First Applications of the SAVE Compozer Method (Non-Vibratory Stone Columns) for Soil Densification in the U.S.

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ABSTRACT: The Vibro-Replacement Method, also known as Stone Columns is one of the most prevalent liquefaction mitigation measure used in the U.S. However, difficulties have been encountered occasionally when applying this method in urban or residential environments because of the potential for negative impacts such as noise and vibration on project neighbors, and the potential for structural damage when it is applied too close to the exiting structures. The SAVE (Silent, Advanced, Vibration-Erasing) Compozer is a newly developed Non-Vibratory Replacement method that does not induce vibration and creates very little noise. The same degree of densification can be achieved when using the SAVE Compozer as can be achieved with conventional Vibro-replacement without the negative impacts of noise or vibration. This paper presents case histories of the first two applications of the SAVE Compozer in the U.S. including verification results of densification performance and vibration monitoring records, together with an overview of the SAVE Compozer method including densification concept, equipment, and execution.

INTRODUTION

When using Vibro-replacement, densification of the subsurface soils is achieved by a combination of vibratory force and enforced placement of coarse grained materials into the ground. As a result of the soil densification and stone placement, the bearing capacity is increased while static settlement is reduced, and for a seismic event, liquefaction is mitigated and dynamic settlements are reduced.

Although Vibro-replacement is suitable for a wide range of soil types, difficulties have been encountered occasionally when applying this method in urban or residential areas. Vibration and noise during the installation of stone columns are generally found to cause discomfort to neighbors in close proximity to the project site. To deal with this issue, the development of new soil densification methods with less vibration and noise has been considered a priority, especially in Japan, a densely populated country with frequent occurrence of earthquakes.

In 1998, shortly after the Hyogoken Nambu Earthquake in Kobe, Japan, the SAVE Compozer method was developed by Fudo Construction Co., Ltd. as the first Non-Vibratory Replacement method.

SAVE COMPOZER METHOD

Figure 1 shows the SAVE Compozer rig operating at an urban site in Japan. The rig is equipped with a new type of forced driving / lifting mechanism. Figure 2 shows the operational sequence. The SAVE Compozer does not require vibration for either initial penetration or column construction. Both operations are completed using a combination of rotational force and downward crowd pressure. By using the SAVE Compozer, the same degree of densification can be achieved as would be expected with conventional Vibro-replacement. Development of the SAVE Compozer has allowed for dependable subsurface soil densification in urban and residential areas. Since its inception, the SAVE Compozer has been applied widely in Japan and has recently been used on two projects in the U.S.

FIG. 1. SAVE Compozer Rig

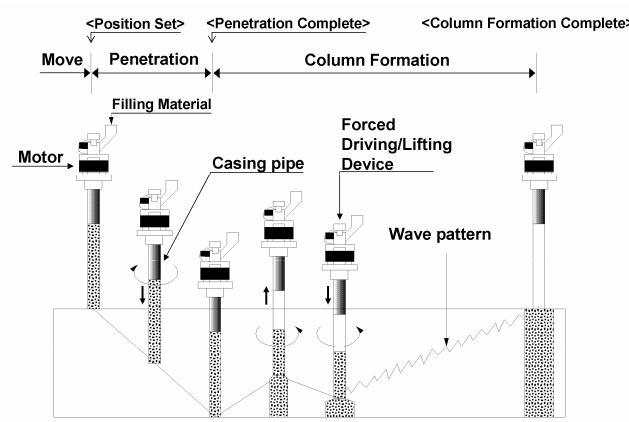

FIG. 2. Densification Sequence

SAVE Compozer has many advantages including::

・*No negative impact to surrounding environment.*
No vibration and low noise during operation of the SAVE Compozer allows stone column construction in urban and residential environments. Figure 3 shows vibration and noise as a function of distance from the equipment for

both the SAVE Compozer and conventional Vibro-replacement.

