Improvement of transition zones for an old embankment

Amélioration des zones de transition d´un ancien remblai

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ABSTRACT

One increasingly important problem associated with conventional railway tracks is the deterioration of the track and increase of differential settlements due to the construction of new underpasses. Critical zones created around the those structures when pushing them against railway embankments impose serious limitation to the operational speed of the lines causing maintenance cost increments. In this paper, the works carried out to improve the transition zones in an old 8 m high embankment, where a concrete underpass was jacked several years ago, are described. In order to determine the variability of the materials involved and to define the behaviour of the embankment and its foundation, a borehole was drilled in the track and a sliding micrometer was installed inside. Besides, the current behaviour of the track under the daily traffic of trains was investigated before and after retrofitting the line.

RÉSUMÉ

Un problème, associé aux lignes ferroviaires conventionnelles, qui s´avère d´une importance croissante est celui de la détérioration de la voie et du progrès des assises différentielles qui l´affectent suite à la construction de nouveaux passages inférieurs. Les zones critiques qui sont crées autour de ces structures quand elles sont poussées à travers les remblais, imposent de graves limitations à la vitesse d´opération des lignes correspondante ce qui fait monter les coûts de conservation. Cet article décrit les travaux qui ont été entrepris pour l´amélioration des zones de transition d´un ancien remblai de 8 m de hauteur, où un passage inférieur en béton avait été poussé en place plusieures années avant. Pour déterminer la variation des matériaux affectés et pour définir le comportement du remblai et de sa fondation un sondage fut effectué dans la voie et un micromètre coulissant fut installé à l´intérieur. De plus, le comportement de la ligne soumise au passage journalier des trains a été analysé avant et après la récupération de la ligne.

Keywords : improvement, railway, track, stiffness, transition zones

1 INTRODUCTION

In the frame of the 6th European Research Program, the Spanish Railway Infrastructure Agency (ADIF) and the Research Center of the Spanish Ministry of Public Works (CEDEX) are participating together with other European institutions in task 2.2 for INNOTRACK (2006-2009) project. The objective of that task is to assess the efficiency of innovative techniques to improve the behaviour of platforms in conventional railway lines.

To carry out the work assigned to the Spanish partners within that task, ADIF selected, at the beginning of the year 2007, the transition zones between an underpass concrete block and an old embankment 8 m high at Montegut, near Lérida, in the conventional railway line Zaragoza-Barcelona (see fig. 1).

The underpass structure consists of a reinforced concrete frame 8 m high and wide (see fig. 2), that in order to provide a safe passage under the track was pushed against the embankment by the time the high speed line Madrid-Zaragoza-Barcelona, running parallell to the conventional line, was constructed (see fig. 3).

The embankment, 650 m in length, has a side slope 2H:1V and a maximum height of about 8 m near the underpass concrete black. The platform, 7 m wide supports a single track with the Spanish gage (1.668 m).

The conventional railway line was equipped with two-block concrete RS type sleepers supporting UIC 54 rails adapted to the abovementioned gage. The sleepers, placed in the track at 0.60 m space intervals, were 2473 mm in lenght, 290 mm wide and 220 mm high. The fastening of the rails to the sleepers incorporated a pad 4.5 mm thick and 200 x 164 mm in plan.

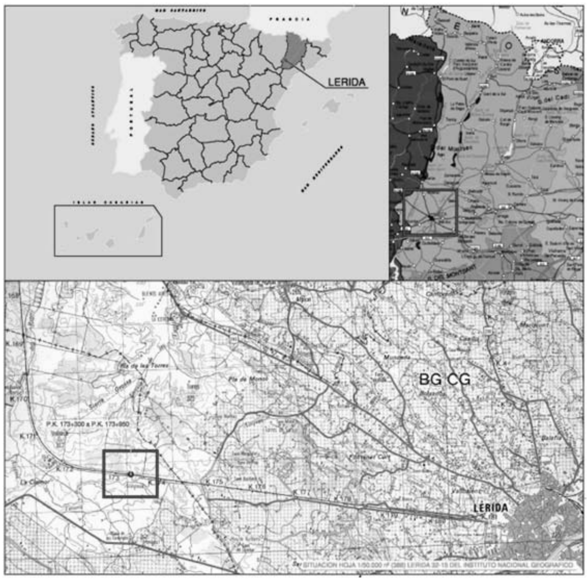

Fig 1. Montagut site in the conventional line Zaragoza-Lerida

At the time at which Montagut was selected to carry out the study, there was in that point of the conventional railway line a strong limitation of speed (10 km/h) for the operation of both conventional and passenger trains due to the bad state of the track, requiring frequent tamping (see fig. 3). To overcome that problem ADIF had prepared a project to improve the core of the embankment at both sides of the concrete block based on the methodology described by Cuéllar (1999) and Santos & Cuéllar

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(2000) for repairing railway embankments without interrupting the traffic of trains by injecting stable mixtures of cement from a side berm previously placed against the embankment (see fig. 4). That technique had been proved to be highly efficient in the improvement of a transition zone of the Amposta viaduct over the Ebro river, as related in a final report for the SUPERTRACK (2005) project, carried out within the 5th Framework Programme of the European Commission.

