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Application of Close-Range Photogrammetry for Post-Failure Reconnaissance of a Retaining Wall

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In Taiwan, typhoons and earthquakes are common natural disasters and both tend to cause failures of geotechnical structures. Consequently, there is much demand for rapid reconnaissance after such failures for the need of emergency response. The displacement and deformation of geotechnical structures are important for evaluating their damage level; however, it is sometimes difficult to approach failure sites and their damage state cannot be closely observed. In order to develop an indirect inspection method, close-range photogrammetry using the relative orientation technique is introduced. It has the capability of providing useful spatial information about an object at a certain distance with satisfactory precision without ground control points, and merely requires two partially overlapping photographs of the same scene taken from different viewpoints and a reference scale provided by any in situ object with a known length. Therefore, it is particularly useful for rapid measurements of damaged geotechnical structures in an inaccessible site.

In order to create a stereomodel of a specific scene using a pair of images from different viewpoints, the fact that projected image rays through conjugate points (image points in an image pair that correspond to the same object point) will intersect in space is used. This procedure is known as relative orientation. Each image has six unknown exterior orientation parameters: three position parameters, (X_L, Y_L, Z_L) and three rotation parameters, (ω, φ, κ). As illustrated in Fig. 1, the six parameters of the first image are fixed if the model coordinate system is defined to be parallel to that of the first image, and one of the position parameters of the second image is fixed for the model scale. Consequently, there will be two position and three rotation parameters of the second image that remain to be determined.

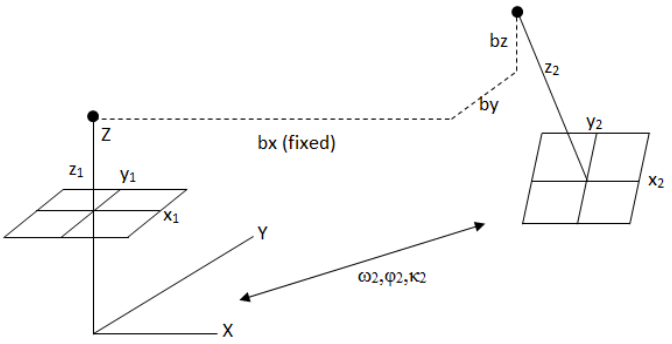


Fig. 1. Relative orientation between a pair of images

Fig. 2 illustrates a pair of partially overlapping images and a pair of conjugate image points. The two image rays defined by each image point and its corresponding perspective center, $\mathbf{a}_1$ and $\mathbf{a}_2$, will exactly intersect. Thus, $\mathbf{a}_1$, $\mathbf{a}_2$, and the vector connecting these two perspective centers, $\mathbf{b}$, can form a triangle, which defines a unique plane. The corresponding coplanar condition among these three vectors can be described as $\mathbf{b}\cdot(\mathbf{a}_1\times\mathbf{a}_2) = 0$. Along with the application of projective geometry and the singular value decomposition (SVD) technique, the relative orientation between an image pair can be uniquely solved according to the coordinates of the conjugate points in the image pair.

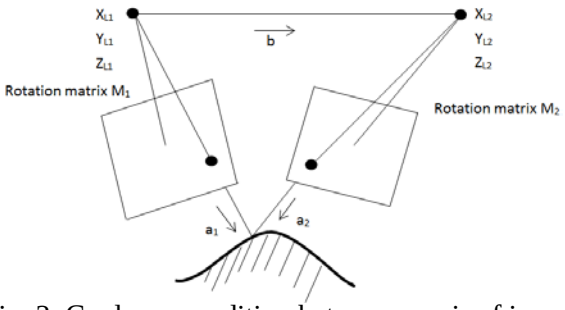


Fig. 2. Coplanar condition between a pair of images

On June 2, 2013, an M_L 6.5 earthquake occurred in Nantou County, Taiwan. The seismic intensity in most areas of Nantou County reached the intensity level with a peak ground acceleration (PGA) range of 80~250 gal, and a retaining wall at Lugu Junior High School was damaged. The wall and its backfill were separated, and a huge crack was induced on its wing wall. In order to demonstrate the proposed method, a pair of images of this case acquired in the field, as shown in Fig. 3, was used as an example. First, about twenty pairs of conjugate points that were well distributed over the images were chosen to minimize the error. By applying the mentioned coplanar condition and the related solution technique, the relative coordinates of these conjugate points were obtained. With the height of the man in the photos and the depth of the unit segment of the wall given, the displacement vector from point B to point A was calculated, and a 31.6-cm forward displacement was thus estimated. This value is close to the 30-cm tape measurement on the top of the retaining wall. Therefore, the accuracy of close-range photogrammetry using relative orientation adopted in this research is considered high enough for rapid reconnaissance after the failure of geotechnical structures.



Fig. 3. Image pair of the retaining wall damage at Lugu Junior High School

Cyclic Pushover Testing of a Shallow Foundation Model

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A footing is a simple type of structure foundation, which is generally used to resist vertical loading from a structure. When the structure is additionally subjected to lateral loading, the induced moments at the column base will rotate the footing to tilt the structure and even jeopardize the stability of the structure. Thus, the moment resistance of a footing is a major concern in foundation design. The footing of a structure subjected to a large earthquake may rock. In recent years, many researchers have attempted to utilize this foundation rocking mechanism in seismic design to isolate seismic waves for reducing the seismic demand. To investigate the applicability of foundation rocking for use in seismic isolation, we designed a rocking-governed footing model and conducted pushover testing on it to study the rotational characteristics of this type of structure.

