ANALYSIS OF LONGITUDINAL AND LATERAL BEHAVIOUR OF A CWR TRACK USING A COMPUTER SYSTEM LONGIN

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Summary

This paper discusses the computer model LONGIN developed at TU-Krakow for the European Rail Research Institute (ERRI). LONGIN is capable to analyse creep phenomena in CWR track such as longitudinal movements due to train braking/accelerating, lateral curve breathing and effect of track maintenance. TU Delft carried out a series of calculations to test the performance and applicability of LONGIN. Some illustrative results are presented and aspects of the use of the software in practice are discussed.

Contents

1 Introduction

Nowadays Continuous Welded Rail (CWR) tracks are widely used in majority European countries. Knowledge about longitudinal behaviour of the CWR tracks subject to various mechanical and thermal loadings is very important since the developing longitudinal displacements and forces can easily lead to occurrence of creep and buckling of the track structure [2]. A procedure for the stability analysis of the CWR tracks based on the Finite Element Method is described in [4]. The approach has been implemented in a software package CWERRI. A recent review of the existing methods for the analysis of the CWR tracks can be found in [3].

A numerical model and a methodology for the analysis of creep behaviour of CWR have been developed at Krakow University of Technology [1]. They have been implemented in a computer program LONGIN. Using this software, the longitudinal displacements and forces in a straight track section resulting from repeated thermal, mechanical and kinematical loads can be evaluated. In the current version of the program, it is also possible to analyse the lateral behaviour of a curve track under thermal loading and the effect of maintenance operations such as de-stressing of rails and rail pull on the longitudinal displacements and forces in the track structure. The software system LONGIN has been tested at Delft University of Technology (Railway Engineering Group). In this paper, some illustrative results obtained using the software are presented and practical experience with the software is discussed.

2 Brief overview of software

Firstly, the analyses performed by the LONGIN and the mathematical model of the CWR track implemented in the software are briefly presented. Then the elastic and geometrical properties of the elements of the track structure and the loads available in the software are described.

2.1 TYPES OF ANALYSES

The computer system LONGIN for analysis of CWR tracks works under Windows environment and can perform the following analyses:

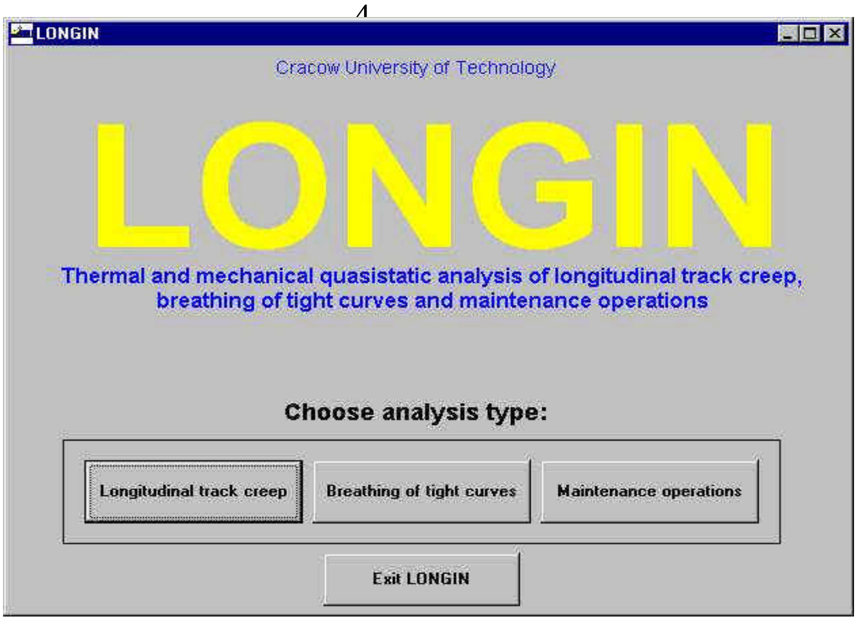
- determination of creep in a track structure caused by braking/accelerating of a train and/or variation of a temperature (module ‘LONGITUDINAL CREEP’)
- evaluation of lateral displacements of sharp curves due to the temperature (module ‘SHARP CURVES’)
- analysis of the effectiveness of maintaining operations such as tamping and de-stressing of the track structure (module ‘MAINTENANCE OPERATIONS’)

The particular analysis (module) can be chosen from the main window (Figure 1). Each module has windows-oriented pre- and post- processors and a solver that runs in DOS mode.

