CETRA2022 11-13 May 2022, Pula, Croatia
7th International Conferenceon Road and Rail Infrastructure

IMPACT OF EUROCODE LOAD MODEL 3 ON THE DESIGN OF HIGHWAY AND EXPRESSWAY BRIDGES

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Abstract

According to Eurocode HRN EN 1991-2 and Croatian National Annex HRN EN 1991-2/NA highway and expressway bridges need to be designed for Load Model 1 (heavy vehicles) and Load Model 3 (special vehicles) traffic loads. Classes of special vehicles are defined in Annex A of HRN EN 1991-2, while the Croatian National Annex requires the use of 15 axle special vehicle with total weight of 3000 kN and axle loads of 200 kN. The simultaneity of LM1 and LM2 is also covered by the standard, depending on the travel speed of the special vehicles. Design practice has shown that these design requirements have notable impact on bridges in the 30 to 100 m span range. In this paper, the results of a parametric study on a group of continuous girder bridges with different spans and carriageway widths are presented, to determine the exact difference in resulting hogging and sagging moments and shear forces between LM1 and LM3 Load Models. Thus, the governing Load Model and its effect on the design for the relevant range of bridges is determined. A recommendation is made as to when each Load Model should be used in design.

Keywords: bridge, continuous girder, traffic load, load models, Eurocode

1 Introduction

Design of the bridge superstructure is predominately determined by the type and magnitude of traffic loads. European design requirements for road bridges define traffic loads, which are specified in Eurocode EN 1991-2 (Croatian standard HRN EN 1991-2 [1]). Four Load Models for vertical loads are specified, with LM1 always to be applied, LM2 only for local verifications, LM3 only where relevant, and LM4 to be applied if defined for the individual project (Table 1). As shown in Table 1, Load Models consist of concentrated axle load(s) and/or uniformly distributed loads and can be used for either local or global structural elements verifications. All but Load Model 3 are obligatory for design of any road bridge and each of them can be relevant depending on the structural element or bridge type and size. Load Model 3, however, is only to be used for bridges on special traffic routes where “abnormal” transport loads are expected. It is not further elaborated in Eurocode which road categories are implied for such a transport. The Croatian National Annex HRN EN 1991-2:2012/NA [2] states that Load Model 3 should be used on highway (speed limit 120 km/h), expressway (speed limit 100 km/h) and similar roads, as well as roads that are expected to carry special heavy transports (which is to be evaluated by Client or Road Authority). If Load Model 3 must be considered, it should be examined whether it yields larger internal forces and stresses in structural elements compared to Load Model 1, and if so, it will govern the design (sizing) of structural elements. This paper will show the results of a parametric study conducted to determine when Load Model 3 might govern the design for various spans of continuous girder bridges and different carriageway widths.

DOI: https://doi.org/10.5592/CO/CETRA.2022.1431

Table 1 EN 1991-2 Load Models for road bridges

Load model	Requirement	Type of load	Verification
1	All road bridges	Axle loads and uniformly distributed load	Global / Local
2	All road bridges	Single axle load	Local
3	Bridges on routes with abnormal transport loads	Special vehicle axle load assemblies	Global / Local
4	All road bridges	Uniformly distributed crowd loading	Global

