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Research Paper

The Performance of Roller Compacted Concrete (RCC) Dam Under Seismic Load

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ABSTRACT: *A dam is a structure built across a stream, a river, or an estuary to retain water. The reservoirs created by dams not only suppress floods, but also provide water for activities such as irrigation, human consumption, industrial use, aquaculture, and navigability. In this modern technology, a few innovations have been created in dam construction, for example construction of Rolled Compacted Concrete dam. The construction of RCC dam gives enormous economic benefits and operating speed compared to traditional concrete dams. This paper focuses on the analysis of a Roller Compacted Concrete (RCC) dam with and without seismic loading and to investigate the effect of hydrostatic pressure on RCC dams and evaluate the stress and displacement. Batu Hampar dam has been chosen to do seismic analysis. This analysis will be conduct using LUSAS Modeller 14.3. Data from the Ranau Earthquake event was used in LUSAS Modeller to get the result. The result shows the displacement and stress before and after applying seismic loading and present of hydrostatic force. From the result of the analysis of RCC dam, and conclusion was conduct and compares between previous case study was conducted to make sure the result within acceptable value.*

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I. INTRODUCTION

Rolled Compacted Concrete (RCC) is one of the technologies that has been introduced in the construction of the dam in Malaysia. First RCC dam that was completely build in Malaysia in 2006 which is Kinta Dam located at Sungai Kinta, Perak. RCC is concrete compacted by roller compaction. According to Z. Heirany [1], RCC is a mix of concrete dam protection and earth dam operation while speeding up construction and reducing administrative costs. Application of RCC is where there is no collapsed concrete that can be delivered, placed, and compacted using regular construction. Impact of earthquakes is one of the major concerns of scientists and engineers for a long time. Many studies have been made to mitigate the seismic responses of structures due to seismic loads [2-22].

Huda et al., [23] conduct an inspection to track the dynamic reaction of the compacted roller concrete dam when exposed to horizontal ground movement by evaluating the relations between the elastic pillars, the water reservoir and the sediments under the reservoir. Two-dimensional finite-infinite component was used for the dynamic study of non-linear elasto-plastic. They studied that sediment in the reservoir can reduce storage capacity and become a primary problem to be dealt. They also detect that the Issues arise from geographical origins, forestry, woodland degradation and other natural events and risks. To obtain the results of the effect of sedimentation, an analysis of dam – reservoir- foundation interaction has been conducted at Kinta dam.

Murat et al., [24] was explored the effects of various reservoir sizes on the chosen RCC dam's earthquake reaction under strong ground motion influence. They introduce two-dimensional earthquake responses of Cine RCC dam recognizing structural and material non-linearity in analyzes of period history. The researcher generally focused on thermal evaluation of RCC dams because kinetic fracturing will contribute to the downstream face leakage route. In this approach, fluid is presumed to be compressible, irrotational, linearly and inviscid. From the analysis, it shown that higher displacements, and higher stresses and compression are obtained when reservoir length extends. Earthquake analyses are performed at 39.69 second and numerical analysis was investigated for different cases.

Khaleed et al, [25] have conduct a case study for Kinta RCC dam to investigate the impact of reservoir hydrostatic pressure on RCC dam and evaluate damages and crack propagation. They made finite element model and a bidirectional time history acceleration are applied to RCC dam. In general view, Khaleed et al, [25] stated that the main failure may occur under seismic loading due to increased soil hydrostatic pressure under the dam foundation and the reservoir water hydrostatic pressure that is stored in the upstream side of the dam. Therefore, the hydrostatic pressure of the reservoir is effective on the action of RCC dam during earthquake movement and this effect must be considered on the seismic assessment of RCC dam. The tolerance of dynamic shearing for dam materials and standard soil surfaces is about that of static shearing or somewhat greater. Thus, under severe excitations, the typical safety function is viewed as a great value to prevent damage in the reservoir. Nevertheless, all shearing resistance is lost if regular soil surfaces undergo surface vibrations, partial or approximate. This can be attributed to either increased hydrostatic stress or lack of shearing strength under sliding earthquake motions.

Next research was conduct by Kartal [26]. He presents the RCC dam's three-dimensional earthquake response with geometric non-linearity. The reservoir water's hydrostatic and hydrodynamic forces was used based on the Lagrangian approach on the liquid finite components. Horizontal displacements under hydrodynamic stress are rising, according to mathematical solutions.

II. RESEARCH BACKGROUND

In this study, Batu Hampar dam was selected for seismic analysis. RCC's seismic reaction is a complex problem under earthquake excitation and need to consider several factors such as a stress and displacement effect. This paper focuses on the analysis of a Roller Compacted Concrete (RCC) dam with and without seismic loading and to investigate the effect of hydrostatic pressure on RCC dams and evaluate the stress and displacement. Finite Element analysis is an effective approach for determining the earthquake effect of roller-compacted concrete (RCC) dams and analyzing the earthquake reaction on RCC reservoirs when seismic load is applied. Batu Hampar dam is located at Ulu Sepri in area Rembau, Negeri Sembilan. Purpose of Batu Hampar dam is for water supply which can carry capacity 3x106 m^3. The height of Batu Hampar dam is 75metres and the length is 236metres. The use of RCC has been expanding for the last 40 years and is now accepted as the most reasonable solution for the design and construction of major projects for hydropower and water resources around the world and was applied in Malaysia for Kinta dam. Kinta dam was built with 81.1m and 63.5m width. The second construction using RCC dam which is Batu Hampar dam in Negeri Sembilan in 2008 and was construct by local contractor.