A column-footing model was designed as displayed in Fig. 1, in which the column height was 80 cm, the footing size was 40 cm×40 cm and the weight of the model was 0.165 kN. The model was placed on dry sand of thickness 1.2 m. Vietnam sand was used for the soil specimen and the relative density of the sand was about 75%, which is categorized as dense sand. As shown in Fig. 1, the model was placed levelly on the sand surface and one side of the footing was adjusted to be orthogonal to the actuator. The center of the footing was set as the origin of the coordinate system, the X axis was set to be parallel with the actuator and the Y axis was set to be orthogonal to the actuator. Mass blocks with weights of 0.905 kN were placed on the top of the column to simulate the weight of the structure. A lateral load was applied at the top of the column along the X axis by the actuator. The test was displacement controlled and contained nine displacement cycles, with each corresponding maximum displacements of ±2 mm, ±4 mm, ±8 mm, ±10 mm, ±20 mm, ±30 mm, ±40 mm, ±50 mm, ±60 mm, respectively (＋for push, －for pull). On the top of the upmost mass block, a tilt meter was placed to measure the rotation of the column. An image measurement system was applied to measure the movement of the model during testing.

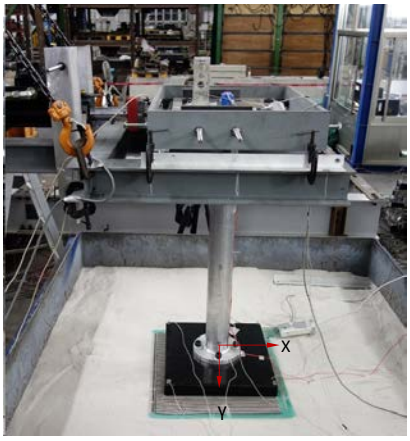


Fig. 1. Cyclic pushover testing

The lateral load-lateral displacement response at the location of the applied load is displayed in Fig. 2, while the lateral load-footing rotation response is shown in Fig. 3. These two curves had similar trends, indicating that the pushover response of the model was governed by the rotational response of the footing. In Fig. 2, the curve showed a highly nonlinear hysteretic response of which the loops were full. The responses of Cycles 1-4 were symmetric in the positive and negative displacements. The damping ratios corresponding to these four loops were about 30%. Once the lateral displacement in the +X direction exceeded 10 mm (the lateral load reached 0.21 kN), the curve became asymmetric in the positive and negative displacement directions. The phenomenon of asymmetry became more significant for larger displacements. For the positive movement, when the displacement exceeded 10 mm, the lateral force reached a maximum of about 0.21 kN and remained constant for further displacement; however, when the displacement further exceeded 30 mm, the lateral resistance decreased and a softening response occurred. For the negative movement, the lateral force increased with increasing lateral displacement and when the displacement reached -60mm, the lateral force was about 0.4 kN. This asymmetry phenomenon was due to the irrecoverable ground displacement under the large lateral load. The model had an eccentricity in +X direction (footing inclination) which caused a decrease in the lateral capacity in the +X direction, but an increase in the –X direction.

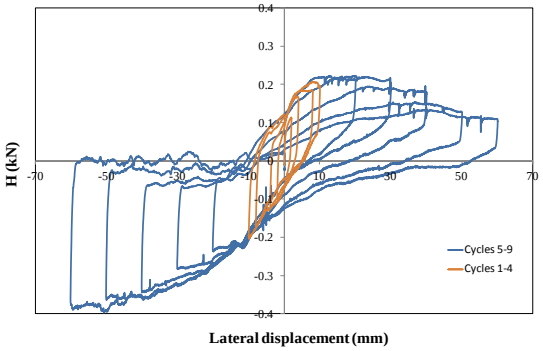


Fig. 2. Lateral load-displacement curve at the position of the applied load

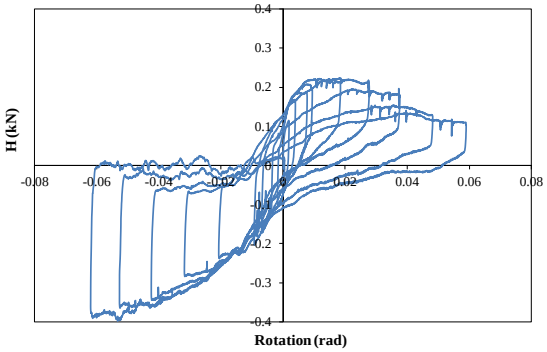


Fig. 3. Lateral load-footing rotation curve

Seismic Test of Centrifuge Pile Model

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Chung-Jung Lee, Wen-Yi Hung, Zong-Han Yang, National Central University

For resource integration of geotechnical laboratories and development of research energy for geo-earthquake engineering in Taiwan, the National Center for Research on Earthquake Engineering (NCREE) and the Civil Engineering Department of the National Central University (NCU) have implemented technical cooperation for centrifuge model testing and analysis in recent years. This article briefly introduces the results of model piles of centrifuge shaking table tests accomplished lately.