2 EN 1991-2 Load Model 3 and possible applications with Load Model 1

Load Model 3 is represented by special vehicles which can vary between 600 kN and 3600 kN total load (Table 2). Axle loads of these vehicles can be 150 kN or 200 kN occupying width of one traffic lane, or 240 kN occupying width of two traffic lanes (Table 2). Each axle consists of two wheels (for 150 kN or 200 kN axle loads) or three wheels (for 240 kN axle load), with the contact surface of each wheel amounting to 1, 2 m x 0, 15 m. Axles are spaced at 1, 5 m and can be grouped in two groups 12 m apart. Croatian National Annex prescribes the use of 3000/200 special vehicle. There are two options to apply Load Model 3 vehicles – the one where special vehicles are traveling at low speed (‹ 5 km/h) and the other where they are traveling at normal speeds (70 km/h). When the vehicles are traveling at low speed, Load Model 3 is to be applied in combination with Load Model 1 in such a way that main notional traffic lane (3 m wide) positioned unfavourably on the carriageway should be loaded by Load Model 3 special vehicle loads. Load Model 1 is then applied with its frequent values in each notional lane and remaining area of the bridge, but not less than 25 m from the outer axles of the special vehicle in the main notional lane. Such arrangement gives an increased value of the vertical loads in the main lane where a special vehicle is positioned (occupying 21 m of length) but decreased values of other loads from Load Model 1 (only 40 % of distributed loads and 75 % of axle loads), and it totally omits any loads from Load Model 1 in the length of 71 m (25+21+25 m) in the main notional lane. Therefore, it should be established whether such load configuration (from now on referred to as LM3) results in larger bending moments in the superstructure, either positive or negative, in comparison to those obtained by applying Load Model 1 (from now on referred to as LM1). This will be explored in detail in section 4. If Load Model 3 vehicles are travelling at normal speeds their axle loads should be amplified by a factor φ=1, 4–L/500 (L is the influence length in [m]), and two special vehicles should be positioned in the main notional lane. No other loads are present in this lane. Frequent values of Load Model 1 loads are applied to the other lanes and remaining area of the bridge. This configuration will not be explored in the scope of this paper, since it is not used in practice due to it yielding a significantly larger bending moments than LM1. It is therefore common practice only to evaluate Load Model 3 with low travelling speed restriction, when it is necessary to include it in the design.

Table 2 EN 1991-2 Load Models for road bridges

Total load	Axles of 150 kN	Axles of 200 kN	Axles of 240 kN
600 kN	4 x 150		
900 kN	6 x 150		
1200 kN	8 x 150	6 x 200	
1500 kN	10 x 150	1 x 100 + 7 x 200	
1800 kN	12 x 150	9 x 200	
2400 kN		12 x 200 6 x 200 + 6 x 200 *	10 x 240
3000 kN ***		15 x 200 *** 8 x 200 + 7 x 200 *	1 x 120 + 12 x 240
3600 kN		18 x 200	15 x 240 8 x 240 + 7 x 240 *

Axles are distanced at 1, 5 m, * Axle groups are distanced at 12 m, *** Defined by Croatian National Annex nHRN EN 1991-2:2012/NA

3 Parametric study

3.1 Bridge type, spans, and cross section

For evaluation of bending moments, shear forces, and torsional moments between LM1 and LM3, a 4-span continuous girder bridge structural system was selected (Figure 1). Spans range from 30 to 300 m, up until 100 m spans are changed every 5 m, and for larger spans every 10 or 20 m. End spans are taken smaller (78, 6 % of middle spans) to even the positive bending moments across all spans. The superstructure cross section was chosen as a steel box girder with span to height ratio fixed at 25. Since the cross section is constant, its stiffness does not influence the bending moments distribution.

