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محاسبهٔ مقاومت موج سازی یک شناور زیر دریایی با استفاده از روش المان مرزی

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چکیده

در این مقاله، برای *محاسبهٔ مقاومت موج سازی* یک شناور زیر دریایی با استفاده از روش المان مرزی (BEM) و المان بندی سطح جسم به وسیلهٔ المان های چهارضلعی هذلولوی و المان بندی سطح آزاد آب دریای اطراف زیردریایی به وسیلهٔ المان های چهارضلعی و همچنین با به کارگیری قضیهٔ گرین برای هر نقطه از میدان جریان، معادلهٔ انتگرالی پتانسیل سرعت را روی جسم و سطح آزاد اعمال شده و با تشکیل سیستم معادلات و اعمال شرایط مرزی، پتانسیل سرعت، محاسبه شده است. سپس، با مشتق گیری از پتانسیل سرعت، مقادیر فشار و نیروها محاسبه گردیده و در نتیجه مقاومت موج سازی مورد بررسی و حل عددی قرار گرفته و نتایج به صورت زیر ارائه شده است. به منظور بررسی صحّت کد نوشته شده، نتایج به دست آمده با نتایج شناور ویگلی [۳] و یک *زیردریایی بیضیگونی UV11* مورد مقایسه قرار گرفته است.

واژه های کلیدی : روش المان مرزی، سطح آزاد، شناور زیردریایی، مقاومت موج سازی

Computations of the Wave-making Resistance of a Submarine, Using Boundary Element Method

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ABSTRACT

This paper is presented to compute the wave-making resistance of an ellipsoid submarine, using boundary element method (BEM), in which the body surface and free surface are discretized into hyperboloidal elements. The fundamental solution of the governing Laplace's equation was obtained using Green's function via boundary integral equation. The linearized free surface boundary condition was applied and the unknowns of the doublet on the body and source on the free surface were obtained by solving the discretized equations. Then, the numerical results of pressure, wave-making resistance, and wave elevation were determined. We presented the results for the Wigley hull and for the submerged moving ellipsoid shape of the submarine UV11. The validity of the numerical results was examined by comparing it with experimental results.

Key Words: Boundary Element Method, Free Surface, Submarine, Wave-making Resistance

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۲-کارشناس ارشد

3-Wigley

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3" 4 " ,)-. *)5)' * + ,-. /01,- 2
?@)A")$ >) 3 ' - , 6- 78 3" 9 :;<=
3?) E) , 2 ' CD78" 6 " ? 6B9-
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" @+)) - , ,I GJK ?6$ 3" 9 , 2
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,)-.)' '" , 2 N MOP - - 6 4
,) 2 :);<=)-) 6 R 9 ' S .$ Q @+
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)'.,) ;B U BV3 ' 3 ' n" 2 "
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:P) a 3 ' 3 ?3 ^" Q : 6Y"
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3?) g)5B^ " M) 3?) R #<3 ^" R
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") 3?) E) ,) 2 P) a 3)' 3 S! B+X
.[8] [4-5] , B X" J! ;B
)- , ! $ 6 /G [6]R [5] iXhI S*I ^"
@+ 3 " R #< " , ' #9b KB Xk " '
6) "' <)+ " 4 ? L7 3" #9)b KB Xk "
*) ")k ' ^" K ?[7]])- .[1] $ 6 1 aS

:))')' g)) 6B)9)-) 3 ' 1)aS P) a
MIT ! 59)) " 603)) 3)) 6B9))- 6)))5
" 6)' S3) N) ?)' ")Q n B - ! ;B
" p) PA[3] ,) !)# +) 2 [8]N9)- :o\ .
1) aS3)' 3?) R)#<^ " ?! ;B 'N " #
*) 3 ! B+)X3) " - R 3" _ " $ 3
E 3 5< 3? E , 2 P a .[9] !
)' 6)' ?* + 6B9-3 ' ! $ E > ;S"
\ . < 2g U<= h S 3? R #<^ " ?! ;B
.[12-13] , B X" 8
R 9) U) BVR)2/a 3)) ,I <G1? 18). n B
1) aS3 ' #S" J O " M)^ " K - 6
)' 3? R #<^ " .$ ' 6 3? E , 2 P a
@+) ?) " ^" K) " 1) aS R #<- K 1 <
n)B)$! ;B) ,< &))' S6 $ 6 U GS
))G ?! ;B) ^" .) - [" 3 Sq J B&'
.,) ! $ [" * R 2/a ? 6 G'hI SM W- B
)S) I)\ ?3)A #) ? G K /1.
?) 6)<r)# 1. 3 A " 8 ' " G K R B'
"))) ^" K) ?! ;B) 3)' 3)) ? D 9)
" $ 6 ")bS " ^" K ' 3 ?)) R 2/a
:P) a 3)' 6)2 J" +)'n)BR)B' M 3 !
.[14] , [11] , [6] " , ' " $ > /1-, 2
E) 6)7/Q:G) S 3?) R)#<^ " M < 2K
,) !)- g)#AUV11 6) " ?3 ' " ? L7
n)B)\ . ^")-) 6) R 9 ! , 'n B
1)$ P) a K) . 6 [" "6<P1J' J 4 7
@+) 3" Y t q#A u 3? E , 2 :P a
,) (? L7) 3") @+ 3 ' " E > ;S" vS
@)+) ,-)).)u" ! $)<SE) K) 3 5)<)-
O+)).)' 3?) E) ,))2 O)\ ! ' g P1J' J
?))- [9]6))5B " 6X)) 'h))$ 3 "))))A
? L7) 6) M) L7) " ")$,-. I 8 sQ
,) 2 3 ")' 3")Y t q)#Au. 6 R 9 ,

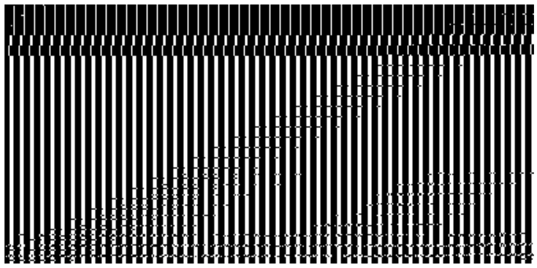
1 -Rankine Source Method
2 - Kelvin's Theory
3 - Navier-Stokes Equations
4 - Singularity
5 -Gad
6 - Dawson
7 - Nakos

8 - Towing Tank
9 -Hump & Hollow

K))u q)#AN M))' - 6 R 9 M 3? E
. " 6 K ' ?, 2

-2

!" #$ %
! N)# 11)$ ")- 6S" 8 ' " 6 " ?
?L7) ? H >);S"' - 5' k " , ! $
., ,- . " U ,A ' 4



.@+ ,- . ? L7 IsBV :(1) &'$

M)- 3 " R x)P 5B) "!)$ 4)VB IsBV
, & " x " a $ ' 6 ? L7 " 3" $ L7
z ")a " $ y A ,& " y " a ,- . FDQ
)B Xk " K _F Y ' ? L7 ' #A,& "
g I) ")8)' 6) " ' " R R ., ! $
K))- $ 6 y 69Q b t EM<t z_@-S
)- ")Y R # . 6 B "]D_ :< G I \
R#))<) 3 !)X")B" p : 72)$ -{ |DPJ
" 9) ,A 2 :P a 3 ' Wp X 6 " J
:)) . R " 6Y))2"))72 K)) R)) 1))Q "
3 " !")# q : 7))2)I r $ 6 ! " J6S P a
< G6 #A4 R " , ' 3 ' ." " JR #<
^ " #- ' R 3 A 1 aS K Xg 5B?]D_
6 " ? - O S $K ' ., ! $! ;B 3? R #<
3)) R))#?3))A #))' " ? L7))))k "))
R))#<))) " 1 +) B_!)- 3?)) g) 6G \' &)b
. 6 , ' R # Wp . $ 6 P)))) a
1 +) B_ (X, Y, Z) 1)- ,A 1 + BK ' :7' "

*I)PS KB Xk " ' (X,Y,Z) [10] 6[M ,A
:[15] $ 6 R ' ? " 8 ' [11] @ $u

$$= \vec{U} . \vec{x} + \; ^2 \; _{n=1} \; ^n \; _n = \vec{U} . \vec{x} + \; _1 + \; ^2 (\; _2 + t \; _t) , \qquad (1)$$

")))' x @+))) 3"))' ,A))) U R "))-
@)St (8 << 1) 6)[M B " _8 @+ ,I GJ
: $ 6 U GS' ' " " 8 ' - , " $

$$t = \tan \frac{}{L} . \qquad (2)$$

U) GS?) h)$ " $_2$ $_1$ 6)[M 3 1 + B_
" R) .,) @)$u ' T ' $_t$ 1 + B_ ! $
)$ 6)) 6[M 1 + Bhl S - 6 " ?F Y
. # \" "(^{2} = 0)]D_ :< G '
]D_ :< G6 4 ? BEM 6 8 ^ " "
" .@) - 6) ! ;B) @ 6 N # w ' "R -
1)$)vSR ' @- y) ' 67)Q ? L7 <I+
)-)- ! ;B 6B QK X•' S? R $6 ? L7
6) 6 S # T $]D_ :< G ' ! DA
" ")$,)- . <I+) " .) -)\" M " ? L7
))$ 6 U)G$?1)$ ' - 6 X•' S? ? L7
:@ -6 ! ;B

$$w = \frac{1}{2} G , \qquad (3)$$

$$G(x, y, z, \; , \; , \;) = G(p, q) = \frac{1}{R} + H(x, y, z, \; , \; , \;) , \qquad (4)$$

!)#)' "]D_ :< G - , 6G' $H *R "* -
!) o _*) B " - - \" ' R 3? h $
)< G1). ? - , [12] K X•' SG .,$ Q 3
(p,q) R ")- 6 , ' [2] G = (p,q)
(x , y , z))7' "K " K o# ., [13] € •' S
q :)72 Is)BV (< , = , >) p :)72 Is)BV
" $,- . <I+ " 3? h $ @- .:< G,
:? S" PA? L7 "

10 - Perturbation Velocity Potential
11 - Trim
12 - Green's Function
13 - Dirac Cunction

•) ? S?)-)- y) R S6 " - " ,< & 3 '
"K)X:7' " , ! $! :#9b ? 3 A #
) ?1 $ ' ! a 1- " p :72 3 ' | # 2B-R S6
;,$

(10)

$$P = (q)\ G(p,q)\ dS_{S_B}$$

)o b., #9b " J 7' " K " C R " -
#9b " J ' @ $ 'B$ p :72 " " @ V'
3 ', :< Gz<@ " , ' ' L7 3 " " "
:? , " PA$ ' ' L7 3 " p - 6B< .

