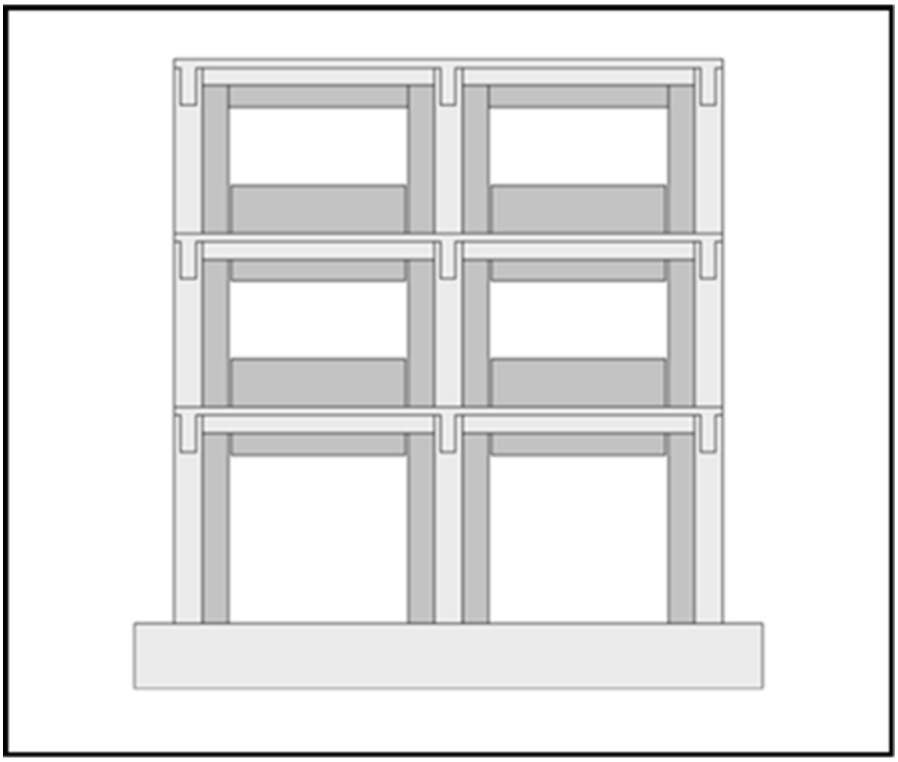
RESILIENCY PROJECT

2019/12 - E-Defense Test Blind Prediction Competition



Supplementary document 1

Building overview, design philosophy, and contest rules

Tokyo Metropolitan Resilience Project of the National Research Institute for Earth Science and Disaster Resilience (NIED)

Contact person: Trevor Yeow (Project Researcher and Blind Prediction Contest Coordinator)

Affiliation: Earthquake Research Institute, University of Tokyo Email: trevoryeow@eri.u-tokyo.ac.jp

Affiliations

FOREWORD

To interested participants,

We would like to invite you to participate in a blind prediction contest to estimate the response of a 3-story reinforced concrete building to be tested at the E-defence facility in December 2019. This test is part of the Tokyo Metropolitan Resilience Project of the National Research Institute for Earth Science and Disaster Resilience (NIED). More information on this project is provided in this document.

The test specimen is designed with the performance objective of continued functionality in severe shaking events. The building has exterior standing, hanging, and wing walls which will be casted to be monolithic with the frame elements as a simple method to increase the building's strength and stiffness. Special detailing is provided to limit damage to these wall elements and ensure that plastic hinges form where intended.

This supplementary document contains information related to the key features of the building and the design philosophy adopted to give interested participants a general overview of the specimen. It will also outline the contest rules. A second supplementary document will be provided containing more detailed building and test information such as member dimensions and reinforcing configurations.

Once again, thank you for showing interest in this competition, and we look forward to your participation.

