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Full Length Research Paper

The evaluation of stone column and jet grouting soil improvement with seismic refraction method: Example of Poti (Georgia) railway

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Studies of surface improvement have been carried out in Georgia-Poti in order to decrease surface deformations since surface conditions of railway line that comes from the harbor are too poor. Stone column and jet grouting methods were evaluated together as surface improvement methods. As engineering parameters on the surfaces which are applied, jet grouting are higher than the other method, it was decided to improve the line within project with this method. This study was carried out in order to present surface parameters obtained with seismic refraction data carried out together with surface improvement practices. Findings show that parameters of shear wave velocity, amplification rate and bearing power obtained with jet grouting practices are higher than those of stone column practices.

Key words: Jet grouting, seismic refraction, soil improvement, stone column.

INTRODUCTION

In condition where problematic surfaces carry risks for engineering constructions, surfaces can be adapted as expected with various soil improvement methods. Bored pile, soil injection, stone column, vibro compaction and jet grouting are common methods used for this aim. Previous similar projects are of importance in order to determine the suitable soil improvement method in relation to project. In soil improvement, how far are the surface conditions improved compared with the beginning should be known. However, it is often hard and long to do it.

In this study, stone column and jet grouting practices carried out at and around the station structure planned to be constructed within a railway line and their improvement performances were determined with a geophysical seismic measurements carried out on-site. For this aim, surface before improvement and surface profiles which are applied separately with both improvement methods were measured.

Study field includes the area of the river reach of Rioni which moves to Black sea in Poti which is the coastal town of Georgia (Figure 1). Railway line is constructed on the alluvium sediments brought by the river.

There are many studies in literature which examine design styles, bearing capacities and effective factors of stone columns in different conditions (Greenwood, 1970; Hughes and Withers, 1974; Shankar and Shroof, 1997; Ambily and Gandhi, 2004). Similarly, there are references about design characteristics of jet grouting practices (Bell and Burke, 1994; Covil and Skinner, 1994; Stroud, 1994; Wong et al., 1999; Wong and Poh, 2000, Sağlamer et al., 2002; Lunardi, 1977; Poh and Wong, 2001). However, there is no study in which the performances of both stone column and jet grouting practices are evaluated. Therefore, the study stands out as the premier for practice conditions. It is thought that the study will give light to future studies.

Geology of study field

Study field and its surrounding is generally composed of a thick plio-quaternary stack based on volcanic and volcanic sedimentary. This

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Abbreviation: SPT, Standard penetration test.

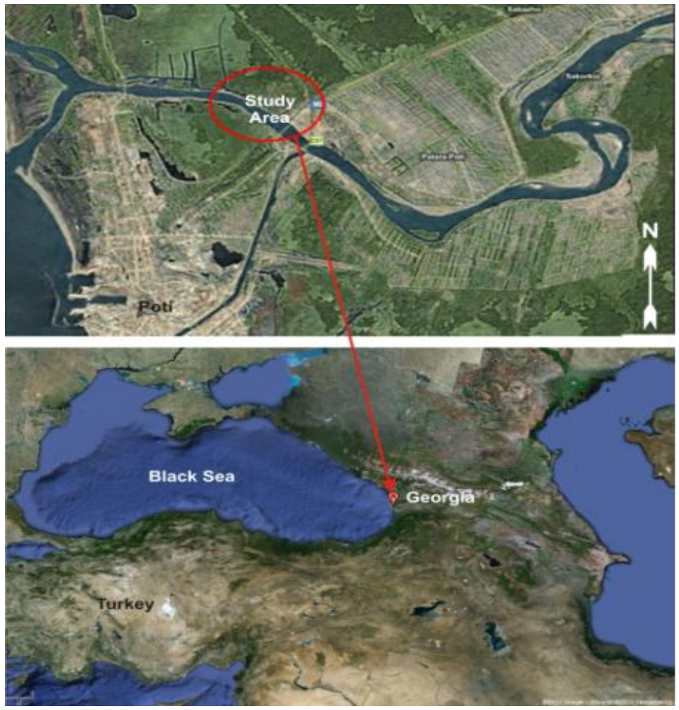

Figure 1. Aerial photograph of study field (Taken from http://maps.google.com).

a. Stone column practice **b.** Jet grouting practice.

