Dam break test for scaled down slab beam and flat slab Domino house structural system

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Abstract. Tsunami is a succession of waves travelling throughout water body which is resulted by the sudden displacement of a substantial volume of water on the ocean. This disastrous event typically generated due to seismic activity occurs on the seabed or any kind of disturbance that happen either naturally or man-made, below or above the ocean. The hydrostatic pressure produced during this catastrophic event might cause significant damage to many common structures should that they are not being built to resist such imposed load by the tsunami. Tsunami field survey observations also indicate that the structural failure would be escalated more in the presence of water borne debris such as wooden logs, vehicles, containers or other heavy objects. Through this paper, the outcomes of the experimental study are obtainable for the quantification of the hydrodynamic pressure force on the structures. The structure used for the experiment is a scaled down 1:10 model by utilizing the flat slab structural system, a typical structural system that being used in most building worldwide other than the slab beam structural system, thus resembling the exact behaviour of failure to the real structure when it imposed with the tsunami pressure.

1. Introduction

In the recent years, several places throughout the globe had been struck by the tsunami. Tsunami which also known as harbour wave is a kind of natural disaster that is generated due to seismic activity or movement of tectonic plate on seabed. These caused the displacement of large volume of water on the ocean and travelled to the land at nearly 800km/hr. One of the deadliest tsunami ever recorded striking the land was in Japan that is generated due to the earthquake event known as Tohoku, one of the massive Earthquakes that ever recorded in the modern history. The earthquake of magnitude 9.0-9.1 (MW) had generates a massive tsunami wave that reaching up to 40.5m height which hit the nearest countryside such as Miyako city in Tohoku and Sendai. This disastrous natural event had resulted in such a substantial losses and damages of properties and structures, which caused by the earthquake shaking as well as the high pressure induced by the tsunami wave. This paper would only focuses on the impact of the hydrodynamic pressure induced by tsunami wave on the structural buildings near the shore, using a scaled down Dom-ino flat slab structure model, without the impact of water borne debris.
1.1. Problem statement
In the pass, the design of building structure is being made by only emphasising the gravitational load that are subjected to the building, where various types of lateral load that might possibly imposed to the building is being ignored and not considered by the engineers. As the result, most of the old stock building does not have the capacity to resist the lateral forces that induced by different kind of natural disaster such as seismic movement during an earthquake event, the flowing water borne debris during tsunami as well as in the event of landslide movement. Besides, most building that being built presently and in the pass typically had adopted the open building architectural concept, which has several flaws and weaknesses for instance like structurally unstable, lack of redundancy and unsymmetrical. Having said that, most of the old stock buildings were containing fragility where improvement of the conventional practice of designing the old building should be made to make it remain relevant to be implemented in the present day and in the future. This had increase the curiosity on how to improve the structural system so that building that being constructed in the future are durable and safer like never before, especially on encountering the impact of natural disaster. This paper would focus on tsunami impact to the structure system only, without considering the non-structural elements. To that sense, the test to simulate the tsunami occurrence have to be made in order to obtain all of the hydrodynamic parameter when tsunami hit the structure, so that the impact of tsunami to typical building are able to be quantified and analysed.

1.2. Objectives
The objectives of this study are:

a) To construct the scale down dom-inos slab beam and flat slab house for dam break test
b) To test the model using dam break test at various impounding water level to obtain the tested static and dynamic parameters of pressure and natural frequencies due to water surge

1.3. Scope of Study
A scaled down 1:10 Dom-inos models being casted based on the basic architectural model known as Dom-inos house, an open floor plan structure consisting of concrete slabs supported by reinforced concrete column. The model cast using mix design with proportion 33.36: 65.88: 31.00: 14.13 of cement, coarse aggregate, fine aggregate and water respectively. The model is tested in dam breaker tank by applying the impounding water in rotating reservoir. The results will be compared with the harmonic vibration test of the structure during the intact condition. Besides that, the water borne debris is not included in this study