2.2 MODELLING OF A TRACK

The behaviour of a track structure is defined by the mechanical and geometrical properties of its elements such as rails, sleepers, fasteners and ballast. The mathematical model of the track implemented in LONGIN has been obtained under the following simplifications:

- each rail is considered as a prismatic and perfectly elastic beam element (Euler beam)


LONGIN

Cracow University of Technology

LONGIN

Thermal and mechanical quasistatic analysis of longitudinal track creep, breathing of tight curves and maintenance operations

Choose analysis type:

Figure 1 Main menu of LONGIN

- each sleeper is modelled by spring element connecting to the rails and providing longitudinal and lateral resistance of the track structure
- fasteners are considered as elements providing longitudinal and torsional stiffness between the sleepers and rails
- ballast is modelled by horizontal and vertical spring elements which provide the longitudinal and lateral stiffness of the track structure and the stiffness in the vertical direction

The model for the analysis of the longitudinal behaviour of the straight track is given in Figure 2.

It should be noted that the lateral ballast resistance is used only in the analysis of the lateral behaviour of the curve track.

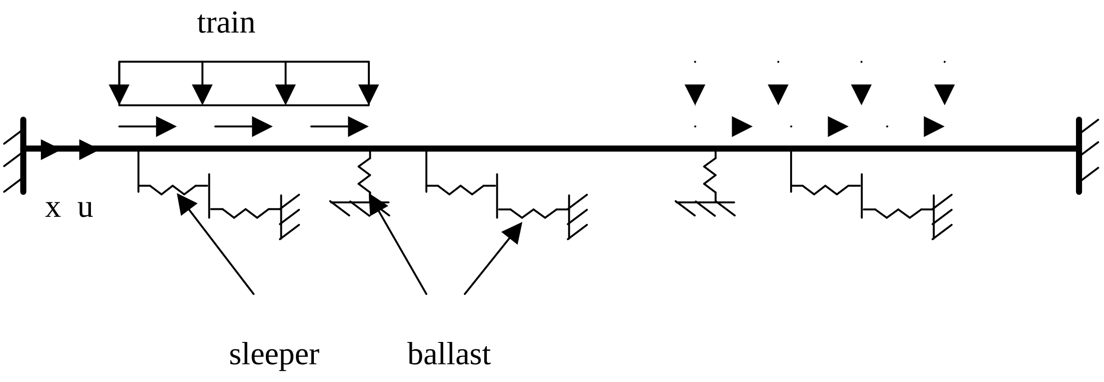


Figure 2 Model of track under moving train loading

2.3 DEFINITION OF THE TRACK PROPERTIES

To perform any of the analyses the material and geometry properties of the elements of the track structure have to be defined.

For the rails the material parameters such as a unit mass, the Young modulus and a coefficient of thermal expansion as well as a moment of inertia in vertical plane and the cross-section area of the rail can be defined. Additionally a moment of inertia of the rail in the horizontal plane can be specified.

The mechanical properties of the fasteners to be defined to perform the analysis comprise the longitudinal resistance and the maximum strength parameters (evaluated for one fastener). Moreover, the fastener with the non-linear longitudinal resistance can be chosen.

The sleepers are defined by the weight per one sleeper and the distance between two adjacent sleepers. The longitudinal stiffness and the moment of inertia in the horizontal plane evaluated for one sleeper can be defined as well.

The ballast properties to comprise the longitudinal resistance per meter of the track, the maximum value of the longitudinal resistance and the stiffness in the vertical direction. It is also possible to choose the longitudinal ballast resistance with non-linear characteristics.

Additionally, several extra parameters of the track structure such as initial longitudinal displacements and the relation coefficients between the value of the uplift and the longitudinal resistance of the fasteners and ballast can be defined. The changes of the longitudinal resistance of the fasteners and ballast due to the maintenance operations can be taken into account as well.

The geometry of the straight track section is defined by the length of the track section. Intervals with varying vertical slope can be defined as well. Besides, it is possible to define some points on the track section where the longitudinal resistance of the ballast differs from the one defined for the whole track. This feature can be used for example to model a part of the track lying on a bridge.

