Fly Ash-Based Stabilizer Sampling in Railway Track Bed and Determination of Young's Modulus

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Abstract

This paper deals with the investigation of the fly ash-based stabilizer used as a layer in railway track bed. It is a "new" material in railway structures. The main purpose of stabilizer is to reinforce railway track bed. The above mentioned fly ash-based stabilizer is a mixture consists of fly ash from Chvaletice plant in the Czech Republic, FGD gypsum, calcium oxide and water. The laboratory tests of the fly ash-based stabilizer have started in 2000 in order to define the key physical properties and also material suitability in the field of railway substructure. For the purpose of the 1:1 scale material verification, a box device with dimensions of 990 × 800 × 2095 mm for full scale testing was designed. On the base of the laboratory tests the 330 m long trial section of railway track was stabilized at the Smiřice railway station. The test layer under track No. 3 was built in April 2005 and the extraction of the material for laboratory test is done on regular basis - each spring and autumn. The paper is focused on sampling of the fly ash-based stabilizer by core drilling for following laboratory tests. The experience with in situ sampling in railway track bed led to recommendation summarized in the conclusion. The layer of stabilizer, which is placed under railway ballast and crushed stone, was uncovered and the boreholes with diameter 100 mm were done. According to the difficulty of sampling it was possible to extract only a small amount of specimens for the determination of the performance and durability of the fly ash-based stabilizer. It was necessary to exclude some of sampled specimens which with high probability include predisposed surface failures that might significantly affect the average value of the young's modulus. The goal was to choose three specimens for the pressure test. Ultrasonic method and also Impulse Excitation Method were chosen as non destructive test methods for the determination of dynamic modulus of elasticity, which could denote the suitable samples for the pressure test. At the end of the paper the results of determined young's modulus and dynamic modulus of elasticity are also described. The most important findings in the comparison of non-destructive and destructive tests are discussed. These results can significantly support the knowledge of the stabilizer in the long-term monitoring of the trial section in Smiřice.

Keywords: fly ash-based stabilizer, core drilling, railway track bed, non-destructive test

Introduction

Since 2000, the Department of Railway Structures, Faculty of Civil Engineering, CTU in Prague has been engaged in experimental research of using fly ash-based stabilizer from the Chvaletice Power Plant (CPP) in the track bed construction. One part of the research plan MSM 6840770005 was the establishment of a trial section for the operational verification of the fly ash-based stabilizer that was used in the track bed structural layers. The objective of the trial section was verifying and also long-term monitoring of the layer of fly ash-based stabilizer that would protect the subgrade composed of rock susceptible to weathering due to water and frost effects (Lidmila, 2005).

The goal of this research was to prepare the samples for the following laboratory tests. The samples come from the layer of fly ash-based stabilizer placed in the track bed in 2005. Because of the uniqueness of the samples the main requirement was the sampling quality in relation to determination of the properties. It was reached by the specified core-drilling method and related preparation of the test specimens. The aim of the preparation was to cut cylindrical samples with the proper ration between the height and the diameter. In relation to other laboratory tests the important research objective was to choose just three of all specimens that were used for the pressure test and determine compressive strength and Young's modulus. The specimen selection was based on non-destructive determination of Young's modulus.

Area description

The trial section is situated at the Smiřice railway station, on rail No. 3, km 32.940 – km 33.270. It was built in April 2005. The Smiřice railway station lies on a national railway track with an axle load of 22.5 tons, on a single-track line Hradec Králové – Jaroměř. The trial section is 330 m long. Three measurement profiles marked P1 (km 32.978), P2 (km 33.108) and P3 (km 33.249) were selected on the trial section for a long-term monitoring of the behaviour of the structural layer of fly ash-based stabilizer.

The used fly ash-based stabilizer from CPP is a mixture of fly ash (52%), FGD gypsum (25%), CaO (3%) and water (20%), (Lidmila and Petrásek,

Fig. 1. The core drilling performed with the drill stand in 2005: a) the drilling rig; b) the low depth borehole

Rys. 1. Wiercenie rdzenia w 2005 roku a) urządzenie wiertnicze; b) płytki otwór

2006). The fly ash-based stabilizer of the above composition was mixed in the CPP mixing centre. It is a material generating hydration heat and hardening in time. Its optimum workability time is up to 4 hours from mixing. The five-year experimental plan was suggested to perform a long-term monitoring of the behaviour of the structural layer of the fly ash-based stabilizer (Lidmila, 2011). The plan contained the scope and methods of in-situ and laboratory tests, including the planned work sequence. The frequency of in-situ tests selected was twice a year, in spring and autumn. The places of in-situ tests were determined by measurement profiles P1, P2 and P3.

