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Probabilistic Response of Reinforced and Prestressed Bridge Cross-Sections

Réponse probabiliste de sections de ponts en béton armé et précontraint

Wahrscheinliche Belastungsantwort von vorgespannten Stahlbetonbrückenquerschnitten

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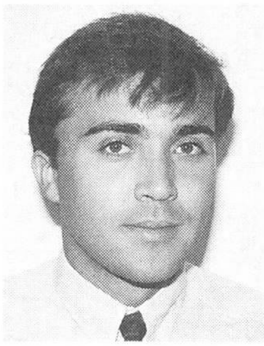

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SUMMARY

This paper is concerned with the recent available data obtained for modeling geometrical and material uncertainties for concrete bridges, and the use of these models to obtain the probabilistic response of reinforced and prestressed concrete bridge cross-sections. A parametric analysis is performed for explanning the basic features to evaluate the real response of existing bridges for reliability analysis and identifying the more relevant parameters for quality control or testing tasks.

RÉSUMÉ

L'article résume les données obtenues pour la modélisation de l'incertitude relative à la géométrie et les propriétés des matériaux employés dans la construction des ouvrages d'art en béton armé et précontraint, et leur utilisation pour la détermination de la réponse probabiliste de sections transversales de ponts. Une analyse paramétrique permet de mettre en évidence les principaux critères pour l'évaluation de la réponse réelle des ponts existants, d'analyser la fiabilité, et d'identifier les paramètres les plus importants à considérer dans le contrôle de qualité ou la rationalisation d'essais.

ZUSAMMENFASSUNG

Dieser Artikel beschreibt die neuesten verfügbaren Daten, die für die Modellierung von Geometrie- und Materialunsicherheiten bei Betonbrücken bestimmt wurden und die Verwendung dieser Modelle zur Bestimmung der wahrscheinlichen Belastungsantwort von vorgespannten Stahlbetonbrückenquerschnitten. Einer Parameterstudie wird durchgeführt, um die Hauptmerkmale der Bestimmung der wirklichen Belastungsantwort von existierenden Brücken sowie deren Zuverlässigkeitsanalyse zu erklären, ausserdem bestimmt sie die wichtigsten Parameter für die Qualitätskontrolle oder vorzunehmende Tests.

1.- INTRODUCTION

In order to obtain an accurate reliability analysis of existing or future structures it is necessary to use more realistic models for materials, geometrical variabilities and structural analysis, taking into account the non-linear behavior [1]. The use of analytical or semi-empirical relations for the obtention of the bridge section resistance available in design code must be improved.

The statistical parameters of geometrical variability and the uncertainties in the physical properties of the involved materials has been normally derived for the available literature data for building [2]. Nevertheless, in bridge construction both the construction considerations stipulated are different and more accurate techniques are used. Thus, a higher quality construction can be obtained. On the other hand, the available data are not directly suitable for other countries with different modes of construction or quality control. So that, more information should be obtained.

Recently, numerical methods to evaluate the structural cross-section response of prestressed and reinforced girders have been developed to obtain ultimate moment and shear responses and the moment-curvature relationship [3], and they has been widely used for bridge evaluation and code calibration [4]. There is a need for the analysis of other concrete bridge typical cross-sections.

2.- GEOMETRICAL VARIABILITY

The parameters involved in the geometrical shapes, alignment, configuration of building components are subjected to uncertainties due to different sources: form works, placement of reinforcing or prestressing steel, placing of concrete, assemblage procedures, etc. Geometrical variations affect both, the self weight of the structural elements, (dead load) and the cross section response (effective depth, concrete covers, etc.) Most of the different literature data available has been collected in Western Europe, USA and Japan, mainly for building structures [5] [6].

2.1.- Experimental data and proposed models

A large experimental data bank has been collected until now in different bridges recently built in Barcelona area (post-tensioned concrete slabs and one box girder bridge). Also, a large data has been obtained from a group of reinforced and prestressed concrete bridges (slabs and girder bridges) demolished, for urbanistic reasons because of the 1992 Olympic Games and the construction of new infrastructure, in Barcelona.

The parameters collected have been: Deck tickness in slab-girder bridges, geometric definition of girders, depth of slabs, thickness of top and bottom slabs in box girder bridge, effective depth of reinforcing, diameter of voids in voided slab, thickness of asphalt.

