UNIVERSITI PUTRA MALAYSIA

NONLINEAR ANALYSIS OF FAILURE MECHANISM OF ROLLER COMPACTED CONCRETE DAM

HUDA ABDUL MALIK THANOON

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By

HUDA ABDUL MALIK THANOON

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

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TO ALL MEMBERS OF MY FAMILY

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

NONLINEAR ANALYSIS OF FAILURE MECHANISM OF ROLLER COMPACTED CONCRETE DAM

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Chairman: Associate Professor Mohd Saleh Jaafar, PhD

Faculty: Engineering

Seismic effects have frequently caused damage to concrete dams. The consequences of a large dam failing can be disastrous, due to large amounts of damage of properties and human lives. Thus, there has been growing work on the safety evaluation of dams.

In this study, seismic hazard assessment of roller compacted concrete (RCC) gravity dam is investigated by considering the effects of dam-reservoir-foundation-sediment-interface interaction. Using finite and infinite element coupled method; two-dimensional seismic analysis is performed to investigate the seismic response of RCC gravity dam. An existing finite element code was modified to include mathematical models to simulate the behavior of discontinuities on the response of the structural system subjected to static and seismic loadings. The discontinuity was modeled by thin layer interface element and formulated to model the contact area along RCC dam-flexible bedding foundation. The discontinuous deformation elasto-plastic computational mechanics was evolved based on the modified Mohr-coulomb criteria to simulate the

behavior of thin layer interface. Safety evaluation is carried out based on the seismic performance and damage criteria, with special emphasis on the deformation behavior at dam–foundation thin layer interface.

The results of nonlinear elasto-plastic analysis demonstrate that the maximum tensile stress occurs at the base of the dam on the upstream heel. Moreover, there is a redistribution of the stresses at thin layer interface with significant stresses reduction; this is due to the release of energy through different mode of deformation in this region. The results demonstrate that the plastic deformation in thin layer interface is allowed to occur whenever seismic stresses exceed the envelope presented by modified Mohr-Coulomb failure criteria and it is mainly in the slipping mode at thin layer interface elements. It is shown from the numerical results, that the computational mechanics was feasible to predict the nonlinear behavior of discontinuities. The results indicate that the modified finite element formulation can provide satisfactory and consistent analysis of thin layer interface behavior under static and seismic excitation. The major advantage of such a formulation is that it permits the computer programming and allows representation of the deformation modes for thin layer, such as debonding, slipping and crushing.

Furthermore, this study examines the earthquake response of RCC gravity dam including comprehensive failure criteria of materials with modeling of cracking and crushing of concrete. Considerable effort has been devoted to include the failure criteria for thin layer interface element in terms of opening and slipping. The finite element code

was developed to include a numerical procedure for computing the nonlinear dynamic response of RCC dam and the failure mechanism for thin layer interface element. The numerical results demonstrate that cracking develops near the base at dam heel and at upstream dam face especially around the opening of the galleries. Then the crack at the neck near the discontinuities is appeared and extended at the slope of the downstream face. Furthermore, the results demonstrate that the mode of failure in thin layer interface elements were opening and slipping. The implemented procedure into finite element code shows that the seismic cracking can be traced and mode of failure of RCC concrete gravity dam and at thin layer interface can be ascertained.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ANALISIS NONLINEAR MEKANISMA KEGAGALAN EMPANGAN KONKRIT PADAT PENGGILING

Oleh

HUDA ABDUL MALIK THANOON

June 2008

Pengerusi: Profesor Madya Mohd Saleh Jaafar

Fakulti: Kejuruteraan

Kesan seismik telah seringkali menyebabkan kerosakan ke atas empangan konkrit. Akibat-akibat kegagalan empangan besar adalah amat membinasakan, disebabkan kerosakannya yang besar ke atas harta benda dan nyawa. Disebabkan itu, semakin banyak kajian telah dijalankan ke atas penilaian keselamatan empangan.