Fly ash-based stabilizer sampling

In-situ tests in Smiřice were complemented by the production of fly ash-based stabilizer test specimens using boreholes of 100 mm in diameter. The layer of the railway ballast and the crushed stone was manually dug out and then the stabilizer layer was uncovered. For drilling the stabilizer layer the rig based on the diamond coring tool Hilti DD130 was chosen. The coring tool contained the diamond core bit, the water supply unit and the power generator. The drilling could be done in two ways: with using the drill stand or hand-guided. Both of the methods were applied in Smiřice in 2005 and then in 2014. The first method with the drill stand (Figure 1a) enabled higher shape precision of the samples thanks to stationary drilling. It was reflected both in the surface quality of the specimens and also the possibility to check the verticality of drilling. Since the layer of the fly ash-based stabilizer in the track bed is placed in a depth of 0.7 m bellow the track, the drill overhang was limited and the height of the drilled samples was only about 10 cm which was unsatisfactory (Figure 1b).

Since the initial experience with core drilling in 2005 was not satisfactory, the sampling method was changed to hand-guided drilling (Figure 2) in 2014. As is shown in Figure 2, the drill in the hole was able to sample the stabilizer within the whole thickness of the layer (up to 280 mm). The handling of the drill in the borehole was improved at the expense of vibrating the core bit caused by lack of stability in hands at the beginning of drilling. The vibration was stabilized about 5 cm in depth. It caused rills on the sample surface. Also the verticality of the borehole was not fully ensured; therefore the samples were not perpendicular.

Non-destructive determination of Young's Modulus

Only the minimum number of samples from four to six samples per cross-section, were taken from the trial section between 2005 and 2011. Such number of specimens did not allow excluding any of them. Significant variance in values of compression strength was caused by low number of samples. In 2014 two technological measures were made to increase the number of specimens. The first one was done to maximize the bottom of the pits in cross-sections P1 to P3. The second one was the introduction of a new measuring profile marked as VP. On the basis of the implementation of this measure about 8 specimens were available in each cross-section.

It was necessary to exclude some of these 8 specimens that with high probability include predisposed surface failures that might significantly affect the average value of compressive strength. Ultrasonic method (ČSN EN 12504-4) and also Impulse Excitation Method (ČSN EN 732011)

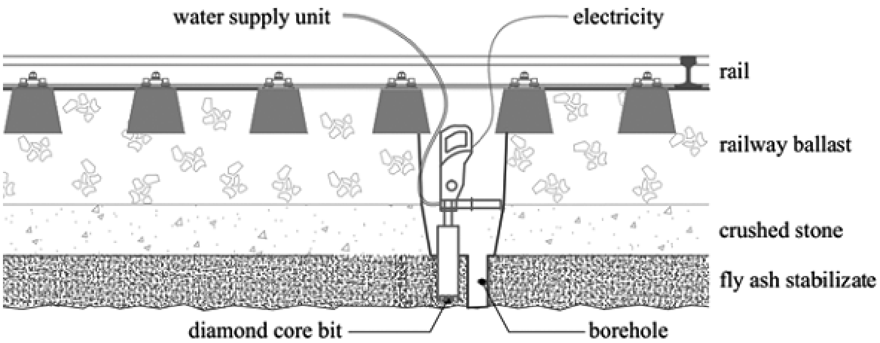

Fig. 2. Fly ash-based stabilizer sampling with core drill in the railway track bed at the Smiřice railway station in 2014

Rys. 2. Pobieranie próbek podbudowy torów stabilizowanych popiołem za pomocą odwiertu na stacji kolejowej Smiřice w 2014 r.

were chosen as a non destructive test methods. These methods are used for determining the dynamic modulus of elasticity for materials based on concrete.