The measurements of all these variables have been analyzed in order to obtain the statistical parameters. A Kolmogorov-Smirnov test has been used to derive the theoretical probabilistic model. The probability distribution function included in these study were: Normal, Lognormal, Truncated Lognormal, Gamma and Truncated Gamma. For each of these distributions the Kolmogorov-Smirnov test provide a rational measurement of the approach. In many cases, all of these functions fitted well the sample, thus to simplify the rational use of the theoretical models the criteria was to select the Normal or Lognormal probability density distributions. The results are summarized in Table 1.

3.- MATERIAL UNCERTAINTIES

The available data and modeling for the physical uncertainties involved in the material and mechanical properties is very large [7] [8] [9]. Anywise, to obtain accurate models it is necessary to define the source and to process the samples that are homogeneous, in order to establish a suitable probability functions for a well definite random variable to use in further calculations.

In this paper, the data collected is restricted to materials recently used in concrete bridge construction in Spain, with a mean quality control of the materials and high quality control of construction.

Parameter X	Xnominal (mm)	Xmean / X nominal	Xmin. / Xmean	Xmax. / Xmean	Standard Dev / Xmean	Type of distribution
Deck Slab Girder Thick.	250.0	1.00	0.79	1.13	0.07	Normal
Horizontal dimensions of Girders	250 - 600	0.99-1.003	0.99	1.007	0.003 -0.007	Normal
Vertical dimensions of Girders	150 600	0.94 - 1.025	0.95	1.05	0.025 0.003	Normal
Depth of cast in situ Slabs	300 1800	0.996	0.94	1.05	0.026 0.015	Normal or Lognormal
Depth of top Reinforc.	266	1.006	0.91	1.07	0.045	Normal
Depth of bottom Reinf.	50	1.41	0.48	1.83	0.27	Normal
Thickness of top slab in Box Girder	250	0.95-1.03	0.89-0.92	1.06-1.10	0.02-0.07	Normal
Thickness of bottom slab in Box Girder	200 350-450	1.002 0.95-1.1	0.987 0.95-0.97	1.012 1.03-1.05	0.011 0.016-0.025	Normal
Diameter of voids (Slab)	1200-1400	0.97	0.98	1.02	0.007-0.008	Normal
Thickness of asphalt	45 - 80	0.95-1.14	0.58-0.76	1.25-1.53	0.26-0.11	Normal or Lognormal

The measurements of geometrical definition of girder cross- sections have been classified in vertical and horizontal dimensions.

Table 1.- Geometrical variability

3.1 - Concerning Concrete

Different samples of compressive strength of concrete have been processed to get the statistical parameters and to obtain a good fit. Normal and Lognormal PDF provide a rational approach for modeling this parameter. It is recommended to use Normal distribution for high quality concrete. The statistical data are summarized in Table 2, for three types of concrete.

Specified fc,k (MPa)	Age at test (days)	fc, mean (MPa)	fc,min / fc,mean	fc,max / fc,mean	C.O.V.	Type of distribution
25	7	22 - 30	0.71-0.85	1.13-1.19	0.08-0.11	Normal Lognormal
25	28	28 - 33	0.74-0.82	1.20	0.09-0.11	Normal Lognormal
30	7	34	0.81	1.19	0.14	Normal Lognormal
30	28	36	0.70	1.20	0.11	Normal Lognormal
35	7	30 - 35	0.72-0.88	1.09-1.16	0.07-0.11	Normal Lognormal
35	28	40 - 42	0.77-0.94	1.05-1.16	0.03-0.10	Normal Lognormal

Table 2 .- Compressive concrete strength

3.2 - Concerning prestressing steel

A large data bank has been processed for two different types of strands, 0.5" and 0.6", and steel 270K (186/167 MPa). The source has been the more important manufacturer of prestressing steel in Spain, which provided hundreds of quality control tests, conform to ASTM A-416 specifications. All these data corresponds to prestressing steel used in post-tensioning concrete bridges in the last 3 years. Analysis of data and results of the Kolmogorov-Smirnov test are summarized in Table 3. An example of the sample is shown in Figure 1.

Type of strand	Parameter X	X mean	X nominal	Xmin / Xmean	Xmax. / Xmean	C.O.V.	Type of distributi.
0.5 "	E modul.	197.0	190.0	0.96	1.04	0.018	Normal Lognormal
0.5 "	Ty, 0.2%	180.6	166.0	0.92	1.08	0.028	Normal Lognormal
0.5 "	T max	195.5	186.0	0.95	1.06	0.017	Normal Lognormal Gamma
0.6 "	E modul.	196.5	190.0	0.95	1.06	0.019	Normal Lognormal
0.6 "	Ty, 0.2%	247.0	238.0	0.94	1.08	0.022	Tr. Gamma Tr. Lognor
0.6 "	T max	271.6	266.0	0.96	1.07	0.018	Lognormal Normal

E = Deformation module (kN/mm2), Tmax = Tensile strength (kN) and Ty,0.2%= Yield force (kN).
Tr. Gamma= Truncated Gamma Tr. Lognorm= Truncated Lognormal.

