Seismic Behaviour of Beris Dam Under Six Earthquake Excitations by using Finite Element Method

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ABSTRACT

This paper focused on the behavior of the dam when exposed to seismic loading and ability of the dam to withstand the applied loads from various seismic events. The chosen concrete dam to be referred to in the two-dimensional analysis is Beris Dam located in Kedah, Malaysia. A nonlinear dynamic analysis is chosen to analyse the behavior of Beris Dam under selected ground motion. Analysis of the dam is performed using the finite element method by utilizing ABAQUS software. From the cracking analysis pattern, a crack appeared at the upstream face of the dam caused mainly by the excessive tensile stress. Based on the results, the displacement of the dam is increased with the increasing of ground motion data where the displacement occurred in the horizontal direction. The maximum stresses exerted by the dam structure do not exceed the allowable capacity of concrete dams. The stress behaviour of the dam was satisfactorily acceptable as the maximum normal stress and shear stress of the dam when numerous seismic loadings are applied do not exceed the allowable stress capacity which is 800 kN/m^2.

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Introduction

Dam is an engineered structure that was built for domestic and industrial water supply or for irrigation works. A multipurpose dam is often designed to provide water- control structures and for generating the hydroelectric power or to reduce the peak discharge of floodwater. However, the dams need to be designed with an ability to resist the natural disasters such as earthquakes and devastating floods as the dam failure would result in life losses and structural damages [1]. In order to acknowledge the geological characteristics of a selected area to establish a dam structure, a geological survey needs to be executed. The geological survey cost a huge amount of money as the earthquake issues need to be considered in designing the dam structure. The effect of an earthquake with Richter magnitude exceeding 6 M caused a destruction to dams. The Shih-Kang dam was seriously damaged due to the Chichi earthquake with 7.6 M that resulted in fractures and split of dam body from foundation bedrock [2]. The damages of Shih-Kang dam also resulted in heavy flooding in the D/S direction and disrupted the power and water resources to the location involved.

Earthquake effects towards concrete dams differ based on the dam types. The consequences of the earthquakes towards the dam can result in the damage and failures of dam structure. The dam’s failure due to the earthquake effects would bring a disaster towards the surrounding area and humans. As a safety measurement, a dam structure should be evaluated on its ability to resist seismic waves. The essential parameter in designing and performance evaluation of the concrete dams is the safety level subjected to the seismic safety. Nonlinear dynamic analysis utilizes the combination of ground motion records with a detailed structural model. Therefore, this method is capable of producing results with relatively low uncertainty. In nonlinear dynamic analyses, the detailed structural model subjected to a ground-motion record produces estimates of component deformations for each degree of freedom in the model [3]. Hence, the study on the seismic assessment of Beris Dam under earthquake loading performed by using nonlinear dynamic analysis utilizing finite element method. Impact of earthquakes has been one of the major concerns of scientists and engineers for a long time. Enhancement on the material performance for the application due to seismic effect was conducted in prevoius studies [4]-[8]. Furthermore, many studies have been made to mitigate the seismic responses of dams [9]-[13], buildings [14]-[18] and bridges [19]-[20] due to seismic loads.

Crack patterns on concrete dams appear as the reaction of the dam structure towards seismic loading. The crack pattern is a parameter of performance of a dam subjected to the different ground motion with varying intensity levels. Thus, the safety measure should be taken by studying the crack pattern to ensure the durability and sustainability of the dam. A safety need for a concrete dam regarding the dynamic loads should be taken into consideration during assessment of the stability of dam structure [21]. For instance, the ability of structure to withstand the applied lateral forces and moments and averting the unnecessary cracking of the concrete dam.

Under the earthquake effect, a concrete structure would undergo cracking and not be able to contain the structural loads [22]. Koyna Dam has encountered crack damage due to the Koyna earthquake that struck with a strength of 6.5 M in December 1967. The dam structure has an elongated shape with a constant cross section. The design of the dam can be determined under planar deformation conditions because the position of the load does not change in direction [2]. There are several factors that lead to the cracking of concrete dams which are the suitability of concrete materials, site selection of the dam, temperature control and maintenance of the dam and lastly, profile design of the dam [23]. These factors need to be considered carefully as the performance of dam structure would be affected when seismic excitations present. Shukai [24] and Santos [25] conducted an efficient numerical framework for the seismic analysis of concrete dams as well.