Fig 2. Reinforced concrete block at Montagut

Fig 3. Conventional line at Montagut

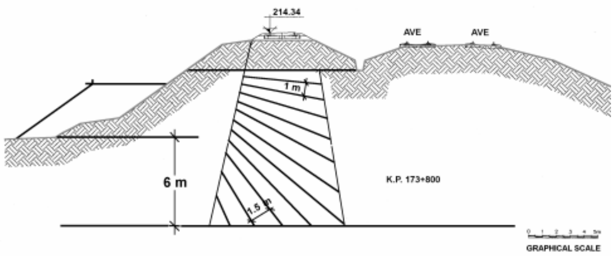

Fig. 4. Initial retrofitting procedure designed

2 MEASUREMENT CAMPAIGNS

In order to assess the amplitude of the treatment, the following measurement campaigns were launched:

2.1 *Sliding micrometer*

On the night of April 22 and 2007 a borehole was drilled in the top of the embankment, inside the track, at a distance of 10 m from the concrete block in the Zaragoza direction and a sliding micrometer of the TRIVEC type was installed inside, up to a depth of 21 m affecting also the embankment foundation.

From the continuous core obteined in the borehole, small pieces of coal mixed with a red brown clay were observed in the upper 4 m of the embankment. Below, and up to a depth of 5 m, a dryer grey sandy fill appeaared. From that level to a depth of 8 m, a more homogeneous material made up of a mixture of sand and silty clay exhibited a high degree of compaction.

Below the embankment, and up to a depth of 16 m, an alluvial sandy clay with small pieces of gravel constitutes the foundation layer of the embankment. Underlying that formation, a sequence of claystone and sandstone layers make up the bedrock at the site.

The sliding micrometer is a high precision tool currently used in geotechnical works to identify problematic zones within earth embankments. It provides the vertical displacement (“z” component) of each borehole wall point to which it is connected. The TRIVEC type provides also the horizontal displacements (“x” and “y” components) of those points.

After the borehole was drilled, a PVC tube provided with metallic reference marks, at about 1 m of separation each other, was installed inside and attached to the borehole walls by means of a stable cement mixture that was injected between the borehole wall and the tube. After the mixture had set up, a reference measurement of the “x”, “y” and “z” coordinates of the metallic marks inside the tube was achieved inserting the TRIVEC probe between two consecutive marks along the tube on May 17th 2007. A second lecture was made on June 12th 2007, after some heavy rains fell on the site. The results obtained are provided in fig. 5 to fig. 7.

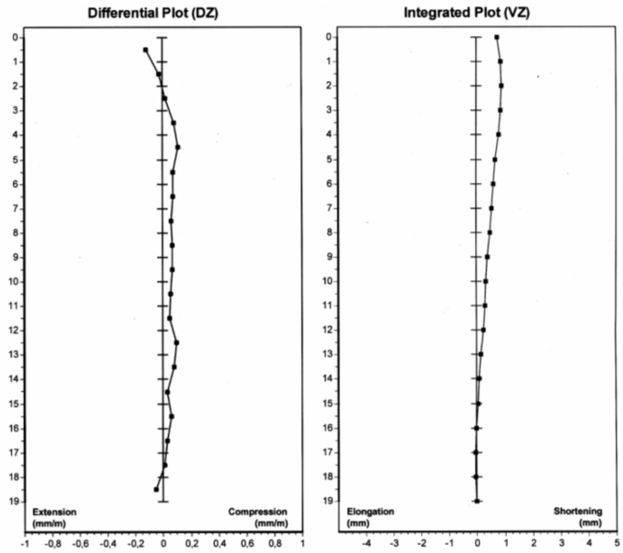

Fig. 5. Relative and accumulated settlements at Montagut

In those figures, the measurements recorded along the three reference axles of the equipment: axle “z” for settlements and axles “x” and “y” for horizontal displacements have been plotted against depth, every one meter. In each figure, two graphs can be observed: the fist, on the left side represents the strains (mm/m) at each depth relative to the reference measurements carried out on May 17th, and the second, on the right side, stands for the accumulated movements (mm) from the bottom of the borehole obtained at each depth. Concerning the behaviour of both, the core and the foundation of the embankment, no significant deformations can be observed in those figures.

2.2 *High precision levelling campaigns*

The objective of these campaigns was to contribute to assess the magnitude of the on going settlements that were throught to be taking place in the track platform.