Table 3 .- Prestressing Steel (270K) properties.

3.3 - Concerning reinforcing steel

The available data for reinforcing steel is not as large as in the case of prestressing. Different quality controls, made in some bridges, provide us the data. The mechanical properties are very related with the bar diameter in the analysis performed. The results are presented in Table 4 although its can not be significant until the data bank will be more representative.

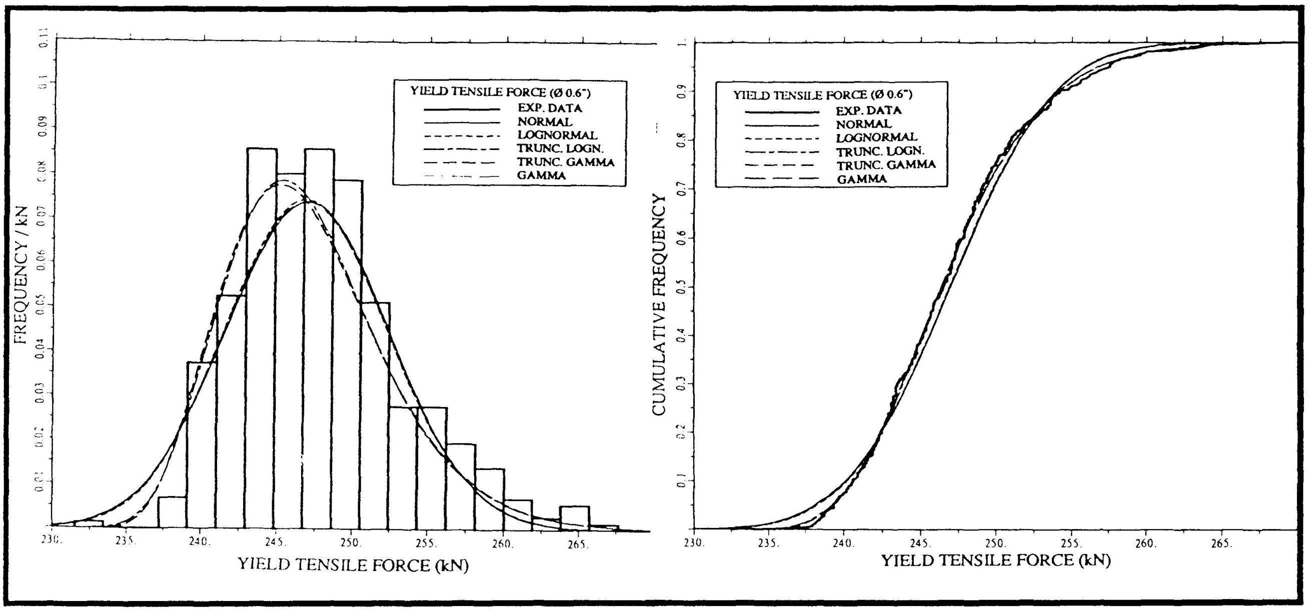


Figure 1.- Histogram, PDF and CDF curves, for yield tensile force prestressing steel. (strand 0.6")

Parameter X	X nominal	X mean	Xmin / Xmean	Xmax / Xmean	C.O.V.	Type of Distribution
Area,real / Area,nom	1.0000	1.003	0.98	1.05	0.002	Normal Lognormal
fy (kN/mm2)	51.0	58.0	0.91	1.10	0.057	Lognormal
f max (kN/mm2)	60.0	67.9	0.98	1.10	0.050	Lognormal

Table 4.- Reinforcing steel parameters (fy = yield tensile stress , f max= maximum tensile stress)

4.- RESISTANCE MODELS

Accurate resistance reliability models to obtain the real response of cross sections must take into account the real strain-stress relationship of the materials involved, and consider the uncertainty in the geometry and material properties [4].

A numerical procedure has been developed, considering the above mentioned needs, to obtain the moment, shear and torque response and the moment-curvature relationship of typical cross-sections of reinforced and prestressed concrete bridges, conform to CEB Model Code [10]. The model has been computerized for easy application. In order to predict the probabilistic response and to fit a theoretical probability distribution a 400 Monte-Carlo simulations, for each case, were performed. The following assumptions were made:

- Strain-stress curves from CEB Model Code.

- The theoretical PDF used in the simulations are in conformity with data bank collected. The user can also use the experimental histogram.

