CETRA 2018

5th International Conference on Road and Rail Infrastructure

17–19 May 2018, Zadar, Croatia

Road and Rail Infrastructure V

Stjepan Lakušić – EDITOR

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PARAMETRIC ANALYSIS OF PEDESTRIAN TIMBER BEAM BRIDGES AND SELECTION OF THEIR OPTIMAL DESIGN

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Abstract

Paper represents results of parametric analysis of timber beam bridges intended to serve pedestrian and cyclist traffic, as well as possible traffic of service and emergency vehicle. Type and position of load-carrying deck, as well as optimal transverse disposition of selected structural form were indicated as immediate goal of the analysis, while the number of main-girders, their cross-sectional type and dimensions, together with accompanying consequences on global stability of the bridge were highlighted as significant parameters. Solid timber deck and cross laminated timber (CLT) deck covered by asphalt layer were considered as the two basic types, while grillage structure using ribbed CLT were considered as an possible alternative. More than 150 examples of prepared finite element models (FEM) of the bridges, classified into four representative groups according to the characteristic transverse layouts were analysed. Static and dynamic analyses were performed by varying both, span of simply supported straight main-girders and useful width of deck which was conditioned by traffic profiles. Results of analysis were given as recommendations and guidelines for the selection of optimal design of the bridge with regard to span and requests on its functionality and durability.

Keywords: parametric analysis, pedestrian and cyclist traffic, timber beam bridges, static and dynamic analysis, optimal design

1 Introduction

The purpose of the preliminary parametric analysis [1] is the choice of the design layout of the pedestrian timber bridge which structural form with simply supported straight main-girders is optimal for particular span and useful width of the deck. This type of timber bridges is of high level prefabrication and therefore suitable to be manufactured, even in The Republic of Croatia. It is applicable in both urban and rural areas (crossings over waterways, other natural obstacles or busy roads), almost regardless of climate zone, as the traffic load effect is crucial for the analysis [2, 3]. This type of assembly simplifies the analysis of the wind [4] loads, and the chosen range of spans excludes dynamic analysis due to the wind. It was presumed that the analysis based only on the verifications of serviceability limit state, can be a satisfactory basis for the optimization, because this structural form is of limited span and sensitive to deflections of members and vibrations due to traffic, for which two goals of performed parametric analysis are set: define criteria of the analysis and evaluation of results, as well as propose solutions which would fulfil the basic demand of mechanical resistance and stability on the economic justified grounds. The results of the analysis are a proposal of the transverse layout type and the kind of the deck, both suitable to variations of spans (from 10 m to 18 m) and the useful width (from 2 m to 4,5 m). The parameters, which were analysed, are: position, type and static systems of the load-carrying deck (open-boarded or sealed solid timber deck and CLT), number and the layout of main-girders and transoms, i.e. geometry of the T-beams with CLT flange (as alternation), and ancillary changes of the type of spatial stabilization. Structural members of standard and high strength were analysed: D30 / D40 (for hardwood solid deck), and C24 / C30 (for stringers of softwood) or GL24 h / GL28 h (for main-girders and transoms). For the CLT decks, an even quality of the layers is considered (planks of the C24 strength class, with thickness d = 22 mm) and the effective depth of 5-layered CLT, d = 100 mm [1].

