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Parametric Analysis of Cross-Frame Layout Using a High-Order Beam Element

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INTRODUCTION

- The goal of the research is to provide guidelines for the design of cross-frame in box girder composite bridges against distortion
- Facts
  - Modern composite bridges started in the 50’s and now they are frequently built
  - Distortion is a well-know phenomenon which has been widely studied

Source: WSP Spain

INTRODUCTION

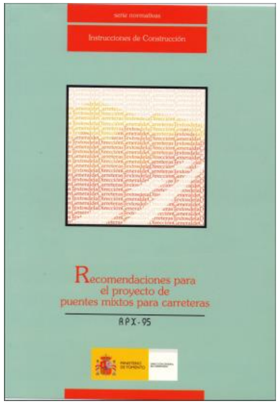
- Motivation
  - Literature usually studies simple bridges or theoretical cases
  - Literature typically do not consider torsion and distortion equations coupled
  - New beam finite elements
    - B3N (Cambronero 2013)
  - Curvature is not usually considered in coupled torsion and distortion equations

- Contribution
  - Study of “real” bridges
    - Widths up to 24 m
    - Spans from 45 to 105 m
  - Update current literature based on uncoupled equations
  - Application of new finite elements to the design of cross-frames
  - Include curvature in coupled torsion and distortion equations

INTRODUCTION

- Objectives
  1. Optimize design of cross-frames
  2. Provide useful recommendations for bridge engineers
  3. Improve current codes
- Example: Cross-frames in codes in Spain

RPX-95



serie normativas

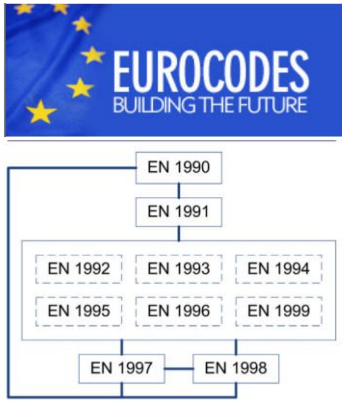
Instrucciones de Construcción

Recomendaciones para el proyecto de puentes mixtos para carreteras

RPX-95

2019 DGC

Eurocodes

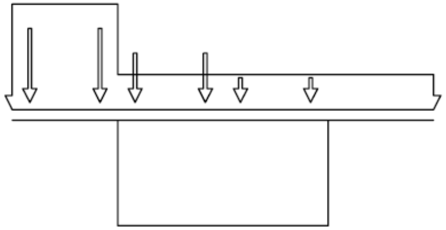


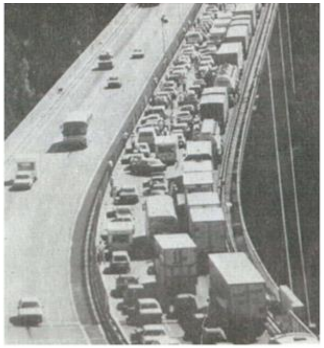
Very restrictive

No mention

BEHAVIOUR OF BOX-GIRDER BRIDGES

- Bridges have to resist vertical loads





Source: Tschemmernegg 1989

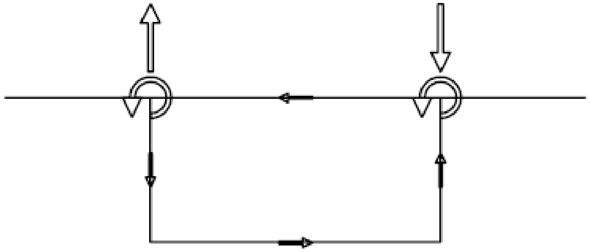
- Box girder bridges are analysed splitting up the structure in different resistant modes (Schlaich 1982)
  - Longitudinal movement (Axial Forces)
  - Vertical deflection (Longitudinal bending)
  - Lateral deflection (Transverse Bending)
  - Rotation along axis (Torsion)
  - Distortion
  - Transverse bending