- All parameters involved to define the cross-section geometry and strain-stress curves are considered as a independent random variable, in statistical sense.

- In each simulation all the above mentioned parameters are actualized.

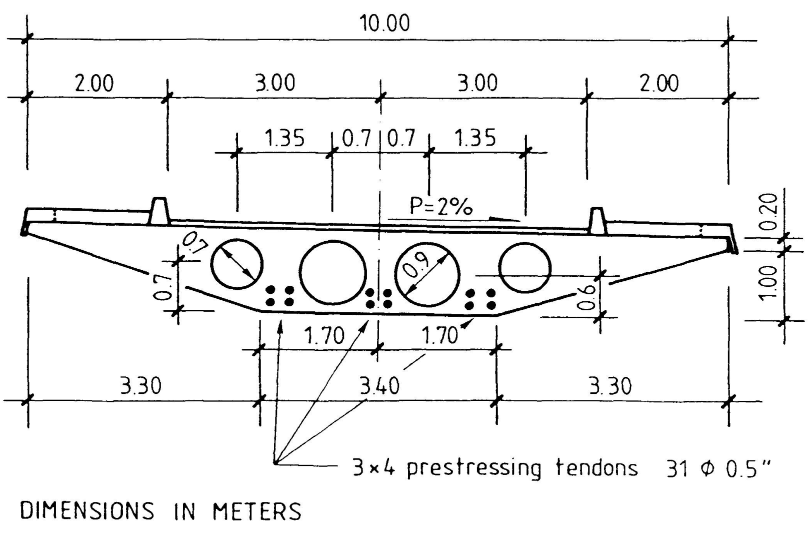
Sensitivity analysis is made, in a recently built bridge in Barcelona (Fig. 2), to reveal the effects on the random response due to selected parameters such as:

- C.O.V of vertical and horizontal magnitudes of geometry, diameter of voids, fc, fct, yield stress of prestressing, effective steel prestress after losses, depth of prestressing.

The parametric analysis concerning C.O.V. is because of this statistic is directly correlated with quality of materials and construction and human error, for new bridges, or with the level of uncertainty in the unknown involved parameters of existing bridges. Thus, the more relevant parameters in the resistance evaluation can be selected and used to rationalize the test tasks and inspections.

4.1- Voided Slab, Margenat Bridge in Barcelona.

This is a simply supported prestressed concrete voided slab, cast in situ in 1991, with a span length of 27.40 m, the cross-section and the placement of prestressing are shown in Figure 2 [11]. The Moment-curvature relationships are shown in Figure 3, with design values (factored resistance) and with mean and characteristic values of parameters involved. Numerical results of the response value analyzed are given in Table 5. Due to the lack of space only the most relevant results of parametric study are summarized in Figures 4, 5, 6 and 7.



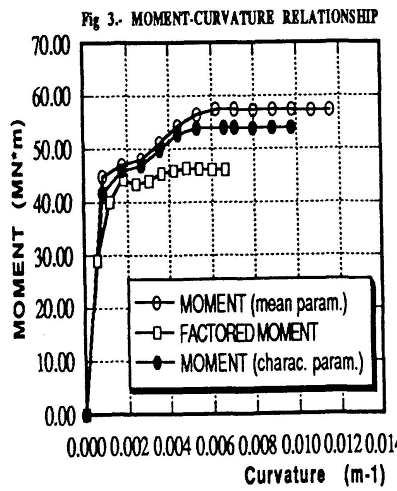


Figure 2.- Margenat bridge. Typical cross-section. Figure 3.- Moment-curvature relationship from decompression of concrete

Parameter X	X mean / X nominal	X mean	Xmin / Xmean	Xmax / Xmean	C.O.V.	Type of Distribution
Ultimate Bending-Moment (MN*m)	1. 254 * 1.067	57.45	0.92	1.10	0.034	Normal Lognormal
M, crack (MN*m)	1.00	32.48	0.90	1.14	0.046	Normal Lognormal Gamma
Inertia section (m4)	1.00	0.829	0.75	1.23	0.089	Lognormal Tr. Lognor. Gamma
Area section (m2)	1.00	6.657	0.91	1.08	0.032	Normal Lognormal

Table 5.- Simulation results. (* design value, factored resistance Øc = 1.5 and Øs = 1.15). Nominal values conform to CEB Model Code, with characteristic parameters.

The real case of cross-section herein studied yield a good example to evaluate the main important parameters involved in its ultimate resistance and serviceability behaviour. It is easy to realize that the most important parameters are related with geometry and not with those concerning with strength of material, due to the ductile behaviour. In the same way, the parametric study varying C.O.V of void diameters and with yield tensile stress of prestressing shows a not important correlation with the section properties analyzed.

