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Effect of the slipstream of passing trains on structures adjacent to the track

International Union of Railways

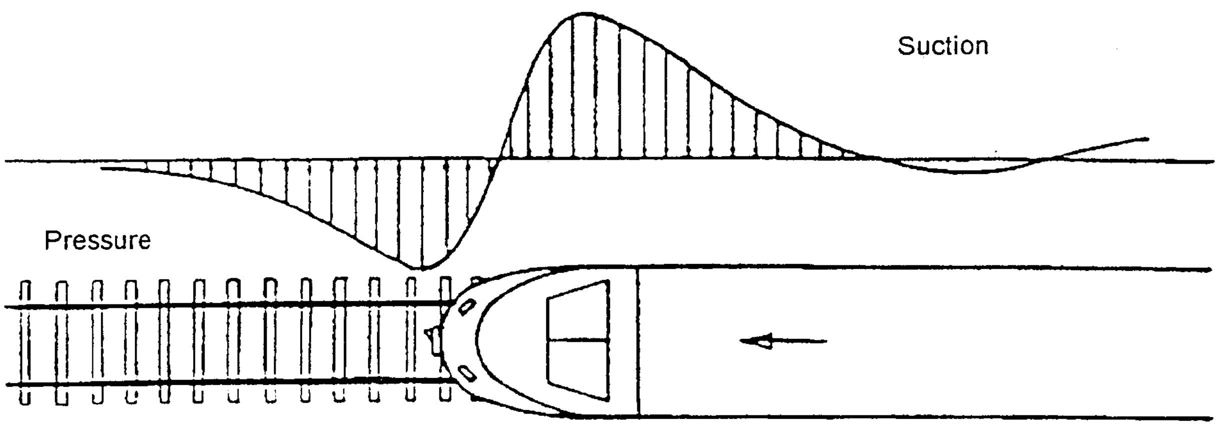
Contents

water	$10\ kN/m^3$	$1000\ kg/m^3$
air		$1.29\ kg/m^3$

1 - General

Structures which are close to the track are subject to a wave of air pressure-suction when a train passes and this wave moves along with the train. The field of pressure on surfaces parallel to the track has the following shape at right angles with the head of the train which is mirrored on the other side.

Figure 1 : Pressure and suction wave on surfaces parallel to the track



The magnitude of these loads (pressure and suction) depends :

a) on the speed of the train, the magnitude of the load increasing with the square of the speed of the train (the dynamic pressure is expressed in association with running of the train in the form $q_d = \frac{1}{2} \cdot \rho \cdot v^2$
where ρ is the air density and v the speed of the train in m/s,

b) on the aerodynamic shape of the train (shape of the head of the train, of the coaches, of the load and of the rear of the train); this is allowed for by coefficient k_1,

c) on the shape and geometrical characteristics of the structure,

d) on the position of the structure with respect to the track, expressed by its distance a_g from the centreline of the track and, therefore, the thickness of the air layer between the surface of the structure and that of the vehicle.

Structures that enclose the tracks, should be less than 15-20 m in length to stay within the field of application of this leaflet; otherwise, the magnitude of the pressure wave also depends on the blocking ratio, that is to say the ratio between the train cross section and the minimum open section of the structure. For structures exceeding 15-20 m in length, the phenomena are similar to those created in a tunnel where the pressure variation generates greater loadings.

For strength and fatigue calculations, the corresponding pressures can be replaced by equivalent substitution loads at the head and at the rear of the train.

These substitution loads must always be arranged perpendicularly to the surface of the structure.

They are defined as characteristic pressure values.

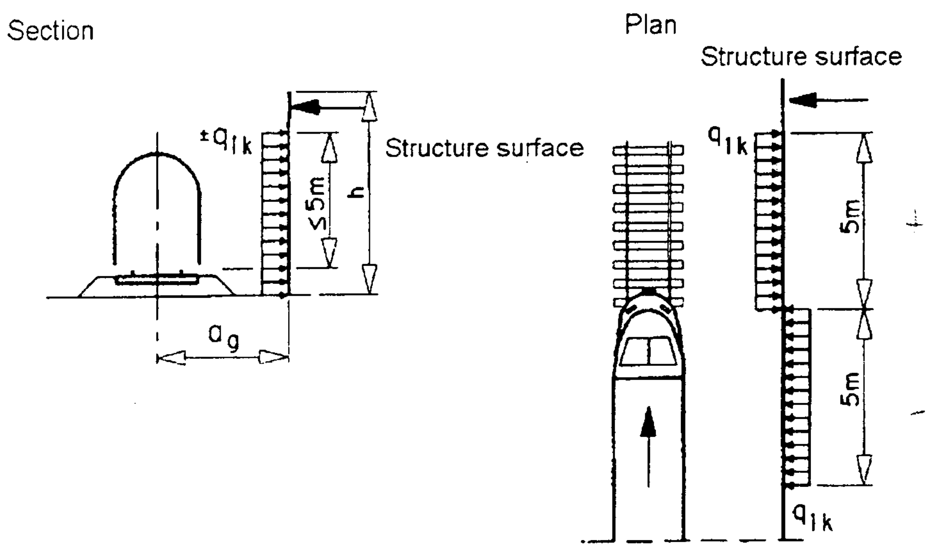
2 - Simple vertical surfaces parallel to tracks

The following features fall in this category of linear structures with simple vertical surfaces parallel to the tracks :

- simple acoustic barriers,
- protection walls,
- facades of buildings close to tracks,
- temporary structures close to th tracks.

In this case the pressure-suction wave is replaced by moving distributed loads + q_{Ik} and - q_{Ik}, 5 m long each with a total height corresponding to the distance between the base, the foot of the screen on the trackformation subgrade, and the point located not more than 5 m above the upper level of the top of the rail (if the screen has an upper level that is less than 5 m from the top of the rail, the load is applied up to the upper part of the screen) (see Fig. 2).

Figure 2 : Diagram of loads on acoustic screen



The characteristics values q_{lk} of the distributed loads are determined from the formula (1) :

$$q_{lk} = k_1 . c_p . \rho / 2 . v^2 \qquad (1)$$

where :

c_p: is the aerodynamic coefficient depending on the distance from track axis : a_g
r: is the air density (normally 1.25 kg/m^3)
v: is the speed of the train (in m/s)
k_1: is the shape coefficient of the train

Values c_p have been obtained through calculations and tests from the general formula :

$$c_p = (q - q_0) / q_d$$

where

q = the local static pressure
q_0 = the reference pressure
q_d = the dynamic pressure (q_d = 1/2.r.v^2)

Formula (1) can also be written :

$$q_{1k} = k_1 \, c_p \, \left(\frac{V}{3.6}\right)^2 \frac{1}{1\,600} \qquad (2)$$

where q_{lk} is in kN/m^2 and V is in km/h,

and c_p is obtained from the formula below :

$$c_p = \frac{1.5}{(a_g + 0.25)^2} + 0.02 \qquad (3)$$

Figure 4 gives, directly in curve-form, pressures ± q_{1k} as a function of train speed V (5 speeds; V = 120 km/h; 160, 200, 250 and 300 km/h) and horizontal distance a_g between track axis and the surface point considered. It is possible to interpolate between these speeds.

