Reinforced Concrete Road Bridges

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Lecture-1

Overview

Introduction

Introduction

A bridge is a structure built to span physical obstacles without closing the way underneath such as a body of water, valley, or road, for the purpose of providing passage over the obstacle.

Natural bridge, Andaman

Natural bridge, Andaman. This was never in use

Introduction (contd ...)

A bridge is a key element in a transportation system for three reasons:

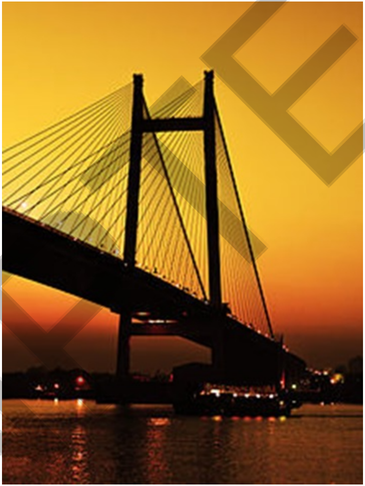
- It likely controls the capacity.
- It is the highest cost per kilometer.
- If the bridge fails, the system fails.

Pamban Bridge, Ramaswaram, 1914

Howrah Bridge, Kolkata, 1943

Mahatma Gandhi Setu,Patna, 1982

Vidyasagar Setu, Kolkata, 1992



Stamps on bridges in India

Landmark Bridges of India

Howrah Bridge

Mahatma Gandhi Setu

Pamban Bridge

Vidyasagar Setu

Published on17th August, 2007

www.indiapost.gov.in

- The bridges mentioned here are not related to the present topic, but are shown here as postal stamps are published by India Post

Introduction (contd ...)

The bridge controls both the volume and weight of the traffic carried.

- If the width of a bridge is insufficient to carry the number of lanes required to handle the traffic volume, the bridge will be a constriction to the traffic flow.
- If the strength of a bridge is deficient and unable to carry heavy trucks, load limits will be posted and truck traffic will be rerouted.

Introduction (contd ...)

Bridges are expensive.

- The typical cost per kilometer of a bridge is many times that of the approach roadways.
- This is a major investment and must be carefully planned for best use of the limited funds available for a transportation system.

Introduction (contd ...)

If the bridge fails, the system fails.

- When a bridge is removed from service and not replaced, the transportation system may be restricted in its function.
- Traffic may be detoured over routes not designed to handle the increase in volume.
- Users of the system experience increased travel times and fuel expenses.
- Normalcy does not return until the bridge is repaired or replaced.

Introduction (contd ...)

A bridge is a key element in a transportation system.

- Balance must be achieved between handling future traffic volume and loads and the cost of a heavier and wider bridge structure.
- Strength is always a foremost consideration but so should measures to prevent deterioration.
- The designer of new bridges has control over these parameters and must make wise decisions so that capacity and cost are in balance, and safety is not compromised.

Introduction (contd ...)

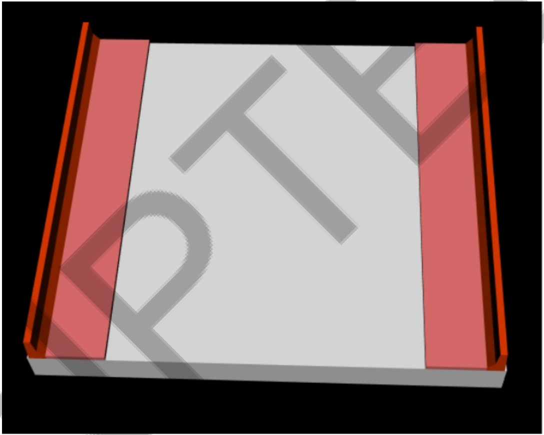
- Bridges can be classified in many ways
- Classification of bridges will be discussed in the next lecture
- For learning purpose, it will be appropriate to classify as:
  - Superstructures
    - Reinforced concrete bridges
    - Prestressed concrete bridges
    - Steel bridges
    - Steel-concrete composite bridges
    - Cable supported bridges
  - Bearings
  - Substructures
  - Foundations

Road vehicles





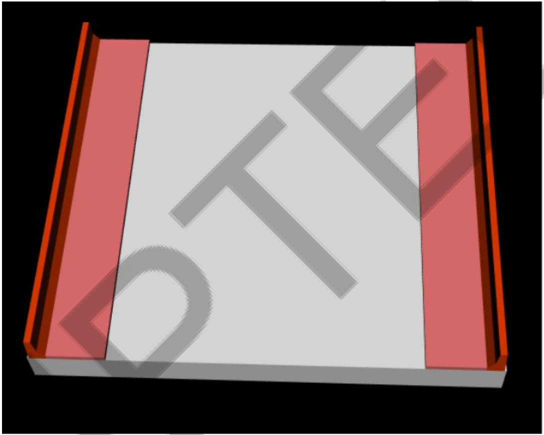
Bridge deck



Bridge deck

Bridge Deck: The load bearing floor of a bridge which carries and spreads the loads to the main beams. It is either of reinforced concrete., pre-stressed concrete, welded steel etc.

Bridge deck



Bridge Deck: The load bearing floor of a bridge which carries and spreads the loads to the main beams. It is either of reinforced concrete., pre-stressed concrete, welded steel etc.

Summary

Summary

- Bridge Engineering, in general, is discussed here

References

References

- Design of Highway Bridges : An LRFD Approach, Second Edition, Richard M. Barker and Jay A. Puckett, John Wiley & Sons, Inc, 2007

Thank you

Reinforced Concrete Road Bridges

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Lecture-2

Overview

1. Classification of bridges
2. Summary
3. References

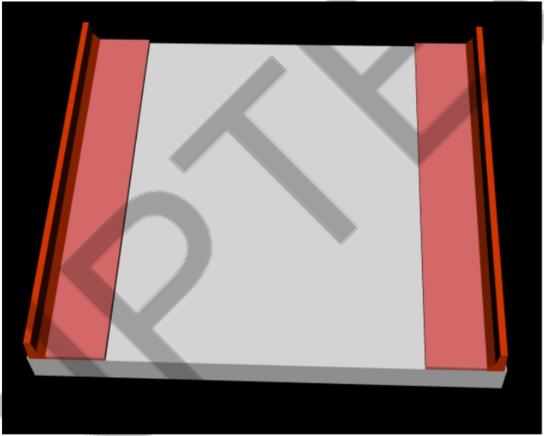
Classification of bridges

Road vehicles





Bridge deck



Bridge deck

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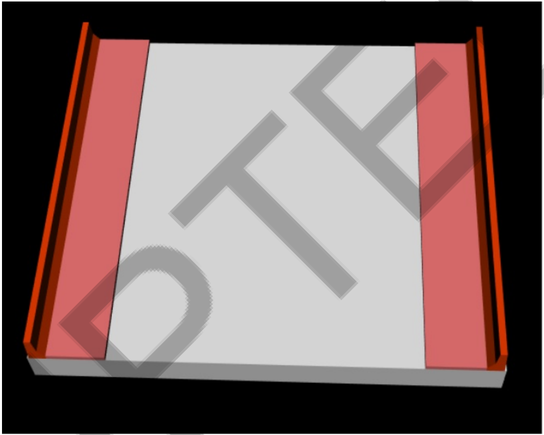
Bridge deck



Bridge Deck: The load bearing floor of a bridge which carries and spreads the loads to the main beams. It is either of reinforced concrete., pre-stressed concrete, welded steel etc.

Classification of bridges

- Bridges can be classified in different ways:
    - Materials
    - Usage
    - Span
    - Structural Form

Classification of bridges

- Materials
  - Concrete
  - Steel
  - Wood
  - Hybrid
  - Stone/brick

Classification of bridges

- Usage
  - Pedestrian
  - Highway
  - Rail

Classification of bridges

- Span
  - Short
  - Mediam
  - Large
  - Long

Classification of bridges

- Structural Form
  - Slab
  - Girder
  - Truss
  - Arch
  - Suspension
  - Cable stayed

Classification of bridges

- Span
  - Short
  - Mediam
  - Large
  - Long

Classification of bridges

- Small span bridges (upto 15m)
  - Culvert Bridge
  - Slab Bridge
  - T-Beam Bridge
  - Wood Beam Bridge
  - Precast Concrete Box Beam Bridge
  - Precast Concrete I-Girder Bridge
  - Rolled Steel Beam Bridge

Classification of bridges

- Medium span bridges (upto 50m)
  - Pre-cast Concrete Box Beam bridge
  - Pre-cast Concrete I-Girder bridge
  - Composite Rolled Steel Beam Bridge
  - Composite Steel Plate Girder Bridge
  - Cast-in-place RCC Box Girder Bridge
  - Cast-in-place Post-Tensioned Concrete Box Girder bridge
  - Composite Steel Box Girder bridge bridge

Classification of bridges

- Large span bridges (50m to 150m)
    - Composite Steel Plate Girder Bridge
    - Cast-in-place Post-Tensioned concrete Box Girder
    - Post-Tensioned Concrete Segmental Construction
    - Concrete Arch and Steel Arch

Classification of bridges

- Long span bridges (over 150m)
    - Cable Stayed Bridge
    - Suspension Bridge

Classification of bridges

- Span can be considered as a general guideline to select the type of bridges
  - Short span (upto 10m)
  - Small span (10m to 20m)
  - Medium span (20m to 50m)
  - Large span (50m to 150m)
  - Long span (over 150m)

Classification of bridges

- Bridges are also classified as
  - Minor bridge (upto 60m)
  - Major bridge (over 60m)

Classification according to structural arrangement

Bridge Deck: The load bearing floor of a bridge which carries and spreads the loads to the main beams. It is either of reinforced concrete., pre-stressed concrete, welded steel etc.

Classification according to structural arrangement

- The classification of the bridge types can also be according to the location of the main structure elements relative to the surface on which the user travels, as follows:
  - Main structure below the deck line
  - Main structure above the deck line
  - Main structure coincides with the deck line

Classification according to structural arrangement

- Main structure below the deck line
  - Masonry arch
  - Concrete arch
  - Inclined leg frame arch
  - Rigid frame arch

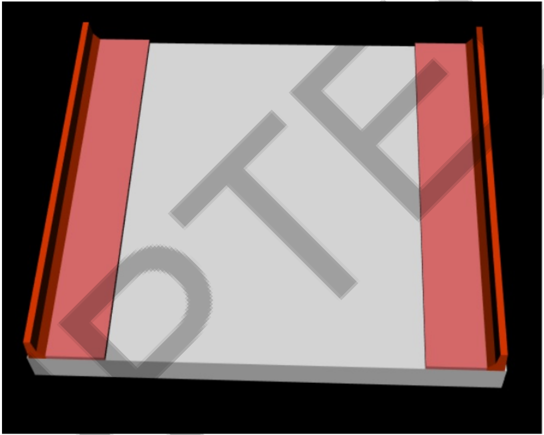
Classification according to structural arrangement

- Main structure above the deck line
    - Suspension bridges
    - Cable stayed bridges
    - Through truss bridges

Classification according to structural arrangement

- Main structure coincides with the deck line
  - Slab bridge
  - T-beam bridge
  - I-girder bridge
  - Steel plate girder
  - Steel box

Bridge deck



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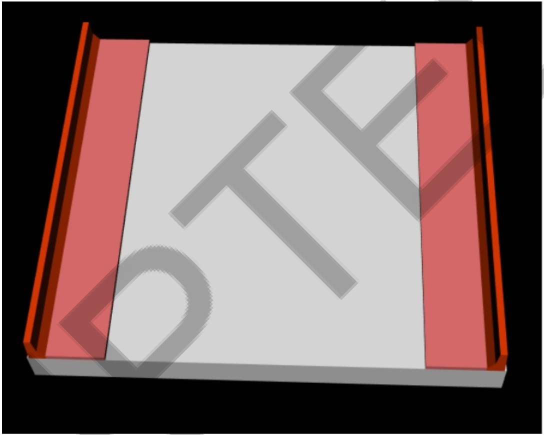
Bridge deck



Bridge Deck: The load bearing floor of a bridge which carries and spreads the loads to the main beams. It is either of reinforced concrete., pre-stressed concrete, welded steel etc.

Reinforced Concrete Road Bridges

- Considering the duration of the present course, reinforced concrete road bridges will be discussed
- The following bridges will be studied in the present course
  - Solid slab bridges
  - RCC T Beam bridges

Summary

Summary

- Bridges are classified according to materials, usage, span and structural forms.

