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Keywords: coastal structures, breakwater design, harbour entrance, concrete armour units, hanbars.

1. Introduction

7KH ¿SÄWLNL +DUERXU 'HYHORS  
LPSURYH PDULWLPH DFFHVV IRU  
VWDELOLVLQJ WKH :DLRHND 5LY  
WUDLQLQJ ZDOO EUHDNZDWHUV  
ZLOO EH WRFDWHGDVW RI WKH H[  
DQG[WHQG RXW WR DSSUR[LPDW  
H[LVWLQJ VKZLGHQHLQJ WRD SU  
QXPI  
FRXS  
HQY



RQDO FK  
DPLF ZL



)LJXUH([LVWLQJ :DLRHND 5LYHU HQWUDQF  
LQFOXGLQJ ULYHU WUDLQLQJ ZRUNV VRX

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¿ SÀWLNL +DUERXU 'HY-H ~~RSJCHW~~ 13LR MHD ~~QDQG~~ TV ILUVW KDUERXU RSHQLQJ LQ RYHU  
-RQDWKDQ &ODUNH \*UDQW 3HDUFH 7RP 6KD ~~QGG~~/DQFH 3DUWQHU (GGLH %HHWKDP

¿ SÀWLNL +DUERXU 'HY-H ~~RSJCHW~~ 13LR MHD ~~QDQG~~ TV ILUVW KDUERXU RSHQLQJ LQ RYHU  
-RQDWKDQ &ODUNH \*UDQW 3HDUFH 7RP 6KD ~~QDQG~~ ~~SDW~~ ~~DE~~ ~~FN~~ ~~DR~~ ~~ON~~ HU (GGLH %HHWKDP

### 3.2

¿SÁWLNL +DUERXU 'HY-HRISPHQW 13LRMHDFODQGTV ILUVW KDUERXU RSHQLQJ LQ RYHU  
-RQDWKDQ &ODUNH \*UDQW 3HDFUH 7RP 6KDDQSDWDEHNDORRQHU (GGLH %HHWKDP

3.4 \*URXQG ,PSURRPHQW

4.1 Armour unit s

7KH FRQFHSW GHVLJQ SUHVHQWHG UHFRPPHQGDWLRQV  
IRU '\QDPLF &RPSDFWLRQ '& \*URXQG  
,PSURYHPHQW DQG JHRWH[WLOH UHLQIRUFHPHQW  
GHSWK RI LPSURYHPHQW KDV EHHQ VKRZQ WR EH FULWLFDO  
IRU WKH VWUXFWXUH WDWDELOLWORDG FDVHV  
DQG LW LV DFNQRZOHGJHG WKDW '& LV RQO\ VXLWDEOH IRU  
VRPH VRLO WSHHVBUR 7ULDOXUH  
ZDV FRPSOHVHGULO\ WR XQGHUVWDQG WKH  
VXLWDELOLW\ RI '& IRU WKH VLWH DQG OLNHO\ GHSWKV RI  
LPSURYHPHQW DQG GHVLRQVFRQFHSW  
GHVLJQ DOVR LQFRUSRUDWHG D KLJK VWUHQQJWK EDVDO  
JHRWH[WLOH DQG WKH '& 7ULDO DVVLVWHG LQ  
XQGHUVWDQGLQJ WKH SRWHQWLDO IRU GDPDJH WR WKH  
JHRWH[WLOH ZKHQ VXEHHFW WR '&

7KH SURSRVHG '& PHWKRQ ZDV HIIHFWLYH LQ  
GHQVLILQJ WKH ZLWSELW WKH WULDO DUHD ZKLFK  
DUH ODUJHO\ UHSUHVHQWDWLYH RI WKH WUDLQLQJ ZDOO ZRUNV  
7KH HQHUJ\ OHYHOV DSSOLHG ZHUH GHWHUPLQHG EDVHG  
RQ SXEOLVKHG UHODWLRQVKLSV WR DFKLHYH WKH WDUJHW  
GHSWK

