(19) Octrooicentrum Nederland

(11) **2021354**

(12) A **OCTROOIAANVRAAG**

(21) Aanvraagnummer: **2021354**

(22) Aanvraag ingediend: **19/07/2018**

(51) Int. Cl.:
G01V 1/30 (2018.01)

(41) Aanvraag ingeschreven:
14/08/2018

(43) Aanvraag gepubliceerd:
15/08/2018

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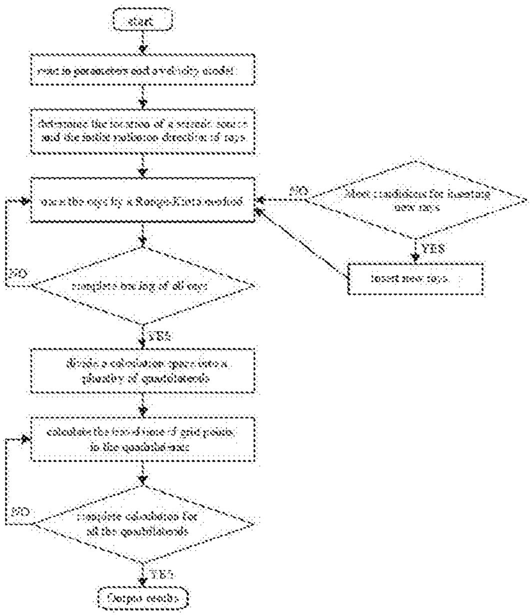
(54) **2-D Seismic Travel Time Calculation Method Based on Virtual Source Wavefront Construction**

(57) The invention discloses a 2-D seismic travel time calculation method based on virtual source wavefront construction. The seismic travel time calculation method comprises the following steps of reading in relevant parameters and a velocity model; tracing rays in different directions from a seismic source by using a Runge-Kutta method, and inserting new rays during ray tracing according to relevant judgement conditions in the ray tracing process; dividing a calculation space into a plurality of wavefront quadrilaterals through discrete points on adjacent rays and adjacent wave front surfaces; finding grid points in the wavefront quadrilaterals; calculating the travel time of the grid point in each of the wavefront quadrilaterals by a virtual source method; and completing the calculation of the travel time of the grid points in all wavefront quadrilaterals. Through adoption of the virtual source method, during calculation of the travel time of the grid points in the wavefront quadrilaterals of the invention, the calculation precision of the travel time of the grid points is improved, and a high-precision seismic travel time calculation method based on wavefront construction is realized.



2-D Seismic Travel Time Calculation Method Based on Virtual Source Wavefront Construction

TECHNICAL FIELD

The invention relates to the field of seismic travel time calculation, in particular to a 2-D seismic travel time calculation method based on wavefront construction.

BACKGROUND

The *Journal of Jilin University* (Earth Science Edition) disclosed, in the 2nd issue of 2008, a paper *Ray-Tracing of Wavefront Construction by Bicubic Convolution Interpolation* published by Han Fuxing et al. The paper introduced an improved seismic travel time calculation method based on wavefront construction, that a bicubic convolution interpolation method was applied to grid point travel time calculation, so as to improve the calculation precision of seismic travel time and the calculation efficiency of the algorithm. Besides, the error analysis on the wavefront construction method based on a bicubic convolution interpolation algorithm was carried out through a homogenous medium, and the analysis results obtained good effects.

The *Chinese Journal of Computational Physics* disclosed, in the 2nd issue of 2008, a paper *Application and Comparison of Different Interpolation Algorithms in Ray-Tracing of Wavefront Construction* published by Han Fuxing et al. In the paper, the application effects of a nearest region interpolation method, a bilinear interpolation method, a piecewise interpolation method and a bicubic convolution interpolation method in ray tracing of wavefront construction were compared and analysed. The model calculation results reflected that the bicubic convolution interpolation method can obtain more accurate ray paths than the other three methods.

The *Progress in Geophysics* disclosed, in the 5th issue of 2009, a paper *Study on Gird Point Positioning and Attribute Evaluation with the Method of Wavefront Construction* published by Han Fuxing et al. The paper introduced how to use a vector product method to judge the relative position relationship of a rectangle grid point and a nonregular wavefront quadrilateral, and provided a corresponding interpolation method for calculating the attribute information of the grid point according to position relationship of the grid point and the nonregular wavefront quadrilateral. The provided method was verified through a homogeneous model and calculation examples, and good calculation results were obtained.

