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Belgian Procedure for the Evaluation of Existing Steel Bridges

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Summary

In Belgium the gap between actual traffic loads and the code loads used for the design of existing bridges is very large. In the draft of the National Application Document (NAD) of ENV 1991-3 a bridge classification useful for a bridge manager is foreseen. This paper presents the background of this classification and a work in progress now in Belgium, concerning the development of methodologies for design and assessment of existing road bridges under actual traffic conditions.

1. Introduction

Road traffic has changed significantly in the last 40 years, particularly in Europe. This change consists of an increase in the number of lorries, and of the weight of the lorries, in the advent of tandem and tridem axles, and more recently in the increase of the percentage of loaded vehicles. Existing bridges have been designed taking into account load models corresponding, in the best situation, to the loads of lorries allowed at that time or to old military loads. The question of the reliability and the durability of existing bridges arises for all bridges, but mainly if the gap between the loads of the models and the actual traffic is high. This is the case in Belgium [1]. During the development of the Eurocode ENV 1991-3 - Traffic loads on bridges - a lot of traffic loads have been recorded and used in order to define scientifically the characteristic loads and the fatigue loads [2] [3].

Many Belgian bridges do not satisfy the ultimate limit state and the fatigue resistance following requirement of the design Eurocodes in preparation (ENV 1992-2 for concrete bridges [4] and ENV 1993-2 for steel bridges [5]) when the loads defined in ENV 1991-3 are considered, but looking also the real traffic conditions during the supposed remaining bridge life. In order to develop a procedure for the classification of the existing bridges following the Belgian National Application Document of ENV 1991-3 [6] case studies are performed.

The aim of this paper is to present the background and the development of the classification, in the frame of the NAD.

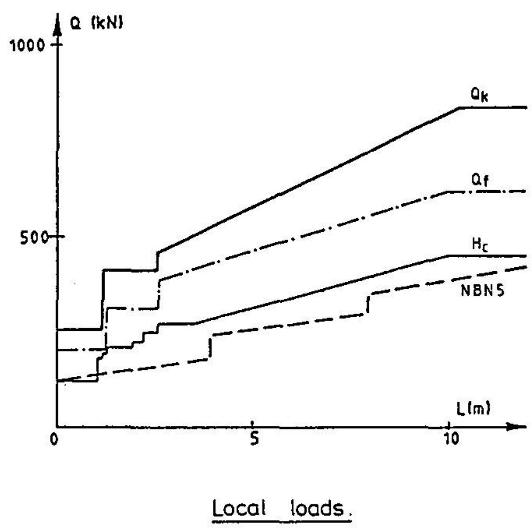
2. Design loads

Since 1952 to 1993, the Belgian bridges have been designed considering the traffic loads defined in the code NBN 5, where in each lane a five axles vehicle of 320 kN (120 + 2 x 60 + 2 x 40) and a distributed load of 4 kN/m² were foreseen, these loads being multiplied by a dynamic factor generally not higher than 1,25 [1]. A vehicle, composed by 3 axles of 200 kN, spaced by 1,5 m and 6 m located on one slow lane, without any other life load, was foreseen as an exceptional vehicle, and was used in the design of some motorway bridges. The code loads are very low, and some times, since 1968, below the loads allowed by the Belgian Highway Code, i.e. : 120 kN for one single axle, 160 to 200 kN for a tandem axle, 200 to 270 kN on a tridem axle and 440 kN on a vehicle.

A new code has been developed in Belgium and published in 1993, the NBN B03-101, where the axle loads are increased (2 x 150 kN on each lane), the distributed load is a little lower (3,5 kN/m²), and a single heavy vehicle is foreseen alone on the bridge (6 x 150 kN) [7]. This code has been used for some bridges since 1986 [8].

Figure 1 compares the total load Q located on a lane, 3,5 meters wide and L meters long, corresponding to NBN 5, to the loads given by the vehicles allowed to run in Belgium HC, to the actual vehicle loads running on European motorways with a return period of one week Q_f (frequent load) and a return period of 1000 years Q_k (characteristic load) [9].

Figure 2 compares the bending moment, dynamic effect included, at the mid-span of a simply supported beam supporting one traffic lane, obtained under several loads. The ratio of the load effect obtained by one load and the NBN 5 loads may reach 1,4 for the allowed loads HC, 2,1 for the frequent loads of a heavy highway traffic Q_f, and 3,0 for the characteristic loads of this traffic or the loads of the main load model of ENV 1991-3 EC. The highest ratio corresponds to short spans (5 to 10 meters), and the ratio decreases when the span length increases. These conclusions are also valid for a lot of other influence lines [10].



