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EFFECTS OF GGBS AND FLY ASH IN BINDERS ON SOIL STABILIZATION FOR ROAD CONSTRUCTION

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Abstract

In this paper we propose a new technique of soil stabilization for road construction based on using new alternative binders. The project aims to evaluate the effects of alternative additive materials in soil stabilization contexts for road construction. The alternative binders (slag, energy ash and bio ash as new alternative road construction material) have been used to complement the traditional binders (cement and lime). The project used five binders and evaluated their effects on soil strength. The proposed method comprises advantages of using the alternative binders which are the residual products contributing to a lower environmental impact. The results have shown that only slag has significant effects on the strength of the stabilized soil, while bio ash and energy ash make a marginal contribution to the increase of strength. This is caused by the twofold reasons. First, the effects of the amount of ashes that should reach a certain threshold with respect to the total amount of binder that must be exceeded to have the effect of the soil mixture. Second, the bio fly ash was stored and it was not completely fresh which may have contributed to the carbonation during the storage period and results in a lower hardening ability. Based on the results of the study we recommend the use of bio fly ash as a supply material andfor its amount to be adjusted so the storage period is not too long. This study verified the effects of slag, cement and lime on stabilization of soil for road construction.

Keywords: civil engineering, building material, lime, cement, fly ash, slag

Rezumat

În această lucrare propunem o nouă tehnică de stabilizare a solului pentru construcția drumurilor bazată pe folosirea de noi lianți alternativi. Proiectul își propune să evalueze efectele materialelor aditive alternative în contexte de stabilizare a solului pentru construcția drumurilor. Lianții alternativi (zgură Merit 5000, cenușă energetică și cenușă bio ca nou material alternativ de construcție a drumurilor) au fost folosiți pentru a completa lianții tradiționali (ciment și var). Proiectul a folosit cinci lianți și a evaluat efectele acestora asupra rezistenței solului. Metoda propusă cuprinde avantajele utilizării lianților alternativi care sunt produsele reziduale care contribuie la un impact mai mic asupra mediului. Rezultatele au arătat că numai Merit 5000 are efecte semnificative asupra rezistenței solului stabilizat, în timp ce cenușa bio și cenușa energetică au o contribuție marginală la creșterea rezistenței. Acest lucru este justificat de două motive. În primul rând, efectele cantității de cenușă care ar trebui să atingă un anumit prag în raport cu cantitatea totală de liant care trebuie depășită pentru a avea efectul amestecului de sol. În al doilea rând, biocenușa a fost depozitată și nu complet proaspătă, ceea ce ar fi putut contribui la carbonatare în timpul perioadei de depozitare și are ca rezultat o capacitate de întărire mai mică. Pe baza rezultatelor studiului, vă recomandăm să folosiți biocenușa ca material de alimentare și să ajustați cantitatea acestuia fără o perioadă prea lungă de depozitare. Acest studiu a verificat efectele zgurii, cimentului și varului asupra stabilizării solului pentru construcția drumurilor.

Cuvinte cheie: construcții civile, materiale de construcție, var, ciment, cenușă zburătoare

1. INTRODUCTION

Stabilization of soil with inorganic binders (lime, cement) is a traditional old technology common in road construction in international perspective [6, 10, 11]. Soil stabilization is widely used in Europe, in the USA and in Australia for road, railway and infrastructure constructions [1, 8, 9, 16]. The traditionof soil stabilization has a long history starting in Roman times when lime stabilization was used in road construction contexts. Roman roads are an important part of the transport infrastructure with remaining traces of ancient roads throughout Europe [5, 7, 22]. Earthworks that existed in ancient times can be identified through archaeological investigations. For example, one of the Roman roads, Via Appia, the southern main road in Rome, was stabilized with limestone as early as in 300 BC with its parts still existing nowadays. In Sweden, surface stabilization has been used since the 1960s when lime and cement were mainly used as binders. Soil stabilization is largely used in Sweden for road improvements, analytical road dimensioning, due to the increased requirements regarding better resource utilization with regard to the environmental standards and economy [2]. Development of the effective methods of soil stabilization contribute to a sustainable road infrastructure and to transport safety [12, 13].