As can be seen from the above examples, conventional 2-D seismic travel time calculation methods based on wavefront construction can improve the calculation precision to a certain extent, but the propagation rule of seismic waves was not considered in the interpolation method, and the calculation precision improved was also limited.

SUMMARY

The invention aims to solve the technical problem of providing a seismic travel time calculation method based on virtual source wavefront construction. In consideration of the propagation rule of seismic waves in a medium, a virtual source calculation method is used to replace a conventional bicubic convolution interpolation method in the process of calculating the travel time of grid points in wavefront quadrilaterals, and the calculation precision and the stability of the seismic travel time calculation method based on wavefront construction are improved.

In order to solve the technical problem, the adopted technical scheme lies in that

a high-precision seismic travel time calculation method based on wavefront construction comprises the following steps:

step 1: reading in relevant parameter files and a velocity model, wherein the parameter files comprise the grid point number, grid spacing, source location, tracing step length, ray angle range, and ray sampling interval of the velocity model;

step 2: tracing rays, and inserting new rays during the tracing to ensure the coverage of the rays, wherein the essence of ray tracing is to solve a kinematics ray tracing equation group by using a Runge-Kutta method, as shown in the formula below:

$$\begin{cases} \frac{dx_i}{d\tau} = v^2 g p_i \\ \frac{dp_i}{d\tau} = \frac{\partial}{\partial x_i}\left(\frac{1}{v}\right) = -v^{-1}\frac{\partial v}{\partial x_i} \end{cases}$$

wherein x_i represents the location component, p_i represents the slowness component, τ represents the seismic travel time, and v represents the seismic velocity;

step 3: dividing a calculation space into a plurality of wavefront quadrilaterals by calculating the spatial position information of discrete points on the acquired rays;

step 4: judging the position relationship of the grid point and the wavefront quadrilateral by a vector product method, and determining the grid point contained in the wavefront quadrilateral;

step 5: calculating the locations of virtual sources corresponding to the points through the relevant information of vertices of the wavefront quadrilateral, and calculating the seismic travel time of the grid points contained in the wavefront quadrilateral based on the locations of the virtual sources; and

step 6: completing the travel time calculations of all grid points and outputting the final travel time calculation results.

Compared with the prior art, the seismic travel time calculation method disclosed by the invention has the beneficial effects that in consideration of the propagation rule of the seismic waves in the medium, the travel time of the grid points in the wavefront quadrilaterals is calculated by a virtual source method, the calculation precision of the grid point travel time is improved, and the calculation precision of the seismic travel time method based on wavefront construction is improved.

BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is a flow chart of a seismic travel time calculation method based on virtual source wavefront construction of the invention.

Fig. 2 is a schematic diagram of calculation region division.

Fig. 3 is a schematic diagram of virtual source seismic travel time calculation, A, B, C and D are four vertexes of a wavefront quadrilateral, O_A, O_B, O_C and O_D are the locations of virtual sources corresponding to A, B, C and D, and R is a grid point in the wavefront quadrilateral ABCD.

Fig. 4 is the relative error of travel time in a conventional wavefront construction method in a homogeneous medium.

Fig. 5 is the relative error of the seismic travel time calculation method based on virtual source wavefront construction in the homogeneous medium.

DETAILED DESCRIPTION

The invention is described in details below with reference to the accompanying drawings and specific embodiments.

Fig. 1 is the flow chart of the seismic travel time calculation method based on virtual source wavefront construction. The realization flow of the method of the invention is specially shown in the figure as follows:

1) reading in relevant parameter files and a velocity model, wherein the parameter files comprise the grid point number, grid spacing, source location, tracing step length, ray angle range, and ray sampling interval of the velocity model;

2) tracing rays, and inserting new rays during the tracing to ensure the coverage of the rays, wherein the ray emission angle range is -80° to +80°, the sampling interval is 3° to 6°, the ray tracing step length is 2ms to 6ms, the essence of ray tracing is to solve a kinematics ray tracing equation group by using a Runge-Kutta method, as shown in the formula below:

$$\begin{cases} \dfrac{dx_i}{d\tau} = v^2 \mathrm{g} p_i \\ \dfrac{dp_i}{d\tau} = \dfrac{\partial}{\partial x_i}\left(\dfrac{1}{v}\right) = -v^{-1}\dfrac{\partial v}{\partial x_i} \end{cases}$$

wherein x_i represents the location component, p_i represents the slowness component, τ represents the seismic travel time, and v represents the seismic velocity;