Conventional Beam Elements

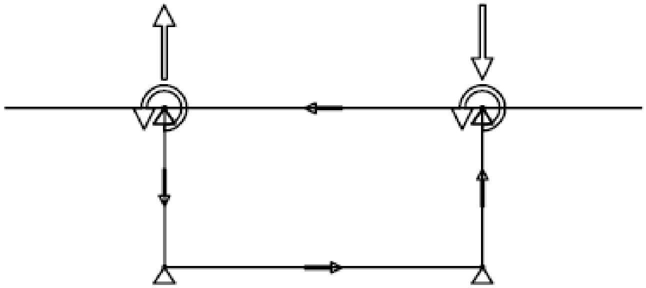
High-Order Beam Elements

BEHAVIOUR OF BOX-GIRDER BRIDGES

- Distortion appears in box girders when external loads that causes torsion are in equilibrium with the internal torsional flux

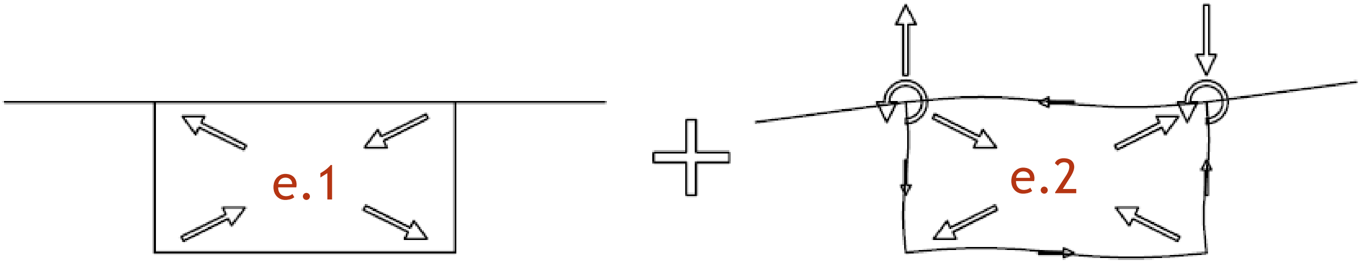


- Despite the fact that it is in equilibrium it generates movements in the plane of the walls. In order to split it up the frame is analysed considering movements restricted

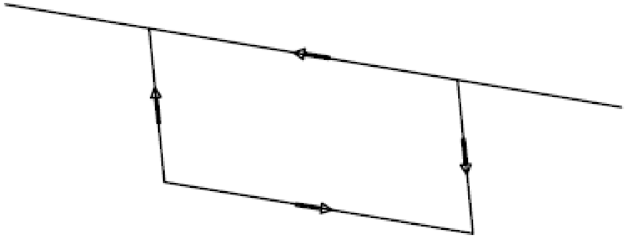


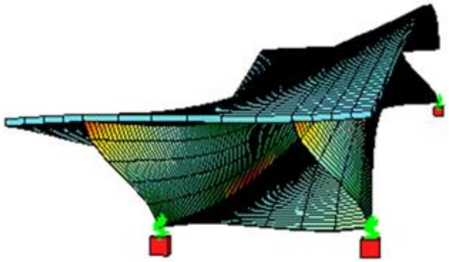
BEHAVIOUR OF BOX-GIRDER BRIDGES

- **Distortion** (e.1) + **Transverse bend.** (e.2)



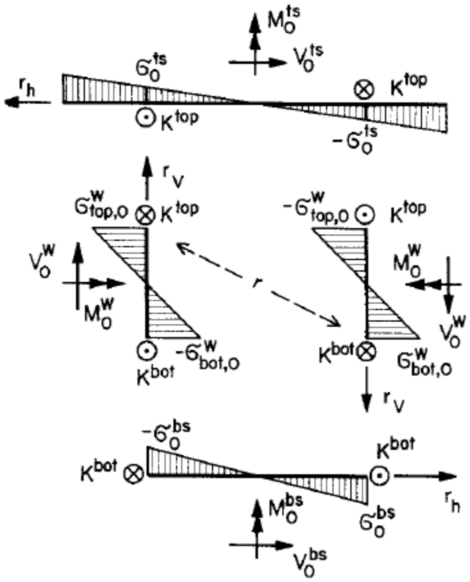
- e.1 Reactions in nodes generate a deflection in the plane of walls



