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DYNAMIC ANALYSES OF DAM RELEVANT STRUCTURE IN NORTHERN THAILAND

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Abstract

Losses caused by dam failure are tremendous. These have the potential of destroying entire cities. The dam is essential for the survival of a community as it provides water supply and power to a community. Although the seismic safety of dams is well established, the study on the seismic safety of dam relevant structures such as control center, gate, powerhouse, and spillway is still necessary. In some cases, dams could withstand the earthquake but they are not able to be operated after the earthquake due to the dam relevant structures' abnormality. On top of that the damage or failure of dam relevant structures could bring about the dam failure and cause disastrous losses to the cities located downstream. For example, the damage of spillway or control center may cause a dam to stop its operation due to the safety issue or even causes the uncontrollable release of the reservoir water. Therefore, this issue must be carried out in a proper way. The main goal of this research is to evaluate the seismic safety of the dam relevant structure in northern Thailand and to ensure that it can be operated normally after the expected large earthquake. This study is divided into three main parts that are; the selection of the representative dam relevant structure and its suitable seismic performance level, the selection of input ground motions, and seismic safety evaluation of the selected dam relevant structure. First, the representative dam relevant structure is selected. Then, the performance goal of the representative structure will be set upon its important and expected performance. Performance Objectives are employed by matching one of the performance levels to a specific ground motion level. For input ground motions, the maximum considered earthquake (MCE ≈ 2,475 years return period) was selected to be used. At this ground motion level, all structural components must be intact, and uncontrollable release of reservoir water must not take place. Unfortunately, due to the lack of strong ground motion records in Thailand, earthquake records were carefully selected by considering the compatibility with the National Standard DPT 1302: Seismic Resistant Design of Buildings and Structures (Thailand). Thereafter, the microtrermor observation, is a non-destructive test, was conducted to obtain necessary parameters on the vibration characteristics of the representative dam relevant structure such as natural period and mode shape. Accordingly, the microtremor test results were used in the verification of the numerical model by comparing with the frequency analysis results. Therefore, seismic safety of a representative structure is then evaluated through the numerical simulations. Results and suggestions on the seismic safety of the representative dam relevant structure are given.

Keywords: Dynamic, Seismic safety, Dam relevant structure, Earthquake

1. Introduction

The damage and loss caused by dam failure are significant and this dam failure has the power to destroy the entire city. Dams are important for the survival of the community as they are an essential water supply and energy sources. Today, the seismic safety of dams is well established. However, earthquake safety studies of dam relevant structures such as control centers, gates, and spillways are therefore necessary.

In some cases, the dam can withstand an earthquake. However, the dam's operation may not be able to continue after the earthquake because the structure associated with the dam is not working properly. Besides, the collapse of the structure may lead to dam failure or loss to society downstream. For example, damage or collapse of the spillway or control center may cause the dam to shut due to safety issues or cause uncontrollable water discharges.

Some researchers [1,2] have proposed the seismic design code for such structures. For example, Wieland and ICOLD have stated that the seismic design of such structures must assure that structures, components, and equipment must be fully functional during and after an earthquake.

In 1996 the Applied Technology Council released the ATC-40 Seismic Evaluation and Retrofit of Concrete Buildings [3] which contains performance-based seismic design and details for seismic analysis and safety evaluation of buildings. The performance-based design method provides information about building behaviors under shaking levels that corresponding to the selected hazards.

In 1997, the NEHRP Guidelines for the Seismic Rehabilitation of Buildings [4] defined levels of operations as follows: Operational, Immediate Occupancy, Life Safety, and Collapse Prevention. Moreover, the guideline regarding the ground motion for long-term earthquakes (2475-year return period) or the Maximum Considered Earthquake Ground Motions (MCE) and Design Basis Event earthquakes (DBE; 475-year return period) by DBE was 2/3 of MCE.

In general, most codes and standards focus on ordinary buildings. Although some codes may provide additional design concepts to evaluate the seismic safety of other important structures, evaluations of dam relevant structures are still seldom. In 2008, Ariga [5] proposed a method to evaluate the seismic safety of spillways accurately by considering all structural components by using numerical simulation with 3D dynamic analyses. Similarly, Adya [6] studied a modeling and numerical simulation for the dynamic analysis of gravity dam spillways. Recommendations regarding the modeling of dam spillways and other factors related to the dynamic analysis of dam spillways were provided.

