UNIVERSITI SAINS MALAYSIA

1st. Semester Examination
2006/2007 Academic Session

October / November 2006

# EAS 665/4 – Bridge Engineering

Duration: 3 hours

**Instructions to Candidates:**

1. Ensure that this paper contains **TWELVE (12)** printed pages including appendices before you start your examination.
2. This paper contains **FIVE (5)** questions. Answer **ALL FIVE (5)** questions.
3. Each question carries equal mark.
4. All questions **CAN BE** answered either in English or Bahasa Malaysia.
5. Each question **MUST BE** answered on a new sheet.
6. Write the answered question numbers on the cover sheet of the answer script.

1. (a) A solid slab highway bridge, with cross-section as shown in Figure 1, has a right (total width) of 12m, a structural depth of 600 mm and a skew of 30°. The specified highway loading is HA and 45 units of HB. The nominal superimposed dead load is equivalent to a uniformly distributed load of 2.5 kN/m$^2$, and the nominal parapet loading is 3.5kN/m along each free edge. Calculate the moments of resistance for bottom reinforcement placed parallel to the slab edges by yield line theory for load combination 1. Neglect the contribution of top reinforcement towards strength. Use the data below.

| Load | $\gamma f_3$ | $\gamma f_2$ |
|---|---|---|
| Dead | 1.15 | 1.2 |
| Surfacing | 1.15 | 1.75 |
| Parapet | 1.15 | 1.75 |
| HA (alone) | 1.1 | 1.5 |
| HA (with HB) | 1.1 | 1.3 |
| HB | 1.1 | 1.3 |
| Footway | 1.1 | 1.5 |

$\gamma f_2$ partial safety factors applied to load, $\gamma f_3$ partial safety factor applied to load effects.

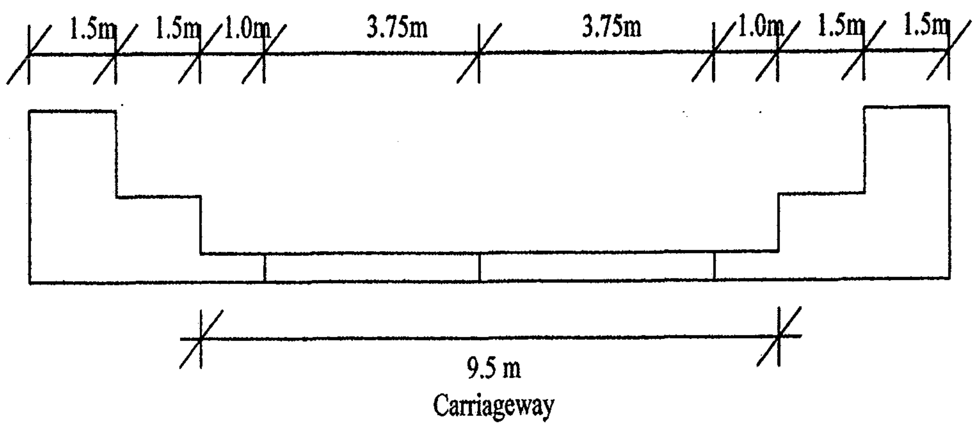



Figure 1 : Cross-Section of Carriageway

(15 marks)

(b) i. Briefly describe the general principles of bearings.
ii. Define permanent and superimposed dead loads for bridge loading.

(5 marks)

2. (a) Design stirrups of 250 N/mm$^2$ characteristic strength to resist an ultimate shear force of 550 kN applied to the section shown in Figure 2. The concrete is of grade 40.

