Available online at www.sciencedirect.com

ScienceDirect

Procedia Structural Integrity 84 (2026) 781–788

Structural Integrity Procedia

www.elsevier.com/locate/procedia

III Fabre Conference: Existing Bridges, Viaducts, and Tunnels: Research, Innovation, and Applications

Some issues in the numerical modelling and analysis of bridges: evidence from case studies

Anna Brunetti[a], Federica Buongiorno[b], Annarita Palmiotta[c,*], Giulia Scipione[a], Anna Lo Monaco[b], Antonella Ranaldo[b], Sandro Carbonari[a], Michele D'Amato[b], Fabrizio Gara[a]

[a]*Department of Construction, Civil Engineering and Architecture (DICEA), Università Politecnica delle Marche, Via Brecce Bianche 12, Ancona 60131, Italy*
[b]*Department for Humanistic, Scientific and Social Innovation (DIUSS), University of Basilicata, Via Lanera 20, Matera 75100, Italy*
[c] *Department of Structural and Geotechnics Engineering (DISG), Sapienza University of Rome, Via Eudossiana 18, Rome 00184, Italy*

Abstract

Finite Element Modeling (FEM) plays a crucial role in accurately simulating the structural response of bridges when subjected to design actions such as traffic loads, seismic forces, wind, thermal effects, etc. In modern engineering practice, advanced numerical modelling techniques are available, offering a wide range of options depending on the type of verification required and the expected results. Sometimes, engineers may adopt either an excessive level of simplification or an unnecessary degree of detail, depending on their confidence in numerical analyses, without fully appreciating the effects and implications that the chosen modelling criteria have on the results. This study explores the role of different modelling criteria in the safety assessment of girder bridge decks subjected to non-seismic actions (such as. traffic and wind actions). The study is performed considering two case studies characterised by different span length, deck width and slab thickness. Effects of modelling criteria in terms of stress resultants on beams and transverse load distribution are presented and discussed, demonstrating the importance of a suitable modelling of the slab with significant thickness.

© 2026 The Authors. Published by ELSEVIER B.V.
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0)
Peer-review under responsibility of the scientific committee of the Conference

Keywords: Bridge Finite Element Modeling, transverse distribution, bridge model, modelling criteria.

* Corresponding author. Tel.: 39 3270012385.
E-mail address: annarita.palmiotta@uniroma1.it

2452-3216 © 2026 The Authors. Published by ELSEVIER B.V.
This is an open access article under the CC BY-NC-ND license (https://creativecommons.org/licenses/by-nc-nd/4.0)
Peer-review under responsibility of the scientific committee of the Conference
10.1016/j.prostr.2026.06.100

1. Introduction

In recent years, the management of existing bridges has become a topic of growing relevance in Italy and across Europe. Following the collapse of the Morandi Bridge, the Italian Ministry of Infrastructure and Transport issued the Guidelines for the classification and management of risk, the safety assessment and monitoring of existing bridges (MIT. 2020. D.M. n.578 of 17.12.2020). The purpose of these Guidelines is to define the procedures for classification, safety assessment, and monitoring of existing structures. The Guidelines represent a substantial advancement by addressing the gaps in the current Italian standards concerning bridges and the assessment of their safety (F. Gara et al., 2024). Since their publication, several studies have investigated, for instance, defect assessment (Ranaldo et al., 2024a; Lo Monaco et al., 2024) and the estimation of the mechanical properties of materials used in bridges with prestressed concrete beams, including both pretensioned and post-tensioned members (Ranaldo et al., 2024b). Conversely, the effects of numerical modelling assumptions on the accuracy of the structural response have been less investigated, despite they play a decisive role in safety assessment (De Matteis et al.,2023), as they govern the accuracy of the predicted response and the feasibility of the analysis in professional practice. Sometimes, engineers tend to either adopt an excessive level of simplification or an unnecessary degree of detail, depending on their confidence in numerical analyses, without fully appreciating the effects and implications of such assumptions on the results.