These curves are valid for trains with an unfavourable aerodynamic shape (shape coefficient k_1 = 1.0 for freight trains; in general this coefficient identifies with low speeds).

The pressures obtained from Figure 4 can be reduced with the factor:

- k_1 = 0.85 for trains that are well shaped aerodynamically (mean speed up to 220 km/h and conventional locomotives that haul passenger trains),

- $k_1 = 0.60$ for trains that are very well shaped aerodynamically (high speed trains like ICE, TGV and ETR).

The curves are only valid for $a_g \geq 2.3$ m. A special study would be required for shorter distances.

To allow for the maximum values of the pressure-suction wave on small-size structural units, pressures q_{1k} should be increased by factor $k_2 = 1.3$ if units are designed with a vertical surface not exceeding 1.00 m in height or 2.50m in width (Fig. 3).

Figure 3 : Example of the height and width of the influence field of a structural unit.

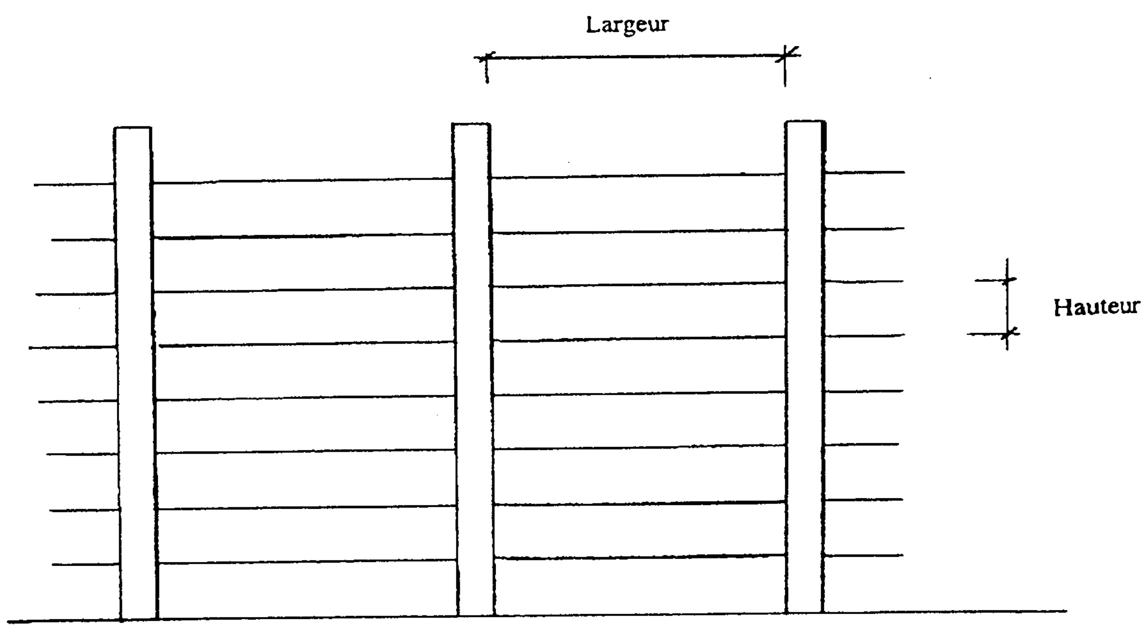
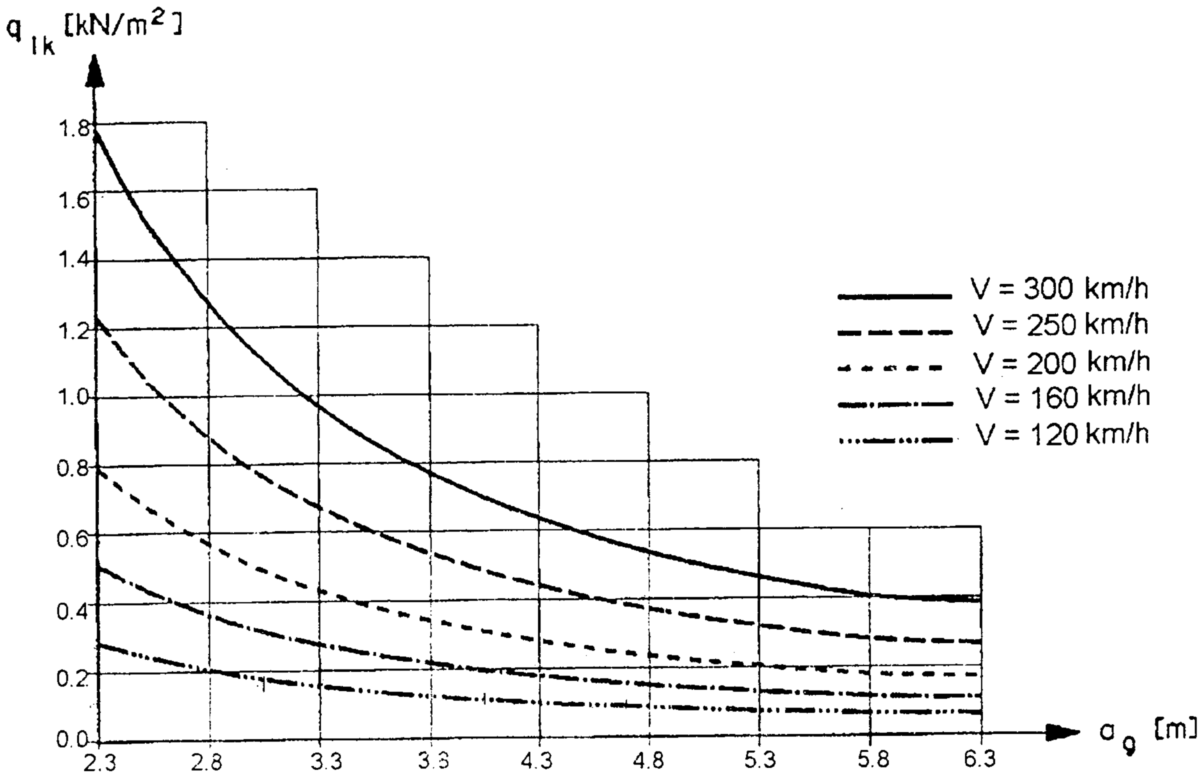


Figure 4 - **Characteristic values of the actions q_{lk} for simple surfaces that are vertical and parallel to the tracks.**



