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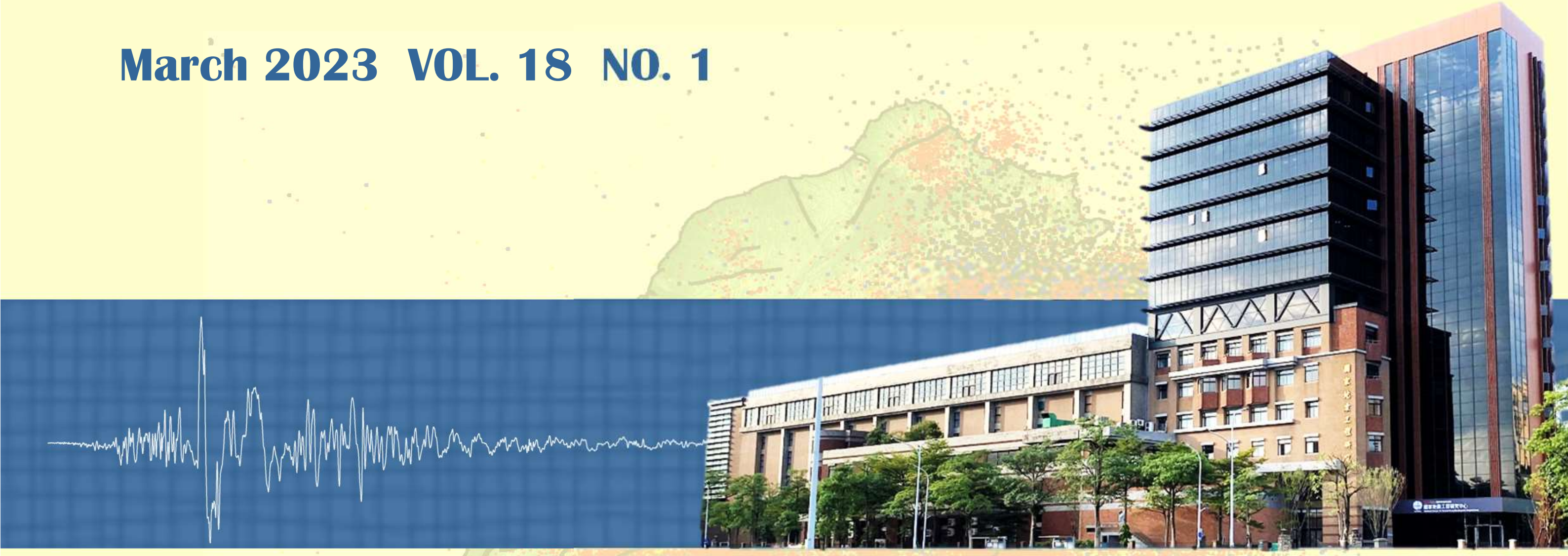

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National Center for Research on Earthquake Engineering

Shaking Table Tests of Suspended Busway Systems

Wei-Chung Chen, Assistant Researcher, NCREE

A busway is a suspended electrical distribution system that uses copper or aluminum conductors with suitable enclosures and a significant amount of protection to prevent the inside conductors from damage caused by foreign bodies. It has a major advantage in that busway systems require less space than traditional cable systems when thousands of amperes of electricity need to be transmitted. This type of system can also help to facilitate the efficient and safe distribution of lines with junction boxes which can be easily increased in number and changed whenever and wherever this is required. Therefore, the busway system is becoming commonly used in important buildings and facilities.

Past earthquake experiences have highlighted that losses from damage to busway systems can be significant. Fig. 1 illustrates an electrical short-circuit caused by misaligned joint connections, which have been shown to be not only a critical threat to life but also to lead to a substantial reduction in the functionality of important facilities. The busway system is essentially composed of combinations of many discrete components however, which makes it difficult to determine the strength capacity of the entire system. In order to understand the seismic performance and dynamic behavior of busway systems subjected to earthquake induced excitation, a series of full-scale shaking table tests were conducted at the NCREE Tainan Laboratory in Taiwan and the E-Defense facility in Japan. This paper briefly introduces the test setup and the failure mechanisms of the busway systems observed during the experiments.

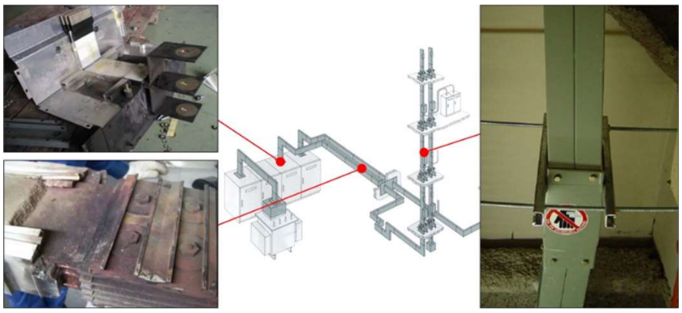

Fig. 1. Electrical short-circuit caused by misaligned joints

2021 Taiwan Shaking Table Test

In 2021, a three-story test frame with an area of 5 m × 5 m and height of 12.7 m was mounted on the shaking table at the NCREE Tainan Laboratory. Two types of busway systems were constructed inside the three-story test frame to investigate the influence of various input motions and layout parameters. Fig. 2 shows the test configurations of the suspended busway systems on different floors, which consist of many line elements joined by different types of connections. A distribution box was installed at the center of the first floor, and two complete metal busway systems were developed from the box through the second floor to the third floor. A portion of a typical cast resin busway system was installed on the second floor. All of the test specimens were made in compliance with the current construction methods in Taiwan. The trapeze systems (see Fig. 3(a)) from which the main runners hang were placed at intervals of 150 cm, and two types of braced frames were adopted for the busway systems with different plenum heights, as shown in Fig. 3(b, c).

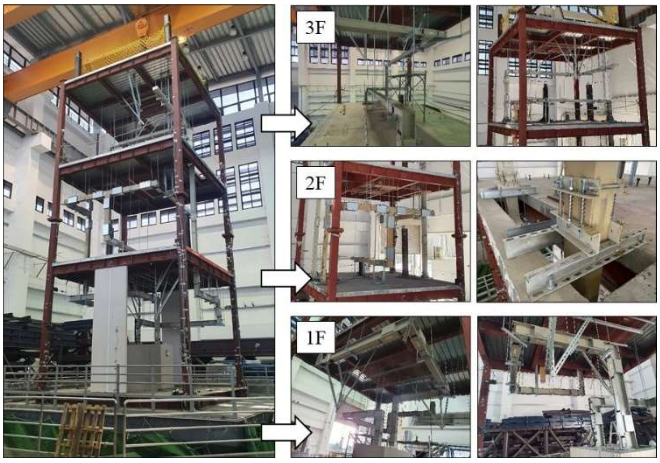

Fig. 2. 2021 Taiwan shaking table test

(a) (b) (c)

Fig. 3. (a) Trapeze systems; (b) suspended braced frame; (c) grounded braced frame

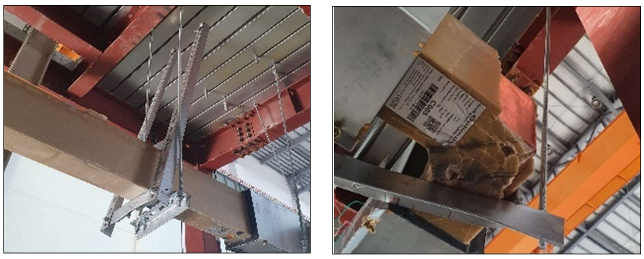

Fig. 4. (a) Failure of braced frames; (b) cracked corner elbow of cast resin busway

The experimental results showed that the traditionally used fixture between the trapeze and the busway component ceased functioning under a 10% JMA Kobe earthquake record excitation, resulting in obvious slippage and dislocation of the trapeze. The braced frame could not effectively resist the seismic force either, resulting in a large displacement of the busway systems. Eventually, some braced frames were completely destroyed and the corner elbow of the cast resin busway was severely cracked under a 40% Takatori Kobe earthquake record excitation, as presented in Fig. 4.

2023 Japan Shaking Table Test

In February 2023, the NCREE was invited to participate in a shaking table test at E-Defense in Japan based on a joint research agreement signed between the NCREE and the National Research Institute for Earth Science and Disaster Resilience (NIED) Japan in 2022. A ten-story steel structure 8 m × 12 m in area and 27 m high was constructed on the shaking table in this test and four busway specimens, including a cast resin busway system and three metal busway systems with different specifications, were installed on the 6th and 7th floors for testing, as shown in Fig. 5. Each specimen had a total length of 14.7 m, which was long enough to effectively represent the configuration of the busway systems in current use.