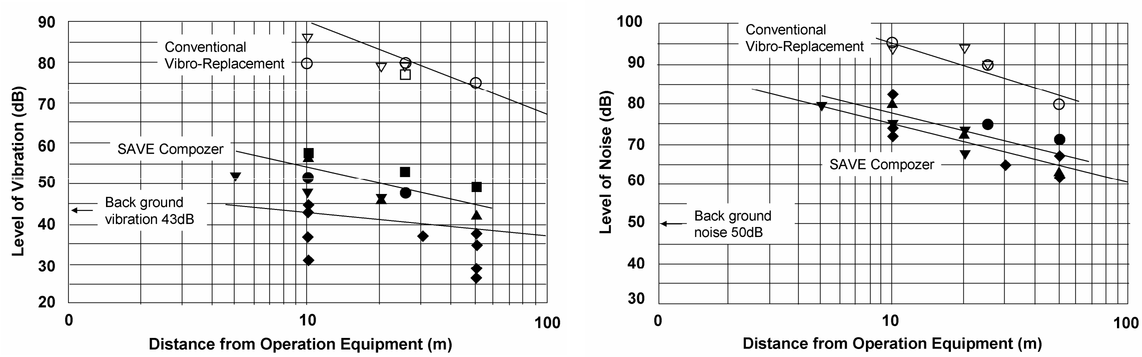

FIG. 3. Decrease over Distance of Noise and Vibration

・*Wide range of filling materials are usable.*

Figure 4 shows the applicable grain size range of suitable backfill materials. The SAVE Compozer can be used to install traditional crushed stone, sand or recycled materials, another added environmental advantage.

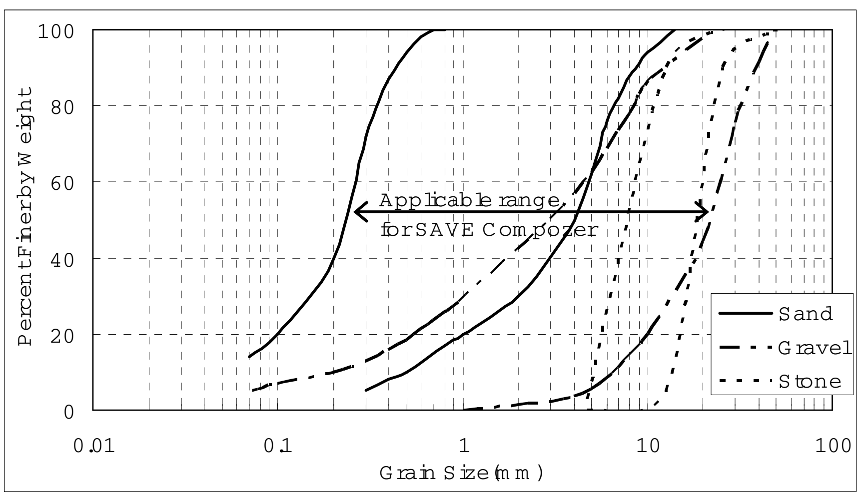

FIG. 4. Applicable Range of Materials

・*Same densification as Vibro-replacement.*

There is no difference in densification effect between vibratory and non-vibratory methods.

・*Excellent reputation in Japan.*

During various earthquakes, the ground improved by the SAVE Compozer has performed very well.

SOUTHERN CALIFORNIA INDUSTRIAL SITE

On this project, ground improvement using stone columns was specified to mitigate liquefaction, reduce static and seismic settlement and increase bearing capacity for a multi-storey parking structure. The stone column layout is shown in Figure 5. The ground improvement adjacent to the existing building located on the east side of the project site was required to be vibration-free. The SAVE Compozer method was chosen to improve the soils within 40-feet of this existing structure. The method was also used adjacent to utility lines located in the public street, while the conventional Vibratory Replacement method was used for the remainder of the site.

