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Probabilistic capacity model for concrete-filled steel tubes

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ABSTRACT: Concrete-filled steel tubular (CFST) columns are increasingly used around the world due to their significant structural and economic advantages. Although considerable research and several experimental tests have been carried out on CFST col-umns, there are no mechanics-based probabilistic models of their axial capacity. The present paper proposes a mechanics-based probabilistic capacity model for the assessment of the ultimate axial capacity of CFST columns. The accuracy of the numerical predictions obtained with the proposed formulation is compared with that of existing capacity equations already in use within technical standards and available in the literature.

1 INTRODUCTION

Concrete-filled steel tubular (CFST) columns are largely employed around the world because they offer two significant advantages. The first one is the composite action of the steel tube and infilled concrete, which enhances the strength and ductility of the columns. The steel tube effectively confines the concrete core, thereby providing a highly ductile response under compression and increasing the overall energy dissipation capacity (Johansson, 2002). The second advantage is the use of the steel tube as a permanent formwork for concrete casting, which helps to reduce construction time and costs. In the last decades, multiple experimental findings (O'Shea and Bridge, 2000; Giakoumelis and Lam, 2004; Zeghiche and Chaoui, 2005; van de Lindt and Gupta, 2006) proved that the axial capacity of CFST columns N_u is generally higher than the sum of the axial capacities of their components, which are the steel tube and the concrete core. This mechanical behaviour is represented by the following inequality:

$$N_u - \left(f_c A_c + f_y A_s\right) > 0, \tag{1}$$

where f_c is the concrete compressive strength, f_y is the steel yielding strength, whereas A_c and A_s are the cross-sectional areas of concrete and steel, respectively. This behavior is attributable to the confinement effect provided by the steel tube on the concrete core. This confinement

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effect, originally highlighted in (Gardner and Jacobson, 1967) determines an increment of the compressive strength of the concrete (Richart, Brandtzæg and Brown, 1928) that varies during the loading process of the CFST columns. The loading process of the CFST columns can be divided into three phases (Johansson and Gylltoft, 2001; Shanmugam and Lakshmi, 2001; Susantha, Ge and Usami, 2001; De Nardin, El Debs, and others, 2004; Sakino *et al.*, 2004).

According to the mechanical behaviour of CFST (Xue, Briseghella, and Chen, 2012), N_u can be estimated as the sum of the axial capacities of steel tube and confined concrete core using specific correction factors as follows:

$$N_u \simeq \left(f_{cc}A_c + \alpha_s f_y A_s\right), \tag{2}$$

where α_s is the factor that accounts for the reduction of the axial capacity due to the presence of the biaxial stress state inside the steel tube, and f_{cc} is the compressive strength of the confined concrete. Following a Mohr-Coulomb strength condition, the resistance of the confined concrete core can be obtained as follows:

$$f_{cc} = f_c + \alpha_c k_c \sigma_{c,r}, \tag{3}$$

in which α_c is a reduction factor related to the geometry of the concrete core, k_c is the confinement coefficient, and $\sigma_{c,r}$ is the radial compression stress.

In the literature, α_c is sometimes referred to as scale factor, and it is usually a function of the outer diameter of the CFST column D, as in (Morino, 2002) and (Hassanein *et al.*, 2018) where it is defined as

$$\alpha_c = \left(1.67D^{0.112}\right)^{-1}. \tag{4}$$

The values adopted for k_c vary within the different formulations available in the literature. While Richart et al. (Richart, Brandtzæg and Brown, 1929) suggested assuming a constant value in the range $4 - 4.1$, Saatcioglu and Razvi (Saatcioglu and Razvi, 1992) showed that k_c can take values in the range $2.5 - 7$, which decreases when the radial compression stress increases. Consequently, they proposed a formulation where k_c depends on $\sigma_{c,r}$ as follows:

$$k_c = 6.7(\sigma_{c,r})^{-0.17}. \tag{5}$$

The maximum confinement stress can be obtained from Barlow's formula (Timoshenko, 1983), assuming that the maximum tensile stress in the steel tube equals the steel yielding strength, and reads

$$\sigma_{c,r} = \frac{2t}{D} f_y, \tag{6}$$

where t is the thickness of the steel tube. By introducing the expressions for f_{cc} (Eq. 3) and $\sigma_{c,r}$ (Eq. 6) into Eq. (2), the axial capacity of CFST columns can be written as follows:

$$N_u \simeq \left\{1 + \left[\alpha_c k_c \left(\frac{2t}{D}\right)\frac{f_y}{f_c}\right]\right\} f_c A_c + \alpha_a f_y A_s. \tag{7}$$

