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Experimental assessment of the dynamic behaviour of the train-track system at a culvert transition zone

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ABSTRACT

This article describes the experimental assessment of the dynamic behaviour of the train-track system at a culvert transition zone located at the Northern line of the Portuguese railway network. Based on receptance tests, the dynamic flexibility of the track along the transition was characterised. From the full track resonance frequency, a reduction of 60% was observed on the dynamic flexibility of the track on the structure in relation to the track on the embankment; The dynamic response of the track was also monitored in different sections for the passage of the Alfa Pendular trains at a speed of 220 km/h. Based on these tests, it was concluded that the displacements of the track on the structure and on the transition wedge were, respectively, 45% and 30% lower than those of the track on the embankment. Despite the significant variations of the dynamic stiffness of the track, the accelerations of the sleepers, after the application of a low-pass filter for eliminating contributions from irregularities of the track and of vehicle wheels, did not exhibit relevant variations along the transition zone. Likewise, no substantial variations were registered in terms of the dynamic loads applied by the train at the monitored track sections. Finally, synchronized measurements of the dynamic response of the track and of the inspection vehicle EM 120 were made at a speed of 100 km/h, where no significant amplifications induced by the transition were recorded for the accelerations on the axles, on the bogies and on the vehicle box.

1. Introduction

Along the railway track it is common to find zones where vertical track stiffness variations occur. These stiffness variations are sometimes abrupt, meaning that great stiffness variations can occur within short distances, as is the case, for example, of transitions from embankment to structures, such as bridges, culverts or tunnels. In-situ continuous measurement of vertical track stiffness with appropriate vehicles such as the RSMV (Rolling Stiffness Measurement Vehicle) developed by Banverket [1] or the one developed by the Federal Railroad Administration (FRA) in the USA [2], showed that stiffness variations as high as two times can occur at embankment-bridge transition zones.

Studies developed by the European Rail Research Institute [3] concluded that transition zones, especially embankment to bridge or culvert transitions, need special attention in terms of inspection, maintenance and renewal works. In comparison to normal track, maintenance frequency at transition zones may be up to five times higher and the costs about two times higher.

The high maintenance needs, call the attention of infrastructure managers and researchers of several countries to transition zones. With the growth of the high speed railway transport and the subsequent increase in safety and comfort requirements, concerns about the performance of these critical zones have increased.

Experimental studies on the performance of transition zones are still a brand new field of research and only a few works have been developed. For example, the European project SUPERTRACK [4] focused its attention on the study of railway transition zones; although this project had a very important experimental component, the study of these critical zones was limited to numerical analyses.

From numerical simulations of transition zones, it has been concluded that the vertical stiffness variations that take place in these zones are responsible for important variations of the wheel-rail contact forces and these variations increase with the increase of stiffness variation and train speed [5–7].

In order to smooth the stiffness variations at transitions zones, special solutions have been proposed. The most common solution adopted on high speed railway lines consists on a technical block placed between the embankment and the structure. This technical block is usually constituted by two wedges, one next to the structure made of granular material treated with cement and another

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located between this and the embankment, made of compacted granular material. The geometry of these wedges varies from country to country as presented in UIC 719R [8]. Although broadly adopted in different countries, there are few experimental studies about the dynamic behaviour of the technical blocks on transition zones.

Lozano and Cuellar [9], within the scope of the European project INNOTRACK, determined the variations in track stiffness on a technical block of one of the abutments of a viaduct located in the Lleida-Martorell sector of the high speed line Madrid-Barcelona-French border. Direct (laser beam) and indirect (integration of geophone signals) methods enable to estimate track displacements that, with the calculation of the wheel loads by mean of the installation of strain gauges in the rail, enable to estimate track stiffness from the circulation of trains. Variations of track stiffness of 1:2 have been obtained in the transition between the concrete support and the soil support. Along the technical block till the plain track zone, track stiffness ranging between 110 kN/mm and 140 kN/mm with stiffness variations between consecutive sleepers of about 10% have been found.