As demonstrated (Plachý, 2010) the Impulse Excitation Method (IEM) is a quick method, the measurement line is small enough and mobile. The dynamic modulus of elasticity were determined based on the equation for vibration of the isotropic beam with continuously distributed mass, based on measured resonant frequencies of longitudinal, flexural and torsional vibration of the specimens, dimensions of the beam and its mass. The measurement line consisted of the acceleration transducer Brüel&Kjær of Type 4519-003, the impact hammer Brüel&Kjær of Type 8206, the vibration analyzer Brüel&Kjær Front-end 3560-B-120 and program PULSE 13.5. The vibration was by the strike of the hammer. The waveforms of the excitation force and the acceleration were recorded and transformed using Fast Fourier Transform (FFT) to the frequency domain. The Frequency Response Function (FRF) as the ratio of acceleration to the excitation force was evaluated from these signals using the vibration analyzer and program PULSE 13.5. The test was repeated four more times for each specimen and the average function of FRF was saved. From an average FRF, the fundamental longitudinal resonant frequency was determined for each specimen. Each specimen was supported in the fundamental longitudinal nodal position in the middle of its span. The acceleration transducer was placed at the centre of one end surface of the specimen. The opposite end surface of the specimen was struck perpendicular to the surface by the impact hammer.

The mass and dimensions of the specimen were measured, the FRF was evaluated and the dynamic modulus of elasticity Edl was determined using the relation:

$$E_{dl} = \frac{5.093 l m f_l^2}{d^2} \qquad (1)$$

where: Edl is the dynamic modulus of elasticity [Pa], fl is the fundamental longitudinal frequency [Hz], d is the diameter of the specimen [m], l is the length of the specimen [m], m is the mass of the specimen [kg].

The measurement line of the ultrasonic method consisted of ultrasonic pulse device Starmans Dio 562 NLF with graphic display providing measurement data, excitator and receiver of ultrasonic waves. Ultrasonic diagnostics is normally used in metallurgy for structuroscopy and for flaw detection of defects. Source of the ultrasonic waves are probes working on a principle of piezoelectric conversion of electric energy into mechanical energy. Conversion of energy in sample is provided as pulses with frequency in kHz. It is needed to establish acoustic coupling on surfaces of a sample. Optimum passage of ultrasonic waves in a sample is ensured with contact liquid medium - conductive gel. The samples were placed on timber bar, because of better handling with the edge parts, which were spread with indifferent gel. The excitator and receiver enclosed to the specimens caused ultrasonic waves of a frequency 50 kHz. The time, during which the wave passes through the mass of the specimen, was displayed on the device. The determining of dynamic modulus of elasticity is based on time of wave passage through specimen, dimensions and at last on the weight of a dried specimen. It was determinate with using relation:

$$E_d = \frac{m}{r^2 \cdot \pi \cdot l} \cdot \left(\frac{l}{t}\right)^2 \qquad (2)$$

where: Ed is the dynamic modulus of elasticity [Pa], r is the radius [m], d is the diameter of the specimen [m], l is the length of the specimen [m],

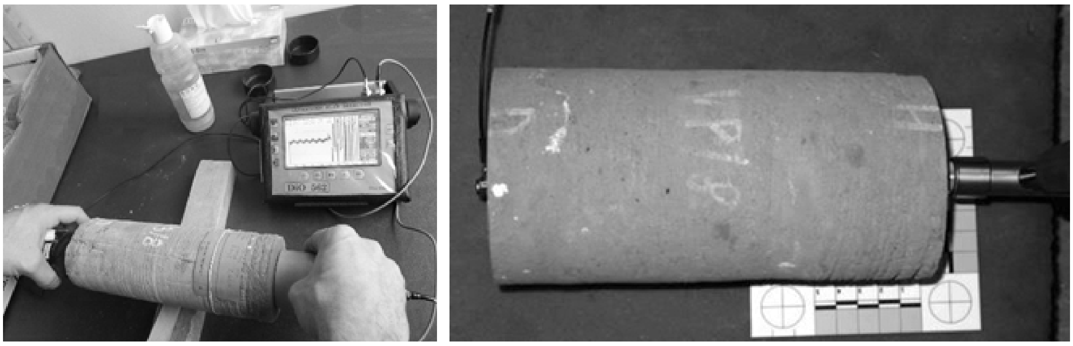

Fig. 3. Non-destructive testing: a) Ultrasonic method; b) Impulse Excitation Method (IEM)

Rys. 3. Badanie nieniszczące: a) metoda ultradźwiękowa; b) Metoda Wzbudzenia Impulsowego (IEM)

