Design of Bridges

BRIDGE ENGINEERING DESIGN

LOADS ON BRIDGES

Lecture No. 2

Summary of Design Steps

The design of bridges generally involves Two main stages:-

- Preliminary design stage
- Final design stage

The stages involved in preliminary and final design steps are as summarized below in the following paragraphs:-

Initial Stage

Review of the design procedure in which it includes; Data collection for design of relevant elements, Selection of the appropriate bridge structure and assumptions of section outlines.

Load Calculation

Number of notional lanes, Dead loads , HA loading, HB loading, HA and HB loading, Footpath loading, Wind load, Load combinations and Load factors.

Analysis Stage
Determination of Shear forces, Bending moments, Combined shear force envelope, and combined bending moment envelope.

Design Stage
Specifying Material properties, Section properties, Section design. Other optional design parameters, Final design, Detailing, checking, Approval of design, Construction, and finally Design variations during construction.

In terms of components, the structural design involves:
Design of Slab or Deck, Longitudinal Beams/Girders, Cross beams-Bearings, Piers and Abutments, Foundations, Guard rails and joints.

Collection of data for relevant parameters
Road classification- Span of bridge, width of the road, design codes, materials availability, available equipment, available skilled labour, existing bridge structures existing civil engineering structures, etc.

Bridge Type Selection
Steel bridge, Timber bridge, Reinforced Concrete bridge, Prestressed Concrete bridge, Composite construction, Cable Stayed, Suspension bridge, Truss bridge, or Arch bridge.

No	Bridge	Materials			Support System	
		RC	PSC	Steel	Simple	Continuous
1	Slabs	X			8m	
2	Slabs		X		20m	
3	Voided slabs	X			10 - 20m	
4	Voided slabs		X		20 - 30m	
5	Beams	X			10 - 25m	
6	Beams		X			10 - 70m
7	Haunched beams		X			Up to 250m
8	Steel girders			X	50m	260m
9	Arch			X	20 - 50m	
10	Arch	X		X	20 - 400m	
11	Truss	X	X	X	40 - 400m	
12	Cable stayed	X			200 - 700m	
13	Suspension			X	Over 500m	
14	Timber beam				Up to 6m	
15	Timber truss					Up to 45m

Preliminary design

- This involves determination of initial dimensions and design elements such as reinforcements, rivets, bolts, welding, etc.
- These dimensions are to be adjusted later in the final or intermediate design
- It serves time not to start directly with the detailed final design.
- But all design parameters are considered
- All design steps are the same as for the final design
- Computer programs can help in shortening the design time.

Assumptions and outline section

- **Outline sketch plan** of the bridge
- Outline sketch of the **transverse section** of the bridge
- Outline sketch of the **longitudinal section** of the bridge
- **Identification** of the beams and slabs
- **Thickness** of the surfacing
- Guardrails and parapets
- Assumed **span** of the beams
- Assumed beam **spacing**

Loads for Bridge Design

1. Dead load; which comprises of:

Self weights of bridge elements

The densities of the materials used are as follows:-

Concrete:	24kN/m^3
Steel:	78.5kN/m^3
Timber:	4-8 kN/m^3
Hollow bricks:	15kN/m^3
Solid bricks	22kN/m^3
Natural stones or rock:	20-28kN/m^3
Railways ballast:	19 kN/m^3

2. Imposed dead load, such as;

Wearing surface,

Railway tracks,

Guardrails,

Prestressing force

3. Vertically imposed loads such as:

Impact

Weight of vehicles, etc.

4. Transverse imposed loads such as:

Skidding,

Centrifugal forces in curves

Wind loads

5. Longitudinal imposed loads such as:-

Braking forces,

Acceleration forces

6. Constraining imposed loads such as:-

Due to **temperature** changes

Shrinkage

Creep

Pier **settlements**

7. Friction forces in the bearings

8. Collision forces

9. Earthquake loads

10. Traffic lanes are lanes that are marked on the running surface of the bridge and are normally used by traffic.

11. Notional lanes are imaginary lanes assumed solely for the purposes of applying the specified live loads.

Highway Bridge Live Loads

12. HA Loading

The (BD 37/01) Design Manual for Roads and Bridges says that Type HA loading is the normal design loading for Great Britain and adequately covers the effects of all permitted normal vehicles other than those used for abnormal indivisible loads. Normal vehicles are governed by the Road Vehicles (Authorized Weight) Regulations 1998, referred to as the AW Vehicles and cover vehicles up to 44 tone gross vehicle weight. Loads from these AW vehicles are represented by a uniformly distributed load and a knife edge load. The loading has been enhanced to cover:

i) impact load (caused when wheels 'bounce' i.e. when stricking potholes).

ii) overloading

iii) Lateral bunching (more than one vehicle occupying the width of a lane).

The magnitude of the uniformly distributed load is dependent on the loaded length as determined from the influence line for the member under consideration. For simply supported decks this usually relates to the span of the deck.

HA loading: is the basic imposed load comprising of

- A uniformly distributed load
- A knife-edge load

HA loading includes a 25% allowance for impact

The intensity of which depends upon the loaded length

No dispersal of load beneath contact area

Knife-edge load is positioned to have the most severe effect,

Alternatively a single 100 kN load with ϕ 340mm or 300mm x 300 mm square contact area.

Table: 2: Notional lanes for design purposes according to the carriageway width

Bridge Loading

Table 2: Notional Lanes for design purposes according to the carriageway width

Carriage Width (m)	5 – 7.5	7.5 – 10.95	10.95 – 14.6	14.6 – 18.25	18.25 – 21.9
No. of Notional Lanes	2	3	4	5	6

Table 3: HA Loading

Loaded length L (m)	< 50 m	50 m - 1600 m	> 1600 m
Uniform Load (kN/m/Lane)	$336(1/L)^{0.67}$	$36(1/L)^{0.1}$	Agreement
Knife edge load (kN/Lane)	120		

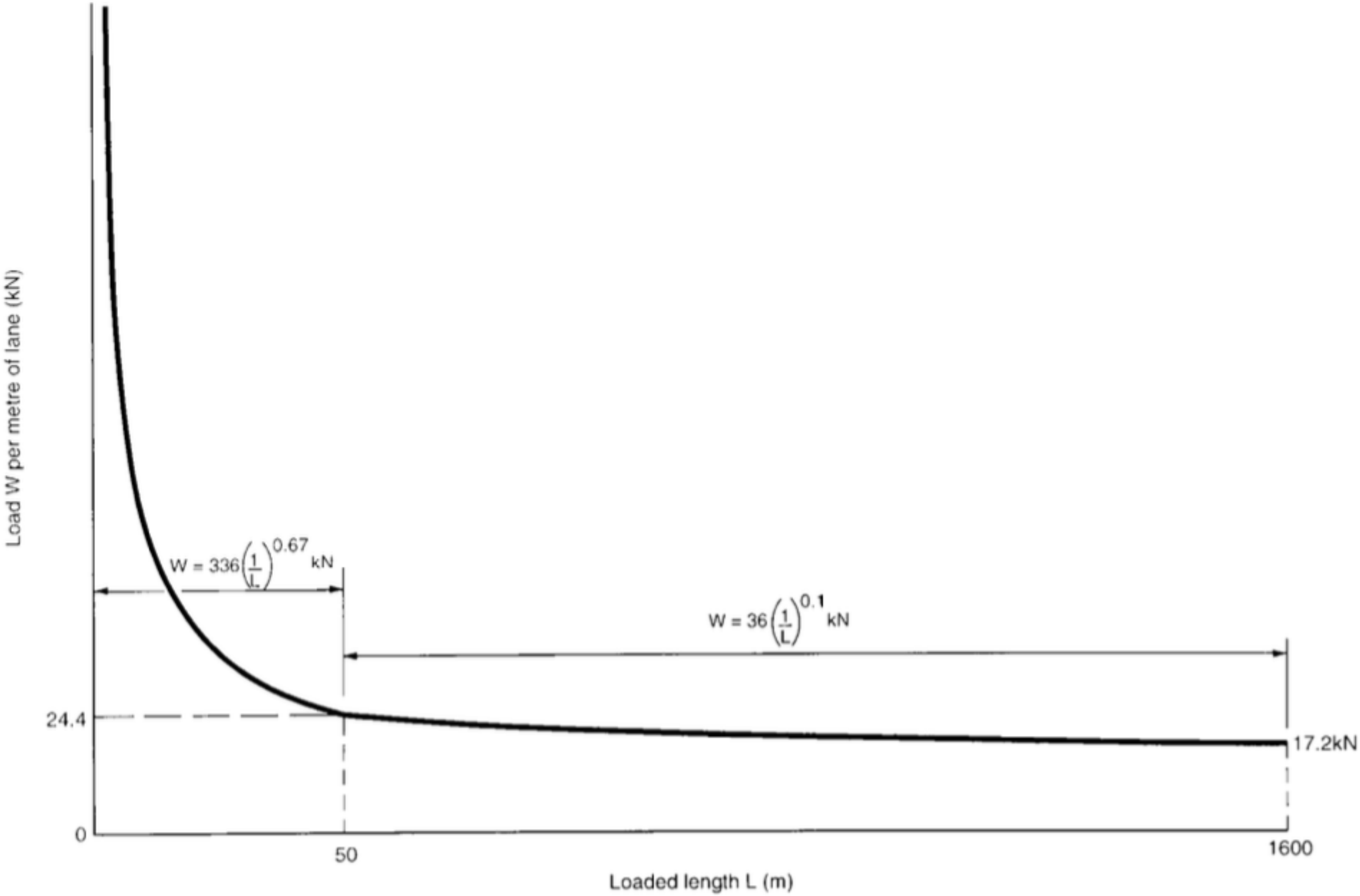


Figure 10. Loading curve HA UDL (Not to scale)

Table 13. Type HA uniformly distributed load.

