JKR Bridge Engineering Competency– Steel Bridge

Loadings on Bridges

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QS World University Ranking 2019	Overall Rank **751-800**
QS Asia University Ranking 2019	Overall Rank **137**
QS World Graduate Employability Ranking 2019	Overall Rank **301-500**
QS World University Ranking By Subject 2019	Overall Rank **9 Subjects**
Students	**47,801**
International Students	**529**
Faculty	**3,313**
International Faculty	**59**

*Data @main campus

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Kelayakan Akademik *Academic Qualification*

Tahun *Year*	**Kelayakan** *Qualification*	**Institusi** *Institution*
2015	**Doktor Falsafah Kejuruteraan Struktur** *PhD Structural Engineering*	University of Surrey, UK
2007	**Sarjana Kejuruteraan Jambatan** *MSc Bridge Engineering*	University of Surrey, UK
2005	**Sarjana Muda Kejuruteraan Awam** *BEng Civil Engineering*	Universiti Teknologi Malaysia

Pengalaman Kerja *Working Experience*

Tahun *Year*	**Pengalaman** *Experience*	**Syarikat** *Company*
2018	-Involved in design team for Pembinaan Jambatan Jalan Bukit Mayang, Damansara	DNP Consult Sdn. Bhd.
	- Involved in supervision team for DASH project	Khairi Consult Sdn. Bhd.
2014-2015	-Involved in design team for Pembinaan Ibu Pejabat Polis Daerah IPD Johor Bahru Selatan -Involved in design team for Projek Tebatan Banjir Kota Tinggi	OMK JP Sdn. Bhd.
2007-2008	-Involved in design team for Pembinaan Bangunan Fakulti Alam Bina, UTM Johor Bahru - Involved in design team for Pembinaan Jambatan Kedua Permas Jaya, Johor Bahru	OMK JP Sdn. Bhd.
2005	-Involved in supervision team for Pembinaan Masjid Kg. Abdul Rahman Yassin, Kluang, Johor	OMK JP Sdn. Bhd

Learning outcome (PLO1/C5)

- Able to demonstrate an understanding of the Limit State Philosophy as applied to the analysis and design.
- Able to apply various load combinations for the analysis and design as specified in British Codes.
- Able to understand and utilize ‘influence lines method’ for the analysis and to establish loaded lengths.
- Able to Demonstrate an understanding of Primary loads on Highway Bridges, Secondary loads on Highway Bridges and application of loads to get maximum loading effects.

Overview

- Bridge Loading BD37/01, BS5400
- Limit State Design
- Other Loads
- Bridge Loading EN1991-1, EN1991-2 Eurocodes

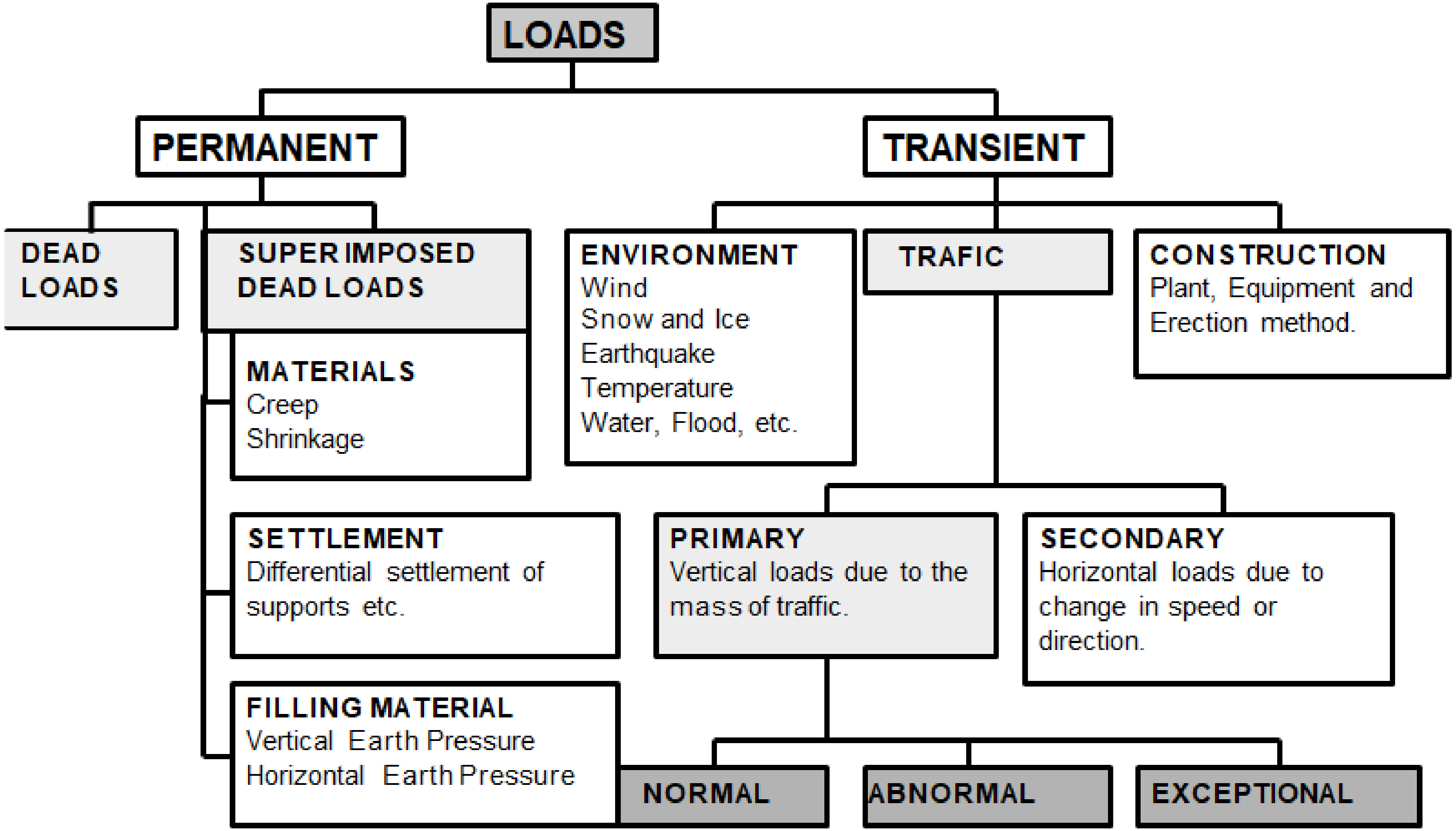
Bridge Loading BD37/01, BS5400

- Loads are the external actions (forces) and internal actions (deformations) applied to the structure.
- Two broad categories of Loads based on their fluctuations in time:
  - ✓ Permanent Loads
  - ✓ Transient Loads

Bridge Loading BD37/01, BS5400 (cont’d)

- Permanent Loads
  - ✓ Loads that are permanent to the bridge and exist throughout their service life.
- Transient Loads
  - ✓ All non-permanent loads are referred to as Transient loads.

Bridge Loading



Bridge Loading BD37/01, BS5400 (cont'd)

- Normal and Abnormal Loading
  - ✓ Normal traffic consists of everyday traffic consisting of a mix of cars, vans, and trucks (defined by loading curve, UDL and KEL).
  - ✓ Abnormal traffic consists of heavy vehicles of 100T or more.
  - ✓ There are also those less frequent loads in excess of 200T. These loads are treated as special cases and would be confined to a limited no. of roads. These were termed as exceptional loads.

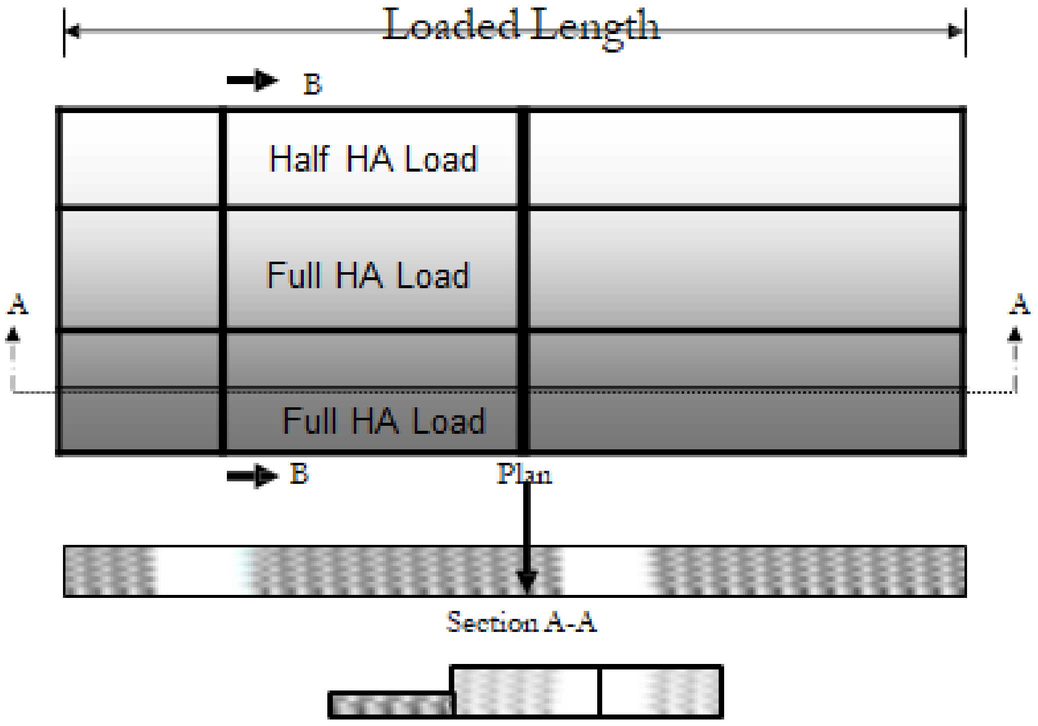
Bridge Loading BD37/01, BS5400 (cont'd)

- Normal and Abnormal Loading

Exceptional Loads

Bridge Loading BD37/01, BS5400 (cont'd)

- HA Loading curve
  - ✓ A widely adopted MOT loading curve with a UDL plus a KEL would constitute normal loading defined as HA loading.
  - ✓ Experience showed extreme improbability of more than two carriageway lanes being filled with the heaviest type of loading.



Bridge Loading BD37/01, BS5400 (cont'd)

- HA Loading curve
  - ✓ Following sequence of vehicles was used in developing the HA loading curves.

Loaded Length	Description
20ft (6m) to 75ft.(22.5m)	Lines of 22T lorries in two adjacent lanes and 11T lorries in the remainder
75ft (22.5m) to 500ft (150m)	Five 22T lorries over 40ft (12m) followed and preceded by four 11T lorries over 35ft.(10.5m) and 5T vehicles over 35ft.(10.5m) to fill the span.

Bridge Loading BD37/01, BS5400 (cont'd)

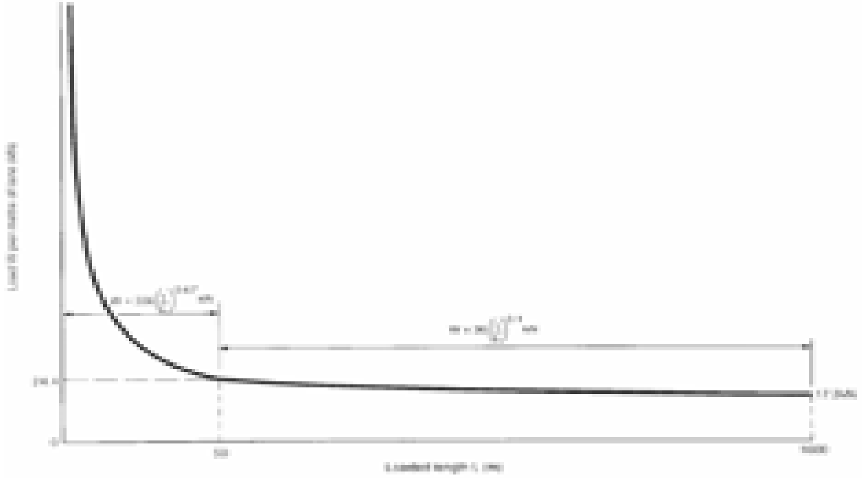
- HA Loading curve
  - ✓ For spans longer than 75ft, an equivalent UDL (plus KEL) was derived by equating the moments and shear per lane of vehicle with the corresponding effects under a distributed load. A 25% increase was considered appropriate for the impact of suspension systems.
  - ✓ These were found to correspond well to the MOT loading curve.
  - ✓ For shorter spans, a more severe concentration of loads was considered appropriate.
  - ✓ A heavy steam roller had a wheel loads of about 7.5T, and adding 25% for impact gave 9T. Two such wheels at 3ft distance was considered suitable for short spans.
  - ✓ Separate loading curve was developed based on the above loading.

