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Trong Vinh Duong, Yu-Jun Cui, Anh Minh Tang, Nicolas Calon ...+1 more authors

Institutions: École des ponts ParisTech, SNCF

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Assessment of conventional French railway sub-structure: a case study

Duong T.V.[1], Cui Y.J.[1], Tang A.M.[1], Calon N.[2], Robinet A.[2]

[1]: Ecole des Ponts ParisTech, U.R. Navier/CERMES, 6 – 8 av. Blaise Pascal, Cité Descartes,
Champs – sur – Marne, 77455 Marne – la – Vallée cedex 2, France
[2]: French Railway Company (SNCF)

Corresponding author:
Prof. Yu-Jun CUI
Ecole des Ponts ParisTech
6-8 av. Blaise Pascal, Cité Descartes, Champs-sur-Marne
F-77455 Marne – la – Vallée cedex - France
Telephone: +33 1 64 15 35 50
Fax: +33 1 64 15 35 62
E-mail: yujun.cui@enpc.fr

Abstract

A statistical study was firstly undertaken on problems occurred in a period of more than one year and related to the circulation of train in the whole conventional French railway network. Emphasis was put on the degradation of track components. The analysis evidenced the particular importance of sub-grade quality in the performance of the whole track. After this general analysis, a conventional railway line in the West of France was investigated. In the sub-structure of this line, an interlayer was identified that has been created mainly by interpenetration of ballast and sub-grade. In the analysis, the degradation rate of this line was correlated with different parameters such as the nature of sub-grades involved along the line and the thickness of different layers. The results showed that the degradation rate is correlated to the thickness of various layers. Furthermore, it was observed that the interlayer plays an important role in the performance of tracks as it represents a transition layer before any train-induced stress is applied to the sub-grade.

Keywords: Conventional French railway network; interlayer; sub-grade; degradation rate; NL; layer thickness.

Introduction

Ballasted tracks are composed of two parts: super-structure (rail, fastening system and sleeper) and sub-structure (ballast, sub-ballast and platform). To ensure the good performance of tracks and thus the normal circulation of train, both super-structure and sub-structure need to be regularly examined and maintained (Burrow et al. 2007). Normally, problems related to super-structure can be visually determined and thus rapidly solved. It is however not the case for those related to sub-structure. Once problems occur in the sub-structure, it is often difficult to explicitly identify and expensive to remediate. Previous studies showed that the cost related to the maintenance of sub-structure often represents a huge budget (Ebrahimi 2011; Indraratna et al. 2011). The experiences in France showed that after the track remedial work to decrease rail deformations, the problems persist and the phenomenon as mud pumping (fine particles of sub grade are pumped up to ballast surface), defects of bearing capacity occurs locally. These observations suggest that problems are highly related to the behavior of sub-structure. From a practical point of view, if the main mechanisms of the occurring problems are not understood, the origin of the problems may remain even though expensive remedial works have been undertaken (Brough et al. 2003; 2006). The variability of sub-grade soils along a line often represents the major difficulty or challenge for both the fundamental investigation and the practical operations.

An appropriate thickness of sub-structure layers is important for adequately distributing the train-induced stress. If the track-bed layers do not have the required thickness, significant stress can be transmitted to the sub-grade soils and important deformations can take place, leading to the degradation of tracks. It is worth noting that the designed thickness of track-bed layers is not the same, depending on the types of lines (for high speed train or normal train), on countries and also on the construction times (Li and Selig 1998a; 1998b; Burrow et al. 2011). In France, the conventional railway lines were constructed long time ago in 1850s, and the design in that time did not follow the current standards

(Trinh 2011) in terms of super-structure composition, sub-structure mechanical behavior and exploitation. This inevitably leads to stability-related problems for the tracks in case of increasing load, traffic and speed of train. In particular, for the conventional railway tracks, as the ballast was mainly installed directly onto the sub-grade during construction, a layer namely interlayer was created mainly by the interpenetration of ballast and sub-grade soils (Calon et al. 2010; Trinh 2011; Trinh et al. 2011; 2012; Cui et al. 2013; Duong et al. 2013a; Duong et al. 2013b). The thickness and the hydro-mechanical behavior of this interlayer can strongly affect the performance of the whole tracks.

This paper aims at assessing the performance of track sub-structure of the conventional French railway network. Firstly, a statistical study on the French railway network was conducted. Problems related to train circulation in the period from January 2010 to May 2011 were collected and analyzed. It was concluded that it is important to conduct a global investigation followed by an in-depth sub-structure one. In particular, the analysis showed that there is a good correlation between the train circulation problems and the presence of fine particles in the sub-structure. After this global analysis, an in-depth analysis was undertaken on one specific line with problems identified. The increase rate of the rail geometrical degradation was studied. This increase rate was then correlated with other parameters such as the natures of sub-grade involved along the line and the thicknesses of different layers.

Assessment of the French railway network

The problems related to train circulation (for instance, forced speed reduction in order to ensure the comfort of passengers) were recorded in the French railway network from January 2010 to May 2011. A total of 1705 cases was involved (Calon 2010). It was found that the causes can come from every track components (steel rail, fastening system, sleeper, ballast, sub-ballast and sub-grade). Four main groups can be defined as presented in Fig. 1, in relation to super-structure; sub-structure; speed reduction due to maintenance/engineering works and “no information” meaning that the cause has not been explicitly found out, respectively. Among the 1705 cases, those related to the super-structure represent 16.13% (275 cases), to the sub-structure represent 17.89% (304 cases), to the maintenance and engineering works represent 12.38% (211 cases), and 53.61% corresponds to “no information” (914 cases). The huge number of “no information” cases is mainly due to the complexity of the track composition; it is often difficult to determine the cause of a problem. On the other hand, this huge number confirms that railway structures is a complex issue that needs extensive investigations in order to reveal the real mechanisms involved in the problems. It is also worth noting that the part of problems related to the sub-structure (17.89%) is a little higher than that related to the super-structure (16.13%). This implies significant maintenance works involving the sub-structure. Note that in the past, most attention has been paid to the super-structure and the consideration given to the sub-structure is not enough to reveal all problems. Among the sub-structure-related problems, there are 186 cases where clayey sub-grade was recorded and very often mud pumping was observed. These zones are henceforth referred to as sensitive zones.

In order to enable the assessment of the French network in terms of economic indicators, the railway lines are classified in different groups according to the nature and the importance of traffic (SNCF 1989). The classification, called UIC groups, is based on the fictive traffic T_{f2} calculated as follows:

$$T_{f2} = S \times T_{f1} \qquad (1)$$

where S is the coefficient of the line quality, and it is equal to 1 for the lines without passenger train or local traffic, to 1.1 for the lines with passenger train at a speed lower than 120 km/h, to 1.2 for the lines with passenger train at a speed from 120 km/h to 140 km/h, to 1.25 for the line with passenger train at a speed higher than 140 km/h. T_{f1} is the fictive weight calculated by:

$$T_{f1} = T_v + K_m T_m + K_t T_t \qquad (2)$$

where T_v is the weight of passenger train (ton/day), T_m is the weight of freight train (ton/day), T_t is the weight of locomotive (ton/day), K_m is a coefficient (1.15 in normal case, 1.3 in the case of 20 ton axle load), K_t is a constant which is equal to 1.4.

According to the value of T_{f2}, the corresponding UIC group can be defined. Table 1 presents all groups. The order in this table follows the decreasing traffic and loading. In France, on the RFF (French Department of Industry) network, there is no line within group 1. Based on the amplitude of fictive traffic, the maintenance policy of SNCF (French Railway Company) was set up accordingly: maintenance operations are undertaken more frequently for the first six groups and less for the other groups.

As the total length of each group is not the same (Table 1), it appears necessary to normalize the number of problems with respect to the length. The number of recorded problems per 1000 km of each UIC group was then determined and the result is presented in Fig. 2. The first category corresponds to the whole data recorded involving the problems related to all track components; the second category corresponds to the sub-structure-related problems. The third category involves the sensitive zones. It is observed that in the first category, the number of problems is indeed larger for the groups 2 to 4. It is group 4 that gathered the most part of problems.

When only the data related to sub-structure was taken into account, the configuration became different and the greatest value was recorded for group 7 (passenger train). The same observation can be made with the data related to the sensitive zones. This finding suggests that the maintenance policy should be changed when referring to the sub-structure and more attention should be paid to the track bed within group 7.