3 - Simple horizontal surfaces above the tracks

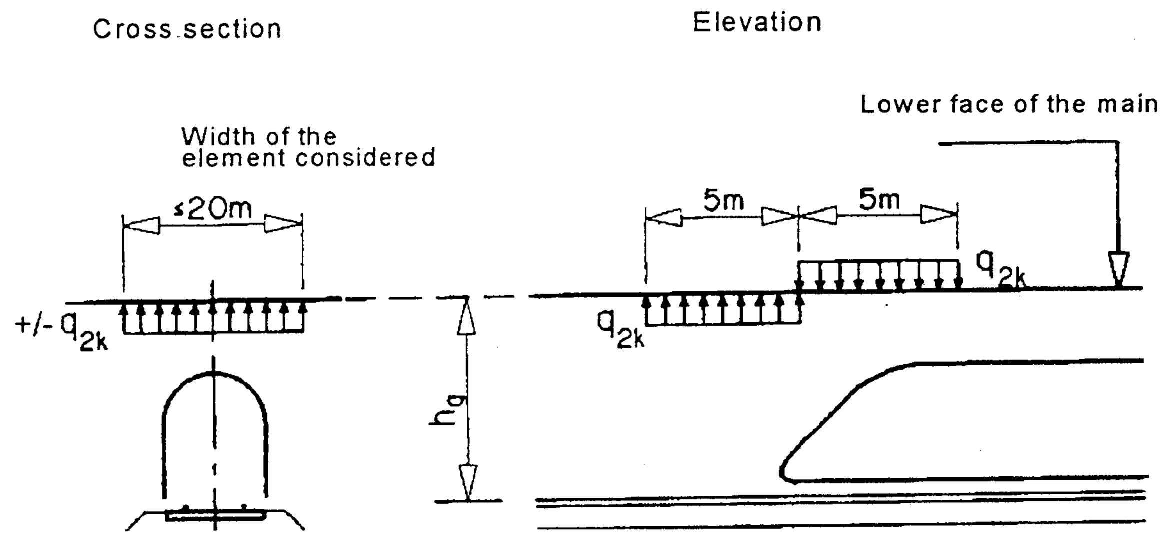
The following structures fall in this category:

- catenary protective structures arranged along the side of long-length bridge deck spans with respect to the width of the railway track formation,
- catenary protective structures arranged along the side of continuous bridge decks with central and end spans,
- very long bridge decks and temporary gangways.

All these structures are considered to be open and, therefore, to have no lateral obstruction.

For this type of structure the pressure-suction wave is replaced by moving, distributed loads + q_{2k} and - q_{2k} each 5m in length and 20m in width centred on the track axis (see Figure 5).

Fig. 5 : **Substitution load q_{2k} for the pressure-suction forces on the horizontal surfaces of structures above the tracks.**



The values q_{2k} of the distributed loads are determined by the formula (4):

$$q_{2k} = k_1 \, c_p \left(\frac{V}{3.6}\right)^2 \frac{1}{1\,600} \qquad (4)$$

where :

V: the train speed
k_1: the train shape coefficient (see Para 1)
c_p: the aerodynamic coefficient, depending on the clearance under the screen: h_g

This coefficient is obtained through the formula:

$$c_p = \frac{2.0}{(h_g - 3.10)^2} + 0.015 \qquad (5)$$

Figure 6 gives, in the form of curves, pressures ± q_{2k} as a function of train speed (speeds V = 120, 160, 200, 250, 300 km/h) and distance h_g between the upper level of the top of the rail and the surface point considered.

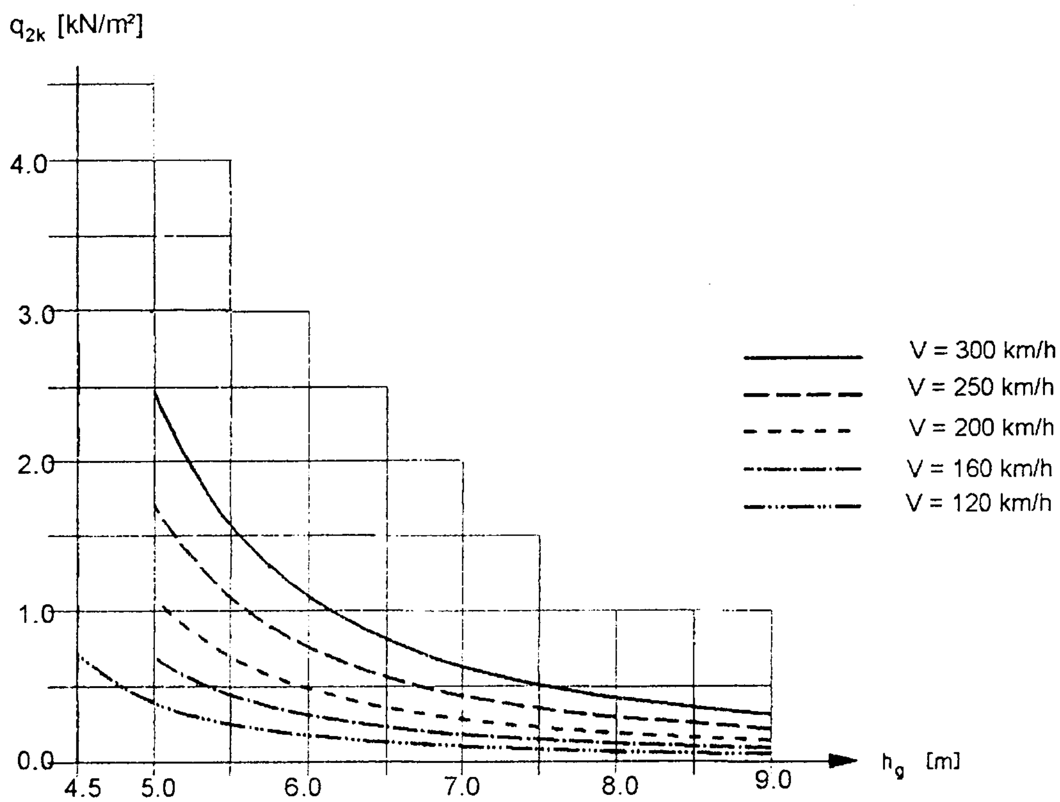
These curves are plotted for trains with a coefficient k_1 = 1.

Pressures ± q_{2k} should be applied over the width of the surface studied up to 10 m on either side of the track axis. In the case of crossing trains, the pressures are aggregated together. However, there is no need to consider more than 2 tracks.

Pressures q_{2k} can be reduced through factor k_1 introduced above depending on the aerodynamic shape of the train (see Para 2).

Pressures q_{2k} on the side bands perpendicular to the track can be reduced through factor 0.75 over a maximum width of 1 m 50.