(11)

$$2\ (p) + \int_{S_B} (q)\ G_n(p,q)\ dS = U\ n_1(p).$$

6)' 1 < ' . $ 1). 3)A ")8)' ' 7' " K
6) X•')S k " :<l+ " q#AR - y , &
)-{ 1 +) B_P)$ ' $ ' h $K 'O B -
R?)&h)I S•')SK) . $ ' 6a7 E " ! $
3 B) KB))X-k)) " ' 1962g) " [29] R B
)B (,) &6') " U- S ? L7 ?)- r > G$
:[14], ! $ R ' ?1 $ ' $ ' 6 "

(12)

$$G(x,y,z,\ ,\ ,\ ) = \frac{1}{R} \frac{1}{R_1} \frac{4}{} K \int_0^{\frac{}{2}} \sec^2 d \int_0 \frac{\exp k(y+\ )}{k\ K\sec^2} \cos k(x\ )\cos \times \cos k(y\ )\sin$$

$$4K \int_0^{\frac{}{2}} \sec^2 d \exp K(z+\ )\sec^2 \times \sin K(x\ )\sec \cos K(y\ )\sin \sec^2 .$$

1)$,) K)X•')S $ 6 ! 9 - " YR #
.)$ ' 6) 3)G') :#9)b 1 +) B_- , $\frac{1}{R}$ * S
: $ 6 U GS? " 8 ' M , 3 B " _

(5)

$$1)\ {}^2G = 0 \quad {}^2H = 0,$$
$$2)\ G(x,y,z,\ ,\ ,0) + K G = 0,$$
$$3)\ \lim_{z} G = 0 \quad G(x,y,z,\ ,\ ,h) = 0,$$
$$4)\ {}_n = U\ n_1.$$

T $ 6P - S< G*I T $]D_ :< GgI T $
3? T $ *I T $? L7 6 6 S #
3 ' *I : # a q#A3 ' gI : #) " U-
) ' 3 " 3?) T))$ Q T)$ (, a q#A
g) ")' ,)))- . ,)& ");<= n_1 K#))\ " .,
,))&)k ") :)72 X g). ., ' L7)) 6 '
) ' L7))) 3 " p = p(x, y, z) 1)+) B_P))a
K)X: J ?! ;B ' ! , ' :7' " ? 5)' ")J
;,$ R S6

(6)

$$\int_S \frac{G}{n} \ G \frac{}{n}\ dS = 2\ (x,y,z),$$

,))) $_n = U\ n_1$ L7))) K)) 3 ")) [?
: $ 6)B

(7)

$$\int_S \frac{G}{n} dS \quad \int_S G U\ n_1 dS = 2\ (p),$$
$$2\ (p) + \int_{S_B} \frac{G}{n} dS = U \int_{S_B} n_1(q)\ G(p,q)\ dS,$$

•)\" ")' T)$ - $ ' B$ G •' S o b
")8 3)A ")8 ' ' - < GK 1. ' -
,))' " $: ' L7 3 " 1 + B_ 2 X
!)a 1- 3 ' " K X: J :7' " !" ' X . 6
6) $ ' ! a ? 6[" ' K p :72 @+ '
) ? " s)' !)a ?)72 " " 1 + BR S
: " , '

(8)

$$\int_S \frac{G}{n} \ G \frac{}{n}\ dS = 4\ (p),$$

(9)

$$4\ (p) + \int_{S_B} (q)\ G_n(p,q)\ dS = U \int_{S_B} n_1(q)\ G(p,q)\ dS$$

(13)

$$R = \left((x \quad)^2 + (y \quad)^2 + (z + \quad)^2 \right)^{\frac{1}{2}},$$

$$R_1 = \left((x \quad)^2 + (y \quad)^2 + (z \quad)^2 \right)^{\frac{1}{2}},$$

3 "q:) S:72 pg B - 72 K ': 8 R R" -
:) S:72 pg B - 72 K ': 8 R' 6GJ@+
. $'6 3 sS@+ 3 " q'
U) BVT)2 " ,A) 1 + BR " , ' '
,) 2 ? L7 " > ;S'1 PJ? *? ADY
? L7) " >);S'3 ' . Q , ' 3? E
:,$ @ QU BVT 2 "

(14)

$$Z(x,y) = \frac{U}{g} \quad _x(x,y,0).$$

E) , 2 3 '! , ' : 7' "@ 6 - " 7 #
))IvB))'6))< 5BE)) 3"))cS' (R_W) 3?))
KB)$)' R S6 3 S! ^ " ? . ' dE6< 5B
' ' L7 3 " " 9 ? 3 X g 5B ' ", 2 K
: " , ' ?*

(15)

$$\frac{1}{\,} P(x,y,z) + U \quad _x(x,y,0)$$

$$g z + \frac{1}{2} \quad . \quad = 0$$

$$P(x,y,z) = \quad U \quad _x + \quad g z ,$$

$$R_W = \int_{S_B} P(x,y,z)\, n_1 ds \quad ,$$

$$R_W = \int_{S_B} U \quad _x n_1 ds = \int_{S_B} U \quad _x n_1 ds ,$$

L7) 3 " p T)2 3)' ,))G 1. ' K ' '
! ;B) ' Q , ' Cg & 2 " $
, / A' . ' Q P a 1' J3? E , 2 R ?
3)A 3 ^ " ? ! ;B ' " P g 5B6X o _
G :)< G6X o _? 6$ 7' " K 6X o _.@ B+
6)P 2S'8 ' ' "G BP< , S ? L7
!)$ -{ : _•' S? 'M "S @ -3 X g 5B
.@ MK'#VS
1 +) B6)< 5B)G K X: J ? ! ;B '
3 " R) ? p :)72) 3 " (X,Y,Z) ,A
3)) S KB)Xk " ' ? L7 @+ L7

3 " #9)b KB)X)k " @+ 3 " , ' #9b
: [15] $ 6 18 . ?h' " 4 ? L7

(16)

$$4 \quad E \quad (p) = \int_{S_B} (q) \frac{\,}{n_q} \left(\frac{1}{R} + \frac{1}{R''} \right) dS +$$

$$\int_{S_B} \frac{\,}{n} \frac{\,}{n_q} \left(\frac{1}{R} + \frac{1}{R''} \right) dS + \int_{S_B} (q) \frac{1}{R} dS,$$

(17)

$$(q) = 2 \frac{(q)}{n_q}, \qquad on \quad S_F ,$$

@+))) L7))))))')))#A:)))/ n_q R ")))-
3 " #9)b " J C (q) 1 + B" ' qB9 $\frac{\,}{n}$
. $'6 4 ? L7
:)72)X . " 65B+)g)B -:)72)' E O \
)X E = 0.5)' ' R ")2 $ ' @+ 3 " g B -
. ' Q E = 1 ' ' R " 2 $ ' ? L7 3 "

+, $ -2-1
)- X U GS ' 3? h $ (16) :< G1. 3 '
: $ 6 !" $ & ' ?"

