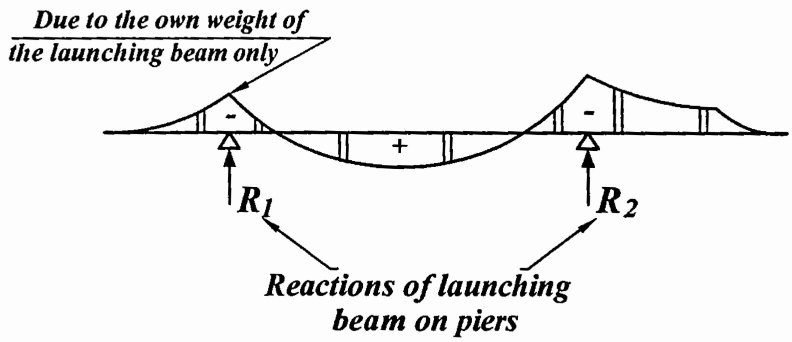
Lifting carriage





$M = P \times a$

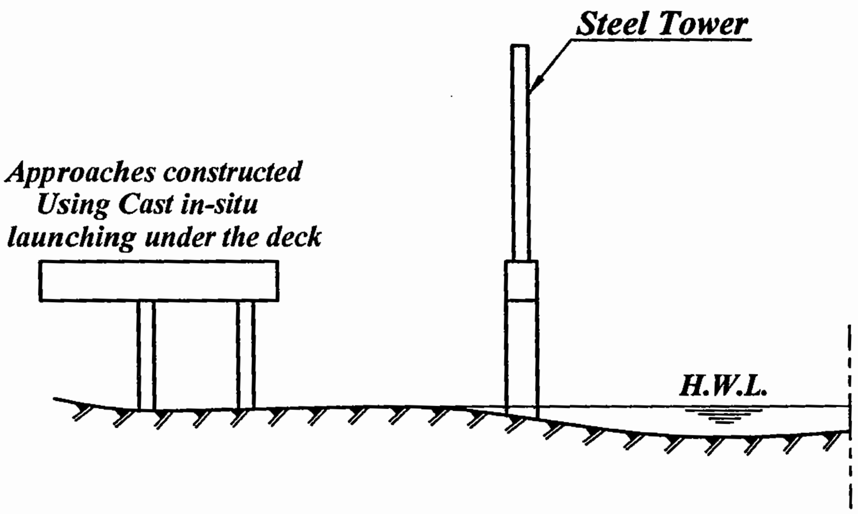
$P_1 = M / a_1$



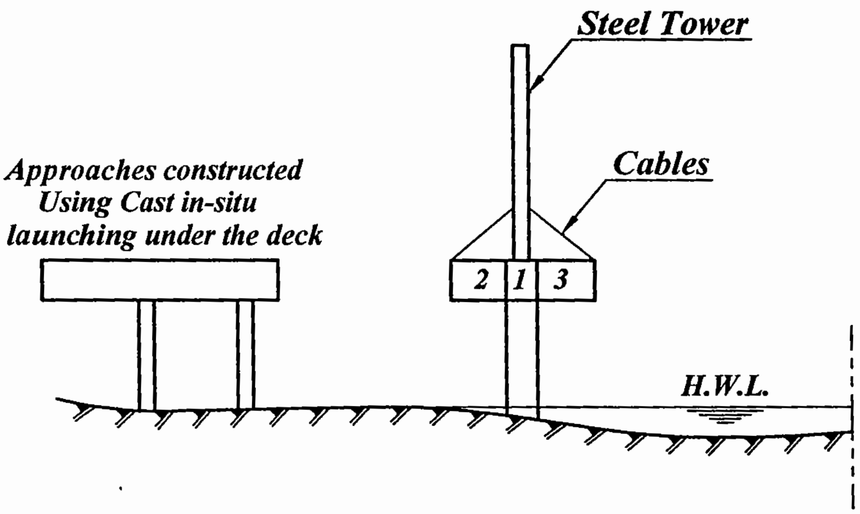
B.M.D. in launching girder

For main bridge

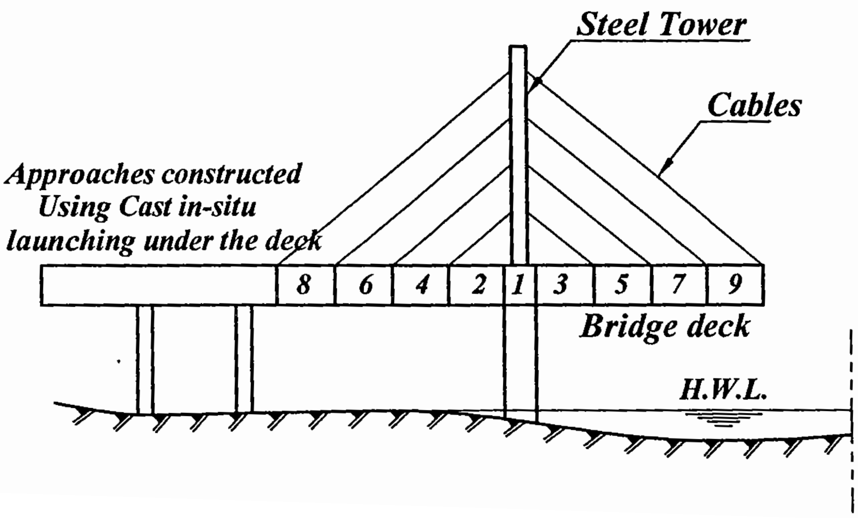
Stage 1: Erection of steel tower



Stage 2: Erection of Cables



Stage 3: Finishing Erection of Cables



Example (2):

Indicate if the following statements is right (✓) or is wrong (X)

1- Assuming the fulfillment of the technical safety during construction of a bridge, the aesthetical aspect is the most important aspect for the choice of the construction technique. (X)

Correct

Assuming the fulfillment of the technical safety during construction of a bridge, the economical aspect is the most important aspect for the choice of the construction technique.

2- Over-stressing and residual stresses of the different structural elements of the end bridge should be avoided during the construction of the bridge. (✓)

3- For bridge construction in Egypt, the deck push system is the most frequent used technique. (X)

Correct

For bridge construction in Egypt, the fixed shuttering system is the most frequent used technique.

4- Wooden shuttering is the much more durable than metal shuttering. (X)

Correct

Metal shuttering is the much more durable than wooden shuttering.

5- For the construction of a cable stayed bridge the launching method is the most suitable method. (X)

Correct

For the construction of a cable stayed bridge the cantilever method is the most suitable method.

6- For the application of the deck push system, the connection between deck and piers must be hinged. (✓)

7- The pre-slab technique can be adapted with a max. spacing between longitudinal beams of 6 m. (X)

Correct

The pre-slab technique can be adapted with a max. spacing between longitudinal beams of 3 m.

8- Launching method with truss girder over the deck level can be combined with the pre-cast technique to construct segmental concrete bridges with spans up to 60 m over very high valley. (✓)

9- If the area under the bridge location is not available to arrange shuttering during the construction of bridges with spans ranges between 30 and 60 m, the cantilever method is the most suitable technique to be adapted. (X)

Correct

If the area under the bridge location is not available to arrange shuttering during the construction of bridges with spans ranges between 30 and 60 m, the launching under the deck method is the most suitable technique to be adapted.

10- For construction of a composite deck of a bridge with a height of 30 m over the water level and spans up to 50 m, the push deck system is an alternative, which could be adapted. (X)

Correct

For construction of a composite deck of a bridge with a height of 30 m over the water level and spans up to 50 m, the launching over the deck system is an alternative, which could be adapted.

11- Pre-cast technique is the most suitable method for construction of bridges with steel decks and spans up to 30 m. (X)

Correct

***Deck Push System** is the most suitable method for construction of bridges with steel decks and spans up to 30 m.*

12- The construction rate of high concrete towers using climbing (jumping) forms is faster than the use of the slip forms. (X)

Correct

*The construction rate of high concrete towers using **slip forms** is faster than the use of **the climbing forms.***

13- During the deck pushing, the produced friction forces between the deck and piers are close to be zero. (X)

Correct

*During the deck pushing, the produced friction forces between the deck and piers **must be considered in design.***

14- The use of additional beams (aids beams) with the launching system reduces the internal forces in the deck during the construction. (✓)

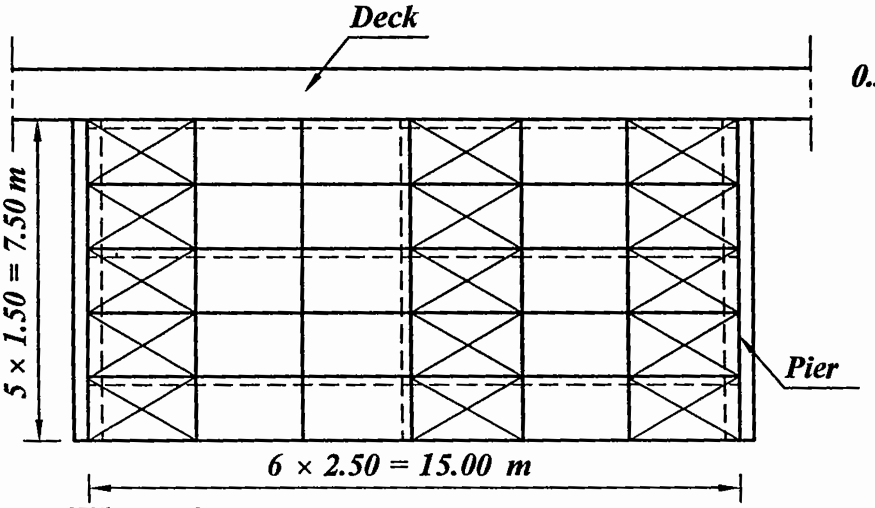
15- During the construction of a bridge using the classic cantilever method, the influnce of the wind load can be neglected. (X)

Correct

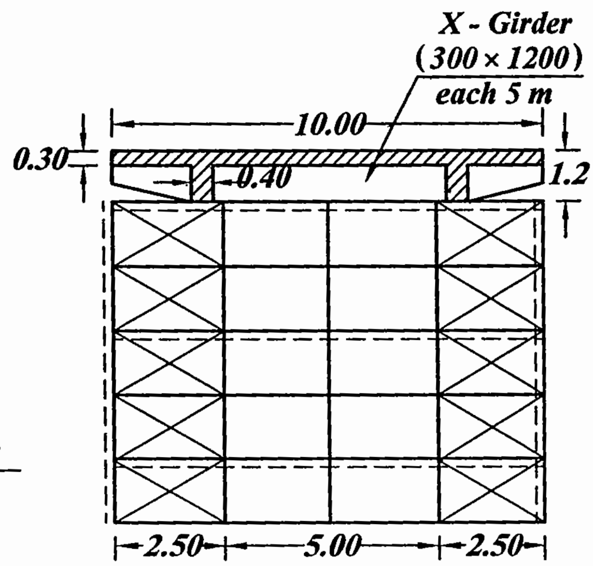
*During the deck pushing, the produced friction forces between the deck the influnce of the wind load **can not be** neglected.*

Example (3):

