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Condition Monitoring of Dual Gauge Switches and Crossings for Assessing Their Dynamic Behaviour Under Railway Traffic

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Abstract

In recent years, a three-rail, dual gauge track system for speeds up to 160 km/h has put into service in some railway lines in Spain. This pretends to solve the historical interoperability handicap caused by the adoption of the Iberian track gauge (1,668 mm) instead of the standard gauge of 1,435 mm in the conventional rail network. The solution includes a novel design of dual gauge switches and crossings (S&C), so there is little experience regarding its behaviour under real operating conditions. For this purpose, this paper presents a monitoring setup for registering vertical displacements and accelerations at different S&C cross-sections under the passing of different types of train traffics. Main results show that the common rail side shows sleeper vertical displacements 2 to 3 times higher than the dedicated rail side. In addition, there are relevant displacement variations along the different analysed sections in both sides and in both track gauges. The gathered data helps understanding and improving the performance of this new track system, which may be exported to other some other countries with different track gauges.

Keywords: switches and crossings, dual gauge turnouts, dual gauge track, train-track interaction, track monitoring, condition monitoring.

1 Introduction

Railway transport takes advantage respect to other means of transport for moving goods at long distances (> 500 km) and for moving people at distances from 200 to 700 km in high-speed services. Nevertheless, railway networks, unlike other means of transport, were conceived as national networks, thus leading to some interoperability problems among different countries. For the case of Spain and Portugal, together with differences in catenary voltage and signalling systems, they have a wider track gauge (1,668 mm) compared to the rest of centre-European countries (1,435 mm). To overcome this handicap, in recent years, a dual gauge, high performance, track system has been implemented in some Spanish lines connecting with the French border. This system consists of a three-rail railway track allowing for both standard and iberian track gauges. Unlike other dual gauge tracks, this system was designed for speeds up to 200 km/h and it is currently operated at speeds up to 160 km/h, bearing all kinds of railway traffic (commuter, regional, long distance and freight trains).

On of the oddest points of this system are switches and crossings (S&C). In conventional railway tracks, S&C are singular spots where some discontinuities in the rolling contact appear, yielding an increase in the magnitude of interaction forces and stresses [1]. For this reason, significant effort has been paid to monitor their working conditions [2]. Condition monitoring in S&C can be carried out either from track side or from vehicle side. The first case includes the use of accelerometers [3], [4], laser scanners [5] or diffuse ultrasonic wave-based sensors [6]. The second case includes the use of axlebox accelerometers [7], [8]. Moreover, the monitoring process can be enhanced by using AI solutions [9].

For the case of dual gauge track systems, the number of related works is lower due to the specificity of such track systems. Related works aim at analysing structural workout [10], passenger train running stability [11], behaviour at higher speeds [12], and thermal track buckling [13]. In dual gauge S&C, there are double crossings and multiple points, increasing the number of discontinuities in the rolling path. Moreover, singularities typical from S&C are combined with particularities of three-rail, dual gauge track systems, making worth to develop a specific setup for the condition monitoring of these particular infrastructure assets.

Figure 1: Dual gauge S&C.

2 Experimental setup

The experimental setup consists in monitoring seven cross-sections of a dual gauge S&C, including switch, closure and crossing panels. Plus, a main track section was also monitored as a reference. This type of S&C allows both track gauges on direct and diverging track, as shown in Figure 1. In this case, the S&C is designed for speeds up to 200 km/h on the direct track and 60 km/h on the diverging track. This type of dual gauge S&C allow several configurations, depending on the side where the common rail is presented respect to the diverging direction. In this case, the S&C diverges towards the common rail, as shown in Figure 1 as well. This means the existence of a set of particular points where stresses and impacts are more likely to occur. These are:

- Switch toes in all three rails
- Obtuse crossing, where the rail of the wider gauge in the diverging track crosses the rail of the narrower gauge of the direct track. In this case, the difference between both gauges, i.e. standard and iberian, is 233 mm. This would mean a huge gap between the wing rail and the crossing nose, so this crossing also has moveable points which eliminates rail gaps and allows a continuous rolling path.
- Trimetallic welds, at the beginning and the end of the double-crossing frog. This type of weld allows the junction between conventional steel and manganese steel.
- Double crossing frog. This element includes the crossing of the diverging rails of both track gauges with the direct common rail. In this case, both crossings are fixed, presenting a double discontinuity in the contact surface for the straight direction of the S&C.

