1. CEDEX’s TRACK BOX

The rail track accelerated testing facility at CEDEX is a 21 m long, 5 m wide and 4 m deep experimental box, built for testing, at 1:1 scale, complete railway track sections of conventional and high speed lines (see Fig. 1). The main advantage of its use lies on the fact that in only one week of normal work, the traffic of the trains, that operate a given railway line over one year, can be simulated. To that aim, as it will be shown in the sequel, either standard train axle loads or wheel load and rail deflection time histories, recorded in operating railway lines, can be used, to feed the track box loading system.

The track box has been constructed with nine fixed steel frames distributed in three different zones (Zone 0, Zone 1 and Zone 2) as sketched in Fig. 4. They give support in each zone, to a moving reaction system constituted by three large horizontal beams equipped, each one of them, with a dynamic actuator (A, B and C in Fig. 4) of 250 KN loading capacity. The actuators are controlled, either independently or simultaneously, by a digital system (FLEXTEST) from MTS, which commands a servohydraulic system provided with three step servovalves that operate under a flow rate of 1800 litres per minute and a pressure of 210 bars.

The loading reaction structure in each zone has been thoroughly investigated, both theoretically and experimentally, to ensure that its natural frequency is well beyond the frequencies associated to the passage of bogies and loading axles of high speed trains circulating at speeds of about 400 km/h, Manzanas et al. (2007). Because of the large dimensions of the box, no significant effects of its boundaries (which are not fully rigid) have been detected in the Finite Element studies carried out so far to assess their influence in the behaviour of the track under static and dynamic loading conditions (see Fig. 2).
2. PHYSICAL MODELS

Trying to reproduce, at 1:1 scale, the cross sections of high speed railway lines, the two physical models depicted in Fig. 3 have been built in CEDEX’s track box. Cross section of Model 1 was uniform along the track box but the cross section represented in that figure for Model 2 represents solely that part of the model built in Zone 0, that between sleeper -6 and +6 (see Fig. 4) where the thickness of the bituminous mix subballast is 12 cm. In order to optimise future designs, the thickness of bituminous subballast at two additional cross sections has been tested, each one in a different zone of the track box: one with 8 cm of mix in Zone 1 between sleeper -16 and -6, and the other with 16 cm in Zone 2 between sleeper +6 and +16.

Fig. 2. Finite Element model of CEDEX’s track box

Fig. 3. Cross sections in Zone 0 of 1:1 scale physical models built in CEDEX’s track box
Challenge G: An even more competitive and cost efficient railway

Fig. 4. Bituminous mix subballast sections tested in CEDEX’s track box

The type of material, state parameters and deformation moduli for the granular layers of each one of the two physical models presented in Fig. 3, as given in CEDEX (2008; 2011 a), are drawn in Tables 1 and 2.

Table 1. Bed layer material properties of physical model 1

<table>
<thead>
<tr>
<th>Track Layer</th>
<th>Type of Mat.</th>
<th>$\omega_L$</th>
<th>$I_P$</th>
<th>$\gamma_D$</th>
<th>$h$</th>
<th>$E_{d2}$</th>
<th>$v_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballast (0.38 m)</td>
<td>ADIF T1</td>
<td>16,5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subballast (0.30 m)</td>
<td>USCS GP</td>
<td>17,4</td>
<td>2</td>
<td>22,0</td>
<td>3,5</td>
<td>170</td>
<td>265</td>
</tr>
<tr>
<td>F. Layer (0.60 m)</td>
<td>USCS GP</td>
<td>17,4</td>
<td>2</td>
<td>21,5</td>
<td>4,0</td>
<td>165</td>
<td>260</td>
</tr>
<tr>
<td>Embankment (2,445 m)</td>
<td>USCS GC</td>
<td>25,6</td>
<td>7</td>
<td>20,2</td>
<td>7</td>
<td>160</td>
<td>250</td>
</tr>
<tr>
<td>F. Layer = Form layer</td>
<td>USCS = Unified Soil Classification System</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Bed layer material properties of physical model 2

