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Analysis of the Invert Damage and its Rehabilitation Design The Saint Louis les Aygalades Tunnel Case Study

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ABSTRACT

The combined effect of time with the non-homogenous mechanical and hydraulic behaviors of the various intermediate layers between the foundation soil and the tracks often result in undesired deformation and misalignment of the tracks, which can compromise performance of the railway tunnel.

The tunnel of Saint-Louis les Aygalades is located on the Paris Marseille mainline. This 476 m long tunnel was built in 1847, from the two portals and two intermediate shafts, under a maximum cover of 35 m in the tertiary formation of Stampien. The section of the tunnel consists of an elliptical vault with large vertical axis resting on the curved sidewalls and supported by a circular invert. The tunnel was entirely lined in masonry bricks with lime mortar.

This paper presents an investigation into the behavior of the tracks in the Saint-Louis les Aygalades railway tunnel. The evolution of the tracks misalignment generated the undulatory deformation of the rails, which was caused by the non-homogeneity of the mechanical and hydraulic properties of the track structure. The modeling of the phases of construction and the time effect using the finite element analysis method made it possible to consider the structural role of the invert in the global stability of the tunnel liner. The study allowed the identification of possible causes of the track misalignment and determination of an appropriate solution. Corrective measures were assessed and applied.

INTRODUCTION

The Saint-Louis Tunnel is located on the double track Paris-Marseille electrified line between Estaque and saint-Louis les Aygalades stations.

This 476 m long tunnel was built in 1847 from two portals and two shafts under a maximum cover of 35 m in the tertiary formation of Stampien. Its layout is straight over the entire length and its slope is +2 mm/m over the first 170 m and then –1.3 mm/m towards the Marseille side portal.

The tunnel geometry consists of an elliptic vault with half large vertical axis (large axis: 10.7 m; small axis: 8.0 m) resting on 11.8 m radius curved sidewalls and closed by a 7.35 m radius arc of circle invert. The tunnel is entirely lined by brick masonry cast with the lime mortar. The theoretical applied brick liner thickness at the crown and sidewalls is estimated at 0.7 m and at the invert at 0.5 m (Fig. 1). Its height under the crown is 7.4 m and its 8.15 m opening at springline allows a double track gauge. The altitude of the top of rail is approximately 52 m.

The drainage in the tunnel ensured by a central and two lateral drains which collect water coming from des duct drains installed during the 1982 rehabilitation work.

The undulatory deformation of the rails is the major damage of this tunnel. This anomaly is treated by a shortening of the cycle of heavy mechanical ballasting.

GEOLOGICAL CONTEXT

The tunnel is mined in the thick stampien formation (tertiary) of Marseille basin. This formation is primarily made up of yellow or gray sandy marl, conglomerate, sand and hard sandstone.

The stampien constitutes the main part of the fluvio-lake basin of Marseille, where the marly sets settled, the predominant feature is composed of terrigenous detrital deposits (silt, sand, clay,…), extracted from surrounding topography. This fluvio-lake paleoenvironment added with a phenomenon of subsidence and incidentally of tectonic movements, produced a structure of lenticular sedimentation, giving the heterogeneity observed in the lithology of this formation. This explains the very rapid vertical and lateral variations of the feature. The stratification seems to be sub-horizontal.

The lenticular character of the formation and the low permeability of the marl do not allow the constitution of large aquifers. However, small water arrival of low flow meet when crossing the lenses of conglomerate, sand or sandstone.

