

## TECHNICAL NOTE

# APPLYING SUN-YUAN LIQUEFACTION DETECTION METHOD IN THE FEBRUARY 2011 CHRISTCHURCH ( $M_w$ 6.3) EARTHQUAKE, NEW ZEALAND

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### SUMMARY

In April 2011, 27 processed seismic acceleration records at 27 seismic stations whose epicentral distances were less than 50 km in Feb. 22 Christchurch, New Zealand earthquake ( $M_w$ 6.3), were collected from GeoNet strong motion data centre. Applying Sun-Yuan liquefaction detection method on the selected records, 9 liquefied sites and 18 non-liquefied sites were blindly identified thereof in May 2011, prior to the real liquefaction reports (papers) been published. Up to present, liquefaction detection results of 11 sites, *i.e.*, 8 liquefied sites CBGS, CCCC, CHHC, CMHS, HPSC, PRPC, REHS and SHLC and 3 non-liquefied sites PPHS, HVSC and LPCC, were confirmed by publications which were consistent with the detections. New approaches and proof (or evidence) need to be pursued to demonstrate the detected results on other sites, *i.e.*, liquefied site LINC and 15 non-liquefied sites.

### INTRODUCTION

Real-time monitoring and warning systems on site liquefaction is a new technique to mitigate and prevent liquefaction hazard [1]. Strong earthquakes are rare scenarios, hence it is uneconomic to strengthen the liquefaction resistant ability by means of foundation treatment unless they are important projects. Besides, it will be extremely expensive to avoid the liquefaction hazard using traditional treatment for wide-spreading facilities such as underground pipelines. With the development of seismic observation and monitoring techniques, real-time monitoring and warning systems are gradually adopted as new tools for liquefaction hazard mitigation. Taking the Super High-Density real-time disaster mitigation system installed by Tokyo Gas Engineering Co. Ltd. for example [2], 3,800 spectral intensity meters have been installed for accurate real-time assessment of liquefaction and the relevant hazard. Once an earthquake occurs the locations of liquefied sites can be immediately identified and corresponding emergent rescue can be speedily conducted. Meanwhile, gasoline devices and power facilities can be shut down by remote controlling system to minimize liquefaction loss.

The key for real-time site liquefaction monitoring and a warning system is to establish an inversion approach to detect liquefied sites. However, it is a complicated new problem. To establish an efficient method for detecting liquefaction and its effects on ground motions there are of many scholars' concerns [3, 4]. The present liquefaction detection method used in Japanese SUPREME system is proposed by Suzuki [5]. Two liquefaction detection methods are proposed by Kostadinov and Yamazaki [1], Miyajima, Kitaura and Nozu

[4], separately. More recently, Sun and Yuan developed a new liquefaction detection method based on frequency decreasing rates with the advantage of accurately distinguishing liquefied and diverse categories of non-liquefied sites [6, 7]. Nevertheless, the paucity of real seismic records on liquefied sites, where only about 10 records have been obtained, leads to doubt of the feasibility and reliability of the existing methods.

On Feb. 22, 2011 an earthquake of magnitude  $M_w$ 6.3 struck the Canterbury region in New Zealand's South Island. Remarkable liquefaction phenomena were reported after the 'quake, because the city is built on deep soft alluvial plains and sediments that are vulnerable to liquefaction. New Zealand is a country with many seismic observation stations properly installed, which can provide high-quality strong motion data. Therefore, it provided a good chance to test the Sun-Yuan liquefaction detection method. In this paper, 27 strong motion records within 50 km epicentral distance are obtained, and consequently, the Sun-Yuan liquefaction detection method is blindly applied on the records to identify liquefaction sites from non-liquefaction.

### SUN-YUAN LIQUEFACTION DETECTION METHOD

Following the procedures described by Sun *et al.* (2007, 2010), the liquefaction detection method is briefly introduced in this section for the readers who are not aware of the approach. By modelling a liquefiable site as a two-degree-of-freedom system (Fig. 1), the natural frequency decreasing ratio of the site (NFDRS) was proposed as a benchmark index, which was defined as follows.

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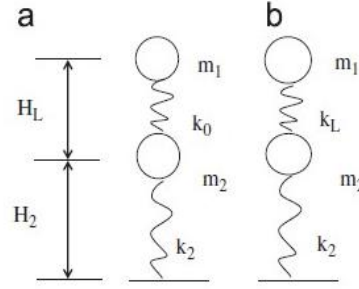


Figure. 1: The two-degree-of-freedom model for a liquefiable site (a) Before liquefaction; (b) after liquefaction.

Through theoretical calculation, the site natural frequency before liquefaction is

$$f_0^2 = \frac{(k_0 + k_2)m_1 + k_0m_2 - \sqrt{[(k_0 + k_2)m_1 + k_0m_2]^2 - 4m_1m_2k_0k_2}}{8\pi^2m_1m_2} \quad (1)$$

and the natural frequency after liquefaction is

$$f_L^2 = \frac{(k_L + k_2)m_1 + k_Lm_2 - \sqrt{[(k_L + k_2)m_1 + k_Lm_2]^2 - 4m_1m_2k_Lk_2}}{8\pi^2m_1m_2} \quad (2)$$

where

$k_0$ = average horizontal stiffness of liquefiable layer before liquefaction;

$k_L$ = average horizontal stiffness of liquefiable layer after liquefaction;

$k_2$ = average horizontal stiffness of non-liquefiable layer;

$m_1$ = mass of liquefiable layer;

$m_2$ = mass of non-liquefiable layer;

The physical essential of the liquefaction process, in the authors view, is a relative change of site natural frequencies. Thereafter, the natural frequency decreasing ratio (NFDRS) is defined as

$$NFDRS = \frac{f_0 - f_L}{f_0} \quad (3)$$

According to numerical simulation, the lower limit of NFDRS tends to be 0.5 [6, 7], indicating liquefaction occurrence when  $NFDRS > 0.5$ , otherwise there is non-liquefaction. As for seismic records, the time-frequency decreasing ratio of the surface acceleration (TFDRSA) is given by

$$TFDRSA = \frac{f_b - f_a}{f_b} \quad (4)$$

where  $f_b$  is defined as the average frequency over 30s of accelerograph before PGA by the zero-crossing method [8], while  $f_a$  is the average frequency over 30s after PGA. Note that the calculation will start from the beginning of the record or terminate at the end of the record for the data with no more than 30s duration in time histories before PGA or after PGA, separately. Besides, a site is judged as non-liquefied if the PGA is less than 0.5 m/s<sup>2</sup> [9].