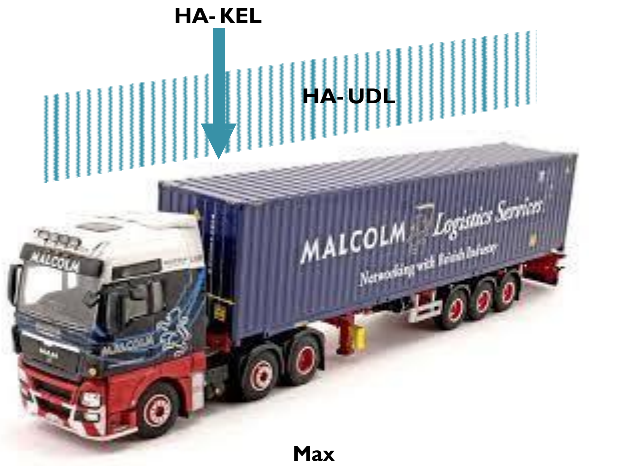
Bridge Loading BD37/01, BS5400 (cont'd)

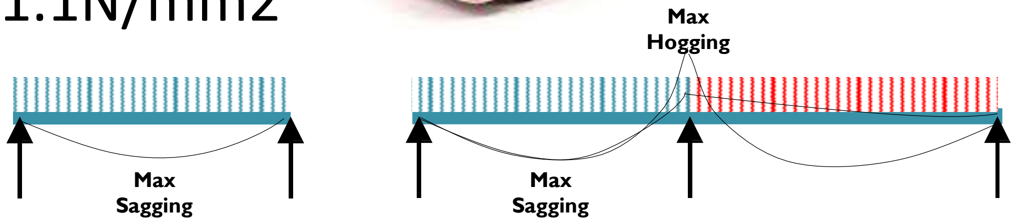
- HA Loading curve
  - ✓ These loading curves have been revised several times since then to incorporate latest information at the time of updating.
  - ✓ The latest guidelines on this is available in BD37/01 and BS5400:part 2, which is attached as an appendix to BD37/01.
  - ✓ Current UK Code for loading is BD37/01 and BS5400/01:part 2.
    - ❑ Normal Loads
    - ❑ Abnormal Loads
    - ❑ Exceptional Loads

Bridge Loading BD37/01, BS5400 (cont'd)

- Normal Loading
  - ✓ UDL + KEL
  - ✓ Two-part curve
  - ✓ Joining point is at 50m.
  - ✓ Valid up to 1600 m
  - ✓ KEL = 120kN per lane
  - ✓ Longitudinal bunching effect through reducing intensity.
  - ✓ Lateral Bunching effect through lane factor.
  - ✓ Local Effects: 100kN wheel load; Max. pressure = 1.1N/mm2

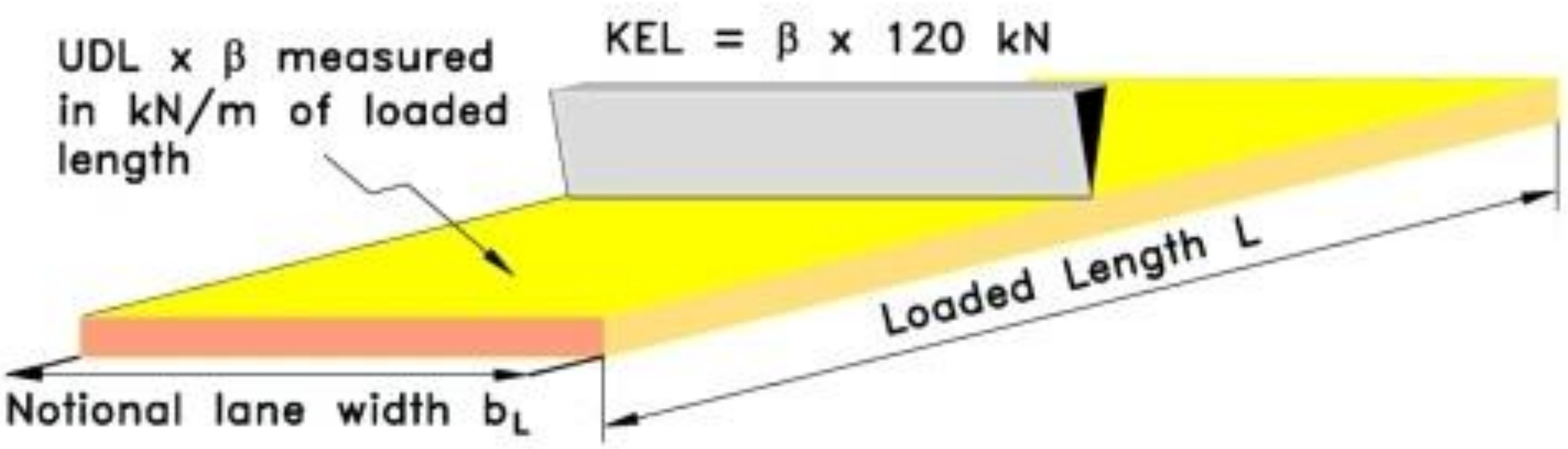






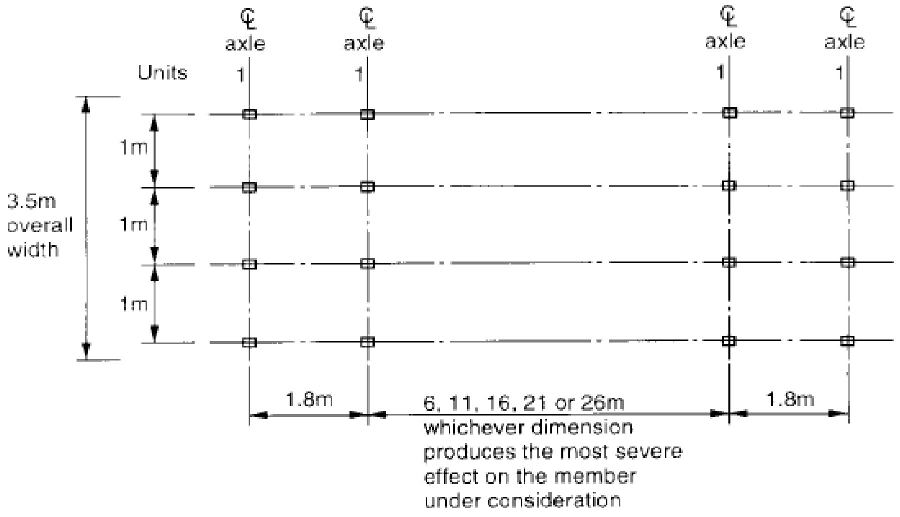
Bridge Loading BD37/01, BS5400 (cont'd)

- Normal Loading



Bridge Loading BD37/01, BS5400 (cont'd)

- Abnormal Loading
  - ✓ Concentrated 16 wheels on four axles.
  - ✓ Described as no. of Units per axle (1 Unit = 10kN)
  - ✓ Max. pressure = 1.1 N/mm2
  - ✓ Varying middle span
  - ✓ Dispersion through surfacing and concrete.

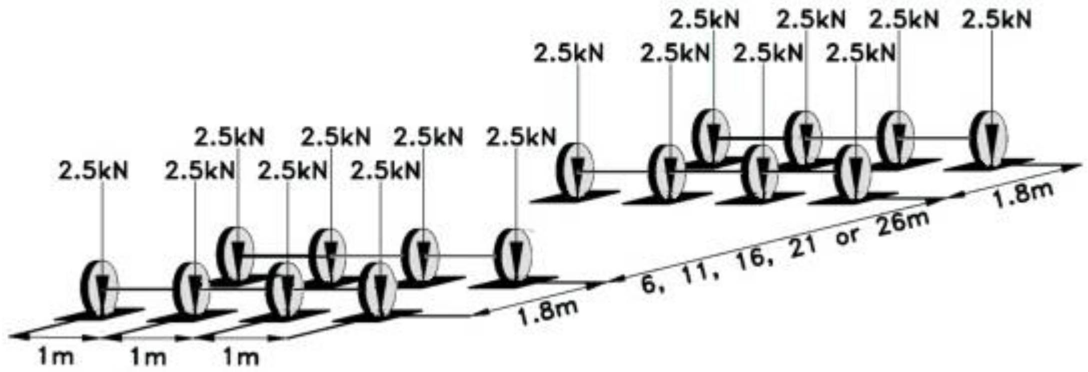


HB Vehicle is given a rating in *units* (one unit being one ton) and referred to the load per axle; eg HB30 units refers to HBVehicle with each axle load (total 4 wheels) of 30 tons.

In the analysis, HB Vehicle shall be allowed to move on anywhere of the bridge to create the most adverse effect to all the bridge elements for design purpose.

Bridge Loading BD37/01, BS5400 (cont'd)

- Abnormal Loading
  - ✓ One unit shall be taken as equal to 10 kN per axle (ie 2.5 kN per wheel). The overall length of the HB vehicle shall be taken as 10, 15, 20, 25 or 30 m for inner axle spacings of 6, 11, 16, 21 or 26 m respectively, and the effects of the most severe of these cases shall be adopted. The overall width shall be taken as 3.5m. The longitudinal axis of the HB vehicle shall be taken as parallel with the lane markings.



Bridge Loading BD37/01, BS5400 (cont'd)

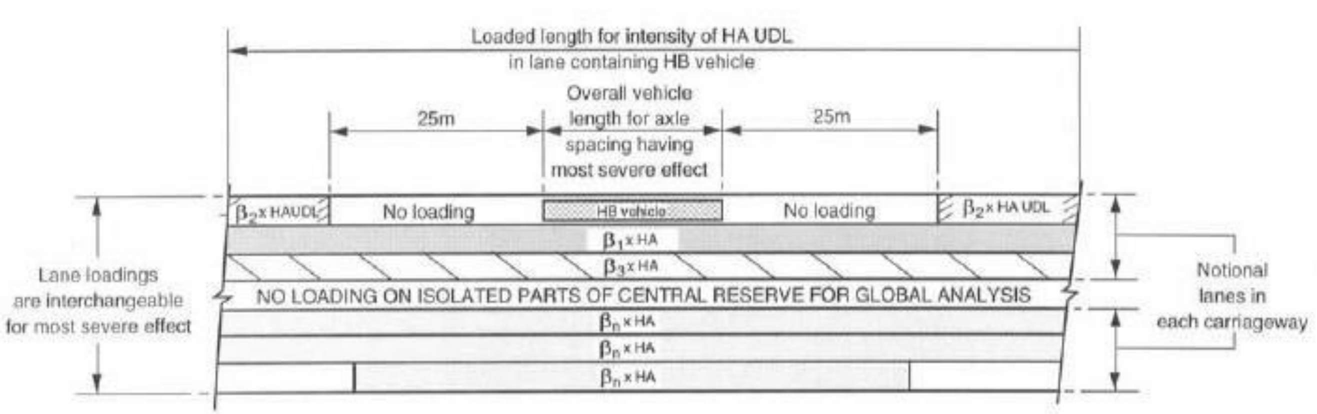
- Abnormal Loading
  - ✓ Bridge engineers shall design the bridge for the maximum traffic load for all the notional lanes (lane reduction factor may be applied) considering the following cases:
    - ❑ HA (UDL+KEL) for all notional lanes;
    - ❑ HB Vehicle together with HA for other notional lanes; refer scenario in figure

Bridge Loading BD37/01, BS5400 (cont'd)

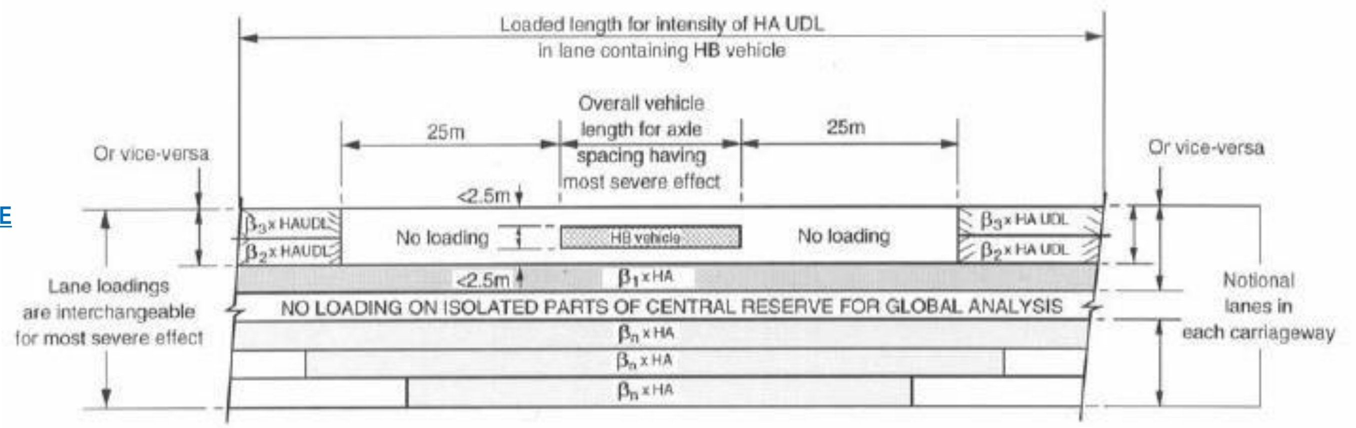
- Load application
  - ✓ All bridges are designed for HA loading and checked for HA+HB Loading.
  - ✓ HB vehicle is placed in one lane or straddled over two lanes.
  - ✓ An unloaded length of 25m in front and rear.
  - ✓ Details in the latter units.

Bridge Loading BD37/01, BS5400 (cont'd)

(1) HB VEHICLE WITHIN ONE NOTIONAL LANE

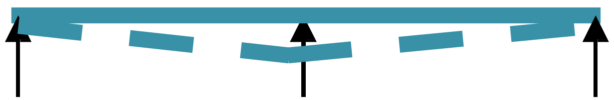


(2) HB VEHICLE STRADDLING TWO NOTIONAL LANE



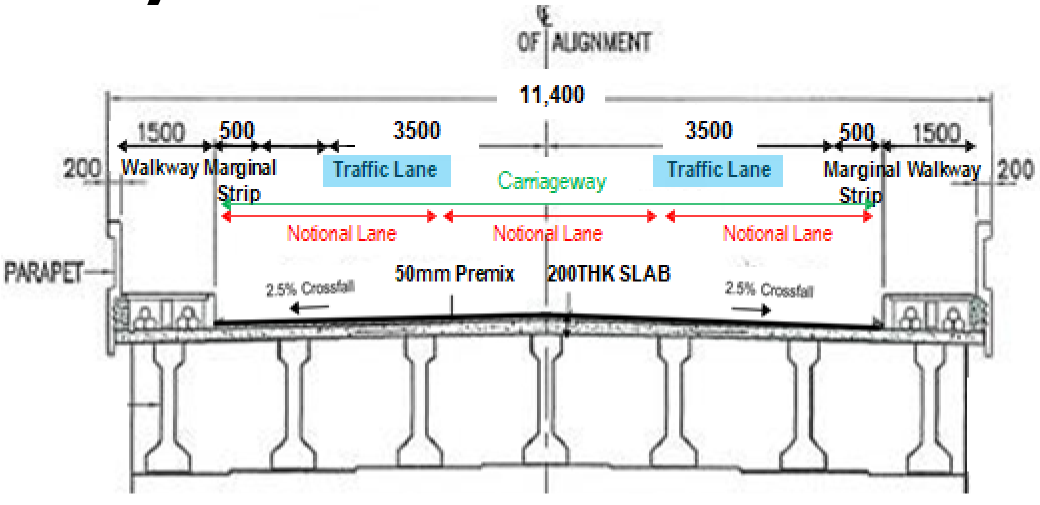
Bridge Loading BD37/01, BS5400 (cont'd)

- Load application
  - **Dead Load** = weight of materials that form part of the bridge structural elements; eg deck slab, precast beams, diaphragm beams, crossheads, pilecaps, abutments, etc.
    Concrete Density for Bridge taken as **25kN/m³
  - **Super-Imposed Dead Load** (SDL) = loads from other materials that are not part of bridge structural elements; eg road surfacing (premix), parapets & handrail, utility pipes, lamp posts etc.
  - **Load due to Backfill Material**; eg soil weight above pilecap, earth pressure behind abutment
  - **Long Term Material Effect**; eg. prestress beam creep and shrinkage effect, redistribution of stresses from construction stages, etc.
  - **Differential Support Settlement**;



Bridge Loading BD37/01, BS5400 (cont'd)

- Load application



Typical Bridge Section

CONCEPT OF NOTIONAL LANES

- **Carriageway** = part of the running surface which includes all traffic lanes, hard shoulders and marker strips. Generally, carriageway width is the *width between raised kerbs*.
- **Traffic Lanes** = lanes that marked on the running surface of the bridge and are normally used by traffic
- **Notional Lanes** = a rational way of dividing the carriageway width into equal parts, measured between the raise kerbs. They are notional parts of the carriageway used solely for the purpose of applying the specified live loads.