2. Literature Review

2.1. Dam Break Test
Dam break is a very popular validation case for tsunami effect study due to its simplicity of set-up with no special inflow or outflow condition is needed. Moreover, the onshore propagation of the tsunami bore is also similar to the dam-break problem. In this study, the dam-break condition was achieved by impounding water in rotation reservoir tank. This tank contained two areas, i.e., the area containing the reservoir water and the flume (it refers to the model area or the impact bed area). The reservoir was a horizontal and rotational cylindrically shaped structure, which was 2 m long and had a diameter of 2.5m. On the reservoir top, there was an opening gate (2m×0.75m). During the tests, when the collected water reached the target level, the reservoir tank was rotated in a clockwise direction with the help of electrical engines, which resulted in the dam-break waves (Marsono, 2016).
2.2. Dom-ino House

Dom-ino house was introduced by Le Corbusier in 1914. This model was proposed an open floor plan consisting of concrete slabs supported by minimal number of thin, reinforced concrete columns around the edges with stairway providing access to each level on one side of the floor plan. Its title, the ‘Dom-ino’ system, references the contraction of the Latin term, domus (house) and the word “innovation”. Composed of three walls, six posts, and staircase, each module can be combined with others so as to construct houses or even monumental edifices. A structural system was conceived - a framework - completely independent of the floor plans of the house: this frame carried the floors and staircases. It was to be fabricated out of standardized elements to be attached to one another permitting great variety in the grouping of the houses.
3. Methodology

**Figure 3** Overview of Domino House (Source: Schneider, 2013)

**Figure 4.** Flowchart of research methodology
3.1. Scaled Down Dom-inon Model Structure Preparation

The small scaled model of dom-inon model was constructed into 1:10 scale from full scale model. The model consists of 3 floor level with thickness of 40mm for each slabs and it has 6 columns in each floor with size of 20mm x 20mm. The slab dimension for ground floor is 943mm long and 586mm width, while for the first and second floor is 743mm long and 586mm width. The floor height from each level is 240mm.

![Figure 5. 3D drawing of Dom-inon flat slab house](image)

![Figure 6. 3D drawing of Dom-inon slab beam house](image)

3.2. Concrete Characteristic Test

3.2.1. Compression Test. Compression test is used to determine the compression strength, $f_{cu}$ of a concrete. Twelve cylindrical with diameter of 50 mm and 100mm height was placed in the Compression Testing Machine. The load was applied at a constant rate of 0.2kN/m$^2$/s until the concrete cylindrical failed. The average maximum load of 12 samples was recorded as compressive strength, $f_{cu}$.

3.2.2. Natural Frequency Test. Two types of natural frequency test conducted to define the characteristic natural frequency of the scaled down structure namely hammer test and harmonic vibration test. The hammer test conducted by hammering the model with the rubber hammer ten times within 10 seconds intervals over one minute. For the harmonic vibration test, it is applied by sweeping the expected first to fifth or highest level of frequencies in building. The test basically helps to predict the dynamic behaviour sustained by the structure, which later allow us to validate the preparation of force, resonance, fatigue and other destructive effects of forced vibrations.

3.2.3. Dam Break Test. In tsunami effect study, dam break test is the most prevalent validation case that can be used because it simple to set-up and no specific inflow or outflow condition is required. Besides, the dam break problem basically resembles the onshore propagation of the tsunami bore. In this experiment, the dam-break condition was attained by accumulating water in rotation reservoir tank. The tank is consisting of two areas, the area that enclosing the reservoir water and the flume (referring to the
model area or the impact bed area). The reservoir was a horizontal and rotational cylindrically shaped structure, which was 2 m long and had a diameter of 2.5m. On the reservoir top, there was an opening gate (2m×0.75m). During the tests, the model structure was initially positioned on a specified spot, then the rotating tank was locked with the opening gate at the top position and it was filled up with water to the required. When the collected water reached the target level, the reservoir tank was rotated in a clockwise direction with the help of electrical engines, which resulted in the dam-break waves, the flowing water in the form of a hydraulic bore, which move passing the structure. To record the water flow hitting the structure as well as height and speed of wave, a CCD video camera were placed at appropriate position to get the best view of the testing process.