In the context of road construction, the stabilization techniques can lead to a significant increase in the service life of the road body and to a reduced use of non-renewable natural resources. At present, cement and lime are preferably used as binders. The choice of binders and proportions of the amount used are often based on the type of soil to be stabilized. In general, fine-grained soil is mostly stabilized by lime, while granular soil by cement. However, to further increase the environmental benefits and effectiveness of soil stabilization, different types of alternative binders can be used. Thus, mixed blended binders are common in

Australia [15]. Previous studies on additional binders have primarily focused on using the residuals as components in unbound materials, geochemical and environmental effects [18, 20, 23, 24]. As a contribution, this study focuses on using the residual products in combination with other binders to optimize their use in terms of technical and economic properties.

2. METHODS

Surface stabilization has mostly been used in existing materials aiming to increase the compressive strength and modulus of the original soil material. In all soils, grain distribution and soil chemistry play an important role in the function of the binder. As an example, lime works well in a clay, but less well in a coarse-grained soil. Since the stabilization takes place in natural soil, the constituent material components are of great importance for the final results. There are recommendations in literature according to which binders provide various results on different soil types. Below is the summary from Sweden, Figure 1 and from Australia, Table 1.

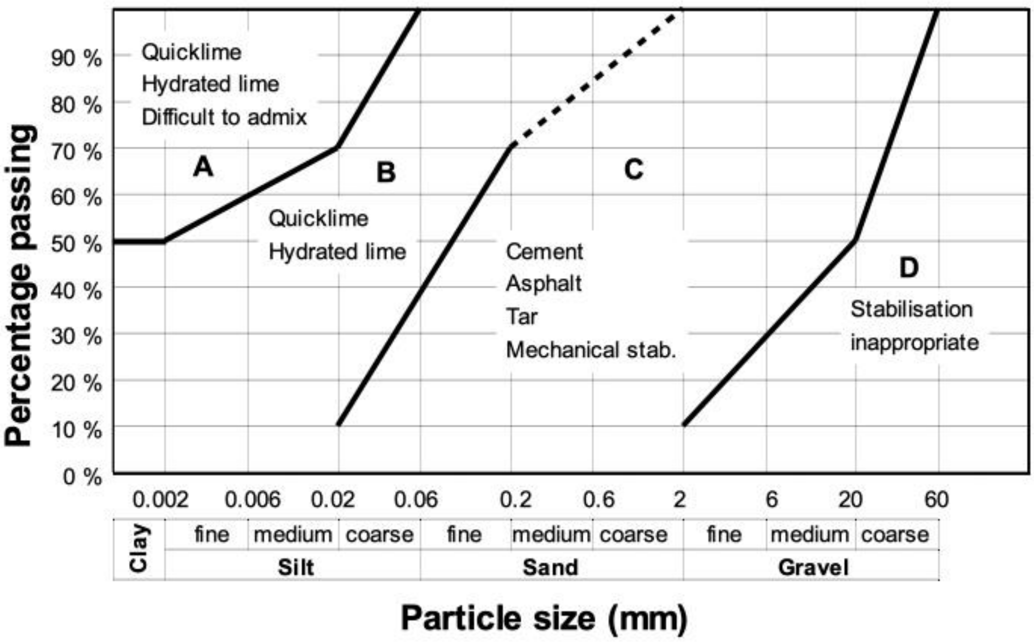

Figure 1. Recommended binders for different soil types (Assarsson, 1968). Note that tar is now classified as an environmental problem.

The purpose of the soil stabilization techniques is to find a binder combination that is optimized with respect to technical properties of an inert ballast soil material. The optimization includes the improvement in technical parameters, such as curing time, increase of soil strength and durability of the material. The expected results is that the traditional binders can be diluted with slag and / or ashes and thus contribute to a better resource utilization.