Loaded length	Load	Loaded length	Load	Loaded length	Load
m	kN/m	m	kN/m	m	kN/m
2	211.2	55	24.1	370	19.9
4	132.7	60	23.9	410	19.7
6	101.2	65	23.7	450	19.5
8	83.4	70	23.5	490	19.4
10	71.8	75	23.4	530	19.2
12	63.6	80	23.2	570	19.1
14	57.3	85	23.1	620	18.9
16	52.4	90	23.0	670	18.8
18	48.5	100	22.7	730	18.6
20	45.1	110	22.5	790	18.5
23	41.1	120	22.3	850	18.3
26	37.9	130	22.1	910	18.2
29	35.2	150	21.8	980	18.1
32	33.0	170	21.5	1050	18.0
35	31.0	190	21.3	1130	17.8
38	29.4	220	21.0	1210	17.7
41	27.9	250	20.7	1300	17.6
44	26.6	280	20.5	1400	17.4
47	25.5	310	20.3	1500	17.3
50	24.4	340	20.1	1600	17.2

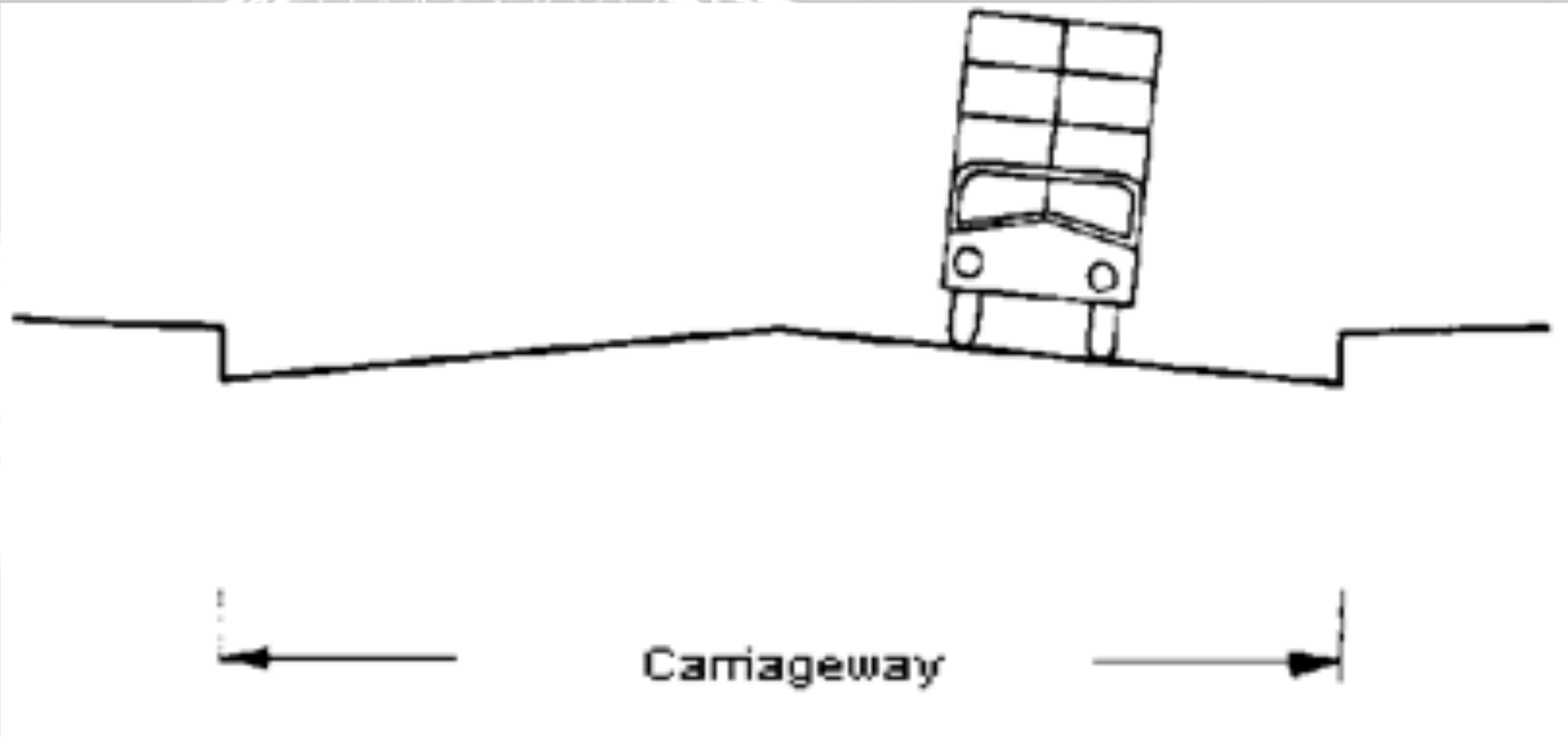
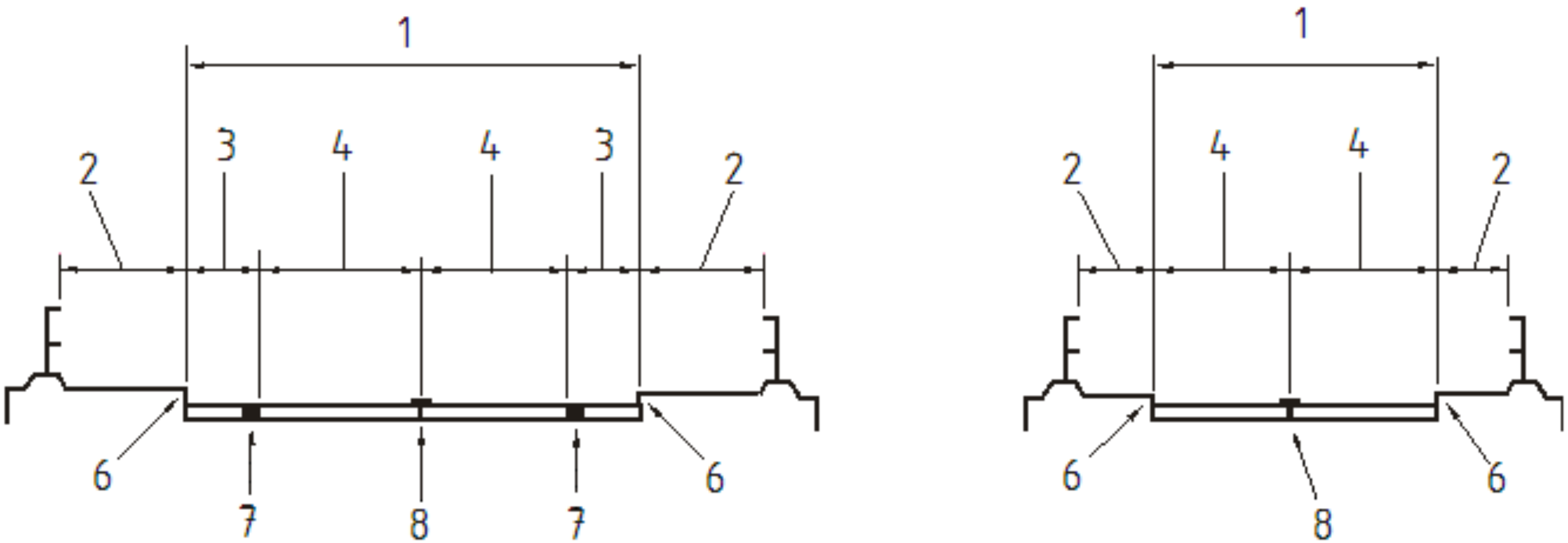


Fig.: Carriageway width

Traffic Lanes



ii) Single 2-lane carriageway

Key

1 Carriageway for the purpose of **3.2.9**

2 Footway or verge

3 Hard strip

4 Inside traffic lane

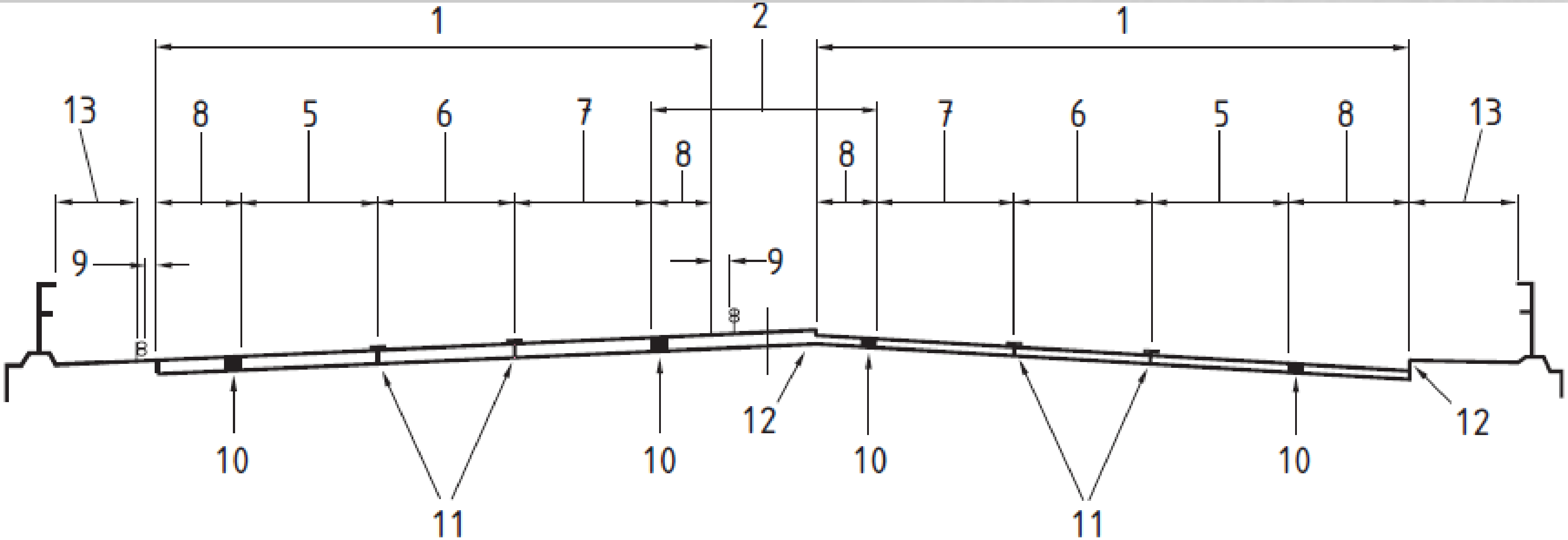
5 Middle traffic lane

6 Raised kerb

7 Edge marking

8 Lane marking

Fig.: Carriageway with two traffic lanes



ii) All-purpose road

Key

1 Carriageway for the purpose of 3.2.9
2 Central reserve – will be split on separate superstructures
3 Verge
4 Hard shoulder
5 Inside traffic lane
6 Middle traffic lane
7 Outside traffic lane
8 Hard strip
9 Setback
10 Edge marking
11 Lane marks
12 Raised kerb
13 Footway