<table>
<thead>
<tr>
<th>Track Layer</th>
<th>Type of Mat.</th>
<th>$\omega_L$</th>
<th>$I_P$</th>
<th>$\gamma_D$</th>
<th>$h$</th>
<th>$E_{d2}$</th>
<th>$v_s$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ballast (0.36 m)</td>
<td>ADIF T1</td>
<td>16,5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F. Layer (0.60 m)</td>
<td>USCS GP</td>
<td>No Plast.</td>
<td>No Plast.</td>
<td>22,5</td>
<td>3,5</td>
<td>420</td>
<td>400</td>
</tr>
<tr>
<td>U. Embank. (1,215 m)</td>
<td>USCS GC</td>
<td>45,5</td>
<td>32,7</td>
<td>17,5</td>
<td>10</td>
<td>170</td>
<td>280</td>
</tr>
<tr>
<td>L. Embank. (1,370 m)</td>
<td>USCS GC</td>
<td>25,6</td>
<td>7</td>
<td>21,2</td>
<td>2</td>
<td>350</td>
<td>380</td>
</tr>
<tr>
<td>U. Embank. = Embankment upper part</td>
<td>L. Embank. = Embankment lower part</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
For the bituminous mix subballast layer of physical model 2 the following properties were determined:

- **Stone aggregates**
  - Fine fraction (0.063 mm/2 mm): 19.3%
  - Large fraction (2 mm/25 mm): 76.4%

- **Bitumen**
  - Type: B 60/70
  - Percentage over the stone aggregates: 5.20%

- **Mix**
  - Marshall density (UNE EN 12697-30): 2.373 Mg/m³
  - Marshall stability: 13.5 KN
  - Marshall slippage: 2.7 mm
  - Bending-tensile resistance to fatigue (NLT-350/90): $\varepsilon_6 = 134.2 \mu\varepsilon$

- From laboratory tests on samples, 10 cm in diameter, obtained with a drilling machine from the bituminous mix compacted in the track box, the following results were obtained:
  - Mix density: 2.24 Mg/m³
  - Dynamic modulus at 10 Hz and 29°C drawn from the master curve (NLT-349/90): 3919 MPa
  - Static modulus at 20°C drawn from the master curve (NLT-349/90 & EN 12697-26): 455 MPa
  - Static modulus at 20°C obtained from unconfined compression tests: 250 MPa

- From in situ falling weight deflectometer tests run on the compacted material at a temperature of 13°C a value $E_{v2} = 500$ MPa was determined.

When constructing a physical model into the box, internal sensors are deployed during the construction process, trying to disturb as less as possible the different bed layers, and control tests are run to ensure that the physical properties of the materials laid out comply with the design specifications. Besides the 47 internal sensors deployed in each zone to monitor the static and dynamic behaviour of the track infrastructure layers shown in Fig. 3, a moving set of 74 sensors are used at the surface of the track to control the performance of the superstructure elements in each track zone (see Fig. 5). This, together with the sensors of the actuators amounts to a total of 128 sensors used for each fatigue test.

![Fig. 5. Moving set of superficial sensors deployed in each zone of the track box](image)

A Hottinger MGC plus modular electronic equipment with a capacity of 128 channels is employed to condition and amplify the signals provided simultaneously by all the sensors. The processing of those signals is accomplished by means of an ORACLE data base system connected to a LABVIEW program. For the reporting of the results obtained, a DIADEM program is also used.
3. SIMULATION OF MOVING LOADS IN THE TRACK BOX

Many static tests carried out in situ and in the track box have shown that the distribution of rail deflections “y” around one loaded point can be fairly well approximated assuming a Winkler type of behaviour for the track:

\[ y(x) = \frac{Q}{K} \exp\left(\frac{-|x|}{L}\right) \left[ \cos\left(\frac{|x|}{L}\right) + \frac{\text{sen}\left(\frac{|x|}{L}\right)}{L} \right] \]  

[2.1]

where \( Q \) = Load
\( x \) = Horizontal distance to the loaded point
\( K \) = Track stiffness \( = \frac{Q}{y_{\text{max}}} \) with \( y_{\text{max}} \) determined at \( |x| = 0 \)
\( L \) = Track elastic length = \( \frac{8EI}{K} \) \( E \) being the rail bending stiffness

Once the Winkler curve has been defined, the percentages of the load \( Q \) supported by each sleeper, (the so called sleeper supporting load), can be easily determined using the concept of track modulus widely accepted in railway engineering. It can be shown that those percentages practically coincide with the ordinates of the Winkler curve at the sleepers divided by \( y_{\text{max}} \). On the other hand, assuming that the load \( Q \) is moving horizontally over the track at a certain speed, “\( v \)”, the deflection of a certain point fixed in the track when the load approaches that point, passes over it and gets away, is given by the following expression:

\[ y(x,t) = \frac{Q}{K} \exp\left(\frac{-(x-va)}{L}\right) \left[ \cos\left(\frac{x-va}{L}\right) + \frac{\text{sen}\left(\frac{x-va}{L}\right)}{L} \right] \]  

[2.2]

where variable \( |x| \), in the domain \( 0 \leq |x| \leq \frac{3}{4} \pi L \), now represents the distance between the fixed point and the moving load at any time “t”.

