The Experimental Estimation of The Elastic Modulus of a Fly Ash Based Trackbed Layer Under Cyclic Loading

Vít LOJDA[1)], Martin LIDMILA[1)], Marek PÝCHA[2)]

[1)] Czech Technical University in Prague, Faculty of Civil Engineering, Thákurova 7, 166 29 Praha 6, Czech Republic; emails: martin.lidmila@fsv.cvut.cz, vit.lojda@fsv.cvut.cz
[2)] University of Birmingham, Birmingham Centre for Railway Research and Education, Gisbert Kapp Building, Edgbaston, B15 2TT Birmingham, United Kingdom; email: mxp418@student.bham.ac.uk

http://doi.org/10.29227/IM-2019-01-22

Submission date: *11-07-2018* | Review date: *02-04-2019*

Abstract

In a railway track structure system, trackbed layers are designed to compensate for insufficient bearing capacity and/or water or frost resistance of natural soil. These, so called, 'capping layers' can be constructed from raw materials like sand or gravel or from industrial materials like asphalt or concrete. However, more environmentally and cost friendly alternatives have been studied in recent years. Fly-ash represents one such promising material and a trial section of a main line track with the capping layer made from a fly-ash-based mixture was constructed in Czech Republic in 2005. The performance of the capping layer in the section has been measured since. In this paper, results of the laboratory estimation of the elastic modulus under cyclic traffic-like induced loading are presented for the most recent group of samples. The results show that the elastic limit of the fly-ash-based material lies well above the stresses induced by railway traffic and that its behaviour is stable under the cyclic loading. This suggests that the mechanical properties of the material may not be determinative for the design of the layer and that the feasibility factors may take precedent. This in turn suggests that either the design strength of the material or the designed thickness of the layer may be possibly reduced.

Keywords: fly-ash stabilizer, trackbed, cyclic loading, elastic limit, elastic modulus

Introduction

A railway track structure is a system designed to provide vertical and horizontal support for passing railway vehicles. To this end, it utilises multiple elements but ultimately the whole system is built upon natural soil. When this soil is too weak to support the track structure or when the soil is susceptible to the ingress of water and/or freezing caused by low temperatures a special layer (called 'capping layer') needs to be designed atop of the natural soil (called 'subgrade') to protect it. This layer can be designed from raw materials, e.g., sand, gravel aggregate, or from industrial materials, e.g., asphalt, concrete. However, in recent years more cost and environmentally friendly alternatives have been studied. Fly ash, a by product of thermal power generation, represents one of the materials under focus. In the Czech Republic as soon as 2005 Lidmila (2005) studied feasibility of using fly ash material (pulverised fuel ash) for railway capping layers. His work culminated in designing and building of a trial section on a main railway line near Smiřice station. In the section, the fly-ash stabilizer capping layer was designed to protect subgrade bedrock consisting of clay limestone (weathered marlite), which is highly susceptible to frost. The trial section was finished in April 2005 and since then biannual measurements have taken place to investigate the behaviour of the track in real conditions. The investigation has consisted of in-situ Plate Load Tests and sample collection for further laboratory testing. First ten years of the research are described in Lidmila & Lojda (2015), Lojda et al. (2015) and Lojda et al. (2017).

Initially, the research focused on rheological changes of the material, e.g., changes in compressive strength, reference density or water content. However, recently the aim of the research has been expanded to investigate the behaviour of the material under dynamic traffic-resembled loading. This paper presents the results of the laboratory investigation into the dynamic behaviour of the fly-ash based material sampled from the capping layer of the trial section. The methodology of the experiment is discussed briefly and results for the first cohort of samples from year 2016 are presented.

Methodology

The aim of the research was to study the behaviour of the fly-ash material from the capping layer under dynamic traffic-resembled loading. A laboratory investigation to be performed on samples collected from the capping layer of the trial section was designed for the task. The samples were collected using core drilling technique, details of which can be found in Lidmila & Lojda (2015). Multiple samples were collected in Autumn 2016 with seven samples selected for the laboratory dynamic testing.