The primary data is the drawing of Batu Hampar dam that can be collect from the owner of the dam which is Badan Kawal Selia Air Negeri Sembilan. While for secondary data is deduce from the previous case study. Previous case study can be reference for data analysis and source of information for this study. For our data of earthquake event, we get from Jabatan Meteorology Malaysia. The seismic excitation from Ranau Earthquake event has been used in the analysis. Data that shown in Figure 1 shows the recorded data during earthquake at apicenter Ranau, Kota Kinabalu used in this study. The details information about this data was tabulated in Table 1.

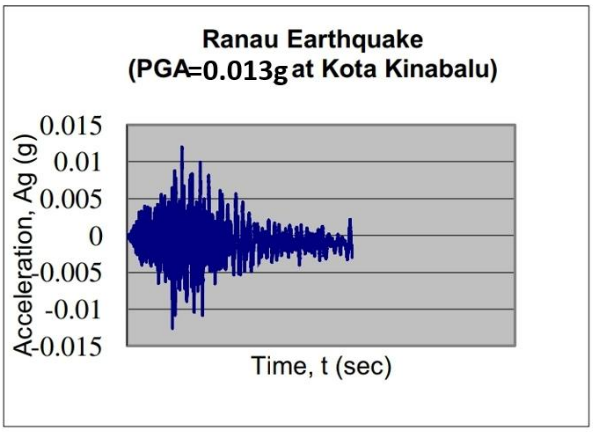

Figure 1 Data of ground acceleration at Kota Kinabalu [19]

Table 1 Ranau Earthquake data [19]

Items	Data
points	3538
time step	0.02 sec.
time duration	56.58 sec.
max PGA	0.013g
station	Kota Kinabalu
Event	Ranau EQ
Date	5-Jun-15

The drawing of 2D Model for Batu Hampar Dam was collect from the Badan Kawal Selia Air Negeri Sembilan which is using coordinate. The coordinate was insert based on the dimension of Batu Hampar dam. Next step in LUSAS Modeller is by inserting it's attribute. Attribute for LUSAS Modeller are surface meshing, geometric, material, support and loading. For the surface meshing, plane stress element structural type and irregular mesh with size element of 5 was used. 0.5 m for thickness was used in the surface geometric for this dam. Material for this dam is reinforced concrete with the properties as shown in Figures 2. The support for finite element analysis for Batu Hampar was assigned as shown in Figures 3. This support is to make sure the structure has strong foundation. Figure 4 shows the direction of hydrostatic forces towards the dam.

