Experiences with jet-grouting technology applied to the remediation of old dump sites

L'application de la technologie de l'injection en jet lors de la réhabilitation de vieilles décharges

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ABSTRACT: The pilot study on a municipal solid waste landfill is under way. In order to chemically immobilize the waste, jet-grouting has been executed on the trial field on the landfill. Three groups of three columns cca 4 m long have been formed using lime and cement mixtures. Laboratory testing has been performed on non-treated waste samples and on the samples treated with lime admixtures. The preliminary test results are presented and some general conclusions are drawn.

RESUME: La recherche d'essai est en cours dans le dépotoir municipal des déchets solides. L'injection en jet a été exécutée dans un champs d'essai dans les limites du dépotoir pour immobiliser chimiquement les déchets. Trois groupes de trois colonnes injectées en jet, longues de cca 4 m, ont été formés à l'aide des mélanges à base de chaux et de ciment. Les échantillons des déchets non traités aussi que les échantillons des déchets mélangés avec la chaux ont été analysés dans le laboratoire. Les résultats preliminaires des recherches sont montrés et quelques conclusions générales en sont tirées.

1 WASTE DISPOSAL IN CROATIA

There has been an increasing environmental awareness in last decades. While in western Europe and in the USA the problems of environmental protection have been tackled in the early 1970s, the same problems have been neglected in Croatia until mid 1980s. The economic reasons and even partly political reasons hindered a serious approach to the solution of the problem. As a result the majority of waste disposal sites are typical unsanitary open dumps located at the edges of the cities.

Along with the efforts to plan and construct new sanitary landfills there is obviously a strong need for a rational approach in the remediation of the existing, mostly uncontrolled landfills in the country. A major project of that kind is the remediation of the existing dump site Jakuševec near Zagreb (Nikolić et al., 1995). The first stage of the works has been recently completed (November 1996). The final aim of the project is to transform the whole site into the first sanitary landfill in Croatia.

According to another approach several regional landfills ought to be constructed. They are intended to accommodate new quantities of waste along with the waste which should be transported from a number of existing dump sites in a particular region. Unfortunately, this seems to be a rather costly solution. Therefore it is obvious that many unsanitary dump sites, particularly in the vicinity of small cities, need a different solution.

Theoretically, both passive and active approaches could be adopted (Gray, 1995). But taking into account the above mentioned situation in the country it can be concluded that some method of active containment could be more appropriate. Consequently, the contamination of the landfilled waste can be reduced by in-situ treatment and intervention.

2 WASTE STABILIZATION BY IN-SITU MIXING

Within the framework of active approaches the methods of chemical immobilization (stabilization and/or solidification) have been mainly applied in the management of hazardous waste (LaGrega et al., 1994).

Stabilization is a process where additives are mixed with waste to minimize the rate of contaminant migration from the waste and to reduce the toxicity of the waste. Solidification is a process employing additives by which the physical and mechanical properties of the waste (strength, deformability, permeability) are altered during the process. Thus, objectives of stabilization and solidification would encompass both the reduction of waste toxicity and mobility, as well as an improvement in the engineering properties of the stabilized material.

Various types of additives (reagents) can be employed. Nearly any reagent which can be mixed with water into a grout is usable. The most frequently used reagents are cement, lime, bentonite etc. which can be mixed with other additives.

Stabilization and/or solidification is usually carried out by mixing the waste with additives in one of the following ways: prior to deposition of the waste or on the deposited waste. In situ mixing is carried out by means of standard construction equipment or by special equipment

with large diameter augers. Unfortunately, neither of the mentioned techniques is suitable for the municipal solid waste type material. This conclusion initiated the idea of applying jet-grouting for this purpose.

Jet-grouting is a well known soil improvement technique which is used in many geotechnical applications. It is a technique of mixing, cutting and/or excavating the in situ material with a liquid injected at high speed to form a homogeneous mass which in time solidifies. This method of obtaining a volume of soil having altered characteristics is basically suitable for the immobilization of material deposited on a municipal solid waste landfill. A reduction in the rate at which contaminants can migrate into the environment can be thus achieved. Application of appropriate additives and successful mixing are the necessary requirement.

