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**RIVAS**  
**Railway Induced Vibration Abatement Solutions**  
**Collaborative project**

**Mitigation measures installed on commercial track**

**Deliverable D3.5**

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**Project Coordinator:**  
**Wolfgang Behr**  
**International Union of Railways (UIC)**  
[ext.behr@uic.org](mailto:ext.behr@uic.org)

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## 1. EXECUTIVE SUMMARY

Within the frame of the EU FP7 project “Railway induced vibration abatement solutions (RIVAS)”, mitigation measures for ground vibrations and ground-borne noise are studied in the case of surface tracks. Work Package 3 task 2.2 focuses on rail fastening systems with very low stiffness for ballasted straight lines. Numerical simulations previously carried out in the WP3 ([1], [2]) have shown that such systems can induce a positive insertion loss up to 20 dB above the vehicle-on-track resonance frequency (i.e. above 40Hz to 50Hz).

Therefore, two systems have been specifically designed by PANDROL in order to be tested on a ballasted track: the DFC set-up which consists of a double layer of pads (under rail pad and under base-plate pad) and the VANGUARD set-up that induces to clip the rail on its web with rubber assemblies so that the vertical stiffness of the fastening system is reduced to its minimum. The installation of these two systems on a ballasted track required a dedicated sleeper to be designed: the SATEBA M260-DFC monobloc concrete sleeper.

Once these components are designed and before they can be installed on a real commercial track, a string of tests have to be carried out to verify that they fulfil the required degree of reliability and safety, particularly for freight traffic conditions. Laboratory tests for track component certification have been done according to the EN 13146 standard [3]. The DFC system in various configurations has passed these tests (different combinations of under rail pad and under base-plate pad: from DFC 0 with an equivalent stiffness close to 75 MN/m to the DFC 3 with an equivalent stiffness equal to 25 MN/m).

The tests performed on VANGUARD have been interrupted as a decision of the SNCF engineering department. Difficulties were encountered in order to perform the fatigue tests using inclined loads, and especially in order to follow the EN 13146-4:2012 requirements with the SNCF test rig. Because the tests were not complete for VANGUARD and as not enough time was left to work on this issue, it was decided to withdraw the VANGUARD installation as a precautionary measure. However, it must be noticed that these fatigue tests were also performed in PANDROL laboratory following the EN 13146-4:2012 and that no counter-argument was found.

In parallel to the certification process, installation of these innovative systems into a real track has been organized by SNCF together with a track-work project team. It took more than one year to make feasible the installation of the DFC systems during a track renewal operation in summer 2013. A test site and a reference site have been chosen to fulfil RIVAS WP1 measurement procedure requirements, and transition zones have been designed to avoid abrupt “gaps” in track stiffness along the track which might cause geometrical defects growth.

The last step before installing and testing the system consisted in designing the in-situ measurement campaign: track and ground dynamic characterization, free-field vibration measurement, rolling noise assessment.

The DFC 0 is now installed on track in the north east of France, in a freight corridor (Florange). The track is in stabilization phase for 2 weeks, and the firsts tests should begin in September 2013.

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### 3. INTRODUCTION

The subtask 3.2 in the Work Package 3 of the RIVAS project is dedicated to mitigation measures for ballasted tracks. In the RIVAS deliverable 3.2 [1], soft fastening systems and under sleeper pads are numerically investigated in terms of track dynamics and ground vibration mitigation effects. These solutions can provide up to 20 dB of attenuation above the vehicle on track resonance frequency at which ground vibration are amplified by around 10 dB.

Under sleeper pads are experimentally investigated in the RIVAS deliverable 3.7 [4], and results from in situ tests with artificial excitations are the subject of the RIVAS deliverable 3.15 [5].

This present deliverable concerns the two innovative fastening systems proposed by PANDROL, member of the RIVAS consortium: the DFC system and the VANGUARD system. The DFC system is a fastening system with two resilient layers and an intermediate base-plate, in which the rail is clamped using FASTCLIP-like clips. Using different materials for both the rail pad and the under base-plate pad, a wide range of low stiffness can be achieved for the global system, from 25 MN/m to 75 MN/m. The VANGUARD system is an innovative fastening where the rail is supported under the head and in the web with rubber assemblies, leaving the foot of the rail suspended.

Laboratory tests were performed on those systems, using a ballast box and a hydraulic jack excitation. The results of these tests as well as additional numerical results are presented in the RIVAS deliverable 3.4 [2]. They confirm the expected Insertion Loss but also raise specific issues concerning the test of soft fastening systems in laboratory. Following these preceding studies, the DFC and the VANGUARD systems are planned to be tested on a commercial track with real pass-bys excitations.

The objective of this deliverable is to give an overview of the preliminary work that is required for a real scale measurement campaign with new track components.

First, the DFC and the VANGUARD systems are presented in detail in Section 4, as well as the new M260-DFC sleeper that was designed to fit both systems. This section includes general overviews of the systems and their components and a description of their mounting procedures.

The two systems and the sleeper were planned to be tested on the French network, in which they have never been installed before. Therefore, these new components need to be certified in order to prove that they satisfy the French requirements in terms of safety. The tests performed in the SNCF track engineering department for the certification of the DFC, of the VANGUARD and of the sleeper, are the subject of Section 5. The nature of the tests and the associated set-ups are described and some results are given as examples. From this certification process, some specific issues arose concerning the test of soft fastening systems. They are discussed in Section 5.5.

The field tests will take place in September 2013 in the North East of France, in a freight corridor. It includes a reference track section and a 150 m long test section equipped with the M260-DFC sleeper and the new fastening systems. This test site is presented in Section 6, as well as the measurements that will be performed.

Of course, these tests were intended and planned under the agreement of RFF, the French infrastructure and track owner. Besides being concerned as owner of the track where the fastening systems will be installed, they are also interested in the performances of soft fastening systems for several long time issues: rail roughness/corrugation evolution, track geometrical defects outbreak, track component deterioration. Therefore, RFF asked for an extended use of the softest DFC system, which will also complete their certification. The track characteristics that will be checked for these two years, and their expected evolutions are presented in Section 8.

## 4. OVERVIEW OF THE TESTED SYSTEM

Two systems manufactured by PANDROL Ltd have been chosen by the RIVAS WP3 partners to be tested on a commercial track: the DFC Valiant and the VANGUARD. Originally designed for slab tracks, they were modified to fit to a common sleeper in order to be installed on a ballasted track. As existing sleepers are not compatible with DFC and VANGUARD, a new sleeper, the M260-DFC, was designed by the RIVAS partner SATEBA.

The DFC and the VANGUARD are introduced in Section 4.1 and 4.2 respectively. Further information can be found in Deliverable 3.4 [2] where the results of preliminary studies are presented:

- Vertical stiffness and Insertion Loss estimation from laboratory tests,
- Insertion Loss estimation from numerical simulation with measured vertical stiffness.

The M260-DFC sleeper is presented in Section 4.3.

### 4.1 PANDROL DFC SYSTEM

The DFC Valiant is a system with two resilient layers and a cast-iron base-plate. The rail is clamped to the base-plate with FASTCLIP-like clips through an intermediate rubber rail pad. The base-plate is fixed to the concrete sleeper with a steel bolt and a cast-iron shoulder through an intermediate under base-plate rubber pad. The different components are represented in Figure 1 and a general view is given in Figure 2.

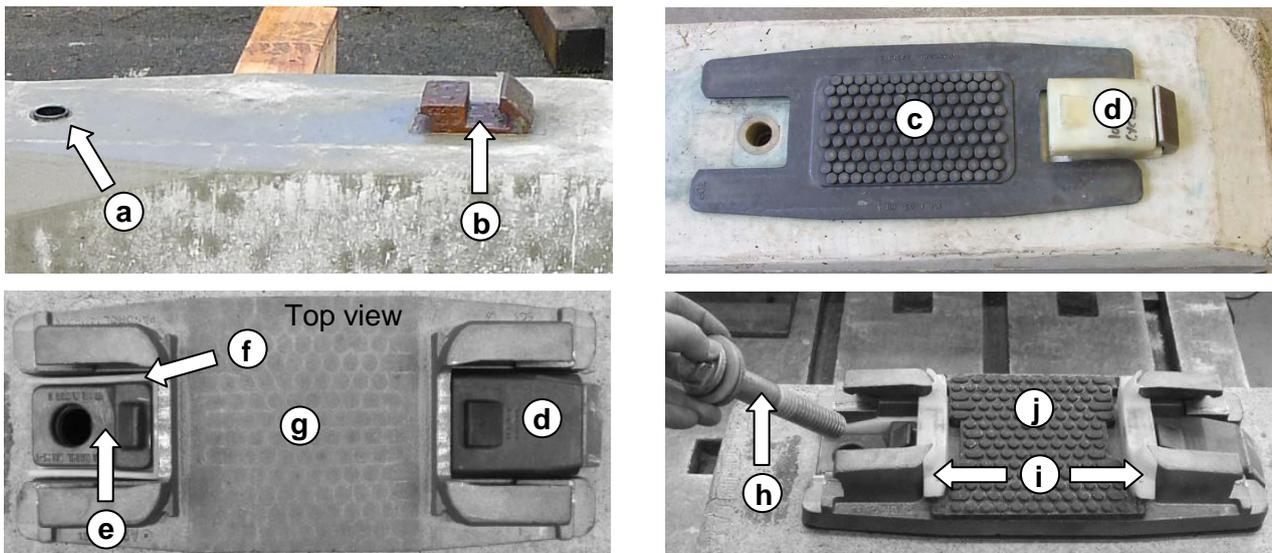


Figure 1: Components of the PANDROL DFC system (base-plate and resilient elements).