Sincerely,
The Resilience Project team

Contents

CHANGE LOG

27th March 2020

- Pg 15 - Updated test plan from three tests (including Takatori record) to five tests (only using artificial record) – contestants had already been notified of this change in Update #2 posted on 16th of December 2019.
- Pg 15 - Updated descriptions on the objectives of each of the five tests performed.
- Pg 16 - Clarified that the provided recorded accelerations have already been time and amplitude-scaled.
- Pg.17 – Clarified that participants only need to predict the response under the 1.0-scaled and 1.5-scaled (first run) events for the competition, though it is encouraged that contests try predicting the response at all five events for research purposes.

1. PROJECT BACKGROUND

1.1 The Tokyo Metropolitan Resilience Project

Tokyo Metropolis, located in the Kanto region, is the capital city of Japan. There are 13.9 million residents living within Tokyo Metropolis (as of June 2019), making it one of the most populated cities in the world and a major global economic power. However, the city rests near the border of several tectonic plates and has a high risk of experiencing significant earthquakes. Due to its social and economic significance, it is of the upmost importance that the city can recover quickly from such natural disasters.

One method to reduce recovery time is to be able to rapidly and reliably assess the safety of buildings. Currently, safety is evaluated using a two-step inspection process in Japan; a rapid visual inspection and a more detailed interior inspection. This time-consuming process can lead to significant disruptions in building occupancy. There is also a possibility of buildings incurring damage which is hidden or difficult to identify which could then pose a threat to its occupants if reoccupied and hinder its surroundings.

To address these needs, the National Researcher Institute for Earth Science and Disaster Resilience (NIED) funded the Tokyo Resilience Project. The project has two key purposes:

1) Data acquisition, processing, and utilization for rapid assessment of building performance from E-defense tests, for both structural and non-structural components, for evaluating the safety for continued building occupation; and,
2) Sensor data acquisition and utilization of real buildings and ground sites

The project is divided into five themes:

1) Comprehensive loss assessment procedure in a pilot metropolitan residential area, with an E-defense test of Japanese-style wooden houses;

2) Enhancing the resiliency of buildings for disaster management and developing a structural health monitoring system to evaluate continuous functionality, with an E-defense test of a reinforced concrete building;
3) Holistic assessment of seismic damage in medical facilities, with an E-defense test of a steel building;
4) Functionality maintenance in indoor space, with E-defense tests of several "test bed" building types for simulating the performance of various non-structural components; and,
5) Data acquisition, processing, and utilization toward establishing damage assessment system. This involves acquiring and processing results from the other four themes, past E-defense tests, and the seismographic network, and utilizing these towards establishing a rapid damage assessment system.

1.2 The 2019 December E-defense Test

The E-defense test for which the blind prediction contest will be held is part of the second theme of the Tokyo Resilience Project. The test specimen is to be representative of buildings used as a "center for disaster management", such as city halls, and will be fitted with various types of non-structural elements. Performance of building components, both structural and non-structural, will be monitored using accelerometers, video cameras, fiber optic cables, among others. From this, a structural health monitoring system will be developed to provide rapid assessment of building damage.

Further information on the building and test details are provided in latter sections of this document.

2. DESIGN PHILOSOPHY OF TEST SPECIMEN

The specimen to be tested at the E-Defense facility in December 2019 was designed by Nikken Sekkei Ltd. It is a 3-story reinforced concrete frame building, with 2-bays in the direction of loading and 1-bay in the perpendicular direction. The test specimen was designed to 80% scale.