For these reasons, Figure 2 shows the different monitored sections, which are further described in Table 1

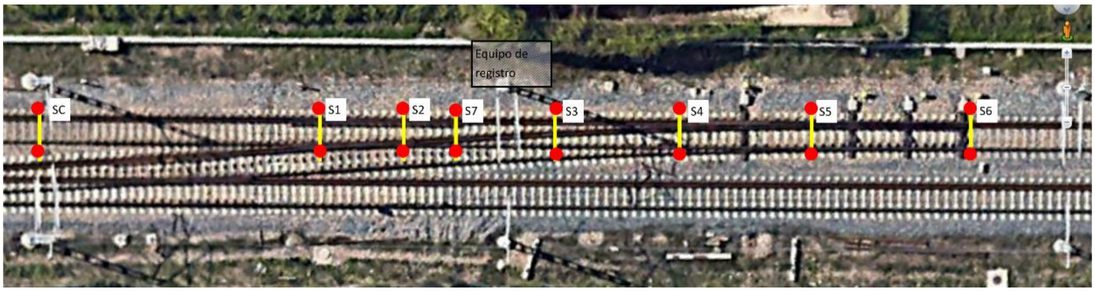

Figure 2: Monitored sections of dual gauge S&C.

All sections, but S3, were fitted with potentiometer displacement sensors. Section 3 was fitted with capacitive accelerometers. In addition, displacements and accelerations were measured in each section at both ends of the respective sleeper or bearer, as represented by the red dots in Figure 2.

Section name	Measured variable	S&C section
S1	Displacement (mm)	iberian rail crossing
S2	Displacement (mm)	standard rail crossing
S3	Acceleration (m/s^2)	closure panel
S4	Displacement (mm)	Obtuse crossing
S5	Displacement (mm)	switch rail joint
S6	Displacement (mm)	switch toe
S7	Displacement (mm)	trimetallic weld
SC	Displacement (mm)	main track (control section)

Table 1: definition and location of monitored sections.

For the case of displacements, sensors were attached to the sleeper. In each measuring point a 50 cm pike was hammered into the ballast so as to have a solid reference. Then, a 5 cm baseplate was screwed to the end of the displacement rod. Figure 3a shows this particular setup.

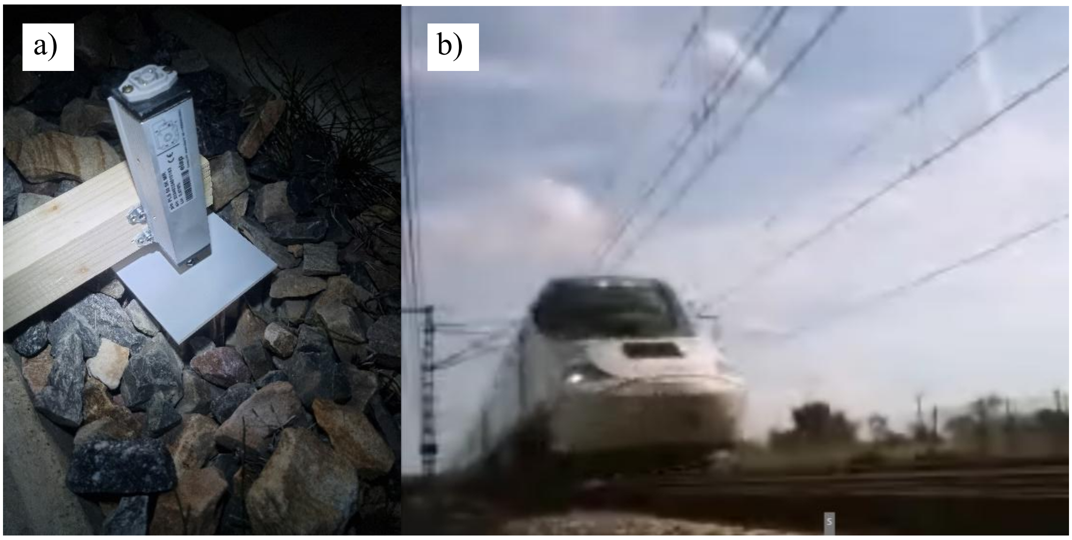

Figure 3: Measurement of sleeper-ballast displacement (a) and video frame for rolling stock identification (b)

Together with the displacement/acceleration data, an ActiveX webcam was connected to the computer to check the rolling stock passing in each measurement, as shown in Figure 3b. All the sensors and the webcam were controlled by a data acquisition software and data were low pass filtered at 300 Hz and sampled at 1 kHz. In order to allow for an automatic data registration, the following trigger conditions were simultaneously set up:

- Displacement sensors achieved a variation of 0.5 mm in less than 0.1 s
- Accelerometers reached an absolute value of 1 m/s^2.