:- . !" /'01 #0 2 $ (i
3 " 1- ,A 3 #A :;<= - " 6 R 'T $ K
3)' *I gI :PS 3? h $., ;8 ' ' @+
: $ 6 R ' ? " 8 ' (1) :< G? 8

(18)

$$: \frac{1}{n} = \vec{U} . \vec{n} , \qquad on \quad S_B ,$$

(19)

$$^2 : \frac{^2}{n} = 0 , \qquad on \quad S_B ,$$

)#A:)/ " ' $\vec{n} = n_x i + n_y j + n_z k$ " ' R " -
., L7 '

: !" 2 $ (ii
:@ -U GS? " 8 ' " f ( ) X

(20)

$$f(\quad) = \frac{^2 (p)}{^2 x_p} + K_0 \frac{(p)}{z_p},$$

:,$ @ Q

? ? L7) 3 " E) > ;S" ' ' ! " " 9 Wp
: 6 , ' ?h' "

(26)
$$P = \rho \quad \frac{}{t} \quad \left| \quad \right|^{2} \quad g z ,$$

(27)
$$= \frac{U}{g} \frac{}{x} , \qquad \text{on} \quad S_F ,$$

: X6 R ' ? " 8 ' M " 9 G6 ' O \

(28)
$$C_P = 1 \quad \frac{}{U} \quad ^{2} .$$

, ; <3 3? E , 2 1 $ - Wp
P) a ? ")8 ' R)#) " 7 #)$ ' 6
: X6

(29)
$$\vec{F} = (F_1 , F_2 , F_3) = \int_{S_B} P \vec{n} \, dS ,$$

(30)
$$\vec{M} = (M_1 , M_2 , M_3) = \int_{S_B} P (\vec{r} \times \vec{n}) \, dS ,$$

,) 2 $R_W = - F_1$,)I GJ " ' $\vec{r}$ h' " K " -
,) DA)')I S)' F_3 3 ;<= . $ ' 6 3? E
. $ ' ,; < / 3 S6 , " - 3 P
(28) (27) h)' " R - K M5 ' 5 " PA '
!)#)' ,); < 3) 3?) E) ,) 2 3)
: $6 U GS? " 8 ' @+ 3 " R 9P \

(31)
$$R_W = \rho \int_{S_B} \frac{1}{2} \quad . \quad \frac{1}{2} U^{2} + g z \quad n_x dS$$
$$\frac{\rho g}{2} \oint_{WL} {}^{2} n_x dl ,$$

(32)
$$C_W = \frac{R_W}{0.5 \rho U^{2} S_{wet}} ,$$

(21)
$$f(\ _1) = 0, \qquad \text{on} \quad S_F ,$$

(22)
$$f(\ _2) = g(\ _1) , \qquad \text{on} \quad S_F ,$$

(23)
$$g(\ _1) = \frac{1}{U} \frac{}{x} (\quad _1)^{2} + ,$$
$$\frac{U}{g} \frac{1}{x} \frac{}{z} f(\ _1) = 0 ,$$

., $\vec{U} = (U, 0, 0)$ E A $K_0 = \frac{g}{U^2}$ R " -

3 4 51 2 $ (iii
., q #A4 " " $,- . 67 a T $ T $ K

(24)
$$0 , \qquad \text{as} \quad z \qquad .$$

[14] 6782 $ (iv
" !)$ < S06a7 E 1 aS3 ' ' " 9B T $
? P) a 0^ " K " $ g #A,Q R
)G 3 !")_ /2B9) ? R)) 3))A^ "
? ! ;B)))' ., ! $! ;B x , & " (22 20)
@)Q(ii , i) 3?) h)$)G (16) :<)G
:,$

(25)
$$\frac{1}{2} \int_{S_B} (\ q) \frac{^{2}}{^{2} x_p} \frac{}{n_q} \left(\frac{1}{R} + \frac{1}{R''} \right)$$
$$U \, n_x \frac{^{2}}{^{2} x_p} \left(\frac{1}{R} + \frac{1}{R''} \right) dS$$
$$\frac{1}{4} \int_{S_B} (\ q) \frac{^{2}}{^{2} x_p} \left(\frac{1}{R} + \frac{1}{R''} \right) dS$$
$$\frac{1}{2} K_0 \quad (\ p) = 0 ,$$

$$(\ q) \frac{^{2}}{^{2} x_p} \frac{}{n_q} \left(\frac{1}{R} + \frac{1}{R''} \right) = U \, n_x \frac{^{2}}{^{2} x_p} \left(\frac{1}{R} + \frac{1}{R''} \right) ,$$

> 08 5 6: ; < = -2- 2
" 1)+) B_ 2 (25 16) G R M#/1 '
.) 6) ,) ' ? L7) @+ L7 3 " R #<

14-Radiation Condition

$$L = \rho \iint_{S_B} \frac{1}{2} \ldots \frac{1}{2} U^2 + g z \; n_z dS - \frac{\rho g}{2} \oint_{WL} \ldots^2 n_z dl \tag{33}$$

$$C_L = \frac{L}{0.5 \rho U^2 S_{wet}} \tag{34}$$

1)' J")2) S6) " $ 0@,<S. " ,; < 3 ")) @)$- 6)5 6< $ ' " "6&I S .,) R)-)k F)8 1)' J M b)" +)' R " 2 3? E , 2 1)$ - C_r[15]! 6J ', 2 ?)< ") A ? 6G' S$ ' 6 ' *) , 2 :, $ @ Q # J ', 2 3 ' .,

$$C_r = f(R_n, F_n) \tag{35}$$

$$C_r = C_{Form} + C_W \tag{36}$$

3)' .,) [16] ' * , 2 C_{Form} 7' " K " - O)\ ")2 KB)$)' !) 6J)',) 2 :P) a M) ' * , 2 :P a ' ? 3? E , 2 ?) ' * , 2 :P a 3 ' ? .,$ @ Q 3)' 6)' S :)7' " .@)!)- ! ;B 6' S h' ")')) ?"))- "))' *) , 2 :P a : $ 6 !")$ &

$$C_{Form} = (K_{Form}) C_{F0} \tag{37}$$

)k " R)' 6- 7)8 ,) 2 C_{F0})7' " K) ")- , 6P \ K_{Form} , ' * , 2 KB X 6)) vSU BV3 ' 3 ' 0.1 S0.05 2 K ')$ ' B b)- 6[ ) " ?3)' $\frac{L}{D}$, P+ b . -)- 3 5 :7)' " . ')Q BX"MK O)\ ")2 : $ ' 6 ?1 $ ' , ! $ [" ITTC hI S

$$C_{F0} = \frac{0.075}{(\log R_n - 2)^2} \tag{38}$$

")$ n)B)' < 2K n B $!" $ - " YR # " 8 ' 6 5 " $: ' * ., ! $ + 2 6 5 : X 6 U GS?* ' 6\ " •' S

$$y = \pm \frac{B}{2}\left(1 - \left(\frac{2x}{L}\right)^2\right)\left(1 - \left(\frac{z}{T}\right)^2\right) \tag{39}$$

")$ ")V' T g)Y L y)A B 7' " K " - . $ ' 6

@ 0A -3

L7 6< 5B< G" 3 A /1. ! " R " , ' 3 ' R)#<)b - 6G)\" &b3) R)#<: ' "@+ 3)' 3 a;)8 6G)\" &b3) R)#<, X 6 3 ' C7) 3 ") ' R b I $ 6 ! ;B L7 O 2S 3 a;)8 3 R #)<K ' ' , 3 a;8 t 6 a)))) B " R))#<))$ X")8 OP 6a7) R " ,))' 3)' . $ 6 3)A3)7Q 3) R #<? Y ' 03 A3 7Q ? 3 59 _ B+' >) 6)/- ")Y ' ., ! $! ;B 3 < <z6G \" &b 3) N)V' K)S@&? 6 6a7 R #< < S R #< 3) ^ " :)# ")- , 6 B;XBP,< ^ " K @)&' +)' 3 R #< < S R #<> 3 A P a K # 6 X " @ 2B+u P a n B" , : P)$) < S6< - 1#A4 Q ! - 1. ,#+J , 3)) .)$) Q n)B" 7QOP @k/ ' ' 4 (, ') . " " $ g Y ' ' ? L7 6P)) . ")' ' 1,5 , K _ . " g Y)GS # ., ! $ B Xk " P a 3 ' @+ ") 0 1L7) 3)' N = 6006) " ?3 ' R #< @+) 3)') R)#<1)- GS- N = 3,2006 " ' , ! $ 4 VB N_{Total} = 3,800 ' ' > # " ? L7 3)' R)#<)GSK 6 R 9 6S P a ' S - ,))I #- 3800))GS,)) 6))- P)) a 1)) aS @B+) ! 5B) h)I S R)#<) " 1 +) Bg_) &)' Wp) . 6 , ' g] X ^ " ? G R #))< " " 9 ")2 ,A 1 + B?_3 X qB9 P)) a ? L7))) 3 " " E)) >));S" @+)) 3 " 3) 3?) E) ,) 2 3 B " $ 6

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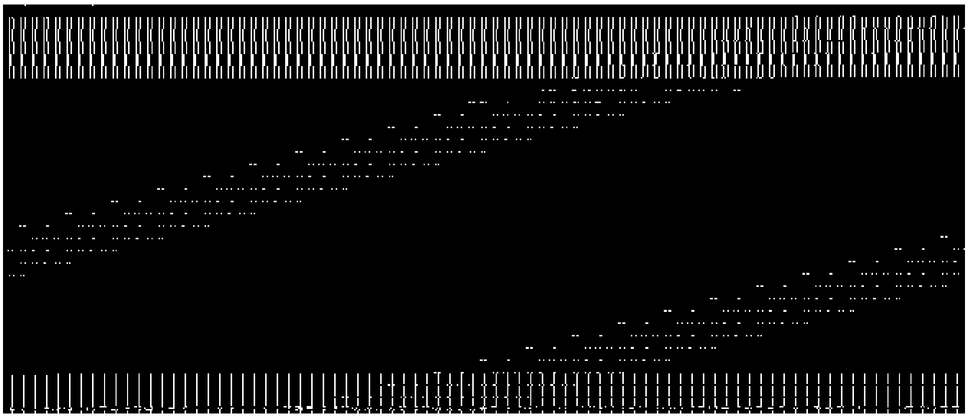
15 - Residual Resistance
16 - Hull form Resistance