In Figure 1 and Figure 2, the letters refer to the following elements: Bolt thread (a); Cast-iron shoulder (b); Under base-plate pad (c); Field side plastic clamp (d); Gauge side cast-iron clamp (e); Plastic insulator (f); Cast-iron base-plate (g); Anchor bolt (h); Side post insulators (i); Under rail pad (j); UIC 60 rail (k); Rail clip and plastic insulator (l).

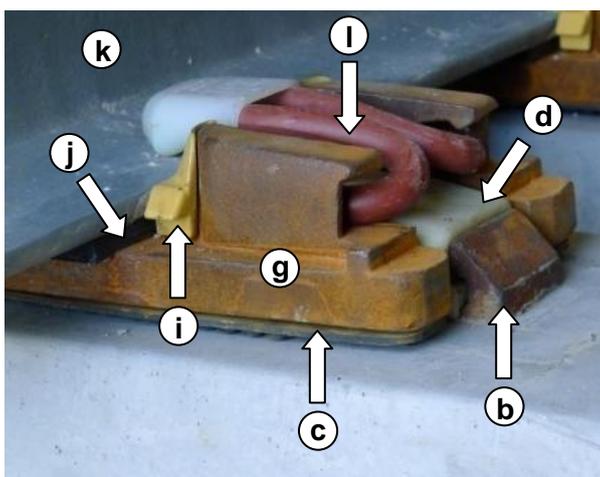


Figure 2: Complete and mounted DFC assembly.

By choosing different materials for the rail pad (j) and the base-plate pad (c), the stiffness of the whole system can vary in a wide range. For the field tests of the RIVAS project, 4 combinations will be tested. These configurations are described in Table 1 according to the type of rail pad and base-plate pad. The vertical dynamic stiffness measured in laboratory following EN 13481-1 are also given for the different pads and for the DFC 0 and DFC 3 assemblies.

Name	Under Rail Pad		Under Base-plate Pad		Global stiffness
	Type	Stiffness	Type	Stiffness	
DFC 0	SNCF std. (9 mm)	120 MN/m	EVA	270 MN/m	75 MN/m
DFC 1	Vossloh 1 (10.5 mm)	60 MN/m	EVA	270 MN/m	55 MN/m <sup>1</sup>
DFC 2	Vossloh 2 (10.5 mm)	40 MN/m	EVA	270 MN/m	36 MN/m <sup>1</sup>
DFC 3	SNCF std. (9 mm)	120 MN/m	Studded rubber	64 MN/m	25 MN/m

Table 1: Description of the 4 different assemblies built up with the DFC system.

## 4.2 PANDROL VANGUARD SYSTEM

The PANDROL VANGUARD is an innovative fastening system where the rail is supported under the head and in the web with rubber assemblies, leaving the foot of the rail suspended. The rubber assemblies are held in place by cast-iron side-plates. The different elements that compose the VANGUARD system are presented in Figure 3, Figure 4 and Figure 5.

As for the DFC Valiant, a cast-iron base-plate is used for the VANGUARD. As shown in Figure 3, the base-plate (1) is slid (2) to the shoulder (b) until it is locked (the shoulder (b) of Figure 1 is hidden under the base-plate in Figure 3). The base-plate is then screwed to the sleeper with a steel bolt (3). An intermediate rubber gasket (4) is placed between the sleeper and the base-plate. Once the base-plate is screwed, the gauge side shoulder (5) is slid to the gauge side (2). The field side shoulder is part of the base-plate. A bump stop pad (6) is placed in the base-plate recess to prevent the rail foot from hitting the base-plate in case of abnormal overload.

The UIC 60 rail (7) is positioned on the base-plate using a 9 mm height wooden spacer between the base-plate and the rail foot (not shown here). The rubber wedges (8) are engaged in the cast-iron side-plates (9) which are then positioned between the base-plate and the rail web. A ductile iron wedge (10) is then engaged between the shoulder and the side-plates for both sides of the rail. These elements are represented in Figure 4 and Figure 5.

<sup>1</sup> The DFC 1 and DFC 2 assemblies are currently being tested; the values given here are first estimates.

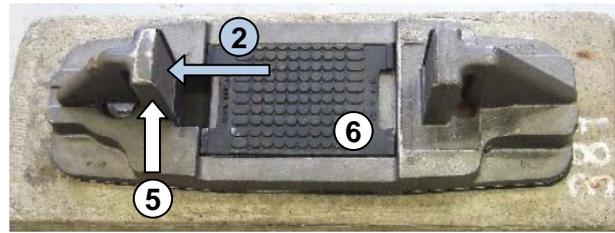
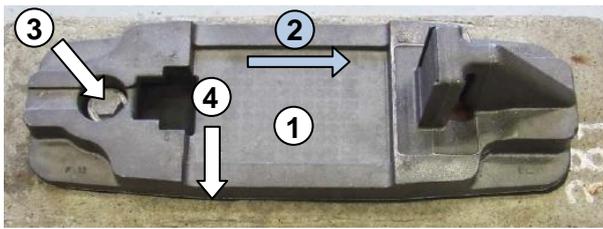


Figure 3: VANGUARD base-plate and bump stop pad.

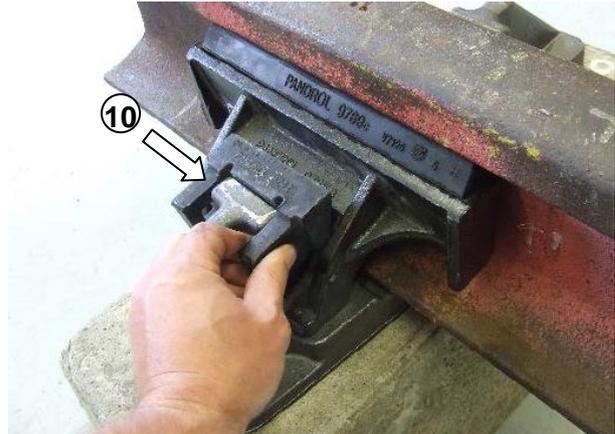


Figure 4: Positioning the side brackets and engaging the wedges.

The wedges (10) are definitively positioned and adjusted (track gauge control) using a hydraulic clamping tool (11) that holds the side-plates under a pressure of 235 bar. Retaining clips (12) (spring steel) are finally placed to secure the full assembly as shown in Figure 5, right.

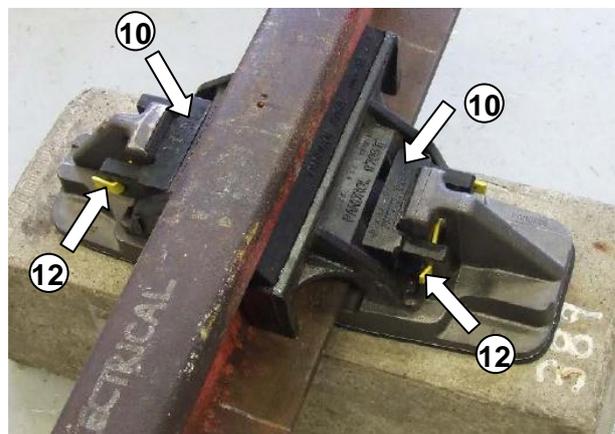
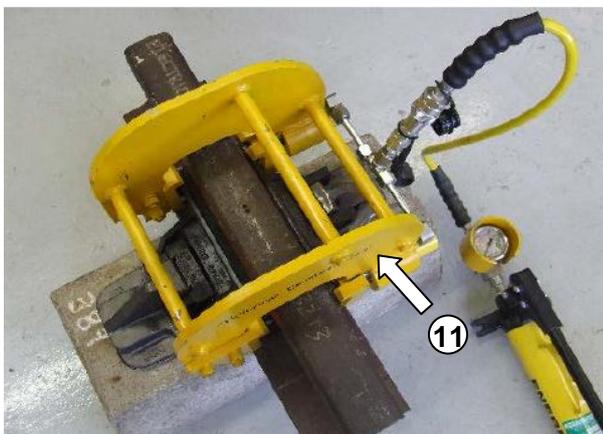


Figure 5: Clamping tool for the final positioning of the wedges.

The vertical dynamic stiffness of the VANGUARD is given at 6 MN/m. This value is much lower than for usual systems installed in France for ballasted track. As an example, the common FASTCLIP system with 9 mm rubber pads is given at 120 MN/m. This very low stiffness for the VANGUARD (and also for the DFC) requires special attention:

#### Height of the rail running surface

The track section that will be equipped with these systems will be bordered on both sides by a regular track of higher stiffness. For a given vehicle load, the deflexion of the rail will be higher for soft systems than for stiff systems. Both the DFC and the VANGUARD have been designed to

account for this effect. The height of the rail rolling surface relative to the sleeper is guaranteed to be the same for DFC and VANGUARD track than for the regular track, under an equivalent static load.

