Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-507

ECSMGE 24
XVIII EUROPEAN CONFERENCE
ON SOIL MECHANICS AND
GEOTECHNICAL ENGINEERING

Pressure cell results for a ballasted railway track section tested in the CEDEX Track Box

Résultats de la cellule de pression pour un tronçon de voie ferrée testé dans la boîte à outils CEDEX Track Box

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ABSTRACT: CEDEX Track Box (CTB) is a 21 m long, 5 m wide and 4 m deep facility whose main objective is to test, at 1:1 scale, complete railway track sections of conventional and high-speed lines for passenger and freight trains, at speeds up to 420km/h. Its special characteristics allow the testing of different railway sections, types of trains, passing by velocities and materials in advance of their use in the real railway. In this work, we present the results obtained from pressure cells located at several depths inside the railway track section, after testing two different types of trains at eight different passing-by speeds (from 50 to 400 km/h). The railway train section tested in this work has the same requirements as the Spanish ballasted high-speed track sections. These tests show the distributions of pressures underneath the superstructure and how they are affected by the different loads of each type of train and the several passing-by speeds.

RÉSUMÉ: Le CEDEX Track Box (CTB) est une installation de 21 m de long, 5 m de large et 4 m de profondeur dont l'objectif principal est de tester, à l'échelle 1:1, des tronçons complets de voies ferrées de lignes conventionnelles et à grande vitesse pour les trains de passagers et de marchandises, à des vitesses allant jusqu'à 420km/h. Ses caractéristiques particulières permettent de tester différents tronçons ferroviaires, types de trains, vitesses de passage et matériaux avant leur utilisation dans le réseau ferroviaire réel. Dans ce travail, nous présentons les résultats obtenus à partir de cellules de pression situées à plusieurs profondeurs à l'intérieur de la section de voie ferrée et après avoir testé 2 types de trains différents à 8 vitesses de passage différentes (de 50 à 400 km/h). La section de voie ferrée testée dans ce travail répond aux mêmes exigences que les sections de voies à grande vitesse ballastées espagnoles. Ces essais montrent la répartition des pressions sous la superstructure et la manière dont elles sont affectées par les différentes charges de chaque type de train et les différentes vitesses de passage.

Keywords: Railway track section; pressure cells; train velocities.

1 INTRODUCTION

Mobility policies in the European Union are encouraging the use of rail transport to promote more sustainable mobility. Considering the lower environmental impact of railway transportation mode compared to other modes of mass transportation (road, air, maritime), the European Green Deal aims to shift to rail transport to reduce CO_2 emissions.

Spain has an important network of high-speed lines, with more than 3,400 km. The vast majority of the railway sections of these lines are built with a ballast layer instead of slab track. In recent years, comparative studies of the pros and cons of one construction system versus the other have pointed to the need for greater maintenance on the sections built with ballast (Charoenwong et al. 2023).

Ballast maintenance operations consist mainly of tamping the layer or replacing the material when track movement levels are excessive. Since one of the main functions of the ballast layer is the absorption of loads transmitted by the train, it is interesting to study how these loads are transmitted to the lower layers of the section and what factors may be involved.

One of the tasks carried out by Laboratorio de Geotecnia - CEDEX is the auscultation of railway sections. This auscultation on real tracks is the perfect complement to the tests carried out at the CEDEX Track Box (CTB) facility.

2 CEDEX TRACK BOX

CEDEX Track Box (CTB) is a 21 m long, 5 m wide and 4 m deep facility whose main objective is to test, at 1:1 scale, complete railway track sections of conventional and high-speed lines for passenger and freight trains, at speeds up to 420 km/h. Figure 1 shows a general view of the testing facility and the hydraulic actuators that apply the loads to simulate the railway traffic (Estaire et al., 2018).

Figure 1. General view of the CEDEX Track Box and the hydraulic actuators.

Its principal advantage is the possibility of performing fatigue tests in a fast way as in 10 working days, the effect of a train passing-by during a year in a real section can be modelled.