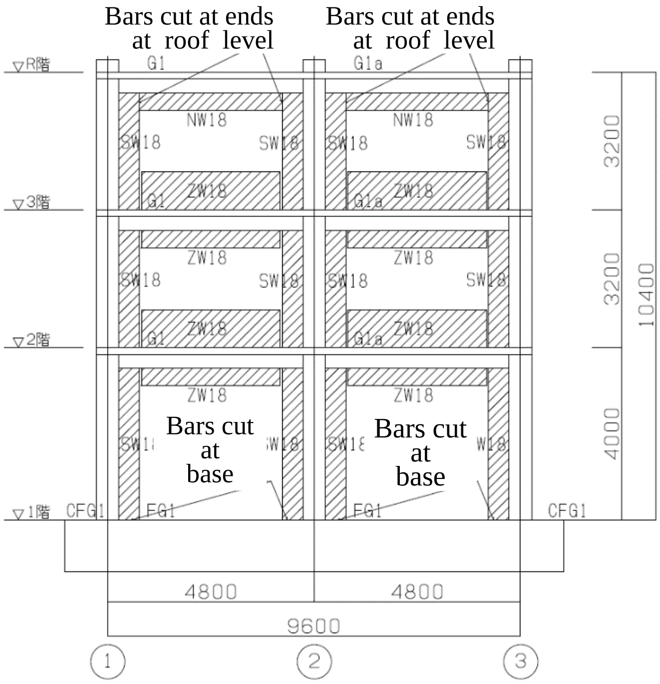
The test specimen is to be representative of buildings of importance, such as city hall buildings where continuous functionality is crucial following severe seismic shaking events. To achieve this performance objective without requiring large frame elements or structural shear walls, the building's strength and stiffness were increased by casting the exterior reinforced concrete spandrel wall elements to be monolithic with the frame elements. Special detailing is provided to ensure that: (i) plastic hinges form at locations of interest to control the deformation mechanism, and (ii) exterior wall element damage is reduced.

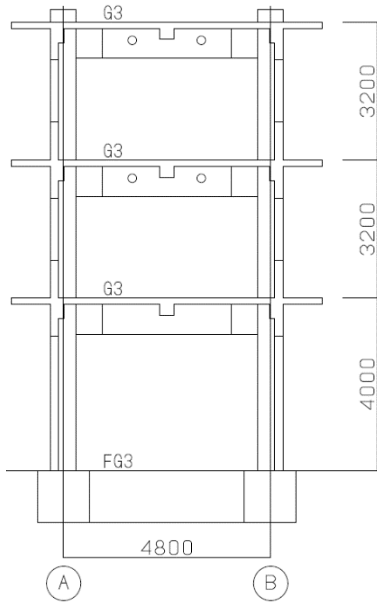
In order to meet the continued functionality performance objective, the following criteria were set:

1) The building (considering effect of spandrel walls) must not exceed 0.33% interstory drift or experience ductility greater than 1.0 at a base shear coefficient of 0.55; and,
2) The building (ignoring spandrel walls) must be able to resist forces corresponding to a base shear coefficient of 0.3.

3. GENERAL BUILDING LAYOUT AND DIMENSIONS

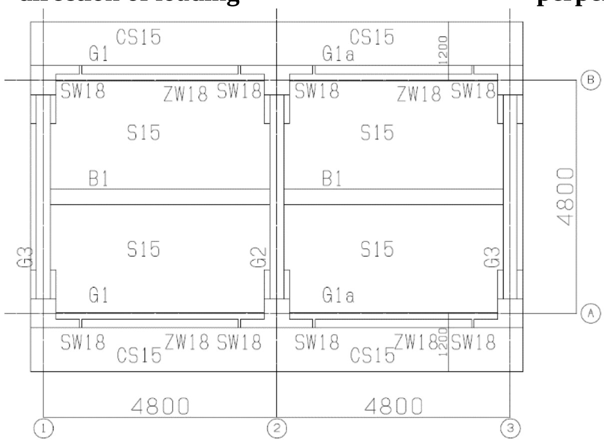
The dimensions of the building are shown in **Figure 1**. It is 3-stories high, with a 1^{st}-to-2^{nd} floor height of 4.0 m, and other floor heights of 3.2 m. It has 2-bays in the direction of lateral loading, and 1-bay in the perpendicular direction. All bays have a centerline-to-centerline span of 4.8 m. Note that the codes included in **Figure 1** (e.g. NW18) are member IDs which is covered in more detailed in the second supplementary document.