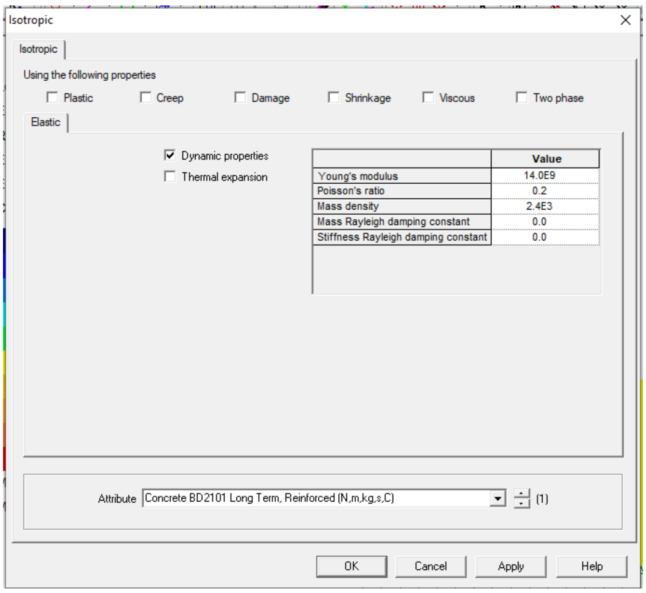

Figure 2 Properties of Reinforced Concrete

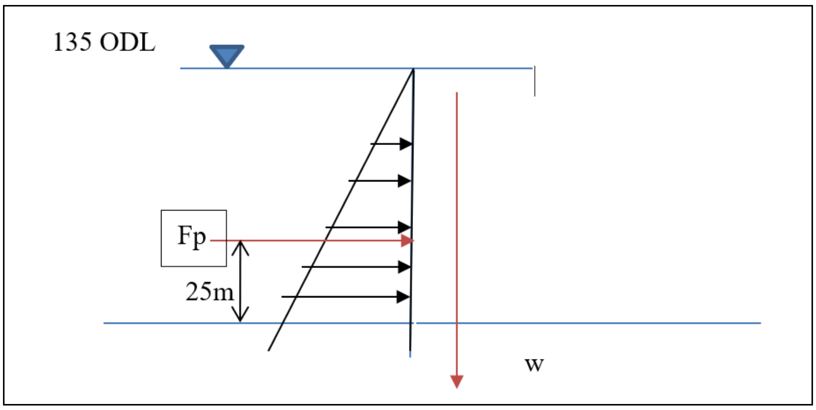

Figure 3 Direction of hydrostatic forces towards the dam

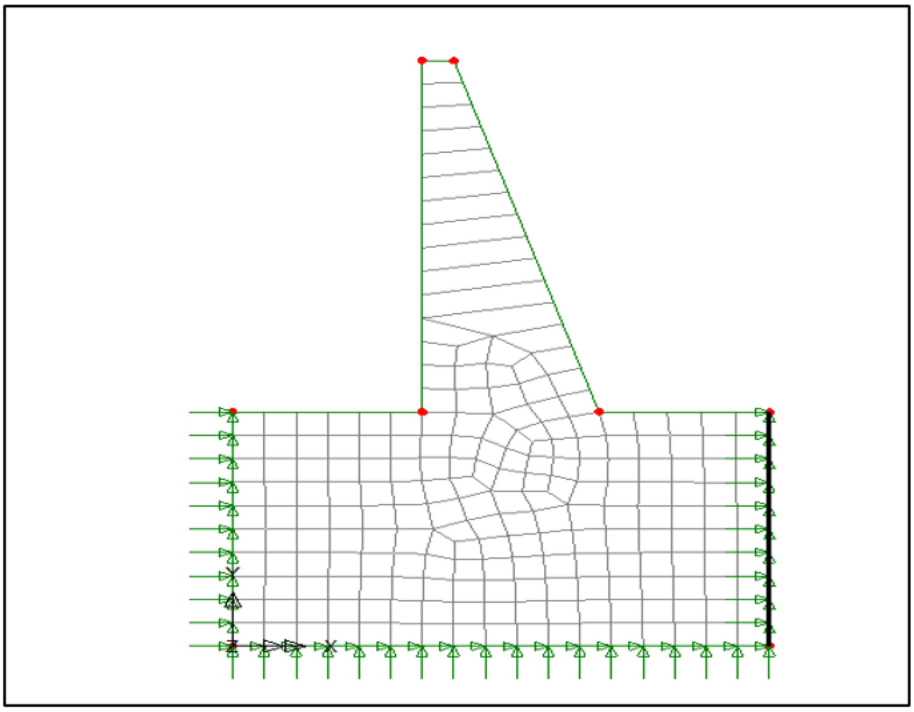

Figure 4 Location of support

For the assignment of loadings, there are a few loadings was considered. First is the loading from gravity which is 9.81m/s². Next is hydrostatic pressure which is F_p can be shown in calculation below.

$$F_p = \frac{wH^2}{2}$$

$$= \frac{(1000x9.8)x\,75}{2}$$

= 367.6 kN/m²

Where

w = specific weight of water (1000 kg/m^3 x9.8m/s^2)

h = Height of dam

For seismic loading, the Ranau earthquake data for the duration of 56.58s from Kota Kinabalu Station will be inserted into the analysis, as shown in Figure 5. The maximum value for the amplitude is 0.013g, and the minimum value is 0.00001g.

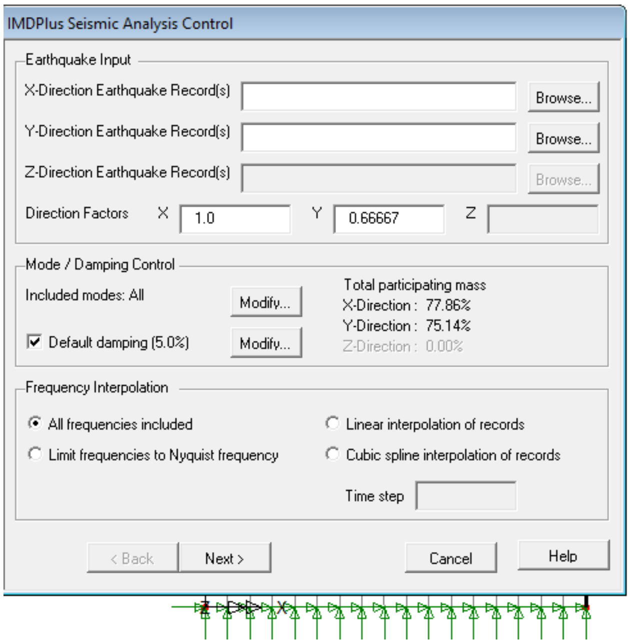

Figure 5 Seismic analysis control in IMD Plus using LUSAS

III. RESULT

An analysis using Lusas Modeller Software was conducted on Batu Hampar Dam with applied seismic loading. Batu Hampar Dam is one of the RCC dam with height of 75m and 236m width. Due to various gravity force, and horizontal component of ground motion, the main dynamic study is conducted using a finite element method or analysis.

This analysis was conducted to get the displacement and stress formation on dam when with and without seismic excitation exerted on it. The period was chosen from maximum data of earthquake event to get maximum value of displacement and stress for the dam analysis. Minimum data was not use because there is only a minor change in ground movement. This will make the dam deformation shift little to nothing for any frequency and the contrast between each form will be difficult to measure. In all analyzes, the rigid foundation was taken into consideration for the model. The base of the dam was attached to the foundation, and there was no slipping at the dam-foundation interface, and there could be a slight displacement.

4.1 Displacement Analysis

4.1.1 EFFECT OF HYDROSATIC WITHOUT SEISMIC LOADING

This analysis was conduct to check the performance of dam under effect of hydrostatic force. Hydrostatic force exerted on dam will effect in horizontal displacement at the crest of dam as shown in Figure 6 and Figure 7. It can be observed that the maximum displacements happened at the crest regions of the dam in horizontal directions after considering the seismic loading and hydrostatic pressure. When maximum frequency applied, the result of displacement is 6.4mm. As clearly shown in the contours by considering load, the crest of the dam experienced the maximum displacement in the horizontal direction. Therefore by comparing the displacements in the horizontal direction for both cases (without and with reservoir effect) it can be understood that the peak horizontal deformation of the dam body increases from 6.4 mm to 3.9 mm by approximately 39% increasing. In particular, when the reservoir water is shocked by seismic load, this influence is more observable on the dam deformation during analysis.

