CETRA 2014

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

Stjepan Lakušić – EDITOR

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA[2014]
3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

TITLE
Road and Rail Infrastructure III, Proceedings of the Conference CETRA 2014

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
"Tiskara Zelina", April 2014

COPIES
400

Zagreb, April 2014.

Proceedings of the
3rd International Conference on Road and Rail Infrastructures – CETRA 2014
28–30 April 2014, Split, Croatia

Road and Rail Infrastructure III

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

ORGANISATION

CHAIRMEN

Prof. Stjepan Lakušić, University of Zagreb, Faculty of Civil Engineering
Prof. Željko Korlaet, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. Stjepan Lakušić
Prof. Željko Korlaet
Prof. Vesna Dragčević
Prof. Tatjana Rukavina
Assist. Prof. Ivica Stančerić
dr. Maja Ahac
Ivo Haladin
dr. Saša Ahac
Josipa Domitrović
Tamara Džambas

All members of CETRA 2014 Conference Organizing Committee are professors and assistants of the Department of Transportation, Faculty of Civil Engineering at University of Zagreb.

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Prof. Vesna Dragčević, University of Zagreb
Prof. Isfendiyar Egeli, Izmir Institute of Technology
Prof. Rudolf Eger, RheinMain University
Prof. Ešref Gačanin, Univeristy of Sarajevo
Prof. Nenad Gucunski, Rutgers University
Prof. Libor Izvolt, University of Zilina
Prof. Lajos Kisgyörgy, Budapest University of Technology and Economics
Prof. Željko Korlaet, University of Zagreb
Prof. Zoran Krakutovski, University of Skopje
Prof. Stjepan Lakušić, University of Zagreb
Prof. Dirk Lauwers, Ghent University
Prof. Zili Li, Delft University of Technology
Prof. Janusz Madejski, Silesian University of Technology
Prof. Goran Mladenović, University of Belgrade
Prof. Otto Plašek, Brno University of Technology
Prof. Vassilios A. Profillidis, Democritus University of Thrace
Prof. Carmen Racanel, Technical University of Civil Engineering Bucharest
Prof. Tatjana Rukavina, University of Zagreb
Prof. Andreas Schoebel, Vienna University of Technology
Prof. Mirjana Tomičić-Torlaković, University of Belgrade
Prof. Audrius Vaitkus, Vilnius Gediminas Technical University
Prof. Nencho Nenov, University of Transport in Sofia
Prof. Marijan Žura, University of Ljubljana

APPLICATION OF INDUSTRIAL WASTE MATERIALS IN SUSTAINABLE GROUND IMPROVEMENT

Mario Bačić[1], Danijela Marčić[1], Tea Peršun[2]
1 Faculty of Civil Engineering, University of Zagreb, Croatia
2 Ing-jet d.o.o., Zagreb, Croatia

Abstract

Urbanization process inevitably leads to lack of suitable construction surfaces for further development activities. Therefore, locations which were in past neglected, due to their inadequate ground characteristics, are nowadays reconsidered for construction purposes. In order to enhance geotechnical characteristics of ground, various ground improvement techniques have been developed. This paper discusses existing technologies which use man-made or natural materials in ground improvement process. One of the biggest issues, regarding technologies which use cement or lime as binder, is in their environmental impact. To produce one ton of improved soil, grouting and admixture techniques require 20 kg of cement or lime which release 18 kg of CO_2 into atmosphere. Hence, these technologies are environmentally suboptimal and there is a large potential in developing new methods which tend to reduce environmental footprint. This can be achieved by partially replacing standard binders with fly ash, which is residual waste material. Other possibility of achieving sustainability is replacement of standard gravel or crushed rock aggregate in stone columns technique with industrial slag. Application of waste materials in sustainable ground improvement is a rapidly-developing research area. Besides potential environmental benefits, utilization of waste materials would also solve issue of their disposal, what is significant due to large deposit amounts of fly ash and slag in region.