Figure 6 : Characteristic values of the actions q_{2k} for simple horizontal surfaces above the track



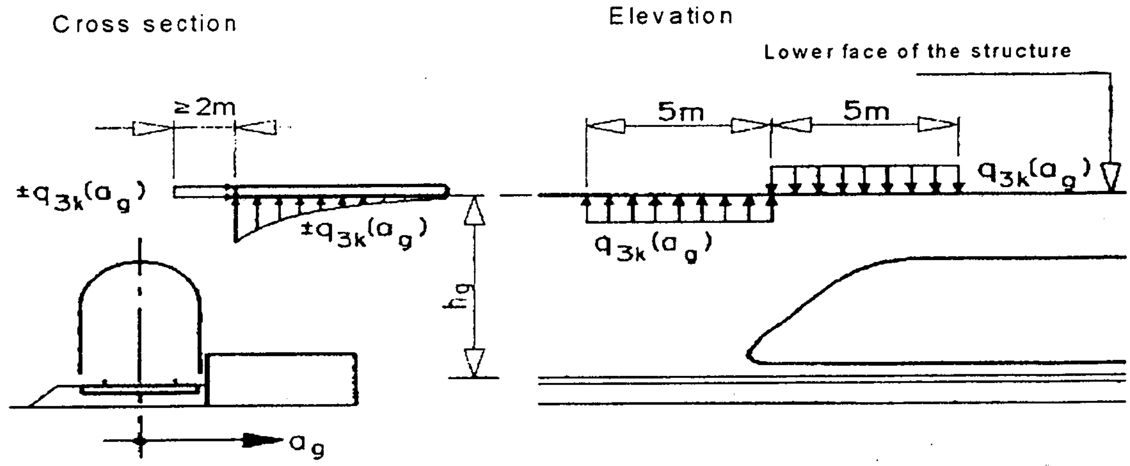
4 - Simple horizontal surfaces close to tracks

The following structures fall into this category:

- platform canopies comprising a roof resting on posts, in other words without any obstruction due to a vertical wall with large surface area or a train standing on the track enclosing the platform with the track concerned. For these structures refer to Paragraph 5 below refers.

In this case the pressure-suction wave is replaced by moving distributed loads ± q_{3k} each 5 m in length, (see Figure 7). Values q_{3k} reduce with the increasing horizontal distance a_g from the track axis.

Figure 7 : **Substitute load q_{3k} for the pressure-suction loads on the horizontal surfaces of structure, close to the track.**



Values q_{3k} of the loads which depend on a_g are determined from the formula (6):

$$q_{3k} = c_p \left(\frac{V}{3.6}\right)^2 \frac{1}{1\,600} \qquad (6)$$

where

$$c_p = \frac{1.5}{(a_g + 0.25)^2} + 0.015 \qquad (7)$$

Figure 8 gives pressures $\pm q_{3k}$ in the form of curves.

They are independent of the aerodynamic shape of the train.

q_{3k} should be calculated at each point of the structure considered as a function of the distance a_g to the axis of the nearest track. The pressures are cumulative for a structure flanked by two tracks.

For heights $h_g > 3.80$ m, the pressures $\pm q_{3k}$ can be assigned factor k_3:

where

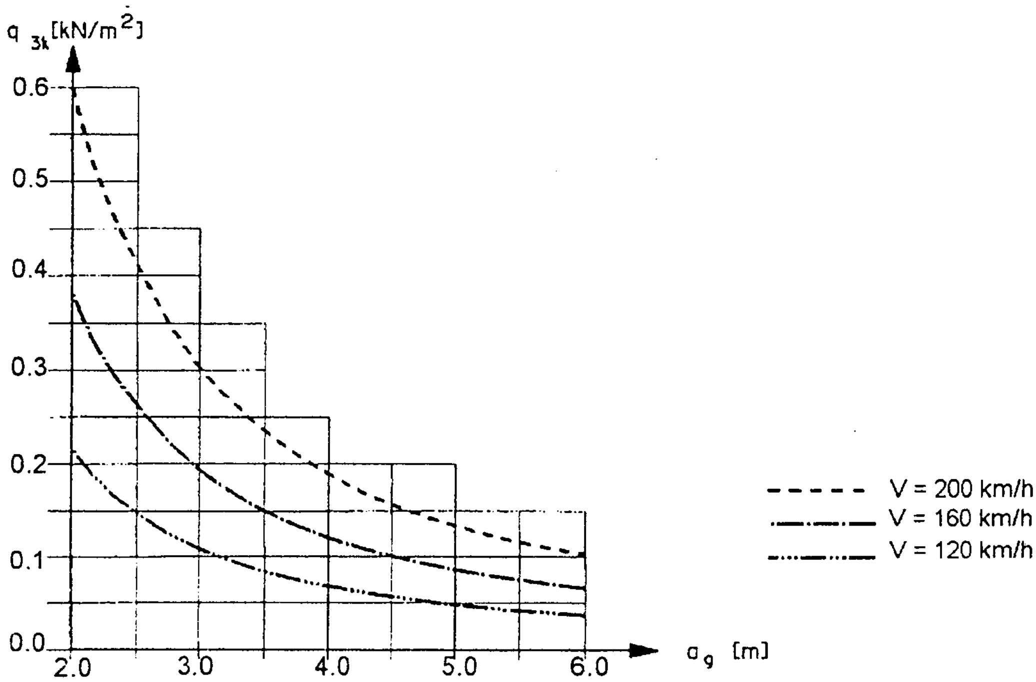
$k_3 = (7.5 - h_g)/3.7$	if	$3.8 \text{ m} < h_g < 7.5 \text{ m}$
$k_3 = 0$	if	$h_g \geq 7.5 \text{ m}$

where

h_g = distance between the top of the rail and the lower face of the structure considered.

For heights $h_g > 7.5$ m, there is consequently no need to consider this pressure q_{3k}.

Figure 8 : Characteristic values of the loads on simple horizontal surfaces close to the tracks.



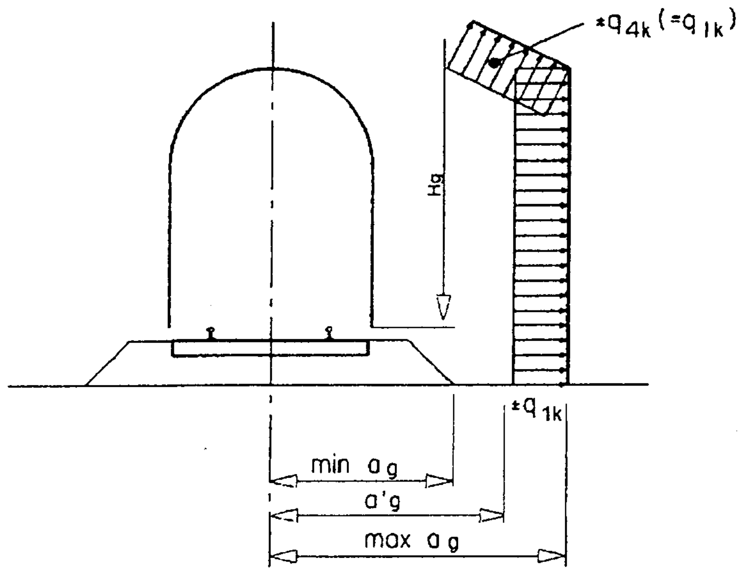
5 - Mixed vertical and horizontal or inclined surfaces close to the tracks

The following structures should be considered as falling in this category:

- acoustic screens with a vertical part plus an inclined or horizontal part, called mixed screens,
- platform canopies comprising a roof and solid vertical screen underneath, which serves as support or space-filler space between the supports,
- platform canopies comprising a roof covering a waiting room or any other enclosed building,
- platform canopies on posts situated between two tracks, where trains can be standing on the other track.

The pressure-suction wave is replaced by moving distributed loads of type $\pm q_{1k}$ each 5 m in length as shown in Figure 9.

Figure 9 : **q_{4k} substitution load for the pressure-suction loads on surfaces of vertical and horizontal or inclined structures close to the tracks**



Because of the obstruction due to the second surface, the outflow of air is prevented so that the substitution loads are greater in this case than with surfaces that are simply vertical or horizontal.

