THE EFFECT OF ISOLATED DAMPING LAYER SYSTEM ON EARTH DAM UNDER EARTHQUAKE LOADING

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DEDICATION

To my respectful parents and beloved wife Tayebeh Alipour as well as my son Arian Gordan

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ABSTRACT

The structural behavior during an earthquake is one of the major concerns for earth dam of a medium size about 30 meter height and 90 meter width. The body crack is created by relative vertical displacement at both edges of the crest.The failure is recorded with the crack development in dam body by interaction between dam and reservoir. To reinforce dams, some methods were used with respect to literature such as perpendicular drain, prefabricated vertical drain, geotextile layers, pile group, micro pile injection and cutoff wall system. This research included three objectives; (i) Identifying damage location in earth dam with respect to case study (Bakun dam), (ii) Studying the effect of Isolated Damping Layer (IDL) system in blanket layer using physical modeling on top of the vibrator table, and (iii) Evaluating slope stability based on seismic motion. In terms of methodology, Finite-Element method using ANSYS13program and equilibrium method using Geostudio 2007 (Slope/W) were used. Series of soil mechanic test to design IDL and small-scale model (1/100) using IDL were carried out. Displacements, shear stresses and shear strains of dam were evaluated using nonlinear analysis under strong earthquake intensity of 0.6g. The major effect on the displacement of dam was due to different foundation properties (soft, medium and stiff soil) in comparison to different core configuration in terms of geometry. The best elastic modulus ratio between unsaturated part of dam and foundation, β was 0.66 for saturated part and foundation, λ was 0.13 in order to reduce response of the earth dam. Time-history and response spectra analysis of Bakun dam showed the minimum relative vertical displacement between both edges of crest by peak ground acceleration less than 0.24g. For all site classes, the displacement ratio (Δ=2) for return earthquake period from 2500 to 500 years was recorded. Based on modal analysis, the rigid behavior of foundation was achieved by modulus ratio more than three. Effect of modulus ratio on dominant frequency was greater than depth ratio. The minimum relative vertical displacement was attained when modulus elasticity ratio between shell and core clay was less than five. The optimal behavior was obtained by using clay in blanket layer when a modulus elasticity ratio was equal to 2.50, between this layer and weak foundation.The blanket layer was designed based on mixed product of laterite soil with shredded tire and micro silica. The main role of silica was to control seepage. The qualified combination by comparison of thirteen samples was distinguished. Subsequently, nine physical models were vibrated using dominant frequency. Most of damage occurred at upstream of one third near to the crest.The best absorption of energy without any destruction was observed when the layer thickness of reinforced blanket was one fourth of dam height.The safety factor was increased using blanket reinforced layer. Finally, IDL system showed the best performance in order to reinforce dam under resonance seismic motion.

ABSTRAK

Pelakuan struktur semasa gempa bumi adalah salah satu daripada kebimbangan utama bagi empangan bumi saiz sederhana untuk ketinggian kira-kira 30 meter dan 90 meter lebar. Keretakan pada empangan tanah disebabkan oleh anjakan tegak relatif pada penjuru struktur tersebut. Kegagalan struktur direkodkan bersama dengan retak dalam badan empangan oleh interaksi antara empangan dan takungan. Untuk mengukuhkan empangan, beberapa kaedah telah digunakan oleh penyelidik yang lepas seperti longkang serenjang, pasang siap longkang menegak, lapisan geotekstil , kumpulan cerucuk, suntikan cerucuk mikro dan sistem dinding potong. Terdapat tiga objektif kajian; (i) mengenalpasti lokasi kerosakan dalam empangan bumi seperti dalam kajian kes (Empangan Bakun), (ii) mengkaji kesan Isolated Damping Layer IDL sistem dalam lapisan selimut menggunakan model fizikal di atas meja penggegar dan (iii) menilai kestabilan cerun berdasarkan gerakan seismik. Untuk menjalankan kajian ini, kaedah Unsur-Terhingga oleh program ANSYS13 dan kaedah keseimbangan dalam Geostudio 2007 (Slope/W) telah digunakan. Beberapa siri ujian mekanik tanah dibuat untuk mereka bentuk (IDL) dan skala kecil model (1/100) menggunakan IDL juga dibuat. Anjakan, tegasan ricih dan tekanan ricih empangan telah dinilai daripada analisis tidak linear di bawah keamatan gempa bumi 0.6g. Kesan yang besar ke atas anjakan empangan adalah kerana sifat-sifat asas yang berbeza (tanah lembut, sederhana dan keras) berbanding dengan konfigurasi teras yang berbeza dari segi geometri. Nisbah modulus elastik antara bahagian tepu empangan dan asas, β adalah 0.66 dan antara bahagian tepu dan asas, λ adalah 0.13 untuk mengurangkan tindak balas empangan bumi. Masa sejarah dan analisis spektrum gerak balas empangan Bakun menunjukkan anjakan tegak relatif minimum antara kedua-dua tepi puncak oleh pecutan bumi puncak kurang daripada 0.24g. Selain itu, nisbah anjakan(Δ=2) untuk kembali pada tempoh gempa bumi dari 2500 ke arah 500 tahun untuk semua kelas tapak direkodkan. Sehubungan dengan analisis modal, tingkah laku tegar asas dicapai oleh nisbah modulus lebih daripada tiga. Anjakan minimum menegak relatif dicapai apabila nisbah modulus keanjalan antara cengkerang dan teras tanah liat adalah kurang daripada lima. Tingkah laku yang optimum ditunjukkan dengan menggunakan tanah liat pada lapisan selimut apabila nisbah modulus keanjalan adalah sama dengan 2.50, antara lapisan ini dan asas tapak yang lemah. Lapisan selimut telah dibuat berdasarkan campuran produk daripada tanah laterit bersama hirisan tayar dan mikro silika. Peranan utama silika adalah untuk mengawal resapan. Kombinasi terbaik diperolehi daripada perbandingan lima belas sampel. Selepas itu, sembilan model fizikal telah digetarkan. Kebanyakan kerosakan berlaku di bahagian satu pertiga puncak. Penyerapan terbaik oleh tenaga tanpa apa-apa kemusnahan diperhatikan apabila ketebalan lapisan penutup bertetulang adalah satu perempat daripada ketinggian empangan. Selain itu, faktor keselamatan telah meningkat dengan lapisan selimut bertetulang. Akhirnya, system IDL menunjukkan kelakunan terbaik bagi memperkuatkan empangan di bawah gegaran sismik resonan.