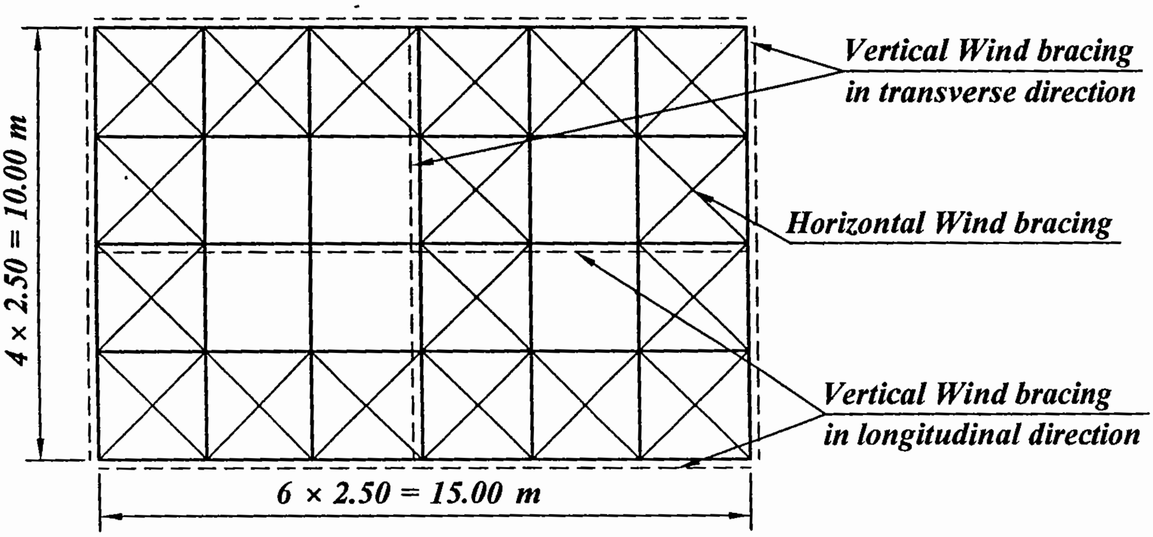
For the following bridge system, a fixed wooden shuttering on the whole length of the bridge was chosen for the construction of each bridge span. For all the shuttering elements, Calculate the design forces using the simplified method, Design the different structural elements of the shuttering system.



Elevation (Longitudinal bracing)



(Transverse bracing)



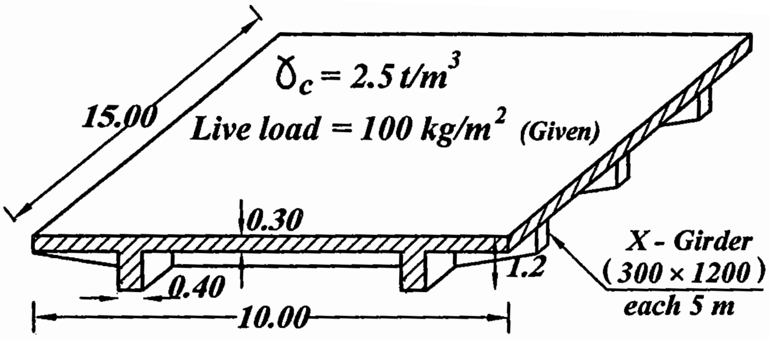
Plan

Given:

- ***For Wood***
  - *Allowable strength in bending and tension* $(F_b) = 72\ kg/cm^2$
  - *Allowable strength in compression* $(F_b) = 56\ kg/cm^2$
  - *Allowable shear strength* $(F_s) = 14\ kg/cm^2$
  - *Available dimension of wood elements* 8×8, 10×10, 12×12 *cm*
- ***Live load*** $= 100\ kg/m^2$
- ***Wind load***
  - *Pressure intensity of wind* $(q) = 70\ kg/m^2$
  - *Drag factor for deck* $(c) = 1.50$
  - *Drag factor for shuttering* $(c) = 2.00$

Solution:

Vertical member:



$$P_{Total} = P_{D.L.} + P_{L.L.} + P_{Wind}$$

$$\text{No. of X-girder} = \frac{Span}{Spacing} = \frac{15}{5} = 3$$

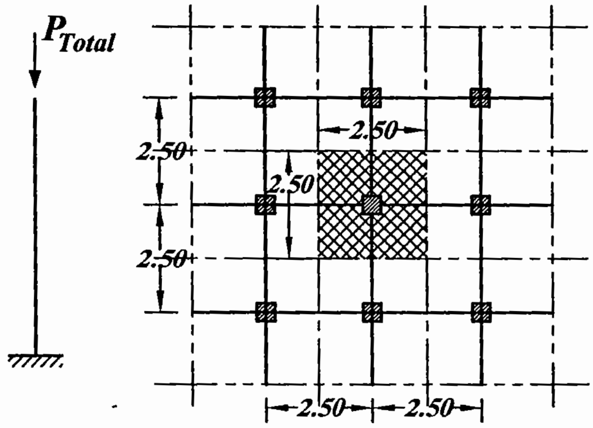
$$\text{Weight of X-girder} = \text{No. of X-girders} \times L \times b \times (t - t_s) \times \gamma_c$$

$$\text{Weight of X-girder} = 3 \times 10 \times 0.3 \times (1.2 - 0.3) \times 2.5 = 20.25\ t$$

$$\text{Own weight} = \frac{\text{wt. of slab} + \text{wt. of main beams} + \text{wt. of X-girders}}{Area}$$

$$= \frac{15 \times 10 \times 0.3 \times 2.5 + 2 \times 15 \times 0.4 \times (1.2 - 0.3) \times 2.5 + 20.25}{15 \times 10}$$

$$= 1.065\ t/m^2$$



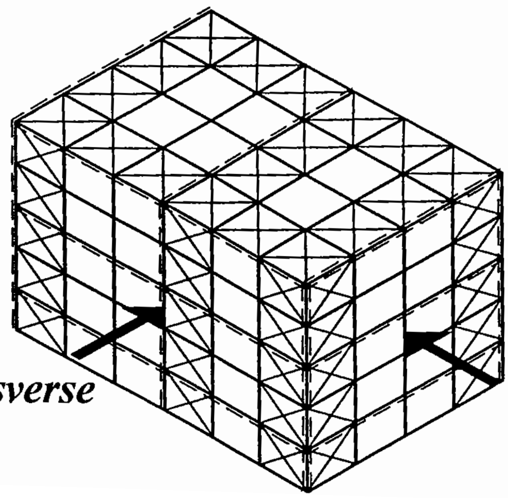
→ $P_{D.L.} = 1.065 \times 2.5 \times 2.5 = 6.66\ t$

$P_{L.L.} = 0.1 \times 2.5 \times 2.5 = 0.625\ t$

To get P_{Wind} we have to calculate the forces on the horizontal & vertical bracing

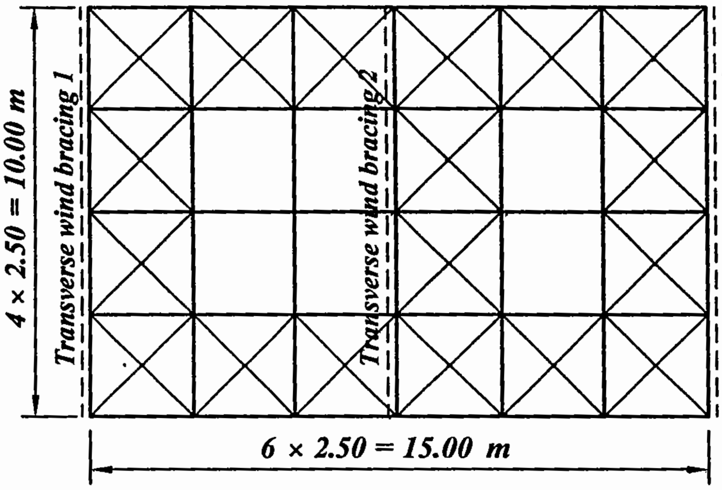
NOTE

يتم حساب القوى الناتجة عن الرياح فى *Vertical member* مرة نتيجة تأثير الرياح فى الاتجاه العرضى *Transverse direction* ومرة أخرى نتيجة تأثير الرياح فى الاتجاه الطولى *Longitudinal direction*

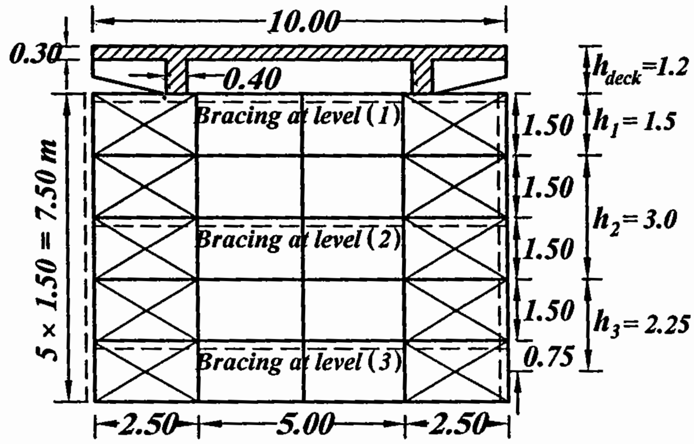


Horizontal bracing:

a- Wind in transverse direction



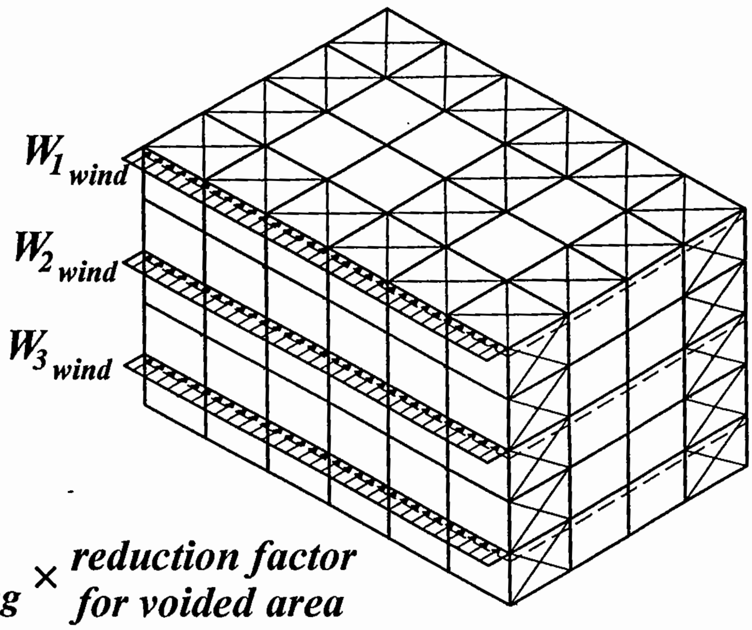
Plan



(Transverse bracing)

$$W_{wind} = C \times q \times h$$

يتم حساب القوى الناتجة عن الرياح
عند كل منسوب لل **bracing**



For level (1)

$$W_{1\,wind} = C_{deck} \times q \times h_{deck} + C_{shuttering} \times q \times h_{shuttering} \times \text{reduction factor for voided area}$$

$$= 1.5 \times 0.07 \times 1.2 + 2.0 \times 0.07 \times 1.5 \times 0.3 = 0.189\ t/m`$$

NOTE

Assume reduction factor for voided area = 0.3 - 0.5 if not given

For level (2)

$$W_{2\,wind} = C_{shuttering} \times q \times h_{shuttering} \times \text{reduction factor for voided area}$$