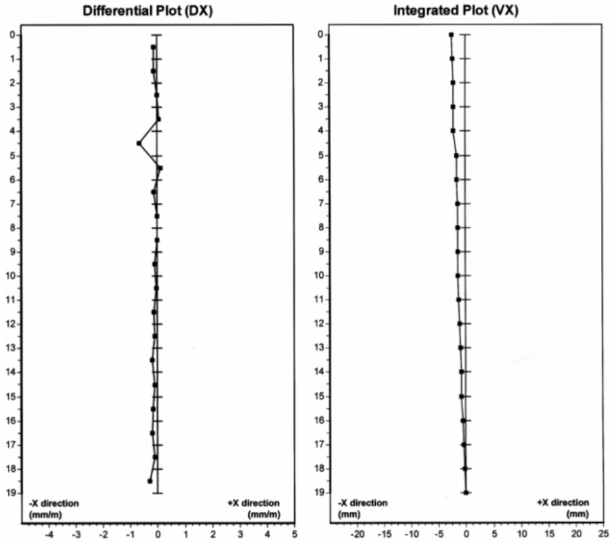

Fig. 6. Relative and accumulated “x” displacements at Montagut

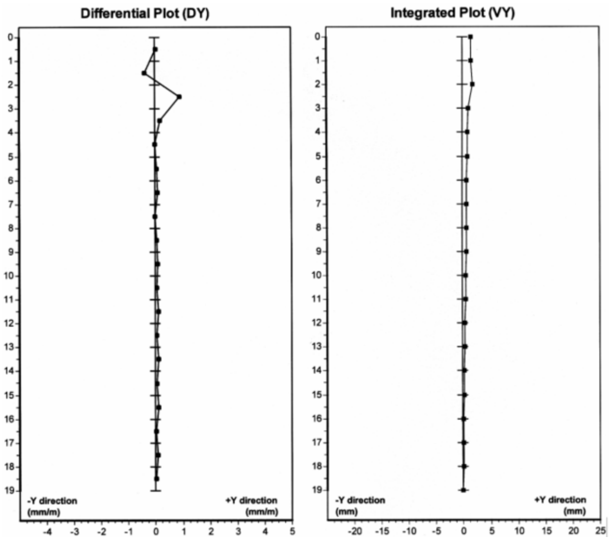

Fig. 7. Relative and accumulated “y” displacements at Montagut

Accordingly, the vertical movements of a total of 22 control points, distributed in a sector comprising 130 m at both sides of the concrete block, were checked in three consecutive levelling compaigns.

The levelling points were installed along the track on the third week of April 2007. Then, reference measurements were obtained on April 25th 2007 followed by two additional campaigns: the first on June 12th 2007 and the second an July 4th 2007.

The levelling surveys were performed with a high precision digital level of the ZEISS DINI 12 type and invar sights 3 m long (see fig. 8). To carry out the surveys a double geometric levelling procedure, forward and backward, was adopted. The error committed in each level measurement made has been less than 0.01 mm.

The differences found between the reference measurements made on April 2007 and the data obtained in the two additional campaigns (June and July 200) were, for all the levelling points, less than 1 mm, corroborating the stable behaviour of the embankment already detected with the sliding micrometer technique.

2.3 *Track stiffness measurements*

To implement the results obtained with the “in situ” campaigns described so far, another campaign was launched in July 2007 to assess the variation of track stiffness, under real operating


Fig. 8. High precision instruments used in the levelling surveys

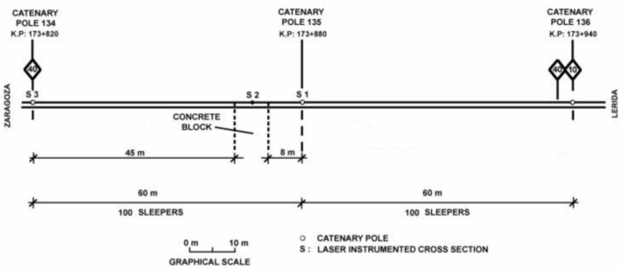

Fig. 9. Track cross sections instrumented on July 2007

conditions, at some representative points of the conventional railway line near the concrete structure. Accordingly, the three cross sections indicated in fig. 9. were chosen.

Cross section S1 was located at K.P. 173+880 in front of catenary pole nº 135 at 8 m from the concrete structure in the Lerida direction. Cross section S2 at K.P. 173+869 in the middle of the concrete structure and cross section S3 at K.P. 173+820 in front of catenary pole nº 134 at 45 m, from the concrete structure in the Zaragoza direction.

In each one of those cross sections, a reference base to monitor the external rail deflection of the track was built: attached to the catenary poles in cross sections S1 and S3 and fixed to the concrete structure in cross section S2.

In that campaign the following sensors were clamped, in each cross section, to the external rail of the track between two consecutive sleepers:

- One laser beam receiver, to measure the vertical deflections of the rail with an estimated error of 0.01 mm (see fig. 10)
- Two extensometer shear bands 2.12 μν/με sensitive, to determine the loads induced by the traffic operating the line (see fig. 11)

The data needed to determine the track stiffness values at the different cross sections were obtained from the passage of passenger and freight trains in both directions during the 3rd, 4th and 5th of July 2007. Also, on the last day, a maintenance unit (locotractor DT-80) and two platform wagons were supplied by ADIF in order to complete the range of loads used so far to determine the mechanical behaviour of the track. Locotractor DT-80 is a two axle locomotive, loading 8 T per wheel, with 6 m axle separation. The two coupled platform wagons, with 8 m axle separation, provided 3.2 T per wheel.