That deflection time history also represents the one that would be obtained at the fixed position by applying on it a loading time history obtained by multiplying, at any time “t”, the deflection “y”, given by eq [2.2], and the track modulus value K. Although that type of fixed-point loading history may simulate adequately well the passage of an axle load and a bogie over one sleeper, the supporting load time histories of the side sleepers are far from being simulated correctly. In order to reproduce in a better way those time histories in track sections 3.5 m long, (including seven sleepers), three dynamic actuators, 1.5 m apart each other, are fed with the same type of fixed-point loading history just described and a time delay, according to the horizontal speed of the load, has been introduced between them. At a given instant, the seven sleepers are subjected to supporting loads induced by the three actuators which combine to yield the instantaneous value of each sleeper supporting load history. By comparing the supporting load time histories induced theoretically in the seven sleepers by the actuators with the theoretical supporting load time history induced at each sleeper (the same for all sleepers) by the passage of a bogie, correction factors to be applied to the amplitudes of the loading time histories of the actuators can be determined.

Fig. 6 shows the two types of theoretical sleeper supporting load time history curves obtained for the track of physical model 2 \( (K = 125 \text{ KN/mm} \ L = 0.740 \text{ m}) \) when correction factors of 0.98 and 1.14 are applied respectively to the amplitudes of the loading time histories set in the central and the two extreme actuators, to simulate the passage at 300 km/h from sleeper -3 to sleeper +3 of a bogie with axle loads of 165 KN 3 m apart: in red the curves reflecting the combining effect of the three actuators and in black, the same curve for all the sleepers representing the passage of the bogie. The deployment of shear strain bands at the neutral fiber of the rail on both sides of sleepers 0, +1 and +2, as shown in Fig. 5, has allowed to verify experimentally for those sleepers the two types of theoretical supporting load time histories exhibited in Fig. 6. By using the same measurement procedures as those set up by CEDEX for INNOTRACK (2009) to get the wheel loads induced in Spanish operating
tracks by high speed trains, the green curves in Fig. 7 representing the supporting load time histories measured at sleepers 0, +1 and +2 have been drawn. It can be seen that they compare reasonably well in the figure with the two types of theoretical curves shown also in the previous figure.

Fig. 6. Theoretical sleeper supporting load time histories simulating the travelling at 300 km/h from sleeper -3 to sleeper +3 of a bogie with 165 KN axle loads 3 m apart in physical model 2 (in red the combined effect of the 3 actuators and in black the bogie effect)
Challenge G: An even more competitive and cost efficient railway

Figure 7. Experimental (green curve) and theoretical (red and black curves) sleeper supporting load time histories, simulating the travelling at 300 km/h from sleeper 0 to sleeper +2 of a bogie with 165 KN axle loads 3 m apart in physical model 2

4. FATIGUE TESTS

Using the methodology described so far, the passage of two types of trains have been simulated in physical model 2: a Eurostar type of train 400 m long with 50 axles (see Fig.8) travelling at 300 km/h and 360 km/h and an ICE 3 type, 200 m long with 32 axles (see Figure 9 ) travelling at 360 km/h. A uniform axle load of 165 kN was adopted for both trains. From the Fourier spectra of the loading signals in those figures, frequencies of 7, 27 and 40 Hz associated to the wagon lengths and to the axle separation in the bogies (3 m and 2.5 m respectively for the Eurostar an ICE-3 trains) can be easily identified.

To run fatigue tests in model 2, the passage of those trains has been simulated with a time interval of 2 seconds between two consecutive units. In that way 4 M axle loads have been applied to the sections in model 2 with 12 cm and 8 cm of bituminous mix subballast. Every 1 M of axle load applications ( the number required to complete one fatigue test, more or less equivalent to the traffic supported by a Spanish high speed line in two years of operation), static loading tests, one with each actuator, were
run firstly to assess the evolution of the mechanical properties of the track, and then ballast was
tamped. To achieve that job, the facility has been equipped with an autonomous tamping machine of
the type used in real lines which, being commercially available, has been modified to fit the geometric
dimensions of the track box loading frames without affecting its tamping capacity.