On the hypothesis that TFDRSA is equal to NFDRS, the criteria for site liquefaction judgment are stated as following:

- (1). If  $PGA \geq 0.05g$  and  $TFDRSA \geq 0.5$ , the site is liquefied;
- (2). Otherwise, the site is non-liquefied.
- (3). When one of the two horizontal components satisfies liquefaction criteria (1), the site is judged as liquefied.

The zero-crossing method [8] is employed to determine the instantaneous frequency process of the surface acceleration time-history. In the author's opinion this method is easy to use for engineering sake and it can provide a unique solution independent of artificial selection. The duration of seismic records is different and is quite long in some cases, but for the identification of site liquefaction we are only concerned with the time around the peak ground acceleration (PGA), rather than the complete duration of the seismic records. In the paper, two time ranges, 30s before the PGA and 30s after the PGA, are selected as the calculation ranges. That is, the total 60s duration including the acceleration amplitudes exhibits remarkable effects on the liquefaction development. The time of PGA occurrence is considered as the boundary of the division and the cycle of PGA is included in the first range. In terms of the dynamic triaxial tests on soil liquefaction by incidence of real seismic waves [10, 11], the liquefaction usually occurs after the input PGA. When liquefaction occurs before the input PGA, the liquefied soil generally has a filter effect and reduces the input PGA to a smaller value. Therefore, no matter what the situation the peak value of the acceleration time-history on the liquefied site always appears before initial liquefaction.

The effects of liquefaction on surface ground motions can be reflected in various aspects such as horizontal and vertical acceleration histories, velocity histories, displacement histories, spectra, and spectrum intensities. Thus different methods of liquefaction identification using different parameters have been proposed in the past. Physically, in the author's opinion the most basic effect of liquefaction on the site response results from the change of the characteristics of the site itself, i.e. the change of natural frequency of the site. This change should be the source of other changes in the ground motion parameters and all other changes are only different forms of the source change. The rapid and obvious reduction of soil rigidity caused by liquefaction is a distinguishing phenomenon in earthquakes, which is far more noticeable than the usual reduction of soil rigidity from dynamic nonlinear behaviour. The decrease in frequency content of the horizontal surface motions resulting from reduction of soil rigidity in the liquefaction process is much larger than the decrease in frequency due to the non-stationary time-frequency process of seismic waves themselves. Therefore, it is reasonable to take the change of the horizontal natural frequency of the site as a fundamental benchmark for

identification of site liquefaction.

Because the frequency content of seismic acceleration on the soft soil layer may reduce to quite low values during earthquakes, e.g. less than 1Hz, the soft sites and the liquefied sites may be confused if the absolute discrepancy of frequency is taken as a threshold. Considering the initial rigidities in different soil layers before earthquakes are different, the relative discrepancy of frequency is taken as the basic judgment index in the liquefaction detection method.

#### EFFICIENCY OF SUN-YUAN METHOD FOR PREVIOUS EARTHQUAKE RECORDS

To verify the Sun-Yuan method, 56 seismic records, including 52 ground records on non-liquefaction sites and 4 ground records on liquefaction sites were obtained from 15 historic earthquakes worldwide and then tested. The records on non-liquefied sites were randomly selected from earthquakes. The sites were categorized according to site classification standards of US geological survey (Table 1). Note that 10 soft sites classified D were used. The results of liquefaction detection are presented in Table 1.

**Table 1 Results of liquefaction detection by Sun-Yuan method for previous earthquake events**

No.	Earthquake	Site Name (Site class <sup>*</sup> )	Liquefaction investigation	TFDRSA	Sun-Yuan method
1	Niigata, Japan, 16/06/1964, M=7.5	Kawagishi-cho, (-)	Y	0.74	Y
2	Friuli, Italy, 05/05/1976, M=6.5	Tolmezzo, (-)	N	-0.53	N
3	Tabas, Iran, 16/09/1978, M=7.4	Dayhook, (-)	N	0.0001	N
4		Taba, (-)	N	-0.3	N
5	Victoria, Mexico, 09/06/1980, M=6.4	Cerro Prieto, (B)	N	0.11	N
6		Chihuahua, (C)	N	-0.02	N
7	Nihonkai-Chubu, Japan, 26/05/1983, M=7.7	Hachirogata, (-)	Y	0.68	Y
8	Superstition Hills, USA, 24/11/1987, M=6.6	Brawley, (C)	N	0.14	N
9		Calipatria Fire Station, (C)	N	0.11	N
10		EL Centro Imp., (C)	N	0.14	N
11		Parachute Test Site, (B)	N	0.17	N
12		Plaster City, (C)	N	0.29	N
13		POE Road, (-)	N	0.24	N
14		Superstition Mtn., (B)	N	0.03	N
15		Westmorland Fire Station, (C)	N	0.13	N
16		Wildlife GL, (-)	Y	0.57	Y
17	Loma Prieta, USA, 18/10/1989, M=6.9	Agnews State Hospital, (C)	N	0.17	N
18		Aped2-Redwood City, (D)	N	0.19	N
19		Corralitos, (B)	N	0.02	N
20		Gilroy Array #2, (C)	N	-0.38	N
21		Gilroy Array #6, (B)	N	0.25	N
22		Halls Valley, (C)	N	0.36	N
23		Hallister-Smith & Pine, (-)	N	0.01	N
24		Richmond City Hall, (C)	N	0.35	N
25		SF Intern Airport, (-)	N	0.19	N
26		Treasure Island, (D)	N	0.28	N
27	Northridge, USA, 17/01/1994, M=6.7	Arleta-Nordhoff Fire Station, (C)	N	-0.02	N
28		LA-Baldwin Hills, (B)	N	0.30	N
29		LA-Century City, (B)	N	0.17	N
30		LA-Hollywood Storage FF, C	N	0.31	N
31		Leona Valley #6, C	N	0.38	N
32		Newhall-Fire Station, C	N	0.35	N
33		Old Ridge Route, (B)	N	0.23	N
34		Tarzana, Cedar Hill, (-)	N	0.45	N
35		Vasquez Rocks Park, (B)	N	0.34	N
36	Kobe, Japan, 16/01/1995, M=6.9	Kakogawa, (D)	N	0.23	N
37		KJMA, (B)	N	-0.09	N
38		Nishi-Akashi, (D)	N	0.20	N
39		Port island, (-)	Y	0.83	Y
40		Shin-Osaka, (D)	N	0.15	N
41		Takatazuka, (D)	N	-1.0	N
42		Takatori, (D)	N	0.31	N
43	Kocaeli, Turkey, 17/08/1999, M=7.4	Ambarli, (D)	N	0.30	N
44		Arcehk, (B)	N	0.17	N
45		Bursa Tofas, (-)	N	0.28	N