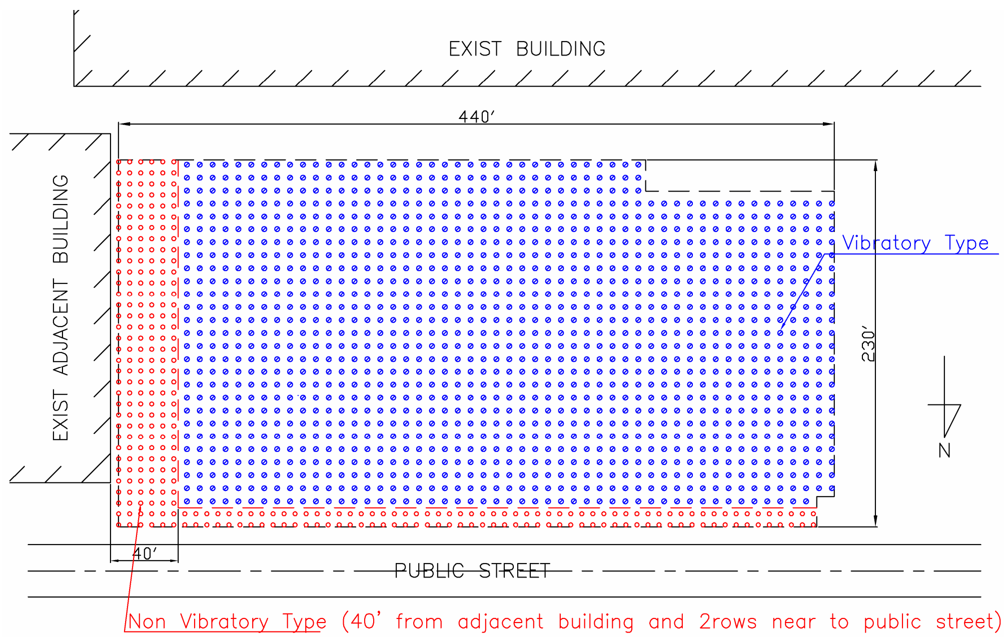

FIG. 5. Drawing of Southern California Industrial Site

Soil Condition and Performance Criteria

The pre-improvement soils investigation consisted of thirteen Standard Penetration Tests (SPT) and sixteen Cone Penetration Tests (CPT). The soils at the site can be characterized as follows:

- Undocumented fill with a thickness varying between 5-feet and 7-feet. The fill consists of sandy silt to silty sand and contains wood and construction debris.
- Predominantly loose to medium dense sand zone with silt layers extended from below the undocumented fill to a variable depth averaging about 33-feet below existing ground surface.
- Interbedded layers of predominantly silts and clays or silty sand layers existed below an approximate depth of 41 feet from the existing ground surface.
- Ground water was encountered at a depth of 8 and 10 feet below the existing ground surface.

The liquefaction analysis was performed using the procedure of Youd and Idriss (1996 NCEER and 1998 NCEER/NSF workshops) using the site design earthquake of Mw 7.5 and PGA of 0.3g. The seismic induced settlement calculations were performed using the procedures of Tokimatsu and Seed (1984) and static settlement calculation was performed using the Schmertmann (1970) procedure. The untreated seismic settlement was calculated to be about 5-inches, and the static settlement at the foundations was calculated to be 4-inches.

The performance criteria for the contractor-designed ground improvement program required that the post-improvement total static and dynamic settlements be limited to 1-inch in each case. In addition the post-treatment clean sand equivalent $(q_{c1N})_{cs}$ tip resistance had to be greater than 100 at a depth of 7-feet below ground surface increasing to 135 at a depth of 41-feet below ground surface.

Construction

Figure 6 shows the SAVE Compozer at work adjacent to the existing building. Although the center-line of the nearest SAVE location was only 10-feet from the wall, the installation of columns was successfully performed without producing any cracks to the wall or other discernible damage to the structure. In this project, recycled concrete materials were used for the filling materials due to economic consideration.