In Thailand, seismic design criteria in National Standards. DPT 1302: Seismic Design of Buildings and Structures (By the Department of Public Works and Town & Town & Country Planning, Ministry of Interior, Thailand) [7,8] provided MCE or DBE. However, the damage level may only prevent the building from collapse. But in reality, the performance level of the structure associated with the dam must be at the operational level.

The moderate to large earthquakes have been reported in Northern Thailand. On May 5, 2014, the 6.1 Mw earthquake in Mae Lao shook north of Thailand and Myanmar. The earthquake resulted in one death and damage to buildings, roads, and temples. It was the strongest earthquake ever recorded in Thailand [9,10].

Therefore, to minimize these limitations, the objective of this research is to propose an approach to assess the earthquake safety of dam relevant structures and to ensure that they can operate normally after the future large earthquake.

2. Site and Ground motions

The selected site of this study is the Kiew Kho Ma Dam, which is an earth dam located in Chae Hom district, Lampang province, Northern Thailand (lat 18–48' – 24” N, Longitude 99-38-48” E). Wang River, which is a branch of the Chao Phraya River which is 61 km northeast of Lampang. This dam is located 90 km away from the 2014 Mae Lao earthquake’s origin. The construction of the dam was started in 2005 and was completed in 2010. This dam is not only built to prevent flooding but also provides water for irrigation, human consumption and industrial use in Lampang The main dam is 43.5 m high and 500 m long and is the earth zone dam with a maximum width of 8 m. The storage capacity is 170 Mm^3. The Kiew Kho Ma Dam consists of three structures associated with the dam, the spillway, the generator and river outlet [11]. In this study, based on available data and its importance to the dam, the dam spillway was selected as a representative dam relevant structure.

2.1 The Kiew Kho Ma Dam spillway

The Kiew Kho Ma Dam spillway is located on the right side of the main dam (from upstream) as shown in Fig. 1 This spillway is a reinforced concrete structure with a radius of 12.5 x 7.00 m (Fig. 2). The overall length of the spillway is 800 m and the width of the drainage channel is 42.5 m. The maximum capacity of the water storage is 352.90 m. (MSL) with a leakage capability of 1,209 m^3/s (1,000-year return period) [11]

Fig. 1 Kiew Kho Ma Dam and its spillway(cite https://www.google.co.th/maps/ place/hl=th)

Fig. 2 Kiew Kho Ma Dam spillway

2.2 Ground motions

The maximum considered earthquake (MCE ≈ 2,475 year return period) was considered in this study. All structural components must be intact and the uncontrollable release of reservoir wáter must not occur. There are several active faults located close to the Kiew Kho Ma Dam. The closest active fault is the Central Phayao fault, which is a normal fault located 20 km away from the site, while the Pua fault is an active normal fault located approximately 100 km from the dam [8].

Due to the lack of ground motion recording data in Thailand, 7 recording earthquakes were therefore chosen from the time-history scaling method. Earthquake records from all over the world were selected by considering the magnitude range of about 6.1 to 6.9, epicentral distance from 0 to 22.5 km and the faulting mechanism is a normal fault. The mean respond spectrum of these selected eaethquakes must be compatible with the target respond spectrum at site following the National Standard DPT 1302: Seismic Resistant Design of Buildings and Structures [7]. All 7 response spectrum of selected earthquakes and their mean spectrum along with the target spectrum at site are shown in Fig. 3.