a) Superstructures: dual carriageway

Fig.: Highway carriageway and 6 traffic lanes

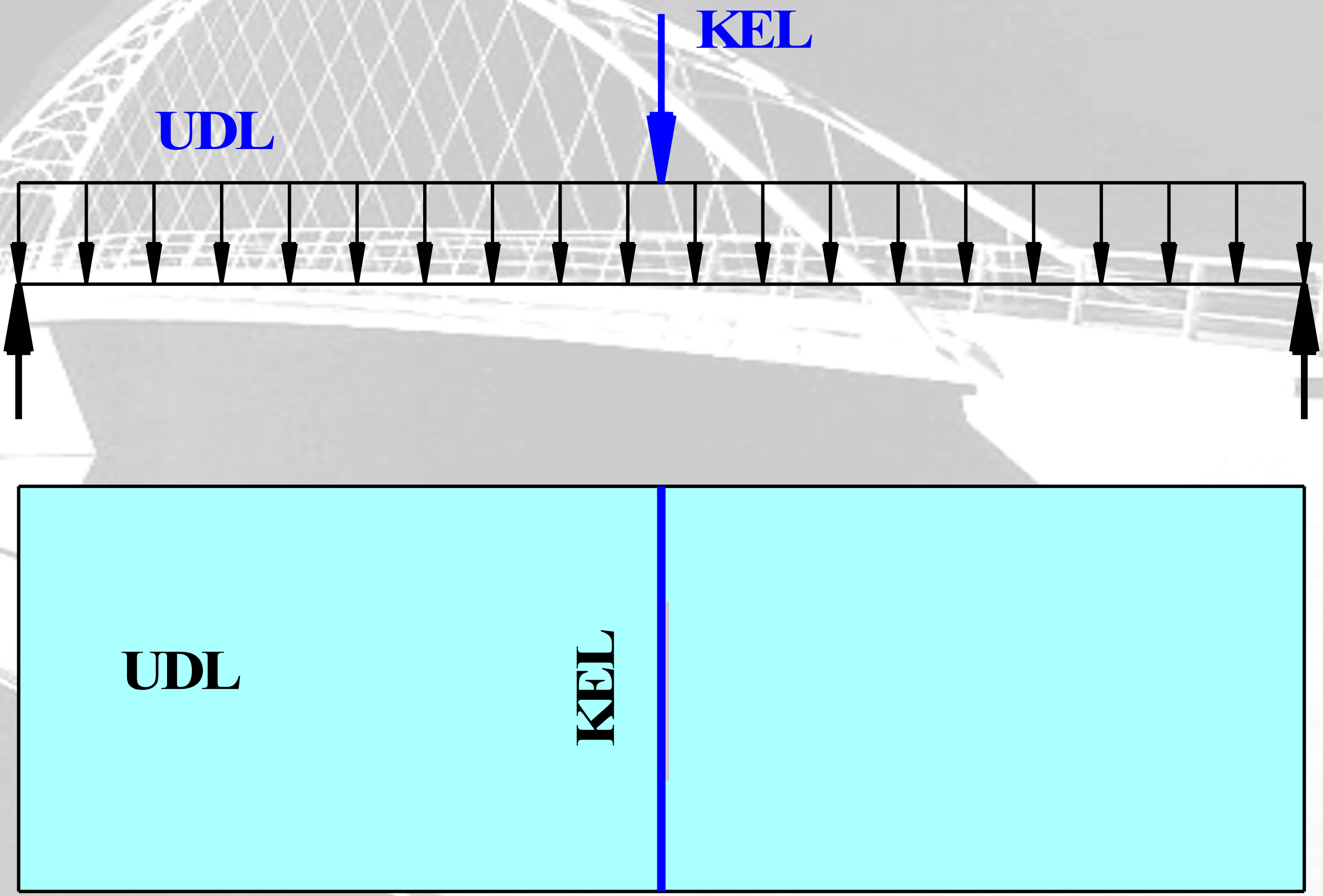


Figure 1: HA Loading

HA Loading

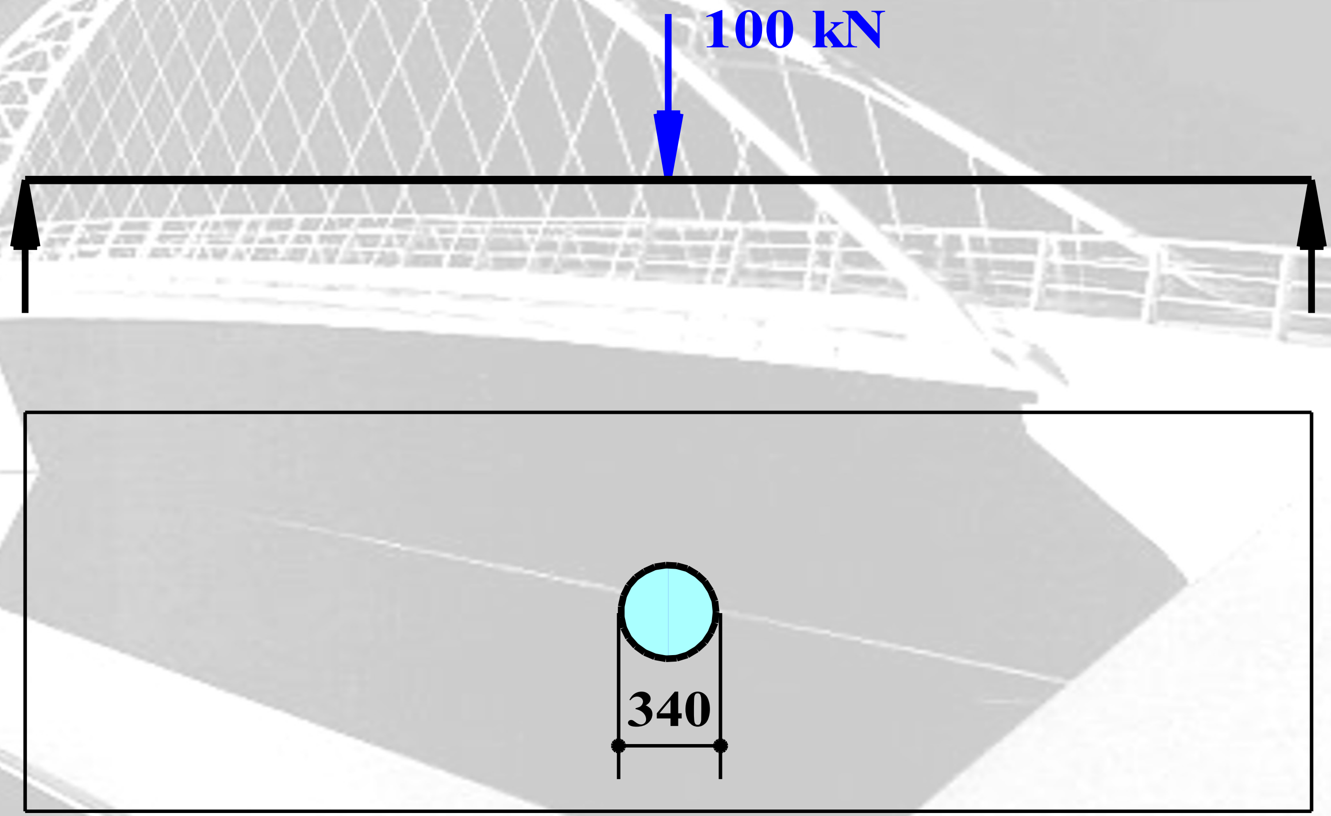


Figure 2: Alternative to HA KEL loading

HA Factors Lane

Table 14 — HA lane factors

Loaded length L m	First lane factor β_1	Second lane factor β_2	Third lane factor β_3	Fourth and subsequent lane factor β_n
$0 < L \le 20$	α_1	α_1	0.6	$0.6\alpha_1$
$20 < L \le 40$	α_2	α_2	0.6	$0.6\alpha_2$
$40 < L \le 50$	1.0	1.0	0.6	0.6
$50 < L \le 112$ $N < 6$	1.0	$7.1/\sqrt{L}$	0.6	0.6
$50 < L \le 112$ $N \ge 6$	1.0	1.0	0.6	0.6
$L > 112$ $N < 6$	1.0	0.67	0.6	0.6
$L > 112$ $N \ge 6$	1.0	1.0	0.6	0.6

NOTE 1 $\alpha_1 = 0.274 b_L$ and cannot exceed 1.0

$\alpha_2 = 0.0137\{b_L(40 - L) + 3.65(L - 20)\}$

where b_L is the notional lane width (m)

NOTE 2 N

shall be used to determine which set of HA lane factors is to be applied for loaded lengths in excess of 50 m. The value of N shall be taken as the total number of notional lanes on the bridge (this shall include all the lanes for dual carriageway roads) except that for a bridge carrying one-way traffic only, the value of N shall be taken as twice the number of notional lanes on the bridge.