Fig. 5. 2023 Japan shaking table test

In order to be able to compare the results with the Taiwan test, not only the traditional fixtures but also hoops between the trapeze and the busway were adopted in the Japan test. In addition, the braced frames tested in the Taiwan test were reinforced with cross bracing and additional customized braces were placed at the positions expected to experience a large response based on prior numerical analysis.

(a) (b) (c)

Fig. 6. (a) Failure of traditional fixtures; (b) cracked cast resin busway; (c) failure of braced frames

The JMA Kobe earthquake record was used as the input motion in this shaking table test, and the test was carried out sequentially using 25%, 50%, 75%, and 100% of the original earthquake record. The experimental results showed that under the 50% JMA earthquake motion, most of the traditional fixtures between the trapeze and the busway components failed, whereas the use of hoops effectively avoided the problem of slippage and dislocation of the trapeze systems, as shown in Fig. 6(a). Failure of the cracked cast resin busway was observed after a 75% JMA Kobe earthquake motion, which resulted in exposure of the conductors as presented in Fig. 6(b). Eventually, most of the braced systems were damaged and deformed under the 100% JMA earthquake motion as shown in Figure 6(c). It is worth noting that none of the busway systems collapsed under such a large magnitude earthquake event.

Conclusion

According to the two shaking table tests, it can be concluded that the displacement responses of the busway systems in Taiwan under small to moderate earthquakes should not be underestimated and some components of the busway are likely to be damaged. This paper suggests that special attention should not just be paid to the fixtures between the trapeze and busway but that braced frames should also be used as seismic preventive measures. It is also important to install protective braces at the horizontal and/or vertical elbows of the busway, which can effectively improve the seismic performance of the entire system.

Shaking Table Tests of Suspended Ceiling Systems

Wei-Chung Chen, Assistant Researcher, NCREE

Past earthquakes have conclusively highlighted that the losses from damage to nonstructural components can be significant. A suspended ceiling system is one of the critical nonstructural components in a building that can experience major damage during earthquakes, which may endanger the safety of occupants and impede the continuous operation of the building and other facilities. In 2011, an appendix referring to ASTM E580-06 and -08 was included in the Taiwanese building seismic design code. This appendix provides explicit guidance for the seismic installation of suspended ceilings. Most construction details are specified for horizontal seismic forces, but the current standard provides limited guidance in terms of vertical motion resistance.

In order to evaluate and better understand the dynamic response and vertical strength capacity of ceiling systems, a series of full-scale shaking table tests of suspended ceilings was conducted to identify the influence of different system conditions and the effects of the protective systems required by the current standard. Based on the test results and the failure mechanisms observed, a revised guidance will be made available for industrial application in the installation of ceilings.

Two shaking table tests of small area ceiling systems were conducted at the NCREE Taipei Laboratory in 2015 and 2016, as presented in Fig. 1. These tests aimed to investigate the seismic performance of suspended ceilings subjected to vertical motion. Based on the test results, a suspended ceiling system constructed in accordance with the current standard displayed good resistance to horizontal forces but became more vulnerable when subjected to vertical forces. The failure patterns indicated that the vertical motions had substantial influence on the seismic performance of the ceiling systems, rendering a revision of the current standard a matter of significant importance.

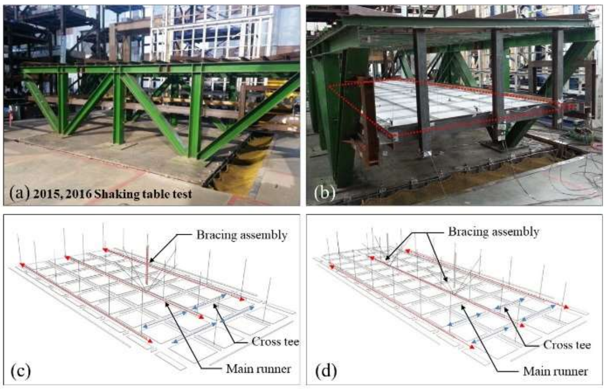

Fig. 1. 2015 and 2016 shaking table tests

In 2019, full-scale shaking table tests of large area ceiling systems were conducted at the NCREE Tainan Laboratory. To effectively simulate the seismic response of a large area ceiling system, an extension steel frame supporting a 10.98 m × 10.98 m ceiling area was mounted on the shaking table, as presented in Fig. 2. Load cells were installed on the bracing wires to determine the effect of the bracing assembly. It was observed that the bracing assembly may not adequately resist the lateral force due to construction problems. The ineffectiveness of the bracing wire was considered to be mainly a result of the slack wire effect, causing the bracing wire to sustain only a small portion of the lateral inertial force. It was also observed that the well-constructed bracing assemblies only provided horizontal resistance to the ceiling grids on which they were installed and could not support the adjacent ceiling grids. As a result, the response acceleration and displacement of the unbraced grids were significantly greater than those of the braced grids, which also made the boundary of the unbraced grids vulnerable to damage.

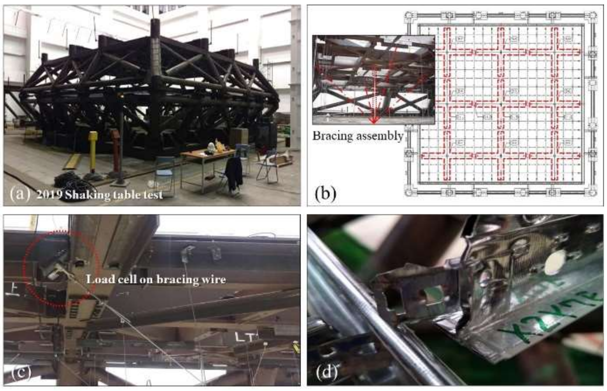

Fig. 2. 2019 Shaking table test

In 2022, a three-story test frame with ceilings of multiple plane elevations installed within was mounted on the shaking table at the NCREE Tainan Laboratory, as presented in Fig. 3. The test results demonstrated that the ceilings with different elevations would have different fundamental periods and led to further unsynchronized movement during earthquakes. It was observed that the conventional ceiling system was seriously damaged due to its inability to accommodate large relative movement at positions with height differentials.

Fig. 3. 2022 Shaking table test

In conclusion, this article summarized several suspended ceiling tests conducted over recent years and suggests applying the test results to revise the existing guidance for the seismic installation of ceilings with the purpose of improving the seismic performance of suspended ceiling systems in Taiwan.

Component Tests on Nonstructural Systems and Equipment

Fan-Ru Lin, Associate Researcher, NCREE
Juin-Fu Chai, Deputy Director General and Research Fellow, NCREE

The immediate usability and normal operation of an important building after a strong earthquake are highly dependent on the seismic performance of its non-structural components, such as its equipment and distribution systems. However, due to the wide variety of non-structural components and the limited availability of seismic test data, the assumption of values for stiffness or strength of specific critical elements of the non-structural components during non-structural seismic analysis is often based on engineering judgment. In order to observe the failure modes and determine the strength of these elements, it is necessary to employ quasi-static loading experimental configurations to establish related appropriate numerical models. Because of this, since 2010, the NCREE has conducted a series of quasi-static tests on vulnerable elements of crucial non-structural components:

1. Anchorage elements (Fig. 1): Non-structural components are typically anchored to the building structure through anchoring elements, such as spring isolators that isolate mechanical vibrations and prevent the vibrations from being transmitted to the building as well as expansion bolts connecting non-structural components and concrete bases. Figure 1 (left) depicts a spring-isolator system bearing the mass of a real cooling tower unit. The test results verified the theoretical values of the horizontal stiffness of the spring isolators. Figure 1 (right) depicts a shear test on an anchor bolt type commonly used in domestic suspended distribution systems. Cyclic horizontal force tests were carried out in accordance with the American Concrete Institute ACI-335.2 requirements to assess the performance of fixing anchors in cracked concrete. Experimental data and ACI-318 standards were used to determine the design strength of these expansion bolts.