46		Duzce, C	N	0.29	N
47		Goynuik, (-)	N	0.06	N
48	Chi-Chi, Taiwan, 20/09,1999, M=7.6	Als, (B)	N	0.03	N
49		CHY002, (D)	N	0.18	N
50		CHY006, (C)	N	0.3	N
51		CHY008, (D)	N	0.2	N
52		CHY014, (C)	N	0.1	N
53		CHY024, (C)	N	0.04	N
54	Tangshan, China, 28/07/1976, M=7.8	Ground, (-)	N	0.26	N
55	Lijiang after shake, China, 05/02/1994, M=6.0	Ground, (-)	N	0.28	N
56	Longling after shake, China, 09/06/1997, M=6.2	Ground, (-)	N	0.24	N

\*Note: the site classification is referred to site class standards of USGS, and ‘-’ means unknown site class.

In an engineering point of view, the author’s think it is important for a liquefaction detection method to discriminate liquefied sites from non-liquefiable soft sites. Comparing the performance of the liquefaction detection methods [12], all the methods correctly detected non-liquefied class B sites, but they obtained diverse results for non-liquefied class C and D sites. To emphasize, the Sun-Yuan method can correctly detect non-liquefied class C and D sites while other methods cannot obtain correct detections especially for the non-liquefied class D sites.

#### INTRODUCTION OF NEW ZEALAND EARTHQUAKE AND LIQUEFACTION PHENOMENA

The 2011 Christchurch earthquake was a magnitude  $M_w$ 6.3 earthquake that struck the Canterbury region in New Zealand’s South Island at 12:51 pm on Tuesday, 22 February 2011 local time (23:51, 21 February UTC). The earthquake

was centred 2 km west of the town of Lyttelton, and 10 km south-east of the centre of Christchurch, New Zealand’s second-most populous city. The focal depth is 5 km which was quite shallow.

Geologically, Christchurch city is built on Canterbury holocene alluvial plains and sediments which are vulnerable to liquefaction [13]. Canterbury Plains are alluvial fans which cover an area of 160 km long by 50 km wide. According to field investigations conducted by the Japanese Geotechnical Society in Christchurch following the Feb. 22 ‘quake, the city had been hit by one of the largest cases of liquefaction in over 30 years of conducting liquefaction surveys. Massive sand ejecta were found in many places in Christchurch city, and liquefaction has caused parts of the city area to be abandoned. Fig. 2 illustrated examples of the liquefaction hazard.

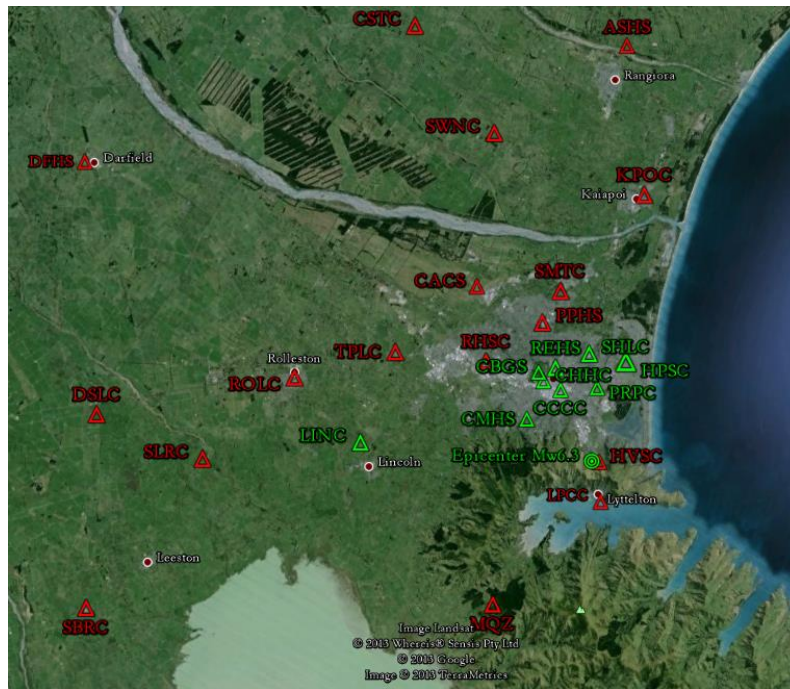


Figure 2: Examples of liquefaction in 2011  $M_w$ 6.2 New Zealand earthquake.

#### GROUND MOTION DATA

New Zealand is a country with good coverage of seismic instruments, which can provide high quality digital strong motion data. In April 2011, 27 acceleration records from the GeoNet strong motion database ([ftp.geonet.org.nz/strong/processed/Proc](http://ftp.geonet.org.nz/strong/processed/Proc)) operated by Institute of Geological and Nuclear Sciences were collected from 27 seismic stations whose epicentral distances were less than 50 km. The corresponding PGA values ranged from 0.3  $m/s^2$  to

16  $m/s^2$ . The station information was taken from GeoNet “Delta” database (<https://magma.geonet.org.nz/delta/>). Fig. 3 marks the locations of the observation arrays, where the records were collected. All ground motion records were processed with a transient band-pass filter between 0.01-0.10 Hz and 24.50-25.50 Hz using a Butterworth filter, and the instrumental data were processed at 0.02s time interval. The liquefaction detection on the New Zealand strong motion records by Sun-Yuan method will be illustrated in the following paragraphs.



