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COMPOSITE BEAM MODELLING AT REAL SCALE INCLUDING BEAM-TO-BEAM JOINT

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Abstract. *This paper deals with the influence of a particular type of beam-to-beam joint on global and local behavior of a continuous composite beam of bridge. The F.E. code "Pontmixte" developed at INSA of Rennes has been already presented and used for various applications in previous papers. The model used by this code permits to include easily a particular finite element representing a joint that enforces the continuity of the composite continuous beam. End-plates welded at the ends of the steel beams are connected with studs to a transverse concrete transverse beam laying on an intermediate support represent the beam-to-beam joint. After a fast description of a 3D model developed with the F.E. code "CASTEM" concerning only the joint, a Moment-Rotation curve will be obtained and computed in "Pontmixte" for numerical simulations. Comparing the results of the original continuous beam (without joint) against the ones obtained with the same beam including the joint at one of the intermediate supports, the performance of a such type of beam-to-beam joint as well as the performance of the specific finite element computed in "Pontmixte" are clearly identified provided some remarks pointed out in the conclusion.*

1 INTRODUCTION

The understanding of the beam-to-beam joint behavior for composite bridges is of a big importance. The French national research calls MIKTI highlighted some joint solutions fundamentally different ones to others. For the first solution, the steel girders are connected with cover-plates and high strength bolts. This solution, generally located near the cross-section of zero bending moment, remains well-known for steel constructions [1] and it is not in need of more numerical modeling investigation so simplified 1D and 2D models could give sufficient information. For the second solution, both ends of steel girders are embedded in a concrete block resisting over the pier. Each steel girder lies directly over its own support in order to avoid a shear force transfer through the mid-cross-section of the embedding. This type of joint is necessarily located at intermediate support and could be investigated by a 3D numerical model similar to the one presented in this paper and concerning the third solution. For the solution under investigation, the steel girders are equipped with butt-plates welded at their ends. These are connected with shear studs to a transverse beam lying on an intermediate pier (Fig.1).

The finite element code Castem [2] is used to propose a 3D model for this type of joint in order to study the influence on the joint behavior of some parameters such as the friction coefficient between the butt-plate and the transverse beam as well as the butt-plate thickness and the connection degree. These future understandings will leads to propose an accurate design method of such joint solution. The behavior of the joint, represented by a moment-rotation curve of the composite cross-section, will be computed in the program Pontmixte [3] considering a specific finite element. The main objective of this work is to propose a first approach taking into account this type of joint to study a continuous composite beam at real scale.

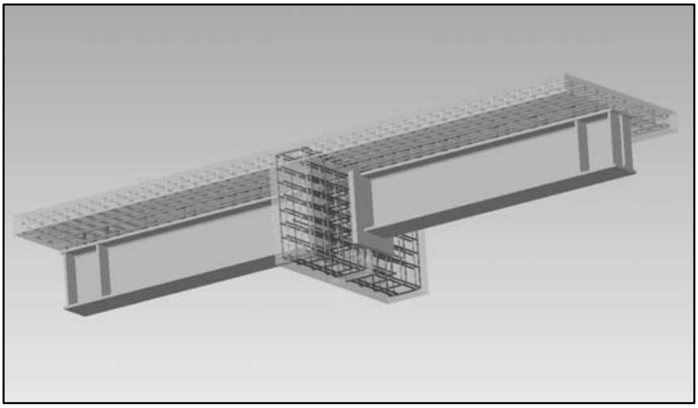


Figure 1: Beam-to-beam joint under investigation.

2 EXPERIMENTAL TEST AND 3-D F.E. MODEL

Geometrical details of the experimental test are given in figure 2. The steel girder is an HEA 500 rolled section in steel grade S355. The width of the slab is 1600 mm and the thickness is 160 mm. The strength class C45/55 is used for the concrete. Several details are given in a companion paper presented by A. Lachal and al. In SDSS'Rio2010. It is pointed out that the rotation ϕ of the joint is calculated as the difference between the rotation θ_1 at the attached beam cross-section and the rotation θ_2 at the axis support cross-section. This detail is considered for experimental as well as for numerical values of the joint rotation.