Figure 8. Eurostar type of train travelling at 300km/h simulated in the track box

Figure 9. ICE 3 type of train travelling at 360 km/h simulated in the track box
4.1 Short term behaviour

From the results provided by 165 kN static tests run in Zone 0 of model 2 it was found that the value of the track stiffness practically keeps constant, around 130 kN/mm, along the 1M axle loads applied in each fatigue test. Ballast compressions, which ranged between 0.260 mm and 0.360 mm at the beginning of the tests, and between 0.245 mm and 0.350 mm at the end, represented 45% of the rail deflections, and the compressions of the form layer and embankment amounted to 20% of those deflections. Compression of the bituminous mix subballast only reached 3% of the rail deflections. Concerning that layer, a constant value of tensile strain of about 40 µε was obtained in all the static tests run with temperatures ranging from 14ºC to 24ºC. That value, much less than the εs value of 134.2 µε obtained in laboratory tests run at 20ºC, points to a layer free of bending-tensile fatigue. Similar values to those just given, were derived from the results provided by 165 kN static tests run in Zone 1.

The fatigue tests in model 1 were performed simulating the passage at 300km/h of a Eurostar type of train 200 m long with 26 axles, and axle loads ranging between 120 kN and 170 kN. Unfortunately, being the first tests run in the track box, much less data than for model 2 are available, but from 195 kN static tests run at the beginning and at the end of one fatigue test with 1 M axle load applications, it was found that the track modulus value practically keeps constant around 100 kN/mm. Ballast compression, as in model 2, represented 45% of the rail deflections and the compression of the remaining bed layers amounted to 30% of those deflections.

The track stiffness values calculated from the amplitude of the rail displacements induced in both models when simulating the passage of the trains was 5% less than the static values. In model 2 a dynamic Young modulus, 2.2 times the static value obtained in laboratory unconfined compression tests, was detected for the bituminous mix subballast layer. The amplitude of the vertical velocity experienced by the rails in both models was on the order of 40-45 mm/s with peak vertical accelerations between 1g and 2g. The sleepers vibrated vertically with velocity amplitudes of 20-30 mm/s and peak accelerations of 0.6g-1.2g. Ballast in contact with the lower edge of the sleepers under the rails vibrated with the same velocity and acceleration amplitudes as the sleepers. Peak vertical velocities 5-15 mm/s were obtained in both models at the upper part of the form layers and in the range 2-4 mm/s at the lower part of the embankments. Measurements of vertical vibrations induced in the surroundings of the track box, at a distance of 1 m from its foundation, led peak velocity values of 1-2 mm/s.

4.2 Long term behaviour

Besides, the contributions to assess the short term behaviour of a track under real loads, as already mentioned, the jewel of the track box crown is the possibility of running fatigue tests in an accelerated way. Figure 10 shows the permanent compressions obtained for the ballast in the last fatigue test carried out in physical model 2 at Zone 0 with 12 cm of bituminous subballast. That test was a three phases fatigue test in which 2,350,000 axle loads of 165 kN were applied. The first 300,000 load applications were achieved simulating the passage of the Eurostar train at 300 km/h. At the end of that phase the speed of the train was increased to 360 km/h, keeping the same axle load amplitude, and 500,000 additional axle loads were applied. In the last phase (from 800,000 to 1,530,000 load applications) the type of train was changed keeping the same passage speed (360 km/h) and amplitude (165 kN) of the axle loads. In that phase, the passage of an ICE-3 train with a bogie axle separation of 2.5 m, instead of the 3-0 m of the Eurostar train, was simulated.

As it can be seen in Figure 10, the permanent compressions of the ballast provided by the displacement transducers installed in sleeper 0 (red curve) and sleeper -2 (blue curve) are practically the same during the first phase of the test. After increasing the passage speed, at the beginning of the second phase, a small jump is detected in both fatigue curves, which being different along that phase, keep nevertheless the same shape and slope. The increase to 40 Hz of the bogie axle passage frequency in the third phase only motivates a slight increase in the slope of both fatigue curves.
Challenge G: An even more competitive and cost efficient railway

**Figure 10.** Permanent compressions of ballast obtained in the three phases fatigue test run in Zone 0 of model 2

Concerning the long term behaviour of ballast subjected to periodic tamping operations, Figure 11 summarises the results of four consecutive fatigue tests (coming to a total of 4 million load applications) carried out in zone 1 of model 2 with 8 cm of bituminous subballast. As already mentioned, ballast was tamped between two consecutive fatigue tests, using the autonomous machine. The fact that the tampers of the tamping machines only affects the upper 15 cm of ballast appears reflected in the difference (14.5%) between the permanent compressions of the ballast reached in the first test and the remaining three tests. After the virgin consolidation experienced by the lower 15 cm of ballast during the first fatigue test, that sublayer, not affected by the tamping operations contributes very slightly to the permanent compression of the ballast layer in the subsequent fatigue tests. Similar conclusion was derived from the analysis of the fatigue tests carried out in Zone 0 with 12 cm of bituminous subballast.