FIG. 6. Adjacent Installation

Result of Post-CPT Tests

A total of seventeen post-improvement verification CPT's were performed. Figure 7 shows the results at the areas improved using the SAVE Compozer. Adjacent pre-improvement test results are also presented. The tip resistance (q_c), sleeve friction (f_s), soil behavior type index (Ic), and normalized tip resistance $(q_{c1N})_{cs}$, respectively, versus depth from ground surface are shown. A comparison between pre-improvement and post-improvement results can be summarized as follows.

- $(q_{c1N})_{cs}$ increased in most of the target treatment zone.
- The increase in f_s is significant. The state of stress (K_0) has been changed as a result of the ground improvement.
- There are some spots that q_c after the densification was smaller than one at pre-densification. The reason of this reduction in q_c is that the soil contained much fines and this made Ic larger than 2.6. Such a high fines contents layer is non-liquefiable layer.
- Seismic settlements were calculated as 0.2-inches at the SAVE Compozer area and 0.9- inches at the Vibo-replacement area.

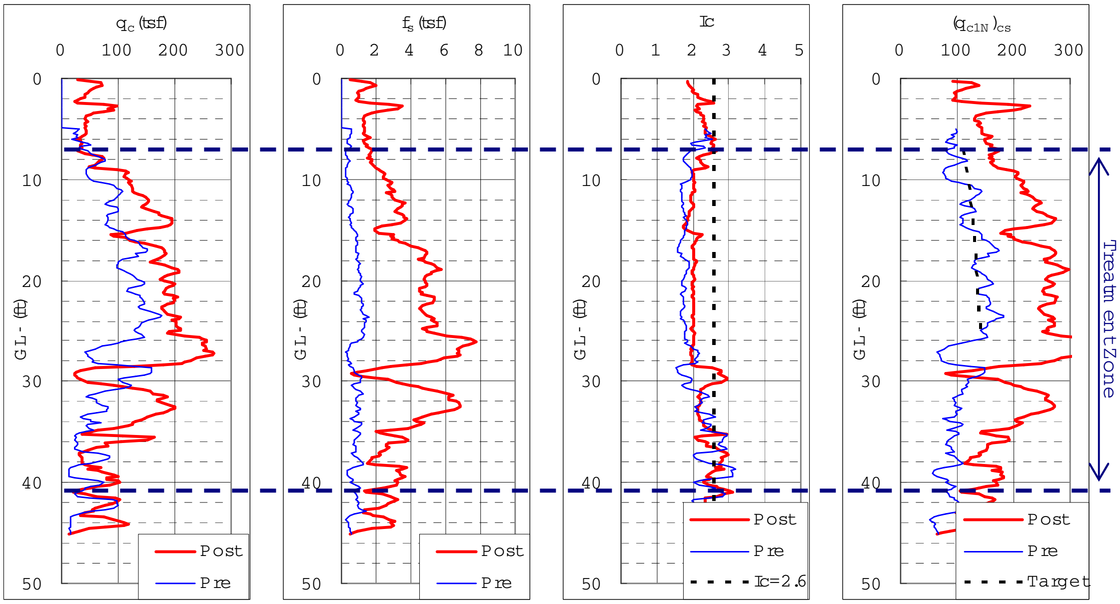

FIG. 7. Pre & Post CPT Result for SAVE Compoze (From GL-7 to GL-41feet)

All post-improvement CPT results, both in the SAVE Compozer and the Vibro-replacement treated areas, satisfied the project criteria. This demonstrates that the SAVE Compozer can achieve improvement results similar to Vibro-replacement results, as has previously been shown with similar comparisons studies conducted in Japan.

Figure 8 shows a comparison of normalized pre- and post-tip resistance with clean sand equivalent $(q_{c1N})_{cs}$ between vibratory and non-vibratory installation methods. To compare the densification data in the same condition, data from similar depths and where the soil behavior type index (Ic) was lower than 2.0 was used. From Figure 8, it can be seen that both the non-vibratory and the vibratory method successfully densified soils that without improvement would not meet the project criteria and there was virtually no difference in the effectiveness of either method.

