Transverse strength of railway tracks: part 3. Multiple scenarios test field

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ABSTRACT. In the present paper the design and construction choices of a test field for the ballast lateral resistance measurement, in order to produce data useful for the development of a numerical model able to simulate the service critical conditions of a continuous welded rail track, are described. Some construction details described herein allow to better understand the methodological approach followed in the design of experiments, the tests management philosophy as well as of the accuracy achieved in their implementation.

KEYWORDS. Ballast resistance; Track stability; Full scale test; CWR track; Railway track; Railway scenarios simulation; Test field.

INTRODUCTION

The analytical and/or numerical determination of the resistance opposed by the ballast to the track displacement due to mechanical and/or thermal loading transmitted or induced by the Continuous Welded Rail (CWR) is a quite complex task. Also, it is necessary to have more reliable data of such resistance for the determination of the service critical conditions of railway lines. Thus, in order to achieve the aforementioned objectives, the use of full scale experimentation, in line or in laboratory, using track sections is unavoidable. Usually, the ballast overall resistance is intended or evaluated as the sum of the three components along the track main directions, both for practical reasons and their easily applicability to any scenario, as well as because sometimes one or more components are used for partial or specific characterizations of the track. In most cases the following constituents are reported in literature: - vertical resistance or bearing capacity; - longitudinal resistance; - lateral displacement resistance. The attention is mainly focused on this latter, due to the role played by the scenarios having the purpose to ensure the stability of the track in making the design choices.

It is well known that the track is composed by: rail, rail fastening system, sleeper, ballast bed and substructures. Among the above elements, it has been proved that an important safety margin is offered by the ballast lateral resistance [1-3], which is the weakest element of the track, since it is the first to fail under the action of the loads acting on the rails. The lateral resistance is mainly due to the friction between the lower face of the sleeper and the ballast. However, significant contributions are also given by the ballast at the sleeper head and at lateral sleeper surfaces. Besides, the magnitude of such resistance depends on several factors, such as: sleeper weight; sleeper width; sleeper length; twin-block sleeper; friction on the lower sleeper surface; increase of ballast grain size; other ballast constituents; increase of lateral shoulder height; ballast shoulder broadening; ballast bed height below the sleeper; ballast height reduction between sleepers; narrower sleeper spacing; rails moment of inertia; track grid torsion-rigidity; track lifting; tamping; dynamic track stabilization; train speeds; increased axle loads; temperature, sleeper anchors and Under Sleeper Pad (USP).

Therefore, owing to the excessive number of samples to be designed, prepared and tested, the experimental evaluation of the contribution related to each one of these parameters in scenarios which are different among them just for one parameter value becomes practically prohibitive.

Several Institutions have conducted studies regarding the contribution to the resistance provided by the geometric parameters of the track and their evaluation [1, 4-6]. Unfortunately, the great part of these studies is incomplete: frequently, the experimental program wasn't completed [1] or some variables have been estimated rather than measured.

Also, the tests are rarely repeated; even when they are, the number of repetitions is low and often defined a priori. Sometimes, the results are partially withheld (See e.g. [4]). Moreover, the data are generally referred to uniform ballast, even if the presence of water pockets [1] or irregularities of any kind alter their behaviour. At the same time, on the basis of these data various models have been developed and numerous software have been implemented to supply with deterministic or probabilistic predictions of the CWR buckling (See e.g. : [2-4, 7-11]). Moreover, these data have also been used to establish a buckling probabilistic risk [7, 12-14] by means of Risk Based Approach, which considers, in addition to an event likelihood, the seriousness of its consequences [7]. As a consequence, the models proposed until now are not very robust, if not even negatively affected by the quality of the data used either as input or for their validation.

These considerations induced RFI to develop together with the DII a research programme regarding the track stability having as main goal the development of a FE model of the track, which is able to identify the critical service conditions of the continuous welded rail of a pre-defined scenario, on the basis of experimental data to be produced by means of full-scale tests carried out on track sections reproducing a remarkable number of real scenarios [15]. The loading systems and the facilities, which were used during the experimental activities, have been designed and manufactured ad hoc [16] in order to achieve a good reliability of the results.