Therefore, the present study aims to analyze different modelling strategies for reinforced and prestressed reinforced concrete (RC) girder bridges, evaluating their efficiency in capturing the distribution of stress results in beams as well as the transverse load distribution capability of the deck, which is given not only by transverse cross-beams but also by the concrete slab that may play a crucial role depending on its thickness. In detail, two case studies, characterised by a different geometry and selected to represent typical decks of simply supported bridges in Italy, are analysed and modelled with an increasing level of accuracy. The increasing modelling complexity foresees: (*i*) a simplified model consisting only of beams and cross-beams arranged in the same plane (Base Model, or *Model 1*); (*ii*) a beam model with elements located at their centroidal axis, where transverse load distribution is also provided by the deck slab modelled through beam elements (Intermediate Model, or *Model 2*); and (*iii*) a more refined model in which girders and cross-beams are represented by beam elements, while the slab is modelled using shell elements (Refined Model, or *Model 3*).

Effects of modelling assumptions, in terms of stress resultants on beams and transverse load distribution capability, are presented identifying the simplest modelling level that preserves the accuracy required for professional applications and discussing the importance of a suitable modelling of the slab with significant thickness.

2. Case studies

The first Case Study (CS1, Fig. 1a) consists of a simply supported two-lane carriageway bridge with a span length of 32 m and a deck width of 12.4 m. Each deck is constituted by four Prestressed Reinforced Concrete (PRC) beams, connected by four PRC cross-beams and a 20 cm thick slab, partially cast in situ. Girders have a T-shaped cross section, whose web tapers at 1.6 m from the supports (Fig. 1b) and have an half-joint configuration. The slab is partially precast since it is constituted by the upper flanges of girders, connected by an in situ cast integrative slab, whose length depends on the beam spacing.

(a) (b)

Fig. 1.(a) Longitudinal view of CS1 and detail of girder geometry at the support (B-B) and at mid-span (C-C)

The composite action among girders is also guaranteed by transversely arranged prestressing tendons along the deck at the level of the slab. Finally, the cross-beams support the slab acting as a composite cross-section.

The second Case Study (CS2, Fig. 2) is a nine spans viaduct with lengths from 19.3 m to 24 m, and a deck width of 9.80 m. The viaduct is characterised of eight Reinforced Concrete (RC) frame piers, each comprising four square cross-section columns connected by one or more levels of tie beams (Fig. 2a). The piers embed a portion of the deck, which is completed by simply-supported sections within the piers. Overall, the superstructure is composed of four rectangular RC beams supported with half-joints and transversely connected by four rectangular RC cross-beams. The deck is completed with an approximately 40 cm thick slab (Fig. 2b).

The present study focuses on a single representative simply supported deck extracted from the case studies, both characterised by 4 longitudinal girders and 4 cross-beams (2 at supports and 2 at mid-span). The main differences between the bridge decks are summarized in Table 1.Table 1 It is worth noting that the modelling of half-joints as well as of the prestressing system is not relevant for the purposes of this research which focuses on the stress resultants distribution along the girders and the transverse load distribution capability.

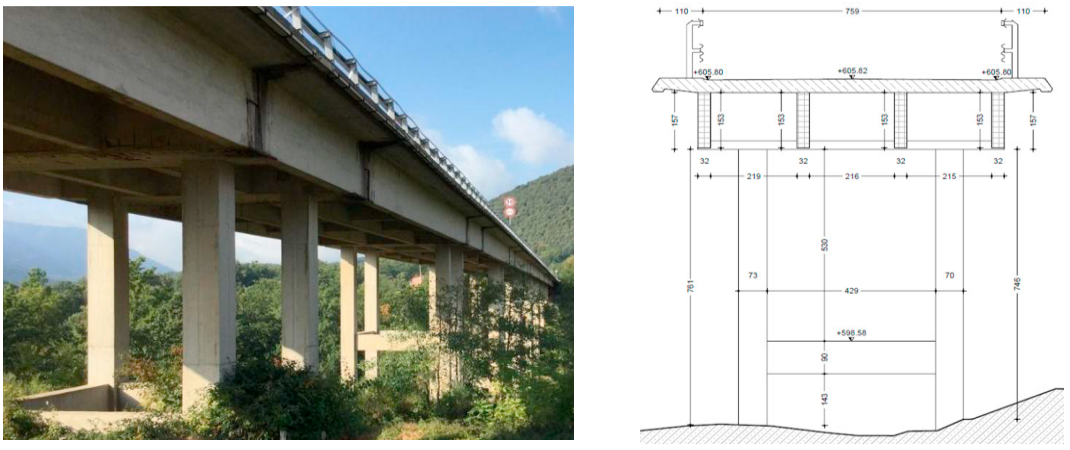
Table 1. Main differences between the two CSs