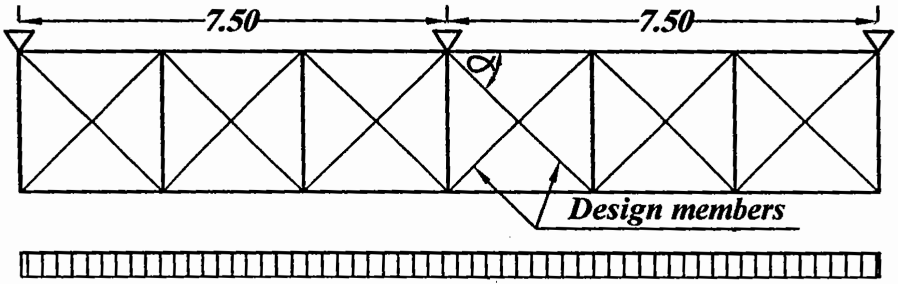
$$= 2.0 \times 0.07 \times 3.0 \times 0.3 = 0.126\ t/m`$$

For level (3)

$$W_{3\,wind} = C_{shuttering} \times q \times h_{shuttering} \times \text{reduction factor for voided area}$$

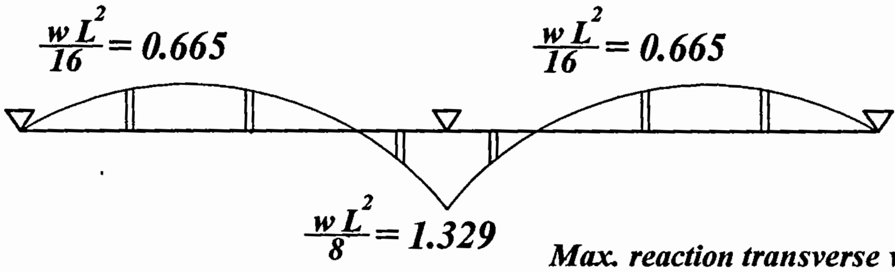
$$= 2.0 \times 0.07 \times 2.25 \times 0.3 = 0.0945 \ t/m`$$

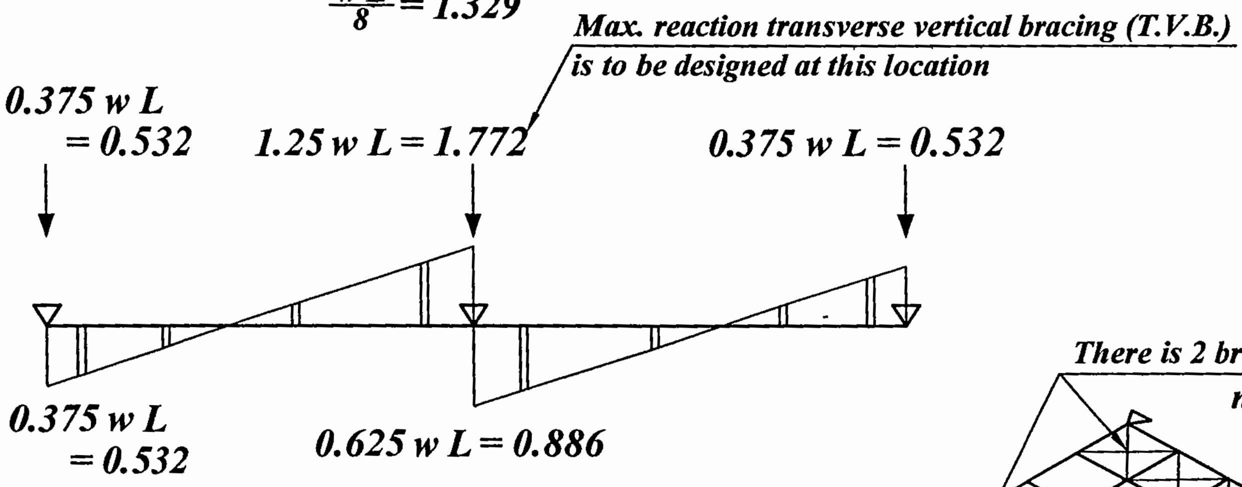
⟶ Solve for bigger value of W_{Wind} which is on level 1

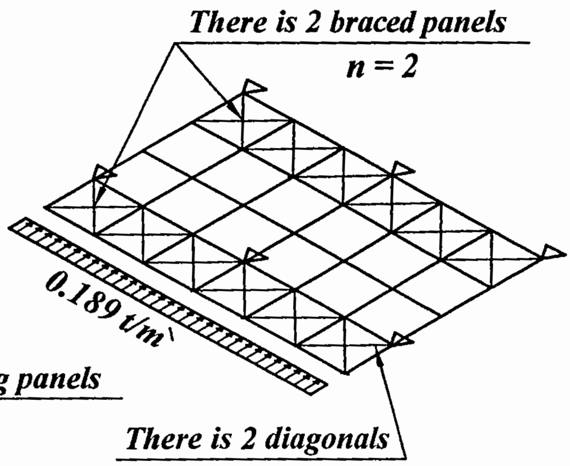


$W_1 = 0.189$ t/m`

Note:
α is the angle between the member and the loaded side direction (Hz. direction)







Max. force in diagonals

$$(F_{Diagonal\ max.}) = \frac{Q_{max.}}{2\ n\ \sin\alpha}$$

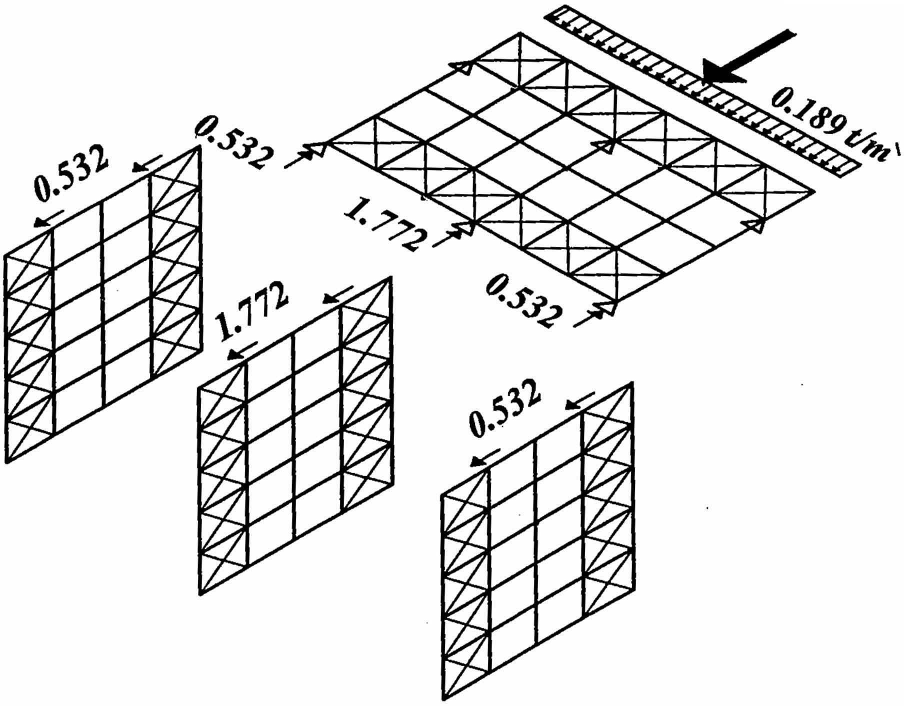
No. of bracing panels (n)

No. of diagonals (2)

$$(F_{Diagonal\ max.}) = \frac{0.886}{2 \times 2 \times \sin 45} = 0.313\ t$$

$$A = \frac{F_{Diagonal\ max.}}{F_{all.}} = \frac{0.313 \times 1000}{56} = 5.593\ cm^2$$

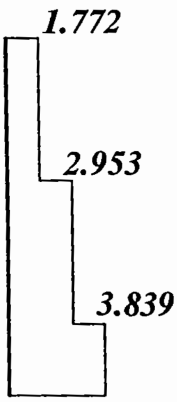
⟶ Use 8 × 8 cm $(A_{8 \times 8} = 64\ cm^2)$



NOTE

The design of the vertical bracing in transverse direction is to be carried out at the bracing resisting the max. reaction from the horizontal bracing i.e. transverse bracing no. 2

For transverse wind bracing (2)



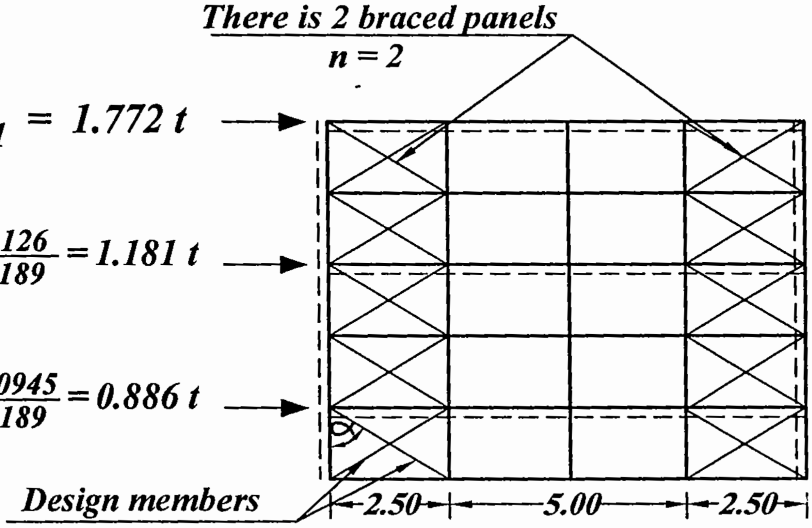
S.F.D.

$$\frac{R_1}{w_1} = \frac{R_2}{w_2}$$

$$R_1 = 1.772\ t$$

$$R_2 = R_1 \times \frac{w_2}{w_1} = 1.772 \times \frac{0.126}{0.189} = 1.181\ t$$

$$R_3 = R_1 \times \frac{w_3}{w_1} = 1.772 \times \frac{0.0945}{0.189} = 0.886\ t$$



$$\alpha = \tan \frac{2.5}{1.5} = 59.04°$$

Note:

α is the angle between the member and the loaded side direction (Vl. direction)

Max. force in diagonals

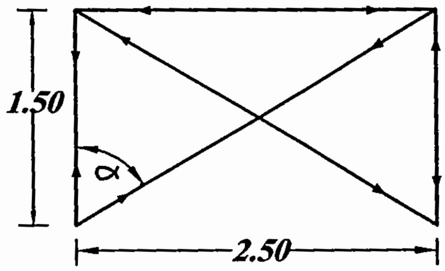
$$(F_{Diagonal\ max.}) = \frac{Q_{max.}}{2\ n\ \sin\alpha} = \frac{3.839}{2 \times 2 \times \sin 59.04} = 1.119\ t$$

No. of diagonals (2) — No. of bracing panels (n)

$$A = \frac{F_{Diagonal\ max.}}{F_{all.}} = \frac{1.119 \times 1000}{56} = 19.986\ cm^2$$