In a more compact form, Eq. (7) can be rewritten as follows:

$$N_u \simeq f_c A_c(1 + \alpha_c k_c \psi + \alpha_a \xi), \tag{8}$$

where $\psi = (2t/D)\ /(f_y/f_c)$ and $\xi = f_y A_s / f_c A_c$. In technical standards and the literature, Eq. (7) is often presented as

$$N_u \simeq \alpha_c' f_c A_c + \alpha_a f_y A_s \tag{9}$$

assuming a constant value for α_c'. The values of α_s, α_c, k_c, and α_c' vary among the available formulations.

2 THEORETICAL BACKGROUND

Following (Gardoni, Der Kiureghian, and Mosalam, 2002), the proposed form of the axial capacity and reduction factors is written as follows:

$$T[C(\mathbf{x},\Theta)] = T\left[\hat{C}(\mathbf{x})\right] + \gamma(\mathbf{x},\theta) + \sigma\varepsilon, \tag{10}$$

where $T(\cdot)$ is a variance stabilizing transformation, $C(\mathbf{x},\Theta)$ is the dimensionless capacity, $\mathbf{x}$ are the measurable capacity variables, and $\Theta = \{\theta,\sigma\}$ are unknown model parameters. On the right side of Eq. (10), $\hat{C}(\mathbf{x})$ is a deterministic model based on mechanics rules (also borrowed directly from technical standards), $\gamma(\mathbf{x},\theta)$ is a correction term based on mechanics rules and evidence derived from the experimental data. The product $\sigma\varepsilon$ is the model error, with model standard deviation σ and normally distributed random variable ε. The model is based on three assumptions: additivity (i.e., the additivity of $\sigma\varepsilon$); homoskedasticity (i.e., the independence of σ from $\mathbf{x}$); normality (i.e., the normality of ε). Through a suitable choice of $T(\cdot)$, such assumptions can be approximately satisfied in the transformed space, within the range of the data used to calibrate the model. The correction term $\gamma(\mathbf{x},\theta)$ is selected as a linear combination of n dimensionless explanatory functions $h_i(\mathbf{x})$ and reads

$$\gamma(\mathbf{x},\theta) = \theta^{\mathrm{T}} \cdot \mathbf{h}(\mathbf{x}). \tag{11}$$

The set of explanatory functions $\mathbf{h}(\mathbf{x}) = \{h_1(\mathbf{x}),..,h_n(\mathbf{x})\}$ is constructed starting from physical variables not included in $\hat{C}(\mathbf{x})$ that may be relevant for the described physical phenomenon, but also from those included in $\hat{C}(\mathbf{x})$ and the effect of which should be recalibrated in light of the available experimental data. The parameters collected into Θ are calibrated using the Bayesian approach (Box and Tiao, 1992). It combines the prior knowledge on the parameters, which is contained in the prior distribution of Θ, $f'(\Theta)$, with the information provided by the data, which is contained in the likelihood function, $L(\Theta)$. The posterior distribution of the parameters $f''(\Theta)$ is defined as follows:

$$f''(\Theta) = kL(\Theta)f'(\Theta), \tag{12}$$

and it is obtained by dividing the product $L(\Theta)f'(\Theta)$ by the evidence k, which is the following normalizing constant:

$$k^{-1} = \left[\int_{\Omega_\Theta} \mathcal{L}(\Theta)f'(\Theta)\mathrm{d}\Theta\right], \tag{13}$$

where Ω_Θ is the parameters space.

