UNIVERSITI PUTRA MALAYSIA

A NUMERICAL TIME INTEGRATION METHOD FOR NONLINEAR SEISMIC RESPONSE ANALYSIS OF ROLLER-COMPACTED CONCRETE DAMS

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By

PARVIZ MORADI POUR

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, In Fulfillment of the Requirements for the Degree of Master of Science

September 2010

DEDICATION

To

The memory of my parents

And

All beloved members of my family

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

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Chairman: Associate Professor Jamaloddin Noorzaei, PhD

Faculty: Engineering

Dam is used as a multi-purpose infrastructure for water supply, irrigation, flood control, and hydropower. The application of roller compacted concrete (RCC) technology to dam construction was originated in the United States about three decades ago.

To ensure the safety of life and public property and to preserve the environmental downstream of the dam, comprehensive studies are warranted. The critical issues in this field are thermal and earthquake analysis of the dam-foundation system, which leads to crack prediction in the dam body as well as sliding and debonding at dam foundation interface.

This study deals with the two objectives; to propose a new numerical method and to apply the method for dynamic analysis of the Kinta RCC dam.

The first objective is to propose a new method with higher accuracy and stability as well as less computational cost. The proposed method involves mathematical formulations and general equilibrium equations for structural dynamics. The

acceleration between two consequent time steps was assumed by a second order parabolic curve. Then, Taylor's series were used in mathematical formulations for any response. Finally, mathematical and structural dynamics equations were combined.

The application of the proposed method has been established by a few examples to illustrate the accuracy of the proposed method for analysis of any structure. Based on this objective, the following conclusions can be drawn:

i) The proposed method is capable of capturing the seismic structural responses of any SDOF and MDOF systems more accurately than Newmark's method.

ii) The proposed method is more stable than Newmark's method and is able to analyze the structure in fewer numbers of iterations or computation cycles, hence less time-consuming.

The second primary objective deals with the structural response of Kinta RCC dam as one of the two RCC dams in Malaysia.

To achieve this objective, the finite element method has been selected. An existing finite element program for two-dimensional analysis has been modified to include the proposed method in the program. This study is also to improve the physical modeling of plane strain problems such as Kinta RCC dam.

The isoparametric elements have been employed to represent the dam body, foundation sections, and thin layer interface elements. The nonlinearity of the dam body concrete and foundation has been taken into account by employing the crack constitutive model and nonlinear elasto-plastic model respectively. Finally, the finite element model was nonlinearly analyzed under Malaysian seismic excitations using the developed FEM program.

i) The results show that the yielding of thin layer interface elements occurs before the dam foundation and RCC materials, and it starts by a slipping mode at the interface between foundation and dam body.

ii) From the seismic fracture analysis of Kinta RCC dam, it was observed that the values of acceleration and stresses of the system are higher than those found by previous researchers. This indicates a fast occurrence of fracture in both thin layer interface elements and dam body.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

KAEDAH PENGAMIRAN MASA BERANGKA UNTUK ANALISIS TINDAKBALAS TAK LELURUS SEISMIK BAGI EMPANGAN KONKRIT PENGGELEK-TERPADAT

Oleh

PARVIZ MORADI POUR

September 2010

Pengerusi: Prof. Madya Jamaloddin Noorzaei, PhD

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Empangan digunakan sebagai struktur pelbagai guna bagi bekalan air, pengairan, kawalan banjir dan hidrokuasa. Aplikasi teknologi konkrit penggelek terpadat (RCC) ke atas pembinaan empangan mula digunakan di Amerika Syarikat sejak tiga dekad lalu.

Bagi memastikan keselamatan nyawa, harta benda awam dan melindungi alam sekitar di hilir empangan, kajian menyeluruh terhadap infrastruktur tersebut telah diwarankan. Isu yang kritikal dalam bidang ini adalah haba dan analisis gempabumi bagi sistem asas-empangan yang membawa kepada jangkaan keretakan di dalam jasad empangan, gelangsar dan nyah-ikatan pada antara muka asas-empangan.