Table 1. Effects from different binders on stabilization of soil types [4]. 1: usually very suitable; 2: usually satisfactory; 3: usually not suitable. Binder types: A – General purpose (GP) cement to AS3972 (Australian Standard). B – General Blend (GB) cement to AS3972. C. – Cementitious blends for binders consisting of fly ash, GP cement GGBS and lime including triple and quaternary blends. D. - Hydrated lime or quicklime. E. – Bitumen to AS2008. F. – Cement/bitumen blends. G. – Insoluble Polymers.

Binder classification	Crushed rock	Well-graded gravel	Silty/clayey gravel	Sand	Sandy / silty clays	Heavy clays
GP Cement (A)	1	1	1	2	2	3
GP Cement (B)	1	1	1	1	1	2
Cementitious blends (C)	1	1	1	1	1	3
Lime (D)	2	2	1	3	2	1
Lime & Cement (C)	3	3	2	3	2	1
Lime & Fly Ash (C)	3	1	1	3	2	2
Bitumen (E)	1	1	2	2	3	3
Cement/Bitumen (F)	1	1	2	2	3	3
Insoluble Polymer (G)	2	1	1	3	1	2

2.1. Implementation

The project is carried out as a laboratory study which includes two traditional binders (cement and lime) and three alternative materials. The alternative materials are slag (Merit 5000), fly ash from SCA Lilla Edet and fly ash from coal combustion (ISO certified). A base course gravel (0-18) is used as the ballast material, Figure 2. The choice of the ballast material is based partly on the soil sample body size, Ǿ = 100 mm, which gives a maximum permissible particle size of 20 mm. Another applied criterion was to use a material with a small variation in the properties and thus to minimize the variation in the results.

Another considered aspect was that the ballast material would be inert and thus not contribute to the increase of soil strength in combination with any binder. In addition, the selected material is a soil samples used in real works. The experimental design was based on the question of how much alternative binders can be used in a stabilized soil with retained or improved properties. To conduct the study, velocities of seismic P-wave (non-destructive test) and uniaxial compressive strength (destructive test) were used as response variables.