2. Non-structural components: To ensure the normal operation of commercial buildings, such as hospitals, as well as to ensure the residual heat removal (RHR) function after strong earthquakes in nuclear power plants (NPPs), the NCREE has conducted four-point bending tests on piping joints for fire protection sprinkler systems (Fig. 2, left) and NPPs (Fig. 2, right). Additionally, compression tests were conducted on busway components (Fig. 3, left). The bending tests for mechanical and threaded piping joints of sprinkler piping systems were conducted according to Factory Mutual FM1920 standards (Fig. 2, left). It is known that flexible and rigid mechanical joints manufactured in Taiwan comply with angular requirements of the National Fire Protection Association NFPA 13, but the one-inch threaded joint is vulnerable. From the results of the subsequent bending-shear test (Fig. 4, left), it has been observed that the failure of the 1-inch threaded joint is primarily due to bending strength. In 2012, pure bending tests were conducted on NPP piping (Fig. 2, right), and the ABAQUS finite element numerical model was adjusted based on the linear and nonlinear stages of the test results. Additionally, the NCREE has conducted a test on busway components (Fig. 3, left). Between 2021 and 2022, the NCREE completed metal material tensile tests and compression tests on busway straight components (Fig. 3, middle) and related spring isolators (Fig. 3, right).

3. Strengthening devices for sprinkler piping (Fig. 4, right and Fig. 5): In this research, these strengthening devices were developed to address three performance points: damage to the anchorage points, water leakage, and torn ceiling boards caused by sprinklers. The proposed strengthening devices include bracing of the main pipe, steel wire support at branch pipes, and hose near the wall penetration. Component tests were conducted for threaded 1-inch hose (Fig. 4, right), 12-gauge and 18-gauge steel wire (Fig. 5, left), and 1¼-inch pipeline bracing adapter plates (Fig. 5, right). The effectiveness of the strengthening devices was verified by comparing numerical models with shaking table tests of a spring piping system. The main failure mode of steel wires, according to the component test results, is the loosening of the sleeves. While the steel mesh provides stiffness and strength for the hose, its ductility and energy dissipation characteristics are dominated by its bellows. The damage to diagonal brace adapter plates occurs at the change in the tapered section of the bottom plate. This follow-up research effectively improved its strength by adjusting the section of the base plate.

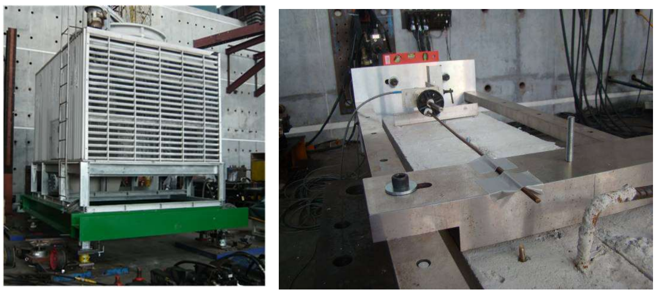

Fig. 1. Cyclic loading tests of spring isolators (left) and wedge anchor bolts (right)

Fig. 2. Four-point bending tests of sprinkler piping joints (left) and NPP piping joints (right)

Fig. 3. Busway (left) compression tests of straight section components (middle) and spring isolators (right)

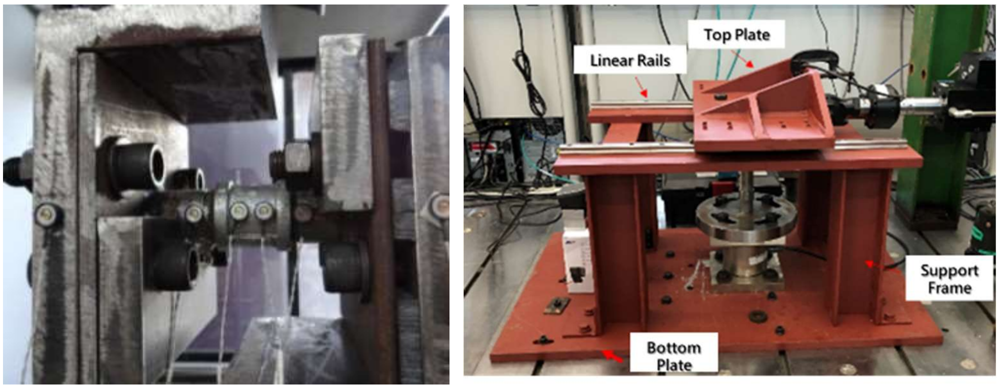

Fig. 4. Bending-shear test on fire-protection piping joints (left) and shear test on 1-inch hose (right)

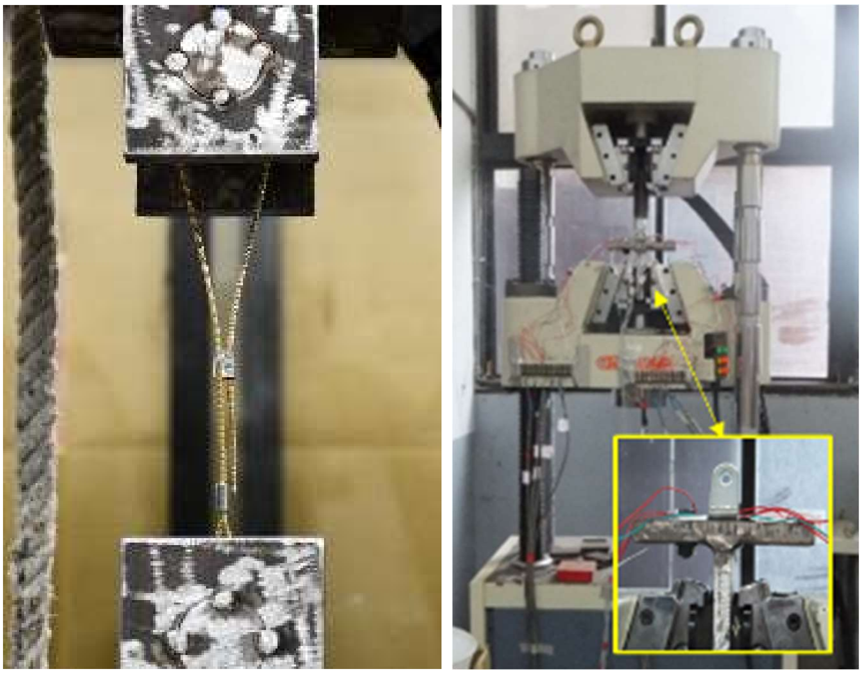

Fig. 5. Component tests of steel wire devices (left) and bracing adapter plates (right) for sprinkler piping

Shaking Table Test Plan for Mitigation Strategy of Liquid Sloshing in Tanks

Wei-Hung Hsu, Assistant Researcher, NCREE
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Liquid storage tanks are commonly used for storing water and other fluids in the oil industry. Similarly, in nuclear power facilities, storage tanks have several uses, for example, as oil tanks, backup water storage tanks, and spent fuel pools. During earthquakes, seismic loading can cause liquid to shake violently. The hydrodynamic behavior is called liquid sloshing. Based on previous research and relevant literature, liquid sloshing has a great impact on these storage facilities. Tank damage is often accompanied by secondary disasters such as fire. Numerous cases of seismic damage to tanks have been documented in the literature, from the Alaska earthquake in 1964 to the 2001 Great East Japan earthquake. These studies have identified liquid sloshing as a significant factor contributing to damage to storage facilities. Studies on complex liquid sloshing have extensively discussed and explored this phenomenon through theoretical and experimental methods, and most have separated the hydrodynamic behavior of liquid sloshing into two modes: impulsive and convective. The convective mode is characterized by low-frequency and can easily resonate with earthquakes that also have low-frequency content. Since the 1960s, scholars have been exploring ways to suppress liquid sloshing and have proposed various methods to reduce damage to liquid storage tanks caused by this phenomenon. According to relevant literature, the methods for suppressing liquid sloshing can be classified into two main categories. The first is an energy dissipation system, such as the application of various baffles. The second is a seismic isolation system, such as the application of a friction pendulum system and lead-rubber bearings.

According to the relevant guidelines and literature as shown in Table 1, the maximum height of liquid sloshing is related to the size of the storage tank and spectrum acceleration. Thus, to reduce the height of liquid sloshing, one approach is to reduce the size of the storage tank parallel to the direction of the shock and to reduce the spectrum acceleration. However, lowering the spectrum acceleration is difficult to achieve in practice since it is related to both the frequency content of ground motion and the frequency of liquid sloshing. In contrast, reducing the size of the storage tank is achievable, for example, by installing a baffle in the tank, which is a common approach.