The testing apparatus consisted of a loading frame Inova Praha ZUZ 200 1350 with hydraulic actuator. The vertical deformation of the samples was measured by means of three absolute LVDT sensors of displacement Ahlborn FWA025T. The sensors were fixed to the sample using two metal rings in accordance with ČSN EN 13286-43. Ahlborn Almemo 2690-8A data logger was used for the experiment. The photo of the testing apparatus can be found on Figure 1.

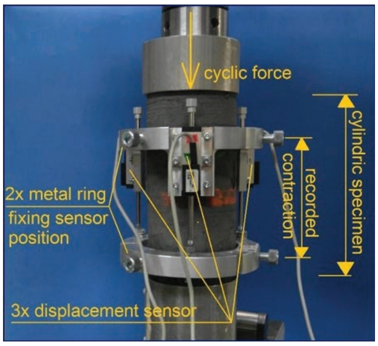

Fig. 1. Testing apparatus
Rys. 1. Aparatura badawcza

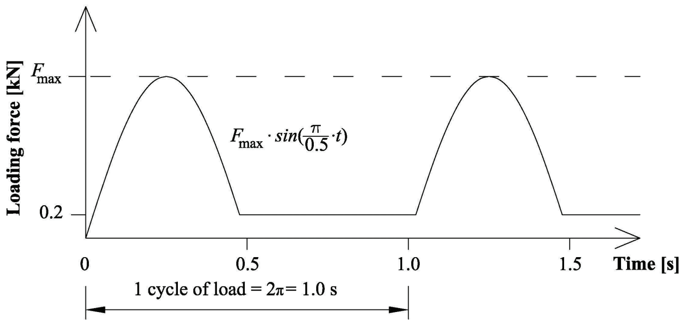

Fig. 2. Illustration of loading function (Lojda, Lidmila, Pýcha 2017)
Rys. 2. Ilustracja funkcji budowania (Lojda, Lidmila, Pýcha 2017)

Because no standard exists in the Czech Republic for testing of trackbed materials under dynamic traffic-resembled loading, a specific loading function was designed for the experiment. The design of the loading function followed recommendations provided in BS EN 13286-7 as closely as reasonably practicable while taking into consideration the limits of the testing apparatus. Hence, the loading function consisted of 0.5 s long loading impulse half-sine in shape followed by 0.5 s of null loading (see Figure 2). This function represented one cycle of loading. The complete loading of the sample then consisted of 500 cycles, applied in five steps, each step with different maximum applied force of 3 kN, 6 kN, 9 kN, 12 kN and 15 kN respectively. Details of the methodology can be found in Lojda et al. (2017).

For the discussion of the results, it is important to mention how the samples were treated with regards to their respective moisture contents. All samples were collected using the same technique as described above but their consequent treatment was different. Samples P3-2 and P3-3 were sealed in plastic containers immediately after drilling, preventing them from a loss of any moisture during transport and storage. The samples were taken out of the containers only immediately before the dynamic testing. Hence the moisture content of the samples P3-2 and P3-3 is expected to have been the natural moisture content of the capping layer material increased by some unknown amount of water which the samples likely absorbed during drilling. Samples P3-5, P3-6 and P3-8 were let to dry naturally in air until the changes in their mass stabilised. Finally, samples P2-1 and P2-2 were first dried in an oven and then re moisturised to achieve a water content of 35-40%, i.e., the natural water content of the fly-ash material in the capping layer. Aim of this artificial moisturising was to create samples with a moisture content close enough to that of the capping layer material as exists in situ, i.e., without the negative effect of the water ingress caused by the core drilling technique.