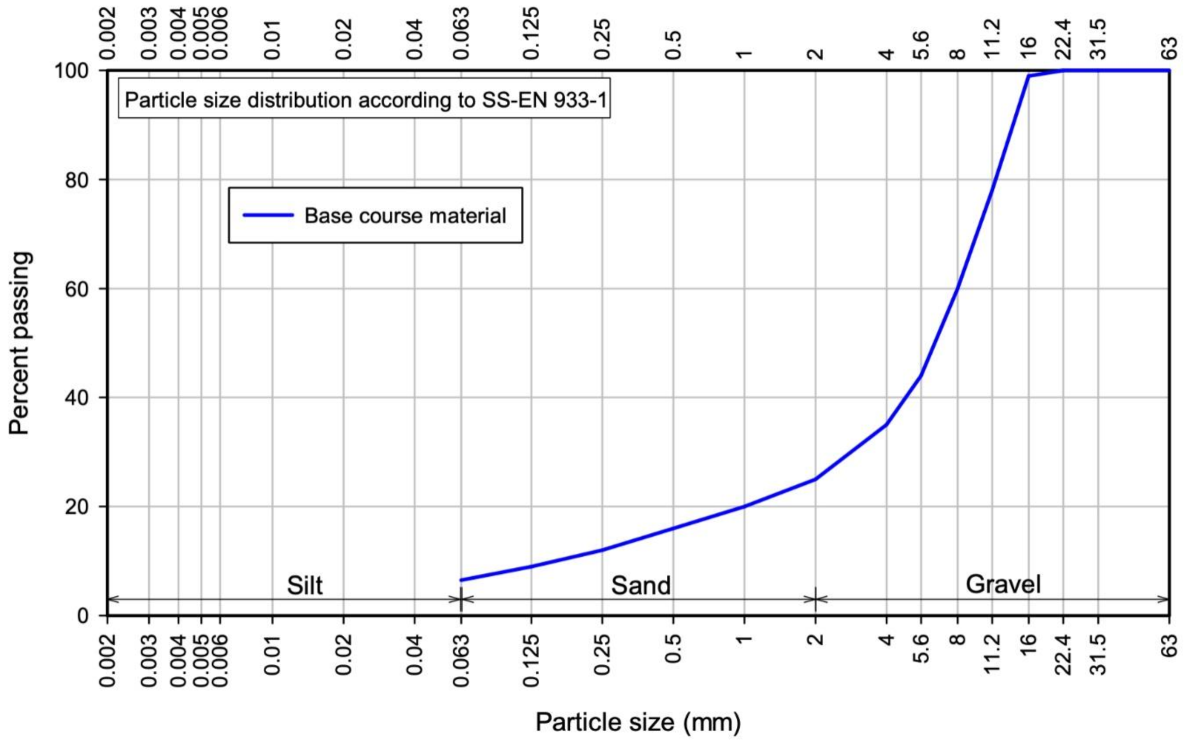

Figure 2. Grain distribution curve for base course material used in the study.

2.2. Storage and sample preparation before compression

After collecting and refining, the specimens were stored for 90 days. During this storage period, the resonant frequency measurements (free-free resonate column) were performed on the soil specimens. After 90 days of storage, the specimens were cut to the correct the length (205 mm). The cuts were made at both ends of each specimen so that two saw surfaces were obtained. After cutting, two longitudinal incisions were made in a plastic tube and specimens were completely deformed. Upon demolding, samples were weighed and measured.

Regarding the demolding, certain forms of inhomogeneity were detected in the specimens. Thus, Figure 3 shows a varied surface porosity arising from the packing cylinder due to the friction between the sharp grains and the plastic. This form of porosity is difficult to completely avoid in a carrier material when it is crushed. Figure 4 shows inhomogeneity between the different layers. The scratching between the bearings has not worked satisfactorily.

Figure 3. Sample body 39. The sample body contains a mixture of all five binders. In the photo, three different subsets can be discerned.

Figure 4. Sample body 27. The sample body contains 1/3 cement, 1/3 lime and 1/3 energy ash. The specimen has a pore system at the packing boundaries.

Some binders gave rise to a greater surface homogeneity than others. One reason for the variation may be how different binders absorbed water during the mixing and during the resting period of one hour before the compression tests.

2.3. Seismic measurements

The seismic velocity of P-waves in the specimens has been measured with the resonant frequency technique, free-free resonate column test using existing methods [17, 19]. All elastic bodies have a set of resonant frequencies (fr) that are directly related to the body's boundary conditions, elastic constants, geometry, and mass. By measuring resonant frequency, mass and geometry of the specimen, its elastic constants (modulus or velocity) can be calculated.

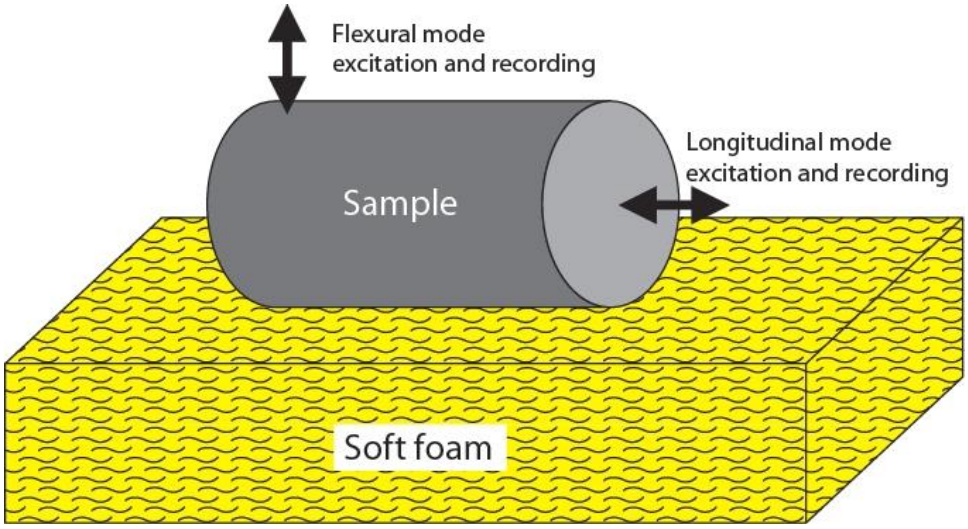

Figure 5. Scheme of the free-free resonant column test.