Problems occurred over a year are presented in Fig. 3a for the sub-structure and in Fig. 3b specifically for the clayey sub-soils (sensitive zones). Very often, the mud pumping phenomenon occurs in the sensitive zones where the fine particles are pumped from sub-grade up to ballast surface and the whole ballast layer becomes fouled and loses all its performance (Selig and Waters 1994; Indraratna et al. 2011). A similar configuration can be observed in two figures. There is a peak around the months of February, March and April. In 2010, in the sensitive zones, the numbers of cases for these three months are 28, 48 and 13, respectively; while those of other months are all lower than 10. It is worth noting that the period from February to April corresponds to late winter and early summer. It was reported in the literature that ballast can be fouled after one winter due to freeze/thaw (Raymond 1999).

Fig. 4 presents the data recorded versus the type of tracks. Track 1 corresponds to the down line, Track 2 corresponds to the up line and "Other" corresponds to the single track line or secondary tracks. In the case of sub-structure-related problems, the number for Track 1 (110 cases) is equal to that for Track 2 (109 cases), while in the case of sensitive zones-related problems, the number for Track 1 (71 cases) is clearly larger than that for Track 2 (51 cases). Note that the drainage condition and the traffic for the Track 1 and Track 2 are not always the same. As the quality of the drainage system is not always the same, the water content can be different, hence different mechanical behaviors of soils can be expected for the two tracks since water content is one of the key parameters governing the behavior of railway sub-structure (Duong et al. 2013b).

Fig. 5 depicts the problems according to the territory. Note that the French railway network is divided into three territories, each consisting of various infra-poles (sub-territory). It can be seen that *Atlantique* is the territory where there is the largest number of problems. This observation is clearer if only the sub-structure is accounted for (Fig. 5b). When considering the configuration in terms of sensitive zones (Fig. 5c), the contrast is even higher: the percentage of problems in *Atlantique* is 60% against 22% in *South-East* and 18% in *North East Normandy*. Note that *Atlantique* is the territory with a long coast of Atlantic Ocean and a large number of harbors with high frequency trading activities. However, *Atlantique* is also the territory having the highest total line length, hence a possible higher problem number.

Fig. 6 shows the distribution of problems in different infra-poles. It can be observed that the problems occurred almost everywhere in France; however, most cases appeared in the infra-poles of “Ouest Parisien” (West Paris) and Poitou Charentes. Based on this observation, one line situated in the infra-pole of Poitou Charentes was selected for further in-depth investigation.

Assessment of a line in the infra-pole of Poitou Charentes

Evaluated line

A segment from kilometer 72 to 140 was selected. Information about the thicknesses of different layers should be estimated based on the data from core samples and from Panda investigation (dynamic cone penetrometer test) coupled with geo-endoscope observation.

This railway line was constructed in 1860s. It is classified in group 6 of UIC (see Table 1). As mentioned before, like other conventional lines, this line was constructed with ballast directly overlying the sub-grade. After years of circulations and operation, an interlayer was created as a result of the interpenetration of ballast and fine particles of sub-grade soils (Trinh 2011; Cui et al. 2013; Duong et al. 2013b).

Geological situation

Fig. 7 presents the geological map of the studied line with the kilometer point (PK) and the geological information. The sub-grade includes five soil types. The first one at the very first kilometer of the line (from PK 74 to 75) consists of the soil of Middle Jurassic, mainly including hard limestone and marl. The thickness of each layer can vary from 10 mm to 1 m and the total thickness can reach 20 m. At PK 75, the line passes through a zone varying from river alluvial silty clay to clay-limestone. The second (from 75 to 76) involves argillaceous limestone, marl, and to a lesser extent fine alluvial deposit and peat. The thickness of these layers varies from some centimeters to 1 m. The third consists mainly of marl (from 76 to 79). The total thickness reaches 40 m. This marl layer can sometime be overlaid by a thin layer of more or less clayey limestone. The fourth group (from 80 to 102) is the alternation of white argillaceous limestone and marl. In several zones, the soil is very clayey with a very thin clay layer of intercalation in marl or limestone. From PK 80 to PK 87, the limestone layers become very hard and resistant. Around PK 87 and PK 89, the line passes through the zones of river alluvial silty clay and sometimes with peat. These zones of peat are very compressible, representing low-quality sub-soils. The fifth type involves marl, white chalky limestone and limestone sub-lithographic (Upper Jurassic). The total thickness is about 30 m. From PK 125 to PK 138, the soil consists of limestone with sandwiched marl. This complex geological situation must be correlated to the large number of problems recorded. The importance of geological situation for the track performance was also reported by Li and Selig (1994), Revees et al. (2005), Bednarik et al. (2010).

Longitudinal Leveling - NL

For a smooth train circulation, rails/wheel contact must present a satisfactory leveling which is defined referring to UIC group. In other words, leveling of rail is an indicator of track quality. Note that the geometrical degradation of tracks that induces changes in leveling can be due to problems related to super-structure, granular materials and platform (Guerin 1996). In the French railway network, the term of longitudinal leveling *NL* (*Nivellement Longitudinal* in French) is used to assess the geometrical state of tracks. A large value of *NL* implies a bad state of railway line. Beyond a certain threshold of *NL*, maintenance is required in order to bring *NL* back to an admissible value (ballast tamping, stone blowing and ballast renewal).

A train namely Mauzin train passes through a line for the measurement of rail deflection (Fig. 8a). *NL* is calculated from the difference between the local leveling of each rail and the average profile of the line.

The principle is to calculate the difference between the represent Euler and Lagrange of the wheel ordinate (Rhayma 2010). From Fig. 8b, this difference N is calculated as follows:

$$\begin{aligned} N &= z_D - \left(z_{D'} - h\right) \\ &= z_D - \frac{1}{\alpha + \beta}\left(\beta z_M + \alpha z_N\right) + h \\ &= z_D - \frac{1}{4\left(\alpha + \beta\right)}\left[\beta\left(z_A + z_B + z_C + z_D\right) + \alpha\left(z_E + z_F + z_G + z_H\right)\right] \end{aligned}$$

NL is the standard deviation of the recorded measurements with a mean value μ and for a distance of 200 m:

$$NL = \sqrt{\frac{1}{M}\sum_{i=1}^{M}\left(N_i - \mu\right)^2}$$

Fig. 9 presents the variations of NL at kilometer 70.3 of Track 2 from 1997 to 2013. It can be observed that the value of NL decreased sharply after each maintenance (in the year of 2001, 2003, 2007 and 2012). However, after the maintenance, the value of NL continued to increase at almost the same rate: a linear increase trend of NL over time can be identified. It is worth noting that the slope represents the increase rate of NL or the degradation rate of tracks. The increase trend of NL persisted after a maintenance, suggesting that ballast replacement did not resolve the problem, and the track degradation was rather related to the sub-structure.

Core sampler train

The core sampler train is a special train which has the function as indicated by its name (SNCF 2011). The train was equipped with drilling equipment. Sample tubes are driven dynamically into track-bed to obtain a continuous core sample composed of ballast and underlying formations (Fig. 10). A digital camera is used taking photographs of the sample. From the photograph (see Fig. 10), the thickness of each layer is analyzed and recorded. It can be seen that a typical track-bed consists of a clean ballast layer underlying fouled ballast layer and/or interlayer and sub-grade soil. The sample tube allows core sample to be taken till a depth of about 1.50 m. This depth is enough for identifying the different layers in the conventional railway track-beds. This investigation method was also reported in Brough et al. (2003; 2006).

Panda cone penetrometer and endoscope

The first Panda penetrometer was presented in 1991 in France (Langton 1999) and it is nowadays widely used thanks to its light weight and easy usage. Panda works following the principle of a dynamic cone penetrometer that uses a manual hammer for driving a standard cone into the soil. The dynamic cone resistance (q_d) is then calculated and plotted versus the corresponding depth, giving the profile of q_d (Langton 1999; Quezada 2012). The cone penetrometer is a useful tool for track-bed investigation and for obtaining information about the in-situ characteristic of ballast and underlying sub-grade material.

Once the Panda test is performed, the rod is removed, leaving a small hole having the rod dimension. This allows an endoscope, a very small digital camera, to be introduced into this hole to take photographs of the materials involved. This provides a visual observation allowing the track-bed components to be distinguished.