Bridge Loading BD37/01, BS5400 (cont'd)

- Load application

Table 4.6 - Number of Notional Lanes, according to BDs

Carriageway Width (m)	Number of Notional Lanes
below 5.0	1
from 5.0 up to and including 7.5	2
above 7.5 up to and including 10.95	3
above 10.95 up to and including 14.6	4
above 14.6 up to and including 18.25	5
above 18.25 up to and including 21.9	6

Bridge Loading BD37/01, BS5400 (cont'd)

- Exceptional loading
  - ✓ Road haulers are called upon to transport heavy items
  - ✓ e.g. power stations, weighing up to 750T (7500kN).
  - ✓ Special flat bed trailers are used with multiple axles
  - ✓ Overall effect of 1.1N/mm2

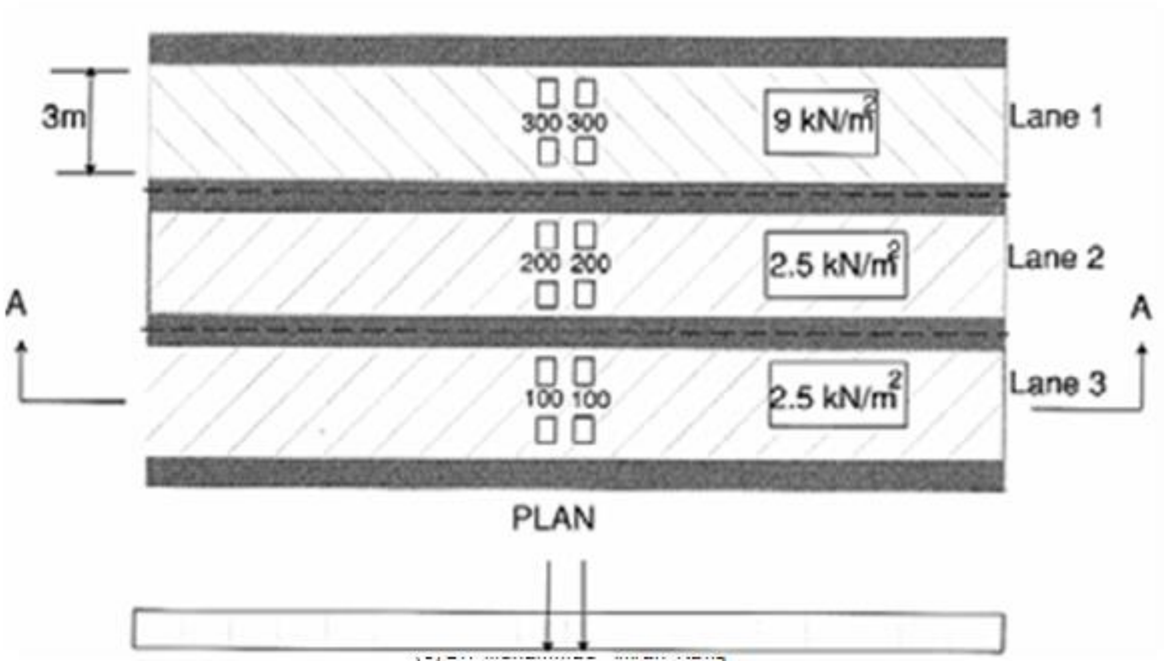

Bridge Loading BD37/01, BS5400 (cont'd)

- Comparison to European specification
  - ✓ The European models for traffic loading are embodied in EC1 (1993).

Load Model	Definition
LM1	General (normal) loading due to lorries or lorries plus cars
LM2	A single axle for local effects
LM3	Special vehicles for the transportation of exceptional loads
LM4	Crowd loading

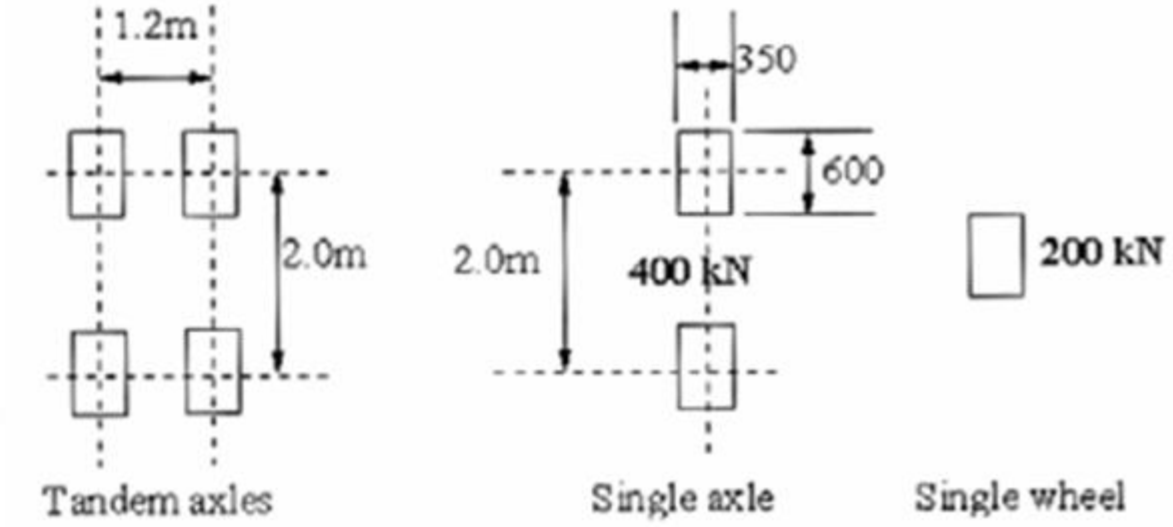
Bridge Loading BD37/01, BS5400 (cont'd)

- General Loading (LM1)
  - ✓A UDL plus double axle tandem per lane.
  - ✓The tandem is dispensed with on the forth lane and above.



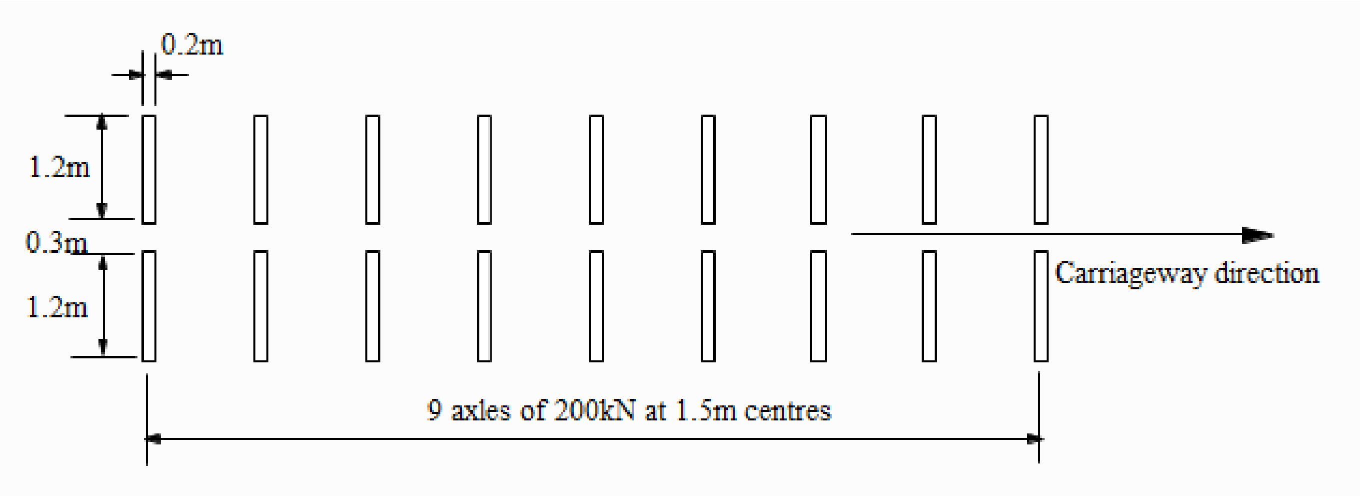
Bridge Loading BD37/01, BS5400 (cont'd)

- Local Loads (LM2)
  - ✓ To study local effects, a 400kN tandem axle is recommended.
  - ✓ Can be replaced by a wheel load of 200kN.



Bridge Loading BD37/01, BS5400 (cont'd)

- Abnormal Loads (LM3)
  - ✓ Abnormal loads are considered similar to the British Code.
  - ✓ Placed in lane(s) with 25m clear space front and back



Bridge Loading BD37/01, BS5400 (cont'd)

- Crowd Loads (LM4)
  - ✓ Most Countries specify a nominal crowd loading of about 5KN/m2.
  - ✓ This is to be placed on the footways of highway bridges or across pedestrian and cycle bridges.
  - ✓ In certain instances, reduction of this loading is allowed for loaded lengths greater than 10m.

To be continued

Learning outcome (PLO1/C5)

- Able to demonstrate an understanding of the Limit State Philosophy as applied to the analysis and design.
- Able to apply various load combinations for the analysis and design as specified in British Codes.
- Able to understand and utilize ‘influence lines method’ for the analysis and to establish loaded lengths.
- Able to Demonstrate an understanding of Primary loads on Highway Bridges, Secondary loads on Highway Bridges and application of loads to get maximum loading effects.

Overview

- Bridge Loading BD37/01, BS5400
- Limit State Design
- Other loads
- Bridge Loading EN1991-1, EN1991-2 Eurocodes

Limit State Design

- Ultimate Limit State Philosophy (BS5400:1)
    - ✓ Ultimate Limit States
    - ✓ Serviceability Limit States
- Ultimate Limit States
    - ✓ Loss of equilibrium (part / whole structure) and overturning
    - ✓ Fatigue Deterioration to failure
    - ✓ Post elastic or post buckling state (ultimate strength of any section of the member).
- Serviceability Limit States
    - ✓ Loss of Utility / cause public concern
    - ✓ Vibration limit state

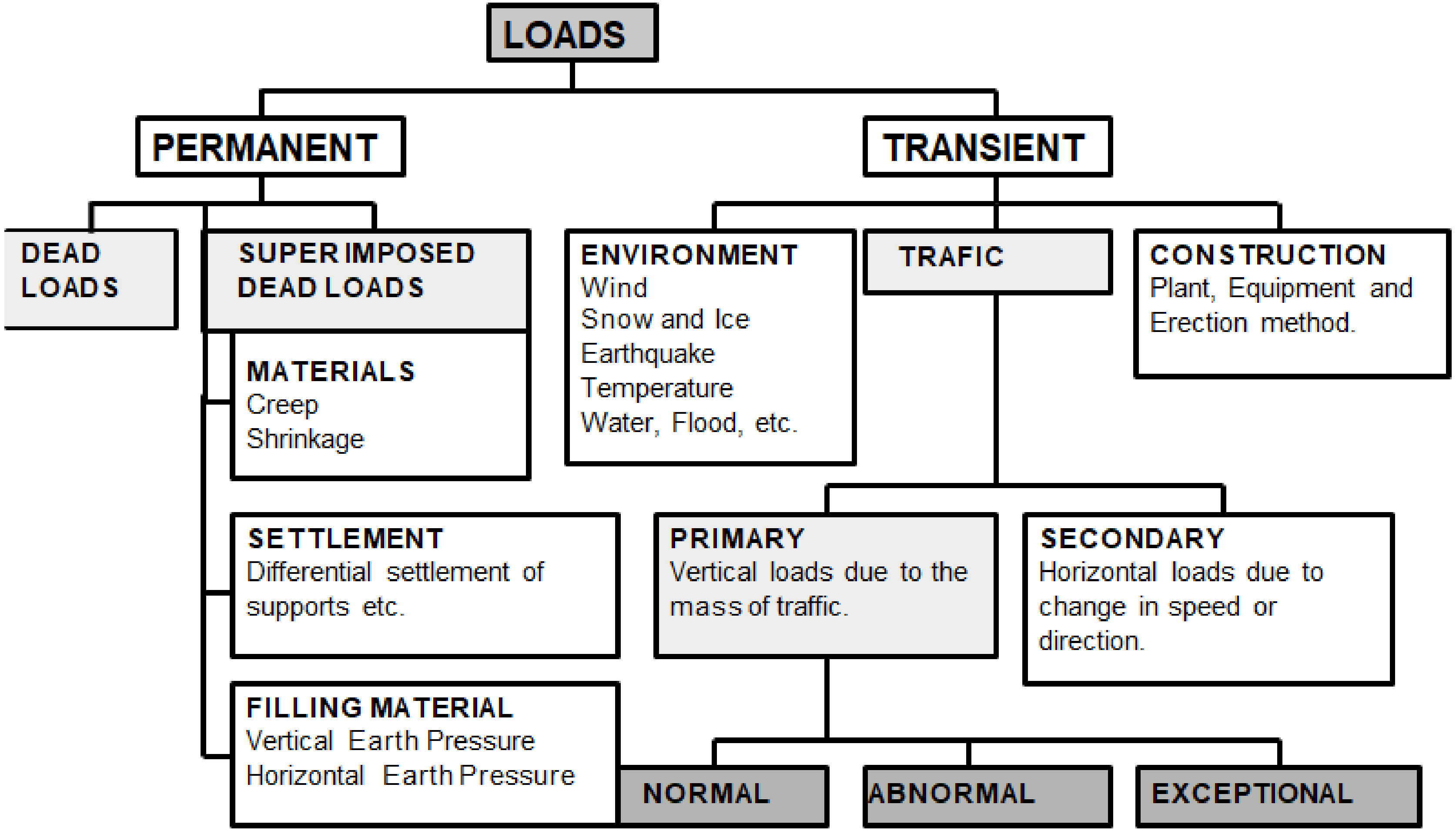
Limit State Design (cont'd)

- Loads considered in the code are Nominal loads.
- 120 years return period is used for load derivations.
- Characteristic strength values are given in the codes.

