Table 6. Effective Improved Depth of GI Technologies in Selection System (Based on Mitchell 2008; Chu et al. 2009)

Tech ID	Effective Depth, Unit: ft (m)	Depth to Liquefiable Soil Profile Bottom, Unit: ft (m)				
		< 10 (3)	10 - 20 (3 - 6)	20 - 40 (6 - 12)	40 - 60 (12 - 25)	> 60 (25)
1	33 - 50 (10 -16)	M	H	H	H	H
2	110 (30 - 35)	L	L	M	M	M
3	Unlimited	M	M to H	M to H	M to H	M to H
4	Unlimited	L	M to H	M to H	M to H	M to H
5	20 - 30 (6 - 9)	H	M	L	NA	NA
6	125 (20 - 65)	L	M to H	M to H	M to H	M to H
7	10 - 12 (3 - 4)	M to H	L	NA	NA	NA
8	Unlimited	L to H	M to H	M to H	M to H	M to H
9	7 - 10 (1.5 - 2.5)	H	L	NA	NA	NA
10	10 (4)	H	L	NA	NA	NA
11	25 - 30 (8 - 10)	L	M to H	H	H	H
12	80 - 100 (25 - 35)	L	H	H	H	H

Depth to Ground Water Table

Fully or partially loose saturated soils in shallow depth (less than 12 to 15 m or 40 to 50 ft) are always an important indication of liquefaction in a seismic region. Also, a high ground water table can be critically influence the improvement effectiveness of GI technologies. The records on depth of the ground water table in case histories are insufficient to conclude a general conclusion on the influence of the water table on technologies selection. Based on well-accepted rules found in the literature (e.g. JGS 1998; Towhata 2006; Mitchell 2013), the suitability evaluation of GI technologies subjected to various depths of ground water table is presented in Table 7.

Table 7. Suitability of Evaluation of GI technologies Subjected to Various Depths of Ground Water Table

Depth to Depth of Ground Water Table, Unit: ft (m)									
Tech ID	< 5 (2)	5-10 (2-3)	10-20 (3-6)	20-40 (6-12)	Tech ID	< 5 (2)	5-10 (2-3)	10-20 (3-6)	20-40 (6-12)
1	T	T	T	T	7	F	F	T	T
2	T	T	T	T	8	T	T	T	T
3	T	T	T	T	9	F	F	T	T
4	T	T	T	T	10	F	F	T	T
5	F	F	T	T	11	T	T	T	T
6	T	T	T	T	12	F	F	F	T

DISCUSSION

In this section, an actual case history involving liquefaction mitigation work using GI methods are provided to illustrate the usefulness of the proposed selection system. The illustrated case example reported the implementation of compaction grouting at a site susceptible to liquefaction damage and various project constraints. As reported by Wijewickreme and Atukorala (2005), the ground improvement was implemented to improve an existing foundation on a liquefied natural gas plant in Delta, British Columbia, Canada. The foundation was a shallow reinforced concrete raft foundation that is about 6 m to 8 m in plan area and 0.75 m in thickness. Ground improvement was applied to densify the foundation soil and to minimize the liquefaction-induced settlement in soils below the foundation.

Field investigation results indicated the site was underlain by 1 m of granular fill over 6 m of silty sand over more than 20 m of river sand. Under the river sand, a thick layer of marine silt extended to a depth of about 75 m. The ground water table was 1 – 2 m below the ground surface. Both cone penetration test (CPT) and standard penetration test (SPT) results indicated that there was a high risk of liquefaction of soils underlying the existing foundation to a depth of about 22 m. A remedial plan was proposed by the engineers to improve the liquefiable soil within a footprint of about 12 m by 12 m and 24 m in depth below the ground surface. However, there were several critical project constraints to consider when selecting the proper remedial technology. These potential constrains included: (1) 2 m of headroom clearance available for construction; (2) potential damage to the existing vibration and settlement-sensitive utilities near the construction site; and (3) accelerated construction schedule. Engineers eventually decided to use compaction grouting as the remedial countermeasure. In addition, the ground surface and adjacent utilities were carefully monitored to prevent the damage to the existing utilities.