This study aims to conduct shaking table tests on square and rectangular tanks with interior baffles and to discuss the effect of baffles on the frequency and height of liquid sloshing. As the baffles are not connected to the bottom of the storage tanks, the liquid inside the tanks will interact with the baffles when it passes through the bottom of the baffles. This interaction potentially causes dissipation of energy and changes the damping of the liquid. This would reduce the height of liquid sloshing and may have an effect on the frequency of liquid sloshing. When a single baffle is installed in a tank, it divides the internal space of the tank into two smaller compartments (as shown in Fig. 1), and the frequency of the liquid sloshing is changed. This may result in different liquid sloshing frequencies and different liquid sloshing behavior in the same tank. Therefore, this study focuses on the influence of the parameters of a single baffle on the frequency and height of liquid sloshing. The parameters include vertical and horizontal positional parameters as shown in Figs. 1 and 2. In terms of input ground motion, a broadband impulse wave will be used to stimulate liquid sloshing and examine the frequency of the sloshing, while a single-frequency sine wave, but with varying frequency, will be employed to investigate the relationship between liquid sloshing and the frequency of the external load. In addition, specific seismic records will be employed to evaluate the effectiveness of a baffle in mitigating the height of the liquid sloshing.

Table 1. Comparison of formulas for estimating the maximum height of liquid sloshing in relevant guidelines.

Guideline	Max. sloshing height	Symbol
API 650	$\delta_s = 0.5DA_f$	δ_s: Max. sloshing height *D*: Diameter A_f: Spectrum acceleration
API 620	$\delta_s = 0.42DA_f$	δ_s: Max. sloshing height D: Diameter A_f: Spectrum acceleration
ACI 350.3-06	$d_{\max} = \frac{D}{2}C_c I$	d_{max}: Max. sloshing height *D*: Diameter C_c: Seismic response coefficient *I*: Importance factor
GIP-3A	$h_s = 0.837RS_{as}$	h_s: Max. sloshing height *R*: Radius S_{as}: Spectrum acceleration
EPRI-1025287	Fundamental mode: $h_s = 0.5\mathrm{L}(\mathrm{SA}_{\mathrm{C1}}/g)$ To consider higher modes: $h_s = 0.6\mathrm{L}(\mathrm{SA}_{\mathrm{C1}}/g)$	h_s: Max. sloshing height *L*: Tank length parallel to shock SA_{C1}: Spectrum acceleration

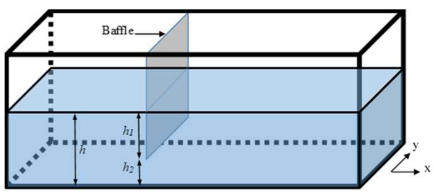

Fig. 1. Illustration of vertical position parameters of a baffle.

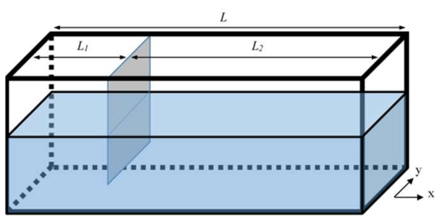

Fig. 2. Illustration of horizontal position parameters of a baffle.

A Comparison of the System Identification Methods in Seismic Qualification Standards

Bai-Yi Huang, Assistant Researcher, NCREE
Juin-Fu Chai, Deputy Director General and Research Fellow, NCREE

The internationally recognized seismic qualification standards for non-structural components and systems (NSCS) (including the IEC 60068 series and AC156 protocol for general purposes, the IEEE 693 requirements for electrical substation equipment, the GR-63-CORE and NTT DOCOMO earthquake resistance test specifications (hereafter referred to as NTT DOCOMO) for communications equipment, and the IEC/IEEE 60980-344 procedures for equipment in nuclear power plants) basically divide the seismic qualification test procedures into two parts: a system identification test and a waveform test. The system identification test is referred to by a different name in each standard (e.g., vibration response investigation, resonant frequency search, swept sine survey, vibration characteristic test, and exploratory test) and is hereafter referred to as the SID test. The testing parameters of the SID test are given in Table 1.

The major purpose of the SID test is to determine the important characteristic parameters of a specimen, such as the natural frequency and the damping ratio. These parameters are usually not for use in evaluating the seismic performance of the specimen but defining the compatibility criteria of the testing response spectrum in the subsequent waveform test or improving the numerical models for simulation with the realistic natural frequency and damping ratio. GR-63-CORE is the only standard that requires that frame-level equipment has a natural mechanical frequency greater than 2 Hz, and it suggests that the natural frequency should be greater than 6 Hz. This does not mean that a specimen with greater natural frequency has better seismic performance, but recommends that manufactures design the structure of the equipment to better avoid its natural frequency being close to that of the building, which is assumed to be between 2 Hz and 5 Hz according to the required response spectrum (RRS) provided by the standard. On the other hand, most of the standards require a SID test to be conducted before a waveform test, but IEEE 693 and NTT DOCOMO require the natural frequency to be compared before and after the waveform test to see if there are significant structural changes. In addition, IEEE 693 describes the method for identifying the damping ratio, such as the decay rate, half-power bandwidth, and frequency or time domain curve fitting method.

As indicated in Table 1, the swept sine test is the major method of conducting the SID test, and uniaxial testing is suggested. However, the parameters may vary across different standards. The amplitudes of input motion are set as 0.1 g or 0.2 g, but a lower input level is allowed to be used to avoid specimen damage in AC156. As far as the sweep rates are concerned, most of the standards suggest upper bounds of the sweep rates to ensure adequate time for maximum response at the resonant frequencies. Only GR-63-CORE allows higher sweep rates to reduce equipment stress. Therefore, the conceptualization of sweep rate may differ across standards, and 1 octave/minute is the only setting that is common. Alternatively white noise, snapback, and man-shake tests are allowed to be adopted as the SID testing method in certain standards. Among these methods, the swept sine and white noise test need to be implemented through a shaking table test and provided with stable and wide-band input motion to excite the specimen. Examples of swept sine and white noise input motions are shown in Figure 1.

In summary, this article reviewed the SID testing methods proposed in internationally recognized seismic qualification standards for NSCS. Most of the standards describe the basic testing parameters and procedures of the swept sine test to determine the natural frequency or damping ratio of a specimen. However, there are very few descriptions of the method for generating the input motion or analyzing the testing data to obtain the characteristic parameters. Thus, a successful SID test still relies on the competence and judgement of the executor.

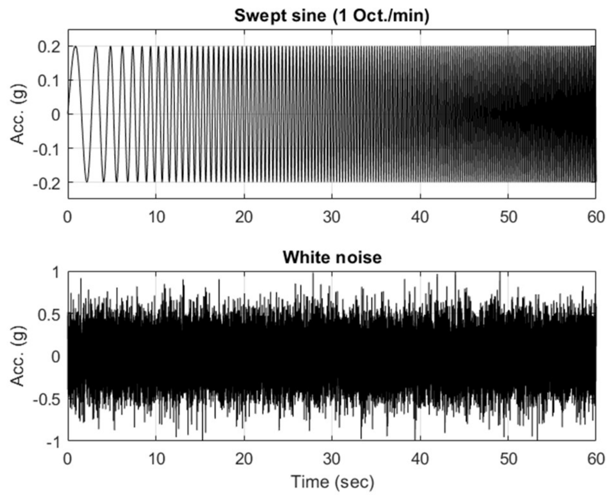

Fig. 1. Examples of swept sine (0.2 g) and white noise (0.25 g) input motions.

Table 1. Testing parameters of the SID test in different standards.

Standard		**IEC 60068-3-3**	**IEEE 693**	**AC156**	**GR-63-Core**	**NTT DOCOMO**
Implementation		Before waveform test	Before and after	Before	Before	Before and after
Swept	Range	1~35 Hz	1~33 Hz	1.3~33.3 Hz	1~50 Hz	0.5~50 Hz
	Amplitude	□2 m/s^2	□0.05 g（default: 0.1 g）	0.1±0.05 g	0.2 g	1 m/s^2
	Sweep rate	□1 oct/min	□1 oct/min	□2 oct/min	□1 oct/min	□1 oct/min
Alternative		White noise (IEC 60068-2-64)	White noise test (□0.25 g), snapback test, man-shake test	N.A.	N.A.	White noise (no further description)

A Study on the Seismic Safety Assessment of Wheelchairs

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Xiao-Li Lin, Assistant Researcher, NCKU

This paper studies factors that may mitigate or exacerbate the overturning risk of a wheelchair during an earthquake due to response behavior and environmental conditions. Shaking table experiments were conducted to test a wheelchair with a dummy on it.

