Jet Grouting to Reduce Liquefaction Potential

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SYNOPSIS: A compaction sand piling technique was abandoned after it caused excessive vibrations in buildings adjacent to the construction site. Various alternatives were evaluated, but none could provide certainty of acceptance by the residential community without causing schedule delay and other construction complications. A vibration-free jet grouting method was therefore adopted for ground improvement to reduce liquefaction potential at the site. Modifications in grouting procedure details were implemented to overcome problems caused by the site conditions.

INTRODUCTION

The site at a proposed station of the Taipei Metropolitan Rapid Transit Systems is underlain by a layer of loose to medium dense silty sand, about 18 meters in thickness. This silty sand layer is sandwiched by very dense Andesite debris layers, consisting of sandy gravels and cobbles. The typical soil profile is shown in Table I.

TABLE I. Typical Soil Profile

Depth (meters)	Soil Type	N-Value
0-2	Fill	8
2-6	Andesite debris (GW)	54-100+
4	(Groundwater table)	
6-8	Silty Clay (CL)	2
8-26	Silty sand (SM) with occasional Andesite debris	3-100+
26-28	Andesite debris	100+

Analysis, using Seed and Idriss method (1971), indicated that the upper part of the loose silty sand layer would likely liquefy under the the maximum credible earthquake.

COMPACTION SAND PILES

Various alternatives were considered for ground improvement over an area of 17 meters by 48 meters to reduce the potential for liquefaction. Based on economical considerations, a total of 445 compaction sand piles were initially planned to densify the upper part of the loose silty sand layer. However, the construction work was suspended after the first few sand piles were driven. Vibrations generated from the sand pile driving and transmitted through the subsoils (Figure 1) were found to be unbearable by the residents near the construction site.

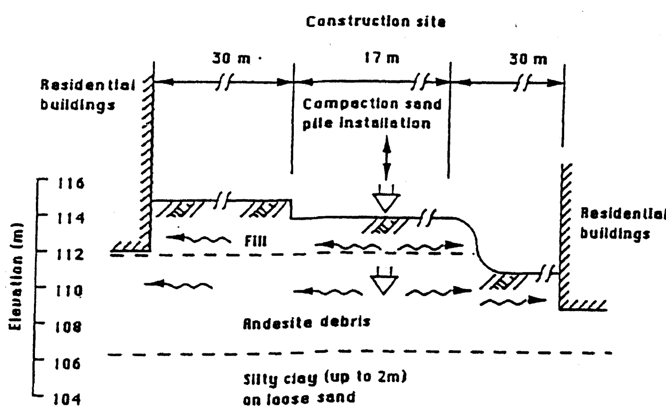

Figure 1. Soil Profile

The compaction sand pile installation equipment was capable of generating a maximum force of 450 kN with a frequency of 600 cycles per minute. Estimated amplitude of vibration was on the order of 0.1 to 0.2 mm at the nearby residential buildings. Different approaches to reduce vibrations caused by the compaction sand pile installation were evaluated. Methods analyzed included predrilling through the Andesite debris layer to reduce vibrations caused by the advancing casing, and vertical trenches around the construction site to screen surface waves propagated through the subsurface soils. Supplemental measures were also required to safeguard the stability of existing structures next to the proposed vertical trenches of 4 meters in depth. After an analysis using

Woods' method (1968), it was concluded that neither one of the above approaches nor a combination of the two would provide certainty of acceptance by the residential community without causing other construction complications and further time delay. Since good community relations and expediency in construction schedule were among the top priorities for this project, a vibration-free jet grouting method was therefore adopted for ground improvement.

JET GROUTING

High pressure cement based jet grout columns (JGC) of 14 meters in depth and 2 meters in spacing were planned for the site improvement. Contract specifications called for coring at a minimum of six JGC locations chosen by the resident engineer and samples taken from the centerline of these JGC's at one meter intervals below elevation 100 meters after the site improvement. Unconfined compressive strength tests performed on selective samples had to meet the minimum strength requirements shown in Table II. Interpolation could be used for intermediate ages.

TABLE II. Required Unconfined Compressive Strength (kN/m^2)

	7-day	28-day
Average at one specified depth	1,000	2,000
Minimum for each sample	700	1,400

FAILURES OF JGC

Engineers were puzzled when coring failed to detect traces of the cement grout after the initial group of jet grout columns were installed. Possible causes were assessed and are summarized as follows:

1. The grouting pressure applied was too high and incompatible with the soil conditions encountered.

2. Part of the cement grout might have been lost with the ground- water which was flowing through porous soil strata towards the adjacent creek.

3. The amount of cement needed for different soil stratum varied significantly and was not accounted for initially.

4. Grout columns failed to maintain vertical alignment when advancing through the upper Andesite debris layer due to the presence of very hard cobbles and gravels. Deflection of the grout pipe not only resulted in non-uniform application of the cement grout, but also made it difficult to find traces of the cement grout in subsequent coring.

MODIFICATIONS OF GROUTING PROCEDURES

To remedy the problems encountered as described above, details of grouting procedures were modified as follows:

1. The grouting pressure was adjusted based on soil conditions encountered at various depths. Typical grouting pressures used are summarized in Table III.

TABLE III. Grouting Pressure

Soil Conditions	Grouting Pressure (kN/m^2)
Loose sandy soils	16,000-18,000
Clayey soils or medium dense sandy soils	18,000-20,000
Others	20,000

2. Sodium silicate was used as an additive to accelerate the hardening process when the grout was applied in Andesite and sandy soil strata. This minimized the loss of cement grout in pervious soil layers.

3. The speed of raising the grout pipe was adjusted to allow for various amounts of cement to be applied in different soil strata. More cement grout, with a lift rate of 19 cm per minute, was applied in the loose sandy soil stratum where ground improvement was needed the most to reduce its liquefaction potential.

4. Predrilling through the upper dense and cobbly Andesite debris layer simplified the task of maintaining vertical alignment of the grout pipe. This also resulted in better quality control and uniformity of the grout applied.

Unconfined compressive strength tests were performed on core samples taken at various depths as required and the test results met the strength requirements as indicated in Table II.

CONCLUSION

Compaction sand piling is an easier and more economical approach for densifying loose sandy soils in general. However, it was unfeasible for this project because of the specific site conditions, protest from the nearby densely populated community, and a very restrictive construction schedule. A vibration-free jet grouting method was therefore used for ground improvement at this site.

Details of grouting procedures, such as predrilling through hard cobbles and gravels, grout application pressure, speed for raising the grout pipe, and amounts of cement and additives, were adjusted for specific soil stratum in order to achieve the intended purpose of this ground improvement.

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