Load effects calculation according to EN 1991-2 Load Model 1

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Abstract. In the present paper, fast calculation method for determination the effects of EN 1991-2 LM1 is presented. The influence lines method was used for calculation. Both bending moments and shear forces at typical section can be easy calculated by using one table.

1. Introduction
Road traffic actions – vertical loads (except fatigue), defined in EN 1991-2 [1]:

- Load Model 1 (LM1) is represented as concentrated and uniformly distributed loads, which cover most of the effects of the traffic of lorries and cars. This model should be used for general and local verifications and is the main load model for bridges with spans more than 7 m;
- Load Model 2 (LM2) can be predominant in the range of loaded lengths up to 3 m to 7 m and normally is used for load effects calculation for short structural members;
- Load Model 3 (LM3) is representing special vehicles (e.g. for industrial transport) which can travel on routes permitted for abnormal loads;
- Load Model 4 (LM4): A crowd loading should be used only for some transient design situations.

Load models defined in EN 1991-2 should be used for the design of road bridges with loaded lengths less than 200 m. The length of 200 m corresponds to the maximum length taken into account for the calibration of LM1.

Loads due to the road traffic, consisting of cars, lorries and special vehicles (e.g. for industrial transport), give rise to vertical and horizontal, static and dynamic forces. The defined load models do not describe actual loads. They have been selected and calibrated so that their effects (with dynamic amplification included where indicated) represent the effects of the actual traffic in European countries.

Because of LM1 is the main load model for bridge design (except fatigue load models), and mention in the paragraph above, gives the author a reason to search a fast calculation method for TS that will give the same effects on simply supported bridges. The presented method below allows designers to use a table for their calculations.

Load Model 1 consists of two partial systems, as follows:

1.1. Double-axle concentrated loads (tandem system: TS), each axle having the following weight:

\[ a_0 Q_k \]  

(1)

1.2. Uniformly distributed loads (UDL system), having the following weight per square metre of notional lane:

\[ a_0 q_k \]  

(2)
Load Model 1 should be applied on each notional lane and on the remaining areas.

On notional lane Number \( i \), the load magnitudes are referred to:

\[
\alpha Q_i Q_{ik} \quad (3)
\]
\[
\alpha q_i q_{ik} \quad (4)
\]

On the remaining areas, the load magnitude is referred to:

\[
\alpha_q q_{ik} \quad (5)
\]

Where: \( \alpha Q_i \), \( \alpha q_i \), and \( \alpha_q \) are adjustment factors that should be selected depending on the expected traffic and possibly on different classes of routes. The values should be accepted in the national annexes.

The values of \( Q_{ik} \), \( q_{ik} \) and \( q_{rk} \) are shown in Table 1 [1].

**Table 1. Load Model 1: characteristic values.**

| Location            | Tandem system TS Axle loads \( Q_{ik} \) (kN) | \( UDL \) system \( q_a \) or \( q_{rk} \) (kN/m²) |
|---------------------|---------------------------------------------|-------------------------------------------------|
| 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                                             |

The details of Load Model 1 are illustrated in Figure 1.

![Figure 1. Load Model 1.](image)

2. **Proposed method**

Bending moment \( (M_s) \) and shear force \( (V_z) \) calculation, at section “s” at a distance “x” from the support of a simply supported beam loaded with two point loads on a distance 1.2 m (the same like an LMI TS in a longitudinal direction), based on the influence line method is shown on Figure 2.
Figure 2. Load effects calculation.

The influence lines are drawn with their positive values above the reference line.

Load effects from that model are as follows:

$$M_{y,s} = \eta_1 + \eta_2$$  \hspace{1cm} (6)

$$V_{z,s} = \eta_3 + \eta_4$$  \hspace{1cm} (7)

Where, \( \eta_1 \) to \( \eta_4 \) are the corresponding influence line ordinates under the point loads.

$$\eta_1 = x \frac{(L-x)}{L}$$  \hspace{1cm} (8)

$$\eta_2 = x \frac{(L-x-1,2)}{L}$$  \hspace{1cm} (9)

$$\eta_3 = \frac{(L-x)}{L}$$  \hspace{1cm} (10)

$$\eta_4 = \frac{(L-x-1,2)}{L}$$  \hspace{1cm} (11)

The maximum bending moment from such point loads is not at the middle of the span. Location of the section with maximum bending moment can be found from the equation:

$$\frac{dM}{dx} = \frac{(2 L - 4 x - 1,2)}{L} = 0$$  \hspace{1cm} (12)

The section with maximum bending moment from LMI TS is at distance from the support:

$$x = \frac{L}{2} - 0,3 \text{ m}$$  \hspace{1cm} (13)

A method that represents tandem system TS with equivalent uniform loads is presented in [2]. The method allows designers to use only uniform loads for bending moment and shear force calculation for simply supported beams. It also gives a possibility for easy preliminary calculations of prestressing force needed to balance the equivalent uniform load. Some calculations and result comparison of load effects in bridge superstructure between common and proposed [2] methods were reported and commented in [4].

3. Load effects calculation from any value of TS

To simplify load effects calculation author propose a table which can be used by designers. Bending moments \( M_{y,s} \) and shear forces \( V_{z,s} \) can be calculated with formulas, as follows:

$$M_{y,s} = k_{My} \sum a_i Q_{ik}$$  \hspace{1cm} (14)

$$V_{z,s} = k_{Vz} \sum a_i Q_{ik}$$  \hspace{1cm} (15)

Values for \( k_{My} \) and \( k_{Vz} \) at typical sections for simply supported beams can be found in Table 2.