→ Use 8×8 cm $(A_{8 \times 8} = 64\ cm^2)$

Vertical member

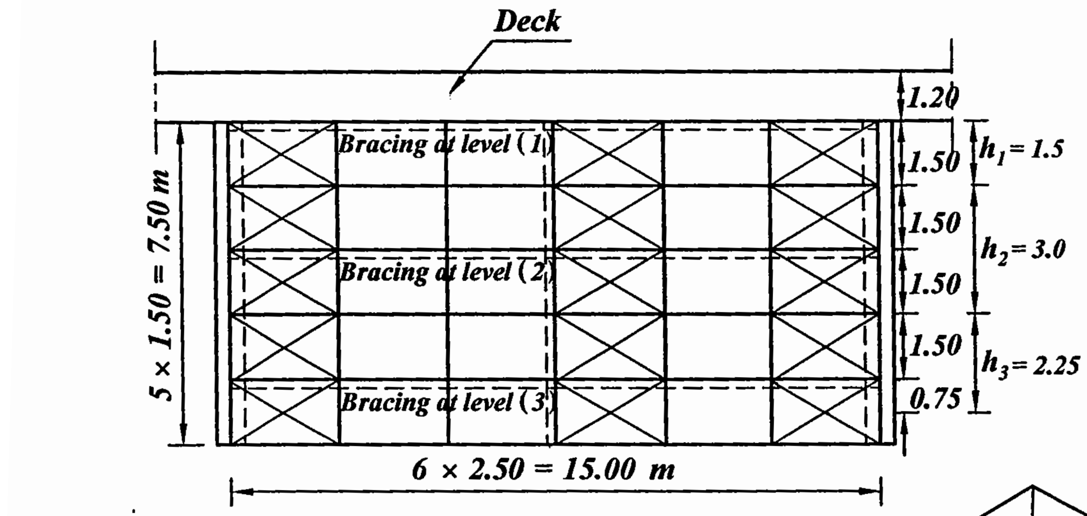


$$\alpha = \tan\frac{2.5}{1.5} = 59.04°$$

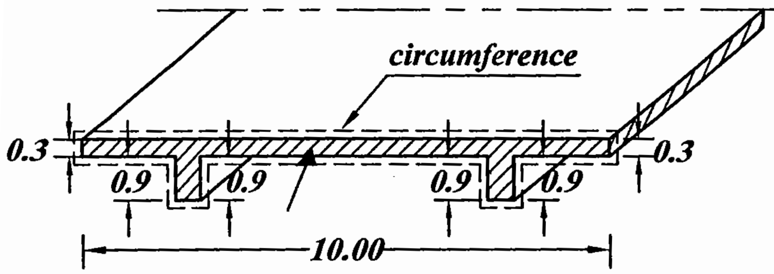
$$P_{wind\ Transverse} = F_{Diagonal\ max.} \times \cos\alpha$$

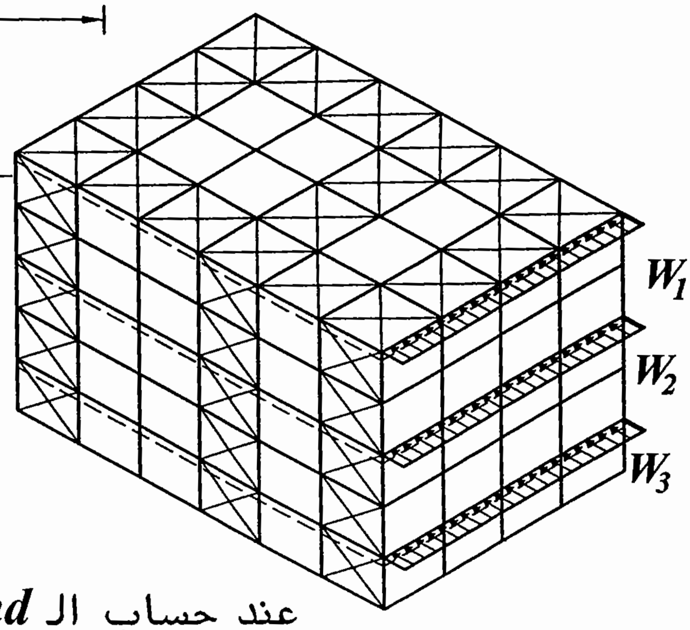
$$= 1.119 \times \cos 59.04 = 0.576\ t$$

b- Wind in longitudinal direction



$$W_{wind} = C \times q \times h$$





For level (1)

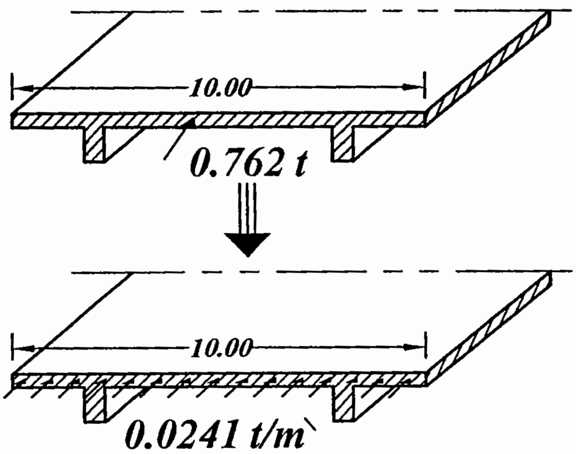
عند حساب الـ *wind* فى الاتجاه الطولى للكوبرى

$$W_{\substack{wind\\deck}} = q \times A_{circumference} \times \text{Friction factor}$$

$$A_{circumference} = (10 \times 2 + 2 \times 0.3 + 4 \times 0.9) \times 15 = 363\ m^2$$

$$W_{\substack{wind\\deck}} = 0.07 \times 363 \times 0.03 = 0.762\ t$$

$$W_{\substack{wind\\deck}} = \frac{0.762}{3 \times 10} = 0.0241\ t/m`$$



the shuttering supports one third of the wind load on the deck in longitudinal direction

تتحمل الشدة الخشبية *1/3* الأحمال الناتجة عن الرياح فى الاتجاه الطولى للكوبرى بينما تتوزع *2/3* الأحمال على الأجزاء المصبوبة سابقا

NOTE

Assume Friction factor = 0.025 - 0.03 if not given

$$W_{wind\ shuttering} = C_{shuttering} \times q \times h_{shuttering} \times \text{reduction factor for voided area}$$

$$= 2.0 \times 0.07 \times 1.5 \times 0.3 = 0.063\ t/m`$$

$$W_{1\ wind} = W_{wind\ deck} + W_{wind\ shuttering} = 0.025 + 0.063 = 0.0885\ t/m`$$

For level (2)

$$W_{2\ wind} = C_{shuttering} \times q \times h_{shuttering} \times \text{reduction factor for voided area}$$

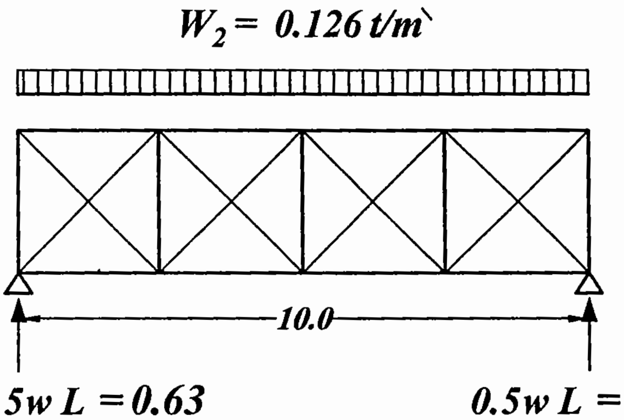
$$= 2.0 \times 0.07 \times 3.0 \times 0.3 = 0.126\ t/m`$$

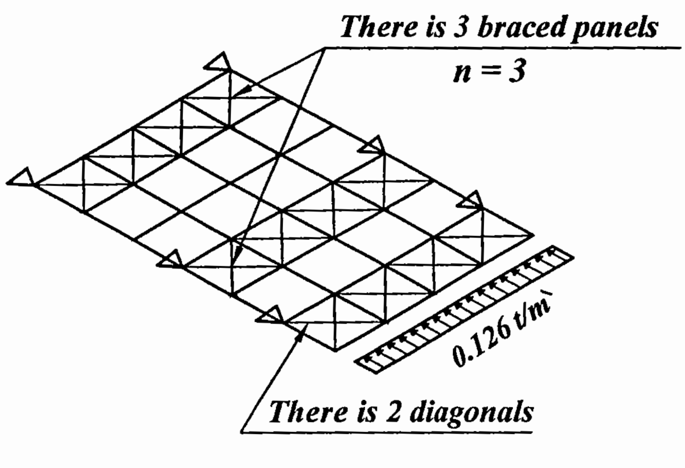
For level (3)

$$W_{3\ wind} = C_{shuttering} \times q \times h_{shuttering} \times \text{reduction factor for voided area}$$

$$= 2.0 \times 0.07 \times 2.25 \times 0.3 = 0.0945\ t/m`$$

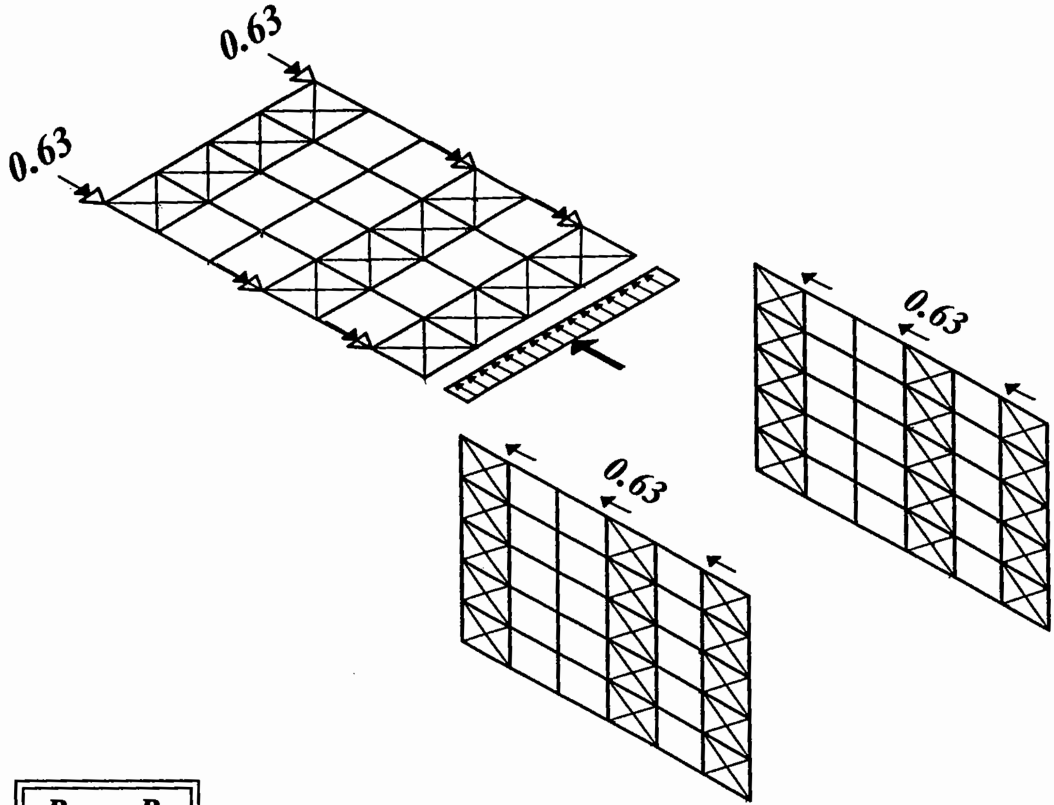
→ ***Solve for bigger value of W_{Wind} which is on level 2***