Introduction

The floor vibration of a building during an earthquake can be simplified as a single frequency motion and the peak acceleration value increases with height in the building. The frequency is the fundamental frequency of the building. As shown in Figure 1, the response amplitude increases at higher floors of a building and becomes closer to a single frequency vibration. The vibration frequency is related to the total height of a building, and generally the total number of floors can be multiplied by 0.1 to estimate its natural vibration period. If a wheelchair user is affected by ground motion due to an earthquake in a building, the natural vibration frequency of the building is a dominant factor in determining the response of the wheelchair, and if there is resonance it is very likely that the wheelchair will overturn.

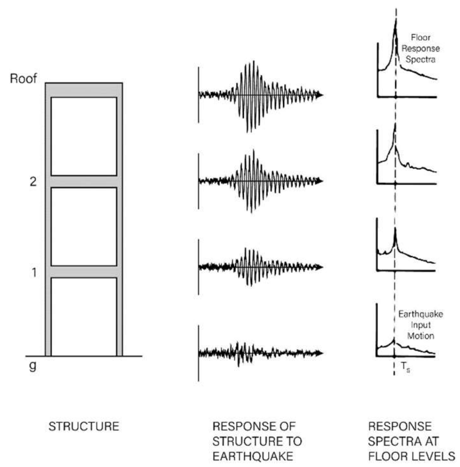


Fig. 1. Structural vibration characteristics

Discussion and Conclusions

Wheelchair vibration modes during earthquakes include walking, rocking, and overturning. We collected the maximum accelerations experienced by wheelchairs recorded in every experiment and plotted the data as line graphs in Figure 2. The horizontal axis is the excitation frequency, the left vertical axis is the maximum acceleration of the wheelchair, and the corresponding reaction mode is marked on the right vertical axis. The line segments represent input accelerations of 300, 250, 200 and 150 gal from top to bottom. It is evident that the curves are not symmetric and are nonlinear in nature. When the input amplitude increases, the main reaction frequency of the wheelchair decreases. As the input acceleration amplitude increases, it is more likely to stimulate the various vibration modes of the wheelchair. In addition, the frequency of each mode is sorted from lowest to highest as: overturning, rocking, and walking.

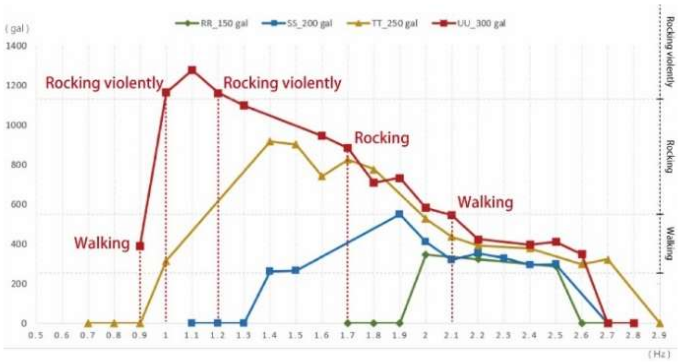


Fig. 2. Maximum wheelchair acceleration at different sinusoidal amplitudes

As shown in Figure 3., an excitation of 300 gal involves a high risk of the wheel-chair overturning in buildings whose heights range from 4 to13 stories, and the highest risk of a wheel-chair overturning is in buildings with 9 to 11 stories.

(Hz)			
Freq.	Period	*10	Building height
3.3	0.303	3.0	3 F
3.2	0.313	3.1	
3.1	0.323	3.2	
3	0.333	3.3	
2.9	0.345	3.4	
2.8	0.357	3.6	
2.7	0.37	3.7	
2.6	0.385	3.8	
2.5	0.4	4.0	4 F
2.4	0.417	4.2	
2.3	0.435	4.3	
2.2	0.455	4.5	
2.1	0.476	4.8	
2	0.5	5.0	5 F
1.9	0.526	5.3	
1.8	0.556	5.6	
1.7	0.588	5.9	6 F
1.6	0.625	6.3	
1.5	0.667	6.7	
1.4	0.714	7.1	7 F
1.3	0.769	7.7	
1.2	0.833	8.3	
1.1	0.909	9.1	9 F
1	1	10.0	10 F
0.9	1.111	11.1	11 F
0.8	1.25	12.5	
0.7	1.429	14.3	
0.6	1.667	16.7	
0.5	2	20.0	20 F
0.4	2.5	25.0	25 F
0.3	3.333	33.3	
0.2	5	50.0	50 F
0.1	10	100.0	100 F

Overturning & Violent rocking
Rocking
Walking
The scope of this study
super high-rise building

Fig. 3. Table of wheelchair vibration response behavior in buildings due to an excitation of 300 gal

Earthquake Behavior of a Steel Angle Supported Hanger Piping System

George C. Yao, Deputy Director General, NCREE; Professor, NCKU
Yi-Kai Yan, Master assistant, NCKU

Many important facilities in buildings, such as central air conditioners and fire sprinkler systems, often use rod-suspended common pipeline hangers (referred to as hangers) for integration and suspension, but appropriate reinforcement measures for such equipment are generally not implemented. According to previous research, the natural vibration frequency of such systems is low and it is easy for them to resonate with the building in which they are installed, which will cause the vibration to be amplified when an earthquake strikes. This may result in collisions with adjacent items or structures and cause pipelines to be damaged and lose proper functionality. Therefore, to improve the seismic performance of hangers, this study discusses the use of angle steel as the suspension member of a hanger. In addition, we consider the relevant domestic and foreign codes for seismic reinforcement design and attempt to understand the basic characteristics of dynamic response and reinforcement effects through system identification and shaking table earthquake simulation experiments.

The system identification results show that an unreinforced single-layer hanger pipeline (Fig. 1) has a longitudinal (X-direction) natural vibration frequency of 1.0 Hz. After reinforcement with an angle steel diagonal brace (Fig. 2), the stiffness is greatly improved and the natural vibration frequency in this direction is increased to 8~10 Hz, which effectively avoids the resonance frequency range of a building. According to the results of seismic simulation experiments on the shaking table, the X-direction vibration of the unreinforced single-layer and double-layer hanger is extremely large when the vibration is 20% of the JMA KOBE seismic record. The maximum displacements are 210 mm and 260 mm, respectively, which significantly exceed the upper limit of displacement of 50 mm stipulated in the National Fire Protection Association (NFPA) 13 specification. After adding X an Y-direction steel angle diagonal braces for reinforcement, the displacements are greatly reduced, with both becoming approximately 1 mm.

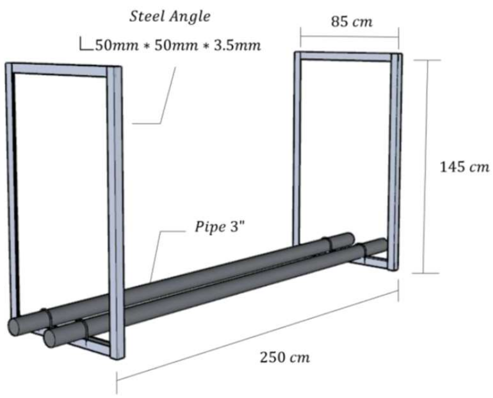


Fig. 1 Geometry and size of hanger

To test the accuracy of the model setting, we used SAP2000 software to establish a numerical model of the hanger according to the test results of the components, conducted modal and dynamic time-history analyses, and then compared the results with the shaking table test results. The results show that both the overall trends of acceleration and displacement are consistent and that the amplitudes match closely, as shown in Figure 3.

