

# Track-Structure Interaction

International course on High Speed Railway Bridges  
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22 september 2005



# Contents

- 1 DESCRIPTION OF THE PHENOMENON
  - Thermal and braking effects in long welded rail
  - Effect of structure within platform
  - Limit states
- 2 REGULATORY ASPECTS
  - Eurocode: EN1991-2
  - UIC 774-3
  - Methods of analysis
- 3 NUMERICAL METHODS FOR ANALYSIS
  - Finite Element Models
- 4 APPLICATION EXAMPLES
  - 475 m viaduct, continuous rail
  - 475 m viaduct, rail with expansion joint
  - Study of braking action

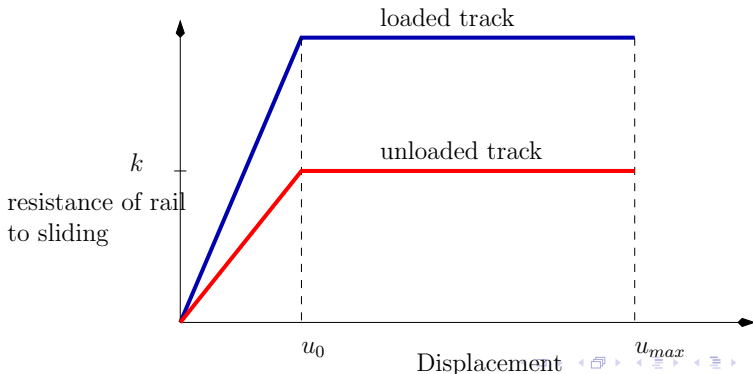
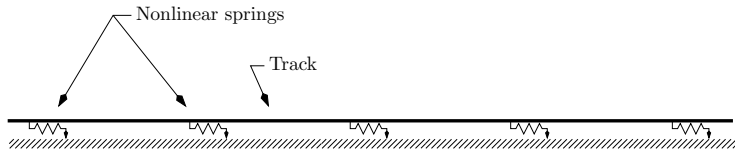


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# Behaviour of track system



## 🔥 Actions:

- horizontal loads from braking and acceleration
- thermal effects inducing rail stresses
- deck bending from vertical loads, inducing horizontal stresses and displacements in rail



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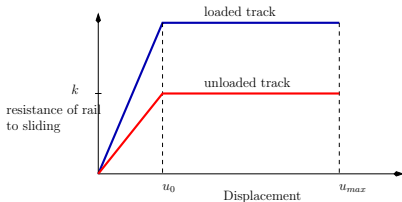
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## 🔥 parameters of rail:

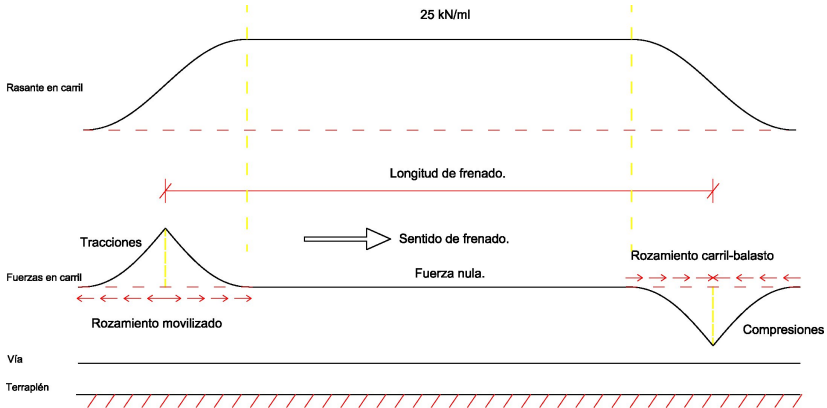


- $u_0 = 2$  mm for ballasted track (sleeper–ballast);
- $u_0 = 0.5$  mm for slab track or frozen ballast (rail–sleeper);
- $k = 20$  kN/m for unloaded track (well maintained)
- $k = 60$  kN/m for loaded track