### Maximum load transmitted to the sleeper

As shown in the RIVAS deliverable 3.4 [1] (confidential), soft fastening systems spread the loads over a longer distance away from the wheel/rail contacts. For a given vertical load applied on the rail over a sleeper, the Table 2 gives the maximum load effectively transmitted to this sleeper depending on the stiffness of the fastening system. Note: the stiffness values given in Table 2 are those used in the deliverable 3.4, they differ from the values given in Table 1 which were since updated from laboratory measurements. This is discussed in more details in Section 5.5.

Fastening system (stiffness)	Maximum load percentage transmitted
VANGUARD (6 MN/m)	24 %
DFC 3 (21 MN/m)	32 %
DFC 2 (37 MN/m)	37 %
DFC 1 (80 MN/m)	42 %
DFC 0 (or FC at 120 MN/m)	47 %

Table 2: Maximum amount of the axle load applied on a sleeper (static) [1].

## 4.3 SATEBA M260-DFC SLEEPER

The DFC Valiant and the VANGUARD were originally designed by PANDROL for slab tracks, and thus, did not fit to any existing sleeper for ballasted tracks. As the field tests were expected to take place in a commercial line, and as the French Railway Network was interested in testing the long time effect of these systems, it was decided to design a new sleeper that should be certified together with the fastening systems. This sleeper should be able to receive the DFC as well as the VANGUARD system.

PANDROL proposed a modified version of the two systems, compatible with a unique fixing system. Following this design, Sateba proposed a new sleeper based on its M260 sleeper, integrating the fixing system made of a cast-iron shoulder and a bolt anchor on each side of the sleeper. This sleeper, the M260-DFC, combined with the two fastening systems ensures a rail level equivalent to that of the Sateba M450 sleeper which is now widely used in the French network.

The M260-DFC sleeper is made of prestressed concrete, with 6 tendons. The dimensions of the sleeper are given in Figure 6.

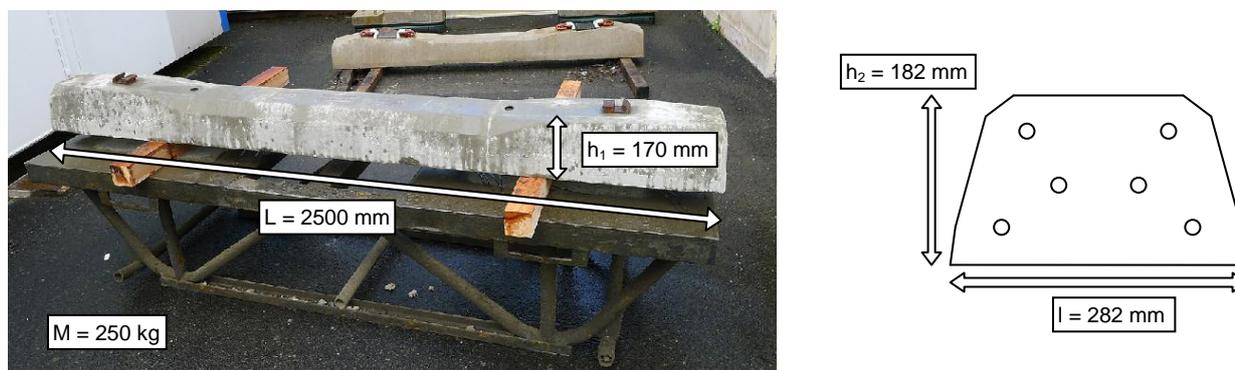


Figure 6: Views and dimensions of the M260-DFC sleeper. Left: general view. Right: front view.

## 5. CERTIFICATION PROCEDURE

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### 5.1 THE NEED FOR A CERTIFICATION PROCESS

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The RIVAS project is an ambitious project where the mitigation measures are not only studied numerically or in laboratory conditions, but also tested on real track. For the innovative fastening systems which are the purposes of this deliverable, their implementation in a commercial track raises many difficulties, almost all dealing with railway safety issues. Indeed, for what concerns the SNCF network, each modification in the track structure (whatever the component), must be preceded by a technical study, in order to ensure that the new component does not compromise the safety of the whole railway system. The nature of these preliminary tests depends on the scope of use for the new component concerned:

- Duration of use in track,
- Track alignment (or curve radius) where the component is used,
- Similarities with existing and certified components.

What is really needed within the RIVAS project is to test mitigation measures on track. This could be achieved by introducing the tested systems in the track (DFC and VANGUARD), testing them, and removing them to recover the track to a standard configuration. In this case, the time spent by the “new component” on track would have been limited, requiring only partial preliminary tests.

However, looking at the specificities of our systems, this option is not reliable:

- VANGUARD and DFC are only compatible with the M260-DFC sleeper, on which other certified fastening systems cannot fit.
- Considering the previous item, a short time use would require the M260-DFC sleepers to be installed and removed from the track, which is economically not relevant.

Then, it was decided to let the M260-DFC sleepers in track for the whole life cycle of the track. After the VANGUARD and DFC in soft configurations are tested, the track will be definitively returned with the stiff version of the DFC. This configuration (DFC 0) is expected to be equivalent to the standard FASTCLIP system in terms of vertical stiffness. A full certification is then required for DFC 0 (+M260-DFC sleeper) while a partial certification is sufficient for the other DFC configurations that will stay on track for a limited period.

Following this decision, many railway workers of different professions inside SNCF were contacted, in order to set up a technical file. As the RIVAS issue was being treated, the infrastructure owners (RFF) showed a strong interest in these innovative solutions. They asked for an extended use of the soft DFC configuration, for a 2-year period. The complete certification of the DFC 3 is then also needed. The reasons for this interest and the expected scientific gains are presented in Section 8.

The description of the certification tests and some of their results are given in the following Subsections 5.2 for the sleeper, 5.3 for the DFC and 5.4 for the VANGUARD.

### 5.2 M260-DFC SLEEPER

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The M260-DFC sleeper has a design very close to the M260 sleeper, which is widely used in the French network. The major differences are listed below:

- The M260-DFC has 6 tendons instead of 5.
- It is not equipped with FASTCLIP inserts but with a plastic bolt thread and a cast-iron shoulder on each side of the sleeper (see Figure 1).

## 5.2.1 Description of the tests

The tests performed on the sleeper follow the EN 13230:2009 standard: *Railway applications – Track – Concrete sleepers and bearers* [7]. They are mainly resistance and wrenching tests. A core extraction and a water absorption rate measurement are also performed.

### Wrenching tests

The cast iron shoulders as well as the bolt thread are pulled vertically (black arrows in Figure 7), each being tested on a proper sleeper. The bolt thread is pulled using a specific bolt and the shoulder using a specially designed item that fits under the recess (both in green in Figure 7). First, the traction force is increased constantly up to 60 kN. The deformation after 3 minutes at 60 kN is measured. Then, the force is increased again from 60 kN until wrenching.

### Resistance tests

The load is applied in the middle of the sleeper and at both rail seats, while the sleeper is laid on 2 fulcrums. What is sought in these tests is the load value when widths of 0.05 mm and 0.5 mm are reached for the wider cracks in the concrete (an example of crack is given in Figure 7 right).

When the sleeper is tested for the centre position (red items in Figure 7), the load is directly applied on top and under the sleeper (called positive and negative). The fulcrums are located at the level of the rail seats (one on each side of the sleeper).

When the sleeper is tested for the rail seat position (blue items in Figure 7), the load is applied through the base-plates (not shown in Figure 7) only on top of the sleeper, on both rail seats. Two fulcrums are located under the sleeper on both sides of the load application axis.

For the positive load test at centre section, only a static load is used. The load increased from 20 kN by steps of 5 kN, staying 5 seconds minimum at each step. For the negative load test at the centre section, only a static load is used. The load increased from 40 kN by steps of 5 kN, staying 5 seconds minimum at each step. For the static load test at rail seat section, the load is increased from 130 kN by steps of 10 kN, staying minimum 5 seconds at each step. For the dynamic load test at rail seat section, the load is increased from 130 kN by steps of 20 kN. Each step is performed with 5000 load cycles from 50 kN to the required load value.

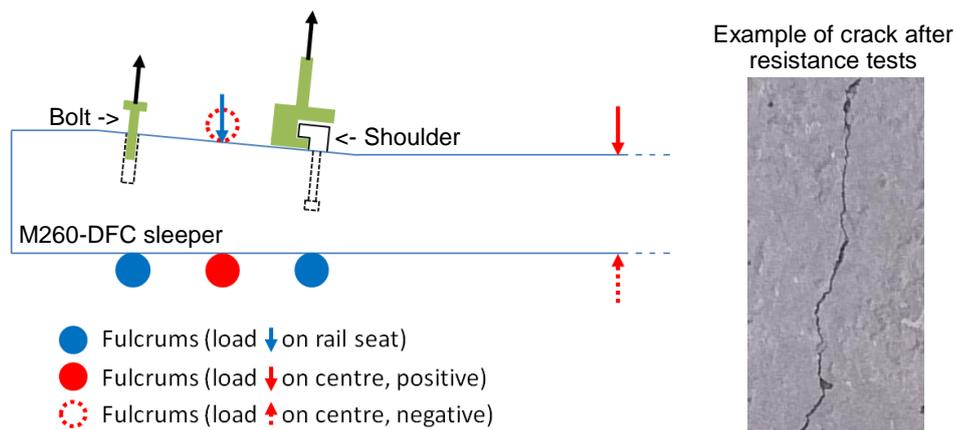


Figure 7: Resistance and wrenching tests performed on the M260-DFC sleeper.