2 Parametric analyses

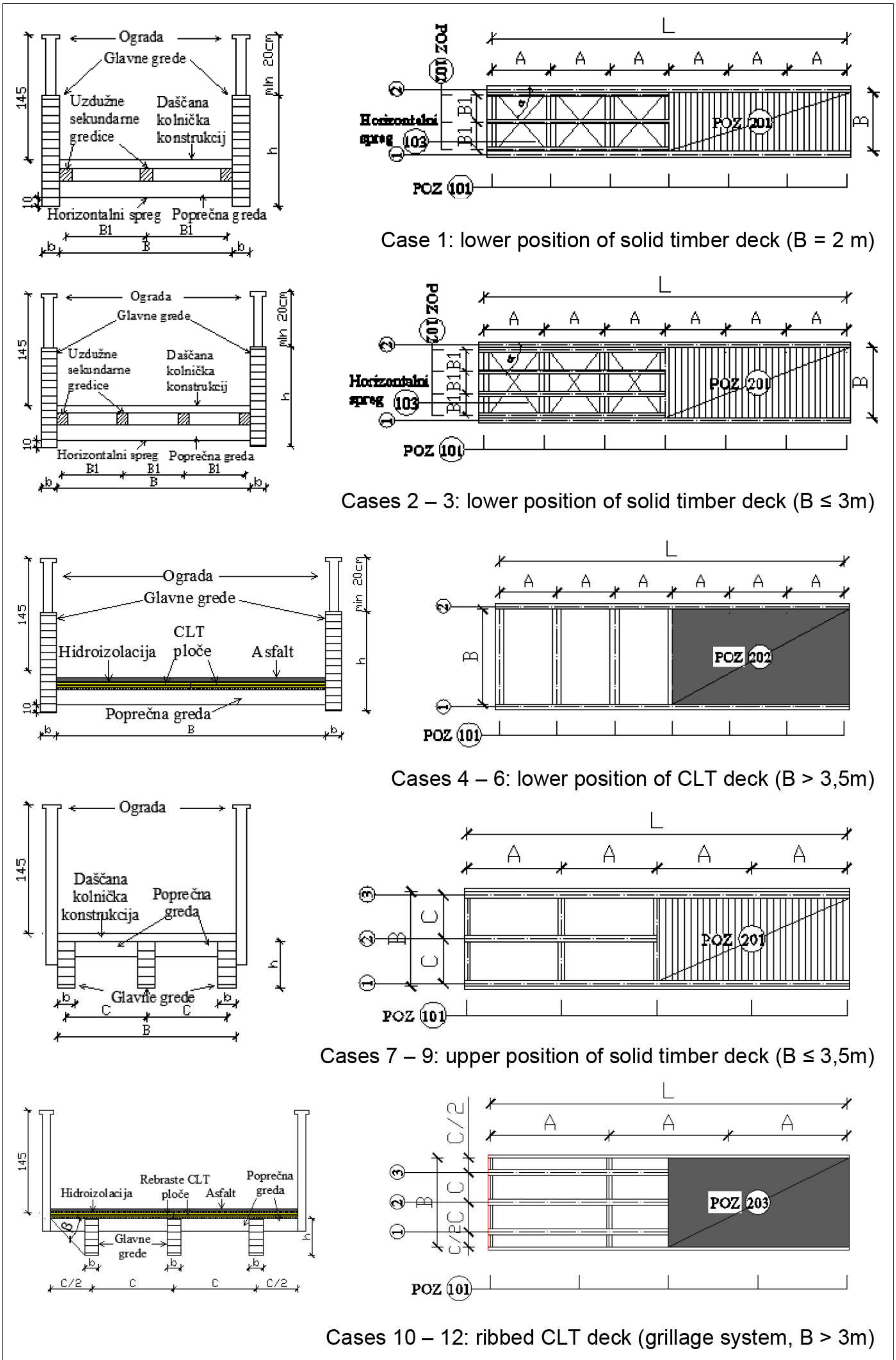
2.1 Parameters, parameter choice criteria and validation of design solution

Optimization of the design solution (layouts) is based on the variations (Fig. 1) of the following parameters of the analysis: span, width of the bridge, type and the position of the deck together with ancillary changes of traverse layouts and spatial stabilization. Satisfying the requirements of the intended purpose, safety and comfort of traffic, was the logical criterion of choosing the analysis parameters. Therefore the analysed effects of the variations of totally 6 types (Table 1) were classified according to width of usable traffic profile (from 2 m to 4,5 m) and the number of traffic lanes on the type of the traverse layout of the bridge. Widths of 3 m upwards enable a mixed traffic (with separations by line or kerbs) [3], and the smallest one (i.e. 2 m), enables traffic of service and/or emergency vehicle [1].

Table 1 Varied useful widths – analysed types of usable traffic profiles [1]

Type	Cases (Fig.1)	Number of traffic lanes		Useful width of the bridge [m]
		pedestrians	cyclists	
I.	1 and 7	2	0	2,0
II.	2 and 8	0	2	2,5
III	3 and 9	1	1	3,0
IV.	4 and 10	2	1	3,5
V.	5 and 11	1	2	4,0
VI.	6 and 12	2	2	4,5

