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, , . 3D WNAD TI . ,2012,55(2):547-559,doi:10.6038/j.issn.0001-5733.2012.02.017.

Song G J, Yang D H, Tong P, et al. Parallel WNAD algorithm for solving 3D elastic equation and its wavefield simulations in TI media. *Chinese J. Geophys.* (in Chinese), 2012, 55(2):547-559, doi:10.6038/j.issn.0001-5733.2012.02.017.

3D WNAD TI

[1,3], [1*], [1], [2]

1 , 100084

2 Department of Mechanical Engineering, University of Louisville, Louisville, KY 40217, USA

3 , 100084

TTI 、AVO . (WNAD) , WNAD (TI) 、 . WNAD , —— (SG) . , WNAD . , WNAD TTI , TI : 、 . TTI , 、 , , .

, , TTI , ,

doi:10.

scale seismic wavefield by using the high-performance computers. Using the parallel WNAD algorithm, we study the elastic wave propagation in the TTI media and observe the important feature of TI media: shear-wave splitting, the quasi body wave coupling and velocity anisotropy. The reflected, refracted, and converted waves are generated at the interfaces. This makes the wavefield complex. To better understand the anisotropic media induced by fracture

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NAD ,

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, , , TI :

, (1) (VTI) ,

. , ;(2)

, (HTI)

" A" ;(3)

[20].

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. 1995

, Olsen [21] 512 CPU

$576 \times 352 \times 116$;

Bohlen[22] MPI

(4 , 2) ,

. Komatitsh [23]

. [24]

, Tape [25]

, 80 CPU

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, ,

WNAD [17,19]

、 (TI) .

2 TI WMAD

2.1 TI

$$\rho \ddot{u}_i = \frac{1}{2}(c_{ijkl}(u_{k,l} + u_{l,k}))_{,j} + f_i \quad i,j,k,l = 1,2,3, \quad (1)$$

$C = \{c_{ijkl}(x,y,z)\}$, ρ

, u_i i , f_i

" · "

, " $_{,j}$ " x_j .

21 [26],

.

, $\theta = 0, \phi = \pi/2$, TTI

VTI ; $\theta = \pi/2, \phi = \pi/2$, TTI

HTI ,

$$= \begin{pmatrix} C_{33} & C_{13} & C_{13} & 0 & 0 & 0 \\ C_{13} & C_{11} & C_{12} & 0 & 0 & 0 \\ C_{13} & C_{12} & C_{11} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{66} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{44} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{44} \end{pmatrix}.$$

2.2 WNAD

, $= \{u_1, u_2, u_3, u_{1,1}, u_{1,2}, u_{1,3}, u_{2,1}, u_{2,2}, u_{2,3}, u_{3,1}, u_{3,2}, u_{3,3}\}^{T}$

, $= \dot{} =$ $\partial \ /\partial t$ " ", $= \dot{} = \ = \partial^2 \ /\partial t^2$ " ".

Yang [16] , 4 Taylor , n 、 $n+1$

$$W_{i,j,k}^{n+1} = W_{i,j,k}^{n} + \Delta t(\dot{W})_{i,j}^{n}$$

y , $p = p_1 \times p_2$

, $\frac{N_1 N_2 N_3}{p_1 p_2}$. t_{grid}, $_1/T$ CPU

, $\frac{N_1 N_2 N_3}{p_1 p_2} t_{grid}$; ,

.

= . $m+1$, x

m .

yz ($\frac{N_2}{p_2} N_3$

( )).

t_{settle}, ( )

t_{com}, x $m(t_{settle} + \frac{N_2}{p_2} N_3 t_{com})$. , y

$m\left(t_{settle} + \frac{N_1}{p_1} N_3 t_{com}\right)$.

( )

$$T_{com} = m\left(t_{settle} + \frac{N_2}{p_2} N_3 t_{com}\right) + m\left(t_{settle} + \frac{N_1}{p_1} N_3 t_{com}\right). \tag{7}$$

,

,

T_{com}. (7) , ,

x y ,

, ,

$4m$ (: ,

,

).

, =

+ ,

$$T_p = \frac{N_1 N_2 N_3}{p_1 p_2} t_{grid} + T_{com}.$$

, 0,

$$T_1 = N_1 N_2 N_3 t_{grid}.$$

$$\frac{T_1}{T_p} = \frac{N_1 N_2 N_3 t_{grid}}{\frac{N_1 N_2 N_3}{p_1 p_2} t_{grid} + T_{com}} = \frac{1}{\frac{1}{p_1 p_2} + \frac{m}{t_{grid}}\left[\frac{2}{N_1 N_2 N_3} t_{settle} + \left(\frac{1}{p_2 N_1} + \frac{1}{p_1 N_2}\right) t_{com}\right]}. \tag{8}$$

(8) , T_1/T_p

:

(1) (t_{settle}, t_{com}).