4. Result and Discussion

4.1. Hammer Test

During this test, five accelerometers were used to measure the natural frequency of the structure. The accelerometers were attached to each level of slab of the structure and label as A1 in the ground floor, A2 in the first floor and A3 in the second floor while for column, accelerometer labelled as A11 was attached to the ground column and A12 to the first floor column. When the load was applied to the ground slab, the accelerometer will record the frequency of the structure and the result will be compare with the frequency of the structure when the structure is applying with the hydrodynamic force from the dam break test. The natural frequency of the model structure obtained through the hammer test is 21.01135 Hz.

![Location of accelerometers for hammer test](image)

4.2. Dam Break Test

In order to figure out the impact of the hydraulic bore on the model structure, eight pressure cells used which being attached to the structure on the selected column and stairs, where the pressure meter were placed fronting to the structure’s upstream face for the pressure time history measurement. To measure the height of water level at the location of the model structure, water level gauges were used. The behaviour of the hydraulic bore recorded using a high speed video camera along with the bore velocity and the impact to the model structure. When the hydraulic bore hit the pressure metre, it will start to record the result of the hydraulic bore impact to the structure in the data logger. Two accelerometers attached to the slab of first (A1) and top floor (A2) to record the frequency of the building during the hydraulic bore impact.
For impounding water-depth 0.625m which equivalent to 1.921m³. The results are as following:

Table 1. The data of hydrodynamic parameters recorded by pressure meter 2

| Time (s) | Velocity (m/s) | Strain | Load Coefficient | Load (N) | Surface area of pressure meter (m²) | Pressure (N/m²) | Frequency (Hz) |
|----------|----------------|--------|------------------|---------|-------------------------------------|----------------|----------------|
| 1st second | 3.00           | 0      | y=0.0444x        | 0.000   | 0.001257                             | 0              | 0              |
| 2nd second | 3.00           | 0.042  | y=0.0444x        | 0.946   | 0.001257                             | 752.543        | 13.83057       |
| 3rd second | 3.00           | 0.042  | y=0.0444x        | 0.946   | 0.001257                             | 752.543        | 0.92773        |

Table 2. The data of hydrodynamic parameters recorded by pressure meter 3

| Time (s) | Velocity (m/s) | Strain | Load Coefficient | Load (N) | Surface area of pressure meter (m²) | Pressure (N/m²) | Frequency (Hz) |
|----------|----------------|--------|------------------|---------|-------------------------------------|----------------|----------------|
| 1st second | 3.00           | 0.027  | y=0.0084x        | 3.214   | 0.001257                             | 2557.109       | 0              |
| 2nd second | 3.00           | 0.054  | y=0.0084x        | 6.429   | 0.001257                             | 5114.218       | 13.83057       |
| 3rd second | 3.00           | 0.027  | y=0.0084x        | 3.214   | 0.001257                             | 2557.109       | 0.92773        |

Table 1 and 2 indicates the different magnitude of pressure that subjected to the pressure meter due to the hydrodynamic wave. For impounding water depth of 0.625m, the maximum height of water reached just after its release from the reservoir tank is approximately at 400mm, which generates the greatest pressure to the model structure. The highest pressure recorded for pressure meter 2 and pressure meter 3 are 752.543 N/m² and 5114.218 N/m² respectively. Pressure meter 3 had recorded the highest value of pressure due to its location which located in the most upstream face of the structure, which being hit by the hydrodynamic wave of the water first before pressure meter 2. The velocity of water travelled in the flume is 3.00m/s, which obtained by calculating the speed of flowing water over the designated grid tiles on the flume. It is found that the pressure imposed by the hydrodynamic pressure during the test towards the model structure does not sufficient enough to displace the scaled down Dom-ino model.
structure. The hydrodynamic pressure exerted to the model structure by the hydraulic bore of the water had produced maximum frequency of 13.831Hz.

