Available online at www.sciencedirect.com

ScienceDirect

Structural Integrity Procedia 00 (2022) 000–000

Structural Integrity Procedia

www.elsevier.com/locate/procedia

II Fabre Conference – Existing bridges, viaducts and tunnels: research, innovation and applications (FABRE24)

Preliminary assessment of pre-1980 girder bridges in the framework of the Italian Guidelines

Giuseppe Santarsiero[a,*], Angelo Masi[a], Valentina Picciano[a], Antonio Musano[b]

[a]*School of Engineering, University of Basilicata, Via dell'ateneo lucano 10, Potenza 85100, Italy*
[b]*Consorzio ReLUIS, Via Claudio 21, Napoli 85125, Italy*

Abstract

The Italian Guidelines issued by the Ministry of Infrastructure and Transportation are devoted to preventing damage on road bridges caused by the lack of maintenance and, in turn, avoiding safety or service problems affecting the infrastructure network. The multilevel approach foreseen by the Guidelines develops through the first three levels to attribute the Class of Attention, whose result indicates subsequent steps for more detailed assessment and monitoring actions to be undertaken. One of these actions is the preliminary verification which is performed by comparing stress values generated by the design load schemes used at the time of construction with the ones obtained by applying the current code. In this paper, preliminary verifications are performed on a series of simply supported girder deck models representative of the Italian state road bridges, obtained through a statistical study on a bridge inventory. Therefore, some performance indices related to the main bridge components are obtained with respect to shear and moment stresses for different bridge configurations in terms of the number of beams, span length, and carriageway width, which can be useful for rapid preliminary assessments of similar bridges.

Keywords: Italian Guidelines; Structural Assessment; Bridge; Reinforced Concrete; Bridge stock.

* Corresponding author. Tel.: +390971205103;
E-mail address: giuseppe.santarsiero@unibas.it

1. Introduction

After the Polcevera Bridge collapse in Genoa (Italy), the Ministry of Infrastructure and Transportation issued the Guidelines for the classification and management of risk, safety assessment and maintenance of existing bridges through Decree No. 578 (on 17 December 2020) (Ministry of Infrastructure and Transportation, 2020). These Guidelines represent a multilevel tool, (from level zero to five), allowing for the bridge assessment starting from the territorial scale to individual structures.

Levels 0 to 2 allow to evaluate the class of attention (CoA) of the bridge considering four different risk types (structure–foundation, seismic, flooding, and landslides). It is worth noting that the class of attention evaluation considers the bridge's ageing and deterioration and, therefore, that the current state of an existing bridge is different from that specified in the design documentation. The class of attention can assume the following results:

- Low
- Medium-Low
- Medium
- Medium-High
- High

Based on the CoA result, further measures must be undertaken. For instance, periodic inspections are sufficient for low and medium-low CoA values, but when the bridge has a medium or medium-high CoA, preliminary assessments are necessary (Level 3 of the Guidelines). Based on the level 3 results, the managing body may decide whether a detailed evaluation of the bridge (Level 4) is necessary, being mandatory in cases where the class of attention is high, providing recommendations for preventive measures (Santarsiero et al. 2023b) and necessary interventions (Sassu et al. 2023).

Previous research mostly concentrated on the evaluation of bridges according to the Guidelines from level 0 to level 2 (Santarsiero et al. 2021), considering the impact of maintenance on the durability of a bridge (Scalbi et al. 2022). Costantino et al. (2022) set up a web platform for the management and analysis of existing bridges mainly focusing on levels from 0 to 2.

Regarding level 3, related to the preliminary assessment of bridges, less research has been found. As an example, the study by Buratti et al. (2019) made a parametric analysis to show the difference in bending stress values based on both old standards used at the time of construction and the loading schemes according to the current Italian standard. However, this study considered deterministic girder deck models for simply supported bridges and viaducts with four different values of the carriage width and span length, without taking into account the transverse load distribution. Moreover, self-weight was not considered in the evaluation as only traffic loads were taken into account.

