UNIVERSITI PUTRA MALAYSIA

PHYSICAL MODELING ON LOCAL SCOUR AT COMPLEX PIERS

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By

SEYED ATA AMINI

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

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Dedicated

To

My parents and my lovely family, wife and son.

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

PHYSICAL MODELING ON LOCAL SCOUR AT COMPLEX PIERS

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SEYED ATA AMINI

December 2009

Chairperson: Associate Professor Thamer Mohammad Ali

Faculty: Engineering

Over the past decades, great strides have been made in the ability to accurately predict design scour depths at simple bridge pier structures. While, many bridge piers are complex in shape, consisting of several components (e.g., column, pile cap and pile group). There is a general lack of confidence in available methods for predicting local scour at complex piers. The main objective of the research is to provide accurate estimating of geometrical characteristics of complex pier and its location relative to undisturbed streambed on scour depth, for improving existing scour prediction methods. Furthermore, the collected data can fill voids in existing data for pier with complex geometries in various locations. In this research, an experimental study on multiple piles and complex piers and its components were conducted. The variables investigated were the dimensions of complex piers and the models location relative to initial streambed. In addition, in the experiments on pile group, the pile spacing, arrangement and submergence ratio were examined. A wide range of experiments on individual components including pile group, pile cap and column and combination of these components such as the column mounted on the pile cap and complex piers were studied. Flow conditions and sediment characteristics were kept constant for all of the experiments. The flow discharge, water depth and flow velocity readings were taken using an Area Velocity Module (AVM). Cohesionless uniform sediment was used with the mean particle sizes, d_{50}=0.8 mm and geometric standard deviation of particles, σ_g=1.34. The experiments were performed under clear-water conditions at threshold flow intensity. The results of experiments on individual components were used to present new methods to predict local scour at pile group, pile cap and column, which is useful to be used for predicting scour at multiple piles and complex piers. Outcomes of verifying these methods show that proposed methods give reasonable scour depth prediction. In addition, it was found that, besides the parameters that affect scour at a uniform pier, the scour depth at complex piers and its components are highly depend on their locations relative to initial streambed. The experimental data obtained on complex pier models was used to evaluate predictions of existing methods. Federal Highway Administration, Hydraulic Engineering Circular No. 18, HEC-18, Florida Department of Transportation, FDOT and Coleman methods for complex piers, were examined. It was found that the results of HEC-18 method have a much larger scatter than FDOT and Coleman methods. In addition, the measured scour depths produced by isolated components were used to evaluate superposition methodology. The upshots indicate that this methodology do not accurately predict the observed scour depth at composite structures.

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

PERMODELAN FIZIKAL PENGERUKAN TEMPATAN PADA TIANG SAMBUT KOMPLEKS

Oleh

SEYED ATA AMINI

Disember 2009

Pengerusi: **Prof. Madya Thamer Mohammad Ali**

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Pada beberapa dekad yang lepas, kemajuan telah dibuat dalam keupayaan kaedah meramal ketepatan kedalaman rekabentuk kerukan pada struktur-struktur ringkas tiang sambut. Namun, banyak tiang sambut adalah dalam bentuk kompleks, yang terdiri daripada beberapa bahagian (cth: tiang, cerucuk tetopi, dan cerucuk kumpulan). Secara umumnya terdapat kekurangan dalam kaedah sediaada untuk meramalkan kerukan setempat yang kompleks. Objektif utama penyelidikan adalah untuk menghasilkan kaedah yang tepat dalam menganggarkan sifat geometri tiang sambut yang kompleks dan lokasi berkenaan berdasarkan kepada dasar saluran tidak terganggu terhadap kedalaman kerukan. Ini adalah untuk tujuan memperbaiki kewujudan kaedah ramalan kerukan. Tambahan pula,data terkumpul menjadi tidak sah berdasarkan data yang wujud untuk geometri tiang sambut yang kompleks di lokasi yang pelbagai. Pemboleh ubah pada siasatan ini adalah rekabentuk struktural tiang sambut yang kompleks dan lokasinya berhubung dengan permulaan dasar saluran. Tambahan lagi, eksperimen-eksperimen terhadap cerucuk kumpulan, ruang cerucuk, nisbah susunan dan nisbah penenggelaman telah diselidiki. Kajian terhadap air jernih kerukan di tiang sambut yang kompleks dan bahagian-bahagian bawah aliran stabil pada had halaju telah dilakukan. Kajian juga telah dilakukan pada jarak lebar eksperimen pada bahagian-bahagian tunggal termasuk cerucuk kumpulan, cerucuk tetopi dan tiang serta gabungan bahagian-bahagian tersebut seperti tiang menaik pada cerucuk tetopi dan tiang sambut yang kompleks (cerucuk kumpulan, cerucuk tetopi dan tiang). Kedalaman aliran pada 0.24 m telah ditetapkan untuk kesemua eksperimen. Aliran pembebasan, kedalaman air dan bacaan halaju aliran telah diambil mengunakan Modul Luas Halaju (AVM). Ketidakjeleketan enapan seragam digunakan dengan purata saiz zarah, d_{50}=0.8 mm dan piawai geometrik lencongan zarah, σ_g =1.34. Eksperimen-eksperimen telah dilaksanakan di bawah keadaan air jernih pada rintangan arus kuat. Keputusan eksperimen pada bahagian-bahagian tunggal digunakan untuk menunjukkan kaedah baru untuk meramal kerukan setempat pada cerucuk kumpulan,cerucuk tetopi dan tiang di mana sangat berguna digunakan dalam kaedah meramal superposisi kerukan pada tiang sambut yang kompleks. Hasil daripada kaedah-kaedah ini menunjukkan kaedah ramalan kedalaman kerukan adalah munasabah. Tambahan pula, telah dijumpai, parameter yang mempengaruhi pengilap pada tiang sambut yang seragam, kedalaman kerukan pada tiang sambut yang kompleks dan bahagian-bahagiannya adalah bergantung kepada lokasi awalan dasar saluran. Bagaimanapun, data eksperimen yang diperoleh pada model-model tiang sambut yang kompleks digunakan untuk menilai kaedah ramalan yang wujud. Pentadbiran Persekutuan Lebuh raya, Pekeliling Kejuruteraan Hidraulik No. 18, HEC-18, Jabaan Pengangkutan Florida, FDOT dan kaedah-kaedah Coleman (untuk tiang sambut yang kompleks telah diselidiki. Ditemui bahawa keputusan kaedah HEC-18 mempunyai taburan yang besar daripada kaedah-kaedah FODT dan Coleman. Tambahan lagi, ukuran kedalaman kerukan yang dihasilkan oleh bahagian-bahagian tercerai digunakan untuk menilai kaedah superposisi. Keputusan menunjukkan bahawa kaedah ini tidak tepat meramal kedalaman kerukan pada struktur-struktur gabungan.