A shape of the curve track is defined by the radius of curvature $[m]$ and the angle $[°]$ of the section. The track sections with and without initial local imperfections can be analysed. For the section without the imperfections a transitional section can be defined as well. Two types of the imperfections can be considered namely local geometrical and local mechanical ones. The geometrical misalignments are defined by a sine function and for the mechanical imperfections a length $[m]$of the interval with reduced lateral stiffness $[\%]$ have to be specified.

2.4 DEFINITION OF LOADS

Two types of loads can be applied to the track section, namely the loads due to braking/accelerating of the train and the thermal loads. The train can be modelled by the (non-) uniformly distributed forces (Figure 2) or by a set of concentrated forces applied at the position of wheel axles of the train. The initial and final velocity of the train, the position where the braking/accelerating begins and the value of its intensity have to be defined as well.

To apply the thermal load an initial and current temperatures of the rails have to be specified. The temperature distribution in the rails can be represented by a constant or sine function; it can also be defined explicitly for each part of the track. The last feature can be used e.g. to analyse the longitudinal behaviour of the track section when some parts of the section lye in a shadow.

A combined train and temperature load can be applied as well. Once defined the train and/or temperature load can repeatedly be applied to the track structure.

It should be noted that for the analysis of the lateral behaviour of the curve track only thermal load can be applied.

3 Numerical results

The LONGIN software has been tested using various track parameters and loads. Some results demonstrating proficiency of the program are presented below.

3.1 CREEP ANALYSIS OF A STRAIGHT TRACK

To test this module, the following input data has been used.

Reference problem

Rail profile: UIC-54
Fastener (good condition): longitudinal stiffness 13333 kN/m^2, maximum strength 40 kN/m
Sleeper: weight 250 kg, spacing 0.6 m
Ballast (good condition):
  Longitudinal stiffness 3000 kN/m^2, maximum strength 15 kN/m
  Vertical stiffness 150150 kN/m^3
Track: length 1000 m
Train: weight 24000 kN, length 300 m
Braking:
  initial velocity 100 km/h, final velocity 80 km/h
  abscissa of beginning of braking 500 m
  intensity of braking 0.05
  number of braking – one time

The resulting longitudinal displacements of the track are shown in Figure 3. As it can be observed, there are no residual displacements in the track structure after the braking. Therefore, no creep occurs in the track section of a good condition under conventional loading.

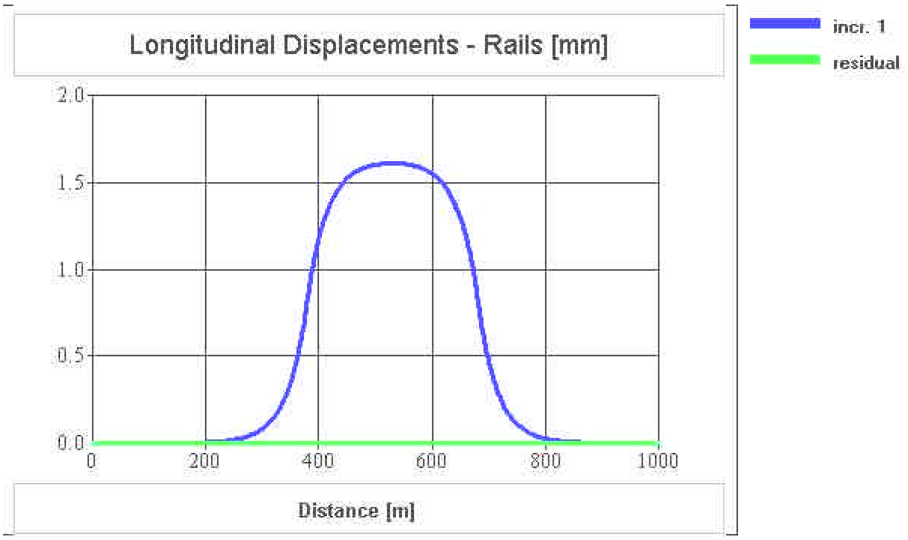


Figure 3 Reference problem (creep analysis)

From Figure 4a it can be seen that the maximum longitudinal displacements of the sleepers $u_s^{\max} = 1.3\ mm$ occur in the middle of the train at the distance of 570 *m*. The corresponding increase of the longitudinal resistance of the ballast can be evaluated as

$$r_b^{\max} = R_b u_s^{\max} = 3.9\ kN/m, \qquad (1)$$

where R_b is the longitudinal resistance of the ballast. The same value of the maximum ballast resistance can be seen in Figure 4b. Since this value lies below the maximum strength of the ballast (15 kN/m), no residual displacements of the sleepers can be seen.