(a) Frame elevation in direction of loading

(b) Frame elevation in perpendicular direction



(c) Plan elevation

Figure 1. Test specimen dimensions

Standing, hanging, and wing walls will be casted to be monolithic with the frame elements in the in-plane frame direction. Gaps are present between the standing/hanging walls and the wing walls at the 2nd and 3rd floor beams to ensure that plastic hinges form where intended and to minimize wall damage. The hanging wall on the roof-level and the wing wall at the base of the ground floor have no gaps, but have their flexural reinforcing cut at plastic hinge locations to avoid issues associated with bar buckling.

4. BUILDING DESIGN OVERVIEW

The information provided in this section were obtained from Nikken Sekkei Ltd's design report.

4.1 Serviceability level design

Based on the Japanese Building Code, the calculation for the base shear coefficient corresponding to serviceability level design at which the building must remain linear, C_i, is calculated using Eq. (1):

$$C_i = Z.R_t.A_i.C_o \tag{1}$$

Where Z = seismic zoning coefficient (taken as 1.0 for the Tokyo region)

R_t = design spectral coefficient

A_i = lateral shear distribution factor

C_o = standard shear coefficient

The design spectral coefficient, R_t, is calculated using Eq. (2):

$$R_t = \begin{cases} 1 & T \le T_c \\ 1 - 0.2\left(\frac{T}{T_c} - 1\right)^2 & T_c < T \le 2T_c \\ 1.6\,T_c/T & 2T_c < T \end{cases} \tag{2}$$

Where T = building period

T_c = soil natural period (ranges from 0.4 s for hard soils to 0.8 for soft soils)

The design period, T, is calculated using Eq.(3):

$$T = (0.02 + 0.01a)h \tag{3}$$

Where h = total superstructure height (in m)

a = ratio of story height consisting of steel columns and girders to entire building

Given that there are no steel members in the building, T is thus calculated as 0.21 s. As T is smaller than T_c for all possible soil type scenarios, R_t is taken as 1.0.

The lateral shear distribution factor for the i^{th} story, A_i, is calculated as:

$$\mathrm{A}_i = 1 + \left(1/\sqrt{a_i} - a_i \right) . \frac{2T}{1 + 3T} \quad (4)$$

Where a_i = ratio of weight supported by i^{th} story versus total building weight

The standard shear coefficient, C_o, is taken as 0.2 for the calculation of C_i. This value is the demand which a building may experience several times during its service life, and thus needs to be considered to ensure minimal loss of functionality in frequent shaking events. Based on the previous assumptions, C_i can be obtained as shown in Table 1.

Table 1. Calculate of design story shear forces

Story	**Height (m)**	**Weight (kN)**	**Weight supported (kN)**	a_i	A_i	C_i	**Total story shear force (kN)**
3	10.4	511	511	0.260	1.44	0.287	147
2	7.2	719	1230	0.624	1.16	0.233	286
1	4.0	740	1970	1.000	1.00	0.200	394

4.2 Performance objective assessment

As described previously, there are two key performance objectives considered in the design of the building; (i) the building should remain elastic and not exceed 0.33% interstorey drift at a base shear of 0.55, and (ii) the bare frame must be able to resist a base shear of 0.3.

Pushover analyses were performed by Nikken Sekkei Ltd which demonstrated that both performance objectives were met. However, as this report is providing an overview of the building for the blind prediction competition, these pushover analyses will not be shown here.