This study was undertaken at the Centrifuge Modeling Laboratory at NCU. The NCU Geotechnical Centrifuge has a nominal radius of 3 m and equips a one-dimensional (1-D) servo-hydraulically controlled shaker. According to the scaling law of centrifuge modeling, the size of pile foundations is reduced to 1/*N* times that of the prototype, where *N* is 80 as corresponding to the artificial centrifuge acceleration in this study. For seismic testing, if the amplitude of input motion is increased *N* times of the prototype and the excitation frequency is reduced to 1/*N* times of the prototype (i.e., the time interval is decreased to 1/*N* times of the prototype), then the seismic behaviors of the centrifugal model and the prototype are the same.

The purpose of this study was to investigate the seismic response of two different piles, namely the S-pile and the L-pile. The S-pile did not contain a pile cap; meanwhile, the L-pile was attached to a tip mass (0.23 kg). Therefore, the diameter of these two piles was 1.27 cm and consisted of a hollow aluminum tube. Further, strain gauges were attached on the surface of the tube. The L-pile and the S-Pile were installed in the center line of the model container and the distance between the two piles was far enough to prevent any interaction between them during shaking.

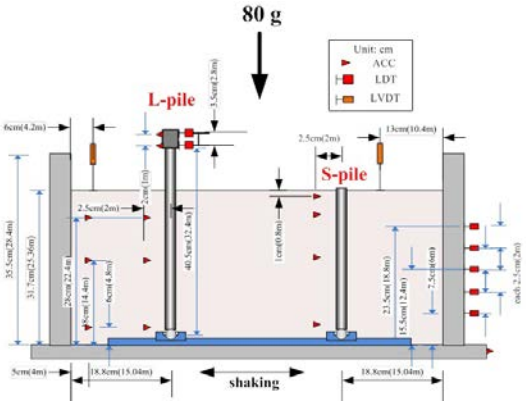


Fig. 1. Layout of centrifuge pile model

During the tests, there were two accelerometers attached at the pile head mass to measure the acceleration history of L-pile. Further, three vertical accelerometer arrays were installed in the near-field of each pile and in the free-filed layers to investigate the effect of soil-pile interaction. The layout of the centrifuge model and its top view are shown in Fig. 1 and Fig. 2, respectively.

After the preparation of the models, the centrifuge was accelerated at 80 g. A shaker was then invoked to excite the model with 1-D waves. In this test, a series of sinusoidal waves with a frequency of 0.5 Hz and excitation amplitudes of 0.02 g, 0.04 g, 0.06 g, 0.08 g, and 0.1 g were selected as input motions to simulate the seismic response of the piles embedded in the dry sand deposits.

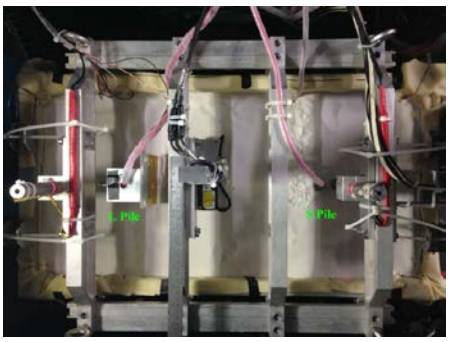


Fig. 2. Top view of the centrifuge specimen

The measured horizontal acceleration histories of the accelerometer at the pile tip mass (Acc_8) on the L-Pile and the input motion (Acc_29) during the 0.06 g sinusoidal test are shown in Fig. 3. Furthermore, to investigate the seismic behaviors of the soil-pile system, the transfer functions of the accelerometers at the L-Pile head mass, free-field array, and near-field array to the input motion respectively were deduced and compared as shown in Fig. 4. From this figure, the fundamental frequency of the dry sand deposit was identified to be about 2.05 Hz (as shown by the green line) and the predominant frequency of the soil-pile system was 0.55 Hz (as shown by the green line). It was found that the fundamental frequency of the dry sand deposit appears in the transfer function of the L-pile to the input motion, indicating soil-pile foundation interaction.

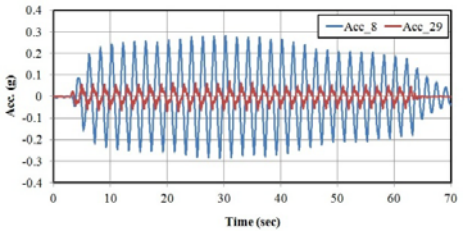


Fig. 3. Acceleration histories of the L-Pile head during the 0.06 g test

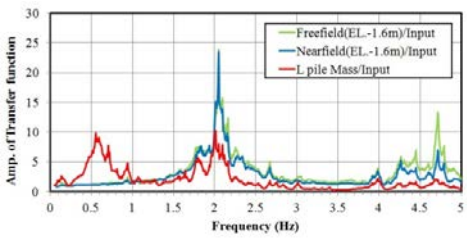


Fig. 4. Comparisons of transfer functions during the 0.06 g test

Experimental Study on the Seismic Performance of Bridge with Spread Footing and Rubber Bearing by Shaking Table Test

Kuang-Yen, Liu, Chia-Han, Chen, NCREE, Kuo-Chun, Chang, Tzu-Chun Tseng, National Taiwan University

Introduction

Spread footing is a widely-used footing type for bridge structure, but it may be exposed due to flooding and induced collapse due to earthquake. Meanwhile, it's been confirmed that the sliding of bearing system can mitigate the damage of bridge column. Therefore, this study aims to investigate the isolation mechanism resulted from bearing sliding and rocking of spread footing, and its effect on the unseating, column hinging, as well as rotation of footing.