)LJXUH '& WULDO ZDV FRQVWUXVHG WR V WKH  
OLNHO\ GHSWK RI LPSURYHPHQW DQG SRWHQWLDO GDPDJH WR  
JHRWH[WLOHV

6LJQLILFDQW GHQVLILFDWLRQ ZDV REVHUYHG LQ WKH VDQGV  
LQ WKH WRS WR P 5HGXFHG OHYHOV RI GHQVLILFDWLRQ  
ZHUH VKRZQ WR H[WHQG WR D GHSWK RI DURXQG WR  
P ZKLFK LDOHTXWYWR P5/ ZKHQ '&  
LV FRPSOHWHG5URQ WKH WUDLQLQJ ZDOOV  
7KH WDUJHW LPSURYHPHQW ZDV GHSWK RI  
DFKLHYHG EDVDO JHRWH[WLOH UHLQIRUFHPHQW ZDV  
DOVR VKRZQ WR EH VLJQLILFDQWO\ GDPDJHG GXULQJ WKH  
'& WULDO HYHQ ZLWK D JUDYHO VDQG 'FXVKLRQ' DERYH WKH  
JHRWH[WLOH %DVHG RQ WKHVH REVHUYDWLRQV IURP WKH  
'& 7ULDO LW ZDV FRQFOXGHG WKDW WKH JHRWH[WLOH  
UHLQIRUFHPHQW ZRXOG EH UHPRYHG IURP WKH GHVLJQ  
DQG DOWHUODVWLRQVRIHQWVZSL OLQJ  
VHOHFWHG WR V&SSOPHQW WKH

4. Key design considerations

%DVHG RQ WKH LQYHVWLJDWLRQV FRQGXFWHG DV SDUW RI  
WKH GHWDLOHG G[VVDJQXSURFHVRU  
FKDQJHV ZHUH PDGH WR WKH GHVLJQ 7KH NH\  
FRQVLGHUDWLRQV DUH RXWOLQHG EHORZ



¿SÁWLNL +DUERXU 'HY-HRISPOH 13LRMHDFVDQGTV ILUVW KDUERXU RSHQLQJ LQ RYHU  
-RQDWKDQ &ODUNH \*UDQW 3HDUFH 7RP 6KDDQSDWDFHNDORRNUHU (GGLH %HHWKDP

OD\HU RI SDWWHUQ SODFHG XQLWV WKH HIIHFWLYH  
LPSHUPHDEOH FUHVW KHLJKW ZDV DOVR XQNQRZQ DV  
GSHHQGLQJ RQ WKH ZDYH DQJOH WKH JDSV EHWZHHQ WKH  
+DQEDU FKLPQH\ V PD\ DOORZ LQFUHDVHG ZDYH  
SHQHWUDWLRQ DQG RYHUWRSSLQJ

6HYHUDO RYHUWRSSLQJ WHVWV ZHUH FRPSOHWHG LQ WKH  
SK\VLFDQ PRGHORVWVZHXG\ GRQH ZLWK  
ZDYHV SHUSHQGLFXODU WR WKH WUDLQLQJ ZDOOV DQG DW DQ  
DQJOH RI GHJUHHV WR WKH ZDOOV 9DULRXV +DQEDU  
VL]HV ZHUH WHVWHG XVLQJ D UDQJH RI ZDYH FOLPDWHV  
7KH UHVXOWV VKRZHG WKDW DV H[SHFWHG RYHUWRSSLQJ  
UDWHV LQFUHDVHG DV ZDYH FOLPDWHV LQFUHDVHG DQG  
FUHVW IUHHERDUGV UHGXFHG GHFUHDVHG DV WKH  
+DQEDU VL]H DQG OD\HU WKLFNQHV LQFUHDVHG  
DEVUELQJ PRUH ZDYH HQHUJ\ DQG GHFUHDVHG ZLWK  
W#B€P R B B O DWX W# @ZDW B€ @Lp MEWLLVCSH € LQ YuDT• €p#  
W `VPBVP X @XK P ÁEYK WR• °P @ ÁKDE€ @W€à  
W R HG0

¿ SÀWLNL +DUERXU 'HY-H'RIS.PCH W 13LR MHFOVD QG TV ILUVW KDUERXU RSHQLQJ LQ RYHU ) \
 -RQDWKDQ &ODUNH \*UDQW 3HDFUH 7RP 6KDDQGSDWOLFNBDOVRQUHU (GGLH %HHWKDP

DJDLQVW ZDYH GRZQ UXVK VXFNLQHQVQGRIRWVHWXUBXDKQJ ZDOOV ZK
 DUPRXU IRRFNWKH WRH DUHD FORYGMW WRVWLQH ZLWK GDPDJH ZHO
 EUHDNZDWHUV ,W LV LPSRUWDQVHYURPV LHFVRFKGFHJHG WKH UHV)
 SHUVSHFWLYH WKDW WKH LQQHU SDQWBYDWKIHY BSDRSDVDFNHSQG DGR
 LQ SODFH DV D EVKHMUHSVOMRPFQBSWKEHLHG URFN VLJH IURP D UDQJH
 RI WKH FRQFUHGWVODKSPIRXUWU WRRQBLWLRQV
 LV WR EH WRGQVWUXWB RQO\ DUPRXU VWRQH VR WKDW