Limit State Design (cont'd)

- The design loads, Q*, are determined from the nominal loads, Q_k, according to the relation $Q^* = \gamma_{fL}$ Qk
  - ✓ where γ_{fL} is a factor given in Part 2 for each load.
    - ➢ γ_{fL} = function (γ_{f1}, γ_{f2})
    - ➢ γ_{f1} takes account of the possibility of unfavourable deviation of the loads from their nominal values;
    - ➢ γ_{f2} takes account of the reduced probability that various loadings acting together will all attain their nominal values simultaneously.

Bridge Loading



Limit State Design (cont'd)

- Load Combinations
  - ✓ The maximum effects of certain transient loads do not coexist with the maximum effects of certain others.
  - ✓ Hence, Load combinations are essential.
  - ✓ Three primary and two secondary combinations of loads are specified in the code. Values of γ_{fL} for each load and for each combination is given in the code.

Limit State Design (cont'd)

- Load Combinations 1

Highway and foot/cycle bridges

- ✓ Permanent loads
- ✓ Primary live loads

Railway bridges

- ✓ Permanent loads
- ✓ Primary live loads
- ✓ Secondary live loads

Limit State Design (cont'd)

- Load Combinations 2
  - ✓ Loads in combination 1 plus
  - ✓ Wind loads
  - ✓ Temporary erection loads

- Load Combination 3
  - ✓ Loads in combination 1 plus
  - ✓ Restraint due to the effects of temperature
  - ✓ Temporary erection loads

Limit State Design (cont’d)

- Load Combinations 4

Highway bridges

- ✓ Permanent loads
- ✓ *Secondary live loads
  - ➢ Along with primary live loads associated with them

Foot/Cycle Track Bridges

- ✓ Permanent loads
- ✓ Vehicle collision loads on bridge supports and superstructure

Railway bridges

- ✓ Permanent loads
- ✓ Vehicle collision loads on bridge supports

*Secondary live loads are be considered separately and need not to be combined.

Limit State Design (cont’d)

- Load Combinations 5
  - ✓ Permanent Loads ⍰
  - ✓ Loads due to friction at bearings

Limit State Design (cont’d)

- Partial Load Factors
  - ✓ Depends upon the uncertainty in loading and the limit state being used (γ_{f1} γ_{f2})
  - ✓ The values of partial load factors are also dependent upon the loading combination being considered
  - ✓ Table 1 of BS5400-2 gives the values for all possible cases.

Limit State Design (cont'd)

- Partial Load Factors

  - For design HA loads considered alone, the partial load factors are as follows.

	For the ultimate limit state	For the serviceability limit state
For combinations 1	1.50	1.20
For combinations 2 & 3	1.25	1.00

Limit State Design (cont'd)

- Partial Load Factors

  - For design HB loads, the partial load factors are as follows.

	For the ultimate limit state	For the serviceability limit state
For combination 1	1.30	1.10
For combinations 2 & 3	1.10	1.00

  - The partial load factor for HA loading when considered in combination with HB loading is same as for HB loading.

Limit State Design (cont'd)

- Partial Load Factors
  - ✓ Design dead loads are obtained by multiplying the nominal dead loads with appropriate partial load factor, γ_{fL}
  - ✓ γ_{fL} should be increased by 1.1 and 1.2 for steel and concrete respectively at ULS when dead loads are not accurately accessed.
  - ✓ The value of γ_{fL} shall be taken as 1.0 if its application on the entire structure or element causes a less severe effect than the case when it is taken as 1.0 at the ULS.

Limit State Design (cont'd)

- Partial Load Factors
  - ✓ Design Superimposed dead loads are obtained by multiplying the nominal superimposed dead loads with appropriate partial load factor, γ_{fL}
  - ✓ γ_{fL} may be reduced to a minimum of 1.2 and 1.0 for ULS and SLS respectively subject to the approval of appropriate authority.
  - ✓ The value of γ_{fL} shall be taken as 1.0 if its application on the entire structure or element causes a less severe effect than the case when it is taken as 1.0 at the ULS.

Limit State Design (cont'd)

- Influence Lines
  - ✓ Influence lines provide a systematic procedure to determine variation of the load effects at a given point in the structure when applied moves load on the structure
  - ✓ Influence lines useful visual aid to determine the distribution of the primary traffic loads to give worst possible effects
  - ✓ Can be used to calculate actual values of the stress resultants.
  - ✓ Generally used by Bridge Engineers in a qualitative manner to locate critical regions for loading.

Limit State Design (cont'd)

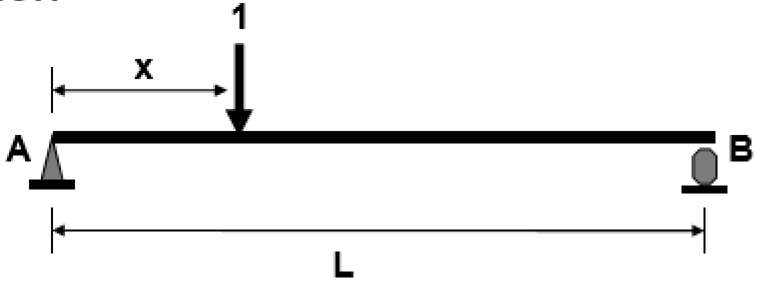
- Influence Lines
  - ✓ Influence lines can be constructed for
    - ➢ Support Reactions
    - ➢ Bending moments
    - ➢ Shear Forces

Recap UG

- shear and moment diagrams represent the effect of fixed loads at all points along the member.
- Influence lines represent the effect of a moving load only at a specified point on a member

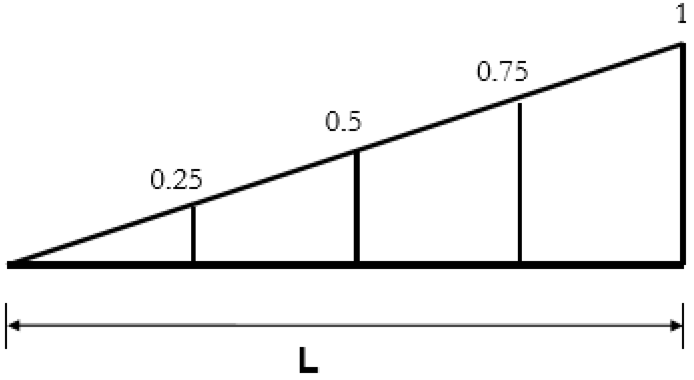
Limit State Design (cont’d)

- Influence Lines (simply-supported span)
  - Support Reaction



  - Influence Line for R_B

$R_B = 1(x)/L$



Limit State Design (cont'd)

- Influence Lines (simply-supported span)
  - Moment and Shear

$R_B = 1(x)/L$

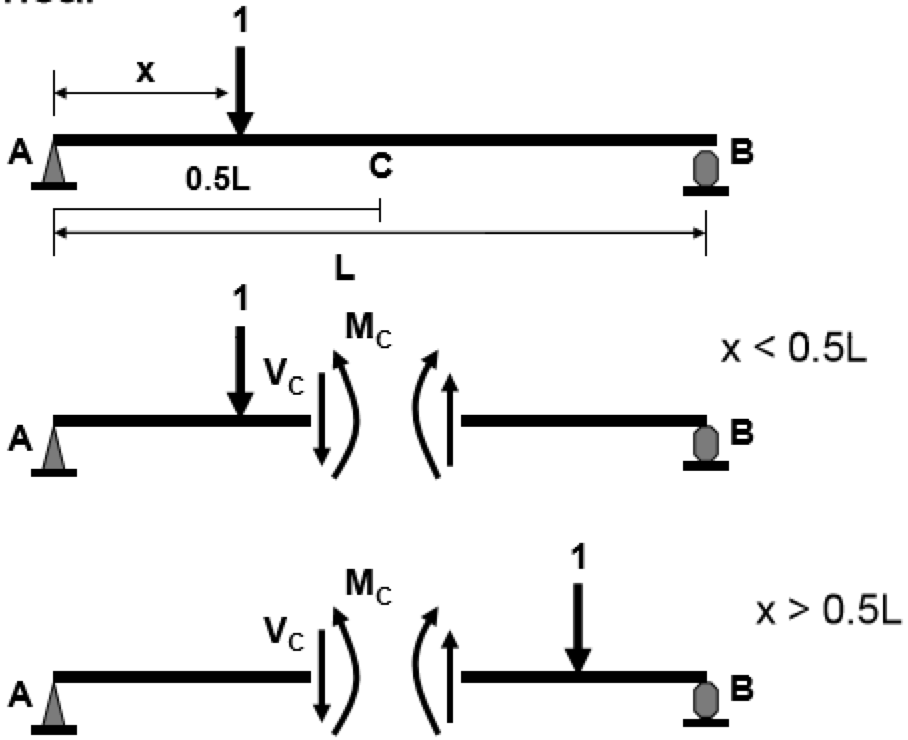
$R_A = 1(L-x)/L$

$V_C = -x/L$

$M_C = x/2$

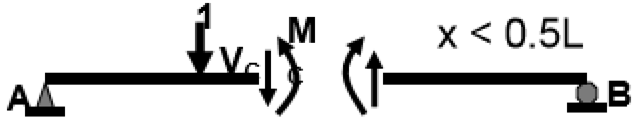
$V_C = (L-x)/L$

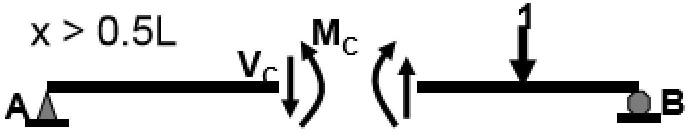
$M_C = (L-x)/2$



Limit State Design (cont’d)

- Influence Lines (simply-supported span)
  - Moment and Shear



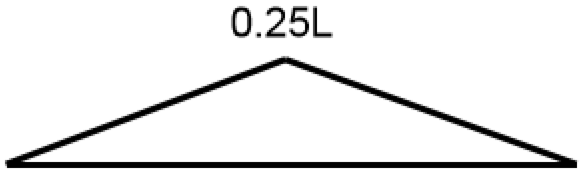


$V_C = -x/L$

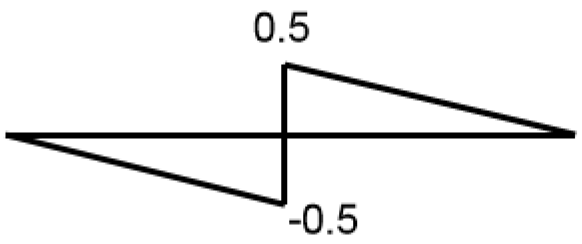
$M_C = x/2$

$V_C = (L-x)/L$

$M_C = (L-x)/2$



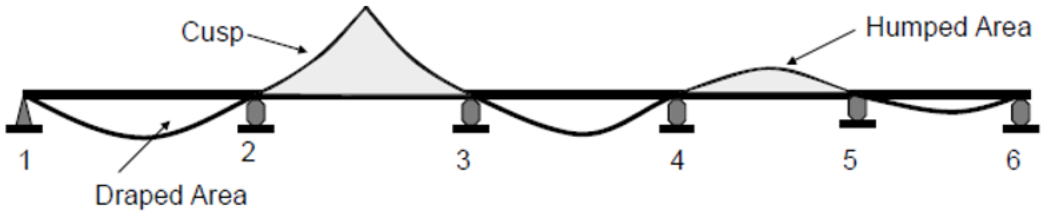
ILD for BM at
Pont C



ILD for SF at
Point C

Limit State Design (cont'd)

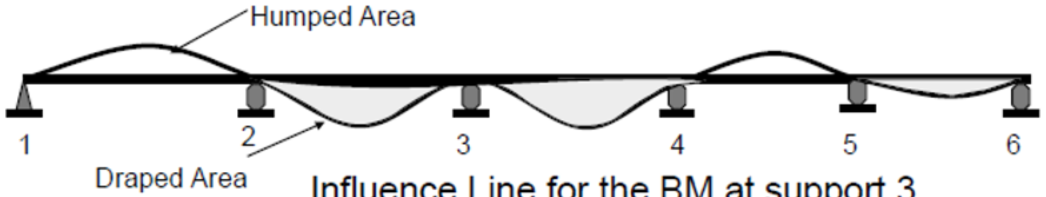
- Influence Lines (for continuous span)
  - The shape rather than the actual values are the dominant features of each line.



  - A Cusped action followed by alternate humped and draped sections.
  - This pattern can be used to sketch ILD for any number of equal or unequal spans.

Limit State Design (cont'd)

- Influence Lines (for continuous span)



Influence Line for the BM at support 3

- Two adjacent draped sections followed by alternate humped and drapped sections.
- The shape provides visual picture of where to place the loads to maximize the effects.

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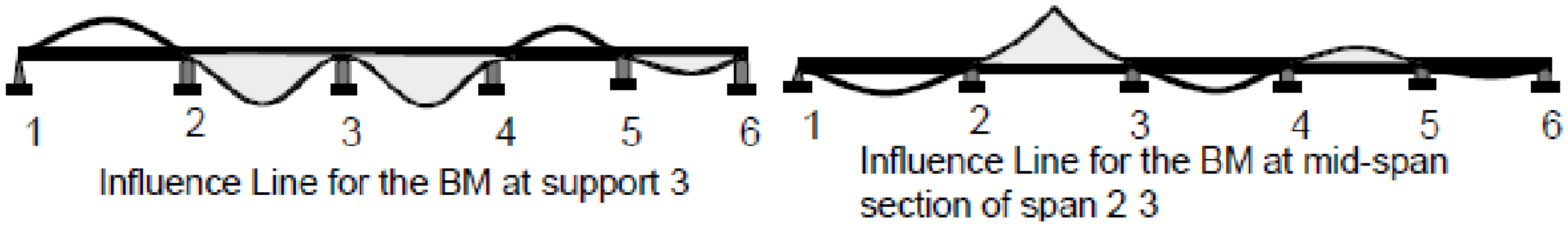
Limit State Design (cont'd)

- Influence Lines (for continuous span)



- The shaded areas shows regions where loads should be provided; Adverse areas.
- Non-shaded areas are Reliving areas
- Under normal cirmcumstances, maximum moments are generally taken as
  - Loading the adjacent spans for internal support.
  - Loading the single span only for mid-span regions.
  - Must be checked for alternate options for sensitivity.

Limit State Design (cont'd)

- Influence Lines (for continuous span)

  ✓ Adverse areas are those areas which if loaded would increase the loading effect under consideration.

  ✓ Relieving areas are those which if loaded would reduce the loading effect under consideration.

  ✓ These are generally established through influence lines.