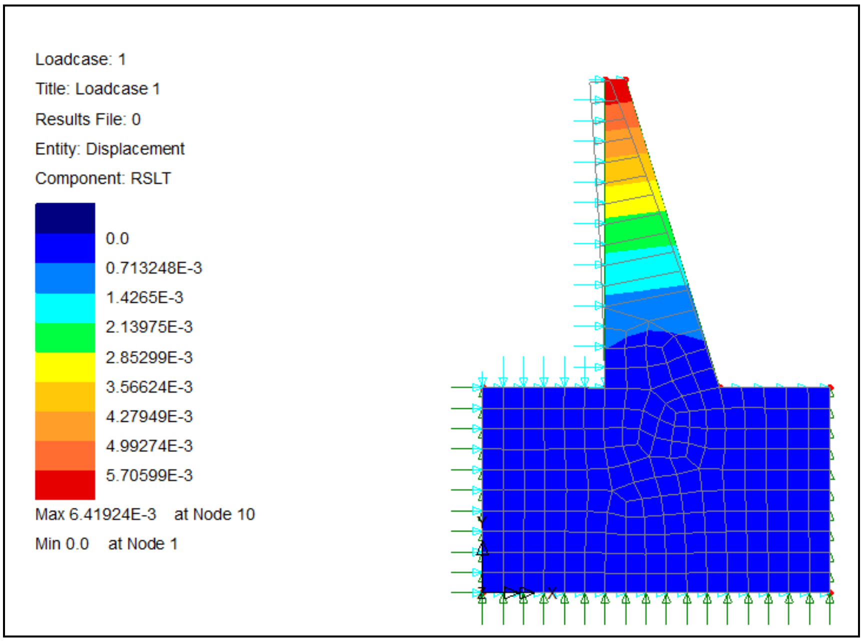

Figure 6 Maximum displacement when applied hydrostatic force is 2.2 mm

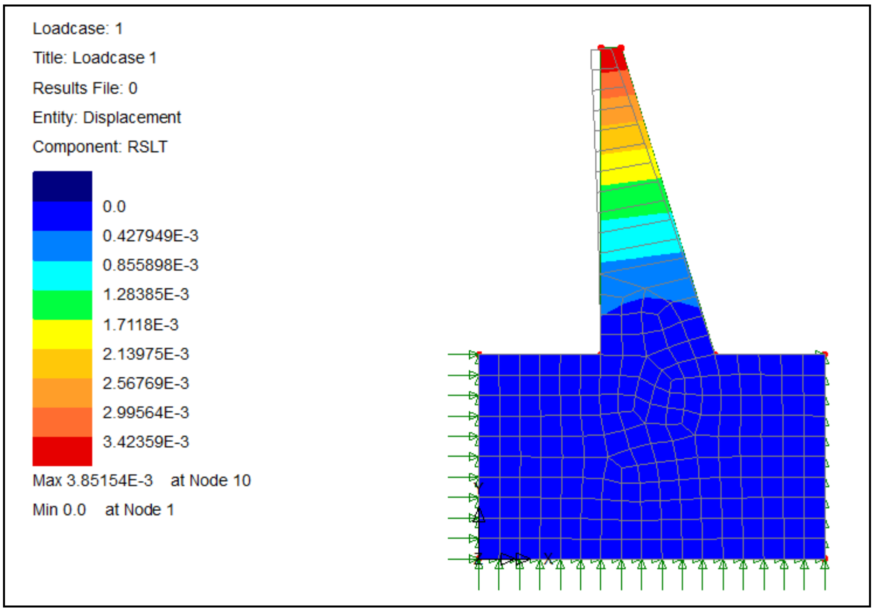

Figure 7 Maximum displacement without hydrostatic force is 0.8mm

From the result of contours above, it can said that the crest of the dam experienced the maximum displacement in the horizontal direction. Maximum displacement when apply hydrostatic force on dam is about 2.2mm while without hydrostatic is 0.8mm. Displacement occur when without apply any hydrostatic force is due to self-weight of dam and due to gravitation force. By comparing the displacements in the horizontal direction for both cases (without and with reservoir effect) it can be understood that the peak horizontal deformation of the dam body increases from 2.2 mm to 0.8 mm. Therefore, it can conclude that about 63% of displacement occur due to hydrostatic effect.

4.1.2 EFFECT OF HYDROSATIC WITH SEISMIC LOADING

Next analysis was conduct on the dynamic analysis of stress in the dam structures when subjected to hydrostatic effect. The purpose of this stress analysis is to determine whether the dam can safely withstand the specified forces. Figure 8 and Figure 9 show the minimum and maximum principal stress counters in Batu Hampar dam body by consideration of seismic excitation and effect of different condition hydrostatic pressure . From the LUSAS 14.3 the positive value would show the structure is in tension, and a negative value is in compression. It can be observed that the maximum displacements happened at the crest regions of the dam in horizontal directions after considering the seismic loading and hydrostatic pressure. When maximum frequency applied, the result of displacement is 6.4mm. As clearly shown in the contours by considering load, the crest of the dam experienced the maximum displacement in the horizontal direction. Therefore by comparing the displacements in the horizontal direction for both cases (without and with reservoir effect) it can be understood that the peak horizontal deformation of the dam body increases from 6.4 mm to 3.9 mm by approximately 39% increasing. In particular, when the reservoir water is shocked by seismic load, this influence is more observable on the dam deformation during analysis.