Analysed useful widths (Table 1) are defined as regulated smallest usable traffic profile, expanded by 0,4 m, i.e. 0,7 m (for mixed traffic) for usage comfort and safety requirements [1]. The criteria of the choice of the range of span (from 10 m up to the 18 m), with the increase of 2 m represents expected widths of obstacles, limitation in the technology of production, transport and assembling, and cost-effectiveness of this type of structural form [2, 3]. The following types of decks (Fig. 2) are characteristic for the intended purpose of the bridge: a) transversal laid planks with castellated section (grooves as anti-slip option) over stringers (sealed deck, Cases 1-3) or main-girders (open-boarded deck, Cases 7-9); b) CLT deck over transoms (Cases 4-6) and c) as flange of glued composite (Cases 10 – 12) with GluLam ribs, i.e. series of T-beams, as the alternative proposal of grillage assembly. Varying the position of the running deck implicates different solutions of providing spatial stability, as well as classification of main-girders into appropriate serviceability class (2 or 3, used in calculation) and hazard class (2 or 3, concerning durability and protection measures) [1].



Case 1: lower position of solid timber deck (B = 2 m)

Cases 2 – 3: lower position of solid timber deck (B ≤ 3m)

Cases 4 – 6: lower position of CLT deck (B > 3,5m)

Cases 7 – 9: upper position of solid timber deck (B ≤ 3,5m)

Cases 10 – 12: ribbed CLT deck (grillage system, B > 3m)

Figure 1 Analysed cases – varying of layout and type of load-carrying deck [1]

Boards with castellated section – type a) used for cases 1 – 3, 7 – 9 (Fig. 1)

Coated CLT plates – used for type b) and c) used for other cases (Fig.1)

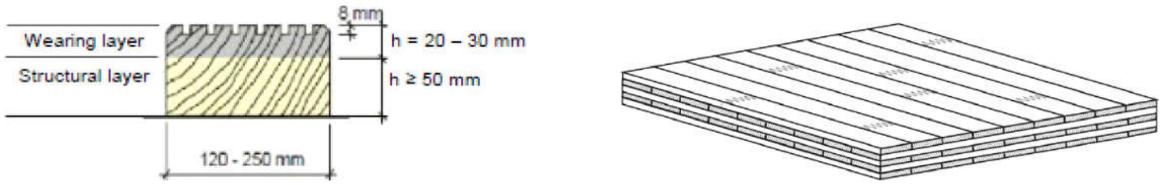


Figure 2 Timber products used for analysed types of decks from a) to c) [1]

The deck in first two types is replaceable, and due to direct exposure (use class 3), requires adequate strategy of surface or preservative treatment, drainage system and sealing. It is particularly valid for CLT, and therefore additional wetting prevention (layers of waterproofing membrane and hydro-insulation) beneath the wearing asphalt course needs to be used together with replaceable side cladding or strips. With this the presumption only, CTL might be classified in serviceability class 2 (prerequisite of its structural use). For c) type, a special strategy of treatment needs to be applied because all parts of the assembly are structural member, irreplaceable within designed working life. Necessary treatment of the main-girders as vital members must be applied in all considered cases: good protective design details, corrosion-resistant metal cover, surface finishes, etc. In all cases with the upper position of the deck, where it acts as "roof", main-girders are "drawn in", and angle ß ≥ 30 (Fig. 1) enables protection from rainfall, while side wooden strips provide additional protection. Side faces of exposed main-girders might be cladded by shiplap boards or louvers [3, 5].
The defined initial criteria of evaluating optimality of the design solution (the type of the deck and layout, the way of ensuring spatial stability) are ratios of quantities of used timber vs. span, expressed: directly, for type of traverse layout, and indirectly, for main-girders only (its depth and number of main beams). Taking into account demands on protection strategy, the most important design criterion is sufficient mechanical resistance and the stability of the entire structure. In accordance with the preliminary level of analysis, verifications of serviceability limit state, such are deflections and vibrations were performed [1].

2.2 Finite element models (FEM) used in static and dynamic analyses

FEM analysis were conducted for the influence of self-weight and permanent load (e.g. concentrated load due to parapet and uniform loads of wearing layer), and the variable loads of snow (with s 2,5 kN/m^2), wind (with its basic velocity of 25 m/s, characteristic for the continental area). Vertical traffic load (pedestrian) was applied as 5,0 kN/m^2, where favourable effects due to the span above 10 m were disregarded [6], and horizontal as 10% of amount of the vertical load. The vehicle traffic was modelled as the moving load, taking into account its position variations inside the usable traffic profile and tracking (Fig. 3) [1, 6].