Experimental program

The major parameters in this experimental study include bearing boundary condition and restrain of footing. The bridge specimen is shown in Fig.1. The superstructure consisting of reinforced concrete girder with the dimension of 500 cm ×50 cm ×20 cm and 18 sets of lead blocks provides 57.7 kN in weight. The substructure is assembled by two sets of A36 steel cap beams, columns, and footing plates. For each single column set, the weight is 3.73 kN. The steel column is 16.9 cm in diameter with thickness of 6.7 mm, and the height is 60 cm. The size for cap beam and footing plate is 51 cm ×30 cm ×5 cm, and 60 cm ×60 cm ×10 cm, respectively. The soil condition is modeled by the rubber pad with hardness of 60, and the size of pad is 100 cm ×100 cm ×10 cm. Total of four elastomeric rubber bearings were used to connect superstructure and substructure. The bearing size is 5 cm ×7.5 cm ×2.5 cm, and subjected to axial compression stress of 3.85 MPa. There are two different types of boundary condition for rubber bearing: semi-rigid and simply-supported. Semi-rigid condition means the rubber bearing is allowed to slide against the RC slab on the top surface but bolted to cap beam at bottom surface. Simply-support condition means the rubber bearing can only exhibit shear deformation and rotation without sliding at hinge end, but can slide at roller end because of attached P



Fig. 1. Experimental setup

In this study, total of six cases were carried out by shaking table test: (1)H0T-P0T, (2)R0T-R0T, (3)H2T-P2T, (4)R2T-R2T, (5)HFixed-PFixed, and (6)RFixed-RFixed. H-P stands for hinge and PTFE case, and rubber bearing was applied to south end of the girder as a hinge, while PTFE-rubber bearing to the north end as a roller. R-R represents the rubber bearing and supports both ends of the girder. 0T and 2T indicates the exposed depth of spread footing as a function of plate thickness. Fixed describe the rigid connection between footing plate and shaking table. The relative density of the sand is about 50%, and the maximum and minimum dry density is 16.3 and 14.4 kN/m^3, respectively. Input ground motions include acceleration records from El Centro in 1940 and TCU076 station in 1999 Chi-Chi earthquake. The peak ground acceleration (PGA) is in the range of 50 gal to 350 gal.

Experimental results

Figure 2 shows the rotation of footing for 0T case under TCU076 ground excitation. Based on the Draft for Specification for Seismic Design of Bridge Structure, the rotation angle at the top of the foundation should be limited to 0.02 rad when the structure was subjected to level III earthquake. It has been shown that the recorded footing rotations for Hinge, RB, or PTFE bearing case exceeded the code regulation at PGA of 200, 250, and 275 gal, respectively. However, there is no collapse for any cases in the tests.

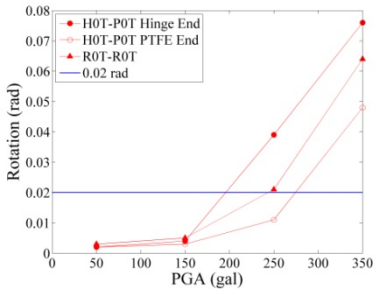


Fig. 2. Maximum rotation of footing under TCU076 ground excitation

Figure 3 shows the global structural response for R0T-R0T case under El Centro earthquake at PGA of 350 gal. Vertical axis represents the inertial force from RC girder, and horizontal axis is the relative displacement between RC girder and shaking table. The lateral force was limited to around 20 kN as a constant value due to remarkable rocking of spread footing, resulting in minor force demand and self-centering mechanism for substructure.

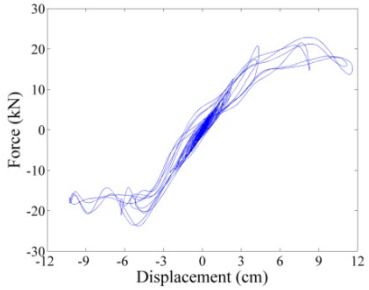


Fig. 3. Hysteresi curve for entire structure

under El Centro eqrthauke (PGA=350gal)

Figure 4 shows the ratio between measured moment and yielding moment for column in TCU076 case. The rigid base require a higher demand for column under hinge bearing. Instead, if the footing is allow to rocking, the column can remain in elastic due to lengthen of structural period, however, the increasing rotation may be reduced by increasing the surcharge loading above the footing. Another approach by changing the bearing condition from Hinge-Roller to RB-RB in fixed base case is also effective to decrease the acceleration of girder and moment demand/capacity ratio of column.