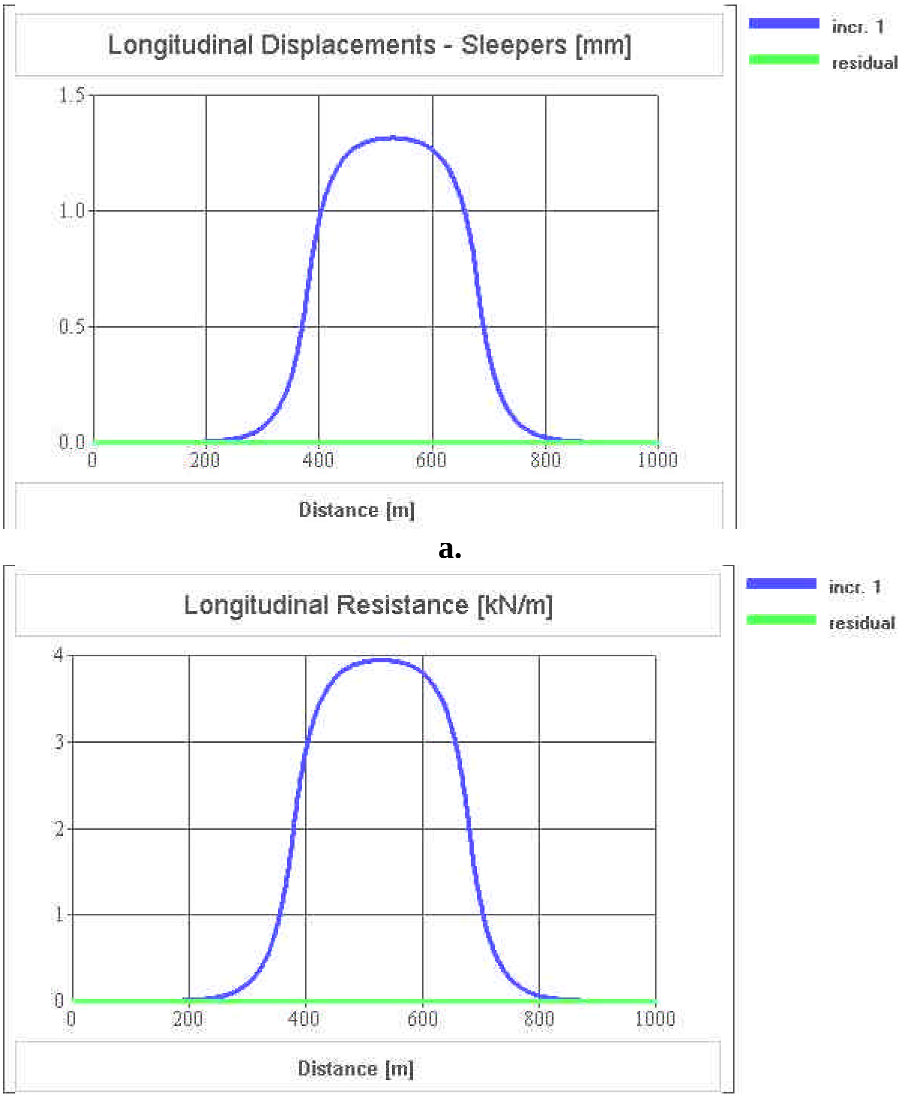
The braking force in this case is

$$F_b = 24000 \cdot 0.05 = 120\ kN\,. \qquad (2)$$

From Figure 5 it can be seen that the peak values of the longitudinal force in the rails are achieved in the beginning and in the end of the train where the track undergoes pressure and tension respectively.

When the weight of the train and intensity of braking have been increased (54000 *kN* and 0.2 respectively) the residual displacements and forces are present in the track structure after the braking. This means that the creep of the track has occurred (Figure 6-Figure 7).

The mechanism of the creep phenomenon can better be understood by varying the elastic properties of the fasteners and ballast. When the resistance of the fasteners is increased the rails and sleepers are then moving together with respect to the ballast. It should be noted that the resistance of the fasteners depends more on friction condition between a rail and a bedding plate and between the bedding plate and the ballast than on the fastening force itself.



a.

b.

Figure 4 Reference problem (creep analysis)

If the resistance of the ballast is increased, the displacements of the sleepers are relatively small whereas the displacements of the rails are extremely large. That means that the rails have been moved relative to the sleepers.