a) sub-model with plate FE for boards

b) traced positions of vehicle

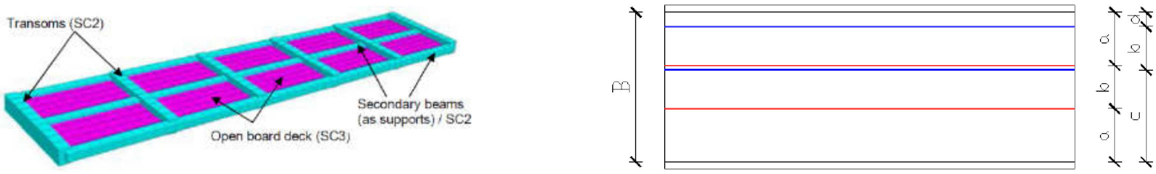


Figure 3 Sub-model for deflection analysis and simulation of moving load [1]

For every considered type of the transverse layout and ancillary solution of spatial stability (Fig. 1, Fig. 2) appropriate 3D FEM was prepared (altogether 4 models with beam and plate FE): to check the instantaneous and the final deflection (using relevant stiffness properties), for checking the deflection due the vehicle (as an independent load) and the vibrations due pedestrians and self-weight load within dynamic analysis. Sub-models were designed to analyse the influence of moving load (Fig. 3), for calculation the deflection of planked deck where the number and cross-section of stringers were varied for its maximal distance of 1m.
All types of prepared FEM-s (Fig. 4) were analysed with span variations. For systems with countersunk deck (cases 1-6), grid of the transoms was followed by the increase in span. For the systems with upper position of deck (cases 7-12), the number of main-girders and/or ribs of T-section were varied using suitable FEM-s. CTL decks (type b, Fig. 2) were modelled simplified, as continuous system over transoms. For the cases 10-12, T-beams (from 3 up to 4) were modelled with bending stiffness $(EI)_{ef}$ of glued composites with full composite action (Fig. 4,e-f). The following dimensions of members were set as constant: structural cross-section of 200/50mm, for planks, where its wearing layer was taking into account as self-weight; rectangular glulam transoms of 200/300 mm, i.e. 160/240mm for softwood transoms (as stiffeners, cases 10-12); the depth of stringers of 160 mm; the width of main-girders of 200 mm; effective thickness of 60 mm for CTL, where 5-layered plate were modelled as 3-layered and traverse layers were taking into account as self-weight. Verification of deflection for sealed planked deck (cases 2-3) passed the system with two inner supports [1].