In the present paper, the preliminary activity of the aforementioned programme, developed during the design and construction of a multiple scenarios test field, is described. The multiple scenarios test field is intended as a test campaign on a track composed of predefined scenarios arranged according to a given sequence. This latter has to be compatible with the operative requirements to be used for their construction as well as with the requirements of the test system and the facilities to be used.

SCENARIOS DEFINITION

Before defining the layout of the test field, it was necessary to establish a construction criterion to be used to identify a standard scenario which allows to represent the corresponding real scenario also providing the widest number of useful and reliable data.

First of all, it was decided to evaluate the ballast resistance referring to the single sleeper. Each test should be repeated at least three or four times under the same conditions, in order to reduce the uncertainty of the result obtained with a test carried out on a single sleeper. Moreover, in order to reduce the test duration, it was decided to run all together the three or four equivalent tests, as it is practically done using the Discrete Cut Panel Pull Test (DCPPT). However, the difference with the DCPPT is in using a number of independent actuators equal to the number of the sleepers by which the scenario under testing is composed [16]. Besides, different scenarios arranged in series, having in common the same short rails were built. This choice was due to economize materials and labour as well as reducing the construction and the operating machines time. To be sure that, during the tests, the displacement of the ballast in the scenario under testing doesn't alter the compaction of the neighbouring scenario not yet tested, it was decided to insert between two adjacent scenarios one or two "neutral" or "buffer" sleepers, which are not involved in the test.

The guidelines useful to define the types of test and their numerousness, needed to evaluate the selected parameters range, have been drawn from the analysis of the data needed to identify the critical service conditions of the track typologies described in the Technical Specification drawn on purpose by RFI [17] as well as those found in literature

The selected parameters are:

- Type of sleeper;
- Ballast consolidation;

- Ballast shoulder length;
- Ballast wall distance from the sleeper head;
- Ballast shoulder shape;
- Sleepers anchor type;
- Cant effect;
- Ballast height reduction between sleepers for a 2 m section (1 m each side in respect to the track longitudinal axis);
- Ballast height under sleeper;
- Applied load;
- type of Ballast.

Indeed, the combination of all these parameters would have lead to define an onerous number of scenarios if a minimum of 3÷4 different values were assigned to each parameter. For this reason, it was decided to construct a limited but significant number of scenarios by which it would be possible to develop, on the basis of the collected results, numerical and mathematical models suitable to effectively simulate all the possible scenarios with the parameters values ranging in the respective pre-established variability fields.
Based on considerations related to either significance or representativeness of given service conditions of the railway network, as well as of scale economy, 28 scenarios, of which the main distinguishing parameters are reported in Tab. 1, has been chosen. The first four of them are of immediate interpretation: the compaction, where present, is equivalent to a 80.000 t traffic; the cant is equal to 16 cm; the sleeper anchors are only installed in four scenarios (having 5 sleepers each) either on all the sleepers (each sleeper) or every second sleeper; the load, where present, is equal to 2 t/sleeper. All the scenarios have in common the ballast material and the ballast shoulder dimension.

Scenario	Sleeper	Height under sleeper (cm)	Ballast wall	Compaction	Cant	Sleeper anchors	Vertical load
01	RFI 230	30	NO	NO	NO	NO	NO
02	RFI 230	30	NO	NO	NO	NO	YES
03	RFI 240	30	NO	NO	NO	NO	YES
04	RFI 240	30	NO	NO	NO	NO	NO
05	RFI 240	30	YES	YES	NO	NO	YES
06	RFI 240	30	YES	YES	NO	NO	NO
07	RFI 240	30	NO	YES	NO	NO	NO
08	RFI 240	30	NO	YES	NO	NO	YES
09	RFI 230	30	NO	YES	NO	NO	NO
10	RFI 230	30	NO	YES	NO	NO	YES
11	RFI 230	60	YES	YES	NO	NO	NO
12	RFI 230	60	YES	YES	NO	NO	YES
13	RFI 230	60	NO	YES	NO	NO	NO
14	RFI 230	60	NO	YES	NO	NO	YES
15	RFI 240	60	NO	YES	NO	NO	NO
16	RFI 240	60	NO	YES	NO	NO	YES
17	RFI 240	60	NO	NO	NO	NO	NO
18	RFI 240	60	NO	NO	NO	NO	YES
19	RFI 230	60	NO	NO	NO	NO	NO
20	RFI 230	60	NO	NO	NO	NO	YES
21	RFI 230	60	NO	NO	YES	NO	YES
22	RFI 230	60	NO	NO	YES	NO	NO
23	RFI 230	60	NO	YES	YES	NO	NO
24	RFI 230	60	NO	YES	YES	NO	YES
25	RFI 230	30	NO	YES	NO	each sleeper	YES
26	RFI 230	30	NO	YES	NO	each sleeper	NO
27	RFI 230	30	NO	YES	NO	every two	NO
28	RFI 230	30	NO	YES	NO	every two	YES