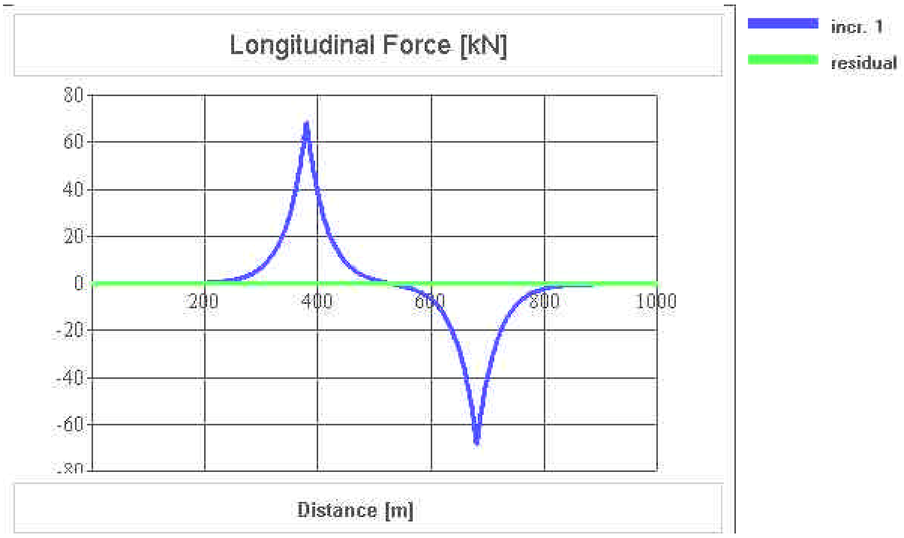


Figure 5 Reference problem (creep analysis)

3.2 DETERMINATION OF LATERAL DISPLACEMENTS OF A CURVE TRACK

Reference problem

The input data is

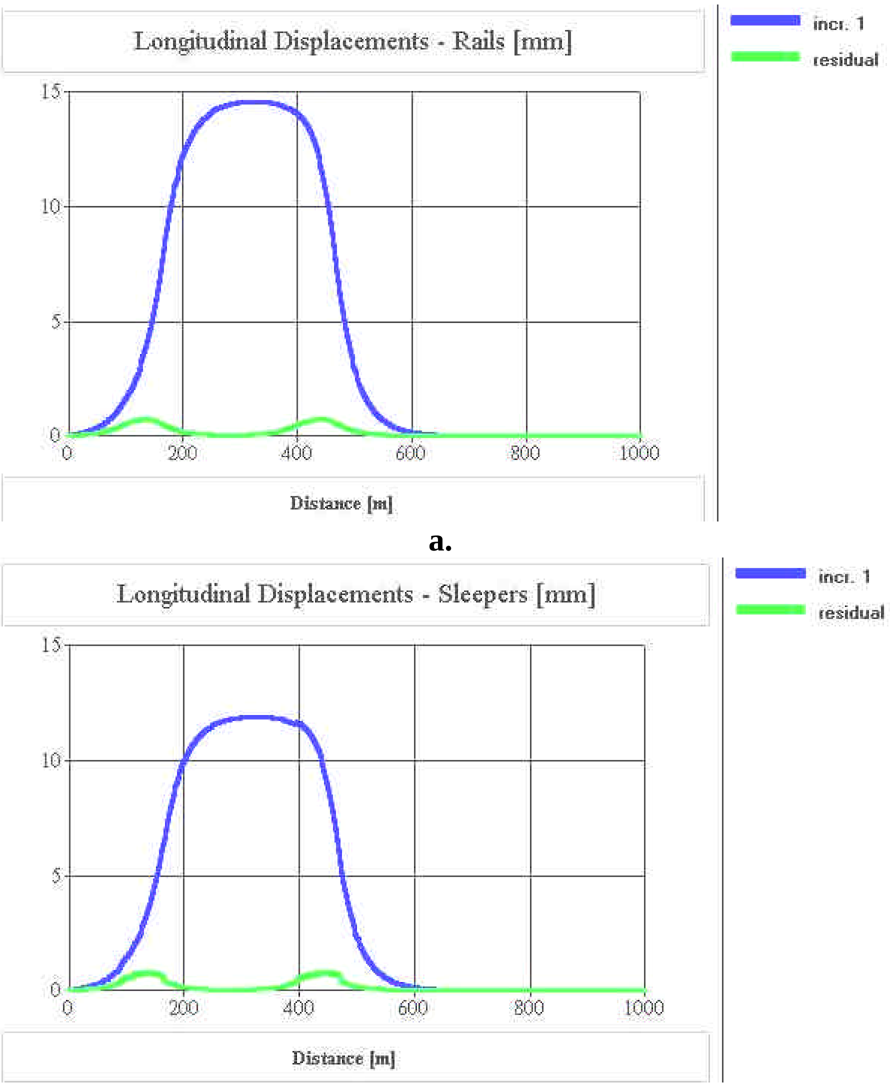
Rail: UIC54
Radius of curvature: 300 m
Half length of arc: 235.62 m
Temperature increase: $50\,°C$
Lateral ballast stiffness:
$4000\ kN/m^2$