Figure 2. Soil improvement studies carried out in study field

stack is generally composed of peat clay – silt and fine-grained sands which are drifted related to wide river systems and their shunts. In the test pit and borings drilled in the study fields; young stack composed of primarily silt-clay and partly sand was observed.

Soil improvement studies

Railway passes over a soil profile where there are young alluvial sediments. Due to this soil structure, there has been need for soil improvement study before the construction of railway. For this reason, first of all, a stone column study was carried out on a certain region around railway line. Then jet grouting manufacture was done on another region within railway location.

Stone columns were done by compressing and stoning aggregate into 80 cm diameter wells. It was projected as forming 80 cm columns in jet grouting practices. Figure 2 shows stone column and jet grouting practices carried out in a,b.

Soil characteristics and application of seismic refraction practice

In order to determine mechanic and seismic parameters of improved soil, both standard penetration test (SPT) and reciprocal, seismic refraction measurements along three (3) profiles were

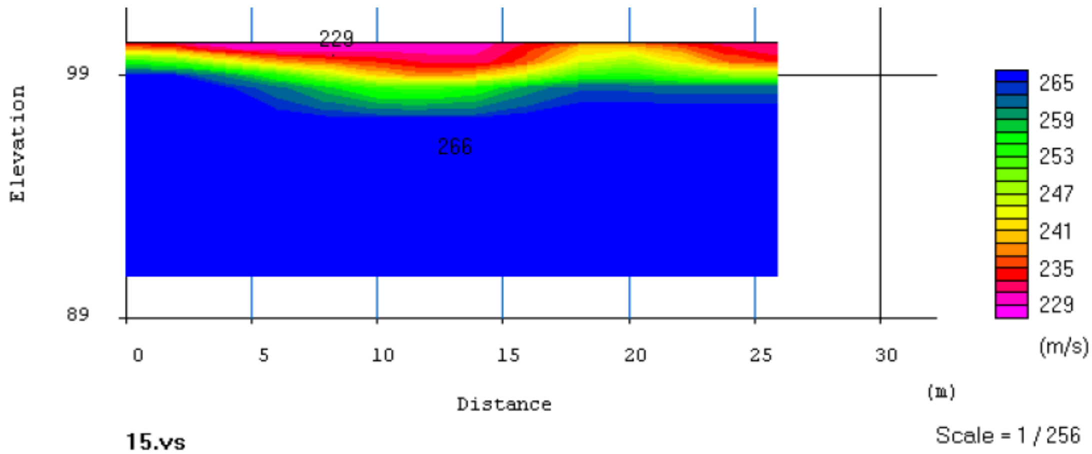

Figure 3. Underground profile and change of V_p speed obtained with seismic tomography.

Table 1. Line 2 obtained from the area where soil improvement was not done and surface parameters obtained from field studies.

Parameter	Environment 1	Environment 2
V_p (m/s)	229	266
V_s (m/s)	90	113
G (kg/cm^2)	100	215
B (kg/cm^2)	512	906
E (kg/cm^2)	281	598
V_p/V_s	2.54	2.35
Soil class	D	D
q_s (kg/cm^2)	1.09	1.87
q_a (kg/cm^2)	0.43	0.79
Compressibility	0.005388	0.004448
SPT - N	5.33	11.31
Bed coefficient (t/cm^3)	1218.18	1381.61
Amplification rate	1.7	
Rate of impedance difference	0.58	

done. Measured locations are named as Line 1, Line 2 and Line 3. Line 1 was chosen in jet grouting field, Line 2 was chosen where there is no soil improvement practice. Line 3 was chosen in the area where stone column improvement was done. Geophone distance was chosen as 2.0 m and shooting point distance was chosen as 2.0 m as well in seismic measurements. In the study; Geometrice seismic measurement device, 14 Hz geophones and other seismic equipments were used.