The relative horizontal and vertical displacements of different dams have been reported by many researchers. Crest displacement normally occurs at the neck and heel of the dam when the body structure is exposed to seismic loading. The maximum horizontal displacement of the dam crest happened due to the hydrostatic pressure [12]. In this study, the maximum crest displacement is investigated to determine the effect of the seismic loading on the dam structure.

Stress appears in the dam structure when seismic loading is applied to the body structure. Through dynamic analysis, the stress distributions in the body structure can be seen. The normal stress and shear stresses of a dam when seismic loading is applied need to be analysed to obtain the ability of dam structure to withstand the applied force. The maximum and minimum stresses are different for each mode of shape under time history data analysis [26]. The capability of a concrete dam to withstand the applied force can be determined by comparing the maximum normal and shear stresses with the allowable stress capacity of concrete [9], [11]-[13].

Research Background

The Beris Dam is chosen for this research to observe the behaviour of the dam under earthquake excitations by using finite element modelling using computer software. This research study begins with the collection of reading concerned with the dam’s performance under earthquake effect followed by data collection of Beris, 2-dimensional modelling of Beris Dam using ABAQUS software and discussion on the crack pattern and behaviour of dam under seismic loading subjected to the seismic safety and finally summary of the main conclusions from the findings of this research paper.

Beris Dam is established in Sik, Kedah, Malaysia. The purposes of Beris Dam are to manage the water flows along Muda River in order to increase the water for irrigation purposes such as paddy and crops, for water supply either for domestic or industrial consumption and others. The dam is a concrete-faced rockfill dam with a total height of 40 meters and can accommodate a gross storage capacity of 122.4 mm^3 with effective storage of 144 mm^3 [27]. Figure 1 shows the typical cross section of Beris Dam while the background and information of structure were tabulated in Table 1 and Table 2.

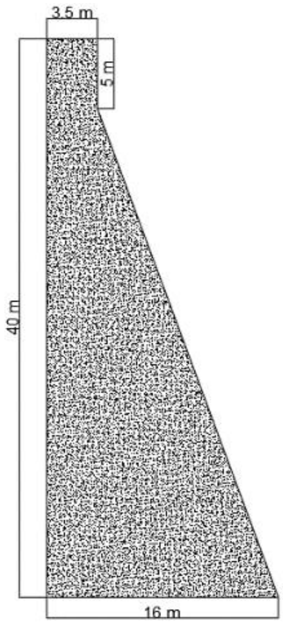


Figure 1: Typical cross section of Beris dam [27]

Table 1: Background of project [27]

Location	Year completed	Year of construction	Project cost
Sik, Kedah	2004	2000	Rm 360 million

Table 2: Information of structure [26]

Item	Description
Reservoir area	16.1 km^2
Crest length	155.0 m
Catchment area	116.0 km^2
Crest elevation	88.0 m
Capacity	122.4 mm^3
Material of structure	Concrete-faced Rockfill
Height	40.0 m
Spillway type	Overflow ogee with sude channel chute and bucket

Modal analysis

The seismic behaviour of Beris Dam due to the seismic excitations is performed by using ABAQUS. The seismic excitation that has been used in the analysis is obtained from the Malaysian Meteorological Department's intensity data and Pacific Earthquake Engineering Research Center (PEER). Table 3 tabulates the list of earthquake events that have occurred at various locations and different recorded intensity data respectively that are essential for data analysis of the 2-dimensional dam model. There are five intensities of motion data based on peak ground acceleration (PGA) which are 0.05 g, 0.10 g, 0.15 g, 0.20 g, and 0.30 g, respectively.