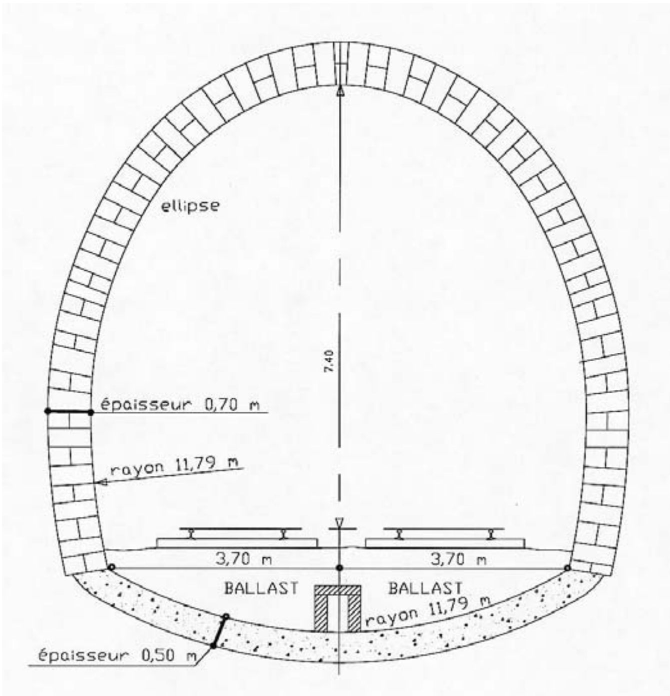

Fig. 1. Typical tunnel section

GEOTECHNICAL INVESTIGATIONS

Several investigation campaigns were carried out in the last 25 years. They include: reconnaissance campaign with the drilling train, drilling for the control of the masonry, 10 openings in the platform to top of the invert, and boring campaign in sidewalls foundation and in platform.

The lithological profile of the platform obtained from the boring results is presented on Fig. 2. The fill material is very heterogeneous and composed of gravel and blocks of various nature (limestone, schist…) packed in a matrix of yellow, brown or sometimes blackish sandy clay, showing scoria, brick fragments, etc….

The tests on the invert show, in particular for the mortar of covering, very low values of mechanical resistance. This fact is confirmed by the very crumbly consistency of the sample of this material, parallel to a very low apparent density. It thus seems, in conclusion, that this invert and more particularly the level of brick masonry- is very decomposed and damaged (fractures, void zones …).

The base of the invert rests in a very systematic way on beige to kaki marl packing gravels locally. With the depth, layers of silts or very cemented fine sandstone and then very consolidated brown marl are observed. The tests carried out on the marl show that they have a medium plasticity index, and globally they are slightly swelling. The results of the compressive strength tests are mediocre to relatively high and indicate a medium quality of the ground for the taken samples. It can be said that the tunnel was mined in a ground constituted in majority of more or less compact marl.

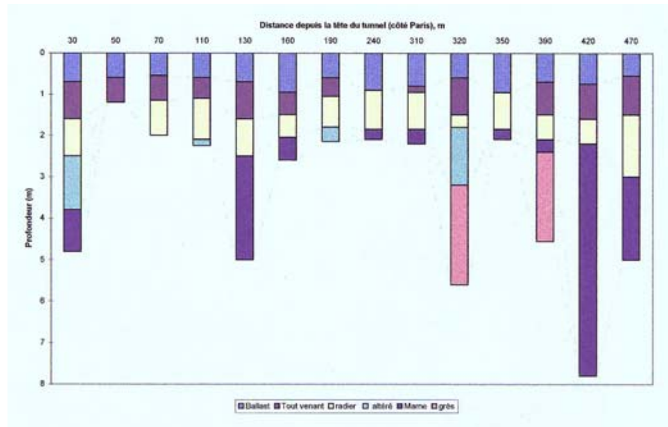

Fig. 2. Interpretation of the borings in platform

A distofor installed at PM 420 under the track 2 shows that during a period of three years from July 1991 to July 1994 the relative deformation between the depths 3.2 and 6.2 m is completely negligible.

The water level recorded in the piezometers, very different from one boring to another (Fig. 3), let suppose that the central drain is probably also considerably disorganized following the example of the invert, and that it does not fulfill sufficiently anymore its role of collecting the subsurface water. The longitudinal profile of water level in the central drain (Fig. 4) recorded in the same year (1991) shows many counter slopes , which globally correspond to the measured piezometric levels.

The low permeability of the underlain original ground prevents any natural drainage. The variable piezometric levels along the tunnel affects the bearing capacity of the surface ground and creates a non-uniform foundation for the tracks. This effect is amplified under the dynamic loading of the axles. The massive grouting carried out in 1982 has certainly modified the hydraulic regime around the tunnel making liner watertight and concentrating the water in the platform.

The evolution of the leveling defects of rail 1 of track1 over a one-year period between March 1990 and March 1991 is presented on Fig. 5. The weak behavior of the tracks is certainly due to the non-homogeneous mechanical and hydraulic characteristics of the foundation layers and especially the first two layers including the fill and relatively deep invert.

