**UNIVERSITI PUTRA MALAYSIA**

# *FLOW HYDRAULICS AND SEDIMENT TRANSPORT IN PERVIOUS ROCKFILL DETENTION DAMS*

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# FLOW HYDRAULICS AND SEDIMENT TRANSPORT IN PERVIOUS ROCKFILL DETENTION DAMS

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**DOCTOR OF PHILOSOPHY**
**UNIVERSITI PUTRA MALAYSIA**

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# FLOW HYDRAULICS AND SEDIMENT TRANSPORT IN PERVIOUS ROCKFILL DETENTION DAMS

**By**

**ALLAHIAR NAZEMI**

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

**October 2011**

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## DEDICATION

**Dedicated to my merciful and patient wife**

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

**FLOW HYDRAULICS AND SEDIMENT TRANSPORT IN PERVIOUS ROCKFILL DETENTION DAMS**

**By**

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**October 2011**

**Chairman: Professor Ir. Lee Teang Shui ,PH.D**

**Faculty : Engineering**

There is growing interest in using pervious rockfill detention dams to control and mitigate floods in Iran. This kind of dam is constructed of rock particles without any core inside and shell on the upstream face. Rockfill detention dams function in such a way that the peak point of outflow hydrograph will be smaller than the peak point of the inflow hydrograph. During the passing of a flood the flow through a rockfill dam is mostly laden with sediment. If sediments pass through, the dam will be safe, function well and downstream scouring will be low. Otherwise, gradually sediment particles will settle in pore spaces of dam and partial clogging occurs. In such cases the flood may overflow the dam, erode the downstream bed, bank and the dam itself and finally may cause damages. Therefore it is necessary to investigate the various aspects of sediment laden flows through the pervious rockfill dam to achieve a safe hydraulic design. Critical hydraulic gradient, sediment transport, water discharge, rating and water surface profile equations are the main components of hydraulic design of flow through pervious rockfill dam. Some semi empirical researches have been conducted in the past to study the problems but the results have indicated some



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limitations and these results cannot be generalized. In this respect scale effect, exclusion of some effective parameters and the formulation of basic equations are the subjects that have to be considered and revised. Regarding these limitations rock particle sizes, sediment particle sizes, dimensions of laboratory rockfill dams and magnitude of Reynolds number which were used in the previous experimental works were small and stand in the lower limits of those are being used in real field condition. In addition by Appling a fixed bed slope flume and sediment free flow in previous researches the effect of bed slope changes and sediment laden (two phase) flow has been excluded. Moreover the formulations of some equations such as critical hydraulic gradient and sediment transport through pervious rockfill dam indicate some ambiguous parameters (critical water discharge and hydraulic gradient) which are undeterminable in real field condition. The main objective of this research is to investigate the non-cohesive suspended sediment laden flow through a pervious rockfill detention dam. From a review of various formulated equations the Sakthivadivel formula (critical hydraulic gradient in laminar flow), dimensional analysis and the pipe theory including Darcy-Wiesbach and continuity equations have been incorporated to develop related formulas. To calibrate and validate the equations formulated, 180 laboratory tests have been conducted. Statistical analysis (by means of SPSS software) and the resulting correlation coefficient ($R^2$) and mean square error (mse) were used as criteria for assessment. Five equations have been improved and developed for the prediction of the critical hydraulic gradient, friction coefficient, rating curve, water surface profile and the sediment transport rate in pervious rockfill dam to overcome the limitations of previous research results. Validation of the above mentioned equations showed good agreement to the real laboratory data with the mean square errors of 4.46E-5, 0.29, 7.7E-6, 5.19E-4 and



