Seismic Analysis of Single Unit Tunnel Form Building Subjected to In-Plane Lateral Cyclic Loading Using Ruaumoko 2D Programme

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Abstract. Seismic effect to the tunnel form building (TFB) will vary depending on the location of the epicentre, magnitude and frequency of the seismic event. This effect can be mitigated by implementing a seismic analysis using the Ruaumoko 2D programme. The seismic analysis was conducted to examine the safety level of the TFB when it was subjected to 10 previous seismic events. The analysis emphasized the in-plane direction of lateral cyclic loading. The 10 selected seismic excitations were Pacoima Dam, El Centro North-South and East-West, Mexico City, Ranau, Lahad Datu, Kunak, Batu Niah, Manjung and Bukit Tinggi. The analysis results of tunnel form building (TFB) in terms of spectral displacements, earthquake excitations, pseudo-spectral acceleration and deformed shape of single unit tunnel form building obtained in this study. Based on these analyses, tunnel form building (TFB) can only withstand low seismic loading with far-field earthquakes. When subjected to a seismic load greater than 5 Richter Scale and near field excitation, tunnel form building will not safe to be occupied.

1. Introduction
Indonesia is one of the most disaster-prone nations on earth. It lies on the Pacific “Ring of Fire”, where tectonic plates strike with many volcanic eruptions and earthquakes occurred [1]. A 7.7 magnitude earthquake hit Palu, Sulawesi on Friday morning, causing a tsunami around 3 meter high. It was the most destructive earthquake to hit Indonesia since the 2004 tsunami in Aceh. Malaysia is in the region of low seismic under long-distant earthquake from Sumatra and near-field earthquakes fault line [2]. The research found that strong earthquakes in the tectonic plates of the Andaman Sea, South China Sea, Sulu Sea and Sulawesi Sea that can generate tsunamis, and are expected to hit Perlis, Kedah, Penang, Perak, Selangor, Sabah and Sarawak but the probability Malaysia will be hit by a strong-scale earthquake is questionable [3]. Even though Malaysia is not in a high seismic zone, but it is encircled by countries such as Indonesia and the Philippines that are in high seismic activity areas. In 2015, Kota Kinabalu, Sabah experienced a 6.0 Richter Scale that affected the structural building in Kota Kinabalu. Despite tunnel form building (TFB) construction method showing good behaviour during earthquake, the abundances of these structures are scattered around the world including Malaysia, Indonesia, Japan, Italy, Spain, and other countries. 50 years ago, the tunnel form building was invented to form repetitive cellular structure and widely used for vertical and horizontal element simultaneously for a modern method of construction [4]. Tunnel form building has its own advantages to quickly construct with high quality, low cost, sustainable, systematic and earthquake safe to construct cellular building such as low and high-rise buildings, hostels, condominiums and others.
In order to perform the seismic analysis subjected to the building software such as Ruaumoko 2D is suitable to be used. Ruaumoko 2D Programming is the inelastic dynamic analysis program which can be run based on the database from previous earthquake records [5]. Therefore, in this study, the seismic analysis of single-unit TFB subjected to in-plane lateral cyclic loading will be investigated using Ruaumoko 2D program. The analysis results in terms of spectral displacements, earthquake excitations, pseudo-spectral acceleration and deformed shape of single unit tunnel form building are discussed in the results and discussion sections.

2. Modelling of Tunnel Form Building

The model was designed as one over third scale single unit of 3-storey tunnel form building as shown in Figure 1. The single unit of tunnel form building model was analyzed under in-plane lateral cyclic loading using RUAUMOKO 2D Programme. In order to represent the effect of existing tunnel form building constructed without considering any earthquake loads in Malaysia, 3-storey single unit tunnel form building was designed based on BS8110 was utilized in this study using hysteresis program in Ruaumoko 2D. In order to develop the hysteresis loop, the Pampanin wall-slab Joint Hysteresis model was used. The experimental hysteresis loops were compared with modelling hysteresis loops. The analysis parameters such as lateral strength, displacement and equivalent viscous damping (EVD) were obtained from this analysis.

Since peninsular Malaysia did not experience any devastated earthquake events previously, ten past earthquake records have been utilized in this study. Earthquake records that have been selected to represent the great, major, strong, moderate, light, minor and very minor with a magnitude ranging in between 3 to 8.5 Richter Scale. These past earthquake records were selected in order to determine the survivability of tunnel form building under various magnitudes and peak ground acceleration of earthquakes.

Meanwhile, the mode shape of the tunnel form building also been examined in this study using DYNAPLOT program. A mode shape is a specific pattern of vibration executed by a lateral load at a specific frequency. Different mode shapes were associated with different frequencies. Most of the seismic loads are live forces acting horizontally on the structure. Typical seismic loads would be an earthquake or a wind load against a facade. The number of deformed shapes depends on the storey
number and type of structural components in the building. From this analysis, lateral displacement can be obtained.

3. Results and Discussion

3.1. Hysteresis Loop Style and spacing

Graph Force (kN) versus Displacement (mm) were plotted based on experimental data and then compared with the modelling results at 0.75% drift as shown in Figure 2. The red line graph represented the data from the experimental result, while the blue line graph represented the modelling results. The maximum push displacement is 19.96 mm and maximum push lateral loading 46.05 kN, while the maximum displacement from the Pampanin Wall-Slab Joint Hysteresis model is 20.30 mm at 46.08 kN. The maximum pull displacement is -17.08 mm at -56.53 kN, while for the model is -17.22 mm and the maximum pull lateral load is -56.54 kN. It shows that the modeling hysteresis loops seem to have a similar pattern with experimental hysteresis loops. Therefore, the Pampanin hysteresis can be used for modeling single unit three-storey building using Ruaumoko 2D programming.

