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Investigation and evaluation of railway ballast properties variation during technological processes

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HIGHLIGHTS

- Variation of railway ballast properties increasing during technological process.
- Aggregates segregation during technological process increase gradation variation.
- Sampling during technological process are assessed by statistical indicators.
- Principle of max standard deviation of aggregates allow compare its homogeneity.
- Compulsory sample size increase then homogeneity of railway ballast decreases.

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ABSTRACT

Railway ballast (RB) layer has to limit tie movement by resisting vertical, lateral and longitudinal forces from the train and the track, to reduce the stresses from train loads applied to the subgrade, thus limiting permanent settlement. It also has to provide immediate water drainage from the track structure, to aid in alleviating frost problems, to facilitate maintenance surfacing and lining operations, to provide support for ties with the necessary resilience to absorb shock from dynamic loads. Secondary functions include retarding vegetation and resisting effects of fouling from surface deposited materials, absorbing airborne noise, providing adequate electrical resistance between rails, facilitating the redesign or reconstruction of the track. These properties are obtained through the use of proper gradation crushed granite, by determining its proper laying and compacting technological parameters, by ensuring sufficient thickness and profile of the layer. This paper presents statistical investigations of the four samples of crushed granite taken from transporter belt (TB), plant stockpile (PS), wagon (W) and railway construction (RC) uncompacted layer used to RB course. The gradation (particle size distribution), density of crushed granite particles (DEN_{P}), water absorption (WA_{24}), Deval index (M_{DE}), Los Angeles coefficient (LA_{RB} coefficient) and resistance to crushing (SZ_{RB}) of four samples were measured. Statistical parameters of crushed granite qualitative indicators, histograms, theoretical curves of normal distribution are presented. Their compliance with normal distribution was verified by employing the criteria of skewness, kurtosis, Pearson, Shapiro-Wilk and Kolmogorov-Smirnov. Dependance of standard deviations of percent passing through sieves on the means of percent passing through these sieves was obtained from regression analysis. The use of Kruskal-Wallis test by ranks showed that means obtained in different sample-taking locations did not differ statistically. The maximum value of standard deviation of this dependance, equal to mean of 50% percent passing, was used to evaluate the homogeneity of crushed granite used to construct the ballast layer according to the variation of its gradation. Absolute allowable error of minimum sample size *n*, equal to 5%, 10%, 15% and 20%, was calculated. Investigation results indicated that due to segregation the homogeneity of the gradation of crushed granite used to construct the ballast layer from its production site to its exploitation site decreased by 78%. During the technological processes of loading, transporting and spreading the gradation has hardly changed.

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1. Introduction

In Lithuania railway transport is a one of the leading GDP (Gross Domestic Product) producer among all transport modes. The length of the railway in Lithuania makes up 1767.6 km [1], and it is very important to maintain the existing and newly constructed tracks in its best possible condition. Railways have many advantages over other transport modes and, as a result, the industry has experienced a significant growth in terms of both passenger numbers and freight tonnage.

The choice of a particular mode of transport as an alternative to another one is subjective and usually based on an individual passenger‘s approach to the evaluation of advantages and disadvantages of some particular means of transport [2]. The paper presents the methods of analysing the reasons for passengers choice travelling by train as an alternative to using air transport and the results obtained in the research. The weight of five subcriteria making the "ride comfort" criterion group was equal to 0.3865 (the largest overall weight).

Railroad construction quality is important as much as railway trains and wagons technical quality for moving loads and passengers trip quality and safety [3,4].

In railroad construction ballast and sub-ballast play a significant role. Railroad ballast has to resist vertical and longitudinal forces, to hold the track in position, to provide energy absorption for the track, to facilitate adjustment of the track geometry, to provide immediate drainage of water falling onto the track, to reduce pressures on underlying materials by distributing loads and to provide energy absorption for the track [5].

Railway track ballast, sub-ballast and railway bed, impacted by the factors of train traffic loading, climate and ambient air, deform, due to which track quality index (TQI) varies [6–8]. The life of ballast depends upon a number of factors, mainly traffic loading, drainage, contamination, and is clearly related to intervention levels and installation quality standards [9].