CSs main details	CS1	CS2
(i) slab thickness (t)	0,20 m	0,40 m
(ii) length spans (l)	32,00 m	19,32 m
(iii) cross-beams spacing (d_s)	11,50-9,00-11,50 m	8,00-5,00-8,00 m
(iv) beam spacing (d_b)	≈ 2.90 m	≈ 2.50 m
(v) beam geometry (g_b)	variable	constant

3. Modelling criteria

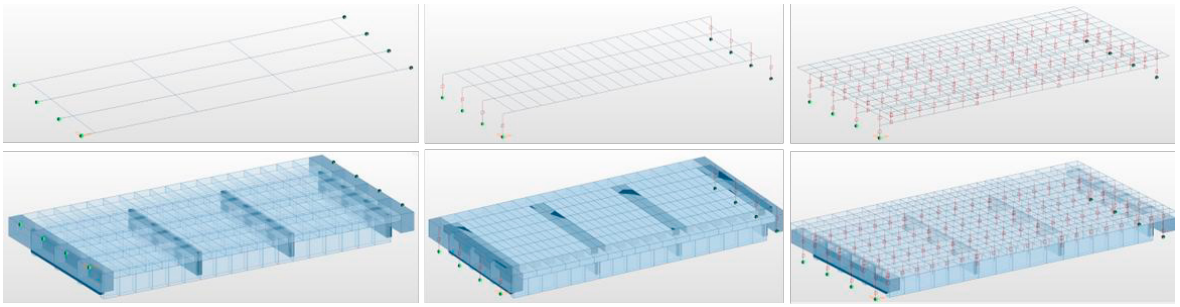
The study is performed with a stepwise modelling approach, considering progressive refinement in the modelling of the girder deck. This refinement influences especially the transverse load distribution, although secondary effects arise from other factors, such as the relative eccentricity between elements and the eccentricity of the supports, which are progressively taken into account by increasing the level of detail.

In particular, for both CSs three different models are carried out, using the Midas Civil software. *Model 1* (Base Model) only involves the modeling of girders and cross-beams as beam elements positioned in the same plane. In this model the eccentricity between components is not considered as shown in Fig. 3a. The slab collaborates with the longitudinal girders only in terms of flexural stiffness, whose contribution is taken into account by considering the effective width of the slab in the cross-section modelling of beams. Therefore, the transverse load distribution is exclusively provided by the crossbeams, neglecting the contribution of the slab.



(a) (b)

Fig. 2.(a) Longitudinal view of CS2 and (b) geometric details



(a) (b) (c)

Fig. 3. Wireframe and extruded views of (a) *Model 1*, (b) *Model 2* and (c) *Model 3* for CS2

In *Model 2* (Intermediate Model), the arrangement of the structural elements reproduces their actual position through the introduction of offsets between components. The key difference is the inclusion of the slab contribution to transverse stiffness, modelled by suitable spaced beam elements as shown in Fig. 3b. Moreover, the supports are modelled at their actual locations, with rigid links used to account for their eccentricity with respect to the deck.

Finally, *Model 3* (Refined Model) provides a more realistic representation of the bridge deck. Specifically, as for the *Model 2*, the actual position of the structural components is reproduced by modelling the elements along their centroidal axes, with rigid links accounting for the corresponding eccentricities, as illustrated in Fig. 3c. Another important difference is that the slab is modelled in its actual position by using a refined shell elements grid; this allows to take into account more rigorously the shear-lag effect that depends on the slab thickness and the load distribution.