Summary

For bridge with spread footing, particularly the aspect ratio of column height to footing width is 1.0; the seismic performance is dominated by rocking of footing rather than sliding of rubber bearing.

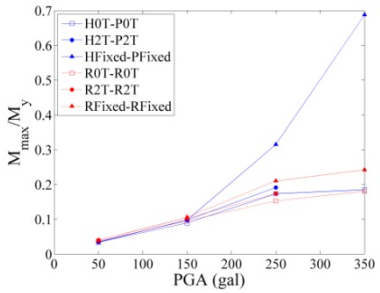


Fig.4. Column moment demand/capacity ratio under TCU076 ground excitation

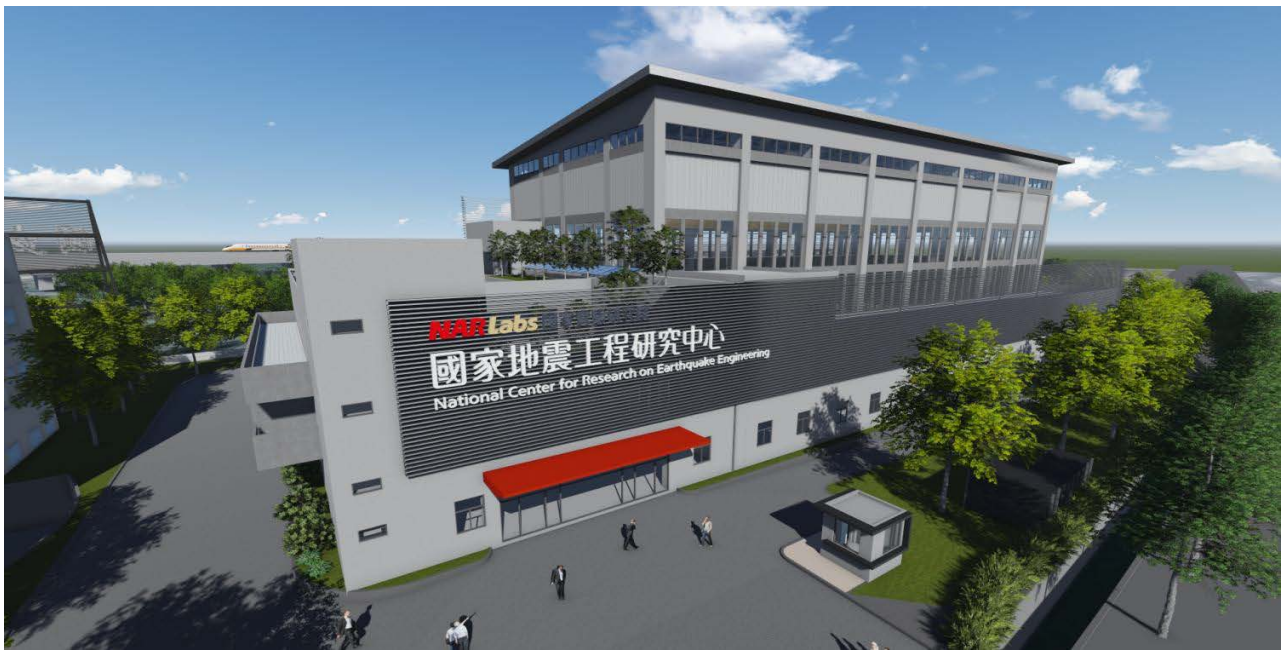
Preliminary Design and Overall Plan of NCREE Southern Laboratory

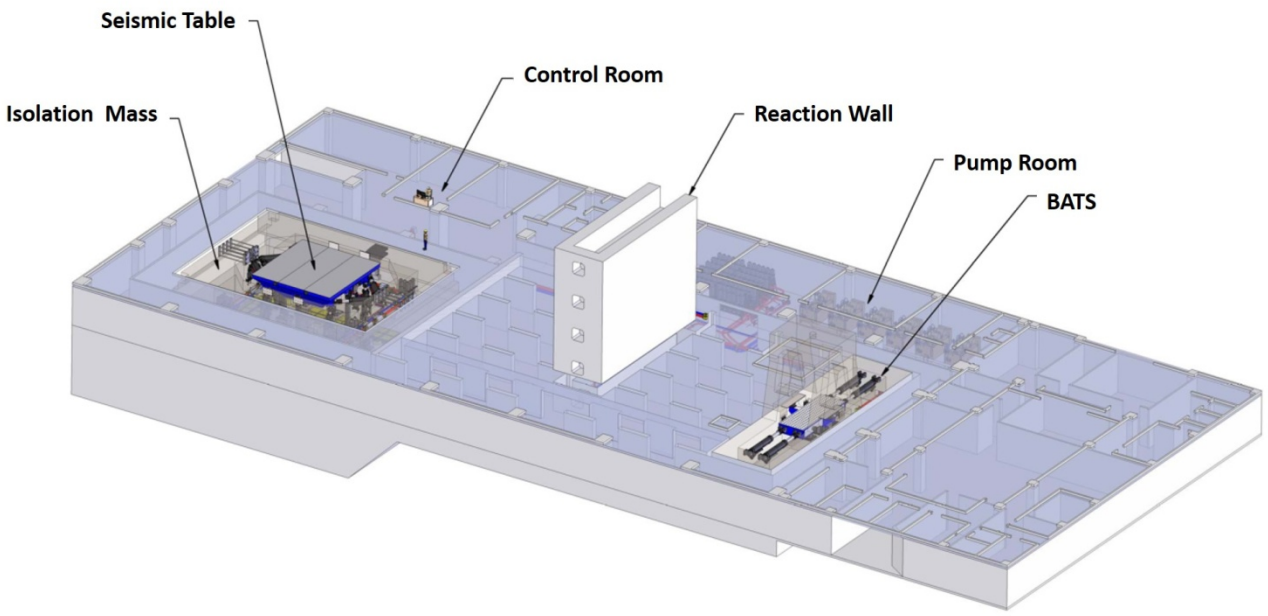
Fu-Pei Hsiao, Pei-Ching Chen, Associate Researcher, NCREE

