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SEISMIC VULNERABILITY ANALYSIS OF VARIOUS TYPES OF DAMS WITH FINITE ELEMENT METHODS

EHSAN NOROOZINEJAD FARSANGI

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Engineering (Civil-Structure)

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Especially Dedicated To My Beloved Father And Mother
For Their Endless Love And Support

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ABSTARCT

In recent years, the seismic verification of structures has dramatically evolved. Malaysia is surrounded by countries such as Indonesia and Philippine that has experienced many great earthquakes; hence it would be unwise to totally ignore the effects of earthquakes on structures in Malaysia.

The purpose of this study is to investigate the vulnerability of existing Dams in Malaysia region under earthquake ground motion because In case of severe ground motions, substantial cracking is likely to develop across significant regions of the dam, and its consequences must be taken into account for a rigorous seismic evaluation. By evaluating the seismic performance of the dams we can predict dam's resistance to prevent economic damage and loss of human life in case of dam failure. In this study we present the results of the case studies of the earthquake response on various types of dams (Concrete, Rockfill and Earthfill Dams). To achieve this purpose, dams have been remodeled using SAP2000 and PLAXIS. Three different analysis methods (Free Vibration, Time History and Response Spectrum) have been implemented in this Project to study the behavior of these dams under earthquake loading, Seismic hazard was represented by the peak ground acceleration at the dam site.

After analyzing the dams in SAP2000 and PLAXIS we will compare the existing stress from the output data with dams' capacity to identify the critical parts of the dams under earthquake loading. This problem can be efficiently tackled with necessary boundary conditions with finite element technique. The dams considered in the present investigation, are analyzed by two dimensional plane strain formulations with four node quadrilateral elements in SAP2000 and 15-noded triangular elements in PLAXIS. We have done the response spectrum and linear time history analysis by using SAP2000 and Non-linear dynamic analysis by means of PLAXIS. Both softwares have included soil-structure interaction in analysis.

ABSTRAK

Dalam beberapa tahun terakhir, pengesahan seismik struktur telah berkembang secara dramatik. Malaysia dikelilingi oleh negara-negara seperti Indonesia dan Filipina yang telah mengalami banyak gempa bumi; maka tidak bijaksana untuk sama sekali mengabaikan kesan daripada gempa pada struktur di Malaysia.

Tujuan kajian ini adalah untuk mengkaji ketahanan empangan yang ada di Malaysia yang dipengaruhi gerakan tanah oleh gempa. Dalam kes gerakan tanah yang kuat, besar kemungkinan keretakan di kawasan penting, dan kemungkinan yang harus diambil kira untuk penilaian sismik yang ketat. Dengan menilai prestasi sismik, anggaran perlawanan rintangan untuk mengelakkan kerosakan ekonomi dan kehilangan nyawa manusia dalam hal kegagalan empangan. Dalam kajian ini, hasil kajian kes dari gempa pada pelbagai jenis empangan (konkrit, batuan dan tanah) dibentangkan. Untuk mencapai matlamat ini, empangan telah di analisa dengan menggunakan SAP2000 dan PLAXIS. Tiga kaedah analisis yang berbeza (Bebas Getaran, Perubahan Masa dan Respon Spektrum) telah dilaksanakan dalam tugas untuk mempelajari perilaku empangan, risiko gempa yang diwakili oleh percepatan tanah maksimum di lokasi empangan.

Setelah menganalisis empangan di SAP2000 dan PLAXIS perbandingan tegasan yang ada dari data keluaran dibuat dengan kapasiti empangan untuk mengenalpasti bahagian kritis dari empangan yang dibebani dengan gempa. Masalah ini dapat diatasi dengan memerhati keadaan had yang diperlukan dengan teknik unsur terhingga. Empangan-empangan yang dipertimbangkan dalam penyelidikan ini, dianalisis oleh dua formulasi dimensi iaitu satah terikan dengan empat nod dan elemen segiempat di SAP2000 dan unsur-15 segitiga nod di PLAXIS. Kami telah melakukan analisis spektrum respon dan analisi perubahan masa secara linar dengan menggunakan SAP2000 dan analisis tidak linar dinamik dengan menggunakan PLAXIS. Kedua-dua perisian telah memasukkan interaksi tanah-struktur dalam analisis.