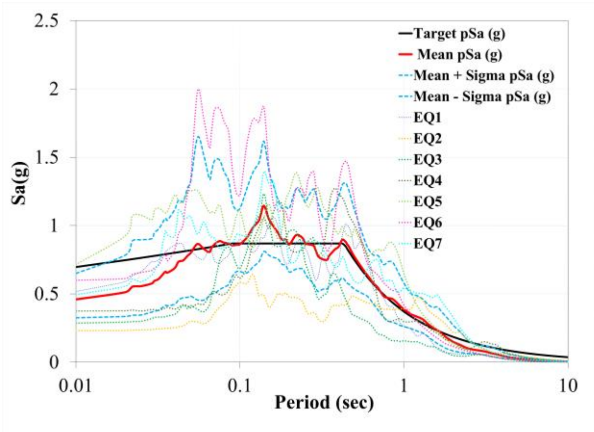


Fig. 3 Response spectrum

3. Numerical model

The commercial finite element package LS DYNA [13] was used in the 3D finite element model adopting a 3D solid element coded ELEMENT_SOLID for concrete elements and a beam element coded ELEMENT_BEAM for reinforcing steel. The model was divided into two main parts: the gantry frame and the spillway. The gantry frame was analyzed using the non-linear behavior of both the concrete (MAT_CONCRETE_DAMAGE_REL3) [14] and the reinforcing steel (MAT_PIECEWISE _LINEAR_PLASTICITY) by considering the perfect bonding between them. For the spillway, linear behavior (MAT_ELASTIC) was assumed. The model is comprised of 210,487 elements with 227,392 nodes (Fig. 4). The model was fixed in all directions at the base. The explicit finite element method was used for the dynamic analysis. The y-directional and x-directional input motions were applied at the model's base. Fig. 5 shows the dimensions of the Kiew Kho Ma Dam's spillway and its components. Fig. 5 illustrates the typical cross-section of the gantry frame's columns and deck.

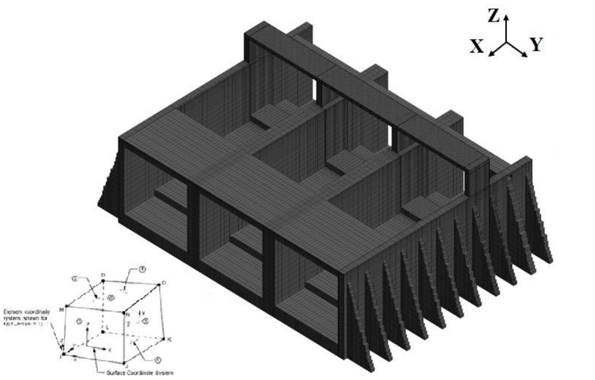
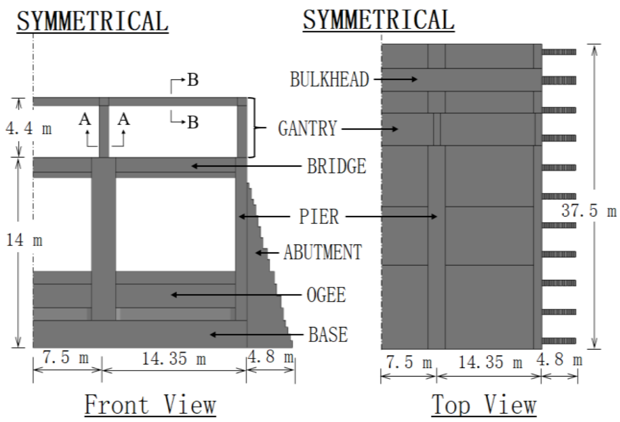
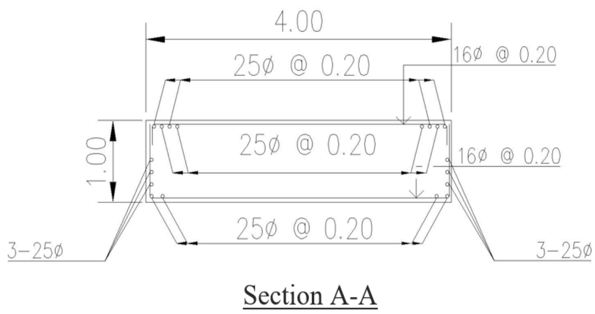