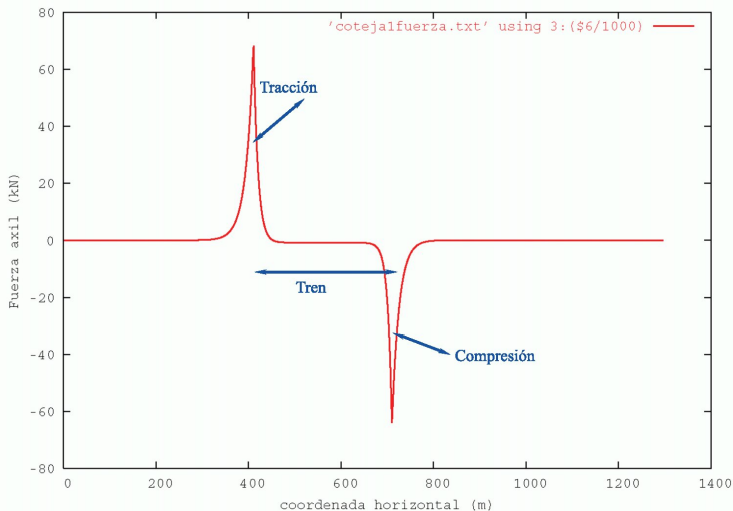


Thermal and braking effects in long welded rail

# Distribution of stress from a) temperature; b) braking

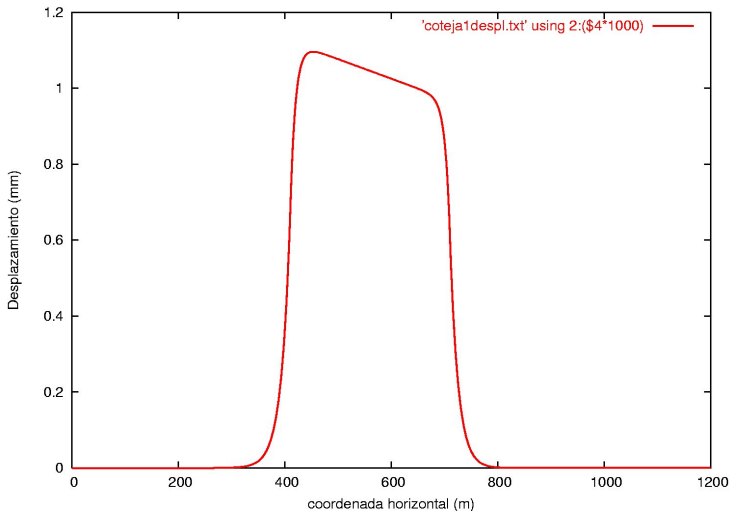


# Rail loads from braking in platform

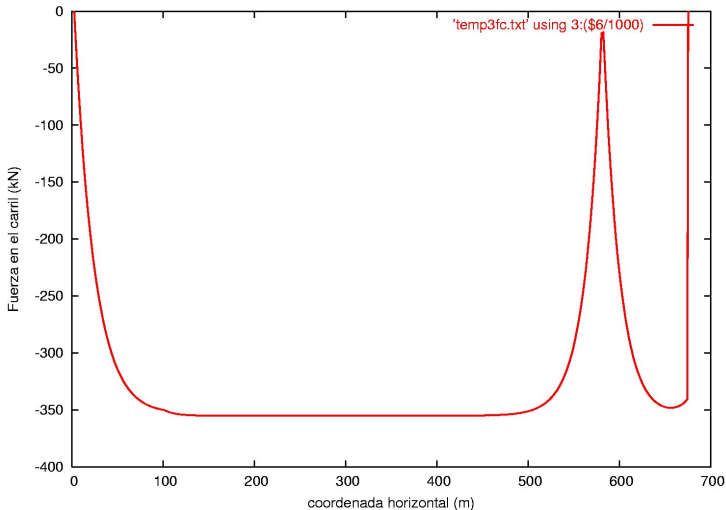


Thermal and braking effects in long welded rail

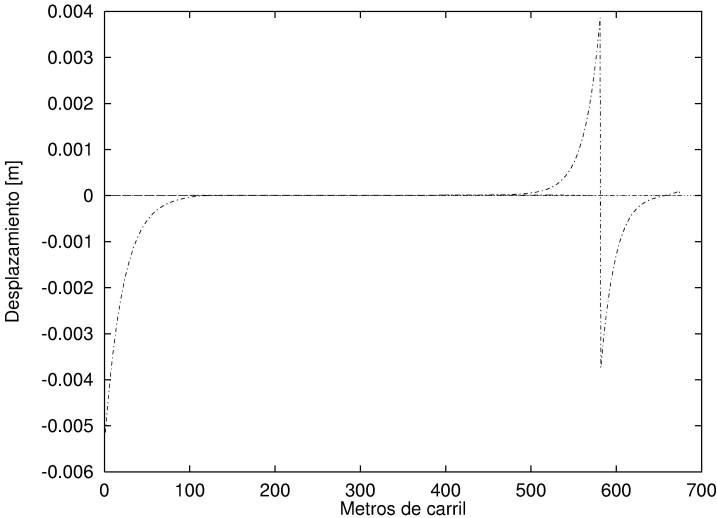
# Rail displacements from braking in platform



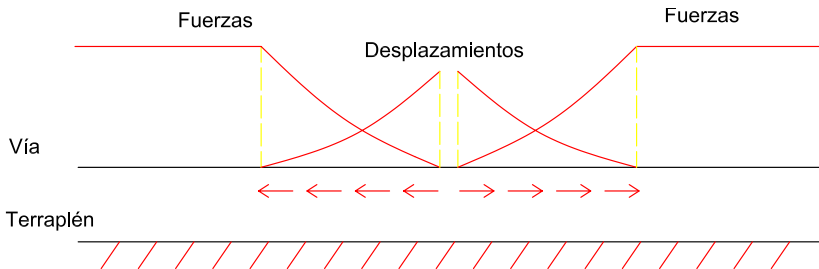
# Rail loads from temperature increment



# Rail displacements from temperature increment



# Relation between relative displacements and rail loads

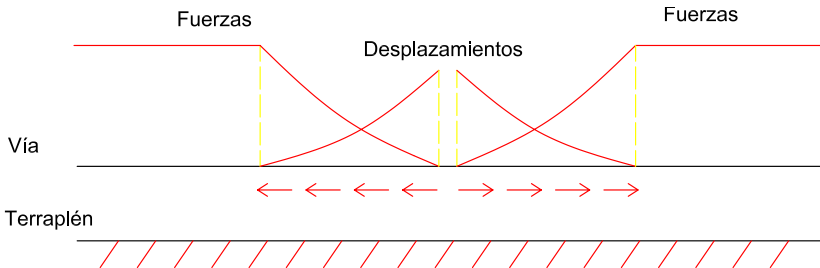


Rail *breathing length*  $\approx 150$  m

(necessary to build up rail compression through accumulated shear loads)