The rotational stiffness of the fasteners is zero. No transition section and no initial imperfections are defined.

The lateral displacements of a half of the section are shown in Figure 8. Despite the relatively high temperature variation ($50°C$) The displacements do not exceed 1.5 mm while the maximum allowable value of the lateral elastic displacements according to the standards of the Dutch Railways (NS) is 2.8 mm. Small oscillations in the displacement values can be observed around the connection point of the curve track to a straight section. Then the displacements become equal to zero.

When the lateral resistance of the ballast is reduced ($800\ kN/m^2$) the lateral displacements become large (Figure 9). Amplitude of the oscillations then increases as well, which finally can become critical.

The oscillations can be reduced when a transition section (length 100 m)



a.

b.

Figure 6 Heavy train, creep occurs

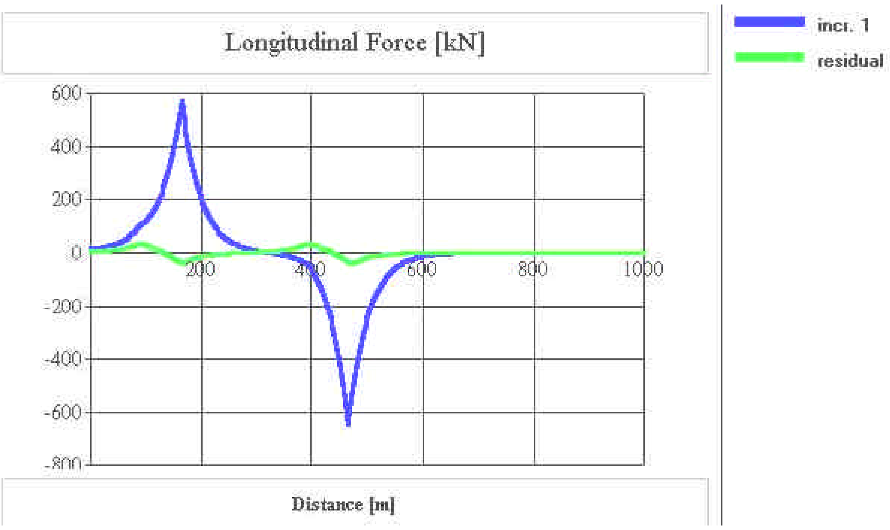


Figure 7 Heavy train, creep occurs

between the curve and the straight sections is introduced (Figure 10). The displacements now gradually decrease and no oscillation in the displacement values can be seen.

Using the software it is also possible to determine the track of a minimum radius of curvature for a prescribed temperature variation such that the lateral displacements are not exceed the maximum allowable value. For example using the data of the reference problem with the transition section of 100 m and the maximum allowable lateral displacement of the ballast $2.8\,mm$ the minimum radius of the curvature (rail profile UIC-54) is 140 m whereas for the rail profile UIC-60 the minimum radius is 160 m.

3.3 EFFECT OF MAINTENANCE OPERATIONS ON LONGITUDINAL DISPLACEMENTS OF A TRACK

Using the software, it is possible to evaluate the longitudinal displacements of the track when one of the rails has been broken. Also the longitudinal displacements and forces in the track structure due to de-stressing and tamping operations can be analysed.

An example of the track behaviour with a broken rail is given below.