**Figure 11.** Ballast fatigue laws obtained in Zone 1 of model 2
Challenge G: An even more competitive and cost efficient railway

In Figure 12 a comparison is made between the long term compression fatigue curves obtained in Zone 1 from the instrumentation installed in the bituminous subballast and granular form layers. In spite of the high quality of the granular material, whose properties are given in Table 2, a better behaviour of the bituminous mix can be observed in that figure.

![Graph showing long term compression fatigue curves](image)

Figure 12. Long term compression fatigue curves obtained in Zone 1 for bituminous mix subballast and granular form layer

In order to compare, with expressions given in the literature, the results obtained for ballast in the track box, a mathematical rule incorporating the permanent compression obtained in the first 165 KN axle load application has been looked for. So far, the following power law has been found as the best formula to fit the experimental data recorded in the tests:

$$\delta_N = \delta_1 N^\beta$$  \[4.1\]

where $\delta_N$ stands for the permanent compression (mm) reached after N number of 165 KN axle load applications 

$\delta_1$ represents the permanent compression (mm) induced in the first 165 KN axle load application

$\beta$ is a constant determined through a linear regression analysis of the compression data obtained in each fatigue test.

Figure 13 shows the type of fitting achieved with that law, of the experimental data provided by the three last fatigue tests run in zone 1 of the track box with 8 cm of bituminous subballast. The regression coefficients $R^2$ obtained for each one of the power laws represented in that figure are given in Table 3 where both values of $\delta_1$ (the one obtained experimentally and the one provided by the regression analysis) are also presented. From the data presented in Table 3 and similar values derived from the results obtained in the fatigue tests run in Zone 0 with 12 cm of bituminous subballast the following expression has been chosen as the most adequate to reproduce the fatigue behaviour of ballast tamped every one million of 165 kN axle load applications, of the type induced by Eurostar trains travelling at 300 km/h.

$$\delta_N = 0.07 N^{0.1625}$$  \[4.2\]
Challenge G: An even more competitive and cost efficient railway

Figure 13. Power law fittings of fatigue ballast curves obtained in Zone 1
Table 3. Power law fitting parameters of ballast fatigue curves obtained in Zone 1

<table>
<thead>
<tr>
<th>FATIGUE TEST</th>
<th>$\delta_1$ (mm) EXPERIMENTAL</th>
<th>$\delta_1$ (mm) THEORETICAL</th>
<th>$\beta$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>SECOND</td>
<td>0.072</td>
<td>0.080</td>
<td>0.155</td>
<td>0.994</td>
</tr>
<tr>
<td>THIRD</td>
<td>0.068</td>
<td>0.083</td>
<td>0.158</td>
<td>0.987</td>
</tr>
<tr>
<td>FOURTH</td>
<td>0.063</td>
<td>0.076</td>
<td>0.162</td>
<td>0.989</td>
</tr>
</tbody>
</table>

5. VALIDATION OF TRACK BOX RESULTS WITH IN SITU MEASUREMENTS

In order to validate the results obtained in the track box, two adjacent experimental sections, 500 m long each, were built at Valdestillas site, located in the high speed line Madrid-Valladolid, 5 km before reaching Valladolid city: one with 12 cm of bituminous mix subballast and the other with 30 cm of granular subballast.

The track embankment at the site, 2 m high, is overlaid at both sections by a 30 cm thick form layer of clayey sand, stabilised with lime, which was compacted to a dry unit weight of 17.3 kN/m$^3$ with a water content of 12%. Plate loading tests run on the top of the embankment and the form layer led to $E_{v2}$ values of 100 Mpa and 125 Mpa respectively.

The granular subballast used in one of the sections, is a non plastic GP material according to Unified Soil Classification System, that was compacted to a dry unit weight of 22.3 kN/m$^3$, with a water content of 4%. Plate loading tests performed at the surface of this layer gave values around 235 Mpa.

