Engineering with Computers (2023) 39:791–807
https://doi.org/10.1007/s00366-022-01673-y

ORIGINAL ARTICLE

Strong form meshfree collocation method for frictional contact between a rigid pile and an elastic foundation

Ashkan Almasi[1] · Tae-Yeon Kim[2] · Jeong-Hoon Song[1]

Received: 4 March 2022 / Accepted: 4 May 2022 / Published online: 30 May 2022

Abstract

I . I T . T . C . T . T

Keywords S 1M 1P 1F 1S

1 Introduction

T . C . H , . A (FEM), (BEM). F / H . 1 S . 2 . B H 3 . P T 4 . W . 5 T 6 9 . T

$\epsilon_T > 0$ μ . U E :

A / C . F ,
C :

1. T
$\mathbf{u}_T = (\mathbf{1} - \square \otimes \square)\mathbf{u}$ Γ_c. N _
t_N $t_N = \epsilon_N \langle g \rangle$
E . (9).
2.

. I . T . A . T ,

B , **a**($\bar{\mathbf{x}}$) , L^2-

M **B**

$\mathbf{p}_m(\mathbf{x}_I;\bar{\mathbf{x}})$ E . (20). I E . (25), **x** $\bar{\mathbf{x}}$ **a**(**x**) , $\square^{\alpha}_{\square} u(\square)$

$\boldsymbol{\alpha}$ α_1, α_2) 2- . I , E . (28)

$\boldsymbol{\alpha}_i$ ' 2- , . . ., $\boldsymbol{\alpha}_1$ 0, 0),

$$\mu \mathbf{n} \cdot \boldsymbol{\epsilon} + \lambda \mathbf{n} \cdot \mathbf{1}(\mathrm{div}\mathbf{u}) = \bar{\mathbf{t}} \quad \text{on } \Gamma_t \tag{36}$$

, C , – , – –

$$\mu(u_{i,j} + u_{j,i})n_j + \lambda \delta_{ij} n_j (u_{k,k}) = \bar{t}_i \quad \text{on } \Gamma_t \tag{37}$$

δ_{ij} , K . F E . (37) PDM, E . (28) , E . (37)

$$\begin{aligned}
&\sum_{J=1}^{N} \{ (\lambda + 2\mu)\, \phi_{IJ}^{1,0} n_1 + \mu \phi_{IJ}^{0,1} n_2 \}\, u_{1I} + \{ \lambda \phi_{IJ}^{0,1} n_1 \\
&\quad + \mu \phi_{IJ}^{1,0} n_2 \}\, u_{2I} \} - t_1(\mathbf{x}_I) = 0, \\
&\sum_{J=1}^{N} \{ \mu \phi_{IJ}^{0,1} n_1 + \lambda \phi_{IJ}^{1,0} n_2 \}\, u_{1I} + \{ (\lambda + 2\mu)\, \phi_{IJ}^{0,1} n_2 \\
&\quad + \mu \phi_{IJ}^{1,0} n_1 \}\, u_{2I} \} - t_2(\mathbf{x}_I) = 0
\end{aligned} \tag{38}$$

$\mathbf{x}_J \in Y_c$. F – ,

F E . (44) PDM, E . (28) , E . (44)

$\mathbf{x}_J \in Y_c$.
T , – – – –

R – , **u**. A N R – , E . (46) – , j

$\frac{\partial \mathbf{R}}{\partial \mathbf{u}}$, – ,

$j + 1$ j N R – n,
C , – .

n. C

T $= 10^{-12}$. F

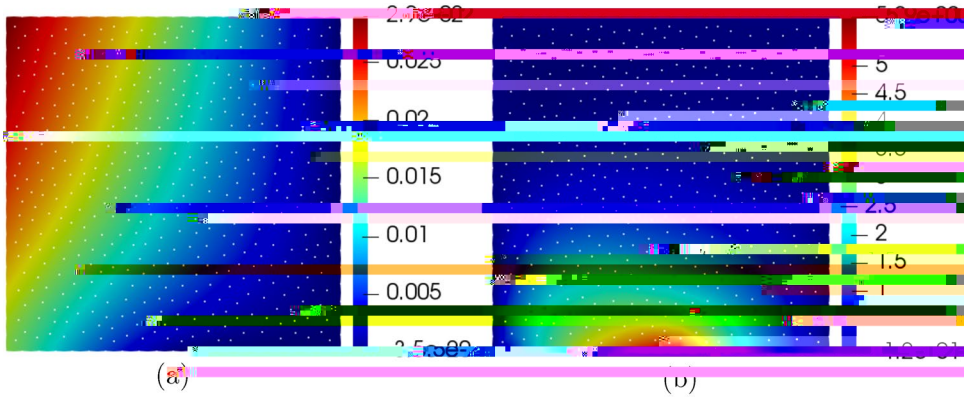
D N R

$j + 1$,

:

1. C

Fig. 4 D a u_{xx} b σ_{xy}



$\epsilon_N = \epsilon_T = 10^5$. N , , F . 2 I F . 3, 558 . T Γ_c D u_{xx} σ_{xy} F . 4. A , , . T F . 11 R F 44 . T (COL) FEM ABAQUS F . 5. N . H F . 5 / . Q