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6.4E-4 respectively. The improved critical hydraulic gradient was calibrated and validated using 36 laboratory test results with a correlation coefficient of 0.92 and a mean square error (mse) of 4.46E-05. Comparing with two equations proposed by earlier researchers (mse, .0003 and 0.029) it showed a better agreement to the observed critical hydraulic gradient. The friction coefficient-Reynolds number equation developed as a basic equation in the pipe theory was calibrated, validated and compared with three equations proposed by previous researchers using 46 laboratory test results. The results showed a correlation coefficient of 0.74 and a mean square error of 0.29 while previous equations have mean square errors of 0.66, 113 and 197. This indicates a better agreement of the predicted friction coefficient (with the improved equation) with the laboratory derived friction coefficient. The rating and water surface profile equations developed and validated using 34 laboratory test results have mean square errors of respectively 7.7E-06 for the rating equation and less than 5.19E-04 for all 34 water surface profiles. These equations when compared with two formulas proposed by previous researchers showed better agreements to the observed upstream water depths and also observed water surface profiles. A sediment transport equation has also been formulated, calibrated, validated using 144 test results and compared with the three equations presented by other researchers. Calibration and validation of the dimensionless sediment transport equation indicated a correlation coefficient ($R^2$) of 0.933 and mean square error of 6.4E-06 respectively. The comparison indicated the mean square errors of 6.4E-4, 7.1E-03, 2.3E-02 and 0.041 respectively for the formula developed and the other formulas, thus suggesting a better agreement for the equation proposed in this study to the laboratory measured sediment transport. In conclusion, the equations developed and validated in this study showed more accurate predictions and



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calculations of hydraulic behaviors of sediment laden flow through rockfill dam than previously presented formulas in this field. These improvements can enable engineers to design safer pervious rockfill detention dams.



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

**HIDRAULIK ALIRAN DAN PENGANGKUTAN ENDAPAN DALAM EMPANGAN TAHANAN ROCKFILL TELAP**

oleh

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Oktober 2011

**Pengerusi:** **Profesor Ir. Dr. Lee Teang Shui**

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Minat mengunakan empangan tahanan timbus batuan telap untuk mengawal dan mengurangkan banjir di Iran semakin bertambah. Jenis empangan begini dibina dengan batuan tanpa teras di dalam dan lapik pada muka di hulu. Empangan tahanan timbus batuan berfungsi supaya titik kemuncak hidrogeraf keluar adalah lebih rendah daripada titik kemuncak hidrogeraf masuk. Pada masa aliran banjir melalui empangan tahanan timbus batuan bermuatan endapan. Sekiranya endapan mengalir lalu empangan itu selamat maka ianya berfungsi baik dan keruk di hilir berkurang. Sebaliknya, endapan semakin lama berkumpul di dalam liang empangan maka sumbat separa akan berlaku. Dalam kes begitu banjir mungkin melimpah empangan, menghakis kawasan dasar dan tepi terletak di hilir dan juga empangan, dan pada akhirnya menyebabkan kerosakan. Oleh demikian, perlulah disiasat lebih mendalam segala aspek aliran berendapan melalui empangan timbus batuan yang telap supaya mencapai rekabentuk hidraul selamat. Kecerunan hidraulik genting, angkutan endapan, pembuangan air, persamaan kadaran dan profil permukaan air adalah



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komponen utama dalam reka bentuk hidraulik yang melalui empangan timbus batuan yang telap. Beberapa kajian separa empirik telah pun dilangsungkan pada masa dahulu demi mengkaji masaalah berkaitan akan tetapi keputusan menunjukkan beberapa pembatasan serta keputusan tidak dapat diteritlak. Dalam perihal ini, kesan sekil, kesan pengecualian beberapa parameter berkesan dan pembentukan persamaan persamaan asas merupakan subjek yang perlu diambilkira dan diubahsuai. Tujuan utama penyelidikan ini adalah mengkaji aliran berendapan tak-kakis melalui empangan tahanan timbus batuan. Berkenaan dengan batasan saiz partikel batu, saiz partikel endapan, dimensi empangan timbus batuan telap makmal dan magnitude Reynolds yang digunakan dalam eksperimen- eksperimen yang sebelumnya adalah kecil dan berada dalam had yang lebih rendah daripada yang sedang digunakan dalam situasi yang sebenar. Di samping itu, dengan Appling flum cerun dasar yang tetap dan aliran mendapan bebas dalam penyelidikan yang sebelumnya dan aliran mendapan sarat (dua fasa) telah dikecualikan. Tambahan pula, fomulasi beberapa persamaan seperti kecerunan hidraulik genting dan angkutan endapan melalui empangan tumbus batuan telap menunjukkan ukuran yang tidak tepat (pelepasan air kritikal dan kecerunan hidraulik) yang tidak dapat ditentukan dalam situasi sebenar 4.46E-5, 0.29, 7.7E-6, 5.19E-4 and 6.4E-4 masing-masing. Daripada pemeriksaan semula beberapa persamaan diterbitkan hukum Sakthivadivel (kecerunan hidraulik genting aliran lamina), analisis berdimensi serta teori paip termasuk persamaan Darcy-Weisbach dan berterusan telah digabungkan demi membangunkan hukum berkaitan. Untuk menentukur dan mempastikan hukum tersebut, 180 ujian makmal telah dibuat. Analisis statistik (dengan perisian SPSS) dan hasil angkali korelasi ($R^2$) dan ralat kuasa punca dua min (MSE) diguna sebagai nilaitara penaksiran. Lima persamaan telah diperbaiki atau dibentuk untuk ramalan kecerunan hidraulik genting,