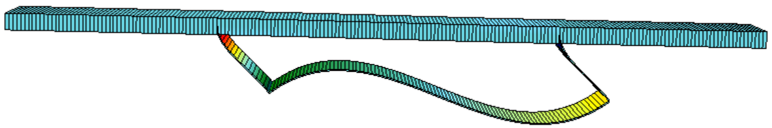


BEHAVIOUR OF BOX-GIRDER BRIDGES

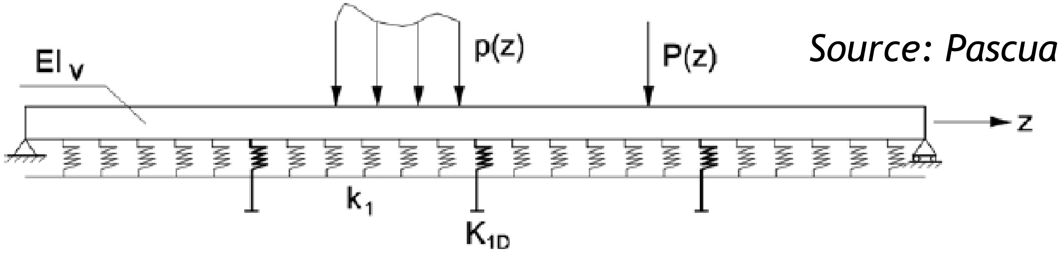
- Distortion resistance mechanism are:
  - Plate action of each wall (Longitudinal Stresses)
  - Frame action



Source: Menn 1986



- BEF analogy



Source: Pascual 2003

BEHAVIOUR OF BOX-GIRDER BRIDGES

- Composite box girder bridges

Frame action is negligible

Longitudinal stresses are high

Cross-frames required in order to increase frame action and control longitudinal stresses

BEHAVIOUR OF BOX-GIRDER BRIDGES

- Stresses due to torsion and distortion in a 100 m bridge considering or not 4 full web diaphragms cross-frames

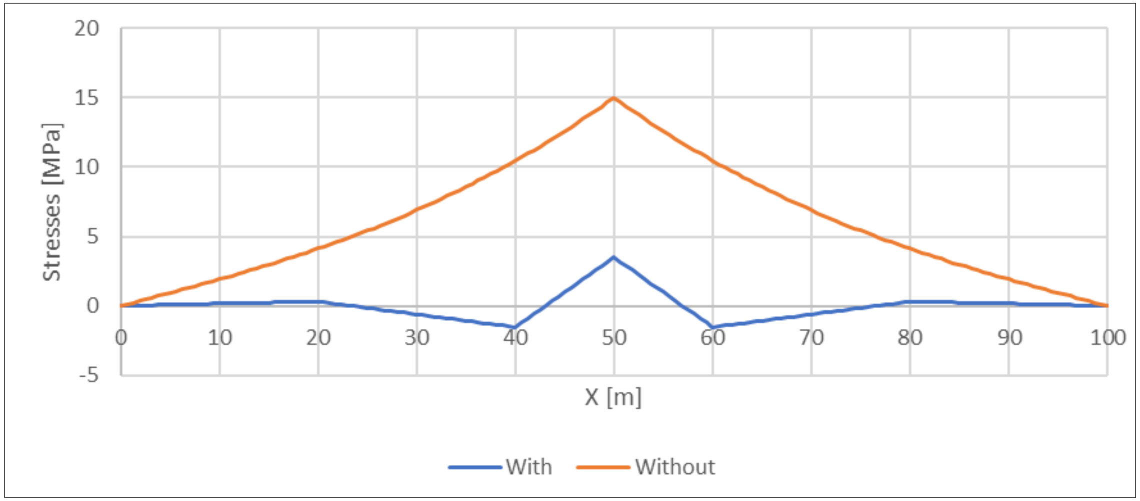


Figure 1

- Stresses are reduced

CROSS-FRAMES

- Cross-Frames layout variables:
  - Spacing
    - Typically between 3-5 m
    - Literature recommends 4-5 cross-frames per span to control distortion
  - Type
  - Stiffness
    - Typically design to bear all torsional loads (Very Stiff)

