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The reverse centrifugal thrust in curves with small radius

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Abstract

In order to increase lateral track resistance on curves the "DINTRA" sleeper was created. This sleeper prototype increases the transverse stiffness in railway curves. During the field validation test of the "DINTRA" sleeper on a railway curve of a track section from the North of Spain, the evolution of the transverse displacement of the railway track and the longitudinal deformation of the rails were monitored. In the course of the field test, a structural phenomenon was detected. There is a transverse displacement of the rails to the inside of the curve. The authors have named "Reverse Centrifugal Thrust in railway curves". This article tries to explain and quantify this observed phenomenon. Authors propose two formulations: first (a) a formulation to determine the temperature increase experienced in the rails that delimits the structural phenomenon of Inverse Centrifugal Thrust, and then (b) a formulation to determine the transverse displacement in railway curves as trains pass under conditions of restricted thermal expansion.

Keywords: reverse centrifugal thrust, railway curves, structural health monitoring, restricted thermal expansion.

1 Introduction

In order to study track performance on curves a track section of narrow gauge was monitored in the north of Spain. Longitudinal deformation of rail and sleeper displacement was measured. Track structural response was obtained; maximum axial tensile deformation in the rail web, lateral displacement of the track section. During this measurement campaign a rare phenomenon was found in this railways section. In a certain period of the day, centrifugal forces produced by train wheels within this curve make the rail track to move inside the curve the named by authors “reverse centrifugal thrust in railway curves” appeared.

Railway track is affected by three types of forces which cause different track performance under their application. In general rail track forces, are higher in magnitude for example with respect to conventional roads and they are sudden and characterized by rapid fluctuations. The track loads considering three main directions are: Vertical, horizontal (transverse - parallel to the track). On the other hand, track loads considering the nature of the loads, these can be quasi-static loads and dynamic loads [1]. The first type (quasi-static) is as a result of the gross tare, the centrifugal force and the centring forces in curves and switches and cross winds, the second type (dynamic), can be produced by track irregularities and irregular track stiffness, discontinuities at welds, switches and joints, irregular rail running surface (rail corrugation) and vehicle defects (wheel flats, natural vibration, hunting movement, etc.). Temperature effects can cause problems such as buckling in the lateral plane is an important effect to consider in safe operations of CWR [2]. Type of track structure, materials geometry and mechanical characteristics or position are important in their behaviour [3,4].

The research presented here concerns to a phenomenon detected in track curves with the special sleepers called “DiNTRA” [5]. This phenomenon observed is in relation with lateral track resistance on curves. Here on track curves, special in those with small radius on which rolling stock circulates, track structure suffers additional force which have to be considered in depth. Rail buckling, wheel flange climbing, sleepers and track lateral movements increase the risk of accidents [6]. This lateral resistance of the track is influenced by various causes such as rail temperature [7], type of sleepers, fastenings, ballast layers, maintenance process of rails and loading condition [8].

The rare phenomenon appeared during field tests in a small radius curve in the north of Spain.

2 Methods

During the empirical validation process of the structural response in railway curves mounted with the "DINTRA" sleeper prototype [5], the structural monitoring of a field test on the Basque Country railway line (narrow gauge) was proposed. It was intended to characterize the track performance when trains pass through a circular arrangement of 154 meters in length and 110 meters in radius (Figure 1). To do this, the authors moved to the location of the curve and carried out a continuous measurement over a 12-hour period of the transverse displacement of the railway and the deformation of the rails caused by the passage of trains and the phenomenon of expansion/contraction of the rails due to thermal surges experienced during continuous measurement, from 9 am at 9 p.m.

Figure 1: Instrumented curve.