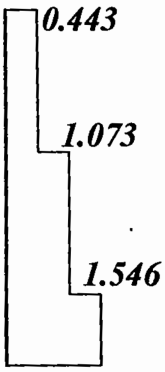


NOTE

لن يتم تصميم الـ ***Hz. diagonal*** وذلك لأن الـ ***shear*** الناتج عن أحمال الرياح فى ***Longitudinal direction*** أقل من الـ ***shear*** الناتج عن أحمال الرياح فى ***Transverse direction***



$$\boxed{\frac{R_1}{w_1} = \frac{R_2}{w_2}}$$

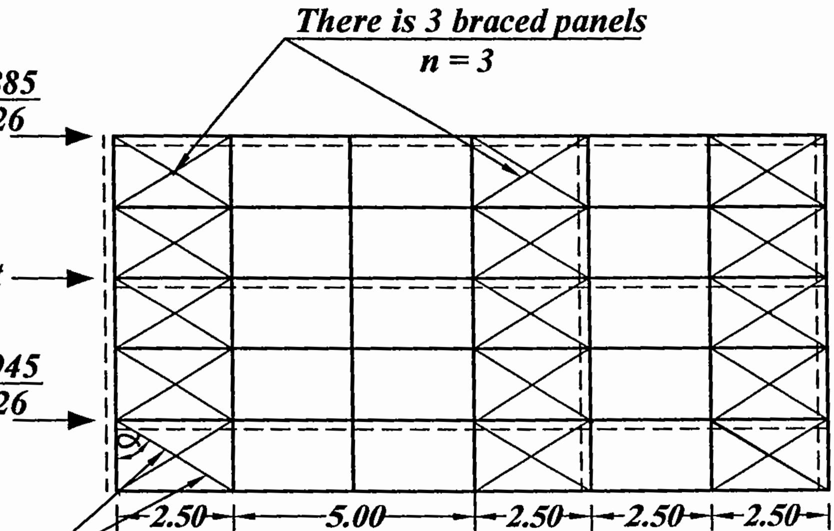


S.F.D.

$$R_1 = R_2 \times \frac{w_1}{w_2} = 0.63 \times \frac{0.0885}{0.126} = 0.443\ t$$

$$R_2 = 0.63\ t$$

$$R_3 = R_2 \times \frac{w_3}{w_2} = 0.63 \times \frac{0.0945}{0.126} = 0.473\ t$$



Design members

$$\alpha = \tan \frac{2.5}{1.5} = 59.04°$$

Max. force in diagonals

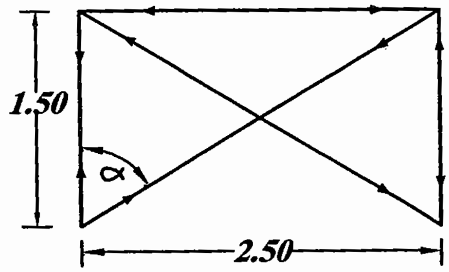
$$(F_{Diagonal\ max.}) = \frac{Q_{max.}}{2\ n\ \sin \alpha} = \frac{1.546}{2 \times 3 \times \sin 59.04} = 0.3\ t$$

No. of diagonals (2) — No. of bracing panels (n)

$$A = \frac{F_{Diagonal\ max.}}{F_{all.}} = \frac{0.3 \times 1000}{56} = 5.366\ cm^2$$

→ Use 8×8 cm $(A_{8 \times 8} = 64\ cm^2)$

Vertical member



$$P_{\substack{wind \\ Longitudinal}} = F_{Diagonal\ max.} \times \cos\alpha$$

$$= 0.3 \times \cos 59.04 = 0.154\ t$$

$$\alpha = \tan \frac{2.5}{1.5} = 59.04°$$

Design of vertical elements

→ *Take* P_{Wind} *the max. of* $P_{Wind\ transverse}$ & $P_{Wind\ longitudinal}$

$$P_{Total} = P_{D.L.} + P_{L.L.} + P_{\substack{Wind \\ Transverse}}$$

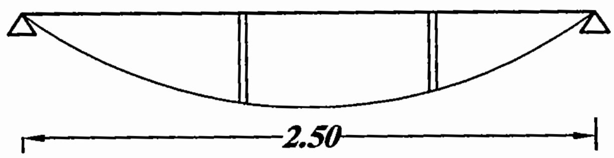
$$= 6.66 + 0.625 + 0.576 = 7.861\ t$$

$$A = \frac{P_{Total}}{F_{all.}} = \frac{7.861 \times 1000}{56} = 140.375\ cm^2$$

→ *Use* $12 \times 12\ cm$ $(A_{12\times12} = 144\ cm^2)$

Design of horizontal members

1- Dead load



→ *Assume* $10 \times 10\ cm$ $\quad \gamma_{wood} = 500\ kg/m^2$

$$Own\ weight = b \times t \times \gamma_{wood}$$

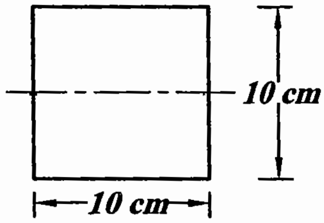
$$= 0.10 \times 0.10 \times 0.5 = 0.005\ t/m`$$

$$M_1 = 0.005 \times \frac{2.5^2}{8} = 0.0039\ m.t$$

2- Settlement of support

→ *take* $\delta = 0.5\ cm$

$E = 90 \times 10^3\ kg/cm^2$ & $L = 500\ cm$

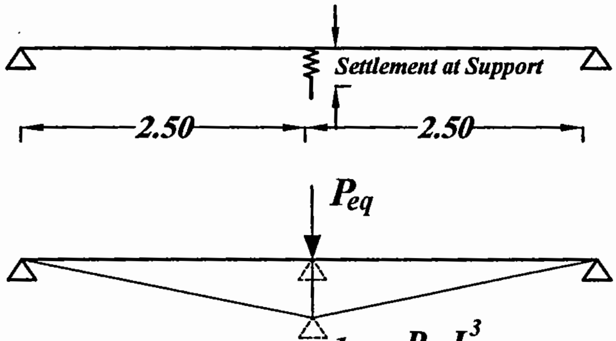


$$I = \frac{b\,t^3}{12} = \frac{10.0 \times 10.0^3}{12} = 833\ cm^4$$

$$\Delta_{max.} = \frac{1}{48} \times \frac{P_{eq}\,L^3}{E\,I}$$

$$0.5 = \frac{1}{48} \times \frac{P_{eq} \times 500^3}{90 \times 10^3 \times 833} \longrightarrow P_{eq} = 14.3942\ kg$$

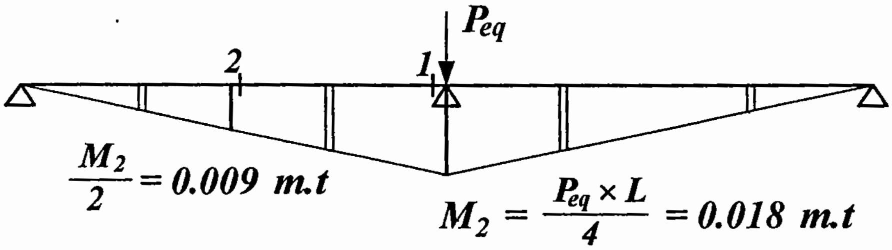
$$M_2 = \frac{P_{eq} \times 5}{4} = 0.018\ m.t$$



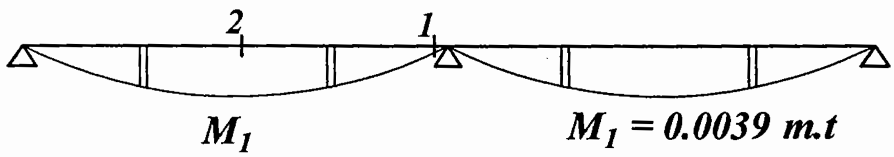
$$\Delta_{max.} = \frac{1}{48} \times \frac{P_{eq}\,L^3}{E\,I}$$

NOTE

Assume allowable settlement = 0.5 cm if not given



Moment due to settlement



Moment due to dead load

$$Sec.(1):\ M_1 + M_2 = 0 + 0.018 = 0.018\ m.t$$

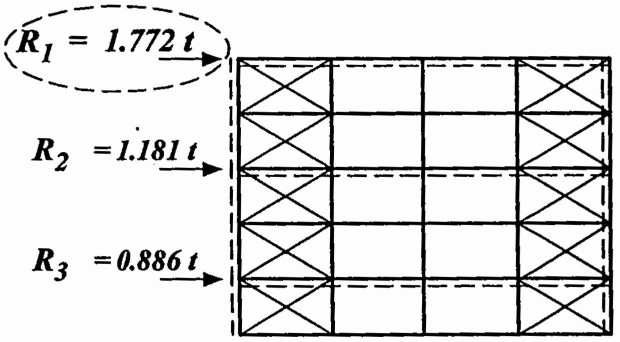
$$Sec.(2):\ M_1 + \frac{M_2}{2} = 0.0039 + \frac{0.018}{2} = 0.0129\ m.t$$

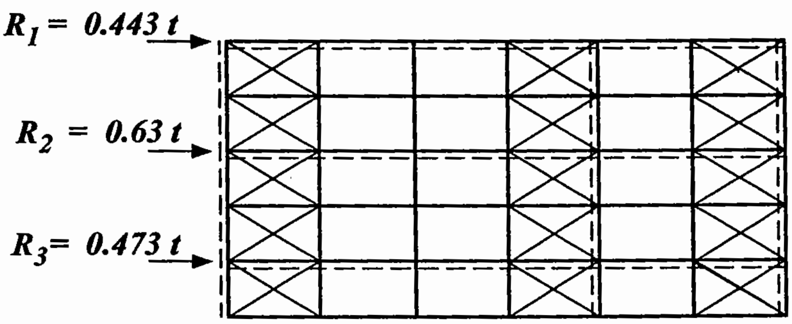
→ take bigger

Design moment $= 0.018\ m.t$

Normal force due to wind

$N = 1.772\ t$ (*max. reaction from both longitudinal and transverse direction*)





Normal force due to wind in transverse direction

Normal force due to wind in longitudinal direction

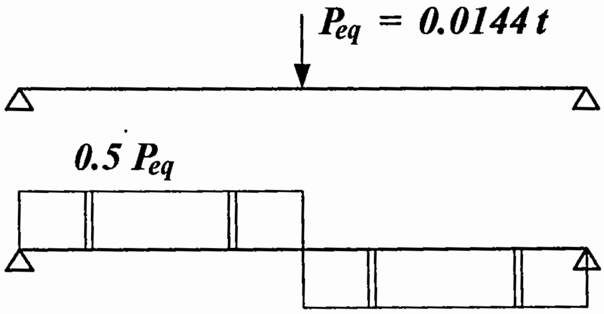
Check stresses of M & N

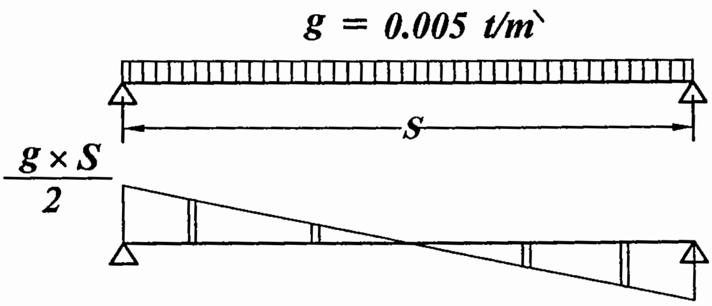
$$f_c = -\frac{N}{A} \pm \frac{M \times y}{I}$$

$$f_c = -\frac{1.778 \times 10^3}{10^2} - \frac{0.018 \times 10^5 \times 5}{833} = -28.24\ kg/cm^2 < 56 \quad Safe$$

$$f_c = -\frac{1.778 \times 10^3}{10^2} + \frac{0.018 \times 10^5 \times 5}{833} = -6.916\ kg/cm^2 < 56 \quad Safe$$

Check shear





$$Q = \frac{P_{eq}}{2} + \frac{g \times S}{2} = \frac{0.0144}{2} + \frac{0.005 \times 2.5}{2} = 0.0134\ t$$

$$q = \frac{0.0134 \times 10^3}{10 \times 10} = 0.13\ kg/cm^2 < 14 \quad Safe$$

Example (4):

For the construction of the following bridge, a steel truss system was chosen to support the bridge deck during construction. The supporting space truss system is supported on piers and temporary steel truss column.