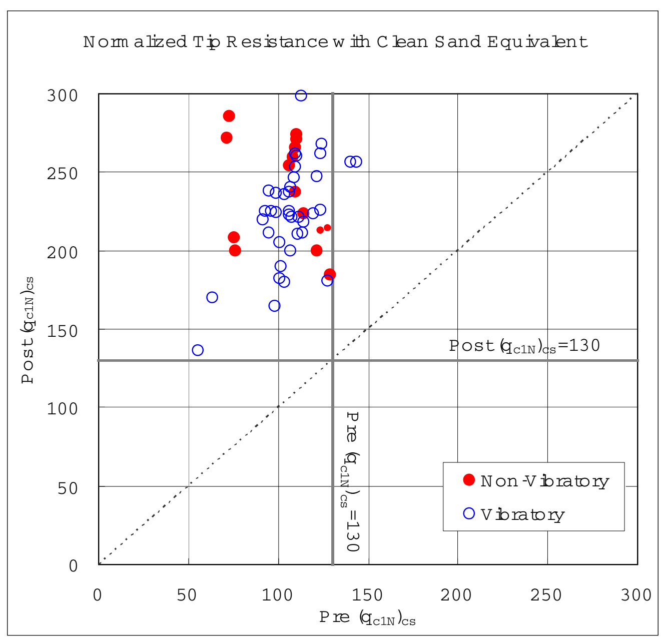

FIG. 8. Comparison of Densification Effect

NORTHERN CALIFORNIA COMMERCIAL SITE

On this project, soil densification by stone columns was planned to mitigate liquefaction and lateral spreading in hydraulically placed fills. The improvement area consisted of a strip of land 2,800-feet long by 40-feet wide alongside a lagoon with a residential neighborhood on the opposite side of the lagoon. A cross section of the site is shown in Figure 9. The project was contractor designed and although the actual method of installation was not specified, the owner was concerned about the impact vibrations might have on the surrounding residences. When the contractor proposed the SAVE-Compozer non-vibratory installation method the owner chose this method over the more traditional vibratory method.

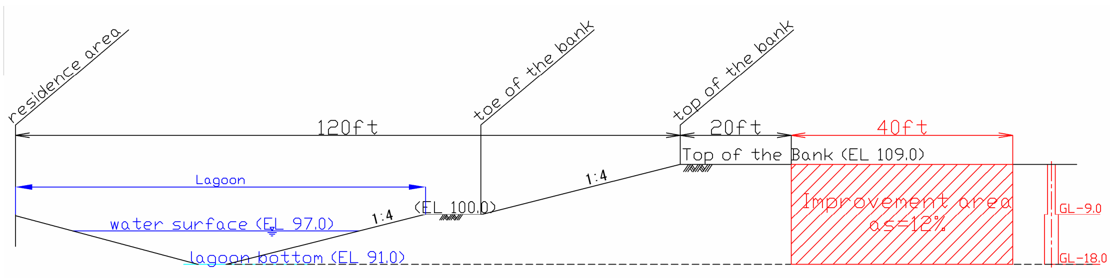

FIG. 9. Cross Section of Northern California Commercial Site

Soil Condition and Performance Criteria

Based on the results of pre-improvement soil investigation tests of the site (two Standard Penetration Tests and twenty-eight Cone Penetration Tests), the subsurface materials were characterized as follows:

- The treatment zone was comprised primarily of fine sands and silty sands, with occasionally sandy silts. These sands were generally fine grained and uniformly graded and were commonly interspersed with layers of soft, plastic clays and some silts.
- The ground water level was the same as the lagoon water level and was encountered at a depth of between 10 and 12 feet below the existing ground surface.

The ground improvement portion of this project was contactor design-build. The performance-based specification required that the soils in the improvement zone must obtain a minimum normalized cone penetration tip resistance $(q_{c1N})_{cs}$ of 130. The column diameter and spacing was selected by the contractor based on the results of the pre-improvement CPT program.