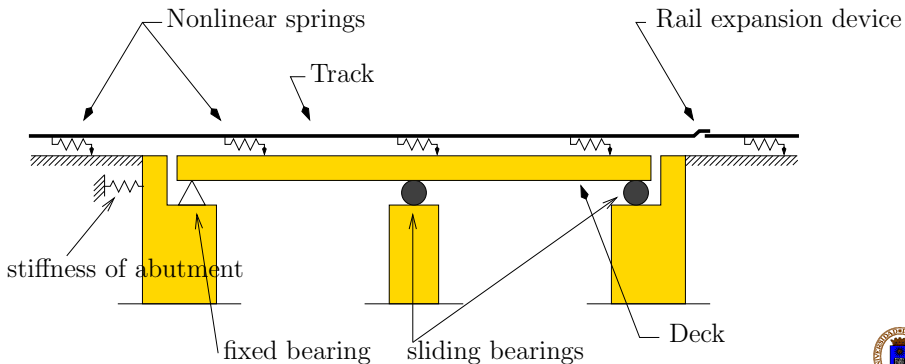
# Relation between relative displacements and rail loads



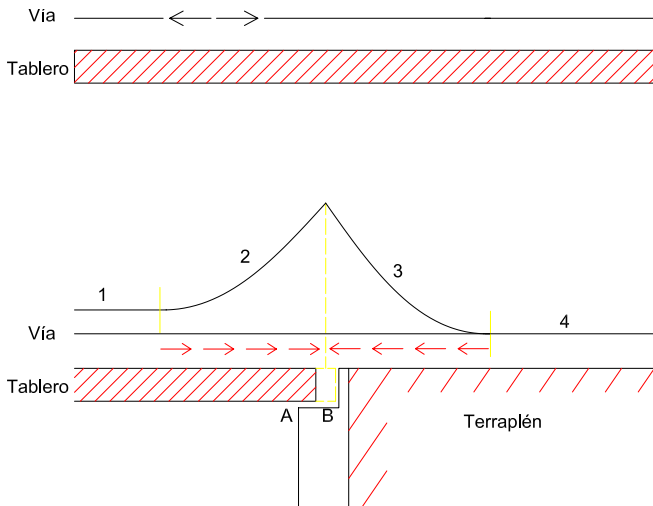
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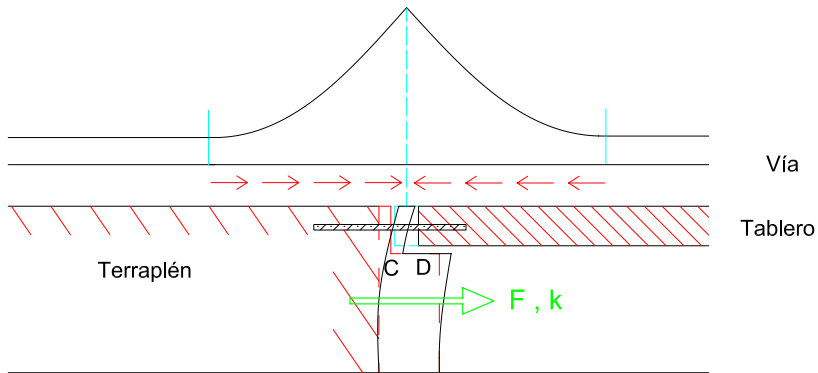
# Schematic model for structure and track



# Effects at free end of deck with continuous rail



# Effects at fixed end of deck with continuous rail



# Criteria for acceptance

Limit states arise from either of:

- Maximum stresses at rail (for HS of type UIC60,  $\sigma_{ult} = 900$  Mpa):
  - total stress including long welded rail thermal stress:  $\sigma = \sigma_{LWR} \pm \Delta\sigma$  (track with expansion devices)
  - stress increment,  $\Delta\sigma$  (continuous track, without expansion devices)
- Maximum relative displacements between rail–deck
- Maximum displacements of deck with respect to abutment



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# Eurocode: EN1991-2

- section 6.5.4: *Combined response of structure and track due to variable actions.*
- define *expansion length*  $L_T$  and other parameters
- Actions: braking and traction, thermal loads, vertical traffic loads, creep and shrinkage.
- Nonlinear models of structure+track, but **allows linear superposition**
- Section 6.5.4.6: simplified calculation for  $L_T \leq 40$  m
- Annex G: simplified calculation for  $L_T \leq 90$  m



# Eurocode: EN1991-2

- Limit rail stress increments:

$$\Delta\sigma_{\text{comp}} \leq 72 \text{ MPa},$$

$$\Delta\sigma_{\text{tens}} \leq 92 \text{ MPa}.$$

- Limit horizontal deck displacement from braking:

$$\delta_B \leq 5 \text{ mm for continuous LWR},$$

$$\delta_B \leq 30 \text{ mm for rail with expansion device and ballast without movement gap},$$

- Limit horizontal deck displacement from bending:

$$\delta_H \leq 8 \text{ mm},$$

- Limit vertical deck displacement from bending:

$$\delta_V \leq 2 \text{ mm}.$$



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# UIC 774-3

- Additional limit for relative rail-deck displacement for braking:  
 $\delta_{RD} \leq 4 \text{ mm}$
- Results for 16 test cases single span + 6 test cases multiple span, to be checked for validation of computer models (minimum 2)



# UIC 774-3

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# Methods of analysis

- EN 1991-2:
  - Simplified calculation formulae and charts, section 6.5.4.6 or annex G
  - Full nonlinear structural models (allow linear superposition)
- UIC 774-3:
  - Pre-dimensioning method for horizontal loads (A.6.1)
  - Simplified methods with diagrams: sections B (single deck,  $L_T \leq 110$  m), or section C for series of decks.
  - Full nonlinear structural models (allow linear superposition)



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# Requirements for FEM

- **Beam** and **truss** elements
- **Nonlinear springs** (node-ground and node-node)
- Capability for solving **nonlinear problems** (iterations for convergence)
- Validate with **test cases** from UIC 774-3
- Our experience: FEAP, ABAQUS adequate