Table 3: Selected earthquake data for analysis of 2D model

Earthquake	Location	Year	Magnitude (M)	Peak ground acceleration (g)	Step (s)
Aceh	Indonesia	2004	9.3	0.012	0.02
Ranau	Malaysia	2015	6.0	0.013	0.02
Chuetsu	Japan	2007	6.8	0.175	0.01
Northridge	USA	1994	6.69	0.194	0.01
Chichi	Taiwan	1999	6.2	0.361	0.01
Trinidad	USA	1983	5.7	0.568	0.01

The material properties of dams such as density, Poisson's ratio, Young's modulus is essential in modelling of dam structure by using finite element method. Some of the mechanical properties of Beris Dam are unknown, hence the data on mechanical properties referred to Koyna Dam's properties. Material behaviours in terms of concrete damaged plasticity are based on Koyna Dam data. Table 4 shows the material properties used in this analysis.

Table 4: Material properties of concrete

Properties of concrete			Value
General properties		Density	2700 kg/m^3
Mechanical properties	Elasticity	Young's modulus	31 GPa
		Poisson's ratio	0.15
	Plasticity	Dilation angle	36.31^o

The dam analysis is carried out by applying several ground motion data on the dimensional model of Beris Dam where the self-weight of dam and hydrostatic pressure is also considered. The value of self-weight of dam or gravity load is 9.81 N/kg while hydrostatic pressure can be determined from Equation 1.

$$F_p = \rho g h \tag{1}$$

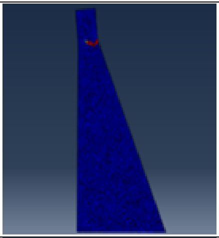
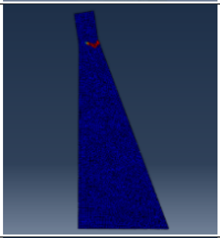
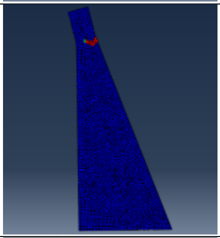
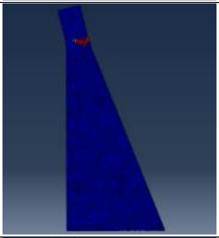
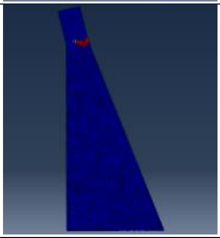
where, F_p = fluid pressure
ρ = fluid density
g = acceleration due to gravity
h = fluid depth

Crack pattern analysis

Crack patterns on concrete dams appear as the reaction of the dam structure towards seismic loading. The crack pattern is a parameter of the performance of a dam subjected to the different ground motion with varying intensity levels. Thus, safety measure should be taken by studying the crack pattern to ensure the durability and sustainability of the dam. However, the cracking pattern depends on the peak ground acceleration (PGA) of the motion. Table 5 shows the cracking pattern of the dam structure underground motion data of the Chichi Earthquake with a minimum PGA of 0.05 g and maximum PGA of 0.30.

Crack patterns appeared at the upstream face of the dam. From Figure 2, the tensile stress distributed in the dam structure indicates that the crack pattern is caused mainly by excessive tensile stress. However, the crack pattern appeared at half of the neck and did not connect with the other side. The connection of the crack pattern indicating the failure of the dam was in good agreement with the results obtained by Azizan et al. [2] and Ghaedi et al. [28]. Crack patterns can be a parameter to observe the capability of a dam to withstand the seismic loading. Therefore, in this analysis, the dam structure has severe damage due to the applied ground motion, yet the damage of the dam is not extreme as the maximum crack pattern appeared is half of the upstream face. The dam is unsafe as the cracking on the dam body required to be repaired to avoid further damages occurred.