Areas which cannot be improved

Surfaces which are composed of sand, silt and peat type organic-originated clays have too low surface values with their natural status. Study fields have put forward that SPT values of the unit are quite low (N30 = 4 - 12). Allowable bearing value found depending on seismic speed is around 0.4 kg/cm^2. From the empirical calculations depending on N30 values, cohesion value was found between 5 and 10 kPa, angle of internal fraction was between 1 and 5.

A test pit of 5.0 m was bored in order to define surface lithology on site. This stack which was defined as current stream bed sediment was observed to have 0.0 to 2.0 m granular embankment, 2.0 to 4.0 m grayish bluish silt sand and 4.0 to 5.0 m organic sand additive sandy silt. With the drillings, it was put forward that the stack sustains this condition. Figure 3 presents surface profile obtained with seismic tomography and change of V_p speeds.

With soil examinations, liquid limit value was 19.12%, plastic limit value 16.67% and natural water content of the soil was found to be 12.50%. According to Unified Soil Classification System (USCS) classification, it was detected that the surface was in the group of ML surface group (inorganic silt and very-fine sand).

Seismic parameters obtained with seismic refraction studies and SPT average values obtained with field drilling in this area where soil improvement was not carried out as given in Table 1.

Areas which are improved with stone column

Stone columns are often used in the improvement of soft and loose

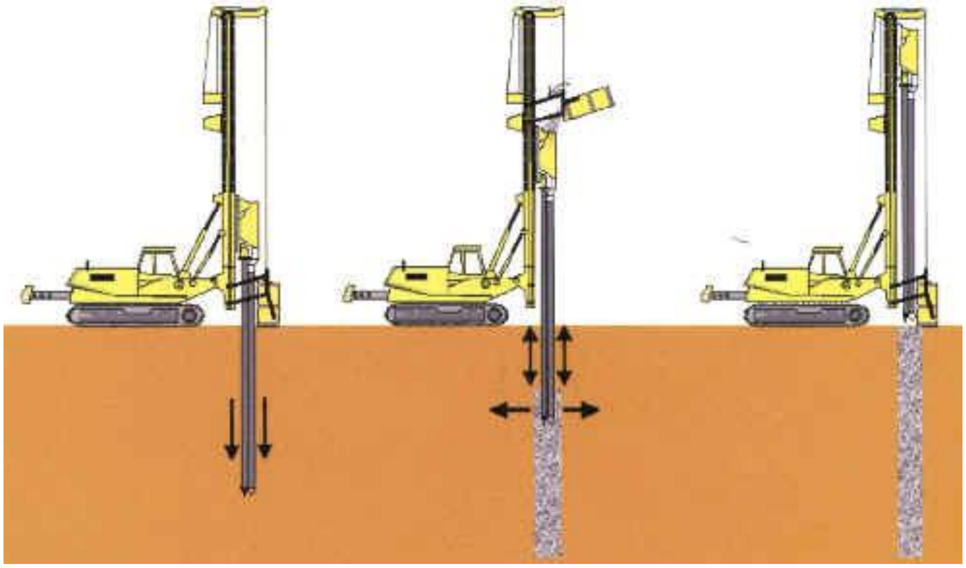

Figure 4. Schematic demonstration of stone column practice.

Table 2. Line 2 obtained from the area where stone column improvement was done and surface parameters obtained from field studies.