Table 1: Combination of parameters characterizing the scenarios chosen for the experiment.

In the construction of the test field the sequence shown in Fig. 1, which has been considered the less expensive among the possible ones, has been used.

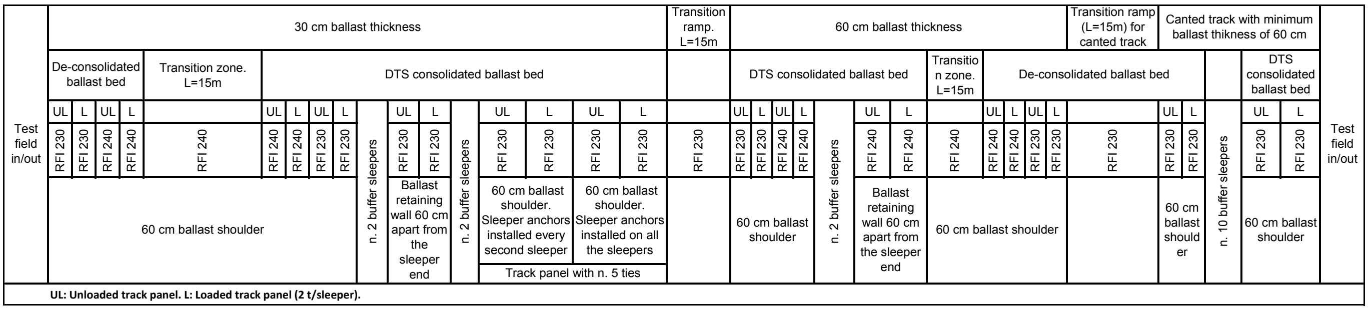

Figure 1: Layout of the test field.

TEST FIELD CONSTRUCTION

For the construction of the test field , it has been used an area of the Campi Flegrei Railway Station (Fig. 2) in Naples (Italy), removing a section of roughly 200 m of two old adjacent tracks and rebuilding a new one having the characteristics defined in the design of the 28 scenarios under testing.

Figure 2: Top view of the selected site.

Once the permanent way has been removed for roughly 200 m, it has been carried out an excavation to eliminate the ballast and the old tracks residuals up to a depth compatible with the level of the new track test which has to be roughly 10 cm above the level of the adjacent track to be used to create the fixed point for the test system. The excavation width is such that there is no interference between the new track profile and the excavation shoulders, neither during the construction phase nor in the following experimental activities.

The subgrade composed by pozzolana has been levelled by the bulldozed and compacted by the roller, checking continuously the depth of the entire excavation for the total length (Fig. 3).

For laying the sleepers, longitudinal references along the test field in the area between the two rails of the new track have been used. On the basis of the aforementioned references, the rails have been marked in correspondence of the points where to place the buffer sleepers. Once the buffer sleepers were positioned in the said space and in the pre-established order, all the other sleepers have been positioned (Fig. 4) according to the layout.

Once the sleepers were laid and spaced at 60 cm, the two rails have been laid on them, tightening the fastening systems (Fig. 5). Tightening has been performed by a hydraulic rail coupling shears, applying a torque equal to 240 mN.

The sleepers forming the scenarios were equipped with Vossloh W 14 fastening system, while, for the intermediate sleepers FS–V–35, the K fastening system have been used.