HB Loading

The (BD 37/0) Design Manual for Roads and Bridges in UK says that Type HB loading requirements derive from the nature of exceptional industrial loads (e.g. electrical transformers, generators, pressure vessels, machine presses, etc.) likely to use the roads in the area.

The vehicle load is represented by a four axled vehicle with four wheels equally spaced on each axle. The load on each axle is defined by a number of units which is dependant on the class of road. Motorways and trunk roads require 45 units, Principal roads require 37.5 units and other public roads require 30 units. Each unit is equivalent to 10kN.

13. HB Loading

HB loading is used for bridges which are on public highways where they may be subjected to **abnormal loads** that are greater than those arising from **HA loading**

- A 16 **wheel vehicle** is specified
- Load/wheel is **2.5 j kN,** where **j** is the number of HB units
- The HB loading can be from **25 HB to 45 HB units**
  E.g. 25 units x 2.5 x 16 wheels = 1000 kN or 100 tons vehicle
  45 units x 2.5 x 16 wheels = 1800 kN or 180 tons vehicle

The actual units to be used for a particular bridge are usually specified by the authority concerned in the respective country

- HB loading also includes a 25% allowance for impact
- The length of the vehicle is varied for the severest effect by dimensions shown in Figure 3.

HB Loading

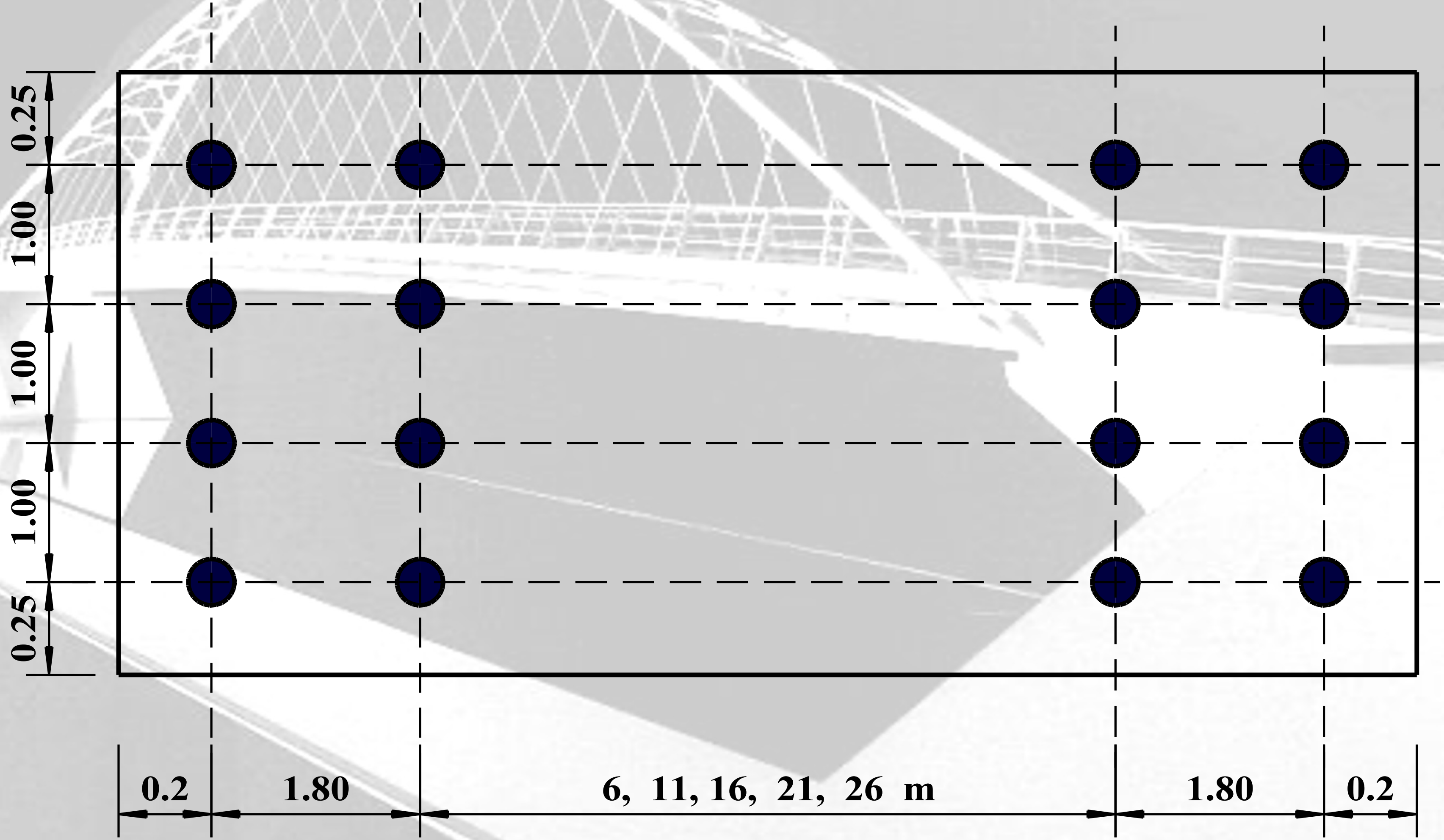


Figure 3: HB Vehicle

Example for 45 HB Units

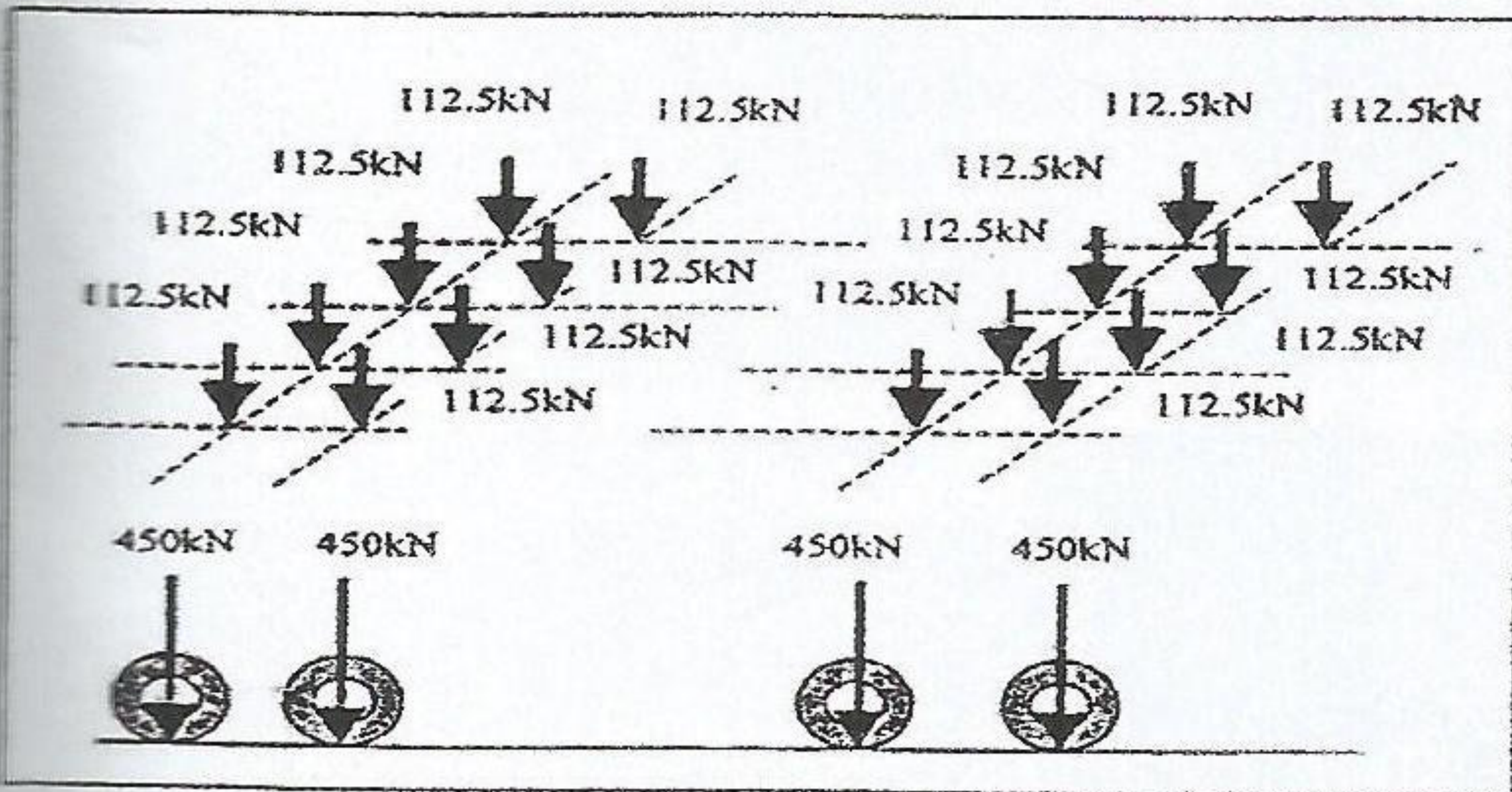


Figure 5.9 – 45 Unit HB

Combination of HA and HB Loading

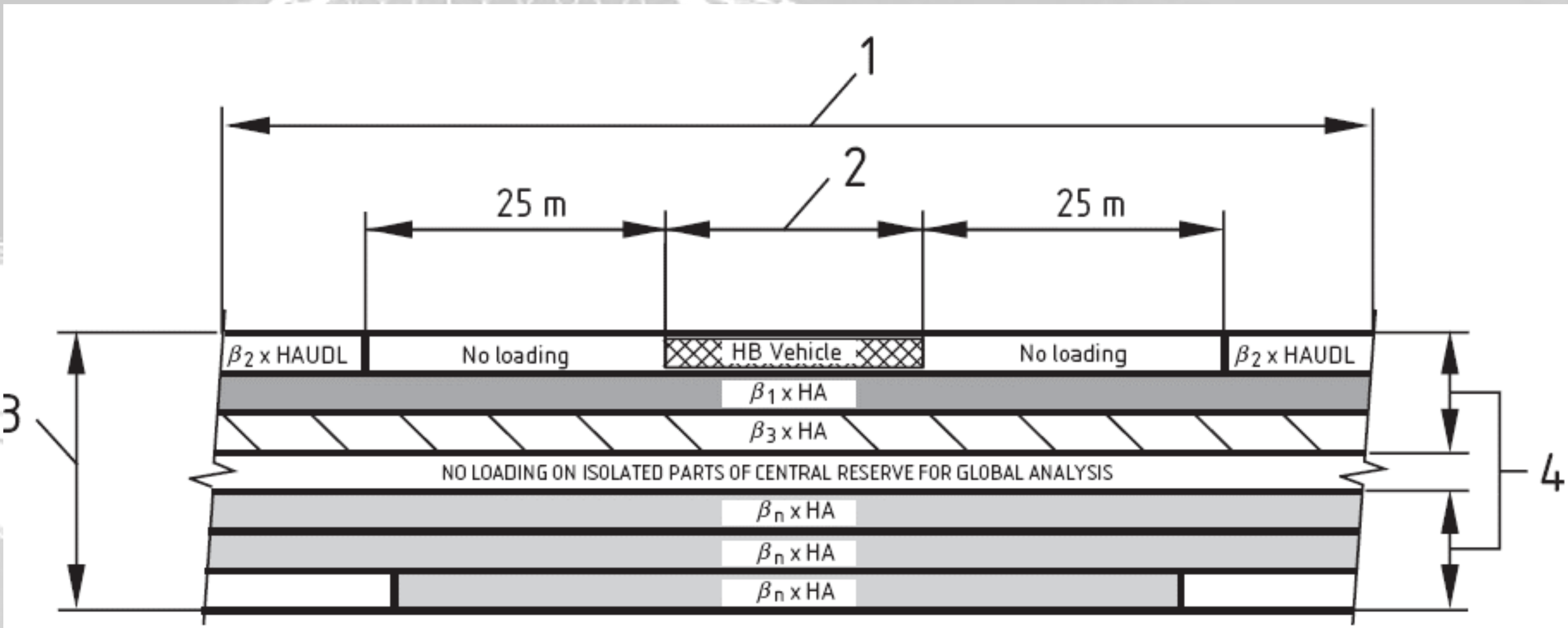


Figure 4: A combination of HA and HB loading: HB within one notional lane

Combination of HA and HB Loading

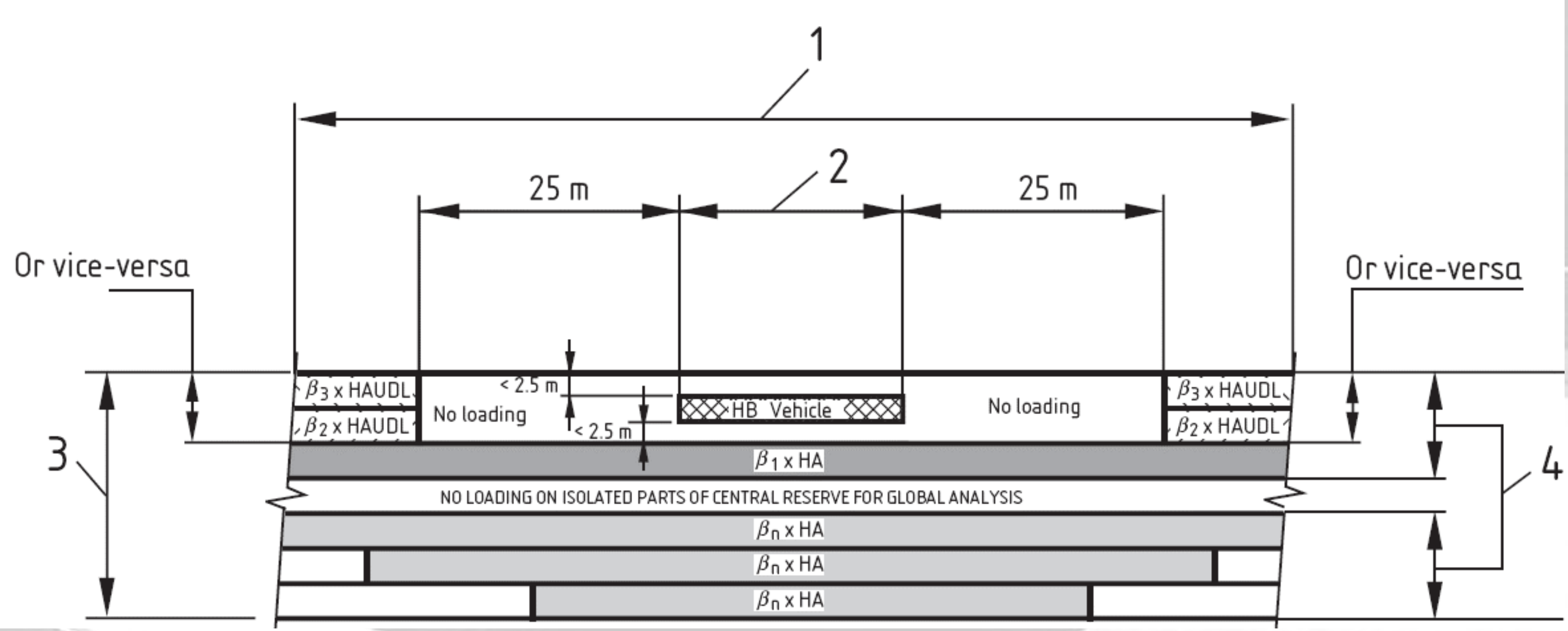


Figure 5a: A combination of HA and HB loading; HB occupying two notional lanes

Figs 4 and 5 give an overview of both HA and HB loading

Lane loads are interchangeable for severest effect

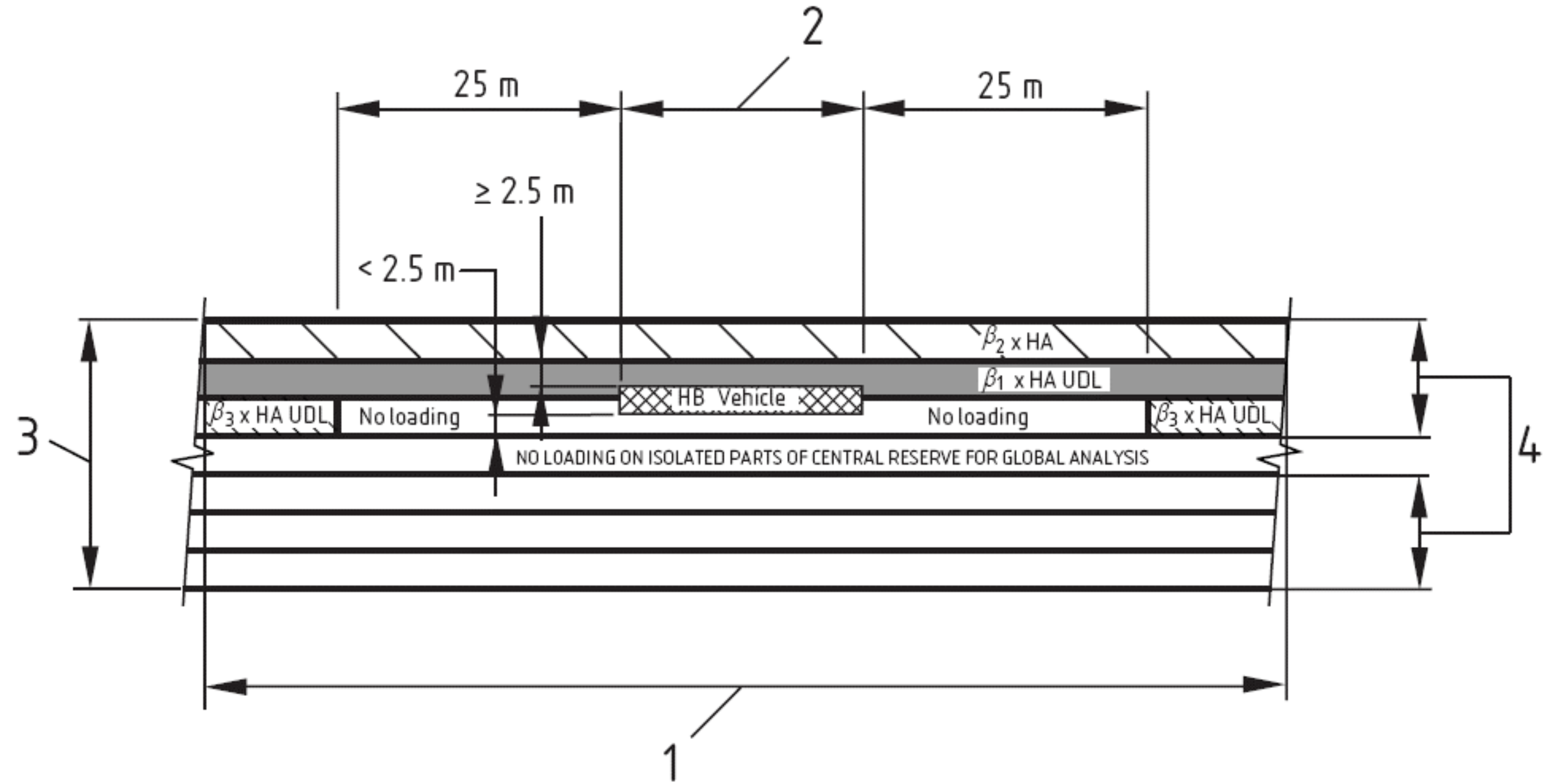


Fig. 5b: A combination of HA and HB loading; HB straddling two notional lanes

Transverse cantilever slabs, slabs supported on all four sides and slabs spanning transversely HA UDL and KEL shall be replaced by the arrangement of 30 unit HB loading.