When comparing the Valdestillas granular subballast section with model 1 built in the track box, almost the same value holds for the mean of the $E_{v2}$ parameters obtained in the subballast and form layers of each track (170 MPa in model 1, see Table 1, and 180 MPa in Valdestillas section).

Also, the components of the bituminous mix subballast used in the Valdestillas section have almost the same characteristic properties than the mix used in the track box, although a lower bending–tensile fatigue resistance ($\varepsilon_6 = 87 \mu\varepsilon$) was obtained for the Vadestillas mix. From laboratory tests run in cylindrical samples, 10 cm wide, obtained in Valdestillas from the drilling of the compacted material, a mix density of 2.32 Mg/m$^3$ and a dynamic modulus, derived from the master curve at 10 Hz and 20ºC, of 7980 Mpa were obtained. Falling weight deflectometer tests run at that site on the compacted material at a temperature of 38ºC led to values around 400 Mpa, which compare reasonably well with the 500 Mpa value obtained in the track box at 13ºC.

The Madrid-Valladolid line was opened to the traffic at the end of the year 2007. Since then, it has been supporting a traffic of about 250,000 axle loads per year.

Using at the two Valdestillas sections, the same type of superficial sensors, as those shown in Figure 5, CEDEX has carried out, so far, in situ measurement campaigns, on: June 2009, November 2009 and November 2010. In those campaigns, the passages of bogie trains, travelling at 250 km/h, with axle load distribution similar to ICE 3 type of train were recorded.

No differences were found in the track stiffness value (120 kN/mm) obtained at the Valdestillas bituminous subballast section in the June and November campaigns of the year 2009, in which mean monthly temperatures of 18ºC and 9ºC were recorded respectively in Valladolid. The same track stiffness value was obtained at that section in the November 2010 campaign. Concerning the granular subballast section, a constant track stiffness value of 110 kN/mm was obtained in all the campaigns. Both track stiffness values compare favourably well with those reported in this document for models 1 and 2 built in the track box. Data provided by other sensors in the Valdestillas sections are currently being analysed.
6. SUMMARY AND CONCLUSIONS

In this report, results are given from the accelerated testing in CEDEX’s track box of physical models reproducing, at full scale, sections of high speed lines on ballast, with granular and bituminous mix subballast layers.

The capability of the track box to simulate the effect induced in real lines by moving loads, travelling at high speed, has been proved both theoretically and experimentally.

The high level of monitorization with which physical models built in CEDEX’s track box can be implemented, makes it an ideal tool to calibrate 3D numerical models (CEDEX, 2011 b).

Track stiffness values determined in the physical models, tested in the track box, compare well with those obtained in repeated measurement campaigns carried out in sections of a high speed line having the same geometry and bed layer types as the track box models. In the light of those results, it is expected that track dynamic parameters, that are being derived at present, from the data obtained in the sections of the high speed line, also agree with those given in this document, when describing the short term behaviour of the physical models.

A small jump was detected in the ballast fatigue tests, when increasing the passage speed of Eurostar trains from 300 km/h to 360 km/h. Also, a slight increase in the slope of that fatigue curve was observed when the axle separation in the bogies was decreased.

For 165 kN axle loads, and temperatures ranging from 14°C to 24°C, it has been proved that bituminous mix subballast layers, with thickness of 8-12 cm, are free of bending tensile fatigue and that under those conditions they experience a long term compression fatigue less than granular layers.

A power law has been found to fit, adequately well, the fatigue curves of ballast, and parameters have been identified to reproduce the permanent compressions of that material tamped, every one million of 165 kN axle load applications of Eurostar trains travelling at 300 km/h.

Concerning innovations recently introduced in the facility, two additional sets of actuators have been acquired: one, similar to that already existing, enabling to run fatigue tests simulating mixed traffic and another, incorporating frequencies in the range 50-300 Hz, of low amplitude, in the loading system. To achieve those objectives, a new control system to command simultaneously both sets of actuators is being developed at present for CEDEX’s track box.

ACKNOWLEDGEMENTS

The authors wish to thank CEDEX’s personnel of the surveying and in situ testing area (Laboratorio de Geotecnia) for providing the data obtained in railway lines that support the results obtained in the track box. Special thanks are extended to Mr. R. Fernández-Hidalgo, Industrial Engineer of Proel Instrumentation Co. for his help in the preparation of this report.

REFERENCES