, 、

, . , $t_{settle}/t_{grid} =$ 0, $t_{com}/$

T_1/T p p ;

(2) (N). ,

,

.

3) . $p_1 p_2$

p_1 p p_1 p_2 $_1$ $_2$ p_1 $_1 =$ p $_2$

T_1/T

4) ($m+1$).

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( ), E

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, “ ” ;

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, .

[17 18, 27]

3

x y

, Fortran .

4

, 5 :

、 VTI , TI

WNAD . ,

TI .

, xoy 1/2

, xoy ; xoz y

1/2 , xoz ; yoz

x 1/2 , yoz

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4.1 1

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4 WNAD

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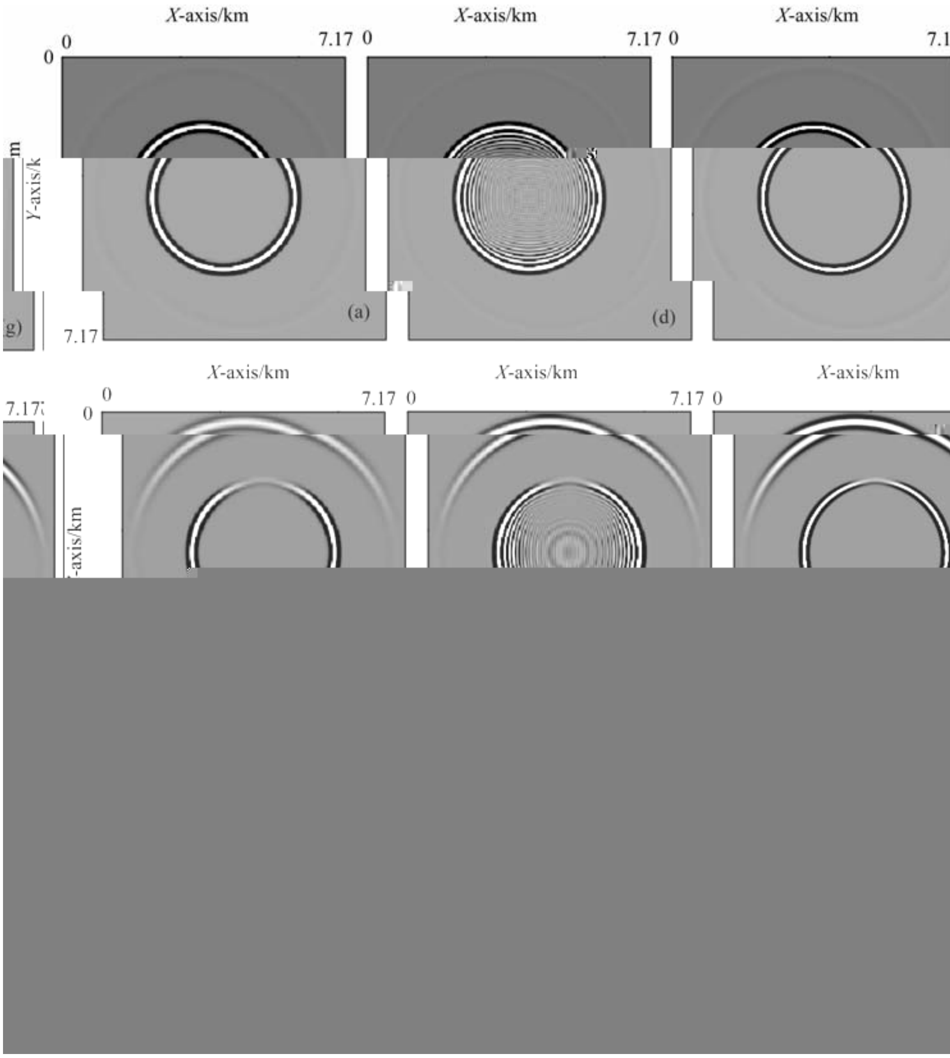
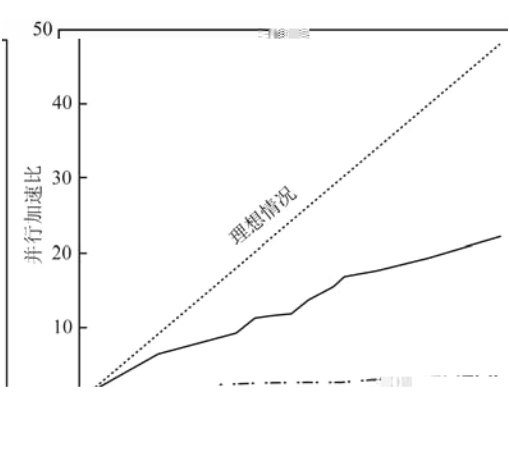


1 u_3 xoy, xoz yoz $T=0.66$ s
(a,b,c) WNAD u_3 ; (d, e, f) u_3 ; (g, h, i) u_3 .