## 5.2.2 Results

The sleeper is certified without any reservation.

### Wrenching tests

Concerning the bolt thread, depending on the sample tested, either the concrete has broken, either the thread has breached. However, this was achieved with forces above the lower limit fixed by SNCF. Concerning the shoulder, it was impossible to wrench it within the limit of the hydraulic actuator.



Figure 8: Wrenching tests applied on the bolt thread. Left: broken concrete. Right: breached thread.

### Resistance test

Nothing special was noticed during the resistance tests. Measured indicators satisfied the limit fixed by the SNCF engineering department.

## 5.3 DFC FASTENING SYSTEM

As previously said in Section 5.1, a complete certification procedure was performed for the DFC 0 and the DFC 3 systems, as they will stay on track for at least two years. These tests were performed at the SNCF track engineering department which is responsible for the certification of all new components that are intended to be installed on track. The DFC systems were sent by PANDROL to SNCF with a complete and detailed technical file, including:

- A description of the DFC components, with technical drawing, pictures of the components and pictures of their manufacturing process.
- Results from laboratory tests performed by PANDROL according to the same standards that are used by SNCF (see Subsection 5.3.1).
- A technical guide for assembly and removal of the systems on/from the sleepers, track construction and component change.
- A maintenance guide.

The tests are described in Subsection 5.3.1 and the results are given in Subsection 5.3.2.

### 5.3.1 Description of the tests

The DFC systems mounted on the M260-DFC sleeper were tested according to the following standards (except for the fatigue tests which are later discussed):

- EN 13146: *Railway applications – Track – Test methods for fastening systems*. This norm describes the different tests that have to be performed in terms of equipment and methodology [3].
- EN 13481: *Railway applications – Track – Performance requirements for fastening systems – Part 2: Fastening systems for concrete sleepers*. This norm describes the parameters to be used in the EN 13146 set-ups and also the limit values for the measured quantities. They are given depending on the vertical stiffness of the tested system and also depending on the type of track.

The nature of the tests performed in the scope of the RIVAS project is briefly presented in this deliverable. For more detailed information, please refer to EN 13146 and EN 13481 standards.

As the DFC system has two resilient pads, some of the tests performed for the complete system were also performed for both pads considered independently. All the displacements were measured with optical sensors.

#### Rail pad thickness before and after repeated loads

The thickness is measured under a 20 kN load. This test is performed before and after a fatigue tests that is described below.

#### Static stiffness before and after repeated loads

This was performed for the complete system as well as for the each of the two pads, as shown in Figure 9. The base-plate pad was tested using the base-plate as exciter (Figure 9, centre). Three cycles are applied between 18 kN and 85 kN. The static stiffness is then estimated as the secant of a 18 kN – 68 kN cycle in the Force/Displacement diagram. The load variation speed is 2 kN/s.



Figure 9: Vertical stiffness measurements. Left: rail pad. Centre: base-plate pad. Right: complete system.

#### Dynamic stiffness before and after repeated loads

This was performed for the complete system as well as for each of the two pads. The same set-up was used for both static and dynamic stiffness measurements (Figure 9). The dynamic stiffness is estimated as the secant of an 18 kN – 68 kN cycle at 4 Hz in the Force/Displacement diagram.

#### Clamping force before and after repeated loads

The 60E1 rail is pulled up until the rail pad is removable by hand. At this point, the traction force and the rail foot displacement are measured. The set-up used is close to the one of Figure 9, right.

#### Creep resistance before and after repeated loads

A section of 60E1 rail is pulled longitudinally until the rail creeps, which is identified as a bending point in the Force/Displacement diagram. The force variation speed is 10 kN/min. The experimental set-up for this test is shown in Figure 10: two displacement sensors in the bottom left corner and the longitudinal actuator in the top right corner.

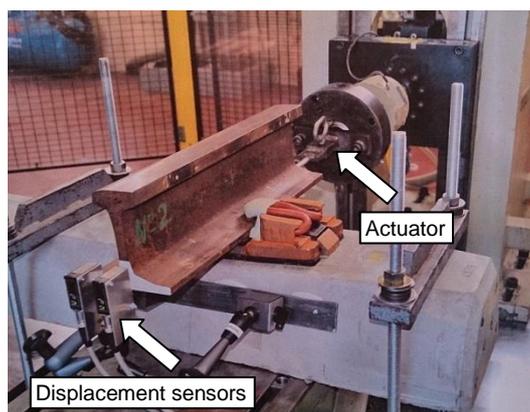


Figure 10: *Longitudinal resistance to creepage test.*

### Clamping torque

A piece of 60E1 rail fastened to the sleeper is pulled on one end until the rail axis is moved of  $1.5^\circ$ . The force is measured every  $0.5^\circ$  from the initial position. This test is repeated for the same rail end but on the opposite direction. A picture of the corresponding set-up is given in Figure 11.



Figure 11: *Clamping torque measurement.*

### Impact load attenuation

A 1 m long piece of modified 60E1 rail is fastened to the sleeper and preloaded (see Figure 12). A mass of 7 kg is dropped from a height of 0.75 m. The strain measured in the sleeper with the tested rail pad is compared to the strain obtained with a reference dense pad. The impact load attenuation is the ratio between the so obtained values.

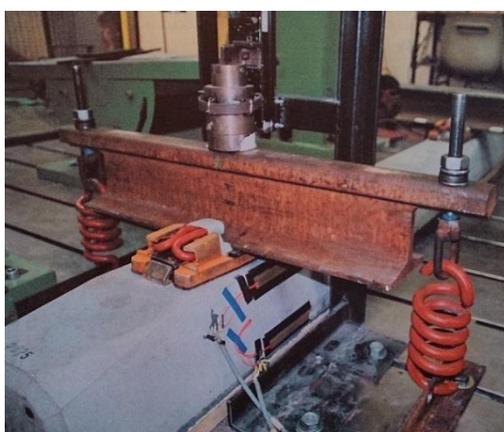


Figure 12: *Impact load attenuation. Preloading springs and mass felt on the rail head.*

### Fatigue tests (repeated loads)

A load is applied to the rail head with an angle to the vertical. The amplitude of the load and the angle of application depend on the system stiffness, and also on the track category the certification is performed for.

#### **Amplitude**

For a given track category (determined by a maximum axle load and a minimum curve radius), the amplitude of the load depends on the vertical stiffness of the system. Two categories are considered in the EN 13146-2:2012, and the respective amplitudes along the application axis are fixed as follows:

- soft systems with stiffness  $< 200$  MN/m, maximum amplitude of 70 kN,
- stiff systems with stiffness  $\geq 200$  MN/m, amplitude of 76 kN.

#### **Variation speed**

A quasi-static case is investigated for which the load variation speed is 100 kN/min. For the dynamic case, the load is applied at 4 Hz.

#### **Angle of application**

This angle depends on the track characteristics for which the system is intended to be certified. For tracks with maximum axle load of 260 kN, the angle is  $33^\circ$  for the track category C (minimum curve radius of 150 m), and  $26^\circ$  for the track category D (minimum curve radius of 400 m). This angle is obtained either by inclining the sleeper (or a 1/2 sleeper) and applying a vertical load or by using inclined arms exciting two rail seats (see Figure 13). For the inclined arms set-up, the EN 13146-4:2012 specifies that the two loading mechanism must allow free rotation of the rail under load and that a pivot linkage must be used either on top of both arms or between the jack and the repartition frame. In order to ensure that the load is equally spread over the two rails, the angle of application must be measured and verify the target at  $\pm 0.5^\circ$ . The load applied with the hydraulic actuator is adapted to the chosen set-up.

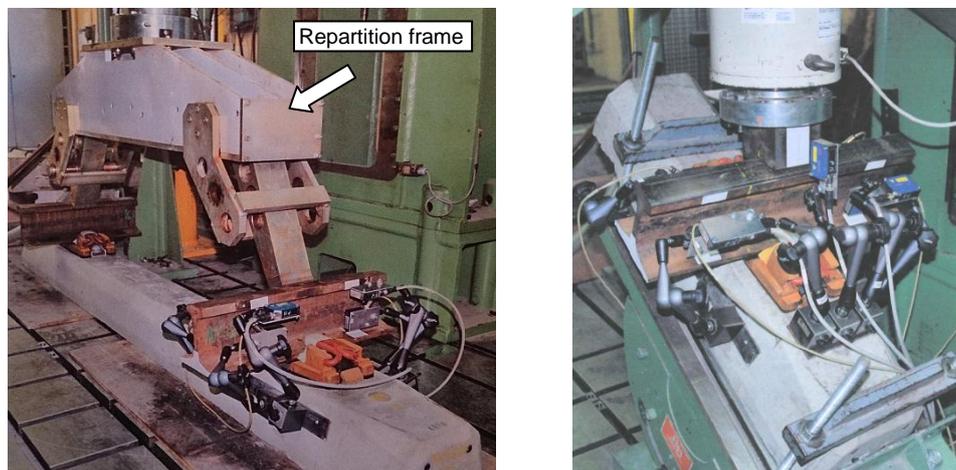


Figure 13: Repeated load tests. Left: inclined arms set-up. Right: inclined sleeper set-up.

