A.N.Z.R.C.

# RAILWAY BRIDGE DESIGN MANUAL

## CHAPTER 1

## LOADING FOR RAILWAY BRIDGES

CONTENTS



## LOADING FOR RAILWAY BRIDGES

### 1.1 GENERAL

#### 1.1.1 Scope

This chapter specifies the loading to be used for the design of steel, reinforced concrete, and prestressed concrete bridges of spans not exceeding 120 m.

The requirements of this Chapter may be adopted for spans longer than 120 m and for other types of bridges except that any special provisions, as may be required, shall be prescribed by the Engineer.

Engineer shall mean the Chief Civil Engineer, Chief Engineer or other duly appointed Engineer of the Railway System involved.

### 1.1.2 Notation

The following notation shall apply to this Chapter unless a contrary intention appears in the text:—

A = axle load, in kilonewtons.

D = effective beam spacing, in metres.

d = beam spacing, in metres.

DL = dead load applicable to the member under consideration.

h = the thickness of a concrete deck slab, in millimetres.

I = the percentage of the live load to be applied as impact.

$I_b$ = the moment of inertia of a beam, in $millimetres^4$.

$k_L$ = a drag coefficient used in calculating the force on a bridge pier in the direction of stream flow.

$k_T$ = a lift coefficient used in calculating the force acting on a prismatic or plate bridge pier in the direction at right angles to the major axis of the pier.

L = span length, in metres, centre to centre of bearings,

or

the length, in metres, centre to centre of supports for stringers, transverse floorbeams without stringers, longitudinal girders and trusses (main members),

or

length, in metres, of the longer adjacent supported stringers, longitudinal beam, girders or truss for impact in floorbeams, floorbeam hangers, subdiagonals of trusses, transverse girders, supports for longitudinal and transverse girders and viaduct columns.

LL = live load applicable to the member under consideration.

n = the ratio of modulus of elasticity of steel to that of concrete.

P = the load on a beam from one track.

$P_L$ = water pressure, in kilopascals, acting on a bridge pier in the direction of stream flow.

$P_T$ = water pressure, in kilopascals, acting on a prismatic or plate bridge pier in the direction at right angles to the major axis of the pier.

R = radius of curve, in metres.

V = speed, in kilometres per hour.

v = weighted velocity of stream current, in metres per second.

X = axle spacing, in metres.

Y = distance, in metres, between centres of single or groups of longitudinal beams, girders or trusses; or length between supports of floorbeams or transverse girders.

## 1.2 LOADING

### 1.2.1 Loads and Forces

(a) Bridges shall be proportioned for the following loads and forces:

1. Dead Load.
2. Live Load.
3. Impact.
4. Centrifugal force.
5. Wind forces.
6. Lateral forces.
7. Longitudinal force.
8. Friction forces.
9. Thermal effects.
10. Earth pressure forces.
11. Earthquake forces.
12. Stream forces.
13. Erection forces.
14. Loading combinations.

(b) Stresses from each of these loads and forces shall be shown separately in the computation sheets.

### 1.2.2 Dead Load

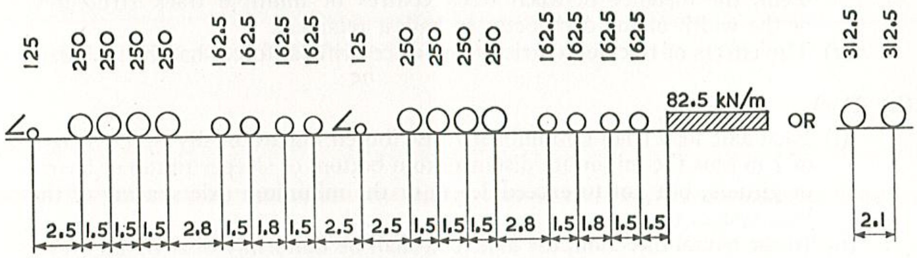
(a) In estimating the loads for the purpose of computing dead load stresses, the following densities shall be used:

| | kg/m³ |
|---|---|
| Steel | 7850 |
| Reinforced concrete | 2400 |
| Prestressed concrete | 2600 |
| Sand, gravel, and ballast | 1950 |
| Asphalt-mastic and bituminous macadam | 2400 |
| Granite | 2750 |
| Paving Bricks | 2400 |
| Timber | 1100 |
| Earth filling materials | 1950 |

(b) The track rails, inside guard rails, and fastenings shall be assumed to have a mass of 300kg per metre.