Based on the available information, the selection result of this proposed system is shown in Figure 2. As can be seen, only the method of chemical grouting/injection systems is recommended. In the system, the selection of adjacent existing utilities (Figure 2) that are sensitive to ground movement and disturbance is the primary reason of removing compaction grouting and other technology candidates from the list. However, as mentioned in the case history, engineers monitored the utilities during the implementation process. Therefore, compaction grouting with careful monitoring work was implemented in this case history.

Within the context of this study, only the important technical related issues are discussed and involved in the proposed selection system. It is imperative that the responsible engineer understand the potential accuracy limitation of the program results, independently cross check the results, and examine the reasonableness of the results with engineering knowledge, experience and all other non-technical matters, as listed in Table 2. In addition, it is well known that the combination of more than one method may be more effective than the adoption of single method. In general, not only the technical issues, which are covered in the system, but also the non-technical issues need to be considered in making decisions on GI technologies.

Figure 2. Selection Result of the Proposed System for the Analyzed Case History


THIS MODULE IS ONLY OFFERED AS A SELECTION GUIDE AND SHOULD NOT BE USED FOR DESIGN.

Your Selections

The selections you made on the previous page are listed below:

Site characteristics:	Constrained, developed sites, urban areas
Primary failure type to protect against:	Vertical settlement
Project constraints:	Existing utilities
Depth to ground water table:	5 to 10 ft
Liquefiable soil conditions:	Liquefiable soils and stable soils are interlayered
Treated soil type:	S-
Peat layer:	No sufficiently thick peat layer present
Shear strength of unstable soils less than 500 psf:	Shear strength 500 psf or greater
Subsurface obstructions:	No surface obstructions
Depth of treatment/remediation zone:	40 to 60 ft
Size of area to be improved:	Less than 10 ft
Improved foundation type:	Shallow foundations
Project/structure type:	Not applicable
Environmental regulations:	No environmental regulatory issues

Return to your selections

Results

The results of your selections are provided in the following table.

Candidate technology	Degree of Establishment	Rapid Renewal	Minimal Disruption	Long Lived Facilities
Chemical Grouting/Injection Systems	3	3	4	4

CONCLUSIONS

A proper selection of GI technologies based on site and project-specific characteristics is the first, and critical, step to achieve an adequate, economical and effective liquefaction mitigation design. In this study, a readily accessible GI technology selection system is proposed. Based on a comprehensive review of case histories of liquefaction mitigation using GI technologies, the screening criteria or reasoning of a technology elimination process in the system is developed based on a suitability evaluation of GI technology subjected to various conditions. This study discusses the influence of selected factors on the technology selection process, primarily from technical aspect. However, several other case-specific issues such as structure tolerable deformation, specified performance criteria, and a combination of improved technologies which are not covered in the system. The case history indicates the usefulness, and also shows the limitation of the proposed system. In summary, the proposed system can assist engineers in identifying the important factors and properly evaluating their influences on the selection of GI technologies for liquefaction mitigation in a faster and more efficient way. The proposed interactive system, based on previous successful experience, is designated to be easily updated to incorporate the new knowledge and findings for further applications.

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Investigation about 2011 Tohoku Earthquake Characteristics and Seawalls response induced by Tsunami

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ABSTRACT: At 14:46 (Japan Time) March 11th 2011, a massive scale earthquake of magnitude 9.0 occurred on the pacific coast along from Sanriku to Ibaraki coast. It was the most powerful known earthquake hitting Japan, and one of the five most powerful earthquakes in the world since modern record-keeping began in 1900. The earthquake triggered extremely destructive tsunami waves of up to 38 meters (124 ft) that struck Japan. In this study, author investigated the characteristics of Tohoku earthquake and tsunami based on the official information. The detailed earthquake response analysis was based on three sets of seismic strong motion data from K-Net by applying software *Viewave*. Response history, response spectrum and Fourier spectrum were derived for in-depth comparison. At last, the investigation of seawalls was conducted to judge seawalls' effect in defending tsunami. Evidence showed seawalls are ineffective when facing the extreme event and it is necessary to rethink the design criteria.