References

References

- Design of Highway Bridges : An LRFD Approach, Second Edition, Richard M. Barker and Jay A. Puckett, John Wiley & Sons, Inc, 2007

Thank you

Reinforced Concrete Road Bridges

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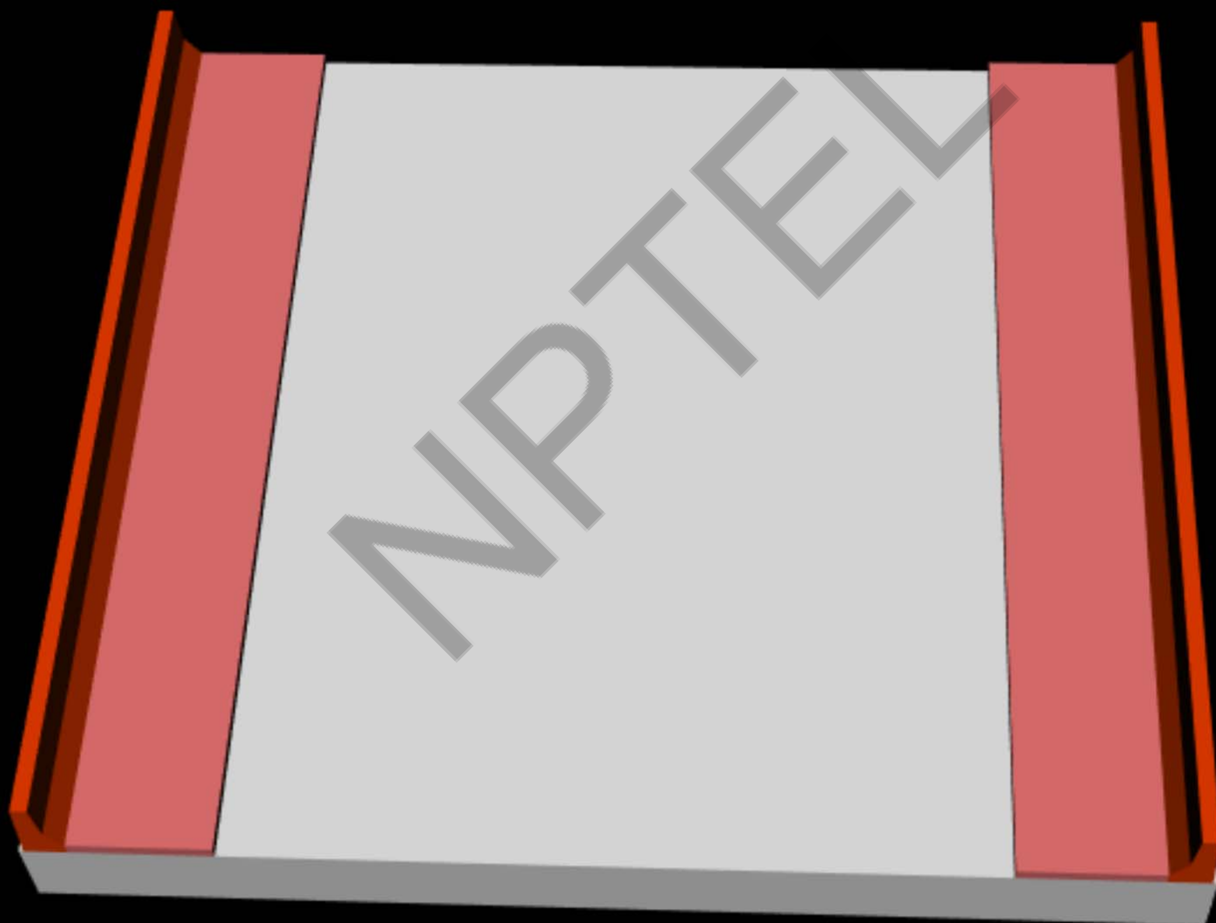
Lecture-3

General Features of Design

and

Vehicle Loading

Deck
Carrigeway, footpath and crash barrier



Standard specifications and code of practice
For road bridges

IRC 5
Section I : General features of design

IRC 6
Section II : Loads and Stresses

Published by

Indian Roads Congress, New Delhi

Bridge Types – Simply Supported

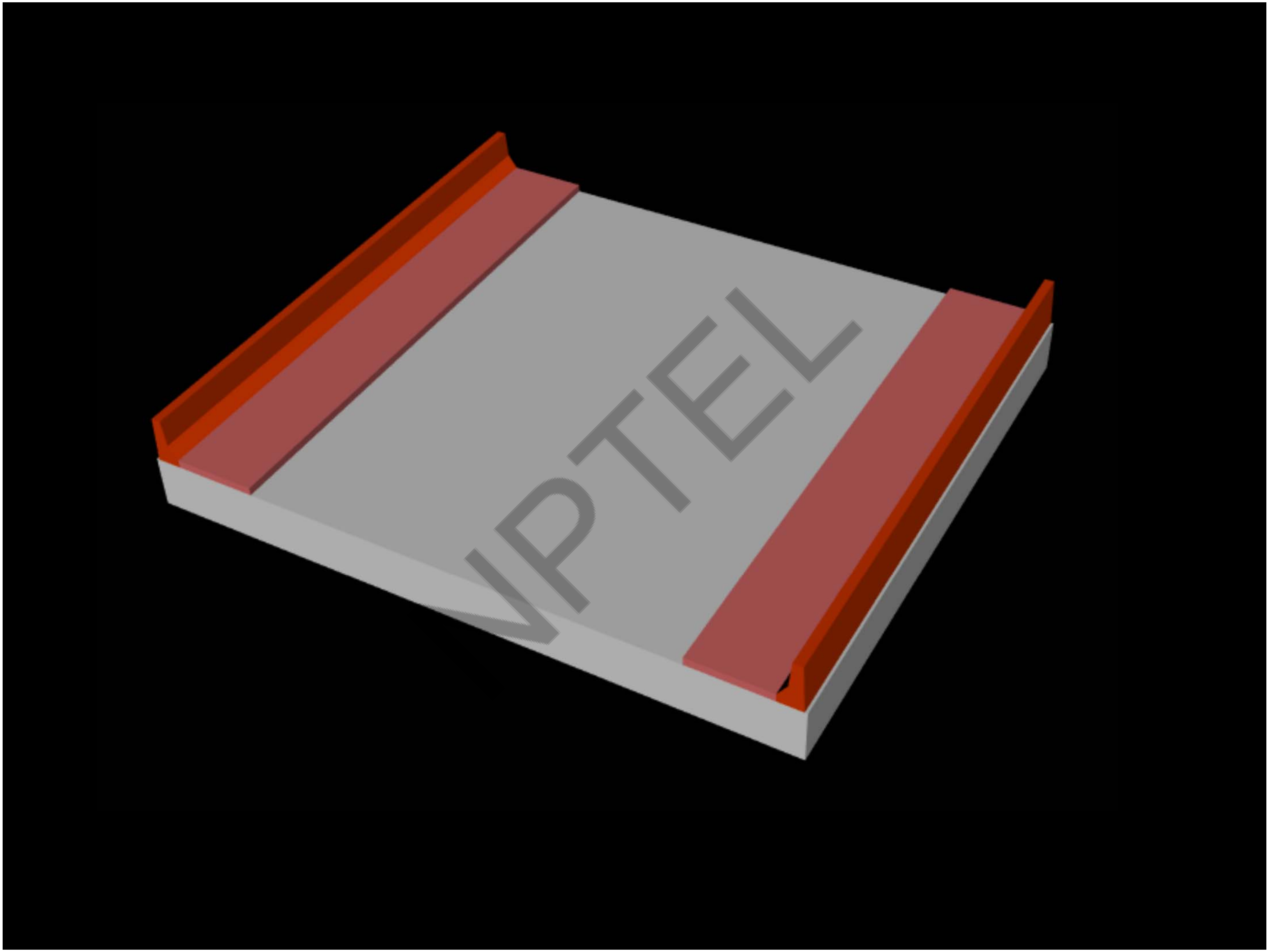
- Solid Slab Bridge
- RCC T Beam

Number of lanes

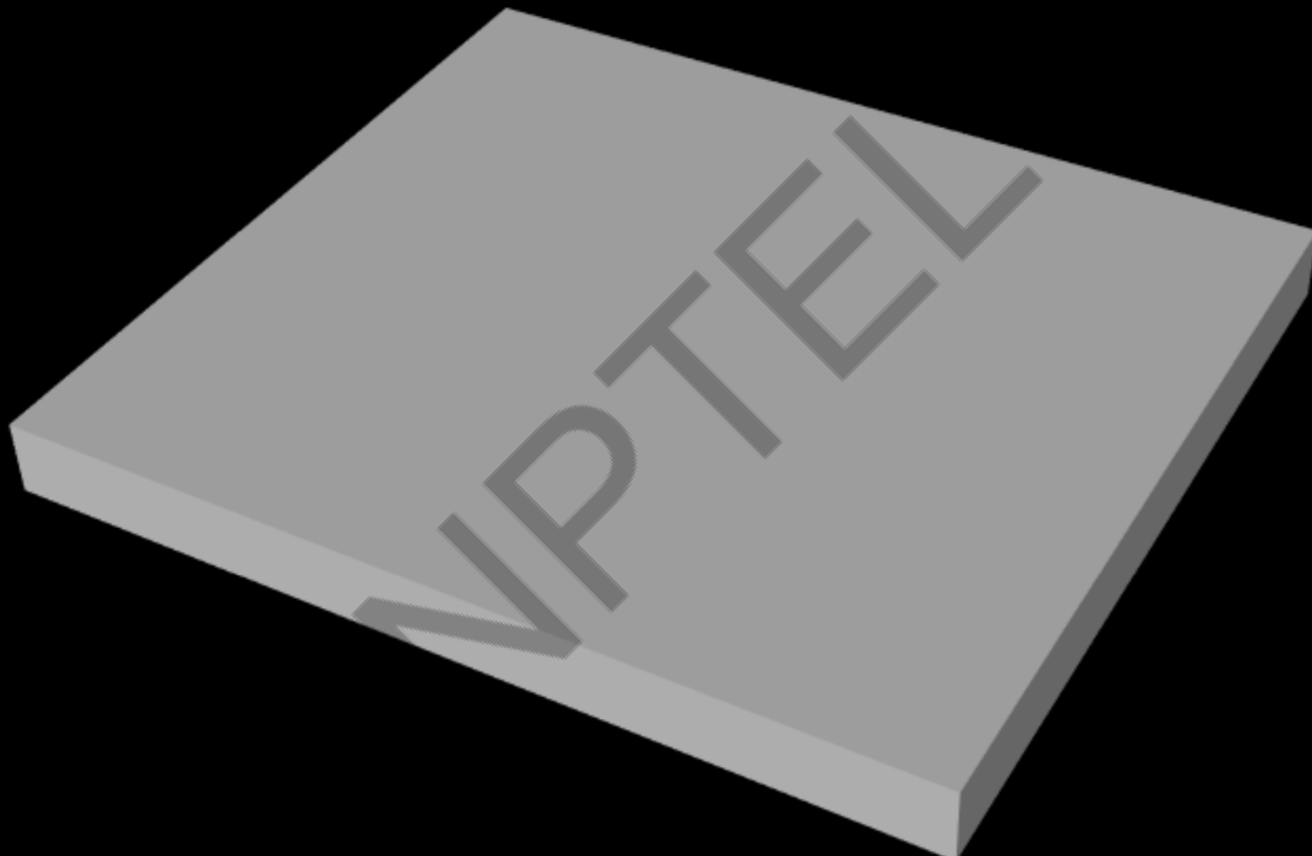
- Single lane
- Double lane
- Triple Lane

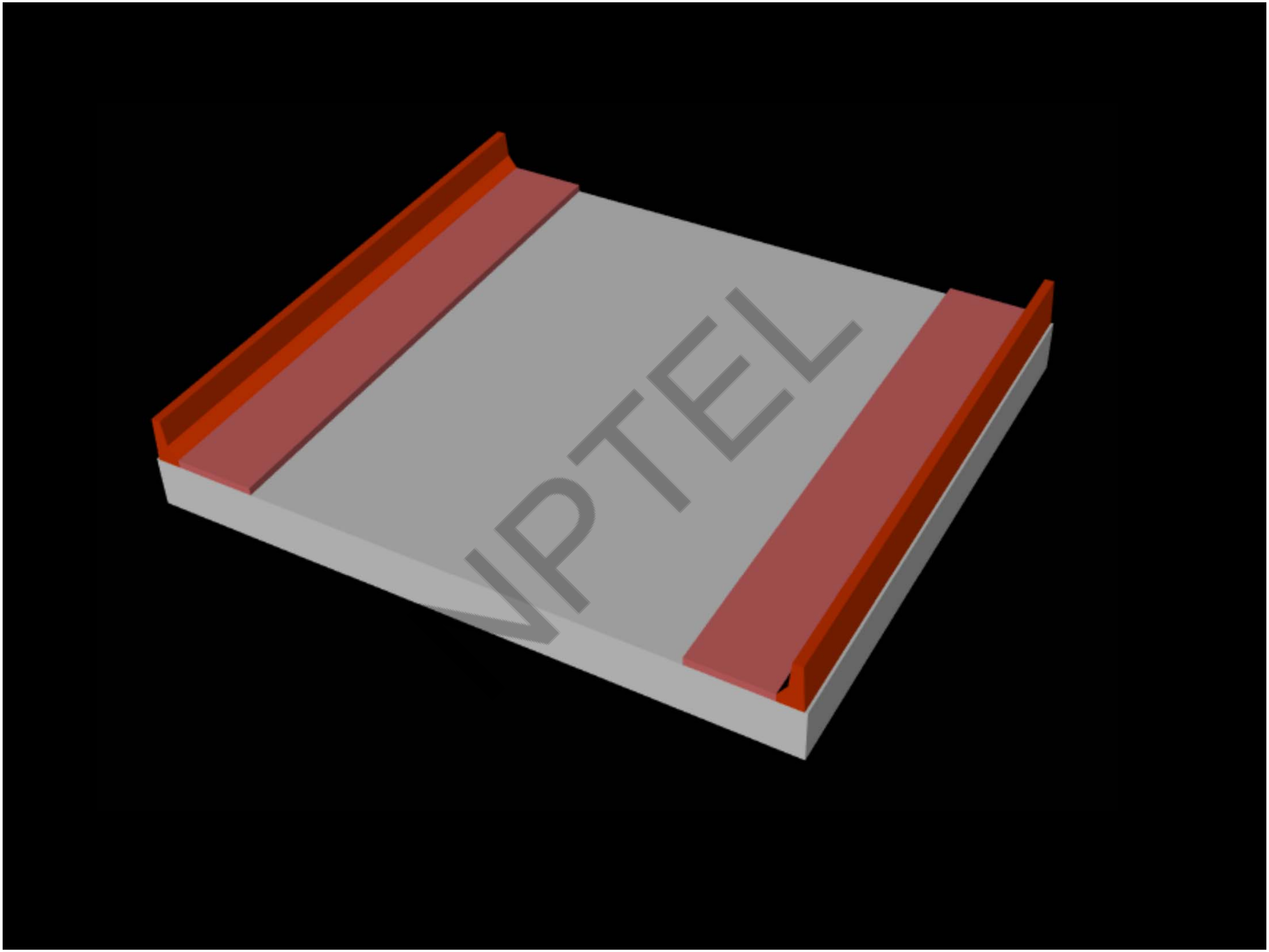
Width of carriageway and footpath

Clause 112 of IRC 5



Deck




NPTEL

112.1. For high level bridges constructed for the use of road traffic only,

the width of carriageway shall not be less than

4.25 m for a single lane bridge and

7.5 m for a two-lane bridge and

shall be increased by 3.5 m for every additional lane of traffic for a multiple lane bridge.