The objective of an adequate treatment should consist of making uniform in an optimal way the reaction of these layers. Fig. 6 compares the first and last leveling records and shows a global heave of the rail of several millimeters in average, resulting from three ballasting campaigns carried out during this period.

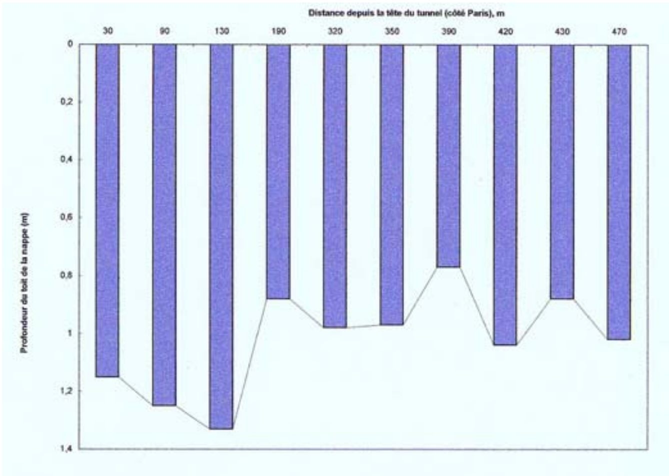

Fig. 3. Piezometric water level (depth below the top of rail)

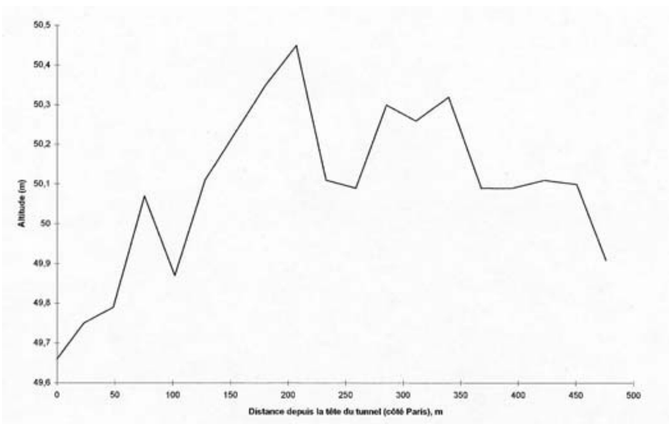

Fig. 4. Water level in the central drain

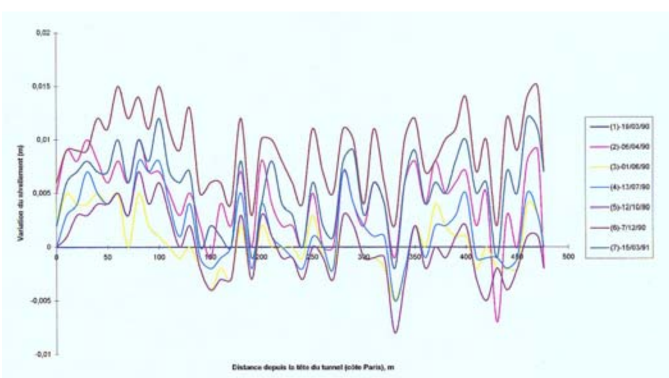

Fig. 5. Leveling defects (track 1, rail 1)

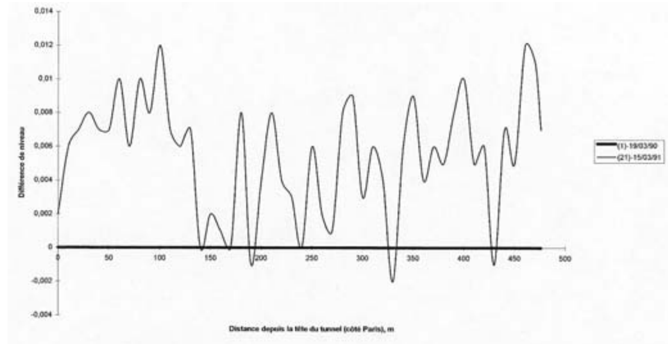

Fig. 6. Difference between first and last leveling

INVERT STRUCTURAL ROLE

In order to determine the structural role of invert, three following analyses are carried out. First, the stress field in liner and surrounding ground is calculated considering the construction of the tunnel and the section shown on Fig. 1. In the second analysis, the same section is considered this time without invert, this can be done using the same mechanical properties for the invert and the ground. The third analysis is devoted to the study of the effect of the invert mechanical behavior deterioration in the course of time. In this analysis, the simulation of tunnel construction phase is identical to that of the first analysis, but in order to apply the long-term effect, a more significant degradation rate of the invert behavior is considered in such way that, in long term, the mechanical properties of invert tend towards those of the ground.

