BRIDGES' RELIABILITY BETWEEN SPECIFIC LOADING CASE AND REALISTIC TRAFFIC

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Abstract - *In this paper the reliability of reinforced concrete bridges is studied in the flexural limit state. The influence of traffic load model on the reliability index will be discussed. For this purpose, the reliability index is calculated for a bridge set under both standard truck loading as presented by Fascicule 61 from the French code and realistic traffic loading based on recorded weigh-in-motion data. The results show that the use of loading standard to predict the structural reliability of the bridges may be over conservative and leads to very low values of the reliability indices.*

Key Words: bridge, reinforced concrete, reliability, traffic, weigh-in-motion.

1. INTRODUCTION

The particularity of infrastructures consists not only in their special structures, but also in the applied load which can be stochastic in some cases such as for road bridges. Under the undefined loading conditions, the evaluation of road bridges may vary considerably from a case to another. The purpose of this paper is to evaluate the reliability of reinforced concrete bridges under both standard and stochastic loading cases. So, the standard truck of system Bc defined in the Fascicule 61[1] is considered in addition to realistic traffic data recorded in European weigh-in-motion station[2].

In such evaluation problems, the reliability theory seems the best choice to deal with the uncertainty of the different parameters. This theory was used in the beginning for software assessment then was transmitted later to the field of structural engineering[3]. It has been largely applied to evaluate the reliability of highway bridges among the civil engineering structures[4].

In order to provide a better understanding of the impact of traffic load on bridge reliability level, a set of single-span simply supported bridges is used for the application. These bridges have different length L, width w and number of girders G.

2. RELIABILITY THEORY

Structural reliability is the probability that a structure will not attain a specified limit state (ultimate or serviceability) at a given period of time. Each limit state can be defined by a particular form of a function called the limit state function or failure function. The general form of a limit state function can be divided into a resistance term R and a load effect term S as follow [5]:

$$G = R - S \quad (1)$$

The limit state function is expressed in terms of the basic variables X which affect the structural performance, so we obtain the following expression of the limit state function:

$$G(Xi) = R(X1, X2, ..., Xn) - S(DD, LL, ...) \quad (2)$$

Where R is the resistance function of system of random variables which influence the limit state, for example for a concrete section these variables are related to material properties and section dimensions, and S is the random function of load effects resulting from dead loads DD and live loads LL.

This definition implies the splitting of the space into two zones: the reliable zone and the failure zone as shown by **Fig-1**. The boundary between these two subspaces is a hyper surface of equation G(X) which is called the failure surface (i.e. R=S). Thus, the probability that G(X) < 0 corresponds to the probability of failure *pf* of the section.

Due to the high number of variables in the limit state function, the analytical calculation of the failure probability or of the reliability index is very complicated.

In this study the first order reliability method or FORM is used to calculate the failure probability because it leads to accurate results [6]. By using FORM method the performance degree can be estimated in term of reliability index.

3. BENDING LIMIT STATE

In this study, the flexural limit state is considered with the following limit state function:

$$G(X_i) = M_R(A_s, f_{ck}, f_{yk}, d, b_0, b_a, ...) - M_a(M_{ss}, M_{traffic}, ...) \quad (3)$$

where M_R is the resistance bending moment and M_a is the applied moment resulting from traffic $M_{traffic}$ and superstructure M_{ss}.