Di dalam kajian ini, penilaian kebahayaan seismik ke atas empangan graviti konkrit padat penggiling telah dikaji dengan mengambil kira kesan-kesan interaksi antara-muka empangan-kolam air-tapak-sedimen. Dengan menggunakan kaedah pasangan elemen finite dan infinite, dua dimensi analisis seismik telah dijalankan untuk menyiasat respon seismik empangan graviti RCC. Kod elemen finite telah diubahsuai untuk mengambil kira model matematik bagi menyimulasi sifat-sifat discontinuous ke atas respon sistem struktur di bawah pengaruh bebanan statik dan seismik. Discontinuous ini telah dimodelkan berpandukan elemen antara-muka lapisan nipis dan dirumuskan untuk memodelkan kawasan pertemuan sepanjang tapak dasar empangan RCC. Discontinuous

kecacatan elasto-plastik mekanik perkomputeran telan diuji berdasarkan kriteria Mohr-Coulomb yang telah diubahsuai untuk menyimulasi sifat antara-muka lapisan nipis. Penilaian keselamatan telah dijalankan berdasarkan pertunjukan seismik dan kriteria kerosakan,dengan tumpuan khas ke atas sifat kecacatan antara-muka lapisan nipis di tapak empangan

Keputusan analisis elasto-plastik nonlinear menunjukkan bahawa tekanan tensile maksimum berlaku di dasar empangan di sebelah tumit hulu sungai. Tambahan pula, terdapat penyebaran semula tekanan di antara-muka lapisan nipis dengan pengurangan tekanan berkesan; disebabkan pelepasan tenaga melalui mode kecacatan yang berlainan di kawasan tersebut. Keputusan juga menunjukkan bahawa kecacatan plastik di antara-muka lapisan nipis masih boleh berlaku walaupun tekanan seismik melepasi envelope seperti yang dikemukakan oleh kriteria kegagalan Mohr-Coulomb yang telah diubahsuai dan kebanyakannya berlaku di mode gelinciran di antara-muka lapisan nipis. Keputusan berangka menunjukkan mekanik perkomputeran adalah sesuai dalam meramal sifat nonlinear dalam discontinuities. Keputusan juga menunjukkan formulasi elemen finite yang telah diubahsuai boleh memberikan analisis yong konsisten dan memuaskan ke atas sifat antara-muka lapisan nipis di bawah pengujaan statik dan seismik. Kelebihan major formulasi ini ialah ia membolehkan pengaturcaraan komputer dan membenarkan perwakilan mode kecacatan untuk lapisan nipis seperti debonding, gelinciran dan penghancuran.

Tambahan pula, kajian ini memeriksa respon gempa bumi empangan graviti RCC termasuk kriteria kegagalan bahan komprehensif dengan model rekahan dan

penghancuran konkrit. Agak banyak usaha telah diberi perhatian untuk mengambil kira kriteria kegagalan bagi antara-muka lapisan nipis dari segi bukaan dan gelinciran. Kod elemen finite telah dikembangkan demi mengambil kira prosedur berangka untuk mengira respon dinamik nonlinear empangan RCC dan kriteria kegagalan untuk elemen antara-muka lapisan nipis. Keputusan berangka menunjukkan bahawa rekahan berlaku berhampiran tapak tumit empangan dan muka hulu sungai empangan terutama di sekeliling bukaan galleries. Kemudian, rekahan di bahagian leher berhampiran dengan discontinuities akan muncul dan teranjur di cerun muka hillir sungai. Tambahan pula, keputusan menunjukkan cara kegagalan di dalam elemen antara-muka lapisan nipis adalah bukaan dan gelinciran. Pelaksanaan prosedur kod elemen finite menunjukkan tekanan seismik boleh dikesan dan cara kegagalan empangan graviti konkrit RCC boleh ditentukan.

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I certify that an Examination Committee has met on 5 June, 2008 to conduct the final examination of Huda A. M. Thanoon on his Doctor of Philosophy thesis entiled "Nonlinear Analysis of Roller Compacted Concrete Dam" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (higher Degree) Regulations 1981. The committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Chairman, PhD
Professor Dr. Shattri Mansor
Pengarah
Pejabat Pembangunan dan Pengurusan Aset
Universiti Putra Malaysia
(Chairman)

Examiner 1, PhD
Professor Dr. Bujang Kim Huat
Jabatan Kejuruteraan Awam
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Examiner 2, PhD
Professor Madya Dr. Ratnasamy Muniandy
Jabatan Kejuruteraan Awam
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Independent Examiner, Phd
Professor Dr. Pradeep Bhargava
Department of Civil of Engineering
Indian Institute of Technology Roorkee
(External Examiner)

HASANAH MOHD. GHAZALI, PhD
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement of the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Mohd Saleh Jaafar, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Jamaloddin Noorzaei, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Thamer Ahmed Mohammed, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

AINI IDERIS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 14 August 2008

DECLARATION

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

HUDA A. M. THANOON

Date:

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