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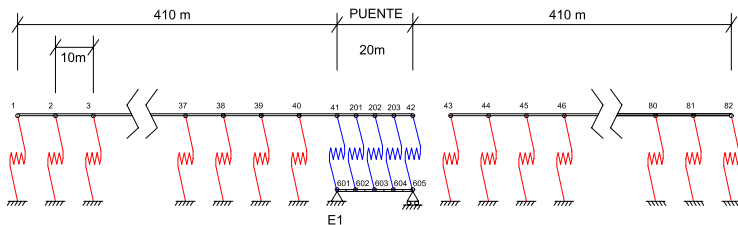


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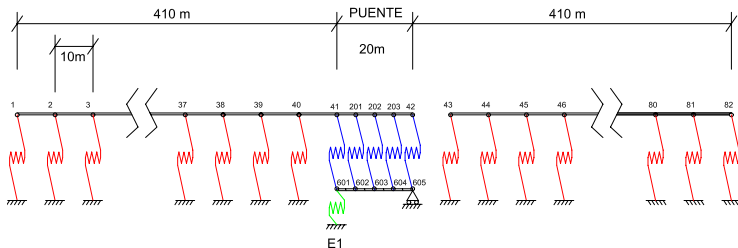
# Model with infinitely stiff abutment



Modelo de un puente de 20m de longitud para el estudio de la interacción carril-tablero.  
 Estribo E1 fijo (rigidez infinita).  
 Carril continuo en el estribo fijo y junta de carril en estribo móvil.



# Model with flexible abutment



Modelo de un puente de 20m de longitud para el estudio de la interacción carril-tablero.  
 Estribo E1 con rigidez finita.  
 Carril continuo en el estribo fijo y presencia de junta de carril en el estribo libre.



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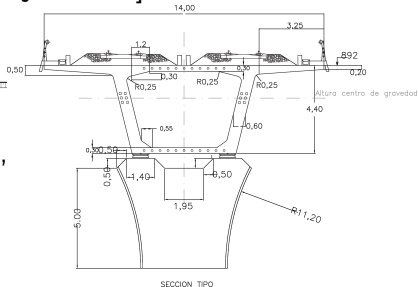
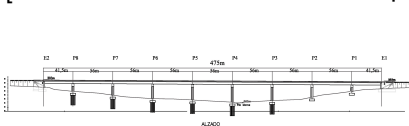
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475 m viaduct, continuous rail

# Prestressed concrete box girder; *pushed*

[F. Ruano, Río Moros, Student project 2005]

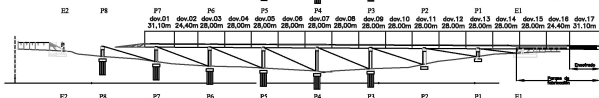


Length 475 m, spans  $L = 56$  m,  
depth  $\frac{1}{\text{span}} = \frac{1}{12.7}$

FASE 5  
(cotas en metros) ESCALA 1:1500



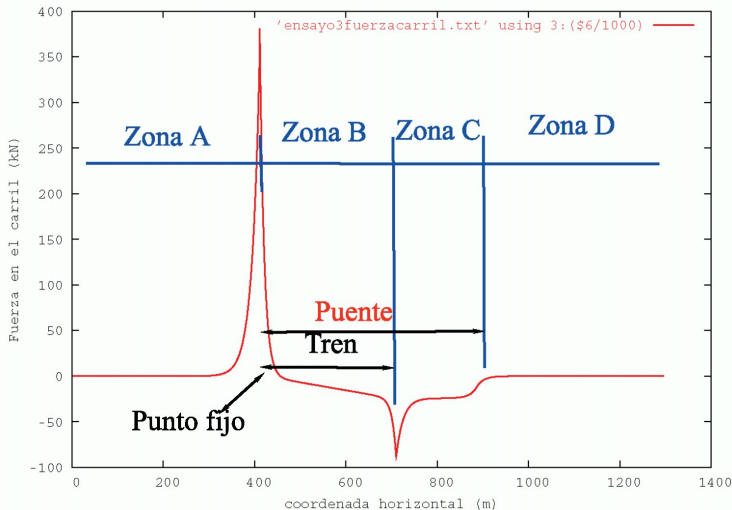
FASE 17  
(cotas en metros) ESCALA 1:1500



475 m viaduct, continuous rail

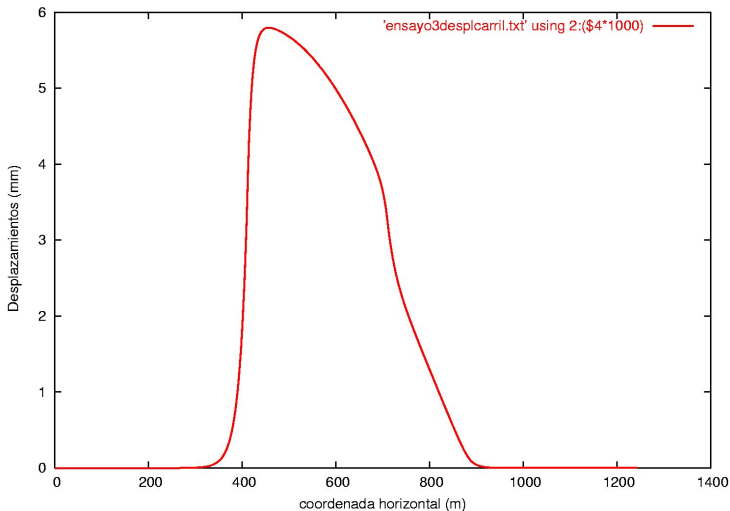
# Rail loads for braking

(direction: left to right →)