The posterior distributions $f''(\Theta)$ obtained after the calibration can be used to find a point estimate for the model by ignoring the epistemic uncertainties in the model parameters. An alternative approach is used in the present study, which also accounts for the epistemic uncertainties in the model parameters. This alternative approach assumes Θ as random variables and find a predictive estimate of $C(\mathbf{x},\Theta)$ in agreement with (Gardoni, Der Kiureghian, and Mosalam, 2002) as follows:

$$\tilde{C}(\mathbf{x}) = \int_{\Omega_\Theta} C(\mathrm{x};\Theta)f''^{(\Theta)}\mathrm{d}\Theta. \tag{14}$$

Since an analytical solution for Eq. (16) is often missing, it is opportune to find a numerical approximation of the distribution of $\tilde{C}(\mathbf{x})$ by sampling from $f''(\Theta)$ and finding the corresponding realizations of $C(\mathbf{x};\Theta)$. In this way, it is possible to assume the sample mean of such realizations as predictive estimate and define the α% confidence interval, where the lower and upper bounds are given by:

$$\{0.5(100-\alpha),\ [100-0.5(100-\alpha)]\}. \tag{15}$$

In this specific case, non-informative priors are chosen in the form of Gaussian distribution with zero means and large variance for all the parameters. In order to facilitate the use of the model and its possible implementation into technical standards, it should be parsimonious (i.e., with a correction term constructed using a limited number of explanatory functions n) and as accurate as possible (i.e., with a small value of standard deviation σ). However, a reduction of n usually entails a higher value of σ. Stepwise deletion allows finding a compromise between parsimony and accuracy. There are several procedures to apply stepwise deletion, and they mostly differ in the deletion criteria, such as the stepwise deletion based on p-values (Stone, 1996).

The stepwise deletion process used in this paper starts with a model that includes all the candidate explanatory functions, and at each step removes the explanatory function with the highest coefficient of variation (COV) of the corresponding θ_i, as proposed in (Gardoni, Der Kiureghian, and Mosalam, 2002). Once an explanatory function is removed, the model is recalibrated and the deletion process repeated. The deletion process ends when either σ grows beyond an undesirable threshold, or the increment of σ is too large compared to the reduction of the model complexity.

3 THEORETICAL BACKGROUND

The model of the axial capacity of CFST columns follows the form presented in Eq. (10). The modeled non-dimensional capacity parameter is $C(\mathbf{x}, \Theta) = \tilde{N}_u(\mathbf{x}_u, \Theta_u)/N_c$, i.e., the ratio between the axial capacity of CFST columns $\tilde{N}_u(\mathbf{x}_u, \Theta_u)$ and the total compressive strength of the concrete core $N_c = f_c A_c$. For this model, the measurable capacity variables are $\mathbf{x}_u = \mathbf{s}$, and $\Theta_u = \{\theta_u, \sigma_u\}$ is the set of unknown model parameters. The variance stabilizing transformation used to approximately satisfy the additivity, normality, and homoskedasticity assumptions is the natural logarithm $T(\cdot) = \ln(\cdot)$ (Box and Tiao, 1992). The chosen deterministic model is the ratio between the plastic compression resistance $N_{pl} = f_c A_c + f_y A_s$ and N_c, i.e., $\hat{C}(\mathbf{x}) = N_{pl}/N_c = 1 + \xi$. Consequently, Eq. (10) is rewritten as

$$\ln\left[\frac{\tilde{N}_u(\mathbf{x}_u, \Theta_u)}{N_c}\right] = \ln(1+\xi) + \gamma_u(\mathbf{x}_u, \theta_u) + \sigma_u \varepsilon, \tag{16}$$

or, equivalently, as

$$\ln\left[\frac{\tilde{N}_u(\mathbf{x}_u, \Theta_u)}{N_{pl}}\right] = \gamma_u(\mathbf{x}_u, \theta_u) + \sigma_u \varepsilon \tag{17}$$

Through this formulation, the axial capacity of the CFST column is expressed as follows:

$$\tilde{N}_u(\mathbf{x}_u, \Theta_u) = N_{pl} \mathrm{e}^{[\gamma_u(\mathbf{x}_u, \theta_u) + \sigma_u \varepsilon]}, \tag{18}$$

and the exponential factor derived from the correction term assumes the meaning of Strength Index (SI), which is a dimensionless parameter that quantifies the strength improvement of CFST columns due to the confinement effect and defined as the ratio N_u/N_{pl} (Wang, Fan, and Lai, 2022). Given the normality assumption, a 67% confidence interval for $\ln\left[\tilde{N}_u(\mathbf{x}_u, \Theta_u)/N_c\right]$ can be found as follows:

$$\{\ln(1+\xi) + \gamma_u(\mathbf{x}_u, \theta_u) - \sigma_u, \ln(1+\xi) + \gamma_u(\mathbf{x}_u, \theta_u) + \sigma_u\}, \tag{19}$$

whereas the corresponding confidence interval for $\tilde{N}_u(\mathbf{x}_u, \Theta_u)$ is

$$\left\{N_{pl} e^{[\gamma_u(\mathbf{x}_u, \theta_u) - \sigma_u]}, N_{pl} e^{[\gamma_u(\mathbf{x}_u, \theta_u) + \sigma_u]}\right\}. \tag{20}$$