After the sleepers positioning and the fastening system tightening, the ballast has been laid (Fig. 6, left) and subsequently settled using the tamping machine, which lifts the track for packing the ballast under the sleepers. Also, during the lifting, the driver controls the position of the rails using the "telescope", assigning the lateral movement to the rails, which is needed in order to ensure the required alignment, by means of a hydraulic system. The final height has been reached by lifting the track step by step.

Figure 3: Excavation for the construction of the test track on the chosen site.

Figure 4: Positioning of buffer sleepers (left) and other sleepers according to the layout (right).

Figure 5: Rails fastened on the sleepers.

Figure 6: Deposition of the ballast (left) and removing of the excess (right).

During the ballast deposition and the related increasing of the height of the track, the universal ballast distributing and profiling machine with shoulder ploughs has been also used (Fig. 6, right) in order to remove the ballast in excess and obtain the desired shoulder shape.

Figure 7: Construction of scenarios with cant.

The last two scenarios have been constructed with a cant equal to 16 cm in respect to the rail level of all previous scenarios (Fig. 7). Later sleeper anchors have been installed on the sleepers (Fig. 8).

Figure 8: Shovels installed on the sleepers.

At the end of the operations above described, the final settlement and the rails cutting, needed to make independent one from the other the different test scenarios, were carried out. Also, the purpose-made planned ballast wall, having dimensions not available off-the-shelf, (Fig. 9) were constructed in situ.

Once the elements characterizing the various scenarios have been prepared and before the ballast settlement of the sections for which it has been foreseen, the rails have been cut in correspondence of the end sleepers or the transition sections among groups of consecutive scenarios different in height and/or in ballast compaction. The sectioning was needed in order to reduce the rails free expansion length and to prevent that the temperature variations would alter the desired configuration of the test track. In particular, the cuts have been performed by disk saw and have left a clearance of roughly 1.0 cm (Fig. 10).

Figure 9: Ballast wall constructed *in situ*.

Figure 10: Cut performed by disk saw.

These discontinuities don't limit the movement of the rolling stock on the track, because the underlying sleepers are equipped with K fastening systems, which allow restoring the rail continuity by the u-bolt plates tightening (Fig. 10).
Before rails cutting, needed to create stand-alone scenarios, the edge and the shoulder has been checked and completed as well as the distances among the sleepers have been verified. The cuts have been performed according to the locations specified in Fig. 11 and the rails have been subsequently drilled (Fig. 12) in correspondence of the loading points of the test system.
A tolerance equal to ± 3 cm has been defined for the distance between the centre-to-centre sleepers in respect to the 60 cm nominal value, whilst for the total length of each scenarios, which are composed of 4 or 5 sleepers, the tolerance value has been chosen equal to ± 4 cm. The dimensions that during the check are found out-of-tolerance have been put into the preset limits modifying the position of the sleepers involved.
The characteristics of the materials and components used to build in a single track all the scenarios to be tested are reported in the Tab. 2.

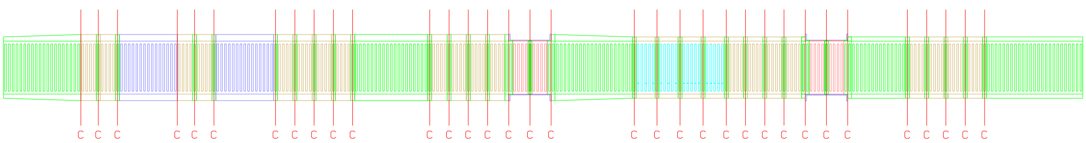

Figure 11: Location of the rails cuts (c: cutting lines).

Figure 12: Drilling of the rails.

Name	*Type*	*Reference Standards*
Ballast	siliceous	RFI DTC INC SP IFS 010 A
Rail	60E1	EN 13674-1
Fastening System	elastic type	EN 13481-2, EN 13146-1÷7
Concrete Sleeper	RFI 230 RFI 240	EN 13230-2:2002

Table 2: Track components.

At the end of all the operations above described, the test field, constructed on the basis of a parametric approach, has been tested as scheduled. A wide range of homogeneous and reliable results have been produced. These results represent the basis for developing a numerical model useful for the evaluation of the safe service conditions of the continuous welded rail track.