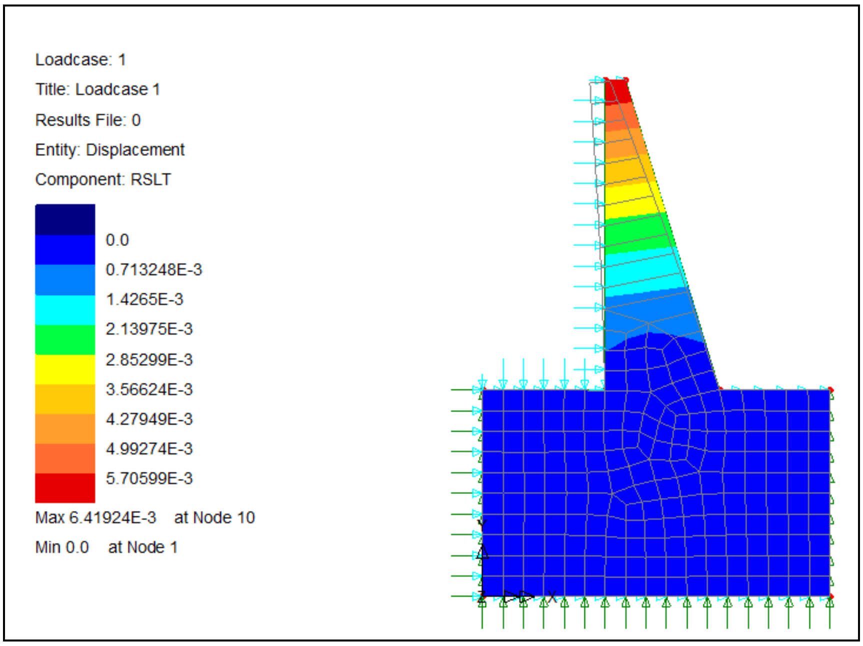

Figure 8 Maximum displacement when applied hydrostatic force is 6.4 mm

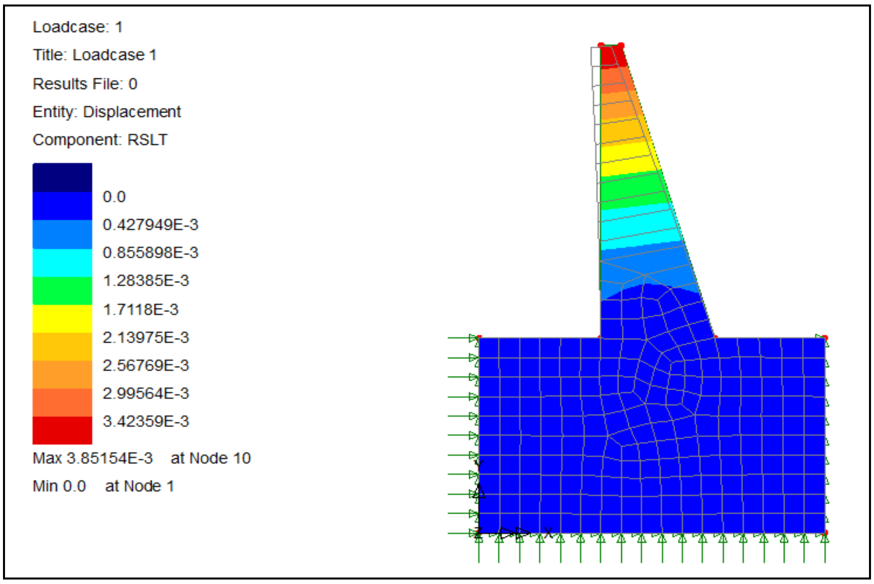

Figure 9 Maximum displacement without hydrostatic force is 3.9mm

4.2 Stresses Analysis

4.2.1 EFFECT OF HYDROSATIC WITHOUT SEISMIC LOADING

The dynamic analysis shows the stress in the dam structures when subjected to hydrostatic effect. The purpose of this stress analysis is to determine whether the dam can safely withstand the specified forces. Figure 10 and Figure 11 show the minimum and maximum principal stress counters in Batu Hampar dam body by consideration of seismic excitation and effect of different condition hydrostatic pressure. From the LUSAS 14.3

the positive value would show the structure is in tension, and a negative value is in compression. From Figure 10 it can said that due to self weight of beam and gravitation force, the maximum stress occurs at the base of dam which is 38kN /m² and from Figure 11 when 367.6 kN/m² of hydrostatic force apply on the dam, the maximum stress is 92kN/m².

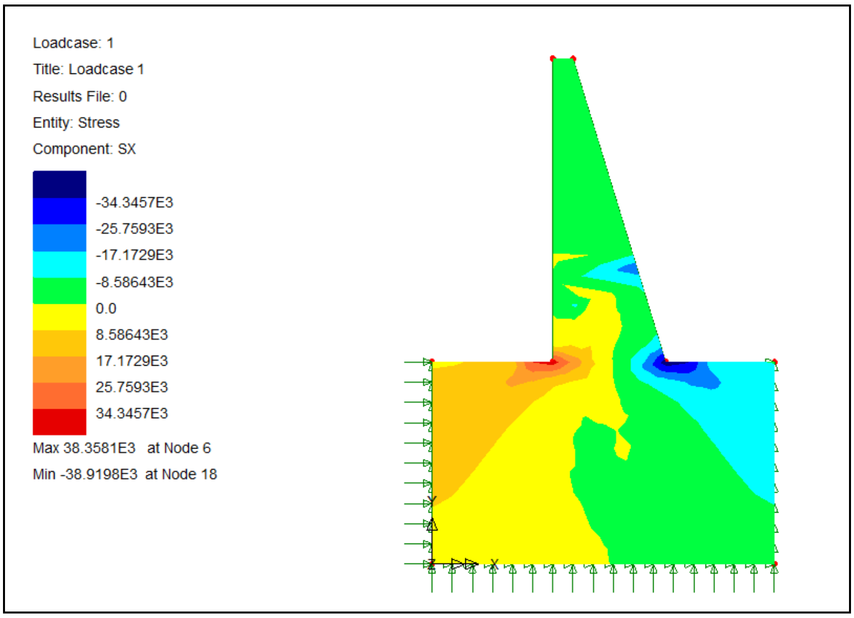

Figure 10 Maximum stress formation without hydrostatic force(38kN/m²)