The experiments used a setup shown in Figure 5 to measure the velocity of seismic P-waves of the stabilized specimen [3, 21]. The method means that the test body is placed ‘free’ on a soft foam rubber and the vibrations are created using a small steel grinder. The resulting ‘free’ vibrations are measured with an accelerometer or a microphone.

The resulting measured free vibrations are transformed into the frequency domain for evaluation of the resonant frequency. The resonant frequency can be observed as peaks in the corresponding amplitude spectrum of the measured signal. A slenderness number of 2, i.e., the length of the specimen is 2 times the diameter of the specimen entails both simple measurements and calculations compared to other geometries.

3. RESULTS

The results present seismic measurements of the P-wave velocities on day 7. Here, the specimens have been stored for 7 days after manufacture. Figure 6 (left) shows a Pareto diagram of all the effects in the cubic model. Pareto diagrams are a simple but powerful tool for identifying significant effects. The explanations of the bars appear more clearly in Figure 6, right.

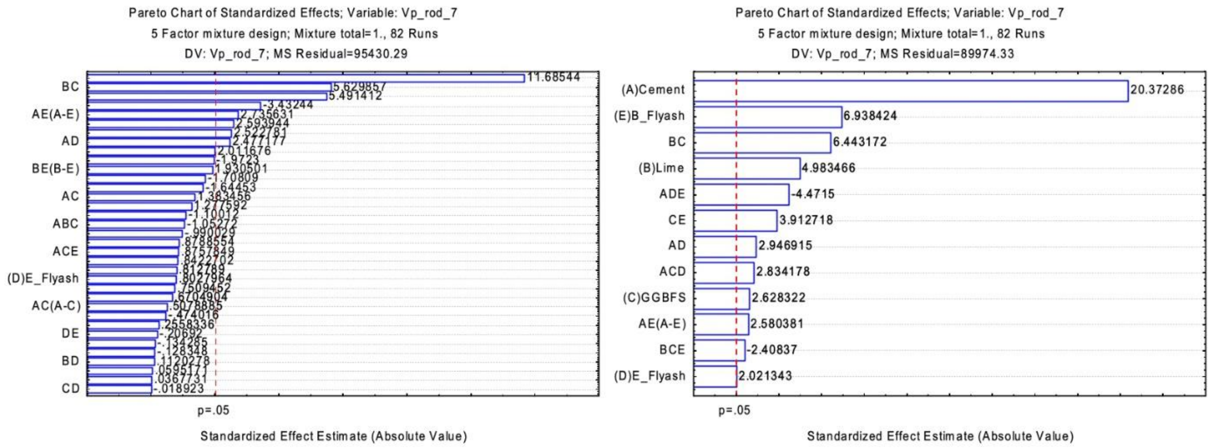

Figure 6. Pareto diagrams. Left: all effects included in the cubic model for the 7-day measurements. Right: all significant effects included in the cubic model.

The figure should be interpreted so that the stacks that do not reach over the red dashed line are not significant for the result, i.e., the compression wave velocity at 7 days. Those combinations are then removed from the model, i.e. backward analysis. Figure 6, right shows that cement, bio fly ash and a combination of lime and slag make the greatest contribution to the compression wave velocity on day 7th of treatment. Table 2 shows pure binders and the two of the binary binders. Figure 6 (right) shows that the effect of ADE (cement, energy ash and bio ash) has a negative interaction, i.e., negative impact on the P-wave velocity. This is clearly seen as a region with low values in Figure 9 (left).