The reproduction of the effect of the approaching, passing-by and departing of a train in a test cross-section, as it occurs in a real track section, is performed by application of loads, unphased as a function of the train velocity which is being simulated, produced by three pairs of hydraulic actuators (each of them can apply a maximum load of 250 kN at a frequency of 50 Hz), placed on each rail and 1.5 m longitudinally separated.

The railway track response, in terms of displacements, velocities accelerations and pressures, is collected from LVDTs, geophones, accelerometers and pressure cells installed both inside the embankment and the bed layers of the track. The railway superstructure response is recorded with mechanical displacement transducers, laser sensors, geophones and accelerometers installed on the different track components (rail, sleeper and railpad).

CTB has been used to research different matters, such as the measurement of track vertical stiffness under different track conditions and the determination of track lateral stability. More detailed information is described at Estaire et al. (2018).

In this work, the tests carried out on the installation were used to determine the vertical pressure in the different layers of the railway section, produced by different types of trains and passing speeds.

3 TESTS DESCRIPTION

3.1 Introduction. General aspects

This work is part of a larger study of ballast degradation as a function of the type of trains and speeds modelled in the tests. The results shown were obtained from the analysis of static and dynamic tests and focused on measurements obtained with pressure cells placed inside the layers of a ballasted track model built in CTB.

The load applied by the trains is transmitted from the rail to the sleepers and the layers constituting the railway section. One of the ballast layer main functions is to absorb these loads. The placement of pressure cells at the different transitions between layers will make it possible to analyse how loads are transmitted from the rail to the embankment and whether the speed of the train passing through has any effect on those pressures.

3.2 Static load tests

The static load is applied by two hydraulic actuators (one in each rail) installed in the central cross-section of the model under study: a typical ballasted rail track.

The static tests, whose aim is to determine the track stiffness, consisted of three loading-unloading cycles in which a maximum load of 95 kN (per actuator) was reached, applied step by step, simulating the effect of a passenger train. The duration of each static test was around 50 minutes. This test is inspired by ADIF technical specification ET 03.360.570.0. Figure 2 shows the three load cycles of each static test.

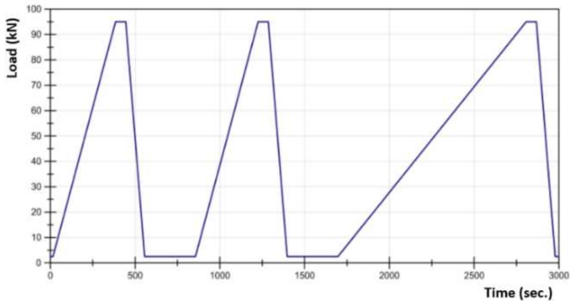

Figure 2. Sequence of load-unload cycles applied in the static tests.

3.3 Dynamic load tests

Dynamic load tests allow the modelling of the passing-by of trains at different speeds. For this purpose, the three pairs of hydraulic actuators (Figure 1) are synchronised in such a way as to reproduce the effect of the approach, passing-by and departure of the train in the central section of the model for any kind of train running up to 420 km/h.

3.4 Description of trains

The following table shows the most relevant characteristic of the trains modelled in the CTB: train type, number of axles and their total weight. Of the types of trains operating on the Spanish network, the following two trains were chosen because of their different axle configuration: bogies (Siemens S103) and isolated wheels (Talgo S112).

Table 1. Main characteristics of trains used in the study.

Train	Number of axles	Total Weight (t)
Talgo S112	21	357.0
Siemens S103	32	463.3

3.5 Passing-by train speeds

For each of the trains described above, dynamic tests were carried out at 50, 100, 150, 200, 250, 300, 350 and 400 km/h. Therefore, a total of 16 tests were performed.

It can be highlighted that the two greater speeds (350 and 400 km/h) are above the current nominal speeds (300 km/h) at high-speed train lines, although 350 km/h is usually used for the approval tests.

3.6 Instrumentation

The railway track section is profusely instrumented. In this work, only the results obtained with pressure cells are analysed. Figure 3 shows the location of pressure cells in the central section of the test and Figure 4 a detail of these cells placed at the sleeper bottom.