E) 3 5< X 6 P a 6) " ? ' ! " ,; <
. 6 , ' ! $ < S

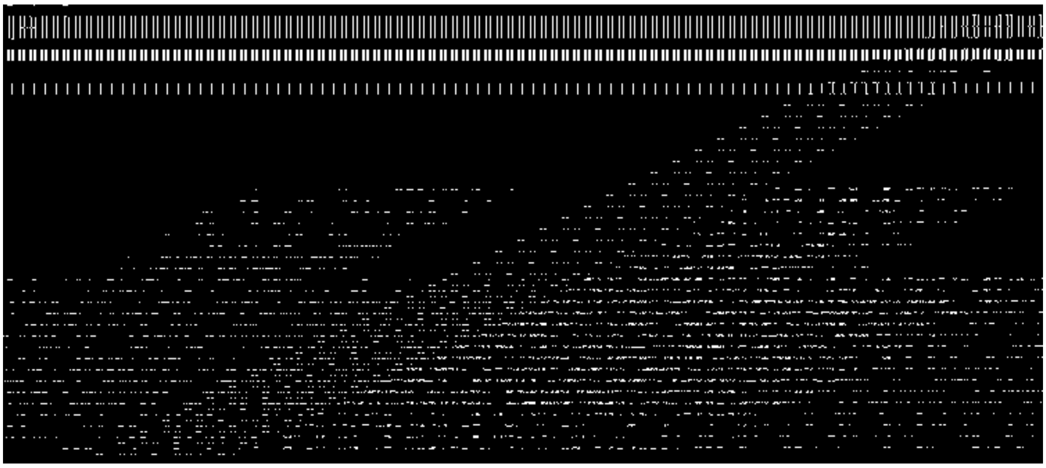
> / B= Ç < = D, 784
"))$)))k ") 6)8 g ,#+J K "
:@# M- 7J 2/5 m g Y G' ' UV11 6) " ?
? 4/5 m :))8 " @# M)))-7)))J1)))a 3/5 m
:))' " R :) ' L7 @ X6)k) " ")t
:))' "4 L7) 3 < <z6G \" &b3 R #<
)- 6s)/V9 † a " 3 a;8 6G \" &b3 R #<

) < S@)# 6) 3 ' R #<" " J6a7 ?" $
2 1)$ " " UV11 6 "))) ?" $ 3))' R #))<
. - 6 ! 9

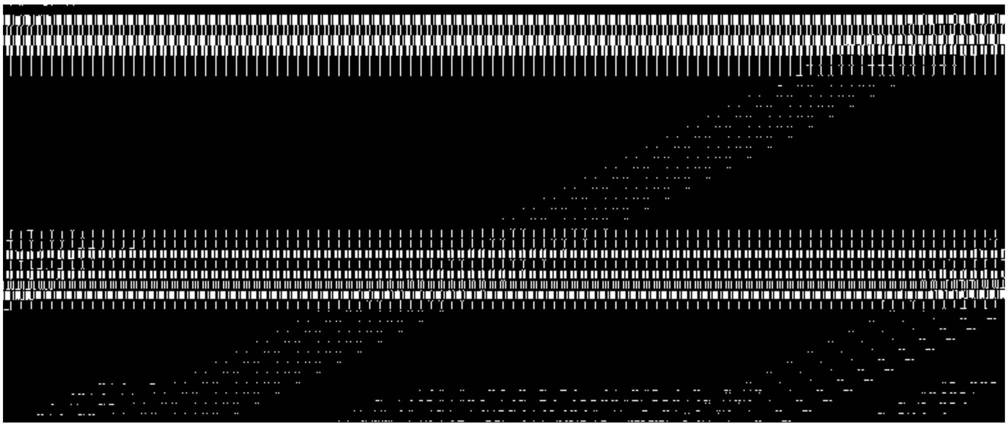
"))$ O)2A) ,#)+)J"))- ,) L)\
3 " E) R))' OP)) " ")J" 9 _qY
)' T ')) 1) _3 1)$. X 6) " 4 L7
V_S = 5 m/s H/D =0/50 h))$ " "E) > ;S"
. **)** 6**)** N **)**# 3 **)**A " **)**8 **)**' " **)**# 3 " " "



.UV11 6 " ?" $: ' 3 ' R #<(2) &'$



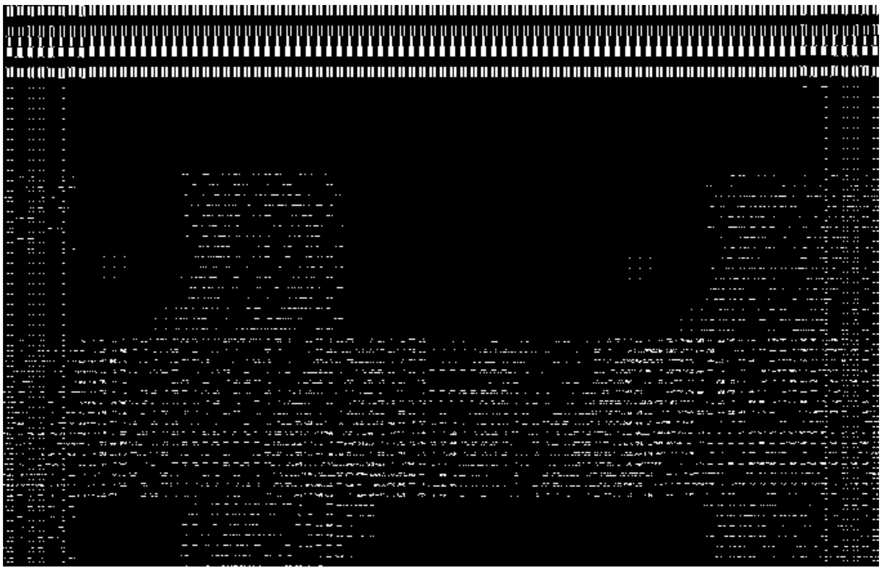
.(V_S = 5 m/s H/D =0/50) ? L7 " ! $ E > ;S".(3) &'$



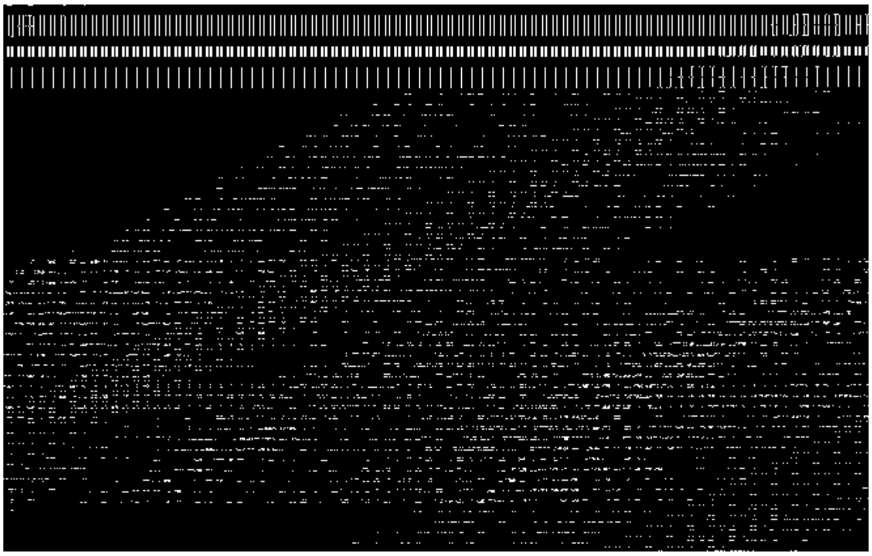
(6< Y,& " 6 ' L7 ") " $: ' L7 ' " 9 G'6' O \ ,A 1 + B•̲ ? S(4) &'$
.(V$_S$ = 5 m/s H/D =0/50) " $,- . ? 6$ † $ E 3Z u "

" $: ' L7 ' " 9 O \ ,A 1 + B•̲ ? S
>);S'") ")$,- . ? 6$ † $ E u "
" (V$_S$ = 5 m/s , A **)** H/D =0/50 3" **)** Y t
:) . " " 9))ƒ̲:27 ., ! $! N # 4 1 $
" 9) ,) ., , ‡' 1' J1 $ " M " $ O2A
,) ? 6)$, ! B , ;/SO2A,#+J " - 6#-
., E :

!) U) BV3) ,A) 3 ' " P a
)A O+). ' ,; < O \ 3? E , 2 O \
A O)+. ' O \ K - , ! $ K GS
! R 9 5 - 6 3 1 $ ")k) " 6[" ?3 '
., ! $



. A O+. ' UV11 6 " ?" $ 3 ' 3? E , 2 O \ :(5) &'$



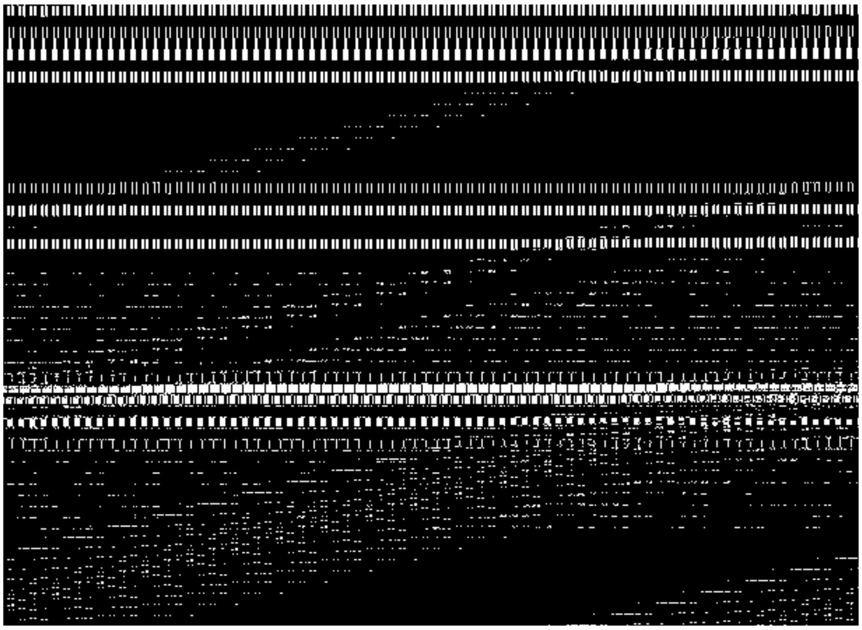
. A O+. ' UV11 6 " ?" $ 3 ' ,; < O \ :(6) &'$

