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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

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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_V 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.

III

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.

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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.

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TABLE OF CONTENTS

INTRODUCTION	12
1.1 TYPES OF SCOUR	12
1.2 HISTORICAL REVIEW	14
1.3 SCOPE OF PRESENT STUDY	15
2.0 LITERATURE REVIEW	17
2.1 INTRODUCTION	17
2.2 RIPRAP AS A SCOUR COUNTERMEASURE	20
2.2.1 FAILURE MECHANISMS	20
2.2.2 ASPECTS OF SEDIMENT MECHANICS WHICH INFLUENCE RIPRAP BEHAVIOUR	23
2.2.3 SIZING AND STABILITY OF RIPRAP MATERIALS	25
2.2.3 LATERAL EXTENT OF RIPRAP PROTECTION	48
2.2.4 THICKNESS OF RIPRAP PROTECTION LAYER	53
2.2.5 PLACEMENT OF RIPRAP	54
2.2.6 FILTER EFFECTS	56
2.2.7 SUMMARY OF RIPRAP PARAMETERS	60
2.3 ALTERNATIVE SEDIMENT BED ARMOURING COUNTERMEASURES	63
2.3.1 HIGH DENSITY RIPRAP	63
2.3.2 BLOCKS - LOOSE, CABLE TIED AND GEOTEXTILE BONDED	64
2.3.3 CONTAINER SYSTEMS	72
2.3.4 SUMMARY OF ALTERNATIVE SEDIMENT BED ARMOURING COUNTERMEASURES	80
2.4 FLOW ALTERING TECHNIQUES	84
2.4.1 FLOW DEFLECTING VANES	83
2.4.2 PIER SHAPE	88
2.4.3 PIER SLOT	91
2.4.4 COLLARS AND HORIZONTAL PLATES	93
2.4.5 SUCTION	98
2.4.6 EXTENDED FOUNDATIONS	99
2.4.7 SACRIFICIAL PILES	102
2.4.9 SUMMARY OF FLOW ALTERING TECHNIQUES	108
3.0 EXPERIMENTAL INVESTIGATIONS	111
3.1 INTRODUCTION	111
3.2 RIPRAP RESPONSES TO LOCAL SCOURING	112
3.2.1 LIVE BED EXPERIMENTS	112
3.2.2 BED AND RIPRAP MATERIALS	118
3.2.3 PIERS AND SCOUR DEPTH MEASUREMENTS	120
3.2.4 APPROACH FLOW	124
3.2.5 FORMING RIPRAP PROTECTIVE LAYERS	127
3.2.6 SYNTHETIC FILTER FABRICS	130

3.2.7 EXPERIMENTAL TECHNIQUE FOR CYLINDRICAL AND RECTANGULAR PIERS	133
3.3 GENERAL BED DEGRADATION	136
3.3.1 0.457 M FLUME	136
3.3.2 BED AND RIPRAP MATERIALS	138
3.3.3 PIERS AND SCOUR DEPTH MEASUREMENTS	140
3.3.4 RATE OF DEGRADATION	140
3.3.5 VELOCITY MEASUREMENT	141
3.3.6 EXPERIMENTAL PROCEDURE	141
3.4 SUBMERGED VANE EXPERIMENTS	142
3.4.1 INTRODUCTION	142
3.4.2 2.4 M FLUME	143
3.4.3 PIERS AND SCOUR DEPTH MEASUREMENT	146
3.4.4 APPROACH FLOW	148
3.4.5 VANE DEFINITION AND MATERIALS	149
3.4.6 SUBMERGED VANE ARRANGEMENTS	151
3.4.7 EXPERIMENTAL PROCEDURE	158
<u>4.0 RIPRAP RESPONSES TO LOCAL SCOURING</u>	<u>160</u>
4.1 FRAMEWORK FOR ANALYSIS	160
4.2 RIPRAP FAILURE MECHANISMS, RESPONSES AND SIZE PREDICTION	164
4.2.1 INTRODUCTION	164
4.2.2 IDENTIFICATION OF FAILURE MECHANISMS	164
4.2.3 RIPRAP RESPONSES TO FLOW VELOCITY	167
4.2.4 DEVELOPMENT OF RIPRAP SIZE PREDICTION EQUATION	173
4.2.5 SUMMARY AND RECOMMENDATIONS	177
4.3 RIPRAP PLACEMENT LEVEL EFFECTS	179
4.3.1 INTRODUCTION	179
4.3.2 PLACEMENT DEPTH EFFECTS ON FAILURE MECHANISMS	180
4.3.3 PLACEMENT LEVEL EFFECTS ON SCOUR REDUCTION	181
4.3.4 DETERMINATION OF PLACEMENT DEPTH FACTOR, K_Y	188
4.3.5 SUMMARY AND RECOMMENDATIONS	190
4.4 THE EFFECT OF PIER DIAMETER AND SEDIMENT SIZE	192
4.4.1 INTRODUCTION	192
4.4.2 EFFECT OF PIER SIZE ON LOCAL SCOUR DEPTHS	193
4.4.3 THE EFFECT OF PIER SIZE ON RIPRAP PERFORMANCE	195
4.4.4 DEVELOPMENT OF PIER/SEDIMENT SIZE FACTOR	199
4.4.5 SUMMARY AND RECOMMENDATIONS	199
4.5 RECTANGULAR PIER EXPERIMENTS	201
4.5.1 INTRODUCTION	201
4.5.2 LOCAL SCOUR DEPTHS FOR UNPROTECTED PIER	201
4.5.3 THE EFFECTS OF PIER SHAPE ON RIPRAP PERFORMANCE	204
4.5.4 FLOW ALIGNMENT EFFECTS ON SCOUR DEPTHS FOR A RECTANGULAR PIER	211
4.5.5 THE EFFECT OF FLOW ANGLE ON THE PERFORMANCE OF RIPRAP LAYERS.	214
4.5.6 SUMMARY AND RECOMMENDATIONS	217
4.6 RIPRAP LAYER THICKNESS EFFECTS	219
4.6.1 INTRODUCTION	219
4.6.2 LAYER THICKNESS EFFECTS ON RIPRAP FAILURE MECHANISMS	220