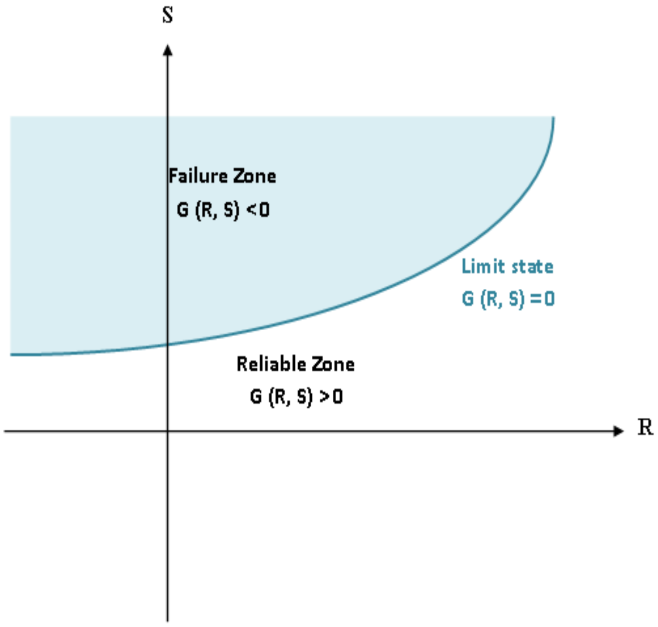

Fig -1: Illustration of the reliability concept

3.1 Calculation of the resistance moment

The resistance bending moment in case of T-section is deduced from the rectangular stress distribution given by Eurocode [7]:

$$M_R = A_s \times (f_{yk}/\gamma_s) \times (d - s/2) \quad (4)$$

$$= A_s \times (f_{yk}/\gamma_s) \times (d - (A_s \times (f_{yk}/\gamma_s)) / 1.134\, f_{ck}\, b_0); \text{ neutral axis in the flange}$$

$$= A_s \times (f_{yk}/\gamma_s) \times [d - (A_s\, (f_{yk}/\gamma_s) - 0.567\, f_{ck}\, (b_0 - b_a)\, h_f) / 1.134\, f_{ck}\, b_0]; \text{ neutral axis in the web}$$

where A_s is the reinforcement area , f_{yk} is the yield strength of reinforcement, γ_s is a partial factor for reinforcing steel =1.15, s is the depth of rectangular stress bloc, f_{ck} is the characteristic concrete compressive strength, d is the effective depth of the cross section, b_0, b_a and h_f are dimension parameters shown in **Fig-2.**

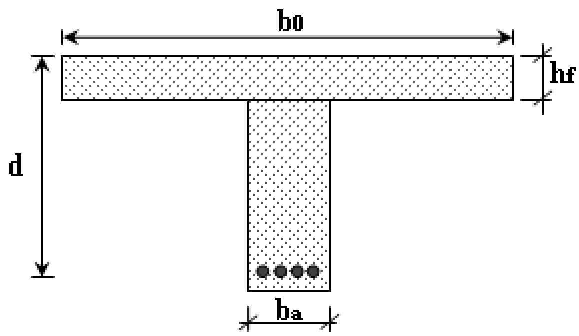

Fig -2: Cross section of the girder

3.2 Calculation of the applied moment

The applied moment is calculated once by considering trucks from system Bc described in the Fascicule 61 of the French code and another time by considering realistic traffic from weigh-in-motion WIM data recorded in some European sites.

3.2.1 System Bc

The Fascicule 61 presents the calibrated traffic load models used for the design of highway bridges. In this study we will consider the system Bc for the reliability evaluation. The number of trucks Bc in a single queue depends on the bridge length. Trucks are positioned laterally in order to obtain the most critical effect on the studied girder. The system Bc is presented in **Fig-3**.

3.2.2 Simulated traffic

The reliability of the bridge set is also evaluated according to WIM data recorded on the Mattstetten motorway in Switzerland in the past 10 years [2]. Based on these data, heavy vehicles or trucks (vehicles with weight more than 3.5 t) can be grouped in twelve classes with number of axles ranging from 0 to 6. The distribution of gross vehicle weight for each vehicle class is fitted to bimodal beta distribution. An example of the gross vehicle weight generation for the vehicle class 112r is shown by **Fig-4.** Monte Carlo simulation is then used to generate vehicle queues according to the given distribution for each vehicle class.