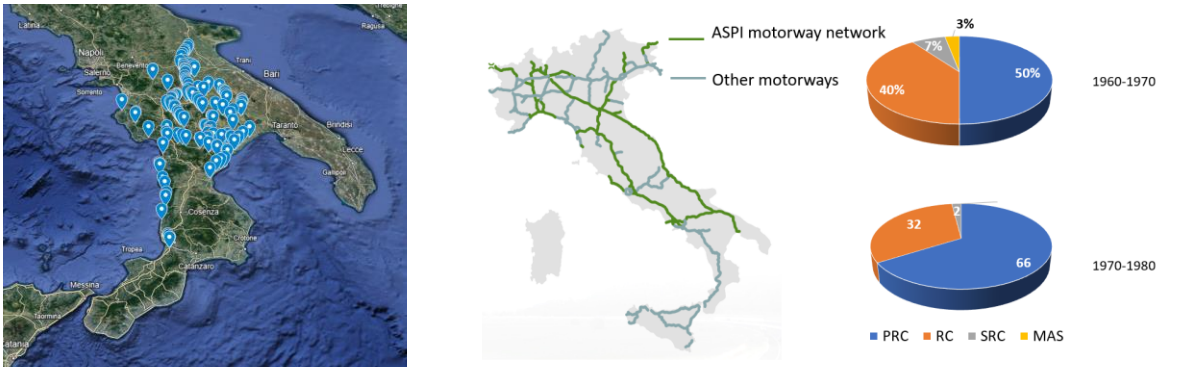
In order to set a probabilistic study on the preliminary assessment of simply supported girder bridges, this paper presents a parametric analysis of deck models defined through a statistical analysis of data collected in a database including bridges along the highways (state roads) in four regions located in south Italy. The study has allowed to obtain a series of graphs useful in comparing bending and shear stress values calculated according to old bridge load regulations with those provided by the current code. This analysis considers bridge sections sampled through the Latin Hypercube Sampling technique from several probabilistic distributions.

These results may be useful for rapid preliminary evaluations on bridges similar to those analysed in this study, for both bending stresses and shear forces.

2. Bridge inventory

This study focuses on simply supported girder deck bridges along the highways of four southern Italy regions, i.e. Basilicata, Calabria, Puglia and Campania (Santarsiero et al. 2023a). Therefore, box deck bridges are not considered in this study. In regions without motorways, like Basilicata, highways are very important for the road transportation network. Along these roads, bridges are mainly simply supported girder deck type with a rather high number of spans. As a source of public information, Google Maps was used to find bridges along the main highways in Basilicata (Google 2023). The total number of bridges was 163 (see Fig. 1a) and, for each structure, the following relevant information was retrieved as, for example, bridge name, length of the structure, number of spans, deck width, number of deck girders, girder transverse spacing, structural material.

The bridge construction period was approximated to the road construction period, in order to establish the design code used at the time of construction.



(a) (b)

Fig. 1. (a) Locations of the 163 bridges included in the database; (b) structural materials of 1960-1980 bridges managed by ASPI.

Most of the bridges have span lengths between 20 and 50 m, while only a few of them (4) have spans larger than 50 m. 36 bridges have spans under 20 m. 39 bridges have span lengths in the range of 20-30 m, and 67 bridges have span lengths from 30 to 40 m. 17 bridges have span lengths in the range of 40-50 m. Based on this data, the subsequent analyses assumed span length values from 20 to 50 m. This assumption is also in agreement with the study in reporting that girder deck bridges have an average span length approximately equal to 33 m. In terms of structural material, 153 bridges out of 163 are prestressed concrete girder bridges. Therefore, the following procedure is specialized for this type of bridges.

It is observed that the selected bridges have a number of deck beams varying from 2 to 16, but decks with 3, 4, 5 and 6 beams are more present having respectively 32, 36, 30 and 32 occurrences. Therefore, later on, only the bridges with 3, 4, 5 and 6 beams are considered.