INTRODUCTION

A major earthquake with magnitude Mw 9.0 occurred in Japan on 11 March, 2011 at 02:46:23PM local time (05:46 UTC), followed by a devastating tsunami. At a recovery cost estimated to exceed $300billion, the Honshu Mw=9 earthquake is the most costly earthquake ever occurred. The death toll reported on 2th April exceeded 12,157 (may exceed 30,000) largely due to the tsunami whose amplitude overwhelmed coastal defenses (which are concluded by Roger (2011)). It is estimated that about 210,000 houses were damaged. The

Tohoku earthquake is rated 4th among the largest earthquake in the world since 1900 and one of 5 earthquakes in the world that have exceeded Mw=8.4 since 2004. The subsequent monster tsunami is reported to have the sea wave with height almost reached 40m, which is remarkable in this earthquake that the majority of collapsed or damaged buildings and houses' damage were resulted from the tsunami rather than earthquake singly.

CHARACTERISTICS OF TOHOKU EARTHQUAKE

Main earthquake information

The epicenter of the earthquake is located about 130 km east of Sendai off the Pacific coast of Honshu and the earthquake magnitude is reported Mw 9.0. The location, depth, and focal mechanism of the March 11 earthquake are consistent with the event having occurred on the subduction zone plate boundary. The mega-thrust earthquake originated at a depth of 32 km near the subduction zone plate boundary between Pacific and North American plates, which generated a devastating tsunami. The convergence of stated two plates causes the offshore sea level uplift, which creates the tsunami. The detail has been reported by USGS (2011).

Analysis of strong-motion data

The analysis of strong-motion data was based on accelerograms recorded during the Tohoku earthquake. National Research Institute for Earth Science and Disaster Prevention (NIED) of Japan established the strong-motion network of K-net after the Hyogo-ken Nanbu earthquake of 1995. NIED has also deployed the network called KiK-net with acceleration sensors installed on the firm bedrock and on the ground surface.

Kyoshin Net (K-NET) is a system which publishes strong-motion data on the Internet, data which are obtained from 1,000 observatories deployed all over Japan. The average station-to-station distance is about 25km. Each station has a digital strong-motion seismograph owns a wide detecting frequency-band and wide dynamic measure range, which can record a maximum measurable acceleration of 2000 Gals. According to National Information Centre for Earthquakes and Disasters introduction, each seismograph has the capacity of 3-axis acceleration detecting, including east-west direction, north-south direction and up-down direction.

The data set from every observatory station is available on the Internet. In this article, software named *ViewWave* is applied. *ViewWave* is created by Toshihide Kashima, acting as a simple viewer for strong motion acceleration records obtained from K-net. *ViewWave* reads strong motion data files and shows acceleration waveforms, Velocity and displacement waveforms, Fourier spectra, and response spectra can be computed and displayed.

Earthquake spectrum analysis from selected strong motion data files

Table 1. Details of Three Observatory Stations

Station	Code/ID	Network	Distance(km)		Horiz Apk(g)
			Epic.	Fault	Ground
Tsukidate - MYG004	MYG004	KNET	125.9	75.1	2.755
IMAICHI	TCG009	KNET	293.8	125.5	1.210
HIRATSUKA-ST6	KNG206	KNET	446.5	220.1	0.375

By applying *ViewWave* and considering different distance from fault, three sets of strong motion data from different K-net observatory stations were picked up here for analysis. They are Tsuidate-MYG004 station, IMAICHI station and HIRATSUKA-ST6 station, respectively. Table 1 shows the details of the stations cited from Strong Ground Motion (2011). Three stations are located along an approximate straight-line with the epicenter. According to different distance from the fault, investigation about different responses and influences to the structures were conducted.

Response analysis according to data of MYG004 station

MYG004 K-NET station records the largest peak ground acceleration among K-NET and KiK-net sites, reaching 2933 gals (3 components vector summation). By applying *ViewWave,* the accelerogram, velocity history of N-S component, E-W component and U-D component are shown in Figure 1,2 below, respectively.