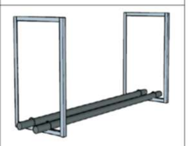
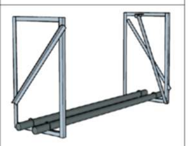
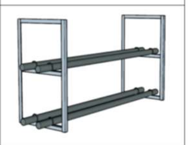
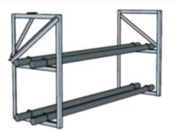
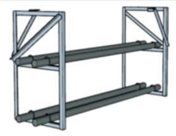
名稱	編號	吊架型式	示意圖
單層角鋼吊架	SA	單層角鋼吊架未進行補強	
補強單層角鋼吊架	SAB	單層角鋼吊架進行X、Y向補強	
雙層角鋼吊架	DA	雙層角鋼吊架未進行補強	
補強雙層角鋼吊架_1X	DAB_1X	雙層角鋼吊架進行X、Y向補強，其中X向僅加設一根斜撐	
補強雙層角鋼吊架_2X	DAB_2X	雙層角鋼吊架進行X、Y向補強，其中X向加設兩根斜撐	

Fig. 2 Specimen details

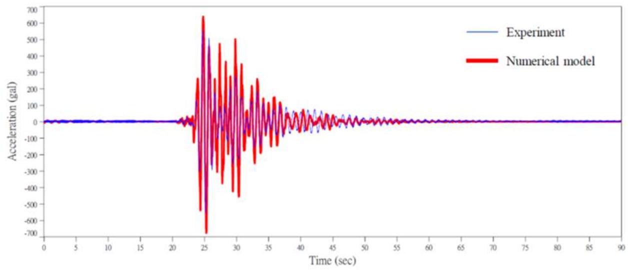


Fig. 3 Comparison of numerical and experimental data

Web Service for Seismic Design Response Spectra for Buildings in Taiwan

Hsun-Jen Liu, Assistant Researcher, NCREE
Xue-Min Lu, Assistant Technologist, NCREE
Yu-Wen Chang and Wen-Yu Jean, Research Fellows, NCREE

In Taiwan, the seismic design code for building structures was first published in 1974 and a total of seven revisions have been made (1982, 1989, 1997, 1999, 2006, 2011, and 2022). These changes update and detail the evolving design earthquake requirements. The latest revision of the Seismic Design Specifications and Commentary for Buildings was formally implemented on October 1, 2022. However, when confronting these changes, such as new formulations, additional active faults, updated parameters/coefficients, and adjusted administrative divisions, there are always inconveniences and difficulties encountered in design earthquake calculations as well as data source management. Most importantly, there is no practicable and reliable tool to apply to the latest seismic design spectra.

In order to assist in follow-up application issues caused by revisions of the seismic design code, the National Center for Research on Earthquake Engineering (NCREE) launched a web service for Taiwan seismic design response spectra for buildings, or "Sederes". Sederes not only integrates the up-to-date map data and revised regulations, but also provides a useful and credible platform. There are six special features of Sederes:

(1) *The latest geographic information*. This includes the 2021 Holocene active fault map derived from the Central Geological Survey of the Ministry of Economic Affairs, the 1100928 version of Taiwan's administrative divisions from the Ministry of Digital Affairs, the national address positioning function from the Ministry of the Interior, and the world map from the OpenStreetMap.

(2) *Alternative site-positioning approaches*. This feature includes direct marking on the map, site address, geodetic coordinates, and administrative divisions.

(3) *Near-fault design spectra calculation*. For near-fault sites, Sederes can automatically show the near-fault names, their corresponding site-to-fault distances, and the maximum near-fault spectral accelerations. The site-to-fault distance can be modified by users for fault zoning considerations or other practical purposes.

(4) *Taipei site reconsideration.* Apart from Table 2-6 of the design code, Sederes provides the site-adjusted spectral accelerations based on the Taipei Basin micro-zonation map illustrated in Figure 2-1 of the design code.

(5) *Enclave site positioning.* For sites located in enclaves such as Sanhe Village and Taiwu Village in Pingtung County, Sederes provides suitable design values based on the Taiwan mapped spectral acceleration diagram illustrated in Figure 2-1 of the design code.

(6) *Full design spectral information.* This includes the following information: site seismic area (general site, near-fault site, or Taipei zone site), mapped spectral accelerations, near-fault names, site-to-fault distances, near-fault spectral accelerations, site classification, site amplification factors, site-adjusted spectral accelerations, effective peak acceleration (EPA), transition periods, and 101 spectral values with or without EPA constraint on long-period range. The design values are provided for return periods of 475 years and 2,500 years.

The web service for Taiwan seismic design response spectra for buildings, i.e., Sederes, was launched on December 30, 2022 and is available at the following URL: https://seaport.ncree.org/sederes. All are welcome to use, give feedback, and promote.

Fig. 1. The web service for seismic design response spectra for buildings in Taiwan (Sederes)

Taiwan ShakeMap Assessment System

Che-Min Lin, Research Fellow, NCREE
Shu-Hsien Chao, Research Fellow, NCREE
Xue-Min Lu, Assistant Technologist, NCREE

The Taiwan National Center for Research on Earthquake Engineering (NCREE) developed the "Taiwan ShakeMap Assessment System" to support loss estimation and emergency response after large earthquakes. The system combines the advanced ground motion prediction equation, earthquake source models, seismic site parameters, and a spatial correlation model to automatically generate an estimated high-resolution shake map, which shows the distribution of ground motion intensities immediately after an earthquake. The estimation is based on observations of the strong motion networks of the Central Weather Bureau (CWB) and NCREE. All the shake maps of the earthquakes that have occurred in Taiwan will be visually presented on a GIS web service.

The system will produce shake maps of various ground motions, including the peak ground acceleration (PGA), peak ground velocity (PGV), and spectral acceleration (SA) for the periods of 0.3 s and 1.0 s, within twenty minutes after an earthquake is announced by the CWB. Users will be able to choose the events and ground motion type to interrogate the entire shake map of the Taiwan island and check details of the intensity for a specific site. The system also provides the observed acceleration waveforms and spectra of strong motion stations and compares them with the Taiwan building code. The active faults and site classification of strong motion stations are also available for reference.

The system has been in service on the website https://seaport.ncree.org/smap/ since the end of 2022.

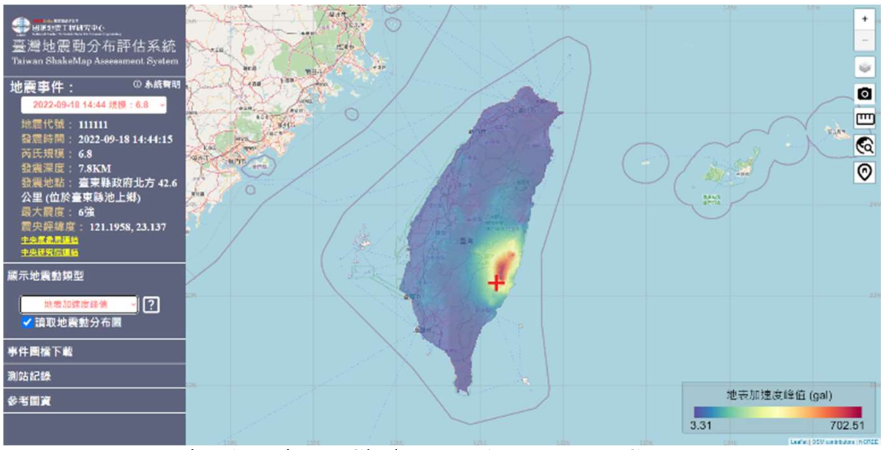


Fig. 1. Taiwan ShakeMap Assessment System

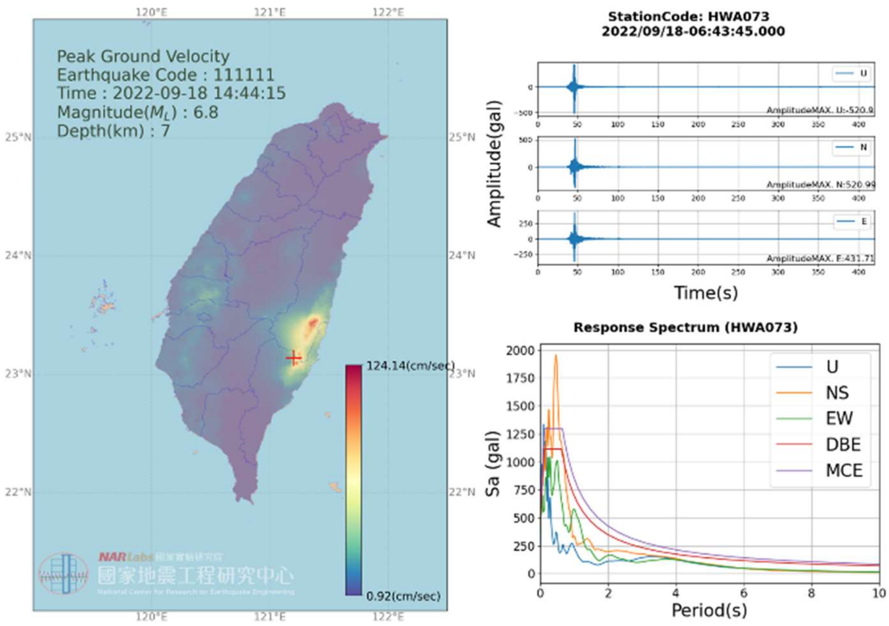


Fig. 2. ShakeMap of PGV and observed acceleration waveforms and spectra

NCREE Conference on Experiments and Engineering Practices

Han-Wei Huang, Associate Technician, NCREE
Chien-Chuang Tseng, Division Director, NCREE
Fu-Pei Hsiao, Division Director, NCREE