It is worth noting that preliminary assessments need to compare stress values computed according to traffic loads related to different regulations. In this paper, the current Italian code, Ministerial Decree of 17 January 2018 (also named DM2018) (Ministry of Infrastructure and Transportation, 2018), should be compared with outdated codes in force before 2018, i.e. in the last 50-60 years. In particular, the code Circular n°384 of 14 February 1962 (Ministry of Public Works, 1962), was used till 1980 for the construction of many important roadways and related bridges since it was the period of maximum economic growth in Italy.

Fig. 1b shows the shares of bridges for each deck material, namely, PRC (Prestressed Reinforced Concrete), RC (Reinforced Concrete), SRC (mixed Steel-Reinforced Concrete) and MAS (Masonry) for the motorway concessionaire Autostrade per L'Italia S.p.a. (Landolfo 2023). As can be seen, in both the 1960-70 and 1970-80 decades, the majority of bridges were built using the PRC system. It is expected that the relative shares of structural materials in terms of total road length are even more unbalanced towards PRC since these structures are often multi-span bridges. Based on this observation, for the sake of simplicity, level 3 assessment will be illustrated only for the period 1960-1980, referring to the code Circular n°384 of 14 February 1962 (Ministry of Public Works 1962).

3. Load schemes

3.1. Circular n°384 of 14 February 1962

This standard considers first-category and second-category bridges. In the subsequent parametric study, only the first category is accounted for to consider the highest values of traffic loads and obtain the most severe stress values.

The load schemes described are as follows (Fig. 2): Load Scheme 1−Indefinite column of 12-ton trucks; Load Scheme 2−Isolated 18-ton road roller; Load Scheme 3−Compacted crowd at a rate of 400 kg/m^2; Load Scheme 4−Indefinite train of military loads weighing 61.5 tons; Load Scheme 5−Indefinite train of military loads weighing 32 tons; Load Scheme 6−Isolated military load of 74.5 tons.

This code prescribed the use of a military load scheme (Schemes 4, 5 and 6) combined with a civilian load scheme (Scheme 1), thus obtaining the heaviest conditions. These loads are arranged to cover lanes 3 m wide for the civilian load scheme (Scheme 1) and 3.5 m wide for the military loads (Schemes 4, 5 and 6). Furthermore, a dynamic amplification factor was used to consider the dynamic effects of traffic loads according to expression (1):

$$\phi = 1 + \frac{(100-L)^2}{100(250-L)} \tag{1}$$

in which L represents the span length.