**Figure 3:** Locations of the strong motion stations where the records were collected in 2011 Christchurch earthquake, New Zealand, and the red triangles represent non-liquefied sites while green triangles represent liquefied sites by Sun-Yuan method.

### LIQUEFACTION DETECTION RESULTS

The detected results by the Sun-Yuan method on the records are presented in Table 2 and Fig. 3. To emphasize, the analysis was conducted in May 2011, prior to the field investigation reports (papers) been published (so-called blind liquefaction

detection). In Fig.3, the red triangles represent liquefied sites while green triangles represent non-liquefied sites. According to the calculated TFDRSA by the Sun-Yuan method in Table 2, 9 liquefied sites (i.e., CBGS, CCCC, CHHC, CMHS, HPSC, LINC, PRPC, REHS, SHLC) and 18 non-liquefied sites are identified.

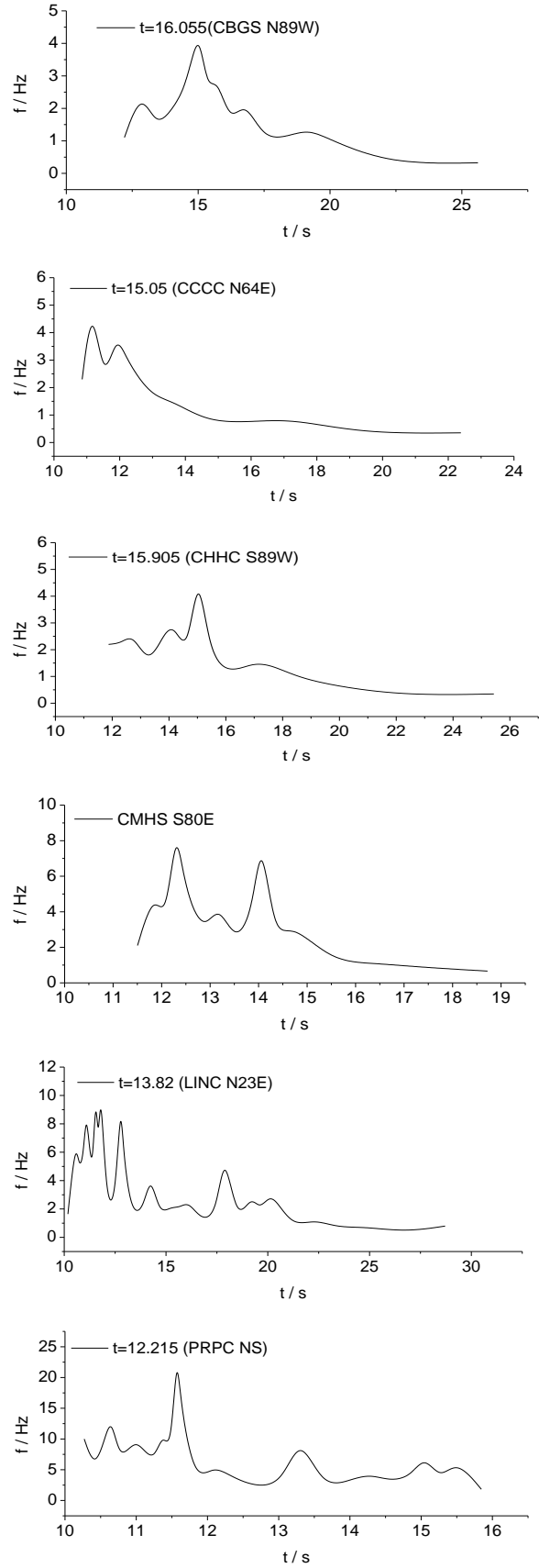
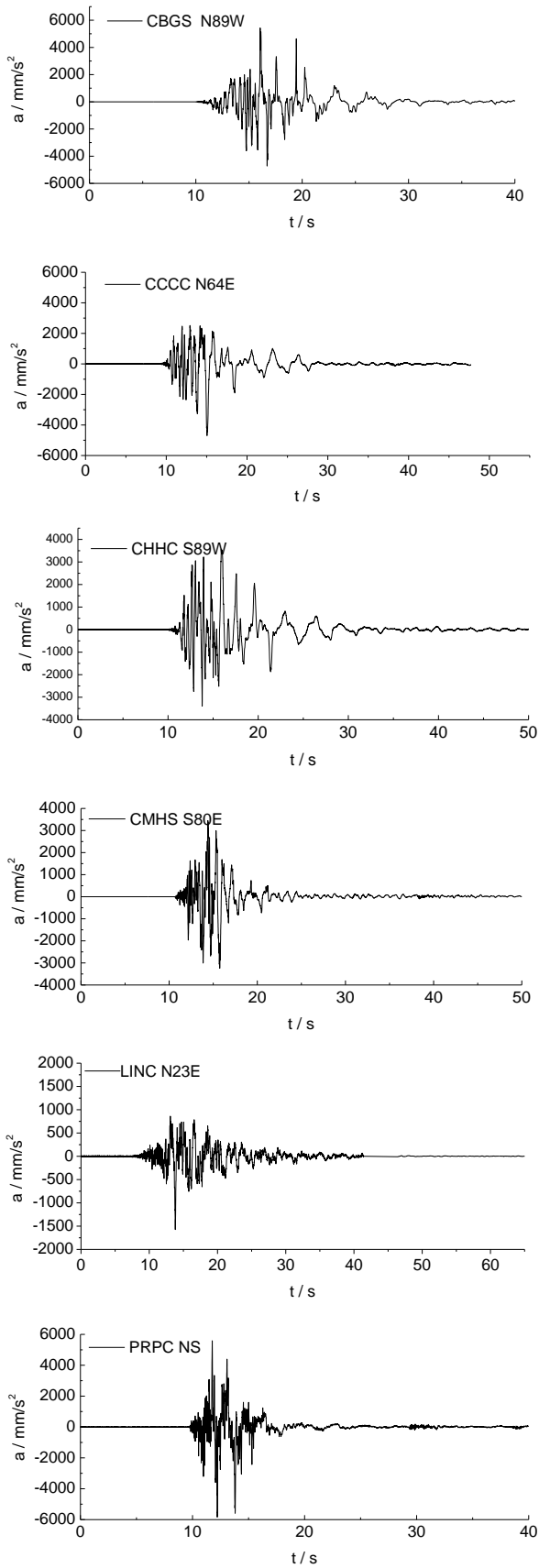
**Table 2. Blind liquefaction detection results by Sun-Yuan method on the 27 seismic records in Feb. 22 Christchurch earthquake**