It's required to :

- ***Calculate the loads on longitudinal truss girder and calculate the internal forces in different structural elements on this truss. Also calculate the maximum deflection of this truss during construction stage.***

- ***Calculate reaction and forces due to wind loads on the piers of the bridge.***

- ***For temporary columns, calculate loads and internal forces and design the different structural elements for the following cases:***

a- Without temporary supporting elements and the temporary columns are connected horizontally into the deck.

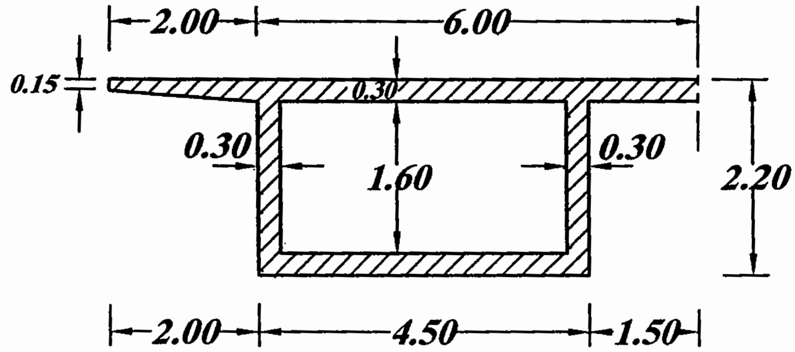
b- With temporary cables connected into the top of the column in longitudinal direction, and temporary columns are not connected into the deck in transverse direction (design cables)

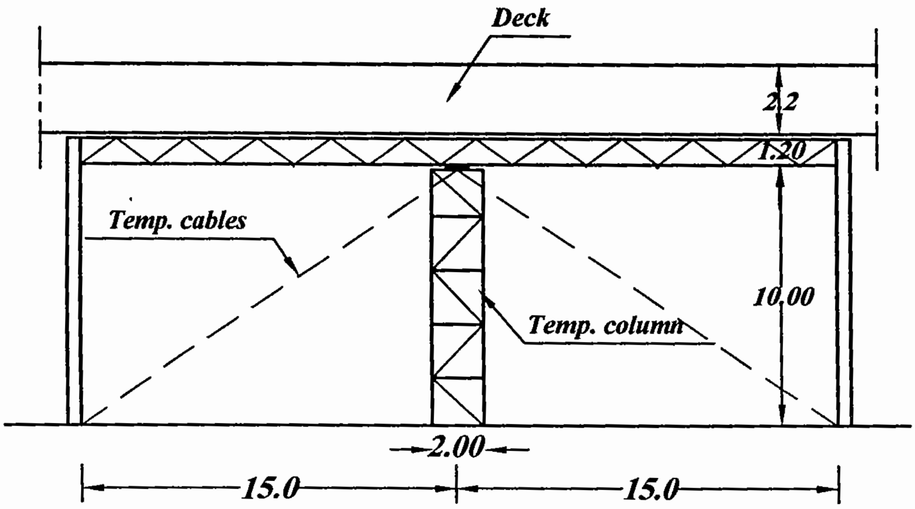
c- With temporary cables in both direction (design cables)

Design Data:

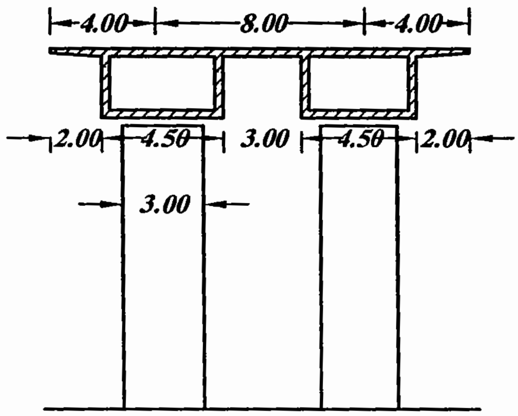
- ***St. 37 for truss girder and temporary columns***
- ***St. 15700 for spiral cables, allowable tensile strength in bending (F_t) = 8000 kg/cm²***
- ***Live load = 100 kg/m²***

- *Wind load*
  - ***Pressure intensity of wind*** $(q) = 70\ kg/m^2$
  - ***Drag factor for deck*** $(c) = 1.50$
  - ***Drag factor for shuttering*** $(c) = 2.00$

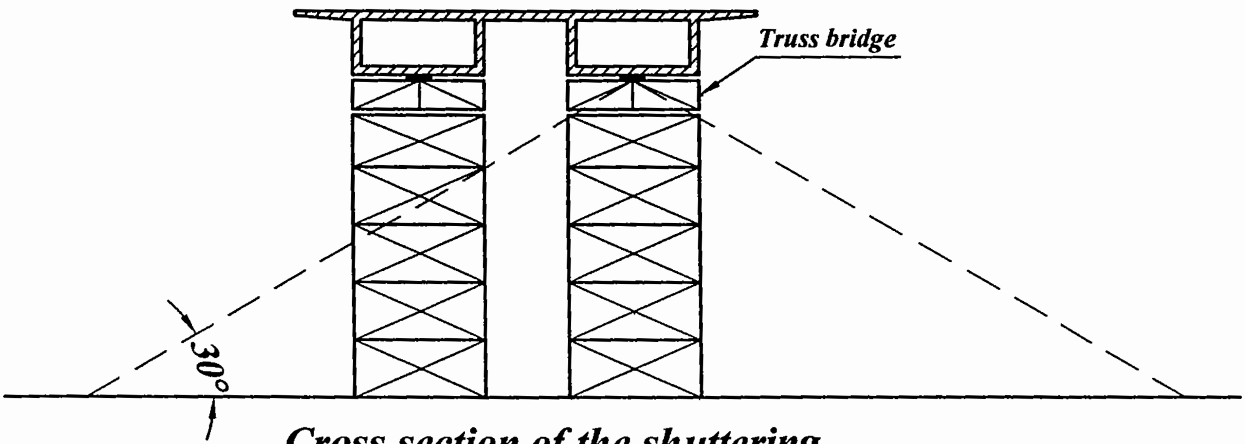




Bridge supporting system in longitudinal direction



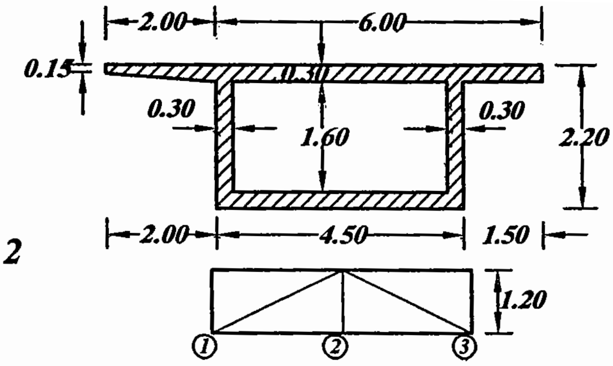
Cross section of bridge



Cross section of the shuttering

Solution:

Vertical loads



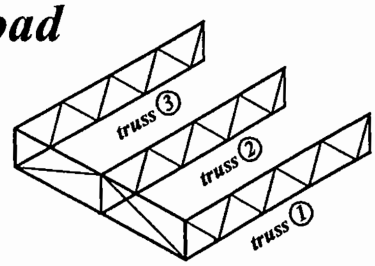
L.L. (given) = 100 kg/m² = 0.1 t/m²

$$W_{D.L.} = A_c \times \gamma$$
$$= (0.3 \times (4.5 + 6.0 + 2 \times 1.6)) \times 2.5 + (\frac{0.3 + 0.15}{2} \times 2 \times 2.5)$$
$$= 11.4 \ t/m'$$

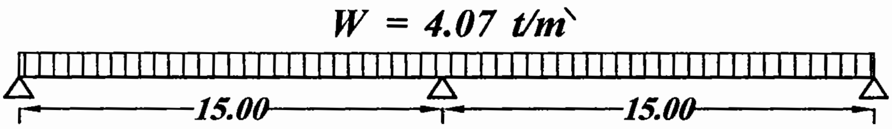
$$W_{L.L.} = 0.1 \times 8.0 = 0.8 \ t/m'$$

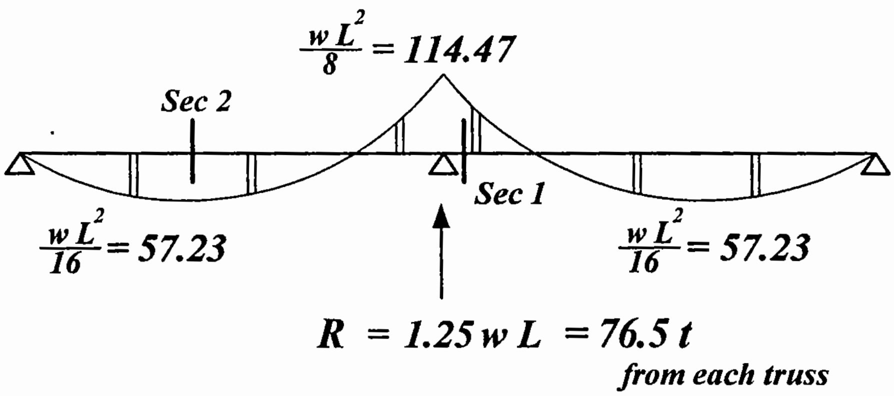
$$W_t = W_{D.L.} + W_{L.L.} = 11.40 + 0.8 = 12.2 \ t/m'$$

There are three vertical trusses carrying this load



$$W/truss = \frac{12.2}{3} = 4.07 \ t/m'$$





Internal forces in truss members

Sec 1

$$C = T = \frac{M}{Y} = \frac{114.47}{1.2} = 95.4 \ t$$

$$f_{all} = 1.4 \ t/cm^2$$

$$A_s = \frac{95.4}{1.4} = 68.14 \ cm^2 \longrightarrow \text{No need to choose section}$$

Sec 2

$$C = T = \frac{M}{Y} = \frac{57.12}{1.2} = 47.5 \ t$$

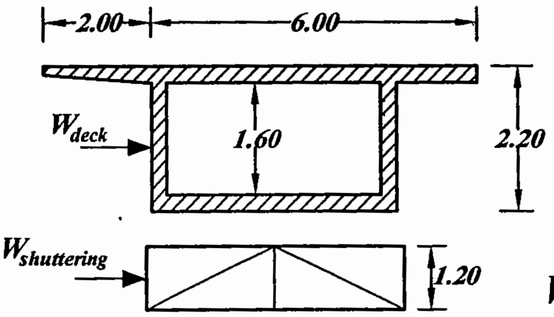
$$A_s = \frac{47.5}{1.4} = 33.9 \ cm^2$$