The Panda tests and endoscope observation were conducted along the studied line according to the SNCF standard (SNCF 2011). The obtained results allowed the thicknesses of different sub-structure layers to be estimated. Fig. 11 presents typical results from Panda test and Endoscope observation at PK 126.7 of Track 1. The correlation between the image of endoscope and the Panda results allowed the identification of a layer of fresh ballast of 0.25 m, a fouled ballast layer of 0.2 m, an interlayer of 0.3 m and the top of sub-grade at 0.95 m depth. As it is very difficult to distinguish fouled ballast layer and interlayer, the sum of thickness of these two layers is accounted for in the following analysis.

Result and interpretation

Fig. 12 depicts the degradation rate (the increase of *NL* per year which was calculated from the slope as presented in Fig. 9) versus the kilometer point for Track 1 and Track 2. On the whole, there is an agreement between the data of two tracks; the peaks of Track 1 appeared almost at the same kilometer points as the peaks of Track 2.

Fig. 13 and Fig. 14 present the degradation rates according to the year of rail (Fig. a) and the year of sleeper (Fig. b) for Track 1 and Track 2, respectively. From these figures, it can be seen that there is no correlation between the year of super-structure (rail or sleeper) and the increase rate of *NL*, even though theoretically in the calculation of *NL*, the super-structure can have an influence on the value of *NL*. It is worth noting that these data correspond to the year of the current super-structure, and that in past the types of rail and sleeper could be different. Thus, it is not possible to exclude the contribution of the super-structure to the degradation of tracks identified. However, as shown in Fig. 9, after the remedial work of tamping, the value of *NL* continued to increase. This suggests that the rail or sleeper type did not clearly influence the evolution of *NL* identified. Furthermore, admitting that the traffic, train load and speed and the type of sleeper in two tracks are not necessary identical, the coincidence between the degradation rates of Track 1 and Track 2 (Fig. 12) confirms that the general cause of the increase of *NL* came from the sub-structure. Based on this observation, the following analysis focuses on the sub-structure.

From Fig. 12, the zones with high degradation rates can be identified. They are around PK 73, 79, 88, from 99 to 103, from 106 to 114 and 122. Referring to the geological information, it can be concluded that these kilometer points correspond to the zones where sub-grades contains large fraction of fine particles. Around PK 73, the sub-grade is rather argillaceous limestone and marl. Around PK 79, the sub-grade is fine alluvial deposits and peat. From PK 88 to 89, it is the alluvial deposits overlying the argillaceous limestone or marl or peat. From PK 98-103, the sub-grade involves argillaceous limestone, marl and fine limestone. Around PK 113, the sub-grade contains sometimes colluviums. It is important to note that these soils are sensitive to changes in water content and train loading. Soils like peat, alluvial deposit and colluviums are very compressible and do not have the required mechanical properties for sustaining the train-induced load. This can explain the high increase rate of *NL* in these zones. From PK 123 to the end of the line, the increase rate of *NL* became low along the line, indicating a good performance of the tracks. This can be also explained by the sub-grade nature: hard limestone is involved along this section. For the first part of the line (up to PK 103), the sub-grade soils are quite variable. These changes in soil natures are also detrimental to the track performance.

From the analysis above, it can be seen that the sub-grade has a significant influence on the performance of railway structure. From a practical point of view, the zones with a sub-grade of low mechanical properties are not apt to become the foundation of railway sub-structure. If it is inevitable, improvement must be conducted in order to meet the requirements, such as a good drainage system or some soil improvements.

Fig. 15 presents the correlation between the degradation rates of Track 1 and Track 2. It is observed that the *NL* of Track 1 increased more quickly than that of Track 2, because more data fall below the equality line. This is in agreement with the finding in the first part of work where the number of sub-structure related problems were recorded (Fig. 4). It is normally admitted that the train heading to the center (up line) carrying more freights and passengers than the train leaving the center (down line). More studies are needed to clarify this observation.

During the assessment of the whole line, the zones where fine particles were found on the ballast layer surface were identified. The degradation rates of these zones are presented in Fig. 15 with the black symbols. It can be seen that most of the zones with the presence of fine particles correspond to the zones with high increase rate of *NL*. These fine particles came probably from the sub-grade when mud pumping occurred. This implies that the sub-grade containing large fraction of fine particles is detrimental to the performance of sub-structure. Indeed, for this kind of sub-grade soils, a decrease of mechanical performance can be expected when the moisture content rises. It appears thereby important to further investigate the effect of water content of sub-soil having large fine particles fraction and also the mud-pumping phenomenon.

Fig. 16 presents the correlation between the thickness of fouled ballast and interlayer (*e*) and the increase rate of *NL* for special zones (Fig. a) and normal zones (Fig. b), for Track 1. The same correlation is presented in Fig. 17 for Track 2. The special zones correspond to the zone of stations, the zones with bridges or viaducts. The other zones are referred to normal zones. For the special zones, Track 1 (Fig. 16a) presents a sharp decrease trend of degradation rate with the increase of *e*, while this trend is not observed for Track 2 (Fig. 17a). For the normal zones, despite the data scatter that can be explained by the presence of fouled ballast taken into account in the study, both Track 1 (Fig. 16a) and Track 2 (Fig. 17a) present a decrease of degradation rate as the layers thickness increases. As mentioned before, in the sub-structure of new lines for high speed train, there are a number of layers protecting more or less the sub-grade. On the contrary, in the sub-structure of conventional lines with the absence of an appropriate transition layer such as the sub-ballast layer, significant stress can be exerted to sub-grade soils, leading to significant deformation of tracks or degradation of tracks. The presence of interlayer somehow plays the role of a transition layer to reduce the stress applied to sub-grade. This explains the decrease trend of the degradation rate with the increase of *e*.

This trend is also observed in Fig. 18 where the layer thickness deduced from Panda penetrometer tests and endoscope observation is used. The trend is not clear for Track 1 but very clear for Track 2. This confirms the positive impact of interlayer in reducing the degradation of tracks with the increase of interlayer thickness. Note that in other countries, the presence of some layers such as capping layer or blanket layer that can protect sub-grade was also reported by Selig and Waters (1994); Radampola et al. (2008); Burrow et al. (2011). In the study of Burrow et al. (2013) on the ole railway embankment, it was found also that the settlement and the plastic strain decreased with the increase of granular layer thickness.

Conclusions

This paper presents a statistical study on the problems related to the train circulation in the French railway network, followed by an in-depth analysis of a conventional railway line in the West of France. The conducted analyses and observations allow the following conclusions to be drawn:

- The maintenance of sub-structure is as important as that of super structure since the number of problems identified in the whole French railway network for sub-structure was slightly larger than that for super structure. In addition, because the problems related to sub-structure cannot be identified as quickly as those related to super structure, it is recommended to pay more attention to sub-structure part.

- The sub-grade quality controls the degradation rate of tracks. The peak values of degradation rate correspond to the zones where sub-grade is not mechanically stable, i.e., soils with large fraction of fine particles. Moreover, frequent changes of sub-grade along a line are also detrimental to the performance of tracks.

- Comparison between the two tracks of the studied line shows that Track 1 (up line) was degraded faster than Track 2 (down line). More studies are needed to clarify this observation.

- There is a reasonable correlation between the degradation rate and the thickness of fouled ballast layer and interlayer, suggesting a positive role of interlayer in reducing the degradation of tracks.

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Table 1: Classification of group UIC

Group UIC	Characteristic T_{f2} Value	Length (km)
Group 1	$T_{f2} > 120000$	0
Group 2	$120000 \geq T_{f2} > 85000$	2385
Group 3	$85000 \geq T_{f2} > 50000$	8968
Group 4	$50000 \geq T_{f2} > 28000$	12218
Group 5	$28000 \geq T_{f2} > 14000$	6807
Group 6	$14000 \geq T_{f2} > 7000$	7381
Group 7 Passenger train and Freight train	$7000 \geq T_{f2} > 3500$	4149 (Pass. Train) and 292 (Frei. Train)
Group 8 Passenger train and Freight train	$3500 \geq T_{f2} >1500$	7607 (Pass. Train) and 1291 (Frei. Train)
Group 9 Passenger train and Freight train	$1500 \geq T_{f2}$	6288 (Pass. Train) and 7942 (Frei. Train)

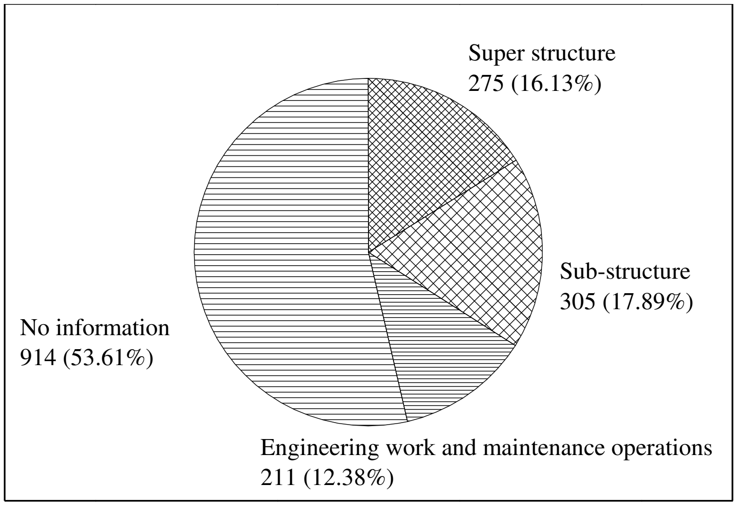


Fig. 1: Cause of the problems for the deceleration of train

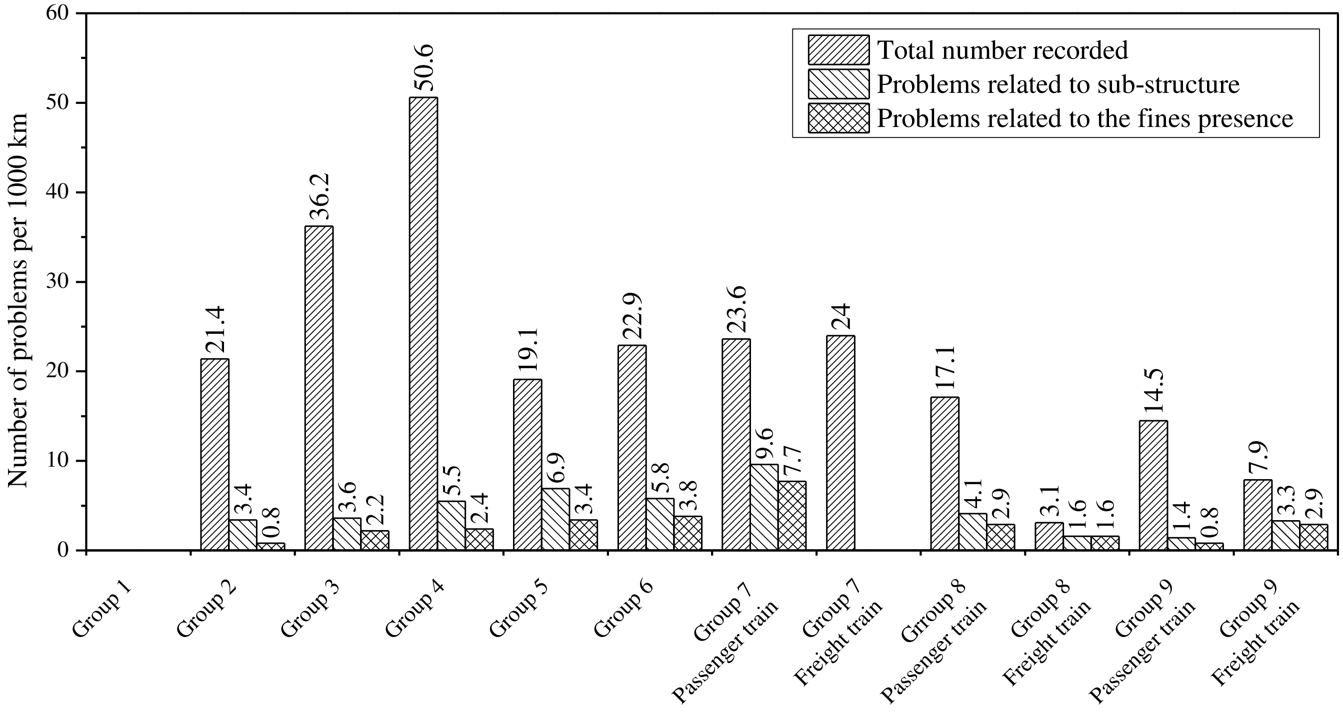


Fig. 2: Number of problems versus group UIC

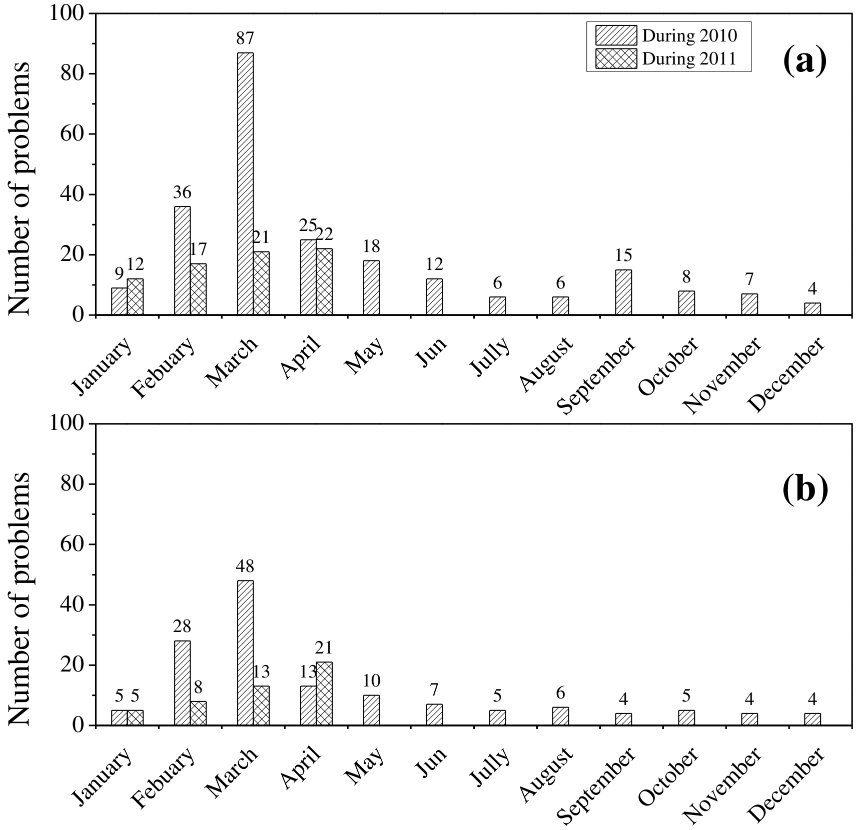


Fig. 3: Problems occurring over one year. a) Problems related to the substructure and b) problems related to the sensitive zones

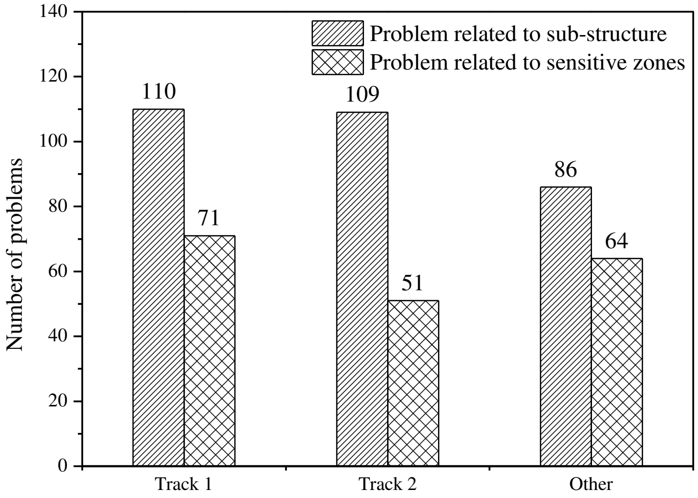


Fig. 4: Problems recorded versus type of track

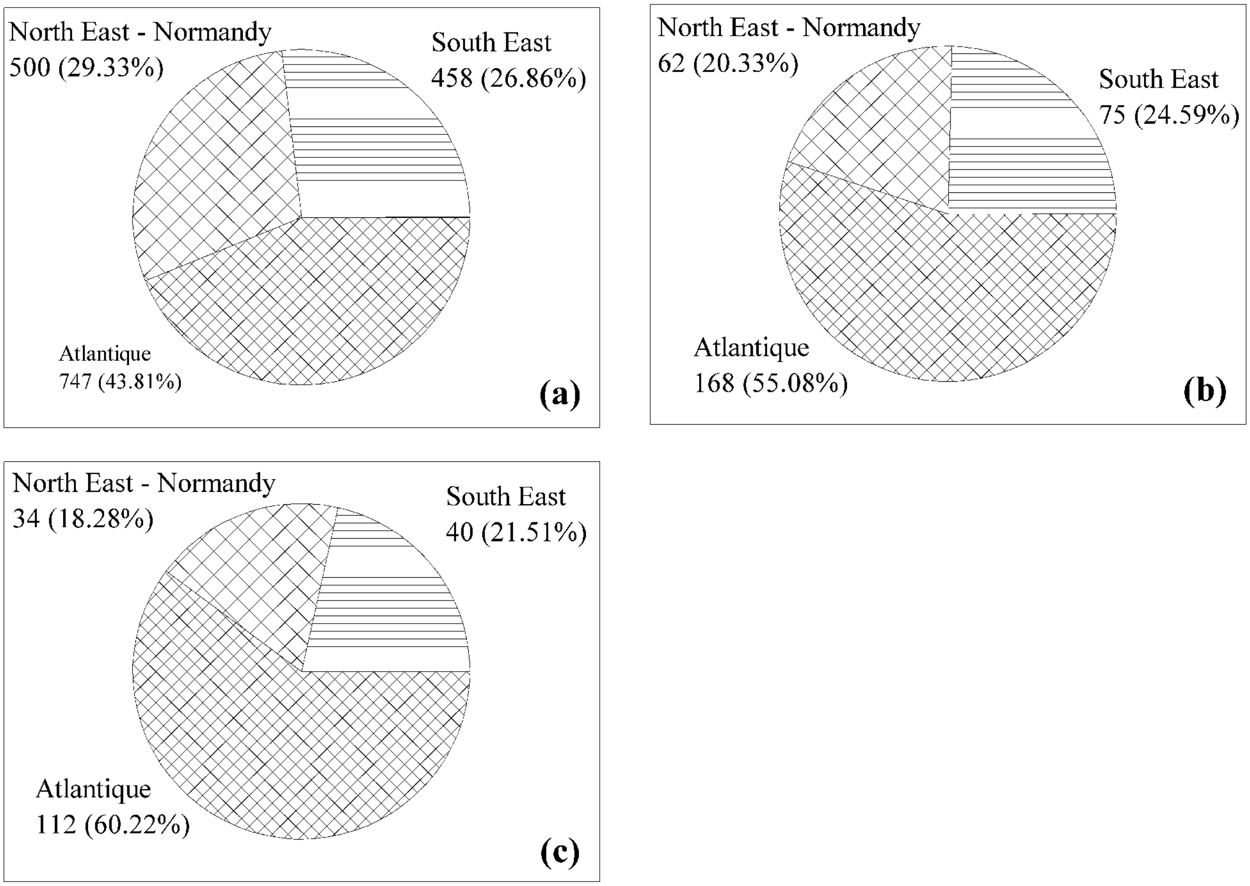


Fig. 5: Classification of problems according to the territory. a) All problems; b) Problems related to sub-structure and c) sensitive zones

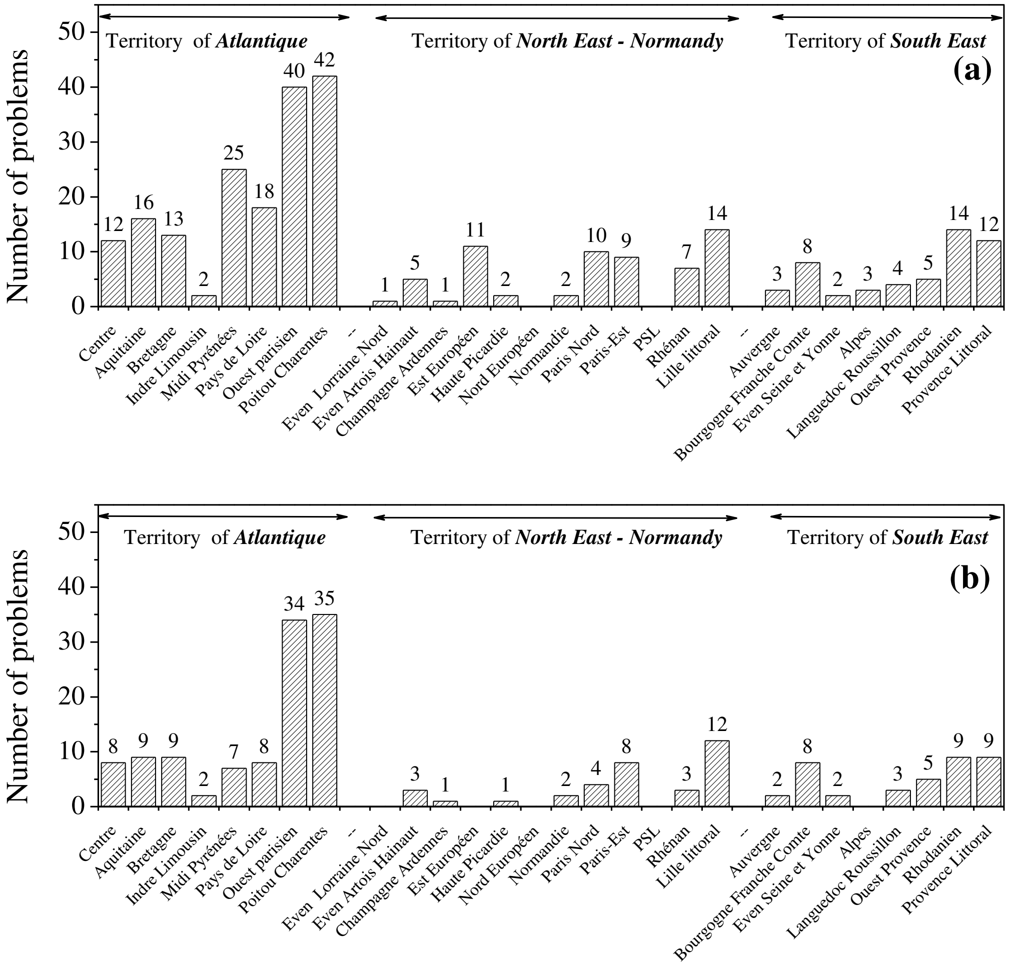


Fig. 6: Classification of problems according to the Infrapole. a) Problems related to sub-structure and b) problems related to sensitive zone

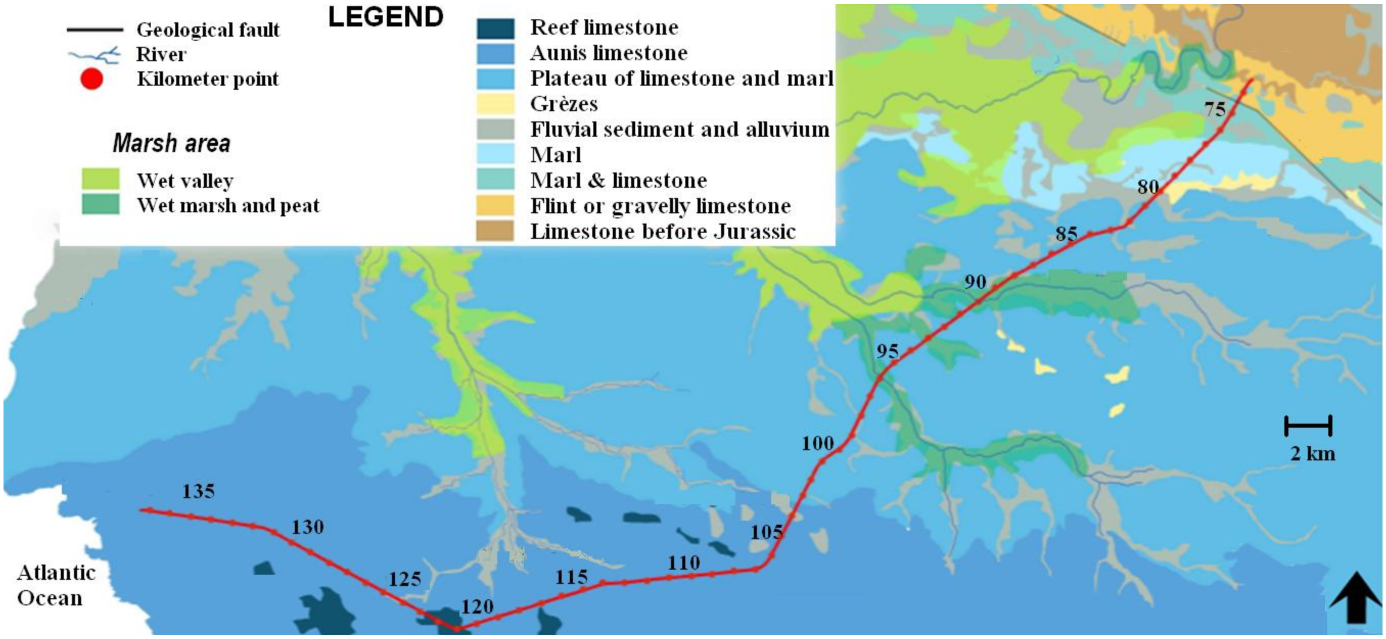
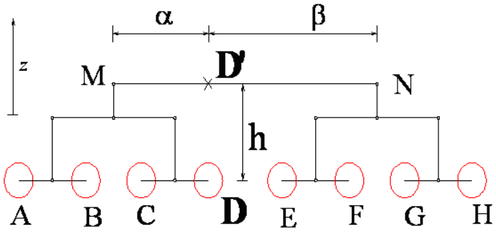


Fig. 7: Geological map of the studied line

Fig 8a: Mauzin train

(*http://lapassiondutrain.blogspot.f)*



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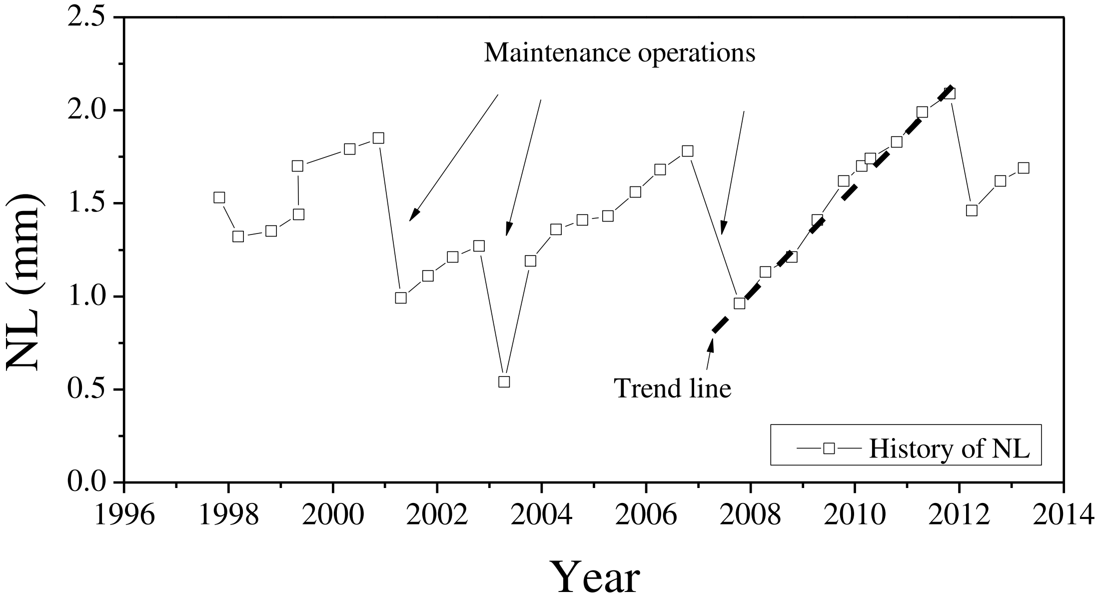

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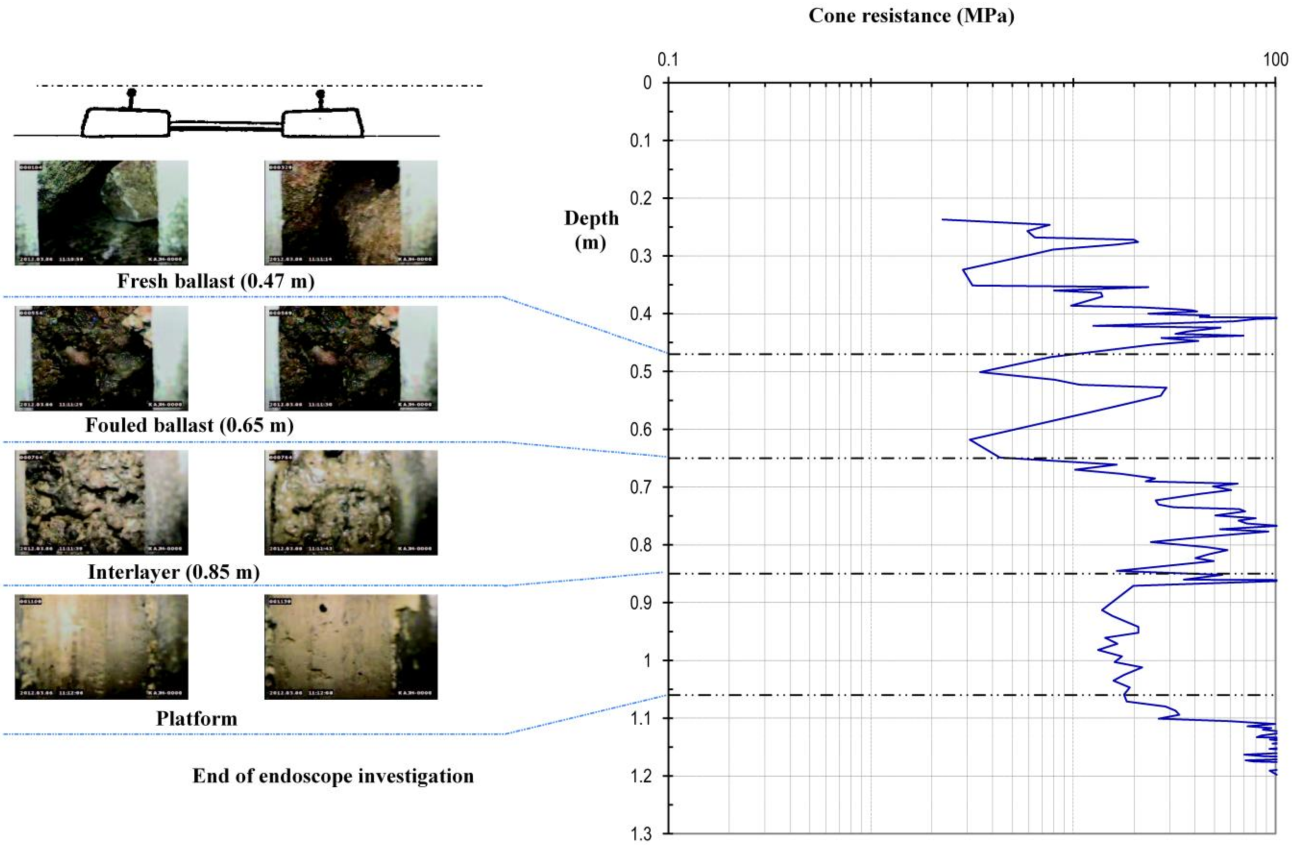

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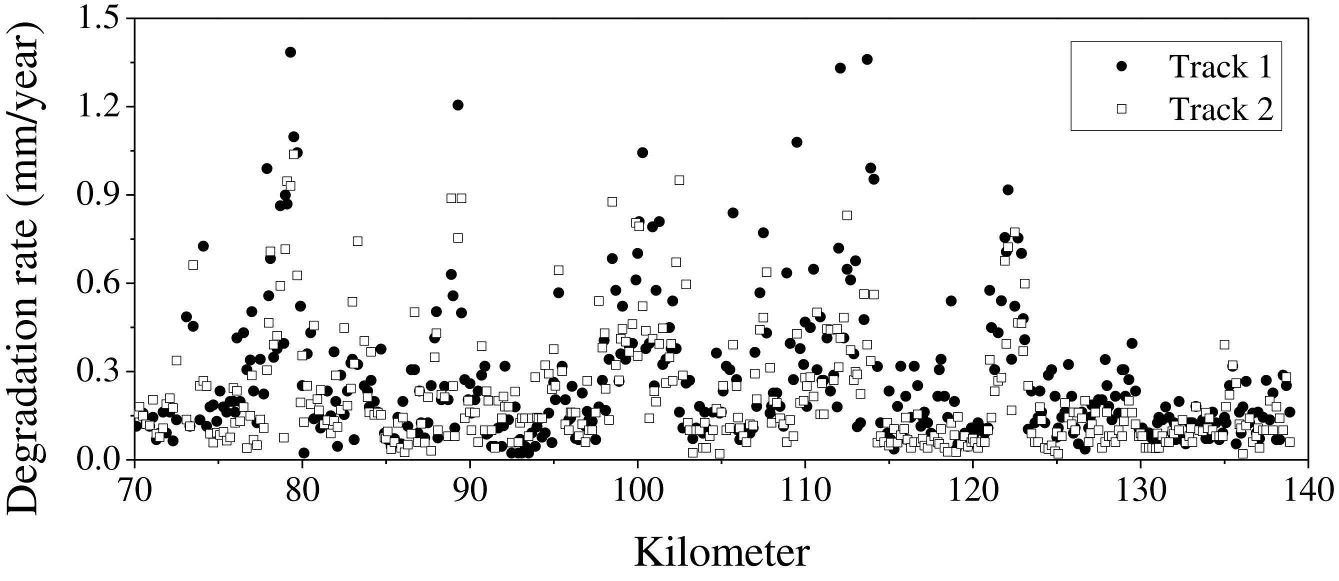
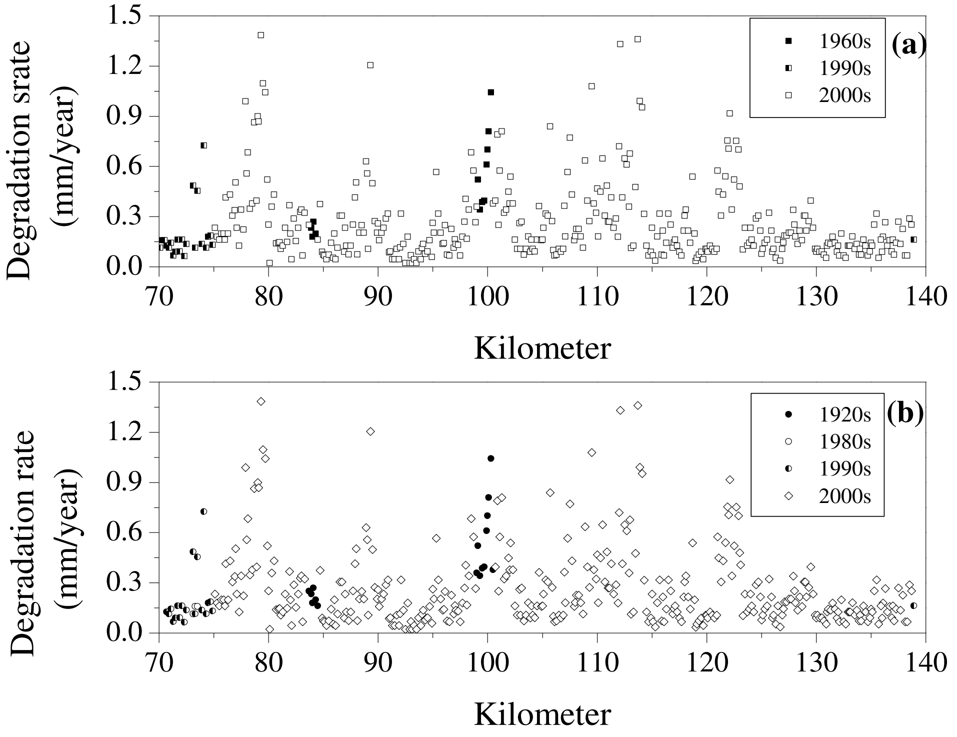


Fig. 12: Degradation rate along the studied line



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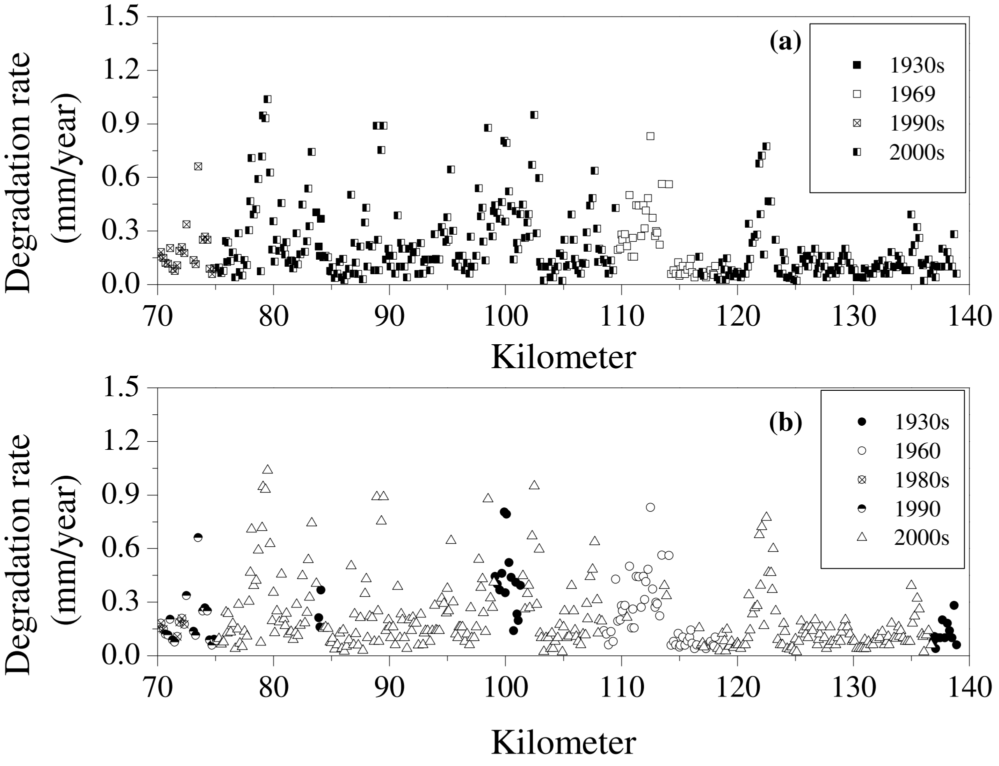

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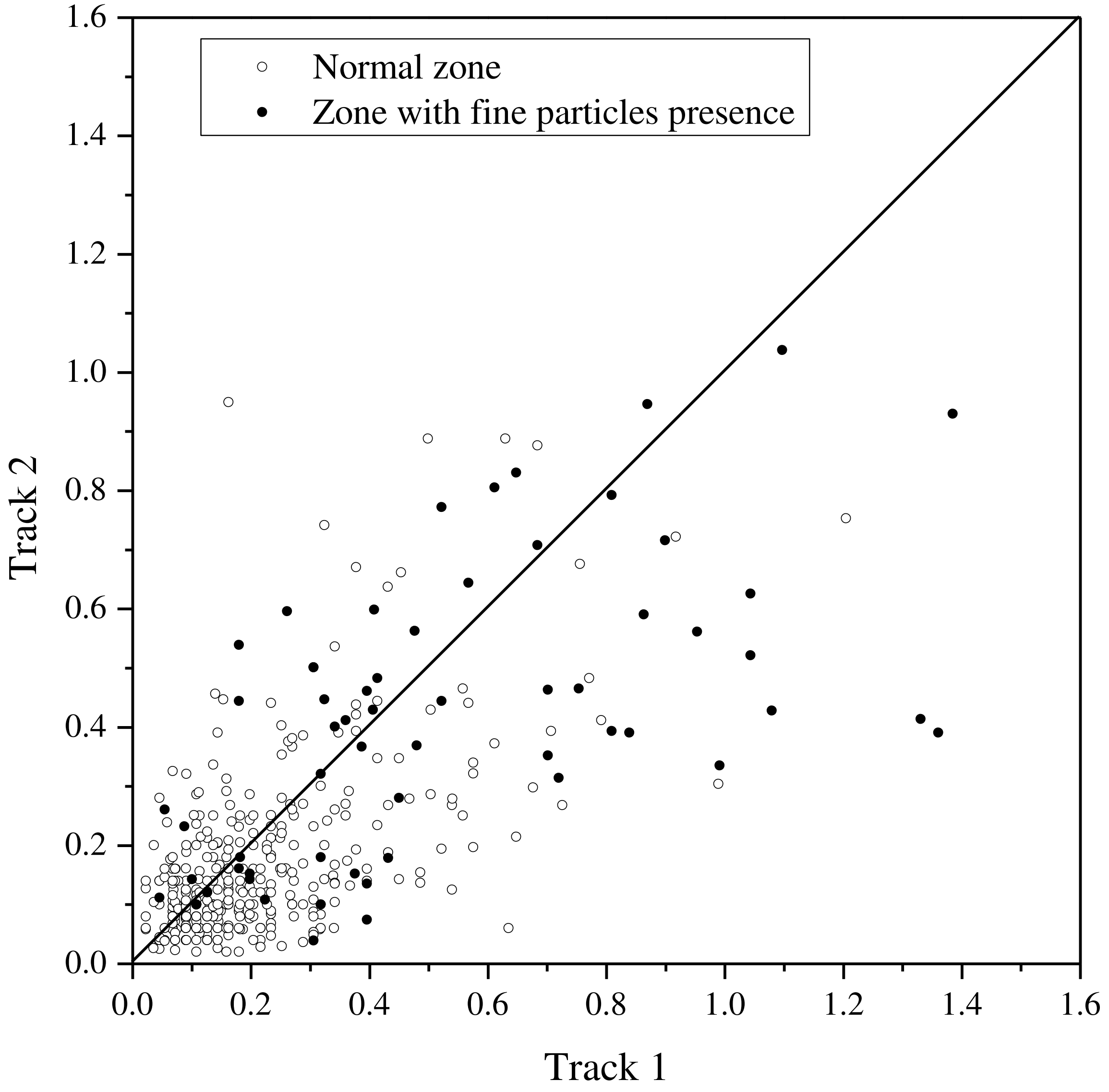


Fig. 15: Correlation between degradation rate of Track 1 and Track 2

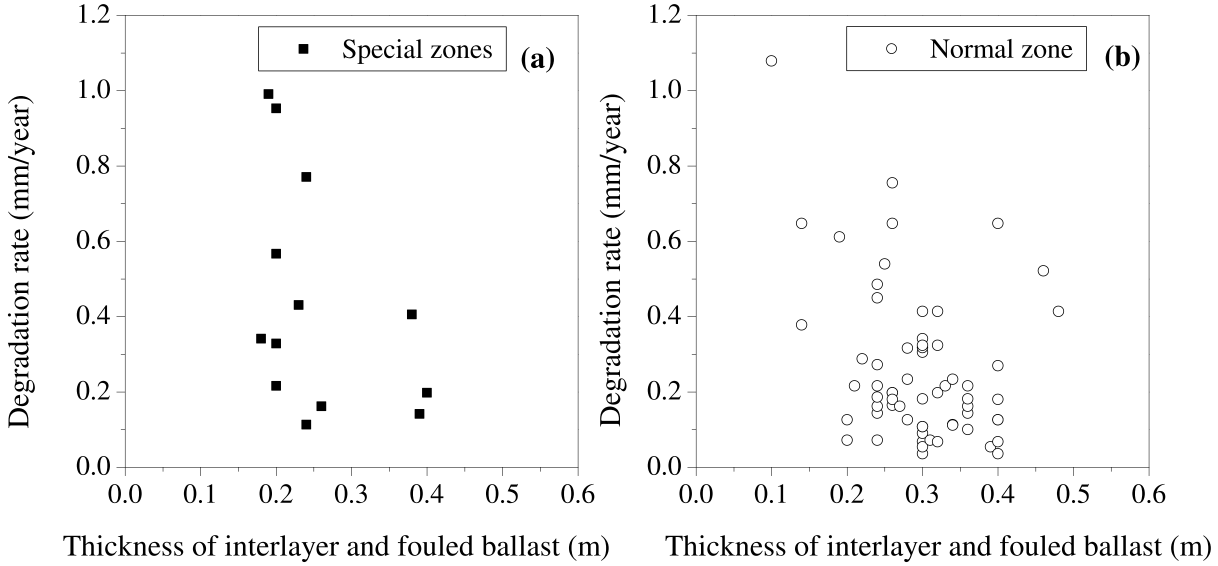
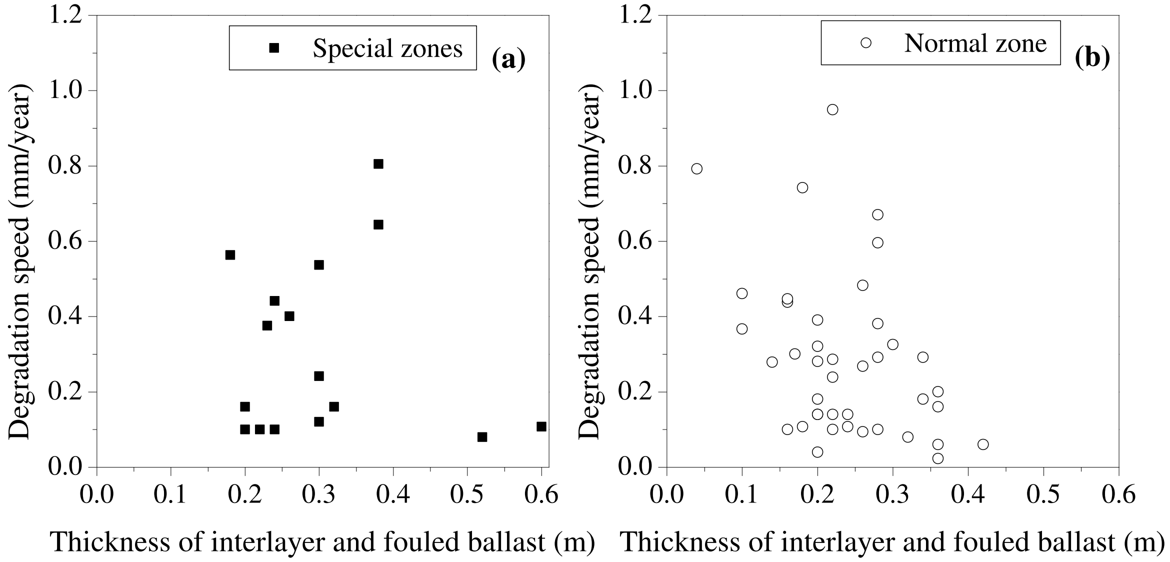


Fig. 16: Correlation of the degradation rate to the thickness of interlayer and fouled ballast for Track 1- Data from coring train. a) special zones and b) normal zone



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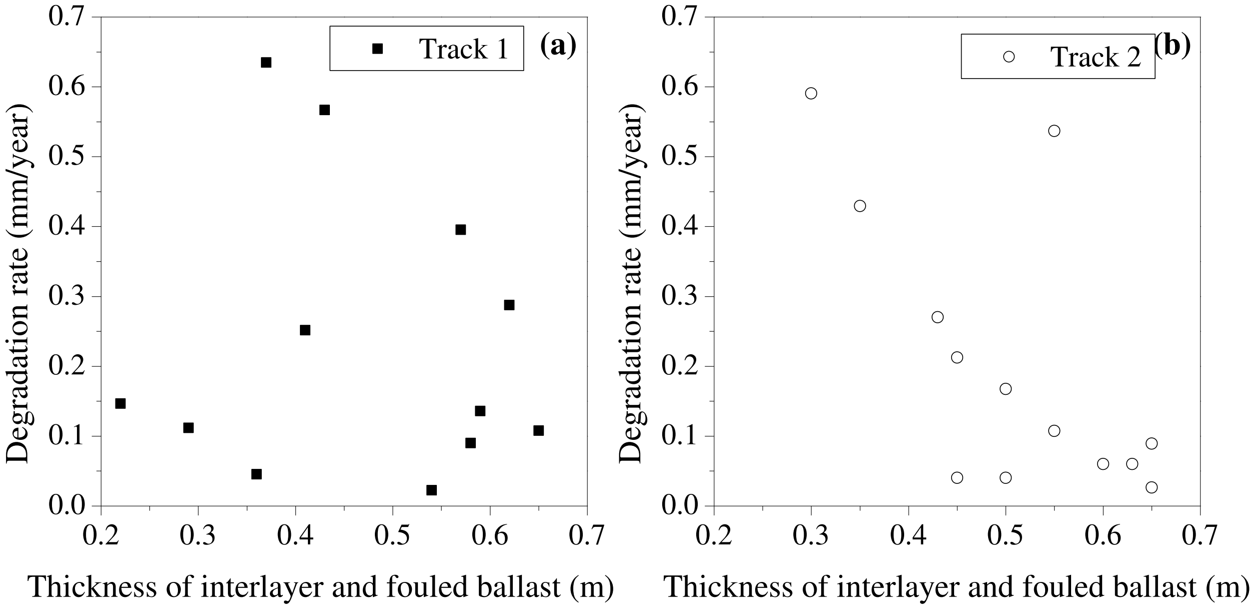

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