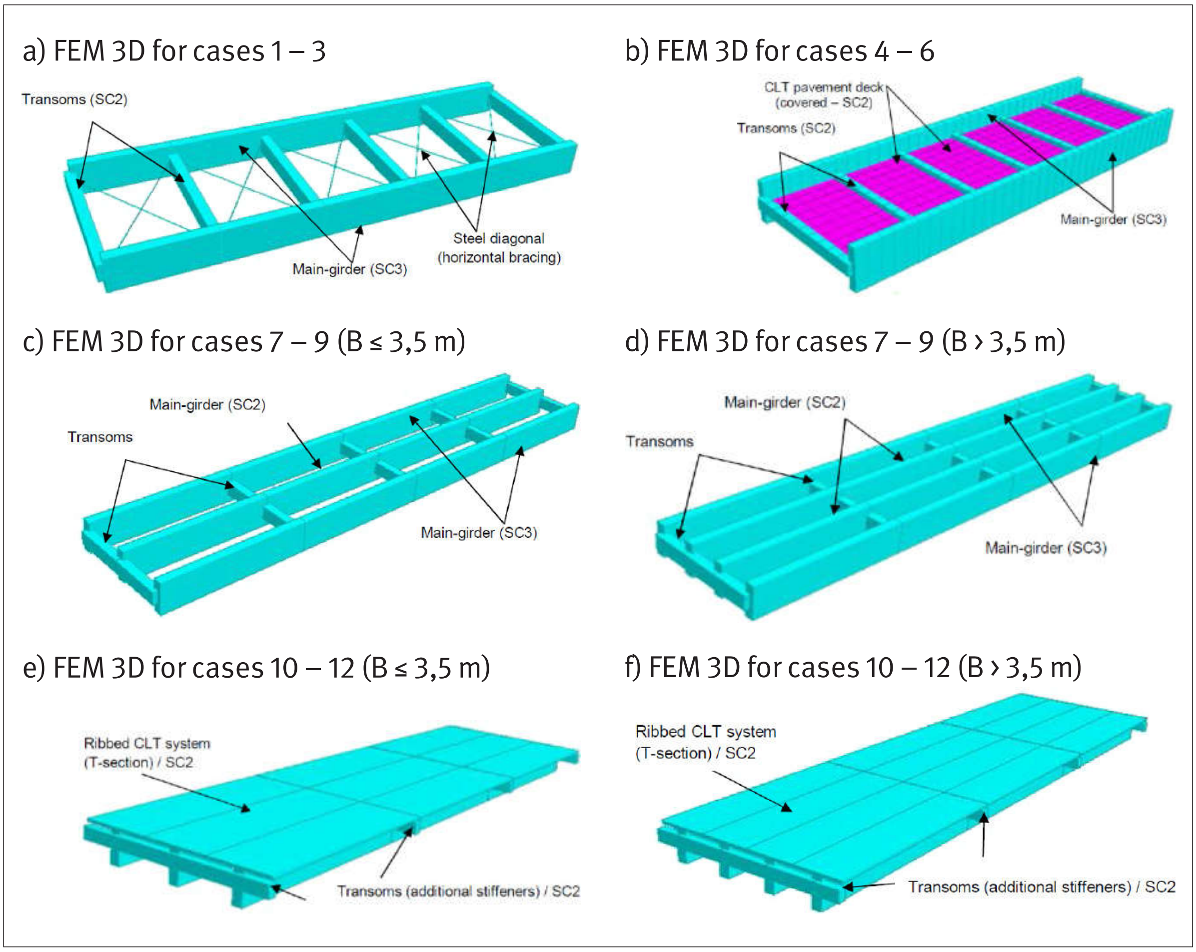


Figure 4 Examples of prepared finite element 3D models (FEM 3D) [1]

Within analyses, norms HRN EN 1995-1-1 and HRN 1995-2 were applied in conjunction with norms HRN EN 1990 and HRN EN 1991-3, HRN 1991-4 and HRN EN 1991-2 (for load analyses) and their National Annexes (valid in The Republic of Croatia). National regulations on basic conditions for public roads and cyclist infrastructure to be met from the point of view of traffic safety were also applied. Detailed list of all used norms and National regulations is available in [1].

2.3 Results of performed static and dynamic analysis

The following limitations of deflections for structural members with its span / were presumed: l/250, for the final, and //300 for the instantaneous deflections (including those caused by load of pedestrians and/or emergency vehicle) [6]. Dynamic analysis were performed using minimal required dimensions of the structural members resulted from implementation of deflection criteria. Calculated vertical vibrations were within range 3 – 5 Hz (for 1st mod of oscillation), while acceleration maxima for individuals or persons in crowds didn't exceed 0,7 m/s^2 [1]. Accordingly to HRN EN 1990/A2 and [4], both confirms deflections as more important criteria for all analysed cases.

3 Discussion of criterion of optimisation and conclusion

Results of application of initial criteria for validating optimality of design solution could be discussed by assessing the following ratios with respect to the span: a) difference among total quantities of material if irreplaceable structural members were made of timber of different quality (Fig. 5) and b) difference between required minimal depths of main-girders (Fig. 6). Criterion a) isn't so efficient because the differences in the consumed material don't exceed 5%. However, since the costs of implementing a protection strategy for structures with partly exposed vital members can be initially estimated in amount of 10 % up to 15 % [5] of total costs, such data may be useful. The following could be noted if usable traffic widths exceed 3 m: by comparing solutions with CLT deck, grillage systems (Cases 10–12) could be assessed as more efficient. Among comparable cases with planked deck, its upper position is more favourable, where cases 1 and 7 with the smallest deck's width, should be observed as an exception. Differences less than 10% between results of analyses performed for different strength classes (Fig. 6) when criterion of required depth of the main-girders applies have negligible impact on the optimization. In order to select suitable layout with respect to the span, additional limitations were introduced to ensure the appropriate lateral torsion stability to main-girders or provide sufficient clearance beneath the bridge (Fig. 7).
Therefore, dimension ratio for rectangular main-girder is limited as 8:1 for cases 1-6 while its maximal depth of 0,7m is assumed for cases 7–12 (Fig. 7). Adopted height of parapet from upper deck surface to handrail is 1,4 m [1, 3].
The results (Fig. 7) point to following: for types from I. up to III. with usable width up to 3 m (Table 1) which are representative for defined traffic, design solutions with sealed deck (cases 1-3) are more favourable as applicable to all spans, while comparable solutions with open-boarded deck (cases 7-9) are unacceptable for spans longer than 12m; for comfortable usable widths up to 4m, i.e. types IV. – V. (Table 1) with CLT deck, detailed analysis should be performed for spans above 15m when usable widths exceed 3,5m. Nevertheless, design solutions presented as cases 4-5 could be recommended as more acceptable in comparison with grillage assemblies (cases 10-11). It is similar for usable widths above 4m (cases 6 and 12), considered as an exceptional for defined intended purpose of bridges. The indirect purpose of performed research is not only to promote timber as a suitable material for bridging, but also to point up the benefits of its use other than aesthetics and load-carrying capacity: high level of prefabrication and ease of erection which is especially significant when minimal disruption of traffic is essential. It is very important to include protection strategy early in planning because it enables to discuss levels of protection and types of construction, taking into account longevity of bridge without major repairs.