For impounding water-depth 1.875m which equivalent to 7.897m³. The results are as following:

Table 3. The data of hydrodynamic parameter recorded by pressure meter 2

| Time          | Velocity (m/s) | Strain | Load Coefficient | Load (N) | Surface area of pressure meter (m²) | Pressure (N/m²) | Frequency (Hz) |
|---------------|----------------|--------|------------------|----------|-------------------------------------|----------------|----------------|
| 1st second    | 4.50           | 0      | y=0.0444x        | 0.000    | 0.001257                            | 0.000          | 0              |
| 2nd second    | 4.50           | 0.042  | y=0.0444x        | 0.946    | 0.001257                            | 752.543        | 1.00708        |
| 3rd second    | 4.50           | 0.042  | y=0.0444x        | 0.946    | 0.001257                            | 752.543        | 0.92773        |

Table 4. The data of hydrodynamic parameters recorded by pressure meter 3

| Time          | Velocity (m/s) | Strain | Load Coefficient | Load (N) | Surface area of pressure meter (m²) | Pressure (N/m²) | Frequency (Hz) |
|---------------|----------------|--------|------------------|----------|-------------------------------------|----------------|----------------|
| 1st second    | 4.50           | 0      | y=0.0444x        | 0.000    | 0.001257                            | 0.000          | 0              |
| 2nd second    | 4.50           | 0.042  | y=0.0444x        | 0.946    | 0.001257                            | 752.543        | 1.00708        |
| 3rd second    | 4.50           | 0.042  | y=0.0444x        | 0.946    | 0.001257                            | 752.543        | 0.92773        |

The table above indicates the different magnitude of pressure that subjected to the pressure meter due to the hydrodynamic wave. For impounding water depth of 1.875m, the maximum height of water reached just after its release from the reservoir tank is approximately at 450mm as observed from high speed video, which generates the greatest pressure to the model structure. The highest pressure recorded for pressure meter 2 and pressure meter 3 are 752.543 N/m² and 7766.034 N/m² respectively. Pressure meter 3 had recorded the highest value of pressure due to its location which located in the most upstream face of the structure, which being hit by the hydrodynamic wave of the water first before pressure meter 2. The velocity of water travelled in the flume is 4.50m/s, which obtained by calculating the speed of flowing water over the designated grid tiles on the flume. It is found that the pressure imposed by the hydrodynamic pressure during the test towards the model structure does not sufficient enough to displace the scaled down Dom-ino model structure. The hydrodynamic pressure exerted to the model structure by the hydraulic bore of the water had produced maximum frequency of 1.0071Hz.
Figure 9. Location of pressure meter for slab beam Dom-in0 house during dam break test

For impounding water-depth 0.625m which equivalent to 1.921m³. The results are as following:

Table 5. The data of hydrodynamic parameters recorded by pressure meter 3

| Time (s) | Velocity (m/s) | Strain | Load Coefficient | Load (N) | Surface area of pressure meter (m²) | Pressure (N/m²) | Frequency (Hz) |
|----------|----------------|--------|------------------|----------|------------------------------------|-----------------|---------------|
| 1st second | 2.25           | 0.054  | y=0.00272x       | 1.985    | 0.001257                           | 1579.157        | 0             |
| 2nd second | 2.25           | 0.109  | y=0.00272x       | 4.007    | 0.001257                           | 3187.749        | 7.703         |
| 3rd second | 2.25           | 0.082  | y=0.00272x       | 3.015    | 0.001257                           | 2398.568        | 0.775         |