KB)X)k " ;<= K q J 1. - , L\ . $
*) , 2) EM;< 2 R " , ' , M<:<l+
3)A 1).) ?)- , (6- 78 , 2 '
?)< ")A ? 6G')S,) W- B)) G
" g).) ' . B+ E" Qa' K † &A? $ ' 6
3? E , 2 :P a F P a ^ " K
)- ,) !)' ? L7))u 6) " ?" $
) 6 R 9 1)8 . n) B B+))A ? 6G)' S
,) 2 :);<= P) a 3)') S6) ^ " K -
. $ 'g PJ1' J O 3" M3? E
6) " ?h)I S !)$) < $E) 3)5< "
)' n)BK)'3 + 2 3 " # K o# UV11
6) 5 ")$)' T)' n)B < 2K " ! ,
!)$])PBJ[10] • ? 6 5 " $ ' T ' n B)
)AO+). ' 3? E , 2 " # 1 $ - (.,
B ")O+. ' "! $ < $E > ;S'3 " #

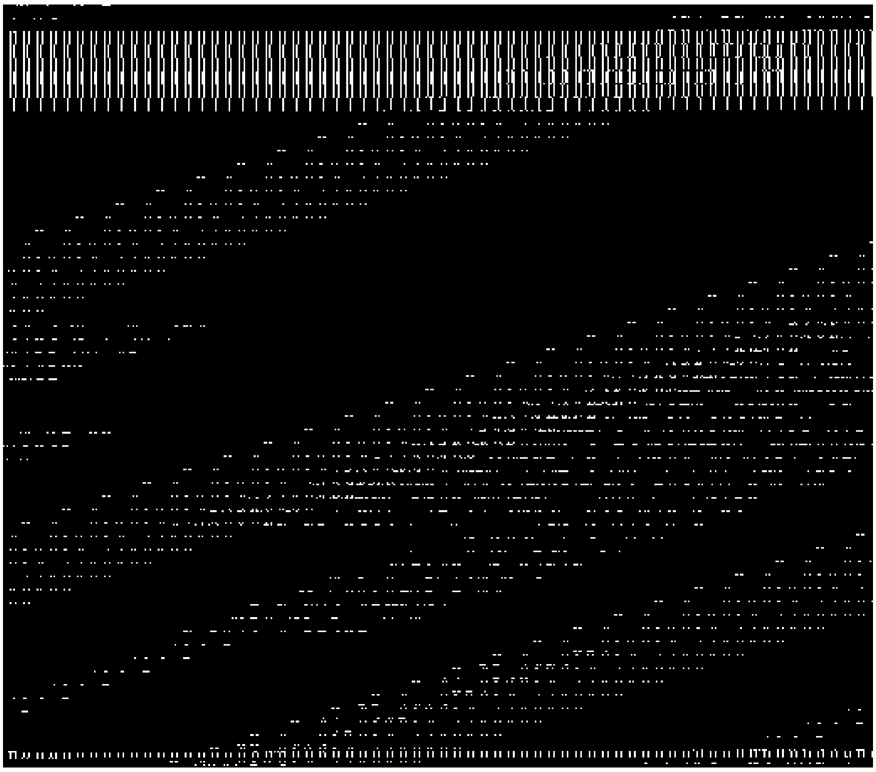
)GR ' B " O+. ' " 9 O \ " # $\frac{x}{C}$ GR '

. - 6 ! 9 U BV A" " $ ' 6 $\frac{x}{L}$

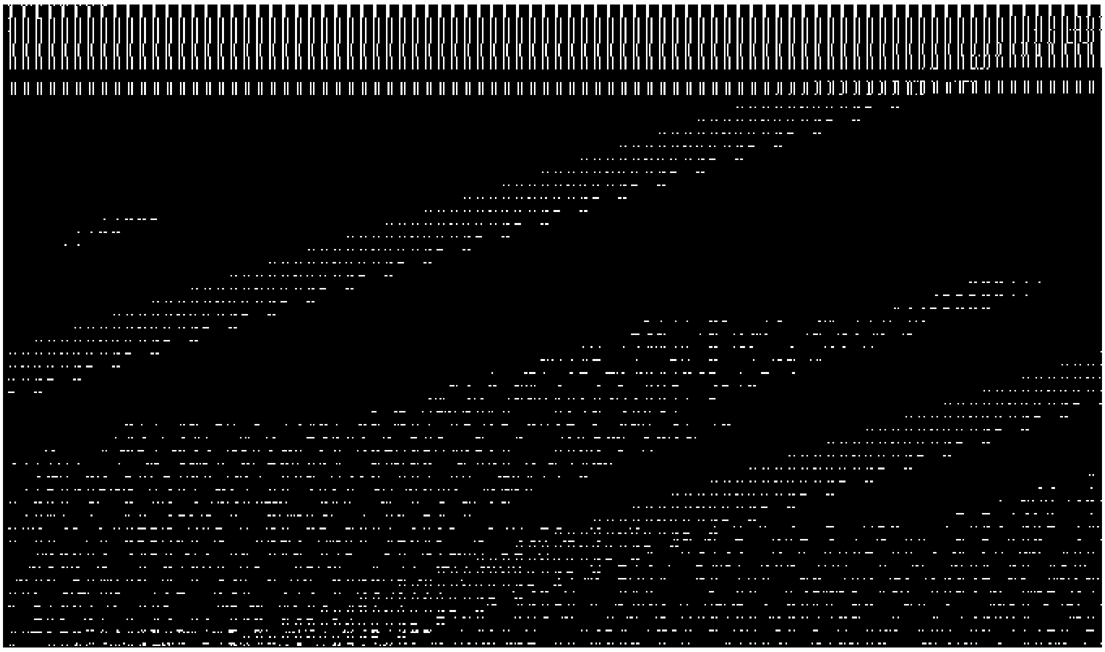
$D/L_S = 0.203$)))')))P)))a)) h)))))$
, ;))<O \ ., B X" 8 M $H/L_S = 0.16$
)-))Q"))2) ˆ)-). $F_n = 0.35$))A"
?)G' , " " $ ' 6 $C_L = 2.6 \times 10^{-4}$)')'
,))b - " +)',; < O \ u.' 6 N - R
,))) 2 ")))# " ., +))) ,)))I # M[ )))R))) b
" 6X) ' K)<I)- " 6X ' 3? E
))A " 6X)))) ' K I $F_n = 0.3$ A
3?))) E , 2 O))\ ., ! B , ;/S $F_n = 0.45$
,) " " Q " 2 @# M- $F_n = 0.46$)A "
6J)', 2 O \ 7 1 $. ' 6 N - R ? W_
6) 3?) E) , 2 ' * , 2 1 $ - !
))))))A" 3")))Y t q))#AO+)).)))' "))$ '
? B9)) 'q))#A")-) 6) N)# $F_n = 0.40$
,) M b)3?) E) , 2 O \ " 2 20[m]
) ' *) ? 6G')$- " ' * , 2 h2
* + 6 " ?3 ' O \ K ., ,A ? 12B+
1)ˆ ,)b * + 3 ' 1' 2 " , b - 6 Q t
R)S6)# \ . ^ " ?! ;B '., ‰"M" +'! Š
!)$ 6G))BP.<# P a " ' * , 2 " 2
! ;B) , 2 K :P a 3 ' 6' S h' " ? - ,