To advance progress in the field of earthquake engineering, the NCREE held two conferences: the NCREE Conference on Experiments and Engineering Practices in Tainan on January 10, 2023 and in Taipei on January 13, 2023. Several research groups that had conducted experimental projects at the NCREE testing facilities in Taipei and Tainan (including shake table tests, reaction wall and strong floor test systems, the multi-axial testing system (MATS), and the biaxial testing system (BATS)) in 2021 were invited to disseminate their latest findings through oral presentations. In addition, Prof. Gilberto Mosqueda from the University of California, San Diego, and Prof. Yail Jimmy Kim from the University of Colorado, Denver were invited as keynote speakers. To foster collaboration between academia, research, and industry, several industry engineers were specially invited to share their practical engineering experience. These conferences provided unique opportunities for academic researchers and industry experts to share knowledge and experience in the field and were also expected to facilitate closer collaboration between academia and industry in the future.

Thirty-two oral presentations were given at the events, covering research topics such as the mechanical properties of newly devised structural members, the effects of using innovative measures in reinforced concrete members, the seismic performance of structural elements and systems, and the seismic performance of nonstructural components and systems. These conferences provided a unique platform for academic researchers and industry experts to exchange knowledge and experience in the field, as well as to share relevant information on planning and executing experimental projects.

Approximately 253 attendees participated in the events. Participants engaged in vibrant discussions that focused on the mechanical behavior and practical applications of several newly developed structural components. Abundant engineering experiences were shared and exchanged, demonstrating the high level of interest and expectations that society holds toward the NCREE research work.

Fig.1. NCREE Conference on Experiments and Engineering Practices in Taipei

Fig.2. NCREE Conference on Experiments and Engineering Practices in Tainan

Fig.3. Prof. Gilberto Mosqueda from the University of California, San Diego

Fig.4. Prof. Yail Jimmy Kim from the University of Colorado, Denver

Seminar of a New Laboratory for Green Energy Facility in NCREE

Chia-Han Chen, Associate Researcher, NCREE
You-Chia Lee, Research Assistant, NCREE
Hong-Hao Hsieh, Assistant Researcher, NCREE
Chiun-Lin Wu and Juin-Fu Chai, Deputy Director General, NCREE
Chung-Che Chou, Director General, NCREE

The National Science and Technology Council project entitled "Smart Disaster Prevention Monitoring Platform for Supporting Structure of Offshore Wind Turbine (OWT)" was proposed by the National Center for Research on Earthquake Engineering (NCREE). This project focuses on three main areas of research and development: (1) design, analysis, and experimental technology for OWTs, (2) smart monitoring technology of OWTs for disaster prevention, and (3) advanced experimental and testing platforms for green energy facilities. Hence, the NCREE plans to establish a new laboratory for the testing and validation of green energy facilities, especially for OWTs.

The new laboratory will consist of two main experimental testing platforms, namely an OWT blade and structure and a geotechnical centrifuge, as shown in Figure 1. On November 4, 2022, an announcement was published on the NCREE official website, requesting domestic universities and colleges to cooperate and participate in the establishment of the laboratory. At the same time, an internal working group was formed and a professional architectural team was invited to assist in the preliminary planning of the laboratory. In order to provide interested domestic universities and colleges with the latest information on the new laboratory for green energy facilities, a seminar was held at the NCREE on February 1, 2023, for the purpose of presenting the preliminary plan and gathering suggestions for the laboratory.

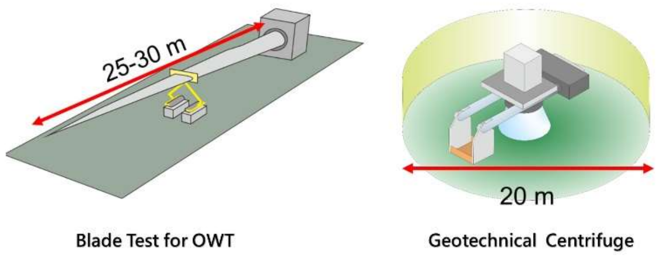


Fig. 1. Schematic drawing of two test platforms

Chung-Che Chou, Director General of the NCREE, opened the event with an introduction to the project's background and the laboratory's specifications and future development. Next, architect Li-Ren Hsiao presented the preliminary plan of the laboratory to the audience, including laboratory space requirements, legal analysis, and cost estimates. The seminar had an agenda for two-way communication between the participants and the NCREE, providing all the distinguished guests with sufficient time to discuss and make suggestions. Figure 2 shows a group photograph of the speakers and participants.

A total of 24 representatives from eight schools attended the seminar: National Taiwan University, the National Taiwan University of Science and Technology, National Central University, National Yang Ming Chiao Tung University, National Cheng Kung University, National Kaohsiung University of Science and Technology, the National Ilan University, and National Taiwan Ocean University, all of which expressed strong willingness to cooperate.

Fig. 2. A group photograph of the speakers and participants

The audio-visual materials of this seminar were immediately made available on the official website of the NCREE to refer domestic universities and colleges to the preliminary plan for the new laboratory. The information can be accessed on the link https://www.ncree.narl.org.tw/home/greenlab or by using the QR code below. The site for the new laboratory will be selected at the end of March 2023.

Prof. Cheng-Horng Lin Awarded the "2022 Executive Yuan Award for Outstanding Science and Technology Contribution" for the Achievement with the TVO Team

Ya-Chuan Lai, Associate Researcher, NCREE

Over 20 years ago, despite only a few scientists believing that the Tatun Volcano Group (TVG) might still be active, Prof. Cheng-Horng Lin, the research fellow (joint appointment) of the National Center for Research on Earthquake Engineering (NCREE), recognized the potential impact of volcanic disasters on urban Taipei. Thus, he devoted himself to volcano research, hoping to apply his expertise in geophysics to identify evidence of active volcanoes. Over 20 years, starting from scratch, broadband seismic stations were gradually added, eventually culminating in the completion of a dense seismic array comprising a total of 40 stations in 2014. The dense broadband seismic array is capable of accurately recording various signals emitted by volcanos.

As part of his daily work routine, Prof. Lin begins by checking numerous seismic waveforms, from which he is able to identify unique signals present in volcanic areas, such as short-duration monochromatic screw-shaped events. In 2016, he successfully discovered evidence of magma reservoirs below the TVG. The existence of magma reservoirs below the TVG was confirmed through the observation of certain characteristics, such as the formation of an S-wave shadow zone on the surface, due to the fact that S-wave cannot be transmitted through a liquid medium, as well as P-wave time delays. It is noteworthy that the confirmation of the existence of the magma reservoir through the S-wave shadow zone was the first in the world. There is now no doubt that the TVG is an active volcano.

To establish a comprehensive volcano monitoring system and integrate the research results, Prof. Lin worked hard to secure support from the National Science Council and other ministries. Thus, the Tatun Volcano Observatory (TVO) was established in 2011. A real-time monitoring system was established, and this included seismic observations, geochemical analyses, crustal deformation studies, and geothermal measurements. Because of long-term continuous real-time monitoring, the TVO can keep track of the activities of the TVG, serving as the frontline guard for the public. The confirmation of the TVG as an active volcano, as well as the establishment of the TVO, has significantly contributed to awareness of potential volcanic disasters in Taiwan. The management of volcanic disasters was officially included in the "Disaster Prevention and Protection Act" in 2017. As a result of these efforts, Prof Lin was awarded the 2022 Executive Yuan Award for Outstanding Science and Technology Contribution.

The New Website of TVO

Ya-Chuan Lai, Associate Researcher, NCREE

Recently, there has been a growing public interest in volcanic issues. It has become a more important task for TVO to effectively convey scientific knowledge about volcanoes through easy and simple demonstrations. With the support of the NCREE, the first popular science website on volcanoes in Taiwan was launched on January 1, 2023. The website is divided into four main parts: understanding volcanoes, deciphering volcanoes, getting close to volcanoes, and volcano news. Through lively explanations, the website aims to disseminate scientific knowledge of volcanoes and the way volcano monitoring works. Animated evidence of the magma reservoir and other research achievements, such as volcano infrasound and heartbeat, is also shown on the website. Additionally, the well-designed volcano experience route combines outdoor activities and volcano science exploration. The website depicts four routes with varying degrees of difficulty. Important information about volcano science and monitoring can be accessed through the stops of the routes and popular science education can easily be carried out in daily life. In addition, real-time monitoring data from TVO is also available on the website. Therefore, web users can gain scientific knowledge of volcanoes while also understanding the activity status of the TVG.