Table 6. The data of hydrodynamic parameters recorded by pressure meter 2

| Time (s) | Velocity (m/s) | Strain | Load Coefficient | Load (N) | Surface area of pressure meter (m²) | Pressure (N/m²) | Frequency (Hz) |
|----------|----------------|--------|------------------|----------|------------------------------------|-----------------|---------------|
| 1st second | 2.25           | 0.042  | y=0.0417x        | 1.007    | 0.001257                           | 801.265         | 7.703         |
| 2nd second | 2.25           | 0.042  | y=0.0417x        | 1.007    | 0.001257                           | 801.265         | 0.775         |

The table above shows the different value of pressure that act toward the pressure meter. For impounding water depth 0.625m, the maximum height of water after it been release from the tank is 400mm which produce the highest pressure to the structure. The highest pressure recorded in pressure meter 3 and pressure meter 2 is 3187.749 N/m² and 801.268 N/m² respectively. Since pressure meter 3 is located in the most upstream faces in the structure, it had recorded the highest pressure value. By calculating the speed of water flow over grid tiles, the velocity of water travelled in the flume is 2.25 m/s. Since the
pressure is not sufficient enough to move the structure, the dom-ino scaled structure is not being displaced. The frequency that the structure produce during the dam break test is 7.703 Hz.

For impounding water-depth 1.875m which equivalent to 7.897m$^3$.

| Table 7. The data of hydrodynamic parameters recorded by pressure meter 3 |
| --- |
| Time (s) | Velocity (m/s) | Strain | Load Coefficient | Load (N) | Surface area of pressure meter (m$^2$) | Pressure (N/m$^2$) | Frequency (Hz) |
| 1st second | 3.6 | 2.745 | $y=0.00272x$ | 100.919 | 0.001257 | 80285.694 | 0 |
| 2nd second | 3.6 | 3.291 | $y=0.00272x$ | 120.993 | 0.001257 | 96255.089 | 1.209 |
| 3rd second | 3.6 | 2.448 | $y=0.00272x$ | 90.000 | 0.001257 | 71599.045 | 0.549 |

| Table 8. The data of hydrodynamic parameters recorded by pressure meter 2 |
| --- |
| Time (s) | Velocity (m/s) | Strain | Load Coefficient | Load (N) | Surface area of pressure meter (m$^2$) | Pressure (N/m$^2$) | Frequency (Hz) |
| 1st second | 3.6 | 0.083 | $y=0.0417x$ | 3.051 | 0.001257 | 2427.582 | 0 |
| 2nd second | 3.6 | 0.167 | $y=0.0417x$ | 6.140 | 0.001257 | 4884.421 | 1.209 |
| 3rd second | 3.6 | 0.125 | $y=0.0417x$ | 4.596 | 0.001257 | 3655.997 | 0.549 |

For impounding water depth 1.5m, the maximum water level after it been release from the tank is 450mm as observe in high speed video. The highest pressure recorded in pressure meter 3 and pressure meter 2 is 96255.089 N/m$^2$ and 4884.412 N/m$^2$ respectively. The water velocity for this test is 3.6 m/s. Since the pressure of water very high, the structure had been displaced about 3 m from its original position.

**Figure 10.** The structure had been washed away by the powerful hydraulic bore

5. Conclusion
From the study conducted, it can be concluded that:

1. This study is capable to determine the hydraulic pressure induced by the hydrodynamic bore of water which resembles the impact of tsunami to the structure, thus can be used to examine the stability of the whole structure against force.
2. The time history vibration measured as frequency (Hz) of the building that induced by the impact of hydrodynamic water bore were also determined.

3. It can be predicted that the higher the level of impounding water depth in rotation tank, which will create greater hydraulic bore and exerts higher hydrodynamic pressure to the model, will cause the model to displace and washed away similar to the real events of tsunami.

4. The frequency of the scaled down Domino model when subjected to the hydrodynamic pressure would be lower than its natural frequency recorded in its intact condition, and become even lower when subjected to the greater hydrodynamic pressure because the structure strength is laterally deteriorating and become less stiff. The results obtained from the test had proved that the invisible cracks will always initiated in the system even if the building is minimally disturbed.

6. References
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