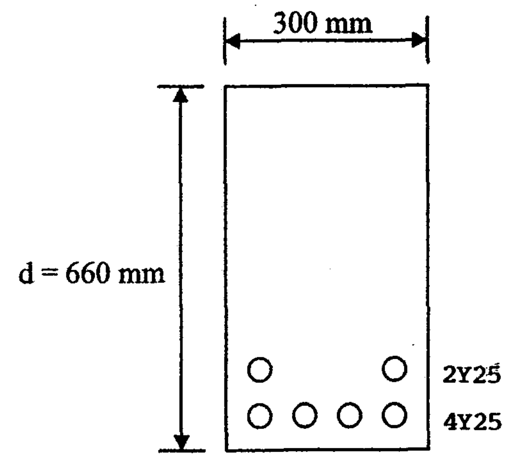
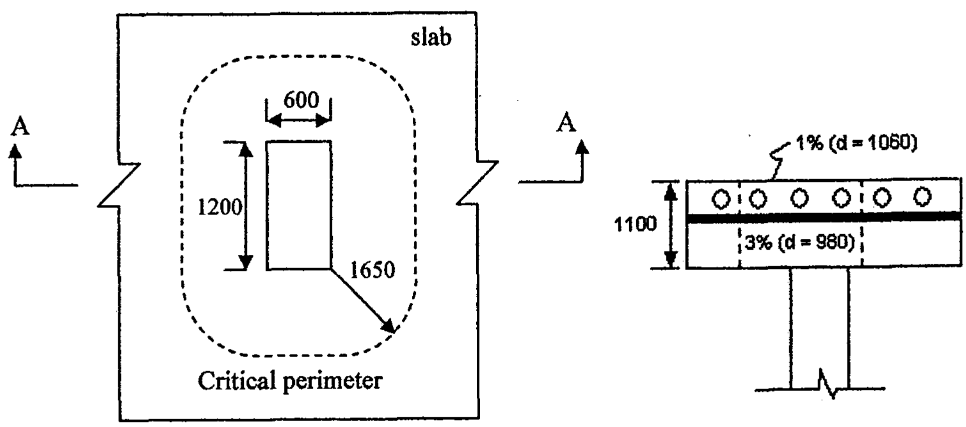



Figure 2 : Cross section of reinforced concrete beam

(5 marks)

(b) Design the slab shown in Figure 3(a) and (b) to resist punching shear if the characteristic strengths of the steel and concrete are 460 and 40 N/mm$^2$, respectively and the column reaction at the ultimate limit state is 15 MN.




(a) Plan

(b) Section A-A

Figure 3(a) and (b)

(10 marks)

(c) List the main advantages to be gained by using continuous deck against simply supported deck.

(5 marks)

3. (a) A reinforced concrete abutment is 8 m high and 12 m wide. At each end of the abutment there is a wing wall which is structurally attached to the abutment. The lateral loads acting on the abutment are the earth pressure, which varies from zero at the top to 5H kN/m$^2$ at a depth H; HA surcharge, the nominal value of which acts at the top of the abutment and may be taken to have a nominal value of 30 kN/m inclusive of abutment. Calculate the resulting moments at critical point using Hillerborg Strip Method. Draw the loading and bending moment diagram. See Figure 4 for detailed information.