3 PRELIMINARY FIELD TEST

Lime (with some other additives) is the type of binder which satisfies previously mentioned requirements and it is acceptable from the environmental point of view. Its application should be proved by suitable field and laboratory tests.

A pilot study was initiated in the first half of 1996. The preliminary field test was performed on a municipal landfill in the vicinity of a small town in the north of Croatia. The site has some elements of a sanitary landfill as the waste was deposited on a horizontal clay stratum, while the existing waste body has top soil cover 50 cm thick. The age of the disposed waste was about two years. The laboratory analysis proved that the waste is composed of 44,3% organic matter and 55,7% inorganic matter.

The aim of the test was to check the effects of jet-grouting technique on the limited area of the landfill. Three groups of three columns cca 4 m long have been formed using cement and lime mixtures. The disposition of the test field is shown in Figure 1.

In each group the waste was treated with a different mixture as shown in Table 1. Reagent proportions in the grout were based on laboratory testing in order to achieve the viscosity of the grout which is typical in jet-grouting execution. These proportions proved to be satisfactory as the execution of jet-grouting was completed successfully.

In each group three columns were executed each having different jet-grouting parameters. These variations (translation and rotation speed of the jet-grouting string) should have indicated the effects of jet-grouting parameters to the characteristics of columns.

Table 1 contains detailed information on jet-grouting parameters.

Approximately three months after the execution of jet-grouting works the surface of the trial field was excavated (approx. 2,0 m top layer) and the following conclusions were drawn:

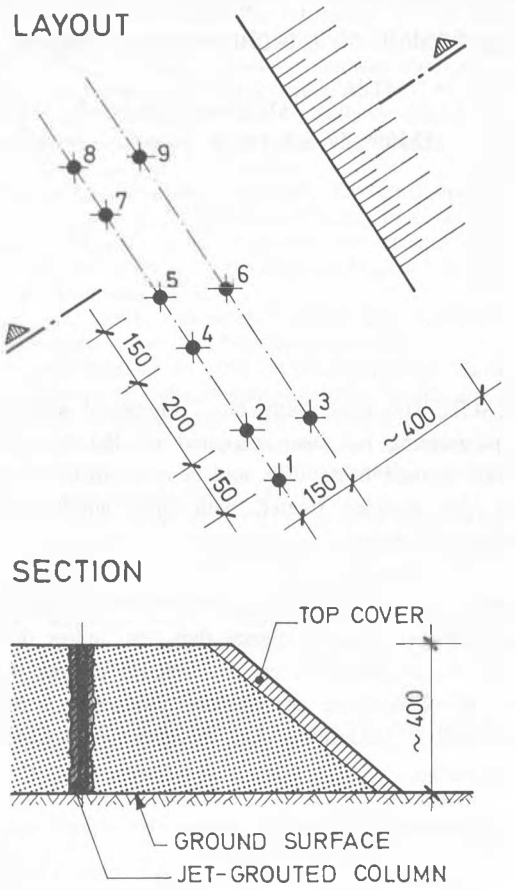

Figure 1. Disposition of the test field

- All admixtures employed resulted in similar effects. The variation in jet-grouting parameters had no major influence. The reason is that in all cases the variation remained within standard limits and due to pronounced heterogeneity of the waste the difference of jet-grouting parameters could not have significant impact.
- The diameters of jet-grouted columns were approx. 80 cm in all cases, which seems to be favourable. The heterogeneity of the waste did not have major influence, with the exception when solid bodies (e.g. huge metal items, concrete blocks, etc.) were encountered.
- In the case of cement grout (columns 1, 2, 3) the jet-grouted elements have hardened. A volume of waste has the shape of a cylindrical body with horizontal discontinuities. This is the consequence of the presence of substantial amount of plastics in the waste.
- Lime grout (columns 4, 5, 6) did not harden at all. This type of the binder could not harden in this circumstances. But lime grout remained in the jet-grouted body. Its colour changed due to mixing with polluted water.
- Lime-cement grout (columns 7, 8, 9) has hardened but its strength was much lower than that of columns 1, 2 and 3.