Limit State Design (cont'd)

- Influence Lines (for continuous span)

Example:

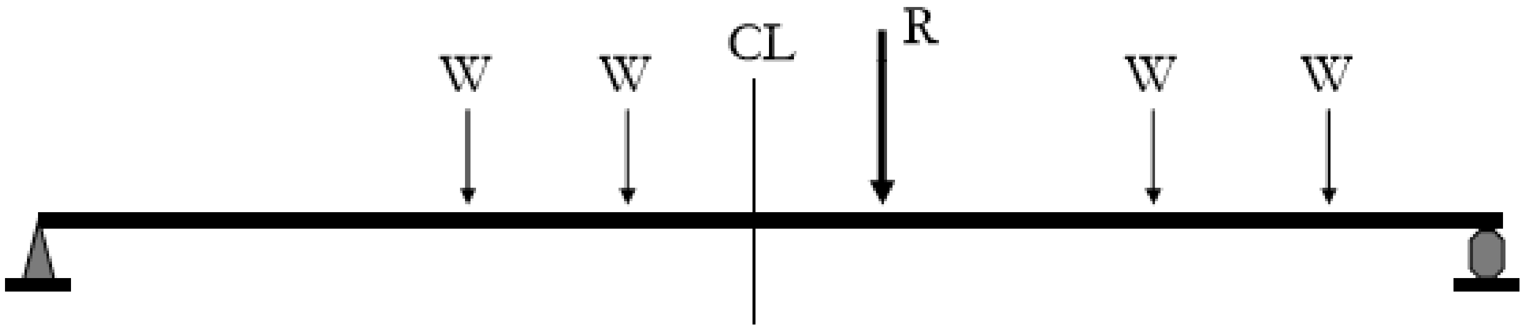
A continuous slab bridge consists of two spans, L1=23.5 m and L2=47 m respectively. If the bridge has a single lane only and is subjected to a UDL of 30kN/m and a point load of150kN at worst position, use influence lines to determine:

1) The BM at the center of the long span
2) The BM at the center of short span
3) The BM at the central support

Limit State Design (cont'd)

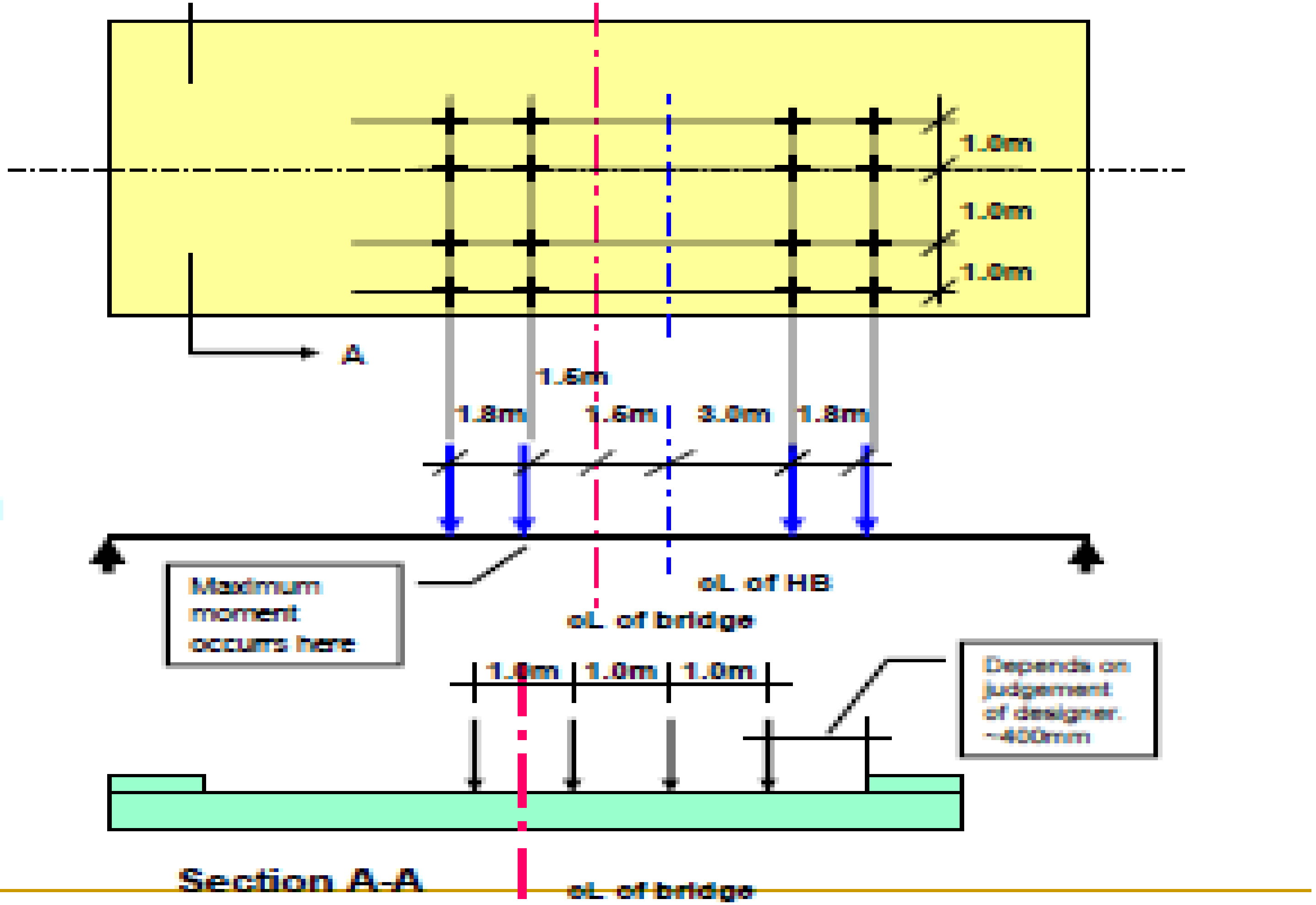
- HB Load location for most adverse effects

  - When a group of wheel loads are acting on a simply supported member, the absolute maximum BM at a point is given when half the distance between the resultant of the wheel loads and the wheel next to it coincides with the centreline of the span. The point of maximum BM is under the wheel considered.



Justification?

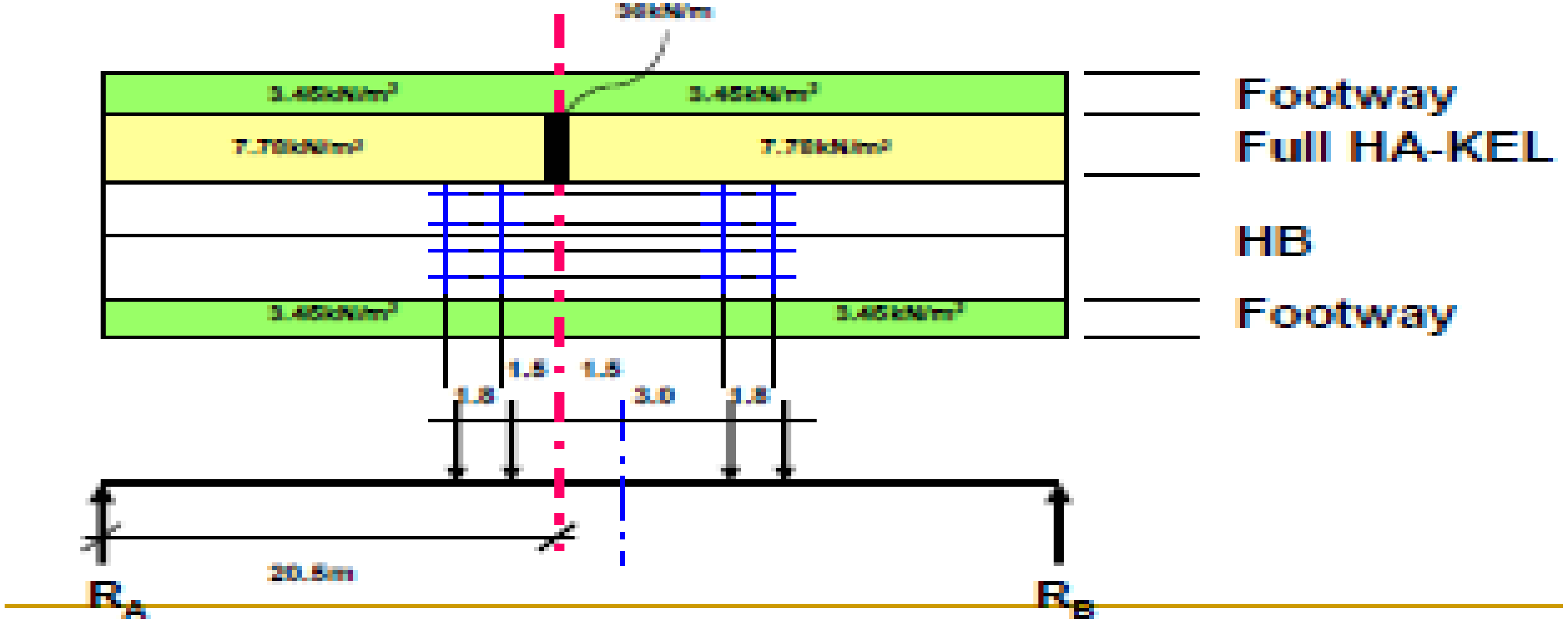
Position of HB Load to produce Maximum Moment