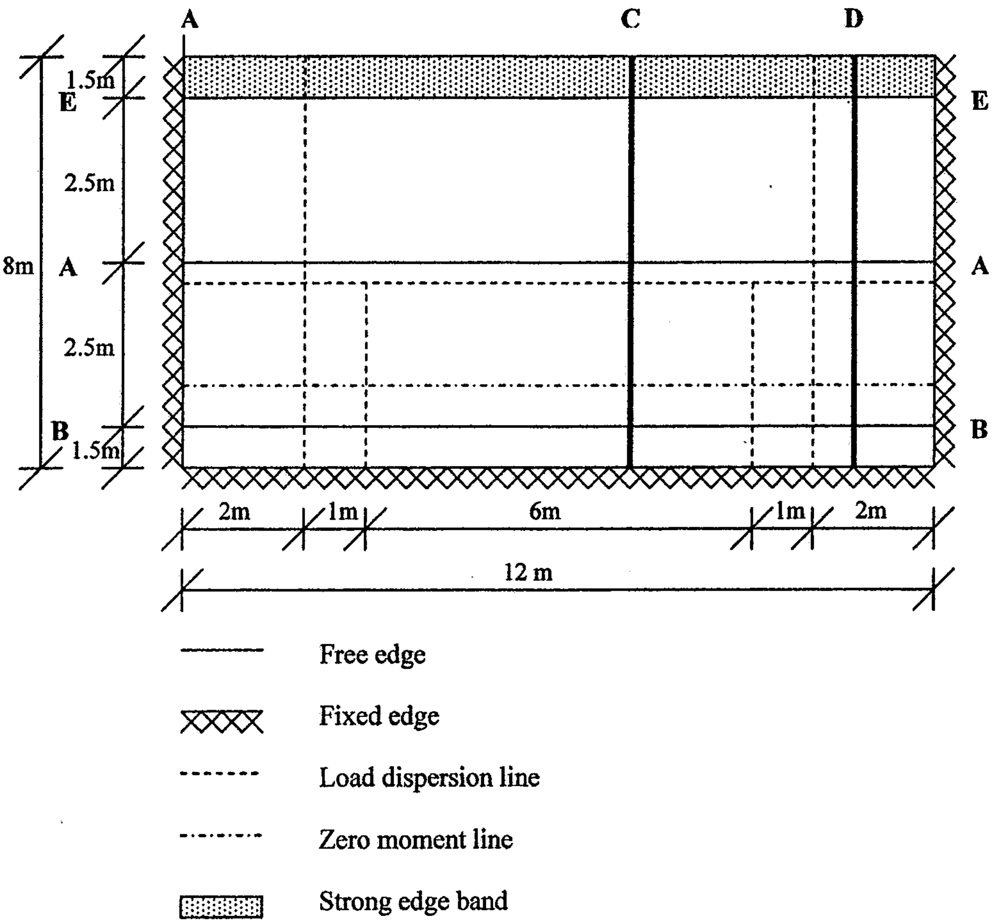



Figure 4

(15 marks)

(b) Briefly describe **TWO (2)** types of bridge bearings to accommodate movements with and without rotation.

(5 marks)

4. (a) Explain briefly **FIVE (5)** general rules for choosing a grillage mesh based on deck and load characteristics.

(5 marks)

(b) Construct using grillage analogy, the layout and load distribution of a simply supported non-skew reinforced concrete bridge experiencing:

i. Axle A of HB Load as per Figure 5 (a) and (b)

ii. Critical Knife Edge Load (KEL)

Sketch all critical sections.

Proposed Bridge Data

| | |
|---|---|
| Span | : 21meter |
| Width | : 14 meter |
| Beam | : Seven precast rectangular beams at 2 meter spacing |
| Beam section | : 300 mm (Width) x 1550 mm (Depth) |
| Slab thickness | : 200 mm |
| Diaphragm | : 200 mm (Width) x 1550 mm (Depth) located at both abutments and at midspan |

(Refer to Appendix A, B and C)

(15 marks)

5. (a) Figures 6(a) and (b) show two different models of grillage. All members in both grillages have the same length L = 10m, flexural rigidity EI = $6.4MNm^2$ and torsional rigidity GJ = $4MNm^2$. A point load P = 60kN acts at joint 1 in the direction of positive Z-axis (directed towards the paper) in both grillages. Form the structural stiffness equations for both grillages. Solutions of the structural stiffness equations are not required. Element stiffness matrix for a grillage element is given in Appendix 1. Justify that member 4-1 in grillage as shown in Figure 6(a) will not be subjected to any twisting moment.