CROSS-FRAMES

- Stresses due to torsion and distortion for different spans considering 4 full web diaphragms cross-frames per span of variable thickness

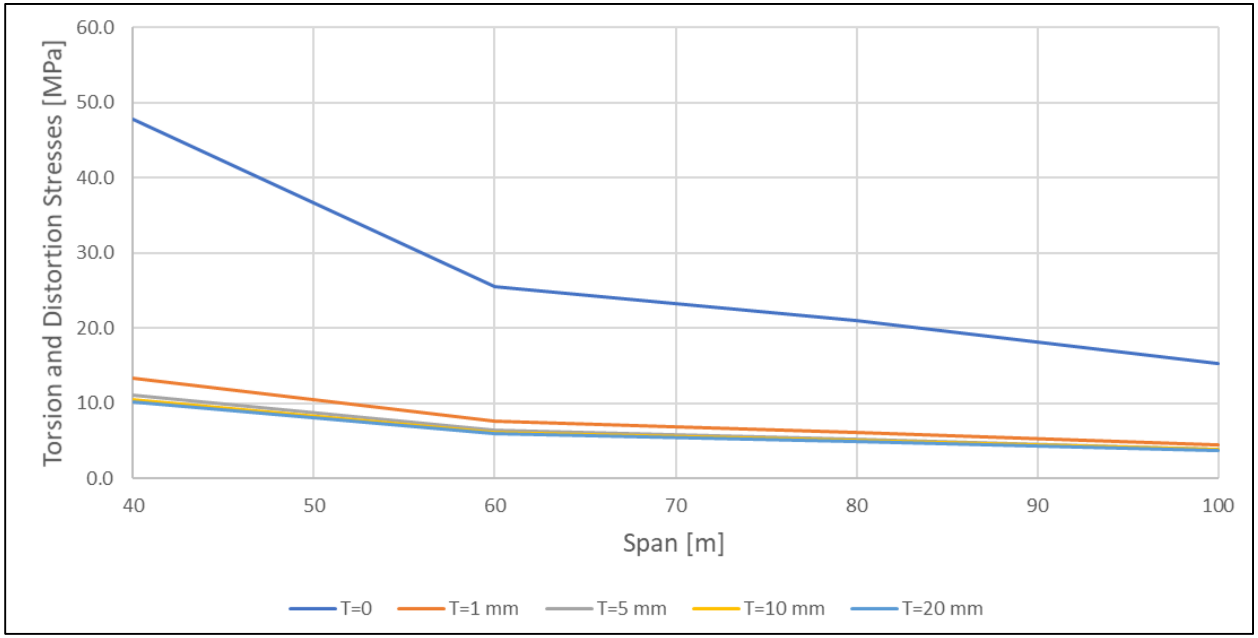
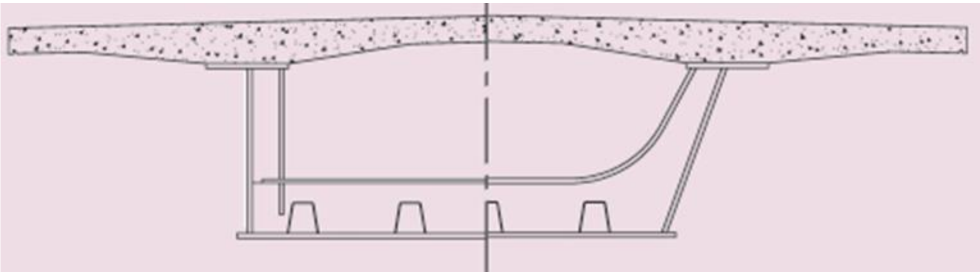


