Numerical analysis of widened deck slab of Gerber-girder bridge

Wojciech Siekierski

Faculty of Civil and Environmental Engineering, Poznań University of Technology
Piotrowo 5, 61-138 Poznań, Poland
e-mail:wojciech.siekierski@put.poznan.pl

Abstract

Many bridges in service today were built in the second half of the 20th century. Some of them have Gerber girders. There are several such bridges that require deck widening due to insufficient throughput. To achieve that, new outermost girders may be added. Sometimes, due to erection convenience, they do not replicate the static scheme of the refurbished structure. The paper shows such case, problems that occurred in the wake of it and offers an alternative concept for deck widening. An analytical method and finite element model are applied to find bending moment distribution in the added slab span. It is shown that the FE analysis is necessary to assess bending moment distribution in added deck slab supported by main girders of different static scheme. The bending moment distribution is sensitive to live loads located over the whole deck width.

Keywords: bridge, Gerber girder, deck slab widening, refurbishment, finite element analysis

1. Introduction

Several beam-girder bridges built in Poland in the second half of the 20th century have Gerber girders. Majority of the structures are RC (reinforced concrete) bridges [4]. Significant number of them are nowadays to narrow to carry traffic safely. Span widening often requires erection of additional girders [3].

The deck of the bridge over Gwda river in western Poland was widened by replacing cantilevers with additional girders made of prestressed concrete – Fig. 1. Theoretical span lengths are: 14.5+21.0+14.5 m. Each of side spans consists of 5.5 m long cantilevers and 9.0 m long simply supported span. RC girder height varies over a distance of 5.0 m in the vicinity of piers.

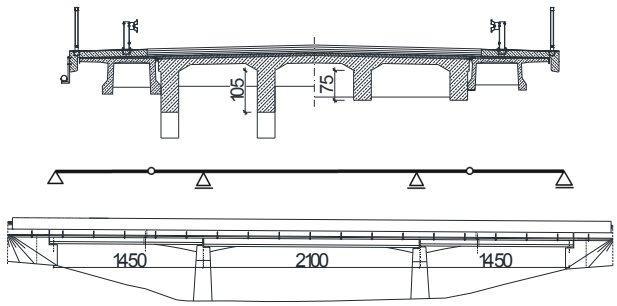

Figure 1: Analysed bridge: cross-section (top), static scheme (centre), side view (bottom)

Due to variations in deflection lines of the outermost RC girders and added prestressed girders the longitudinal joint of "old" deck slab and added girders lost its water tightness. The outermost RC girders experienced extensive damage caused by water leaks. The access to the damaged girders is limited due to close vicinity of the added girders.

2. Alternative concept of span widening

An alternative method of the described span widening is to use continuous steel-concrete composite girders instead of simply supported prestressed girders (Fig. 2). In such case erection requires less labour on site in comparison to Gerber beam static scheme. There are no transverse stiffeners between the outermost RC girders and the steel-concrete composite girders. Their co-operation is provided only by added deck slab that is connected to the outer face of the outermost RC girders (vertical interface) and to the "old" deck slab (horizontal interface) with adhesive anchors.

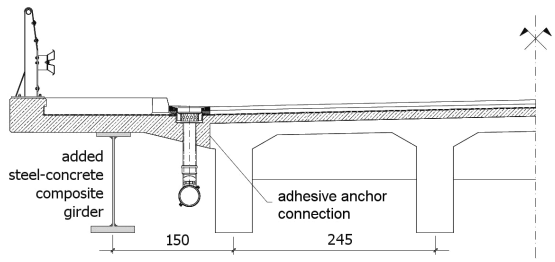

Figure 2: Additional steel-concrete composite girder ("new" concrete shaded)

3. Analysis of the added deck slab

The deck slab is supported by girders. In side spans of the bridge, the boundary conditions for the outermost span of the slab differ from one girder to the other. The outermost girder of the initial structure is an Gerber RC-girder whereas the adjacent (added) girder is a continuous steel-concrete composite girder.

Analytical method of analysis of RC deck slab in multi-girder road bridges is based on setting the degree of slab flexural restraint (α) produced by girder torsional rigidity [2]. The value of α is computed as follows:

$$\alpha = \frac{1}{1 + \frac{k \cdot l^2}{b} \cdot \frac{I_s}{I_T}} \tag{1}$$

where: I_s – slab moment of inertia in bending, I_T – girder moment of inertia in torsion, b – girder axial spacing, l – cross-beam axial spacing, k – a coefficient accounting for the distance of given location to the nearest cross-beam (see Table 1).

Table 1: Rule for setting the *k* coefficient

x/l	0.0	0.1	0.2	0.3	0.4	0.5
k	0	0.225	0.400	0.525	0.600	0.625

Note: *x* – the distance to the nearest cross-beam

Bending moments in slab span and at slab support are computed as follows:
– bending moment at the support (girder):

$$M_{el.su} = \alpha \cdot \overline{M}_{su}, \tag{2}$$

– bending moment at the mid-span:

$$M_{el.sp} = M_{sp} - \alpha \cdot \left(M_{sp} - \overline{M}_{sp}\right). \tag{3}$$

where: α – degree of slab flexural restraint at the support, $\overline{M}_{su}$, $\overline{M}_{sp}$ – bending moments at the support and at the mid-span respectively, for a fixed beam, M_{sp} – bending moment at the mid-span, for a simply supported beam.

