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An efficient method for analysis of service load stresses in bridge gusset plates

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ABSTRACT

The paper presents modified beam-element modelling of bridge truss girders. Despite its simplicity the technique provides satisfactory accuracy of assessment of stress distribution in bridge truss gusset plates. The modification consists in the introduction of shell elements modelling gusset plates into a beam-element model of a truss girder. In the paper the modified beam-element modelling of a scaled bridge truss girder is compared to regular hybrid modelling that employs beam elements to model members and shell elements to model joints. The ability of both techniques to predict stress in a gusseted joint of the lab tested scaled girder is investigated. Stresses based on recorded strains and those computed using the described technique are compared. Modified beam-element modelling is shown to be a relatively easy and accurate method for bridge gusset plate analysis.

1. Truss structures in bridge construction

In modern bridge construction trussed structures are still applied as main girders [4,22] – Fig. 1. Truss bridges of long spans often have two decks: the upper one usually carries road traffic and the lower one – railway. A similar arrangement is used in cable-stayed bridges with trussed decks – Fig. 2.

The mentioned types of truss structures have often a "W" bracing. Another common feature is the fact that spacing of deck cross beams is usually smaller than spacing of truss girder nodes – the cross beams are connected to truss flanges at their nodes and between them. Such flanges simultaneously carry axial forces (as truss members) and bending moments (as beams). Flexural stiffness of the flanges is significantly larger than in the case of a traditional cross beam arrangement (connections only at flange nodes). The flanges that pick loads from intermediate cross beams are called rigid to stress the difference. A truss girder with a rigid flange is shown in Fig. 3.

In the bridge structures shown in Figs. 1 and 2 bracing-to-flange connections usually employ twin gusset plates, which are separate elements welded to truss flange or integrated into flange side walls. Such joints are shown in Fig. 4a and b, respectively. In both cases bracing members are connected to gusset plates either by welding or by HSFG (high strength friction grip) bolts.

2. Techniques for analysis of bridge truss girders

2.1. Beam-element modelling

Beam-element modelling is a common method of bridge truss girder analysis. It is effective in terms of assessment of internal force distribution. The range of its applications is wide – member design, member connection design, assessment of bridge load carrying capacity, strengthening design, fatigue strength analysis, test loading design, dynamic analysis [1,2,5,18,26].

The main disadvantages of this method arise from the assumption of dimensionless joints. It limits the applicability of the beam-element modelling in gusset plate design. Application of beam analogy to stress analysis in gusset plates is known to be inaccurate in terms of estimation of stress distribution. Whitmore criterion [24] and its modifications, i.e. Thornton method [20] and modified Thornton method [25], neglect the influence of mutual interaction of members within boundaries of a gusset plate on stress distribution in the plate.

Moreover, the assumption of dimensionless joints usually leads to underestimation of truss girder flexural stiffness. In reality, truss girder joints, due to their structural arrangement and dimensions, enhance the stiffness. It is so especially in the case of classic bridge truss girders. In the case of truss girders with rigid flanges the influence of gusset plates on the truss girder flexural stiffness is rather limited [1].

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2.2. Shell-element modelling

Due to development of hardware and software, shell-element modelling of bridge truss girders is more and more popular. However, it is still time consuming in terms of model preparation, results analysis and their application to structural design.

Shell-element modelling of steel structures takes into account structural details such as stiffeners, joint layout and dimensions as well as connectors. It is crucial especially for joint analysis.

In the case of bridge truss joints with gusset plates, a large number of connectors (rivets or bolts – Fig. 4) makes it necessary to apply simplified methods of connector modelling. The methods are (based on [16]):

- Modelling of connector effects with appropriate kinematical constraints applied at nodes of finite elements that model connected members [21].
- Modelling of connector effects by applying pressure to appropriate surfaces of shell elements that model members connected with HSFG bolts [10] or rivets [7].
- Modelling of rivets or bolts with beam elements that connect nodes belonging to finite elements that model connected members; the connected nodes are situated on the longitudinal axis of actual connector and the bolthole is neglected [6,17].
- Beam-element modelling of connector accompanied by displacement compatibility constraints applied to shank ends and bolthole edges [10].
- Beam-element modelling of connector shank and head [3,10] – Fig. 5.

Simplified modelling of ordinary bolt usually simplifies (and sometimes falsifies) real bolt-member interaction in a computational model. It refers mainly to bearing of bolt shank against the connecting element through-thickness bolthole walls as well as bolt head and nut washer against outermost member surfaces. In the case of HSFG bolts the consequences of simplified modelling of bolts are limited. This is because such bolts introduce mainly pressure between connected members. Provided there is no slip, bolt shank carries only tension. Thus only the bearing of bolt head against outermost member surface needs to be taken into account. This makes beam-element modelling of friction grip bolt an attractive solution, especially when it is accompanied by shell-element modelling of connected steel members. In this technique it is possible to consider variations of pressure introduced by bolts and slip near boundaries of surfaces of contact.