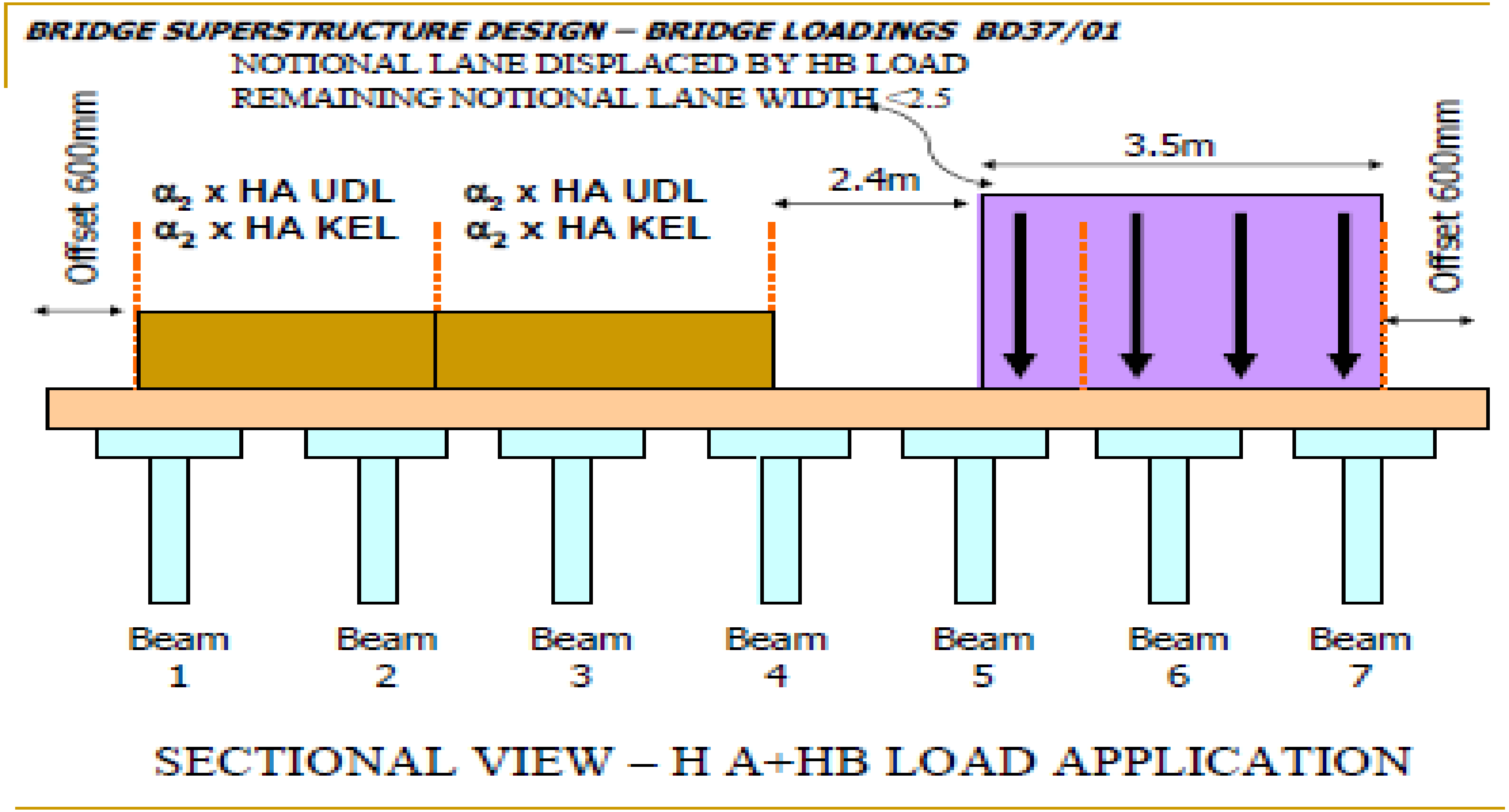
- Example

1 unit of HB load = 10 kN/axle

30 units of HB = 300 kN/axle



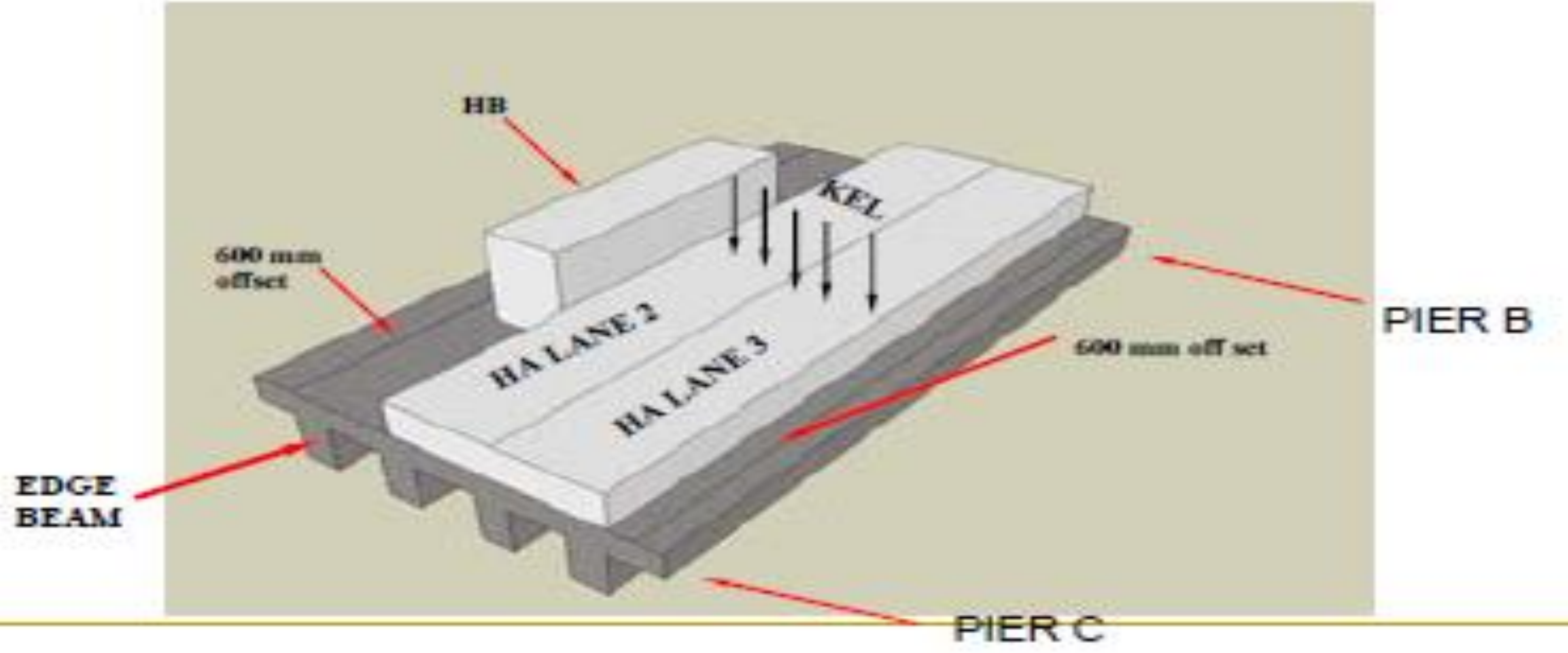
- Example



BRIDGE SUPERSTRUCTURE DESIGN – BRIDGE LOADINGS BD37/01
NOTIONAL LANE DISPLACED BY HB LOAD
REMAINING NOTIONAL LANE WIDTH <2.5
Offset 600mm
α_2 x HA UDL
α_2 x HA KEL
α_2 x HA UDL
α_2 x HA KEL
2.4m
3.5m
Offset 600mm
Beam 1
Beam 2
Beam 3
Beam 4
Beam 5
Beam 6
Beam 7
SECTIONAL VIEW – H A+HB LOAD APPLICATION

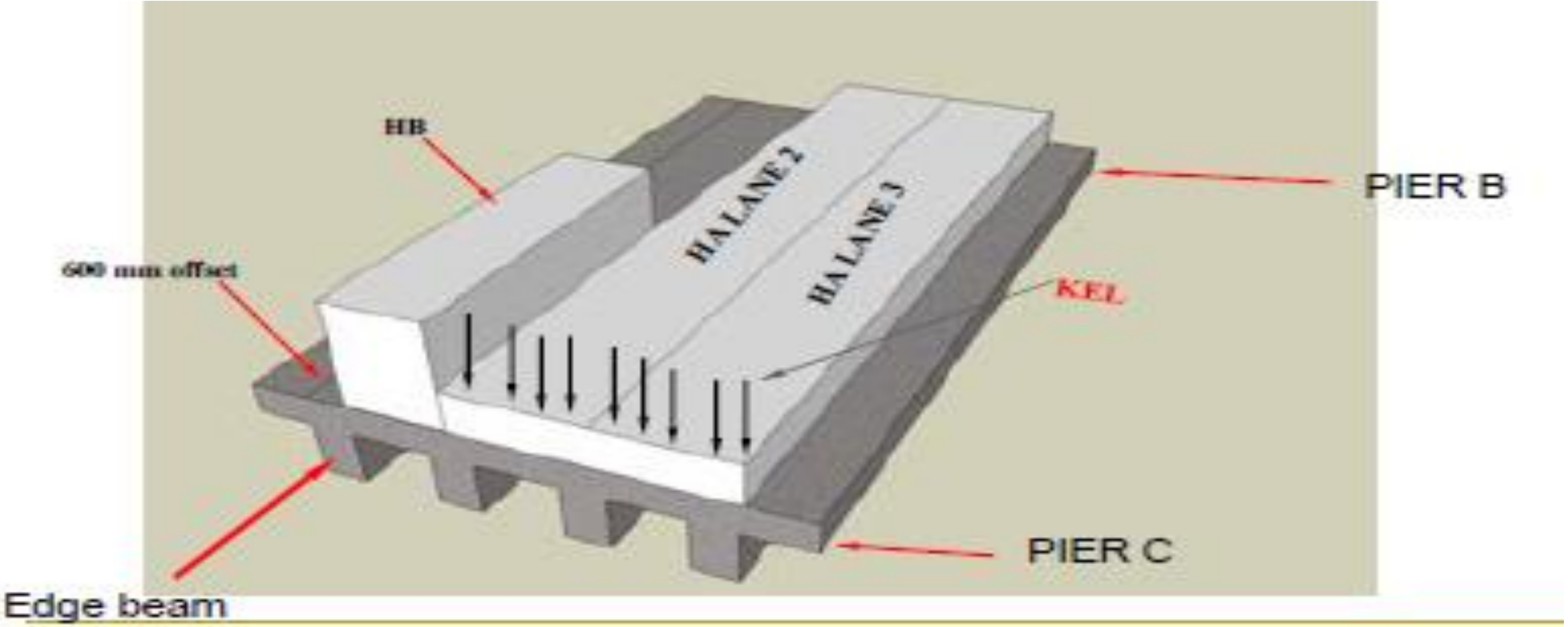
- Example

Load combination for worst edge beam Bending Moment (BM)

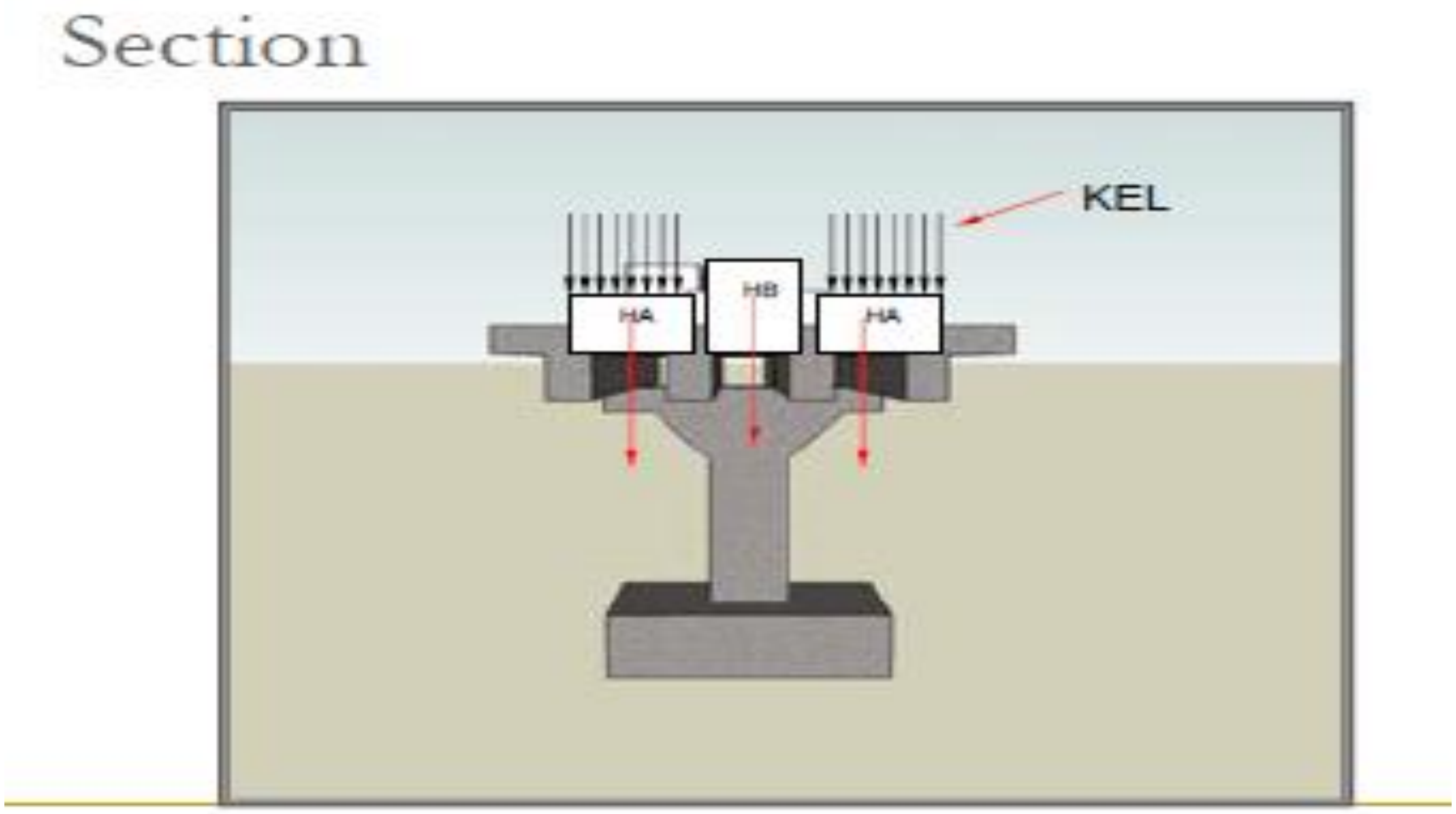


- Example

LOAD COMBINATION OF MAX SHEAR FOR EDGE BEAM



- Example



To be continued

Learning outcome (PLO1/C5)

- Able to demonstrate an understanding of the Limit State Philosophy as applied to the analysis and design.
- Able to apply various load combinations for the analysis and design as specified in British Codes.
- Able to understand and utilize ‘influence lines method’ for the analysis and to establish loaded lengths.
- Able to Demonstrate an understanding of Primary loads on Highway Bridges, Secondary loads on Highway Bridges and application of loads to get maximum loading effects.

Overview

- Bridge Loading BD37/01, BS5400
- Limit State Design
- Other loads
- Bridge Loading EN1991-1, EN1991-2 Eurocodes

Other loads

- Highway Bridges
  - ✓ Accidental wheel loading
  - ✓ Loads due to vehicle collision with parapets
  - ✓ Vehicle collision loads on highway bridge supports and superstructures
  - ✓ Centrifugal loads
  - ✓ Longitudinal loads (traction and braking)
  - ✓ Accidental loads due to skidding
- Foot/Cycle track Bridges
  - ✓ Vehicle collision loads on bridge supports and superstructure
- Railway Bridges
  - ✓ Nosing
  - ✓ Centrifugal loads
  - ✓ Longitudinal loads

Other loads (cont'd)

- **Accidental Wheel Loading**
  - ✓ For the elements of the structure supporting outer verges, footways or cycle tracks not protected from vehicular traffic by an effective barrier.
  - ✓ The load consists of a tandom axle arrangement.
  - ✓ Any single or group of wheels can be considered to get worst effects.
  - ✓ The elements shall be designed to sustain local effects of the nominal accidental wheel loading.
  - ✓ Dispersion and distribution is permitted.
  - ✓ Combination 1 only, γ_{fl} being 1.5 and 1.2 for ULS and SLS.
  - ✓ Shall not be considered as acting with any other primary live loads.

Other loads (cont'd)

- **Vehicle collision with parapets**
  - ✓ Local effects of the load shall be considered in the design of elements supporting parapets.
  - ✓ Global effects (in addition) of vehicle collision with high level of containment parapets shall be considered.
  - ✓ Separate loads for local and global analysis.
  - ✓ Load combination 4 only. No co-existence with other secondary loads.
  - ✓ Rules for the design of highway parapets itself are given in separate DBRB manual.

Other loads (cont'd)

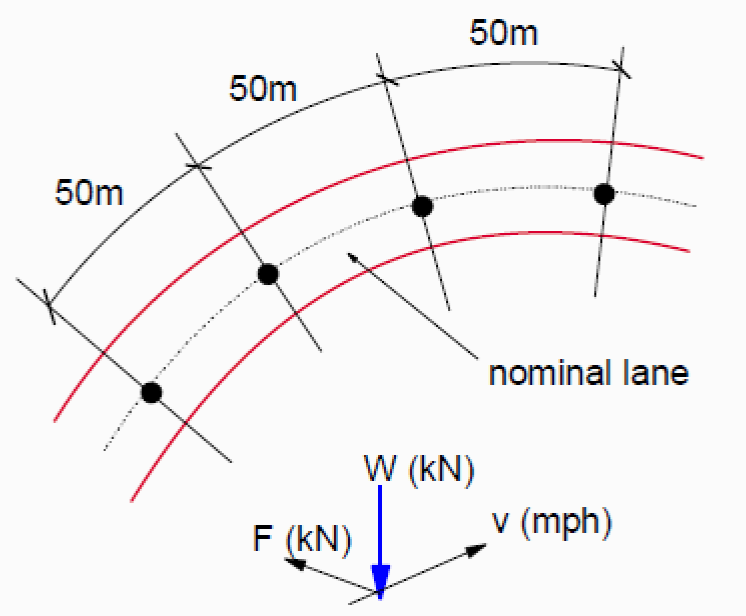
- **Vehicle collision loads on bridge supports and superstructures**
  - ✓ The details of the collision loads are given in BD 60/04.
  - ✓ Nominal loads on superstructures:
    - ➢ A single nominal load of 50kN in any direction between the horizontal and vertical.
    - ➢ Applied to the bridge soffit.
  - ✓ No associated primary live load is required to be considered.
  - ✓ Vehicle collision loads on supports and superstructures are considered separately in combination 4 only.
  - ✓ Co-existence with other secondary live loads is not required.

Other loads (cont'd)

- **Centrifugal Loads**
  - ✓ Applied if the horizontal radius is less than 1000m.
  - ✓ The force is based on the centrifugal acceleration
    - a = velocity^2 / radius of curve
  - ✓ The force can be computed using Newton's law of motion
    - $F = mV^2 / r$
  - ✓ Code suggests this value to be $$F_c = \frac{40000kN}{r+150}$$
  - ✓ This value relates to the 40t (400kN) vehicle travelling at 70mph.
  - ✓ Applied in any two notional lanes in each carriageway at 50m centres.
  - ✓ For single lane carriageway, it is applied at 50m centres in that lane.