### 1.2.3 Live Load

(a) The recommended live load for each track is the Metric Cooper M 250 in Fig. 1.2.3




Axle loads shown in kilonewtons.
Axle spacings shown in metres.

Fig. 1.2.3

(b) The Engineer shall specify the live load to be used, such load to be proportional to the recommended load, with the same axle spacing.
(c) For bridges on curves, provision shall be made for the increased proportion carried by any truss, girder, or stringer due to the eccentricity of the load.
(d) For members receiving load from more than one track, the proportions of full live load on the tracks shall be as follows:
For two tracks, full live load.
For three tracks, full live load on two tracks and $\frac{1}{2}$ on the other track.
For four tracks, full live load on two tracks, $\frac{1}{2}$ on one track, and $\frac{1}{4}$ on the remaining one.
For more than four tracks, as specified by the Engineer.
The selection of the tracks for these proportions shall be such as will give the greatest live-load stress in the member under consideration.

### 1.2.4 Distribution of Live Load for Steel Structures

#### 1.2.4.1 *Open-deck structures*

(a) Timber bridge transoms shall be designed on the assumption that the maximum wheel load on each rail is distributed equally to all transoms or fractions thereof within a length of 1.2 m, but not to exceed 3 transoms and is applied without impact.
(b) For the design of beams or girders, the live load shall be a series of concentrated loads. No longitudinal distribution of such loads shall be assumed.
(c) Where two or more longitudinal beams per rail are properly diaphragmed, in accordance with Clause **2.11.4** and symmetrically spaced under the rail, they shall be considered as equally loaded.

#### 1.2.4.2 *Ballasted-deck structures*

(a) Design

The designated lateral and longitudinal distribution of live load is based on the following assumptions:

(i) Standard timber sleepers are used which are not less than 2.45 m long, approximately 200 mm wide, and spaced at not over 600mm centres. If another type of sleeper or greater spacing is used, the design shall be modified for the greater load concentrations, or increased thickness of ballast used, or both.
(ii) Not less than 150mm of ballast is provided under the sleepers.
(iii) The designated widths for lateral distribution of load shall not exceed 4.0m, the distance between track centres of multiple track structures, or the width of the deck between ballast retainers.
(iv) The effects of track eccentricity and of centrifugal force shall be included.

(b) Deck

(i) Each axle load shall be uniformly distributed longitudinally over a length of 1 m plus the minimum distance from bottom of sleeper to top of beams or girders, but not to exceed 1.5 m or the minimum axle spacing of the load system used.
(ii) In the lateral direction, the axle load shall be uniformly distributed over a width equal to the length of sleeper plus the minimum distance from bottom of sleeper to top of beams or girders.
(iii) The thickness of the deck shall be not less than 12 mm for steel plate, 75 mm for timber, or 150 mm for concrete.

(c) Transverse steel beams

(i) For ballasted decks supported by transverse steel beams without stringers, the portion of the maximum axle load on each beam shall be as follows:

$$P = \frac{1.15AD}{X}$$

$$\text{For moment: } D = d\left(\frac{1}{1+\frac{d}{LH}}\right)\left(0.4 + \frac{0.305}{d} + \frac{\sqrt{H}}{12}\right)$$

but not greater than d or X

$$\text{Where } H = \frac{0.12\, nI_b}{Lh^3} \qquad \text{for end shear: } D = d$$

(ii) The load P shall be applied as two equal concentrated loads on each beam at each rail, equal to P/2. No lateral distribution of such loads shall be assumed.

(iii) D = d for bridges without a concrete deck; or for bridges where the concrete slab extends over less than the centre 75 percent of the floorbeam.

(iv) If d exceeds X, P shall be the maximum reaction of the axle loads, assuming that the deck between the beams acts as a simple span.