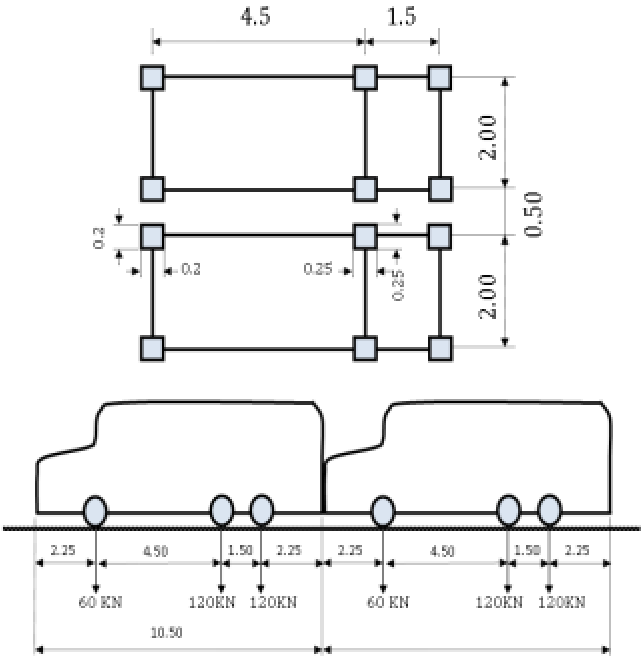

Fig -3: In plan and side views of system Bc

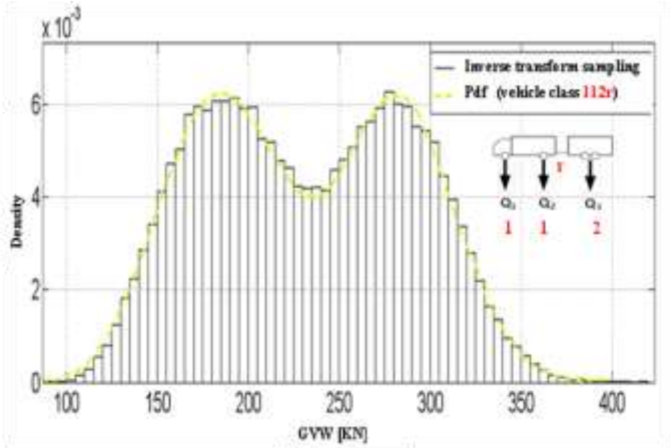

Fig -4: Gross vehicle weight distribution for the vehicle class 112r

3. RESULTS AND CONCLUSION

The reliability indices are calculated for a set of 21 single-span simply supported bridges. Each bridge is designated by its length L, width w and number of girders G. The bridges are chosen to be representative of the most common existing reinforced concrete bridges.

The limit state function given by equation (3) is used in the reliability calculation for the flexural limit state. First order reliability method, FORM, is used to calculate the reliability indices using a Matlab Toolbox.

The different distributions of random variables included in the reliability calculations are given by **Table -1**.

Table -1: Distribution of random variables

Description	Variable	Distribution	Mean	COV	Ref.
Area of reinforcement	A_s	Normal	Nominal	0.035	[8]
Effective height of section	d	Normal	Nominal	0.0229	[9]
Yield stress of steel	f_{yk}	Normal	600 (MPa)	0.1	[10]
Concrete compression strength	f_{ck}	Normal	40 (MPa)	0.15	[10]
Dead load moment	M_{DL}	Normal	Nominal	0.07	[9]
Superstructure moment	M_{SS}	Normal	Nominal	0.1	[9]
Live load moment	M_{LL}	Normal	Nominal	–	–

The calculated reliability indices for the bridge set are given by **Fig -5**. A large difference can be noticed between the reliability indices under truck Bc and those under realistic traffic data. The increase of the reliability index, when considering realistic traffic data, is given in **Fig -6** for all the bridges.