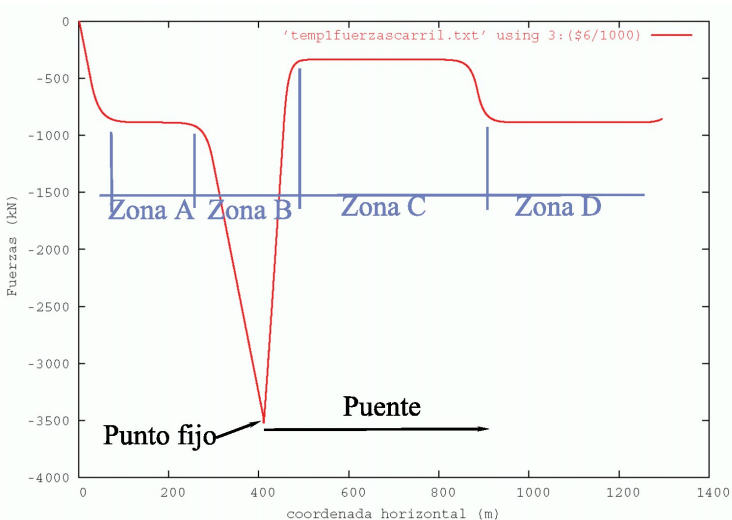
475 m viaduct, continuous rail

# Rail displacements for braking



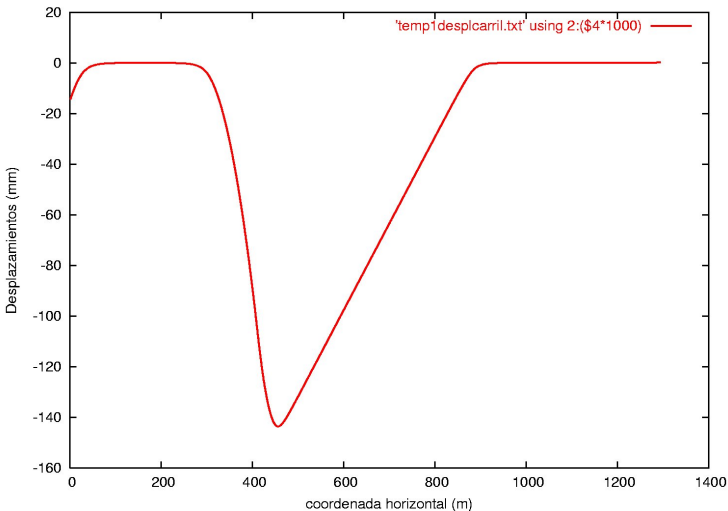
475 m viaduct, continuous rail

# Rail loads for thermal action



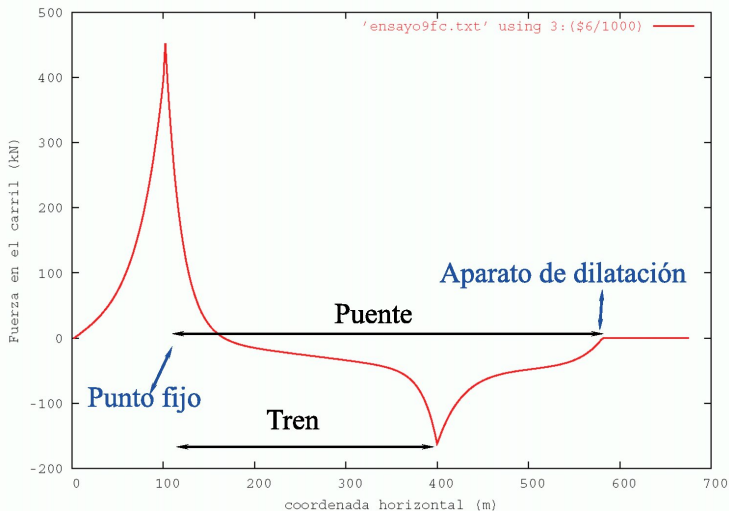
475 m viaduct, continuous rail

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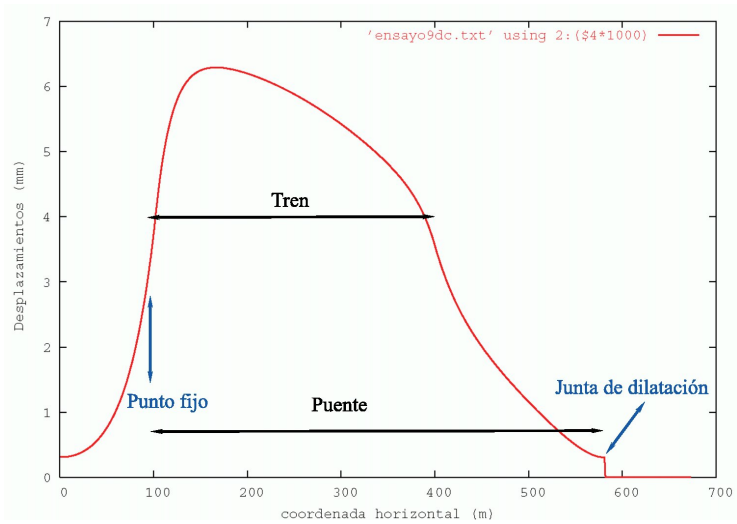
475 m viaduct, rail with expansion joint