5. NON-STRUCTURAL ELEMENTS

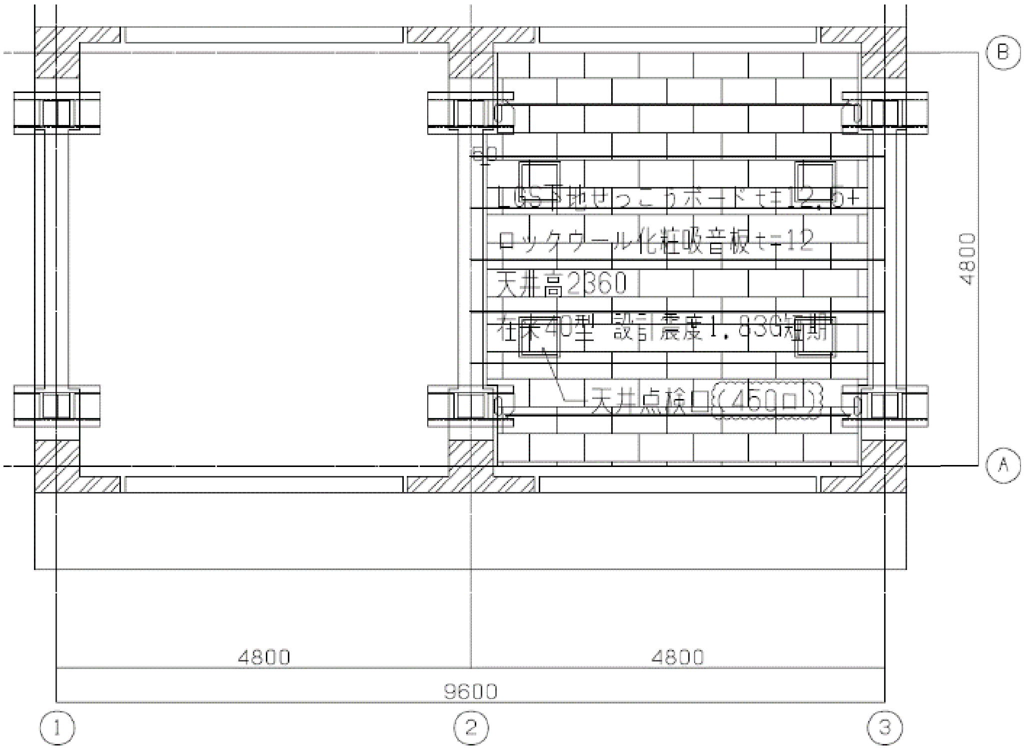
There are 4 types of non-structural elements which are planned to be added to the test building; (i) suspended ceilings, (ii) windows, (iii) exterior tiles, and (iv) plant on the roof. Two variations will be considered for each non-structural type; one with common detailing and another with more resilient detailing.

Ceilings will be located under the 3rd floor and roof levels and will only be installed in one bay as measuring instruments are required on the other. The two ceiling variants are braced and unbraced ceilings. As the available area is relatively small, it is not possible to install one of each variant per floor. As such, the braced ceiling will be installed under the roof level where the acceleration demand is expected to be greater. An illustration of the suspended ceiling setup is shown in **Figure 2**.