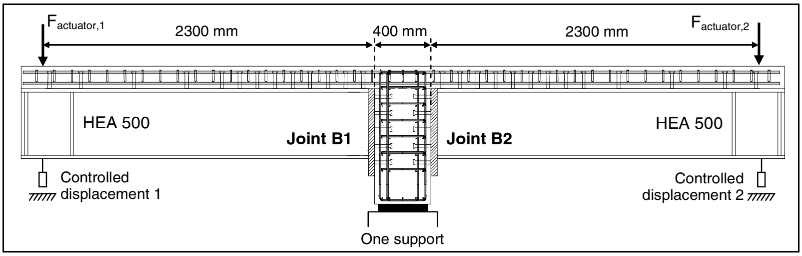


Figure 2: Geometrical details.

The 3-D finite element model developed on Castem uses principally cube finites elements with 8 nodes. The concrete slab including reinforcing bars and vertical shear studs uses 22140 elements, the steel girder, the stiffeners and the butt-plates 4974 elements, the transverse beam with horizontal shear studs 5576 elements and a small transversal steel girder used to applied the load 246 elements. The model uses the symmetry and contains 32936 finite elements. Figure 3 shows the top and the side views of the mesh (the concrete was removed for best clearance).

The mechanical properties are summarized as follows:

- For the concrete slab, perfect-plastic Drüker-Prager behavior model is used (Fig.4) with Mazars damage model. This isotropic scalar model is well-adapted to monotonic loading and depends on some parameters that are easily identified. The initial cracking of the slab due to the cyclic pre-loading of the specimen test is taken into account by an exponent variation of its Young's modulus (Fig.5) from the plane of symmetry ($E^c/100$) till the end cross-section (E^c = 35200 MPa) with the parameters $C_1 = 0.019$ and $C_2 = 1.853$.

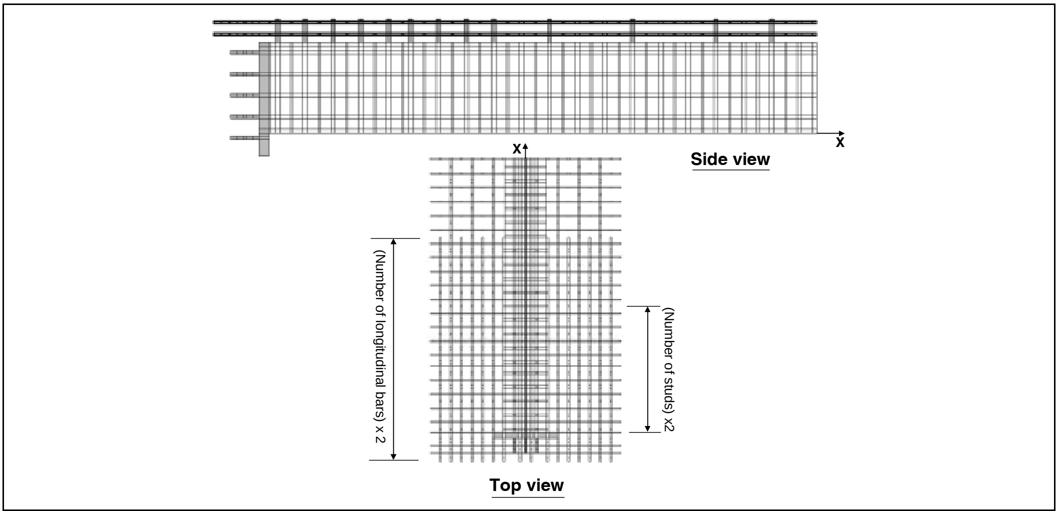


Figure 3: The 3D-model mesh – Top and side views.

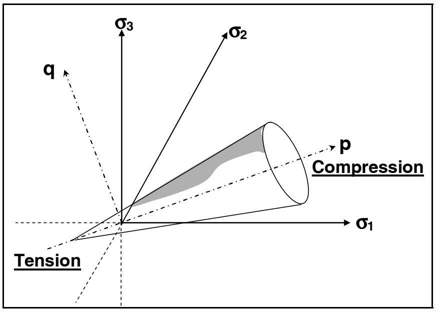


Figure 4: Drüker-Prager behavior model.