Due to the higher level of modelling detail, *Model 3* is expected to provide the most realistic prediction of the structural response and therefore it is adopted as the benchmark model for comparisons. In the present work, the transverse distribution capability is evaluated starting from the bending moment (M_y) distribution along the longitudinal beam. Therefore, as previously stated, the presence of half-joints and prestressing is not relevant. As for the model mesh, only the spacing of the transverse beams simulating the slab in Model 2 and the shell dimensions in Model 3 can play a significant role. Preliminary analyses are considered to define the previous two models avoiding mesh dependent results. In detail, all models adopt a mesh spacing of approximately 0.5 m.

4. Results

The results are organized into two parts: a preliminary investigation of the transverse load distribution, aimed at assessing the load-transfer mechanism across the bridge deck (§4.1), and the static analysis of the CSs under the Ultimate Limit State (ULS) load conditions prescribed by the Italian Building Code (NTC 2018) (§4.2).

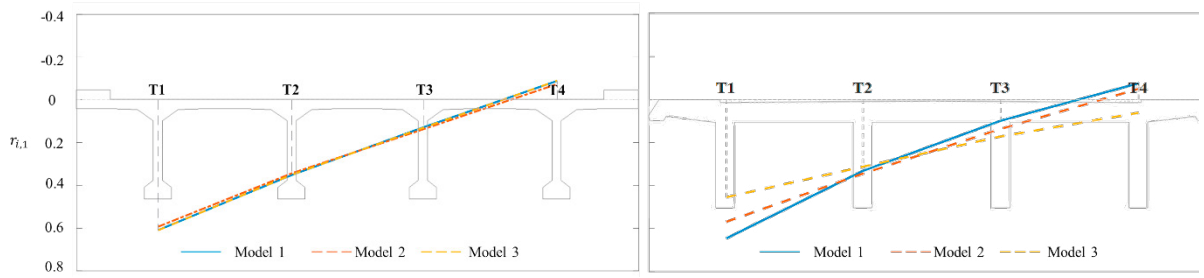
4.1. Transverse load distribution capability

In order to compare the different transverse load distribution capability of the three modelling criteria, a static load case is considered. Specifically, a unit uniformly distributed linear load is applied to the edge beam (T1 in Fig. 4), which, in view of the transverse distribution of traffic loads, represents the member of greatest interest for verification purposes. The chosen load condition, adopted instead of the fundamental combination typically used for ULS safety assessment, enables the transverse behavior of each model to be examined while avoiding effects arising from the different transverse and longitudinal load distributions, which is typical of each model and CS considered. Indeed, the two CSs are characterised by the different number of lanes and their positions with respect to the beam axes, by the different amount of the remaining areas, and by different areas of influence which must be considered for distributing the movable load over each deck. In addition, the latter areas are also a function of the modelling strategy.

By referring to the mid cross-section, the transverse load distribution capability for the *i*-th beam is quantified by means of the transverse distribution factor r_i, defined as the ratio between the resulting bending moment M_i at mid-span of the *i*-th beam, and the sum of bending moments in all beams at the same longitudinal cross-section:

$$r_i = \frac{M_i}{\sum_i M_i} \quad (1)$$

Fig. 4 plots the transverse distribution factor obtained from all the models and for both the CSs. For CS1, it can be observed that, despite the substantial differences in modelling assumptions, all models exhibit an almost identical response, denoting that the key role in the transverse load distribution is played by the cross-beams, while the slab is almost negligible. In addition, a rigorous modelling of the beams centroids is of less importance. On the contrary, for CS2 the transverse load distribution is more influenced by the modelling criteria. In particular, *Model 1* is the least efficient in the transverse distribution of loads whereas *Model 3* is the most performant one. The higher sensitivity of this CS to the beam-slab interaction is reasonable due to the higher slab thickness-beam spacing ratio t/d_b (0.16 for CS2 versus 0.07 for CS1), providing a pronounced load redistribution when a more refined criterion is adopted. Table 2 summarizes the distribution factors obtained from the analyses.