In order to characterize empirically the structural response of the track during the field test, two groups of sensors were installed in the section of the railway located in the center of the circular arrangement (Figure 2): (a) one unit of potentiometric displacement transducer to characterize the transverse displacement experienced by the instrumented railway track section (Figure 3); (b) four units of bidirectional strain gauge model to characterize the longitudinal strain experienced in the web of the UIC-54 rails (Figure 4). The strain gauges installed in the web of the rails are connected through the use of a Wheatstone half-bridge electronic assembly, this assembly allows determining the evolution of the longitudinal strain of the web of the rails, compensating for the effects local conditions caused by thermal variations during the course of the field tests, twelve hours (from 09 to21). The acquisition, recording and monitoring of the information provided by the sensors is carried out through a Structural Monitoring System (SMS) composed of the following elements: (a) a Modular Central Data Acquisition and Processing Unit model with the capacity to simultaneously manage the signal from up to eight Data Acquisition Units (DAU); (b) an extensometer DAU model that facilitates analog signal processing from strain gages; (c) a voltage signal DAU model that facilitates analog signal processing from displacement transducer; (d) a workstation responsible for communicating with MCDA&PU and recording and viewing data provided by sensors through a Data Acquisition and Monitoring Program designed and programmed by authors.

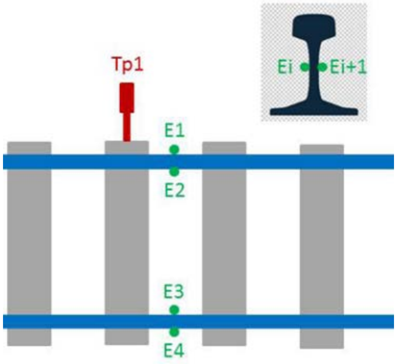

Figure 2: Sensors scheme.

Figure 3: Potentiometric displacement transducer.

Figure 4: Strain gauges in the web of the rails.

3 Results

The structural monitoring began at 9:00am on October 8, 2020, with an outdoor temperature of 13ºC. The following variables were measured: a_longitudinal deformation experienced by the rails "εi" (Figure 5); and b_displacement of the railway "Tp1" (Figure 6). In the initial moments, an increase in temperature was observed. The structural behaviour of the railway in the initial instants corresponds to that is expected when a train passes through a curved section, the centrifugal force exerted by the train's wheels on the railway generates: a_axial tensile deformation in the rails (Figure 5) and b_displacement of the railway towards the outside of the curve (Figure 6). The increase in environment temperature, added to the sunlight from the rails, leads to a progressive increase in the energy of compression axial deformation in the rails.

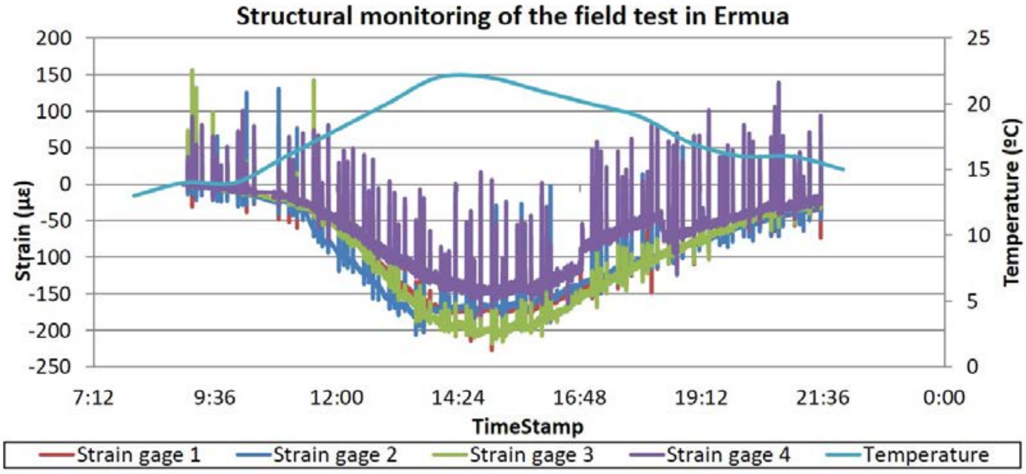

Figure 5: Structural response: a_Longitudinal strain of the rails.