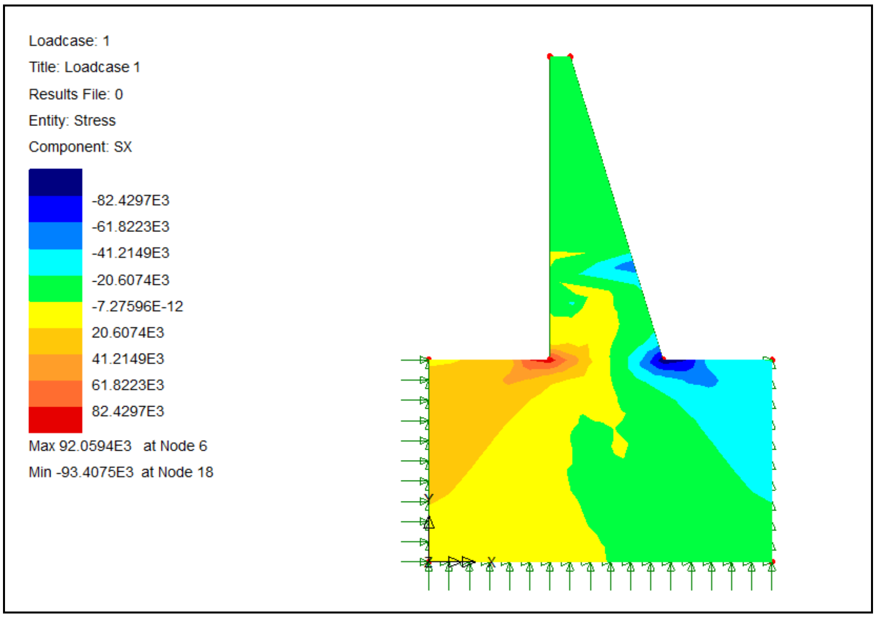

Figure 11 Maximum stress formation with hydrostatic force(92kN/m²)

4.2.2 EFFECT OF HYDROSATIC WITH SEISMIC LOADING

The dynamic analysis shows the stress in the dam structures when subjected to the seismic loading and hydrostatic effect. Figure 12 and Figure 13 show the minimum and maximum principal stress counters in dam body by consideration of seismic excitation and effect of different condition hydrostatic pressure. As shown in figures above, the maximum principal stress at the upper part of dam foundation when insert hydrostatic effect. Maximum value of stress was recorded at Node 6 which is 400.66kN/m² and minimum stress is 271.19kN/m² at Node 16

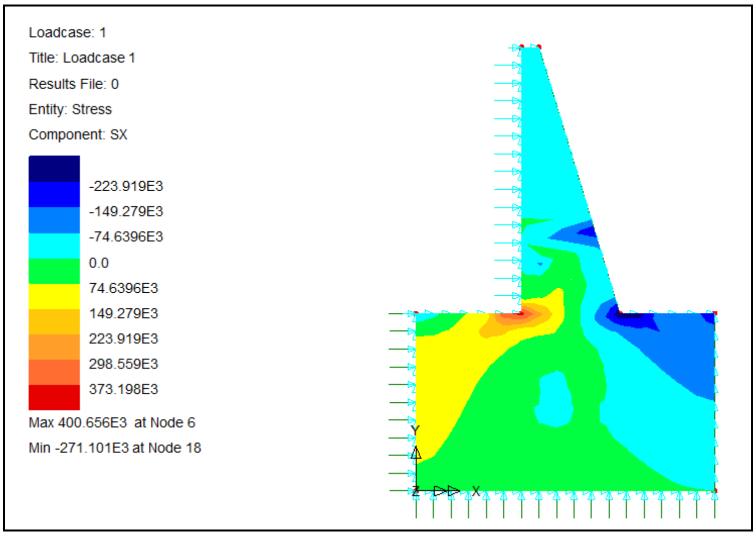

Figure 12 Maximum stress formation with hydrostatic force(400.65kN/m²)

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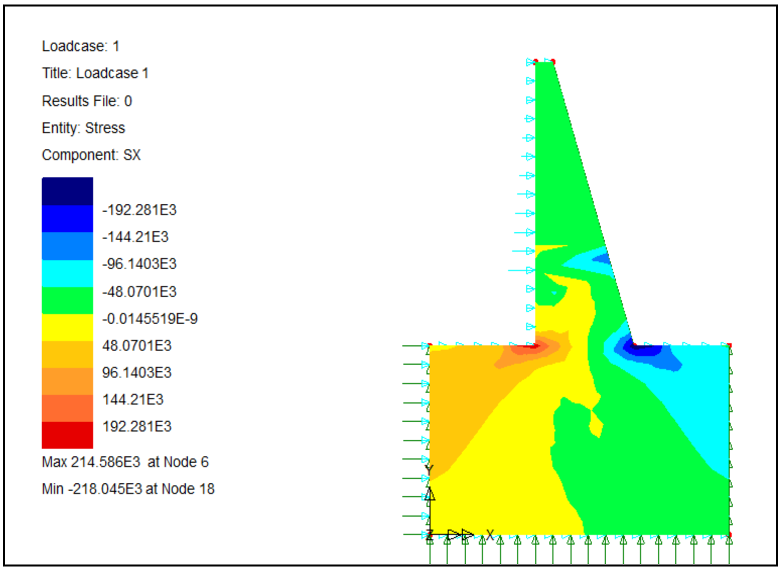