Fig. 1. Group photograph with the Vice President of the Executive Yuan, Prof. Cheng-Horng Lin, his family, and his work team (credit National Science and Technology Council).

Fig. 2. New popular science website of the TVO (https://tvo.ncree.narl.org.tw/)

Workshop on Strong Earthquake Building Health Analysis and Structural Safety Maintenance Management

Shu-Hsien Chao, Division Director and Researcher, NCREE

The Taiwan Architecture and Building Center, the National Center for Research on Earthquake Engineering (NCREE), the Chinese Institute of Civil and Hydraulic Engineering, the Chinese Society of Structural Engineering, the Federation of the Real Estate Development Associations of the Republic of China, the Sanlien Science Education Foundation, and P-waver Incorporation held a workshop on Strong Earthquake Building Health Analysis and Structural Safety Maintenance Management at the Chang Yung-Fa Foundation on December 20, 2022. This workshop featured 10 invited speeches delivered by experts from industry, government, and academia. The group photograph is shown in Figure 1. Director Chung-Che Chou and Dr. Shu-Hsien Chao from the NCREE were invited to offer presentations at the workshop.

This workshop aimed to evaluate available technologies for improving the safety and serviceability of a building throughout its entire life cycle. Taiwan lies on the boundary between the Philippine Sea Plate and the Eurasian Continental Plate. There are therefore many active faults, resulting in frequent seismic activity. As a result, residential areas can experience medium- to large-scale earthquakes during their lifetime. Due to nearby active faults, the metropolitan areas may also be impacted by near-fault seismic waves. If the fault becomes active and triggers a large-scale earthquake, numerous building structures in the metropolitan area will probably be damaged. Therefore, it is beneficial to install a structural monitoring system to conduct structural health diagnosis and receive early warning messages when the structure is damaged after an earthquake.

Director Chung-Che Chou delivered a presentation outlining the NCREE's emergency response after Guanshan and Chihshang earthquakes, which occurred at 9:41 p.m. on September 17th (UTC+8) and 2:44 p.m. on September 18th (UTC+8) 2022. The earthquakes, which registered ML 6.4 and 6.8, struck Guanshan and Chihshang in Taitung. Dr Chou also introduced the structural monitoring systems that were installed in several buildings and bridges in Taiwan by the NCREE in cooperation with the Central Weather Bureau, National Yang Ming Chiao Tung University, the National Laboratory Animal Center, and the Freeway Bureau, Ministry of Transportation and Communications. The structural monitoring system measures and records the structural vibration responses in order to provide early warning and evaluate the structural health status after an earthquake. The website "Taiwan Structural Monitoring Data Hub (TSMOD)" was created to display the data from structural monitoring systems and the analysis results. The structure monitoring data collected from these buildings during the two earthquakes were analyzed immediately to assess whether any damage had occurred as a result of the earthquakes. The above-mentioned structural monitoring data will be used to continuously develop and improve the technologies of structural system identification, damage assessment, post-earthquake structural safety rapid assessment, earthquake early warning, structural seismic response analysis, and simulation. These efforts aim to accomplish the ideal goal of implementing smart structural disaster prevention applications.

The installation of structural monitoring systems in Taiwan is limited. Furthermore, there is a lack of structural monitoring systems installed for building structures situated near active faults in Taiwan. Therefore, Dr. Chao delivered a presentation focusing on developing and integrating three major technologies: damage characteristics of near-fault seismic waves, the production technology of high-precision seismic motion maps (Shake-Map), and the empirical equation for structural damage estimation, to develop a general-purpose structural damage warning service technology, which applies to general building structures without installing structural monitoring systems. After an earthquake, users will only need to provide basic information about the target structure, such as its location, construction year, number of floors, building height, and structure type; the service of structural health status assessment can then be conducted for the target structure. When building structures near active faults without structural monitoring systems are damaged due to near-fault seismic waves, structural damage early warnings can be obtained through the rapid access of information using the technology developed in this research. This can assist the government and the public to plan and implement rapid response actions after a large-scale earthquake. It is also beneficial in reducing the impact caused by near-fault seismic waves and the loss of life, economy, and property.

Fig. 1 Group Photograph of Workshop

CES 2023—NCREE showed the 5D Smart Building Platform

Ren-Zuo Wang, Research Fellow, NCREE
Chih-Shian Chen, Assistant Research Fellow, NCREE
Jui-Mien Li, Assistant Research Fellow, NCREE

The Consumer Electronics Show 2023 (CES 2023), one of the annual events in the technology industry, has returned after the COVID pandemic. This exhibition was held in Las Vegas over four consecutive days and covered digital transportation, digital healthcare services, Web 3.0, the metaverse, sustainable technology, and human security. The focus was on innovative products that help solve world challenges, demonstration of innovative concepts such as energy conservation and power generation, solutions to food shortages, sustainable agriculture, smart cities, and access to drinking water.

In order to promote communication between startups in Taiwan and the international media, enhance the international reputation of Taiwan's startups, and facilitate international collaboration for Taiwan's startups, the National Science and Technology Council, the National Development Council, the Ministry of Economic Affairs, and the Ministry of Digital Affairs advocated Taiwan's scientific research and innovation before CES 2023, which had its highest attendance yet. Delegates from many countries attending the exhibition witnessed Taiwan's outstanding scientific research and technology achievements. The two-way communication between startups and government officials is expected to create more opportunities for cooperation for new startups in the post-pandemic era.

The SmartES of the National Center for Research on Earthquake Engineering (NCREE) had also been selected by the National Applied Research Laboratories to display the "5D Smart Building Platform" developed by the NCREE in the Taiwan Tech Arena at CES 2023. The main feature of this platform is that data management, display, and calculation for all personnel can be integrated in the 3D GIS map with a large number of maps and databases. Through this platform, we can assist government officials at all levels and managers of private enterprises to provide maintenance management strategies through AI technology.

During CES 2023, delegates from the United States, Canada, Japan, South Korea, Switzerland, Sweden, and South Korea came to the TTA Pavilion to visit the exhibition. More than 15 countries participated in an exchange of expertise with the "5D Smart Building Platform". The Korean Demo Show was held on the main stage of the Korean Pavilion and the technical briefing of the “5D smart building platform” was also held with the Korean manufacturers.

Fig. 1. Group photograph of the press conference before CES 2023.

Fig. 2. The NCREE attendance at the opening ceremony of CES 2023 at the TTA Hall

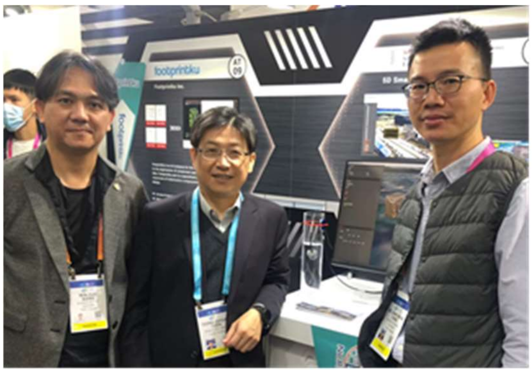


Fig. 3. Vice Minister Chen Tzong-Chyuan visited the 5D smart building platform team.

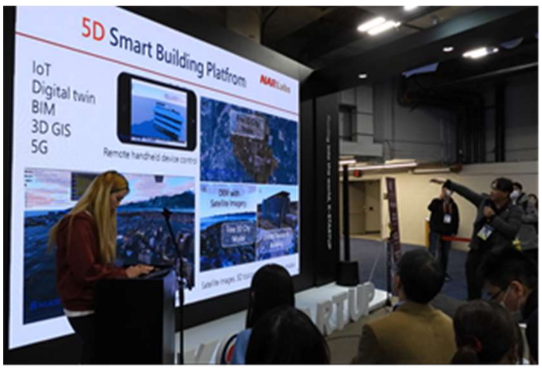


Fig. 4. Conducting an exchange of knowledge on the "5D smart building platform" at the Korea Pavilion.