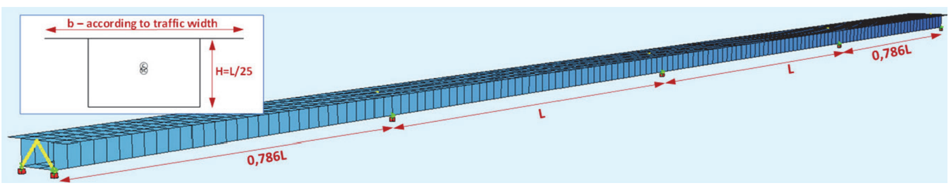


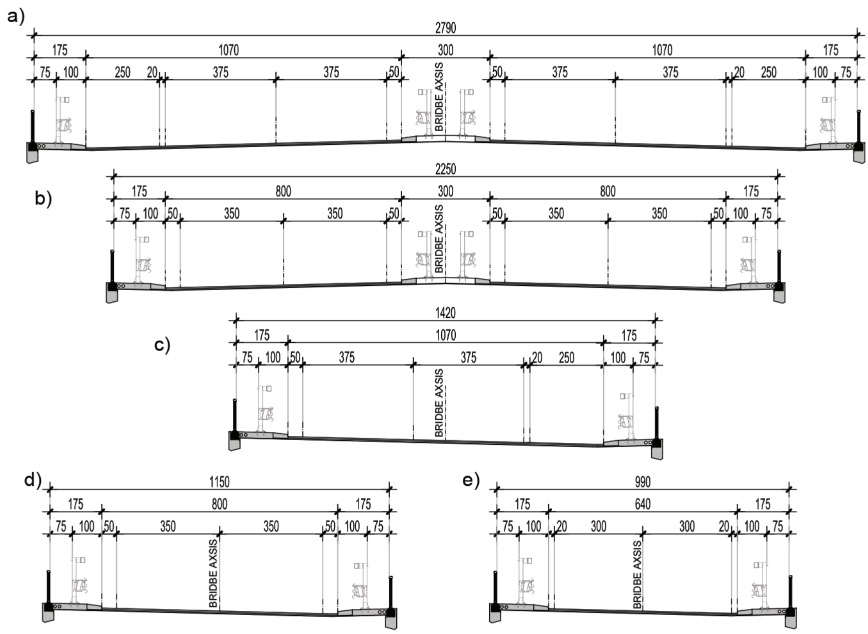
Figure 1 Structural system of parametric study bridge

3.2 Traffic width and load application

Traffic load is greatly influenced by the traffic width of the carriageway and remaining area of the bridge. Therefore, it is important to distinguish between carriageway widths in regard to road category. Road category depends on the speed limit which determines the width of the traffic lanes, edge lanes and shoulders on the carriageway [3]. These values are shown in Table 3 for three different speed limits which were selected for parametric analysis. Speed limit on highways is 120 km/h, on expressways 100 km/h and on local roads 60 km/h. This last one was included only as a reference to determine trend in the results change, but also since it is theoretically possible (not excluded by standards) that a lower road category bridge may carry special vehicles of LM3. Highway and expressway carriageway from Table 3 is only reserved for one driving direction. For a complete road (both driving directions), either twin bridges, or one wide bridge are possible. These will be regarded as a “one driving direction” or “two driving directions” bridges in future discussion.

Table 3 Traffic width and bridge width for road speed limits

Speed limit [km/h]	Traffic width			Bridge width	
	Carriageway [cm]	**Sidewalks / Corridors** [cm]	**Kerbstone + railing** [cm]	**One driving direction** [cm]	**Two driving directions** [cm]
120	250+20+2x375+50	75	100	1420 c)	2790 a)
100	50+2x350+50	75	100	1150 d)	2250 b)
60	20+2x300+20	75	100	-	990 e)



Included in the bridge width are also areas for sidewalk (corridor), safety railings and kerbstones, which are present on both sides of the bridge These were taken as fixed values shown in Table 3. For two driving directions bridge, an additional 300 cm was added as a central dividing area, accommodating kerbstones, safety railings and a middle corridor. All these variations give a total of 5 possible bridge widths according to the speed limit and driving directions (Table 3) which will be analysed and compared for LM1 and LM3 traffic loads. Traveling loads were positioned both longitudinally and transversely by FEM software according to the influence lines for each of the internal forces – positive and negative bending moments, shear forces, and torsional moments. Figure 2 shows LM3 load schemes for a 120 km/s speed limit road bridge with one driving direction (a) and two driving directions (b). Main notional lane is always positioned by the edge of the kerbstone to yield maximum torsional moments. Load Model 3 special vehicle (3000/200) travelling at low speed (‹5km/h) is positioned in the main notional lane, with 25 m behind and in front of the special vehicle remaining unloaded. The rest of bridge (main notional lane, other lanes, and remaining area) is loaded with LM1 loads taken with its frequent values (reduced by factor 0, 4 for uniformly distributed loads and by factor 0, 75 for axle loads – figure 2 does not show this reduction). Number of lanes with axle loads are determined according to carriageway width shown in Table 4. Two lanes (each 3 m wide) are possible only for a one directional 100 km/h speed limit bridge and for 60 km/h speed limit bridge. All other bridges can accommodate three lanes with axle loads.