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H	dam height
B	dam width
γ	density
E	Young's modulus
E_m	degraded elastic modulus
E_0	original modulus
g	gravity
p	hydrodynamic pressure
m	equivalent mass of water storage
C	ratio between seismic acceleration and gravitational acceleration
w	density of water (kg/m^3)
y	distance of cross section from dam crest (m)
u	unknown relative displacements vectors
$\dot{u}$	unknown relative velocities vectors
$\ddot{u}$	unknown relative accelerations vectors
M	mass matrix of the soil-structure system
C	damping matrix
D	dynamic amplification factors
β	frequency ratio
ξ	damping ratio
ϖ	frequency of earthquake excitation
ω	frequency of structure
ω_i	angular frequencies of vibration modes

σ_i	Stress in *i* direction
v , μ	Poisson's ratio
ϕ	Friction angle
ψ	Dilatancy angle
ε_i	Strain in *i* direction
φ	total porosity of concrete

CHAPTER 1

INTRODUCTION

1.1 Introduction

An earthquake is produced by the sudden rupture or slip of a geological fault. Faults occur at the intersection of two segments of the earth's crust. Peninsula Malaysia lies in the Eurasian Plate and also within the Indian-Australian Plate. Geologically, small faults also exist in East Malaysia. Records have shown that we do sometimes experiences some off-set tremors originating from the Indonesian zone. Thus there is a need for some seismic checking to be incorporated in the design process so that the structures would be resistant to earthquake.

In the recent years, the issues of seismic safety of dams have become a major concern in the planning and designing of new dams proposed to be built and for safety evaluation of existing dams in seismic regions. Prediction of the performance of the dams during earthquakes is one of the most challenging and complex problems found in the field of structural dynamics.

Water with good quality and in sufficient quantity is a basic requirement for humanity. Reservoirs and dams that create those reservoirs provide a means to balance the fluctuation of natural water flow. Multipurpose reservoirs can serve for drinking water, irrigation in agriculture, production of clean and renewable energy, recreation and flood protection. So, the dams and study of theirs stability under variable loading especially earthquake forces play a vital role in the infrastructure of many states for the provision of water resource and saving money.

Finite Element Method (FFM) is a numerical method that can be used to solve different kinds of engineering problems in the stable, transient, linear or nonlinear cases *(Bathe, 1996).* Among finite element method software's, SAP2000 and PLAXIS are known as the most precise and practicable softwares in industry and university researches. They are used for dynamic analysis such as earthquake and water wave loading on structures.

1.2 Problem Statement

There are many reasons for Malaysia to worry about earthquake. New revelations indicate Malaysia is moving closer towards the rumble zone. Malaysia is inching closer to rumble zones and will not be immune to earthquake forever. Year after year, neighboring tectonic plates inch towards from all directions and on mounting because the Australian, Eurasian and Philippine plate around Malaysia are moving . *Azlan (2005)* stated that Peninsular Malaysia does lie on faults but have been known to be non-active faults. Malaysia is located in low seismic activity area but the active earthquake fault line through the center of Sumatera just lies 350 km from peninsular.

Sabah, which experienced the highest earthquake magnitude recoded with 4.8 Richter in the last century occurred about 90 KM from Miri, Sarawak have cause several building crack. The plates are moving closer toward and shift a few centimeters was recorded after the incidents have been reported *(Hendriyawan et. al, 2003)*. Thus, this study will demonstrate the behavior of Dams under earthquake effect. The Dams will be modeled and analyzed with SAP 2000 and PLAXIS to determine their seismic vulnerabilities.