Fig. 1 The wave-field snapshots of displacement component u_3 on the xoy-, xoz and yoz-plane at $T=0.66$ s
(a,b,c) The wavefield snapshots of u_3 with coarse grid by using the WNAD algorithm; (d,e,f) The wavefield snapshots of u_3 with coarse grid by using the staggered grid method; (g, h, i) The wavefield snapshots of u_3 with refined grid by using the staggered grid method.



2 WNAD ( ) ( )

Fig. 2 The speedup of WNAD algorithm (solid line) and staggered grid (dot dash line) method

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, ,
p , ,
. 2
($p=16$) , $p=1$.)

4.2 2 VTI

,
VTI
, VTI 、
.
2 $0\leqslant x,y,z\leqslant 7.98$ km,
: $C_{11}=$ 11

1

. $\Delta x=\Delta y=\Delta z=20$ m, $\Delta t=1$ ms.

3 $T=1.45$ s

. 3 , xoy ,

: P S

.

VTI , xoy .

xoz yoz ,

: P (qP) S (qS)

, ,

(Cusp).

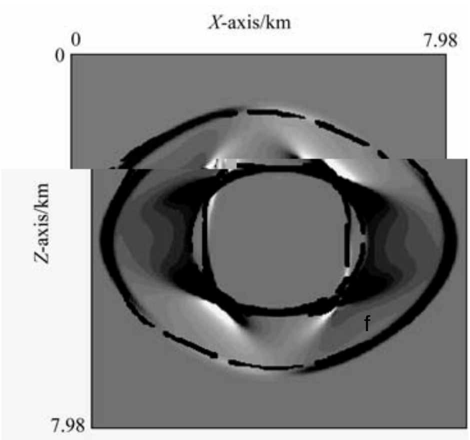
tc´ a

.

5 3 . $0\leqslant x,y,z\leqslant 11.98$ km, VTI ($z\leqslant 6.58$ km), TTI ($z>6.58$ km).

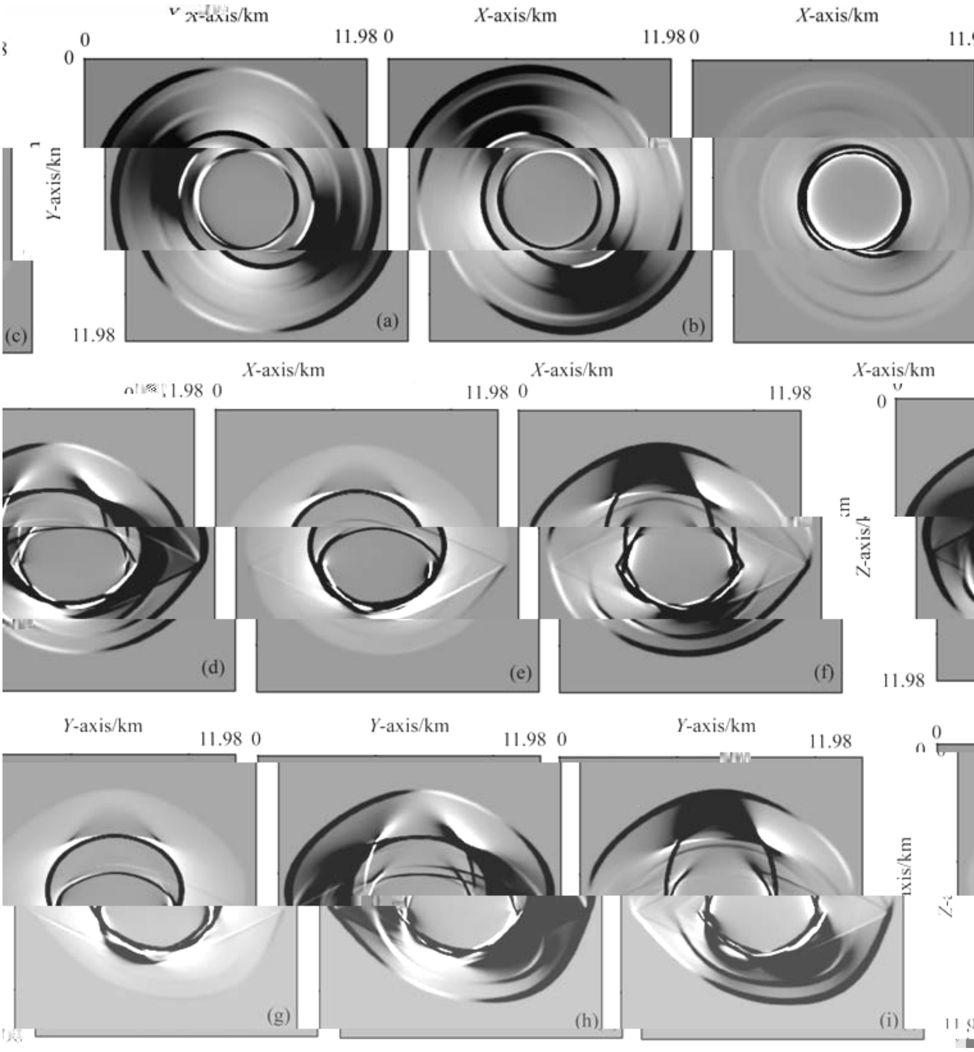
, :$C_{11}=25.2$ GPa, $C_{33}=15.0$ GPa, $C_{13}=6.11$ GPa, $C_{44}=4.38$ GPa, $C_{66}=6.57$ GPa; $\rho=2.1$ g/cm^3.