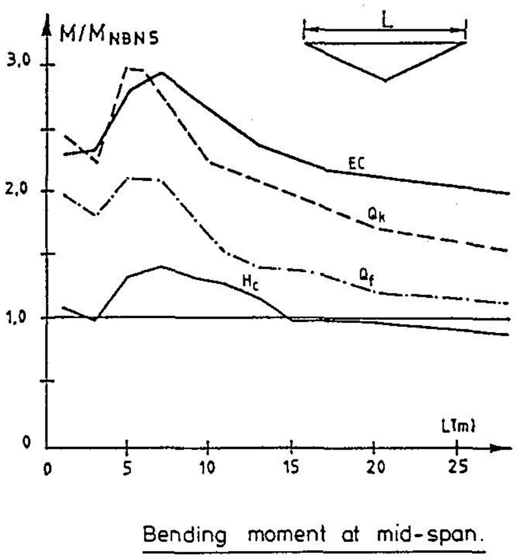


Fig. 1 Local loads *Fig. 2 Bending moment at mid-span*

As the same loads are foreseen on each lane by the NBN 5 code and the loads foreseen in ENV 1991-3 are decreasing with the number of lanes, the ratio between the load effects is below 3 when two lanes are considered, and from 4 lanes the NBN 5 loads produce higher load effects than the Eurocode loads. Elsewhere, the frequent loads are lower than the NBN 5 loads on two lanes, longer than 14 meters, i.e. in main girders (see Table 1).

Number of lanes	NBN 5	ENV 1991-3	
		Q_k	Q_f
1	320 + 14 L	600 + 28 L	450 + 11 L
2	640 + 28 L	1000 + 37 L	750 + 15 L
3	960 + 42 L	1200 + 46 L	900 + 18 L
4	1280 + 56 L	1200 + 54 L	900 + 21 L

Table 1 *Total loads in kN and kN/m (lane width : 3,5 m., lane length : L > 16 m)*

3. Definition of the Belgian bridges classification

Existing bridges have not been designed for the Eurocode loads. Nevertheless, failure produced by traffic loads are very rare up to now, because a high safety factor is included in the design, so that the actual reliability of the bridges is comparable in Belgium and in the other European countries [11]. The Belgian National Application Document of ENV 1991-3 is now drafted to define 4 classes useful for the bridges managers [6] [12].

The classes correspond to a gradual reduction of the reliability in the ultimate limit state, where the characteristic loads and the safety factor decrease :

- Class 1 concerns the design of new bridges. The loads correspond to the Eurocode loads, with two little modifications : the heavy loads foreseen on lane one are applied inside the limits of the actual carriageway, excluding hard strips, and no axle loads are foreseen on lane 3 ($\alpha_{Q3} = 0$).
- Class 2 concerns repair of bridges. Lane one should be located on the notional lanes, excluding hard shoulders. The loads are reduced to the infrequent loads : $\alpha_Q = \alpha_{q1} = 0,8$, but $\alpha_{qi} = 1$ for $i > 1$. This reduction corresponds to a shorter return period (1 year instead of 1000 years) and to a good roughness of the pavement. Under a heavy highway traffic the reliability factor of the bridge reaches here 4,7 instead of 6 for class 1.
- Class 3 concerns the existing bridges where no traffic limitation should be required. The loads correspond to the loads defined for class 2, but here the position of lane 1 may be imposed. For local effects, that result from the action of one single vehicle alone, the set of 5 lorries defined in Fatigue Load Model 2 is considered, because this model is more accurate in this case (table 3). If FLM 2 is used, the load of one axle should be multiplied by a dynamic factor $\Delta\varphi = 1,3$. For class 3, a reduction of the safety factors γ_G and γ_Q is admitted, so that the reliability factor decreases to 4, that corresponds to the ISO Recommendations [13].
- Class 4 concerns existing bridges, where traffic is limited. Here, the work in progress should propose practical solutions concerning the loads limitations.

Table 2 summarises the definition of the bridge classes in discussion for the Belgian NAD.

Class	1 European	2 Belgian	3 acceptable		4 limited traffic	
Load models	LM1 and LM2	LM1 and LM2	LM1	FLM2	LM1	FLM2
$\alpha_{Q1} = \alpha_{Q2} = \beta_Q$	1	0,8	0,8	1	C_Q	C_Q
α_{Q3}	0	0	0	-	0	-
α_{q1}	1	0,8	0,8	-	C_q	-
α_{qi} (i > 1)	1	1	1	-	C_q	-
γ_G	1,35	1,35	1,1		1,1	
γ_Q	1,35	1,35	1,2		1,2	

***Table 2** NAD Bridge classes*

4. Durability

The bridge classification has been defined in function of the ultimate limit state design. But the existing bridges have proved that they are able to support the actual traffic loads. Following the requirements explained above, an element on an existing bridge presents a lower reliability if it is admitted in class 3 instead of class 2. The bridge manager has to receive an answer to the question : how long should the resistance be sufficient to avoid collapse ? This question receives an answer by a fatigue assessment.