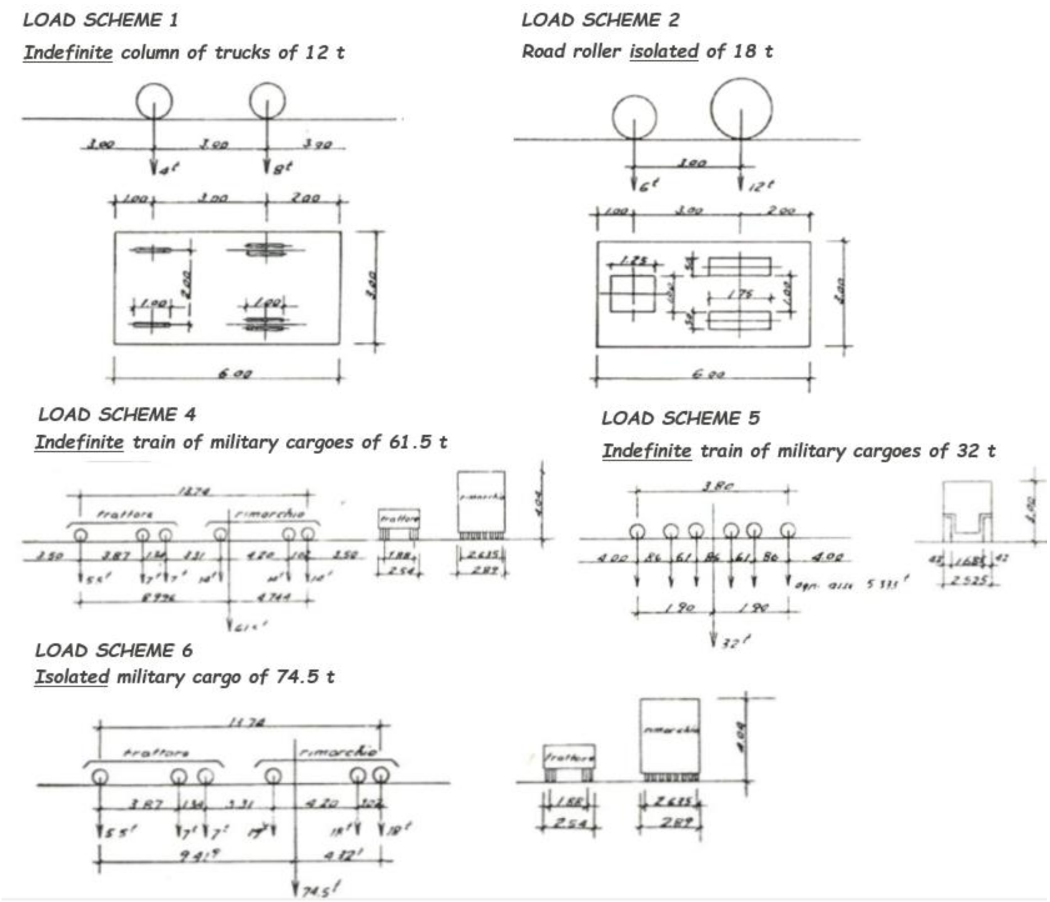


Fig. 2. Military load schemes according to Circular n°384 of 14 February 1962.

Based on real bridge design documents, the self-weight of the deck typologies of bridges built referring to this code was also evaluated in order to perform the subsequent preliminary assessment, accounting for all the dead and live loads. More detail about this aspect can be found in (Santarsiero et al. 2023a).

3.2. *Ministerial Decree of 17 January 2018 (current Italian code)*

This is the standard currently used for bridge design in Italy, providing guidelines for the design of road bridges. The standard considers two types of bridges: first-category bridges and pedestrian bridges. In the following, only the first-category bridges are considered since they allow any type of vehicle transit.

It foresees six load schemes, while the main load pattern used to design and check for global equilibrium and safety is Load Pattern 1 (Fig. 3).

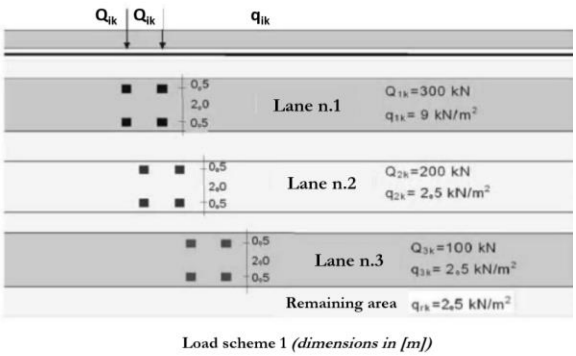


Fig. 3. Load schemes according to DM2018.

No dynamic amplification factors are required, which are already accounted for in the loading schemes.

Load pattern 1 is applied along conventional lanes, having a width that depends on the carriageway width (w). Moreover, the number of lanes (n_l) is computed using the indications reported in Ministry of Infrastructure and Transportation (2018).

4. Deck typologies

To define a set of girder decks representative of the entire bridge database, three deck properties were considered, namely (i) number of longitudinal girders, (ii) spacing between girders, and (iii) total deck width.