The near-fault effect on buildings and infrastructure is a significant issue for human life and property in Taiwan due to the existence of numerous active faults. It is well-known that special characteristics with large displacements and high velocities can be observed close to a fault. However, it is difficult to reproduce such a near-fault earthquake record by using the existing test facilities of NCREE. As a result, experimental studies on near-fault effects have been rarely conducted. The National Applied Research Laboratories has planned to establish a southern laboratory of NCREE. It is to be equipped with a high performance six degree-of-freedom seismic simulation testing system, which can simulate near-fault motions. Once this laboratory is completed, NCREE can provide better seismic experimental services, which are beneficial for improving public safety during earthquake disasters, to government agencies, academia, and the industry.

The Southern Laboratory of NCREE, which is composed of a research building and a laboratory building, will be located at the eastern part of the Gueiren Campus of National Cheng Kung University (NCKU) in Tainan City. It will have a standard conference room that can accommodate up to 180 people on the first floor of the research building. The laboratory is a reinforced concrete building with a steel structural roof. It will facilitate a high performance seismic simulation testing system, and a biaxial dynamic testing system (BATS). In addition to these facilities, a reaction wall and a strong floor test system will be constructed. The dimensions of the reaction wall will be 12 m (height) × 15 m (width) × 5 m (thickness).

The seismic simulation testing system (referred to as a shaking table) can possess six degrees of freedom to simulate earthquake motions along three axes. The size of the shaking table is 8 m x 8 m with a self-weight of 1000 kN. Experimental specimens with a maximum weight of 2500 kN can be accommodated on the table. The shaking table is driven by eight high performance servo-hydraulic actuators. Four of them are installed horizontally while the others are mounted vertically. The weight of the shaking table and the above specimen is balanced by four static supports; therefore, the four vertical actuators have minimum responsibility for applying a dynamic loading. The hydraulic power is provided by five electrical pumps which offer a total continuous flow rate of 3,500 lpm with a working pressure of 210 kg/cm^2. To satisfy the performance requirements of near-fault ground motions, accumulator banks are equipped to provide the supplemental pressure and flow to operate the shaking table with a peak flow rate of 26,000 lpm. The maximum horizontal stroke and velocity of the shaking table are ±1.0 m and ±2.0 m/s, respectively. The maximum accelerations for the bare table in the horizontal and vertical directions are ±2.5 g and ±3.0 g, respectively. The reaction forces of the actuators are provided by the reaction mass with a weight of 40,000 kN. The reaction mass is isolated from the fixed foundation by air springs and dampers in order to reduce the vibration impact to the research building.





BATS is planned and designed to serve the industry for conducting performance tests of full-scale isolation devices and dampers. Its overall appearance is similar to the existing multi-axial testing system (MATS) at NCREE; however, the dynamic capacity is enhanced significantly to meet the test requirements for full-scale isolation devices. The maximum longitudinal stroke, velocity, and force capacity of BATS are ± 1.2m, ± 1.0 m/s, and ± 4.0 MN, respectively. Meanwhile, the maximum vertical stroke and velocity are ± 75 mm and ± 150 mm/s, respectively. A maximum vertical compressive force of 60 MN, which includes a dynamic force of 30 MN and a static force of 30 MN, can be achieved. In addition, a vertical tensile force of 8.0 MN is attainable to allow BATS to apply cyclic loading on test specimens vertically. The hydraulic distribution system is designed to provide as much flexibility as possible to meet the various testing scenarios in the laboratory. As a result, a peak flow rate of 18,620 lpm is available in BATS when the shaking table is not conducting any tests.

The reaction wall and strong floor system is used to evaluate the seismic behavior and performance of large or even full scale structures and members. Conventional testing methods, such as monotonic loading tests, cyclic loading tests and pseudo-dynamic tests, can be executed at the Southern Laboratory. Furthermore, a peak flow rate of 11,000 lpm is available due to the flexibility provided by the hydraulic distribution system as mentioned before. Therefore, dynamical tests, such as real-time hybrid simulation, and performance tests of dampers and semi-active devices, can be also conducted using the reaction wall and the strong floor system.

In conclusion, the near-fault effect on buildings and infrastructure can be investigated, performance tests of full-scale isolation devices can be executed, and advanced experimental techniques can be further developed once the Southern Laboratory is completed.