Loads $\pm q_{4k}$ (= q_{1k}), shown in the curves in Figure 4, are applied perpendicularly to the surfaces considered.

These values shall be determined for fictitious distances:

$$a'_g = 0.6 \text{ min. } a_g + 0.4 \text{ max } a_g \qquad (8)$$

where

min. a_g =	minimum distance of the surface from the track axis
max. a_g =	maximum distance of the surface from the track axis

If max a_g > 6 m, then max a_g = 6m is assumed.

Coefficients k_1 and k_2 are also applicable in this case.

6 - Closed surfaces enveloping the tracks over a limited length (15 to 20 m)

The following structures fall into this category:

- structures containing a horizontal screen above the tracks and at least a vertical screen,
- scaffolding (serving to support the form for bridge deck for example),
- provisional structures (service walkways),
- catenary protective structures on overhead bridge abutments close to the tracks (portal structure, frames, etc.).

The loads ± q_{1k} applied on the vertical surface over the whole of its height (even if this is greater than 5 m) and ± q_{2k} applied on the horizontal surfaces are determined as in Sections 2 and 3 above, and should be considered as moving distributed loads, 5 m in length for each of the opposite-sign loads.

These loads are systematically assigned the coefficient :

k_4 = 2 for loads q_{1k}

and

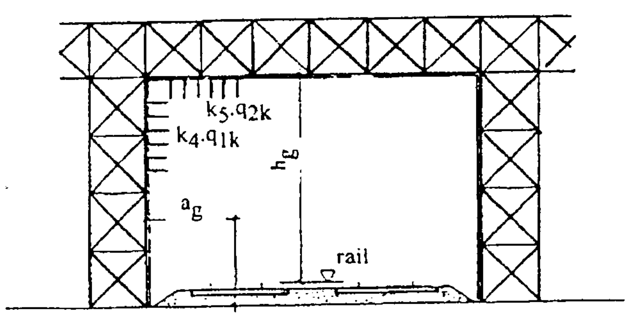
k_5 = 2.5 for loads q_{2k} (if the surfaces enclose one track)
k_5 = 3.5 for loads q_{2k} (if the surfaces enclose two tracks)

In the case of two tracks, the value of k_5 allows for the passing of 2 trains.

The actions above are independent of the aerodynamic shape of the train.

The values calculated on this basis account for the dimension perpendicular to the tracks of the supports on both sides of them.

Figure 10 : Substitution loads k_4 q_{1k} and k_5 q_{2k} for the pressure-suction loads on the vertical and horizontal surfaces of provisional surfaces enclosing the tracks



7 - Combined effect of slipstream and wind forces

Structures situated close to the track are subjected, among other things, to the combined aerodynamic effect of wind and of the slipstream produced by passing trains.

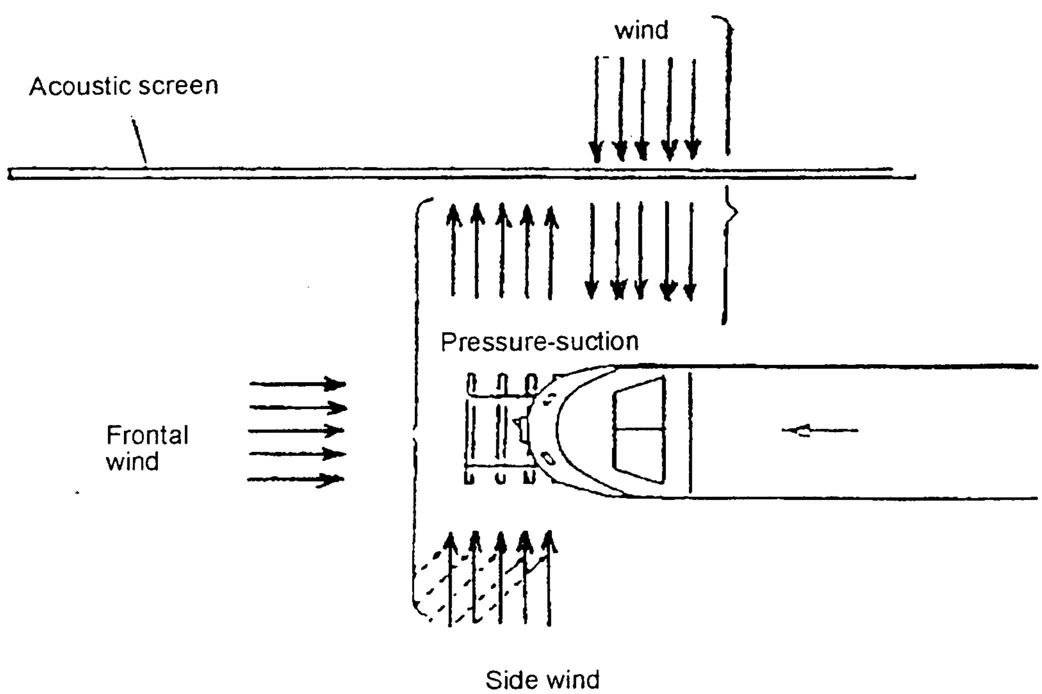
When a train runs close to a structure, for example an acoustic screen, air flow conditions are modified when the wind blows. Thus, for example, aerodynamic coefficients are generally smaller when a train passes than without a train, when the effect of the wind is applied perpendicularly to the vertical surface of a structure parallel to the track. As the differences cannot be quantified by a general rule, the effects of the wind and passing trains should be determined separately for this case.

Conversely, with frontal wind, wind speeds and train speeds should be added and the substitution loads for the pressure-suction wave should be determined for the resulting speed (see Figure 11).

For acoustic screens, the resulting loads are, in general, greater for a wind perpendicular to the screen than for a wind coming from the front (see example in Para. 8).

When the structure is not directly subjected to the wind, loads q_{1k} shall be determined for train speeds which are increased by the speed of the frontal wind.

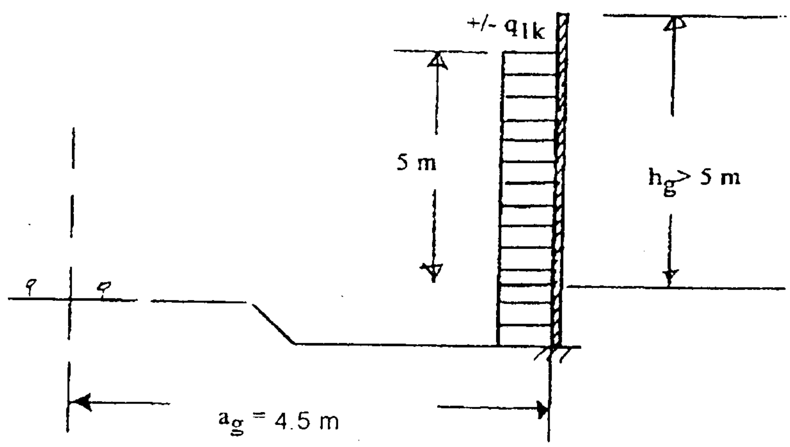
Figure 11 : Simultaneous effect of wind + slipstream