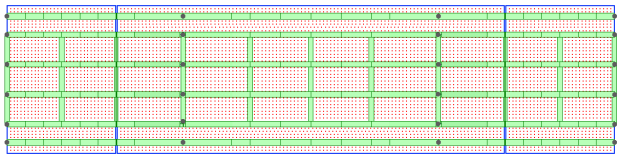

Figure 3: FEM model (bottom view)

FEM model of the initial bridge together with additional steel-concrete girders (Fig. 3) was created in Autodesk Robot environment [1]. Two-node beam elements were used to model RC ribs and steel beams and 4-node shell elements were used to model deck slab, both of 6 degrees of freedom at node. All elements were situated in the deck slab centre plane. Appropriate offsets for centres of gravity of the elements modelling RC ribs and steel girders were declared. The ”old” slab, after refurbishment, is assumed to be 30 cm thick and the added one – 20 cm thick. The flexural stiffness (*EI*) of RC girder, with respect to the stiffness of the added steel-concrete composite girder, is: 0.60 in the side spans, 1.16 in the middle span and 3.28 at piers. Modulus of elasticity for “old” concrete is 30 GPa (B30), for “new” concrete” – 32 GPa (C30/37) and for steel – 210 GPa. Two load cases of uniformly distributed load of 10 kN/m^2 were considered: A – applied to the outermost slab span (between the outermost RC girder and the steel-concrete composite girder), B – applied to all slab spans. In both cases the whole length of the bridge side span was loaded.

4. Analysis results

Diagrams of bending moment at the mid-span and at the support of the added slab span, computed according to the analytical and numerical methods, are shown in Fig. 4. Symbols in the legend denotes: Msu-a, Msp-a – bending moment at the support and at the mid-span respectively, according to the analytical method, Msu-nA, Msp-nA – bending moment at the support and at the mid-span respectively, according to the numerical analysis of the load case A, Msp-nB – bending moment at the mid-span, according to the numerical analysis of the load case B.

While computing the degree of slab flexural restraint it was assumed that at supports the steel-concrete girders are restrained against torsion, as if there was a cross-beam.

In terms of the load case A the assessment based on the degree of slab flexural restraint underestimates the slab bending moments at the RC girder (Msu-a line in Fig. 4) near abutment and pier in comparison to FEM results (Msu-nA line). The bending moment at the added slab mid-span at Gerber hinge, suggested by analytical method, is also underestimated. According to numerical analysis, generally, slab bending moments at the RC girder (Msu-nA line) are larger than at the steel-concrete composite girder. The only exception is the ordinate “9” that denotes location of Gerber hinge in the RC girder (orange dot in blue circle). FEM analysis shows that, near the Gerber hinge, there is sagging bending of deck slab at the outermost RC girder (Msu-nA line). Local increase of bending moment at the added slab mid-span (Msp-nA line) can be seen near the Gerber hinge.

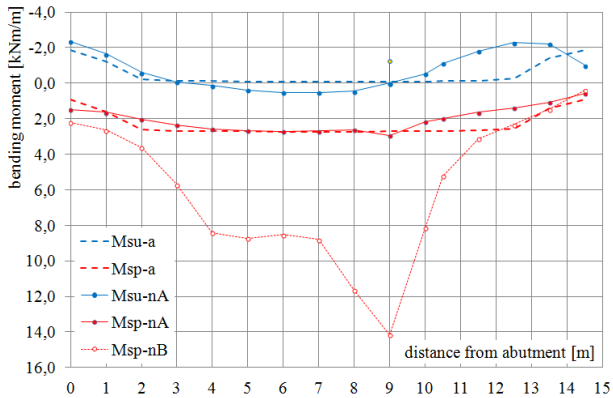

Figure 4: Bending moments in added deck slab

The sagging bending of the added slab span is even more explicit when all span slabs are loaded (load case B). Diagram of bending moment at the added slab mid-span (Msp-nB line) shows that the outermost slab spans carries loads located on the whole simply supported portion of the side bridge span. Bending moments due to this action are much larger than based on the analytical method. Magnitude of the bending moments depends on the flexural rigidity of the steel-concrete composite girders. The more rigid the beam the larger the bending moments at the added slab span.

5. Conclusion

It is possible to widen a RC-girder Gerber bridge with extra continuous girders and to join the two parts with newly added RC deck slab. Distribution of bending moment in the added slab span (i.e. the span between the initially outermost RC girders and added steel-concrete composite girders) differs from the assessment based on the analytical method. That is why static analysis of the added slab has to be based on numerical modelling. The analysis should consider live loads acting on the whole width of the bridge span with Gerber hinge. Reinforcement in existing slab should be checked against modified bending moment distribution.

References

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