#### **Measured quantities**

The rail foot displacement parallel to the rail vertical axis (from foot to head) is measured for 4 points: 2 points on each side of the rail, split on both sides of the fastening system. The rail head displacement (perpendicular to the rail foot displacement) is only measured on one side of the rail, for two points. These quantities are measured during the load cycles, and their residual values are also measured after cycles in order to be compared to the initial values. These measurements will be called "rail tilt" measurements.

### Load cycles

All the tests mentioned “before and after repeated loads” are performed before and after the fatigue tests described here. The rail tilt (described in the previous paragraph) is also measured before and after the fatigue tests, for a static and a dynamic excitation. The fatigue cycles consist in applying the dynamic excitation for  $3 \times 10^6$  cycles.

### Electrical resistance

Two pieces of rail are mounted on a sleeper which is exposed to a highly humid environment. The electrical resistance between the two rails is measured.

### Exposure to hard environmental conditions.

A piece of rail fastened to a piece of sleeper is exposed to a salty environment for 300 hours. The rail and the fastening system are then completely demounted and remounted. Each component is analysed with specific care.

## 5.3.2 Results

For each DFC system tested, the SNCF test laboratory produced a detailed test report that includes all the results of the certification tests. In this deliverable only some results are presented: example of curves that are used to extract indicators and also numerical values of some indicators extracted from the measurements. The results are not discussed in terms of good or bad values as such subjective criteria are not given in any standard.

### Dynamic stiffness before and after repeated loads

Force versus displacement curves are given in Figure 14 for the DFC 0 and in Figure 15 for the DFC 3.

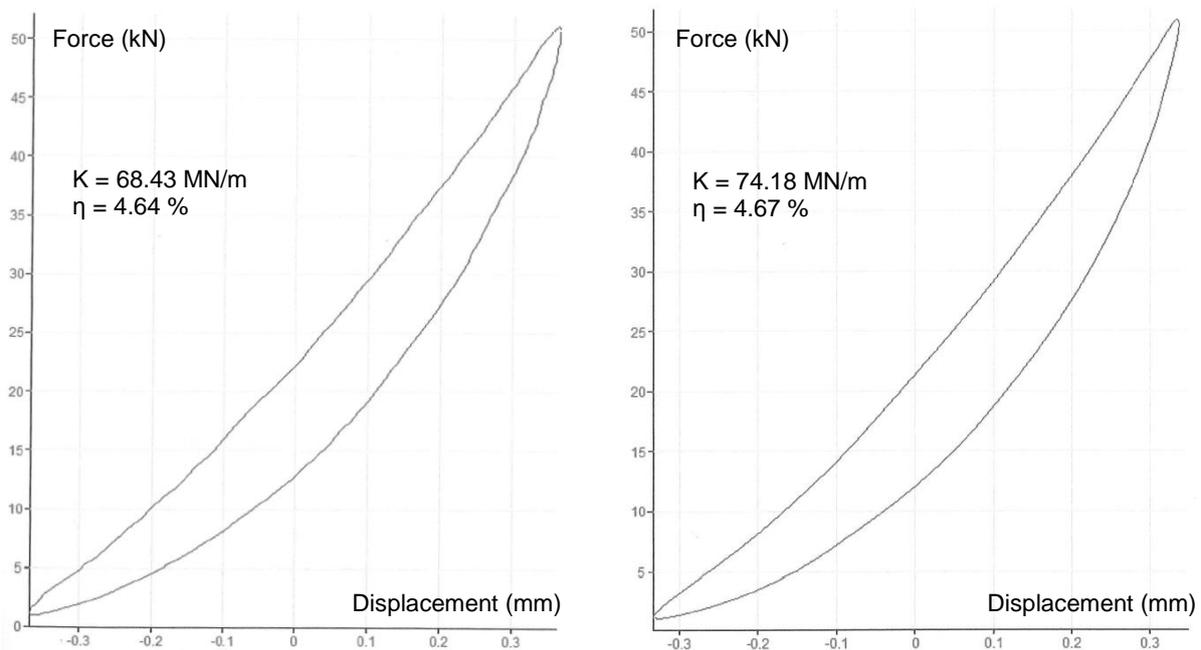


Figure 14: Vertical dynamic stiffness for DFC 0, before (left) and after (right) fatigue tests.

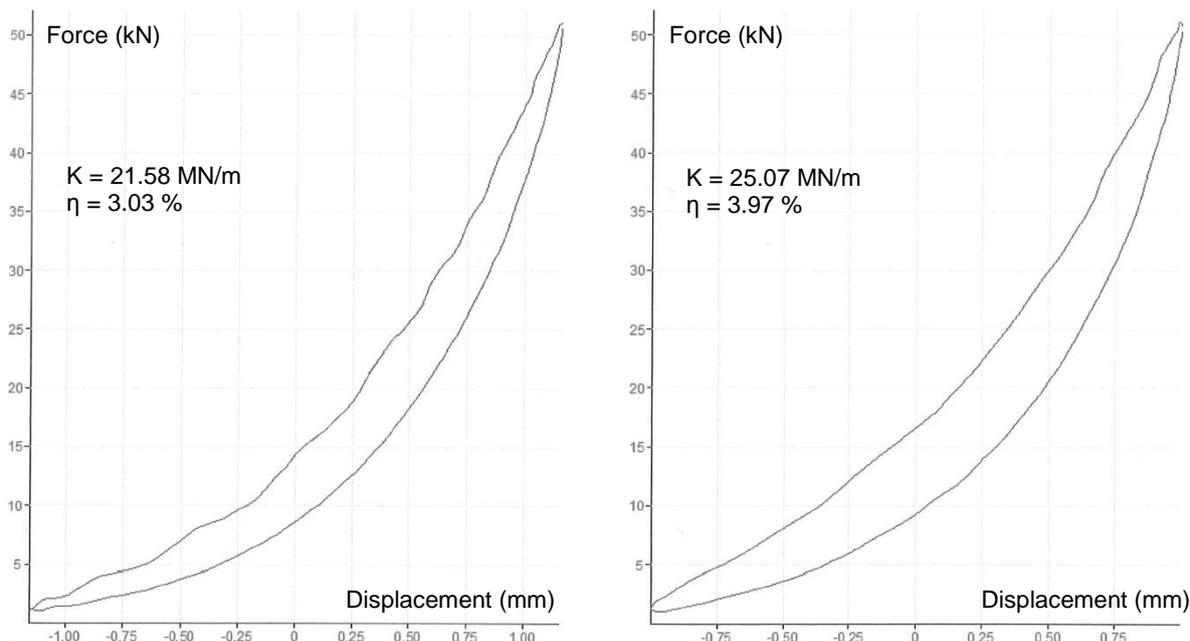


Figure 15: Vertical dynamic stiffness for DFC 3, before (left) and after (right) fatigue tests.

From Figure 14 and Figure 15, it is clear that the DFC systems have a non linear stiffness with respect to the load (banana shaped curves). This behaviour which is well known for rail pads seems to be more important for the DFC systems, and also more important for the softest systems.

Clamping force before and after repeated loads

DFC 0: 16.4 kN before fatigue tests and 14.7 kN after.

DFC 3: 15.5 kN before fatigue tests and 16.4 kN after.

These values do not move in the same way, which is an interesting but not understood result.