The Groundbreaking Ceremony of the Southern Laboratory of NCREE

Ho-Hsiung Yang, Associate Engineer, NCREE

Following the Chi-Chi earthquake in 1999 in Taiwan, much attention has been raised on the near-fault effects of ground motion, which is one of the threats from earthquakes that people in Taiwan have to face. However, the existing test facilities of NCREE in Taipei are not quite appropriate for the study of near-fault effects. Therefore, NCREE was determined to establish a new laboratory, which will be located at the Gueiren Campus of the National Cheng Kung University (NCKU) in Tainan City in southern Taiwan. Major test facilities in the Southern Laboratory of NCREE include a high performance 8 m × 8 m six degree-of-freedom seismic simulation testing system, which will be capable of simulating near-fault motions, a reaction wall and strong floor system, and a biaxial dynamic testing system.

To announce the commencement of construction of the Southern Laboratory of NCREE and pray for success, a groundbreaking ceremony was held on January 6, 2015. The ceremony was hosted by the Vice Premier of the Executive Yuan, San-Cheng Chang, and co-hosted by the Deputy Minister of Ministry of Science and Technology, Chung-Liang Chien, the Mayor of Tainan City, Ching-Te Lai, the President and Executive Vice President of NCKU, Hwung-Hweng Hwung and Huey-Jen Su (who is now the President of NCKU), the President and Vice President of NARLabs, Ching-Hua Lo and Tung-Yang Chen (who is now the Executive Vice President of NCKU), and the Director and Deputy Director of NCREE, Kuo-Chun Chang and Chien-Chz Hsu. In addition, important guests from the government, academia, and industry totaling more than 100 participated in this special event.

The construction and equipment cost of the Southern Laboratory of NCREE is estimated to be about 1.3 billion NTD, and it is scheduled to be completed by the end of 2016 and to commence a trial run in 2017. It will feature a seismic simulation testing system with higher performance than the existing one at the NCREE laboratory in Taipei, which can be employed to assess the seismic capacity of buildings and to verify the capability of seismic resistant techniques. In the future, NCREE can provide better seismic experimental services, which are beneficial for improving public safety during earthquake disasters, to government agencies, academia, and the industry.







Planning, Design, and Construction of a 1/13 Scaled RC Containment Vessel

Hsuan-Chih Yang, Chiun-Lin Wu, Yu-Chih Chen, Hu-Jhong Lu, Chang-Ching Chang, NCREE
Thomas T.C. Hsu, Yi-Lung Mo, Ken Cong-Hieu Luu, University of Houston

Introduction

It has been more than 60 years since the first commercial operation of nuclear power plants (NPP). The Three Mile Island, Chernobyl, and Fukushima accidents are the three most well known events that led to setbacks in the development of nuclear power industry. A reinforced concrete containment vessel (RCCV) is considered to be one of the key contributors to a NPP system's Defense in Depth (DID) strategy. The NCREE and the University of Houston, USA, cooperated to design and build a 1/13-scaled RCCV shell specimen to investigate the mechanical behavior and the failure mechanism of reinforced concrete cylindrical shells. This investigation provides a reliable finite element analysis for the design and safety assessment of the nuclear containment vessel.

Planning and Design

The RCCV under study is a hollow cylindrical shell structure with a rigid top stub and a strong bottom basemat. The prototype ABWR cylindrical shell has an outer diameter of 33m, a wall thickness of 2 m, and a clear height of 29.5 m (Fig. 1). Considering research demands, cost effectiveness and inherent facility limitations, the project design team drafted a good number of scaled models and evaluate the pros and cons of each model (Fig. 2). Comparisons revealed that the 1/13-scaled model could be manufactured accurately to represent the prototype. This resulted in a shell specimen design of 250 cm in outer diameter, 15 cm in thickness, and 225 cm in clear height (Fig. 3).

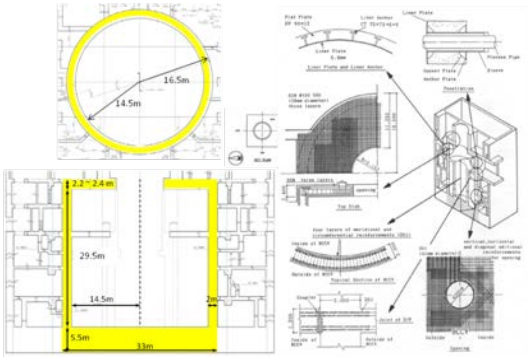


Fig. 1. Schematic drawings of nuclear RCCV

The compressive strength of concrete and tensile strength of steel reinforcement are 350 kgf/cm^2 and 3600 kgf/cm^2, respectively. The reinforcement of the cylindrical wall is scaled-down quite accurately from the prototype; the reinforcement ratio is 2% in the longitudinal and hoop reinforcement.