All the system, including the sensors, the data acquisition module and the computer, was fed by means of solar panels and batteries. The system registered a total of 95 trains for 2 days, including long distance, regional, commuter and freight trains.

3 Results

For showing the main findings, train series 130 and 100 have been chosen among all the measurements. Both series are used in Spain for long-distance, high-speed services and have similar features. Series 130 was manufactured by Talgo and has two locomotives with a Bo’-Bo’ wheelset arrangement, placed at the ends of the composition. Between both locomotives there are 11 passenger cars, resting on single articulated wheelsets, placed between its adjacent cars as usual in Talgo layouts. Traction wheelsets have an axle load of 18 t, whereas trailer wheelsets have an axle load of 15.3 t. Series 100 was manufactured by Alstom. Again, it has two locomotives with a Bo’-Bo’ wheelset arrangement, placed at the ends of the composition. Between both locomotives there are 8 passenger cars, resting on articulated bogies placed between its adjacent cars. Traction wheelsets have an axle load of 17.2 t, whereas trailer wheelsets have an axle load of 15.8 t. In the measuring point, train series 130 were running on the iberian gauge, whereas train series 100 were running on the standard gauge. Figure 4 shows train series 130 (a) and 100 (b)

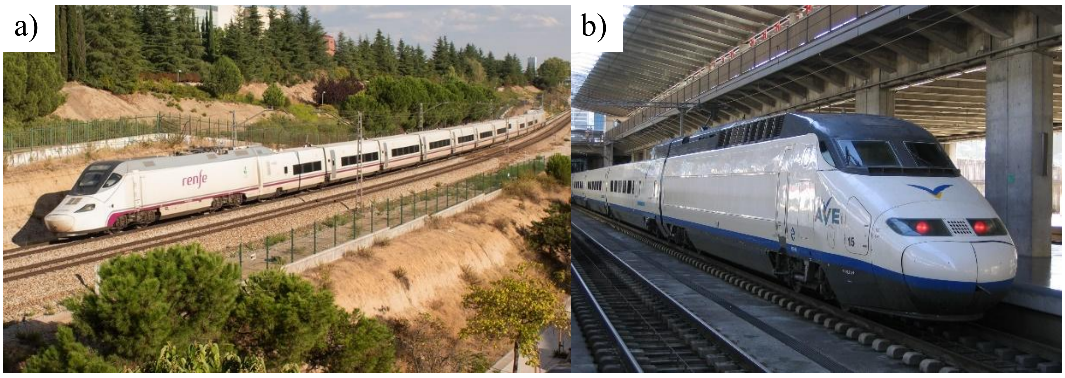

Figure 4: Train series 130 (a) and series 100 (b)

Within this framework, Figures 5 and 6 show the sleeper settlements at section 2 (standard gauge diverging rail crossing with the direct common rail) for all wheelsets of train series 130 and for both the common rail (inner rail) and the iberian gauge rail (outer rail), respectively. In each figure, a total number of 7 train runs from the same train series is represented, giving an idea about the scattering of results.