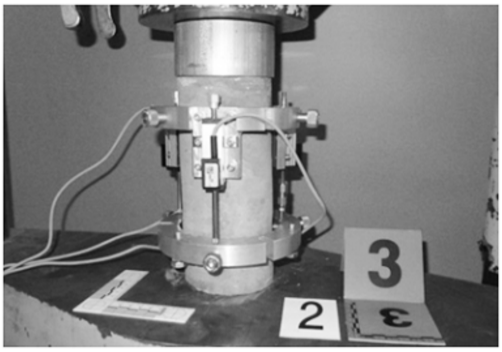

Fig. 4. Pressure test of ash-based stabilizer sample placed in the loading frame in according to ČSN EN 13286-43

Rys. 4. Próba ciśnieniowa próbki stabilizowanej popiołem umieszczonej zgodnie z normą ČSN EN 13286-43

m is the mass of the specimen [kg], t is time of passage through specimen [s].

Destructive determination of Young's Modulus

In the field of building materials, there are several procedures for measuring the modulus of elasticity depending on the material. There is a well-known method in measuring of the Young's modulus of concrete or wood. This method uses measuring of deformation and strain gauges. Strain gauge technology for fly ash stabilized product cannot be recommended because of the preparation bonded joint. For hydraulically bound materials the recommended methodology of measurement is shown in EN 13286-43. This methodology was used assuming that the fly ash stabilize might be considered as a stabilized material that contains hydraulic binders.

Results and discussions

Evaluated laboratory tests are summarized in Tab. 1, 2 & 3. It could be difficult to objectively evaluate the values because of the number of completed experiments. In the field of non-destructive determining of the dynamic modulus of elasticity the technical literature is focused on concrete or on rocks, e.g. (granite, sandstone). Comparative data for fly ash-based stabilizer was not found. As a consequence three hypothesis based on concrete were proposed. Hypothesis No. 1: The dynamic modulus of elasticity determined by non-destructive method is about 20–30% higher than static Young's modulus. This hypothesis is not applicable to fly ash-based stabilizer. The partial results in Table 3 show major differences (more than 100%). Hypothesis No. 2: In general, the values of the static Young's modulus should be lower than the dynamic modulus of elasticity. This was also confirmed in fly ash-based stabilizer with moisture of 30% (Tab. 3). For concrete, there is a relative coefficient which is the IEM from 0.81 to 0.95 depending on the concrete class. For fly ash-based stabilizer with moisture 30% the relative coefficient could be calculated from Table 3. In the IEM it moves in the range of 0.42 to 0.64. Hypothesis No. 3: dynamic modulus elasticity of fly ash-based stabilizer determined by ultrasonic method is about 10% to 20% higher than in the IEM. This hypothesis was confirmed considering that fly ash stabilized is presumably the higher range of 10% to 50%. The specimen identified as VP9 was with negative relative difference – 7.7%. Such result might help to identify a specimen with predisposed area (crack).

Tab. 1. Non-destructive determination of dynamic modulus of elasticity- Impulse Excitation Method (IEM) and ultrasonic method; dried samples

Tab. 1. Nieniszczące badanie modułu elastyczności za pomocą metody IEM i ultradźwiękowej; próbki suche

Specimen	Method	
	IEM	Ultrasonic
	[GPa]	[GPa]
P1/7	5,1	6,1
P2/2	5,8	8,5
VP9	4,2	3,8

Tab. 2. Non-destructive determination (IEM) of dynamic modulus of elasticity-comparison between samples with 30% mass moisture and dried samples

Tab. 2. Nieniszczące (IEM) badanie modułu elastyczności porównanie próbki suchej i próbki o wilgotności 30%

Specimen	Moisture of test specimens	
	w=0% (dried)	w=30%
	[GPa]	[GPa]
P1/7	5,1	4,3
P2/2	5,8	5,0
VP9	4,2	3,4

Tab. 3. Comparison between static (Young's modulus) and dynamic modulus of elasticity determined with destructive (Compression test) and non-destructive methods (IEM), samples with 30% mass moisture

Tab. 3. Porównanie statycznego (moduł Younga) I dynamicznego modułu elastyczności określone za pomocą metody niszczącej (test ściskania) I metody nieniszczącej (IEM), próbki o wilgotności 30%

Specimen	Method	
	Compression (Young's modulus)	IEM (Dynamic modulus of elasticity)
	[GPa]	[GPa]
P1/7	2,0	4,3
P2/2	3,2	5,0
VP9	2,3	3,4