112.1. (contd..)

Road bridges shall provide for either one lane, two lanes or multiple of two lanes.

Three-lane bridges with two directional traffic shall not be constructed.

112.1. (contd..)

If a median/central verge is constructed in a wide bridge thus providing two separate carriageways, the carriageway on each side of the verge shall provide for at least two lanes of traffic and width thereof shall individually comply wit the minimum requirements stipulated above.

The width of central/verge/median, when provided, shall not be less than 1.2 metres.

In addition, cross-sections of 2-lane and multi-lane bridges shall satisfy the following :

i) For all minor bridges of total length upto 60 m, width between the outermost faces of the bridge shall be equal to the full roadway width of the approaches subject to a minimum of 10 m for hill roads/other district roads and 12 m for other cases.

ii) For two lane bridges having total length more than 60 metres in non-urban situations, the width of the bridge shall provide for 7.5 m carriageway plus a minimum of l.5 m wide footpath on either side, wherever required.

iii) For two lane bridges having total length more than 60 m in urban situations, the overall width between the outermost faces of the bridge shall be equal to the full roadway width of the approaches.

iv) For multi-lane bridges, in both urban and non-urban situations, the overall width between the outermost faces of the bridge shall be the same as the full roadway width of the approaches. Wherever footpaths are provided, their width shall not be less than 1.5 m. The width of the median in the bridge portion shall be kept same as that in the approaches.

v) For bridges on expressways, the provisions in sub-clause (iv) shall be satisfied and the carriageway width shall not be less than the width of carriageway in the approaches plus hard shoulders

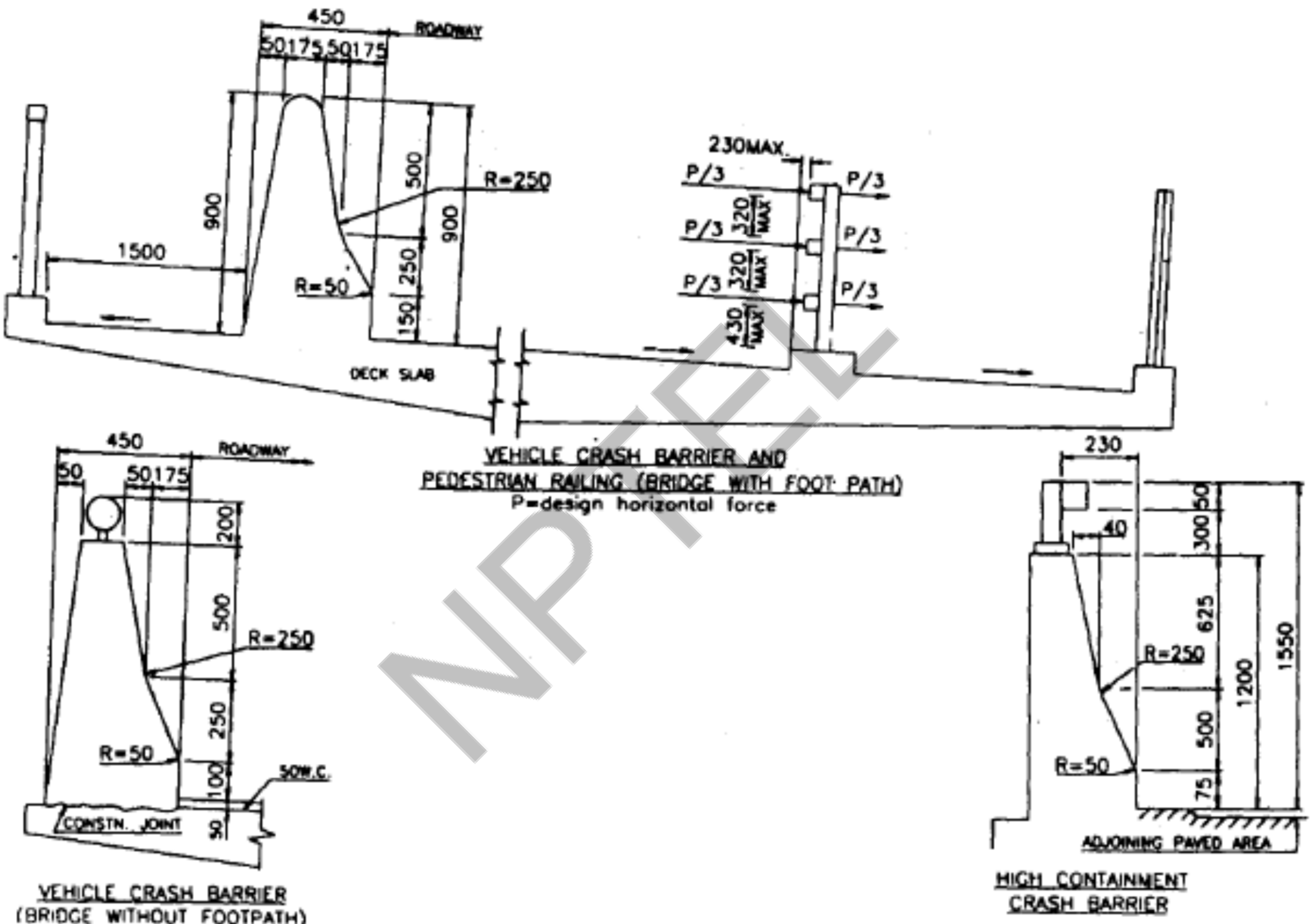


Fig. 4(a). Typical Sketches of Crash Barriers (Clause 115.4.3)
(All Dimensions are in Millimetres)

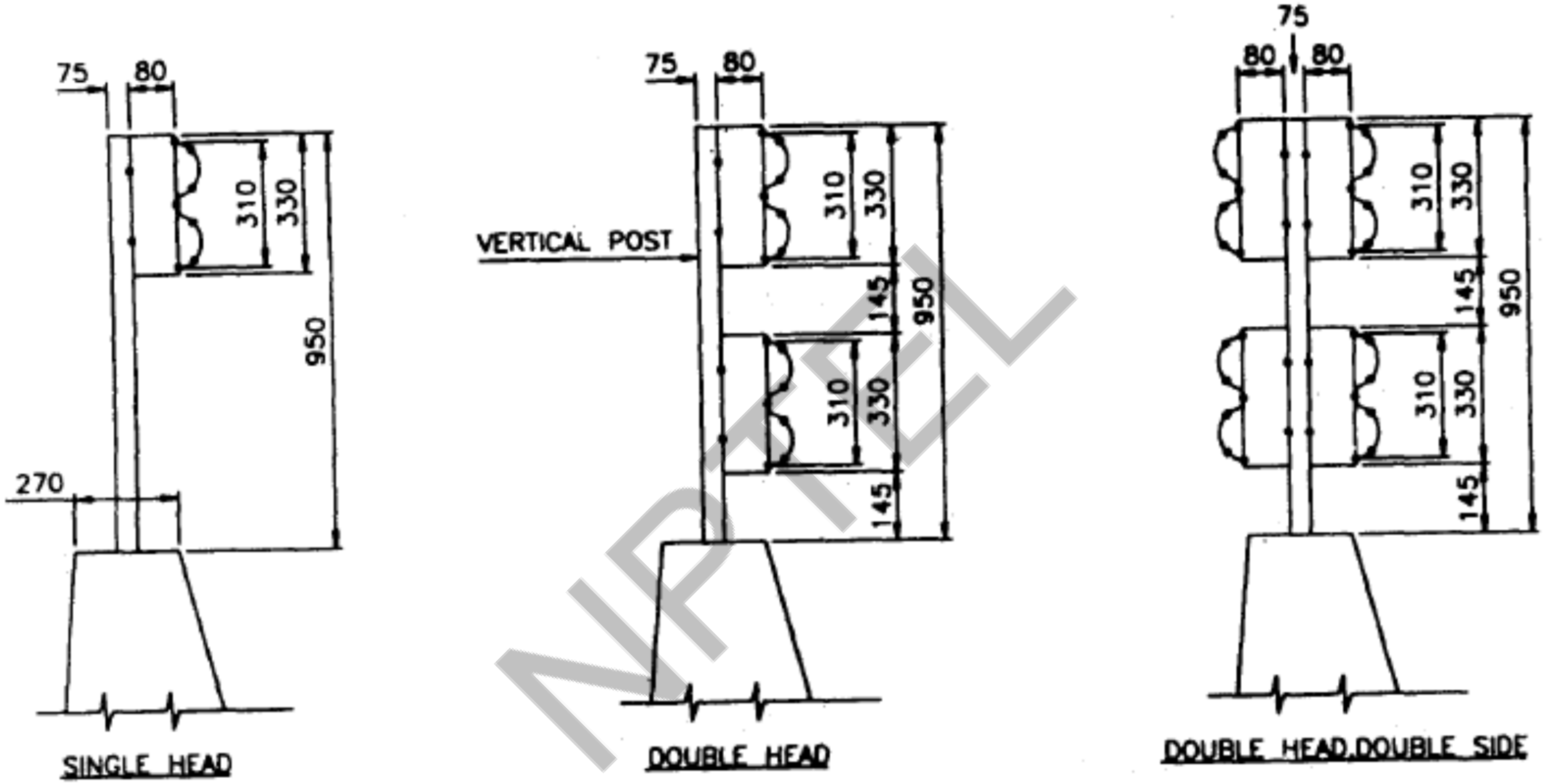


Fig. 4(b). Various Type of Crash Barriers (Clause 115.4.3)
(All Dimensions are in Millimetres)

