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Mechanical characterisation of the fouled ballast in ancient railway track substructure by large-scale triaxial tests

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Abstract

In the track substructure of ancient railways in France, a fouled ballast layer has often been created with time. The mechanical behaviour of this coarse soil was studied in the laboratory using a large-scale triaxial cell. The soil taken from the fouled ballast layer of an ancient railway was re-compacted to a dry density of 2.01 Mg/m^3 at three water contents (4, 6, and 12%) corresponding to three values of the initial degree of saturation (32, 48, and 100% respectively). Both monotonic and cyclic triaxial tests were performed under constant water content conditions. The experimental results gave the following evidence of the significant effect of the water content on the soil mechanical behaviour: (i) the lower the compaction water content, the higher the shear strength; (ii) a permanent axial strain of 0.4% was found after a large number of cycles at a water content of 4%, while it was 1.4% at the higher water content of 6%. For the saturated soil specimen, failure was even observed after a limited number of cycles. Based on the results obtained, a constitutive model for permanent deformation was elaborated, that accounts for the stress level, the number of cycles and the soil water content.

Keywords: Fouled ballast; Railway track substructure; Large-scale triaxial test; Cyclic behaviour; Water content effects; Constitutive modelling

1. Introduction

A fouled ballast layer refers to a layer within the railway track substructure, located in between the ballast and the subgrade soil (UIC, 2003). For the new high-speed lines in France, a sub-ballast layer or capping layer has been designed and constructed according to the technical specifications of the French National Railway Company (SNCF, 2006). By contrast, in the substructure of ancient railway tracks, there is no such sub-layer and a fouled ballast layer was created naturally. After Fortunato et al. (2010), the formation of this layer can be attributed to various mechanisms, for example, grain size modification in ballast particles due to cracking, weathering or crushing, the infiltration of materials from the surface, the infiltration of materials from an underlying layer, and the weathering of the sleepers. In order to respect the new requirements corresponding to the increase in load and the speed of trains, numerous ancient railway lines have been modernised, repaired or rehabilitated in France. Preliminary investigations conducted at different sites show that poor drainage was the major cause of track deterioration.

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Nomenclature

C_u	coefficient of uniformity
c	apparent cohesion
D	diameter of specimen
d	diameter of grain
d_{max}	maximum diameter of grain
d_x	diameter of grain defined by x% passing grain size
N	number of cycles
q	deviator stress
q_{max}	maximum deviator stress
Δq	amplitude of cyclic deviator stress
Δq_{max}	maximum amplitude of cyclic deviator stress
p	mean stress
Δp	amplitude of cyclic mean stress
Δp_{max}	maximum amplitude of cyclic mean stress
S_r	degree of saturation
S_{ri}	initial degree of saturation
w	water content
OMC	optimal moisture content
ε_1	axial strain
ε_1^p	permanent axial strain
ε_1^r	reversible axial strain
ε_1^p(N)	permanent axial strain at N cycles
ε_1^{p*}(N)	permanent axial strain from 100 cycles to N cycles
ε_v	volumetric strain
ε_{vmax}	maximum volumetric strain
ε_v^p	permanent volumetric strain
φ	friction angle
υ	Poisson's ratio
σ_3	confining pressure

For this reason, a drainage system has been installed systematically (SNCF, 2006) in spite of the extra costs. On the other hand, it has been observed that some substructures of ancient railways in excavation zones without drainage systems do not show any stability problems, indicating the necessity of optimising the design of drainage systems. Actually, the railway platform stability is closely related to the mechanical sensibility of the fouled ballast to variations in the water content; thus, it is obviously necessary to better understand its hydro-mechanical behaviour.

Large-scale triaxial tests are usually carried out to study the mechanical behaviour of ballast-based materials under static and cyclic loading. Most works have been performed on ballast (Raymond and Williams, 1978; Stewart, 1986; Raymond and Bathurst, 1994; Indraratna et al., 1998; Suiker et al., 2005; Lackenby et al., 2007; William and Peter, 2008), while a few works have been carried out on sub-ballast (Suiker et al., 2005). The test results show that under cyclic loading, these materials tend to compact. This compaction behaviour generally causes an increase in the mechanical strength and stiffness. Generally, after a large number of loading cycles, the resilient behaviour stabilizes, but the permanent strain increases (Kalcheff and Hicks, 1973; Brown, 1974; Li and Selig, 1994; Selig and Water, 1994; Gidel et al., 2001; Malla and Joshi, 2008; Ekblad, 2008). According to Selig and Water (1994), failure induced by the accumulation of plastic strain under repeated loads takes place when the material becomes saturated or when the drainage capacity is insufficient. This shows the significant effects of the water content and the drainage conditions on the mechanical behaviour.

The influence of the water content on the permanent deformation of Unbound Granular Materials (UGM) was studied by Gidel et al. (2002), Ekblad (2006), and Werkmeister et al. (2003). The results show that the water content strongly affects the resilient modulus and the permanent deformation under cyclic loading; increasing the water content causes a reduction in the resilient modulus and an increase in the permanent deformation. These kinds of studies on the hydro-mechanical behaviour of coarse-grained materials for railway application remain rare.

In constitutive modelling, the permanent deformation is usually predicted by accounting for the stress level (Shenton, 1974; Lekarp and Dawson, 1998) or the number of cycles (Barksdale, 1972; Paute et al., 1988; Sweere, 1990; Hornych et al., 1993; Wolff and Visser, 1994). Gidel et al. (2001) proposed a model to predict the permanent deformation of UGM as a function of both the stress level and the number of loading cycles based on the results of triaxial tests with a multi-stage loading procedure. Pérez et al. (2006) also proposed a model accounting for the effects of both the stress level and the number of cycles, but the experimental data considered for the model calibration were from the cyclic triaxial tests following a standard procedure, i.e., single-loading stage procedure.

In the present paper, the effects of the water content of the fouled ballast on its shear strength parameters and permanent deformation were investigated by carrying out both monotonic and cyclic triaxial tests. Based on the results obtained and the model presented by Gidel et al. (2001), a constitutive model was elaborated, allowing the determination of permanent strain by taking into account the stress level, the number of load cycles, and the water content.

2. Soil studied

The soil studied was taken from Sénissiat (North-West of Lyon, France), located along an ancient line from Bourg-en-Bresse to Bellegarde. At the moment of sampling, the line was being rehabilitated; the ballast layer had been removed for this purpose. Fig. 1 presents a picture taken during the sampling. A visual examination shows a 0.3-m fouled ballast