Other loads (cont'd)

- **Centrifugal Loads (cont'd)**
  - ✓Acts as a point load in radial direction at the surface and parallel to it.
  - ✓Associated primary live load: a vertical load of 400kN is considered with each centrifugal load.
  - ✓It is considered to be uniformly distributed over a notional lane for a length of 6m.
  - ✓Combination 4 only
  - ✓Coexistence with other secondary loads is not required



Forces at each centrifugal load

Other loads (cont’d)

- **Longitudinal Loads**
  - ✓ Due to traction or breaking of vehicle.
  - ✓ Applied at the road surface and parallel to it in one notional lane only.
  - ✓ The design longitudinal load is the severe design load from
    - ➢ Nominal load for type HA: 8kN/m of loaded length plus 250kN subjected to a maximum of 750kN applied uniformly to a notional lane width and loaded length.
    - ➢ Nominal load for type HB: 25% of the total nominal HB load equally distributed between 8 wheels of 2 axles of the vehicle, 1.8m apart.
    - ➢ Note that the partial factor for HA and HB is different.
  - ✓ Associated primary live load: Type HA or HB load as appropriate to the case considered.

Other loads (cont’d)

- **Accidental load due to skidding**
  - ✓ A single point load is considered in one notional lane only
  - ✓ It is considered to be acting in any direction on and parallel to the surface of the highway.
  - ✓ Nominal load is taken as 300kN.
  - ✓ Associated primary live load: Type HA loading
  - ✓ Combination 4 only
  - ✓ Co-existence with any other secondary load is not required.

Other loads (cont'd)

- **Wind Load**

- The wind actions on a bridge depend on site conditions and geometrical characteristics of the bridge. The maximum pressures are due to gusts that cause local and transient fluctuations about the mean wind pressure. Design gust pressures are derived from the design wind speed defined for a specified return period.
- BD37/01 Gives the values of wind pressure and wind speeds for the 'Loaded Case' and 'Unloaded Case'.
- Exposed area of traffic on bridges has the length corresponding to the maximum effects and in general a height of 2.50m above the carriageway in highway bridges and 3.70m above rail level in railway bridges.

Other loads (cont'd)

- **Temperature Load**
  - ✓Temperature variation and their effects on bridge decks
  - ✓Effective Bridge Temperature
  - ✓Superstructure movements due to temperature variations
  - ✓Temperature differences within the superstructure
  - ✓Effects of temperature loads (internal stresses)

Other loads (cont'd)

- **Temperature Load (cont'd)**
  - ✓ Effects of temperature changes on bridges superstructures
    - ➢ The variations in temperature cause two type of effects in the bridge superstructure.
      1) Annual variation (slow process)
         - ❖ Causes variation of temperature in entire deck section.
         - ❖ Results in overall movement of bridge superstructures.
         - ❖ Affects the design of both bearings and expansion joints.
         - ❖ Generate stresses if restrained against the movement

Other loads (cont'd)

- **Temperature Load (cont'd)**
  - ✓ Effects of temperature changes on bridges superstructures
    - ➢ The variations in temperature cause two type of effects in the bridge superstructure.
      2) Daily variation (fast process)
         - ❖ Causes temperature differences within deck section.
         - ❖ Results in differential movements across the section;
         - ❖ Generates residual stresses within the cross-section.
         - ❖ Also generate additional stresses at the supports, if restrained against movements.

Other loads (cont'd)

- **Temperature Load (cont'd)**
  - Factors affecting bridge temperature
    - The location with respect to the sun.
    - The time of the day.
    - The intensity of the sun rays (weather conditions).
    - Wind (direction and amount of)
    - Thermal conductivity of the material (steel or concrete)
    - Cross-sectional make-up of the structure
    - Depth of the surfacing.

Other loads (cont'd)

- **Temperature Load (cont'd)**
  - ✓ Effective Bridge Temperature
    - ➢ Effects of seasonal temperature variations cannot be isolated from the daily variations.
    - ➢ The temperature differences always exists within the cross-section.
    - ➢ Hence an averaged temperature of the cross-section is needed to calculate overall deck movement, termed as 'effective bridge temperature'.

Other loads (cont'd)

- **Temperature Load (cont'd)**
  - ✓ Effective Bridge Temperature (cont'd)
    - ➢ Effective Bridge Temperature is defined as the temperature which governs the longitudinal movement of the deck.
    - ➢ It is a theoretical temperature derived by weighing and adding temperatures at various levels within the superstructure.
    - ➢ The weighing is carried out in relation to the area of cross-section at various levels to the total cross-sectional area.

Other loads (cont'd)

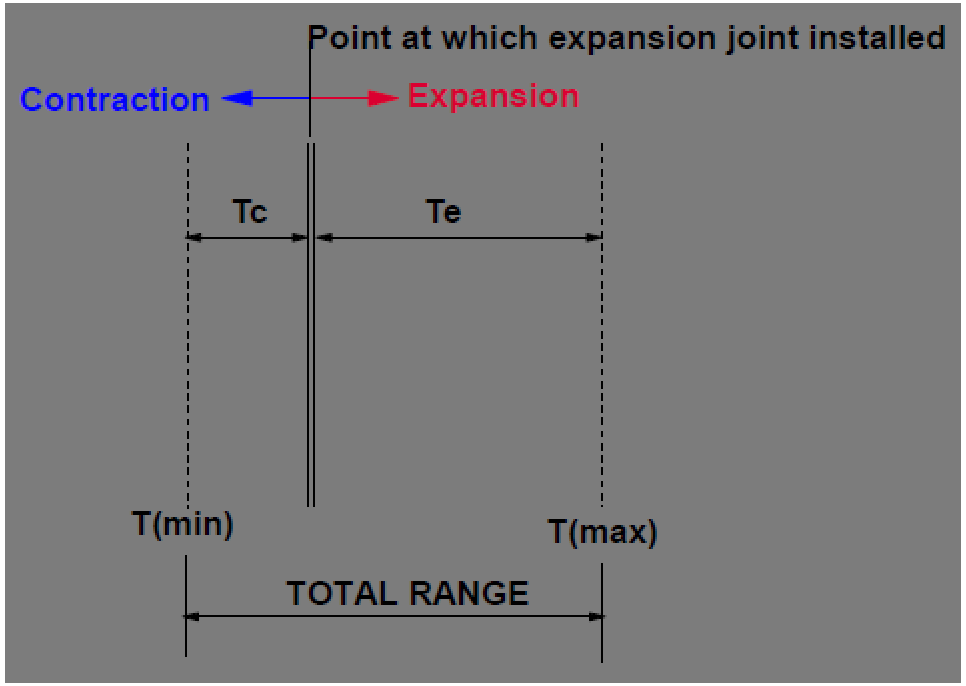
- **Temperature Load (cont'd)**
  - ✓ Effective Bridge Temperature (cont'd)
    - ➢ The minimum and maximum effective bridge temperatures depends upon the type of construction and minimum and maximum shade air temperatures.
    - ➢ These values are given in Table 10 and 11 of the code.

Other loads (cont'd)

- **Temperature Load (cont'd)**
  - ✓ Superstructure movements due to temperature variations
    - ➢ The temperature at the time when bridge is restrained is considered as datum.
    - ➢ The movement of the bridge (or stresses due to temperature restraint) shall be determined for the range between datum temperature and
      - ❖ Maximum effective bridge temperature (for expansion).
      - ❖ Minimum effective bridge temperature (for contraction).

Other loads (cont'd)

- **Temperature Load (cont'd)**
  - ✓ Superstructure movements due to temperature variations(cont'd)



Other loads (cont’d)

- **Temperature Load (cont’d)**
  - ✓ Superstructure movements due to temperature variations(cont’d)
    - ➢ The thermal movement of a bridge takes place about a point called the thermal center or the stagnant point.
    - ➢ This defines the length and direction over which movement will occur.
    - ➢ For simple bridge arrangements, this could be e.g. a fixed bearing.
    - ➢ The change of length of the superstructure is given by

$$\Delta L = L\alpha\,(\Delta T)$$

Where

ΔL = Change in Length

L = Original Length

ΔT = Range of effective bridge temperatures.

α = Coefficient of thermal expansion.

Other loads (cont'd)

- **Temperature Load (cont'd)**
  - ✓ Temperature Difference
    - ➢ Temperature Distribution is the variation of temperature through any vertical section of a bridge deck at any instant in time.
    - ➢ Exists in the deck due to daily temperature changes and other effects.
    - ➢ Temperature Difference is the difference in temperature between minimum temperature at a cross-section and other levels of the deck.

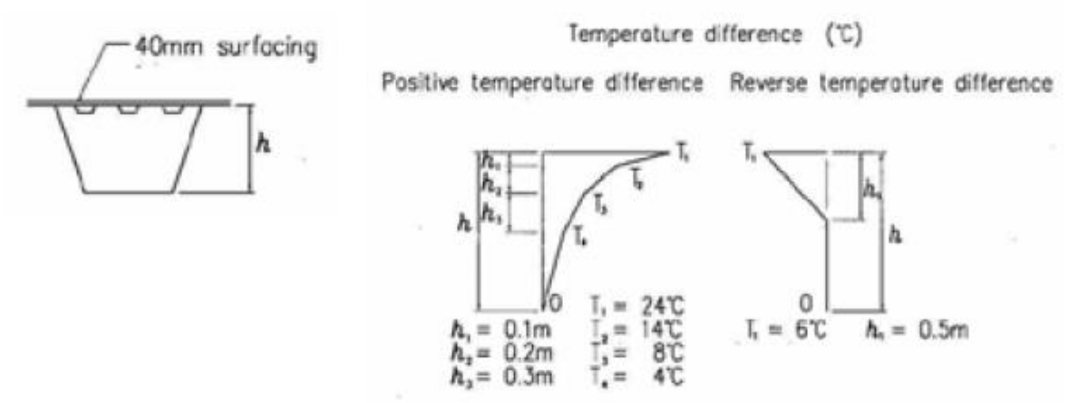
Other loads (cont'd)

- **Temperature Load (cont'd)**
  - ✓ Temperature Difference (cont'd)
    - ➢ Positive temperature difference occurs when the heat is gained through the top surface of the superstructure.
    - ➢ Reverse temperature difference occurs when the heat is lost from the top surface.

Other loads (cont’d)

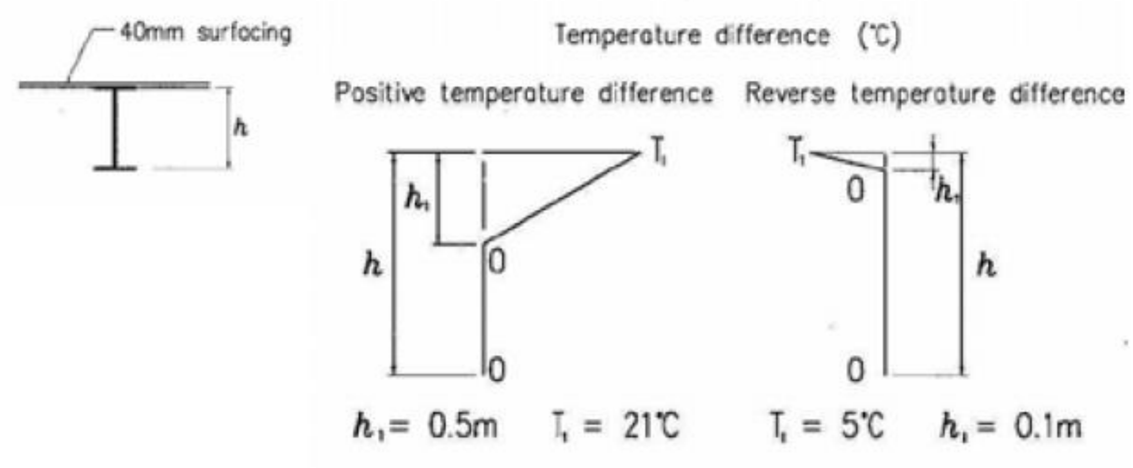
- **Temperature Load (cont’d)**
  - ✓ Temperature Difference (cont’d)

▪ Group 1: Steel deck on steel box girders



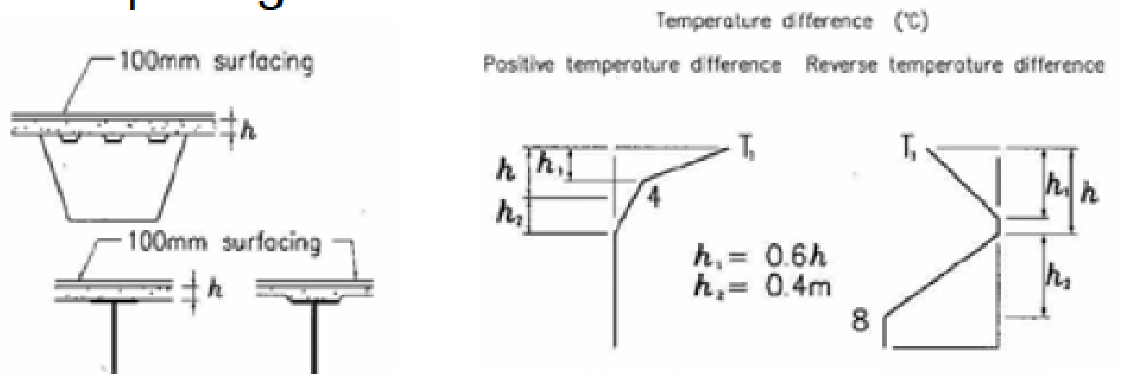
▪ Group 2:

Steel deck on steel truss or plate girders



Other loads (cont’d)

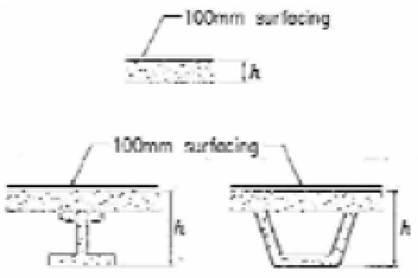
- **Temperature Load (cont’d)**
  - ✓ Temperature Difference (cont’d)
    - Group 3: Concrete deck on steel box, truss or plate girders

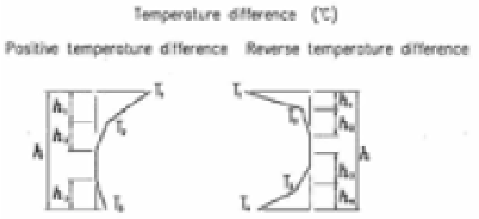


h	T_1
m	℃
0.2	13
0.3	16

h	T_1
m	℃
0.2	3.5
0.3	5.0

    - Group 4: Concrete slab or deck on concrete beams or box girders





$h_1 = 0.3h$ but $\le 0.15m$
$h_2 = 0.3h$ but $\ge 0.10m$ but $\le 0.25m$
$h_3 = 0.3h$ but $\le$ (0.1m + surfacing depth in metres)
(for thin slabs, h_3 is limited by $h - h_1 - h_2$)

$h_1 = h_4 = 0.20h$ but $\le 0.25m$
$h_2 = h_3 = 0.25h$ but $\le 0.20m$

h	T_1	T_2	T_3
m	℃		
≤ 0.2	8.5	3.5	0.5
0.4	12.0	3.0	1.5
0.6	13.0	3.0	2.0
≥ 0.8	13.5	3.0	2.5

h	T_1	T_2	T_3	T_4
m	℃			
≤ 0.2	2.0	0.5	0.5	1.5
0.4	4.5	1.4	1.0	3.5
0.6	6.5	1.8	1.5	5.0
0.8	7.6	1.7	1.5	6.0
1.0	8.0	1.5	1.5	6.3
≥ 1.5	8.4	0.5	1.0	6.5

Other loads (cont'd)

- **Temperature Load (cont'd)**
  - ✓ Effects of Temperature loads
    - ➢ Steps in calculations
      - ➢ Calculate strains from the temperature distributions using $\varepsilon=\alpha T$.
      - ➢ Calculate restraint stresses using $\sigma=E.\varepsilon$
      - ➢ Calculate the restraint force and moments. This will give balancing force and moments.
      - ➢ Calculate the stresses due to axial release.
      - ➢ Calculate the stresses due to bending release.
      - ➢ Evaluate the final residual stresses.