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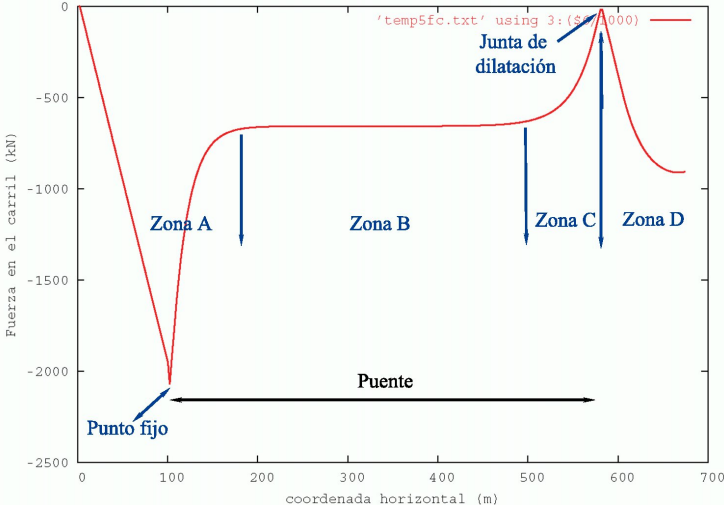
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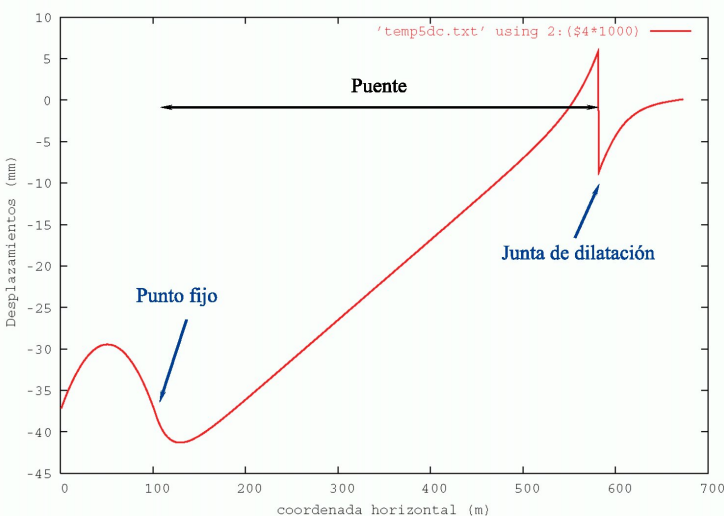
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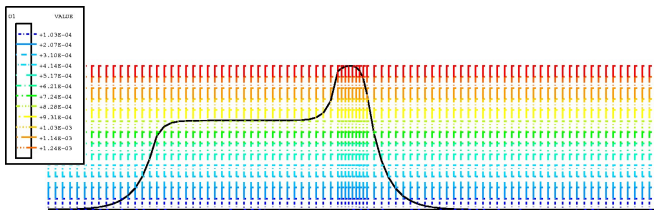
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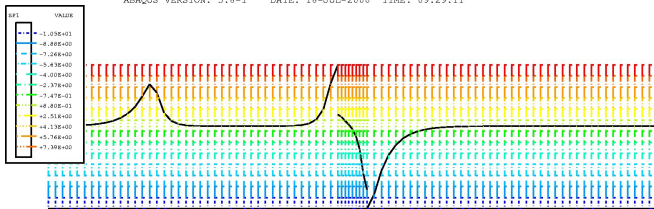


Study of braking action

# Braking, $L = 40$ m, $K = 10^5$ kN/m, continuous rail



RESTART FILE = or10-40 STEP 1 INCREMENT 1  
 TIME COMPLETED IN THIS STEP: 1.00 TOTAL ACCUMULATED TIME 1.00  
 ABAQUS VERSION: 5.8-1 DATE: 18-JUL-2000 TIME: 09:29:11

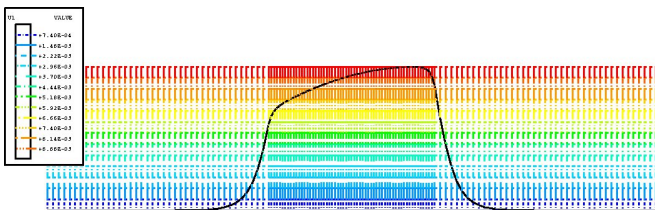


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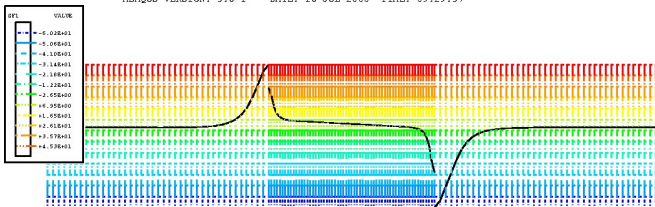


Study of braking action

# Braking, $L = 300$ m, $K = 10^5$ kN/m, continuous rail



3 1  
RESTART FILE = or10-300 STEP 1 INCREMENT 1  
TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
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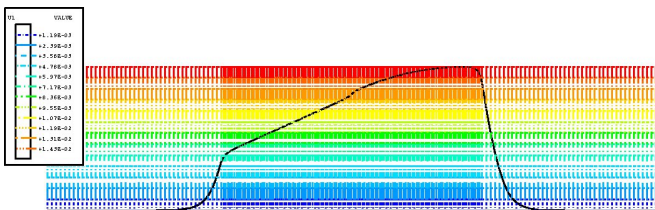


3 1  
RESTART FILE = or10-300 STEP 1 INCREMENT 1  
TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
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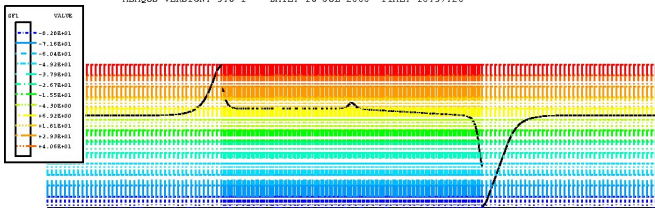