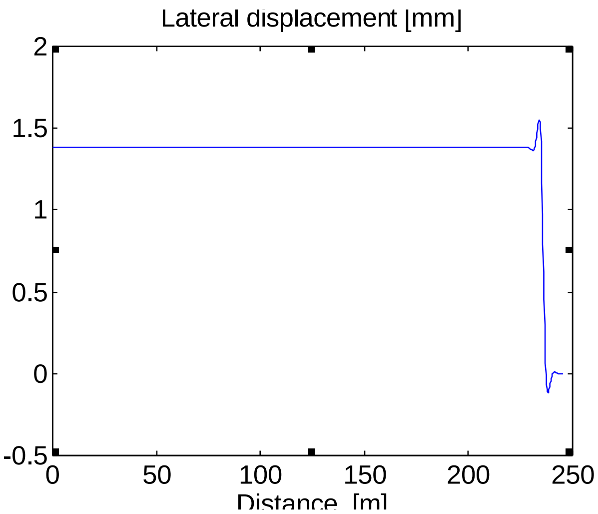


Figure 8 Reference problem

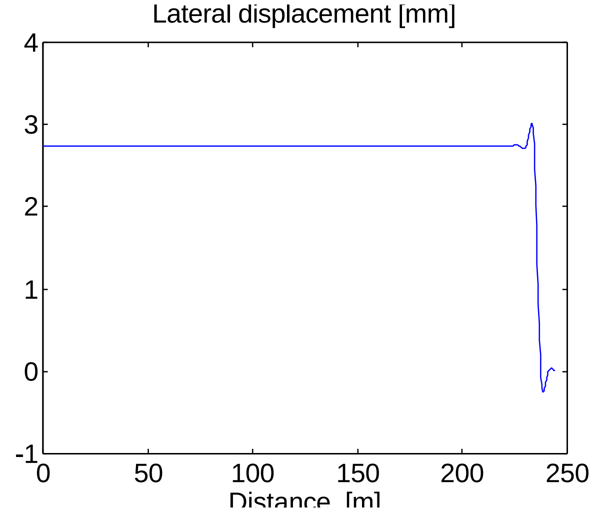
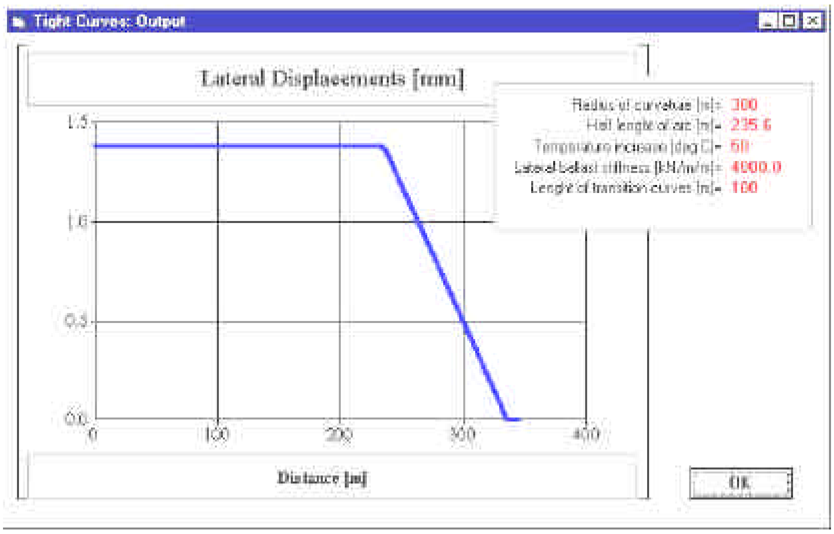


Figure 9 Results with reduced lateral stiffness of ballast

Input data: see reference problem
for creep analysis.
Fastener: torsional stiffness
50 $kN\,m/rad$
Temperature variation: $-50°C$

The results are shown in Figure 11. From this Figure it can be observed that the resulting gap has a length of approximately 70 mm. The longitudinal force in the broken rail is zero in the region of the gap. Because of the rotational stiffness of the fasteners, the longitudinal force in the not broken rail slightly reduces as well.