The construction document is not available, but the elliptic shape of the vault and the study of the construction files of other tunnels of the same line built in the same time in the area, let suppose that the method of excavation was the English method, meaning that the complete section was excavated in only one phase and that the liner was installed thereafter starting with the invert, then the sidewalls and to finish with the vault.

The problem is analyzed by the convergence confinement method using the finite element method. The CESAR-LCPC software developed by the Laboratoire Central des Ponts et Chaussées is used. It allows taking into account the construction sequences and the elastic and elastoplastic material behaviors. The analysis includes three following phases: excavation, liner installation and long-term effect.

In the first phase, the excavation of the tunnel is simulated. The relaxation coefficient is taken equal to 0.5. The parabolic criterion is used to model the elastic and elastic perfectly plastic behavior of the marl.

The second phase corresponds to the modeling of the liner installation. The remainder of the deconfinement force is applied on the extrados of the liner. The parabolic criterion is used to represent the elastoplastic behavior of the brick masonry.

The long-term behavior of the materials is taken into account in the third phase. The method used is a simplified approach, rigorous only in the case of linear visco-elastic materials. It consists in simulating the change of mechanical characteristics of materials in long-term.

Fig. 7 shows the mesh used for analysis. Because of the symmetry of the geometry, loading and boundary conditions, only half of the system is modeled. Also because of symmetry, the degrees of freedom of horizontal displacements along the axis of symmetry are restrained. In order to eliminate the edge effects, the ground is modeled over a distance equal to four times the tunnel width in the horizontal direction and four times its height under the invert. To ensure the precision of the results, a sufficient number of finite element layers is used in the two directions.

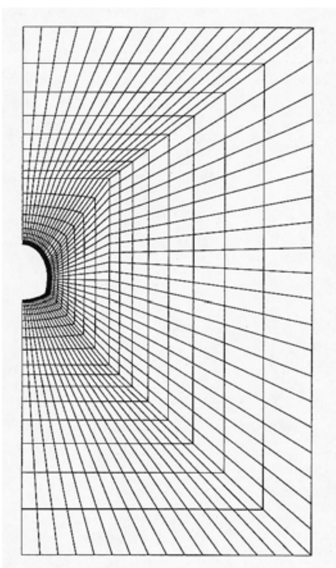

Fig. 7. Analysis model

The mechanical properties required for analysis are given in Table 1. These parameters are, either from the laboratory test results on the taken samples, or from a research in literature.

Table 1. Mechanical properties of the soil and the liner

Parameter	Marl	Brick
Young's modulus (Mpa)	50	6200
Poisson ratio	0.3	0.2
Compressive strength (Mpa)	5	7
Tensile strength (Mpa)	0.5	0.7
Unit weight (kN/m^3)	23	22
Lateral earth pressure coefficient	0.5	-

INTERPRETATION OF THE RESULTS

Figures 8a and 8b present the variation of normal stresses σ_{xx} and σ_{yy} along the intrados of the liner resulting from the last phase of the three analyses. The isovalues of total plastic strain for the three cases are shown on Fig. 9. According to these figures, it can be noted that there is no need for invert to ensure the structural function of the tunnel liner. Moreover, the three analyses show that there is no creation of significant structural cracks in the vault and sidewalls, which is compatible with the observation of the liner. It can be concluded that the reconstruction of the invert, expensive because of the methods to be used for the underpinning of the sidewalls, is not necessary in this particular case.