(a) (b)

Fig. 4. Transverse distribution factors obtained for (a) CS1 and (b) CS2

Table 2. Distribution coefficients (r_i) for CS1 calculated for the different numerical models

CS/Model	*T1*	*T2*	*T3*	*T4*
CS1/Model 1	0.609	0.351	0.128	0.089
CS1/Model 2	0.593	0.343	0.137	-0.074
CS1/Model3	0.614	0.349	0.126	-0.089
CS2/Model 1	0.645	0.332	0.098	-0.075
CS2/Model 2	0.574	0.347	0.138	-0.059
CS2/Model3	0.454	0.312	0.172	0.062

Fig. 5 shows diagrams of bending moments obtained in all the beams of CS1 and CS2, named T1, T4, T3 and T4. By assuming the results of *Model 3* as reference, the efficiency of *Model 1* and *Model 2* in capturing the actual load distribution capability of the deck is compared by normalizing bending moments with respect to the maximum value in beam T1 of *Model 3*, measured at midspan. As for CS1, diagrams confirm the limited contribution of the slab to the transverse distribution load mechanism, as well as the almost identical efficiency of *Model 1* and *Model 2* with respect to the benchmark *Model 3*. Conversely, for CS2, diagrams reveal that *Model 2* is able to provide a satisfactory estimation of bending moments in T1 (i.e. for T1 the normalized bending moment is almost one), while the bending moment obtained from *Model 1* is 20% higher than the benchmark value (i.e. for T1 the normalized bending moment is 1.2); in addition, it is worth noting that *Model 1* and *Model 2* show the same efficiency in capturing bending moment in the remaining beams (from T2 to T4), as demonstrated by the values of the normalized bending moments.

4.2. Distribution of bending moments on beams at ULS

In order to provide an insight of practical interest, the comparison of the models has been extended to include the bending moments associated with the fundamental load combination prescribed by the Italian building code NTC 2018 (§2.5.3), which is commonly used for the ULS safety checks. For the applications, the traffic load is assumed as the primary action, considering *Load Model 1* (NTC 2018, §5.1.3.3.3), while the wind action is assumed as secondary load. Similarly to Fig. 5, Fig. 6 presents a comparison of the bending moments normalized with respect to the maximum midspan bending moment of beam T1 obtained in *Model 3*, again assumed as reference. As for the CS1, a good agreement among the different modelling approaches is also observed under the ULS load combination.

Focusing on the most loaded beam, *Model 1* proves to be the most conservative for verification purposes, exhibiting a midspan bending moment ratio greater than 1.