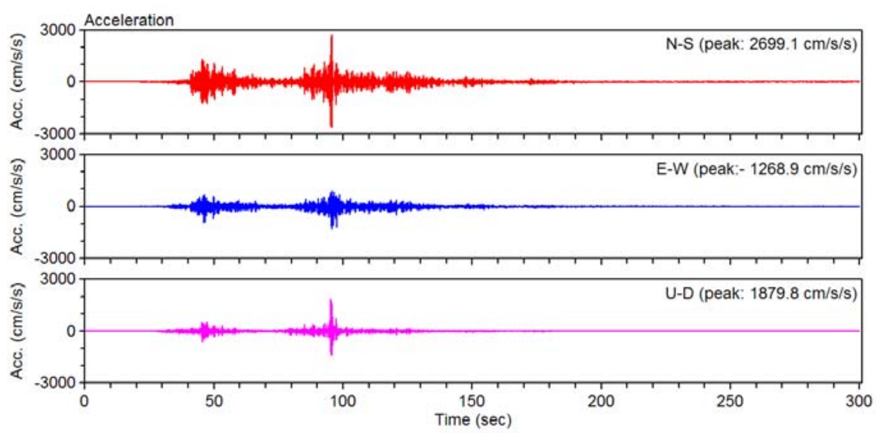

Fig. 1. Accelerogram at MYG004 station

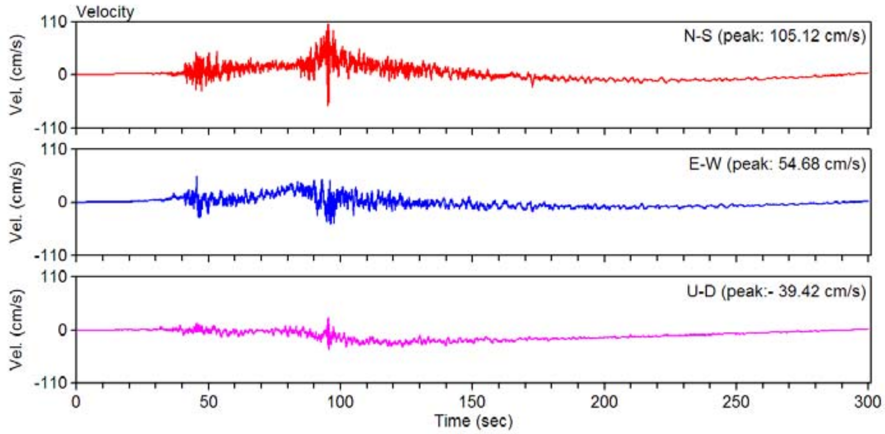

Fig. 2. Velocity time history at MYG004 station

As mentioned, the software use trapezoid parabolic rule to integrate acceleration to derive velocity. As described above, two remarkable phases of ground motion can be perceived, while the second phase is more predominant than the first one. And the N-S component response is stronger than the other two components, which suggest that slip direction is better to confirm NS than EW. The PGA reaches 2700 Gal and PGV reaches 106 cm/s in the NS component, which indicates the severe magnitude of Tohoku earthquake.

To investigate the structure response of Tohoku earthquake at MYG004, velocity spectrum at 1% damping ratio and 5% damping ratio is constructed for analysis as presented in Fig. 3.