Kajian ini merangkumi objektif berikut: Mengemukakan cadangan kaedah berangka baru dan aplikasi kaedah ini untuk analisis dinamik empangan RCC Kinta.

Objektif pertama adalah untuk mencadangkan kaedah baru dengan ketepatan yang tinggi, kestabilan dan mengurangkan ulangan pengiraan. Kaedah yang dicadangkan melibatkan formulasi matematik dan persaman seimbang am dalam dinamik struktur.

Pecutan antara dua tempoh masa berturutan ditentukan oleh lengkung parabolik turutan kedua. Kemudian siri Taylor telah digunakan dalam formulasi matematik untuk sebarang tindak balas. Akhirnya persamaan matematik dengan persamaan dinamik struktur dapat digabung.

Aplikasi kaedah yang dicadangkan telah diwujudkan oleh beberapa contoh sistem darjah kebebasan tunggal (SDOF) dan darjah kebebasan pelbagai (MODF) untuk menggambarkan ketepatan kaedah yang dicadangkan dalam penyelesaian apa-apa jenis struktur.

Berdasarkan objektif ini berikut adalah kesimpulan yang ditemui:

i) Kaedah yang dicadangkan adalah mampu untuk mengesan tindak balas struktur seismik bagi apa-apa sistem SDOF dan MDOF lebih tepat berbanding Kaedah Newmark.

ii) Kaedah yang dicadangkan lebih stabil dari kaedah Newmark dan boleh menganalis struktur pada bilangan yang kurang ulangan atau kitaran pengiraan, dan dengan itu kurang penggunaan masa.

Objektif yang kedua adalah berkenaan tindak balas struktur empangan Kinta RCC sebagai salah satu dari pada dua empangan RCC di Malaysia. Untuk mencapai objektif ini kaedah elemen terhingga telah dipilih. Program elemen terhingga yang ada untuk analisis dua dimensi telah diubahsuai untuk memasukkan kaedah yang dicadangkan ke dalam program. Dalam penyelidikan ini, satu cadangaan juga telah dibuat untuk memperbaiki permodelan fizikal masalah ketegangan satah seperti empangan RCC Kinta.

Unsur separameter telah digunakan untuk mewakili empangan, bahagian asas dan unsur antaramuka lapisan nipis. Ketaklurusan konkrit dan asas badan empangan telah diambilkira dengan menggunakan masing-masing model retakan konstitutif dan

model ketaklinearan plastik-elasto. Akhirnya, Ketaklurunsan model unsur terhingga telah dianalis di bawah ujaan seismik Malaysia menggunakan kod FEM yang telah dibangunkan.

i) Keputusan menunjukkan bahawa alahan unsur antaramuka lapisan nipis terjadi sebelum asas empangan dan bahan RCC, dan ia bermula dengan mod gelongsoran pada elemen antaramuka lapisan antara asas dan empangan.

ii) Daripada analisis seismik empangan RCC Kinta, didapati nilai pecutan dan tegasan adalah lebih tinggi daripada yang telah dilapurkan oleh penyelidik terdahulu. Ini menunjukkan berlakunya kegagalan dalam unsur lapisan antaramuka nipis dan di ikuti oleh kegagalan empangan.

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I certify that an Examination Committee has met on 21 September 2010 to conduct the final examination of Parviz Moradi Pour on his thesis entitled "A Numerical Time Integration Method for Nonlinear Seismic Response Analysis of Roller-Compacted Concrete Dams" in accordance with the Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia (PU. (A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted in fulfillment of the requirement for the degree of Master of Science. Members of the Supervisory Committee were as follows:

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously and is not concurrently submitted for any other degree at Universiti Putra Malaysia or any other institutions.

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PARVIZ MORADI POUR

Date:

TABLE OF CONTENTS