Keywords: ground improvement, sustainability, fly ash, slag, deep soil mixing, vibro-stone columns

1 Introduction

Cities worldwide are rapidly developing and the rate of urbanization is such that by 2050 two-thirds of the world's population will live in urban areas [1]. The urbanization leads to development of industrialization process which brings along a number of negative effects to the environment and on social life. One of such negative effects is production of industrial waste materials, where the process of waste management is very complex and it deals with huge amounts which need to be disposed in a proper manner, with primarily all safety aspects met, following the other aspects (finances, time, etc.). For some time, there is worldwide trend of reusing industrial waste as secondary raw material in many applications. The reason for this is twofold – due to the rapid consumption of natural resources they become more expensive, while on the other hand waste material landfills are becoming larger, and countries are committed to their reuse and recycling. Further, it is inevitable to find solutions for lack of suitable construction surfaces for further development activities caused by urbanization process. Two solutions are possible to overcome the problem of construction site deficiency. First one is expansion of cities in underground where increasing number of underground structures gives rise to the

complexity of underground building systems. Second solution is to 'stay on surface' and to utilize the ground which is, from geotechnical aspect, originally unsuitable for construction.
These two problems of non-satisfactory ground characteristics and accumulation of industrial waste materials on deposits can be dealt through a ground improvement as one of disciplines which tend to reuse waste materials. In second part of 20th century, a series of techniques for engineering treatment of ground were developed in order to enhance its geotechnical characteristics making it suitable for construction. But even though these techniques lead to enhancement of ground characteristics, they sometimes require usage of large amounts of natural resources and can cause, to a lesser or greater extent, pollution of the surrounding environment. Cerić et al. [2] analysed risks of ground improvement and stated that risks may impact time, cost, quality, or the environment. This negative environmental footprint can be manifested not just through pollution of environment, but also through extensive usage of natural resources. Two waste materials, most commonly mentioned in terms of ground improvement, are fly ash and slag, Fig 1.

Figure 1 Industrial waste materials: fly ash (left) and slag (right)

With the aim of responsible waste management Croatian Government has adopted, in 2005, the 'Waste Management Strategy', which is based on reducing the amount of waste by the separation of waste and the promotion of its reusing. However, this concept of waste reuse is not implemented on large scale. Since application of ground improvement techniques is emerging discipline with large number of projects in Croatia, it is interesting to mention some potential positive environmental aspects of using waste materials for ground improvement.

2 Sustainable ground improvement using fly ash

Fly ash is a by-product from combustion of coal in thermal power plants and it became available in the 1930s. Approximately at the same time, a research based on the use of fly ash in concrete started, where shortly thereafter, industry based on fly ash started its ascent when it was used in concrete to build dams. From the point of fly ash application in ground improvement, techniques which use cement and lime to improve the characteristics of the ground are interesting. Production of standard binders, cement and lime, consume large amounts of natural raw materials and fossil fuels. As a result of chemistry, this leads to the release of significant amounts of CO_2 into the atmosphere. Any reduction in the consumption of cement and lime for soil stabilization process so far (according to previous experience of 2-5% by weight of cement stabilized soil) will contribute in reducing the consumption of natural raw materials and fossil fuels and thus reducing CO_2 emissions [3].
Today, dominant application of fly ash is through chemical soil stabilization techniques which form a mixture of soil and binder and which are applicable in shallow layers, where expansion, rise of pressures and shear strength present a serious problem in geotechnical engineering. Expansion characteristics come to the fore at the surface, where soils are most susceptible to climate change. Numerous studies show that fly ash has a high level of effectiveness in reducing expansive characteristics of soils. When such soils were treated with fly ash, they