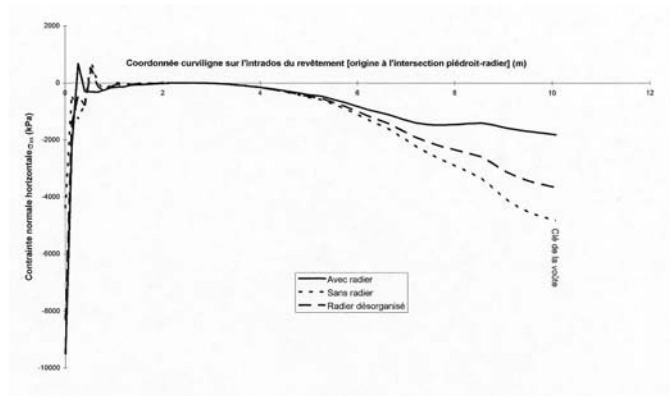

Fig. 8a. Variation of the horizontal normal stress σ_{xx} along the tunnel intrados

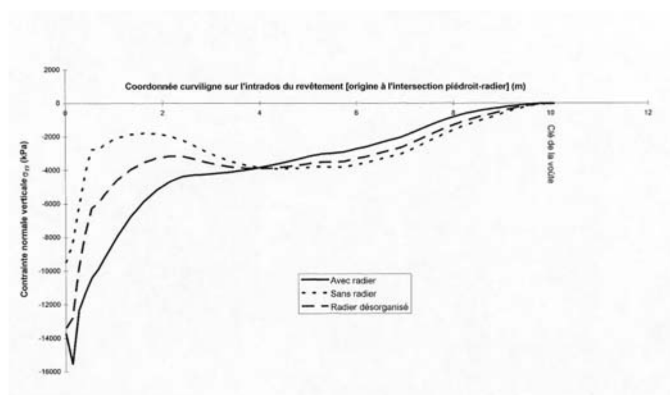

Fig. 8b. Variation of the vertical normal stress σ_{yy} along the tunnel intrados

Fig. 9a. Isovalues of total plastic strain for the analysis with invert

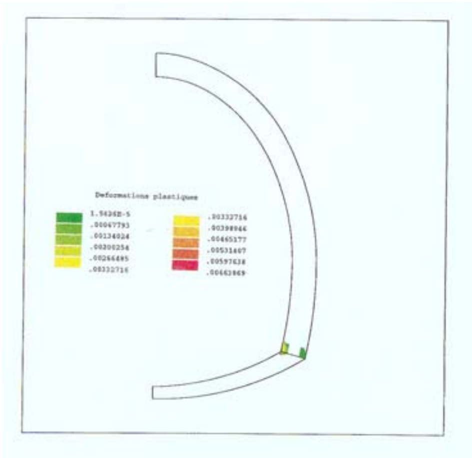

Fig. 9b. Isovalues of total plastic strain for the analysis without invert

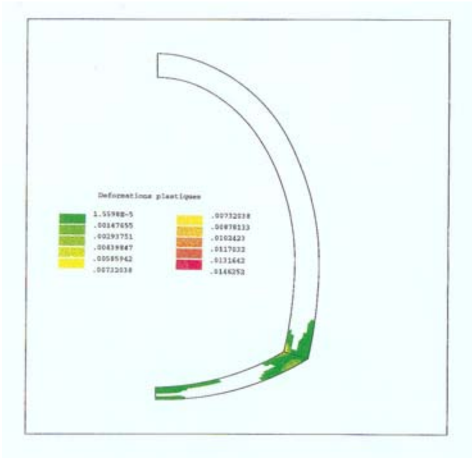

Fig. 9c. Isovalues of total plastic strain for the analysis with disorganized invert

DESIGN OF A REHABILITATION SYSTEM FOR THE PLATFORM

In the previous paragraph, It was explained why this pathology is not a structural problem for the tunnel and why the repair of the invert is not necessary. In other words in this particular case, the pathology is purely a problem of the track behavior due to the nonhomogeneity of the mechanical and hydraulic behaviors of the intermediary layers between the rail and the foundation soil or more particularly the layers of fill and disorganized invert. It is recalled that the supporting soil is primarily constituted of impermeable and relatively compact marl. The proposed solution includes three following stages.

In the first stage, 1.25 m of the ballast layer and a part of the fill layer is removed. The excavation sequences will be programmed in order to minimize the size of the soldier pile lagging wall between the two tracks.