Figure 13 Maximum stress formation without hydrostatic force(214.59kN/m²)

Comparison of the stress value when before and after applied hydrostatic effect can be seen in Figure 12 and Figure 13. When applied the hydrostatic pressure, the maximum stress is 400.66kN/m² while when not applied hydrostatic force the stress is 214.59kN/m² which is lower by 41.8% than after applied loading. Areas of stresses is larger at the base compared to at crest. This is due to effect of hydrostatic and self weight of dam. Therefore, the dam may occur failure at the heel region compared to the crest. As menuoved, the peak principal stress occurs at base level of the dam body which causes sliding due to the hydrostatic pressure, whereas the minimum principal stress happens at the downstream sides as illustrated in figure below.

It is clearly seen that in maximum and minimal stress different between before applying hydrostatic pressure and after applying hydrostatic pressure. To determine if the stress imposed on the dam will endure the seismic effects, it is important to compare the actual stresses obtained from the test with the allowable material. The stress allowable capacity of concrete was about 800 kN/m² as shown in Table 2.

Table 2 Allowable stress for concrete [19]

Normal Stress (Max.)	Shear Stress (Max.)	Allowable Capacity
221.248kN/m²	436.699kN/m²	800kN/m²

It can be shown that the typical stress and shear stress that the dam possesses did not surpass the material's permissible capacity. Thus, possibilities to failure when earthquake with the same frequency can be avoided.

IV. CONCLUSION

A finite element earthquake analysis of RCC dam using Lusas Software has been successfully conducted to find the performance and the behavior of the dam. In completing this analysis, a few research was conduct from previous case study and from the case study there are a lot can be learned about the analysis of dam especially in RCC dam. The method of this analysis has been clearly described by step previously, and the procedure is implemented in a computer program using LUSAS 14.3. The analysis of the RCC dam which is Batu Hampar Dam is considered as linear dynamic analysis.

Based on the dynamic evaluation, the dam's output can be assumed a successful outcome due to the reasonable maximum displacement value of 3.48 mm. The stress behavior of the dam was also satisfactorily acceptable because the maximum normal stress which is 400.65 kN/m² respectively does not exceed the allowable stress capacity which is 800 kN/m². The results obtained from the linear dynamic analysis conducted in this project was also shown that LUSAS 14.3 capable in analyzing seismic response and hydrostatic response.

Compare between the results from the previous case study also was conducted to make sure the acceptable value that was get from LUSAS 14.3. Result for stress and displacement from case study that was conduct by Khaleed et al, in 2002. The result for displacement that was get from LUSAS 14.3 is for with seismic loading and hydrostatic force 6.4mm while the result that conducts by Khaleed et al is 8.6mm. For the stress analysis, maximum stress that was get is 400kN/m² compared to case study that was conducted by Khaleed et al the maximum stress is 137kN /m².

Dam analysis is importance to make sure there is no failure occurs. Impact of dam failure will cause many loses. Besides benefiting farmers, dams also help to avoid loss of life and properties caused by floods. Flood protection dams impound floodwaters and then discharge them to the river below the dam or retain or redirect water for other purposes. Dam also acts as hydropower to the human uses. Example of dam that acts as hydropower is Bakun Dam. Purpose of hydropower dam is to provide demand of electricity around it. In some cases, dams provide enhanced protection for the environment, such as hazardous waste retention and deleterious subsidence.

Before constructing any dam, there must a few designs consideration need to be included to avoid failure when in use. Example of design consideration are:

1. Doing hydrology study at area of construction. Hydrology is a method of predictions, such as the frequency of natural events. Mathematicians can attempt to forecast occurrences based on historical experience, but Nature is uncertain in terms of time and degree of phenomenon. Based on past knowledge, the low flow dynamics of the river would monitor the necessary reservoirs and catchment.
2. Next is by considering the loading and factor of safety of that the dam will support. Static and dynamic loading like earthquake loads acting on the body of the dam must be calculated and analyzed.
3. Besides, the design of foundation must be strong enough to carry unpredictable natural event such as flood. The foundations of the dam must be sufficient to endure the applied loads on it by the structural elements, both instantly after having to fill the reservoir and in the long term, without undue deformation. With period, disintegration by attenuation and sediment load of water can occur, while soft rocks and clays usually exhibit lesser strengths under applied load than under extremely distressed.

REFERENCES

[1]. Z. Heirany. (2017). Seismic Behavior Of RCC Dams Including The Effect Of. Journal Of Applied Engineering Sciences, 39-4

[2]. Ismail, R. and Ibrahim, A. (2021). "Structural Pounding: Due to Structures Configurations and Effects of Earthquakes." Malaha PLT. ISBN: 978-967-2424-16-1.

[3]. Ismail, R. (2020). "Characterization and Performance of Nanocomposites Elastomer Incorporating Carbon Nanotubes and Microcarbonyl Iron Fillers." PhD Thesis, Universiti Teknologi MARA.

[4]. Ismail, R. (2008). "The Application of Artificial Neural Network in Seismic Evaluation of Building." M.Eng. Thesis, Universiti Teknologi Malaysia.