CONCLUSIONS

During a wide research programme focusing on the development of a computational model for the study of the stability of the continuous welded rail track, a preliminary and substantial experimental activity has been carried out on full scale sections of modular scenarios implementing numerous and different track construction and service conditions. This activity has required a preliminary design of the test field as well as suitable test system with related facilities, in order to produce sufficient and reliable data for the implementation of a numerical model. In this paper, for the sake of the length, only the main stages of the design and construction of the test field have been described. Moreover, some details have been synthetically discussed in order to provide the reading key of the adopted methodological approach and the accuracy achieved during its implementation. N. 28 scenarios composed of n. 14 different typologies were constructed in a short track of just 180 m, preparing them for the use of a test system designed on purpose [16]. The experimental results reported elsewhere [18] confirm, due to their variety, homogeneity, numerousness and reliability, the validity of the design choices adopted both in defining the test field and in designing the test system.

BIBLIOGRAPHY

[1] ERRI DT202/DT363: Improved knowledge of forces in tangential tracks including switches, Determination of lateral and longitudinal ballast resistance of a railway track by experimental tests, 2 (1997).

[2] Kish, A., Samavedam, G., Wormley, D., New track shift safety limits for high speed rail applications, In: Proceedings of World Congress on Railway Research, Cologne, Germany, (2001).

[3] Analyses of track shift under high speed vehicle-track interaction, US Department of Transportation, DOT/FRA/ORD-97/02, DOT VNTSC-FRA-97-3 (1997).

[4] Esveld, C., Improved knowledge of CWR track, Delft University of Technology, Delft, (1997).

[5] CEPAV UNO – Unieco: Relazione Tecnica Sistema Alta Velocità Linea Milano Napoli, tratta Milano Bologna; Sovrastruttura ferroviaria, valutazione delle condizioni di stabilità del binario AV; RTDV-2008-029-01.

[6] Sussmann, T., Kish, A., Investigation on the influence of track maintenance on the lateral resistance of concrete tie track, In: TRB annual meeting, (2004).

[7] Kish, A., Samavedam, G., Risk analysis based CWR: track buckling safety evaluations, In: Proceedings of the International Conference on Innovations in the Design & Assessment of Railway, (1999).

[8] Van, M.L., Buckling Analysis of Continuous Welded Rail Track, Heron, 41 (1996) 3.

[9] Esveld, C., A new set of computer models for analyzing CWR, Delft University of Technology, Delft, (1997).

[10] Esveld, C., A better understanding of continuous welded rail track, Rail Engineering International Edition, 4 (1996).

[11] Lim, N. Y., Parametric study on stability of continuous welded rail track- ballast resistance and track irregularity, Steel Structures, 8 (2008) 171-181.

[12] Sung, W., Shih, M., Lin, C., Go, C. G., The critical loading for lateral buckling of Continuous Welded Rail, Journal of Zehjiang University Science, 6A (8) (2005) 878-885.

[13] UIC Code 720 R, Laying and maintenance of CWR track, (2005).

[14] Kish, A., Sussmann, T., Trosino, M., Effects of maintenance operations on track buckling potential, In: Proceedings of International Heavy Haul Association, (2003).

[15] De Iorio, A., Grasso, M., Penta, F., Pinto, P., Pucillo, G. P., Rossi, S., Testa, M., Farneti, G., Transverse strength of railway tracks: part 1. Planning and experimental setup, Frattura ed Integrità Strutturale, 30 (2014) 478-485; doi: 10.3221/IGF-ESIS.30.58.

[16] De Iorio, M. Grasso, F. Penta, G. P. Pucillo, V. Rosiello, Transverse strength of railway tracks: part 2. Test system for ballast resistance in line measurement, Frattura ed Integrità Strutturale, 30 (2014) 578-592; doi: 10.3221/IGF-ESIS.30.69.

[17] Technical Specification, RFI, Rome, (2008).

[18] De Iorio, A., Grasso, M., Penta, F., Pucillo, G. P., Rosiello, V., Lisi, S., Rossi, S., Testa, M., About Track Resistance Evaluation on the Running Surface: Role of the Ballast Surrounding the Sleeper, submitted to Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit.