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Geotechnical works impacting existing railway infrastructure – French practice in railway safety measures

Travaux géotechniques en interface avec l'infrastructure ferroviaire existante – Pratique française des mesures de sécurité ferroviaire

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ABSTRACT: The railway network in Europe spans approximately 200,000 km of track. Since 2012, a single interoperable European railway area facilitates the transportation of both passengers and goods across the continent. The needs for higher efficiency transportation modes are rapidly growing, and the shift towards rail in the EU is expected to accelerate because of its high environmental performance, sustainability, and safety. Meanwhile, the existing infrastructure is aging, with many assets being over a century old (earthworks, bridges, and tunnels). To meet these new challenges, modernization of the existing network is imperative. The regeneration of railway structures generally involves significant geotechnical engineering works due to the lack of available space or assets that are at the limit in terms of stability. These works are becoming increasingly complex and must be carried out with minimal traffic disruptions. In many countries, national guidelines have been published to assist engineers in the design and execution of geotechnical works near existing railway infrastructure. However, there are no European recommendations or standards. In order to discuss these national recommendations at the European level, this paper gives an overview of design, execution and control rules applied in France for geotechnical works on existing railway infrastructure. First, the characteristics of the French railway network are presented. Then, the main risks associated with geotechnical works close to railway traffic are identified. Finally, the implications of incorporating railway safety in the design and execution of works are highlighted.

RÉSUMÉ: Le réseau ferroviaire européen s'étend sur environ 200,000 km de voies. Depuis 2012, un espace ferroviaire européen unique et interopérable facilite le transport de passagers et de marchandises à travers le continent. Les besoins en modes de transport plus efficaces dans l'UE augmentent rapidement, et la transition ferroviaire devrait s'accélérer davantage en raison de ses performances environnementales, de durabilité et de sécurité élevées. Dans le même temps, l'infrastructure ferroviaire existante est vieillissante, de nombreux ouvrages ayant été construits il y plus d'un siècle (ouvrages en terre, ponts et tunnels). Pour répondre à ces nouveaux défis, la modernisation du réseau existant est impérative. La régénération des ouvrages ferroviaires implique généralement des travaux géotechniques importants en raison du manque d'espace disponible ou d'ouvrages à la limite en termes de stabilité. Ces travaux deviennent de plus en plus complexes et doivent être réalisés avec un minimum de perturbations pour les circulations. Dans de nombreux pays, des référentiels nationaux ont été publiés pour aider les ingénieurs à concevoir et à exécuter des travaux géotechniques à proximité des infrastructures ferroviaires existantes. Il n'existe cependant aucune recommandation ou norme européenne. Afin de présenter ces recommandations nationales au niveau européen, cet article donne un aperçu des règles de conception, d'exécution et de contrôle appliquées en France pour les travaux géotechniques sur les infrastructures ferroviaires existantes. Dans un premier temps, les caractéristiques du réseau ferroviaire français sont présentées. Ensuite, les principaux risques liés aux travaux géotechniques proches du trafic ferroviaire sont identifiés. Enfin, les implications de l'intégration de la sécurité ferroviaire dans la conception et l'exécution des travaux sont soulignées.

Keywords: Railway; safety; infrastructure.

1 INTRODUCTION

In Europe, the needs for higher efficiency transportation modes of passengers and goods across the continent are rapidly increasing. Transport by rail is viewed by many as a promising solution because of its high environmental performance, sustainability, and safety. Growth of the railway industry is expected to accelerate in the future.

The rail network in Europe spans approximately 200 000 km of track. Since 2012, a single interoperable European railway area is established (Directives 2012/34, 2016/2370 and 2016/797 of the European Parliament). Infrastructure managers are required to grant non-discriminatory open access to railway infrastructure for domestic and international rail services. Meanwhile, the existing infrastructure in Europe is aging, with many assets being over a century old (earthworks, bridges, and tunnels).

To meet this future challenge of higher traffic and increased capacity, modernization of the existing European railway network is imperative. The regeneration of railway structures generally involves significant geotechnical engineering works due to the lack of available space or assets that are at the limit in terms of stability. These works are becoming increasingly complex and must be carried out with minimal traffic disruptions (Renard, 2011).

In many countries, national guidelines have been published to assist engineers in the design and execution of geotechnical works near existing railway infrastructure. However, there are no European recommendations or standards. The current technical specifications for interoperability (STI; EU regulation n°1299/2014) do not cover geotechnical works.

To discuss these national recommendations at the European level, this paper gives an overview of some design, execution and control rules applied in France for geotechnical works on existing railway infrastructure. First, the characteristics of the French railway network are presented. Then, the main risks associated with geotechnical works close to railway traffic are identified. Finally, the implications of incorporating railway safety in the design and execution of works are discussed.

2 OVERVIEW OF FRENCH RAIL INFRASTRUCTURE

The French railway network consists of 30 000 km of line, including 2 600 km of high-speed line, on which travel 15 000 trains per day. The map of the national rail network highlights the density of the tightly knit network in France (Figure 1).

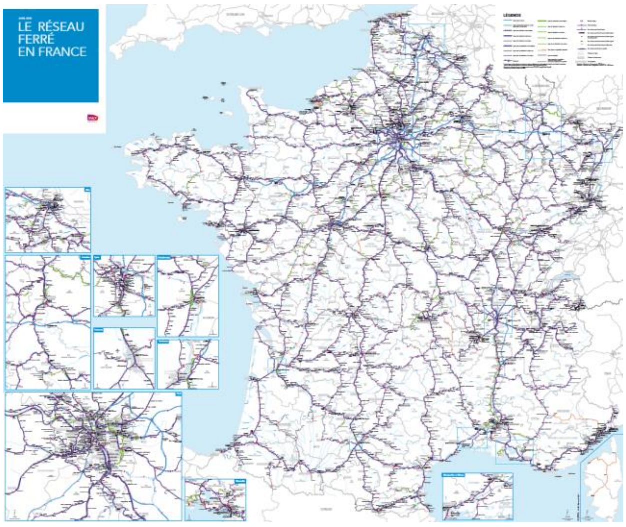

Figure 1. Map of the national rail network (from SNCF Réseau website).

Most main lines are standard UIC 1.435 m gauge, with only a few exceptions. A maximum permissible load of 22.5 tonnes per axle or 8 tonnes per linear metre is generally permitted.

The French railway network is composed of individual assets. The total number of earthworks is estimated at around 100 000 units, with a wide variety of structures (constitution, geometry, etc.) in many different environments (floodplains, rocky slopes, etc.). Over 32 000 rail bridges with a span greater than 2 meters were counted in a survey from 2018, with roughly 5 000 steel deck structures, 7 500 filler beams, 5 700 reinforced concrete or prestressed concrete bridges, 14 000 masonry bridges. There are approximately 20 000 retaining walls and 300 km of masonry covered slopes along the tracks in France. Lines pass through 1550 tunnels over a total length of 638 km, with an average tunnel span of 400 m (UIC, 2018).

Most of the assets were constructed 100 to 150 years ago during the industrial development of the second half of the 19th century. Structures are likely to deteriorate over time due to internal or external factors (Talfumière, 2011). These are mainly increase in traffic and loads and exposure to attacks from their environment (aggressive chemical conditons, erosion, submerssion, etc...). Degradations can lead to irreversible deformations with alterations of track geometry and/or more or less sudden failures in certain cases. A general lack of investment in maintenance and renewal projects over the years has resulted in poor track conditions in certain areas. Elsewhere, many assets have been reinforced at least once since their construction but these reinforcements are also aging and can become less efficient.

Geotechnical works carried out in operated railway environments are strongly impacted by the constraints and risks brought about by train traffic. These specific risks are discussed in the following paragraph.

3 MAIN RISKS FOR GEOTECHNICAL WORKS NEAR OPERATED RAILWAYS

In addition to geotechnical hazards encountered in any ground engineering project, there are specific risks associated with works carried out near operated railway infrastructure. These are mainly related to:

- exposure of workers/equipment to moving trains / airflow effect
- exposure of workers/equipment to high voltage electrical installations
- potential damages to rail infrastructure with impact on traffic safety (disturbing signaling equipment, instability, and track geometry modifications)

In general, the closer the works are to the tracks, the greater the risks and the higher the costs of construction. Malfunction of signaling equipment can cause accidents such as train collisions. Damage to rail infrastructure caused by geotechnical works can have serious impacts on traffic safety. Overall stability must obviously always be guaranteed (equilibrium of the ground and of the structure at the Ultimate Limit State). Allowable displacements at the Serviceability Limit State (SLS) are often a major concern for projects near existing railway infrastructure. Indeed, unrestrained alterations of track geometry can ultimately lead to train derailment. Therefore, displacements are often a critical issue for projects.

The main risk treatment measures applied for the design and execution of geotechnical works in France to guarantee railway safety are presented in the following paragraph.

4 RAILWAY SAFETY IN DESIGN AND EXECUTION OF GEOTECHNICAL WORKS IN FRANCE

4.1 Standards and reference guides

Eurocodes are preferably applied for the design of geotechnical works on existing railway structures. However, there are instances where recent standards are difficult to apply, for example to justify the stability of old existing structures or for financial reasons. A risk tolerability principle known in France as GAME (*Globalement Au Moins Equivalent* meaning "globally at least as good") is used as an alternative in some cases.

In addition, a complete collection of reference guides published by SNCF give further design prescriptions and most importantly guidance on execution of works near operated railway systems. Some important documents are in the reference list (IG90032; IG90033; MT40200; IN1226). The rules described in SNCF guidelines are applicable to works on the French railway network presented in paragraph 2. The purpose is to guarantee safe rail operations without unexpected traffic disruptions or accidents.

4.2 General risk treatment measures

4.2.1 Use of construction machinery near operated tracks

To mitigate the risks related to moving trains and electricity, safety perimeters for the use of construction machinery and equipment near the tracks are defined in IG90033 as protective measures. These perimeters apply to most machines used for geotechnical works such as mechanical excavators, piling and drilling rigs. When railway traffic is maintained while works are carried out, machines must under no circumstances enter the "Prohibited Zone" limited by a vertical plane 3 m from the track centreline or from any electrical installation (Figure 2). If there is a risk of accidental overturning of a piece of equipment, the limit of the prohibited zone is placed at 3 m from the nearest rail. Cranes and other lifting equipment can only operate outside a "Protection Zone" defined by a vertical plane 5 to 6 m from the axis of the track (included expected load sway). These limits also apply to boring rigs used for ground investigations.

Vibrations generated by powerful mechanical equipment (rotary hammer drills, hydraulic rock breakers, compactors, etc.) have the potential to cause significant disturbances to existing railway infrastructures. Continuous vibration monitoring is compulsory for works within 30 m of existing tracks. Allowable thresholds are set in SNCF standard IN1226 (2009).

Contractors are required to obtain specific qualifications from SNCF to be authorized to carry out works near operated tracks.

Various technologies exist to warn workers of approaching trains.

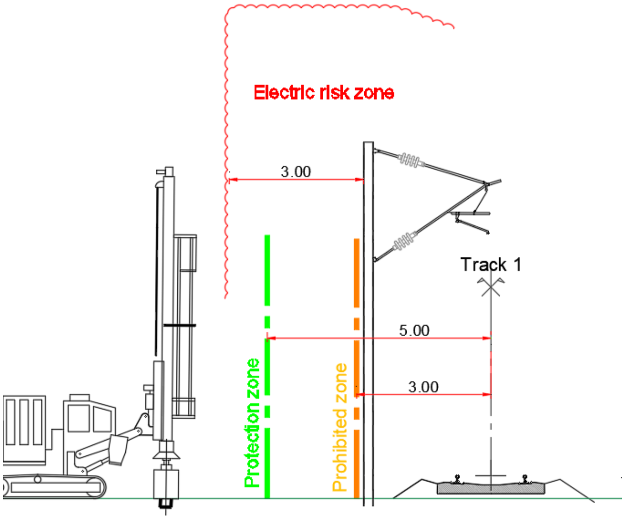

Figure 2. Zones for the use of construction machinery near the tracks following IG90033 (SNCF, 2018)

4.2.2 Track geometry quality

Settlements and displacements caused by geotechnical works are assessed in terms of track geometry. The main parameters used are (Figure 3):

1. Alignment
2. Track gauge
3. Cross level
4. Twist
5. Longitudinal level

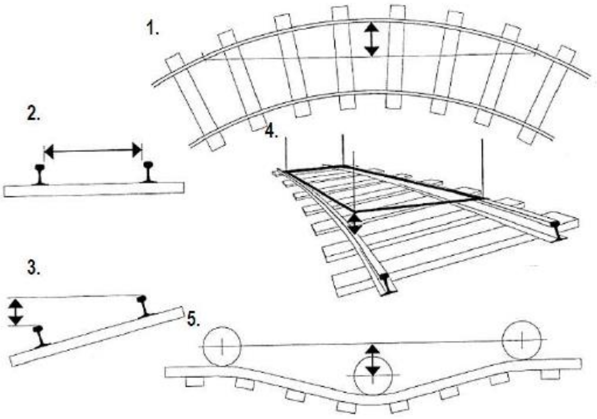

Figure 3. Schematic representation of principal track geometric parameters (Calon, 2016).

Maintaining the safety and regularity of railway operations requires that the characteristics of the traffic be considered (type, speed and frequency of traffic, importance of the line, etc.). For design, allowable track displacements depend on local conditions and vary depending on traffic speed: the faster the trains, the lower the allowable displacements. Limit values for tracks, switches and crossings in France are defined by reference guide MT40200. For each geometry parameter, the following thresholds are specified:

- Immediate Action Limit (IAL): Value which, if reached or exceeded, requires immediate measures to be taken to maintain track performance and guarantee traffic safety.
- Intervention Value (IV): threshold beyond which it is necessary to plan a short-term corrective intervention in order to avoid reaching the IAL.
- Alert value (AV): Alteration threshold beyond which specific monitoring should be carried out.

Examples of allowable longitudinal and cross levels against maximum train speed taken from MT40200 are presented in Figure 4 and Figure 5. Allowable longitudinal levels decrease linearly with traffic speed. Variations in allowable cross levels are less pronounced between 60 and 220 km/h, illustrating the higher risks for traffic safety in case of transverse default, even at moderate speed. Twist faults are of particular concern as they may cause the wheels to lose contact with the rail and derail the vehicle.

Integrating track geometry in design of geotechnical works often has important implications for projects. During initial design phases, it is recommended to limit anticipated track displacements below alert values (AV). When this is unachievable, different options are possible depending on local context:

- Reduce train speeds temporarily during works to maintain expected displacements below acceptable values,
- Perform frequent track geometry corrections by ballast maintenance to always guarantee satisfactory geometry during works,
- Carry out works during traffic interruptions (generally nights or weekends).

Such impacts on railway traffic must be anticipated. In France, traffic is planned 3 years in advance. Sufficient time must therefore be allowed between design and execution to allow for potential impacts on traffic to be incorporated in the transportation timetables. Selecting the most appropriate design option requires a global analysis balancing the potential benefits against costs and disadvantages (including operating losses for speed limitations and traffic interruptions).