8 - Application examples

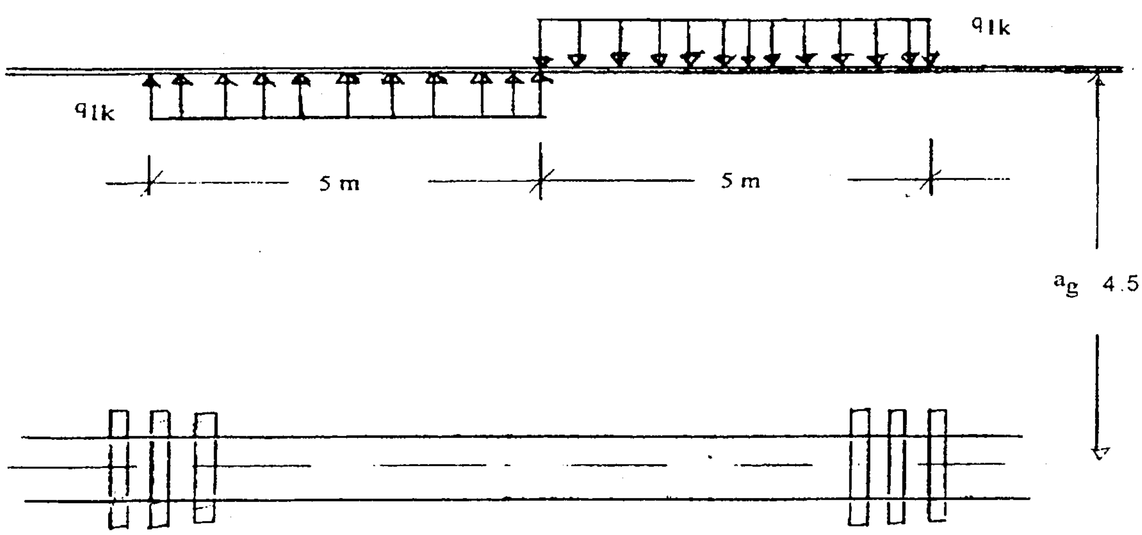
Example No. 1 : Acoustic screen parallel to the track

Cross-section :



Loads q_{1k} due to the pressure-suction wave caused by the passing of a train shall be applied over the whole height of the screen, but not beyond a value 5 m above the upper level of the rail. In the direction of travel, the loads are applied over a length of 5 m with + q_{1k} and then on 5 m with - q_{1k}.

Plan view :



Case 1 :

High speed train with a very favourable aerodynamic shape (k_1 = 0.6) and V = 300 km/h.

q_{1k} (k_1 = 1.0) = 0.59 kN/m^2 (see Fig. 4)
q_{lk} (k_1 = 0.6) = 0.6 . 0.59 = 0.354 kN/m^2

Case 2 :

Locomotive-hauled passenger train with a favourable aerodynamic shape (k_1 = 0.85) and V = 200 km/h.

q_{1k} (k_1 = 1) = 0.26 kN/m^2 (see Fig. 4)
q_{lk} (k_1 = 0.85) = 0.85 . 0.26 = 0.221 kN/m^2

Case 3 :

Freight train with unfavourable aerodynamic shape (k_1 = 1.0) and V = 120 km/h.

q_{lk} (k_1 = 1.0) = 0.094 kN/m^2 (see Fig. 4)

The determining load is that for case 1.

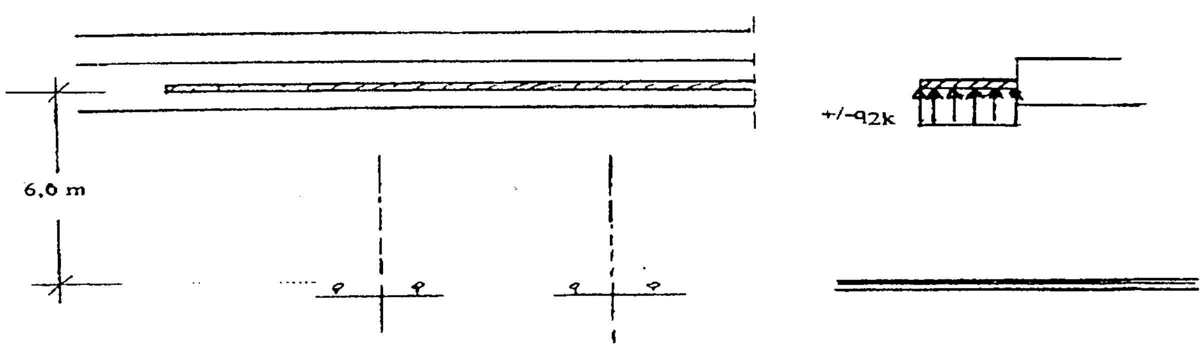
Where structures have a height of less than 1 and/or a width of less than 2.5 m, the determinant forces shall be increased by a factor k_2 = 1.3 (see Fig. 3).

q_{1k} =1.3 . 0.354 =0.460 kN/m^2

These loads should also be applied, for example to posts when their distance apart is less than 2.5 m.

The loads due to the winds should also be considered when calculating the loads due to the pressure-suction wave. As a general rule the loads due to the wind that occur perpendicularly to the track are the determining factor when designing acoustic screens (see example 7).

Example No. 2 : Catenary protective structure above one or several tracks



Case 1 :

High speed train with a very favourable aerodynamic shape (k_1 = 0.6) and V = 300 km/h.

q_{2k} (k_1 = 1.0) = 1.10 kN/m^2 (see Fig. 6)
q_{2k} (k_1 = 0.6) = 0.6 . 1.10 = 0.658 kN/m^2

Case 2 :

Locomotive hauled passenger trains with a favourable aerodynamic shape (k_1 = 0.85) and V = 200 km/h.

q_{2k} (k_1 = 1) =0.488 kN/m^2 (see Fig. 6)
q_{2k} (k_1 = 0.85) =0.415 kN/m^2

Case 3 :

Freight train with an unfavourable aerodynamic shape (k_1 = 1.0) and V = 120 km/h.

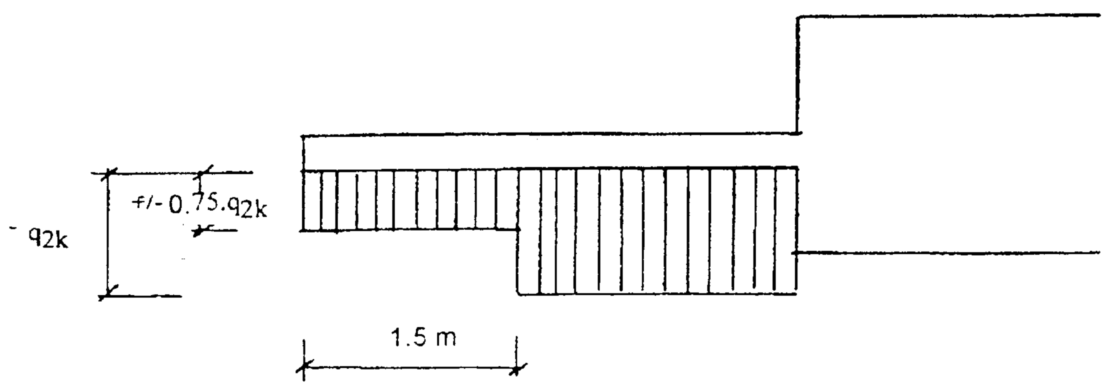
q_{2k} (k_1 = 1.0) = 0.176 kN/m^2 (see Fig. 6)

The determining load is obtained from case 1.