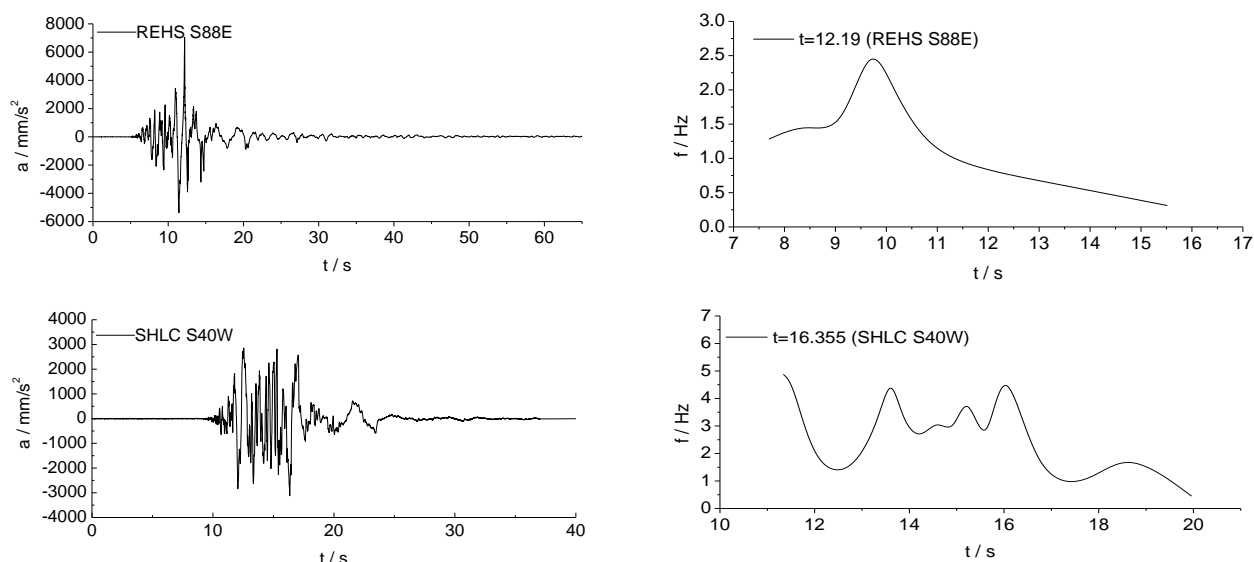
No	Station Code	Station Name	PGA (mm/s <sup>2</sup> )		TFDRSA		Detection
			$A_{H1}$	$A_{H2}$	$A_{H1}$	$A_{H2}$	
1	AMBC	Amberley HDC	293.0	326.1	0.41	0.16	N*
2	ASHS	Ashley School	911.1	752.6	0.14	-0.05	N
3	CACS	Christchurch Canterbury Aero Club	1803.6	2238.3	-0.02	0.22	N
4	CBGS	Christchurch Botanic Gardens	4433.7	5430.3	0.22	0.52	Y**
5	CCCC	Christchurch Cathedral College	4701.2	3771.2	0.44	0.75	Y
6	CHHC	Christchurch Hospital	3387.1	3577.1	0.38	0.60	Y
7	CMHS	Christchurch Cashmere High School	3449.4	3927.5	0.22	0.68	Y
8	CSTC	Cust School	762.4	807.2	0.11	0.37	N
9	DFHS	Darfield High School	482.3	643.0	-0.12	-0.14	N
10	DSLCL	Dunsandel School	453.8	669.9	-0.04	-0.21	N
11	HPSC	Hulverstone Drive Pumping Station	2116.2	2885.9	0.81	0.18	Y
12	HVSC	Heathcote Valley Primary School	16467.7	12446.4	0.05	0.42	N
13	KPOC	Kaiapoi North School	2117.4	1860.8	0.04	0.09	N
14	LINC	Lincoln Crop and Food Research	1572.5	1211.2	0.62	0.32	Y
15	LPPC	Lyttelton Port Company	8937.5	9373.8	0.05	0.07	N
16	MQZ	McQueen's Valley	1460.8	1211.2	-0.19	0.21	N
17	PPHS	Christchurch Papanui High School	2088.4	1948.9	0.44	0.01	N
18	PRPC	Pages Road Pumping Station	6566.5	5841.2	0.54	0.49	Y
19	REHS	Christchurch Resthaven	7049.8	3640.6	0.58	-1.66	Y
20	RHSC	Riccarton High School	2843.0	2450.6	0.03	0.16	N
21	ROLC	Rolleston School	1739.1	1910.1	0.17	-0.59	N
22	SBRC	Southbridge School	479.1	677.4	0.25	0.15	N
23	SHLC	Shirley Library	3410.8	3121.1	0.62	0.23	Y
24	SLRC	Selwyn Lake Road	722.3	1020.6	0.34	0.32	N
25	SMTC	Styx Mill Transfer Station	1821.4	1384.0	0.45	0.24	N
26	SWNC	Swannanoa School	1879.9	2047.7	0.07	0.25	N
27	TPLC	Templeton School	1233.2	1012.4	0.37	0.35	N

Note: N\* represents non-liquefaction ; Y\*\* represents liquefaction.