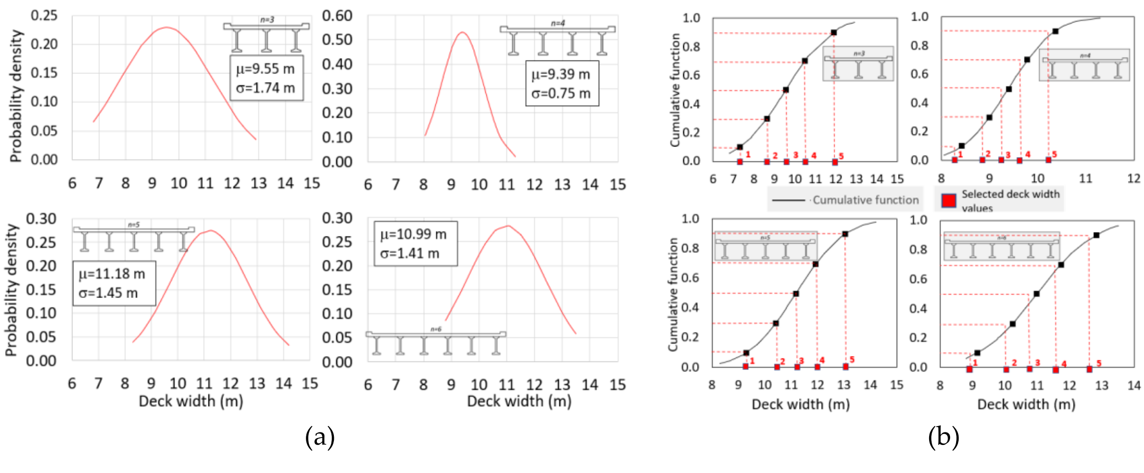
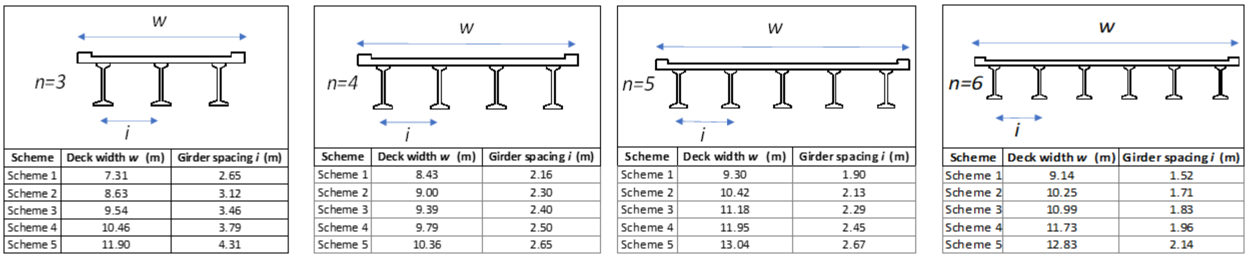


Fig. 4. (a) Deck width probability distributions and (b) cumulative functions.

These latter are statistically obtained by a sampling technique across the probabilistic distributions of the deck properties above mentioned that are partially dependent on each other. It is assumed that the number of girders is an independent variable while the deck width and spacing between girders are dependent variables.

It is assumed that the deck width (w) has a Gaussian probability distribution. Considering the bridge database, and the mean and the standard deviation values of w, the probability density functions can be obtained regarding w for the different number of deck girders (n varying from 3 to 6), resulting in four probability distributions (Fig. 4a), also reporting mean and standard deviation values. From the probability distributions, the cumulative functions were determined (Fig. 4b), which allowed using Latin Hypercube Sampling (LHS) technique, representing a stratified sampling, allowing for a statistically representative description of the stock, even with a limited number of samples. The red dots in Fig. 4b represent different width values w, for each number of girders. This is done by splitting the range 0-1 of the cumulative functions (vertical axis) into five intervals of equal width (having a size of 0.2).

Hence, five girder deck types are defined for each of the n values, which are therefore analysed considering four values of the span length L (20, 30, 40, 50 m). Finally, 5 × 4 × 4 = 80 configurations are set in total (Fig. 5).



Scheme	Deck width w (m)	Girder spacing i (m)
Scheme 1	7.31	2.65
Scheme 2	8.63	3.12
Scheme 3	9.54	3.46
Scheme 4	10.46	3.79
Scheme 5	11.90	4.31

Scheme	Deck width w (m)	Girder spacing i (m)
Scheme 1	8.43	2.16
Scheme 2	9.00	2.30
Scheme 3	9.39	2.40
Scheme 4	9.79	2.50
Scheme 5	10.36	2.65

Scheme	Deck width w (m)	Girder spacing i (m)
Scheme 1	9.30	1.90
Scheme 2	10.42	2.13
Scheme 3	11.18	2.29
Scheme 4	11.95	2.45
Scheme 5	13.04	2.67

Scheme	Deck width w (m)	Girder spacing i (m)
Scheme 1	9.14	1.52
Scheme 2	10.25	1.71
Scheme 3	10.99	1.83
Scheme 4	11.73	1.96
Scheme 5	12.83	2.14

Fig. 5. Deck types for the selected number of girders.