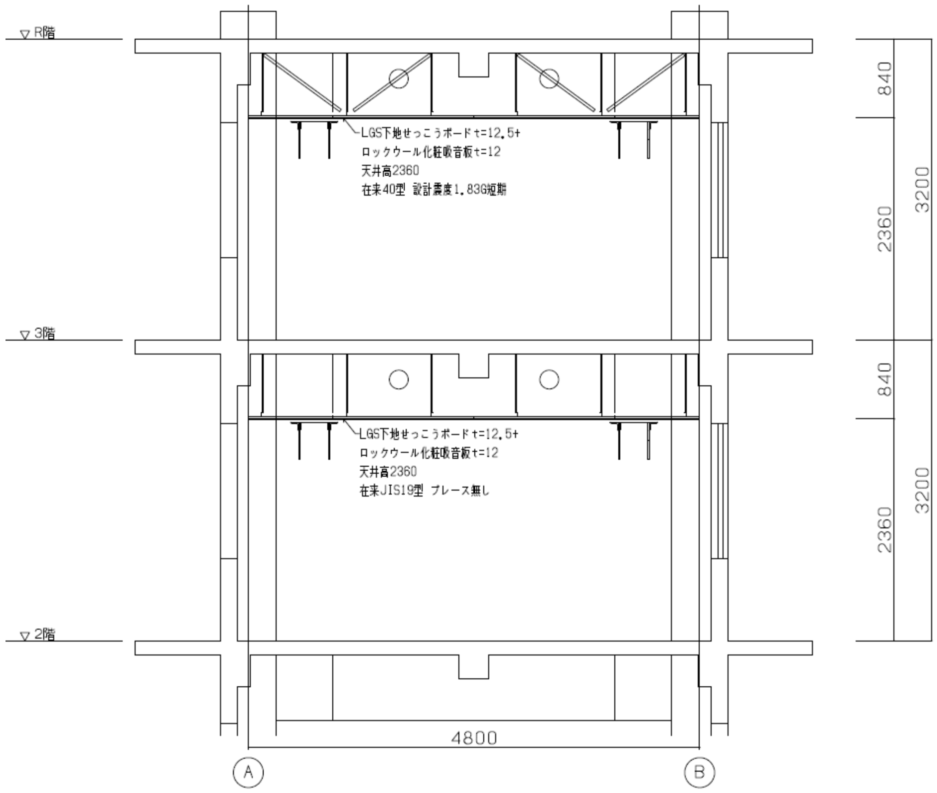
Windows will be installed between the 2nd-3rd and 3rd-roof stories as shown in **Figure 3**. These will again be placed on only one bay. The resilient window option will placed between the 2nd-3rd floors where the drifts are expected to be the largest.

Tiles will be attached to the building on only one bay and one side of the building but will cover the entire height of the building, as shown in **Figure 3**. The left half of the tiles will be attached using typical mortar, while the right half uses a special adhesive to allow some relative deformation between the tiles and frame.

There are plans to install plant equipment on the roof. However, funding arrangements and construction details are still being finalized at the time of producing this document. If this component type is confirmed to be included, construction details will be provided to contest participants once available.