Results and Discussion

During the experiment, the applied force and the resulting deformation of the samples were recorded. This enabled to calculate the applied stresses and corresponding strains in the samples and to plot hysteresis loops for every sample and every step of loading, as shown on figures below. This form was chosen because hysteresis loops indicate the behaviour of the material under investigation, i.e., its linearity or nonlinearity, damping properties and ratchetting or shakedown behaviour.

Results for samples P3-2 and P3-3, which were both taken from the same measuring location on the trial section (profile P3) and which were prevented from drying, are presented on Figure 3. Results for samples P3 5, P3 6 and P3 8, taken from the same profile as samples P3 2 and P3 3 but allowed to dry naturally, are presented on Figure 4. Finally, results for samples P2 1 and P2 2, taken from different profile (P2) and artificially moisturised, are presented on Figure 5.

First, it can be seen that the results for sample P3-2 (Figure 3a) and sample P2 2 (Figure 5b) are invalid. The sample P3-2 seems to exhibit negative permanent strains in the fifth step of loading.

This was caused by the loosening of the screws fixing the two steel rings onto the sample during the fifth step of the loading. Hence, results for the fifth step of loading for sample P3 2 should not be considered valid because of the error in the apparatus. On the other hand, results of the sample P2 2 represent invalid results caused by a non homogeneity in the

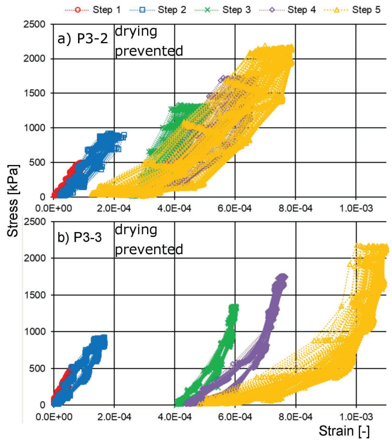

Fig. 3. Hysteresis loops for samples with prevented drying; a) sample P3-2, b) sample P3-3

Rys. 3. Pętle histerezy dla próbek z zapobieganiem suszeniu; a) próbka P3-2, b) próbka P3-3

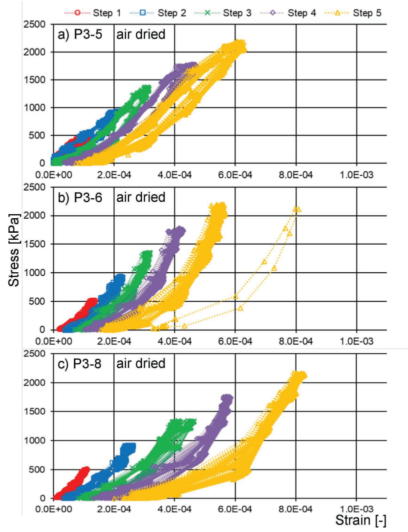

Fig. 4. Hysteresis loops for samples allowed to dry naturally; a) sample P3 5, b) sample P3 6, c) sample P3 8

Rys. 4. Pętle histerezy dla próbek pozostawionych do naturalnego wyschnięcia; a) próbka P3 5, b) próbka P3 6, c) próbka P3 8

material. It can be seen from Figure 5b that the sample exhibits extremely large strains even under low load. This was caused by a layer of slag formed across the whole diameter of the sample. The sample reached its strength limits during the fifth step of loading and collapsed. Hence, the results for sample P2 2 cannot be considered representative as well.

It can be seen from the remaining figures that the results are remarkably consistent across all samples, regardless of the moisture content. All samples exhibit close to purely elastic behaviour for the first two steps of loading, i.e., up to the loading of 1000 kPa, and then start to behave non linearly with hysteresis loops gaining typical convex shape (Pýcha 2016). However, it does not seem that loading limits were reached as all samples seem to exhibit shakedown behaviour even for the last step of the loading.