Table 1. Jet-grouting parameters

Column No.	Column length [m]	Grouting pressure [bar]	Withdrawal speed [cm/min]	Grout composition: Cement [kg]	Lime [kg]	Water [L]	Density [kg/dm^3]	Binder consumption [kg]
1	2,60	400	120	150	0	150	1,45	450
2	4,00	400	60	150	0	140	1,52	600
3	4,00	400	40	150	0	140	1,51	225
4	4,00	380	120	0	90	225	1,16	270
5	4,00	380	120	0	90	225	1,21	315
6	4,00	400	40	0	90	225	1,20	360
7	4,00	380	120	150	60	188	1,29	300
8	3,00	380	60	150	60	188	1,29	225
9	4,00	380	40	150	60	188	1,27	300

In general the in situ works could be described as successful. It seems that the most favourable grout is the lime-cement mix. The corresponding jet-grouted elements reached a certain degree of strength which is necessary to reduce the potential washing out of lime. At the same time lime has the possibility to react with the waste material.

Total of 33,6 m jet-grouted columns have been executed. As the average diameter was cca 80 cm, a volume of 16,8 m^3 was treated.

Taking into account the prices in Croatia (expressed in DEM) the cost of grouting material (lime, cement) is 50 DEM/m^3 and the total cost is cca 160 DEM/m^3. This can be considered an acceptable price provided that the final result of the applied treatment is satisfactory.

The above cost estimate is made on the basis of the prices which are at the lower acceptable limit, but all expenses are completely covered. There is no available firm data for other countries but according to the rough estimate the total cost should not exceed the sum of 200 DEM/m^3.

In fact the real cost will be even somewhat higher because of jet-grouted columns overlapping in case of treatment of the complete body of a landfill. But on the other hand it should be mentioned that all works are performed in-situ and there is no excavation, transportation or mixing of the waste. All these features make the proposed method attractive.

4 LABORATORY TESTING

During the excavation on the trial field a number of samples were taken in order to be tested in the laboratory. The samples of non-treated waste were taken in order to characterize the waste and to mix waste and various proportions of lime and cement in laboratory conditions. The aim of the chemical analysis described hereafter was to evaluate the effectiveness of stabilization.

In the present paper only the tests related to lime mixtures are presented. For this phase of testing five samples were prepared. Their mass ratio is presented in Table 2. Two samples remained non-treated (samples No. 4 and No. 5) and three waste-lime mixes were obtained by adding various amount of lime to the waste from sample No. 4 (samples No. 1, 2 and 3). Each sample was mixed with distilled water in a 3-liter watertight containment. They were left for a period of five months before performing chemical analysis. The analysis was performed on the fluid phase of the samples. This fluid can be identified as leachate which could actually migrate from the landfill into the environment.

The quantities of lime given in Table 1 (columns 4, 5 and 6) correspond to the standard viscosity required in jet-grouting works. The grout consisted of cca 0,4 kg of lime in 1 L of water which corresponds to the ratio given for sample No. 1 in Table 2. It can be assumed that this quantity of lime is excessive in relation to the quantity which is actually needed for the immobilization of waste. Consequently two more diluted admixtures (samples No. 2 and No. 3) were prepared.

Table 2. Composition of samples (in mass proportion)

Sample No.	Waste	Water	Lime
1	1	0,40	0,15
2	1	0,45	0,10
3	1	0,50	0,05
4	1	0,66	-
5	1	0,66	-

Some results of the chemical analysis, done at the Department of fluid analysis and ecology, INA-Naftaplin Co., Zagreb, are shown in Table 3.

Comparing the contaminant concentrations in non-treated samples it should be noted that a significant heterogeneity of the sample composition is present. Some concentration values exceed the regulatory levels.

The pH of the waste-lime mixes is obviously greater than the pH of the non-treated waste as the immediate consequence of lime influence. The same applies to the increased concentration of calcium and probably ammonium. The concentration of almost all other cations has been reduced. The concentration of oils and COD may be considered unchanged. Another obvious impact of lime content is the disappearance of heterotrophic bacteria in waste-lime samples.