5. Level 3 assessment

Based on the above-illustrated deck typologies, the structural analysis in terms of bending and shear stresses is carried out through the Courbon Engesser method (Petrangeli 1997), obtaining the design values that should have been used at the time of the bridge design according to the outdated standard C1962 (Ministry of Public Works, 1962). This allows to obtain the stress values acting on the external girder, which is the most stressed among the deck girders. The stress values need to be computed also according to the current code Ministerial Decree of 17 January 2018 (Ministry of Infrastructure and Transportation, 2018).

A preliminary assessment is made through the definition of performance indices I, derived from the ratio between stress values of the old code and those from the current code in terms of both bending (M) and shear stress (T), through expressions (2) and (3) respectively:

$$I_M = \frac{M_{1962}}{M_{2018}} \tag{2}$$

$$I_T = \frac{T_{1962}}{T_{2018}} \tag{3}$$

When I_M and I_T are higher than 1.0, the design stress values are above those used for the assessment according to the current code. Contrarily, values below 1.0 identify a design capacity gap. I_M and I_T are representative of the main girder structural performance under the assumption of no degradation phenomena (Masi and Santarsiero 2013). Moreover, I_T gives indications not only on the shear design resistance of girders but also regarding the design vertical action of bearing devices. The above-mentioned performance values for the 80 cases obtained using the 20 deck types and the four span length values are shown on the vertical axis in the graphs of Figures 6 and 7, reporting the span length on the x-axis.

Generally, I_M (Fig. 6) increases with the span length, indicating that major flexural strength gaps are observed for shorter bridges. No big differences are observed among the different schemes with the same number of girders except when n = 3 for which some significant differences are observed at higher span length values. In terms of I_T, (Fig. 7) the curve trends are almost the same, showing differences among schemes with the same n value (e.g. n = 3 in Fig. 7) that spread for high span length values.

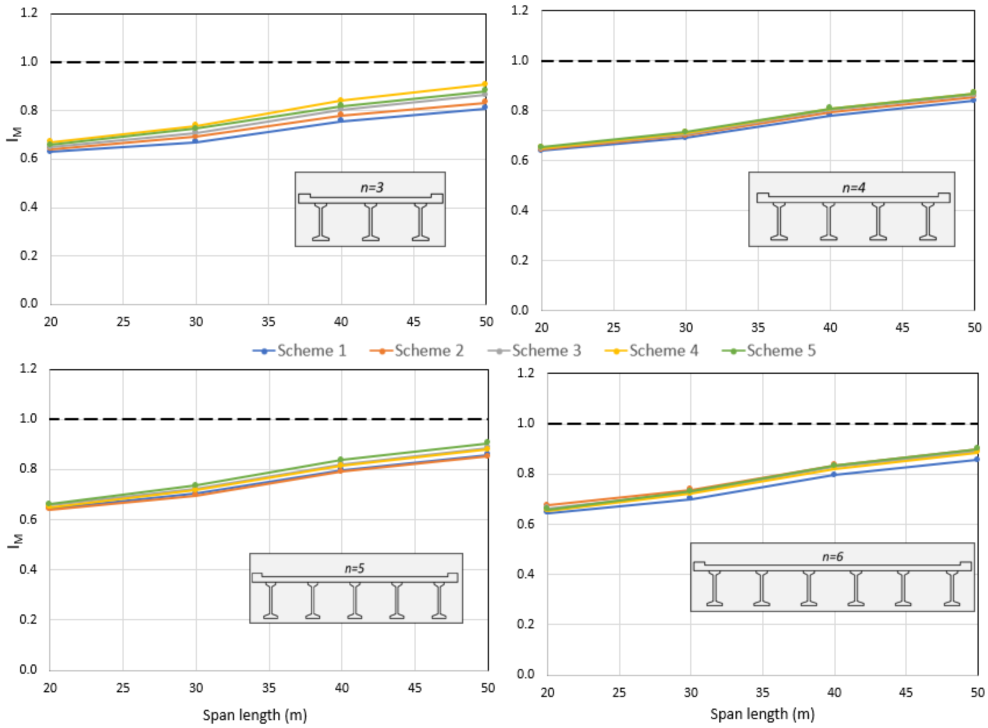


Fig. 6. Performance indices I_M for Circular 1962.