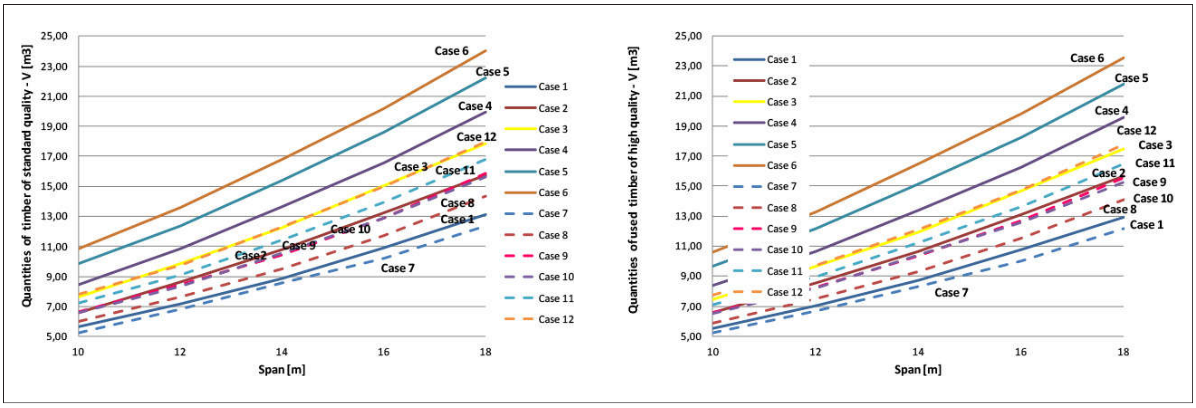


Figure 5 Quantity criterion – the effects of using different strength classes [1]