HA and HB Loading Example

Example 1: Determine design HA loading for a simply supported bridge deck having carriageway width = 7.3m and loaded length = 18m

Reference	Calculations
	Carriageway = 7.3m wide Deck span = 18m (centre to centre of bearings for a simply supported single span) Design for a metre width of deck :
Cl 3.2.9.3.1.	**Number of notional lanes** Number of notional lanes = 2 Notional lane width (b_L) = 7.3/2 = 3.65m
Cl 6.2.1. Table	**Norminal HA UDL** Loaded length = 30m < 50m W= $336(1/L)^{0.67}$ =48.5 kN/m (per notional lane)

Reference	Calculations
Cl 6.2.2.	**Knife Edge Load (KEL)** KEL = 120 kN (per notional lane)
Cl 6.4.1. Cl 6.2.7	**Distribution of HA Loading** (L =18m) **α_1 = 0.274 b_L and cannot exceed 1.0** **(0 < L ≤ 20m)** **α_1 = 0.274 x 3.65 = 1.00** For a metre width of deck : HA UDL = 48.5/3.65 = 13.29 kN/m HA KEL = 120/3.65 = 32.88 kN Y_{fL} = 1.50 (Ultimate limit state - combination 1) Design HA loading for a metre width of deck : HA UDL = 1.5 x 13.29 = **19.93 kN/m** KEL = 1.5 x 32.88 = **49.32 kN**

Reference	Calculations
Clause 6.3	**Type HB Loading** Assume the road over the bridge is not a Principal Road then we need to check for **30 units** type HB loading
Cl 6.3.1	**Nominal load** = 30units x 2.5kN = 75kN per wheel = 75 x 4 = 300kN per axle and = 300x 4 = 1200kN for the whole vehicle
Cl 6.3.4	**γ_{fL} = 1.30 (Ultimate limit state - combination 1)** Design load per wheel = 75 x 1.3 = **97.5kN** Design load per axle = 97.5 x4 = **390kN** Design load per whole vehicle = 390 x 4 = **1,560kN**

14: Pedestrian Loading

Loaded length L (m)	< 36 m	36 m - 1600 m
Uniform Load (kNm^2)	5	Kx5

$$K = \frac{\text{Nominal HAUDL for appropriate loaded length (in n kN/m)} \times 10}{L + 270}$$

The imposed load on pedestrian and cycle track bridges is uniformly distributed and depends upon the loaded lengths as follows:

If $L \leq 36$m then **P = 5** kN/m^2

If $36 < L < 1600$ m then **P = 5K**

In the case of footpaths on road bridges which are **not protected** from highway traffic by any effective barrier, any four wheels of 25 units of HB loading acting alone in any unfavourable position should be considered.

15. Accidental wheel loading

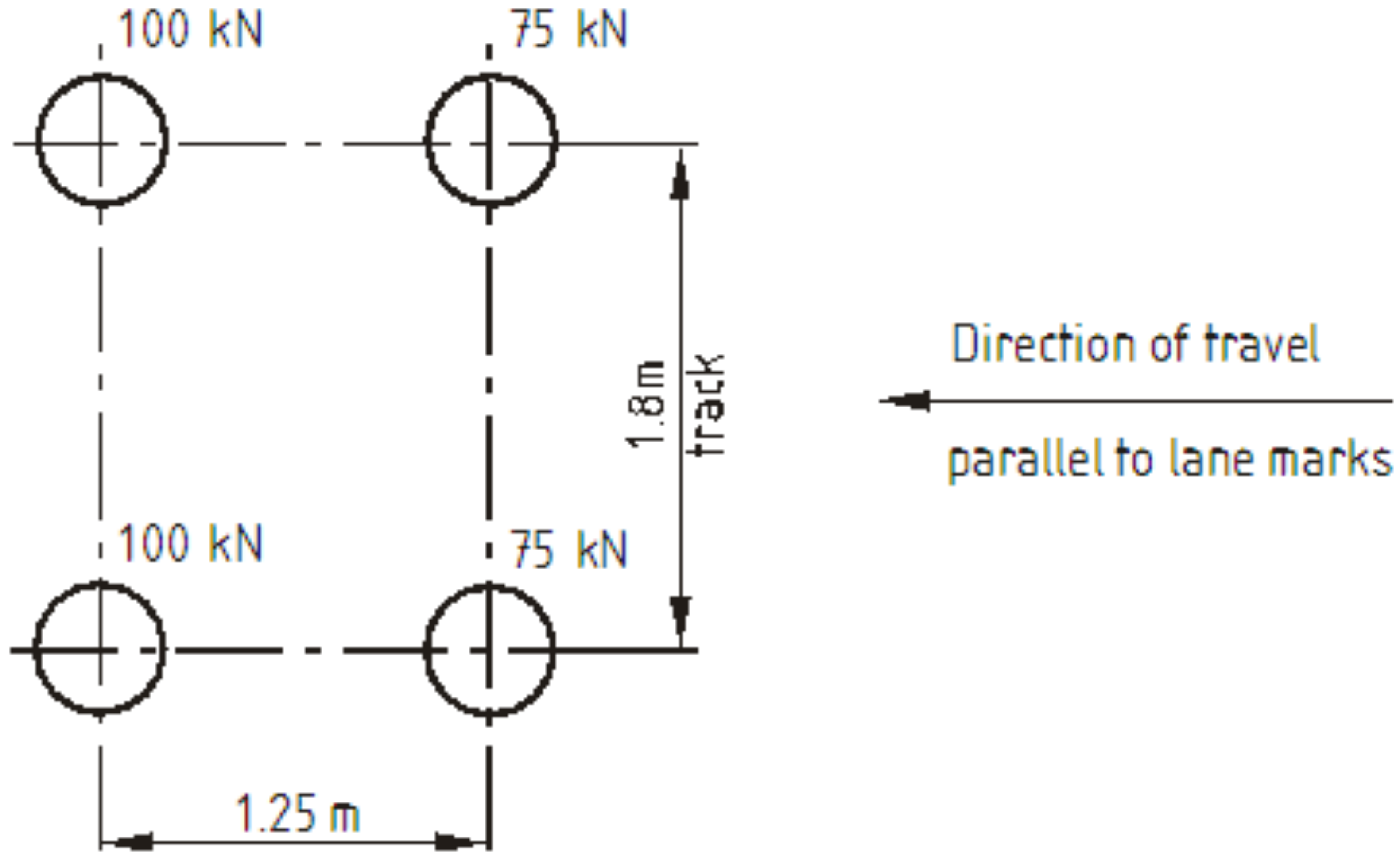


Figure 14 — Accidental wheel loading

16. Centrifugal Force

This transverse load arise when a vehicle moves in a curve.

The forces considered above all act vertically according to the law of gravity. When a vehicle moves at a speed of not less than 80 km/hr in a curve, a centrifugal force, F_c, acting in the transverse section of the bridge and directed away from the curve center results. The resultant force is defined by the expression:

$$F_c = \frac{m.v^2}{R}$$

where ***m*** = mass of vehicle in **Tons**

v = speed of vehicle in **m/s**

R = radius of curve in **m**.

BS 5400 Part 2 gives a nominal centrifugal load defined by:

$$F_c = \frac{30000}{R + 150} kN$$

where ***R*** is the same as above

The force F_c can be applied as a single load or subdivided into $1/3F_c$ and $2/3F_c$ then placed at 5.0m c/c longitudinally in combination with a vertical load of 300kN.

18. Accidental load due to skidding

On straight and curved bridges, a single point load in one single lane in the direction of the highway shall be considered in which the nominal load is 300 kN

19. Longitudinal load due to braking and traction

- The nominal load for HA shall be 8 kN/m of loaded length plus 250 kN but < 750 kN applied to an area of one notional lane x loaded length.
- The nominal load for HB shall be 25% total nominal HB load applied between the 8 wheels of two axles of the vehicle 1.8 m apart.

20. Loads due to Temperature Variations

The coefficient of thermal expansion shall be taken as **12×10^{-6}** for structural steel and concrete, but if limestone aggregates are used then a value of **7×10^{-6}** can be used. Expansion joints can be determined using these coefficients.