Fig. 12 shows the rail deflection time histories obtained in the three cross sections under the passage of the locotractor convoy at 10 km/h in the Zaragoza-Lerida direction on the 5th of July. Slightly different values were obtained for the convoy travelling in the opposite direction.

Fig.10. Laser receiver clamped to the base of the exterior rail

Fig.11. Shear bands stuck to the interior web of the rail

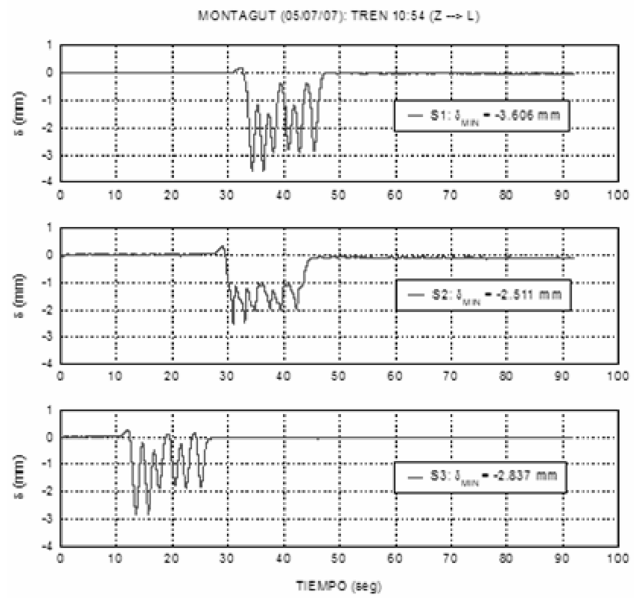

Fig. 12. Locotractor rail deflection time histories on 05-07-07

Converting the shear band micro-strains into shear forces and adding the shear forces provided by two consecutive shear bands, the load time histories induced by any moving car in anyone of the three cross sections instrumented can be obtained. Unfortunately shear band Q1 installed in cross section S1 in the Lerida side failed on the last day (5th of July). Fig. 13 shows the load time histories induced in the remaining cross sections, S2 and S3, by the locotractor unit that day. It can be seen that they are almost the same.

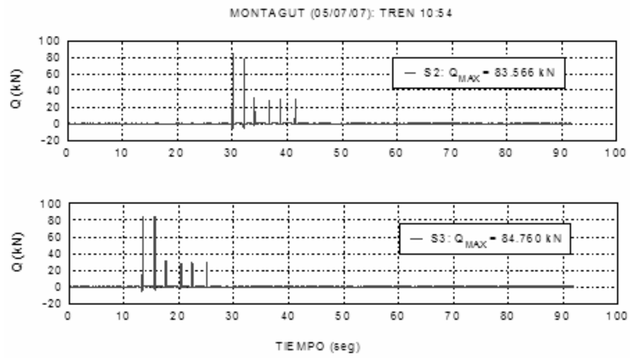

Fig. 13. Locotractor load time histories on 05-07-07

When locotractor wheeel loads were plotted against rail deflections obtained in cross sections S2 and S3, as it has been done in fig. 14, the existence of a “seating load”, reflecting in both cross sections a poor mechanical behaviour of the ballast, was clearly revealed. The same “seating load” as those shown in fig. 14 would have been also obtained in cross section S1 had the shear band Q1 of that cross section worked properly on the 5th of July. Assuming in cross sections S1 the same locotractor convoy load time history as in cross sections S2 and S3 (see fig. 13) the following track stiffness K values have been derived from the loads and deflections induced by the locotractor locomotive travelling in both directions:

- Cross section S1: K = 25 kN/mm
- Cross section S2(4T): K = 35 kN/mm
- Cross section S3: K = 30 kN/mm

On the 5th of July 2007, when monitoring the pass of the locotractor convoy over the concrete block, the laser system was moved by mistake to cross section S2(4T) located four sleepers more in the Lleida direction, at 2.4 m from cross section S2, so data concerning the rail deflection in cross section S2 were not collected that day. The track stiffness value for cross section S2(4T) given above was estimated assuming for cross section S2(4T) the same load time history as the one recorded in cross section S2 when the locotractor convoy passed over the concrete block that day. Due to that error, the rail deflection time history assigned to cross section S2 in fig.12 really corresponds to cross section S2(4T).

Concerning data provided by the passage of commercial trains over the three cross sections, fig. 15 shows the rail deflections induced in each one of them by the passage of a 32 axle TALGO train travelling in the Lerida-Zaragoza direction. The effect of each axle load can be clearly distinguished in fig. 16 where data provided by the same train circulating in the opposite direction have been also included.