(v) For bridges with concrete decks, the slab shall be designed to carry its portion of the load.

(d) Longitudinal steel beams or girders.

(i) Axle loads shall be distributed equally to all beams or girders whose centroids are within a lateral width equal to the length of sleeper plus twice the minimum distance from bottom of sleeper to top of beams or girders.

(ii) For the design of beams or girders, the live load shall be a series of concentrated loads. No longitudinal distribution of such loads shall be assumed.

### 1.2.5 Distribution of Live Load for Concrete Structures

(a) The axle loads on structures may be assumed as uniformly distributed longitudinally over a length of 1 m, plus the depth of ballast under the sleeper, plus twice the effective depth of slab, limited, however, by the axle spacing.

(b) Live load from a single track acting on a structure with ballasted deck or under fills shall be assumed to have uniform lateral distribution over a width equal to the length of sleeper plus the depth of ballast and fill below the bottom of sleeper, plus twice the effective depth of slab, unless limited by the extent of the structure.

(c) The lateral distribution of live load from multiple tracks shall be as specified for single tracks and further limited so as not to exceed the distance between centres of adjacent tracks.

(d) The lateral distribution of the live load for structure under deep fills carrying multiple tracks, shall be assumed as uniform between centres of outside tracks, and the loads beyond these points shall be distributed as specified for single track.

### 1.2.6 Impact Load on Steel Structures

(a) Impact load shall be determined by taking a percentage of the live load specified in Clause **1.2.3** and shall be applied vertically and equally at top of each rail.

For open-deck bridges the percentages to be used shall be determined by the applicable formula below. For ballasted-deck bridges the percentage to be used shall be 90 percent of that specified for open-deck bridges.

For rolling equipment without hammer blow (diesels, electric locomotives, wagons, etc.):

For L less than 25 m .............. $\frac{31}{Y} + 40 - \frac{3L^2}{150}$

For L 25 m or more .............. $\frac{31}{Y} + 16 + \frac{183}{L-10}$

(b) For members receiving load from more than one track, the impact percentage shall be applied to the static live load on the number of tracks shown below:

Load received from:

Two tracks:

| | |
|---|---|
| For L less than 55 m ........ | Full impact on two tracks. |
| For L from 55 m to 70 m .... | Full impact on one track and a percentage of full impact on the other as given by the formula 450 — 6.5L. |
| For L greater than 70 m ...... | Full impact on one track and none on the other. |

More than two tracks:

| | |
|---|---|
| For all values of L .......... | Full impact on any two tracks. |

### 1.2.7 Impact Load on Reinforced Concrete Structures

**1.2.7.1**

The impact load shall be applied vertically and equally at the top of each rail, and shall be computed from the following formula:—

$$I = \frac{100LL}{LL + DL} \quad \text{(Maximum of 60 percent)}$$

**1.2.7.2**

Where, by reason of the mass of the structure or other features, the effect of impact may be dissipated, the Engineer may use his judgement in reducing the percentage produced by the above formula.

### 1.2.8 Impact Load on Prestressed Concrete Structures

**1.2.8.1**

The impact load shall be applied vertically and equally at the top of each rail and shall be computed from the following formula:—

$$I = 35 - \frac{L^2}{47} \quad \text{(Minimum of 20 percent)}$$

**1.2.8.2**
Where, by reason of the mass of the structure or other features, the effect of impact may be dissipated, the Engineer may use his judgement in reducing the percentage produced by the above formula.

### 1.2.9 Centrifugal Force

(a) On curves, a centrifugal force corresponding to each axle load shall be applied horizontally through a point 2 m above the top of rail measured along a line perpendicular to the line joining the tops of the rails and equidistant from them. This force shall equal the percentage $\frac{V^2}{1.27R}$ of the specified axle load without impact.

(b) On curves, each axle load on each track shall be applied vertically through the point defined in Paragraph (a). Impact load shall be applied as specified in Clauses **1.2.6, 1.2.7,** and **1.2.8**, as applicable.

(c) On curves, the loads on a stringer, girder or truss toward the outside and inside of curve shall be determined separately, and the greater section required shall be used on both sides. For members toward outside of curve, the full impact of Clauses **1.2,6, 1.2.7,** and **1.2.8**, as applicable, and the centrifugal force at maximum permissible speed, shall apply.