Load combinations

Three principal and two secondary combinations of loads are specified in BS 5400: Part 2: 2006:

Principal combinations

Combination 1: permanent + imposed loads

Combination 2: permanent + imposed + wind loads

Combination 3: permanent + imposed + constraining loads

Secondary Combinations

Combination 4: permanent + collision loads

Combination 5: permanent + friction loads at bearings

Partial Safety Factors to be Taken for Each Load Combination

Table 1 — Loads to be taken in each combination with appropriate γ_{fL}

Clause number	Load		Limit state	γ_{fL} to be considered in combination				
				1	2	3	4	5
5.1	Dead:	steel	ULS[a]	1.05	1.05	1.05	1.05	1.05
			SLS	1.00	1.00	1.00	1.00	1.00
		concrete	ULS[a]	1.15	1.15	1.15	1.15	1.15
			SLS	1.00	1.00	1.00	1.00	1.00
5.2	Superimposed dead:	deck surfacing	ULS[b]	1.75	1.75	1.75	1.75	1.75
			SLS[b]	1.20	1.20	1.20	1.20	1.20
		other loads	ULS	1.20	1.20	1.20	1.20	1.20
			SLS	1.00	1.00	1.00	1.00	1.00
5.1.2.2 and 5.2.2.2	Reduced load factor for dead and superimposed dead load where this has a more severe total effect		ULS	1.00	1.00	1.00	1.00	1.00
5.3	Wind:	during erection	ULS		1.10			
			SLS		1.00			
		with dead plus superimposed dead load only, and for members primarily resisting wind loads	ULS		1.40			
			SLS		1.00			
		with dead plus superimposed dead load plus other appropriate combination 2 loads	ULS		1.10			
			SLS		1.00			
		relieving effect of wind	ULS		1.00			
			SLS		1.00			
5.4	Temperature:	restaint to movement, except frictional	ULS			1.30		
			SLS			1.00		
		frictional bearing restaint	ULS					1.30
			SLS					1.00
		effect of temperature difference	ULS			1.00		
			SLS			0.80		
5.6	Differential settlement		ULS	1.20	1.20	1.20	1.20	1.20
			SLS	1.00	1.00	1.00	1.00	1.00

5.6	Differential settlement		ULS	1.20	1.20	1.20	1.20	1.20
			SLS	1.00	1.00	1.00	1.00	1.00
5.7	Exceptional loads			To be assessed and agreed between the engineer and the relevant authority				
5.8	Earth pressure: retained fill and/or live load	vertical loads	ULS	1.20	1.20	1.20	1.20	1.20
			SLS	1.00	1.00	1.00	1.00	1.00
		non-vertical loads	ULS	1.50	1.50	1.50	1.50	1.50
			SLS	1.00	1.00	1.00	1.00	1.00
		relieving effect	SLS	1.00	1.00	1.00	1.00	1.00
			ULS	1.00	1.00	1.00	1.00	1.00
5.9	Erection: temporary loads		ULS		1.15	1.15		
			SLS		1.00	1.00		
6.2	Highway bridges live load:	HA alone	ULS	1.50	1.25	1.25		
			SLS	1.20	1.00	1.00		
6.3		HA with HB or HB alone	ULS	1.30	1.10	1.10		
			SLS	1.10	1.00	1.00		
6.5		footway and cycle track loading	ULS	1.50	1.25	1.25		
			SLS	1.00	1.00	1.00		
6.6		accidental loading[c]	ULS	1.50				
			SLS	1.20				

[a] γ_{fL} shall be increased to at least 1.10 and 1.20 for steel and concrete respectively to compensate for inaccuracies when dead loads are not accurately assessed.

[b] γ_{fL} may be reduced to 1.2 and 1.0 for the ULS and SLS respectively, subject to approval of the relevant authority (see **5.2.2.1**).

[c] Accidental wheel loading shall not be considered as acting with any other primary live loads.

ULS: ultimate limit state SLS: serviceability limit state

5.3	**Temperature**	Restraint due to range	UL S SL S	1,30 1,00
		Frictional bearing restraint	UL S SL S	1,30 1,00
		Effect of temperature difference	UL S SL S	1,00 0,80
5.6	**Differential settlement**		UL S SL S	To be assessed and agreed between the engineer and appropriate authority

5.8	**Earth pressure**	Retained fill and/or live load surcharge	ULS	1,50 1,50 1,50 1,50 1,50
			SLS	1,00 1,00 1,00 1,00 1,00
		Relieving effect	ULS	1,00 1,00 1,00 1,00 1,00
5.9	**Erection:** temporary loads		ULS	1,15 1,15

6.2	**Live loading**:			
		HA alone	ULS	1,50 1,25 1,25
			SLS	1,20 1,10 1,00
		HA with HB or HB alone	ULS	1,30 1,00 1,10

6.5	**Centrifugal** load and associated primary live load		ULS SLS	1,50 1,00
6.6	**Longitudinal load:**	HA and associated primary live load	ULS SLS	1,25 1,00
		HB and associated primary live load	ULS SLS	1,10 1,00
6.7	Accidental skidding load and associated primary live load		ULS SLS	1,25 1,00
6.8	Vehicle collision load with bridge parapets and associated primary live load		ULS SLS	1,25 1,00
6.9	Vehicle collision load with bridge supports**		ULS SLS	1,25 1,00

7	Foot/cycle track bridges: live load and parapet load	ULS	1,50	1,25	1,25	1,25
		SLS	1,00	1,00	1,00	1,00

8	Railway bridges: type RU and RL primary and secondary live	ULS	1,40	1,20	1,20
		SLS	1,10	1,00	1,00

*γ_L shall be increased to at least 1.10 and 1.20 for steel and concrete respectively to compensate for inaccuracies when dead loads are not accurately assessed

γ_L may be reduced to 1.2 and 1.0 for the ULS and SLS respectively subject to approval of the appropriate authority

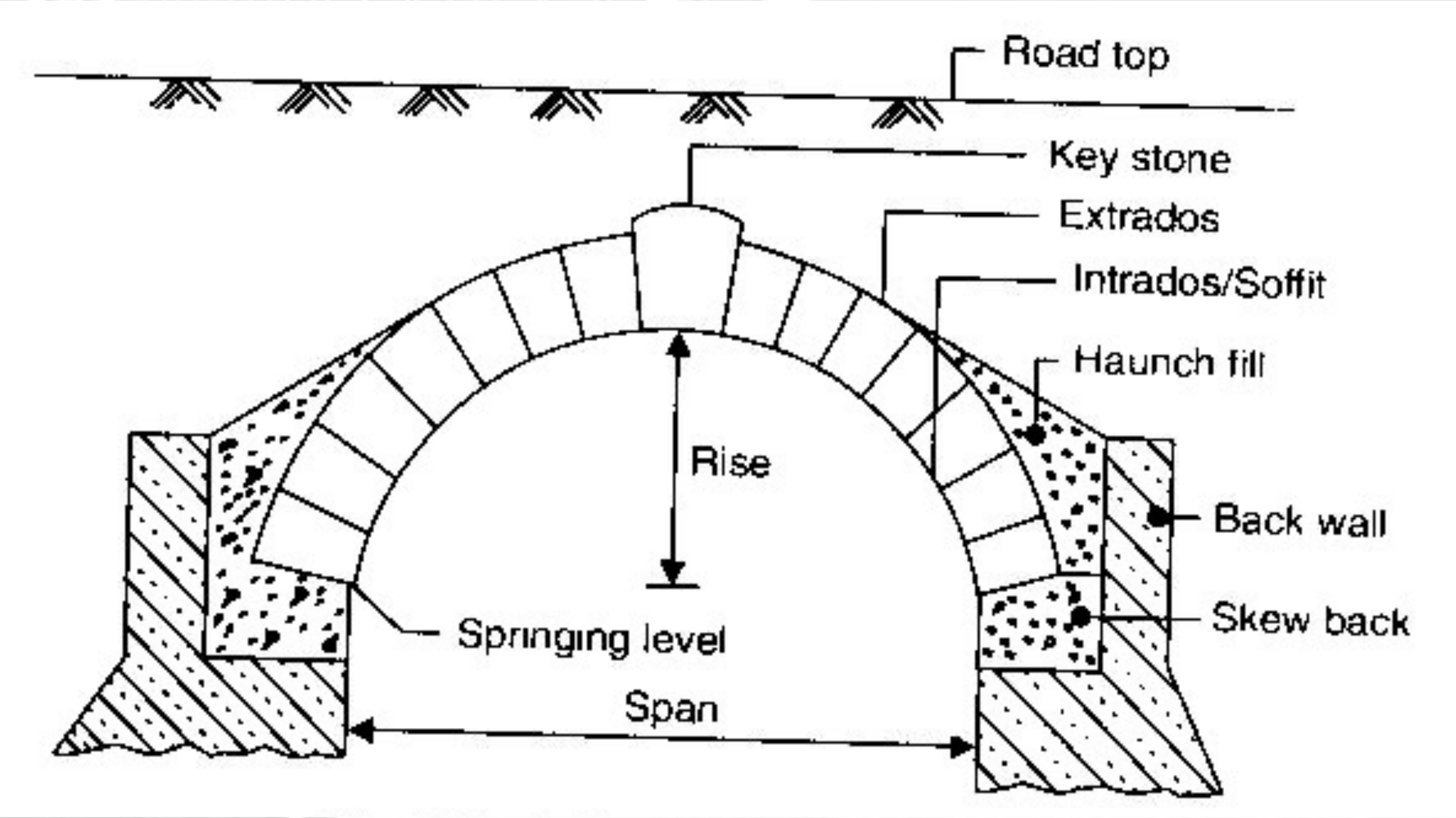
** This is the only secondary live load to be considered for foot/cycle track bridges

Design Internal Actions

Load Cases:

Case 1: Maximum mid span moment
Case 2:: Maximum end span moment
Case 3: Maximum over support moment
Case 4: Maximum shear force at piers
Case 5: Maximum shear force at abutments

STONE ARCH BRIDGES



Salient parts of an Arch Ring

Example 2

The following data pertains to a site, where a masonry arch bridge is proposed to be constructed. Design the arch bridge and its components.