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LIST OF SYMBOLS

δ	- Displacement
$\dot{\delta}$	-Velocity
$\ddot{\delta}$	-Acceleration
T	-Priod
f	-Frequency
σ	-Stress
τ	-Shear stress
ϵ	-Strain
θ	-Slope
γ	-Density
ϕ	-Angle of friction
C	-Cohesion
SF	-Safety factor
PGA	-Peak ground acceleration
°	-Degree
ζ	-Damping ratio
υ	-Poisson's ratio
E	-Modulus elasticity
λ	-Gradient
2D	-Two dimensional analysis
3D	-Three dimensional analysis
FEM	-Finite Element Method
FDM	-Finite Difference Method
ω	-Natural frequency of the system
BS	-British Standard

H -Height

W -Width

Hz -Hertz

m_v -Coefficient of Volume Compressibility

c_v -Coefficient of Consolidation

g -Gravity

LIST OF APPENDIX

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Nowadays, dam construction is critical trend in the world in order to access some requirements. The major purposes defined by water supply and electricity. In this context, some important aspects investigated by initial phase of design. One of the main problems is structural behavior during an earthquake. Besides, there are some case studies of damages. The earth dam damaged while some type of body cracks made in dam or foundation. Some phenomena occurred such as overflow, piping and structural failure in parallel to development of cracks. In brief, evaluation of earth dam in order to earthquake effects is one of the major purposes of design.

Dynamic analysis of earth dam is one of the main purposes through design process. According to the literature, there are some studies in this area like reinforcement techniques, shaking table test, data monitoring and numerical analysis. In terms of the numerical method, two famous methods such as Finite-element or Finite-difference are used. Besides, not only the effect of material properties on dynamic trend but also comparison of the two and three-dimensional analysis were reviewed. In addition, the distribution of frequency and acceleration evaluated for structure. In terms of earth dams under seismic load or earthquake, the integrated response is the increase of acceleration and displacement at the crest based on nonlinear aspect. The main role of this process appeared by interaction between dam and reservoir. It seems to be that, improvement of earth dam behavior with reinforced techniques is required.

Seismic-resistant capacity of the earth dams is a great issue within earthquake active zone. However, dynamic behavior is one of the main concerns. For a realistic evaluation of the seismic risk, one must consider some uncertainties. They are some major aspects such as site geology, material stiffness, and analysis method. In addition, depth investigation in this domain indicated that numerical methods applicably used to assess dynamic behavior during the earthquake. Moreover, the numerical results verified by some experimental tests like shaking table and centrifuge.

1.2 Problem Statement

In terms of problem statement, failure mechanism is the main problem in earth dams. Before failure, some significant factor like freeboard, overflow and piping that should critically controlled by design approach. Overflow is very huge danger for dam, and should avoid. In fact, most of the reports in order to damage in dam related to the overflow. Therefore, freeboard design is very important to control overflow. It is important to note that the wave height in reservoir increased during earthquake. Moreover, interaction between dam and reservoir is very effective to dam behavior under seismic load. It is worth noting that piping is other problem in this category. This phenomenon related to the body cracks. In addition, body cracks are directly corresponded to deformation during an earthquake. In this case, the plastic deformation created by relative displacement. After all, the main goal in order to control dynamic behavior is the relative displacement during earthquake with respect to damage.