Dividing the axle loads by the rail deflections given in fig. 16, the track stiffness values provided in fig. 17 were obtained. Focussing attention only on the locomotive effects, the following set of representative values was identified:

- Cross section S1: K = 35 kN/mm
- Cross section S2: K = 20 kN/mm
- Cross section S3: K = 40 kN/mm

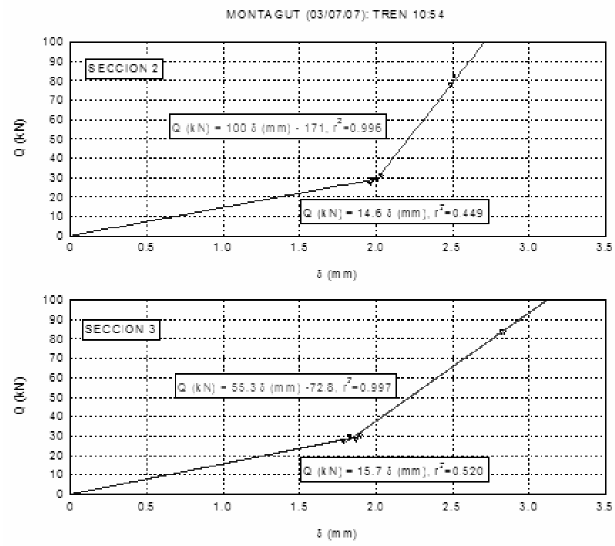

Fig. 14. Locotractor “seating loads” detected on 05-07-07

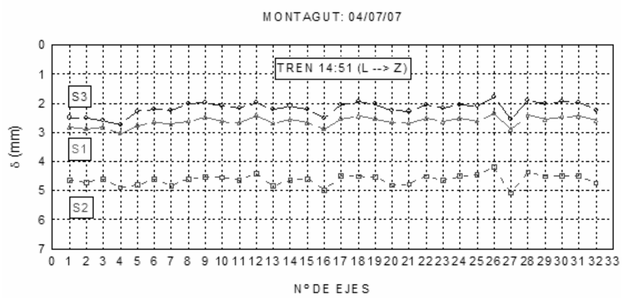

Fig. 15. One direction Talgo train rail deflections on 04-07-07

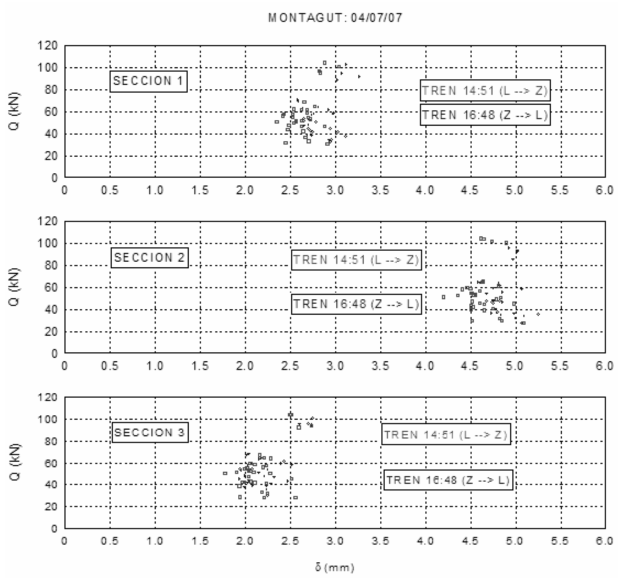

Fig. 16. Two direction Talgo train data on 04-07-07

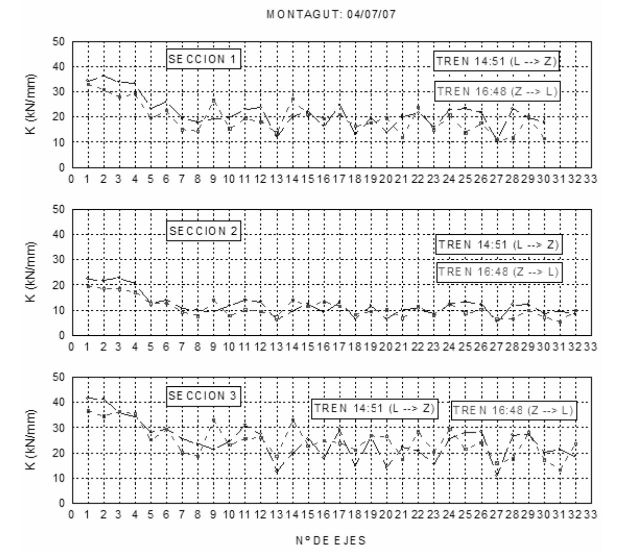

Fig. 17. Track stiffness values obtained on 04-07-07

To reinforce the new material, two layers of high elastic modulus geogrid were designed to be laid out as indicated in fig. 18: one at the bottom of he excavation that had to be carried out on the top of the embankment to replace material (see fig. 19) and the other at mid-depth.