4.6.3 HOW LAYER THICKNESS AFFECTS SCOUR REDUCTION ABILITY OF RIPRAP LAYERS	222
4.6.4 SUMMARY AND RECOMMENDATIONS	227
4.7 FLOW DEPTH	228
4.7.1 INTRODUCTION	228
4.7.2 FLOW DEPTH INFLUENCES ON UNPROTECTED LOCAL SCOUR DEPTHS	228
4.7.3 THE INFLUENCE OF FLOW DEPTH ON RIPRAP PROTECTION LAYER PERFORMANCE	230
4.7.4 SUMMARY AND RECOMMENDATIONS	234
4.8 THE USE OF FILTERS TO ENHANCE RIPRAP PERFORMANCE	235
4.8.1 INTRODUCTION	235
4.8.2 440 MM FLUME EXPERIMENTS	236
4.8.3 1.52 M WIDE FLUME	243
4.8.4 SUMMARY AND RECOMMENDATIONS	246
4.9 PIER RIPRAP PROTECTION - SUMMARY	248
4.9.1 PROPOSED RIPRAP SIZE PREDICTION EQUATION	248
4.9.2 RIPRAP FAILURE MECHANISMS	248
4.9.3 SAFETY FACTOR	249
4.9.3 RIPRAP LAYER PLACEMENT EFFECTS	250
4.9.4 PIER SIZE/SEDIMENT SIZE EFFECTS	250
4.9.5 RECTANGULAR PIERS - ALIGNED AND NON-ALIGNED WITH APPROACH FLOW	250
4.9.6 RIPRAP LAYER THICKNESS EFFECTS	251
4.9.7 FLOW DEPTH EFFECTS	251
4.9.8 THE USE OF FILTER LAYERS	252
4.9.9 DESIGN GUIDE FOR RIPRAP PROTECTION LAYERS	252
5.0 SEDIMENT BED DEGRADATION EFFECTS ON RIPRAP	254
<hr/>	
5.1 INTRODUCTION	254
5.2 RIPRAP RESPONSES TO DEGRADATION IN A UNIFORM SEDIMENT	256
5.2.1 FAILURE MECHANISMS	256
5.2.2 LOCAL SCOUR DEPTHS EXPERIENCED BY RIPRAP LAYERS	258
5.2.3 INFLUENCE OF LAYER THICKNESS ON RIPRAP PERFORMANCE	262
5.3 RIPRAP RESPONSES TO DEGRADATION IN A NON-UNIFORM SEDIMENT	266
5.3.1 INTRODUCTION	266
5.3.2 FAILURE MECHANISMS UNDER DEGRADATION IN A NON-UNIFORM BED	266
5.3.3 LOCAL SCOUR DEVELOPMENT IN A DEGRADING, NON-UNIFORM SEDIMENT	268
5.3.4 LAYER THICKNESS EFFECTS FOR A NON-UNIFORM SEDIMENT	271
5.4 SUMMARY AND RECOMMENDATIONS	272
6.0 MODEL STUDY OF THE HUTT RIVER ESTUARY BRIDGE	274
<hr/>	
6.1 INTRODUCTION	274
6.2 PIER AND RIPRAP MODEL DESIGN	275
6.2.1 DEVELOPMENT OF APPROPRIATE MODEL SCALES	275
6.2.2 MODEL CONSTRUCTION	278
6.2.3 APPROACH FLOW	280
6.2.4 SEDIMENT BED LEVELS AND SCOUR DEPTH MEASUREMENTS	281
6.2.5 RIPRAP DESIGN AND IMPLEMENTATION	282