Table 1 shows the set of non-dimensional candidate explanatory functions $h_{ui}(\mathbf{x}_u)$ used in the initial step of the stepwise deletion process. The first explanatory function $h_{u1}(\mathbf{x}_u)$ takes into account a possible constant bias. The second and third explanatory functions, $h_{u2}(\mathbf{x}_u)$ and $h_{u3}(\mathbf{x}_u)$, are suggested by the formulation proposed by the Eurocode 4 (Eurocode 4, 2004) and are used to evaluate the possible effects of the relative slenderness λ_r defined as follows:

$$\lambda_r = \left(\frac{N_{pl}}{N_{cr}}\right)^{\frac{1}{2}}, \tag{21}$$

where

$$N_{cr} = \frac{\pi^2 EI_{eff}}{L^2} \tag{22}$$

is the elastic critical normal force for the relevant buckling mode, L is the length of the CFST column, and EI_{eff} is the characteristic value of the effective flexural stiffness of the cross-section given by

$$EI_{eff} = E_s I_s + 0.6 E_c I_c. \tag{23}$$

Herein, I_s and I_c are the second moments of area of the steel tube and concrete core, respectively. Moreover, E_s and E_c are the Young modulus of steel and concrete, respectively.

Table 1. Set of non-dimensional candidate explanatory functions $h_{ui}(\mathbf{x}_u)$ used in the initial step of the stepwise deletion process.

Explanatory functions		
$h_{u1}(\mathbf{x}_u) = 1$	$h_{u6}(\mathbf{x}_u) = \psi$	$h_{u10}(\mathbf{x}_u) = \xi$
$h_{u2}(\mathbf{x}_u) = \lambda_r$	$h_{u7}(\mathbf{x}_u) = \lambda_r\psi$	$h_{u11}(\mathbf{x}_u) = \lambda_r\xi$
$h_{u3}(\mathbf{x}_u) = \lambda^2{}_r$	$h_{u8}(\mathbf{x}_u) = \lambda_r^2\psi$	$h_{u12}(\mathbf{x}_u) = \lambda_r^2\xi$
$h_{u4}(\mathbf{x}_u) = \lambda$	$h_{u9}(\mathbf{x}_u) = \lambda\psi$	$h_{u13}(\mathbf{x}_u) = \lambda\xi$
$h_{u5}(\mathbf{x}_u) = \frac{t}{D}$	—	$h_{u14}(\mathbf{x}_u) = \frac{t}{D}\xi$

Similarly, $h_{u4}(\mathbf{x}_u)$ explores the possible contribution of the geometric slenderness ratio $\lambda = L/D$, whereas $h_{u5}(\mathbf{x}_u)$ reflects the contribution of the relative thickness of steel tube and concrete core. The explanatory functions $h_{u6}(\mathbf{x}_u)$-$h_{u9}(\mathbf{x}_u)$ and $h_{u10}(\mathbf{x}_u)$-$h_{u14}(\mathbf{x}_u)$ search for the interactions between the same effects relevant for the explanatory functions $h_{u1}(\mathbf{x}_u)$-$h_{u5}(\mathbf{x}_u)$ and the contributions due to the confinement effect and steel tube (i.e., ψ and ξ, respectively). The model $\tilde{N}_u(\mathbf{x}_u, \Theta_u)$ is calibrated with records from the database analysed in (Thai *et al.*, 2019). The database contains tests conducted on both rectangular and circular CFST columns and includes data obtained from specimens with high-strength materials and slender sections. Some of the data are collected from tests where the normal force is applied in an eccentric position (i.e., tests where the members are subjected to combined axial compression and bending moment). Only data from tests without eccentricity of the applied axial loads and CFST columns with circular cross-section are herein used for the calibration of $\tilde{N}_u(\mathbf{x}_u, \Theta_u)$, thereby resulting in a total of 815 records. Figure 1 presents the results of the stepwise deletion process for the axial capacity model. For each step, the figure shows the value for the posterior mean of σ_u, which is represented by a square, and the coefficients of variation of the θ_{ui}'s related to the h_{ui}'s included at that step, which are represented by dots. The dots with a cross denote the coefficients of variation of the terms that are dropped. The red line represents the value of σ_u at the first step, and it is used to facilitate the comparison with the values of σ_u in the following steps. The figure also explicitly shows the values of σ_u at some selected steps.