5.- CONCLUSIONS

5.1.- Conclusions concerning geometrical and material variability.

Due to the lack of data available for modeling geometrical and material variability in concrete bridges an important experimental data has been collected and presented. The statistical analysis of data fairly shows that different statistical parameters has to be considered in the analysis of reinforced and prestressed concrete bridges, which usually have a more accurate construction than buildings.

5.2. - Conclusions concerning probabilistic response of concrete bridges

The scarcity of analysis of the most typical cross-sections in concrete bridges has conducted to develop a numerical procedure to obtain the probabilistic response, in terms of moment, torque and shear, taking into account the non-linear behaviour of materials and the uncertainties in the parameters involved. A parametric study has been presented as a guideline to determine the sensitivity of resistance and geometrical properties of the cross-section to different varying C.0.V. of main parameters. The results show that the most important parameters to be correctly and accurately evaluated are cross-section geometry and depth of prestressing steel.

Fig.4.- Influence of C.O.V. depth prestressing

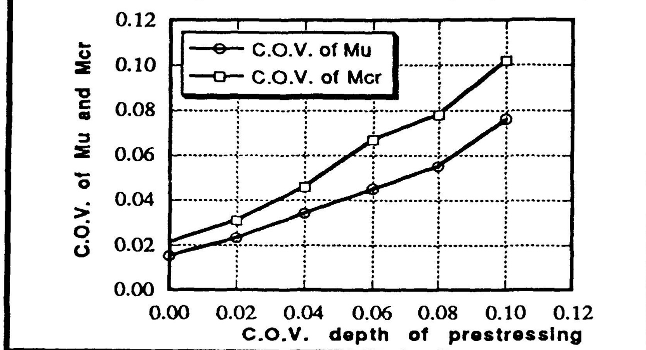


Fig 5.- Influence of Slab depth

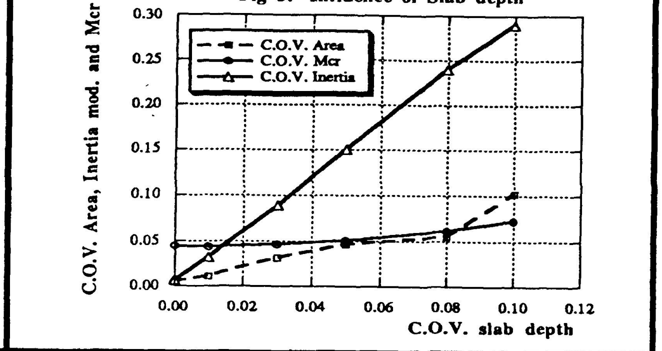


Fig 6.- Influence of C.O.V of Tx

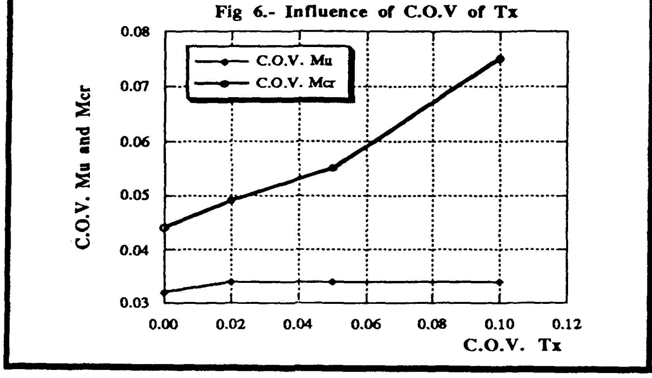
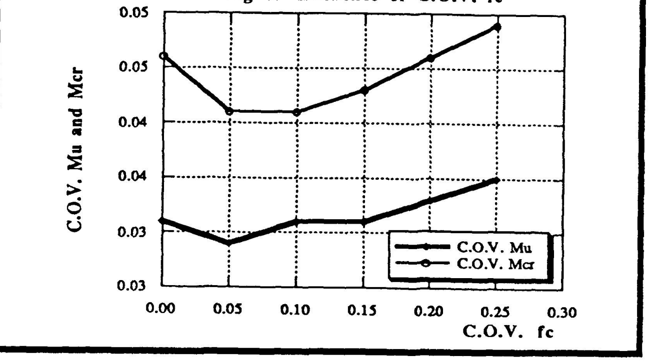


Fig 7.- Influence of C.O.V. fc



Note: Tx=prestress after losses, fc= compressive concrete strength.

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