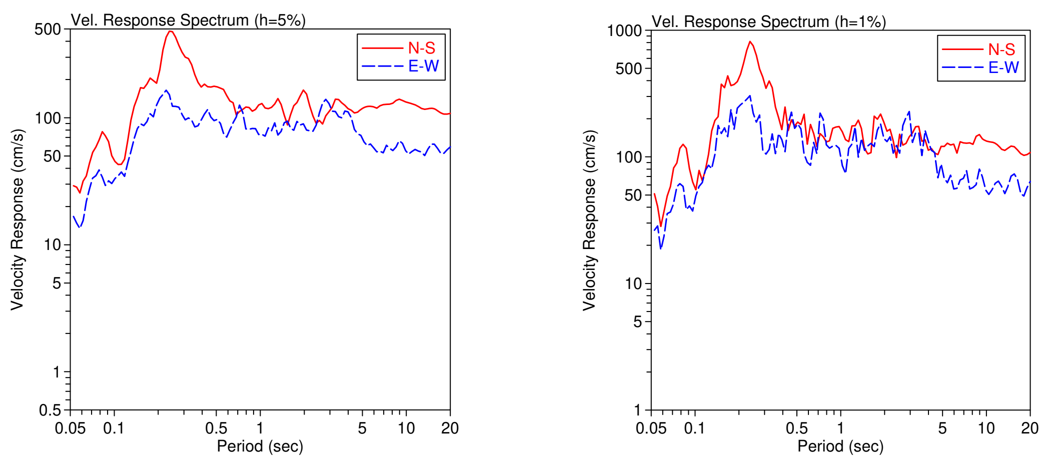

Fig. 3. Velocity response spectrum with damping ratio 1% and 5%

According to Velocity response spectrum, damping is very significant influence on the earthquake response spectrum.

When damping ratio 1%, Peaks of Velocity Response Spectrum are 814.97cm/s at T=0.238s in N-S and 304.00cm/s at T=0.238s in E-W. On the other hand, with damping ratio 5%, Peaks of Velocity Response Spectrum are 480.32cm/s at T=0.238s in N-s and 164.53cm/s at T=0.226s in E-W.

The peak velocity response reduces near a half when damping ratio increases from 1% to 5%. And the effect of damping in reducing the response is decided by the natural vibration period T of the system. It is apparent adding dampers on the structures can reduce the response without changing the natural vibration periods of the structure, while conclusion dampers are acting an important role in earthquake mitigation is verified and suggested from this analysis.

Then Pseudo-DVA spectrum with 5% damping ratio is constructed. As Fig. 4 shown, the trend of N-S component and E-W component confirms identical trend. Through reading the combined D-V-A spectrum, estimation about the different structure responses can be acquired in this Tohoku earthquake in terms of the natural period of the structure. Moreover, discussion should be focused in time spacing from T=0.1s to T=0.23s, this region is so-called acceleration sensitive regions, which means structures with natural period within this range are more sensitive to the change of acceleration.

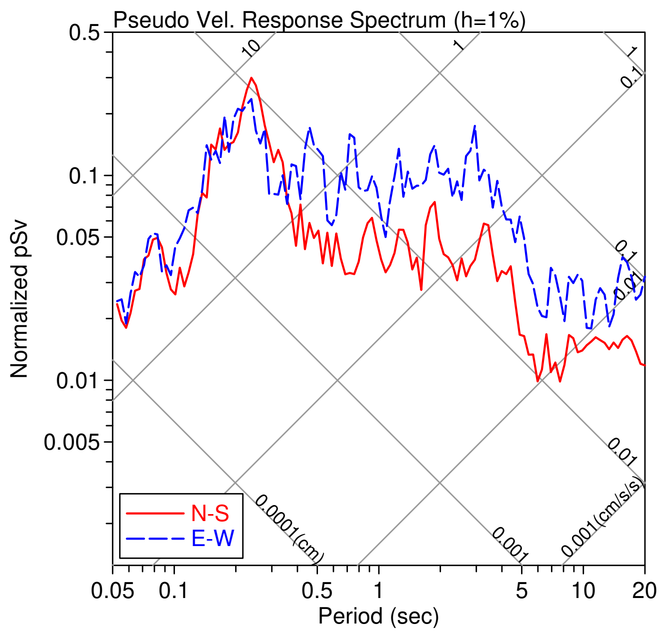

Fig. 4. DVA response spectrum

Then Fourier spectrum and Power Spectrum are constructed for analysis of frequency domain as well. The parzen window width for smoothing is set to 2Hz, and the damping ratio is 5%. As Fig. 5 shows, the bandwidth is concentrated within a small range centered in about 5Hz, which indicates the energy concentration. Fourier and Power spectrum depict that when structures have natural frequency of 5Hz, the response to earthquake is most serious and strongest.