Figure 2

CROSS-FRAMES

- Objective of the research
  - Spacing
    - Vary between 3-5 m based in other requirements
  - Stiffness
    - Obtain the minimum to satisfy an stress limit
  - Type
    - Study non frequent types in Spain



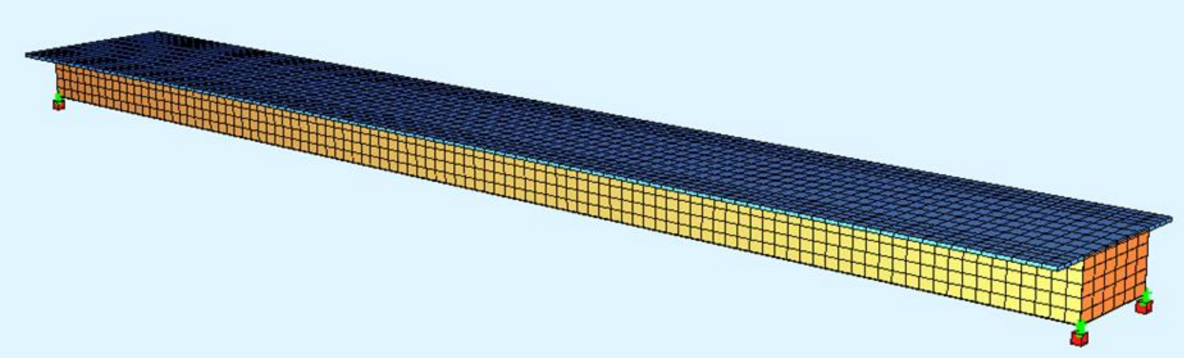
Source: Setra

ANALYSIS OF DISTORTION

- The state of the art is based on Dabrowski and Vlasov equations:
  - Torsion (Vlasov):
    - $E_0 \ I_a \ \theta_z^{IV} - G_0 \ I_t \ \theta_z^{II} = m_t$
  - Distortion (Dabrowski):
    - $E_0 \ K_d \ \psi_d + E_0 \ I_d \psi_d^{IV} = m_d$
- Research based on revised equations (Cambronero 2013)
  - Torsion:
    - $E_0 \ I_a \ \theta_z^{IV} - E_0 \ I_{wdwa} \psi_d^{IV} - G_0 \ I_t \ \theta_z^{II} - G_0 \ D_{tdta} \psi_d^{II} = m_t$
  - Distortion:
    - $E_0 \ K_d \ \psi_d - E_0 \ I_{wdwa} \theta_z^{IV} + E_0 \ I_d \psi_d^{IV} - G_0 \ D_{tdta} \ \theta_z^{II} - G_0 \ D_{tdtd} \psi_d^{II} = m_d$
  - Both equations are coupled and have been implemented in a finite element call B3N

ANALYSIS OF DISTORTION

- A comparison between equations has been performed
  - Reference solution: FEM model
  - Vlasov and Dabrowski equations: Classic Theory
  - Cambronero equations: B3N