Application of shell-element modelling seems to be justified when beam-element modelling is insufficient in terms of accuracy of stress or stiffness distribution assessment.

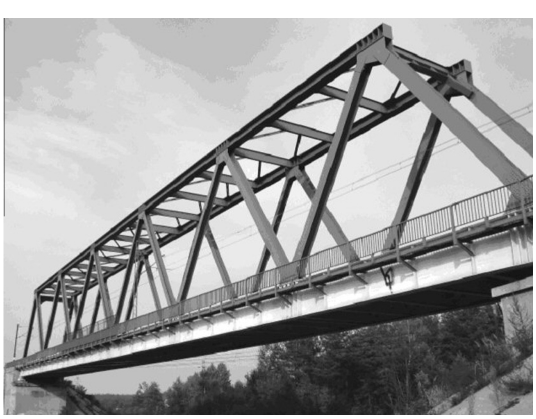

Fig. 1. Trusses as main girders.

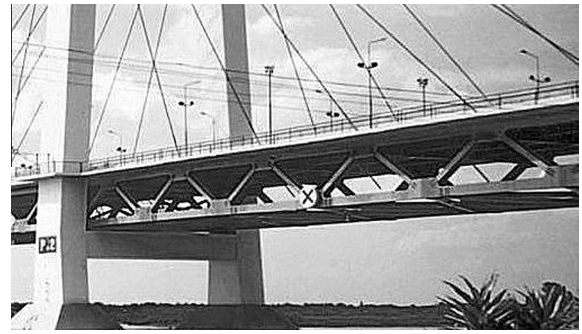

Fig. 2. Trussed deck of cable-stayed bridge.

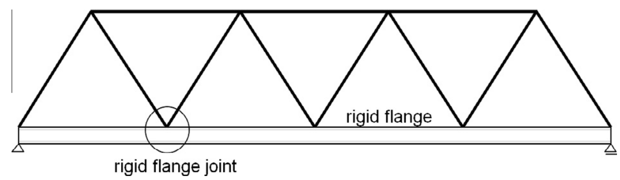

Fig. 3. A truss girder with a rigid flange.

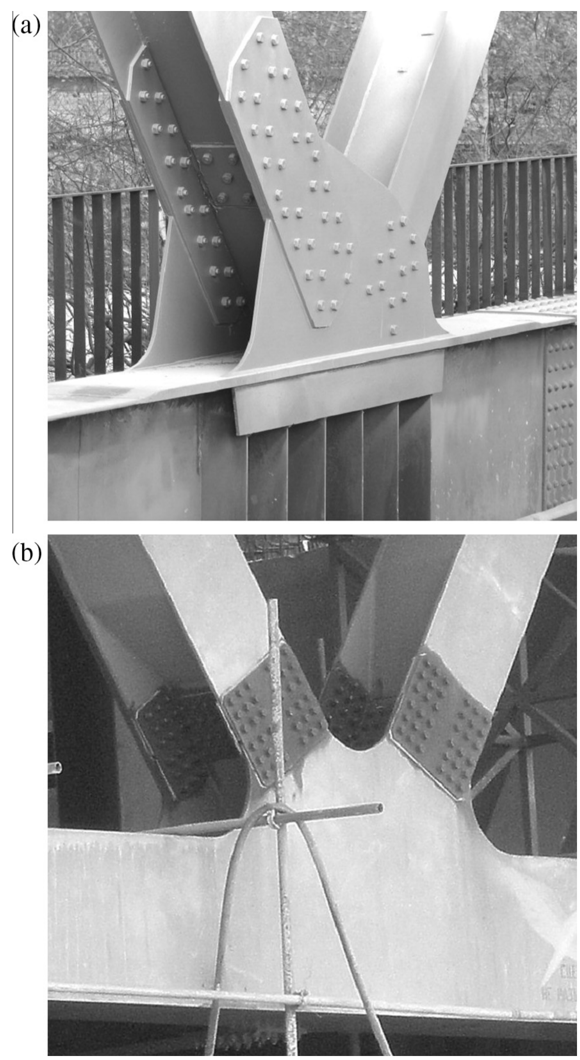

Fig. 4. Truss girders joints: (a) twin gusset plates as separate elements and (b) gusset plates integrated into flange side walls.