Parameter	Environment 1	Environment 2
V_p (m/s)	176	278
V_s (m/s)	77	135
G (kg/cm^2)	68	308
B (kg/cm^2)	266	894
E (kg/cm^2)	189	828
V_p/V_s	2.29	2.06
Soil class	D	D
q_s (kg/cm^2)	0.87	2.24
q_a (kg/cm^2)	0.38	1.09
Compressibility	0.006626	0.00401
SPT – N	7.24	16.03
Bed coefficient (t/cm^3)	930.93	1429.76
Amplification rate	2.6	
Rate of impedance difference	0.39	

surfaces. With this practice, it is possible to decrease consolidation duration depending on field and soil conditions, increase bearing capacity and prevent liquefaction. Ground subsidence can be decreased up to 50% with stone column practices. Apart from this, stone column practices are commonly used for minimizing the liquefaction on surfaces which are suitable for liquefaction during earthquake rather surface improvement. The practice includes compression of aggregate placing it into well-hole which is drilled (Figure 4).

In this study, first of all, stone column manufacture was done for soil improvement in railway line. The practice was done by compressing and stoning aggregates in 20 mm dimensions into 70 mm diameter wells. Stone columns length of 8 m. Seismic measurement and field studies carried out following stone column practice show that both seismic parameters and SPT-N values increased (Table 2). Allowable bearing value found depending on seismic speed is 2.0 kg/cm^2.

Areas which are improved with jet grouting

Jet grouting is a well known soil improvement technique which is able to create consolidated elements in the subsoil with different shapes and dimensions and also with good mechanical characteristics and reduced permeability. The technique involves eroding and mixing the *in situ* soil with water cement grout (Figure 5). The grout mix is jetted, with the aid of special tools, at very high speeds (800 to 900 km/h) created by high pressures (400 to 500 bars = 7.000 to 9.000 psi).

In the other part of study, 80 cm of columns were prepared and jet

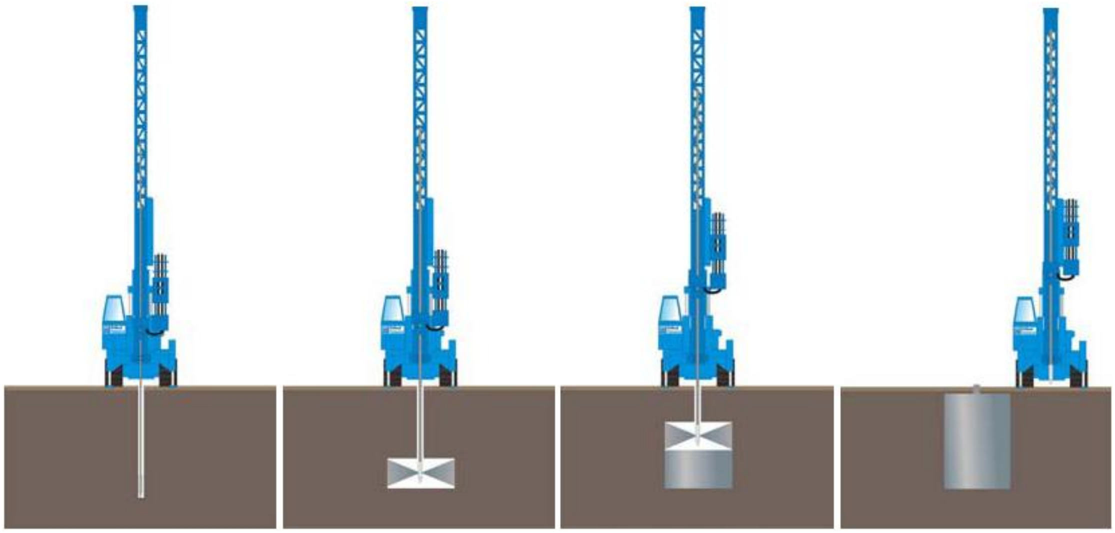

Figure 5. Schematic demonstration of jet-grouting practice (Küçükali, 2008).

Table 3. Soil parameters obtained from Line 1 taken from the field which is improved with jet grouting and from field studies.