Rectangular and circular pressure cells of 25x15 cm and 17 cm diameter were used respectively. The measuring range of these cells varies according to the interface analysed: 0-1 MPa at sleeper-ballast, 0-0.5 MPa at ballast-subballast, 0-1 MPaat subballast-form layer and 0-0.2 MPa at form layer-embankment interfaces. Cell pressures are located under the rails to measure the stress peak since it is known that the contact surface and the stress distribution beneath the sleeper are not uniform.

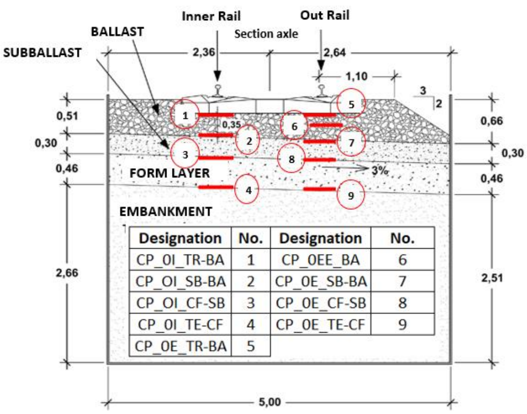

Figure 3. Load configuration for each train at CTB.

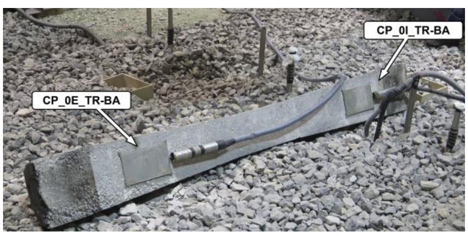

Figure 4. Pressure cell placed under the sleeper.

4 RESULTS OBTAINED

4.1 Results in the different layer interfaces

Figure 5 shows the variation of pressure with depth, measured by pressure cells, during the third cycle of static tests. The vertical stress distribution due to a rectangular load according to Fadum's theory is also shown.

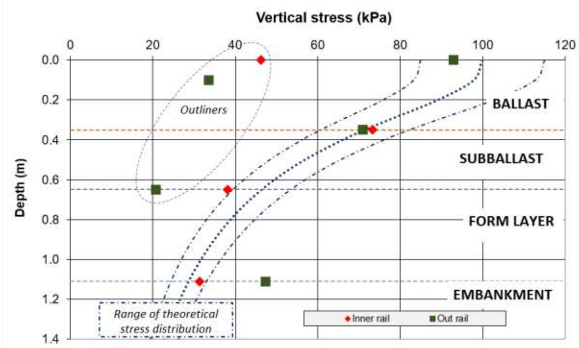

Figure 5. Pressure values measured by a pressure cell and theoretical stress distribution.

The measured values globally follow Fadum's theory which shows the stress distribution inside the track bed layers. This implies that in the subballast top surface, the stress is reduced to 70% of the stress transmitted by the sleeper while in the form layer and the embankment below, the vertical stress is around 30-40% of the initial stress.

On the other hand, three of the nine measures can be considered as outliners, two of them being relative to the ballast layer. This is due to the great size of the ballast particles which provokes that the stress in the ballast layer is transmitted through contact points whose loads are difficult to capture by the measuring surface of the pressure cells. This difficulty in obtaining accurate pressure measurements with this type of instrumentation is one of the main aspects to be highlighted as a result of the present work.

4.2 Results obtained with train speed variation

This section shows the measurements obtained with the pressure cells placed under the inner rail in the dynamic tests for different train speeds. Figure 6 shows the maximum pressure values, relative to the values obtained at 50 km/h, for the two trains modelled, as a function of the train speed. The graphs also include the dynamic amplification factor DAF [$DAF = \frac{1}{\sqrt{1-\left(v/v_{crit}\right)^2}}$] for a critical velocity (v_{crit}) of

- 600 km/h, a typical value of a high-speed line, to model the platform layers, and
- 430 and 450 km/h, to model the ballast layer.

