Pier Scour Countermeasures

by

Christine S. Lauchlan

A thesis submitted in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

Supervised by
Dr. B.W. Melville

Department of Civil and Resource Engineering
The University of Auckland
Private Bag 92019
Auckland
New Zealand

January 1999

ABSTRACT

Riprap is the most commonly employed countermeasure where bridge piers need to be protected against possible undermining by scour. An extensive review of available design techniques revealed a wide range of equations and proposed design procedures but no generally accepted method for riprap sizing and implementation. The aim of this study was to develop a design procedure for riprap protection at piers which can be used in most river environments.

The failure mechanisms and stability of riprap layers around cylindrical and rectangular shaped piers were examined in a comprehensive experimental study. The study assessed the importance of various riprap, flow, sediment, and pier parameters. Parameters for investigation were determined by dimensional analysis and included riprap placement and arrangement.

A riprap size prediction formula was developed based on an allowable maximum local scour depth of up to 20%. This equation has been incorporated in a design approach which was tested through a model study of the Hutt Estuary Bridge. The influence of various parameters on riprap stability are incorporated in the equation by way of adjustment factors.

The adjustment factors, K_Y and K_D, represent the effects of riprap placement and pier/sediment size ratio effects respectively. They were deemed the most important parameters in riprap layer performance and are therefore included in the riprap size prediction formula. Additional experiments using synthetic filters have shown their ability to eliminate local scour, however they are susceptible to failure under degrading bed conditions.

Degrading bed conditions cause the riprap to subside as a layer with the downward movement of the surrounding bed. Subsidence allows the layer to withstand rapid short term degradation. However long term degradation will ultimately result in failure of the stone protection.

A preliminary experimental study of the use of submerged vanes as a scour countermeasure was performed. Submerged vanes have been used previously in channel protection with much success. Results indicate that vanes with a length to height ratio greater than one can reduce the maximum local scour depth in live bed conditions by as much as 34%. Further testing is required to develop a complete design procedure.

Acknowledgments

This study was carried out under the supervision of Associate Professor B. W Melville to whom I express my sincere appreciation for all the guidance, encouragement, advice and general help throughout. His ideas and direction have been invaluable.

The financial support provided by the University of Auckland, Transit New Zealand and the National Cooperative Highway Research Program - Project 24-7 is gratefully acknowledged.

During the project many people have helped and guided me and I would like to thank the following people:

Dr S. Coleman for his advice, ideas and friendship along the way. His encouragement and commiseration especially in the lab have been priceless.

Carlos Toros Escobar for his ideas and advice throughout the project. I hope that the final report has not caused you too many gray hairs.

Jim Bickner, Mark Byrami, and Ray Hoffmann for all their assistance in the laboratory. Hopefully from now on there will be no need to replace more equipment as I'm sure I managed to break most of it at some stage.

My fellow room mates: Darrin Bell, Anna Hadfield, Paul Corney and Carla Harris for their help, encouragement, humour and friendship along the way.

And finally to my parents, Tracey, Steven, and best friends Alison and Hera for support and patience as this project has developed.

TABLE OF CONTENTS

List of Symbols

α	angle of the pier to the approach flow
Al	pier alignment factor
b	width of the pier (for non cylindrical piers)
c	extent of lateral coverage of the riprap layer
D	pier diameter
D_{30}	riprap size (size for which 30% by weight is finer than the stated size)
d_{50}	mean sediment size (size for which 50% by weight is finer than the stated size)
D_{50}	mean riprap size
DG	degradation level
d_r	depth of scour experienced by the riprap layer
d_s	depth of scour below original bed level
d_{smax}	maximum depth of scour below original bed level
σ_g	geometric standard deviation of sediment or riprap size
e	longitudinal spacing of vanes
Fr	flow Froude number
g	gravitational acceleration ($g = 9.81\ m^2/s$)
γ_s	unit weight of stone
γ_w	unit weight of water
H	height of submerged vanes measured from the average bed level
'K' factors	used to denote an adjustment factor for a specific flow, sediment, riprap or pier parameter
l	length of the pier (for non cylindrical pier)
L	length of submerged vanes in the streamwise direction
n	Manning's roughness coefficient
N	number of vanes
N_{sc}	stability number
ρ	density of the fluid
ρ_r	density of the riprap stones
ρ_s	density of the bed sediment
S_f	safety factor
Sh	shape factor
S_r	specific gravity of the riprap stones
S_s	specific gravity of the bed sediment
t	thickness of the riprap layer