In the first step, the selection process removes h_{u4}, which is the term associated with the parameter that has the largest coefficient of variation, θ_{u4}, being COV $_{\theta_{u4}} = 1.57$. One term is removed at each step up to Step 10, which leads to the elimination of θ_{u12} and a 5% cumulative increase in σ_u. The process stops at Step 11 because removing h_{u1}

would result in a cumulative increase in σ_u higher than 10%, which is deemed excessive, and because the additional step would entail an increase in σ_u equivalent to the cumulative increase of the first 10 steps. The 10% threshold is chosen to have a parsimonious model that could be adopted in technical standards. Moreover, the difference in accuracy between the reduced model and the full model (i.e., the model obtained without applying the stepwise deletion process) is limited. The reduced model resulting from the selection process has $\gamma_u(\mathbf{x}_u, \theta_u)$ in the following form:

$$\gamma_u(\mathbf{x}_u, \theta_u) = \theta_{u0} + \theta_{u2}\lambda_r + \left(\theta_{u10} + \theta_{u14}\frac{t}{D}\right)\xi \ . \tag{24}$$

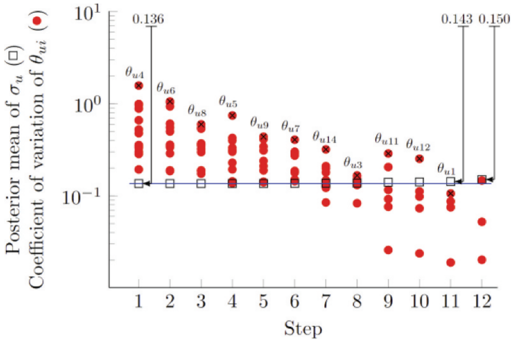

Figure 1. Stepwise deletion process for the axial capacity model.

This formulation suggests that there may be a systematic bias in the deterministic predictions obtained with N_{pl} because h_{u1} is retained in the model. It also shows that λ_r plays a significant role in reducing the axial capacity of CFST columns. The combined effect of h_{u10} and h_{u14} likely accounts for the confinement effect, which is proportional to the compressive strength of the steel column and depends on the t/D ratio. Table 4 gives the posterior statistics of the five model parameters. Figure 2 shows the predicted versus measured capacity for each test. The closer the data points are to the 1:1 lines (i.e., the continuous lines in the figure), the more accurate are the predictions. Figures 2(a) and 2(b) compare predictions made considering the plastic resistance to compression.

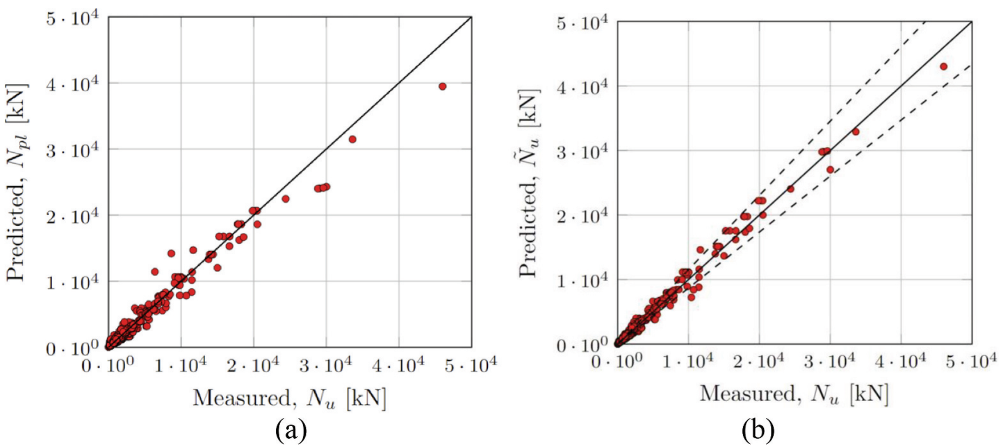

Figure 2. Predicted versus measured values of the axial capacity: (a) predictions with plastic resistance to compression; (b) predictions with proposed probabilistic model.