- The transverse beam is supposed to be a homogenized material. In order to take into account the reinforcing bars that are not included in the model, the Young's modulus is considered equal to $1{,}3E^c$. As-well-as the slab, this material behavior is perfect-plastic Drücker-Prager with 45MPa for yield compression and 7MPa in tension.

- The adherence between the upper flange of the girder and the slab is neglected, only the studs insure the transfer of the shear forces at the interface. For this material, also a perfect-plastic Drücker-Prager model is adopted with a compression resistance equal to 4,5MPa and a tension resistance equal to 0MPa; the Young's modulus is equal to E^c. Oppositely, the friction between the butt-plate and the transverse beam have a significant importance mechanically and also numerically and could not be neglected. Numerically, if no material is provided at the interface, the contact could cause the divergence of the iterative process. Mechanically, perfect-plastic Drücker-Prager model with 45MPa in compression and 0MPa in tension could be adopted but in future developments, specific contact elements have to be used.

The Young's modulus is equal to $1,3E^c$ to provide the concrete cracking of the transverse beam during the contact with the butt-plate.

- Mechanical characteristics of steel materials (girder, stiffeners, reinforcing bars, butt-plate and studs) are given on table 1. Their behavior model is elastic-plastic with kinematic hardening (Figs.6) (f_y is the elastic limit stress and f_u the ultimate limit stress).

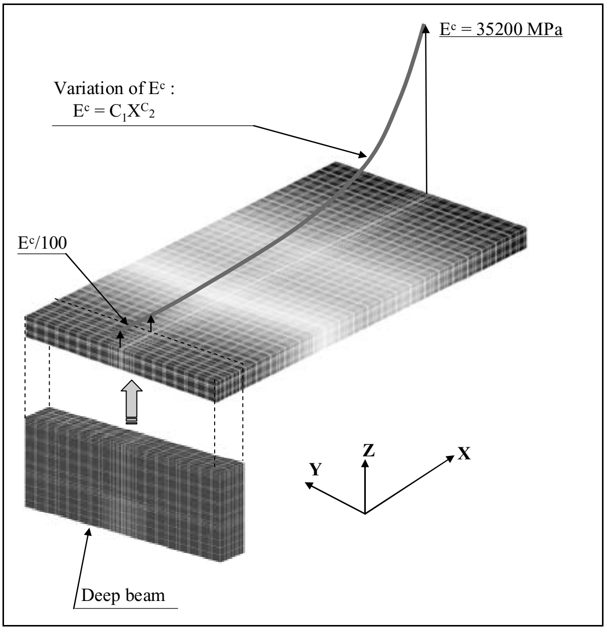


Figure 5: Young's modulus variation of the concrete slab.

Table 1 – Mechanical characteristics.

Material	Girder – Stiffeners – Butt-plate	Reinforcing bars	Studs
E (MPa)	200000	200000	200000
f_y (MPa)	430	585	350
f_u (MPa)	525	680	580

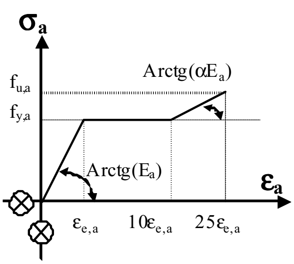


Figure 6.a: Girder–stiffeners–butt-plate.

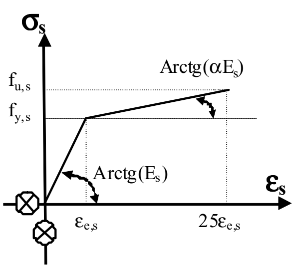


Figure 6.b: Bars.

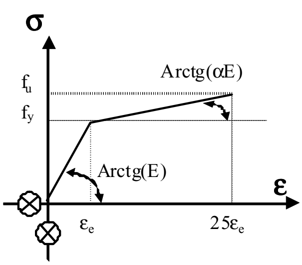
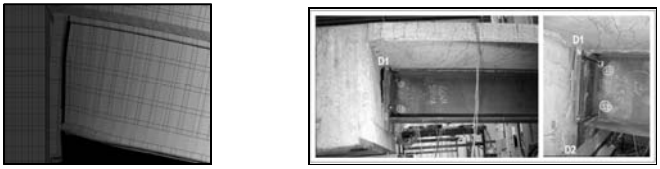