Conclusions

For the analysis of the characteristics of fly ash-based stabilizer layer it is definitely recommended using the method in which the specimens are sampled by using core drilling. The core drilling method enables the samples to be put to the destructive and also non-destructive tests. It is farther more recommended using compressive strength as well as measuring of the static modulus of elasticity as the destructive tests. In case that there is a very low number of samples it is advised to do non-destructive tests before destructive testing. Regarding the non-destructive test it is suggested using the measuring of dynamic modulus of elasticity by the Impulse Excitation Method (IEM). Non-destructive tests enable to predict the non-homogeneities in mass of the samples. The non-homogeneities may significantly influence the measured value of compressive strength and Young's modulus of elasticity. It is necessary to do the laboratory tests of fly ash-based stabilizer with naturally moisture. It is not possible to consider the laboratory values that were collected by testing dried samples as the characteristics values. These appear in practical application of fly ash-based stabilizer with naturally moisture in the railway track bed.

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Badanie stabilizatora na bazie popiołu lotnego w podbudowie torów kolejowym oraz określenie modułu Younga

Niniejsza praca dotyczy badań stabilizatora na bazie popiołu lotnego użytego jako warstwa podtorza kolejowego. Jest to "nowy materiał" stosowany w budowie szyn. Głównym celem stabilizatora jest wzmocnienie podtorza kolejowego. Wspomniany stabilizator na bazie popiołu lotnego jest mieszanką składającą się z popiołu lotnego powstałego ze spalania rośliny Chvaletice, rosnącej w Republice Czeskiej, gipsu z odsiarczania spalin, tlenku wapnia oraz wody. Testy laboratoryjne stabilizatora na bazie popiołu lotnego rozpoczęto w 2000 r. w celu określenia kluczowych właściwości fizycznych oraz wyboru najodpowiedniejszego materiału stosowanego do budowy trakcji. W celu sprawdzenia materiału w skali 1:1, stworzono specjalne urządzenie w kształcie skrzyni o wymiarach 990×800×2095 mm, co umożliwiło przeprowadzenie testówpełnowymiarowych. Na bazie testów laboratoryjnych przeprowadzono stabilizację próbnego odcinka trakcji szynowej o długości 330 m na stacji kolejowej w miejscowości Smiřice. Warstwa próbna została położona przy trakcji nr 3 w kwietniu 2005 r. Próbki materiału są regularnie pobierane do testów laboratoryjnych każdej wiosny i jesieni. W pracy skupiono się na próbkach stabilizatora na bazie popiołu lotnego wywierconych z rdzenia na potrzeby testów laboratoryjnych. Rekomendacje przedstawione we wniosku zostały oparte na doświadczeniach przeprowadzonych na próbkach pobranych z wyżej wymienionego podtorza.Warstwa stabilizatora, położona pod nawierzchnią torową oraz skruszonym kamieniem, została odkryta, a następnie wywiercono otwory o średnicy 100 mm. Z powodu utrudnień związanych z poborem próbek, udało się uzyskać tylko niewielką ich ilość potrzebną do określenia skuteczności i wytrzymałości stabilizatora na bazie popiołu lotnego. Z badań należało wyłączyć niektóre próbki, które z dużym prawdopodobieństwem miały predyspozycje do wad powierzchniowych, przez co mogły znacznie wpłynąć na średnią wartość modułu Younga. Celem był wybór trzech próbek do przeprowadzenia prób ciśnieniowych. Do testów wybrano metody ultradźwiękową oraz wzbudzenia impulsu, które są nieinwazyjnymi metodami badawczymi, dzięki którym sprawdza się dynamiczny moduł sprężystości, co pomaga w doborze odpowiednich próbek potrzebnych do przeprowadzenia prób ciśnieniowych. Na końcu pracy badawczej opisano wyniki oznaczenia modułu Younga oraz modułu sprężystości. Omówiono najważniejsze wnioski, które uzyskano na podstawie porównania testów inwazyjnych oraz nieinwazyjnych. Wyniki niniejszych badań znacząco wzbogacają wiedzę na temat zmian właściwości stabilizatora stwierdzone w wyniki długoterminowych obserwacji odcinka próbnego w Smiřice.

Słowa kluczowe: stabilizator na bazie popiołu lotnego, wiercenie rdzeniowe, podtorze kolejowe, testy nieinwazyjne