The acceleration time-histories and time-frequency curves for the detected liquefied sites by the Sun-Yuan method are presented in Fig.4. For site CBGS, the calculated maximum

TFDRSA is 0.52 from the N89W record, so the site is judged as liquefied and for site CCCC, the maximum TFDRSA is 0.75 from N64E record, so the site is also judged as liquefied.

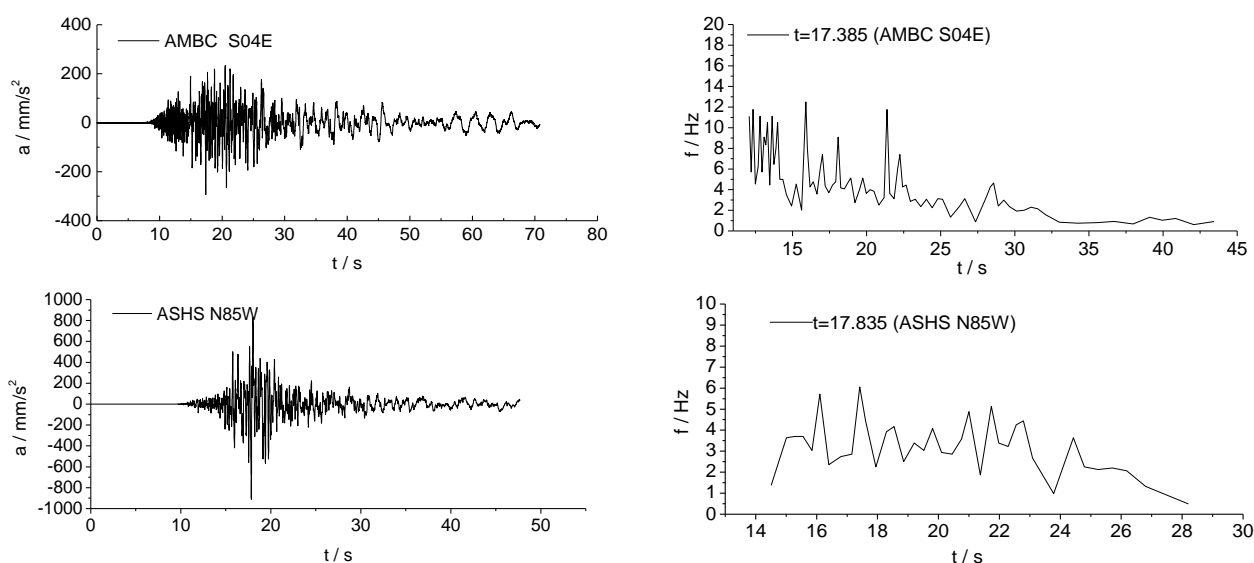




**Figure 4:** Acceleration time histories and corresponding time-frequency curves of the detected liquefied sites ('t' represents the time of PGA arrivals).

The typical acceleration time-histories and time-frequency curves for the detected non-liquefied sites by the Sun-Yuan method are presented in Fig.5, taking AMBS and ASHS for examples. For site AMBS, the calculated maximum TFDRSA

by the Sun-Yuan method is 0.41 from S04E component, while for site ASHS the maximum TFDRSA is 0.14 from N85W component. Therefore these sites were non-liquefied.



**Figure 5:** Representative acceleration time histories and corresponding time-frequency curves of the detected non-liquefied sites.

### CORRECTION OF TWO ABNORMAL DETECTED RESULTS

Two detections at site Hulverstone Drive Pumping Station HPSC and site Cust School CSTC in Table 2 seems unreasonable. For site HPSC record (Fig. 6), many high-frequency components appear in the neighbouring 14s before and after the PGA in the two horizontal acceleration records, especially for N04W component in which the acceleration instantaneous frequency after 14s reaches 22~30 Hz. Generally, high frequency components appear earlier than low frequency components in seismic waves. To compare with it, site HVSC which is close to the epicentre can represent the seismic characters of the earthquake. Fig. 7 plots

HVSC acceleration time histories and the time-frequency curves in which high frequency components appear at the middle of seismic wave cannot be distinguished. That is, high frequency components which appeared in the middle of seismic wave were not a representative character of the earthquake but an abnormal behaviour. We confirmed that high frequency noise of above 20 Hz has to be removed from the records. Note that the selected records have been processed with a transient band-pass filter between 0.01-0.10 Hz and 24.50-25.50 Hz using a Butterworth filter. By filtering the high frequency components larger than 20 Hz, site HPSC is finally judged as liquefied site with TFDRSA of 0.81 in N04W component (Fig. 8).

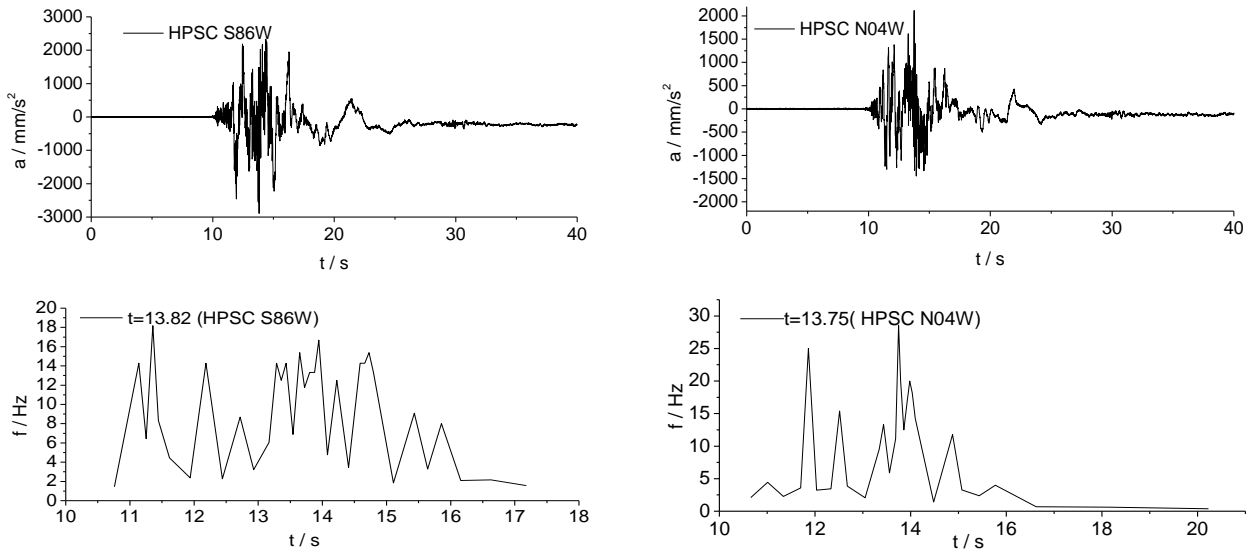


Figure 6: Acceleration time histories and time-frequency curves for the records of site HPSC.