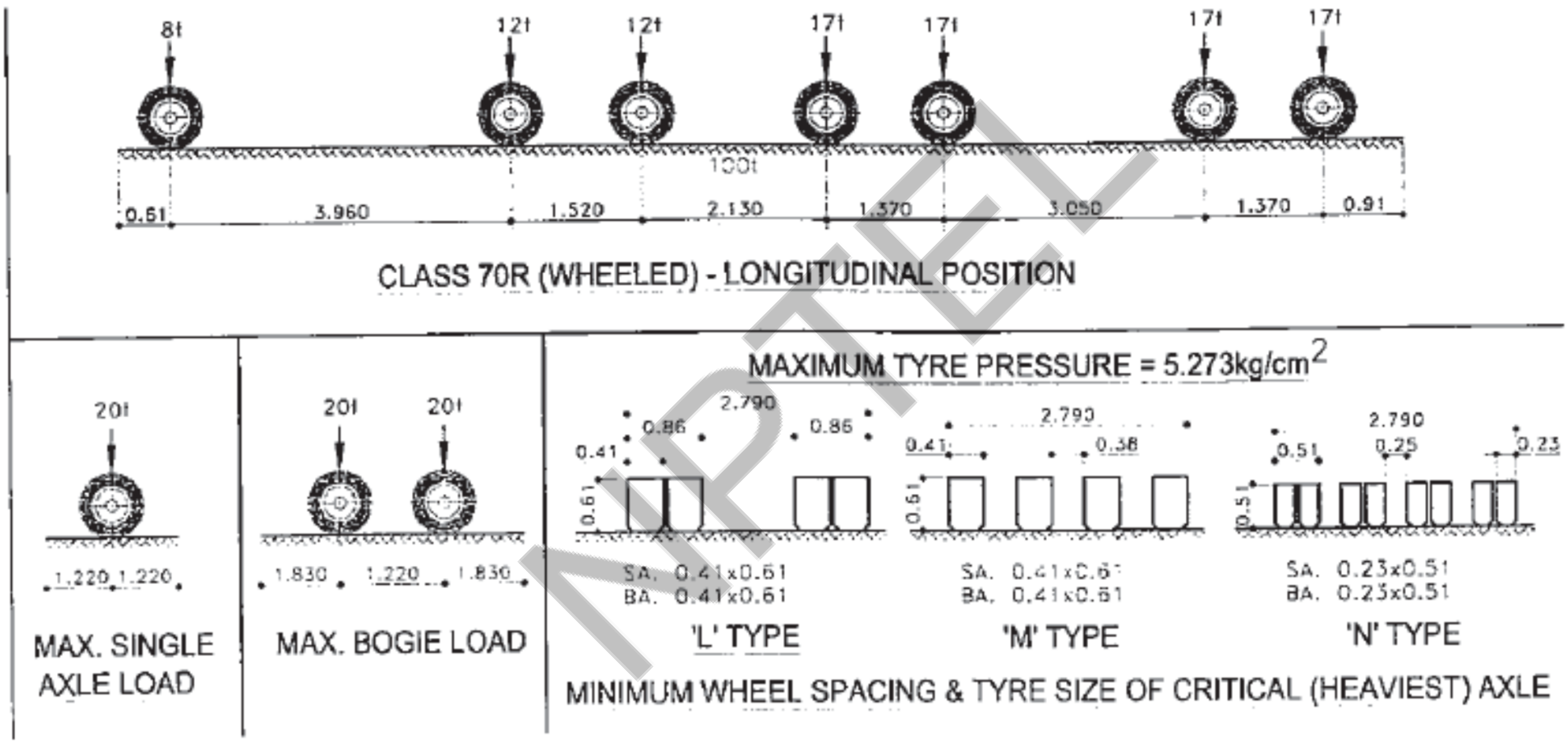
IRC Loading

IRC 6 : 2014

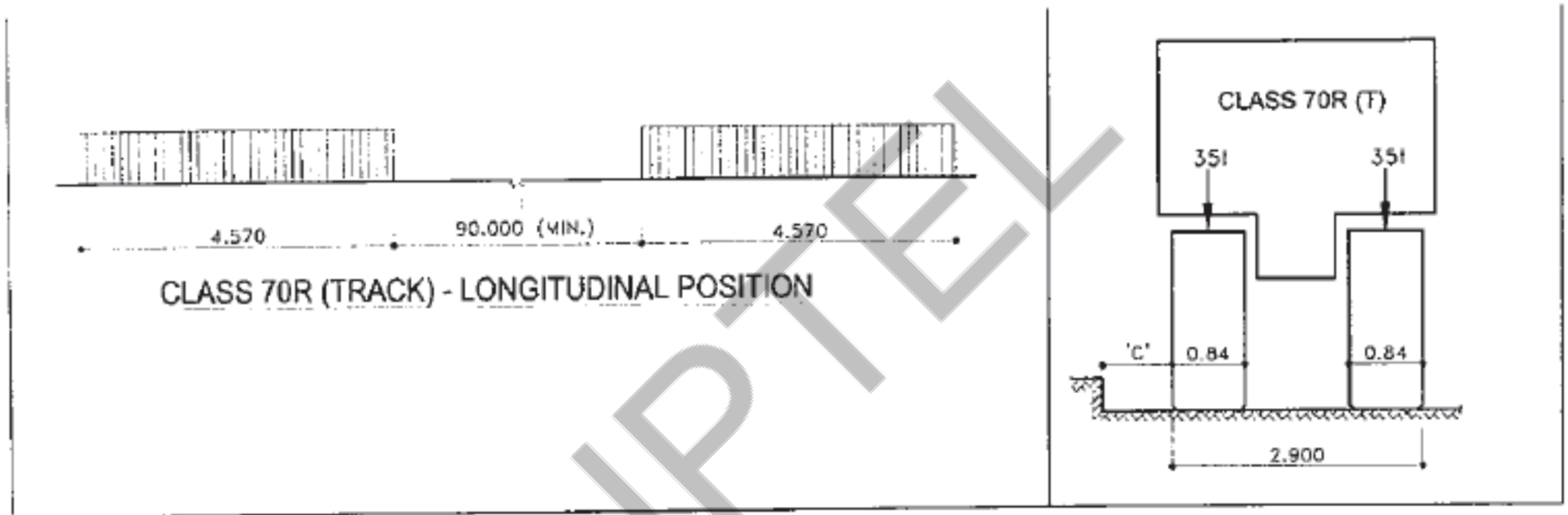
Class A Loading – Wheeled Vehicle

IRC 70R Loading – Tracked Vehicle

IRC 70R Loading – Wheeled Vehicle



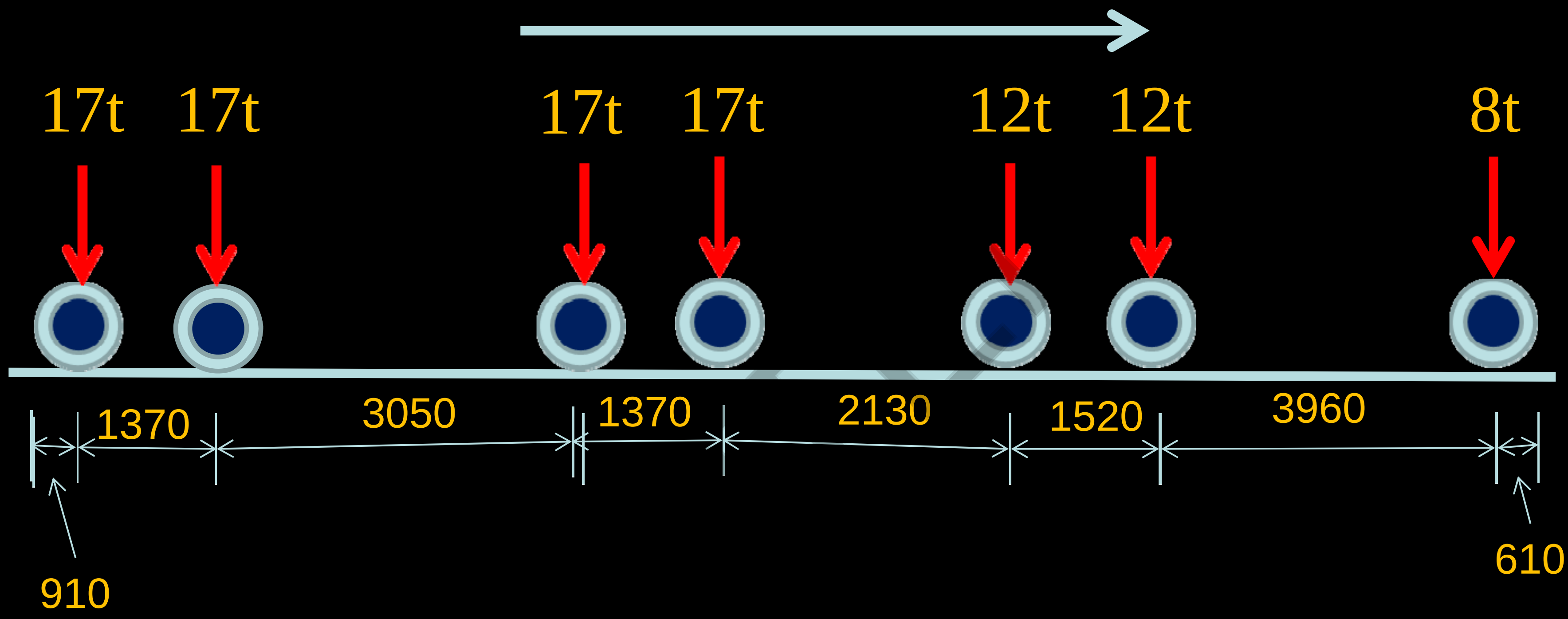
WHEEL ARRANGEMENT FOR 70R (WHEELED VEHICLE)



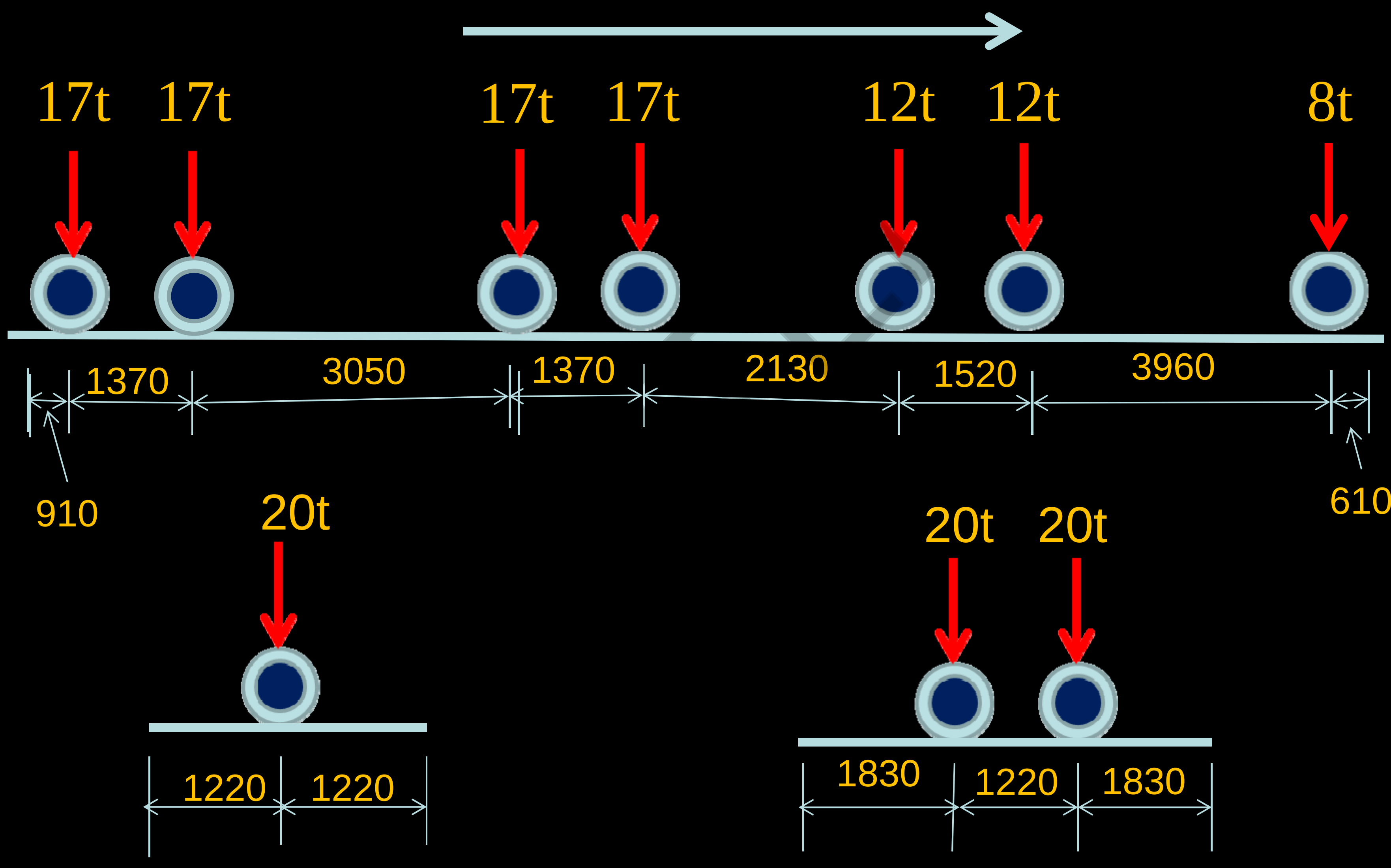
WHEEL ARRANGEMENT FOR 70R (TRACKED) VEHICLE

Fig. 1 Class 70R Tracked and Wheeled Vehicles (Clause 204.1)