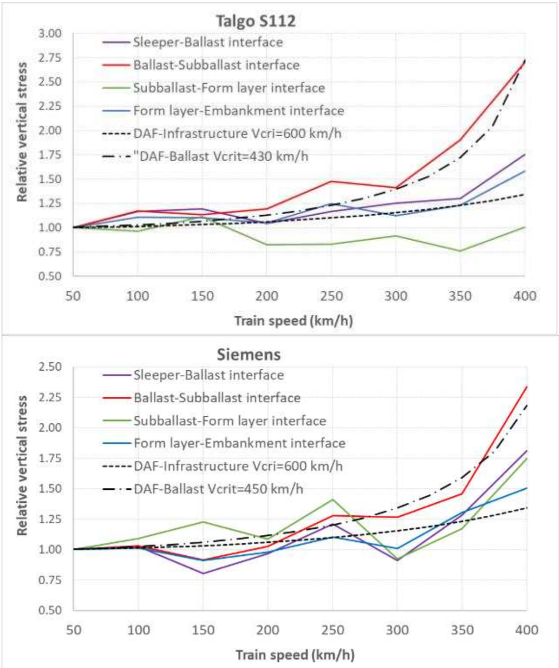

Figure 6. Relative pressure cell measurements placed under the inner rail and Dynamic Amplification Factor.

These graphs show that the vertical stresses are fluctuant due to the problems derived from this kind of measurements, although an increasing trend can be seen, similar to the one shown by DAF. An increase of around 20%, relative to the static value, when the speed is 300 km/h is seen. However, two aspects show a significant increase, out of the general trend: the measurements done in the ballast-subballast interface (plotted with red lines) and the ones obtained in the tests performed at 400 km/h.

Finally, Figure 7 and Figure 8 show the vertical stress measured in the ballast-subballast interface during the tests in which trains were modelled running at 50 and 300 km/h. The stresses measured follow quite well the loads imposed by the train axle.

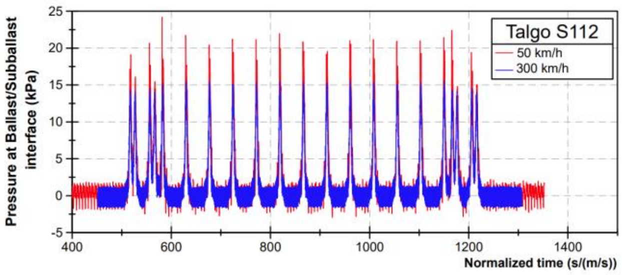

Figure 7. Vertical stress measured during the modelling of Talgo S112 train at 50 and 300 km/h

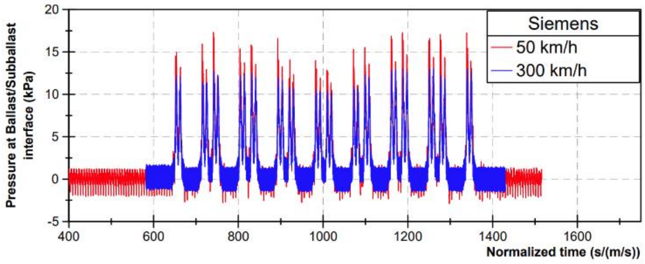

Figure 8. Vertical stress measured during the modelling of Siemens train at 50 and 300 km/h

5 CONCLUSIONS

The CTB allows modelling and measuring the response of a railway track section under laboratory conditions. This work shows the results obtained on pressure cells placed at different depths of the section, which were tested with the passage of two types of trains at different speeds.

The results show that the measurements obtained with this instrumentation are a bit erratic, on many occasions, due to the difficulty of measuring normal pressures in a granular medium by a flat surface where several contact points are produced. The fact that the pressure, in the different interfaces present in railway sections, transmitted by the trains, follows Fadum's law of load distribution under a rectangular load was verified. The increase of the vertical stress with the speed of the trains and the fact that, during the pass-by of trains at different speeds, the normal pressure varies according to the loads imposed by the train axles were also observed.

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