Table 5: The crack pattern of Beris dam under Chichi earthquake data

Earthquake intensity	Normal stress
0.05 g	
0.10 g	
0.15 g	
0.20 g	
0.30 g	

Crest displacement analysis

Crest displacement occurs when seismic loading is applied to the dam structure. Maximum crest displacement is observed to determine the deformation and performance of the dam. Table 6 tabulates the maximum crest displacement of the dam under several sets of ground motion data. Based on the results, the displacement of the dam is increased with the increase of ground motion data. The increasing deformation of the dam should be taken into consideration when evaluating the safety of the dam. Figure 2 shows the maximum crest displacement of the dam where the displacement occurred in the horizontal direction. Ghaedi et al. [28], Hong et al. [29], and Chen et al. [30] reported that the displacements occurred in the same direction at the crest of the dam. The maximum crest displacement indicates the ability of the dam to resist the applied load based on its capacity. Therefore, the crest displacement would be increased if greater motion data is present. The maximum crest displacement is related to the crack pattern and stress distribution in assessing the safety of the dam under earthquake excitations.

Table 6: Maximum crest displacement of Beris dam under selected ground motion (unit in cm)

EQ Data	Aceh	Ranau	Chuetsu	Trinidad	North-ridge	Chichi
0.05g	0.000	0.000	1.38	0.05	0.11	8.95
0.10g	0.000	0.000	3.45	0.25	0.18	10.20
0.15g	0.001	0.001	5.59	0.42	0.28	15.43
0.20g	0.001	0.001	7.54	0.75	0.32	21.88
0.30g	0.002	0.002	9.035	0.88	0.44	21.88

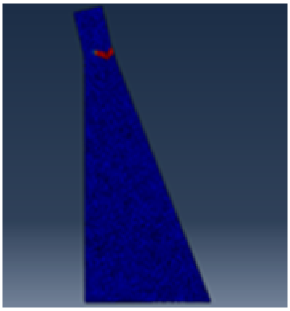


Figure 2: The maximum crack pattern of Beris dam (21.88 cm)

Stress analysis

The dynamic analysis shows the stress in the dam structures when subjected to the dynamic loading. Stress analysis is crucial to observe the performance of a dam where the ability of the dam to resist the applied forces. Normal stress and shear stress are the parameters observed in this analysis. The positive value of stress indicates that the structure is in a tension state. While the negative value of stress shows that the structure is in a compression state. Self-weight of the dam which is the gravity force and the hydrostatic pressure are the static forces that need to be considered in the shear force state. Figure 3 illustrates the stress distribution of normal stress and shear stress.

Based on Figure 3, the dam structure is in compression state when normal stress is exerted on the dam body while the structural body consists of the tension force more than compressive force when shear stress is presented. The maximum compressive force occurred due to the high hydrostatic force exerted on the dam structure. Tension force occurs in the body structure depending on the type of dam, the magnitude of earthquake loading and the distribution of the peak ground acceleration. The more tension force exerted in the dam structure is due to the rigidity of the dam structure depending on the height of the dam [12].

The tensile force is only presented near the neck of the dam. Critical force tends to happen near the crest of the dam due to the tendency of the body structure to resist the force exerted from the core and foundation [27]. This acceleration shows that the crest of the dam on the upstream side is the most critical zone if an earthquake occurs and is highly affected by both ground motion characteristics such as acceleration, duration, and frequency and characteristics of dams such as material properties [12]. Therefore, under the ground motion data with a maximum PGA of 0.3 g and minimum PGA of 0.05 g, the dam structure has more compressive force in the dam structure. The lower peak ground motion applied to the structure could help to reduce the forces exerted on the dam. In Malaysia, the dam structure would survive during an earthquake event as the magnitude of the earthquake that normally happens in surrounding Malaysia is quite lower than other countries.

The comparison of the maximum stresses exerted by the dam structure with the allowable capacity of the dam was done to determine whether the stresses obtained from the analysis are acceptable. Table 7 shows the comparison of the maximum stresses with the allowable stress capacity of the concrete dam among six different earthquake events.