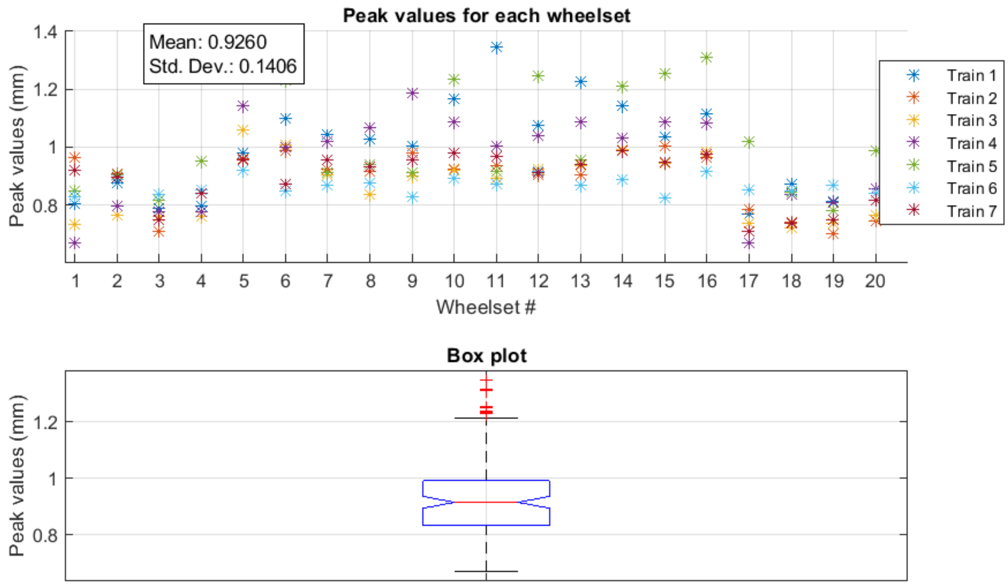

Figure 5: sleeper settlements for each wheelset of train series 130 at section 2, inner rail.

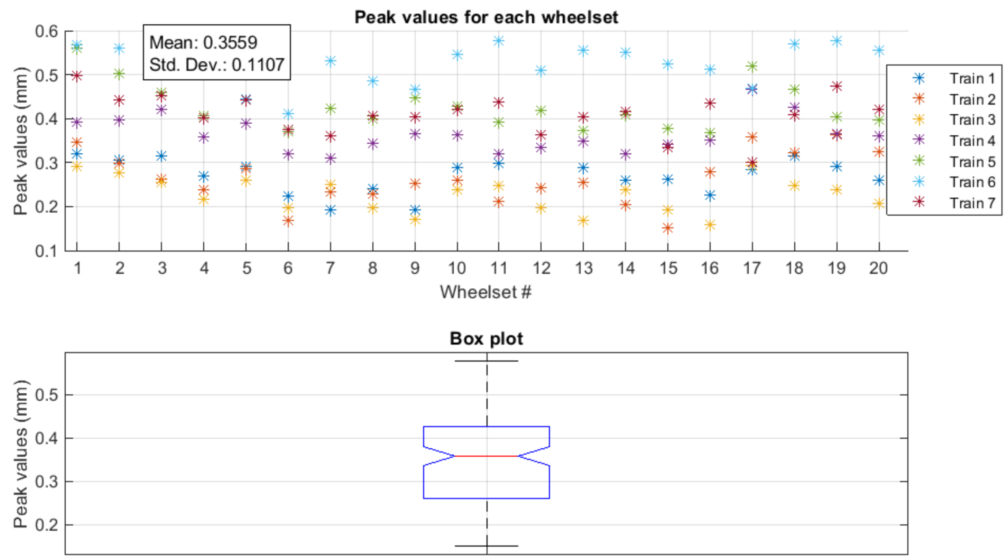

Figure 6: sleeper settlements for each wheelset of train series 130 at section 2, outer rail.

In these measurements, all trains were running at speeds between 127 and 158 km/h. As one can see, the inner rail shows higher settlements, since this rail presents the gap in the rolling path caused by the presence of the frog. Settlements in the inner rail are 3 times higher than in the outer rail. For the case of the inner rail, there are peaks above 1.2 mm that can be considered as outliers, as shown in the box plot of Figure 5. In addition, in the inner rail, trailer wheelsets (# 5 to 16) show higher settlements compared to motor wheelsets. On the contrary, no significant differences are found in the sleeper settlements between motor and trailer wheelsets in the outer rail.

In an analogue way, Figures 7 and 8 show the sleeper settlements at the same section for all wheelsets of train series 100 for both the common rail (inner rail) and the standard gauge rail (outer rail), respectively. In this case, only 3 trains of the same kind were recorded, with speeds of 144, 147 and 143 km/h, respectively. For this case, settlements in the inner rail are 2.6 times higher than in the outer rail. Compared to series 130, settlements are slightly lower in both rails, due to a slightly lower axle load and a better train/track interaction dynamics. Furthermore, there are no significant differences between motor and trailer wheelsets. Regarding the dispersion of results, box plots in these figures show significant variation ranges compared to their respective mean values despite their similar train speeds. This finding highlights the fact that there are several parameters influencing train/track dynamic interaction which produce important uncertainties in the settlements estimation.