Lower San Fernando dam suffered an underwater slide during the San Fernando earthquake, 1971. Fortunately, the dam barely avoided collapse, thereby preventing a potential disaster of flooding of the heavily populated areas below the dam[Karl V, 1971].

Two decades later, the 1994 Northridge earthquake put the Los Angeles Dam with concrete face rock-fill dam (CFRD) to the test [Robert et al, 1994]. The Northridge earthquake was almost equal in magnitude to the previous San Fernando earthquake. Ground shaking was very strong, with amplitudes among the highest ever recorded but consistent with the USGS estimates. Yet the dam showed only minor deformation and superficial cracking. Despite the intense shaking, the crest of the dam moved only 1 inch sideways and settled only 3.5 inches. Moreover, longitudinal crack reported in Fengshou reservoir dam. Dam was 200 meters (656 feet) long, 0.6 meters (2 feet) wide and 3 meters (10 feet) deep at its largest degree.

Furthermore, On May 12, 2008, a strong earthquake with 8.0 Richter scale jolted Wenchuan County in Sichuan province of China [Xu Zeping, 2008]. Zipingpu concrete faced rock-fill dam, which is only 17 km away from the epicenter, survived from the earthquake. However, it is also suffered severe damages during the strong earthquake.

1.3 Aim of Research

The main aim of this research work is improvement of earth dam behavior under earthquake by new reinforcement technique. This study tried to introduce Isolator Damper Layer (IDL) system in order to reinforce dam with respect to increase resistance under the strong earthquake.

1.4 Objectives of Research

To achieve such aim the following objectives are considered for the research work:

i. To identify the location of damage by evaluating the effect of material properties in dam body and performing vibration analysis, time history and response spectrum analysis.

ii. To study the effect of blanket layer using Isolated Damping Layer (IDL) system between dam and foundation to control dynamic behavior by investigating material properties, layer thickness and reinforcement arrangement.

iii. To evaluate slope stability in earth dam by evaluating the safety factor under static and dynamic load conditions.

1.5 Scope of Research

This scope covers all objectives as mentioned in last section. Finite –Element method (FEM) is performed using Ansys13 program for numerical analysis such as time-history and response spectra in order to consider the location of damage. In parallel, evaluation of slope stability by Geostudio 2007 (Slope/W) program was performed utilizing equilibrium method to compute safety factor in both static and dynamic load conditions. Moreover, the British standard is applied for IDL geotechnical tests. Furthermore, for small-scale physical modeling, the short homogenized dam of 16.5 meter with scale ratio (1/100) is tested on top of the vibrator table. In addition, in terms of critical situation for earthquake effect, the resonance condition is evaluated according to dominant frequency. The vibrator table functions in one dimension (vertical motion) only and the duration is two minutes for all samples. The reason for two minutes is about background in Sumatra fault that is near to Malaysia. In terms of limitation for this research, Local soil (Laterite) is used from campus of the University Teknologi Malaysia. Vibrator table is used with capacity equal 250 kg. Data logger is used to record data in each two seconds during the vibration.

1.6 Significance of the Research

This research covers earthquake effect on some structures such as earth dam; homogenize embankment, concrete face rock-fill dam and embankment-bridge. This research also includes a case study for Bakun dam in the east of Malaysia. In addition, this research is the pioneer study to introduce new material (IDL), as can be used to increase structural resistance under seismic load. According to the use of blanket layer reinforced with new material (IDL), dam performance during the strong intensity of ground motion like resonance condition is very good. It is worth noting that, this material can use for different structures based on next study.

1.7 Organization of thesis

The organization of the thesis can described briefly as follows:

- Chapter 1 is the Introduction, which explains on the background, the aim, objectives, and scope.
- Chapter 2 is on Literature review that explains analysis of earth dam during an earthquake. This chapter included comprehensive review in some methods such as Finite-Element method (FEM), Finite-Difference method (FEM), Plane stress (3D), Plan strain (2D), Free vibration analysis, Time-history analysis, Response spectra analysis, Reinforcement techniques, Data monitoring and Shaking table test.
- Chapter 3 is Research Methodology that explains the methodology to complete the research besides the data collection and analysis technique used in this study.
- Chapter 4 is Analytical and experimental tests that includes dominant frequency and slope stability in dam, experimental test to design Isolated Damping Layer (IDL) and small-scale physical modeling.
- Chapter 5 is Time-history analysis with case study (Bakun dam).
- Chapter 6 is conclusion and recommendation that explains the significance of the research finding including recommendation or suggestion and benefit of the research for future study.

1.8 Summery

Introduction of thesis presented in this chapter. In addition, problem statement and aim of the research are described. Moreover, objectives of study based on scope with are explained. Finally, the significant points of present study and thesis organization are presented in this chapter.

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