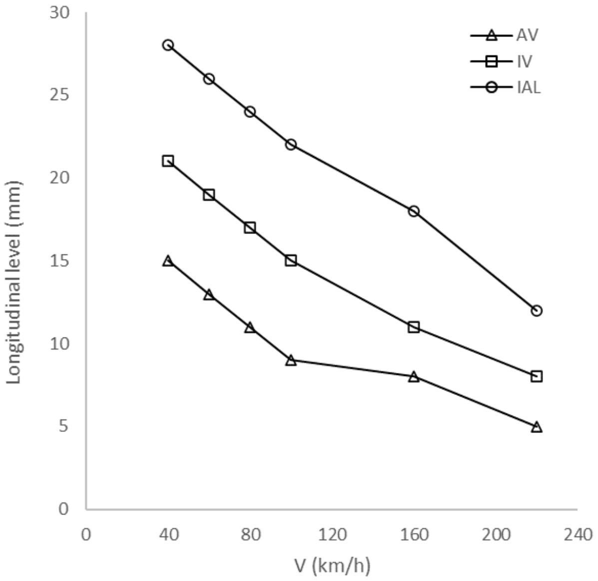

Figure 4. Examples of allowable longitudinal levels versus maximum train speed V (from MT40200 SNCF, 2021; measured over a wavelength of 15m)

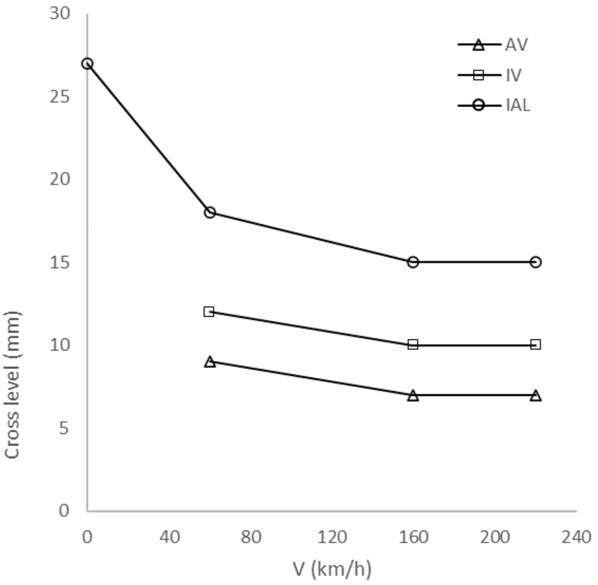

Figure 5. Examples of allowable cross levels versus maximum train speed V (from MT40200; SNCF, 2021)

It is important to note that the magnitude of allowable tracks displacements discussed above is millimetric whereas the commonly acknowledged precision for geotechnical settlement calculations is centimetric. Eurocode 7 asserts that understanding of the ground conditions depends on the extent and quality of the geotechnical investigations. Nevertheless, settlement calculations remain inaccurate and only give an approximate value. It is important that the uncertainties underlying settlement estimates be fully understood by all parties involved in such geotechnical projects (consultants, contractors, and infrastructure managers). In all projects with risks of track geometry modifications, it is appropriate to apply the approach known as "the observational method". The possibility for design adjustments during construction based on track geometry monitoring data must always be anticipated.

4.3 Excavations / retaining structures near operated tracks

According to reference guide IG90033, the effects of excavations near operated tracks must be considered when they are executed below a theoretical plane P0 inclined at 2 (horizontal direction) for 1 (vertical direction) and passing through a point located 3 meters from the axis of the track (Figure 6). Supports (i.e. retaining walls) are compulsory for excavations penetrating the theoretical plane P1 inclined at 3 (horizontal direction) for 2 (direction vertical) from the crest of the ballast.

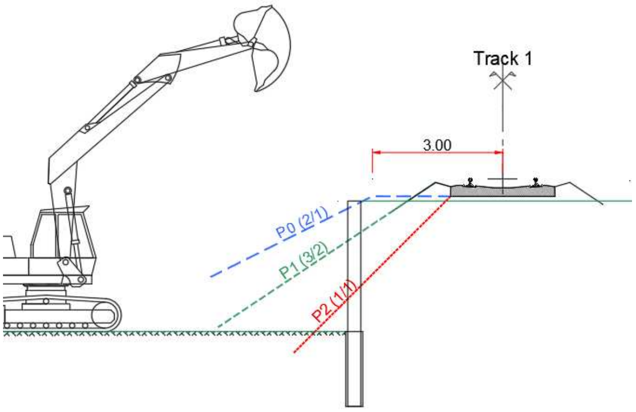

Figure 6. Excavation geometry near operated tracks from IG90033(SNCF, 2018)

Maximum allowable wall displacements are imposed in IG90033 based on the distance to the track and the depth of excavation. The displacements are also a function of the type of support and train speed, but do not depend on the surrounding ground conditions. The values were derived by SNCF from parametric studies on finite element models.