When there is a girder bridge superstructure system, the designer should calculate the load redistribution between beams first. There are several hand calculation methods and some details about such calculations, according to the transversal stiffness of the bridge superstructure with comments can be found in [3] and [5].

Comments for the influence of different load distribution in load effects calculation can be found in [4].
Table 2. Values for $k_i$ at typical sections for simply supported beams.

| Span, [m] | $x = 0$ | $x = L/8$ | $x = L/4$ | $x = 3/8 L$ | $x = L/2$ | $x = L/2 - 0,3 m$ |
|-----------|---------|-----------|-----------|-------------|-----------|-------------------|
| $k_{Vz}$  | $k_{My}$ | $k_{Vz}$  | $k_{My}$  | $k_{Vz}$    | $k_{My}$  | $k_{Vz}$          |
| 6         | 18.0000 | 15.5000   | 19.5000   | 23.6250     | 24.00     | 8.0000           |
| 7         | 18.2857 | 16.0000   | 23.2500   | 28.3125     | 29.00     | 8.2857           |
| 8         | 18.5000 | 16.0000   | 27.0000   | 33.0000     | 34.00     | 8.5000           |
| 9         | 18.6667 | 16.1667   | 30.7500   | 37.6875     | 39.00     | 8.6667           |
| 10        | 18.8000 | 16.3000   | 34.5000   | 42.3750     | 44.00     | 8.8000           |
| 11        | 18.9091 | 16.4091   | 38.2500   | 47.0625     | 49.00     | 8.9091           |
| 12        | 19.0000 | 16.5000   | 42.0000   | 51.7500     | 54.00     | 9.0000           |
| 13        | 19.0769 | 16.5769   | 45.7500   | 56.4375     | 59.00     | 9.0769           |
| 14        | 19.1429 | 16.6429   | 49.5000   | 61.1250     | 64.00     | 9.1429           |
| 15        | 19.2000 | 16.7000   | 53.2500   | 65.8125     | 69.00     | 9.2000           |
| 16        | 19.2500 | 16.7500   | 57.0000   | 70.5000     | 74.00     | 9.2500           |
| 17        | 19.2941 | 16.7941   | 60.7500   | 75.1875     | 79.00     | 9.2941           |
| 18        | 19.3333 | 16.8333   | 64.5000   | 79.8750     | 84.00     | 9.3333           |
| 19        | 19.3684 | 16.8684   | 68.2500   | 84.5625     | 89.00     | 9.3684           |
| 20        | 19.4000 | 16.9000   | 72.0000   | 89.2500     | 94.00     | 9.4000           |
| 21        | 19.4266 | 16.9266   | 75.7500   | 93.9375     | 99.00     | 9.4266           |
| 22        | 19.4545 | 16.9545   | 79.5000   | 98.6250     | 104.00    | 9.4545           |
| 23        | 19.4783 | 16.9783   | 83.2500   | 103.3125    | 109.00    | 9.4783           |
| 24        | 19.5000 | 17.0000   | 87.0000   | 108.0000    | 114.00    | 9.5000           |
| 25        | 19.5200 | 17.0200   | 90.7500   | 112.6875    | 119.00    | 9.5200           |
| 26        | 19.5385 | 17.0385   | 94.5000   | 117.3750    | 124.00    | 9.5385           |
| 27        | 19.5556 | 17.0556   | 98.2500   | 122.0625    | 129.00    | 9.5556           |
| 28        | 19.5714 | 17.0714   | 102.0000  | 126.7500    | 134.00    | 9.5714           |
| 29        | 19.5862 | 17.0862   | 105.7500  | 131.4375    | 139.00    | 9.5862           |
| 30        | 19.6000 | 17.1000   | 109.5000  | 136.1250    | 144.00    | 9.6000           |
| 31        | 19.7000 | 17.2000   | 147.0000  | 183.0000    | 194.00    | 9.7000           |
| 32        | 19.7600 | 17.2600   | 184.5000  | 229.8750    | 244.00    | 9.7600           |
| 33        | 19.8000 | 17.3000   | 222.0000  | 276.7500    | 294.00    | 9.8000           |
| 34        | 19.8286 | 17.3286   | 259.5000  | 323.6250    | 344.00    | 9.8286           |

Values rounded to 4 decimal places.
4. Conclusion
Presented method for fast calculation of load effects from tandem system TS which is a part of the main load model LM1 simplify many hard calculations for the designers. It can be used not only for a preliminary calculations and obtaining balancing loads and also in many calculation tasks in the engineering practice in connection with the bridge design. This method also minimizes the risk of calculation mistakes in the load effects calculation and gives a possibility to easily calculate the maximum bending moment, which is not at the middle of the beam.

References
[1] EN 1991-2 Eurocode 1: Actions on structures - Part 2: Traffic loads on bridges
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[3] Safronov V and Slavchev V 2004 Analysis about the size of bending moments in beam superstructure bridges with different spans and transversal stiffness from loads according standards published in different periods of time in Bulgaria Int. Scientific Conf. VSU/2004 (Sofia, Bulgaria)
[4] Vasilev L 2014 Calculation of load effects in a bridge superstructure under different load models 14th Int. Scientific Conf. VSU/2014 (Sofia, Bulgaria)
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Note: Values in Table 2 are 10 times scaled.