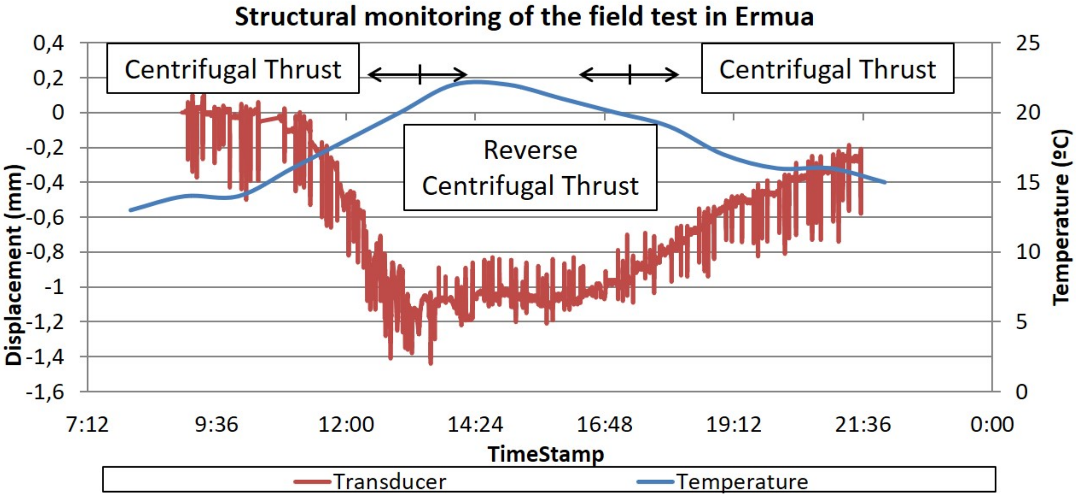

Figure 6: Structural response: b_Displacement of the railway section.

At 1:00pm a turning point appeared in the structural response (figure6) to the passage of trains. At this point, the displacement of the sleeper towards the outside of the curve was 0.98mm and the temperature was 20°C. From this point, a phenomenon occurred that the authors have called “Reverse Centrifugal Thrust” (RCT) in railway curves with small radius, which is why the centrifugal force exerted by the train wheels on the rails as they pass along the railway causes a displacement towards the interior of the curve (figure8).

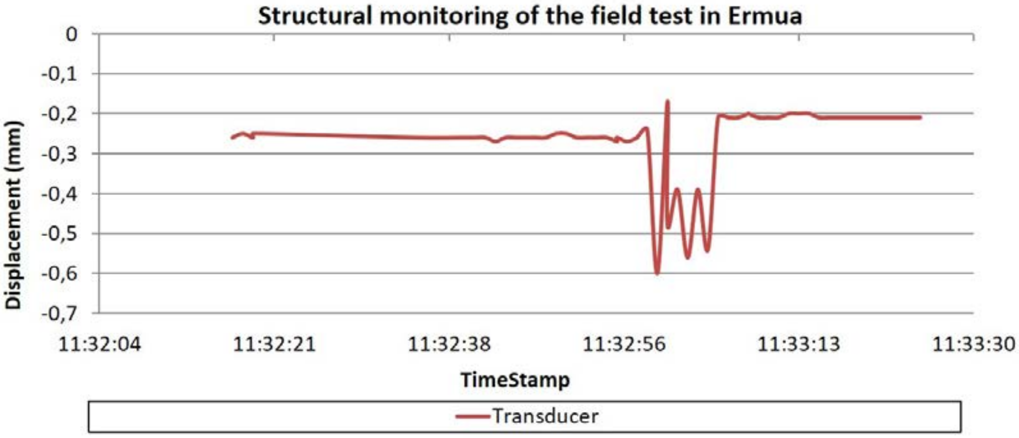

Figure 7: Sleeper displacement: a_Centrifugal thrust.