Radius of curvature [m]= 300
Half length of arc [m]= 235.6
Temperature increase [deg C]= 50
Lateral ballast stiffness [kN/m/m]= 4000.0
Lenght of transition curves [m]= 100

Figure 10 Curve track with transition section

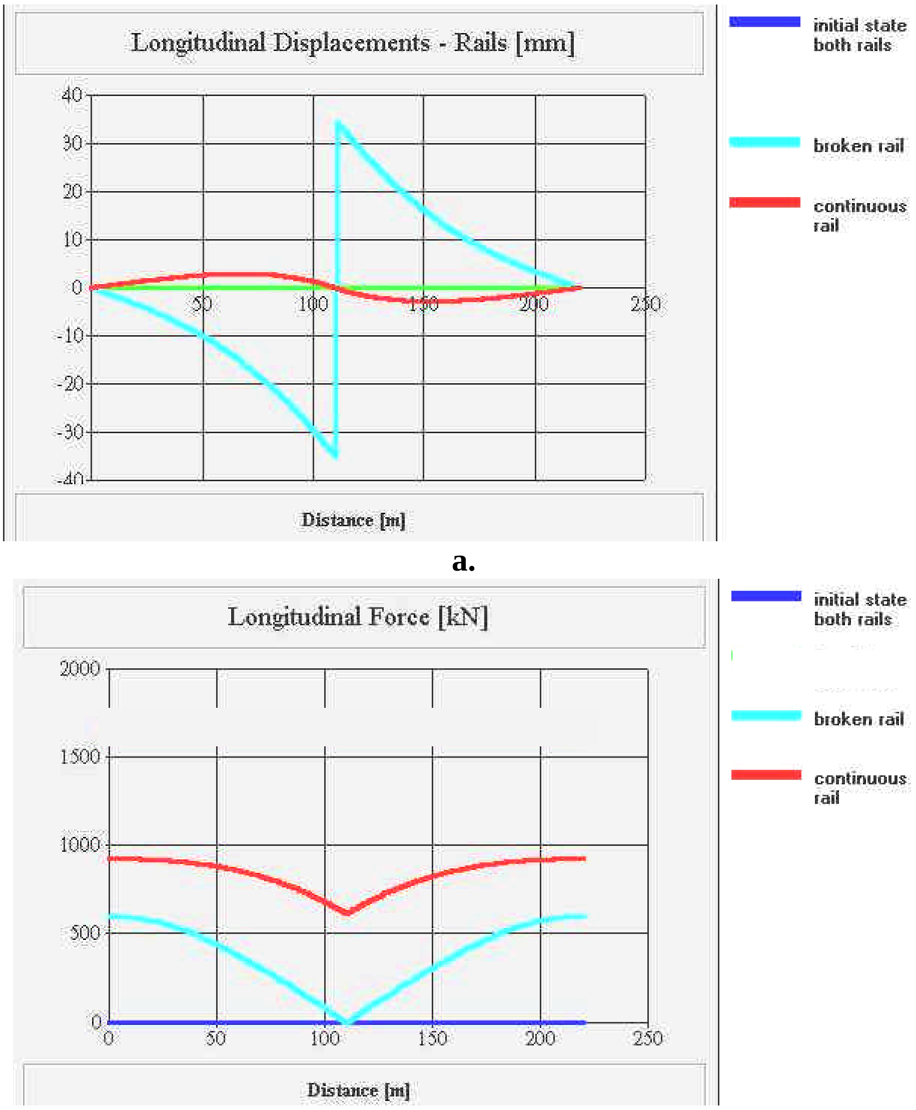
4 Conclusions

A software system LONGIN for analysis of the longitudinal and lateral behaviour of a CWR track is presented.

The software works under Windows environment and has user-friendly interface.

The software performs the three types of numerical analysis. The analysis of longitudinal creep of the track as a result of braking/accelerating of a train that includes the effect of thermal forces. The analysis of the lateral displacements of a curve track caused by the temperature variation. And the analysis of the longitudinal displacements after maintenance operations.

All the analyses have been intensively tested. Based on these results it can be concluded that the software provides a quite realistic information about the behaviour of the CWR track. Using the software various factors affecting the longitudinal and lateral behaviour of the CWR tracks can be investigated.



a.

b.

Figure 11 Displacements and forces due to broken rail

References

1. ERRI-D202 (1997) Analysis of Factors That Influence Longitudinal Behaviour of CWR Track Including Lateral Movements of Sharp Curves. *ERRI D 202 RP5*, European Rail Research Institute, Utrecht, draft report by Czyczula, W., Krakow University of Technology
2. Esveld, C. (1989) *Modern Railway Track*. MRT-Productions, Duitsburg
3. Samavedam, G. (1994) Theory of CWR tracks stability. *Report ERRI D202*
4. Van, M.A. (1997) Stability of CWR track. *Ph.D. Thesis*. Delft University of Technology