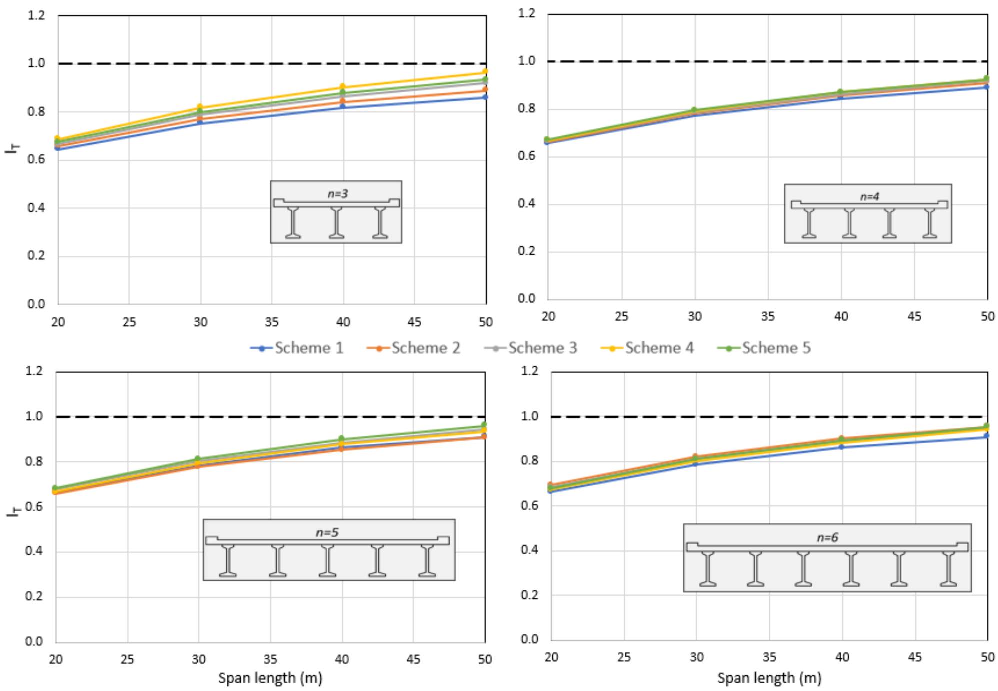


Fig. 7. Performance indices I_T for Circular 1962.

For bridges with a 30 m span length, I_M results averagely around 0.75, while at 40 m span length is about 0.80.

For 30 m long spans, I_T is averagely near 0.80, while for 40 m spans is between 0.85 and 0.90. Therefore, the shear strength gap is slightly lower than that related to bending moment stresses.

6. Conclusions

This paper presented a methodology for rapid level 3 assessment according to the Italian Guidelines for risk classification and management, safety assessment and monitoring of existing bridges. These assessment activities are necessary in case the class of attention result is medium or medium-high, and are performed by comparing the stress values used for design purposes at the time of construction and those obtained by applying the current code. The parametric analysis here presented is based on deck schemes obtained through a statistical analysis and sampling on a purposely built database of bridges located in four southern Italy regions. The outdated code used in this study is the one that was in force for about 20 years (from 1962 to 1980), which characterised the construction of the major bridge structures in Italy. Performance indices are calculated for 20 deck types and 4 span length values in terms of moment and shear. Shear performance indices are generally higher than bending moment ones. The former vary in the range of 0.63-0.97, being higher for high span length values, while the latter are in the range of 0.61-0.95 and averagely lower than those related to shear, highlighting a more significant gap. The results of this parametric analysis can be helpful for rapid preliminary assessment of highway bridges with geometric features of the same type here considered.