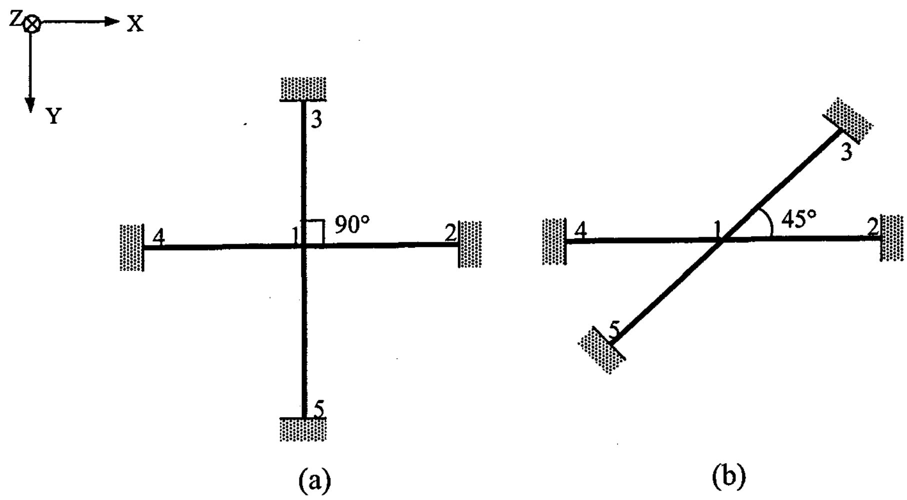



Figure 6

(12 marks)

5. (b) Girder with the sectional shape of constant wall thickness as shown in Figure 7(a) and (b) are being considered for use in a bridge deck structure. Discuss the relative torsional stiffness and strength of the two sections shown under the action of a twisting moment, M. Length of girder is L, modulus of rigidity for the material is G and torsional constant J is given by the following formula:

$$J = \frac{4A^2}{\oint \frac{ds}{dt}}$$

where A : area enclosed by median line of section, s : length along median line and t : thickness of section.

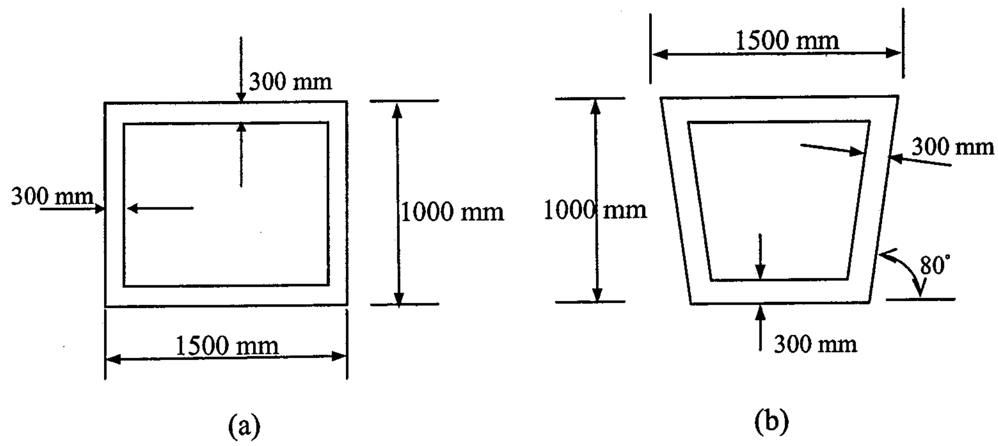



Figure 7

(8 marks)

APPENDIX A

British Standard

# Steel, concrete and composite bridges

Part 2. Specification for loads

## 1. Scope

**1.1 Documents comprising this British Standard.** This specification for loads should be read in conjunction with the other Parts of BS 5400 which deal with the design, materials and workmanship of steel, concrete and composite bridges.

**1.2 Loads and factors specified in this Part of BS 5400.** This Part of BS 5400 specifies nominal loads and their application, together with the partial factors, $\gamma_{fL}$, to be used in deriving design loads. The loads and load combinations specified are for highway, railway and foot/cycle track bridges in the United Kingdom. Where different loading regulations apply, modifications may be necessary.

**1.3 Wind and temperature.** Wind and temperature effects relate to conditions prevailing in the United Kingdom and Eire. If the requirements of this Part of BS 5400 are applied outside this area, relevant local data should be adopted.

## 2. References

The titles of the standards publications referred to in this Part of BS 5400 are listed on the inside back cover.