From the maximum applied stress and the maximum corresponding elastic strain it was possible to calculate elastic modulus E in every cycle of the loading. The results are summarised in Table 1, with n/v indicating that the results for a given sample and step of loading are not valid (see explanation above). The arrows represent changes in the values of elastic moduli in given cycles. It can be seen that for the first two steps the value of the elastic modulus either keeps constant or changes only slightly, which corresponds well with the assumption of a linear behaviour. For the other three steps, the value of the modulus increases significantly with the number of loading cycle in each step. This corresponds well with the assumption of shakedown behaviour. However, for the last three steps the elastic modulus does not have significant physical meaning because of the convex shape of the hysteresis loops and the non linear behaviour.

The average values of the elastic modulus are approximately 7000 MPa for samples with high water content and approximately 5500 MPa for samples with low water content, which corresponds well with the values obtained in the previous investigations with Impulse Excitation Method and Ultrasonic Method (Lidmila, Lojda 2015).

Conclusions

This paper presented research into the behaviour of fly ash based trackbed material under dynamic traffic resembled loading. During the investigation, laboratory testing of samples collected from a trial railway track section with a capping layer made of fly ash material was performed.

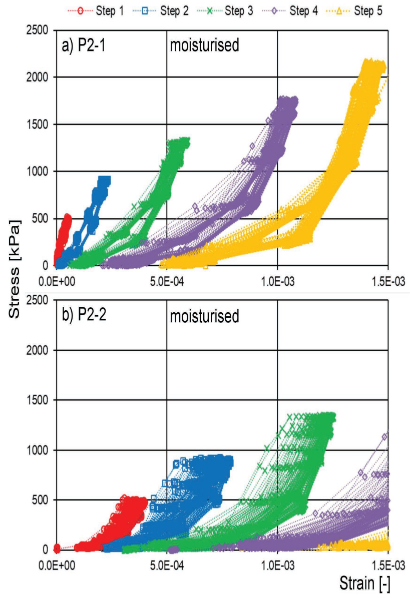

Fig. 5. Hysteresis loops for samples artificially moisturised; a) sample P2 1, b) sample P2 2
Rys. 5. Pętle histerezy dla próbek sztucznie nawilżonych; a) próbka P2 1, b) próbka P2 2

Tab. 1. Summary of elastic moduli in each loading step for different samples
Tab. 1. Podsumowanie modułów sprężystości w każdym etapie budowy dla różnych próbek

Sample	Water content	Elastic modulus of a sample *E* in a step in [MPa]				
		1	2	3	4	5
P3-2	Drying prevented	6500	6500→5500	n/v	n/v	n/v
P3-3	Drying prevented	8000	7000→6000	8000	6000→7000	4000→4500
Average		**7250**	**6750→5750**	-	-	-
P3-5	Air dried	5000→4500	4500	5000	5000	4500→5000
P3-5	Air dried	5000→6000	6000→7000	7000	7000	6500→7000
P3-8	Air dried	6000→7000	4500→5500	4000→5000	4000→5000	4000→5000
Average		**5300→5800**	**5000→5600**	n/a	n/a	n/a
P2-1	Moisturised	10,000	4500→5500	3000→3500	2000→3000	2000→3000
P2-2	Moisturised	n/v	n/v	n/v	n/v	n/v

The results shown that the material behaves linearly up to the load of 1000 kPa and non linearly with shakedown behaviour above that value. Hence, 1000 kPa can be considered the elastic limit of the fly ash trackbed material studied in this research (see Lojda et al, 2017, for details about the mixture used). This value was valid across samples with various moisture content. The value of 1000 kPa is significantly higher than most stresses induced in trackbed at the capping layer level below sleepers for even the highest train speeds. Hence, this suggests that the mechanical properties of the material are sufficient and that other properties, e.g., feasibility of construction, chemical consistency, economic factors, may take precedent during the design of a capping layer from the fly ash based material.

Acknowledgements

Financial support for the research presented in this paper was granted from Competence Centres programme of Technology Agency of the Czech Republic (TAČR) within the Centre for Effective and Sustainable Transport Infrastructure (CESTI), project number TE01020168. This support is hereby gratefully acknowledged.