![Figure 2. Hysteresis Loops Comparison between Experimental and Modelling Results](image)

3.2. Equivalent Viscous Damping (EVD)

Figure 3, the EVD for the 1st cycle is higher than the 2nd cycle because at the first impact of the earthquake the tunnel form building absorbs the energy as compared to the aftershock to overcome the elastic strain force in the structure. Both cycles start at 0% EVD at 0.01% of drift and increase to 7.96% for the 1st cycle and 7.21% for the 2nd cycle. At 0.1% drift the 1st cycle shows a gradual increase from 7.96% EVD to 12.80% EVD while for the 2nd cycle, it dropped from 7.21% EVD to 6.37% EVD and start to increase linearly until reaching the maximum 11.06% of EVD at the 0.5% drift. This happened due to the energy released from the tunnel form building and start to crack. The 1st cycle absorbs more energy compared to the 2nd cycle.
Figure 3. Equivalent Viscous Damping (EVD) Comparison Between the 1st Cycle and 2nd Cycle

3.3. Ruaumoko 2D

The wall-slab connection and wall-foundation connection are noted as nodes and the main structural component was designed as a fixed connection while the floor slab and shear wall are noted as elements. The 8 numbers of node and 9 numbers of the element are shown in Figure 4. The green circle is for the node and the blue circle is for the element.

Figure 4. The Numbering system of 9 numbers of elements and eight numbers of node using Ruaumoko 2D

3.4. Dynaplot

The purpose of DYNAPlOT is to plot the hysteresis loops or to plot the time history results by non-linear dynamic analysis programs RUAUMOKO-2D. This analysis generates each graph for each ten-past earthquake accelerograms of pseudo-spectral displacement (PSD) and pseudo-spectral acceleration (PSA) from 0%, 2%, 5%, 10% and 20% of damping as shown in Figures 5 and 6, respectively.
3.5. Past earthquake records

Ten previous earthquake records were chosen based on the Magnitude, PGA and the location of the earthquakes. Three past earthquake records have been selected from abroad, and seven past earthquake records have been selected from East and West Malaysia. Table 1.0 displays the classification of these earthquakes according to the magnitude and year of occurrence. The three previous earthquake reports from overseas were the 1985 Mexico City Earthquake, the 1940 El-Centro North South Earthquake, and the 1971 Pacoima Dam Earthquake. These four earthquakes have magnitudes ranging from 6.6 to 8.1 Richter Scale, from mild to large earthquakes. Whereas other seven past earthquake records occurred in Malaysia, namely the 2015 and 2008 Ranau Earthquake, 2008 Lahad Datu Earthquake, the 2012 Kunak Earthquake, the 2010 Batu Niah Earthquake, the 2009 Manjung Earthquake and the 2007 Bukit Tinggi Earthquake. These seven earthquakes range in magnitude from 2.8 to 5.9 Richter Scale, which represent from very minor to light earthquake events.
Table 1. Classification of ten past earthquake records

| Classification | Range | PGA  | Magnitude | Represented ground motion records |
|----------------|-------|------|-----------|----------------------------------|
| Great          | >8    | 1.230| 8.1       | 1985 Mexico City                 |
| Major          | 7-7.9 | 0.348| 7.1       | 1940 El-Centro North South       |
| Strong         | 6-6.9 | 1.190| 6.6       | 1971 Pacoima Dam                 |
| Moderate       | 5-5.9 | 0.135| 5.9       | 2015 Ranau, Sabah                |
| Light          | 4-4.9 | 0.000081| 4.5       | 2008 Lahad Datu, Sabah           |
|                |       | 0.000015| 4.3       | 2011 Tawau, Sabah                |
| Minor          | 3-3.9 | 0.3783| 3.7       | 2012 Belaga, Sarawak             |
|                |       | 0.000640| 3.3       | 2010 Batu Niah, Sarawak          |
| Very minor     | <3.0  | 0.001741| 2.8       | 2009 Manjung, Perak              |
|                |       | 0.000031| 3.0       | 2007 Bukit Tinggi, Pahang        |

4. Conclusion

Based on this seismic analysis of single-unit tunnel form building subjected to in-plane lateral cyclic loading using Ruaumoko 2D Programme, several findings and conclusion can be obtained. Hysteresis, Ruaumoko 2D and Dynaplot indicate the results of nonlinear dynamic analysis of a tunnel form building subjected to several past earthquakes records. Hysteresis loop of the modelling result using the HYSTERES program in Ruaumoko 2D programming has a similar shape and pattern as the experimental hysteresis loop for both loading and unloading condition. The ten past earthquake records were analyzed using Ruaumoko 2D to gain the mode shape, structure deformation and earthquake excitation for each ground motions. The highest percentage different for maximum pseudo-spectral displacement (PSD) is 54.57% recorded at 4.50 and 4.60 seconds, respectively obtained from 2008 Ranau Earthquake. Meanwhile, the lowest PSD obtained from 2009 Manjung Earthquake with 26.15% percentage difference between 5% and 20% damping recorded at 4.50 and 4.60 sec, respectively.

The highest percentage different for maximum pseudo-spectral acceleration (PSA) is 77.72% obtained from 2015 Ranau Earthquake. The lowest percentage different is 38.59% obtained from 2008 Ranau Earthquake recorded at 0.10 second for both 5% and 20% damping. Meanwhile, the earthquake data with a magnitude greater than 5 scale Richter have caused tunnel form building not survive. Therefore, it can be concluded that TFB will survive under a low seismic loading (magnitude less than 5 Scale Richter) and long-distant earthquake excitation.

5. References

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