Evaluation de la dégradation du ballast ferroviaire à partir des simulations par éléments discrets des conditions de voie et de l'essai Micro-Deval

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Résumé :

En raison de la circulation des trains et des opérations de maintenance (bourrage), les grains de ballast ferroviaire s'usent. Cela entraine une perte graduelle de performance qui nécessite finalement le renouvellement de l'ensemble du ballast. Afin de prédire l'évolution de cette dégradation, une étude multi-échelle est proposée. Des simulations par éléments discrets de l'essai d'attrition Micro-Deval permettent relier le chargement microscopique à la production de particules fines observée expérimentalement. La même approche numérique est utilisée avec des simulations du trafic des trains et de l'opération de bourrage pour déterminer les chargements microscopiques caractéristiques avec les conditions de voie.

Abstract :

Track ballast is the granular layer upon which the rails and sleepers are laid in ballasted railway tracks. Ballast main function is to transfer and distribute the dynamic stresses imposed by the circulation of trains to the geotechnical structure supporting the track. It also affixes the sleepers both longitudinally and laterally and facilitates the correction of geometric defaults of the track during the maintenance operations (tamping). It is composed of centimetric-sized irregular grains with diverse mineralogical origins depending on the solicitations of the track. Since ballast performance strongly depends on the shape and size of the grains, both impact and wear resistance are required features for aggregates composing the ballast layer. However, after some years of service of high-speed railway lines in France, ballast has been proven not to be resistant enough. Grains wear faster than expected due to both the traffic of trains at high speed and the accumulation of tamping operations. Ballast replacement has therefore been required much before than its originally expected lifespan. Thus, in order to achieve the goal of prolonging ballast life, it is necessary to obtain a predictive model of ballast wear when it is subjected to complex mechanical loads.
Under the combination of both the dynamic stress imposed by the circulation of trains and tamping operations, ballast is gradually worn by fragmentation of grains and attrition at the contacts. The direct consequence of this degradation is the evolution of grain size and shape: the grading curve is moved towards the fine particles (d < 0.5 mm) and the grains progressively lose their angularity. Eventually the cumulated wear will no longer allow ballast to perform properly: the internal friction

angle is reduced limiting both the anchorage of sleepers and the distribution of loads to the platform. In addition, the presence in excess of fine particles renders tamping ineffective (fast evolution of track defaults) and reduces the permeability of the track. The mass flux of generated fine particles strongly depends on the loading conditions. The classically used Archard's model assumes that the generated volume of wear is proportional to the normal force and the relative displacement between the surfaces, which can be directly related to the work made by friction forces. Therefore it is crucial to quantify the forces involved at the contact scale and relate them to the relative displacement between ballast grains when they are in sliding contact, i.e. the microscopic load path.
Empirically, attrition resistance of railway ballast is characterized by the Micro-Deval standard test. 10 kg of grains are turned at 100 RPM inside a 40 cm long drum with a 20 cm inner diameter during 140 minutes. The numerous contacts within the device, both between grains and with the steel drum, produce an accelerated wear process in the aggregates which causes changes in the morphology of ballast grains similar to those produced in the track. Micro-Deval applies partially representative solicitations of the track on a limited volume of grains. Nevertheless, the conditions and loads to which ballast grains are subjected inside the drum are not actually well known. Understanding them is essential in order to link the test conditions to the experimental results.
Hence, in the proposed paper, discrete elements simulation of ballast is proposed in order to assess the load at the contact scale, i.e. to undertake a scale change moving from the track scale to the contact one. The goal is not to numerically model degradation but to extract characteristic microscopic load path (and other statistical parameters of the distribution of contact forces) from simulations and to predict degradation from these data. Thus the Micro-Deval test is simulated to link the microscopic load path with the production of fine particles observed experimentally in the test, using Archard equation as a first approach. Using the same numerical approach at the track scale, simulations of circulation of trains and maintenance operations allow the determination of the microscopic loading in track conditions. Loads and displacements are then compared to those determined for the Micro-Deval in order to discuss the relevance of this test.

Mots clefs : grains de ballast, méthode des éléments discrets, usure, Micro-Deval