3) dividing a calculation space into a plurality of wavefront quadrilaterals with

the four points on adjacent rays and adjacent wave front surfaces as the vertices of each of the wavefront quadrilaterals, by calculating the spatial position information of discrete points on the acquired rays (as shown in Fig. 2);

4) firstly, roughly screening a grid point that can be positioned in the coverage area of each of the wavefront quadrilaterals through the positions of the vertices of the wavefront quadrilateral, then judging the position relationship of the grid point and the wavefront quadrilateral by a vector product method, and determining the grid point contained in the wavefront quadrilateral;

5) calculating the locations of virtual sources corresponding to the vertices through the information such as the ray directions of the vertices of the wavefront quadrilateral, the seismic travel time, and the seismic velocity, as shown in Fig. 3: supposing that the four vertices of a wavefront quadrilateral are A, B, C and D respectively, and R is a grid point in the wavefront quadrilateral, wherein after the locations of the virtual sources O_A, O_B, O_C and O_D corresponding to A, B, C, and D are calculated through relevant information, the expression of seismic travel time at point R is:

$$\tau_R = \frac{\left(|O_A R| + |O_B R| + |O_C R| + |O_D R|\right)}{4 * V_R}$$

$|O_A R|$, $|O_B R|$, $|O_C R|$ and $|O_D R|$ respectively represent the distance from O_A, O_B, O_C and O_D to point R, and V_R represents the seismic velocity at point R; and

6) completing the travel time calculations of all grid points and outputting the final travel time calculation results.

The calculation precision of the method disclosed by the invention is analysed and verified below by a homogeneous model.

Fig. 4 and Fig. 5 are absolute errors of a conventional wavefront construction method and a virtual source wavefront construction method in a homogeneous medium model respectively. The number of horizontal grid points of the homogeneous medium model is 761, the number of vertical grid points is 777, the horizontal grid spacing and the vertical grid spacing are 10m, the speed is 1000m/s, and a seismic source is positioned at 3800m. As can be seen from the figures, compared with the conventional wavefront construction method, the calculation precision of the seismic travel time calculation method based on virtual source wavefront construction is greatly improved.

The travel time of the grid points in the wavefront quadrilaterals of the invention is calculated by the virtual source method, the calculation precision of the travel time of the grid points in the wavefront quadrilaterals is improved, and a high-precision seismic travel time calculation method based on wavefront construction is realized.

Conclusies

1. Tweedimensionale seismische reistijdberekeningswerkwijze op basis van een virtuele bron met een golffrontconstructie, **met het kenmerk, dat** de volgende stappen worden omvat:

stap 1: lezen in relevante parameterbestanden en een snelheidsmodel, waarbij de parameterbestanden het rasterpuntnummer, rasterafstand, bronlocatie, traceringsstaplengte, straalhoekbereik en straalbemonsteringsinterval van het snelheidsmodel omvatten;

stap 2: traceren van stralen en invoegen van nieuwe stralen tijdens het traceren om de dekking van de stralen te garanderen, waarbij de essentie van het traceren van de stralen is om een kinematische straaltracering-vergelijkingsgroep op te lossen met behulp van een Runge-Kutta-methode, zoals weergegeven in de onderstaande formule:

$$\begin{cases} \dfrac{dx_i}{d\tau} = v^2 g p_i \\ \dfrac{dp_i}{d\tau} = \dfrac{\partial}{\partial x_i}\left(\dfrac{1}{v}\right) = -v^{-1}\dfrac{\partial v}{\partial x_i} \end{cases}$$

waarin x_i de locatiecomponent weergeeft, p_i de traagheidscomponent weergeeft, τ de seismische reistijd weergeeft en v de seismische snelheid weergeeft;

stap 3: verdelen van een berekeningsruimte in een aantal vierhoeken van het golffront door middel van het berekenen van de ruimtelijke locatie-informatie van discrete punten op de verworven stralen;

stap 4: beoordelen van de locatiebetrekking van het rasterpunt en de vierhoek van het golffront door middel van een vectorproductmethode, en het bepalen van het rasterpunt dat zich in de vierhoek van het golffront bevindt;

stap 5: berekenen van de locaties van virtuele bronnen die overeenkomen met de punten door middel van de relevante informatie van hoekpunten van de vierhoek van het golffront, en berekenen van de seismische reistijd van de rasterpunten die zijn opgenomen in de vierhoek van het golffront op basis van de locaties van de virtuele bronnen; en

stap 6: voltooien van de reistijdberekeningen van alle rasterpunten en het uitvoeren van de resultaten van de uiteindelijke reistijdberekening.