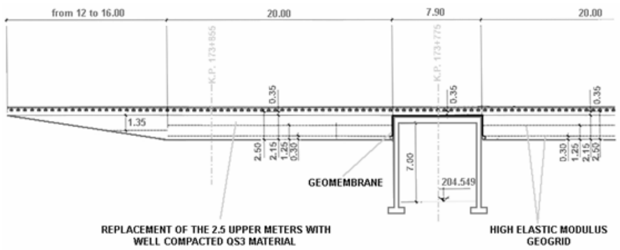

Fig. 18. Final solution to improve transition zones at Montagut

Fig. 19. Excavation for replacing the upper 2.5 m

3 FINAL SOLUTION ADOPTED

Based on the results provided by the abovementioned measurement campaigns ADIF decided not to proceed to the already foreseen injection treatment of the embankment core, but to improve only 20 m, at both sides of the concrete block, replacing the 2.5 upper meters of the embankment by well compacted sandy gravel of the QS3 type recommended by UIC (2008).

It was also decided to improve the ballast behaviour on top of the concrete block and at both sides of it, along sections longer than 100 m, replacing the existing layer by a 0.35 m thick layer of high quality ballast. Over those track sections the two block sleepers were replaced by one block sleepers.

The retrofitting campaign was launched in the summer of 2008. It took only six days to carry out all the reparation works. After finishing those works, the operation of the line was resumed at a maximum travelling speed of 160 km/h. A view of the line after it had been improved is given in Fig. 20.

Fig. 20. Line view after improvement

4 RESULTS OBTAINED

In order to assess the efficiency of the final solution adopted, a last in situ campaign was undertaken on the 16th and 17th of October 2008 aimed to determine the improvement achieved in the track stiffness values over the concrete block and the adjacent transition zones. During those days cross sections S0 S1N, S2N and S3N indicated in fig. 21 were monitored with the same type of sensors as those used when instrumenting cross sections S1, S2 and S3 on July 2007, the only significative difference resting on the use in this time of movable tripods (validated in other measurement campaigns) as reference bases for the laser systems.

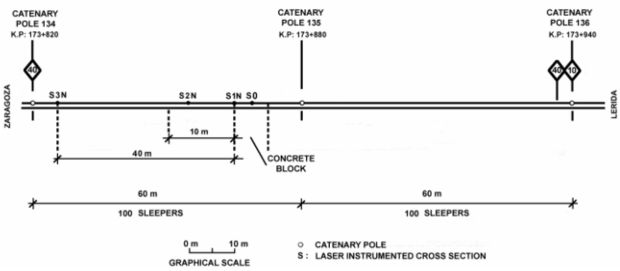

Fig. 21. Track cross sections instrumented on October 2008

On October 16th, three laser systems were installed in cross section S1N, which for that purpose was subdivided in other three cross sections denominated S1N1, S1N2 and S1N3. To identify each one of them, sleepers over the concrete block were given an integer number: starting with 0 at the center of the structure and increasing continuously in the Zaragoza direction. Accordingly, laser system in cross section S1N1 was located between sleepers 3 and 4, and those corresponding to cross sections S1N2 and S1N3 between sleepers 6 and 7 and sleepers 8 and 9 respectively. It was also checked that sleepers 6 and 7 were still in the concrete block with sleeper 7 just at its edge, in the Zaragoza direction, while sleepers 8 and 9 clearly laid on the transition zone very close to the concrete block (see fig. 22).

Those laser systems were moved to cross sections S0, S2N and S3N on the 17th of October.

The locotractor convoy provided by ADIF during those days consisted of a locomotive with 6 T wheel loads and two platform wagons providing 1 T per wheel each, see fig. 23.

Fig. 24 shows the rail deflection time histories induced in cross sections S1N1, S1N2 and S1N3 by the locotractor convoy travelling at 4 km/h in the Lerida-Zaragoza direction on the 16th of October. The same type of information obtained in cross sections S0, S2 and S3 on the 17th of October is provided in fig. 25.

Fig. 22. Laser systems at cross section S1N on October 2008

Fig.23. Locotractor convoy provided by ADIF on October 2008

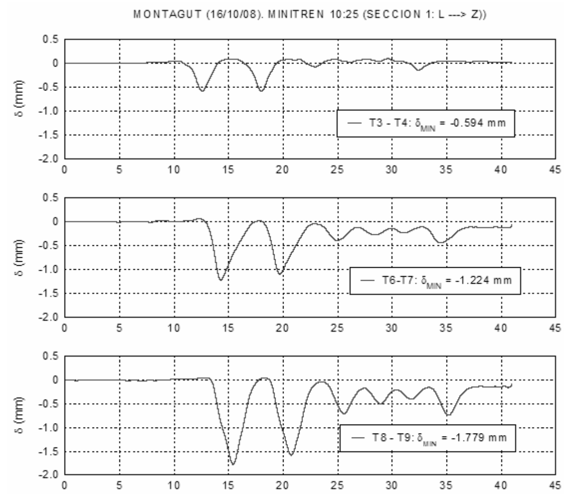

Fig. 24. Locotractor convoy data provided on 16-10-08

Plotting locotractor wheel loads against rail deflections, graphs similar to the one presented in fig. 26, for cross section S0, were obtained in all the other cross sections on the 16th and 17th of October. They all reflect the non-existence of seating loads associated to a poor mechanical behaviour of the ballast.