(a) Plane elevation



(b) Side elevation

Figure 2. Suspended ceiling overview

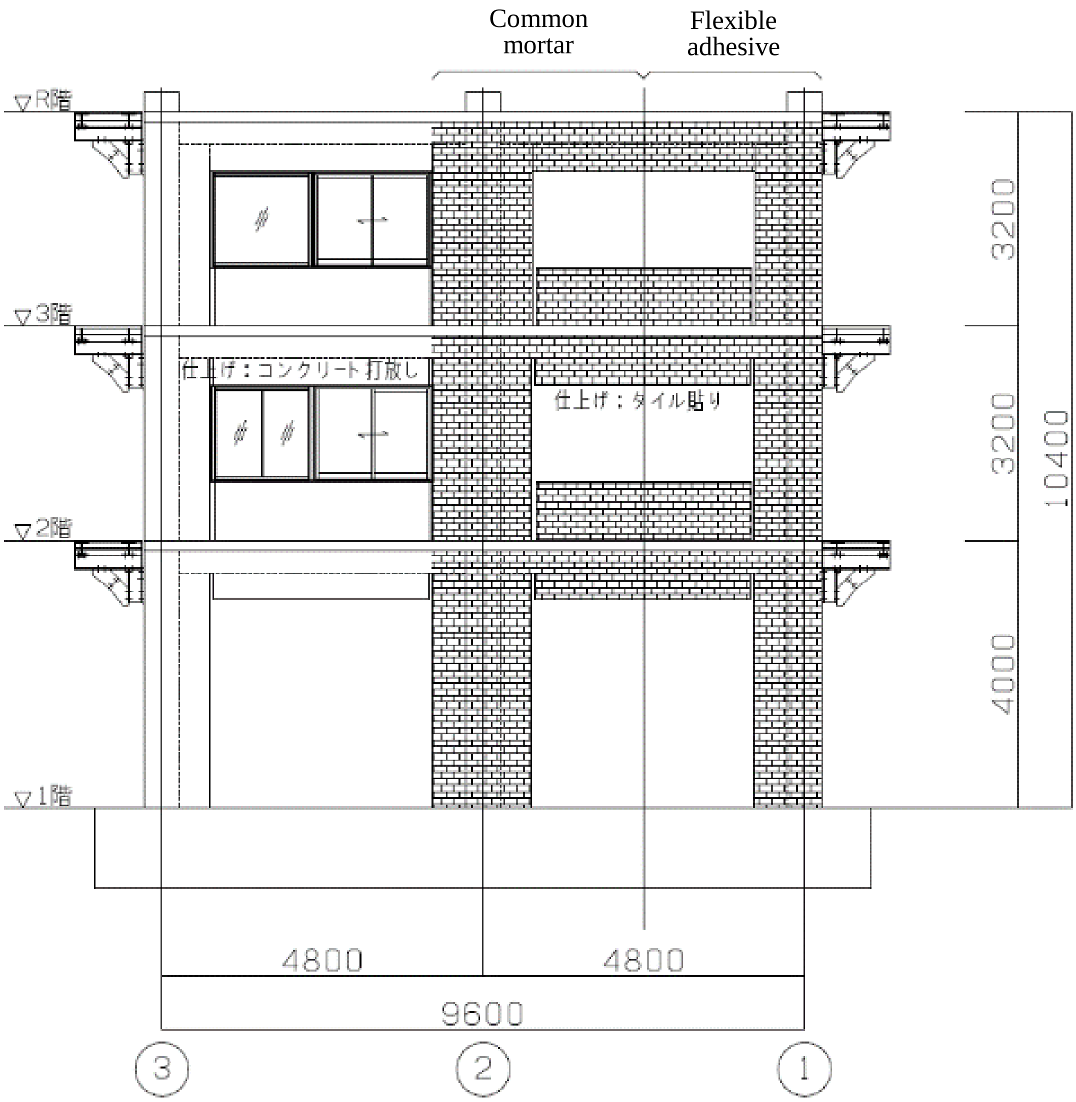
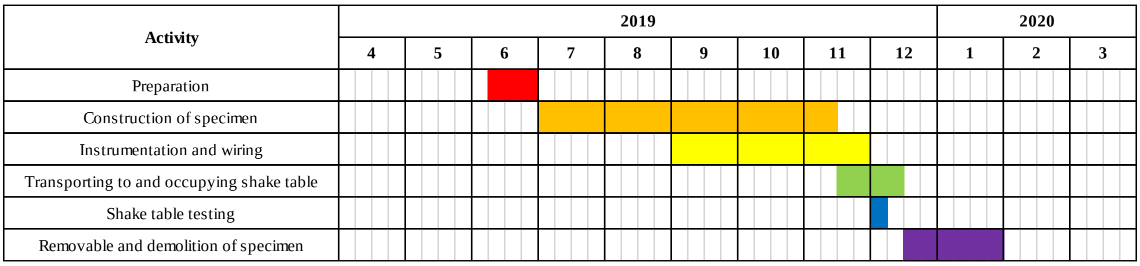


Figure 3. Window and tile configuration (note – tiles are only provided on one side of the building, while windows are placed on both sides but on the same bay)

6. TEST PROGRAM

The schedule for the test program is shown in Table 2.

Table 2. Test schedule



The earthquake simulation tests was performed over the first week in December 2019. **[27th March 2020] Five tests were performed using an artificial record, with scale factors of 0.2, 1.0, 1.5, 1.5 again, and 1.6.**

~~*Three tests will be performed using the following records:*~~

~~*1. Artificial record at 100% shaking intensity*~~

~~*2. Artificial record at 150% shaking intensity*~~

~~*3. JR Takatori north-south component (scale factor TBD)*~~

The artificial record at 100% shaking intensity is representative of the Japanese Building Code. **[27th March 2020] The objectives of each of the five tests were as follows**