IRC 70R Wheeled Vehicle

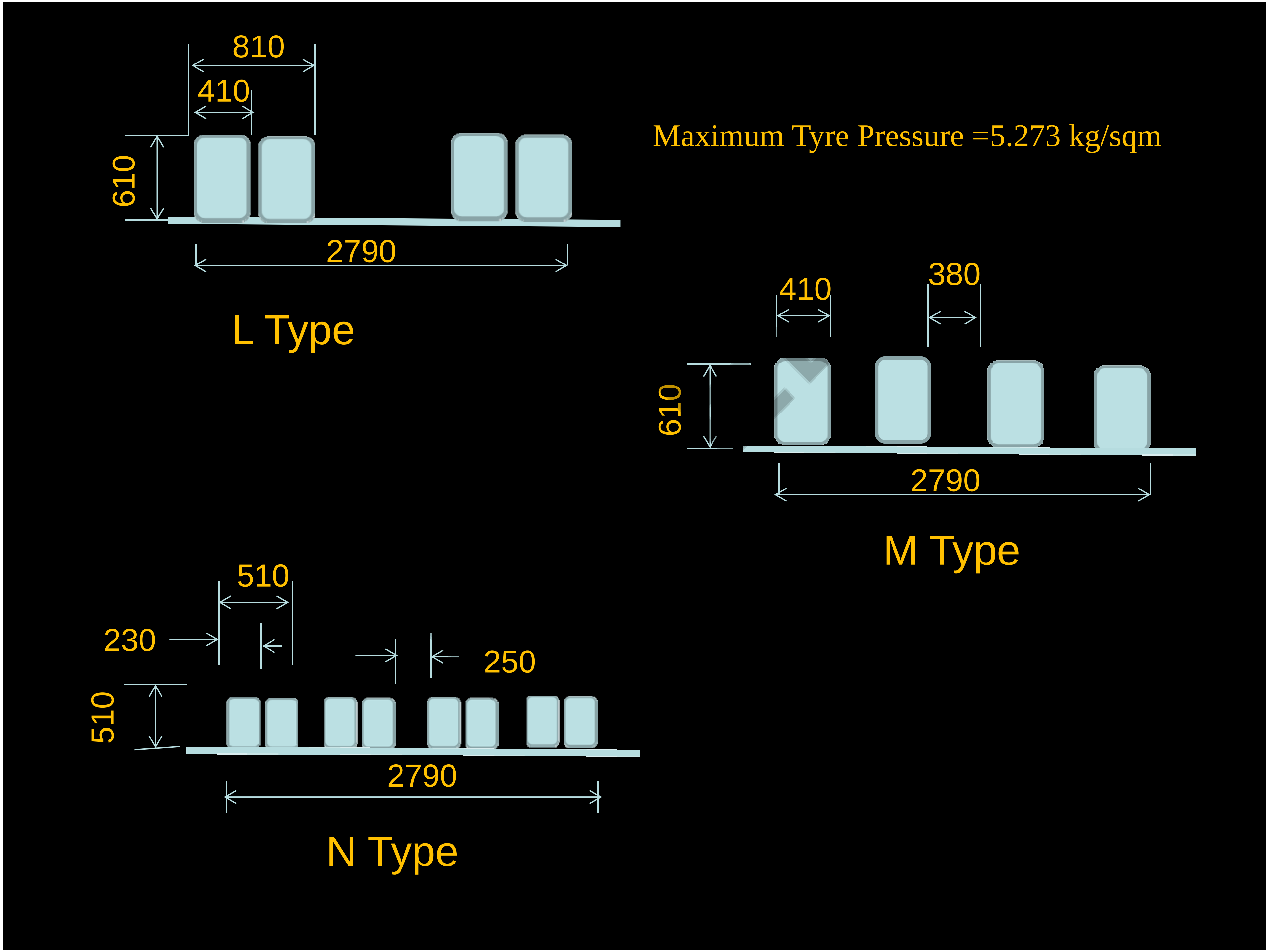


IRC 70R Wheeled Vehicle

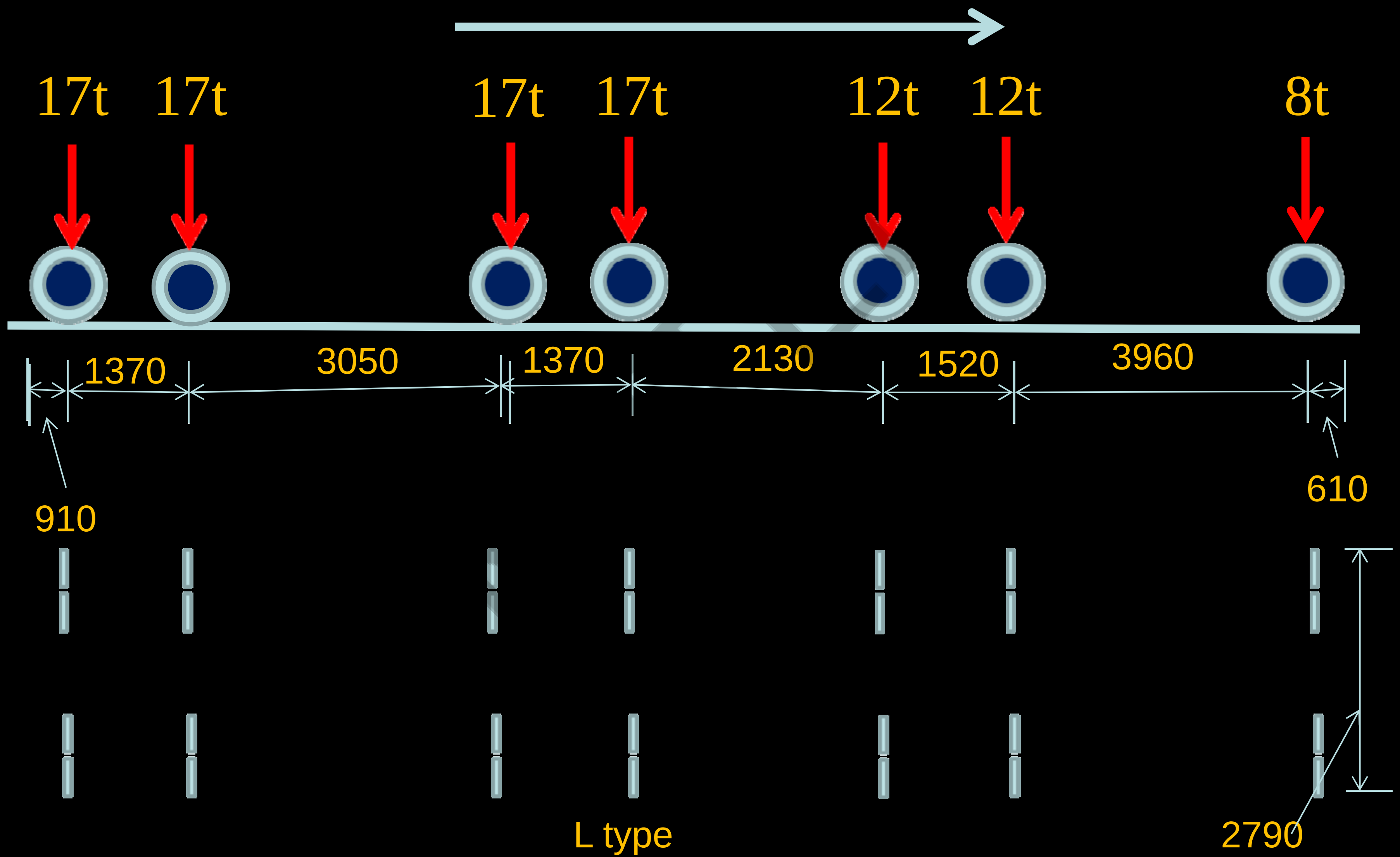


Max. Single Axle Load

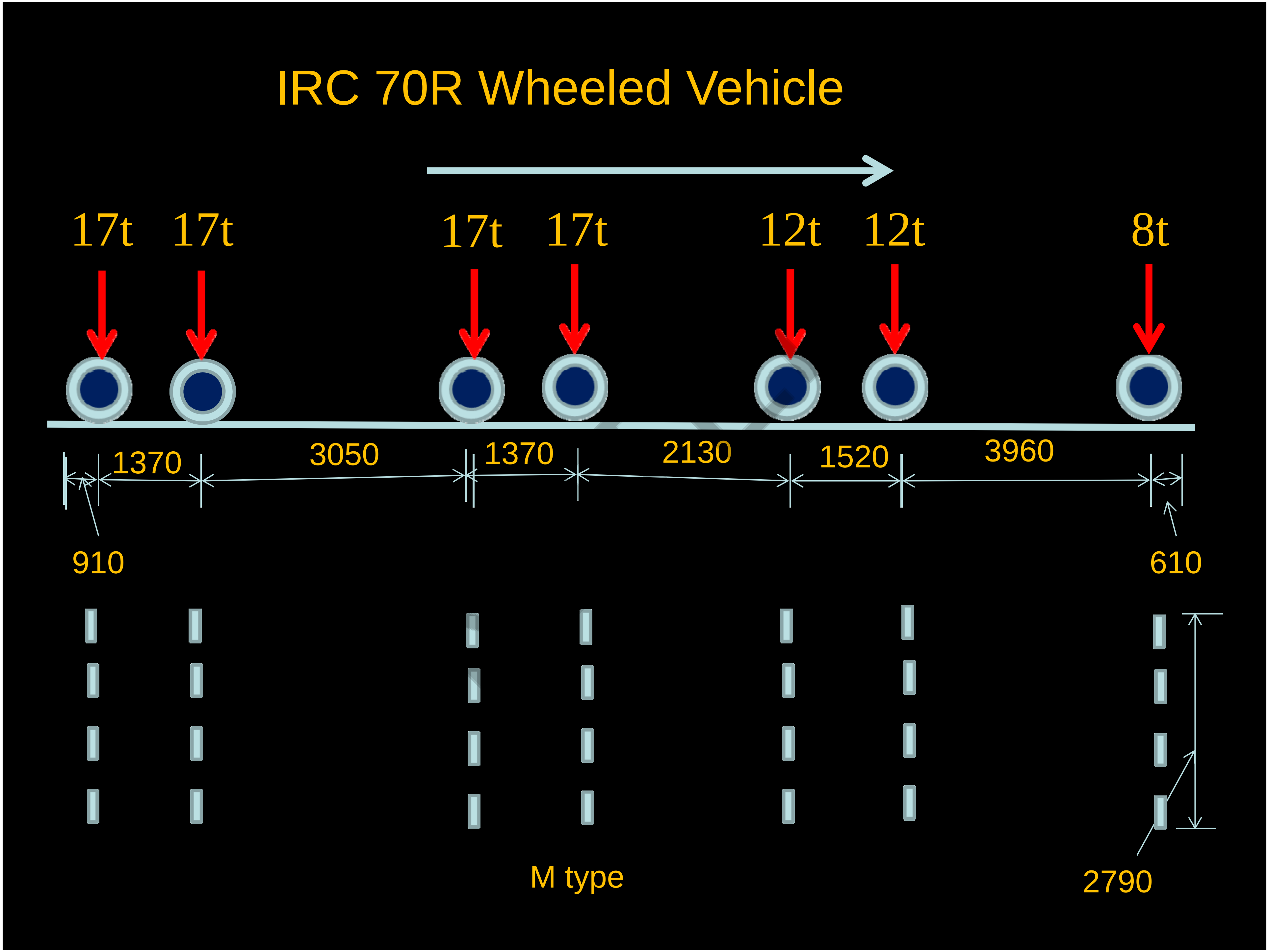
Max. Bogie Load


810
410
610
2790
L Type
Maximum Tyre Pressure =5.273 kg/sqm
410
380
610
2790
M Type
510
230
250
510
2790
N Type

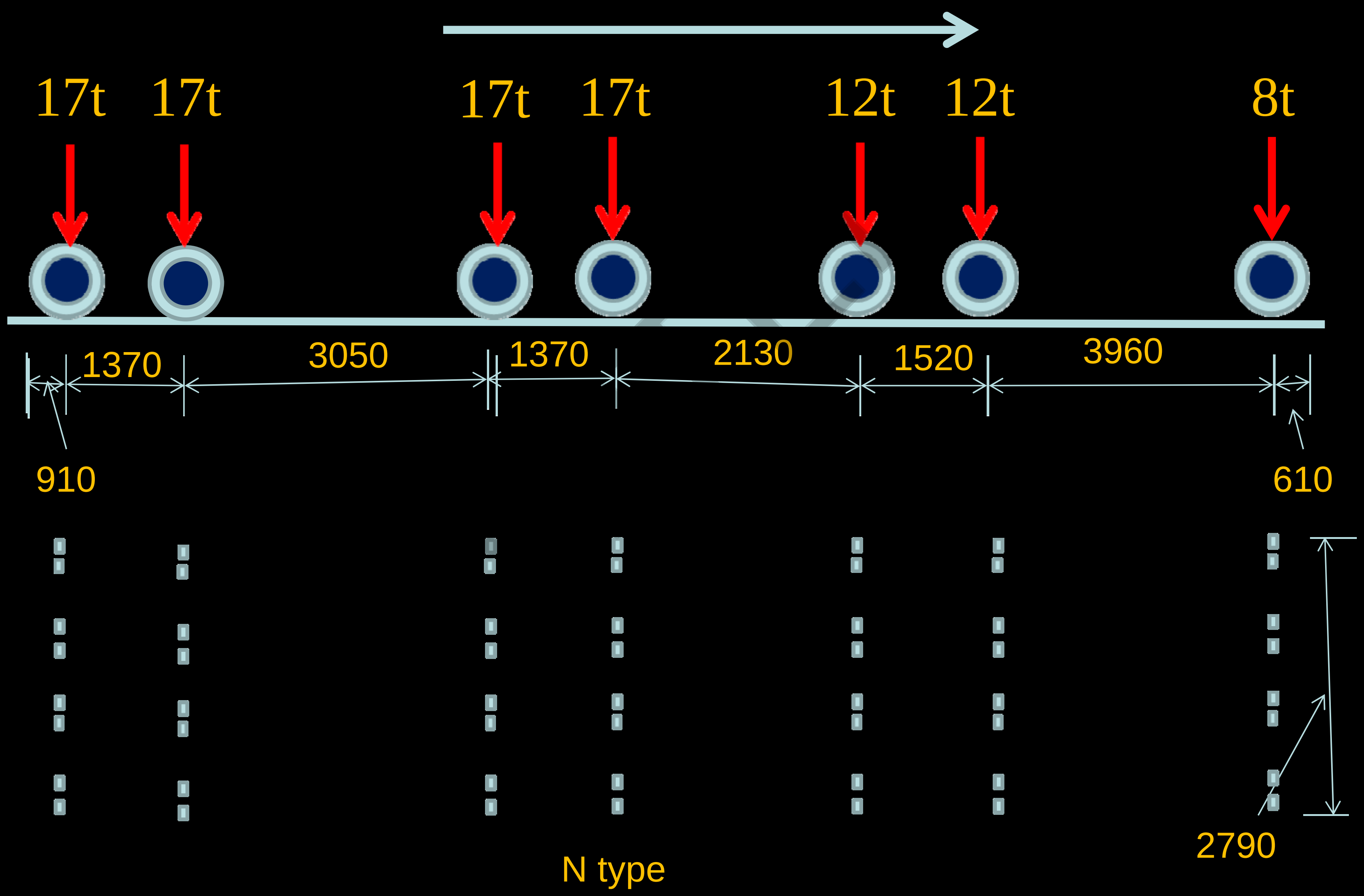
IRC 70R Wheeled Vehicle



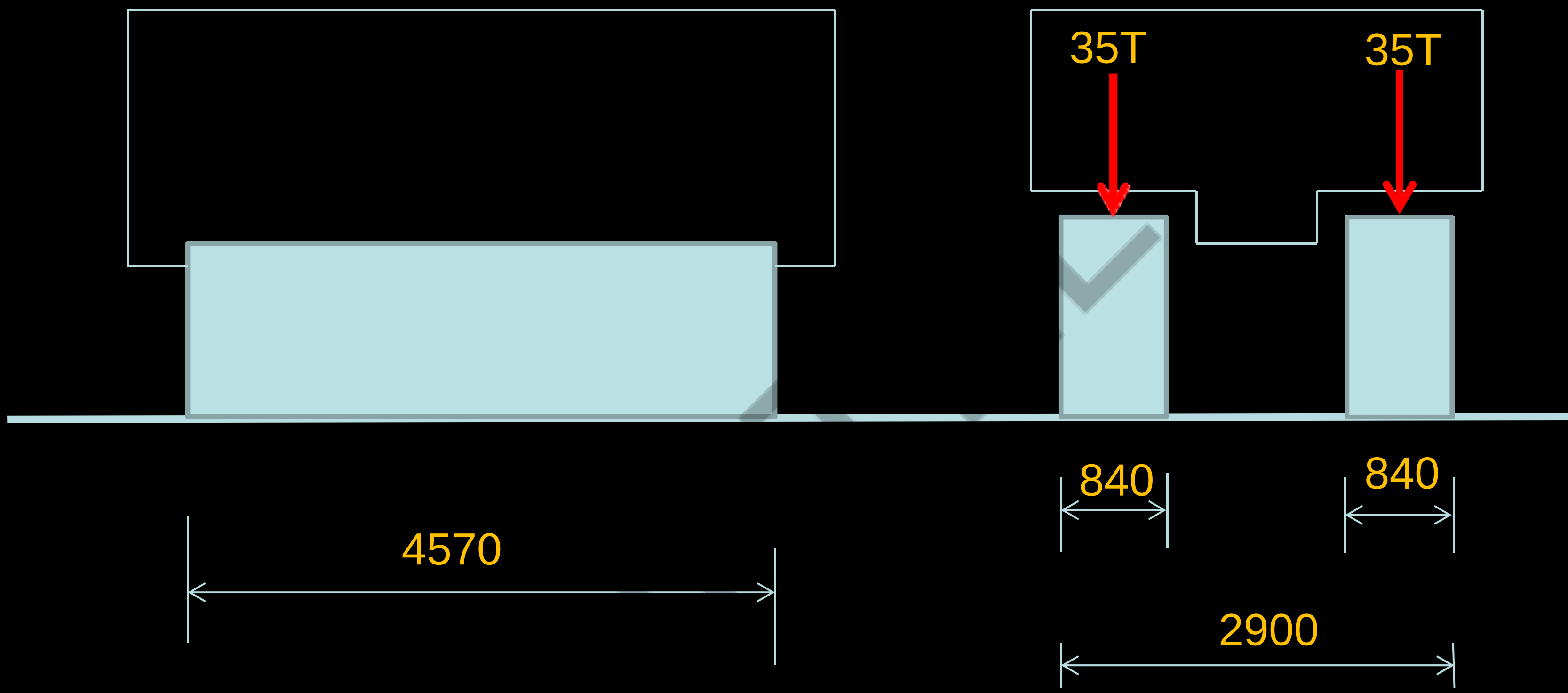
The nose to tail spacing between two successive vehicles shall not be less than 30m