did not show a significant improvement of the current strength, but the seven-day strength was significantly higher than that of expanding soils. To prevail problems of soil expansion, unsatisfactory shear strength or stiffness, a cement or lime can be partially substituted with fly ash which has pozzolanic characteristics. When used for stabilization of foundation soil under roads, it is desirable to use fly ash of C class, according to ASTM D 5239 standard, because of its pozzolanic characteristics. F class fly ash is not recommended in this application, due to its insufficient pozzolanic characteristics, but instead it can be efficiently used in well graded sandy soil as suitable filler, where it can 'complement' the missing fraction of sandy soils. This would increase density, and thus compaction characteristics, and decrease permeability. As such it could be effectively used to form embankments.
Some tests, in which fly ash was used in grouting techniques, were carried out but the results are not as satisfactory as is the case when using it for the soil stabilization. However, good results were obtained in technique of deep soil mixing. This technique can achieve great depth of soil improvement, but the soil is improved only locally. This is in contrast with soil stabilization method, which encompass a large area but the depth is limited to a couple of meters of surface. Technology includes rotation of mixing equipment down to the planned depth of the column, Fig 2. On its way down, equipment breaks soil structure and, after reaching the final depth, the equipment is taken out to the surface by rotating in opposite direction than the one when going down. In its return, mixture containing binder is implemented in the soil, under pressure, thus forming the final cylindrical pillar of improved soil. In his research, Hansson [4] has completely substitute lime with fly ash in deep soil mixing technique. Results showed unsatisfactory results, considering that it was still necessary for mixture to have cement or lime. However, more satisfactory results were obtained as a result of mixing fly ash, cement and lime where fly ash involved with as much as 70%, indicating the potential use of larger amounts fly ash in the process of deep soil mixing.

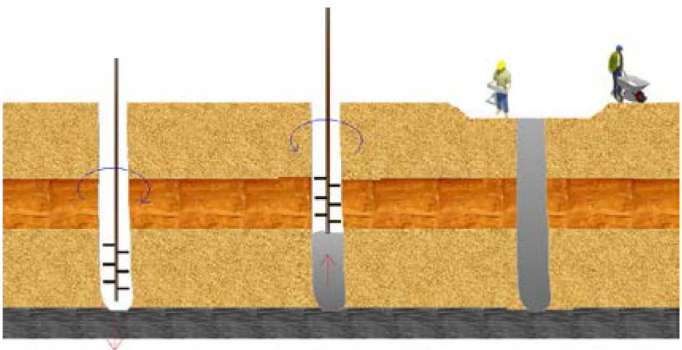

Figure 2 Deep soil mixing technique

A similar mixture, with large amounts of fly ash, was used by Ohishi [5]. He conducted a series of analysis and experiments in order to determine the characteristics of the mixture. The motive for research was the idea that this kind of mixture can be used in deep soil mixing for the execution of the foundation pit in the following way. The excavation of the pit included the construction of the diaphragm to greater depths since the subsoil had extremely unfavorable characteristics. By using deep mixing technique, an artificial layer within the thick layer of soft soil was formed and the diaphragm was ending in this layer. Requests for this layer implied sufficient strength to support the walls of the diaphragm, but at the same time it had to be soft enough so that diaphragm can be easily constructed.
The main problem that arises when using fly ash is finding a market in which there is a demand for it. The largest producers of coal combustion by-products (CCP) are associated in the organizations which represent the interests of CCP producers in the market. Furthermore, the

organizations of individual countries or regions are united in a worldwide umbrella organization of The Worldwide Coal Combustion Product Council. And while the annual production of fly ash quantities are rising, regulations and laws for their disposal all the more restrictive. However, governments of some countries provide significant incentives to civil engineering companies and to specific projects in order to encourage fly ash usage.

