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Original Research Article

Stress concentration factors of shear connection by composite dowels with MCL shape

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ABSTRACT

In this paper, the authors present studies leading to the evaluation of the elastic resistance of the steel part of a continuous shear connection named MCL dowel. The MCL dowel is now the most commonly used shape of continuous connector, chosen among many others for its combination of good fatigue, elastic, and ultimate resistances. A method for the calculation of stress in the steel dowel is described in the paper. It is based on mathematical derivations followed by FE analysis. It is assumed that the steel connector is stressed as a result of a global stress state at the dowel root (being a part of the entire beam) and of a local effects of longitudinal shearing between the steel and concrete parts. Results of the mathematical derivations are confirmed experimentally. Full-scale tests of beam elements were performed with measures of strain in many points of selected connectors. A comparison of strains derived from the proposed design methodology and measured during the experimental tests is shown and discussed. The results herein presented are fundamental research which were one of backgrounds for fatigue limit states of composite dowels for purposes of implementation of composite dowels to the second version of Eurocode 1994-2.

1. Introduction

In the framework of the project *Precobeam* [1], a new method in steel-concrete composite beams was developed to connect a steel beam with a concrete slab using continuous shear connectors instead of widely used headed studs. These connectors were formed by cutting the web of an I-beam with specific line, so to obtain two T-beams which webs were terminated by connectors, see Figs. 1, 2 and 3.

After casting and hardening of concrete part of composite beam, the connectors embedded in the surrounding concrete guaranteed an effective transfer of the longitudinal shear forces between steel and concrete part of the beam. This was because of interlocking of concrete dowels between steel connectors. This way new, effective method of composition steel and concrete parts into one composite beam was developed. Contrary to headed studs, application of continuous shear connectors allowed for obtaining steel part of a composite beam in a fully automatic way. Advantage of composite beams with this type of connectors is also significant reduction of steel consumption, as in compressed parts of cross-section steel may be completely eliminated and replaced by much cheaper concrete.

During the realization of the project [1], several static and cycling tests have been carried out on elements (POST elements, newly designed NPOT elements and beams) with

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Nomenclature

MCL	modified clothoidal shape of the connector, considered in the paper (Fig. 4)
NPOT	new push-out test [1], modified version of POST, in which applied force generates tensile stress in the connector's base
FEM	finite element method
$\sigma_G(s)$	stresses at the dowel's edge caused by global effects (normal force and bending moment in the beam) at the s-coordinate point, including notch effect
s	local coordinate at the dowel's edge (Fig. 5)
σ_N	stress value at level of the base of the connector caused by global effects calculated by any means (e.g. with the well-known methods of theory of elasticity), without a notch effect (Fig. 5)
$A_G(s)$	function describing the change of σ_N stresses at the edge of the connector in correspondence of the coordinate s [1,15,21]
$\sigma_L(s)$	stresses (reduced or principal) at the dowel's edge caused by local effects (longitudinal shearing force acting on the connector) at the s-coordinate point, including notch effect
σ_{VL}	Stress value at level of the base of the connector caused by local effects calculated by any means (e.g. with the well-known methods of theory of elasticity), without a notch effect
$A_L(s)$	function describing the change of σ_{VL} stresses at the edge of the connector in correspondence of the coordinate s [1,15,21]
f	function describing resultant stresses at the edge of connector being the sum of $\sigma_G(s)$ and $\sigma_L(s)$ (which are defined above)
$\frac{1}{k_L}$ and $\frac{1}{k_{L,1}}$	stress concentration factor for stresses resulting from longitudinal shearing force, respectively for reduced and first principal stress
$\frac{1}{k_G}$ and $\frac{1}{k_{G,1}}$	stress concentration factor for stresses resulting from global effects, respectively for reduced and first principal stress

connectors having various shapes [1,2]. The strain on open connectors, which are an integral part of the web of the steel beam, depended not only on the longitudinal shearing forces, but also on the global distribution of normal stresses in the beam. Since bridge engineering was the main area of application of the solutions being considered, a lot of attention was paid to fatigue resistance and therefore also to the need to determine the state of stresses in the connector, so its elastic resistance. Problems with fatigue resistance had already been noticed in the framework of the Precobeam project [1]. When searching for the optimal shape of the connector (see also [3–5]), fatigue cracks propagating until total rupture of the steel beam were observed during the cyclic tests [1,6–9]. The optimal shape was supposed to combine a both high ultimate and fatigue resistance, high ductility and the simplicity of cutting the beam in order to manufacture it [10]. Finally, for the construction of a bridge, as shown in [11] a method was developed for cutting the web so that the continuous move of the cutter resulted in two identical T-beams with connectors based on a clothoidal line (see Figs. 1, 2 and 3). Extensive studies on this shape, considered optimum and from here on referred to as the MCL dowel (Fig. 4), were carried out after completion of the Precobeam project, in the framework of the ELEM project [12] – to determine the limit capacity, and [13,16] – elastic and fatigue capacity. The results of studies related to the ultimate capacity have been published, among others, in [13,14,17]. The rest of this article focuses on identifying the elastic capacity of the MCL dowel.

2. General idea of elastic resistance evaluation

Continuous connectors that are part of a steel beam (and of the composite one) cannot be treated the same way as discrete connectors (for ex. headed studs). That is because the stress distribution within the connector is not only the result of the longitudinal shear forces acting on it (named hereafter as local effects), but also of the stress associated with the global internal forces in the steel beam: bending moment and axial force, named hereafter as global effects. The concept of elastic capacity developed by Lorenc [15] assumes a linear summation of the above mentioned effects in each point of the connector's edge. [21] is summary of [15] in English. Therefore, to determine the resultant distribution of stresses on the edge of the connector, it is first necessary to determine the distribution of stresses on its edge, deriving from both the longitudinal shear force acting on the connector (local effects) and the normal stresses present at the base of the connector and linked to the global bending moments and axial forces in the beam (global effects). The determination of the normal stresses caused by global effects at the base of the connector is relatively simple. Stress state depends only on the geometry of the connector, which is treated as a notch geometry, increasing the normal stresses at its base. It is then assumed

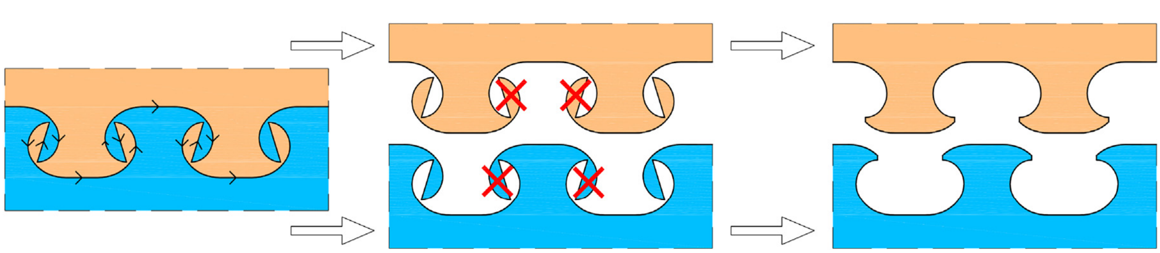

Fig. 1 – General idea of cutting an I-beam so to obtain steel continuous shear connectors (on example of MCL shape).