Fig.4 Kiew Kho Ma Dam spillway model





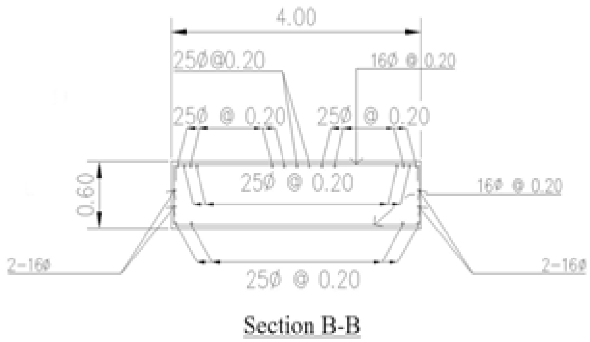


Fig.5 Kiew Kho Ma Dam spillway's typical sections

3.1 Material properties

The spillway is a reinforced concrete structure. The material properties of reinforcing steel and concrete were obtained from the design drawing and the design specification. Table 1 shows the parameters used in this study, such as modulus of elasticity (E), Poisson Ratio (υ), density (ρ), compressive strength (f_c'), tensile strength (f_t).

Table - 1 Material properties

Component	E (GPa)	υ	ρ (kg/m^3)	f_c' (MPa)	f_t (MPa)
Gantry Frame	-	0.19	2,400	32	3.2
Longitudinal bar	204	0.30	7,830	-	300
Stirrup	204	0.30	7,830	-	300
Spillway	26.7	0.19	2,400	-	-

4. Natural frequency

The results obtained from the measurement of natural frequency using ambient vibration method found that in the fundamental mode in the y and x-direction are 8.25 Hz and 21.25 Hz, respectively.

For the values obtained from the modal analysis using finite element model. The fundamental mode are 7.76 Hz and 20.70 Hz in the y and x- direction, respectively.

From the measurement and analysis using the finite element method, it was found that the natural frequency values were similar. The deviation from the ambient vibration measurement is 5.90% and 2.57% for the y and x-direction, respectively (Table 2). Also, it is found that the building is most sensitive in the y-direction or along the longitudinal direction especially the gantry frame structure, which can be observed from the vibration characteristics as shown in Fig. 6.

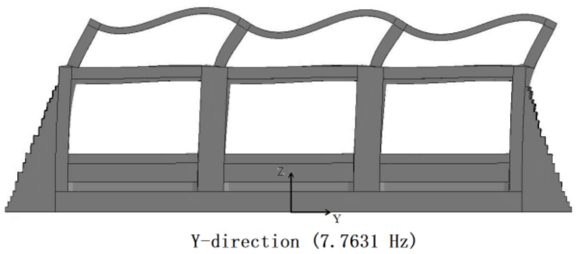


Fig. 6 Fundamental mode

Table - 2 Material properties

Mode Shape	Frequencies (Hz)		Error %
	Ambient vibration	Analysis	
Y-translation	8.25	7.76	5.90
X-translation	21.25	20.70	2.57
Torsional	N/A	8.96	-

5. Structural responses

The structural response of the Kiew Kho Ma Dam's spillway using finite element analysis is expressed through deformation, acceleration, stress, and plastic strain. Fig. 7 gives an observation point about the structural response of the model.

By considering the acceleration responses, the average maximum acceleration Ay is approximately 3.23 m/s^2. The maximum acceleration can be observed from point A (top of the pier). The average maximum amplification ratio (Ay, max / PGA) is approximately 0.97 for point A and 0.91 for point B, respectively. The de-amplification of the acceleration of the gantry frame can be found in all cases. This reduction is due to the plastic deformation and energy dissipation of the materials used in the gantry frame.

Fig. 8 shows the displacement time-history plots for points A and B when subjected to EQ1. Table 3 shows the average results such as displacement, story drift, acceleration, acceleration amplification ratio of all analysis cases. The average maximum longitudinal displacement, Uy is 8.02 cm which can be found at the top of the gantry frame, while the average maximum displacement of Ux is insignificant. The average maximum story drift of the gantry frame (2) is about 4.16 cm while the average maximum story drift of the spillway pier (1) Approximately 8.60 cm according to the Thai national standard DPT 1302 [7,8], maximum story drift must not exceed 0.01 H (H is the height). The allowable maximum story drift is 4.4 cm for gantry frame (2) and 14 cm for spillway pier. Therefore, the overall structural behavior was met the seismic design criteria as the maximum story drift was found to be lower than the allowable story drift.