F 6 . T ,

4.3 Hertzian contact problem

H FEM

4.4 Frictional contact between a rigid pile and an elastic foundation

Fig. 19 C
a u_{xx} b u_{yy}

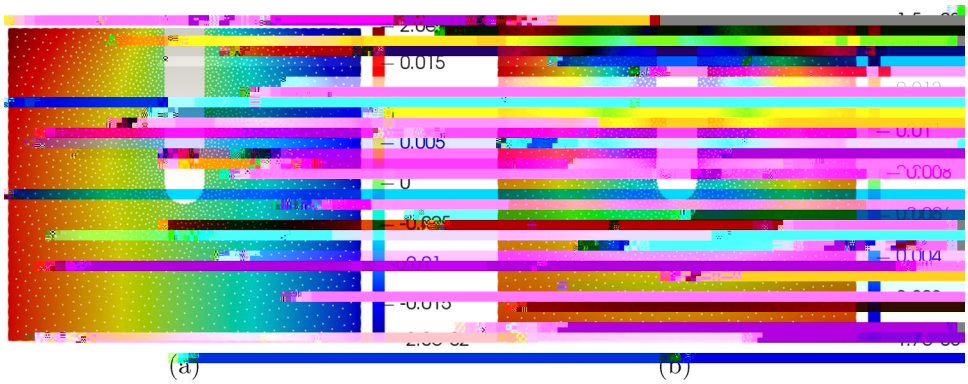
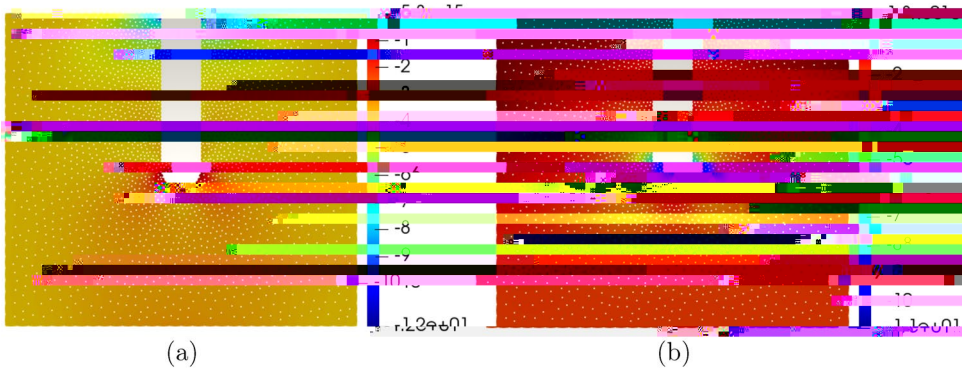


Fig. 20 C
a σ_{xx} b σ_{yy}



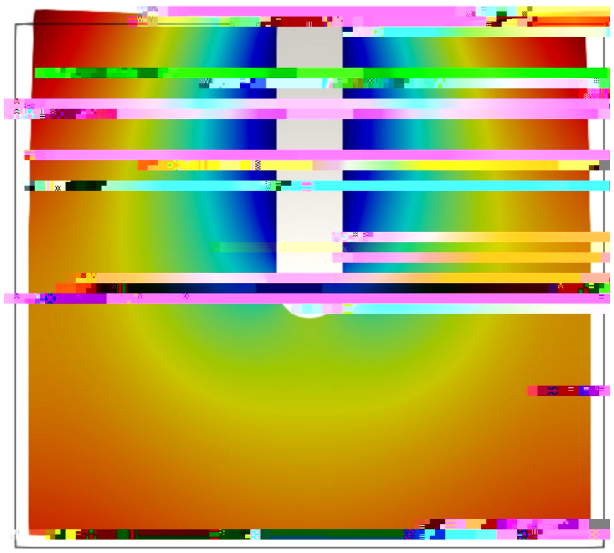


Fig. 21 C
15)

5 Conclusion

I
. T

T
. A N R
. T
F
; . D
T
T
T
. R FEM
2D . T
T 2D
M E t_x
F

T . . . . . , K^c _ , . . . _ _ .

. . . $K^N_{I1J1}, K^N_{I2J1}, K^N_{I1J2}$ K^N_{I2J2} _ . . . E . (56). T . . . . . , . . . _ , K^{stick} E . (57) . . _

T . . . . . , $\mathbf{f}^c_{stick}$ . . . , _ .

T . . . . . , K^c _ , . . . _ _ .

T . . . . . , . . . _ , K^{slip} E . (59) . . _

T . . . . . , $\mathbf{f}^c_{\text{slip}}$

26. L S, L WK (1999) R . I J N M E 45(3):251 288
27. L S, L WK (1999) R . I J N M E 45(3):289 317
28. K DW, K (2003) P . I J N M E 56(10):1445 1464
29. L S-H, K K-H, -C (2016) P . I J I E 87:132 145
30. F , M JG, S J-H (2017) B . J C S 20:187 197
31. S J-H, F , K T- , -C, M JG, R - T (2018) P . I J M M D 14, 491 509. :// /10.1007/ 10999-017-9386-1
32. A A, B A, K T- , M JG, S J-H (2019) S . J E M 145(10):04019082
33. -C, S P, R T, S J-H (2019) N . E A B E 98:310 327
34. B A, K T- , L W, S J-H (2019) S . C , M A M E 351:404 421
35. C J-S, W H-P (2000) N . C , M A M E 187(3 4):441 468
36. L G, B T (2001) E G . E C 18(1/2):62 78
37. J, G B, G J J , K E (2005) M 2
38. E A B E 29(2):95 106
38. D L L, E J, H TJ, R A (2015) I : N . C M A M E 284:21 54
39. K R, N
38.