Figure 7 and Figure 8 present the theoretical example of an excavation located 5 m from an operated track. For both types of wall, allowable displacements decrease with traffic speed. Higher displacements are permitted for propped walls (Figure 8). Below 3 to 4 m, the allowable displacements decrease. This is asssumed to account for the greater risks associated with deep excavations.

Experience gained from imposing these thresholds for over 20 years in France has proven the effectiveness of the method applied to maintain the geometry of tracks near open cuts.

In certain cases, it may be required to reduce traffic speed as a safety measure to increase admissible displacements for the design of retaining walls.

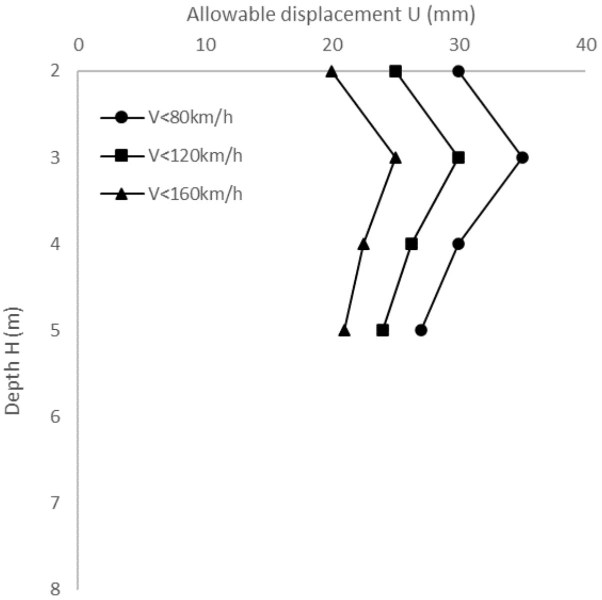

Figure 7. Example of allowable displacements for cantilever walls located 5 m from an operated track (IG 90033, Hécran=3m)

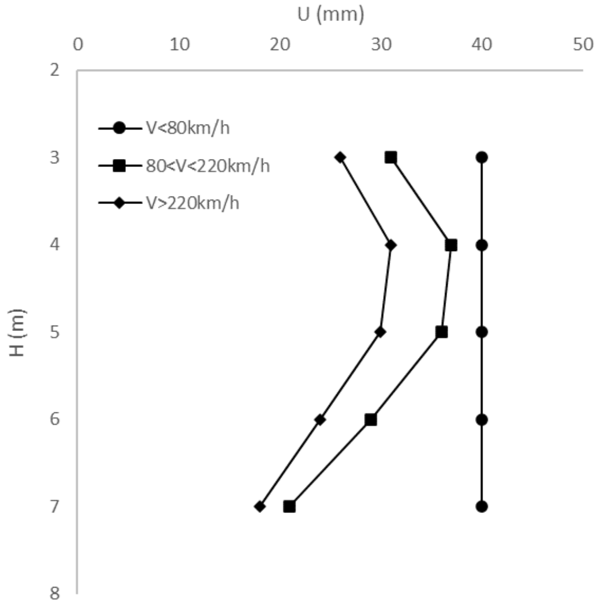

Figure 8. Allowable displacements of anchored/propped walls located 5 m from an operated track (IG90033; SNCF, 2018)

5 CONCLUSIONS

In this paper, specific risks for geotechnical works near operated railways are highlighted. In France, practice of railway safety measures is based on national reference guides validated by years of experience. Railway safety in projects can be achieved in part by takin into account traffic characteristics (especially speed) as design parameters. Geotechnical works will inevitably become more and more frequent within the interoperable European railway area. Hence, all infrastructure managers and operators would benefit from sharing local experiences and combining best-practices to guarantee a uniform level of safety everywhere in Europe.

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