4 COMPARISON BETWEEN STANDARDS AND LITERATURE FORMULATIONS

Figure 3 presents a comparative assessment of the axial capacity of CFST columns in terms of the ratio between numerical predictions and corresponding experimental values $r_u = N_u pre/N_u exp$. The figure presents both predictions made with code-conforming formulations (ACI Committee 318, 1995; Eurocode 4, 2004; AISC Committee and others, 2010; GB 50923-2013, 2013) and with formulations from the literature (Goode and Narayanan, 1997; Giakoumelis and Lam, 2004; Ho and Le, 2021). A short presentation of these formulations is provided in Appendix. This assessment is intended to analyse the differences between the formulations and should not be considered as a competitive evaluation of their accuracy. This is because the existing formulations considered for the present comparative assessment might have been developed on a testing dataset instead of the complete dataset, or because the code-conforming formulations require design values and are not intended for mean values, or even because the considered formulations may not be valid for the intervals of the parameters in the considered dataset. Table 2 shows the statistics of the distributions of r_u obtained from the different formulations considered in the comparative assessment.

Table 2. Comparison between literature and technical standards, where S.D stands for Standard Deviation while M.S.E. for Mean Square Error.

Formulation	Mean	S.D.	M.S.E.
EC4	1.084	0.593	0.359
AISC	1.091	0.472	0.231
ACI	1.033	0.453	0.206
Goode et al. (1997)	0.627	0.284	0.219
Giakoumelis and Lam (2004)	1.293	0.546	0.384
Xue et al. (2013)	0.912	0.189	0.044
Ho and Le (2021)	1.188	0.230	0.056
Proposed	1.011	0.155	0.024

It can be observed from Figure 3 and Table 2 that all code-conforming formulations tend to underestimate the axial capacity of CFST columns. The formulations collected from the existing literature show a progressive increment of accuracy in time. Particularly, the formulation proposed by Ho and Le (Ho and Le, 2021) based on support vector machine and the one proposed

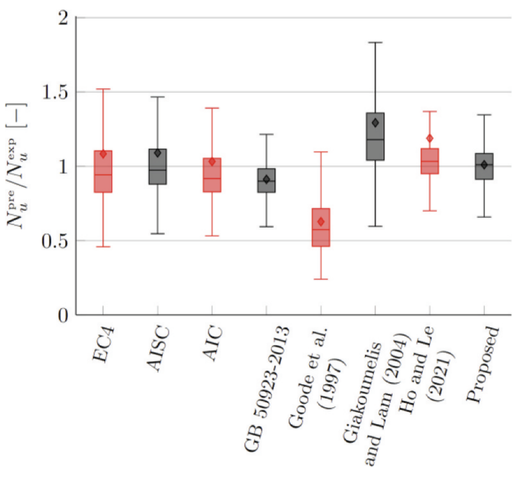

Figure 3. Comparison among predictions of the axial capacity of CFST columns in terms of box plot of the ratio between numerical predictions and corresponding experimental values $N_u pre/N_u exp$ (complete dataset of 815 samples).

in the present study show comparable levels of accuracy. The main difference with the earliest formulations (Goode and Narayanan, 1997; Giakoumelis and Lam, 2004) is the lack of the confinement effect, which is either not considered (in (Goode and Narayanan, 1997)) or overestimated (in (Giakoumelis and Lam, 2004)).

5 DERIVATION OF UNCERTAINTY FACTORS FOR DESIGN APPLICATION

The potential use of the proposed formulation for practical applications requires the definition of an uncertainty factor γ_{Nd} for the calculation of the design value of the axial capacity. Such uncertainty factor is needed to avoid the underestimation of the axial capacity due to the involved uncertainties, in such a way that the design can ensure a safety margin in compliance with code regulations. The code-format design axial capacity can be defined as follows:

$$N_{ud} = \frac{\eta}{\gamma_{Nd}} \tilde{N}_u(\mathbf{x}_{ud}, \Theta_u), \tag{25}$$

where η is a conversion factor that depends on the technical standard (Eurocode 4, 2004) and $\mathbf{x}_{ud}$ is the vector of the design values of the capacity variables. In a similar fashion, for CFST columns with axial load applied in eccentric position or with debonding, the code-format design axial capacity reads