LQ D ULYHU VFRXU VLWXDWLRQ WKH VWRQVHYG VORSH KDV PRUH
 HYHQ DQG FRQWLQXR XV SURWHFWLHVODLVGVGHVLUQDEFIOWKHURBSÀWLNL +
 D ULYHU VFRXU SHUVSHFWLYH UHOLHG RQ WKH FROOHFWLRQ RI VL
 DGGLWLRQDO GDWD QXPURXV QXP
 PRGHOV DQG FRQVWUXFWLRQ WULDO
 ZDV RIWHQ LWHUDWLYH ZLWK UHVXO
 VWUHDPV IHHGLQJ EDFN LQ WR DV
 HOHPHQWV DQG UHVXOWLQJ LQ VLJQL
 GHVLJQ DQG D JUHDWHU FRQILG
 FRQVWUXFWDELWLW\ DQG XOWLPDW
 VWUXFWXUHV

6. \$FNQRZOHGJHPHQWV

7KH DXWKRUV DFNQRZOHGJH ¿ SÀWLNL
 7KH %D\ RI 3OHQW\ 5HJLRQDO &RXQF
 =HDODQG OLQLVWU\ RI %XVLQHVV
 )LJXUH([DPSOH RI 3K\VLFDQ PRGHO WHVWYKPFQW WKU IXOGLQJDQGLV
 SHUIRUPDQFH RI D IDOOLQJ URFN DSURQ XVLQJ WKUHH %D\ HUY RI
 DUPRXUDQFN QXGHUOD\HU > @
 GHVLJQ WR OLIH

\$SURQV DUH GHVLJQHG WR EH FRQVWUXFWHG WCUHH OD\HUV
 WKLFN ZLWK WKH H[SHFDWLHQW KReferenZs OO LQLWLDQO\ IDOO WR
 DQ DSSUR[LPHDWHVORSH LQ UHVSRQVH WR HHWKDP ( &WXDOLQJ IXPHULFDO
 VFRXU DQG XOWLPDWHO\ IRUP D ¿K\VLFDQVORSHXQGHQOLQJ IRU ¿SÀWLNL
 H[WUHPH VFRXU HYHQWV¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿
 DQG FRQWLQXR XV SURWHFWLRQ RFDVVDVWRQHOD\HU WKLFN
 > @ %ODFND 0 - &DUOH\ - 7 &R\ 5 -

)DOOLQJ DSURQ ZLGWKV ZHUH V.LJHG SEVWVPRQW WKHWKH XVH RI &RQF
 PD[LXPX SUHGLFWHG ULYHU VFRXU SURXUKEQLWKRQKQ: QVMDNDZLDHURDVW
 GHILQHKEH QXPULFDO PRGHOLQJ DQG HPSULFDQ SURFHHGLQJV \$C
 FDOFXODWLRQV RI SUHGLFWHG VFRXU (&DQG IVDVYDWLHQLQJ DQDQXDO
 EHG OHYHOV RQ WKH VHDZDUG V¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿¿
 WUDLQLQJ ZDOOV 5HVVDUFK &HQWUH :DWHUZD\ (SHULP
 \$UP\ RUSV RI (QJLQH 9LFNVEXUJ 869

7KH URFN WRH DSDURQLHGURRKOJ D UDQJH
 RIHPSLUURDQXQDQ ZLWK WKH DGRSWHG
 PHWKQR YDU\LQJ GHSHQGLQJ RQ ZDWHU GHSWK \$W
 KLJKHU ZDWHU OHYHOV ODUJHU ZDYHV FDQ UHDFK WKH
 VWUXFWXUH EXW WKH WRH LV VXEPHUVHG DQG ZDYH IRUFHV
 DUH UHGXFHG /RZHU ZDWHU OHYHOV DOORZ IRU ZDYH
 DFWLRQ WR DFW PRUH GLUHFWO\ RQ WKH WRH KRZHYHU GXH
 WR GHSWKZDYLWLQH VPDOOHU \$ UDQJH RI ZDWHU
 OHYHOV ZDYH KHLJKWV DQG PHWKRGV ZHUH DVVHVVHG
 DQG WKH FULWLFDO ZDWHU OHYHO DQG DVVRFDLWHG
 PHWKRGGRORJ\ XVHG LQ VLJLQJ WKH URFN

5RFN VLJLQJ ZDV YDOLGDWHG ZLWK SK\VLFDQ PRGHO
 WHVWLQJ DV D UDQJH RQFDXWGHG OHYHOV WKLV L
 DGGUHVVLQJ FRQFUHQV WKDW HPSLULFDO FDOFXODWLRQV
 PD\ XQGHUVWLPDWH WRH DUPRXU VLJLQJ DV WKH KHDGV