Vibration Monitoring

In order to confirm that the SAVE-Compozer method did not negatively impact he neighborhood, the owner carried out continuous vibration monitoring at the residences while the installation work was in progress. The location of the monitoring points and the proximity of the construction activities at the time the monitoring was performed are shown in Figure 10. The owner had established two monitoring points and the minimum distance between the production operation and monitoring point was 140-feet.

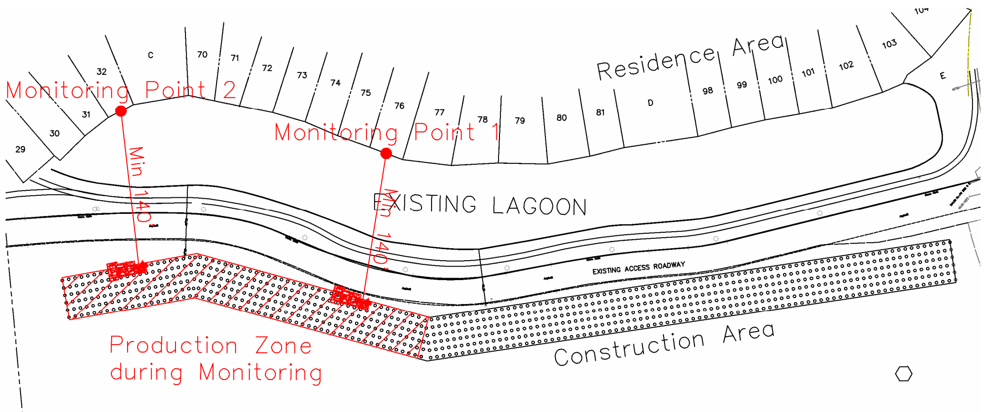

FIG. 10. Vibration Monitoring Point

Figure 11 shows the Peak Particle Velocity (vertical) for the SAVE rig at this project, the historical data for the SAVE rig in Japan, and data for the vibratory method, all plotted versus distance from the source The straight line indicates the average vibration level by the SAVE Compozer vibrations based on studies performed in Japan. From this graph, the monitoring results of vibration at this project were lower than the average vibration level caused by the SAVE Compozer work in Japan.

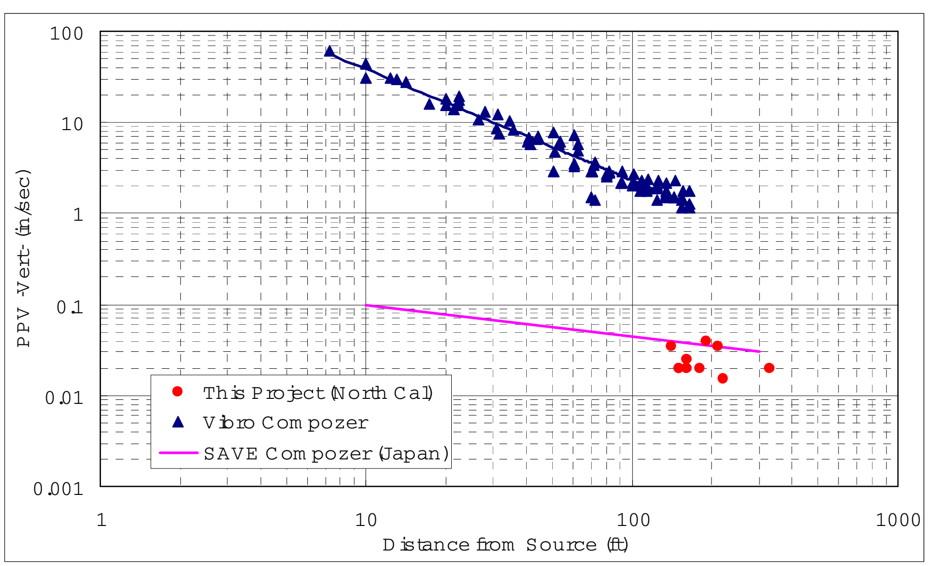

FIG. 11. Vibration vs. Distance from Source

Result of Post CPT Tests

A total of fifty-five post-improvement CPT's were performed on the soils improved with the SAVE Compozer method. Figure 12 shows the pre- and post-improvement CPT results for the site including; tip resistance (q_c), sleeve friction (f_s), soil behavior type index (Ic) and normalized tip resistance with clean sand evaluation $(q_{c1N})_{cs}$, all versus depth from the ground surface (GL).