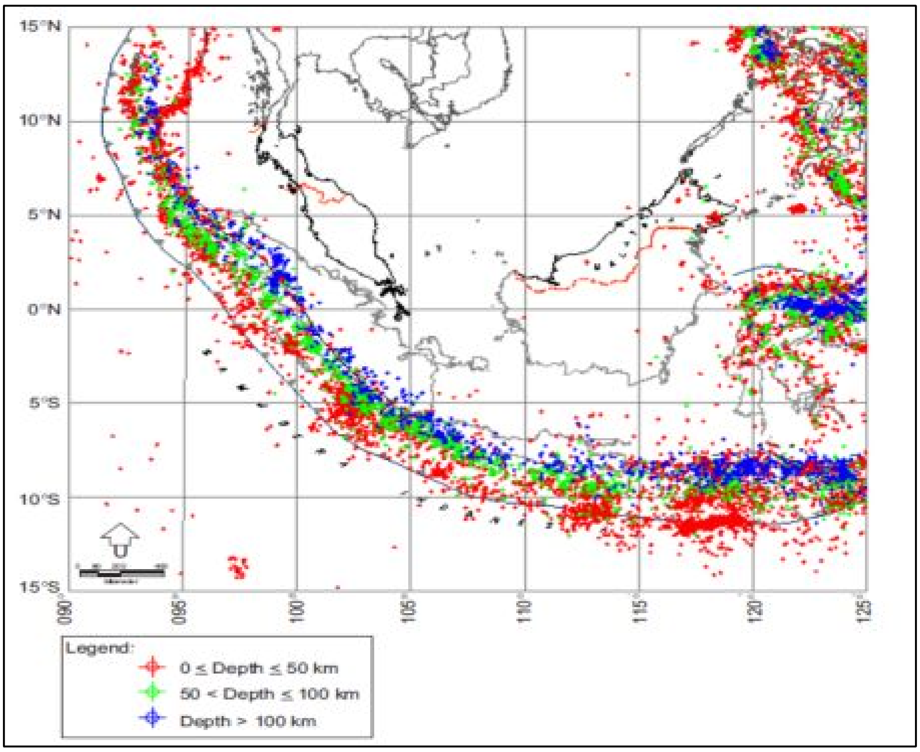

Figure 1.1: Historical earthquakes around Peninsular Malaysia [Mω > 5] *(Adnan. A. 2005)*

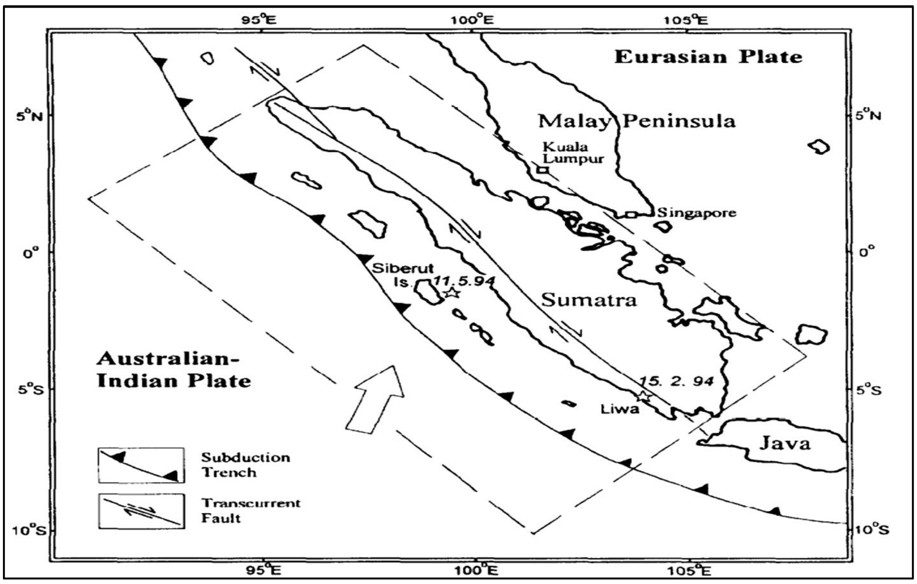

Figure 1.2: Active Faults Around Peninsula Malaysia *(Sun. J. et. al 1995)*

1.3 Objectives

The objectives of this project are:

- To remodel the Dams using finite element modeling with SAP2000 and PLAXIS.
- To determine the vulnerability of existing dams in Malaysia under earthquake load
- To determine the earthquake design criteria for new dams located in Malaysia region
- To study the performance of existing Dams while seismic activity occurs using time history, response spectrum and free vibration analysis.

1.4 Scope Of Study

1. Various dams from different locations have been identified for the finite element analysis. The dams are as follows:

Rockfill Dams:

- *Sarawak- Batang Ai Dam*
- *Sabah-Babagon Dam*
- *Terengganu-Kenyir Dam*

Earthfill Dams:

- *Kuala Lampur- Batu Dam*
- *Penang- Ayer Itam Dam*
- *Johor- Labong Dam*
- *Pahang- Jor Dam*

Concrete Dam:

- *Perak- Chenderoh Dam*

2. Seismic vulnerability analysis will be performed on the identified Dams.

3. Modeling the Dams using plane strain modeling.

4. Model the dams only using 2 dimensional views.

5-Linear Response spectrum and Time History by SAP2000 and Non-Linear Time History analysis by means of PLAXIS.