## 3. Principles, definitions and symbols

**3.1 Principles.*** Part 1 of this standard sets out the principles relating to loads, limit states, load factors, etc.

**3.2 Definitions.** For the purposes of this Part of BS 5400 the following definitions apply.

**3.2.1 loads.** External forces applied to the structure and imposed deformations such as those caused by restraint of movement due to changes in temperature.

**3.2.1.1 load effects.** The stress resultants in the structure arising from its response to loads (as defined in **3.2.1**).

**3.2.2 dead load.** The weight of the materials and parts of the structure that are structural elements, but excluding superimposed materials such as road surfacing, rail track ballast, parapets, mains, ducts, miscellaneous furniture, etc.

**3.2.3 superimposed dead load.** The weight of all materials forming loads on the structure that are not structural elements.

**3.2.4 live loads.** Loads due to vehicle or pedestrian traffic.

**3.2.4.1 primary live loads.** Vertical live loads, considered as static loads, due directly to the mass of traffic.

**3.2.4.2 secondary live loads.** Live loads due to changes in speed or direction of the vehicle traffic, e.g. lurching, nosing, centrifugal, longitudinal, skidding and collision loads.

**3.2.5 adverse and relieving areas and effects.** Where an element or structure has an influence line consisting of both positive and negative parts, in the consideration of loading effects which are positive, the positive areas of the influence line are referred to as adverse areas and their effects as adverse effects and the negative areas of the influence line are referred to as relieving areas and their effects as relieving effects. Conversely, in the consideration of loading effects which are negative, the negative areas of the influence line are referred to as adverse areas and their effects as adverse effects and the positive areas of the influence line are referred to as relieving areas and their effects as relieving effects.

**3.2.6 total effects.** The algebraic sum of the adverse and relieving effects.

NOTE. Where elements in a positive area of influence line are being considered the total effects may be negative, in which case the equivalent positive value will be the least negative effect, and where in negative effects are being considered the total effects may be positive, in which case the equivalent negative value will be the least positive effect. In either case the maximum negative or positive total effect should also be considered.

**3.2.7 dispersal.** The spread of load through surfacing, fill, etc.

**3.2.8 distribution.** The sharing of load between directly loaded members and other members not directly loaded as a consequence of the stiffness of intervening connecting members, as e.g. diaphragms between beams, or the effects of distribution of a wheel load across the width of a plate or slab.

**3.2.9 highway carriageway and lanes** (figure 1 gives a diagrammatic description of the carriageway and traffic lanes).

**3.2.9.1 carriageway.** That part of the running surface which includes all traffic lanes, hard shoulders, hard strips and marker strips. The carriageway width is the width between raised kerbs. In the absence of raised kerbs it is the width between safety fences, less the amount of set-back required for these fences, being not less than 0.6 m or more than 1.0 m from the traffic face of each fence.

**3.2.9.2 traffic lanes.** The lanes that are marked on the running surface of the bridge and are normally used by traffic.

**3.2.9.3 notional lanes.** The notional parts of the carriageway used solely for the purpose of applying the specified live loads.

3.2.9.3.1 *Carriageway widths of* 4.6 m *or more.* Notional lanes shall be taken to be not less than 2.3 m nor more than 3.8 m wide. The carriageway shall be divided into the least possible integral number of notional lanes having equal widths as follows:

| carriageway width m | number of notional lanes |
|---|---|
| 4.6 up to and including 7.6 | 2 |
| above 7.6 up to and including 11.4 | 3 |
| above 11.4 up to and including 15.2 | 4 |
| above 15.2 up to and including 19.0 | 5 |
| above 19.0 up to and including 22.8 | 6 |

*Attention is drawn to the difference in principle of this British Standard from its predecessor, BS 153.

APPENDIX B



For the serviceability limit state, nothing shall be done during erection that will cause damage to the permanent structure or will alter its response in service from that considered in design.

**5.9.1 *Temporary loads***

**5.9.1.1** *Nominal loads.* The total weight of all temporary materials, plant and equipment to be used during erection shall be taken into account. This shall be accurately assessed to ensure that the loading is not underestimated.