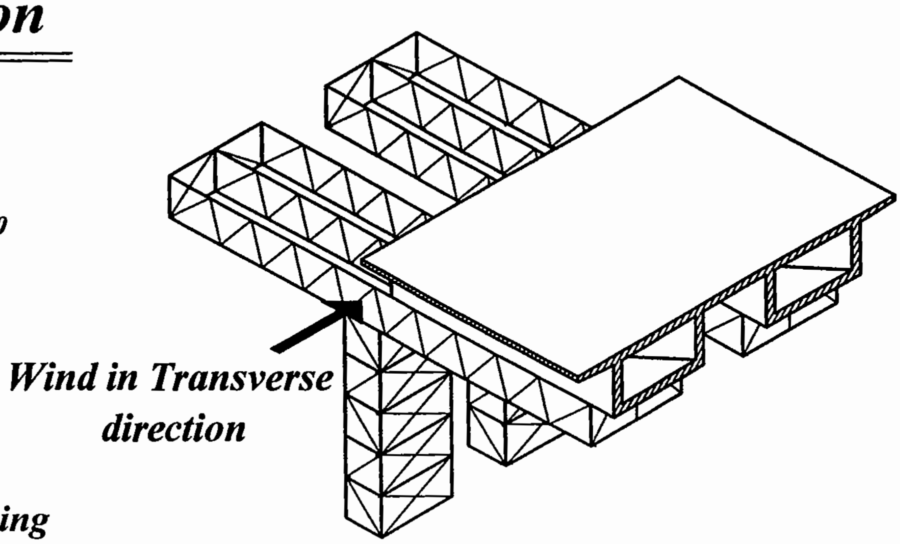
NOTE

Assume allowable steel strength $(F_{all}) = 1.4 \ t/cm^2$ if not given

Horizontal loads

a- Transverse direction

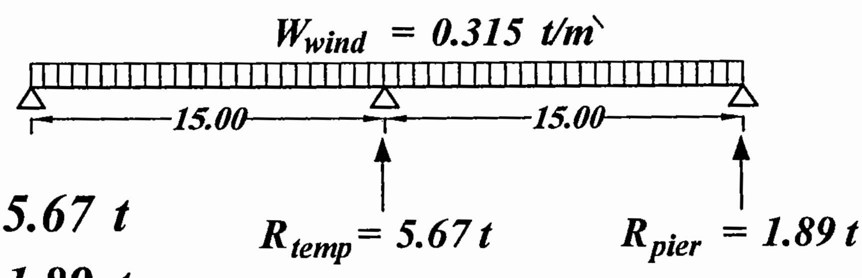




$$W_{wind} = W_{deck} + W_{shuttering}$$

$$W_{wind} = C_{deck} \times q \times h_{deck} + C_{shuttering} \times q \times h_{shuttering} \times \text{reduction factor for voided area}$$

$$= 1.5 \times 0.07 \times 2.2 + 2.0 \times 0.07 \times 1.2 \times 0.5 = 0.315 \ t/m'$$



$$R_{temp} = 1.2 \times 0.315 \times 15 = 5.67 \ t$$

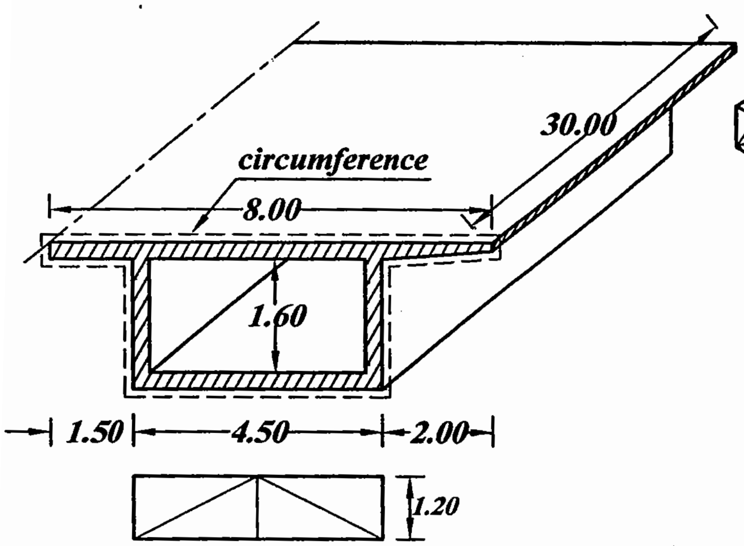
$$R_{pier} = 0.4 \times 0.315 \times 15 = 1.89 \ t$$

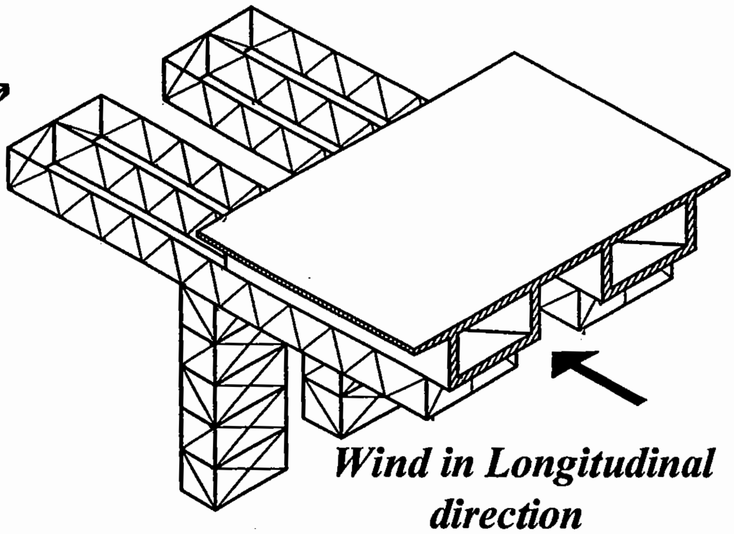
NOTE

Reactions can be calculated using 1.25wL and 0.375wL as before

Assume reduction factor for voided area = 0.3 - 0.5 if not given

b- Longitudinal direction





$$W_{wind} = W_{deck} + W_{shuttering}$$

$$W_{deck} = q \times A_{circumference} \times \text{Friction factor}$$

$$A_{circumference} = (2 \times 8.0 + 2 \times 1.6) \times 30 = 576\ m^2$$

$$W_{deck} = 0.07 \times 576 \times 0.025 = 1.0\ t$$

$$W_{shuttering} = C_{shuttering} \times q \times A_{shuttering} \times \text{reduction factor for voided area}$$

$$= 2.0 \times 0.07 \times (1.2 \times 4.5) \times 0.5 = 0.38\ t$$

$$W_{wind\ longitudinal} = 1.0 + 0.38 = 1.38\ t$$

This load is resisted by 2 Piers and 1 temporary column (3 elements)

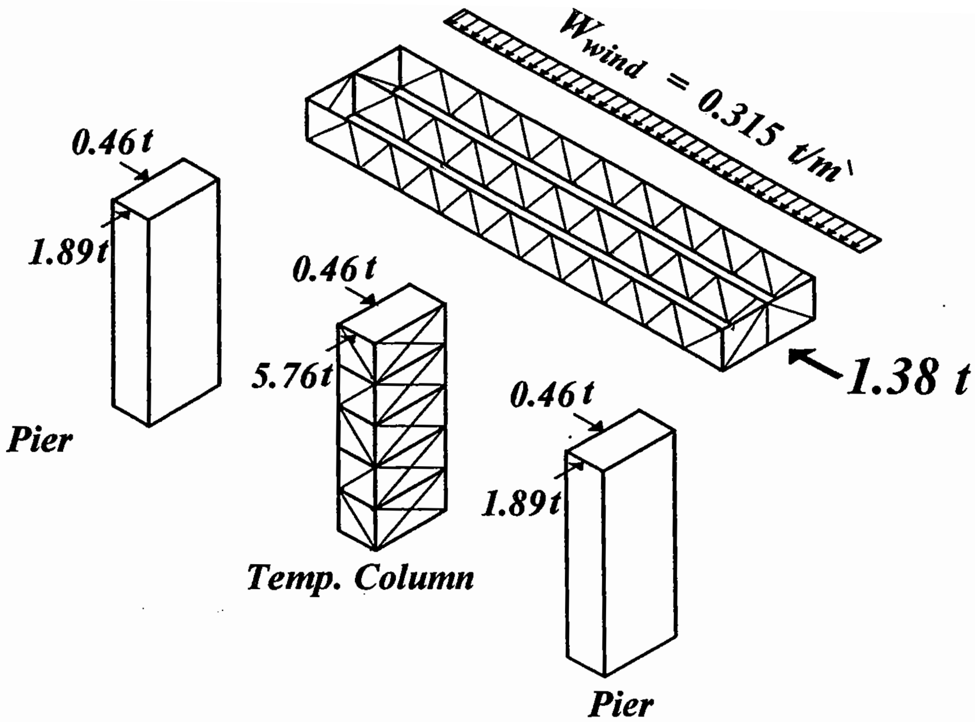
$$W_{wind} \text{ resisted by each element } = \frac{1.38}{3} = 0.46\ t$$

Total wind loads on pier

$$R_{transverse} = 2 \times 1.89 = 3.78\ t$$
$$R_{longitudinal} = 2 \times 0.46 = 0.92\ t$$

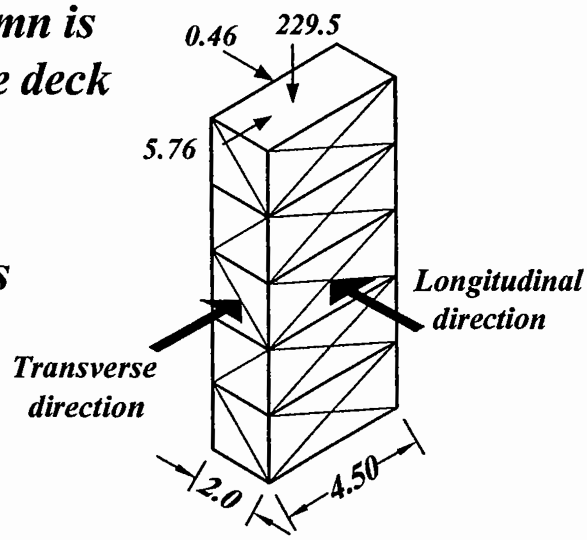
NOTE

- *Reactions are multiplied by 2 as calculated reactions is due half bridge only*
- *Assume Friction factor = 0.025 - 0.03 if not given*



Loads on temporary columns

Case (a): ***No temporary cables and column is connected horizontally into the deck***