Table 2. Explanation of designations in the Pareto diagrams and binders

Designation	Binder	Text in Figure
(A)	Cement	Cement
(B)	Lime	Lime
(C)	Slag	GGBFS (Merit)
(D)	Fly Ash type E (Energy Ash)	E_Flyash
(E)	Fly Ash type B (Bio Ash)	B_Flyash
(AB)	Cement and Lime	
(AC)	Cement and Slag	

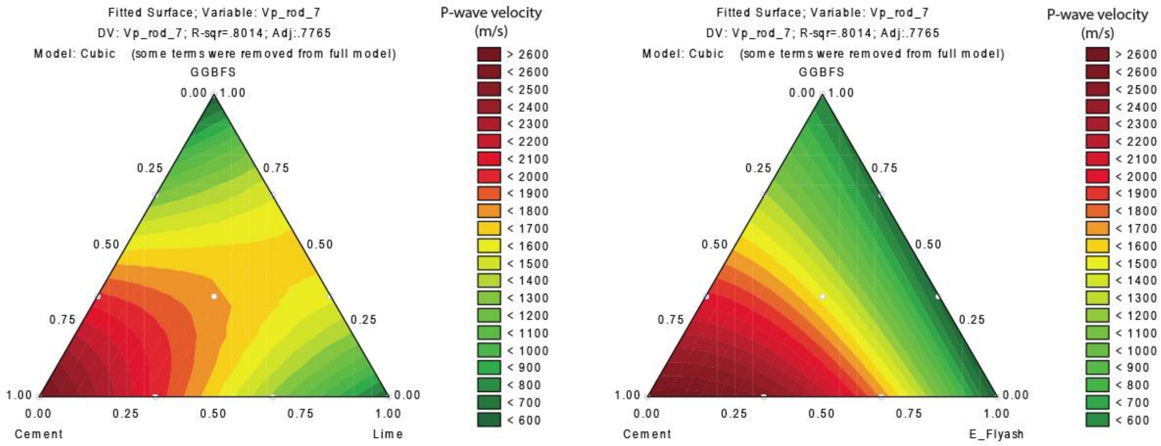

Figure 7. Response of soil surface on seismic P-waves, measured on day 7th. Binders: cement, lime and slag (left); cement, energy fly ash and slag (right).

In the corners of the triangle in Figure 7 (left) there is only one binder. In this case, the binder was blended by cement, lime and slag, respectively.

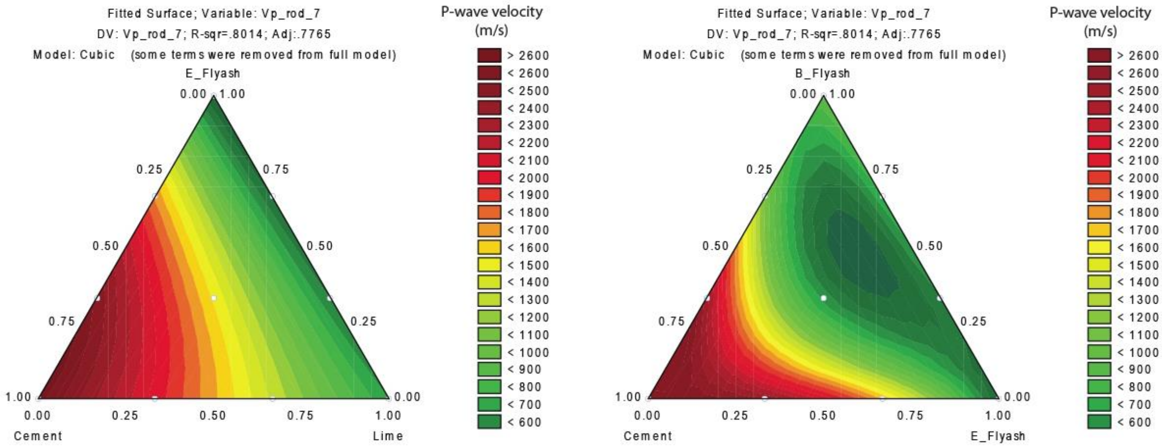

Figure 8. Response of soil surface on seismic P-waves on day 7th. Binders: cement, lime, energy ash (left); cement, energy fly ash and bio fly ash (right).