, , $\theta=\pi/4$, $\phi=\pi/6$. (5.98 km, 5.98 km, 5.78 km),



4 u_2 *yoz*

h



6 3 u_1、u_2、u_3 (T=1.62 s)

(a, b, c) xoy ;(d, e, f) xoz ;(g, h, i) yoz .

Fig. 6 The wavefield snapshots of displacement component u_1, u_2 and u_3 in two-layer model 3 (T=1.62 s)

(a, b, c) In xoy-plane; (d, e, f) In xoz-plane; (g, h, i) In yoz-plane.

, , 8 . xoz , qP x z , qP , qP u_2 ; qS qS , qS qS . yoz , x , , HTI , HTI : qP z , y , qP u_1 ; qS z ; .

4.5 5

, , . 5 (8) WNAD . 8 , 1 . 1 ,

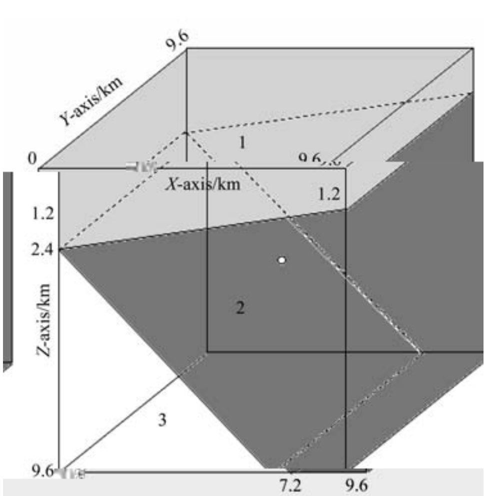
1 5

Table 1 The parameters of model 5

	v_p/(km·s^{-1})	v_s/(km·s^{-1})
1	3.086	1.38
2	5.5	3.0
3	2.7	1.55

7 4 u_1 、u_2 、u_3 (T=1.62 s)
(a, b, c) xoy ;(d, e, f) xoz ;(g, h, i) yoz .

Fig. 7 The wave-field snapshots of displacement component u_1, u_2 and u_3 in the model 4 (T=1.62 s)
(a, b, c) In xoy-plane;(d, e, f) In xoz-plane;(g, h, i) In yoz-plane.

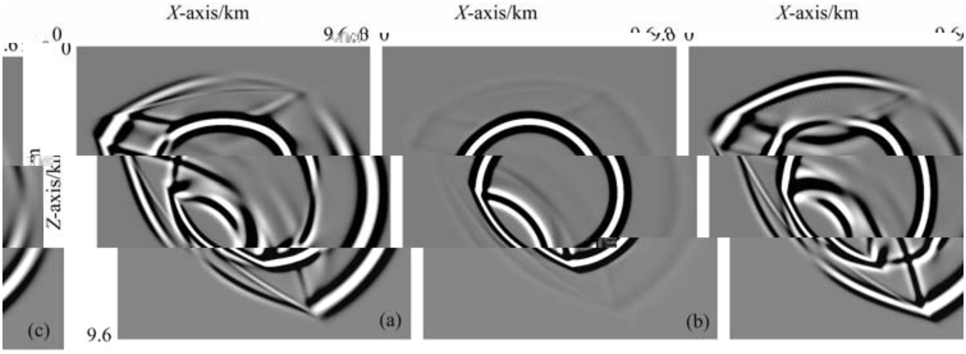


8 (5)

Fig. 8 Three-layer model with tilted discontinue surface (model 5)

2.17. , 1. $\Delta x=\Delta y=\Delta z=20$ m, $\Delta t=1$ ms, WNAD T= 0.9 s xoz 9. 9 、 . , , . WNAD , .

5



9 5 u_1(a)、u_2(b)、u_3(c) xoz

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