Study of braking action

# Braking, $L = 600$ m, $K = 10^5$ kN/m, continuous rail



3 1  
RESTART FILE = or10-600 STEP 1 INCREMENT 1  
TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
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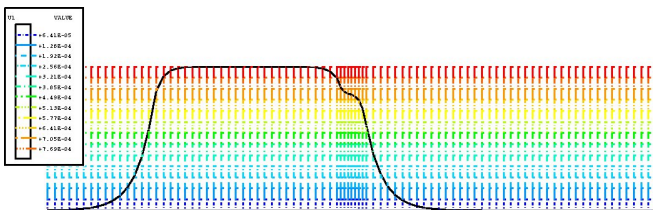


3 1  
RESTART FILE = or10-600 STEP 1 INCREMENT 1  
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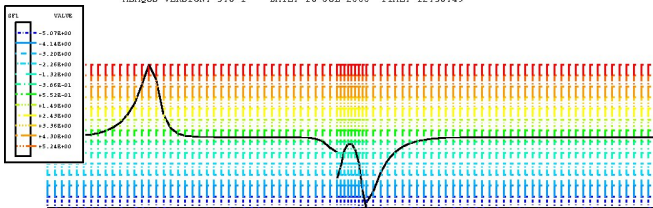


Study of braking action

# Braking, $L = 40$ m, $K = 5 \cdot 10^5$ kN/m, continuous rail



RESTART FILE = or50-40 STEP 1 INCREMENT 1  
 TIME COMPLETED IN THIS STEP: 1.00 TOTAL ACCUMULATED TIME: 1.00  
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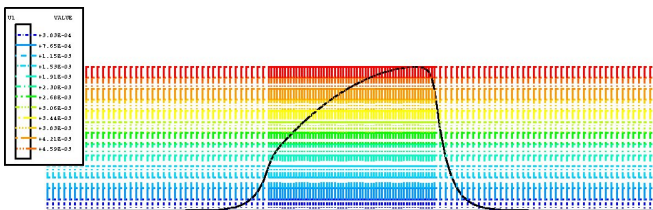


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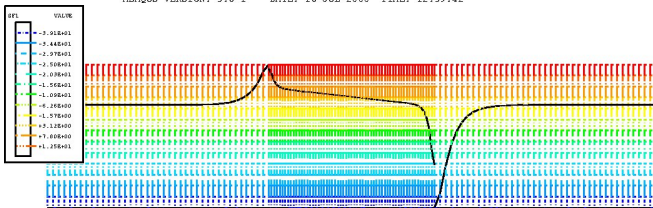


Study of braking action

Braking,  $L = 300$  m,  $K = 5 \cdot 10^5$  kN/m, continuous rail



RESTART FILE = or50-300 STEP 1 INCREMENT 1  
 TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
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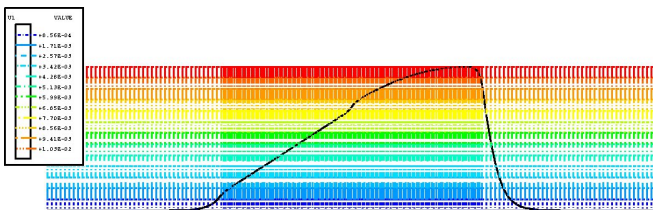


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 TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
 ABAQUS VERSION: 5.8-1 DATE: 18-JUL-2006 TIME: 12:39:42

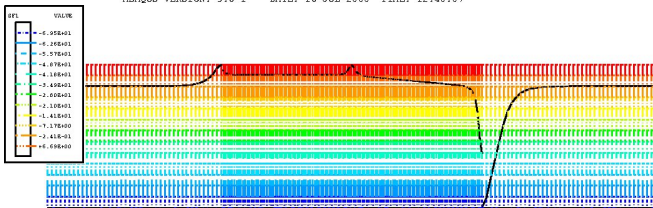


Study of braking action

Braking,  $L = 600$  m,  $K = 5 \cdot 10^5$  kN/m, continuous rail



RESTART FILE = or50-600 STEP 1 INCREMENT 1  
TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
ABAQUS VERSION: 5.8-1 DATE: 18-JUL-2006 TIME: 12:40:07

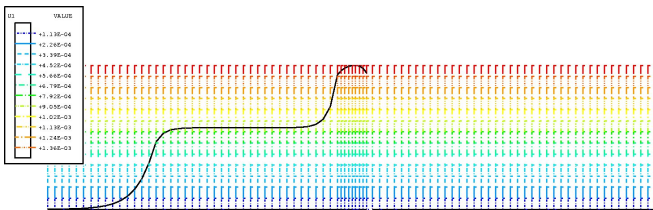


RESTART FILE = or50-600 STEP 1 INCREMENT 1  
TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
ABAQUS VERSION: 5.8-1 DATE: 18-JUL-2006 TIME: 12:40:07

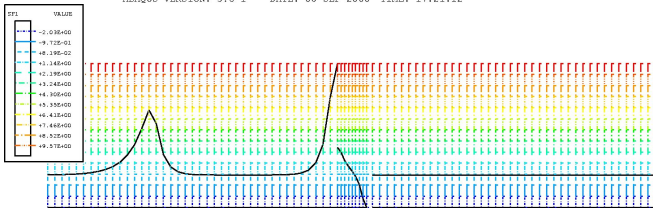


Study of braking action

Braking,  $L = 40$  m,  $K = 10^5$  kN/m, expansion device



RESTART FILE = ojd10-40 STEP 1 INCREMENT 1  
 TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
 ABAQUS VERSION: 5.8-1 DATE: 06-SEP-2000 TIME: 17:21:12

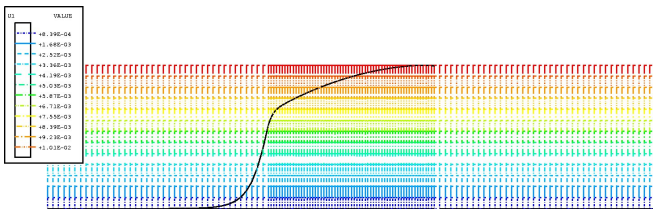


RESTART FILE = ojd10-40 STEP 1 INCREMENT 1  
 TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
 ABAQUS VERSION: 5.8-1 DATE: 06-SEP-2000 TIME: 17:21:12