Literatura – References

1. LIDMILA, Martin. Ecological Exploitation of Waste Materials from Thermal Power Plants in Construction of Rail Bed. Prague, 2005. 145 p. Doctoral thesis on the Faculty of Civil Engineering at Czech Technical University in Prague on the Department of Railway Structures.
2. LIDMILA, Martin and LOJDA, Vít. Fly Ash-Based Stabilizer Sampling in Railway Track Bed and Determination of Young's Modulus, Journal of the Polish Mineral Enginerring Society. [online] 2015, vol. 16, no. 2, [cit. 2018-03-17] pp. 11–16. ISSN 1640-4920.
3. LOJDA, Vít, LIDMILA, Martin, PÝCHA, Marek. Determination of the Elastic Modulus of Fly Ash-based Stabilizer Applied in the Trackbed. In BILY, Petr; KOHOUTKOVA, Alena. Building up Efficient and Sustainable Transport Infrastructure 2017 (BESTInfra2017). BestInfra 2017 : 21. 9. 2017, CTU in Prague. Bristol: IOP Publishing Ltd, 2017, vol. 236, ISSN 1757-899X.
4. LOJDA, Vít, PROŠEK, Zdeněk, KOPECKÝ, L. and LIDMILA, Martin, 2015. Effect of Microstructure on Mechanical Properties of Fly Ash-Based Stabilizer. In: Proceedings of the 1st Inernational Conference RISEM. Prague: CTU in Prague. 2015. p. 149–152.
5. LOJDA, Vít et al., Microstructural Analysis of Fly Ash-Based Stabilizer for Track Bed, Curich : Trans Tech Publications, 2017, vol. 731, pp. 66–73, ISBN 978-3-0357-2138-6.
6. PÝCHA, Marek. Dynamic Elasto-Visco-Plastic Material Model for Modelling of Light Weight Deflectometer Test - a Uniaxial Preliminary Study, Mres thesis, Birmingham : University of Birmingham, 2016.

Eksperymentalna ocena sprężystego modułu warstwy nośnej na bazie popiołu lotnego w obszarze obciążenia cyklicznego

W systemie konstrukcji torów kolejowych warstwy nośne są zaprojektowane tak, aby kompensować niedostateczną nośność i/lub odporność na wodę lub mróz naturalnej gleby. Te tzw. warstwy zamykające mogą być zbudowane z surowców takich jak piasek lub żwir lub z materiałów przemysłowych, takich jak asfalt lub beton. W ostatnich latach badano alternatywy bardziej przyjazne dla środowiska i kosztów. Popiół lotny stanowi jeden z takich obiecujących materiałów, badania w Czechach prowadzono od 2005 r. Wykonano próbny odcinek głównego toru linii kolejowej z warstwą przykrywającą wykonaną z mieszanki na bazie popiołu lotnego. Wydajność warstwy przykrywającej w przekroju została zmierzona. W niniejszej pracy przedstawiono wyniki laboratoryjnej oceny modułu sprężystości przy obciążeniu indukowanym podobnym do ruchu cyklicznego dla najnowszej grupy próbek. Wyniki pokazują, że granica sprężystości materiału na bazie popiołu lotnego leży znacznie powyżej naprężeń wywołanych ruchem kolejowym i że jego zachowanie jest stabilne pod obciążeniem cyklicznym. Sugeruje to, że właściwości mechaniczne materiału mogą nie być decydujące dla konstrukcji warstwy i że materiał może być zastosowany. To z kolei sugeruje, że można albo zmniejszyć wytrzymałość projektową materiału, albo zaprojektowaną grubość warstwy.

Słowa kluczowe: stabilizator na bazie popiołu lotnego, warstwa nośna, obciążenie cykliczne, granica sprężystości, moduł sprężystości