**5.9.1.2** *Design loads.* For the ultimate limit state for combinations 2 and 3, $\gamma_{fL}$ shall be taken as 1.15, except as specified in 5.9.1.3.

**5.9.1.3** *Relieving effect.* Where any temporary materials have a relieving effect, and have not been introduced specifically for this purpose, they shall be considered not to be acting. Where, however, they have been so introduced, precautions shall be taken to ensure that they are not inadvertently removed during the period for which they are required. The weight of these materials shall also be accurately assessed to ensure that the loading is not over-estimated. This value shall be taken as the design load.

**5.9.2 *Permanent loads***

**5.9.2.1** *Nominal loads.* All dead and superimposed dead loads affecting the structure at each stage of erection shall be taken into account.

The effects of the method of erection of permanent materials shall be considered and due allowance shall be made for impact loading or shock loading.

**5.9.2.2** *Design loads.* The design loads due to permanent loads for the ultimate limit state for combinations 2 and 3 shall be as specified in 5.1.2 and 5.2.2, respectively.

**5.9.3** ***Disposition of permanent and temporary loads.*** The disposition of all permanent and temporary loads at all stages of erection shall be taken into consideration and due allowance shall be made for possible inaccuracies in their location. Precautions shall be taken to ensure that the assumed disposition is maintained during erection.

**5.9.4** ***Wind and temperature effects.*** Wind and temperature effects shall be considered in accordance with 5.3 and 5.4, respectively.

**5.9.5** ***Snow and ice loads.*** When climatic conditions are such that there is a possibility of snowfall or of icing, an appropriate allowance shall be made. Generally, a distributed load of 500 N/m² may be taken as adequate but may require to be increased for regions where there is a possibility of snowfalls and extremes of low temperature over a long period. The effects of wind in combination with snow loading may be ignored.

## 6. Highway bridge live loads

**6.1 General.** Standard highway loading consists of HA and HB loading.

HA loading is a formula loading representing normal traffic in Great Britain. HB loading is an abnormal vehicle unit loading. Both loadings include impact. (See appendix A for the basis of HA and HB loading.)

**6.1.1** ***Loads to be considered.*** The structure and its elements shall be designed to resist the more severe effects of either:

design HA loading (see 6.4.1) or

design HA loading combined with design HB loading (see 6.4.2).

**6.1.2** ***Notional lanes, hard shoulders, etc.*** The width and number of notional lanes, and the presence of hard shoulders, hard strips, verges and central reserves are integral to the disposition of HA and HB loading. Requirements for deriving the width and number of notional lanes for design purposes are specified in 3.2.9.3.

**6.1.3** ***Distribution analysis of structure.*** The effects of the design standard loadings shall, where appropriate, be distributed in accordance with a rigorous distribution analysis or from data derived from suitable tests.

**6.2 Type HA loading.** Type HA loading consists of a uniformly distributed load (see 6.2.1) and a knife edge load (see 6.2.2) combined, or of a single wheel load (see 6.2.5).

**6.2.1** ***Nominal uniformly distributed load (UDL).*** The UDL shall be taken as 30 kN per linear metre of notional lane for loaded lengths up to 30 m, and for loaded lengths in excess of 30 m it shall be derived from the equation

$$W = 151\left(\frac{1}{L}\right)^{0.475} \quad \text{but not less than 9.}$$

where $L$ is the loaded length (in m) and $W$ is the load per metre of lane (in kN).

Values for this load per linear metre of notional lane are given in table 13 and the loading curve is illustrated in figure 10.