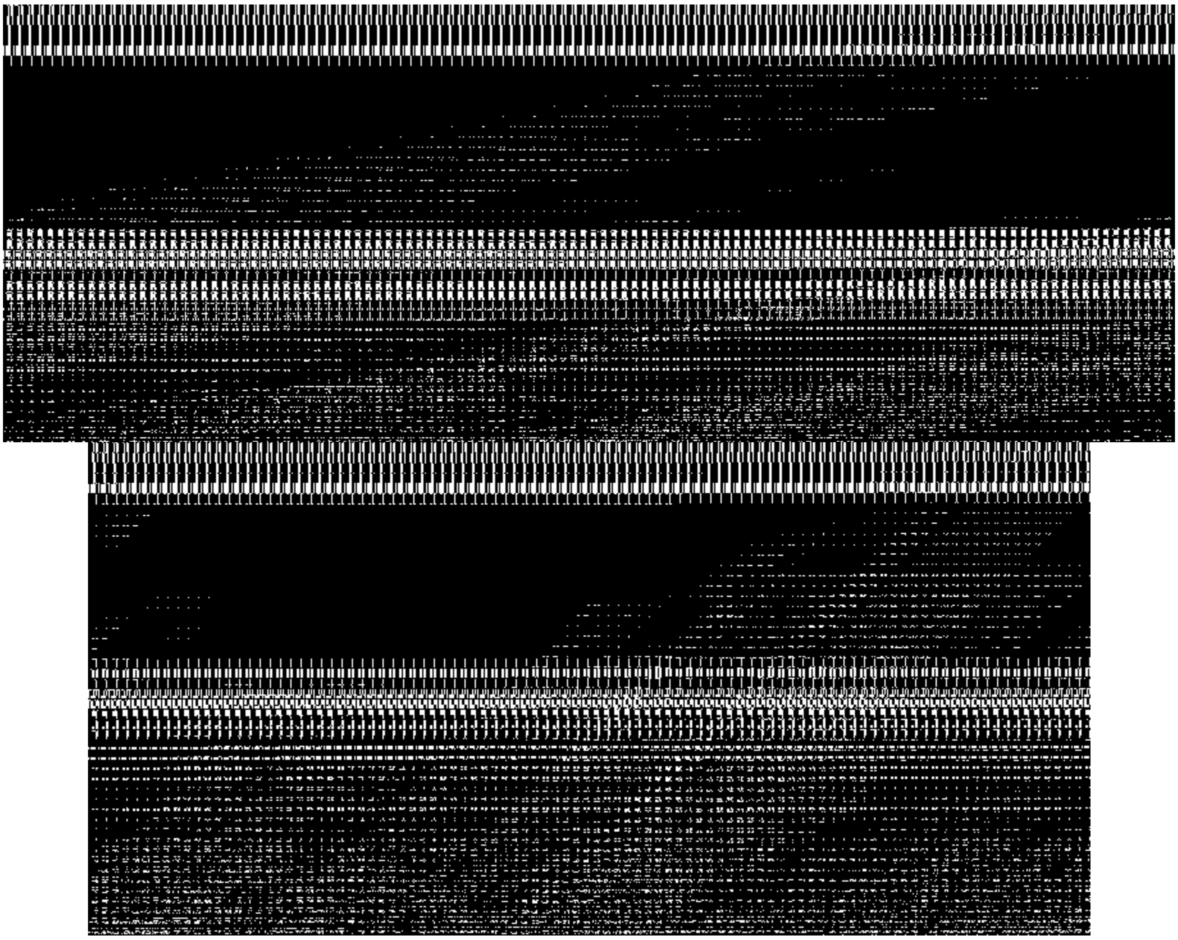
.$F_n = 0.40$ A " 3" Y t q#AO+. ' ! 6J ', 2 O \ :(7) &'$



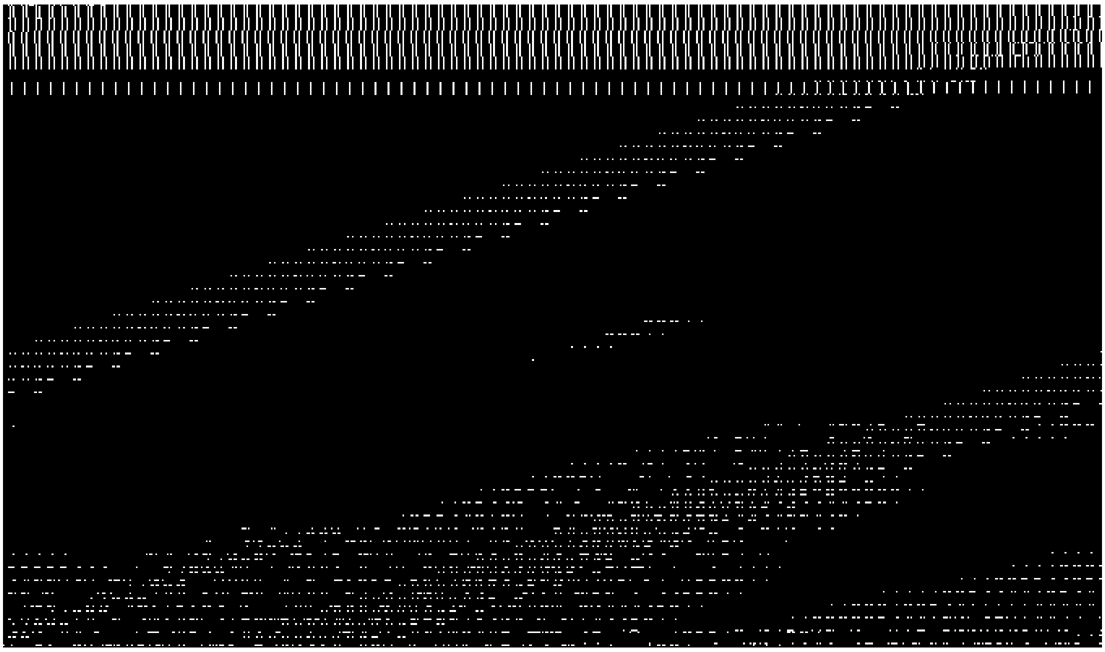
6 5 " $3 '6 59 ?n B < 2K " ! , 'n BK '3? E , 2 2 :+ 2 :(8) &'$
.[10] • ?! $ B X '



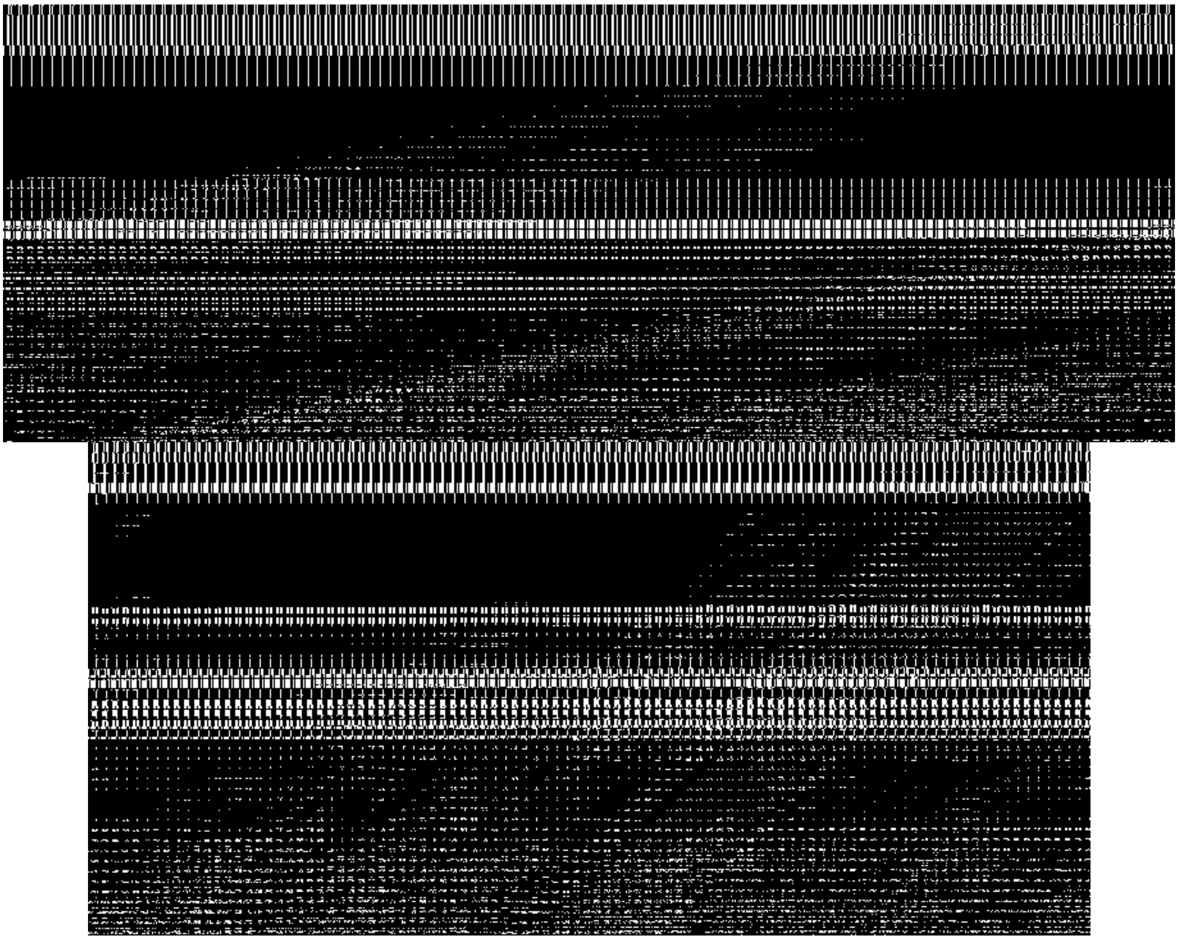
.Fn = 0.24 A " UV11 6 " ?hI S! $ < SE 3 5<:(9) &'$



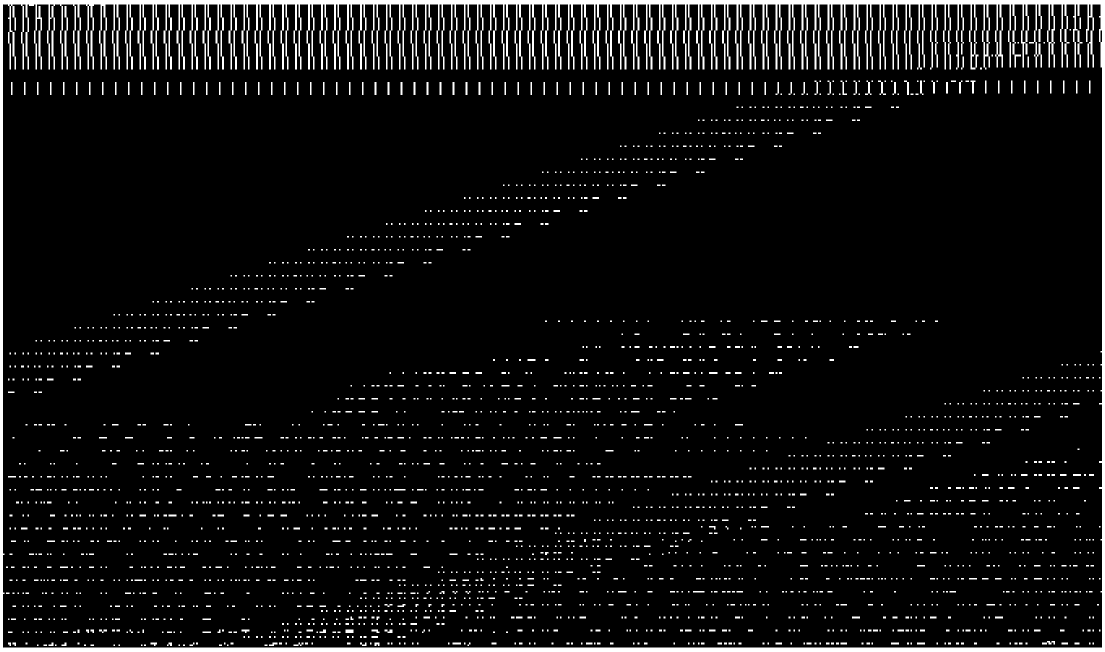
.Fn = 0.24 A " 6 5 " $n B ! , 'n BK '" 9 O \ E > ;S":+ 2 :(10) &'$