Creep resistance before and after repeated loads

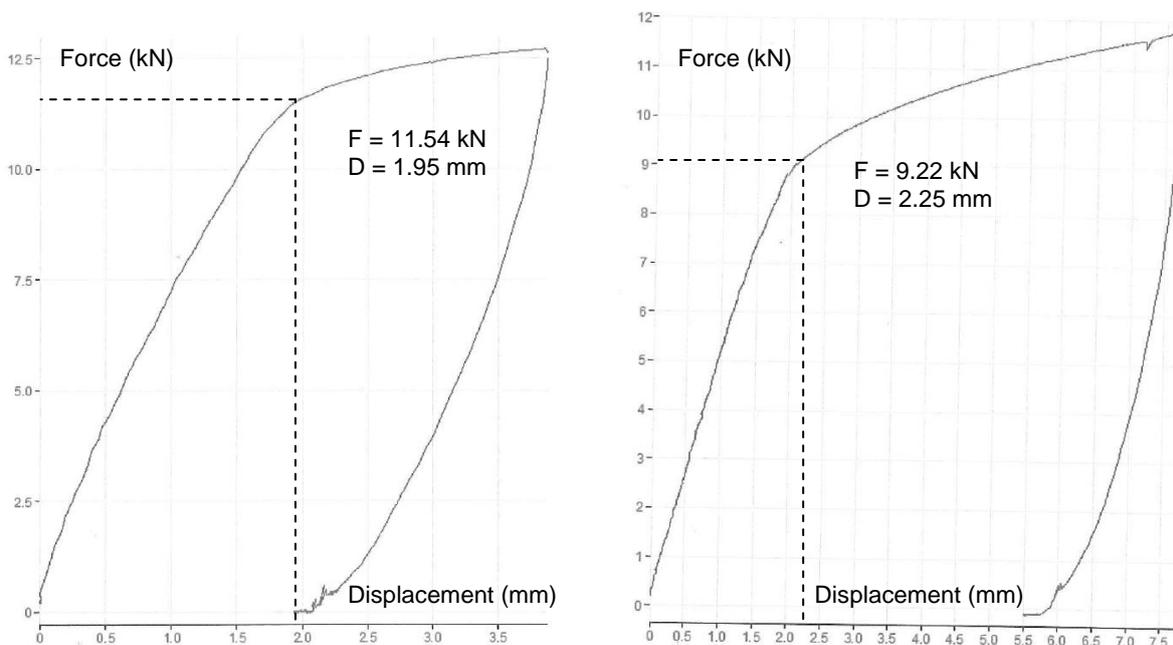


Figure 16: Creep resistance before fatigue tests for DFC 0 (left) and DFC 3 (right).

The stiffest DFC shows a higher creep resistance than the softest DFC. After fatigue tests, the creep resistance was 10.64 kN for DFC 0 and 9.10 kN for DFC 3.

### Clamping torque

In Figure 17, the rail displacement in degrees (relative to the rail longitudinal axis) is plotted against the applied torque in kN/m. The blue curve is the forward movement and the red curve the backward movement.

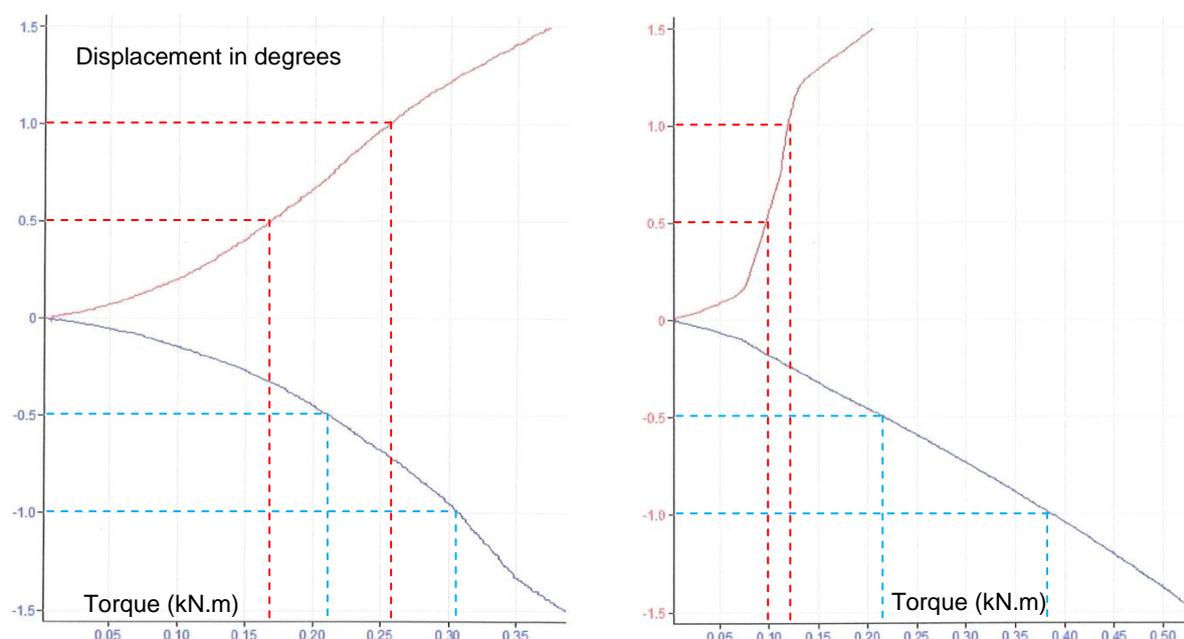


Figure 17: Clamping torque for DFC 0 (left) and DFC 3 (right).

DFC 0, forward: 0.30 kN.m at 1° and 0.21 kN.m at 0.5 °.  
 DFC 0, backward: 0.25 kN.m at 1° and 0.17 kN.m at 0.5 °.  
 DFC 3, forward: 0.39 kN.m at 1° and 0.22 kN.m at 0.5 °.  
 DFC 3, backward: 0.12 kN.m at 1° and 0.10 kN.m at 0.5 °.

### Fatigue tests

First, inclined loads were applied with the inclined arms set-up (Figure 13, left), as it is the set-up usually used by the SNCF engineering department. For this configuration, their habit is to use one arm fixed to the frame and the other arm free to rotate with respect to the frame. A pivot is used between the hydraulic actuator and the repartition frame. The tilt measurements are performed on the side where the arm is free to move. During the tests, the angle between the arms and the frame has to be controlled as specified in the standard part EN 13146-4:2012. Indeed, it is required to verified that the load is equally distributed over each arm and then over each fastening system.

As this requirement created difficulties to be achieved, it was decided to use the inclined sleeper set-up shown on Figure 13 (right).

At this time, the DFC 0 and the DFC 3 configurations have been tested and received agreement from the SNCF engineering department in order to be installed in the French network.

The DFC 2 system is currently being tested.

### Exposure to hard environmental conditions, Impact load attenuation and Electrical resistance

There was nothing to report concerning these tests. The look of the system after being exposed to hard environmental conditions is given in Figure 18.

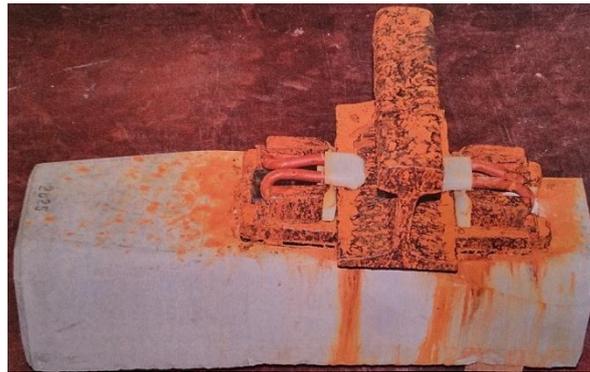


Figure 18: DFC system after exposure to hard environmental conditions (salty fog).

## 5.4 VANGUARD FASTENING SYSTEM

The tests performed on the VANGUARD system are the same tests as those performed on the DFC system. They are described in Subsection 5.3.1.

The first tests performed on the VANGUARD system were the repeated inclined loads as they seemed to be the most critical tests for soft fastening systems (as encountered with the DFC 3 system). The VANGUARD system was first tested with the inclined arms set-up (Figure 13, left), using one fixed arm and the other free to pivot. Here again, the angle between the free arm and the frame was measured several times, but always out of the limits fixed by the standard.

The next step would have been to use the inclined sleeper set-up in order to perform the fatigue tests correctly in accordance with EN 13146-4:2012. Unfortunately, the date of installation on track was approaching, and as the certification process was running out of time, priority was given to the DFC configurations.

This was also supported by another problem related to VANGUARD installation on track, and the way the stresses in the rail should be homogenized, as discussed later in Section 6.2. This homogenization is required by the SNCF engineering department after each change from one fastening system to another. The company that will proceed to this operation uses an automatic machine that needs to hold the rail under its head, which is not convenient with VANGUARD as this system uses this part of the rail to fasten it.

Nevertheless, the certification of the VANGUARD system will be completed, but with the inclined load set-up. It must also be noticed that the fatigue tests were performed in PANDROL laboratories following EN 13146-4:2012 requirements, and that no problem was found.

## 5.5 CERTIFICATION OF SOFT ASSEMBLIES FOR BALLASTED TRACKS: A SPECIFIC ISSUE

Today's tendency for fastening systems used on track is to use more and more soft systems. This is mainly due to these two reasons:

- There is a strong demand for ground-borne vibration reduction in urban areas where the railway traffic is getting denser, and also in exposed freight corridors. Soft fastening systems are economically viable solutions compared to ballast mats (in the case of existing tracks) and to the isolation of buildings from vibration.
- Soft systems are expected to improve some track performances and to maintain them for a longer time: roughness generation and growth, corrugation, ballast settlement, rail cracks, etc. These points are discussed in more detail in Section 8.

Due to evident safety reasons, the normative context that frames railway applications is very complete and complex. The standards are built based on the experience of the whole railway community, which implies that their writing is a long process.

In EN 13146-4:2012 (fatigue tests with repeated inclined loads), fastening systems are differentiated depending on their vertical dynamic stiffness in only two different categories: those which stiffness is below 200 MN/m and those which stiffness is greater or equal to 200 MN/m. This means that the classical SNCF fastening system with stiffness around 120 MN/m is treated in the same way as the VANGUARD with stiffness around 6 MN/m. It can therefore be questioned if the use of the same amplitude for all the systems below 200 MN/m is really representative to what they will experience on track, in real conditions. As already mentioned in the RIVAS deliverable 3.4 [2], the use of very soft fastening systems has a strong influence on the loads experienced by these systems.