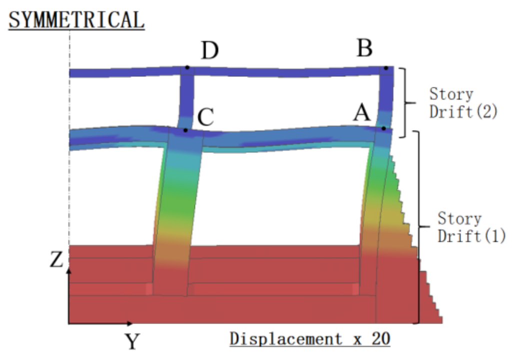


Fig. 7 Observation points

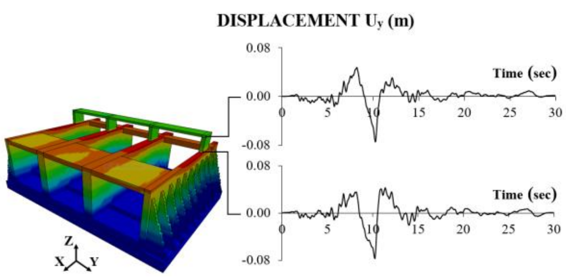


Fig. 8 Displacement, Uy subjected to EQ1

Table - 3 Average structural responses

Node	Elv (m)	Uy (cm)	Ay (m/s2)	Story drift (cm)	$A_{y,MAX}$ /PGA
A	14	8.60	3.23	8.60(1)	0.97
B	18.4	8.02	3.06	4.16(2)	0.91

Structural damage can be observed via the effective plastic strain. This effective plastic strain can be captured only when using non-linear material models. Therefore, only the damage to the gantry frame can be assessed. For the concrete, the damage can be found mostly around the lower part of the gantry columns. The results also showed that the gantry columns at both ends were subjected to less damage than those at the center. Similar results were obtained for the reinforcing steel, as the damage can be observed mostly at the lower portion of the gantry columns, and the inner gantry columns experience slightly higher damaged than those at both ends.

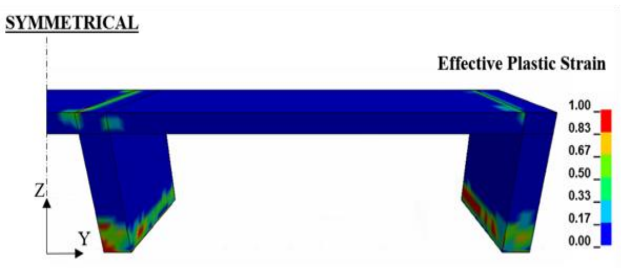


Fig. 9 Effective plastic strain in concrete (EQ1)

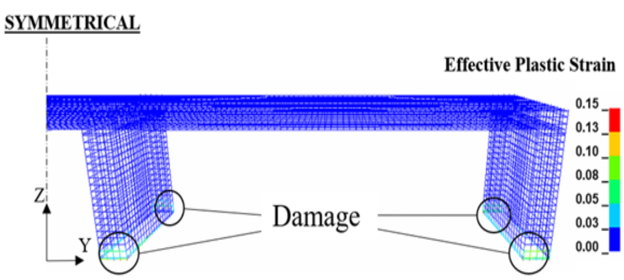


Fig. 10 Effective plastic strain in reinforcing steel (EQ1)

6. Conclusions

This study was conducted to assess the earthquake safety of the spillways of the Kiew Kho Ma Dam. Considering the importance of the dam spillway, under MCE, all structural components must not be destroyed and the uncontrollable release of reservior water must not take place. The seismic analyses were done to get structural responses from the input earthquakes. The results show that only small damage of the gantry frame was observed. For concrete, the damage was mainly found in the lower part of the gantry columns. For reinforcing steel, the damage was mostly found in the lower part of the gantry columns. Moreover, the maximum story drift of the gantry frame was less than allowable story drift provided by Thailand National Standard DPT 1302 [7,8] (4.16 cm < 4.40 cm). Therefore, it can be summarized that the Kiew Kho Ma Dam's spillway is safe against MCE, as it satisfies the expected seismic performance level.

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