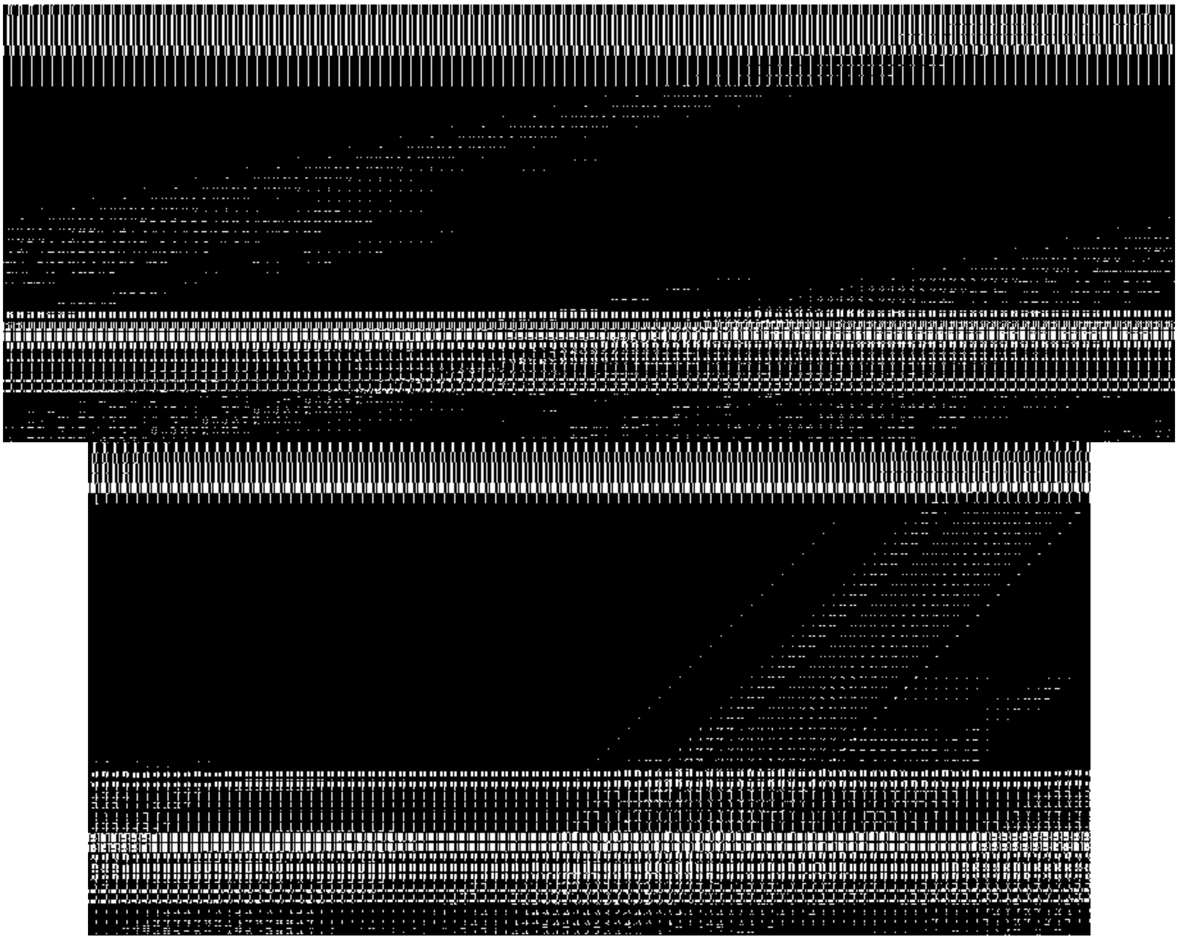
.Fn = 0.26 A " UV11 6 " ?hI S! $ < SE 3 5<:(11) &'$



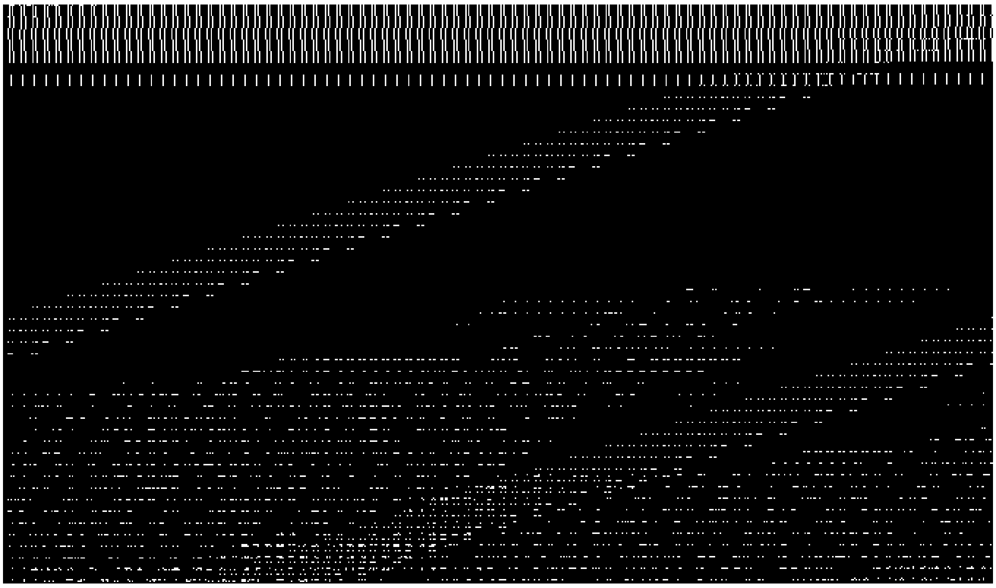
.Fn = 0.26 A " 6 5 " $n B ! , 'n BK '" 9 O \ E > ;S".+ 2 :(12) &'$



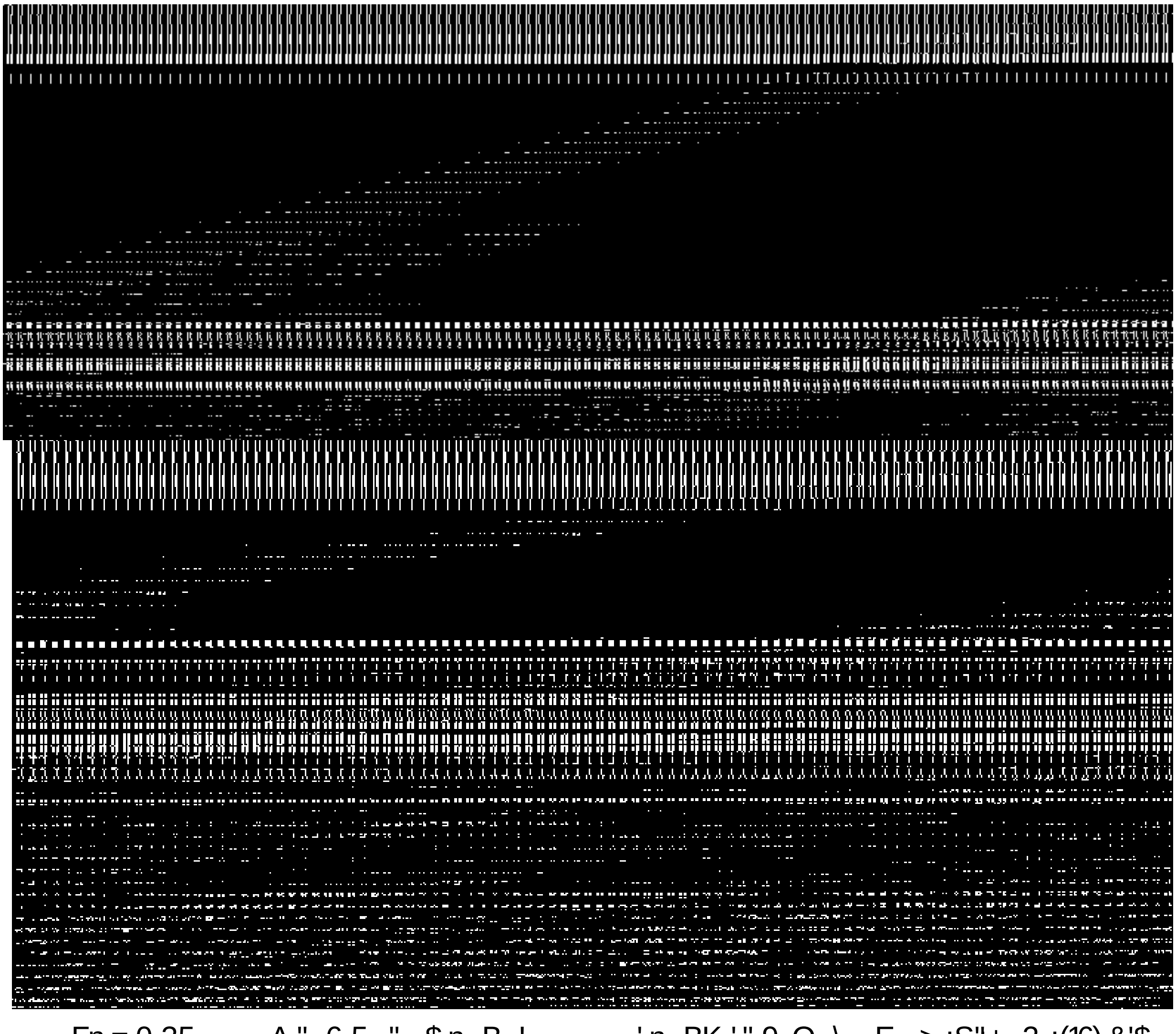
.Fn = 0.32 A " UV11 6 " ?hI S! $ < SE 3 5<:(13) &'$