Up to now, few fatigue assessments have been performed on existing bridges. The fatigue life depends on the stress ranges $\Delta\sigma$ resulting from the traffic loads. Therefore the expected fatigue life is longer for an element admitted in class 2 than in class 3.

A fatigue life assessment needs information concerning the traffic in the past and in the future. It should be possible to collect data on the traffic running on the bridge today, by counting the number of the main types of lorries, and also by recording the axle loads of the vehicles. In some cases, the loads may be estimated from existing data and from the values given in the Eurocode ENV 1991-3 for a set of 5 lorries (table 3). In all cases estimations are needed for the past and the future.

For some roads, traffic data is available. This data can be used for evaluating fatigue life by applying the procedure presented at the IABSE Symposium in San Francisco [14]. The accuracy of the assessment depends on the accuracy of the available data.

5. Classification of existing bridges

The comparison of the loads prescribed by the Belgian code NBN 5 and the Eurocode ENV 1991-3 shows that existing bridges supporting heavy motorway traffics present weak points mainly located at the decks, concrete slabs or orthotropic steel decks, while main girders of large bridges should present a high safety factor.

The evaluation of an existing bridge starts by checking all sections and details, where some should satisfy the requirement of class 1 or class 2.

If that is not the case, the requirements of class 3 are to be checked. In general the infrequent loads of LM1 are considered and, only if the load effect analysed may result from the action of one vehicle alone on the bridge, the set of lorries (FLM2) is to be considered.

If the requirements of class 3 are not verified, the bridge falls in class 4 and traffic limitations are needed, if the bridge has to be maintained in service as long as possible with acceptable safety conditions. The evaluation should lead to one or several of the following limitations :

1. position of the slow lane, where the heaviest lorries are running,
2. restriction for crossing and overtaking of lorries,
3. distances between lorries in one lane,
4. gross weight of a vehicle.

These limitations create different types of hindrance to the traffic.

The elements presenting a bad classification and a short life time should be pointed out, and the bridge manager should pay particular attention to these elements during the periodical inspections. On the basis of all this information the bridge manager can make the right decision : changing the traffic flow conditions, limiting the vehicle loads, rebuilding the bridge, etc.

Class 4 may limit the gross weight of the lorries, because the ultimate limit state is not satisfied for some load effects, by considering the vehicles of FLM2 (Table 3). The limitation may result from the action of a single axle (190 kN), a tandem axle (280 kN), a tridem axle (360 kN) or the gross weight (630 kN). The definition of the highest vehicle gross weight should take into account two points :

1. the lightest vehicle comprising the critical axle :
   - a two-axled vehicle of 280 kN, if the limitation results from a simple axle,
   - a three-axled vehicle of 360 kN, if the limitation results from a tandem axle,
   - a half trailer of 630 kN, if the limitation results from a tridem axle.
2. the weight of the vehicles allowed to run in Belgium are around 40 % lower than the weight of the vehicles of FLM2.

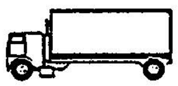
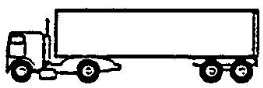
	Vehicle	EC : FLM2	Belgium : HC		EC/HC
1		90 190 280	70 120 190		- 1,58 1,47
2		80 140 140 360	60 100 100 260		- 1,40 1,40 1,38
3		90 180 120 120 120 630	50 120 90 90 90 440		- 1,50 1,33 1,33 1,33 1,43
4		90 190 140 140 560	70 120 100 100 390		- 1,58 1,40 1,40 1,44
5		90 180 120 110 110 610	50 90 100 100 100 440	70 120 70 90 90 440	- - - - - 1,45

Table 3 *Vehicle loads*

6. Need for case studies

The definition of the bridge classes is introduced in the draft of the Belgian NAD of ENV 1991-3. In annex M of the NAD the rules described above are in discussion. In order to finalise the draft, a reliability study is needed, based on case studies.The open questions concern the classification of existing bridges in class 3 and class 4.

The questions to solve for class 3 concern :
- the factor to apply on the main load model (LM1) :
  on the axle loads : $\alpha_Q = 0{,}7$ to $0{,}8$
  on the distributed loads : $\alpha_{q1} = 0{,}4$ to $0{,}8$
  $\alpha_{qi} = 0{,}4$ to $1{,}0$
- the definition of a dynamic effect to apply on some axles of FLM2,
- the transverse position of the loads of lane 1 or FLM2 : everywhere on the carriageway, or on the actual slow lane,
- the values of the safety factors : $\gamma_G = 1{,}1$, $\gamma_Q = 1{,}2$.