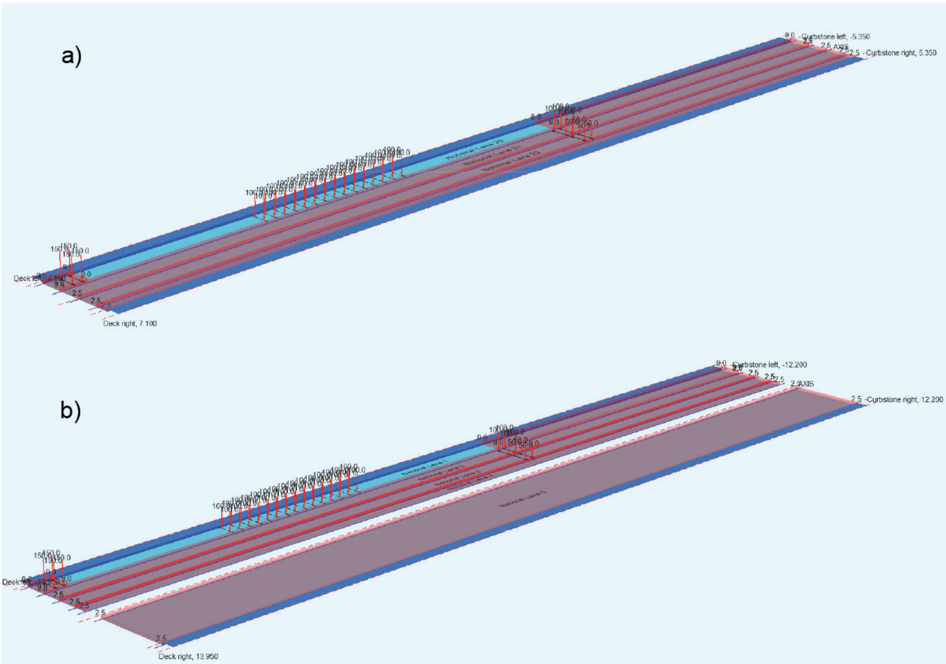


Figure 2 a) LM3 traffic load with 3000/200 special vehicle for one driving direction bridge; b) and two driving direction bridge

4 Comparison of results

Internal forces for LM1 and LM3 traffic loads are compared at ULS (traffic loads multiplied by a factor of 1, 35). Positive and negative bending moments for both load Models are shown in Figure 3 (one driving direction, speed limits 120 km/h and 100 km/h) and Figure 4 (two driving directions, speed limits 120 km/h, 100 km/h and 60 km/h). Left side parts of the figures show direct comparison between factorised positive and negative bending moments. Although the analysis was done for spans up to 300 m, presentation is given only for spans from 30 to 130 m, since this range area was proven as the relevant one for this comparison. For spans larger than 130 m, LM1 bending moments are always much larger. Right side parts of the figures show the percentage difference of LM3 in regard to LM1 bending moments calculated as:

$$\Delta M_y[\%] = (M_y^{LM1} - M_y^{LM3}) / M_y^{LM1} \tag{1}$$

Where M_y^{LM1} and M_y^{LM3} are bending moments due to LM1 and LM3, respectively. A negative difference shows where the LM3 moments are larger, and therefore LM3 is governing for the design. Table 4 show the exact percentage difference for each of the spans.