### 1.2.10 Wind on Loaded Bridge

(a) The wind pressure on the bridge shall be considered as a moving load acting in any horizontal direction. On the train it shall be taken at 4.4 kN per metre on the one track, applied 2.5 m above the top of rail. On the bridge it shall be taken at 1.5 k Pa of the following surfaces:
  (i) For girder spans, 1½ times the vertical projection of the span.
  (ii) For box girder spans, the vertical projection of the span.
  (iii) For truss spans, the vertical projection of the span plus any portion of the leeward trusses not shielded by the floor system.
  (iv) For viaduct towers and bents, the vertical projections of all columns and tower bracing.

(b) The wind force on girder spans and truss spans, however, shall not be taken at less than 3.0 kN per metre for the loaded chord or flange, and 2.2 kN per metre for the unloaded chord or flange.

### 1.2.11 Wind on Unloaded Bridge

If a wind pressure on the unloaded bridge of 2.4 kPa of surface as defined in Clause **1.2.10** combined with the dead load, produces greater stresses than those produced by the wind forces specified in Clause **1.2.10** combined with the stresses from dead load, live load, impact, and centrifugal force, the members wherein such greater stresses occur shall be designed therefor.

### 1.2.12 Lateral Forces from Equipment (Steel Superstructures Only)

(a) A single moving concentrated lateral force equal to ¼ of the weight of the heaviest axle in the specified design live load shall be applied at the base of rail in either direction and at any point along the span in addition to the other lateral forces specified. On spans supporting multiple tracks, the force shall be applied on one track only.

(b) The only resulting stresses to be considered are axial stresses in members bracing the flanges of stringer, beam, and girder spans, the chords of truss spans and in members of cross frames of such spans, and stresses from lateral bending of flanges of longitudinal flexural members having no bracing system. The effects of lateral bending between braced points of flanges, axial forces in flanges, vertical forces, and forces transmitted to bearings, shall be disregarded.

### 1.2.13 Stability of Spans and Towers

In calculating the stability of spans and towers, the live load on one track shall be 17.5 kN per metre, taken without impact. On multiple-track bridges, this live load shall be on the leeward track.

### 1.2.14 Bracing between Compression Members

The lateral bracing of the compression chords or flanges of trusses and deck girders and between the posts of viaduct towers shall be proportioned for a transverse shear in any panel equal to $2\frac{1}{2}$ percent of the total axial stress in both members in that panel, in addition to the shear from the specified lateral forces.

### 1.2.15 Longitudinal Force

(a) The longitudinal force from trains shall be taken as 15 per cent of the live load without impact.

(b) Where the rails are continuous (either welded or fishplated joints) across the entire bridge from embankment to embankment, the effective longitudinal force shall be taken as $\frac{L}{365}$ (where L is the length of the bridge, in metres) times the force specified in (a), but the value of $\frac{L}{365}$ shall not exceed 0.80.

(c) Where the rails are not continous (broken by a movable span, sliding rail expansion joints, or other devices) across the entire bridge from embankment to embankment, the effective longitudinal force shall be taken as the entire force specified in (a).

(d) The longitudinal force shall be taken on one track only and shall be distributed to the various components of the supporting structure, taking into account their relative stiffness where appropriate, and the type of bearings.

(e) The longitudinal force shall be assumed to be applied at the base of rail.

### 1.2.16 Friction Forces

(a) For expansion and contraction of the structure due to variations of temperature or other causes, the forces due to friction on the expansion bearings under dead loads shall be taken into account and the following coefficients of friction shall be used:

| Type of Bearing | Coefficient |
|---|---|
| Steel plate on steel plate | 0.25 |
| Steel plate on phosphorbronze plate | 0.15 |
| Steel plate on recessed bronze alloy plates in which the recesses are filled with a special lubricant | 0.10 |
| Polytetrafluorethylene on stainless steel | 0.05 |
| Steel roller bearings | 0.03 |
| Steel rocker bearings | 0.02 |
| Specially hardened and tempered steel roller bearings where the bearing surfaces are protected against deterioration | 0.02 |

(b) Where a low coefficient of friction in a bearing would increase the stresses in other parts of the structure, the design shall allow for the lowest possible value of the coefficient of friction that may be expected.