**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 |
| Up to 30 | 30.0 | 73 | 19.7 | 160 | 13.6 |
| 32 | 29.1 | 76 | 19.3 | 170 | 13.2 |
| 34 | 28.3 | 79 | 18.9 | 180 | 12.8 |
| 36 | 27.5 | 82 | 18.6 | 190 | 12.5 |
| 38 | 26.8 | 85 | 18.3 | 200 | 12.2 |
| 40 | 26.2 | 90 | 17.8 | 210 | 11.9 |
| 42 | 25.6 | 95 | 17.4 | 220 | 11.7 |
| 44 | 25.0 | 100 | 16.9 | 230 | 11.4 |
| 46 | 24.5 | 105 | 16.6 | 240 | 11.2 |
| 49 | 23.8 | 110 | 16.2 | 255 | 10.9 |
| 52 | 23.1 | 115 | 15.9 | 270 | 10.6 |
| 55 | 22.5 | 120 | 15.5 | 285 | 10.3 |
| 58 | 21.9 | 125 | 15.2 | 300 | 10.1 |
| 61 | 21.4 | 130 | 15.0 | 320 | 9.8 |
| 64 | 20.9 | 135 | 14.7 | 340 | 9.5 |
| 67 | 20.5 | 140 | 14.4 | 360 | 9.2 |
| 70 | 20.1 | 145 | 14.2 | 380 and above | 9.0 |
| | | 150 | 14.0 | | |

NOTE. The loaded length for the member under consideration shall be the base length of the adverse area (see 3.2.5). Where there is more than one adverse area, as for continuous construction, the maximum effect should be determined by consideration of any adverse area or combination of adverse areas using the loading appropriate to the base length or the total combined base lengths.

**6.2.2** ***Nominal knife edge load (KEL).*** The KEL per notional lane shall be taken as 120 kN.

**6.2.3** ***Distribution.*** The UDL and KEL shall be taken to occupy one notional lane, uniformly distributed over the full width of the lane and applied as specified in 6.4.1.

**6.2.4** ***Dispersal.*** No allowance for the dispersal of the UDL and KEL shall be mad

**6.2.5** ***Single nominal wheel load alternative to UDL and KEL.*** One 100 kN wheel, placed on the carriageway and uniformly distributed over a circular contact area assuming an effective pressure of 1.1 N/mm² (i.e. 340 mm diameter), shall be considered.

Alternatively, a square contact area may be assumed, using the same effective pressure (i.e. 300 mm side).

APPENDIX C

6.3.4 ***Design HB loading.*** For design HB load, $\gamma_{fL}$ shall be taken as follows.

| | For the ultimate limit state | For the serviceability limit state |
|---|---|---|
| For combination 1 | 1.30 | 1.10 |
| For combinations 2 and 3 | 1.10 | 1.00 |

**6.4 Application of types HA and HB loading**

6.4.1 ***Type HA loading.*** Type HA UDL and KEL loads shall be applied to two notional lanes in the appropriate parts of the influence line for the element or member under consideration * and one-third type HA UDL and KEL loads shall be similarly applied to all other notional lanes except where otherwise specified by the appropriate authority. The KEL shall be applied at one point only in the loaded length of each notional lane.

Where the most severe effect is caused by locating portions of loaded length on one side of the superstructure over one portion of its length and on the other side of the superstructure in a longitudinally adjacent portion of its length, this shall be taken into consideration, using the loading appropriate to the combined length of the loaded portions.

6.4.1.1 *Multilevel structures.* Where multilevel superstructures are carried on common substructure members (as, e.g., columns of a multilevel interchange) each level shall be loaded and the loaded length shall be taken as the aggregate of the loaded lengths in each superstructure that has the most severe effect on the member under consideration.

6.4.1.2 *Transverse cantilever slabs, central reserves and outer verges.* HA UDL and KEL shall be replaced by the arrangement of HB loading given in **6.4.3.**

6.4.1.3 *Combined effects.* Where elements of a structure can sustain the effects of live load in two ways, i.e. as elements in themselves and also as parts of the main structure (e.g. the top flange of a box girder functioning as a deck plate), the element shall be proportioned to resist the combined effects of the appropriate loading specified in **6.4.2.**

6.4.1.4 *Knife edge load (KEL).* The KEL shall be taken as acting as follows.