3 Sustainable ground improvement using slag

Slag is a waste product generated by the purification of metals, its casting and alloying and it can be divided into iron slag (blast furnace slag) and steel slag (steelmaking slag). Three types of blast furnace slag can be distinguished – air cooled, pelletized and granulated slag. Air-cooled slag is formed by slow cooling of slag deposited outside of power plants. The most common use of this slag is as aggregate in concrete and asphalt mixtures, as well as ballast material in railways or filling material in the embankments. Pelletized slag is obtained by cooling the molten mass with controlled amount of water, air or foam. This type of slag, due to low weight, is frequently used for construction of embankments on low bearing soils. Granulated slag is formed by rapid cooling the slag to the glassy state, using jets of water or air. As a product, sand-size grains are formed which, when grinded and with water added, show pozzolanic properties. This makes granulated slag usable for the cement industry and consequently in shallow soil stabilization and deep soil mixing technique. One of advantages of using granulated slag as cement components is in more efficient grinding than standard cement which saves considerable amounts of energy (only 10% of the total energy required for the production of Portland cement).
However, if the slag is coming from steelmaking, due to significantly lower quantities of C3S than in Portland cement, it does not have very good pozzolanic characteristics. It can be therefore potentially used as aggregate in concrete or as filling material in embankments, a railway ballast material or to form a road substructure. In studies, in which the comparison is made between layers containing steelmaking slag and layers with natural aggregate, it is shown that the slag layers achieve greater strength immediately after compaction of the material. Increased strength can be justified by the shape of the slag grain, which favors the "fixing" of grain after installation and compaction, forming a very solid, compact and durable surface that can be submitted to heavy traffic loads. This characteristic of being able to be utilized as aggregate is of interest in one of soil improvement technique – vibro-stone columns. A method of vibro-stone columns consists of formation of columns in the ground by using heavy vibrator which displaces in-situ ground and compacts the imported material, Fig 3.

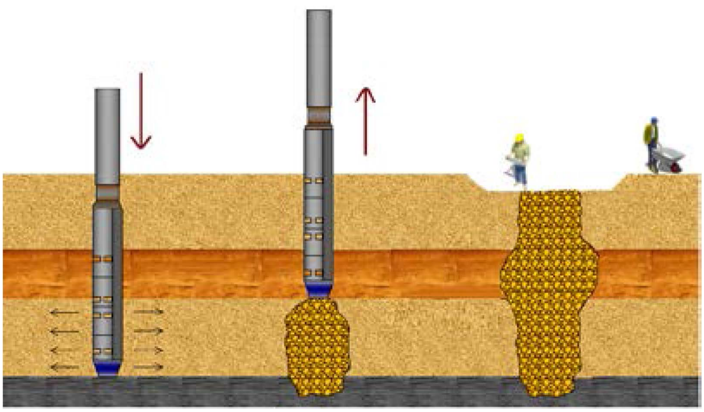

Figure 3 Vibro-stone columns (vibro–replacement) technique

This method has increasing trend of usage in Croatia. For example, on seven sections of Zagreb-Macelj motorway, 13 090 of vibro-stone columns were made, total of 104 780 m'. As aggregate filler, crushed stone obtained from quarries was used. This, in addition to the financial burden, also contributed to the depletion of natural resources. At the same time, Croatia is faced with increasing amounts of steelmaking slag to be deposited in landfills, what represent a major environmental problem.

An idea of using slag as an aggregate for vibro-stone columns is not new. Even in 'BRE Report 391 – Specifying vibro-stone columns' [6], a steelmaking slag is mentioned as one of aggregate potentially to be used in vibro-stone columns. In Saudi Arabia, until today, over one million tons of steelmaking slag was incorporated in soil through this technique [7]. However, this extent of application practice is not implemented worldwide, because possibility of application largely depends on type of slag and ground conditions. A range of testing procedures must be conducted prior to implementation. This includes both laboratory test of slag as well as field trial area where its interaction with surrounding soil will be examined. Extensive load trial tests provide most reliable interpretation of soil improvement, even though degree of improvement can be tested with alternative, simpler methods, such as Spectral Analysis of Surface Waves [8].