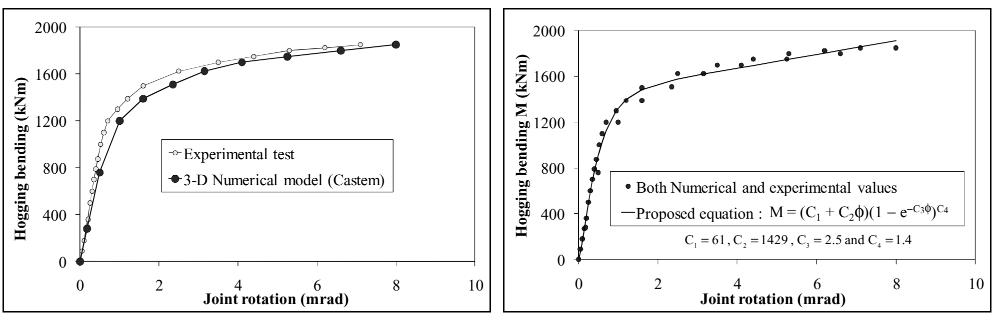
Figure 6.c: Studs.

The model as-well-as the specimen test is loaded until cracking of one of the constitutive materials. The test was stopped for a load equal to 900 kN. Figures 7 show the butt-plate deformation at this stage of loading comparing the model and the experimental test.



Figures 7: The 3D-model and the experimental test at end-loading.

The Moment-Rotation (M-ϕ) curve of the joint is compared between the 3D model and the experimental test in figure 8.a. The initial stiffness of the numerical (M-ϕ) curve appears lower than the one of the experimental test and for the same rotation, the resistance is also lower in the numerical curve. This is mostly due to the assumption of the Young's modulus variation of the slab taking into account its initial cracking. The considered value of $E^c/100$ at the joint cross-section could be greater and the curves should be closer than the ones given in figure 8.a. Nevertheless, using all the points coming from the numerical and the experimental results, a non-linear regression with multiple parameters leads to the proposed equation given in figure 8.b. This equation depends on 4 parameters C_1 to C_4 (given in figure 8.b). The values of these parameters depend on the geometrical and the mechanical properties of the tested model. This equation has an oblique asymptote that remains available until a rotation of 8×10^{-3} rad. and clearly leads to a horizontal asymptote and then decreases for higher values of rotations. Finally, this model will be computed in the program "Pontmixte".



Figures 8: Comparison between experimental and numerical results (a) and proposed equation (b).

3 COMPUTING THE PROPOSED MODEL IN "PONTMIXTE"

The finite element computed in "Pontmixte" could be defined as a fiber composite beam element with 2D integration (Fig.9). The slab is reinforced by longitudinal bars about 1% of its area. Supposing that the joint is located at the node (i) of a regular composite finite element, a virtual finite element representing the joint (i_1-i_2) is used. This element has no dimension and will change the stiffness of the finite element (i-j) at the node (i) considering new variations K_a, K_c and K_ϕ. The connection between the classical composite finite element and the one including the joint is shown in figure 10 with different degrees of freedom.

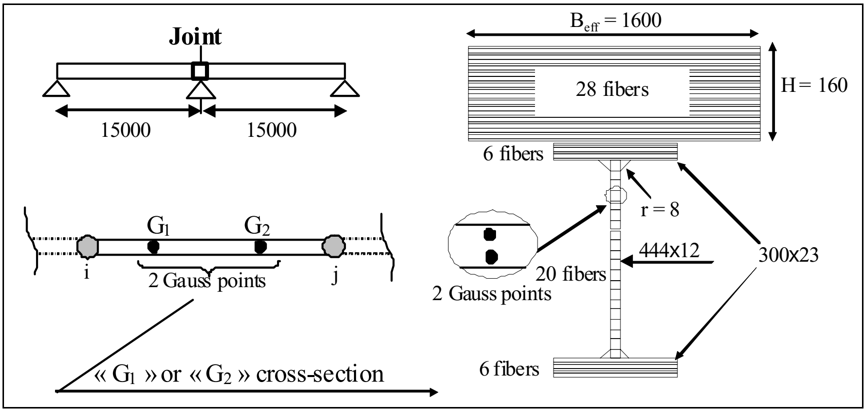


Figure 9: Fiber model computed in « Pontmixte ».