IRC 70R Wheeled Vehicle
17t
17t
17t
17t
12t
12t
8t
1370
3050
1370
2130
1520
3960
910
610
M type
2790

IRC 70R Wheeled Vehicle



IRC 70R Tracked Vehicle



The nose to tail spacing between successive vehicles shall not be less than 90m

70R Loading

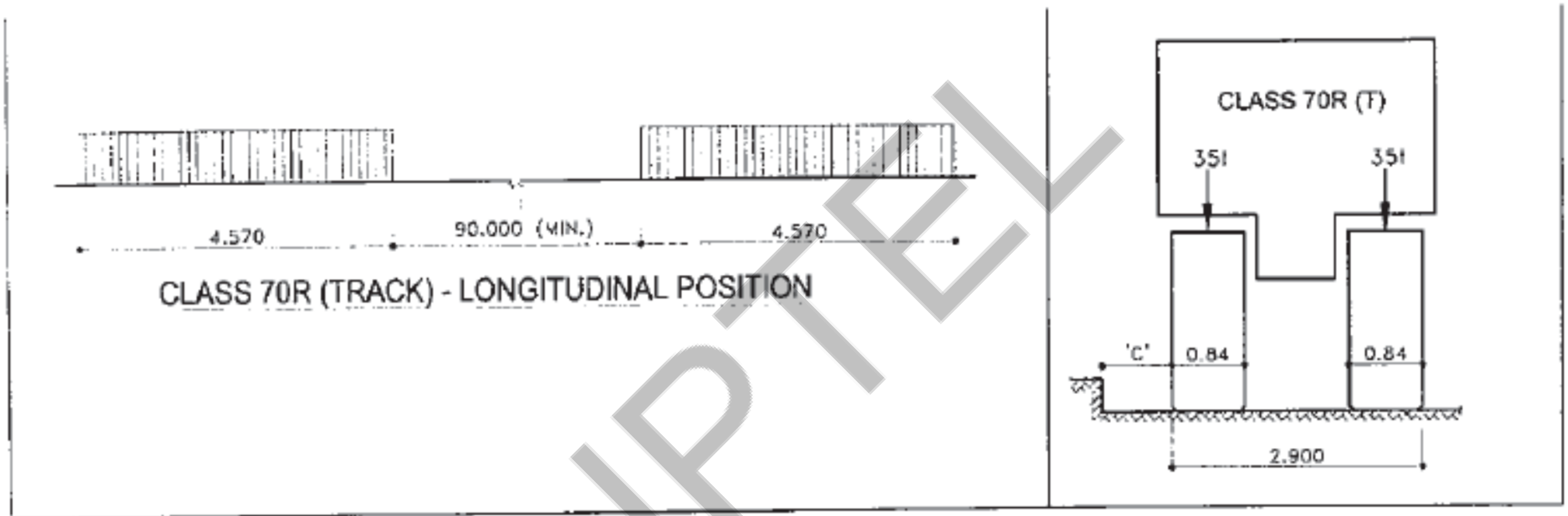
1) The nose to tail spacing between two successive vehicles shall not be less than 90 m for tracked vehicle and 30 m for wheeled vehicle.

2) For multi-lane bridges and culverts, each Class 7OR loading shall be considered to occupy two lanes and no other vehicle shall be allowed in these two lanes.

The passing/crossing vehicle can only be allowed on lanes other than these two lanes. Load combination is shown in Table 2 of IRC:6-2014.

3) The maximum loads for the wheeled vehicle shall be 20 tonne for a single axle or 40 tonne for a bogie of two axles spaced not more than 1.22 m centres.

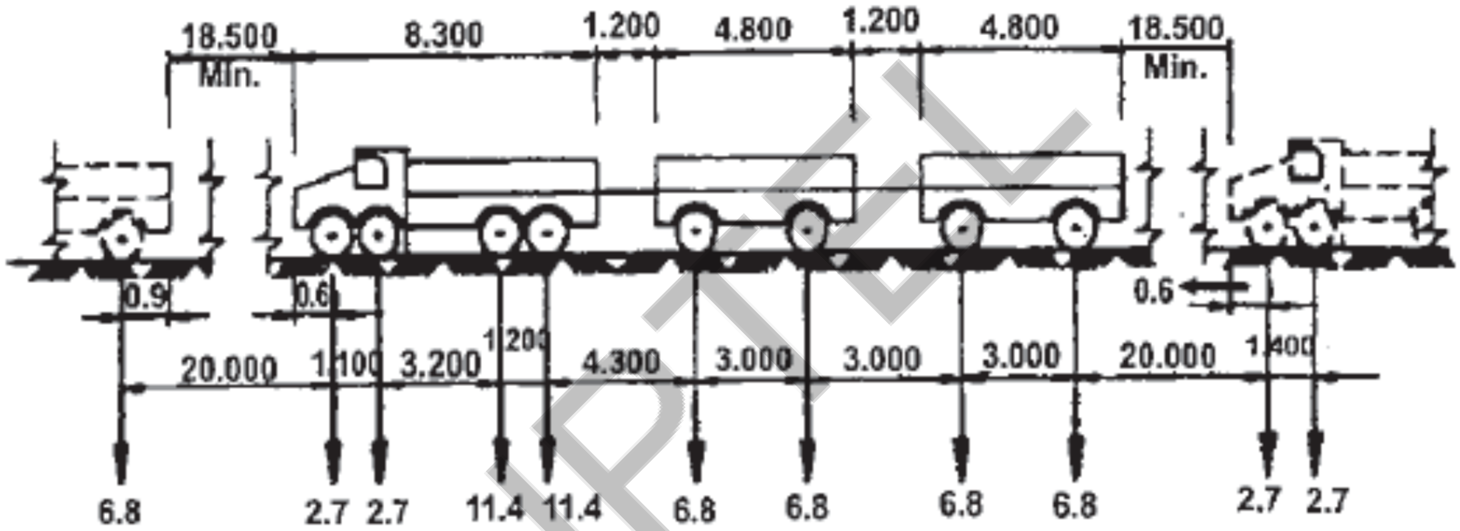
4) Class 7OR loading is applicable only for bridges having carriageway width of 5.3 m and above (i.e. 1.2 x 2 + 2.9 = 5.3). The minimum clearance between the road face of the kerb and the outer edge of the wheel or track, ·c·, shall be 1.2 m.



WHEEL ARRANGEMENT FOR 70R (TRACKED) VEHICLE

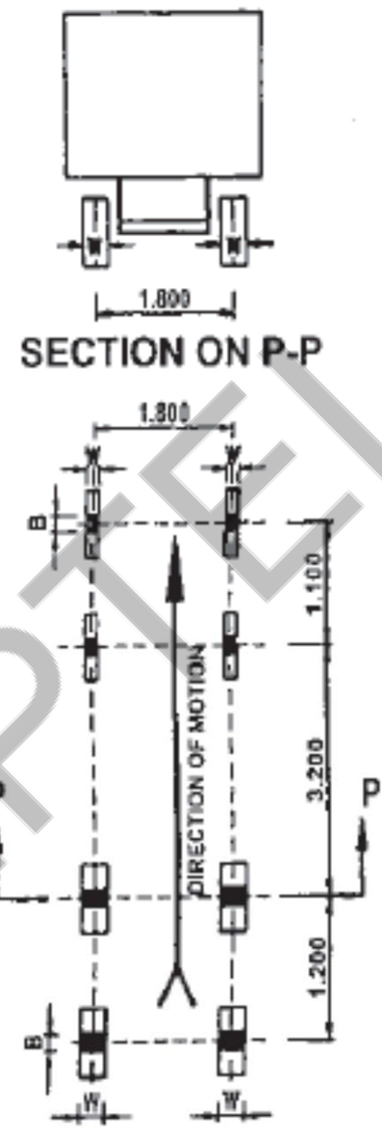
Fig. 1 Class 70R Tracked and Wheeled Vehicles (Clause 204.1)

5) The minimum clearance between the outer edge of wheel or track of passing or crossing vehicles for multilane bridge shall be 1.2 m. Vehicles passing or crossing can be either same class or different class, Tracked or Wheeled.



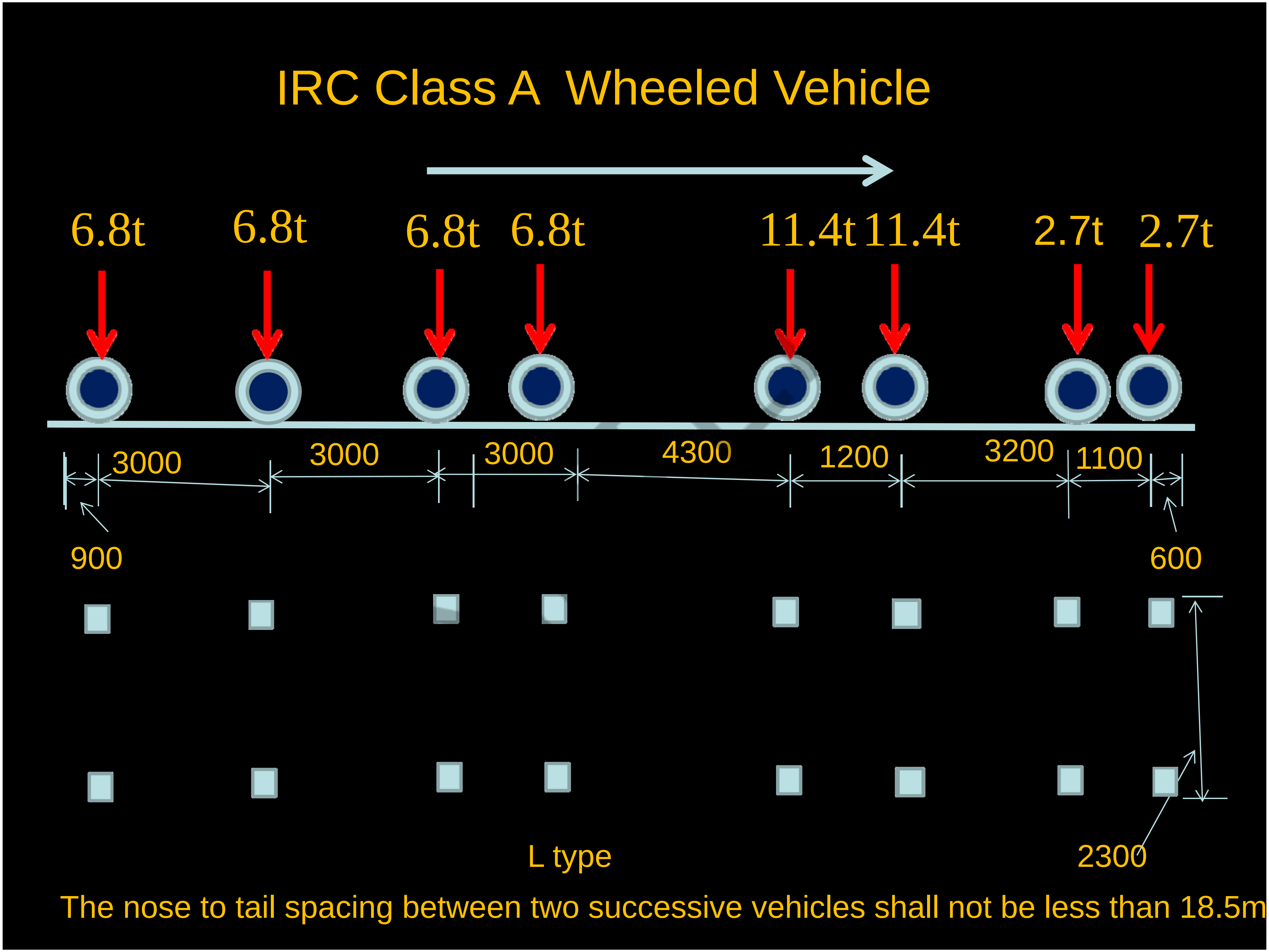
Class A Train of Vehicles

Fig. 2 Class 'A' Train of Vehicles (Clause 204.1)



PLAN

DRIVING VEHICLE



IRC Class A Wheeled Vehicle
6.8t
6.8t
6.8t
6.8t
11.4t
11.4t
2.7t
2.7t
3000
3000
3000
4300
1200
3200
1100
900
600
L type
2300
The nose to tail spacing between two successive vehicles shall not be less than 18.5m

Class A Loading

1) The nose to tail distance between successive trains shall not be less than 18.5 m.