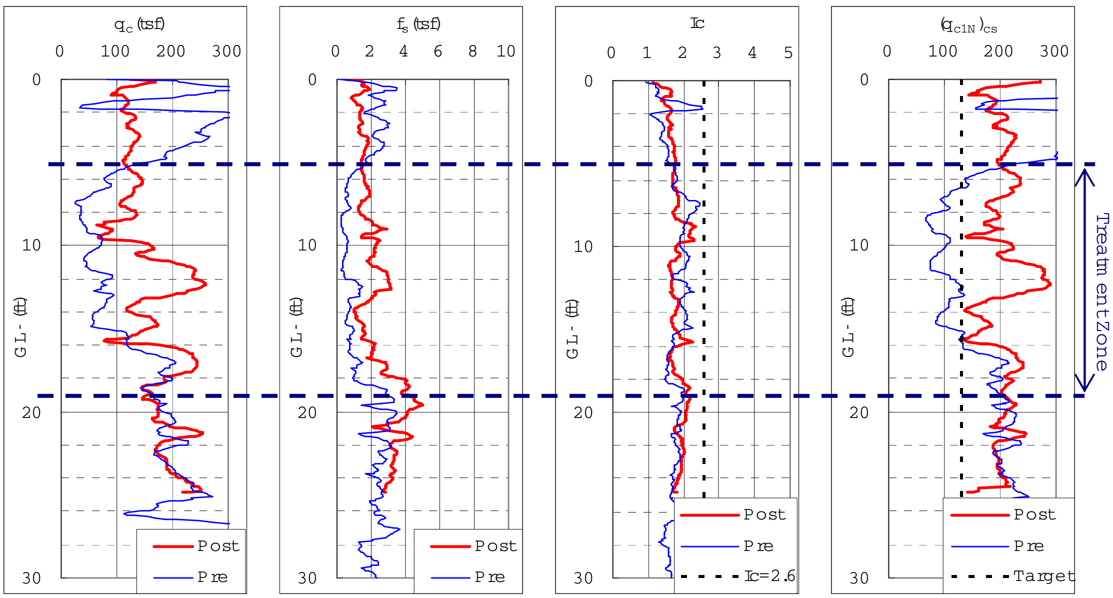

FIG. 12. Pre & Post CPT Results (Treatment Zone GL-5 to GL-19feet)

A comparison of the pre- and post-improvement test results can be summarized as follows.

- $(q_{c1N})_{cs}$ increased in most of the target treatment zone.
- The increase in f_s was smaller than at the Southern California site.
- The upper 5-feet (GL to GL-5feet) was not intended to be improved with the SAVE method. The results indicate a lower q_c than in the pre-improvement condition due to disturbance from SAVE production.

The subsurface soils were successfully densified to meet the project performance criteria except for a very small area where the soils contained a high percentage of fines and were considered unsuitable for improvement using the stone column method. The successful densification of the soils at this site confirms the SAVE Compozer's ability to densify soils similar to the Vibro-replacement method.

CONCLUSIONS

In Japan, demand for the SAVE Compozer is increasing due to increased building construction in urban areas. Since its introduction in 1998, the SAVE Compozer has been used on more than 500 projects in Japan with a total installed linear footage in excess of 190,000 feet.

This paper presents information on the first two applications of the SAVE Compozer in the U.S. The test results presented here demonstrate the SAVE Compozer can achieve densification comparable to that which can be achieved using vibratory methods, but without the negative impacts of noise and vibration. These results and conclusions are similar to experiences gained from use of the SAVE Compozer method in Japan over the past ten years.

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