Figure 3: Stress distribution of Beris dam

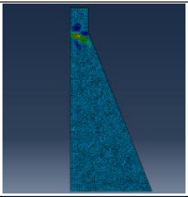
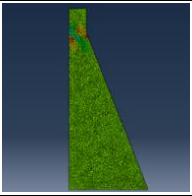
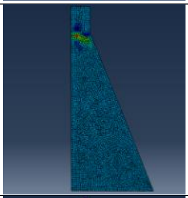
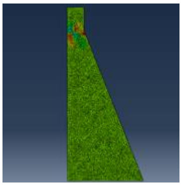
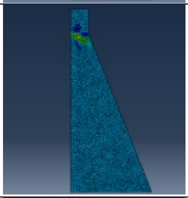
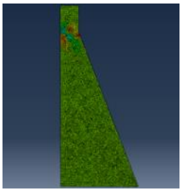
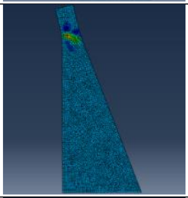
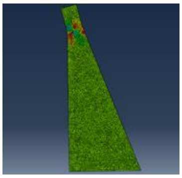
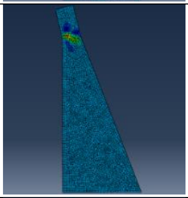
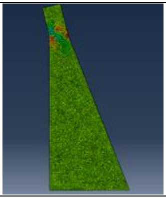
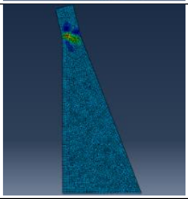
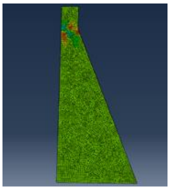
Earthquake data	Normal stress	Shear stress
Aceh		
Ranau		
Northridge		
Chichi		
Cheutsu		
Trinidad		

Table 7: Comparison of maximum stresses with allowable stress capacity

Earthquake data	Normal stress (kN/m^2)	Shear stress (kN/m^2)	Allowable capacity
Aceh	600.70	289.50	800
Ranau	603.20	290.2	800
Northridge	612.40	295.80	800
Chichi	614.50	294.70	800
Cheutsu	610.70	296.60	800
Trinidad	602.30	297.30	800

Based on the table above, the maximum stresses exerted by the dam structure do not exceed the allowable capacity of concrete dams. Therefore, the maximum normal stress and shear stress were considered acceptable. The performance of the dam also can be evaluated from the maximum stresses obtained from the analysis. As the value of stresses is acceptable, it can be said that the dam can withstand the load applied and exert maximum stresses lower than allowable capacity. The results obtained in this study agreed well with that reported by Ismail et al. [9].

Conclusion

The seismic behavior of the dam such as crack pattern, displacement, and stress is obtained from the finite element analysis to measure the capability of the dam to withstand the seismic loading applied. The method has been explained previously and the analysis is carried out by using ABAQUS software. The seismic behaviour of Beris Dam is analyzed under 6 selected ground motion data with a minimum PGA of 0.05 g and maximum PGA of 0.30 g. Based on the analysis, the crack patterns appeared mostly at the upstream face of the dam and resulted in damage to the dam body but not too extreme as the applied loads are inadequate to break or split the neck of the dam. The dam is considered unsafe as the cracking pattern shown is severe even though the applied loads are not enough to break the neck of the dam. The performance of the dam can be considered a satisfactory result due to the acceptable maximum crest displacement of the dam under seismic excitations which is 21.88 cm. The stress behaviour of the dam was also satisfactorily acceptable as the maximum normal stress and shear stress of the dam when numerous seismic loadings are applied do not exceed the allowable stress capacity which is 800 kN/m^2. The obtained results from this dynamic analysis indicated that ABAQUS software is able to analyze the seismic behaviour of a body structure under ground motion data. The maximum crest displacement was discussed by comparing the maximum crest displacement of the dam under different ground motion data. The findings in this research paper are important as a safety measure to overcome the dam's failure due to the earthquake as the consequence of the failure of the dam to resist seismic loading is tsunami and surroundings damage.

Contributions of Authors

The authors confirm the equal contribution in each part of this work. All authors reviewed and approved the final version of this work.

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Conflict of Interests

All authors declare that they have no conflicts of interest

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References

[1] Mahmoodi, K., Noorzad, A., Mahboubi, A., & Alembagheri, M., "Seismic performance assessment of a cemented material dam using incremental dynamic analysis", *Structures*, vol. 29, pp. 1187–1198, 2021.