- **0.2-scaled: to evaluate whether serviceability requirements were satisfied;**
- **1.0-scaled: to confirm that the building was mostly elastic and that the interstory drift was less than 0.33%;**
- **1.5-scaled (run 1): to evaluate the building's performance under the demands required for buildings with post-disaster functionality;**
- **1.5-scaled (run 2): to evaluate if the building is capable of surviving an "aftershock" of equal intensity to the main shock (as required in Japanese Building code);**

- **1.6-scaled: to observe the building's response under highly non-linear behaviour.**

~~*The first test is to confirm that the peak interstory drift of any floor at a base shear coefficient of approximately 0.55 is less than 0.33%. The second test is to observe if continued functionality can still be achieved at more significant events.*~~

~~*The final test using the Takatori record is to observe the building's dynamic behaviour close to its safety limit of 2% interstory drift. However, the specimen cannot exceed 2% drift for safety reasons. As such, the exact scale factor which can be used is yet to be determined.*~~

It should be noted that all records used were time-scaled by $0.8^{0.5}$ due to the specimen being 80% of full-scale. **[27th March 2020] The recorded shake-table accelerations, which have already been time and amplitude-scaled, have been uploaded to the competition website.**~~*The unscaled records are available on the competition website.*~~

7. CONTEST RULES

The proposed contest rules are as follows:

1. Contestants may participate as a team or as an individual, though the same person may not be involved with multiple submissions

2. Contestants are to predict the following response **[27th March 2020] under the 1.0-scaled and 1.5-scaled (first run) events (though contestants are encouraged to predict the response for the other three events for research purposes, though these will not be considered towards determining the top teams)**:
   - Roof displacement history relative to the shake table surface for each of the three ground motions applied in time intervals of 0.01 s.
   - Peak interstory displacement of each floor for each of the three ground motions applied.
   - Peak base shear coefficient for each of the three ground motions applied.

3. Contestants should submit their results in a spreadsheet provided. In addition, contestants should provide a short summary of their numerical approach.

4. Contestants will be provided building drawings, including detailing of non-structural components. Material test results will also be provided to contestants once available.

5. Unfiltered shake table recordings from the experimental tests will be provided to participants mid/late December 2019.

6. A representative from the top three teams will be invited to present their modelling approach at a special session at the World Conference in Earthquake Engineering in Sendai, 2020.

7. Accuracy of the displacement history response for all three earthquake simulation tests will be assessed using sum-squared-error (SSE) as follows:

$$SSE = \sum_{i=1}^{n} \left(x_{predicted} - x_{measured}\right)^2$$

Where $x_{predicted}$ is the predicted relative roof displacement value, $x_{measured}$ is the measured relative roof displacement value, and *n* is the number of datapoints.

8. Accuracy of the peak drift responses will be assessed using sum-squared-error of natural log (SSENL):

$$SSENL = \sum_{i=1}^{n} \left(\ln(Drift_{predicted}) - \ln(Drift_{measrued})\right)^2$$

Where $Drift_{predicted}$ and $Drift_{measured}$ are the drifts corresponding to predictions and measurements, respectively.

9. Accuracy of the base shear coefficient response will also be assessed using SSENL using base shear coefficient values instead of drifts.

10. For each of the three building response categories, contestants will receive a score based on the error recorded, with 1st place (lowest error) receiving 1 point, 2nd place receiving 2 points, etc. The top three teams will be the teams with the three lowest total score. If the top three cannot be determined due to multiple contestants being tied with the same score, the tied contestants will then be ranked according to their placement in the "roof displacement history" category.

Example

Consider the following scenario where six participants are ranked in each of the three categories. Team C and E are automatically in the top 3 as both teams have the lowest points total in the competition. While B and F are tied in terms of total points, team B has a higher placement in the "roof displacement history" category and thus would also be awarded the final position in the top three.

Team	**Placing**			**Total**
	Roof displacement history	**Peak interstory displacement**	**Peak base shear coefficient**	
A	3	6	6	15
B	2	4	4	10
C	4	1	1	6
D	6	5	5	16
E	1	3	2	6
F	5	2	3	10