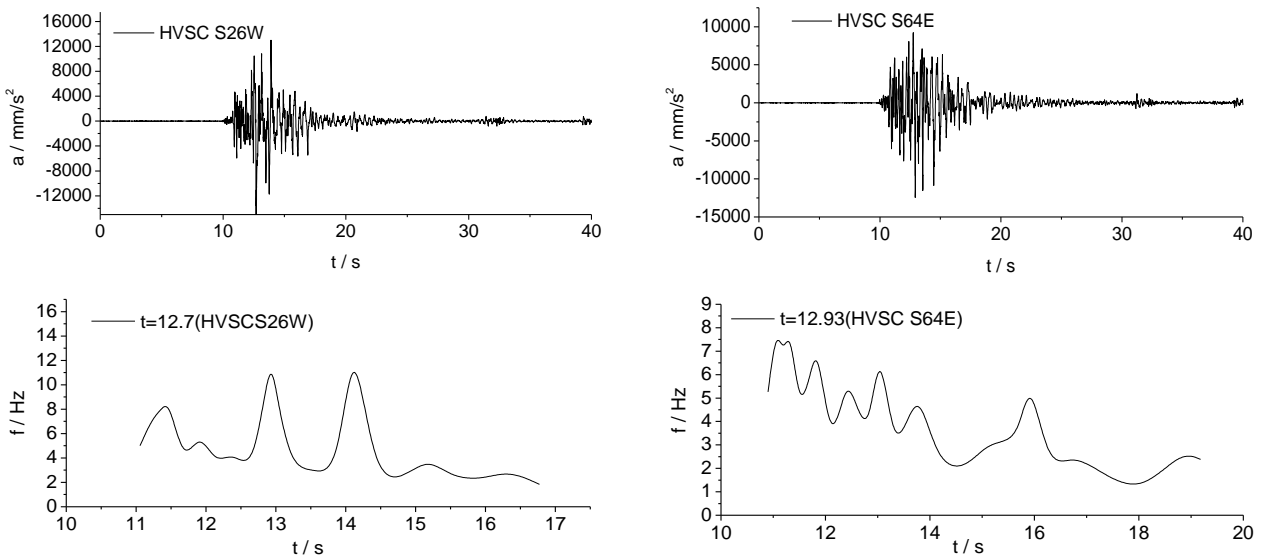


Figure 7: Acceleration time histories and time-frequency curves for the records of site HVSC.

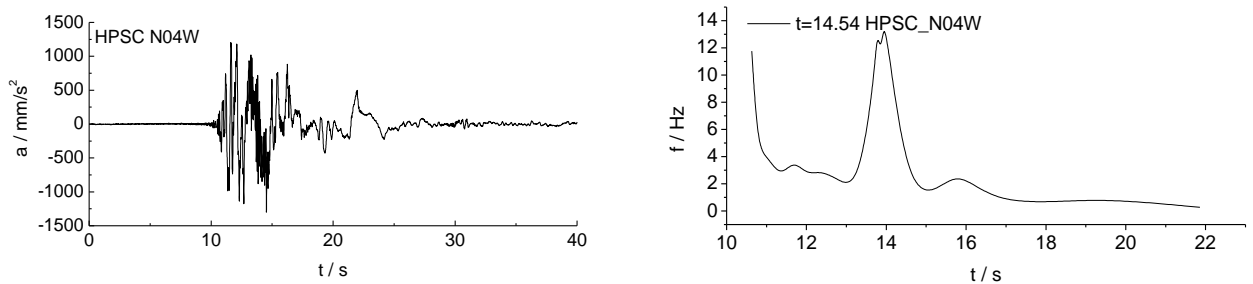


Figure 8: Corrected acceleration time history and the time-frequency curve of site HPSC.

At the site CSTC, the calculated TFDRSA of S02E component is 0.53 so that liquefaction was identified. As Fig. 9 shows the acceleration time-history of the S02E component and its time-frequency curve, the high-frequency components of about 25 Hz appeared at around 14s and then sharply decreased to 5 Hz, but the corresponding amplitude was too small to trigger liquefaction. The non-stationary of seismic