Design data:

Span length: **10 m**

No. of spans: **two**

HFL of the stream: **108 m**

Bed level: **105 m**

Stream bund top level: **108.75 m**

Road top level: **113.00 m**

Stream bed width: **25 m**

Slope of the stream bund: **1:1**

Slope of the road bund: **2:1**

Road width: **two lane (7.5 m)**, with **600 mm** wide kerbs

Design of the Superstructure

Rise of the arch intrados: 1/3 to ¼ of span

Therefore the rise, r = span/4 = 10/4 = 2.5 m

Radius of the arch intrados

$$R = \frac{S^2 + 4r^2}{8r}$$

R = $(10^2 + 4 \times 2.5^2)/(8 \times 2.5)$= **6.25 m**

Thickness of the arch ring as given by Trautwynes Rankine formula is:

$$t = \frac{\sqrt{R + 0.5S}}{7} + 0.06$$

$$\frac{\sqrt{6.25 + 0.5x10}}{7} + 0.06 = 0.55m$$

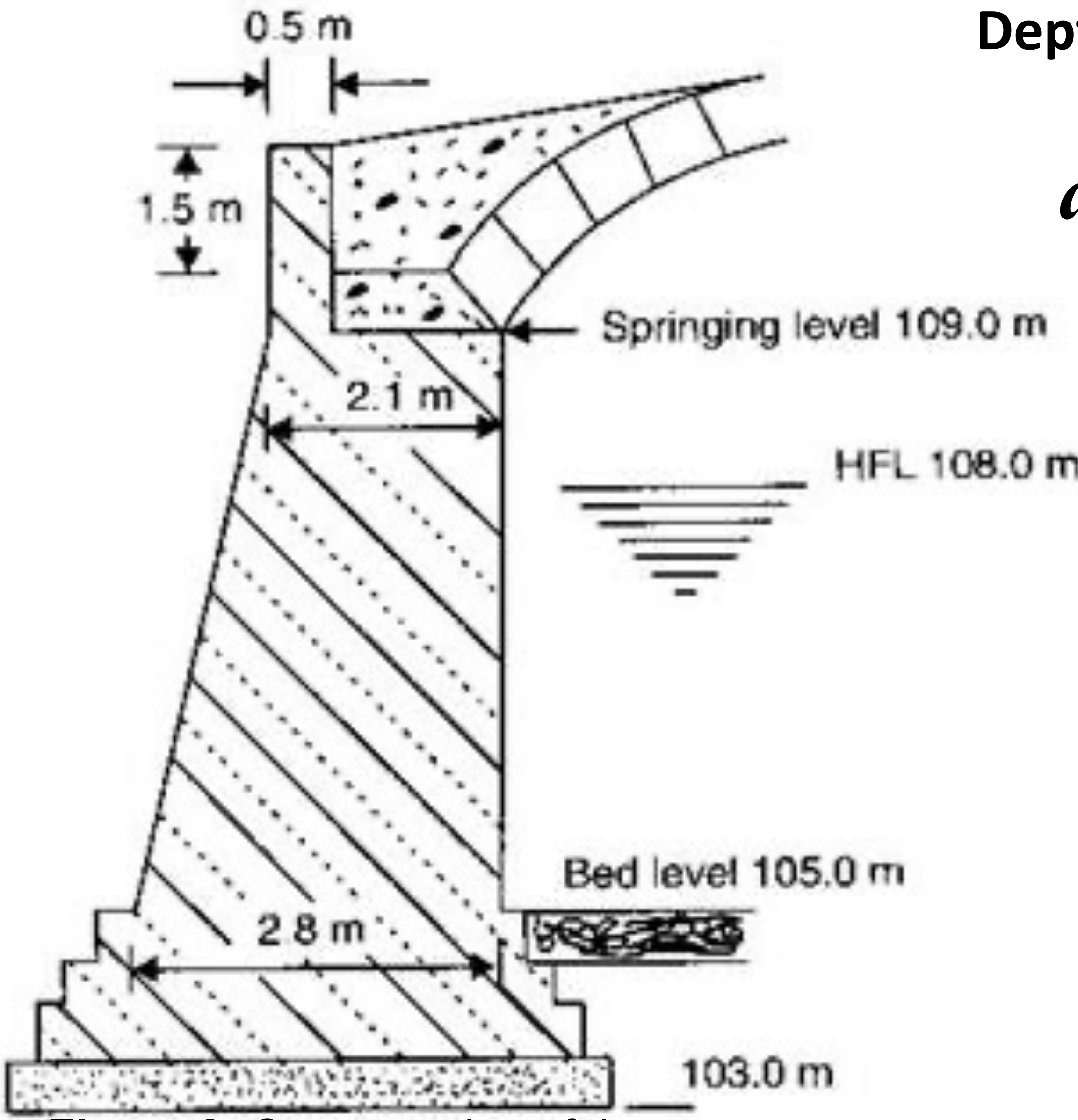


Figure 2: Cross-section of the abutment (Example 1).

Depth of the haunch filing

$$d = \frac{r + t}{2}$$

hence,

d = (2.5 + 0.55)/2
= 1.525 m,
say 1.5 m

The height is with respect to the springing level. The filling is made tangential to the arch extrados.

Design of the Abutment

The springing level is assumed to be 1 m above HFL. The top width of the abutment at the springing level is (see Fig. 2) given by Trautwyness formula

$$a = 0.6 + \frac{2}{10}R + \frac{1}{10}r$$

Top width, a = 0.6 + (2 x 6.25)/10 + 2.5/10 = 2.10 m

The front face of the abutment is made vertical while the back is provided with a batter to keep the resultant within the middle-third of the base.

Back batter

$$b = \frac{S}{24r}$$

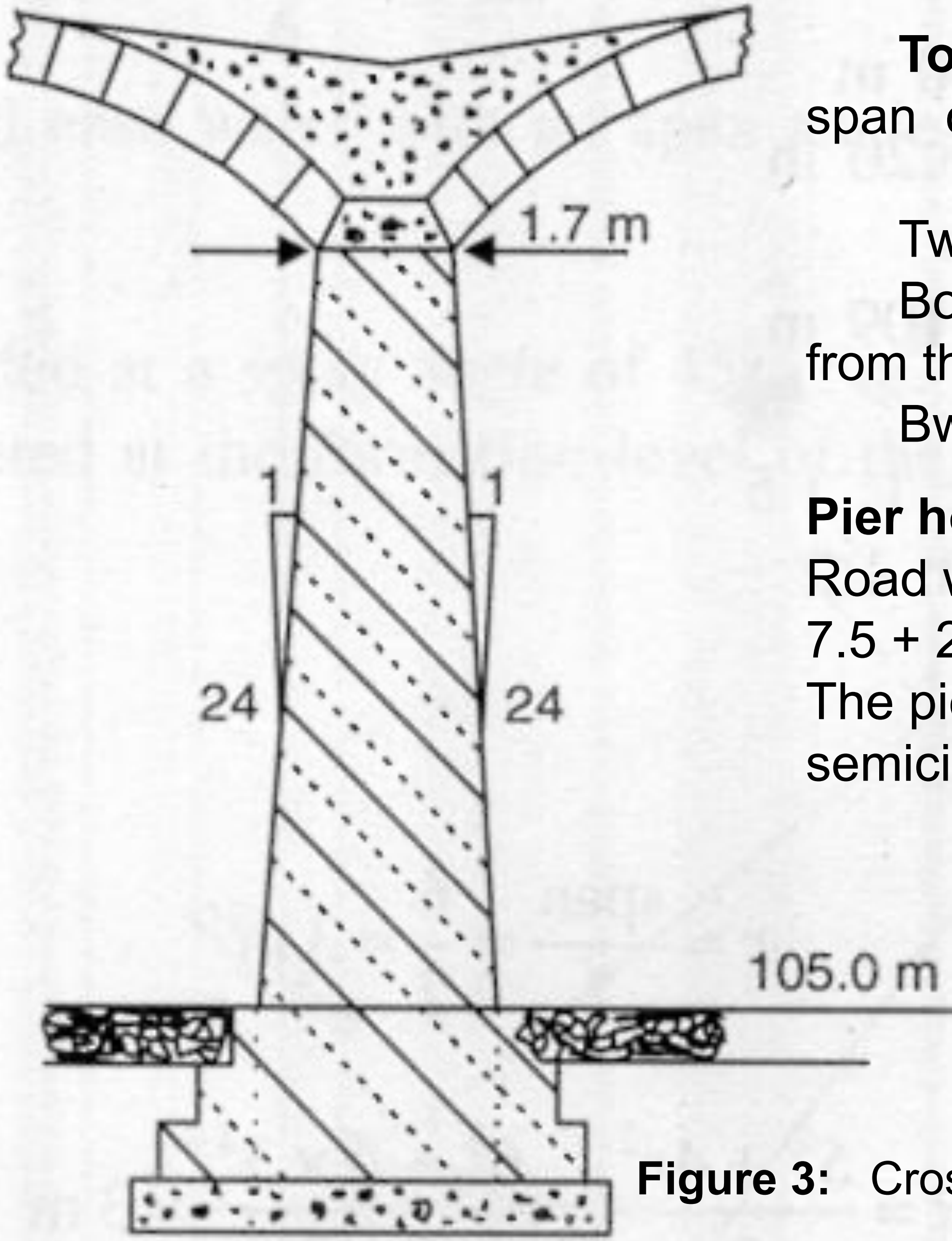
, $\boldsymbol{b}$ = 10/(24 x 2.5) = 1/6

Base width at bed level = Top width + height x 1/6

Base width = 2.1 + (109 -105)/6 = 2.77, say 2.80 m

Design of Pier

As the height of the pier is more than 3 m, a batter of 1 in 24 has been provided to both sides of the pier (See Fig. 3).



Top width, Tw = 1/6 to 1/7 of span or 2r +0.3, whichever is lesser

Tw = (1/6) x 10 = 1.7 m

Bottom width, Bw, is deduced from the slope of the pier

Bw = 1.7 + 2(1 x 4/24) = 2.0 m

Pier horizontal length =
Road width + 2 (kerb width) =
7.5 + 2 x 0.6 = 8.7 m
The pier is provided with a semicircular cut and ease water.

Figure 3: Cross –section of the pier (Example 2).

Design of the End Connectors

The return type of wing wall is proposed here. The top width of the wing wall is 0.5 m.

Bottom width = 0.25 (Height of the wing) = 0.25 (113 – 105) = 2.0 m

The return length can be calculated considering the profile of the stream bund and road bund.

L = (Projected width of the stream bund slope) + clearance + (projected length of the road bund slope)

or L = 3.75 + 1.00 + 2 (4.25) = 13.25 m

The end connection details are shown in Plate 1.

Plate 1 shows the drawing details of the bridge.

Details of the bridge.