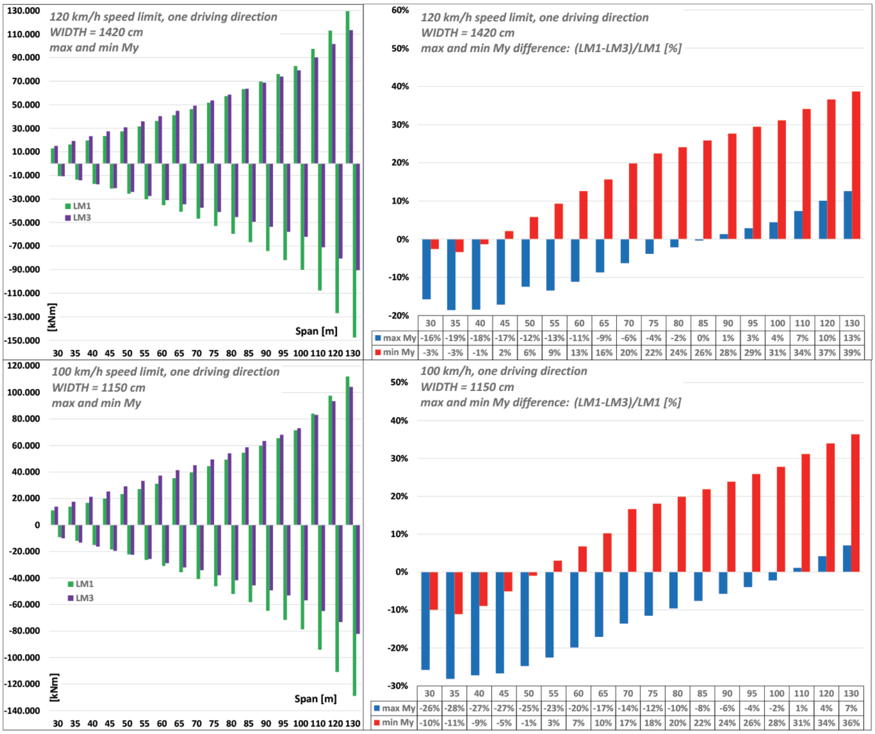


Figure 3 LM1 and LM3 bending moments comparison for one driving direction bridges, for spans from 30 m to 130 m

Shear forces comparison was also made but it is not presented here since the difference follows the same trend as the positive bending moment, i.e., areas where LM3 positive bending moments are larger is the same as the area where LM3 shear forces are larger (the difference percentage is also similar).
Since this analysis is done for a closed box girder section, it is important to emphasise that girder bending moments can be larger for an open (ribbed) section of the bridge. For open sections, an additional bending moment for each girder derives from torsional effect on the section (warping) when asymmetrical load is applied. To evaluate this effect, traffic load schemes were always placed in the most asymmetrical position (main notional lane alongside kerbstone). It was observed that the torsional moment is always larger for LM3 for all bridge widths up until the 130 m bridge span. Therefore, it can be concluded that for open bridge sections, the influence of torsion may yield larger bending moments for edge girders, depending on their position in regard to main notational lane. This effect must be evaluated on case-to-case basis and the comparison in Figures 3 and 4 is no longer valid.