Parameter	Environment 1	Environment 2
V_p (m/s)	414	675
V_s (m/s)	210	341
G (kg/cm^2)	629	2057
B (kg/cm^2)	1605	5318
E (kg/cm^2)	1669	5467
V_p/V_s	1.97	1.98
Soil class	C	C
q_s (kg/cm^2)	2.94	5.92
q_a (kg/cm^2)	1.49	2.99
Compressibility	0.002653	0.001629
SPT – N	38.11	> 50
Bed coefficient (t/cm^3)	1864.322	2397.748
Amplification rate	2.0	
Rate of impedance difference	0.50	

grouting practice was done in the improvement area of jet grouting columns length of 11 m. With the practice carried out, it was seen that there is an increase in soil seismic parameters and in SPT-N values. Allowable bearing value which is around 0.4 to 0.5 kg/cm^2 in its primary condition has increased to the level of 2.9 to 3.0 kg/cm^2. Table 3 shows seismic refraction measurements and SPT-N values obtained from field studies after jet grouting practice.

Figure 6 presents images from seismic refraction practices applied to all soil profiles explained above for the evaluation of soil improvement performances.

Evaluation of soil improvement performances

Eurocode 8 (EN, 1998) groups soil into four (4) according to their shear wave velocity (V_{s30}) (Table 4). Evaluation of shear wave speeds obtained with seismic refraction studies shows that soil class is C for the soil which is improved with jet grouting. Soil class is defined as D for other conditions.

Table 5 presents soil parameters which are not improved, which is improved with stone columns and jet grouting all together.

As can be observed in Table 5, seismic speed and elasticity parameters obtained in the field improved with jet grouting are higher than that of stone column improved. Allowable bearing values of each environment calculated from seismic speed values are given in Table 6. Findings show that bearing power of soil improved with jet-grouting is 50% higher than that of stone column improved soil.

RESULTS AND DISCUSSION

Stone column and jet grouting are commonly used impro-

Figure 6. Images from seismic refraction studies carried out in study field.

Table 4. Soil classification according to V_{s30} values in Eurocode 8 (EN, 1998).

Soil class	Description	Characteristics (m/s)
A	Rock or rock-like formations	$V_s > 800$
B	Very hard sand, aggregate or very hard clay	$360 < V_s \leq 800$
C	Hard or medium-hard sand, aggregate or hard clay	$180 < V_s \leq 360$
D	Cohessionless soil from loose to medium-hard	$180 > V_s$

Table 5. Change in the parameters of speed and elasticity according to soil conditions.

Soil condition	V_p (m/s)	V_s (m/s)	V_p / V_s	E (kg/cm^2)	G (kg/cm^2)	Soil class
Unimproved soil (Line 2)	245	102	2.45	440	100	D
Stone column improved soil (Line 3)	278	135	2.06	828	308	D
Jet grouting improved (Line 1)	675	341	1.98	5467	2057	C

Table 6. Allowable bearing values obtained for soil which improved and not improved with jet grouting.

Study field	Allowable bearing values (kg/cm^2)
Natural soil surface	0.4
Stone column improved area	2.0
Jet-grouting improved area	3.0

ving methods in the scope of soil improvement. However, evaluation of performances after applications is not done in most of the engineering projects. In fact,

superiority of improving methods should be known and its utilization for the suitable engineering projects must be carried out.

Seismic refraction studies are suitable geophysics studies that can be used in order to determine change in seismic parameters of soil on a surface which is improved.

In this study, performance of stone columns and jet-grouting practices carried out in the location of railway which is dominated by poor soil conditions. For this reason, both seismic refraction and on-site tests were carried out on the field. All the data obtained show that soil conditions obtained with jet grouting practices are higher than those of stone column practices.

Notations: V_p**,** P wave value; V_s**,** S wave value; **G,** shear; modulus; **B,** bulk modulus; **E,** elasticity modulus; V_p/V_s**,** frequency rate; q_s**,** dynamic surface bearing power; q_a**,** dynamic allowable bearing value.

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