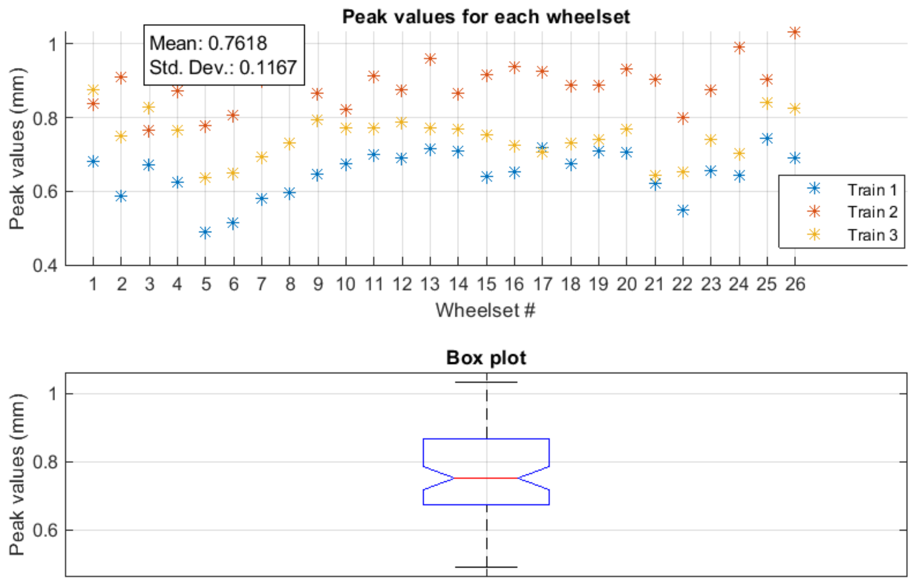

Figure 7: sleeper settlements for each wheelset of train series 100 at section 2, inner rail.

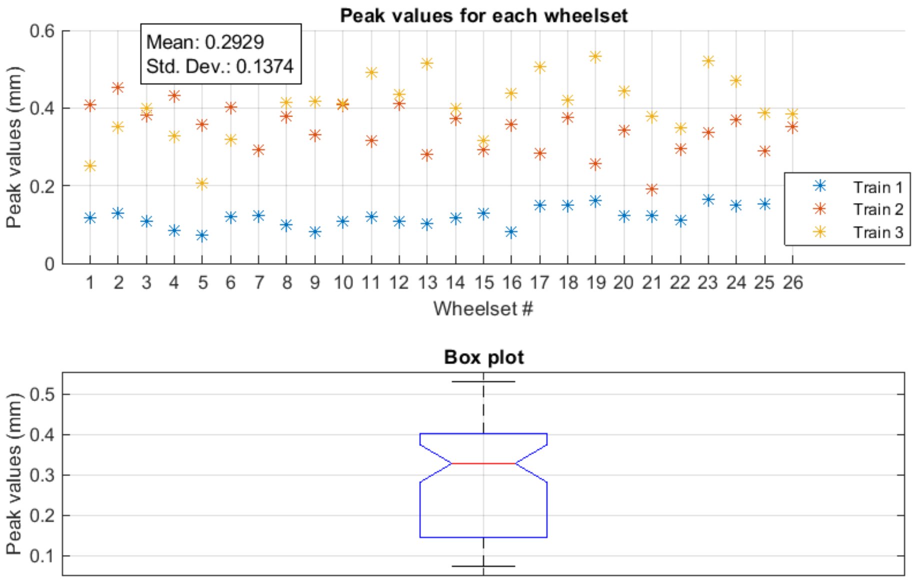

Figure 8: sleeper settlements for each wheelset of train series 100 at section 2, outer rail.