(a) On plates, right slabs and skew slabs spanning or cantilevering longitudinally or spanning transversely: in a direction parallel to the supporting members or at right angles to the unsupported edges, whichever has the most severe effect. Where the element spans transversely, the KEL shall be considered as acting in a single line made up of portions having the same length as the width of the nominal lanes and having the intensities set out in 6.4.1. As specified in 6.4.1, the KEL shall be applied at one point only in the loaded length. Where plates or slabs are supported on all four sides see **6.4.3.1.**

(b) On longitudinal members and stringers: in a direction parallel to the supports.

(c) On piers, abutments and other members supporting the superstructure: in a direction in line with the bearings.

(d) On cross members, including transverse cantilever brackets: in a direction in line with the span of the member.

6.4.1.5 *Single wheel load.* The HA wheel load is applied to members supporting small areas of roadway where the proportion of UDL and KEL that would otherwise be allocated to it is small.

6.4.2 ***Types HB and HA loading combined.*** Types HB and HA loading shall be combined and applied as specified in **6.4.2.1** and **6.4.2.2.**

6.4.2.1 *Type HB load.* Type HB loading shall be taken to occupy any transverse position on the carriageway, and in so doing will lie either wholly within one notional lane or will straddle two notional lanes. No other primary live loading shall be considered for 25 m in front of, to 25 m behind, the HB vehicle in the one lane occupied by the HB vehicle when it is wholly in one lane or in the two lanes when the HB vehicle is straddling them.

Only one HB load is required to be considered on any one superstructure or on any substructure supporting two or more superstructures.

6.4.2.2 *Associated type HA loading.* Where the HB vehicle is wholly within one lane, the remainder of the loaded length of this lane shall be loaded with full HA UDL only, of intensity appropriate to the loaded length that includes the total length displaced by the HB vehicle. Full HA loading shall be considered in one other notional lane, together with one-third HA loading in the remaining lanes.

Where the HB vehicle straddles two lanes, the following alternatives for associated HA highway loading shall be considered:

either

(a) the remainder of the loaded length of both straddled lanes shall be loaded with full HA UDL only, of intensity appropriate to the loaded length that includes the total length displaced by the HB vehicle; all other lanes shall be loaded with one-third HA loading;

or

(b) the remainder of the loaded length of one straddled lane shall be loaded with full HA UDL only and the remainder of the loaded length of the other straddled lane shall be loaded with one-third HA UDL only. The intensity of the full HA UDL and one-third HA UDL shall be that appropriate to a loaded length that includes the total length displaced by the HB vehicle. Full HA loading shall be considered in one other notional lane, together with one-third HA loading in the remaining lanes.

Figure 12 illustrates type HB loading in combination with type HA loading.

6.4.3 ***Highway loading on transverse cantilever slabs, slabs supported on all four sides, central reserves and outer verges.*** Type HB loading shall be applied to the elements specified in **6.4.3.1** to **6.4.3.3.**

6.4.3.1 *Transverse cantilever slabs and slabs supported on all four sides.* Transverse cantilever slabs shall be so proportioned as to resist the effects of the appropriate number of units of type HB loading placed in one notional lane in combination with 25 units of HB loading placed in one other notional lane. Proper consideration shall be given to transverse joints of transverse cantilever slabs and to the edges of these slabs because of the limitations of distribution. ‡

This does not apply to members supporting transverse cantilever slabs.

6.4.3.2 *Central reserves.* On dual carriageways the portion of the central reserve isolated from the rest of the carriageway either by a raised kerb or by safety fences is not required to be loaded with live load in considering the overall design of the structure, but it shall be capable of supporting 25 units of HB loading.

*In consideration of local (not global) effects, where deviations from planarity may be critical, the application of the knife edge load without the UDL immediately adjacent to it may have a more severe effect than with the UDL present.

†In considering plates and slabs care should be taken to ensure that the free edge is adequate to resist the effects of the associated HB vehicle specified.

‡ This is the only exception to the rule that not more than one HB vehicle shall be considered to act on a structure. The 25 unit vehicle is to be regarded as a substitute for HA loading for these elements only.