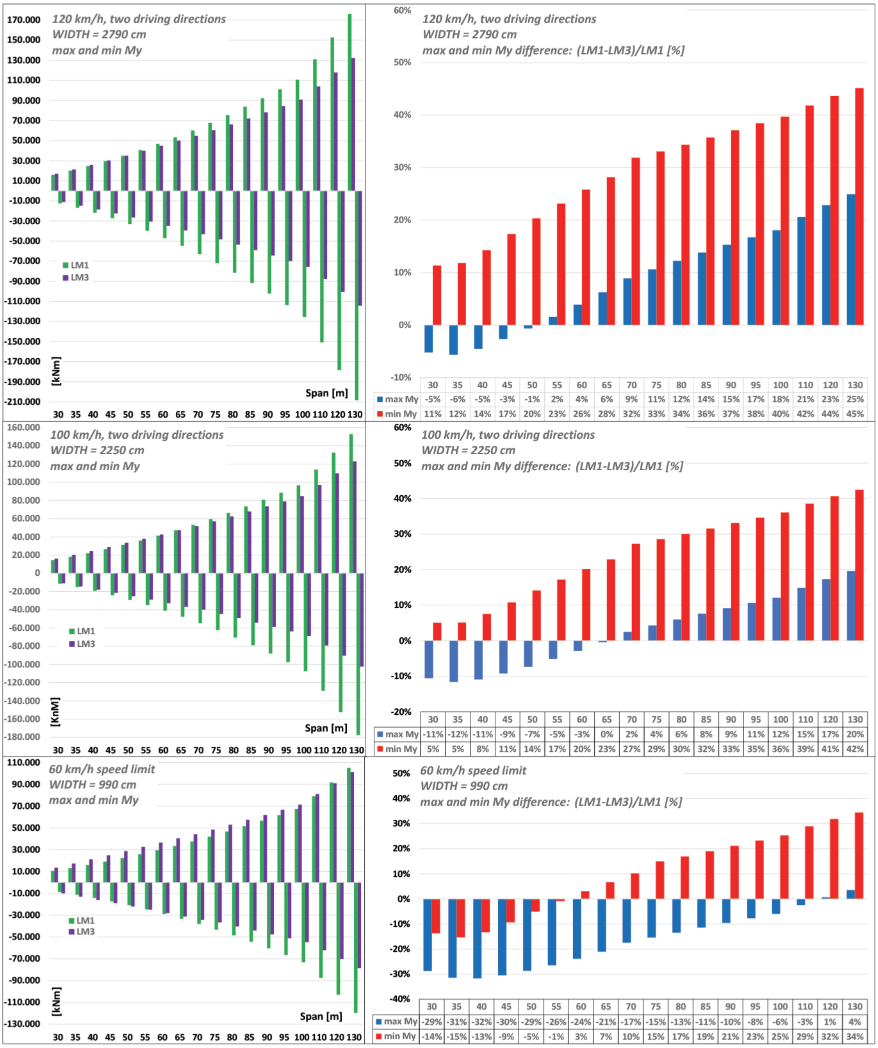


Figure 4 LM1 and LM3 bending moments comparison for two driving direction bridges, for spans from 30 m to 130 m

Table 4 Range of spans and bridge widths where LM1 or LM3 are governing

	Width [cm] \ Span [m]	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	110	120	130	140	150
max M_y, max $\|V_z\|$	2790	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2250	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1
	1420	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1	1	1	1
	1150	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1	1
	990	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	1	1	1	1
min M_y	2790	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2250	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	1420	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	1150	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	990	3	3	3	3	3	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Overall	2790	1&3	1&3	1&3	1&3	1&3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2250	1&3	1&3	1&3	1&3	1&3	1&3	1&3	1&3	1	1	1	1	1	1	1	1	1	1	1	1
	1420	3	3	3	1&3	1&3	1&3	1&3	1&3	1&3	1&3	1&3	1&3	1	1	1	1	1	1	1	1
	1150	3	3	3	3	3	1&3	1&3	1&3	1&3	1&3	1&3	1&3	1&3	1&3	1&3	1	1	1	1	1
	990	3	3	3	3	3	3	1&3	1&3	1&3	1&3	1&3	1&3	1&3	1&3	1&3	1&3	1	1	1	1

5 Conclusion

Parametric analysis showed that LM3 yields larger positive bending moments and shear forces for spans up to 110 m, and larger negative bending moments for spans up to 55 m, depending on the bridge width. For bridges with wider carriageway, LM1 is governing at smaller spans, from 55 m for positive bending moments and for all spans for negative bending moments. Table 4 shows areas of spans and bridge widths in which either LM3 (label "3" in Table) or LM1 (label "1" in Table) are governing. Overall, when both positive and negative bending moments are evaluated for a complete bridge design, Table 4 shows areas when both load Models must be included in the design (label "1&3" in the Table). For open (ribbed) section bridges, warping effect from torsion can produce larger bending moments from LM3 in edge girders for spans up to 130 m, and therefore they must be additionally evaluated.

References

[1] HRN EN 1991-2:2012, Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges (EN 1991-2:2003+AC:2010), Croatian Standards Institute, Zagreb, Croatia, 2012.

[2] HRN EN 1991-2:2012/NA:2012, Eurocode 1: Actions on structures – Part 2: Traffic loads on bridges-National Annex, Croatian Standards Institute, Zagreb, Croatia, 2012.

[3] NN 110/2001 (1829): Pravilnik o osnovnim uvjetima kojima javne ceste izvan naselja i njihovi elementi moraju udovoljavati sa stajališta sigurnosti prometa, Ministry of the Sea, Transport and Infrastructure, Croatia, 2001.