[2] Azizan, N. Z. N., Majid, T. A., Nazri, F. M., Maity, D., & Abdullah, J., "Incremental Dynamic Analysis of Koyna Dam under Repeated Ground Motions", *IOP Conference Series: Materials Science and Engineering*, vol. 318, no. 1, pp 1-12, 2018.

[3] Manjhi, R. M., "Approaches for analysis of seismic behavior of structures: A review", *International Research Journal of Engineering and Technology*, vol. 5, no. 9, pp. 1306-1313, 2018.

[4] Ismail, R. Rajhan, N. H., Hamid, H. A., & Ibrahim, A., "Experimental data for effect of carbon black loading on tensile, hardness and rebound of magnetic iron filled natural rubber composites", *Data in brief,* vol. 25, no. 104166, pp. 1-10, 2019.

[5] R Ismail, A Ibrahim, M Rusop, A Adnan, "Dynamic mechanical properties of natural rubber vulcanizates with different carbon nanotubes-loaded", *AIP Conference Proceedings*, vol. 2151, no. 1, pp. 1-7, 2019.

[6] R Ismail, A Ibrahim, M Rusop, A Adnan, "Magnetic properties of carbon nanotubes-natural rubber composites", *AIP Conference Proceedings*, vol. 2151, no. 1, pp. 8-14, 2019.

[7] R. Ismail, A. Ibrahim, H. Hamid, M. Rusop, A. Adnan. "Experimental study on mechanical properties of elastomer containing carbon nanotubes", *Journal of Engineering Science and Technology*, vol. 13, no. 3, pp. 565 – 664, 2018.

[8] Rozaina Ismail, Azmi Ibrahim, Hamidah Mohd.Saman@Hj. Mohamed, Mohamad Rusop Mahmood, Azlan Adnan. "Experimental data for the magnetic properties of vulcanized natural rubber nanocomposites using vibrating sample magnetometer (VSM)", *Data in brief,* vol. 46, no. 108872, pp. 1-13, 2023.

[9] Ismail, R., Hussin, N.S.A., Ibrahim, A, Rusop. M., Adnan, A., "The Performance of Roller Compacted Concrete (RCC) Dam Under Seismic Load", *Journal of Architecture and Civil Engineering*, vol 6, no. 6, pp. 13-23, 2021.

[10] A Faisal, TA Majid, F Ahmad, F Tongkul, SM Sari. "Influence of large dam on seismic hazard in low seismic region of Ulu Padas Area, Northern Borneo", *Natural hazards, vo*. 59, no. 1, pp. 237-269, 2011.

[11] Ismail, R. and Ismail, M.I., "Dynamic Analysis of Concrete Faced Rockfill Dam Using Finite Element Method", *Journal of Engineering and Applied Sciences*, vol. 12, no. 7, pp. 1772-1776, 2017.

[12] Ismail, R. Kamsani, M.H. and Mohd Nadzri, N.I., "Seismic Analysis of Concrete Dam by Using Finite Element Method", *MATEC Web Conference*, vol. 103, no. 02024, pp. 1-9, 2017.

[13] Rozaina Ismail, A'in Fatin Najihah Akmat, Ade Faisal, Azmi Ibrahim, Azlan Adnan, Izzul Syazwan Ishak, "Behaviour of Earth Fill Dam under Earthquake Load Using Finite Element Method: A Case Study of Semenyih Dam", *Journal of Sustainable Civil Engineering and Technology*, vol. 1, no. 2, pp. 63-77, 2022.

[14] Ismail. R., Shamsudin. N., Arshad. M.F., Ibrahim. A., Rusop. M., Adnan. A., "2-Dimensional Finite Element Analysis of Reinforced Concrete Buildings Subjected to Seismic Load", *Journal of Architecture and Civil Engineering*, vol. 6, no. 6, pp. 01-06, 2021.

