8th. World Congress on Computational Mechanics (WCCM8)
5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 – July 5, 2008
Venice, Italy

EFFECT OF AXIAL RESTRAINT IN COMPOSITE BARS UNDER NONLINEAR INELASTIC UNIFORM TORSION BY BEM

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Key Words: *Torsion, shear stresses, bar, beam, twist, elastoplastic, inelastic, plastic.*

ABSTRACT

One of the problems often encountered in engineering practice is the analysis of members of structures subjected to twisting moments, while both material inelasticity and geometric nonlinearity are important for investigating the ultimate strengths of bars that fail by torsion. Moreover, composite beams or columns offer significant advantages, such as high load capacity with small cross-section and economic material use, good fire resistance etc.

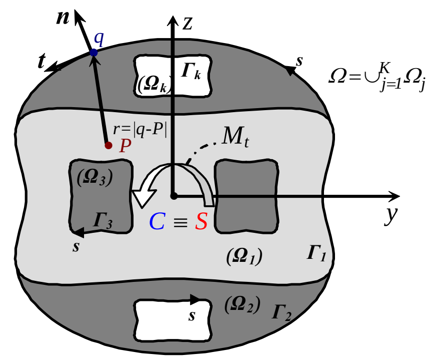

Fig.1. Composite bar subjected to twisting loading.

In this paper the effect of axial restraint in composite bars under nonlinear inelastic uniform torsion is investigated employing the boundary element method. The arbitrarily shaped doubly symmetric cross section of the bar consists of materials in contact, each of which can surround a finite number of inclusions. The bar is subjected to uniform torque while the warping of the cross section is not restrained. The stress - strain relationship for the material is assumed to be elastic-plastic-strain hardening. The incremental torque-rotation relationship is computed based on the finite displacement (finite rotation) theory, that is the transverse displacement components are expressed so as to be valid for large rotations and the longitudinal normal strain includes the second-order geometric nonlinear term often described as the “Wagner strain” [1]. The proposed formulation does not stand on the assumption of a thin-walled structure and therefore the cross section’s torsional rigidity is evaluated exactly without using the so-called Saint –Venant’s torsional constant. The torsional rigidity of each cross section is evaluated directly employing the primary warping function of the cross section [2] depending on both its shape and the progress of the plastic region. A boundary value problem with respect to the aforementioned function is formulated and solved employing a BEM approach. The developed procedure retains most of the advantages of a BEM solution over a pure domain discretization method, although it requires domain discretization, which is used only to evaluate integrals. The proposed formulation procedure is based on the assumption of no local or lateral torsional buckling or distortion and includes the following essential features and novel aspects compared with previous ones:

i. Large deflections and rotations are taken into account, that is the strain-displacement relationships contain higher order displacement terms.
ii. The influence of the axial restraint to the torsional stiffness of the bar is demonstrated, while the values of the arising axial force of the bar are also presented for each load step.
iii. For each one of the materials of the cross section, material inelasticity is taken into account, that is the elastic-plastic incremental stress-strain relationship is derived from the von Mises yield criterion, a strain flow rule and a strain hardening rule. Integrations of stress resultants for every iterative step and restoration of equilibrium for every converged incremental step are performed numerically using a set of monitoring stations distributed over the area of the cross section.
iv. The present formulation is applicable to bars of arbitrarily shaped doubly symmetric composite cross section, while the case of a homogeneous cross section can be treated as a special one.
v. The present formulation does not stand on the assumption of a thin-walled structure and therefore the cross section's torsional rigidity is evaluated exactly without using the so-called Saint –Venant's torsional constant.
vi. The boundary conditions at the interfaces between different material regions are taken into account.
vii. The proposed method can be efficiently applied to composite beams of thin or thick walled cross section and to laminated composite beams, without the restrictions of the "refined models".

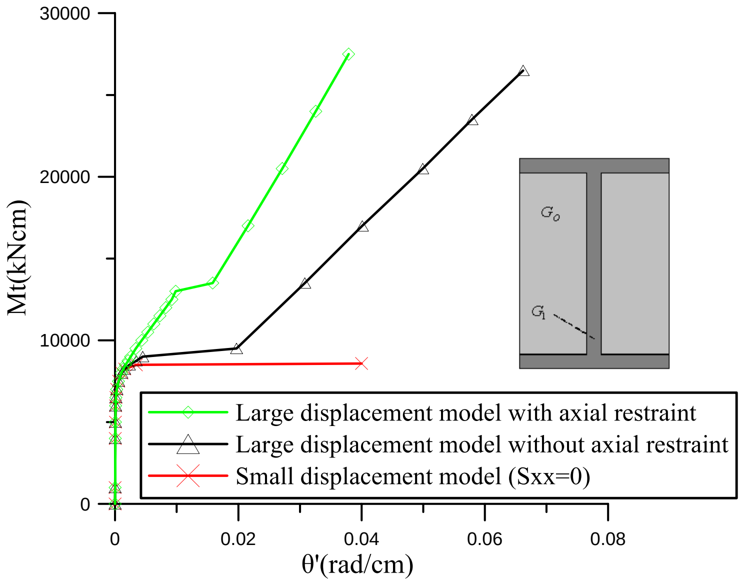

Fig.2. Torque-twist curves for a composite cross section.

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