On Department of Materials, Faculty of CE in Zagreb, a series of tests were conducted tests on steelmaking slag from landfills in Split and Sisak [9]. This was done in order to examine the slag's potential as aggregate in concrete. In addition, some other properties of slag were presented, which authors considered as interesting to compare with standard dolomite aggregates. According to report [6], the material used as aggregate in the vibro-stone columns must be clean, hard and inert material, with sufficient hardness and weathering resistance to prevent degradation during installation which would lead to forming of sand or silt particles, and consequently lower friction angles. Material needs to have less than 5% of fine-graded fraction and grain size usually between 20 and 75 mm (depending on the method of execution). It also must suit the soil conditions in which columns are formed. British standards further require that the aggregate with value of the impact (BS 812-112) and the value of crushing (BS 812-110) larger than 30% are not suitable for use in vibro-stone columns, as well as aggregates which degrade or significantly weather when saturated. The following rules also apply: fragmentation resistance LA_{50} (ie Los Angeles coefficient ‹50), freeze / thaw resistance MS_{35}, no dicalcium silicate (Ca_2SiO_4) and iron disintegration, volume instability (expansion) less than 5% and sulphate content less than 0.5%. Table 1 presents some results of slag testing from Split and Sisak which are of interest for vibro-stone columns application.

Table 1 Possibility of using slag from Split and Sisak in vibro-stone columns

Criteria	Split (ST)	Sisak (SI)	stone column use ST / SI
clean, hard and inert	yes	yes	yes / yes
requested fraction	achievable	achievable	yes / yes
fine-graded fraction ‹ 5 %	‹ 5 %	‹ 5 %	yes / yes
fragmentation resistance ‹ LA_{50}	24.8 (LA_{25})	21.7 (LA_{25})	yes / yes
freeze / thaw resistance ‹ MS_{35}	8.3 (MS_{18})	5.7 (MS_{18})	yes / yes
no Ca_2SiO_4 & iron disintegration	no	no	yes / yes
volume instability ‹ 5 %	1.6 %	2.2 %	yes / yes
sulphate content ‹ 0.5 %	‹ 0.5 %	‹ 0.5 %	yes / yes

Even though results from Table 1 show good potential for Croatian slag to be used in vibro-stone columns, additional test must be conducted prior to any finite conclusions. These especially include testing of value of the impact and value of crushing according to British standard. Some investigations made on slag from Germany [10] show that these parameters could be achieved since value of impact was in range of 18-22 % and value of crushing was in range 13-15%, all lower than requested 30%. Even though Steel Slag Coalition confirmed that usage of steel slag is safe for environment, extra care for heavy metals and other harmful substances in slag needs to be conducted. There are tests which have purpose of secretion testing, such as DEV-S4 method described in DIN 38 414. This technique was introduced in the third part of the EN 1744.

4 Fly ash and slag quantities in Croatia

In Croatia, the only coal combustion thermal power plant, Plomin, is located on the east coast of the Istrian peninsula. It is the only thermal power plant due to the fact that energy sources in Croatia are mostly focused on hydropower. Today two blocks of Plomin annually use about 800 000 tons of imported (USA, Colombia, Venezuela, Russia, South Africa, Indonesia and China) coal. When Plomin operates in normal mode, approximately 90 000 tons of fly ash is produced and it is used as raw material in cement factory. In present, there is no deposited fly ash in Croatia. However, until 2017 a construction of a new block is planned, with total annual coal usage increase up to 1.9 million tons. This would mean significantly higher amounts of produced fly ash. Same as in Croatia, where deposition of fly ash is managed properly due to small deposits, neighboring Slovenia has also ‘settled problem’ with fly ash. With total three thermal power plants in operation, Slovenia annually produces around 970 000 tons of fly ash of which most is used as fill material in construction and mining operations, while only a small portion is deposited. However, if fly ash is needed for soil improvement, it can be found in neighboring countries of Bosnia and Herzegovina and Serbia which still have huge deposits of fly ash due to large quantities of fly ash produced on annual basis. Additionally, these two countries still do not have a clear vision on managing fly ash and deposits are increasing. Four thermal power plants in Bosnia and Herzegovina, which is characterized by extremely large amounts of coal resources, produce annually around 2 million tons of industrial ashes (more than 9 million of coal is combusted). In Serbia, situation is even more alert, since five thermal power plants combust more than 35 million of coal per year, with close to 7 million tons of industrial by-products annually produced. Currently, only in Serbia there are around 180 million tons of deposited industrial by-products.