ANALYSIS OF DISTORTION

- Stresses have been obtained for different geometries

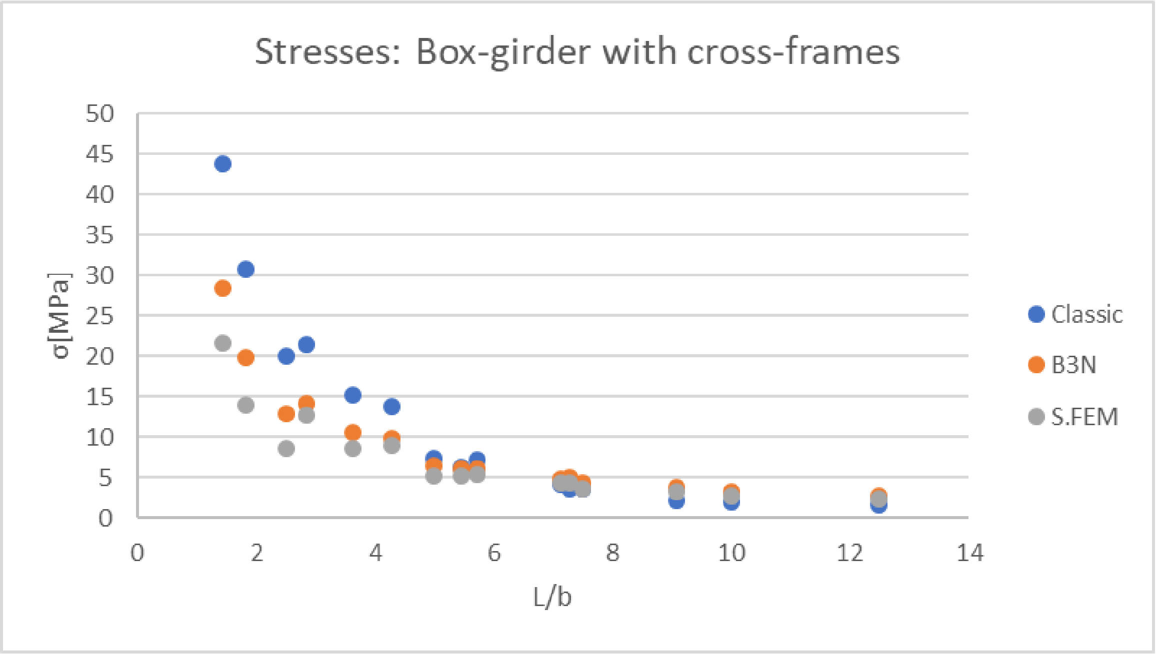


Figure 3

ANALYSIS OF DISTORTION

- Stresses have been compared with FEM model
  - Accuracy has been improved in B3N
  - Stresses are not underestimated

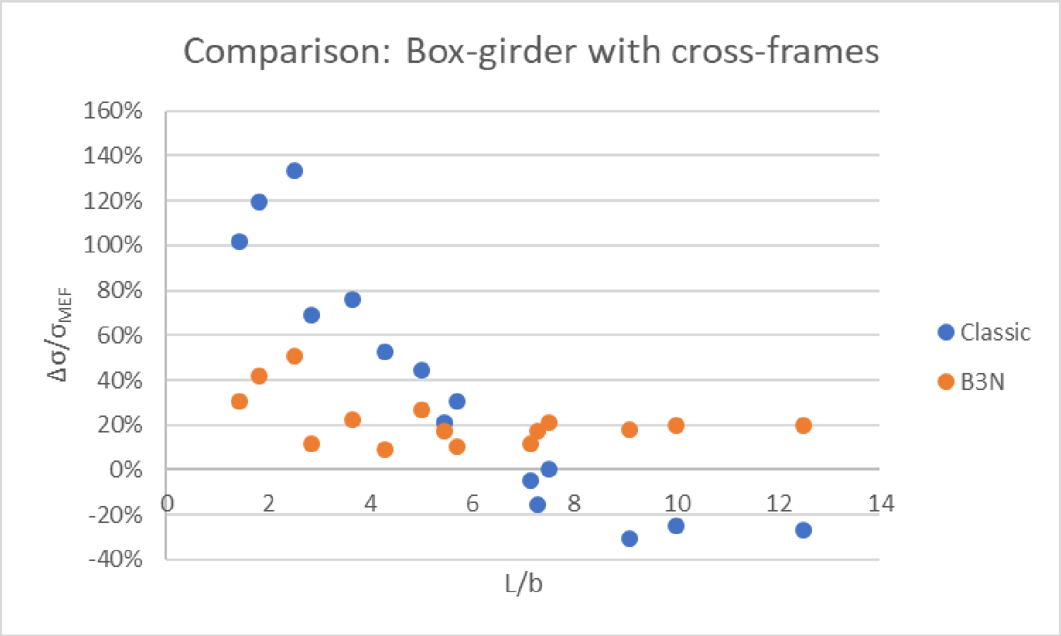


Figure 4

THANK YOU FOR YOUR ATTENTION

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