Acknowledgments

This research is funded by CSLLPP (High Council of Public Works as part of the Italian Ministry of Infrastructure and Transportation) in the framework of the agreement with the ReLUIS consortium for the research project “Accordo attuativo del DM 578 del 2020 a 204 del 2022” WP4, Task 4.2.

References

Buratti, G., Cosentino, A., Morelli, F., Salvatore, W., Bencivenga, P., Zizi, M., De Matteis, G., 2019. Alcune considerazioni sull’evoluzione normativa dei carichi da traffico nella progettazione dei ponti stradali in Italia. In Proceedings of the XVIII Convegno «L’ingegneria Sismica in Italia», ANIDIS, Ascoli Piceno, Italy, 15–19 September 2019.

Costantino, G., Messina, D., Recupero, A., Rossi, P. P., & Spinella, N., 2022. A web platform for management and analysis of existing bridges. Procedia Structural Integrity, 44, 1220-1227. https://doi.org/10.1016/j.prostr.2023.01.157

Google Maps, 2023. Available online: https://www.google.com/maps (accessed on 06 December, 2023).

Landolfo, R., 2023. Bridges with Steel and Steel-reinforced concrete structure. Conference “The experimental application of the Guidelines on existing bridges”. Rome 24-25 October 2023.

Masi, A., Santarsiero, G., 2013. Seismic tests on RC building exterior joints with wide beams. Proc. of the 2nd International Symposium on Materials Science and Engineering Technology (ISMSET 2013, June 27-28, 2013, Guangzhou, China). Advanced Material Reasearch. Vol 787: 771-777

Ministry of Public Works, 1962. Norme Relative al Calcolo dei Ponti Stradali: Roma, Italy, 1962. (In Italian)

Ministry of Infrastructure and Transportation, 2018. DM 17/01/2018: Aggiornamento delle Norme tecniche per le costruzioni, Suppl. or. n.30 alla G.U. n.29 del 4/2/2008, 2018. (In Italian, accessed on 08/02/2023). https://www.gazzettaufficiale.it/eli/gu/2018/02/20/42/so/8/sg/pdf

Ministry of Infrastructure and Transportation, 2020. D.M. 17/12/2020 n.578: Linee guida per la classificazione e gestione del rischio, la valutazione della sicurezza ed il monitoraggio dei ponti esistenti; Ministero delle Infrastrutture e dei Trasporti: Rome, Italy, 2020. (In Italian)

Petrangeli, M.P., 1997. Progettazione e Costruzione di Ponti, IV ed.; Masson, Ed.; Milano 1997.

Santarsiero, G., Albanese, P., Picciano, V., Ventura, G., & Masi, A., 2023a. Level 3 Assessment of Highway Girder Deck Bridges according to the Italian Guidelines: Influence of Transverse Load Distribution. Buildings, 13(7), 1836. https://doi.org/10.3390/buildings13071836

Santarsiero, G., Masi, A., Picciano, V., Digrisolo, A., 2021. The Italian Guidelines on Risk Classification and Management of Bridges: Applications and Remarks on Large Scale Risk Assessments. Infrastructures 2021, 6, 111. https://doi.org/10.3390/infrastructures6080111.

Santarsiero, G., Picciano, V., Masi, A., 2023b. Structural rehabilitation of half-joints in RC bridges: A state-of-the-art review. Struct. Infrastruct. Eng. 2023a, 1–24. https://doi.org/10.1080/15732479.2023.2200759.

Sassu, M., Puppio, M. L., Doveri, F., Ferrini, M. & Mistretta, F., 2023. A time and cost-effective strengthening of RC half joint bridges exposed to brittle failure: application to a case study, Structure and Infrastructure Engineering, DOI: 10.1080/15732479.2023.2275689

Scalbi, A., Zani, G., Di Prisco, M., Mannella, P., 2022. The role of maintenance plans on serviceability and life extension of existing bridges. Struct. Concr. 2022, 24, 127–142. https://doi.org/10.1002/suco.202200379.