Because of the presence of several tracks and the possibility of trains passing, the load should be multiplied by 2:

q_{2k} = 0.658 x 2 = ± 1.32 kN/m^2

In the edge zone on a strip 1.50 m wide the load can be reduced by multiplying it by factor 0.75 (see figure below).

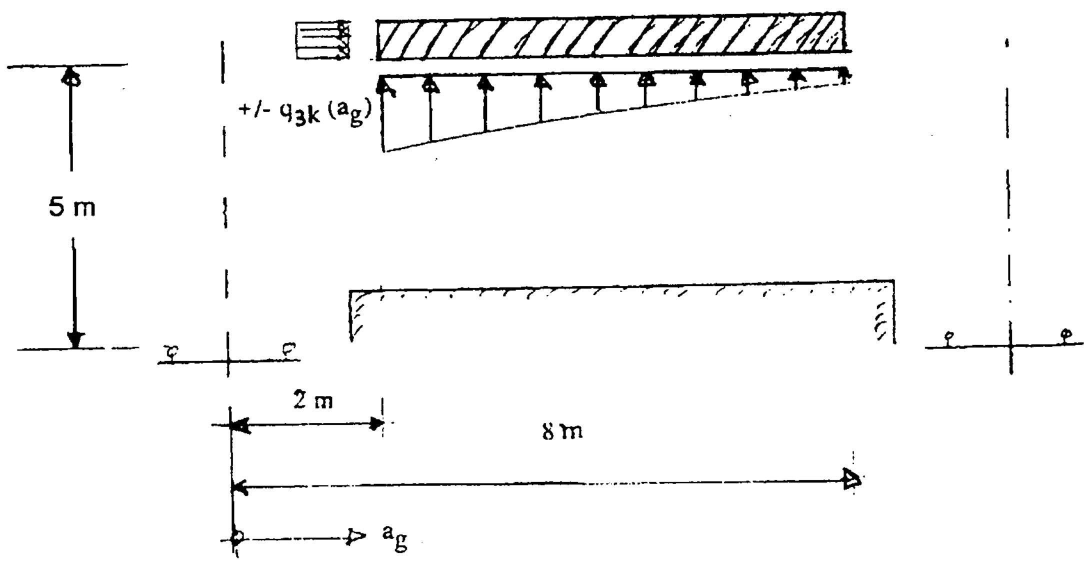


The loads due to wind should also be considered together with the loads due to the pressure-suction wave.

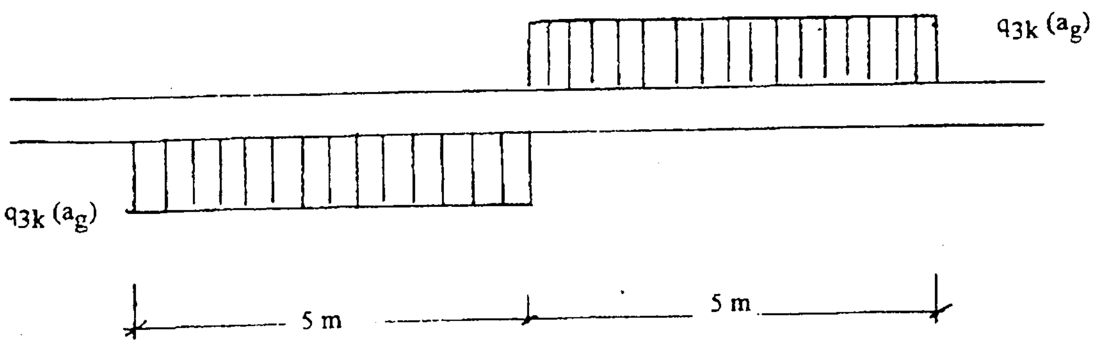
Frontal winds are generally the determining factor for catenary protective structures. In this case train speeds and wind speeds should be aggregated to determine the loads q_{2k} from Fig. 6.

Example No. 3 : Platform canopy

Section



Elevation



Train speed V = 200 km/h.

The effect of the aerodynamic shape is negligible. Therefore, for all the trains (as specified in Fig. 8):

q_{3k}	$(a_g = 2.00)$	=	0.600 kN/m^2
q_{3k}	$(a_g = 5.00)$	=	0.134 kN/m^2
q_{3k}	$(a_g = 8.00)$	=	0.071 kN/m^2

As the distance h_g between the top of the rail and the lower face of the canopy exceeds 3.80 m, the loads can be reduced by factor k_3:

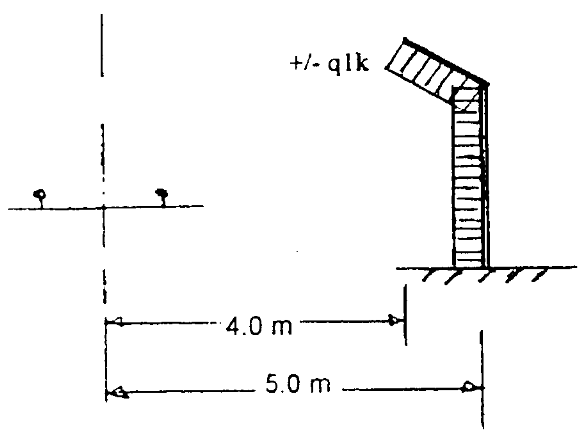
$$k_3 = (7.5 - 5.00)/3.7 = 0.675$$

The effects of a second passing train and of the wind must be considered together with the loads due to the pressure-suction wave of a train.

In the case of a side wind, only the loads on the canopy side are increased.

In the case of a frontal wind, the train speeds and wind speeds should be aggregated to determine the loads q_{3k} from Figure 8 for the resulting speed value.