Another solution for the transition zone consists in the introduction of an approach slab, as applied, for instance, in embankment-culvert transitions in conventional railway lines in the Netherlands. Hölscher and Meijers [10] carried out tests in one of those transitions, which exhibited pathologies due to a quicker settlement of the approach slabs than of the embankment, originating differential settlements which gave rise to hanging sleepers over the approach slab.

Observations of sleeper displacements during the passage of in-service trains have shown that the transition slab does not behave as intended and amplifies track displacements. Dynamic vertical movements of the approach slabs were about four times greater than those of the free track on the embankment and over eight times greater than on the culvert itself. This resulted on unsupported or hanging sleepers on the approach slab [11,12].

For the study of the development of the hanging distance of the sleepers, dynamic measurements were made of the displacements of the railway track due to the passage of trains along the transition. The dynamic displacements of the track were indirectly obtained by integration of the signals of geophones and accelerometers. The procedure was validated by comparing the displacements obtained by integration with the displacements measured directly through a high speed video camera [13].

The experimental work presented in this paper is part of a comprehensive study involving the experimental and numerical assessment of the dynamic behaviour of the train-track system at a culvert transition zone (designated as PH126A) located at km 40 + 250 of the Northern line of the Portuguese railway network where Alfa Pendular trains travel at a speed of 220 km/h. The transition is constituted by a soil-cement wedge placed between the embankment and the culvert structure.

In order to analyse the dynamic behaviour of this transition zone the development of an experimental work seemed essential. The main scope of this work was to measure different quantities that enabled to understand the behaviour of the track along the transition zone when loaded by railway traffic. The analysis of the stiffness variation that occurs along the transition was a very important objective of this work, as well as the analysis of the efficiency of the transition zone solution adopted for this case where the culvert concrete structure is located under the ballast layer, very close to the track surface.

Thus the experimental work consisted in: i) performing receptance tests for the characterisation of the dynamic stiffness of the track in various transition zones; ii) performing dynamic tests for the passage of Alfa Pendular trains at a speed of 220 km/h, for the characterisation of the dynamic response of the track in terms of rail displacement and sleeper acceleration along the transition zone as well as rail-sleeper relative displacement and train dynamic loads; iii) synchronized monitoring of the dynamic response of the track and of the inspection vehicle EM120 from REFER, in order to relate the accelerations of the axle, bogies and vehicle box with its position in the transition.

2. Description of the transition zone

An embankment consisting of a culvert transition zone located in the Northern line of the Portuguese railway network (designated as PH126A) was selected as the test site for this study (Fig. 1).

Fig. 2 schematically presents the transition zone studied: in Fig. 2(a) is presented a top view, in Fig. 2(b) a longitudinal section of the track in the culvert zone.

As can be seen in the top view, there are four parallel tracks at this site. The ones labelled VAE and VDE constitute the main tracks of the line.

Between the culvert and the embankment in both sides, there are soil-cement wedges with a length of 12 m and 8.8 m of width. These wedges are located under the sub-ballast layer and are 2 m high near the structure and 0.5 m high at the other end.

The foundation soil properties were established based on information collected from geotechnical survey carried out near PH126A [14]. The embankment characteristics were established based on information available in the documents of the geotechnical control carried out during the construction. With this information it was stablished a deformation modulus of 285 MPa for the foundation soil and 80 MPa for the embankment.

The culvert consists of a concrete box, 3.4 m high and 2.1 m wide, and is founded on a rockfill base of 1.5 m high that is wrapped in geotextile. The ballasted track is composed of a ballast layer with 0.45 m high. The sub-ballast layer is 0.55 m high in the track over the soil-cement wedge and over the embankment and 0.25 m high over the culvert. The sleepers are prestressed concrete monoblock elements of 315 kg of weight, in terms of geometry the sleepers are 2.60 m long and 0.30 m high with the cross-section shape depicted in Fig. 2(b). The sleepers are evenly spaced of 0.6 m. The rail is UIC60 type and the track gauge is equal to 1.678 m. The rail pads are from Vossloh (model Zw687a) and have a static stiffness equal to 450 kN/mm.

3. Track receptance tests

Track receptance tests enabled to assess the dynamic flexibility of the track. The test consisted of the application of a series of hammer impacts on the rail with time intervals of about 2–3 s and the

Fig. 1. Culvert transition PH126A.