[5]. Adnan, A. Alih, C.S, and Ismail, R. (2008). "Predicting of Bridge Conditionbased on Seismic Zonation by Using Artificial Neural Network." pp 112-127, Chapter 8 in Book of Advances in Earthquake Engineering Applications, Penerbit UTM.

[6]. Adnan, A. and Ismail, R. (2008). "Database System and Digital Earthquake Evaluation of Buildings." pp 128-144, Chapter 9 in Book of Advances in Earthquake Engineering Applications, Penerbit UTM.

[7]. Adnan, A. Ramli, Z. Hendriyawan, Jati Sunaryati, Tan Chee Wei, Meldi, R. Ismail, Suriyana Abd. Rahman, Sophia C. Alih, Taksiah Abd Majid, Azmi Ibrahim, (2008). "Seismic Performance of Dam and Tunnels." Final Report, Volume C, MOSTI, ASM, UTM.

[8]. Ismail, R. (2006). "Earthquake Design of Fixed Offshore Platform by Using Visual Basic 6.0." Bachelor Degree Thesis, Universiti Teknologi Malaysia.

[9]. Ismail, R. Rajhan, N. H., Hamid, H. A., & Ibrahim, A. (2019). "Experimental data for effect of carbon black loading on tensile, hardness and rebound of magnetic iron filled natural rubber composites." Data in brief, 25 (104166).1-10. Elsevier Publishing.

[10]. Ismail, R., Ibrahim, A., Rusop, M. and, Adnan, A. (2019a). "Dynamic mechanical properties of natural rubber vulcanizates with different carbon nanotubes-loaded." AIP Conference Proceedings 2151 (1), 020027.
[11]. Ismail, I., Ibrahim, A., Rusop, M., and Adnan, A. (2019b). "Magnetic properties of carbon nanotubes-natural rubber composites." AIP Conference Proceedings 2151 (1), 020028.
[12]. Ismail, I., Ibrahim, A., Hamid, H., Rusop, M., and Adnan, A. (2018a). "Experimental study on mechanical properties of elastomer containing carbon nanotubes." Journal of Engineering Science and Technology, 13(3), 565 – 664.
[13]. Ismail, R., Ibrahim, A. and Adnan, A. 2018b. "Damage Assessment of Medium-Rise Reinforced Concrete Buildings In Peninsular Malaysia Subjected To Ranau Earthquake." International Journal of Civil Engineering and Technology, 9(7), pp. 881–888.nce, 103, 02024.
[14]. Ismail, R., Ibrahim, A., Hamid, H., Rusop, M., and Adnan, A. (2018a). "Experimental study on mechanical properties of elastomer containing carbon nanotubes." Journal of Engineering Science and Technology, 13(3), 565 – 664.
[15]. Ismail, I., Ibrahim, A., and Adnan, A. (2018b). "Damage Assessment of Medium-Rise Reinforced Concrete Buildings In Peninsular Malaysia Subjected To Ranau Earthquake, International Journal of Civil Engineering and Technology." 9(7), pp. 881–888.nce, 103, 02024.
[16]. Ismail, R.; and Ismail, M.I. (2017a). "Dynamic Analysis of Concrete Faced Rockfill Dam Using Finite Element Method." Journal of Engineering and Applied Sciences, 12(7), 1772-1776.
[17]. Ismail, R.; and Abdul Karim, M.R. (2017b). "Concrete Bridge Pier Performance Under Earthquake Loading." Journal of Engineering and Applied Sciences, 12(9), 2254-2258.
[18]. Ismail R.; Ibrahim, A.; and Razali, N. (2017c). "Vulnerability study of public buildings subjected to earthquake event." MATEC Web Conference, 103, 02023.
[19]. Ismail, R.; Kamsani, M.H.; and Mohd Nadzri, N.I. (2017d). "Seismic Analysis of Concrete Dam by Using Finite Element Method." MATEC Web Conference.
[20]. Ismail, R., Rosni, J. E. M., & Nadzri, N. I. M., 2017e. Performance of rockfill dam under dynamic loading. In AIP Conference Proceedings (Vol. 1892, No. 1, p. 120012). AIP Publishing.
[21]. Ismail, R., & Ismail, M. I., 2017f. Dynamic analysis of Concrete Faced Rockfill Dam using finite element method. Journal of Engineering and Applied Sciences, 12(7), 1772-1776.
[22]. Ismail, R., and Zamahidi, N. F. (2015). "An evaluation of High-Rise Concrete Building Performance Under Low Intensity Earthquake Effects." InCIEC 2014, Springer Singapore, pg 79-86.
[23]. Huda A.M., M.S. Jaafar,J. Noorzaei,Waleed A. Thanoon,T. A. Mohammed. (2010). Modelling The Effects of Sediment on The Seismic Behaviour of Kinta Rcc Dam. Pertanika J. Sci. & Technol., 43 – 59.
[24]. Murat Cavusli, Ismail Hakki Ozolcer, Murat Emre Kartal. (January 2017). The Effect of Reservoir Length on The Earthquake Behaviour of Rcc Dams. Journal of Science And Technology.
[25]. Khaleed Ghaedi, Parveen Khunzaei, Ramin Vaghei, Amir Fateh. (N.D.)(2002). Reservior Hydrostatic Pressure Effect On Roller Compacted Concrete Dam.
[26]. Kartal, M. E. (July 2012). Three-Dimensional Earthquake Analysis Of Roller-Compacted Concrete Dams. Natural Hazards And Earth System Science, 2369–2388.