$$N_{ud} = \frac{\eta}{\gamma_{Nd}} \tilde{k}_e(\mathbf{x}_{ed}, \Theta_e) \tilde{N}_u(\mathbf{x}_{ud}, \Theta_u), \tag{26}$$

and

$$N_{ud} = \frac{\eta}{\gamma_{Nd}} \tilde{k}_d(\mathbf{x}_{dd}, \Theta_d) \tilde{N}_u(\mathbf{x}_{ud}, \Theta_u), \tag{27}$$

respectively. The estimation of γ_{Nd} is performed by assuming that the design value is less than the corresponding experimental value with a probability equal to p as

$$P\left[N_{ud} < N_u^{exp}\right] = p. \tag{28}$$

The value of p depends on the reference technical standard. The estimation of γ_{Nd} is performed with $\eta = 1$ and characteristic values of compressive concrete strength and steel yielding stress equal to those in the experimental database used for the model calibration. The ratio of the number of samples for which $N_{ud} > N_u^{exp}$ and the total number of samples is used to estimate $P[N_{ud} < N_u^{exp}]$ and the corresponding value of γ_{Nd}. Table 3 compares the values of γ_{Nd} obtained for three different technical standards, namely Eurocodes, AASHSTO, and GB50923-2013.

The European building code sets p as $\Phi(\alpha_R \beta_{LS})$, where $\Phi(\cdot)$ is the standard Normal cumulative distribution function, α_R is the sensitivity factor for the capacity, and β_{LS} is the safety index relevant to the considered limit state. Assuming a 50-years reference period and an ultimate limit state, $\Phi(\alpha_R \beta_{LS})$=0.9988. For AASHSTO, the value of p is derived as $p = \Phi(3.5) = 0.9997$ because $\beta = 3.5$ is the target reliability index. Following the specifications of the GB50923-2013 technical standard, the value of p is derived assuming a ductile failure and the 2nd safety level, which lead to $p = \Phi(3.2) = 0.9993$. The calibration of γ_{Nd} is performed with all available data, including those with eccentric applied axial load and debonding. The accuracy in approaching the target values of p and, consequently, in defining an accurate value of γ_{Nd} is determined by both the number of available samples and the distribution of N_u^{exp}. Since 1006 tests are used, the probability values closer to the target values of p are $p^* = 1004/1006 = 0.9980$, $p^* = 1005/1006 = 0.9990$, and $p^* = 1006/1006 = 1.000$. The values of γ_{Nd} corresponding to the target values of p are obtained by linear interpolation. Table 3 shows the results of the calibration.

The higher values of γ_{Nd} derived for the AASHTO compared to those obtained for the Eurocode 4 and GB50923-2013 are due to both the higher target reliability index and the higher design values of the compressive concrete strength and steel yielding stress.

Table 3. Model uncertainty factors for γ_{Nd} for the proposed axial capacity derived according to the three different technical standards.

Technical Standard	Target p value	γ_{Nd} p=0.998	γ_{Nd} p=0.999	γ_{Nd} p=1.000	γ_{Nd} Interp.
EC4	0.9988	1.599	1.815	—	1.772
AASHTO	0.9997	—	2.276	3.128	2.872
GB50923-2013	0.9993	—	1.642	2.484	1.895

6 CONCLUSIONS

The beneficial interaction between steel tube and infilled concrete core has promoted the large diffusion of CFST columns in many projects over the years. To begin with, the concrete core prevents the inward local buckling of the steel tube. At the same time, the steel tube confines the concrete core. Such synergy results in high load-carrying capacity and enhanced ductility, that come together with economic and construction efficiency benefits due to the use of the steel tube as permanent formwork. Motivated by these attractive features, a large amount of experimental, analytical, and numerical studies about CFST columns under axial load have been performed in the last decades, but a probabilistic capacity model has not been proposed yet. Hence, the present study is meant at filling this gap and, to this end, proposed a comprehensive probabilistic model for the axial capacity of CFST columns. The probabilistic models for the axial capacity is derived by means of a Bayesian approach taking into rational account, both, model parsimony and model accuracy. The predictive performance of the proposed probabilistic capacity models are discussed within a comparative assessment that involves existing formulations collected from some available technical standards and previous researches. To foster the use of the proposed formulation for design purposes, the paper also provides uncertainty factors calibrated to meet the reliability levels required by three different technical standards.

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