According to Error! Reference source not found. the highest increase of the reliability index is about 218% for the bridge L8w9.5G6 under realistic traffic data. The average increase is about 140% for all the bridges.

So, the standard truck loads used for the design of highway bridges are general and don't represent the reality. The use of these standard truck loads for the evaluation purpose may lead to underestimate the reliability. So, early intervention on maintenance will be expected for the strengthening and structural upgrades. In other words, it is a waste of money with little efficiency.

It is not cost effective to rely on design traffic loads for the structural evaluation of road bridges. Each bridge has its special loading conditions. Traffic monitoring constitutes an important step to get more accurate results about the structural performance.

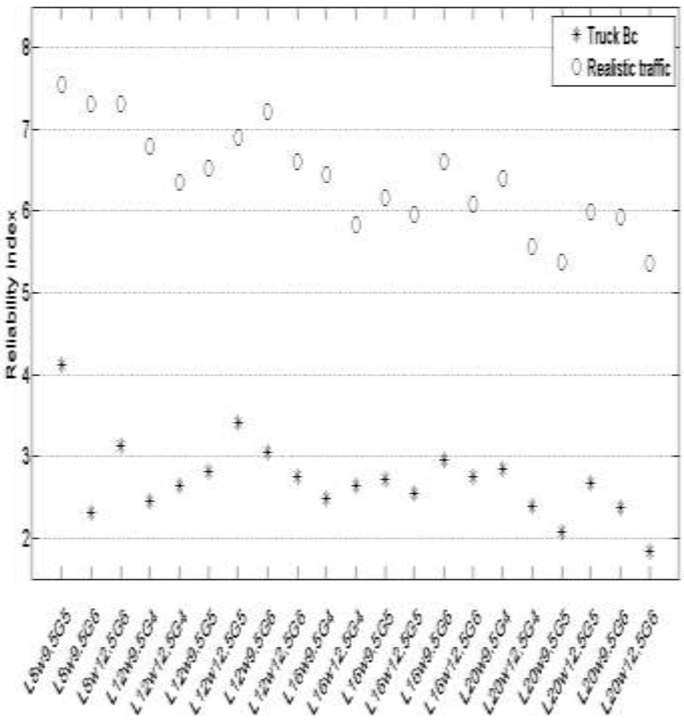

Fig -5: Reliability indices for the bridge set under truck Bc and realistic traffic

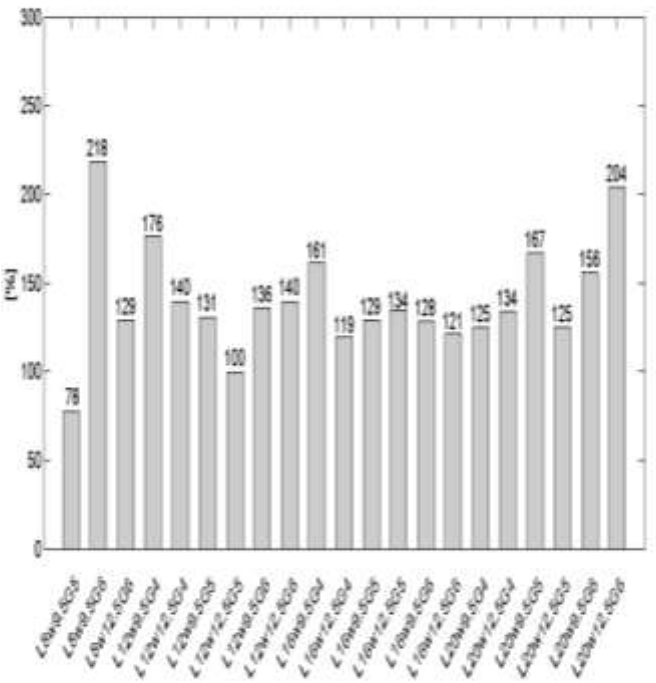

Fig -6: Percentage increase between reliability indices under realistic traffic and standard truck Bc

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