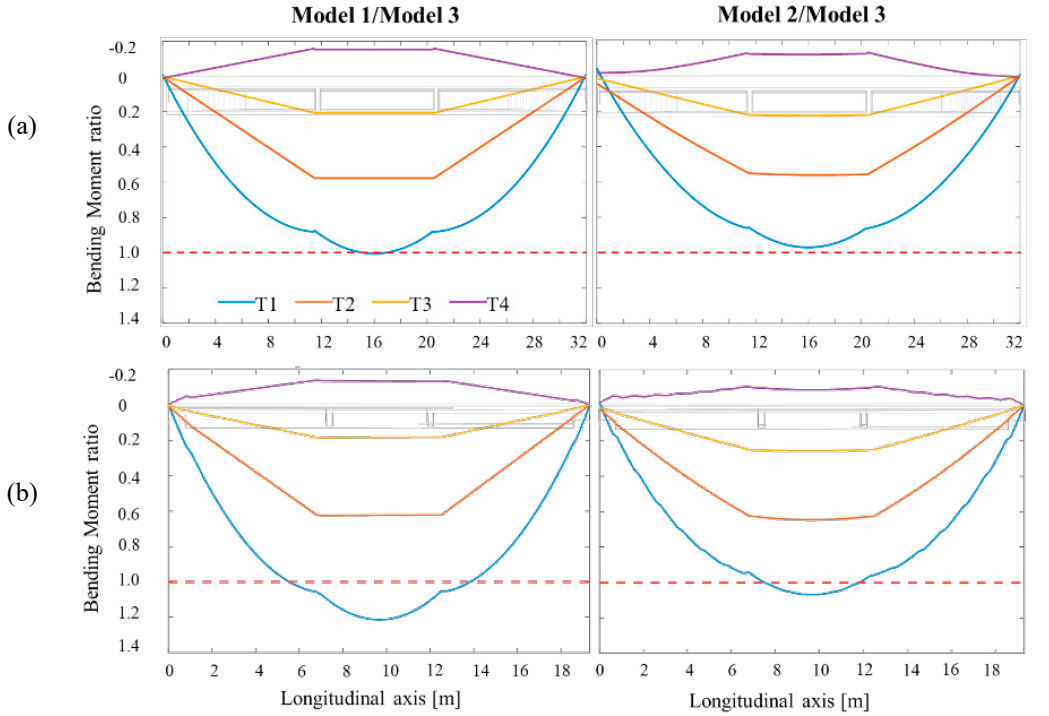


Fig. 5. Comparison of normalized bending moments for a uniform distributed load on T1 for (a) CS1 and (b) CS2

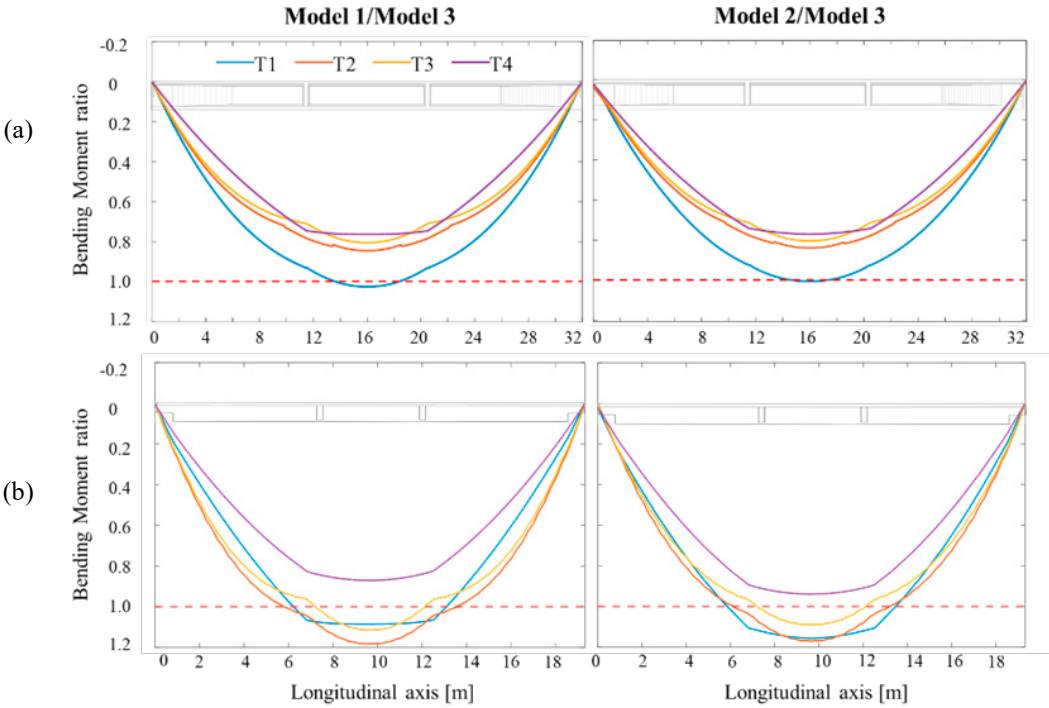


Fig. 6. Comparison of normalized bending moments for the ULS combination for (a) CS1 and (b) CS2