2) For single lane bridges having carriageway width less than 5.3 m, one lane of Class A shall be considered to occupy 2.3 m. Remaining width of carriageway shall be loaded with 500 Kg/m2 , as shown in Table 2 of IRC:6-2014.

3) For multi-lane bridges each Class A loading shall be considered to occupy single lane for design purpose.

Live load combinations as given in Table 2 of IRC 6 shall be followed.

4) The ground contact area of the wheels shall be as under:

Axle load (tonne)	Ground contact area B (mm)	W (mm)
11.4	250	500
6.5	200	380
2.7	150	200

Impact Factor

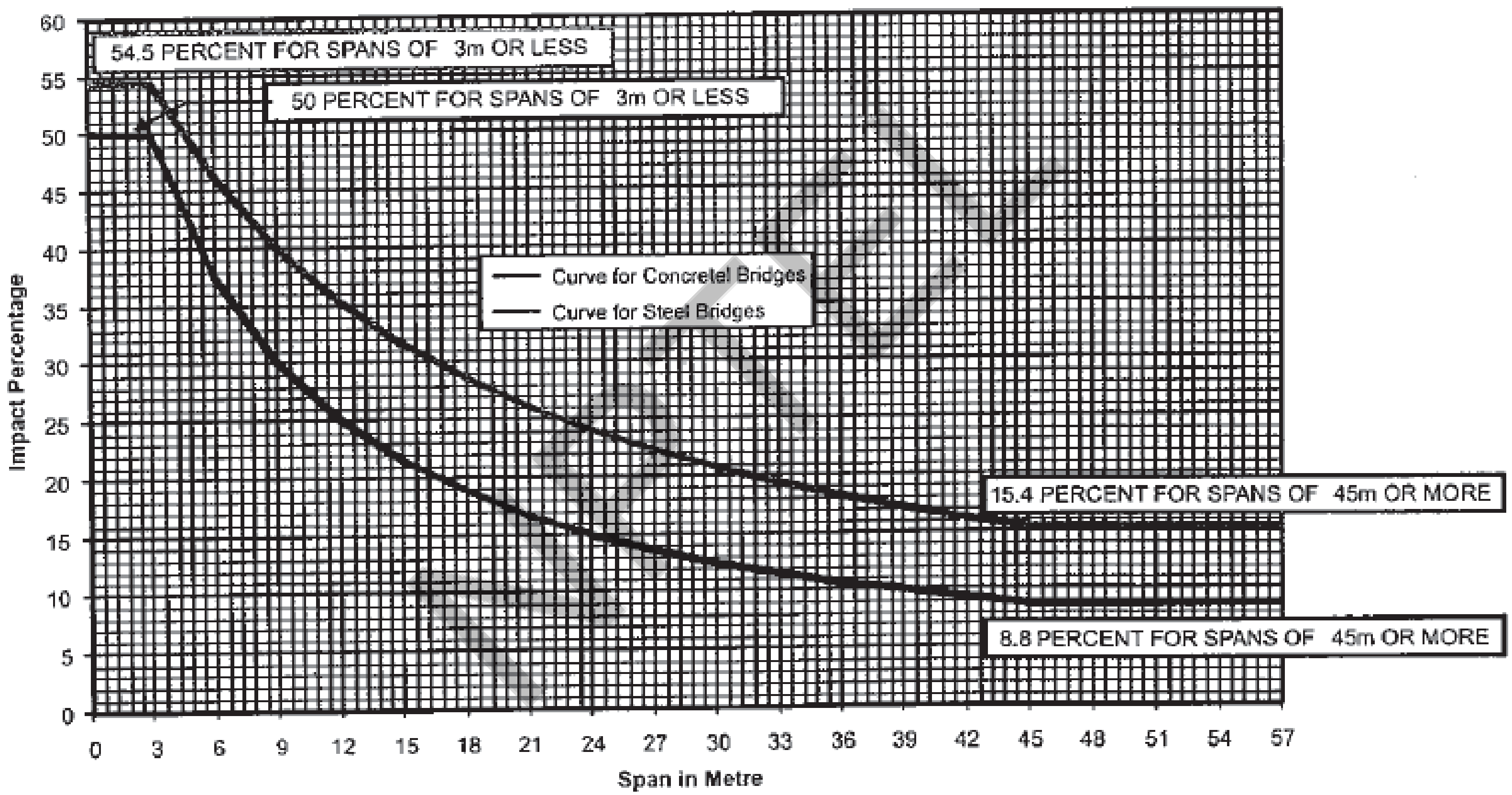


Fig. 5 Impact Percentage for Highway Bridges for Class A and Class B Loading (Clause 208.2)

Summary

- General features of design are discussed

- Vehicle loadings considered for design are also discussed

References

Standard specifications and code of practice
For road bridges

IRC 5
Section I : General features of design

IRC 6
Section II : Loads and Stresses

Published by

Indian Roads Congress, New Delhi

Thank you

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Lecture-4

Overview

1. IRC Loading
2. Summary
3. References

IRC Loading

Simply supported beam

Figure 1: Simply supported beam

Simply supported beam with IRC Class A loading

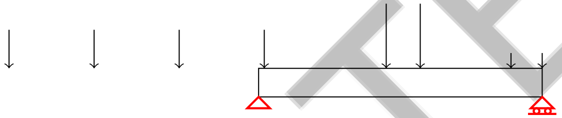


Figure 2: Simply supported beam with IRC Class A loading

Simply supported beam with IRC 70R loading

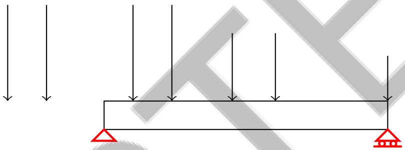
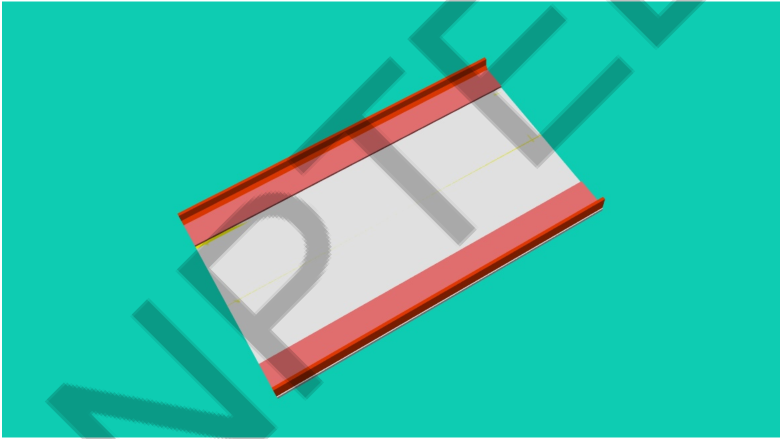


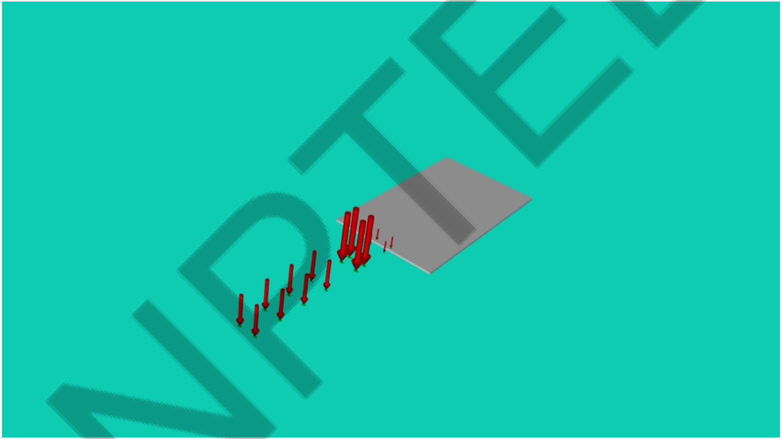
Figure 3: Simply supported beam with IRC Class A loading

Road vehicles

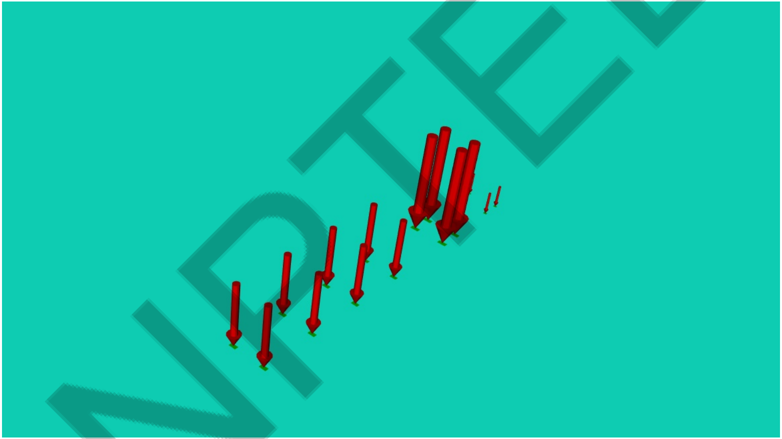
Deck



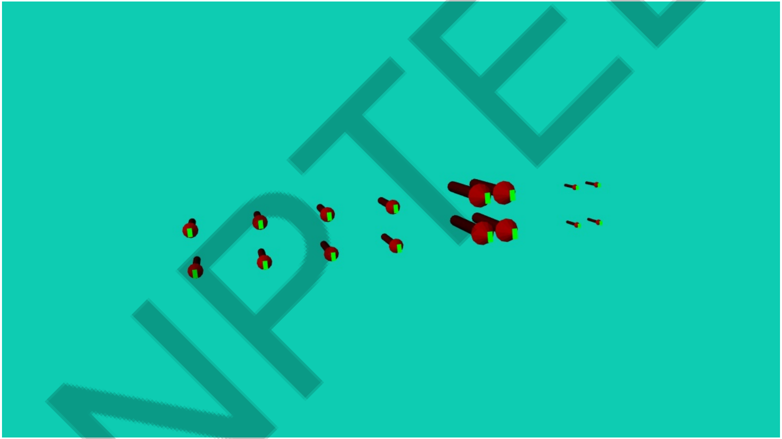
IRC Class A loading



IRC Class A loading



IRC Class A loading



Summary

Summary

- Bending moments and shear forces, for a simply supported beam, are computed for IRC loading, Class A and 70R.

References

References

- Standard specifications and code of practice for road bridges

  IRC 5 Section I : General features of design, 1998

  IRC 6 Section II : Loads and Stresses, 2014

  Published by Indian Roads Congress, New Delhi

Thank you

Reinforced Concrete Road Bridges

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Lecture-5

Design codes

Overview

1. Structural Safety
2. Calibration of partial safety factors
3. Procedure for calibration of partial safety factors
4. Example : calibration of partial safety factors
5. Summary

Structural Safety

Structural Safety

- Structural safety appears in different forms when criteria for design are stated in codes and specifications.
- The most commonly encountered criteria for design are :
  - Allowable stress design(ASD)
  - Ultimate strength design(USD)
  - Load and resistance factor design(LRFD)

Structural Safety(contd...)

- Allowable stress design(ASD)
  - Structural members are designed such that the computed elastic stress is less than or equal to a fraction of a limiting value such as the yield stress of the material
  - The computed elastic stress is obtained from an analysis of the structure using specified design loads.

Structural Safety(contd...)

- Ultimate strength design(USD)
  - Design loads are increased by a factor
  - The computed strength of a structural member is reduced by a factor
  - The computed strength of a structural member is based on ultimate behaviour
  - An elastic analysis is used to obtain the member forces

$$V_u \leq \phi V_n \tag{1}$$

where ϕ is a strength reduction factor, V_n is the nominal shear strength of the beam and V_u is the factored shear force at the section under consideration

Structural Safety(contd...)