Finally, in order to analyse the settlement variation along the S&C and compared to a main track section, Figure 9 shows the settlements produced by the first wheelset of each train series at both ends of each monitored section. Sections are represented according to their position along the S&C and the trains running direction, taking as a reference the switch toe section. This figure shows that, in general terms, settlements in the inner rail are larger than in the outer rail, including the control section. This behaviour is caused by the additional stiffness that the double rail provides in the outer side of the track, which spreads the vertical loads in a longer space and yields lower settlements. Furthermore, in those sections where there is a discontinuity in the rolling path and wheel/rail impacts are produced, settlements increase significantly. This increment is particularly important in section S1, coinciding with the second crossing. Despite this, even in the outer rail of the iberian gauge, where no discontinuities are found, settlements vary from 0.1 to 0.56 mm between sections S7 and S2, meaning a strong stiffness variation in such a short distance.

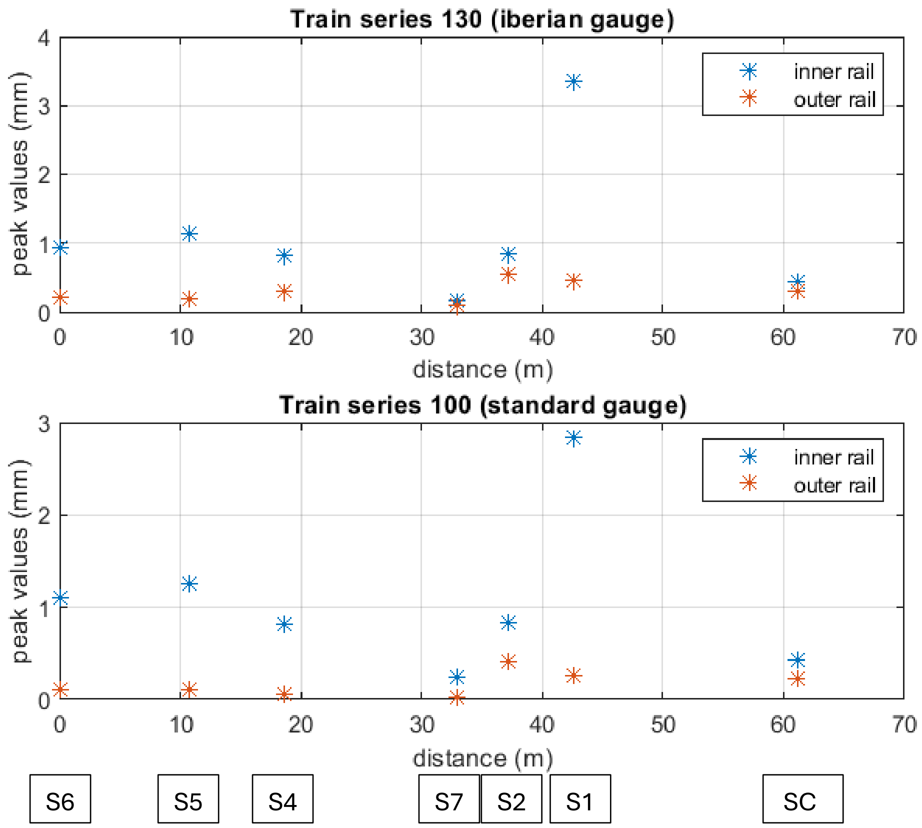

Figure 9: sleeper settlements at different sections for train series 130 and series 100

4 Conclusions and Contributions

An experimental setup for monitoring the mechanical behaviour of a dual-gauge switch and crossing (S&C) against the passing of railway traffic has been presented. The monitoring setup measures vertical displacements or accelerations at seven different cross-sections of a S&C, plus an additional section at the main track. Each cross-section includes two measuring points located at both ends of the respective sleeper or bearer. The setup recorded 95 train passages, including long distance, commuter and freight trains, running on both gauges, i.e. iberian and standard. As main findings, firstly, a significant dispersion in the vertical settlements can be appreciated for trains of the same series running at similar speeds and similar axle loads. This finding is recurrent in different sections in both sides and for trains running on both gauges. Furthermore, settlements in the inner rail are consistently larger than in the outer rail for all sections and gauges. The differences increase in those sections which present a discontinuity in the rolling path. Finally, settlements also vary significantly along the different sections, being larger in the inner rail but relevant in the outer rail as well. Therefore, this dataset can be useful for delving in understanding the behaviour of this kind of S&C and for calibration and validation of different finite element and discrete element models.

Acknowledgements

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