[15] R. Ismail, A. Ibrahim and A. Adnan, "Damage Assessment of Medium-Rise Reinforced Concrete Buildings in Peninsular Malaysia Subjected to Ranau Earthquake", *International Journal of Civil Engineering and Technology*, vol. 103, no. 02024, pp. 881–888, 2018.
[16] MZAM Zahid, TA Majid, A Faisal, "The Effect of Behaviour Factor on The Seismic Performance of Low-Rise and High-Rise RC Buildings", *Journal of Engineering Science and Technology*, vol. 12, no. 1, pp. 31-41, 2017.
[17] Ismail, R., and Zamahidi, N. F., "An evaluation of High-Rise Concrete Building Performance Under Low Intensity Earthquake Effects", *InCIEC 2014*, vol.1, no. 1, pp. 79-86, 2015.
[18] Ismail R., Ibrahim, A., and Razali, N., "Vulnerability study of public buildings subjected to earthquake event", *MATEC Web Conference*, vol. 103, no. 02023, pp. 1-9, 2017.
[19] Ismail, R., and Abdul Karim, M.R., "Concrete Bridge Pier Performance Under Earthquake Loading", *Journal of Engineering and Applied Sciences*, vol. 12, no. 9, pp. 2254-2258, 2017.
[20] Ismail. R, Ibrahim. A, Adnan, "Determination of Shear Wave Velocity Profile by Using Multi-Channel Analysis of Surface Wave (MASW)", *Journal of Architecture and Civil Engineering*, vol. 7, no.2, pp. 01-06, 2022.
[21] Tosun, H., "Earthquakes and Dams. Earthquake Engineering - From Engineering Seismology to Optimal Seismic Design of Engineering Structures", *Intechopen*, vol.1, no.1, pp. 410, 2015.
[22] Sun, D. & Qingwen Ren, Q., "Seismic Damage Analysis of Concrete Gravity Dam Based on Wavelet Transform", *Shock and Vibration*, vol 2016, no. 6841836, pp. 1-8, 2016.
[23] Lin, P., Wei, P., Wang, W. & Huang, H., "Cracking Risk and Overall Stability Analysis of Xulong High Arch Dam: A Case Study", *Computational Methods for Fracture*, vol. 8, no. 12, pp. 1-18, 2018.
[24] Shukai Ya, Sascha Eisenträger, Yanling Qu, Junqi Zhang, Thomas Kuen, Chongmin Song, "Seismic analysis of post-tensioned concrete gravity dams using scaled boundary finite elements implemented as ABAQUS UEL", *Soil Dynamics and Earthquake Engineering*, vol. 164, no. 107620, pp. 1-25, 2023.
[25] Das, S.K., Mandal, K.K. & Niyogi, A.G. "Finite element-based direct coupling approach for dynamic analysis of dam–reservoir system", *Innovative Infrastructure Solutution*, vol. 8, no. 44, pp. 1-22, 2023.
[26] Ismail, R., Ibrahim, A., & Adnan, A., "Damage Assessment of High-Rise Reinforced Concrete Buildings in Peninsular Malaysia Subjected to Ranau Earthquake", *IOP Conference Series: Materials Science and Engineering*, vol. 513, no. 1, pp. 0–7, 2019.

[27] Department of Irrigation and Drainage, https://www.water.gov.my/index.php/pages/view/1257, last accessed 2022/6/23.
[28] Ghaedi, K., Hejazi, F., Gordan, M., Javanmardi, A., Khatibi, H. & Joharchi, A., "Seismic Response Characteristics of RCC Dams Considering Fluid-Structure Interaction of Dam-Reservoir System", *Computational Overview of Fluid Structure Interaction*, vol. 1, no. 97859, pp. 1-23, 2021.
[29] Hong, Z., Na-li, W. & Gao, L., "Seismic response of concrete gravity dam reinforced with FRP sheets on dam surface", *Water Science and Engineering*, vol. 6, no. 4, pp. 409-422, 2013.
[30] Chen, D. H., Yang, Z. H., Wang, M., & Xie, J. H., "Seismic performance and failure modes of the Jin'anqiao concrete gravity dam based on incremental dynamic analysis", *Engineering Failure Analysis*, vol. 100, pp. 227– 244, 2019.