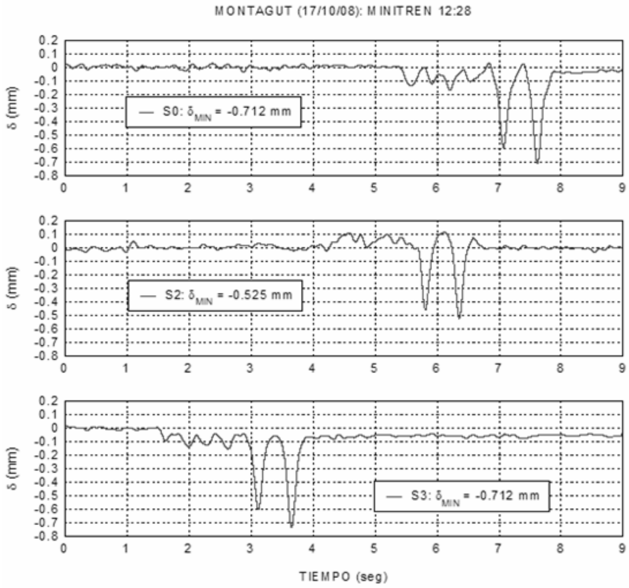

Fig. 25. Locotractor convoy data provided on 17-10-08

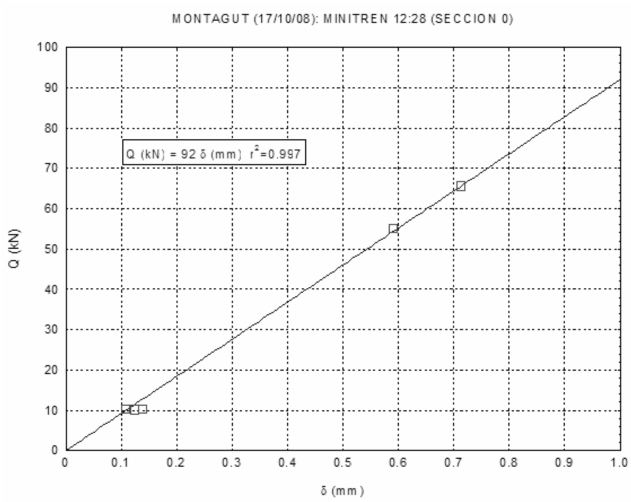

Fig. 26. None seating load detected in cross section S0

The effect on the different cross sections of commercial trains operating the line at speeds higher than 150 km/h is presented in fig. 27 and fig. 28. In those figures the load time histories induced by Talgo trains on the two groups of cross sections analysed on the 16th and 17th of October are also given. From the wheel loads in both figure the following mean values can be derived:

- For cross section S1N: 64 kN
- For cross sections S0, S2N and S3N: 55 kN

Dividing those loads by the mean values of the deflections induced in the different cross sections, the following track stiffness values have been evaluated:

- On 16-6-08:
  - Cross section S1N1: K = 120 kN/mm
  - Cross section S1N2: K = 81 kN/mm
  - Cross section S1N3: K = 58 kN/mm
- On 17-10-08:
  - Cross section S0: 86 kN/mm
  - Cross section S2N: 95 kN/mm
  - Cross section S3N: 85 kN/mm