Unlike fly ash, Croatian slag deposits are huge. While some closed factories have exported their deposits of slag or used it to form embankments, 1.8 million tons of steelmaking slag from landfills in Sisak and 30 000 tons of steelmaking slag from landfills in Split are still on deposits without vision for their management. It is expected that amount of slag from Split will be doubled within one year. Slag from Sisak and Split is easily available as an aggregate for vibro-stone columns.

5 Conclusion

Soil improvement techniques lead to enhancement of soil characteristics, but require usage of great amount of natural resources and they can cause, to a lesser or greater extent, pollution of the surrounding environment. In the same time, urbanization leads to industrialization process which brings along a number of negative effects, such as deposition of large amounts of industrial waste materials. To achieve sustainability, fly ash and slag can be incorporated in soil improvement techniques and thus achieving dual positive effect – reducing pollution and extensive usage of natural resources while in the same time reducing waste material deposit amounts. Fly ash can be efficiently used as partial replacement for cement and lime in techniques of shallow soil stabilization or deep soil mixing. Depending of their origin and on type of their cooling, slags can be used also as replacement of cement or lime (granulated slag) or they can be used as an aggregate. This later application is especially interesting to be used as material in vibro-stone columns technique where it could replace natural gravel or crushed stone. In region, Bosnia and Herzegovina and Serbia have huge deposits of fly ash which can be potentially used for soil improvement. Unlike fly ash, slag deposits in Croatia are large and there is huge potential of using them as material for vibro-stone columns. Some preliminary laboratory results show that Croatian slag meets requirements for being used in vibro-stone columns, but more extensive laboratory and field test are necessary.

References

[1] The United Nations Human Settlements Programme, www.unhabitat.org, 21.01.2014.

[2] Cerić, A., Marčić, D. & Kovačević, M.S.: Applying the analytic network process for risk assessment in sustainable ground improvement, Građevinar, 65 (10), pp. 919-929, 2013.

[3] Kovačević, M. S., Simović, R., Bjegović, D., Rosković, R. & Peček, N.: Soil improvement with nano waste particles, Proceedings of the International Symposium: Non-Traditional Cement & Concrete III, Brno, pp. 362-371, 2008.

[4] Hansson, N.: Deep soil stabilization with fly ash, MSc thesis, Department of Earth Sciences, Uppsala University, Sweden, 2008.

[5] Ohishi, K.: Application of coal fly ash for improving soils prior to excavation, Proc. International Conf. on Engineering Materials, vol. 2, Ottawa pp. 531-541, 1997.

[6] Building Research Establishment Report 391 – Specifying Vibro Stone Columns, 2000.

[7] Slag product applications, www.globalslag.com, 01.02.2013.

[8] Kovačević, M. S., Marčić, D. & Gazdek, M.: Application of geophysical investigations in underground engineering, Tehnički vjesnik, 20 (6), pp. 1111-1117, 2013.

[9] Netinger, I., Jelčić Rukavina, M. & Bjegović D.: Mogućnost primjene domaće zgure kao agregat u betonu, Građevinar, 62 (1), pp. 35-43, 2010.

[10] Motz, H., Geiseler, J.: Products of steel slags an opportunity to save natural resources, Waste management, 21 (3), pp. 285-293, 2001.