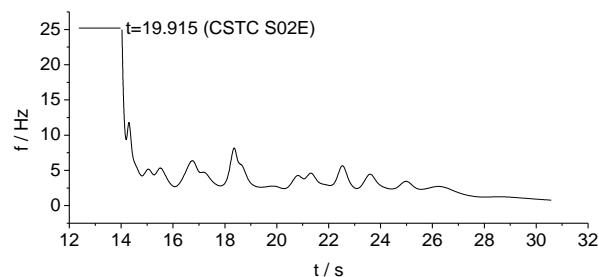
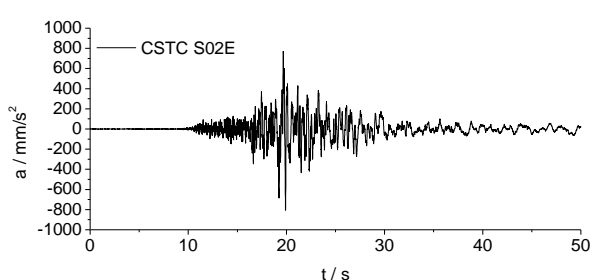
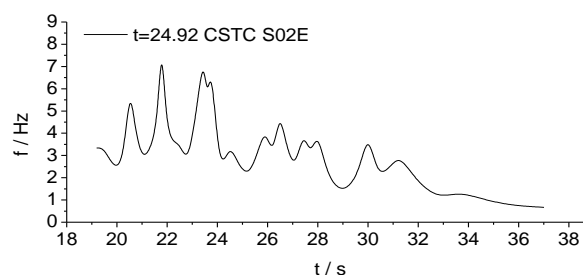
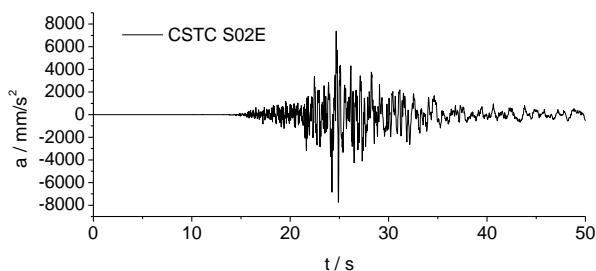
waves by means of a zero-crossing method was analysed [14] for 2,130 seismic records which revealed that the initial zero-crossing frequency ranges never exceeded 20 Hz, as listed in Table 3. Therefore, the author's technically removed the high frequency components higher than 20 Hz, and obtained TFDRSA value 0.37 as shown in Fig. 10. As a result, the site CSTC is corrected as non-liquefied.

**Table 3. The zero-crossing frequency\* [Hz] ranges for horizontal seismic accelerations.**

PGA(g)		Hard ground	Medium-hard ground	Medium-soft ground	Deep soft soil ground
0.09-0.18	Near field**	14.9	13.9	13.0	11.0
	Far field**	14.3	12.9	11.7	9.6
0.18-0.35	Near field	15	14.1	13.2	11.2
	Far field	14.5	13.1	11.8	9.7
0.35-0.70	Near field	15.2	14.2	13.3	11.3

\*Note: zero-crossing frequency: numbers of zero-crossing per unit time as second;

\*\*Near field means the epicentral distance is less than 1,000km while far field means epicentral distance is larger than 1,000 km.

**Figure 9: Acceleration time history and time-frequency curve of site CSTC.****Figure 10: Corrected acceleration time history and time-frequency curve of site CSTC.**

### COMPARISON BETWEEN THE BLIND DETECTION AND THE PRESENT SITUATION

In May 2011, we obtained the liquefaction detection results from 27 selected seismographs, including 9 liquefied sites and 18 non-liquefied sites (Table 2), and consequently submitted a manuscript paper to Bulletin of the New Zealand Society for Earthquake Engineering for review in July 2011. We emphasize the issue in order to highlight on blindly applying the Sun-Yuan liquefaction detection results on the records. The New Zealand strong motion data, on one hand, tested the validation of the liquefaction detection method; on the other, it paves the way for site liquefaction monitoring implementation of the method.

Prior to July 2011, sites CBGS, CMHS and SHLC were reported liquefaction and site PPHS was reported non-liquefaction according to internet news, but the confirmative investigation report was not available by then. In September 2011, Prof. John X. Zhao from GNS, New Zealand, confirmed the liquefaction of CBGS, CMHS and SHLC and non-liquefaction of PPHS during his academic visit to the Institute of Engineering Mechanics (IEM), meanwhile sites CHHC, HPSC and PRPC were also confirmed liquefaction. Till December 2011, the publications [15, 16] confirmed the liquefaction sites, *i.e.*, CBGS, CHHC, CMHS, SHLC, HPSC and PRPC; on the other hand, stations CCCC and REHS were on liquefied sites and HVSC and LPCC were non-liquefied sites.

Therefore, the liquefaction situation of 11 sites has been confirmed, including 8 liquefied sites CBGS, CMHS, SHLC,

CHHC, HPSC, PRPC, CCCC, and RESC, and non-liquefied sites PPHS, HVSC and LPCC. These sites were all correctly detected blindly by the Sun-Yuan method. However, the detected liquefaction site LINC and other 15 non-liquefied sites need further confirmative investigation.

Concluding on the calculated TFDRSA values in the past and Christchurch earthquakes, the TFDRSA value for non-liquefied sites value never exceeds 0.45, while it ranges 0.50 to 0.83 for liquefied sites. The mean values are 0.15 and 0.67 for non-liquefied and liquefied sites, respectively. The distinct dividing point, *i.e.*, 0.5, for non-liquefaction and liquefaction verifies the feasibility of TFDRSA in Sun-Yuan liquefaction detection method.

### CONCLUDING REMARKS

By means of blind detection, 27 seismic records are analysed by the Sun-Yuan liquefaction detection method to identify corresponding liquefied sites in the February 2011, New Zealand, earthquake. The main conclusive points can be outlined hereafter.

1. The Sun-Yuan method is a liquefaction detection method based on surface seismic records using a core parameter TFDRSA. According to previous study, the Sun-Yuan liquefaction detection method has a fairly high success detecting rate, as well it can discriminate non-liquefaction sites of diverse site categories, typically for non-liquefaction soft sites and liquefaction sites.

2. The TFDRSA index can effectively discriminate liquefied sites from non-liquefied sites according to the analytical results of real seismic records in the previous and recent Christchurch earthquakes. It never exceeds 0.45 for non-liquefied sites and is larger than 0.50 for liquefied sites, while the mean TFDRSA values are 0.15 and 0.67 for non-liquefied and liquefied sites, respectively.
3. Applied to the collected 27 New Zealand strong motion records of Feb. 22, 2011 Christchurch earthquake, the Sun-Yuan method blindly detected 9 liquefied sites and 18 non-liquefied sites.
4. Up to now, 11 sites, including 8 liquefied sites and 3 non-liquefied sites, have been confirmed, which demonstrates the detection results by Sun-Yuan method are correct on the 11 sites.
5. For future work, we would like to find ways to confirm detected liquefaction site LINC and other 15 non-liquefaction sites, and cast light on the application of the Sun-Yuan liquefaction detection method in engineering practice.

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