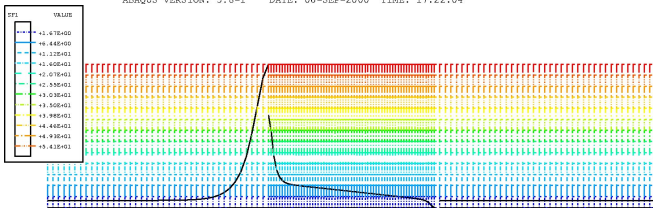


Study of braking action

Braking,  $L = 300$  m,  $K = 10^5$  kN/m, expansion device



2  
3 1  
RESTART FILE = ojd10-300 STEP 1 INCREMENT 1  
TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
ABAQUS VERSION: 5.8-1 DATE: 06-SEP-2000 TIME: 17:22:04

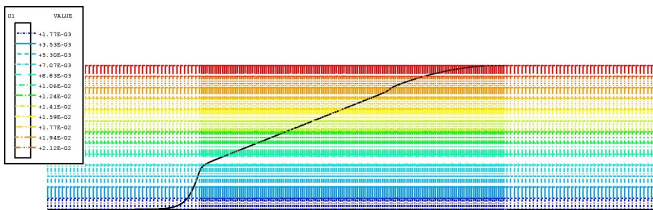


2  
3 1  
RESTART FILE = ojd10-300 STEP 1 INCREMENT 1  
TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
ABAQUS VERSION: 5.8-1 DATE: 06-SEP-2000 TIME: 17:22:04

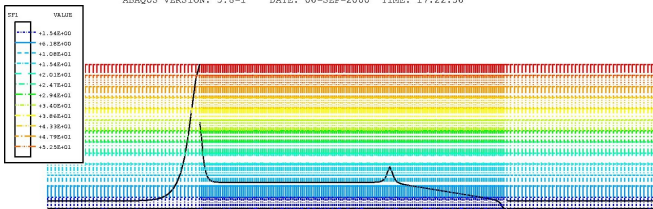


Study of braking action

# Braking, $L = 800$ m, $K = 10^5$ kN/m, expansion device



RESTART FILE = ojd10-800 STEP 1 INCREMENT 1  
 TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
 ABAQUS VERSION: 9.8-1 DATE: 06-SEP-2000 TIME: 17:22:36

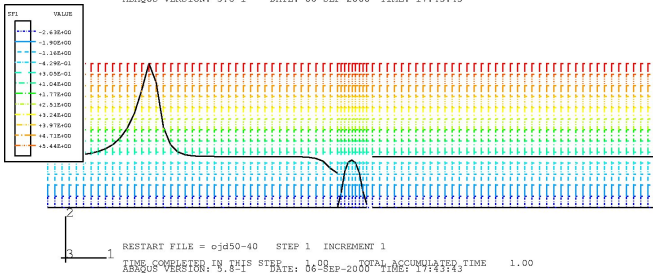
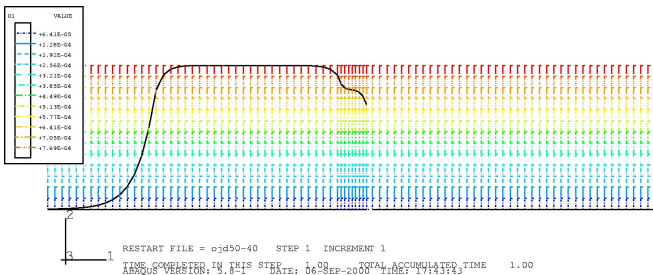


RESTART FILE = ojd10-800 STEP 1 INCREMENT 1  
 TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
 ABAQUS VERSION: 9.8-1 DATE: 06-SEP-2000 TIME: 17:22:36



Study of braking action

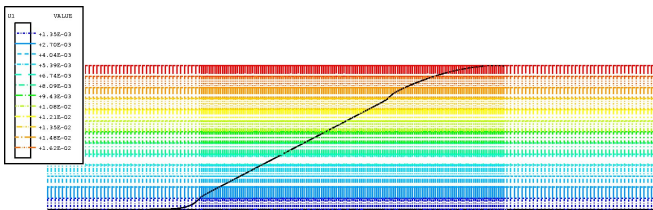
Braking,  $L = 40$  m,  $K = 5 \cdot 10^5$  kN/m, expansion device



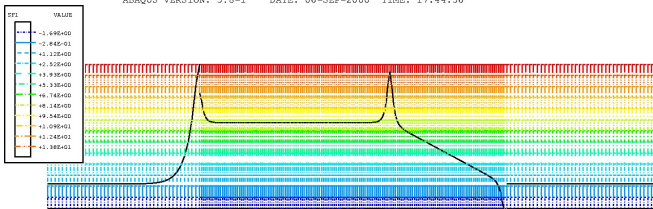


Study of braking action

Braking,  $L = 800$  m,  $K = 5 \cdot 10^5$  kN/m, expansion device



RESTART FILE = ojd50-800 STEP 1 INCREMENT 1  
 TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
 ABAQUS VERSION: 9.8-1 DATE: 06-SEP-2000 TIME: 17:44:56



RESTART FILE = ojd50-800 STEP 1 INCREMENT 1  
 TIME COMPLETED IN THIS STEP 1.00 TOTAL ACCUMULATED TIME 1.00  
 ABAQUS VERSION: 9.8-1 DATE: 06-SEP-2000 TIME: 17:44:56