(c) Longitudinal forces resulting from expansion and contraction of spans supported on elastomeric bearings shall be calculated in accordance with the requirements of Section **2.13**.

### 1.2.17 Thermal Effects

(a) Provision shall be made for stresses or movements resulting from variations in temperature. The rise and fall in temperature shall be fixed for the locality in accordance with Table **1.2.17**

Drawings shall indicate the mean temperature on which the design for thermal effect has been based.

TABLE 1.2.17

TEMPERATURE RANGES FOR VARIOUS CLIMATIC CONDITIONS

(i) Metal Structures

| Climatic Conditions | Mean Temperature | Range Rise | Range Fall |
|---|---|---|---|
| Cold | 10 °C | 28° C | 28° C |
| Moderate | 21° C | 28° C | 28° C |
| Hot | 27° C | 28° C | 28° C |

(ii) Concrete Structures

| Climatic Conditions | Mean Temperature | Range Rise | Range Fall |
|---|---|---|---|
| Cold | 10° C | 22° C | 22° C |
| Moderate | 16° C | 19° C | 19° C |
| Hot | 21° C | 17° C | 19° C |

(b) Due consideration shall be given to the difference between the ambient temperature and the internal temperature of the structure (especially for massive concrete members) and to the differences in temperature between different portions of the structure, in particular the temperature difference between the deck surface and the underside of the super-structure.

(c) Allowance shall be made for stresses, both longitudinal and transverse, resulting from the deck of a bridge being warmer than the soffit. The following criteria shall be used for all structural types and all materials except timber:—

The temperature variation is in the form of a 6th power parabola with its origin 1.5 m below deck level. The temperature runs from a maximum of 25° C above ambient temperature at deck surface level to ambient temperature at a depth of 1.5 m. For structures deeper than 1.5 m, the part below the 1.5 m level is at ambient temperature. For structures shallower than 1.5 m, the soffit is at a temperature between ambient and 25° C deduced from the parabola.

(d) The coefficient of expansion of steel and concrete shall be taken as 0.0000117 per Celsius degree.

### 1.2.18 Earth Pressure Forces

Earth pressure forces are considered in Chapter

### 1.2.19 Earthquake Forces

### 1.2.20 Stream Forces

(a) All piers and other portions of structures which are subject to the force of flowing water, debris, or floating logs shall be designed to resist the maximum forces induced thereby. Special consideration shall be given to the forces imposed on the superstructure of bridges submerged during flooding.

(b) For bridge piers parallel to or within 5 degrees of the normal direction of stream flow, it shall be assumed that variations in stream flow pattern during flooding will produce flows with a maximum variation in direction of $\pm$ 10 degrees from the pier centreline.
The drag force on piers in the direction of the flow shall be calculated from the formula: $P_L = k_L v^2$
Where $P_L$ = water pressure, in kPa, due to drag force applied in the direction of the stream flow to the vertical projection of the pier at right angles to that direction.
$k_L$ = drag coefficient having the values given below:—

| Pier Shape | Value of $k_L$ |
|---|---|
| Square and rectangular sections | 0.70 |
| Octagonal sections | 0.40 |
| Circular sections | 0.35 |
| Angle ends where the included angle is 30 degrees or less | 0.25 |

For two column piers, the pressure shall be taken as $1\frac{1}{2}$ times the value for one column.
However, on prismatic or plate piers, a horizontal lift force acting at right angles to the major axis of the pier shall also be applied and shall be calculated from the formula:

$$P_T = k_T v^2$$

where $P_T$ = water pressure, in kPa, due to lift force applied to the vertical projection of the pier along its major axis.
For plate piers having an angle of attack of 10 degrees or less $k_T$ shall be taken as 0.26.

(c) The centre of pressure for stream current shall be assumed to act at a level measured below the water surface which is one-third the distance from the water surface to the stream bed.