Table 3. Contaminant concentrations in the liquid phase

Parameters	Sample No. 1 [mg/dm^3]	Sample No. 2 [mg/dm^3]	Sample No. 3 [mg/dm^3]	Sample No. 4 [mg/dm^3]	Sample No. 5 [mg/dm^3]
pH value - units	12,39	11,21	11,53	7,78	7,96
Magnesium (Mg^{2+})	0,22	0,40	0,40	84,00	17,00
Calcium (Ca^{2+})	1030,00	1260,00	1250,00	250,00	50,00
Chromium (total)	0	0	0	0	0
Copper (Cu^{2+})	0,20	0,30	1,14	0,30	0,03
Zinc (Zn^{2+})	0,12	0,03	0,09	4,40	0,15
Nickel (Ni^{2+})	0,22	0,5	1,35	0	0
Iron (Fe^{2+})	0,12	0	0,10	25,00	0
Lead (Pb^{2+})	0	0,12	0,20	0,40	0
Cadmium (Cd^{2+})	0	0	0	0	0
Manganese (total)	0	0	0	1,90	0
Ammonium (NH_4^+)	29,00	193,00	171,00	9,40	3,6
Total oil	5,42	9,13	14,06	12,53	4,05
Mineral oils	0,15	0,25	0,36	0,27	0,11
COD , mgO_2/dm^3	319,90	627,00	870,20	230,30	486,30
Number of hetero-trophic bacteria/ 1 mL	0	11	0	1600	1320

The samples which were obtained from the jet-grouted volume of the landfill are to be tested for the possible field reaction between injected grout and waste material. The tests should reveal the actual degree of immobilization achieved in the landfill.

5 CONCLUSIONS

The initial phase of the pilot program has been presented. Although a number of issues should be resolved some general conclusions and recommendations can be given.

Jet-grouting technique could be considered as one of the feasible solutions for the immobilization of the municipal solid waste. The technique can be easily adapted to the specific needs of geomorphologic conditions at the site. Moreover, there is no need for excavation works, removal of the waste, mechanical mixing, etc. In addition, the approximate cost estimate indicates that jet-grouting can be advantageous to similar mixing techniques. A similar application of the same technique has been proposed recently (Čorko et al., 1996) in the context of remediation of soil contaminated by hydrocarbons.

As far as the execution of jet-grouting is concerned it can be said that the works on the trial field can be described as successful. But the main unresolved issue which remains in the present phase of the research is the choice of the appropriate reagents. This ought to be defined in the course of laboratory testing in the near future.

While on the present trial field only single jet-grouted columns were executed, next trial field is planned to encompass a greater volume of landfill body. Figure 2 presents a possible jet-grouted pattern.

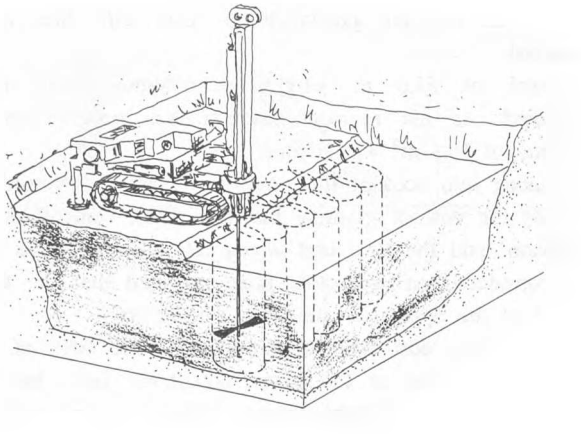

Figure 2. Typical jet-grouting pattern on a landfill

REFERENCES

Čorko, D., Kovačić, D., Najman, D. 1996. Immobilization of soil contaminated by hydrocarbons (in Croatian). In V. Simović (ed.), *Congress of Croatian Civil Engineers '96.* 339-344, Zagreb: Croatian Society of Civil Engineers.

Gray, D.H. 1995. Containment strategies for landfilled wastes. In Y.B. Acar & D.E. Daniel (eds), *Geoenvironment 2000, Geotechnical Special Publication No. 46,* Vol. 1: 484-498, New York: ASCE.

LaGrega, M.D., Buckingham, P.L. & Evans, J.C. 1994. *Hazardous waste management.* New York: McGraw-Hill.

Nikolić, S., Pletikapić, Z. & Herenda, J. 1994. New method of waste disposal at Jakuševec site (in Croatian). *Geotechnical Engineering in Cities - Proceedings of the Second Conference of the Croatian Society for Soil Mechanics and Foundation Engineering,* Vol. 1: 165-178.