Other loads (cont'd)

- **Temperature Load (cont'd)**
  - ✓ Effects of Temperature loads

➤ Example

Determine the stresses induced by both the positive and reverse temperature differences for the concrete box girder bridge shown in Figure 6.4. {A=940,000mm2, I=102,534x106 mm4, Depth to neutral axis = 409mm, βT = 12 x 10-6, E = 34 kN/mm^2).

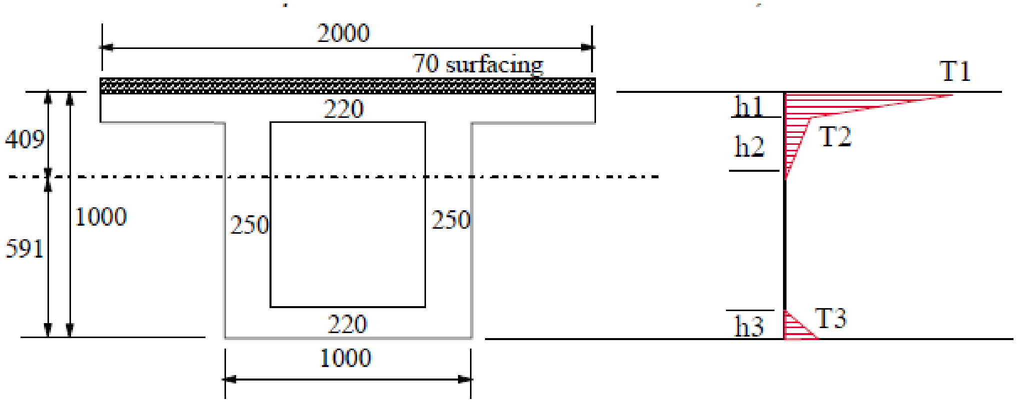


Figure 6.4: Box girder dimensions & temperature distribution

Other loads (cont'd)

- **Pedestrian Load**
  - ✓ Elements supporting footways / cycle tracks only
    - ➢ UDL, uniform over the entire length and width.
    - ➢ Crowd loading is considered if appropriate.
    - ➢ Loaded lengths of 36m and less, UDL = 5kN/m2.
    - ➢ Loaded lengths of >36m, UDL = k x 5kN/m2.

      K = (nominal HA UDL for appropriate L x 10) / (L + 270)
    - ➢ If deck width > 2m, UDL is further reduced by 15% on the 1st m and by 30% on 2nd m in excess of 2m. No further reductions.

Other loads (cont'd)

- **Pedestrian Load**
  - ✓ Elements supporting footways / cycle tracks and a carriageway
    - ➢ Nominal pedestrian Live load (UDL)= 80% of the Nominal pedestrian load (Previously calculated).
    - ➢ For L>400m crowd loading is considered
    - ➢ For a main structural member, carrying two or more notional traffic lanes, pedestrian loading can be reduced further.
      - ❖ Footways: 50% of pedestrian loading
      - ❖ Cycle Tracks: 20% of pedestrian loading
    - ➢ The reductions shall not apply if only one out of two footways are considered loaded.

To be continued

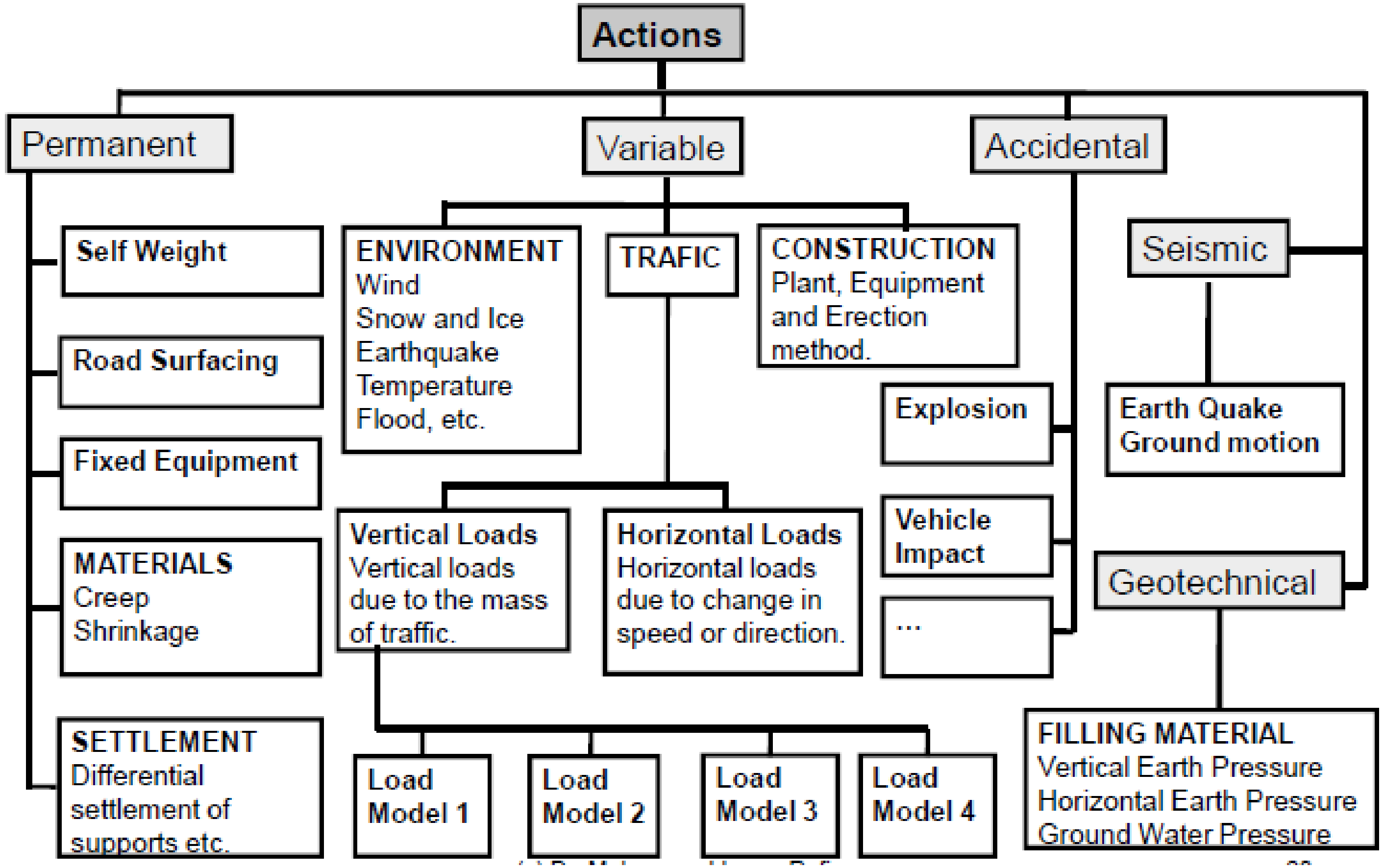
Learning outcome (PLO1/C5)

- Able to demonstrate an understanding of the Limit State Philosophy as applied to the analysis and design.
- Able to apply various load combinations for the analysis and design as specified in British Codes.
- Able to understand and utilize 'influence lines method' for the analysis and to establish loaded lengths.
- Able to Demonstrate an understanding of Primary loads on Highway Bridges, Secondary loads on Highway Bridges and application of loads to get maximum loading effects.

Overview

- Bridge Loading BD37/01, BS5400
- Limit State Design
- Other loads
- Bridge Loading EN1991-1, EN1991-2 Eurocodes

Bridge Loading EN1991-1, EN1991-2 Eurocodes



Bridge Loading EN1991-1, EN1991-2 Eurocodes (cont’d)

- ✓ Eurocode uses concept of lead and accompanying variable for combining different variable actions for design.
- ✓ Lead variable action have most predominant effects on structures
- ✓ All variable actions other than the Lead variable are accompanying variable actions
- ✓ If unsure, have to try different possibilities to obtain most unfavourable effects.

Bridge Loading EN1991-1, EN1991-2 Eurocodes (cont'd)

✓ Carriageway width

➢ Carriageway width is the width between raised curbs or vehicle restraint systems.

Table 4.1 - Number and width of notional lanes

Carriageway width w	Number of notional lanes	Width of a notional lane w_l	Width of the remaining area
$w < 5{,}4$ m	$n_1 = 1$	3 m	$w - 3$ m
$5{,}4 \text{ m} \leq w < 6$ m	$n_1 = 2$	$\frac{w}{2}$	0
$6 \text{ m} \leq w$	$n_1 = Int\left(\frac{w}{3}\right)$	3 m	$w - 3 \times n_1$
NOTE For example, for a carriageway width equal to 11m, $n_1 = Int\left(\frac{w}{3}\right) = 3$, and the width of the remaining area is $11 - 3 \times 3 = 2$m.			

Bridge Loading EN1991-1, EN1991-2 Eurocodes (cont'd)

✓ Numbering Notional Lanes

- Lane nos. are interchangeable, similar to BS5400.
- A lane no. should appear only once on two separate parts on the same deck.
- Separate lane numbering for each carriageway, for two separate parts on two independent decks.
- If two decks supported on same piers, one numbering for the two parts for substructure design.

Bridge Loading EN1991-1, EN1991-2 Eurocodes (cont’d)

✓ Vertical Traffic Actions

- Four Load models are defined in EN1991-2.
- Two more predominant are LM1 and LM2, which represents the normal traffic loads for bridges.
- LM3 refers to special vehicle.
- LM4 is a crowd loading model.

Bridge Loading EN1991-1, EN1991-2 Eurocodes (cont'd)

- ✓ Vertical Traffic Actions (cont'd)
  - ➢ Load Model 1
    - ❖ This loading mode is similar to HA loading of BS5400.
    - ❖ Two parts load model.
      - o UDL System, $\alpha_q\ q_k$
      - o Tandem System (TS), $\alpha_Q\ Q_k$

Location	Tandem system *TS*	*UDL* system
	Axle loads Q_{ik} (kN)	q_{ik} (or q_{rk}) (kN/m^2)
Lane Number 1	300	9
Lane Number 2	200	2,5
Lane Number 3	100	2,5
Other lanes	0	2,5
Remaining area (q_{rk})	0	2,5

Bridge Loading EN1991-1, EN1991-2 Eurocodes (cont'd)

- ✓ Vertical Traffic Actions (cont'd)
  - ➢ Load Model 1 (cont'd)
    - ❖Adjustment factors given in National Annex.

Location	α_Q for tandem axle loads	α_q for UDL loading
Lane 1	$\alpha_{Q1} = 1{,}0$	$\alpha_{q1} = 0{,}61$ (See note)
Lane 2	$\alpha_{Q2} = 1{,}0$	$\alpha_{q2} = 2{,}2$
Lane 3	$\alpha_{Q3} = 1{,}0$	$\alpha_{q3} = 2{,}2$
Other lanes	—	$\alpha_{qn} = 2{,}2$
Remaining area	—	$\alpha_{qr} = 2{,}2$

NOTE α_{q1} *should be taken as 1,0 for 4.4.1 (2) of BS EN 1991-2*

Bridge Loading EN1991-1, EN1991-2 Eurocodes (cont'd)

- ✓ Vertical Traffic Actions (cont'd)
  - ➢ Load Model 2
    - ❖ Single axle load, $\beta_Q\ Q_{ak}$
    - ❖ Q_{ak} = 400kN
    - ❖ Distributed equally between two wheels
    - ❖ Generally critical for loaded lengths between 3 to 7m.
    - ❖ One or both wheel may be applied.
    - ❖ β_Q =1.0
    - ❖ National Annex choose wheel size as 0.4 x 0.4m

Bridge Loading EN1991-1, EN1991-2 Eurocodes (cont'd)

- ✓ Vertical Traffic Actions (cont'd)
  - ➢ Load Model 3
    - ❖ Also termed as Special vehicle.
    - ❖ To be used for main route bridges.
    - ❖ Not actual loads but models.
    - ❖ NA2.16 defines the special vehicles
      - o 3 SV models for STGO (Special type general order vehicles)
      - o 4 SOV models (Special order vehicles).
    - ❖ Reflects abnormal and exceptional vehicle loads (in BS5400 terms).

Bridge Loading EN1991-1, EN1991-2 Eurocodes (cont'd)

- ✓ Vertical Traffic Actions (cont'd)
  - ➢ Load Model 4
    - ❖ Also termed as Crowed loading.
    - ❖ Be applied on bridges where crowd load is more likely, e.g. Bridges serving sports stadium, or close to town centers.
    - ❖ Be used for general verification only.
    - ❖ For Transient design situations only.
    - ❖ UDL of 5 kN/m^2.
    - ❖ Include dynamic amplification.

Bridge Loading EN1991-1, EN1991-2 Eurocodes

Example 1

Determine LM1 values for the following loaded lengths.

1) 17m
2) 50m
3) 149m

Bridge Loading EN1991-1, EN1991-2 Eurocodes

Example 2

Show plan arrangement for LM1 loading to give

1) Worst bending moment
2) Worst shear force

Assume Two spans of 20m each, Carriageway width = 11m

End