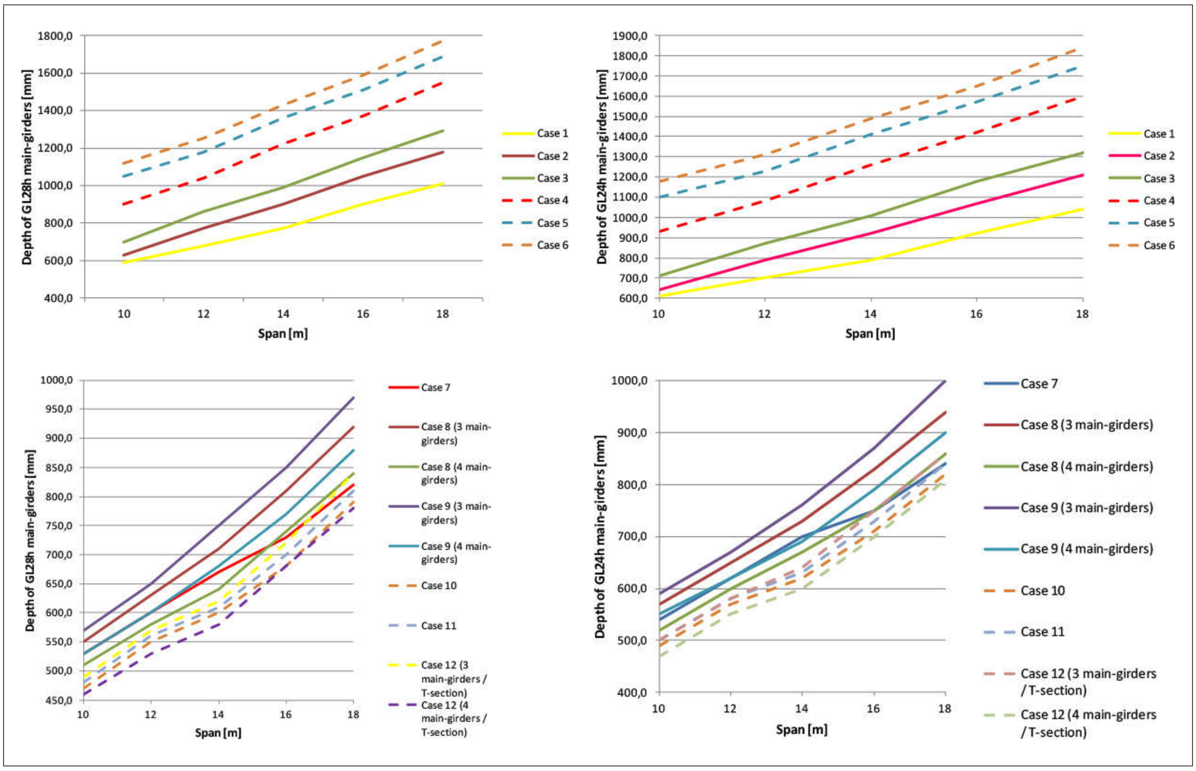


Figure 6 Criterion of required depth of main-girder considered strength class [1]

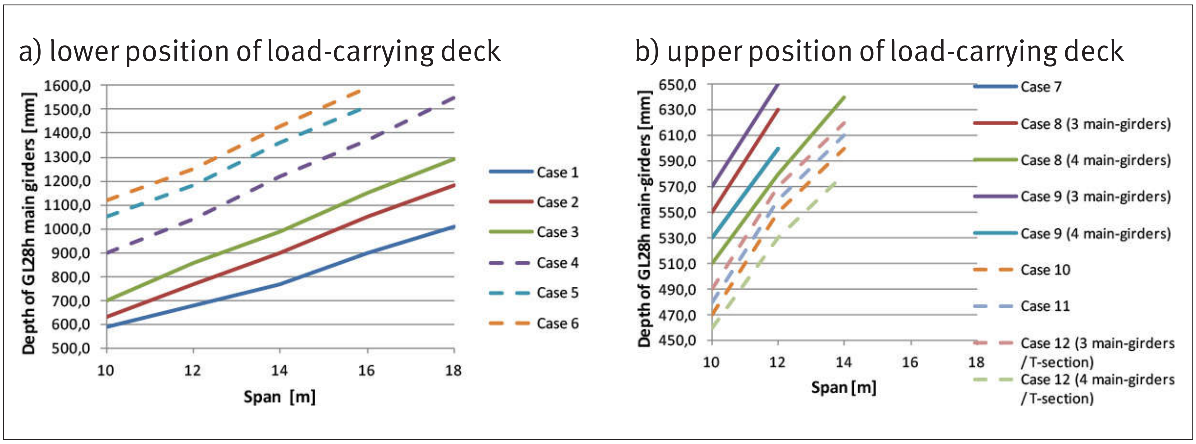


Figure 7 Proposals for optimal design solutions with respect to the span [1]

References

[1] Franolić, F.: Parametarska analiza pješačkih drvenih grednih mostova, Master thesis, Faculty of Civil Engineering of University in Rijeka, pp. 91, 2017.

[2] Ritter, M.A.: Timber bridges: design, construction, inspection and maintenance, US department of agriculture, Forest Service, EM 770-8, 1990.

[3] Mettem, C.J.: Timber bridges, First edition, TRADA Technology Ltd, 2011.

[4] Kreutzinger, H.: Dynamic design strategies for pedestrian and wind actions, Proceedings of "Footbridge 2002" International Conference, Paris, 2002, pp. 129-141

[5] Schwaner, K.: Protection and durability of wooden bridges, Innovative Wooden Structure and Bridges, IABSE Conference Report, Lahti, Finland, 2001, pp. 85-96.

[6] HRN EN 1995-2:2013/NA (2013): Eurokod 5: Projektiranje drvenih konstrukcija – 2. dio: Mostovi – Nacionalni dodatak, HZN, Zagreb, 2013