(d) For piers inclined at an angle of more than 5 degrees to the normal stream flow direction, and subjected to flows of considerable depth and velocity, the above formulas may give results appreciably lower than the actual force occurring, and a more accurate investigation should be made. Where required, model testing shall be carried out.
However, in the case of single cylindrical or octagonal piers, which, because of their shape, experience only a drag force acting in the direction of flow of the stream, then, for consideration of its effect on the pier foundations, the drag force may be divided into its two component forces acting parallel to and at right angles to the bridge centreline.

(e) Where debris is likely, allowances shall be made for the stream force exerted on a raft of debris of the following dimensions:—

(i) Depth of raft = 3 metres

(ii) Length of raft—

(a) for non-submersible bridges (where the superstructure is clear of maximum flood level):

Length = half sum of adjacent span lengths with a maximum of 12 metres

(b) for submersible bridges (where the maximum flood level is at underside of superstructure or higher):

Length = half sum of adjacent span lengths.

The Engineer, at his discretion, may reduce the depth of the raft for small streams below 3 metres but the minimum value shall be 1 metre.

For debris, the drag force pressure shall be calculated in accordance with the formula for drag force pressure given in (b) above and shall act in the direction of the stream flow. The value of $k_L$ for debris shall be 0.52.

(f) Where floating logs are likely, the force exerted by such logs hitting piers shall be calculated on the assumption that the log has a mass of 2 tonnes and travels at the velocity of the stream current.

The log shall be assumed to be stopped in the following distances:

| | |
|---|---|
| For solid type concrete piers | 75 mm |
| For column type concrete piers | 150 mm |
| For timber piers | 300 mm |

Should fender piles or timber sheathing be placed upstream from the pier to absorb the energy of the blow, the stopping distances may be increased.

(g) Consideration shall be given to the stability of piers during erection particularly where piers are inclined at an angle to the stream flow.

(h) Due allowance shall be made for the effects of buoyancy on the substructure, including piling, and on the superstructure where appropriate.

### 1.2.21 Erection Forces

The loading due to all permanent and temporary material, together with all other forces and effects which can operate on any part of the structure during erection, shall be taken into account.

### 1.2.22 Loading combinations

The following groups represent various combinations of loads, forces or effects to which a structure may be subjected. Each part of the structure or the foundation on which it rests shall be designed for all the combinations which are applicable to the particular site or type of structure. The basic allowable stresses and foundation and pile loads given in this Manual shall be increased as shown in Table 1.2.22 for the various groups of loads, forces and effects, except that no increase shall be permitted for members designed to carry wind and dead loads only.

Due allowance shall be made in design for the effects of erection methods, differential settlement and rotation where these become significant under the action of the various combinations of applied loads.

Loads shall not be included in load groups in those cases where such inclusion would reduce the stress level or foundation or pile load.

## TABLE 1.2.22

## ALLOWABLE STRESSES AND FOUNDATION AND PILE LOADS FOR VARIOUS LOADING COMBINATIONS

| Group | Loading Combination | Percentage of Allowable Stresses |
|---|---|---|
| 1 | DL + LL + I + CF + E + S + T | 100 |
| 2 | Group 1 + LF + W + WL | 120 |
| 3 | Group 1 + LF + B + SF | 120 |
| 4 | Group 2 + B + SF | 130 |
| 5 | Group 3 + (DB or LG) | 130 |
| 6 | Group 4 + (DB or LG) | 135 |
| 7 | DL + E + B + SF + W + S + T | 120 |
| 8 | Group 7 + (DB or LG) | 130 |

where DL = dead load
- LL = live load
- I = impact of live load
- CF = centrifugal force
- E = earth pressure
- LF = longitudinal force from live load
- W = wind force on structure
- WL = wind force on live load
- S = shrinkage
- T = thermal effects including temperature gradients through the cross section of structural elements
- B = buoyancy
- SF = stream flow pressure (excluding effect of debris and log impact)
- DB = debris
- LG = log impact
- EQ = earthquake

(Note: Earthquake to be included with adjustments and additions as required following advice from New Zealand System).

In no case shall the section of the member or size of foundation or pile groups be less than that required to meet the provisions of Group 1 alone.