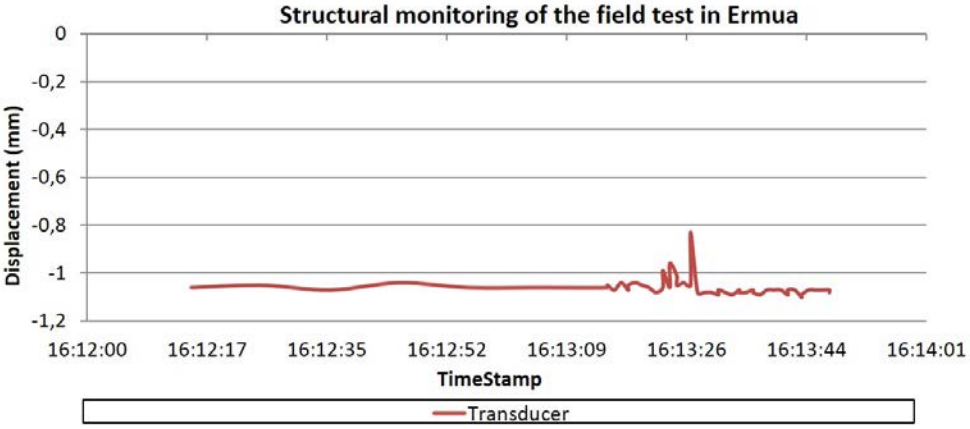

Figure 8: Sleeper displacement: b_Reverse centrifugal thrust.

The maximum displacement towards the inside of the curve reaches a value of 0.31mm and the temperature was 22ºC. A possible explanation can be that the displacement caused by the deviation forces towards the inside of the curve generated by the decompression of the rail as the trains pass is greater than the displacement caused by the centrifugal force exerted by the train wheels.

The phenomenon was observed under certain values (Table 1), small curves in narrow gauge in a determined range of temperatures with DINTRA sleepers. Measurement devices were checked and moving material were passengers and freight trains, excessive and insufficient cant has been discarded as an explanation to the phenomenon.

VARIABLE	VALUE OF RANGE
Track gauge	Narrow gauge (1.000mm)
Rail	UIC 54
Sleeper	DINTRA [5]
Curve cant	110 mm
Environmental temperature	20 – 22 ºC
Train Speed	60.1 Km/h (16.7 m/s)
Total train weight	224 T
Length of the curve	154 m
Radius of the curve	110 m

Table 1: Environment, track and vehicle parameters.

4 Conclusions and Contributions

During field validation tests of the structural response of the sleeper type DINTRA [5], the authors detected a turning point in the structural response in railway curves. This rare phenomenon appeared in a determined curve, with a non-usual sleeper and a certain train load and speed. Due to this singularity authors have tried to identify and quantify it. This inflection point defines a structural phenomenon that the authors have named "Reverse Centrifugal Thrust in railway curves" due to its nature.

Thermal conditions of the environment make this phenomenon appeared in a determined period of time. Narrow gauge, type of rail, type of sleeper, environmental temperature, very small radius curves, certain train speed, determined train weight, track cant in the curve make this unusual performance appeared in this section.

This article shows and tries to explain this unusual track performance in this curve of small radius. Excessive and insufficient cant in the curve, malfunctioning o measurement devices and wrong procedure during field measurements have been discarded as a possible explanation to the phenomenon. It should be understood that the absolute displacement of the railway, the sum of the total energy of compression deformation of the rail, due to its restricted expansion, and the inverse centrifugal force, is towards the outside of the curve. However, the relative displacement of the railway generated by the Reverse Centrifugal Thrust (RCT) when the train passes the railway is towards the inside of the curve.

It is necessary to get more measurements in the same area or in other curves with similar characteristics to extent these conclusions and give them a general result for any type of railway track.

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