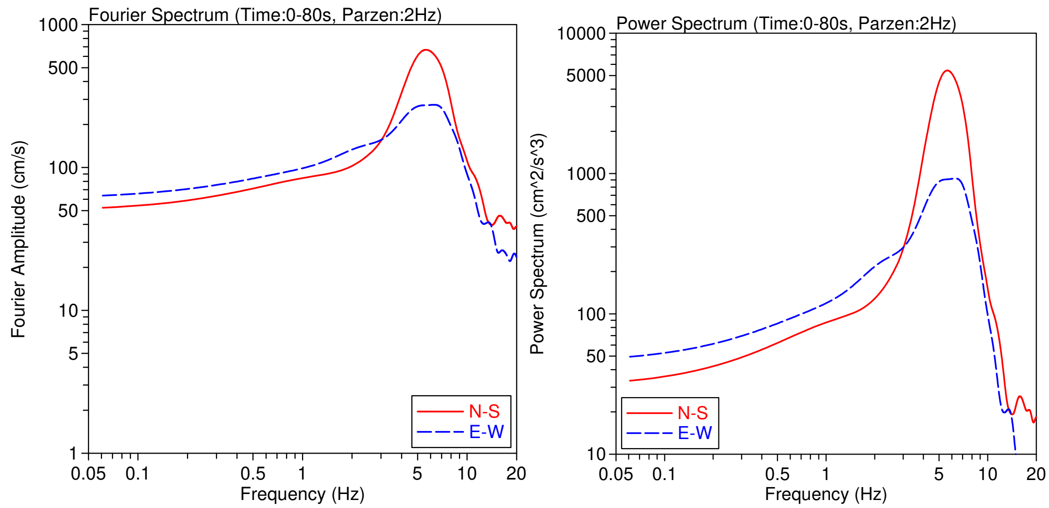

Fig. 5. Fourier spectrum and power spectrum

Response analysis according to data of TCG009 station

TCG009 station is located at 125.5km away from the fault, and records 1.21g PGA. Same method applied as MYG004 station, investigation of the accelerograms and relative spectrum dating from TCG009 station are carried out.

From the accelerograms and velocity time history in Fig. 6 and 7, the attenuation is quite obvious compared with MYG004 due to longer distance from fault. And the damping effect gives a significant reduction to the response, shown in the Fig. 8. Furthermore, it's still necessary to emphasis the damping study. In the DVA spectrum as illustrated in Fig. 9 and 10, observation of a wider and more obvious displacement sensitive region from T=0.3s to 10s is conducted. It means that the ground motion displacement have more influence on the structure response than acceleration and velocity. In terms of different components of earthquake excitation, N-S and E-W component shares much of the characteristics. The peak Fourier amplitude of E-W component is even larger than counterpart of N-S component. It shows that the excitation source is quite complicated in Tohoku earthquake.

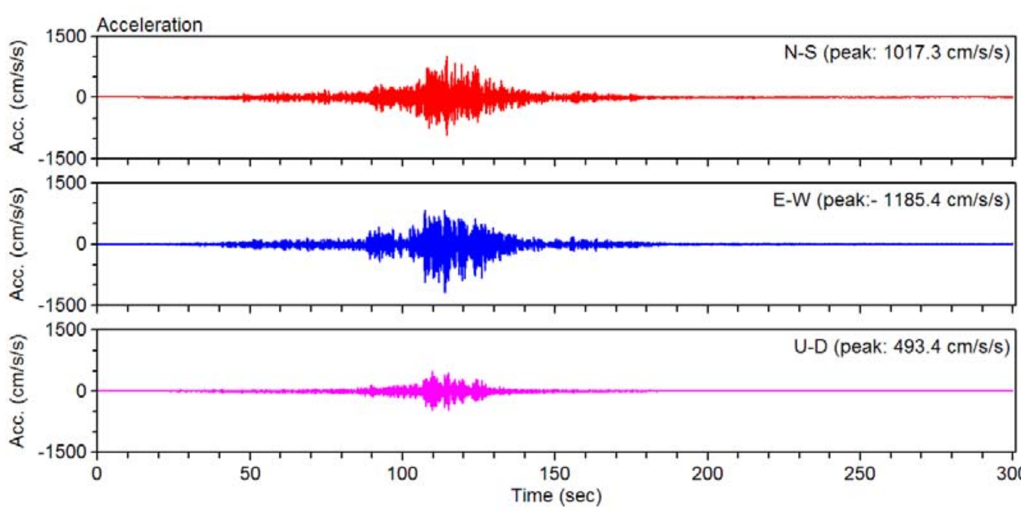

Fig.6. Accelerogram at TCG009 station