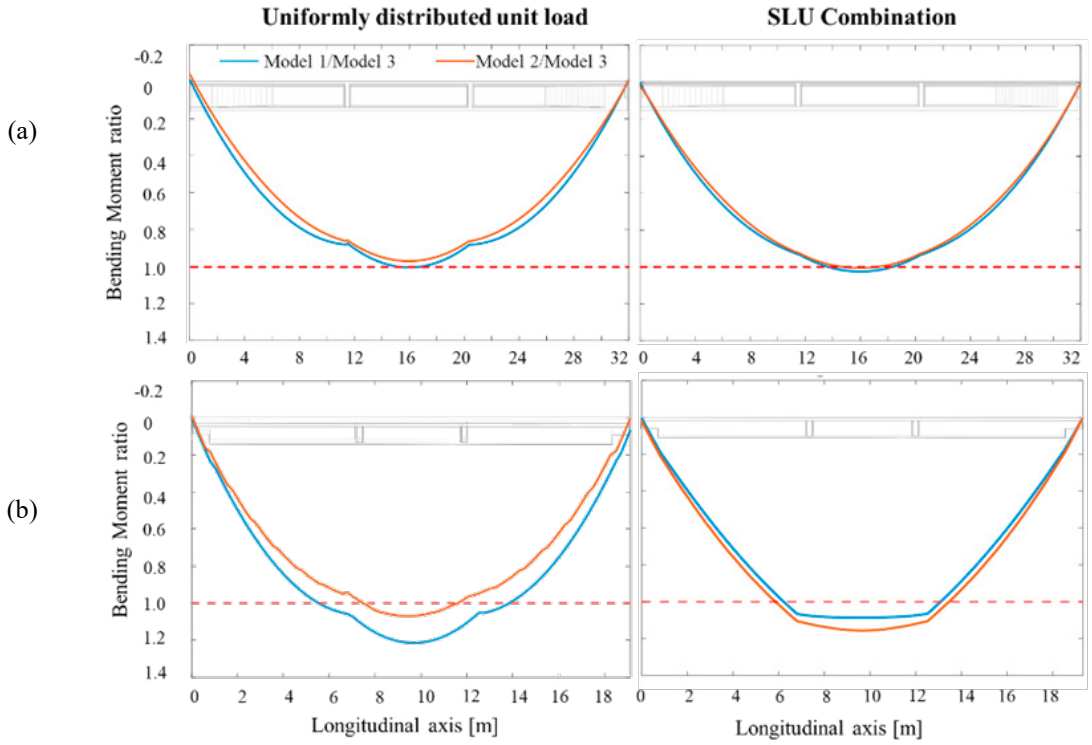


Fig. 7. Comparison of normalized bending moments under uniform distributed and ULS load on T1 for (a) CS1 and (b) CS2

As for the CS2, as already observed, its geometric properties make it more sensitive to the modelling criteria. Also, the normalised bending moments in *Model 1* and *Model 2* are always higher than the Model 3 one, assumed as reference. This result is due to the fact that the *Model 3* better describes the transverse load distribution, since the bending moments of the beams are closer (Fig. 6). The greater flexural stiffness of the slab distributes the applied load more evenly among the beams reducing, consequently, the load and bending moments on the beam T1.

To clarify the above discussion, Fig. 7 presents a comparison of the bending moments of beam T1, normalised with respect to the maximum value obtained with the *Model 3*. The comparison is carried out for both the unit load case and the ULS load combination (the latter plotted in Fig. 6), for case studies CS1 and CS2, respectively. With reference to the CS1, since the bending moment ratio is about equal to 1 for both load configurations, the results show a substantial equivalence between the simple models, that are *Model 1* and *Model 2,* and the *Model 3*. With reference to the CS2, bending moment ratios are always greater than 1, as proof of the fact that in the Model 3 the contribution of the transverse load applied and, therefore, the bending moments are lower with respect to the *Model 1* and *Model 2.*

5. Conclusions

The role of different modelling assumptions as well as model detailing on the static response of girder decks subjected to non-seismic actions has been investigated in this work with reference to two case studies, characterised by different span length and geometries. The main difference between the two case studies concerns the ratio between the slab thickness and the beam spacing, which differs by approximately one order of magnitude for the two case studies and is responsible for the different contribution of the slab on the transverse load transfer mechanisms.