6.3 LOCAL SCOUR AT EXISTING BRIDGE PIERS	285
6.4 PHYSICAL MODELLING OF RIPRAP PROTECTION MEASURES	288
6.4.1 TEST 1	289
6.4.2 TEST 2	291
6.4.3 TEST 3	291
6.4.4 TEST 4	293
6.4.5 TEST 5	294
6.4.6 SUMMARY OF RIPRAP PROTECTION LAYER RESULTS	295
6.5 SUMMARY AND RECOMMENDATIONS	297
6.5.1 LOCAL SCOUR DEPTHS	297
6.5.2 RIPRAP PROTECTION DESIGN	298
<u>7.0 SUBMERGED VANES</u>	<u>299</u>
7.1 INTRODUCTION	299
7.2 CLEAR WATER EXPERIMENTS - TYPE I VANES	300
7.2.1 INTRODUCTION	300
7.2.2 OBSERVATIONS AND THE EFFECTS OF VANE AND LAYOUT PARAMETERS	303
7.3 MOBILE BED EXPERIMENTS - TYPE I VANES	307
7.4 MOBILE BED EXPERIMENTS - TYPE II VANES	310
7.4.1 INTRODUCTION	310
7.4.2 PARAMETER INFLUENCES	312
7.5 SUMMARY AND RECOMMENDATIONS	314
<u>8.0 SUMMARY AND CONCLUSIONS</u>	<u>317</u>
8.1 RIPRAP AS A PIER SCOUR COUNTERMEASURE	317
8.2 A DESIGN GUIDE FOR RIPRAP INSTALLATIONS TO PROTECT BRIDGE PIERS	322
8.3 SUGGESTIONS FOR FURTHER RIPRAP RESEARCH	324
8.4 SUBMERGED VANES AS A SCOUR COUNTERMEASURE	324
8.5 SUGGESTIONS FOR FURTHER RESEARCH OF SUBMERGED VANES	325
<u>REFERENCES</u>	<u>327</u>
<u>APPENDIX 1: UNPROTECTED SCOUR DEPTH MEASUREMENTS</u>	<u>337</u>
A1-1 SCOUR DEPTHS RECORDED FOR CYLINDRICAL PIER IN THE 0.44 M WIDE FLUME	337
A1-2 SCOUR DEPTH MEASUREMENTS FOR THE RECTANGULAR PIER IN THE 0.44M FLUME	343
A1-3 COMPARISON OF PROBE AND PERISCOPE SCOUR MEASUREMENTS	346
A1-4 SCOUR DEPTH MEASUREMENTS FOR THE 1.52 M WIDE FLUME	347
<u>APPENDIX 2: VELOCITY MEASUREMENTS</u>	<u>349</u>
A2-1 VELOCITY PROFILES RECORDED IN THE 0.44 M WIDE FLUME	349

A2-2 VELOCITY PROFILES RECORDED IN THE 1.52 M WIDE FLUME	355
<u>APPENDIX 3 - RIPRAP EXPERIMENTAL RESULTS</u>	<u>357</u>
A3-1 RIPRAP EXPERIMENTS IN 0.44 M WIDE FLUME	357
A3-2 EXPERIMENTS IN THE 1.52 M WIDE FLUME	359
A3-3 EXPERIMENTS PIER/SEDIMENT SIZE RATIO	360
A3-4 RESULTS OF RECTANGULAR PIER EXPERIMENTS	361
A3-5 RIPRAP THICKNESS EXPERIMENTAL RESULTS	363
A3-6 RIPRAP FLOW DEPTH EXPERIMENTAL RESULTS	364
<u>APPENDIX 4 - RIPRAP RESPONSES TO A DEGRADING BED</u>	<u>366</u>
A4-1 EXPERIMENTAL SETUP FOR DEGRADATION EXPERIMENTS	366
A4-2 VELOCITY MEASUREMENTS IN THE 0.457 M WIDE FLUME	366
<u>APPENDIX 5 - HUTT ESTUARY BRIDGE STUDY DATA</u>	<u>368</u>
<u>APPENDIX 6 - SUBMERGED VANE EXPERIMENTAL DATA</u>	<u>376</u>
A6-1 VELOCITY MEASUREMENTS	376
A6-2 SCOUR DEPTH PROFILES	377

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 ($g = 9.81 \text{ m}^2/\text{s}$)
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