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I certify that a Thesis Examination Committee has met on 30 December 2009 to conduct the final examination of Seyed Ata Amini on his thesis entitled “Physical Modeling on Local Scour at Complex Piers” in accordance with the Universities and University Colleges Act 1971 and 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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This thesis was submitted to the Senate of Universiti Putra Malaysia has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of supervisory committee were as follow:

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Date: 17 March 2010

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 University Putra Malaysia or at any other institution.

Ata Amini
Date: 26 January 2010

TABLE OF CONTENTS

Page

CHAPTERS

1 INTRODUCTION

2 LITERATURE REVIEW

3 MATERIALS AND METHODS

4 RESULTS AND DISCUSSIONS

5 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

ABBREVIATIONS

A	constant number
a	pier width
a^*_{pg}	equivalent full depth pile group
Al	parameter describing the alignment
a_{proj}	sum of non-overlapping projected widths of piles
b	width of pile cap
B	pier projection width
b^*_{pg}	width of a full depth solid pier that would yield the same scour depth as the full depth pile group
B_1	approaching flow width
b_c	width of column component at complex pier
b_e	equivalent cylindrical pier diameter relative exposure of the column, pile-cap and pile-group elements
b_{pc}	width of pile cap component at complex pier
C	constant number
Comp	soil compact ratio
D	diameter of cylindrical pile
D^*	effective diameter for complex pier components
D^*	foundation diameter in nonuniform cylindrical pier
d_{50}	median sediment size
D_e	the equivalent diameter of the nonuniform pier
$d_{s(ES)}$	scour depth around an equivalent solid pier at the same skew angle to flow direction.
f_{cb}	extension length of pile cap face out from column face
f_{cl}	extension length of pile cap face out from column face
f_{pb}	extension length of pile cap face out from nearest pile centerline
f_{pl}	extension length of pile cap face out from nearest pile centerline
Fr_1	Froude Number directly upstream of the pier = $V_1/(gy_1)$
h	height of pile cap relative to undisturbed streambed

IWC	Initial Water Content
k	turbulent kinetic energy
K	correction factors for specific conditions
K_1	correction factor for pier nose shape
K_2	correction factor for angle of attack of flow
K_3	correction factor for bed condition
K_4	correction factor for armoring by bed material size
K_{ci}	correction factor for suspended pile cap in i^{th} case
K_D	sediment size factor
K_{Gmn}	correction factor for pile group spacing and arrangements
K_h	pile group height adjustment factor
K_{hpg}	the height factor for pile group at complex piers
K_I	flow intensity factor
K_m	coefficient for number of aligned rows
K_s	foundation shape factor
K_{Smn}	correction factor for spacing at exposed pile group arrangements
K_{sp}	coefficient for pile spacing
K_t	time factor
K_{yb}	flow depth-pier size factor (dimension of length)
K_θ	foundation alignment factor
l_{pc}	length of pile cap in line with flow
L	length of pier
l_c	length of column component at complex pier
m	number of pile in line with flow
MAE	mean absolute error
n	number of piles normal to the flow
N	number of data
p	represents predicted scour depth
PF	prediction factor
q	unit flow rate
R	correlation coefficient