Three modelling criteria are considered, differing in their level of detail, especially in the accuracy of slab modelling and its impact on capturing the transverse load distribution: (*i*) a base model, *Model 1*, in which the slab contributes only to the longitudinal stiffness of girders, *(ii)* an intermediate model, *Model 2*, in which the transverse collaboration of the slab is simulated through suitably spaced transverse beams, and (*iii*) a refined model, *Model 3*, in which the slab is modelled as shell elements. The performance of the three models in capturing the distribution of

loads among the structural members is assessed with both reference to a uniform line load applied on the edge beam of the girder deck and the load configuration at ULS for non-seismic actions, which is governed by traffic loads, distributed over the deck according to the influence areas.

With regard to the line load, the simplified models (e.g. *Model 1* and *Model 2*) lead to conservative results in terms of bending moment on beams when compared with the *Model 3*. In addition, as expected, the model detailing appears to be significant only if the contribution of the slab on the load distribution mechanisms is relevant due to the significant stiffness. Consequently, greater differences between the adopted models are observed for the case study with the higher slab thickness-beam spacing ratio. For low values of the slab thickness-beam spacing ratio slight differences among the results of the three models are obtained and the base model (*Model 1*) proves adequate for estimating stress resultants in the beams for safety assessment purposes.

In conclusion, the modelling criteria may significantly affect the safety assessment depending on the geometry and slab thickness-beam spacing ratio of the girder deck.

In future additional studies will be conducted according to parametric schemes, by varying the slab thickness and the beam spacing in order to assess the influence of the different modelling strategies as a function of these parameters.

References

De Matteis, G., Caprili, S., Carbonari, S., Chisari, C., D'Amato, M., Mattei, F., Zizi, M., Braga, F., Dall'Asta, A., Gara, F., Salvatore, W., 2023. Critical issues in safety assessment of existing reinforced concrete bridges by means of nonlinear analysis. Procedia Structural Integrity, 44, 681-688.

Gara, F., Carbonari, S., Nicoletti, V., Martini, R., Brunetti, A., Dall'Asta, A., & Torsani, A., 2025. Assessment and management of existing bridges following the innovative Italian guidelines: A pilot study. International Journal of Bridge Engineering, Management and Research, 2(1), 21425008-1.

Lo Monaco, A., Palmiotta, A., Ranaldo, A., D'Amato, M., Lippolis, A., Vacca, V., & Sarno, R., 2024. Structural defects for condition assessment of existing bridges: Some results of a territorial case study. Procedia Structural Integrity, 62, 153-160.

MIDAS Information Technology Co., Midas Civil 2025 v9.6.0 Analysis Reference, Chapter 2: Analysis Method (pag. 294-332)

MIT, Instructions for the application of the Italian building code M.D. (17/01/2018), Istruzioni per l'applicazione dell'«Aggiornamento delle "Norme tecniche per le costruzioni"» di cui al D.M. 17 gennaio 2018 (in Italian). Rome, Italy: Italian Ministry of Infrastructure and Transportation, 2019.

MIT, Ministerial Decree M.D. (17/01/2018), Aggiornamento delle "Norme Tecniche per le costruzioni" (in Italian). Rome, Italy: Italian Ministry of Infrastructure and Transportation, 2018.

MIT. Ministerial Decree M.D. n.578 (17.12.2020) - Guidelines for risk classification and management, safety assessment and monitoring of existing bridges (last update DM n.204 of 01.07.2022 - in Italian). MIT. https://www.mit.gov.it/nfsmitgov/files/media/normativa/2022-09/ALL_DM_204_Allegato_A_-_LL.GG_._Ponti_e_V.pdf M.P.W. (1962).

Ranaldo, A., Buongiorno, F., Monaco, A. L., Palmiotta, A., Natali, A., Sangiuliano, L., D'Amato M. & Salvatore, W., 2024a. Half-joints degradation: analysis of some case studies. Procedia Structural Integrity,62, 408-415.

Ranaldo, A., Lo Monaco, A., Palmiotta, A., D'Amato, M., Lippolis, A., Vacca, V., & Sarno, R., 2024b. A preliminary investigation on material properties of existing prestressed concrete beams. Procedia Structural Integrity, *62*, 145-152.