- Load and resistance factor design(LRFD)
  - This method has been introduced by the American Institute of Steel Construction(AISC).
  - It is characterized by an expression of the form

$$\sum \gamma_i Q_i \leq \phi R_n \tag{2}$$

    where γ_i is the load factor for the ith load effect, Q_i is the ith load effect, ϕ is a resistance factor, and R_n is the nominal resistance(strength).
  - A similar method is used in the AASHTO specification Standard Specifications for Highway Bridges

Reliability Index

- The reliability index, β, for a linear limit state function, $g = R - Q$ is

$$\beta = \frac{\mu_R - \mu_Q}{\sqrt{\sigma_R^2 + \sigma_Q^2}} \tag{3}$$

Calibration of partial safety factors

Calibration of partial safety factors

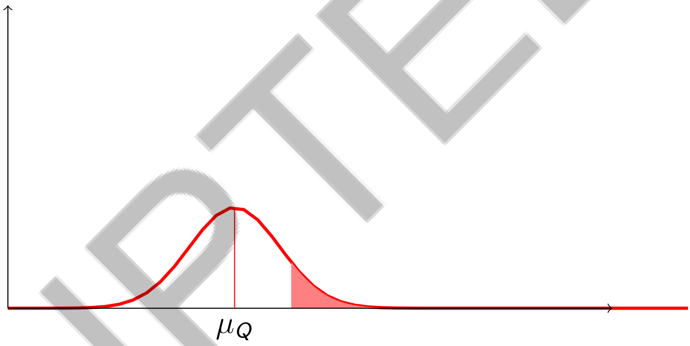

Figure 1: Relationships among nominal load, mean load and factored load

Calibration of partial safety factors

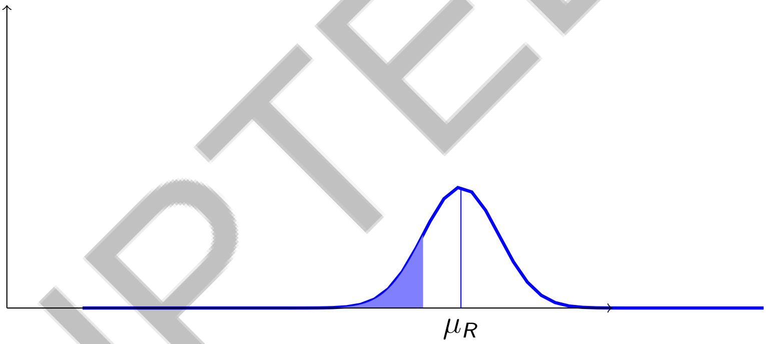

Figure 2: Relationships among nominal resistance, mean resistance and factored resistance

Calibration of partial safety factors

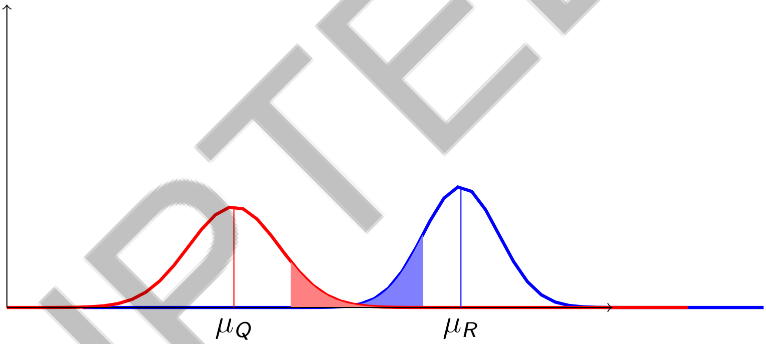

Figure 3: Relationships among nominal, mean and factored load and resistance

Calibration of partial safety factors(contd...)

- In load and resistance factor design (LRFD) or limit state design (LSD), load components are multiplied by load factors and resistance is multiplied by a resistance factor.
- The basic form of the LRFD equation is

$$\phi R \geq \sum \gamma_i Q_i \tag{4}$$

- where γ_i is a load factor applied to load components (or load effect) Q_i and ϕ is a resistance factor applied to the resistance(measure of load carrying capacity) R.

Calibration of partial safety factors(contd...)

- The basic form of the LRFD equation is

$$\phi R \geq \sum \gamma_i Q_i \tag{5}$$

- In words, the equation says that the capacity of the structural member (modified by the factor ϕ) must be larger than the total effect of all the loads acting on the member.

Calibration of partial safety factors(contd...)

- Forward problem: To determine β given a limit state function (or performance function) and the mean and variance (or standard deviation or coefficient of variation) for each of the random variables used in the limit state function.
- Inverse problem: A target β is specified and it is then necessary to determine the required mean values of the resistance and loads to achieve the target.
- This means that we need to find the design point $\{z^*\}$ corresponding to the target β.

Calibration of partial safety factors(contd...)

- Assume that the design points $\{z^*\}$ (in reduced coordinates) corresponding to a target β is known. To get the corresponding design point $\{x^*\}$ in original coordinates, the following relation is used for each variable.

$$x_i^* = \mu_{x_i} + z_i^* \sigma_{x_i} \tag{6}$$

- Since the design point must be on the failure boundary, the limit state function must satisfy

$$g(x_1^*, x_2^*, ..., x_i^*) = 0 \tag{7}$$

- For design purposes, it is necessary to relate each design point value x_i^* to a value of the variable used in design (e.g. a nominal design value specified by the code).

Calibration of partial safety factors(contd...)

- If the nominal design value of X_i is denoted by $\widetilde{x}_i$, then the partial safety factor γ_i is defined as

$$\gamma_i = \frac{x_i^*}{\widetilde{x}_i} \tag{8}$$

- The partial safety factor is nothing more than a scaling factor that allows the designer to convert a nominal design value of a variable to the value needed to satisfy the limit state function for a target β.

$$g(x_1^*, x_2^*, ..., x_i^*) = 0 \tag{9}$$

Procedure for calibration of partial safety factors

Procedure for calibration of partial safety factors

- Formulate the limit state function and the design equation
- Determine the probability distributions and appropriate parameters for as many of the random variables $X_i (i = 1, 2, ..., n)$ as possible
- It is assumed that the coefficient of variation or standard deviation is known for all random variables

Procedure for calibration of partial safety factors(contd...)

- There can be at most only two unknown mean values in the analysis
- Typically, one unknown mean value corresponds to the resistance variable, and the other unknown mean value corresponds to a load variable
- For the first iteration, the limit state function g=0 is evaluated at the mean values to get a relationship between the two unknown means

Procedure for calibration of partial safety factors(contd...)

- Obtain an initial design point $\{x_i^*\}$ by assuming values for n-1 of the random variables X_i.
- Note : mean values are often a reasonable initial choice
- Solve the limit state equation $g = 0$ to obtain a value for the remaining variable. This ensures that the trial design point is on the failure boundary

Procedure for calibration of partial safety factors(contd...)

- For each of the design point values x_i^* corresponding to a nonnormal distribution, determine the equivalent normal mean $\mu_{x_i}^e$ and standard deviation $\sigma_{x_i}^e$
- If one or more x_i^* values correspond to a normal distribution, then the equivalent normal parameters are simply the actual parameters. Since some of the mean values are not known in advance, it may not always be possible to carry out this step

Procedure for calibration of partial safety factors(contd...)

- Determine the partial derivatives of the limit state function with respect to the reduced variables

$$\{G\} = \left\{ \begin{array}{c} G_1 \\ G_2 \\ . \\ . \\ G_n \end{array} \right\} \quad where \quad G_i = -\frac{\partial g}{\partial Z_i} \tag{10}$$

Procedure for calibration of partial safety factors(contd...)

- Consider the column vector $\{\alpha\}$ using

$$\{\alpha\} = \frac{[\rho]\{G\}}{\sqrt{\{G\}^T[\rho]\{G\}}} \tag{11}$$

- where $[\rho]$ is the matrix of correlation coefficients,

Procedure for calibration of partial safety factors(contd...)

- Determine a design point in reduced variates for n-1 of the variables using

$$z_i^* = \alpha_i \beta_{target} \tag{12}$$

- where β_{target} is the target reliability to be found.
- Design the corresponding design point values in original coordinates for the n-1 values using

$$x_i^* = \mu_{x_i}^e + z_i^* \sigma_{x_i}^e \tag{13}$$

Procedure for calibration of partial safety factors(contd...)

- Determine the value of the remaining random variable (i.e.the one not found in previous steps) by solving the limit state function g=0.
- Update the relationship between the two unknown mean values(if applicable).

$$\gamma_i = \frac{x_i^*}{\mu_{x_i}} = \frac{\mu_{x_i} + z_i^* \sigma_{x_i}}{\mu_{x_i}} = 1 + z_i^* V_{x_i} = 1 + \alpha_i \beta V_{x_i} \tag{14}$$

$$Therefore, \quad \mu_{x_i} = \frac{x_i^*}{1 + \alpha_i \beta V_{x_i}} \tag{15}$$

Procedure for calibration of partial safety factors(contd...)

- Repeat steps until $\{\alpha\}$ converges.
- Once convergence is achieved, calculate the design factors.

$$\gamma_i = \frac{x_i^*}{\tilde{x}_i} \tag{16}$$

Example : calibration of partial safety factors

Example : calibration of partial safety factors

- Consider the fundamental case

$$g = R - Q \tag{17}$$

where R is the resistance and Q is the load.

- A possible design equation (in LRFD format) is

$$\gamma_R \mu_R \geq \gamma_Q \mu_Q \tag{18}$$

- The nominal values are assumed to be equal to the mean values
- Assume, V_R as 10 percent and V_Q as 12 percent
- To determine the partial safety factors that must be used in design to achieve the reliability index, β_{target}=3.0
- Assume that both R and Q are normally distributed and uncorrelated

Example : calibration of partial safety factors(contd...)

- The limit state function :

$$g = R - Q \tag{19}$$

where R is the resistance and Q is the load.

- Obtain and initial design point, say $r^* = q^*$.
- There are two variables, so we have two unknown mean values
- Use limit state function at the mean values to relate the two unknown mean values. This results, $\mu_R = \mu_Q$

Example : calibration of partial safety factors(contd...)

- Determine the $\{G\}$ vector:

$$\begin{aligned} G_1 &= -\frac{\partial g}{\partial R}\sigma_R = -\sigma_R = -V_R\mu_R = -0.1\mu_R = -0.1\mu_Q \\ G_2 &= -\frac{\partial g}{\partial Q}\sigma_Q = \sigma_Q = V_Q\mu_Q = 0.12\mu_Q \end{aligned} \tag{20}$$

- Note that $\mu_R = \mu_Q$ is used to evaluate G_1

Example : calibration of partial safety factors(contd...)

- Calculate α. The correlation matrix $[\rho]$ is the identity matrix. It means that variables are uncorrelated

$$\begin{aligned}
\{\alpha\} &= \frac{[\rho]\{G\}}{\sqrt{\{G\}^T[\rho]\{G\}}} \\
&= \frac{1}{\sqrt{(-0.1\mu_Q)^2 + (0.12\mu_Q)^2}} \left\{ \begin{array}{c} -0.1\mu_Q \\ 0.12\mu_Q \end{array} \right\} \\
&= \frac{1}{0.156\mu_Q} \left\{ \begin{array}{c} -0.1\mu_Q \\ 0.12\mu_Q \end{array} \right\} \\
&= \left\{ \begin{array}{c} -0.641 \\ 0.769 \end{array} \right\}
\end{aligned} \tag{21}$$

Example : calibration of partial safety factors(contd...)

- Determine a new design point for n-1 variables. Calculaute z_Q^* in this way

$$z_Q^* = \alpha_Q \beta_{target} = 0.769(3.0) = 2.31 \tag{22}$$

- Determine q^* using

$$q^* = \mu_Q + z_Q^* \sigma_Q = \mu_Q(1 + z_Q^* V_Q) = \mu_Q(1 + 2.31(0.12)) = 1.28\mu_Q \tag{23}$$

- Determine r^* by solving g=0. Thus $r^* = 1.28\mu_Q$.
- Before iterating again, get an improved estimate of μ_R in terms of μ_Q for use in calculating $\{G\}$ and $\{\alpha\}$.

$$\mu_R = \frac{r^*}{(1 + \alpha_R \beta_{target} V_R)} = \frac{1.28\mu_Q}{1 - 0.641(3.0)(0.10)} = 1.58\mu_Q \tag{24}$$

Example : calibration of partial safety factors(contd...)

- The results of subsequent iterations are shown in Table-2

Table 2 : Iteration results

	Iteration number		
	1	2	3
$r^*(start)$	μ_Q	$1.28\mu_Q$	$1.22\mu_Q$
$q^*(start)$	μ_Q	$1.28\mu_Q$	$1.22\mu_Q$
$\mu_R(start)$	μ_Q	$1.58\mu_Q$	$1.60\mu_Q$
α_R	-0.641	-0.796	-0.800
α_Q	0.769	0.605	0.600
$r^*(end)$	$1.28\mu_Q$	$1.22\mu_Q$	$1.22\mu_Q$
$q^*(end)$	$1.28\mu_Q$	$1.22\mu_Q$	$1.22\mu_Q$
$\mu_R(end)$	$1.58\mu_Q$	$1.60\mu_Q$	$1.60\mu_Q$

Example : calibration of partial safety factors(contd...)

- Assuming the mean values are the nominal design values, the design factors are

$$\begin{aligned} \gamma_R &= \frac{r^*}{\mu_R} = \frac{1.22\mu_Q}{1.60\mu_Q} = 0.763 \\ \gamma_Q &= \frac{q^*}{\mu_Q} = \frac{1.22\mu_Q}{\mu_Q} = 1.22 \end{aligned} \tag{25}$$

- Assume $\mu_R = 10$. From the design equation, $\gamma_R \mu_R \geq \gamma_Q \mu_Q$, the minimum required μ_R to achieve $\beta = 3$ would be

$$\mu_R = \frac{\gamma_Q \mu_Q}{\gamma_R} = \frac{(1.22)(10)}{0.763} = 16.0 \tag{26}$$

Example : calibration of partial safety factors(contd...)

- If the partial safety factors are calibrated correctly, a nominal resistance of 16 will ensure a target $\beta = 3$ is acheieved if the nominal loading is equal to 10.
- For this simple case of a linear limit state function, it can be checked with the following equation

$$\beta = \frac{\mu_R - \mu_Q}{\sqrt{\sigma_R^2 + \sigma_Q^2}} \tag{27}$$

- Substituting all the variables determined into this expression and noting that $\sigma_R = V_R \mu_R$

$$\beta = \frac{\mu_R - \mu_Q}{\sqrt{\sigma_R^2 + \sigma_Q^2}} = \frac{16.0 - 10}{\sqrt{[(0.1)(16.0)]^2 + [(0.12)(10)]^2}} = \frac{6.0}{2.00} = 3.0 \tag{28}$$

Summary

Summary

- Basic principles of design codes are discussed.

References

- Reliability of structures, A. S. Nowak and K. R. Collins, McGraw-Hill

Thank you