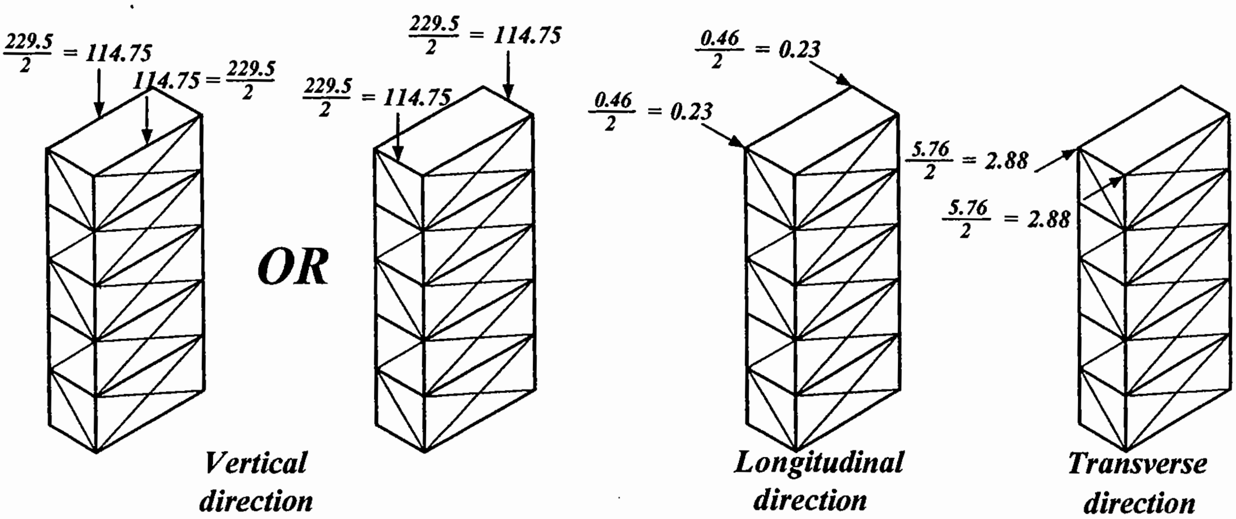
Vertical loads

The column is supporting 3 trusses

$$R_V = 3 \times 76.5 = 229.5 \ t$$

NOTE

Each load is transfered to no. of braced panels

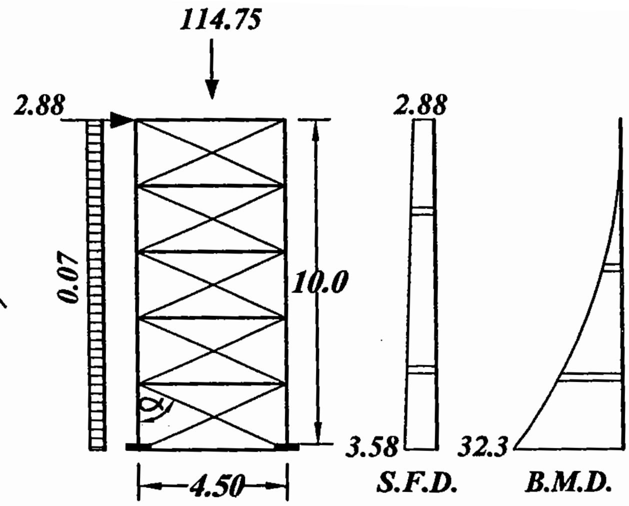


Wind loads in transverse direction

$$W_T = C \times q \times \frac{b}{2} \times 0.5$$

No. of bracing panels (the 2 in the denominator)

$$= 2 \times 0.07 \times \frac{2}{2} \times 0.5 = 0.07\ t/m'$$



$$\alpha = \tan \frac{4.5}{2.0} = 66.03°$$

$$N_{max} = \frac{114.75}{2} + \frac{32.3}{4.5} = 64.55\ t$$

$$A_s = \frac{64.55}{1.4} = 43.04\ cm^2$$

$$\text{Max. force in diagonals } (F_{Diagonal\ max.}) = \frac{Q_{max.}}{2 \sin \alpha} = \frac{3.58}{2 \times \sin 66.03} = 1.95\ t$$

No. of diagonals (the 2 in the denominator)

$$A_s = \frac{1.95}{1.4} = 1.399\ cm^2$$

> **NOTE**
> α is the angle between the member and the loaded side direction (Vl. direction)

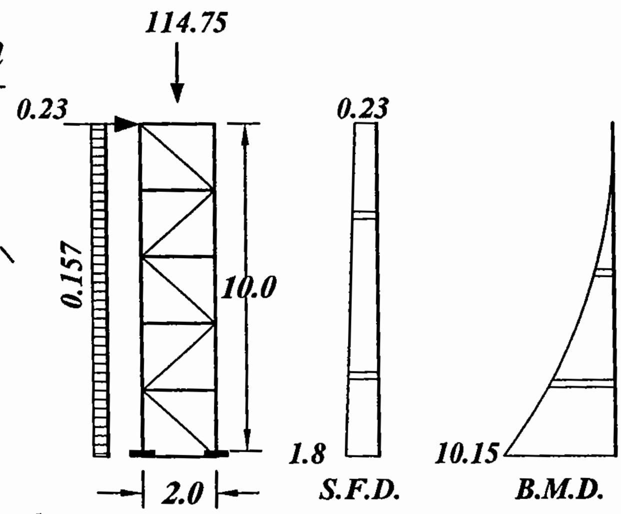
$$\text{Max. force in Horizontal} = Q_{max} = 3.58\ t$$

$$A_s = \frac{3.58}{1.4} = 2.557\ cm^2$$

Wind loads in longitudinal direction

$$W_T = C \times q \times \frac{b}{2} \times 0.5$$

$$= 2 \times 0.07 \times \frac{4.5}{2} \times 0.5 = 0.157\ t/m'$$



$$N_{max} = \frac{114.75}{2} + \frac{10.15}{2} = 62.45\ t < 64.55\ t$$

Reaction in transverse direction (64.55 t) — not critical

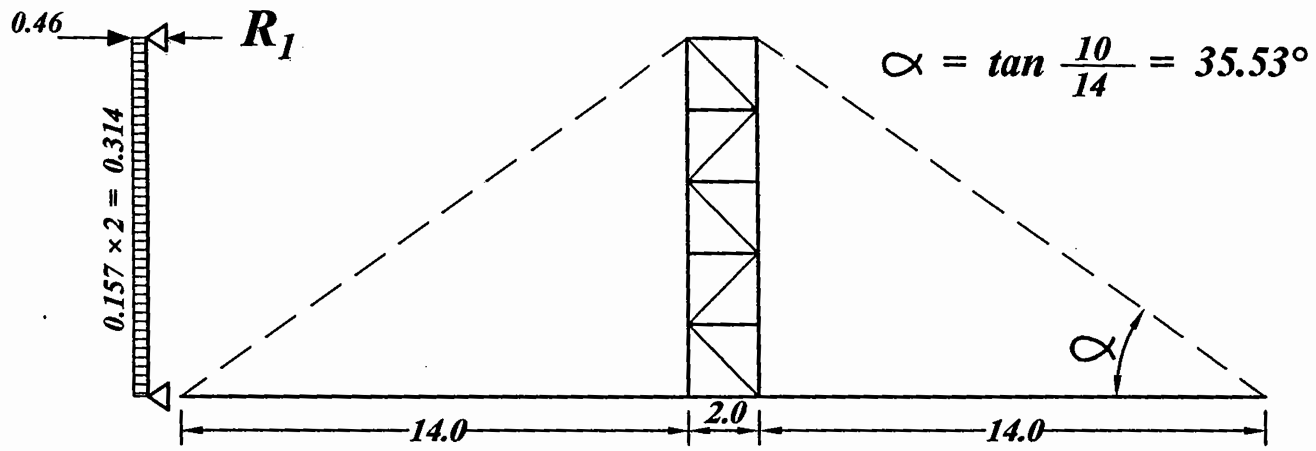
$$\alpha = \tan \frac{2.0}{2.0} = 45°$$

$$\text{Max. force in diagonals } (F_{Diagonal\ max.}) = \frac{Q_{max.}}{1 \sin \alpha} = \frac{1.8}{\sin 45} = 2.54\ t$$

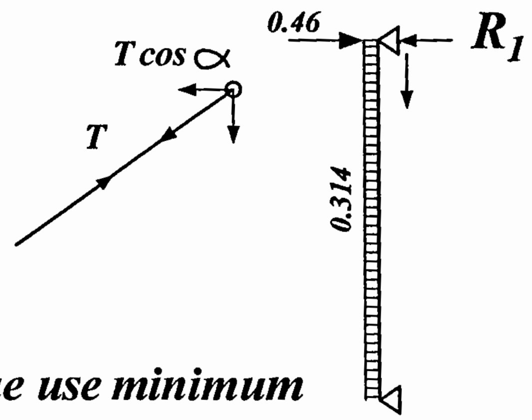
No. of diagonals (the 1 in the denominator)

$$\text{Max. force in Horizontal} = Q_{max} = 1.8\ t$$

Case (b): Temporary cables in longitudinal direction



$$R_1 = 0.46 + 0.314 \times \frac{10}{2} = 2.03\ t$$



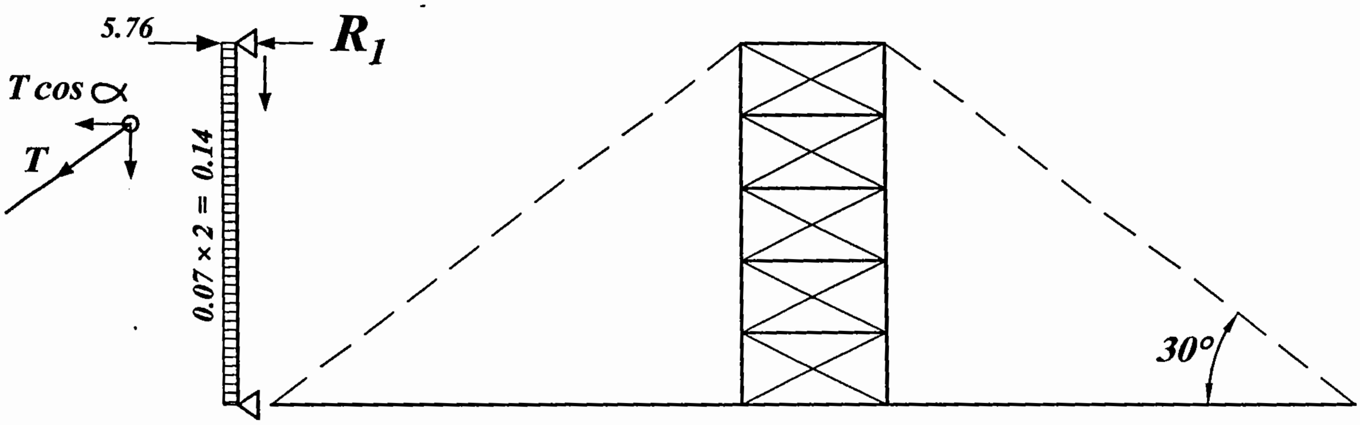
$$T = \frac{R_1}{\cos \alpha} = \frac{2.03}{\cos 35.53} = 2.49\ t$$

$$A_s = \frac{2.49 \times 1000}{8000} = 0.31\ cm^2$$

→ *Very small value use minimum available cables*

Case (c): Temporary cables in longitudinal and transverse direction

We designed temp. cables in logitudinal direction in previous step



$$R_1 = 5.76 + 0.14 \times \frac{10}{2} = 6.46\ t$$

$$T = \frac{R_1}{\cos \alpha} = \frac{6.46}{\cos 30} = 7.46\ t$$

> **NOTE**
> *We designed temp. cables in longitudinal direction in previous step*

$$A_s = \frac{7.46 \times 1000}{8000} = 0.93\ cm^2$$

→ *Very small value use min. available cables*