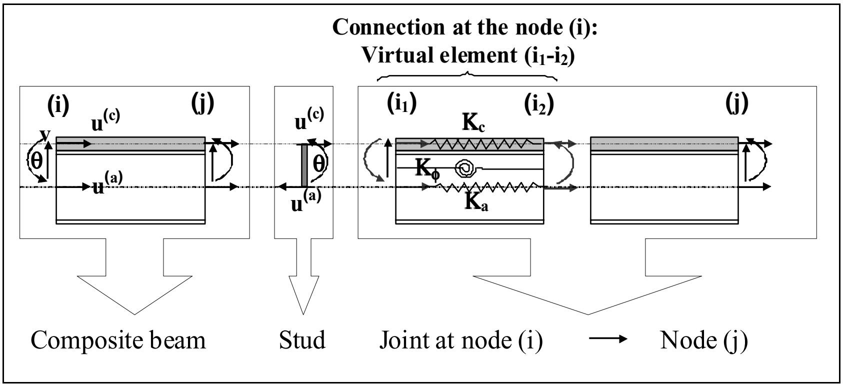


Figure 10: The joint F.E.

Figure 11 shows how the composite beam element could include the changes in the stiffness matrix to take into account the joint at the node (i) for example. Now, what values should be taken for K_a, K_c and K_ϕ during the iterative process?. For the beginning (iteration 0), we propose to take following classical values: $K_a = (EA)_a / L$, $K_c = (EA)_c / L$ and $K_\phi = (EI)_a / L$. It is noted that:

$(EA)_a$: product of young's modulus and area of the steel girder,
$(EA)_c$: product of young's modulus and area of the concrete slab,
$(EI)_a$: product of young's modulus and inertia of the steel girder.

For the iteration I ≥ 1, the value of K_ϕ at the iteration (I) is obtained from the one at iteration (I-1) using the curve (M-ϕ) of the proposed model (Fig.8.b). It is pointed out that the rotation ϕ in the proposed formulae corresponds to the difference between θ_{i1} and θ_{i2} of the virtual finite element. In order to use simple formulae for K_a and K_c, the hypothesis done is:

$$\frac{K_\phi^{(I)}}{K_\phi^{(I-1)}} = \frac{K_a^{(I)}}{K_a^{(I-1)}} = \frac{K_c^{(I)}}{K_c^{(I-1)}} \qquad (1)$$

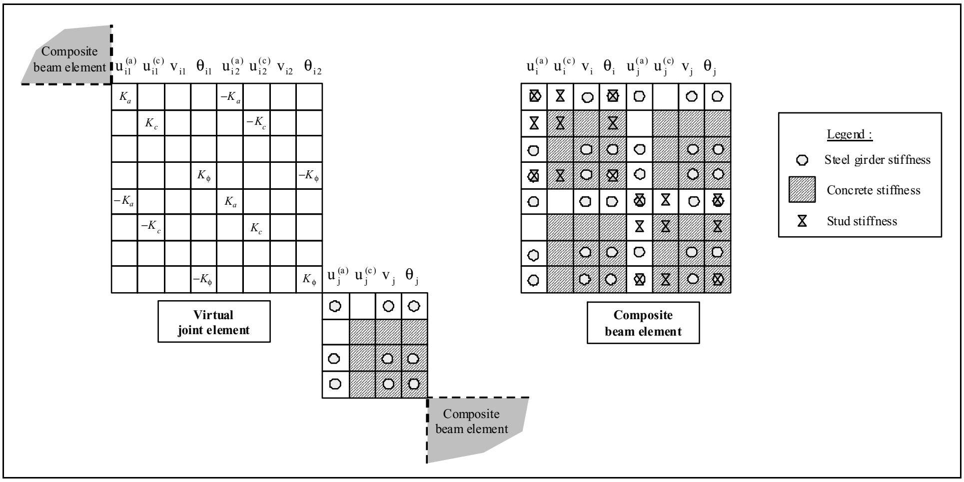


Figure 11: The stiffness matrix scheme.