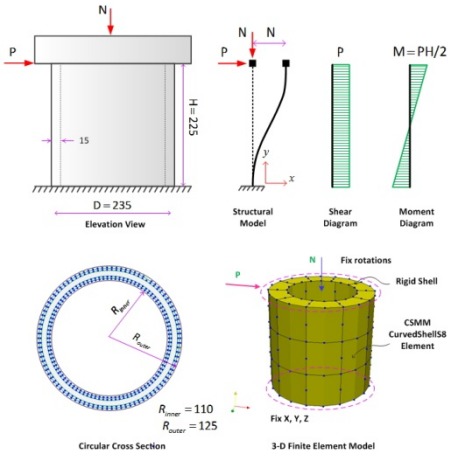


Fig. 2. RCCV numerical model for pre-test strength prediction

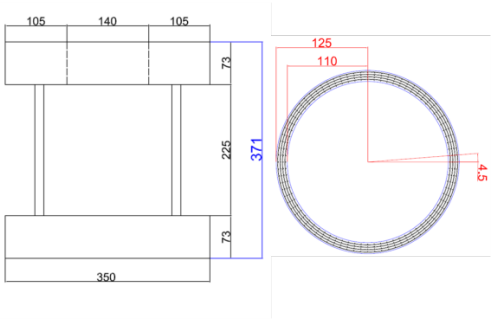


Fig. 3. Schematic drawing of 1/13 scaled RCCV specimen

Construction

The RCCV specimen's top loading stub and bottom basemat were constructed as steel boxes to have sufficient rigidity to avoid unfavorable occurrence of cracks and structural nonlinearity during tests. In addition, the concrete aggregate size and mix proportion of the cylindrical wall need to be carefully designed to maintain workability and quality of concrete casting (Figs. 4-6).

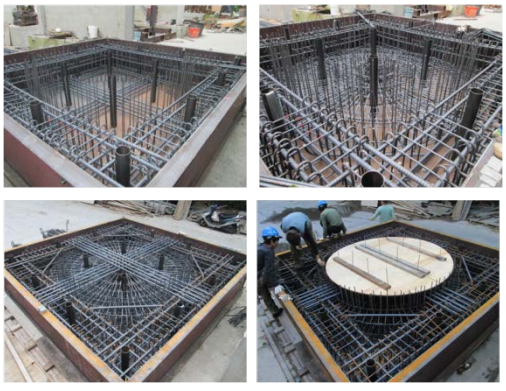


Fig. 4. Construction of basemat



Fig. 5. Construction of cylindrical wall

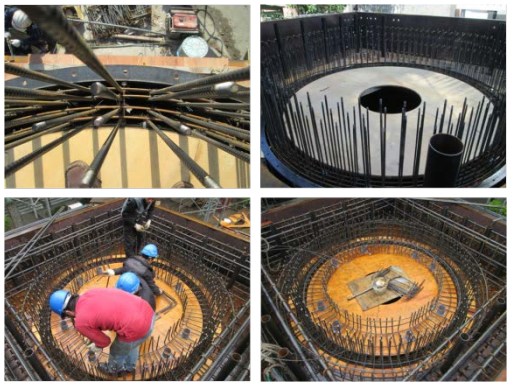


Fig. 6. Construction of loading stub

The pre-test finite element simulation showed that the specimen's ultimate lateral strength was around 5880 kN. To be conservative, eight 980 kN actuators are employed in the lateral direction to apply reversed cyclic loads, and four 980 kN actuators in vertical direction to maintain double curvature and constant axial load of the specimen. The test setup and loading protocol are given in Figs. 7-8. During the test, the 3D deformations of the cylindrical wall are monitored by a variety of advanced optical measurement systems, including four NDI Optotrak Certus HD motion trackers, two Pentax LiDAR scanners, and twelve Cannon full-frame digital cameras. In addition, the traditional force and displacement transducers as well as the SR4 strain gauges are installed. As such, the global and the local damage characterizations could be comprehensively measured.

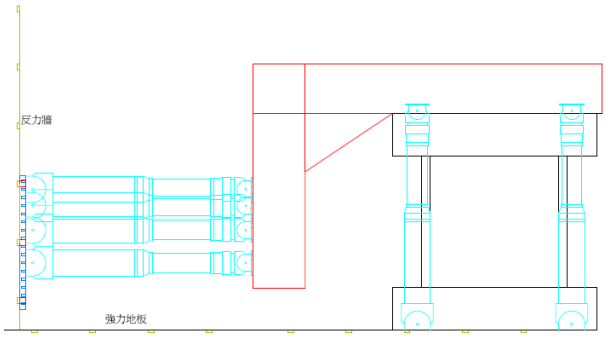


Fig. 7. East-West elevation of test setup

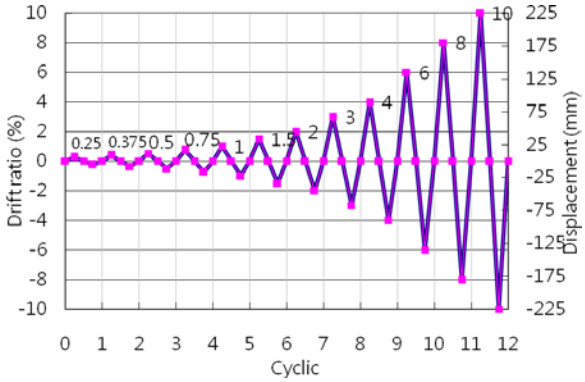


Fig. 8. Loading protocol

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