The second stage consists of compacting the remainder of the fill and disorganized invert in order to obtain a uniform foundation with homogeneous and controlled mechanical and hydraulic properties. A perforated pipe surrounded by sand achieves the function of central drain (Fig. 10). The compaction method (compactor, number of passes, …) will be selected according to the work constraints in order to obtain an optimal dry density. From the structural point of view, alternation of the work is not necessary and the excavation on the track can be done over the entire length of the tunnel at the same time.

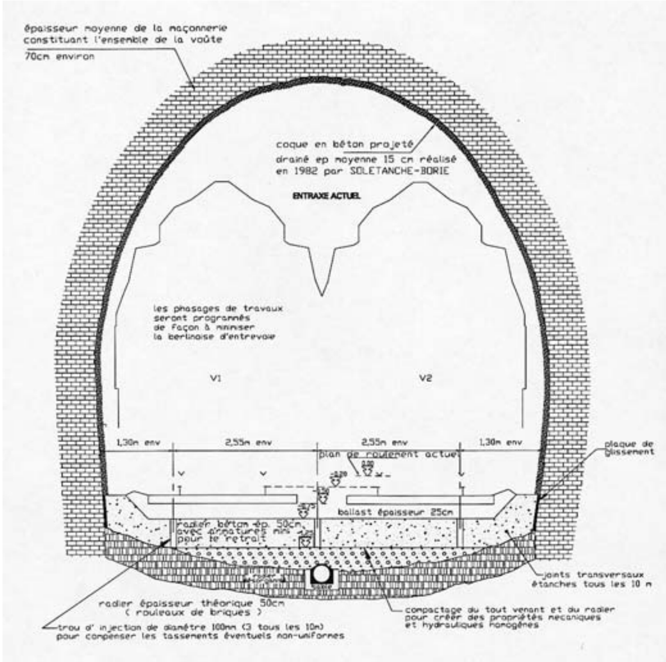

Fig. 10. Suggested solution

In the last stage, a 50 cm thick reinforced concrete slab will be built on the compacted base. To reinforce this slab, minimum shrinkage reinforcement is used as well as a low water cement ratio to reduce the number and the size of the cracks generated by the shrinkage. In order not to disturb the stress field and the load transfer path in the liner, the slab will not be embedded in the masonry of the sidewalls. The rails and the ties will be posed on a layer of 25 cm thick ballast.

The watertight transversal joints are considered every 10 meters to perceive the possible anomalies on the foundation of this slab before its brutal rupture. In each 10 m panel, nine 10 cm diameter holes are also envisaged. They can be used for the grouting under the slab if a significant differential settlement between the two adjacent panels would occur in the course of time.

The compacted intermediary layer between the concrete slab and the marly ground plays two important roles from the mechanical point of view. First, it has a uniform rigidity, large enough to be able to support the platform without generating unacceptable differential settlement. Then at the same time, it is flexible enough to be able to absorb possible swelling pressures of the marl. In addition, from the hydraulic point of view, as this layer is much more permeable than the marl, the interface water between the concrete and the marl are evacuated more easily towards the central drain.

CONCLUSION

This paper presents an example of platform damage and the problem of rail behavior in an old railway tunnel (Saint-Louis les Aygalades tunnel). The evolution of the leveling defect of the rails in the course of time put in evidence the undulatory deformation of the rails caused by the nonhomogeneity of the mechanical and hydraulic behaviors of the platform. The modeling of the construction phases and the long-term effect using the finite element method was allowed to estimate the structural role of the invert in the global stability of the tunnel liner. A rehabilitation system of the platform adapted to the possible causes of the observed damages was proposed.

REFERENCES

Humbert, P. [1989], "*CESAR-LCPC : Un code général de calcul par éléments finis*", Bulletins de liaison des Laboratoires des Ponts et Chaussées, Vol. 160, pp. 112-114.

Nasri, V., P. Ramondenc and J.P. Magnan [1998], "*Conception d'un système de renforcement pour le tunnel ferroviaire de la Nerthe"*, Bulletin des laboratoires des Ponts et Chaussées Vol. 217 pp. 53-59.

Panet, M. [1995], "*Le calcul des tunnels par la méthode convergence-confinement*", Presses de l'ENPC, Paris, p 177.