In the middle of the triangle there are 1/3 each of the three binders. There is a mixture of two adhesives on the boundary. Thus, there are different ratios of cement and lime on the horizontal boundary. The interaction between lime and slag is clearly seen in Figure 7, left and in Figure 9, left. If there was no interaction, the compression wave velocity would be at the same level for the binary mixtures of slag and lime. Figure 7 (right) and Figure 8 (left) show rather weak interaction between the cement and energy ash.

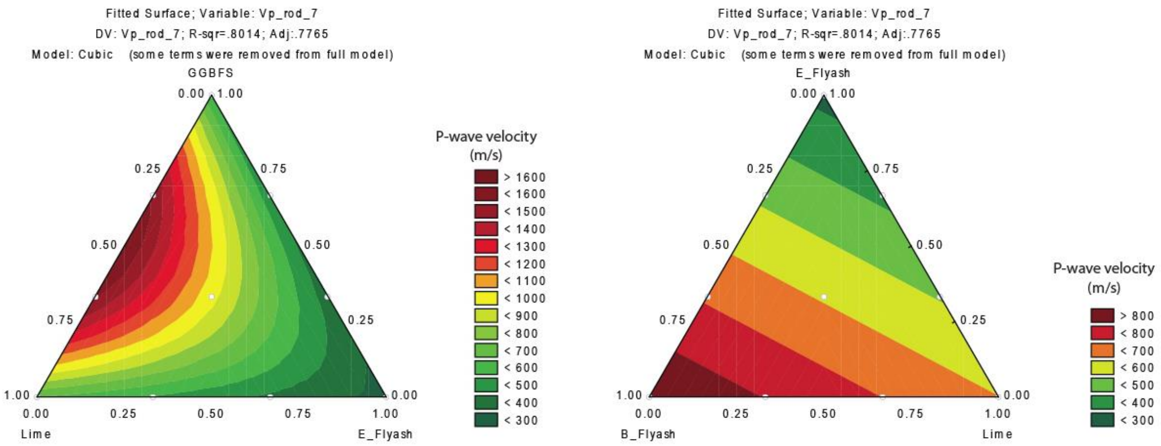

Figure 9. Response of soil surface on seismic P-waves on day 7th. Binders: lime, energy fly ash and slag (left); bio fly ash, lime and energy fly ash (right).

Figure 9 (right) only shows linear effects with bio ash giving the largest contribution and energy ash giving the lowest contribution. No effects of the lime's pH-raising effects can be seen after 7 days. It is worth noting that for Figures 7 to 9 the degree of explanation is 80 %, i.e., the model explains 80 % of the variations in the results, which can be considered as good in this context.

4. CONCLUSIONS

The project demonstrated the evaluation of the effects of alternative binders in soil stabilization contexts for road construction. The alternative binders (slag, energy ash and bio ash) were used to complement the traditional binders (cement and lime). The project has included five different binders: cement, lime, GGBS, energy ash and bio ash. The alternative binders are residual products and can thus contribute to a lower environmental impact. The results have shown that only slag has significant effects on soil strength. The bio ash and energy ash make a marginal contribution to the strength of the stabilized soil.

A possible explanation for why ashes do not affect stabilization may be that a certain threshold value with respect to the total amount of binder that must be exceeded to have the effect of the mixture. Another aspect regarding the bio fly ash as a new alternative road construction material is that it was stored and it was not completely fresh. This may have contributed to carbonation during the storage period and results in a lower hardening ability. At the same time, one should consider whether fresh ash is produced in sufficient quantity to be used as a sustainable alternative to the traditional binders.

The recommendation for future studies is to use bio fly ash for smaller local projects as supply and demand can be balanced without prolonged storage times. This study verified previously observed effects of slag in combination with cement and lime [14]. However, the impact of ashes on bonding and strength should be further studied. The supplementary study should preferably be extended by further tests to increase objectivity.

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