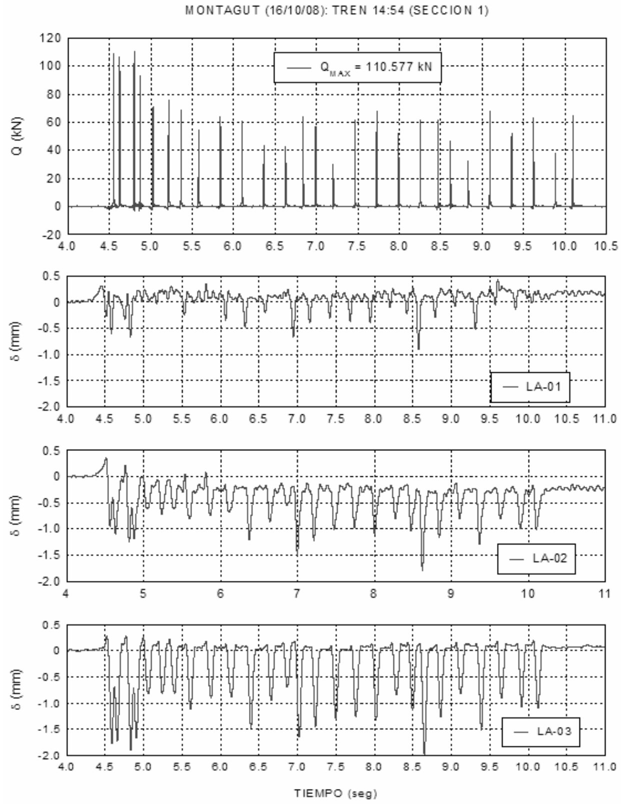

Fig. 27. Talgo train time history data in cross section S1N on 16-10-08

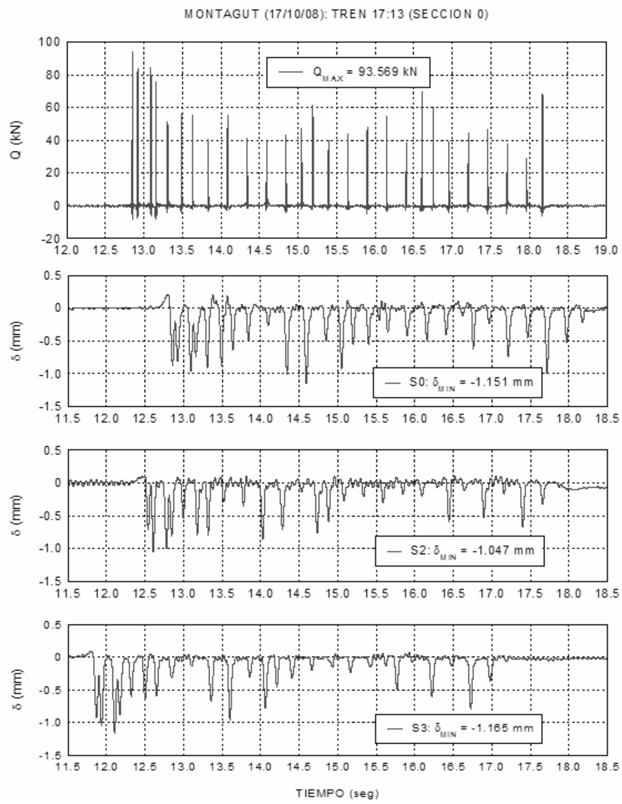

Fig. 28. Talgo train time history data in cross sections S0, S2N, and S3N, on 17-10-08.

5 SUMMARY AND CONCLUSIONS

Table 1 summarizes the results obtained in the site before and after implementing the improvement solution described in the paper.

Table 1 Track stiffness values

MONTAGUT before (04/05-07-07)		
CROSS SECTION	LOCOTRACTOR (10 km/h)	TALGO TRAINS (10 km/h)
S1: 8m from concrete block (Lérida)	25 kN/mm	35 kN/mm
S2: In the middle of concrete block	-	20 kN/mm
S3: 45m from concrete block (Zaragoza)	30 kN/mm	40 kN/mm
MONTAGUT after (16-10-08)		
CROSS SECTION	LOCOTRACTOR (4 km/h)	TALGO TRAINS (150 km/h)
S1N1: 2m from the middle of concrete block	105 kN/mm	120 kN/mm
S1N2: At the edge of concrete block (Zaragoza)	50 kN/mm	81 kN/mm
S1N3: At the edge of the transition zone (Zaragoza)	35 kN/mm	58 kN/mm
MONTAGUT after (17-10-08)		
CROSS SECTION	LOCOTRACTOR (40 km/h)	TALGO TRAINS (160 km/h)
S0: In the middle of concrete block	92 kN/mm	86 kN/mm
S2N: 10m from concrete block (Zaragoza)	105 kN/mm	95 kN/mm
S3N: 40m from concrete block (Zaragoza)	90 kN/mm	85 kN/mm

From the content of this document and in the light of the values given in table 1, the following conclusions have been drawn:

- The geotechnical investigation carry out in the conventional railway line Zaragoza-Lerida, as described in the paper, turned out to be crucial in order to define the type and extension of the most adequate solution to get rid of the strong limitation of speed with which that line was being operated at Montagut in 2007.
- From measurements made in the line, monitoring the pass of maintenance units and commercial trains, the final solution adopted has been proved to be very efficient.
- Track stiffness values obtained after the treatment over the underpass concrete block and the two adjacent transition zones are 2.5 to 4 times higher than those determined before.
- In a zone of the line at 40-45 m from the concrete block, where only the superstructure of the track has been replaced, new track stiffness values 2 to 3 times the old values have been found.
- When implementing the type of solution described in the paper, special attention should be focussed on the local details of the construction work carry out between the concrete block and the adjacent embankment, since a loss in the track stiffnes of 30% has been detected when analysing the pass of maintenance and commercial trains from the structure to one of its transition zones.

ACKNOWLEDGEMENTS

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