Considering a given vertical point force  $F$  applied to the rail, the effective load that is transmitted to the sleepers through the fastening systems depends on the track stiffness and on the sleeper distance with respect to  $F$ . This effect is represented in Figure 19 where the load transmitted to the sleepers surrounding the force  $F$  is given at scale for DFC 0 (dark blue) and VANGUARD (yellow). The maximum load experienced by the fastening system is directly above the force and is  $F/2$  for DFC 0 and  $F/4$  for VANGUARD. For the DFC 0, the third sleeper away from the forcing point is no longer excited as the load is spread over a shorter distance than for the VANGUARD.

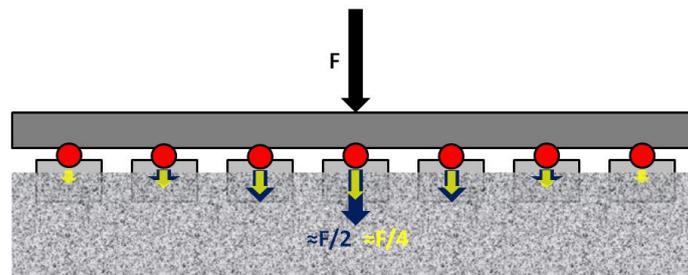


Figure 19: Load spread over the sleepers for DFC 0 (dark blue) and VANGUARD (yellow).

This difference in the maximum load rate applied to the system has two major consequences:

- The static preload around which the fastening system will work dynamically is not the same considering soft or stiff systems. As it is known that the elastic properties of railway pads are not linear with this preload, it might be useful to take this effect into account when determining the vertical stiffness of a fastening system. In the RIVAS deliverable 3.4 [2], the vertical stiffness of the VANGUARD and of the DFC assemblies was estimated with a set-up that included a preload. When the VANGUARD was being tested, the amplitude of the preload was reduced, admittedly for issues related to the hydraulic jack end of course, but it led to more consistent results.
- The maximum value for the load considered in the fatigue tests should be representative to the lateral forces experienced by the rail head in real conditions. This includes centrifuge inertia as well as the swaying forces arising from the wheel/rail excitations due to some geometrical defects (wheel flats, hanging sleepers, rail cracks and so on). For soft systems, these forces are also spread over more fasteners. Therefore, the amplitude of the maximum load applied in the fatigue tests should be adapted in order to account for this effect.

The last point concerning the soft fastening systems issue is the way the inclined load is applied within the fatigue tests. If the inclined arms set-up is used, it is imperative to scrupulously respect the angle of application in order to follow the EN 13146-4:2012 requirements. As it has been experienced during the tests of the DFC 3 and the VANGUARD, this task is harder to achieve for soft systems. It seems therefore preferable to use the inclined sleeper set-up.

## 6. DESCRIPTION OF THE FIELD TESTS

The field tests will be performed during September 2013. The selected site is presented in Section 6.1 and the different assemblies that will be tested are detailed in Section 6.2. The measurements that will be performed on this site are listed in Section 6.3.

### 6.1 SNCF LINE SELECTED FOR THE TESTS

The site for the field tests has been selected considering the following requirements:

- Try to install the M260-DFC sleepers within a track renewing operation (at least sleeper renewing) in order to minimize the installation costs.
- Track in alignment including two sections of 100m circulated by the same trains: a reference zone and a test zone.
- Track with UIC 60 rail (DFC and VANGUARD are designed for this type of rail).
- Line with freight traffic.
- Easy access around the test and the reference sections (sensors placement and equipment conveyance).
- Allowing measurements at an appropriate date *i.e.* after the sleepers and the system are produced and soon enough before the end of the project.

Under these requirements, only 1 site was eligible. It is located in the North-East of France, on the line 204000 between the kilometer marker 272 and 273 near the city of Florange.

Everywhere on the line but the test section, M450 sleepers will be installed. Their height is 220 mm which is the equivalent height of the M260-DFC sleepers (170 mm) plus the extra height due to the DFC base-plate. This ensures the rail to be leveled along the track.

Nevertheless, according to the French railway legislation, this type of change in the fastening system must be done for at least 150 m, consecutively. The zone is then considered as a homogeneous section and not as a specific spot that would require additional tests and survey.

The stiffness of the fastening system will vary from 120 MN/m in regular track (FASTCLIP system directly installed on the sleeper) to 25 MN/m in the test section equipped with DFC 3. If a running train would experience such a gap in the track stiffness, it would lead to high wheel/rail interaction forces which are potentially damageable for the rail and the track foundation (ballast). In order to avoid this risk, the stiffness variation from stiff track to soft track is achieved using transition zones with intermediate stiffness (see RIVAS deliverable 3.4 [2] for more details).

A satellite view of the test site is given in Figure 20 in which the different zones are located.



Figure 20: Test site with reference section, test section and transition zones (GoogleEarth).

## 6.2 CONFIGURATIONS TESTED

As previously said in Section 5.4, the VANGUARD system will not be tested within this measurement campaign and only the DFC system will be tested. The Table 3 gives an overview of the different configurations that will be sequentially installed on each zone of the tests section, including the Under Rail Pad type (URP) and the Under Base-plate Pad type (UBP).

Config.	Sleeper	M450	M450	M260	M260	M260	M450	M450
	Length	20m	20m	25m	100m	25m	20m	20m
DFC 0	URP	120 MN/m						
	UBP			270 MN/m	270 MN/m	270 MN/m		
DFC 1	URP	60 MN/m						
	UBP			270 MN/m	270 MN/m	270 MN/m		
DFC 2	URP	60 MN/m	40 MN/m	60 MN/m				
	UBP			270 MN/m	270 MN/m	270 MN/m		
DFC 3	URP	60 MN/m	40 MN/m	120 MN/m	120 MN/m	120 MN/m	40 MN/m	60 MN/m
	UBP			64 MN/m	64 MN/m	64 MN/m		

Table 3: The different configurations that will be tested sequentially.

Each configuration will be tested for 3 days which corresponds to approximately 30 trains. After each configuration is tested, an intervention on track has to be planned in order to change the different pads as follows:

- DFC 0 → DFC 1: 230 m of URP to change.
- DFC 1 → DFC 2: 190 m of URP to change.
- DFC 2 → DFC 3: 150 of URP and 150 of UBP to change.

These changes will be operated by the private company which is in charge of the track renewal. These operations are not harmless as they will be achieved by day, in summer, with potentially high temperatures of the rail. This will require 150 m of rail to be fully unclipped which could lead to disastrous buckling of the rail. This is usually not allowed in the French network.

Therefore, a complete study was performed by the SNCF engineering department concerning this issue. As the concerned section is in alignment, the URP and UBP changes have been authorized under certain conditions:

- Unclip and re-clip the rail at a temperature close to the release temperature of the rail (temperature at which the strains have been released in the rail after the renewing operation).
- Homogenization of the strains in rail along the whole section (test section + transition zones) after every URP or UBP change.

For the duration of the construction, the work is done on day time with no commercial train on the track. Every night, the freight traffic starts again with around 10 trains per night. The speed is limited for 7 days after a track section is rebuilt, which is the time required for the track to be stabilized. Then, the trains will run at 90 km/h. Therefore, if the DFC 0 system is installed on day D, the measurements can start on day D+7.

## 6.3 MEASURED QUANTITIES

The RIVAS measurements will be performed during the track renewal campaign that ends in November 2013. During day time, the track is closed and accessible in safety conditions for long time slots between some work trains pass-bys. Track and soil characterization are then performed on day time, as pass-by measurements are acquired on night time using automatic triggers.

Most of the measurements concern the reference site as well as the test site, for each configuration tested, as required in the RIVAS deliverable 3.1 [6]. They will be performed by two teams: the SNCF Railway Tests Agency (AEF) and VIBRATEC, member of the RIVAS consortium.

### 6.3.1 Track and soil characterization

The track and soil characterization measurements that will be performed are listed in Table 4.