4 THE RESULTS

The beam under investigation has 2 spans of 15m length and the mechanical characteristics of the materials are the same than those given on table 1. The slab is fully connected to the girder and the load is uniformly distributed all along the beam (Fig.12). The transverse beam is located on the intermediate support and the butt-plates are at 200mm on both sides of the axis of the support. The nodes concerned by the virtual joint elements are at these butt-plate cross-sections.

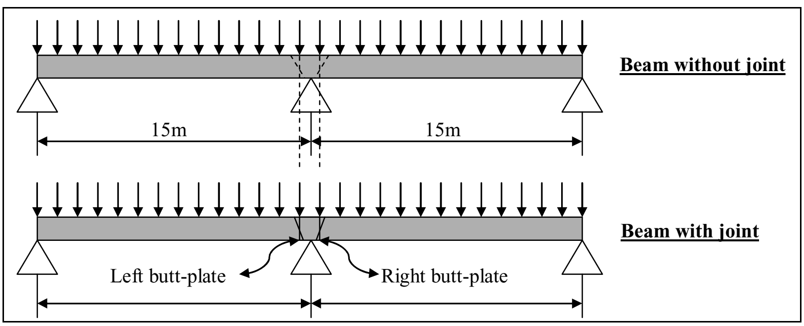


Figure 12: Beam under investigation – with and without joint.

The discontinuity of the continuous beam needs a correction because there are no studs on 400mm depth of the transverse beam. A previous design of the joint based on an analytical elastic method comparing a panel with or without joint leaded to consider twice number of longitudinal bars and studs on 15% length of span left and right the intermediate support [4]. It appears in figure 13, that this correction is over estimated, the beam without joint is less resistant than the one with joint. On the same figure, the comparison between the computed 3-D model and the numerical curves is satisfactory. In figure 14, the cross-section rotations are plotted all along the beam at the end step loading (arriving to 95%$M_{pl.Rd}$). The joint influence is not only local but it changes the rotations as well as the deflections (Fig.15) of all the other cross-sections along the beam and leads to a new equilibrium of the internal forces.

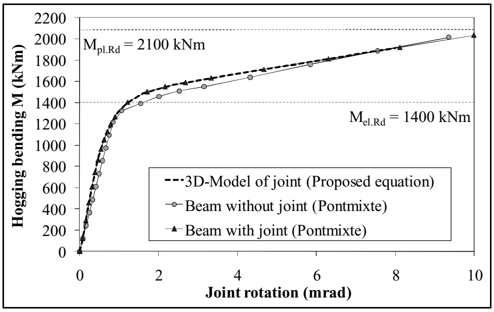


Figure 13: Influence of the joint on (M-ϕ) curve.

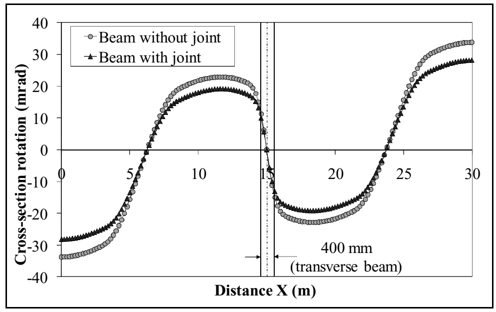


Figure 14: Influence of the joint on (θ-X) curve.

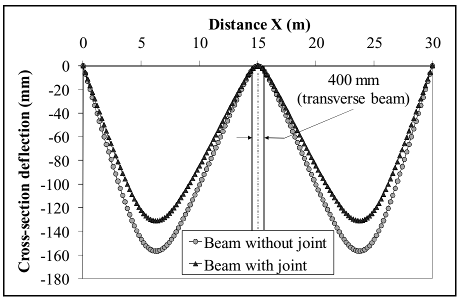


Figure 15: Influence of the joint on deflection curve.

5 CONCLUSION

This work shows that it is possible without computing difficulty to take into account beam-to-beam joints in the non linear calculation of a composite continuous beam at real scale. The additional reinforcing (bars and studs) considered to correct the discontinuity on the pear has a special importance; the proposed model should lead by numerical simulations to a design method more accuracy than the one used for this example. This work depends on many parameters such as the butt-plate thickness, the friction between the butt-plate and the concrete of the transverse beam and the connection degree that should be taken into account in future 3D model.

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