Example No. 4 : Mixed acoustic screen



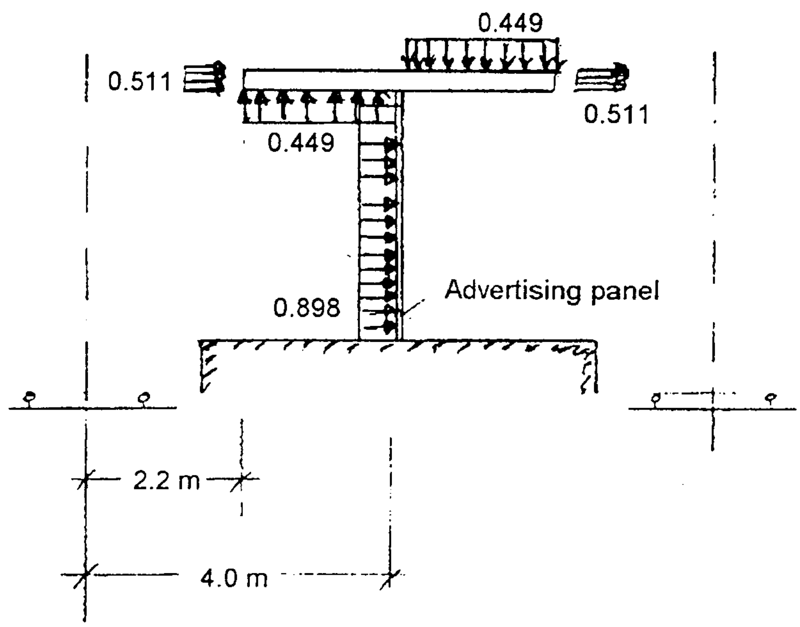
Passenger trains (k_1 = 0.85) with V = 220 km/h

a'_g	$= 0.6 . 4.0 + 0.4 . 5.0 =$	4.40 m	
q_{1k}	$(k_1 = 1.00 ; a'_g - 4.40)=$	0.328 kN/m^2	(see Fig. 4)
q_{1k}	$= 0.85 \times 0.328 =$	± 0.279 kN/m^2	

The working length is the same as for example 1 with 5 m for + q_{1k} and then immediately afterwards 5 m with - q_{1k}. To design small elements, the loads should be multiplied by factor k_2 = 1.3.

The effect of the wind should be considered in identical manner to example 1.

Example No. 5 : Platform canopy with obstruction due, for example, to the presence of advertising panels



Loads in kN/m²

Locomotive-hauled passenger train (k_1 = 0.85) with V = 220 km/h

a'_g	= 0.6 . 2.20 + 0.4 . 4.0 =		2.92 m	
q_{1k}	(k_1 = 1.0 ; a'_g = 2.92)	=	0.528 kN/m^2	(from Fig. 4)
q_{1k}	= 0.85 x 0.528	=	± 0.449 kN/m^2	

Because of the possible effect of a second train, the following values should be used :

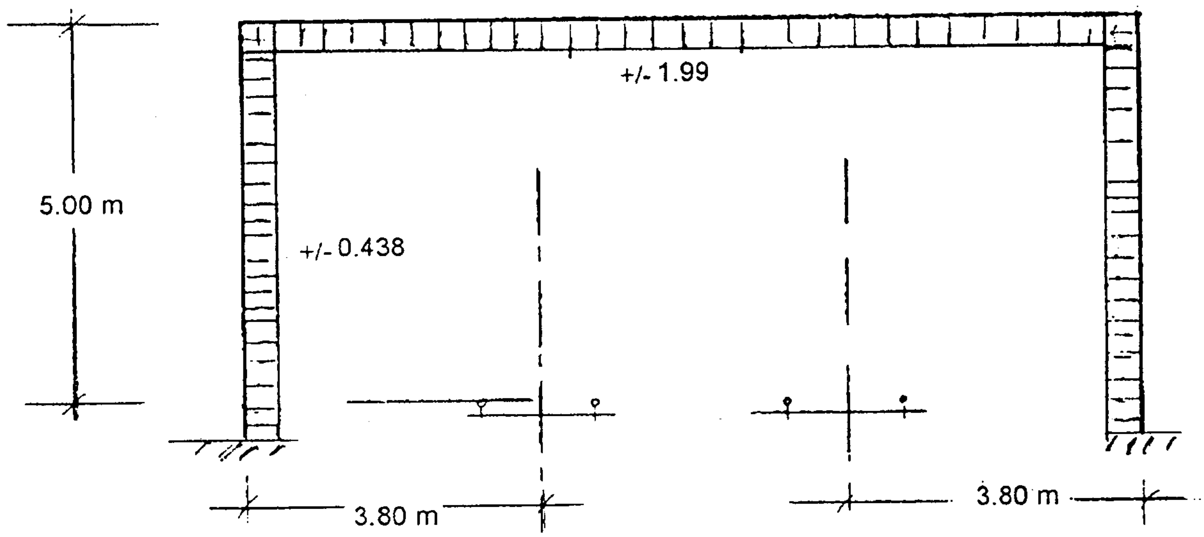
- on a vertical screen : $2q_{1k}$ = 0.898 kN/m^2
- on an alternating ½ roof : q_{1k} = 0.445 kN/m^2

The forces on the side can be determined from Fig. 8 with:

q_{3k} (a_g = 2.20) = 0.511 kN/m^2

To cater for wind-induced loads see example 3.

Example No. 6 : Scaffolding spanning 2 tracks



Train speed V = 160 km/h

The effect of the aerodynamic shape of the train is negligible. Thus for all trains :

Loads on vertical surfaces:

$q_V = 2.00 \cdot q_{1k} (a_g = 3.8) = \quad 2.0 \cdot 0.219 = \pm 0.438 \text{ kN/m}^2$

Loads on horizontal surface :

$q_h = 3.5 \cdot q_{2k} (h_g = 5.0) = \quad 3.5 \cdot 0.569 = \pm 1.99 \text{ kN/m}^2$

The working length parallel to the track on which the load is applied is 5 m for + q_V and + q_k followed by a length of 5 m for - q_V and - q_k.

The determining wind load is, in general, that of the frontal wind, the speed of which must be added to that of the train before calculating the loads q_V and q_k.

Example No. 7 : Acoustic screen with wind effect

Example 1 can be used again with :

a_g = 4.30 - and a train with coefficient k_1 = 0.85 V = 200 km/h
wind speed v = 27.8 m/s ⇒ V = 100 km/h

Case 1 : side wind :

a_g = 4.30 m V = 200 km/h k_1 = 0.85

q_{1k} = 0.85 . 0.281 = 0.239 kN/m² (see Fig. 4)

In the case of wind as per Appendix 6A5 to part 2.1 of EC1 :

V_{ref} = 22.0 m/s (zone 1).

q_{ref} = reference pressure of wind as specified in 6.7.1

$$q_{ref} = \frac{\rho}{2} \_ V^2_{ref} = \frac{1.25}{2} . \overline{22.0}^2 = 0.302 \text{ kN} | \text{m}^2$$

For a zone 1 area and a height of 6.00 - :

$C_e(z)$ = 2.5 (exposure coefficient)
C_d = 1 (dynamic coefficient)
$C_{pe.10}$ = 1 (external pressure coefficient)

and

w_e = external pressure = q_{ref} . $C_e(z_c)$ = 2.5 . 0.302
w_e = 0.755 kN/m²

from which

q_{total} = $W_e + q_{1k}$
= ± 1.00 kN/m²

For this aggregate, the partial safety factors have been assumed to be identical.

Case 2 : Head wind

a_g = 4.30 m

V = 200 + 100 = 300 km/h

k_1 = 0.85

q_{1k} = 0.85 . 0.633 = 0.538 kN/m² < 1.0 kN/m²

With this comparison it can be seen that the “side wind” case is decisive.

Application

With effect from 1 January 1996

All UIC Members

Record references

- Sub-Committee 7J for Bridges : Paris, January 1990;
  Ways and Works Committee : Paris, June 1990;
  Board of Management : Paris, December 1990.