Reference site			Test site		
AEF			AEF		
Nature	When ?	Description	Nature	When ?	Description
Low frequency track receptance	Before and after the tests	Excitation with large hammer, on the rail, at mid-span and above a sleeper, 10 impacts	Low frequency track receptance	DFC 0, DFC 1, DFC 2 and DFC 3	Excitation with large hammer, on the rail, at mid-span and above a sleeper, 10 impacts
High frequency track receptance	Before and after the tests	Excitation with small hammer, on the rail, at mid-span and above a sleeper, 10 impacts	High frequency track receptance	DFC 0, DFC 1, DFC 2 and DFC 3	Excitation with small hammer, on the rail, at mid-span and above a sleeper, 10 impacts
Near Field to Free Field Ground Vibration Transfer Function	Before the tests	Excitation with large hammer on a steel plate close to the track, Ground vibration sensors, 70 impacts	Near Field to Free Field Ground Vibration Transfer Function	Before the tests	Excitation with large hammer on a steel plate close to the track, Ground vibration sensors, 70 impacts
Track to Ground Vibration Transfer Function	Before and after the tests	Excitation with large hammer, on the rail, at mid-span and above a sleeper, 70 impacts	Track to Ground Vibration Transfer Function	DFC 0, DFC 1, DFC 2 and DFC 3	Excitation with large hammer, on the rail, at mid-span and above a sleeper, 70 impacts
Rail Roughness	No specification	Following EN 15610	Rail Roughness	No Specification	Following EN 15610
MASW Soil Characterization	Option	Depends on Soil/Soil TF	MASW Soil Characterization	Option	Depends on Soil/Soil TF
VIBRATEC			VIBRATEC		
			Track to Ground Vibration Transfer Functions along the Rail	DFC 0 and DFC 3	Excitation with large hammer on the rail, each 1 m, over 17 m, Ground vibration sensor.
			Sleeper to Ground Vibration Transfer Function	DFC 0 and DFC 3	Excitation with large hammer on 1 sleeper, on both sides of the rail

Table 4: Track and soil characterization measurements.

The soil characterization will be investigated in a first phase with these two measurements: rail to ground and ground to ground transfer functions. For the latter one, the ground will be excited with a large impact hammer close to the ballast embankment (for reference and test site) through a massive steel plate. The ground vibration will be measured at a distance of 8 m (three times), 16 m and 32 m to the track<sup>2</sup>. These transfer functions will be useful to immediately quantify the homogeneity between the soils of each site. Following the first conclusions obtained with this basic soil characterization, a MASW (Multichannel Analysis of Surface Waves) characterization of the soils might be performed.

Track receptances and roughness measurements are planned for two major issues: better knowledge of the track and indirect Insertion Loss assessment.

Vibratec, member of the RIVAS consortium, proposed additional measurements for further investigations. In order to assess ground vibration with a line source approach, they will measure the track to ground transfer function for consecutive points over 17 m along the rail.

<sup>2</sup> The ground vibration at pass-by (see Table 5) will be measured at the same locations, with the same sensors.

### 6.3.2 Pass-by measurements

The pass-by measurements that will be performed are listed in Table 5.

Reference site		Test site	
AEF		AEF	
Nature	Description	Nature	Description
Vertical Ground Vibration	Accelerometers at 8 m (3 times), 16 m and 32 m to the track	Vertical Ground Vibration	Accelerometers at 8 m (3 times), 16 m and 32 m to the track
Vertical Rail Vibration	Accelerometer under the rail foot at midspan	Vertical Rail Vibration	Accelerometer under the rail foot at midspan
Vertical Sleeper Vibration	2 accelerometers on both sides of the rail, for 2 consecutive sleepers	Vertical Sleeper Vibration	2 accelerometers on both sides of the rail, for 2 consecutive sleepers
Pass-by Noise	1 microphone at 7,5 m to the track, at 1,2 m height	Pass-by Noise	1 microphone at 7,5 m to the track, at 1,2 m height
Train Speed and Axles Detection	2 electromagnetic detection pedals at one section's end	Train Speed and Axles Detection	2 electromagnetic detection pedals at one section's end
VIBRATEC		VIBRATEC	
X		Rail/Sleeper Vertical Relative Displacement (DFC 0 and DFC 3)	2 displacement sensors on 7 consecutive sleepers
		Vertical Sleeper Vibration (DFC 0 and DFC 3)	2 accelerometers on both sides of the rail, for these 7 sleepers
		Low Frequency Vertical Sleeper Vibration (DFC 0 and DFC 3)	1 accelerometer with mechanical low-pass filter on 5 of the 7 sleepers

Table 5: *Pass-by measurements.*

With SNCF measurements (AEF), equivalent levels at pass-by will be processed and the mitigation of ground borne vibration will be directly assessed in terms of Insertion Loss. Vibratec measurements will assess an indirect estimation of the wheel/rail contact force.

## 7. SUCCESSFUL INSTALLATION

While this deliverable was under its final reviewing process, the M260-DFC sleepers equipped with the DFC 0 systems were successfully installed, as shown in Figure 21.



Figure 21: *M260-DFC sleepers and DFC system installed on track. Test track and construction train (left). Transition between M450 sleepers with FASTCLIP and M260-DFC sleepers with DFC 0 (right).*

## 8. LONG TIME SURVEY

After the tests, the soft configuration of the DFC will stay on track for 2 years, as demanded by the French infrastructure owner RFF. The first reason why a long time survey is undertaken is because a new component is installed on track. The definitive certification of the DFC system will be delivered only after a certain time during which potential defects or breakdowns are inspected. Moreover, following on from the RIVAS results, it is important to verify that the mitigation performances of the DFC are lasting with time.

However, there are some specific effects that are expected from soft and very soft fastening systems. Some of them have already been shown from numerical studies and/or measurements, as for example:

### Roughness/Corrugation Generation and Growth

The roughness/corrugation generation and growth is mainly related to the tribological properties of the rail, of the wheel and of the wheel/rail contact, but it is also dependant on the wheel/rail interaction forces. These forces are driven by the vehicle and track dynamics, and therefore by the properties of the track components. In his PhD thesis [8], Croft showed numerically that soft fastening systems can reduce the development of the acoustic roughness (wavelengths between 1 cm and 50 cm approximately). Concerning corrugation, even if the phenomena at work are more complex, the characteristics of the wheel/rail interaction forces are still determining. In this case, soft systems are also expected to be a potential mitigation measure, as mentioned by Grassie in [9] for example. Measurements are currently being performed on the French high speed network using soft rail pads within a FASTCLIP system. The stiffness of these pads is 40 MN/m which is quite stiffer than the 25 MN/m of the DFC 3. The long time survey of the DFC 3 system will then show if softer systems lead to even "better" roughness or if a lower limit should be considered.

Some other effects are for the moment only expected, and will then be investigated with this long time survey of the DFC 3 system.

### Reduction of track geometrical defects

With soft fastening systems, there is less energy transmitted from the wheel/rail contacts to the track than for stiff systems. This energy is dissipated by the resilient elements but is also kept in and dissipated by the rail, which besides may lead to an increase of the rolling noise. With less energy being transmitted to the track, it can reasonably be expected that track degradation will happen later and with less magnitude. Ballast settlement phenomena and also hanging sleepers' outbreak might be limited, with the following effects:

- Less maintenance needed, increase of the track life cycle.
- Less parametric excitation due to more homogeneous longitudinal track properties, and therefore less ground vibration.

Therefore, the following measurements will be performed during the two years of use of the DFC 3: longitudinal geometry (roughness and long wavelength defects), ballast settlement, ground vibration and general inspections.

## 9. CONCLUSION

There is a long way to go from the numerical assessment of the mitigation measure performances to the measurement of these performances in real traffic conditions. In this deliverable, all the steps that make up this process are presented for what concerns the test of the PANDROL DFC and VANGUARD systems.

From existing designs intended for slab tracks, PANDROL, Sateba and SNCF worked together to design new versions of DFC and VANGUARD, and also a new sleeper (M260-DFC) on which both systems are compatible. Based on the DFC design (under base-plate pad, cast-iron base-plate and rail pad), 4 DFC assemblies are proposed with different global stiffness achieved using different materials for the pads. They are called DFC 0 to DFC 3, and their stiffness varies from 25 MN/m to 75 MN/m. The VANGUARD stiffness is 6 MN/m.

In order to be installed in a track with a commercial freight and passenger traffic, these new components were required to meet specific criteria related to railway security. Moreover, as RFF showed his interest for soft fastening systems by asking for a two-year test of the DFC system, a complete certification process was finally needed for the DFC and the M260-DFC sleeper. During the certification tests which were performed by the SNCF track engineering department, difficulties were encountered to follow EN 13146-4:2012 requirements when applying inclined loads to the DFC 3 and the VANGUARD. Solutions were found for the DFC 3, which is now authorized by SNCF track engineering department to be put in the selected test track on the French railway network. Unfortunately, due to a lack of time between the certification and the field tests, the VANGUARD system has to be put aside, and therefore will not be tested on track for the moment.

The work performed in the Work Package 1 of the RIVAS project led to a detailed procedure for the experimental assessment of the efficiency of a mitigation measure. Following these requirements, a test section has been found with a track renewal operation planned at an appropriate date with respect to the end of the RIVAS project. Pass-by measurements and standstill track and ground characterisation will be performed on two straight track sections: a reference section with no mitigation measure, and a test section where the 4 DFC systems will be sequentially installed and tested. These measurements will allow direct and indirect estimation of the Insertion Loss.

As the DFC 3 system (the softest one with 25 MN/m) will stay on track for two years, complementary studies will also be performed throughout these two years. The influence of this very soft fastening system will be checked on the rail roughness/corrugation evolution, on the track geometrical defects outbreak and on the ballast settlement. A better behaviour of these track characteristics towards track maintenance, noise and ground vibration issues is expected. The mitigation of ground borne vibration with the DFC system will be assessed in terms of immediate effects as well as long term effects.

We are proud to announce that the M260-DFC sleepers equipped with the DFC systems are installed on track since August 2013.

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