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angkali gesaran, lengkung kadaran, profil permukaan air dan kadar angkut endapan di dalam empangan timbus batuan untuk mengatasi masalah ataupun batasan data-data kajian yang sebelumnya. Pengesahan persamaan yang dinyatakan di atas menunjukkan persetujuan baik untuk data makmal sebenar dengan ralat sisihan piawai . Kecerunan hidraulik genting diperbaiki, ditentukur dan dipastikan dengan 36 ujian makmal dengan keputusan angkali korelasi 0.92 dan 0.94 masing masing, dan ralat kuasa punca dua min (MSE) 4.46E-05. Dibandingkan dengan persamaan yang telah dicadangkan oleh penyelidik terlebih dahulu (MSE 0.0003 dan 0.29 masing masing) maka terdapat kesesuaian lebih bermakna dengan kecerunan hidraulik genting yang diperhatikan. Persamaan angkali gesaran – nombor Reynolds terbentuk sebagai persamaan asas dalam teori paip telah ditentukur, dipastikan dan dibandingkan dengan tiga persamaan yang dikemukakan oleh penyelidik terlebih dahulu melalui keputusan 46 ujian makmal. Didapati angkali korelasi 0.74 dan ralat kuasa punca dua min 0.29 lebih bermakna manakala ralat kuasa punca dua min persamaan dahulu adalah 0.66, 113 dan 197. Ini merupakan lebih persetujuan didapati diantara angkali gesaran diramalkan (dengan persamaan diperbaiki) dengan yang dihasilkan daripada ujian makmal. Persamaan kadaran dan profil permukaan air yang dibangunkan dan dipastikan dengan 34 ujian makmal mempunyai ralat kuasa punca dua min 7.7E-06 dan kurang daripada 5.19E-04 masing masing. Persamaan tersebut bila berbanding dengan yang dikemukakan penyelidik terlebih dahulu menunjukkan persetujuan lebih baik kepada ukur dalam di hulu yang diperhatikan dan profil permukaan air yang diperhatikan. Satu persamaan pengangkutan endapan juga diterbitkan, ditentukurkan, dipastikan dengan keputusan 144 ujian dan dibandingkan dengan tiga persamaan dahulu. Tugas penentukuran dan kepastian persamaan pengangkutan endapan tak-berdimensi menghasilkan angkali korelasi



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($R^2$) 0.933 dan ralat kuasa punca dua min sebanyak 6.79E-06 masing masing. Keputusan sedemikian ralat kuasa punca dua min persamaan penyelidik dahulu sebanyak 6.4E-04, 7.11E-03, 23E-02 dan 0.041 menggambarkan bahawa persetujuan yang lebih baik dicapai oleh persamaan yang dicadangkan oleh kajian ini. Sebagai kesimpulan, dibandingkan yang sama terdapat dalam rujukan bidang kajian ini, persamaan yang dibangunkan dan dipastikan dalam kajian ini menghasilkan ramalan dan kiraan sifat hidraulik lebih tepat untuk kes aliran berendapan melalui empangan timbus batuan telap. Dengan syor yang dikemukakan dalam kajian ini, maka rekabentuk empangan tahanan timbus batuan telap yang lebih selamat dapat dihasilkan.

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## APPROVAL

I certify that a Thesis Examination Committee has met on 7 October 2011 to conduct the final examination of Allahiar Nazemi on his thesis entitled "Flow hydraulics and sediment transport in pervious rockfill detention dams" in accordance with the Universities and University College Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The committee recommends that the student be awarded the Doctor of Philosophy.

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## DECLARATION

I declare that 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 other institutions

**ALLAHIAR NAZEMI**

Date: 7 October 2011

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