The questions to solve for class 4 concern :
- the kind of limitation,
- the definition of admitted loads,
- the position of the admitted loads.

The bridges for the case studies in Belgium are chosen between bridges built during the last 30 years in the frame of the development of the motorway network. The evaluation is performed in several successive steps using the modern design means available :
1. the main load model, LM1 of ENV 1991-3 is used in order to check the requirements of the design Eurocodes for ULS [4] [5], that leads to class 1 or class 2,
2. for elements that don't satisfy the condition above, the requirements of class 3 are checked,
3. for elements that don't satisfy the condition of class 3, traffic limitations should be defined as explained for class 4 in section 5,
4. a fatigue assessment is performed following the design Eurocodes [4] [5],
5. taking into account all data available, a fatigue assessment is performed following the procedure described in [14] and [15] : in this frame the following fatigue load models are used :
   - for concrete slabs : FLM3 or FLM4
   - for orthotropic steel decks : FLM2 or FLM4
   - for main girders in steel : FLM1 or FLM3
   The actual frequency of the type of vehicles should be introduced directly in FLM4, and by the means of a correction factor in FLM3.
   It has been shown that, if the number of vehicles per year is very high, FLM1 or FLM2 leads to less severe and more realistic conclusions than FLM3 [15] [16],
6. for some important elements, detailed ultimate limit state analysis and fatigue assessment should be performed by considering complete load spectra available for real recorded traffic with the means of a simulation programme [9]. This analysis is needed in order to find the right conclusions for the definition of the bridge classes.

7. Work in progress

A research programme is running now in Belgium in order to develop a methodology for design and reassessment of bridges, with the participation of the Universities of Liège and Ghent. The choice of the bridges to analyse has been made in conjunction with the Belgian Authorities, members of the group, which provide for the detailed construction drawings. The choice will be made for bridges most sensitive to the increase of the traffic loads, where consequently the security could be the least, and where the life duration could be the shortest.

Using a previous study, the three next bridge types are retained :

1. Slab and beams bridges, with prefabricated prestressed concrete beams, with or without bracing, where the slab, beams and bearings will be examined.
2. Frame bridges with or without earth overloading, with deck and walls to be examined.
3. Steel bridges with orthotropic deck, with principally deck and bracing to be examined.

The results obtained for slab and beams bridges should lead to conclusions concerning some composite bridges.

Three steel bridges should be analysed :
- one movable bridge with open stringers,
- one box girder bridge with trapezoidal stringers,
- one box girder bridge with open stringers.

More information is given in [17].

The objectives of the case studies will be the following :

1. to develop a detailed calculation procedure, applicable to the reassessment of the existing bridges and for the design of new bridges, so the bridge engineers would have completely treated examples at their disposal ;
2. to show shortcomings of the Eurocodes being prepared and to bring up solutions ;
3. to show eventual difficulties in applying some prescriptions, with possible solutions ;
4. to test alternative procedures, and to highlight their advantages ;
5. to test the fatigue calculation described in Bruls' doctorate thesis [9], to propose formal rules for Eurocodes ENV 1992-2 and 1993-2 [4] [5] and to specify the cases where fatigue calculation is needed ;
6. to define a procedure for the estimation of the life duration of an existing bridge, related to the peculiar traffic breakdowns using the bridge since its erection ;
7. to study the importance of the dynamic magnification included in the Eurocode 1.3. loads in the particular case of the deck of frame bridges with an earth overloading [2],
8. to show the weak points of the existing Belgian bridges and to propose solutions to the bridge managers for increasing the life duration ;
9. to bring out conclusions about the design of the examined bridge cases, and to propose eventually more performing solutions for the design of new bridges ;
10. to define the best system of road-signs able to express the strength requirements.
11. as the fatigue calculation of bridges is not yet generally used, it is useful to precise the conditions where no fatigue calculation is needed.
12. furthermore, for simple and frequent structure elements, solutions completely worked out will be given in tables.

8. Conclusions

This paper has shown the gap between the actual traffic loads and the code loads used up to now in Belgium for the design of bridges. A bridge classification for existing bridges is in discussion in the frame of the NAD of the Eurocode ENV 1991-3 - Traffic loads on bridges. In order to solve practical problems of such a classification, a research programme supported by the Authorities is in progress. Case studies are being performed on bridges that are most influenced by the high axle loads of the actual traffic. The case studies should show where and in which type of bridge the weakest points are located, and should give a better idea on the risk of damage. This information is needed for the bridge management in order to avoid structural failure and traffic restriction, for example. Although the first results are more optimistic than the direct comparison of the loads, we have to wait for the research work to be completed (1998) before drawing the final conclusions.

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