From the economic standpoint, the cost of fuel consumed by railway transport makes up one-seventh of that of the road transport. Additional advantages include low pollution and high safety levels. The main disadvantage of the high cost of repair and maintenance activity is an improper stress distribution within the foundations under the track. This problem can be caused by breakage and attrition in the ballast or deterioration of the subgrade [10–12]. Considering that, maintenance costs for rail track subsystem may represent about 55% of the total maintenance costs [13].

The whole maintenance demand of the track depends on its initial quality. However, due to a small contact area between the sleeper and the ballast (3 to 5%), initial settlements by cracking of the ballast are unavoidable. As long as the ballast stones cannot bear the concentrated forces, cracking will occur, until more and more stones come into contact, which increases the contact area. Unfortunately, these initial settlements are not similar but differ from sleeper to sleeper, which forms initial failures, causing dynamic forces, increasing the failures, increasing the forces, and so on and finally causing the need for maintenance. The consequences of ballast wear are therefore vertical alignment failures and pollution of ballast bed. In principle, in order to improve the situation, two solutions exist: first, to increase the quality of ballast and second, to reduce forces in ballast [14].

Ballast is mostly produced from natural deposits of granite, trap rock, quartzite, dolomite, limestone or other natural soils. Railway ballast is generally composed of uniformly graded angular aggregate. As ballast ages, it can be progressively fouled by numerous fine materials, the accumulation of which in the voids of ballast can result in a decrease in shear strength with reduced resiliency and drainage capability of the ballast [5]. Ballast materials forming part of railway structures are subjected to cyclic loads. As a result of these loads, ballast densification, aggregate degradation, and lateral spread of the ballast material underneath the ties take place inducting permanent deformations on the railways [15].

The degradation of track geometry induces an evolution of the initial gradation and angularity due to fouling or numerous maintenance operations. The usual process for track or ballast renewal is based on some investigations about the track geometry and substructure and the efficiency of maintenance operations [16]. The bearing capacity depends on the qualities and thicknesses of soils that compose the subgrade, from the formation layer to the lower layers. These models can establish the tensional and deformation state of each cross-section of materials and layer, which is an important tool in the design phase of railway track [17]. The migration of particles and the interaction between ballast and sub-soil layers are one of the biggest problems in exploiting roads [18]. Substructure instability can be caused by weak subgrade soils, ballast breakdown, poor-quality ballast, thickness of the ballast and top formation layers. Sources of ballast fouling consist of ballast particle degradation, infiltration of fine foreign particles from the track surface, sleeper wear, as well as sub-ballast and subgrade infiltration [19].

The instability of railway components may be caused by too weak building materials used, ballast fragmentation, its poor quality, insufficient thickness of ballast and other materials used in the layers. Ballast decline is caused by ballast particle degradation, penetration of other materials into the layer, wear of rails as well as mixing of ballast and sub-ballast layer materials [19].

The obtained results [20] confirmed that for impact-load components over 100 Hz, the ballast layer resists because of its high rigidity and can reduce the impact loads substantially. However, the ballast layer is almost non-resistant to the low-frequency load components, which are not reduced enough.

Kennedy et al. [21] presents the measured settlement results of full-scale testing of unreinforced and polymer-reinforced ballast railway track under laboratory conditions. The measured settlement profile of each track specimen is monitored up to a maximum of 500.000 load cycles at different load levels and formation conditions. The polymer treated track is observed to reduce permanent track settlement by 99%, effectively giving slab-track like performance.

The obtained results [22] indicate that the use of 10% of crumb rubber (by volume) could reduce ballast degradation and at the same time as the capacity of the ballast layer to dissipate energy is increased, its stiffness is reduced as well. Additionally, based on the present laboratory study, the track settlement could be reduced with 10% rubber particles used as elastic aggregates.

Execution of tamping is highly dependent on the condition data and there is no well-structured track degradation analysis that helps to make long-term maintenance plans. The evaluation of the standard deviation for the longitudinal level at which tamping is executed indicates that the execution of tamping is not optimally planned ([23,24].

Caetano and Teixeira [25] propose a railway track geometry degradation model that considers uncertainties in the forecast by defining a track geometry reliability parameter. The degradation model integrated in a multiobjective optimization approach assesses railway track maintenance strategies considering cost-reliability trade-off.

The Bayesian model for rail track geometry degradation allows to asses the evolution of uncertainty associated with degradation parameters throughout the rail track life-cycle. Prior probability distributions were fitted to track geometry degradation, showing that Log-Normal distribution is the most suitable distribution to model deterioration parameters [26].

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