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Original Research Article

Generalized model of imperfection forces for design of transverse roof bracings and purlins

Antoni Biegus, Dariusz Czepiżak *

Wrocław University of Science and Technology, Faculty of Civil Engineering, ul. Wybrzeże Wyspiańskiego 27, 50-370 Wrocław, Poland

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ABSTRACT

The EN 1993-1-1 calculation model of initial, equivalent bow imperfection forces q_d acting on the bracing system assumes that the stabilized member is uniformly compressed within his length. But this assumption is incorrect. The distribution of the axial compression force in the restrained roof rafter varies along its length and usually has a parabolic shape. This paper proposes refined generalized models for identifying the imperfection forces in members to be restrained, having an initial bow imperfection with maximum amplitude e_0. The models were derived on the basis of the real parabolic shape of the axial forces distribution in restrained roof girders. The effect of lateral imperfection amplitude e_0 of the restrained girder is accompanied by twist imperfection ϕ_0 measured as the angle of rotation of the webbed girder plane or the plane passing through the truss top and the bottom chords. The latter imperfection profile component generates additional horizontal imperfection forces $H_{1,i}$ not included in the current design codes. Analytical relations for calculating imperfection force q_{di} and force $H_{1,i}$ are provided in order to evaluate the state of stress in both the purlins and the bracings. The considered problem is illustrated with a calculation example.

1. Introduction

Plain (truss or plated) roof girders are stable and sufficiently rigid in their plane. However, bracings are used to stiffen them in the roof plane. Bracings are major critical components of the roof supporting structure. The principles of their design and construction have been established on the basis of many years of experience. But the theoretical basis [e.g. 1–7,9,10,12,13,16] for calculating bracing loads was developed, using an "imperfect" analytical model of a (precurved) element to be restrained, as late as in the last twenty years of the 20th century. Due to the spatial roof structure's complexity and the high costs involved, no experimental studies of the stress of bracings are conducted.

Standard EN 1993-1-1 [8] recommends the "imperfect" model for computing bracings. The model is based on the following assumptions:

* Corresponding author.
E-mail addresses: Antoni.Biegus@pwr.wroc.pl (A. Biegus), Dariusz.Czepizak@pwr.wroc.pl (D. Czepiżak).
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1. the roof bracing system is considered in isolation from the building structure,
2. the bracing imperfection of the compressed chord (flange) is represented by a parabola,
3. the axial compressive force in the restrained girder chord (flange) is constant.

The computational model presented in EN 1993-1-1 [8] is invalid for the restrained roof girder parts since they are stressed by variable longitudinal forces and so do not satisfy assumption 3. This paper proposes, among other things, a new generalized model for computing the equivalent imperfection forces of restrained elements stressed by a variable longitudinal axial force. Thanks to this model the bracing system stress generated by real roof girder imperfection forces can be analyzed.

According to EN 1993-1-1 [8], the model with an initial bow deflection with amplitude $e_0 = L/500$ (L – the span of the member) [4,5,11,14,15] is used in the analysis of bracings protecting compression members against lateral buckling. Its equivalent imperfection force is uniformly distributed as $q_{d1}(x) = q_{d1} = \text{const}$ (Fig. 1c).

The total imperfection force q_{d1} produced by the initial bow deflection (Fig. 1a) for m members to be braced is calculated from the expression [8]

$$q_{d1,m} = 8\frac{e+\delta_{q,w}}{L^2}\sum_{j=1}^{m} N_{Ed,j}, \tag{1}$$

where: e – the total imperfection of m members to be restrained

$$e = \frac{L}{500}\sqrt{0.5(1+m^{-1})}, \tag{2}$$

$N_{Ed,j}$ – the axial force in the j-th member to be restrained, $\delta_{q,w}$ – the bracing system midspan deflection caused by imperfection forces q_{d1} and all the external loads, determined using the first-order theory (when the system is analyzed using the second-order theory, $\delta_{q,w}$ can be assumed to be equal to 0), L – the span of the member, m – the number of the members to be restrained.

In the imperfection force q_{d1} calculation model according to EN 1993-1-1 [8] it is conservatively assumed that the restrained member is uniformly compressed within its length: $N_1(x) = \text{const}$ (Fig. 1b) and the value of the axial force is assumed to be equal to the maximum force acting in the restrained member $N_1(x) = N_{Ed,max}$.

The assumption: $N_1(x) = \text{const}$ does not agree with the real nonuniform distribution of the axial force along a roof girder (rafter) and is incorrect when the lateral bracings are to be calculated. Usually the force changes parabolically, with possible changes of its sign (compression → tension). As proven in [1,2] and [12], the seemingly safe assumption $N_1(x) = \text{const}$ may lead to the underrating of the stresses in purlins and bracings, generating an unsafe situation for structures calculated for q_{d1} assumed according to EN 1993-1-1 [8].

For example, for the plain webbed I-section girders of portal frames, being simply supported and uniformly loaded, the resultant flange force (axial force) $N_3(x)$ in the laterally restrained top flange varies within the member's length and has a parabolic distribution (Fig. 2d) described by the relation

$$N_3(x) = 4N_{Ed}\frac{x}{L^2}(L-x). \tag{3}$$

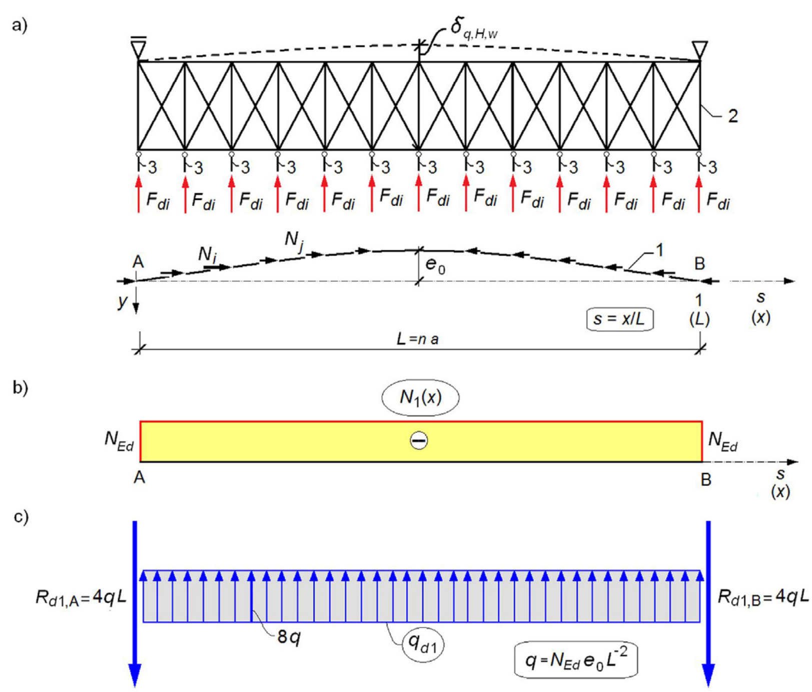

Fig. 1 – Bracing system calculation model according to EN 1993-1-1 [8]: (a) scheme of bracing system and member to be restrained, (b) distribution of $N_1(s)$ in member, (c) loadings q_{d1} from imperfections; 1 – member to be restrained, 2 – bracing system, 3 – purlin.