.Fn = 0.32 A " 6 5 " $n B ! , 'n BK '" 9 O \ E > ;S".+ 2 :(14) &'$



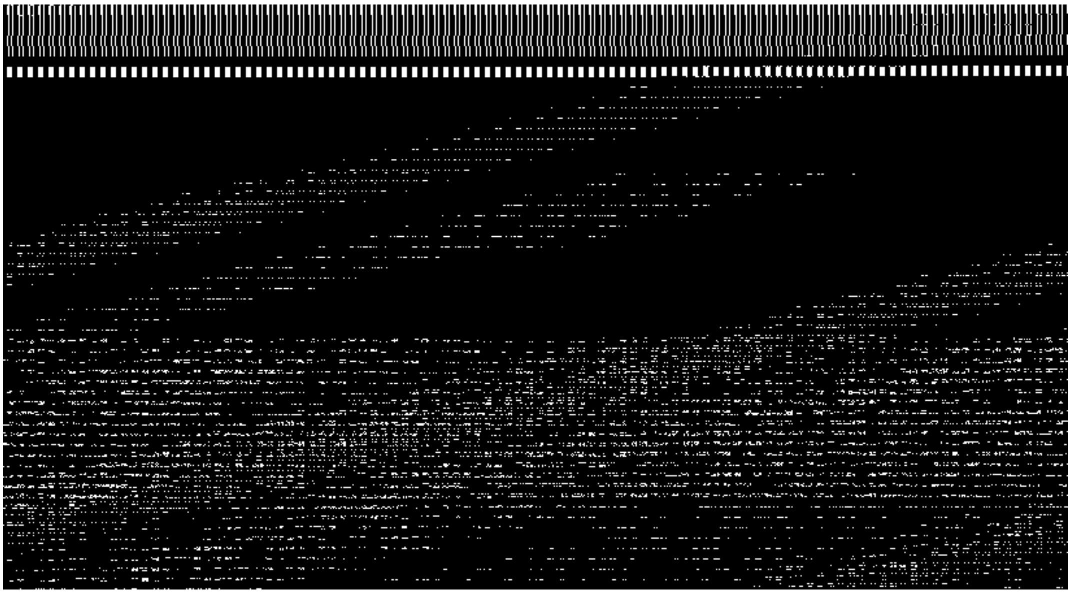
Fn = 0.35 A " UV11 6 " ?hI S! $ < SE 3 5<:(15) &'$



.Fn = 0.35 A " 6 5 " $n B ! , 'n BK '" 9 O \ E > ;S".+ 2 :(16) &'$

K) .) !))$))B X [5])'0))B)-ƒ P) a g PJ1' J - , !)$ Œ/V9 17 1 $ ")+ 2 . $ ' 6 NV' , \"

))' T))' n B3 ' ")<)2 K) " 6S P)a n B 1))$ n)BK)) .@ !)- + 2) M R X6 ')A " , ;))<3) 3?)) E ,) 2 O \ ? R)X6) ')' T ')) n B. $ ' 6 U BV



. [10] • 0R 6X ' n B \ . ^ " K ' , ; < 3? E O \ :+ 2 :(17) &'$

")Q ' U) BV3) ,A) ")- , K 5 ' ")$ O)2A,#+J t) " ! $ < SE 1Q S 3) ,A)) "))S6 ^ " K X 6 " 8 O) 3) 6 59) _U BV)A U B)V - [" "6< P1)' J 3?) E) ,) 2 :P a 3 ' & S\ . ^ " - 3 g I) 3)' 3? : KB Xk " ' , ! $! ;B ^ " 3?) R)#<^ " ? 6)P - S)Y ' R S6 EM<) 6- 7))8 ,) 2))- ! ;B)) 3?) :)) 3")cS . " , ' " k " n B # 1 aS"? +

0A K0785

")8)' ? L7) 3? +)< K)X•' S?! ;B !)$)B X' - ' <)2 K " - ,) 6$ " 67/Q ,)/J 3 " ^ " K) !) ,) ' n BqPY., , 2 3 R " , ' R - g 3 ' 6P . " 6)' ,) ' J !)$) E > ;S" 3? E n)B6)' S n)B ' ! , ' n B:+ 2 ? 6 G . # 6 [" 6< P1)' J :P) a 6) " ' 3)' 3? R #<^ " g . ' g #))AUV11 6[" ?" $ 3 ' 3? E , 2 T P B) 1)' J3) ; n)B P a K ?., ! $: $ 6 !")$ M &) ' " " 3)- , R)X6) ' " $ 3 ' 3? E , 2 :+ 2 - 1 6[' " +',I ' J? 3? R #<^ " - 6 R 9 , " " Q "' k K 3 ' ")$,A) N M))' !)$) < SE) > ;S"- 2 !) , ' n B" - " @ 2B∓ PS6 " ? 5 1)$.,) !)- R # " Q 6' Q ' > \ K

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1. Gadd, G.E., "A Method of Computing the Flow and Surface Wave Pattern Around Full Forms", The Royal Institute of Naval Architects (RINA), 1975.
2. Dawson, C.W., "A Practical Computer Method For Solving Ship – Wave Problems", The 2nd Int. Conf. on Num. Ship Hydr., Berkeley, CA, 1977.
3. Nakos, D.E. and Scvlavonos, P.D., "Kelvin Wake and Wave Resistance of Cruiser and Transom

11. Hong, S. and Choi, H., " Steady and Unsteady Ship Wave by a Higher Order Boundary Element Method", The 19th Symp. of Naval Hydrodynamics, 1996.
12. Ghassemi, H., "Hydrodynamic Simulation of the Ellipsoid in Steady Flow Condition", PRADS, The Netherland, 1998.
13. Ghassemi, H., Kohansal, A.R., and Ghamari, I., " Non-linear Free Surface Flows Due to the Lifting and Non-lifting Moving Bodies", ISME, Tehran, 2009.
14. Wehausen, J.V., "The Wave Resistance of Ship", Advances in Applied Mechanics, Vol. 13, pp. 93-245, Tokyo, Japan 1973.
15. Larsson, L. and Baba, E., "Ship Resistance and Flow Computation ", Advances in Marine Hydrodynamics, Ed. M. Ohkusu, Computational Mechanics Puplications, Chap. 1, pp 1 – 75, 1996.
16. Janson, C.E., "A Method for the Prediction of Wave Resistance, Lift and Induced Drag", Ph.D. Disseration, Naval Architecture and Ocean Engineering Dep't., Chalmers Univ. of Tecnology, Gotehenburg, Sweden, 1993.
17. Susuki, K. and Kai, H. "Fundamental Investigation on Wave Making Interaction around Multi-Hull Vesse", The 6th Int. Conf. on Hydrodynamics, Australia, 2004.

Ship", J. Ship Research, Vol. 38, No. 1, pp. 9 – 29, 1994.
4. Park, K., Suzuki, K., and Ikehata, M., "Application of Panel Method to Second Order Theory of Free Surface Flow Around Ships " The 5th Symp. on Non-linear and Free Surface Flows, Hiroshima, 1997.
5. Doctors, J. and Beck, R., "Numerical Aspects of the Neumann–Kelvin Problem", J. Ship Research, Vol. 31, No. 1, pp. 1-13, 1987.
6. Proceeding of the Workshop on Wave Resistance Comp., Vol. 1, Bethesda, Maryland, USA, 1979.
7. Tsutsumi, T., "Calculation of the Wave Resistance of Ship by the Numerical Solution of Eumann–Kelvin Problem", The Workshop on Ship, Vol. 2, Bethesda, Maryland, USA, 1979.
8. Liu, H. and Kodama, Y., "Computation of Wave Generated by a Ship, Using a N-S Solver with Global Conservation", J. Society of Naval Architects of Japan, Vol. 173, No. 2, 1993.
9. Abbaspour, M. and Kasaeyan, M., "Application of BEM Method to 3-D Submerged Structures with Open End", Interaction and Radiation, OMAE 99/OFT-4242, Newfoundland, Canada, 1999.
10. Nakos, D.E., " Ship Wave Patterns and Motions by a 3-D Rankine Panel Method", Ph.D. Disseration, MIT, Mass.,1990.