2. Seismische reistijdberekeningswerkwijze gebaseerd op de virtuele tweedimensionale golffrontconstructiebron volgens conclusie 1, **met het kenmerk, dat** de bij de stap 5, wanneer de seismische reistijd van de rasterpunten die zijn opgenomen in de vierhoek van het golffront wordt berekend door middel van een virtuele bronmethode, vier hoekpunten van een vierhoek van het golffront als respectievelijk A, B, C en D worden verondersteld, en R een rasterpunt in de vierhoek van het golffront is; en nadat de locaties van de virtuele bronnen O_A, O_B, O_C en O_D die overeenkomen met A, B, C en D worden berekend door middel van relevante informatie, de uitdrukking van seismische reistijd op punt R is:

$$\tau_R = \frac{\left(|O_A R| + |O_B R| + |O_C R| + |O_D R|\right)}{4 * V_R}$$

waarin $|O_A R|$, $|O_B R|$, $|O_C R|$ en $|O_D R|$ respectievelijk de afstand van O_A, O_B, O_C en O_D tot punt R weergeven, en V_R de seismische snelheid in punt R weergeeft.

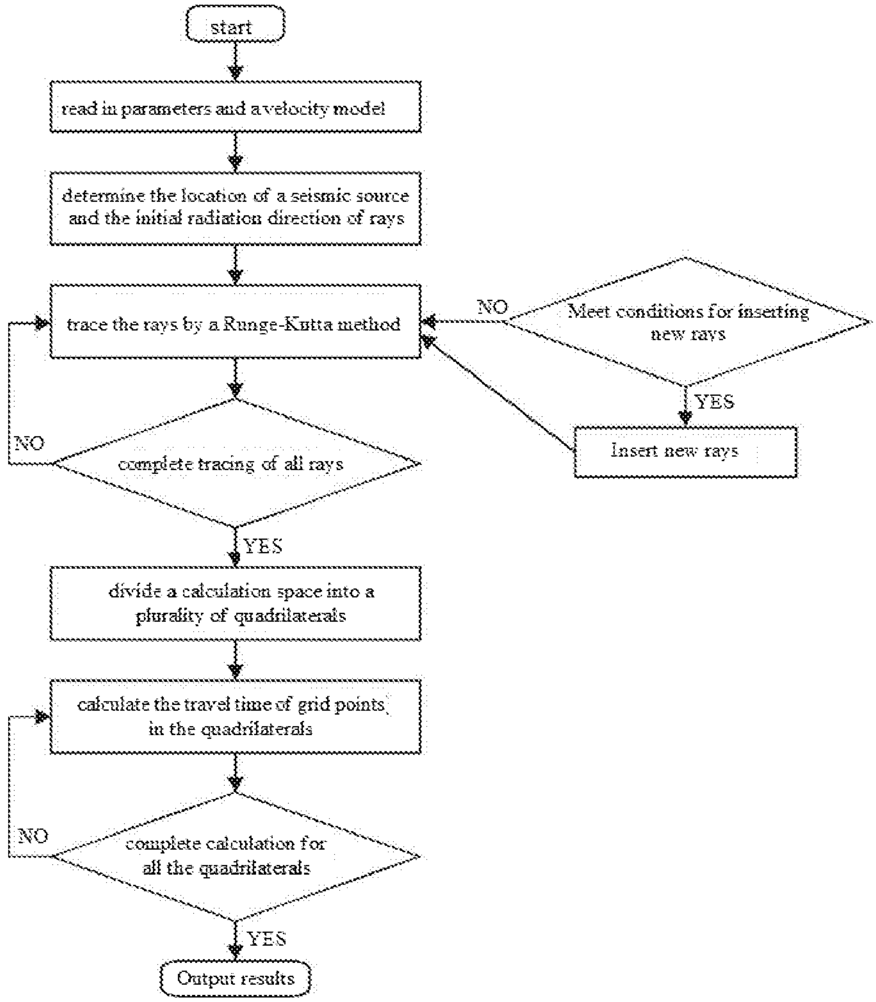

start
read in parameters and a velocity model
determine the location of a seismic source and the initial radiation direction of rays
trace the rays by a Runge-Kutta method
NO
Meet conditions for inserting new rays
YES
Insert new rays
NO
complete tracing of all rays
YES
divide a calculation space into a plurality of quadrilaterals
calculate the travel time of grid points in the quadrilaterals
NO
complete calculation for all the quadrilaterals
YES
Output results

Fig 1

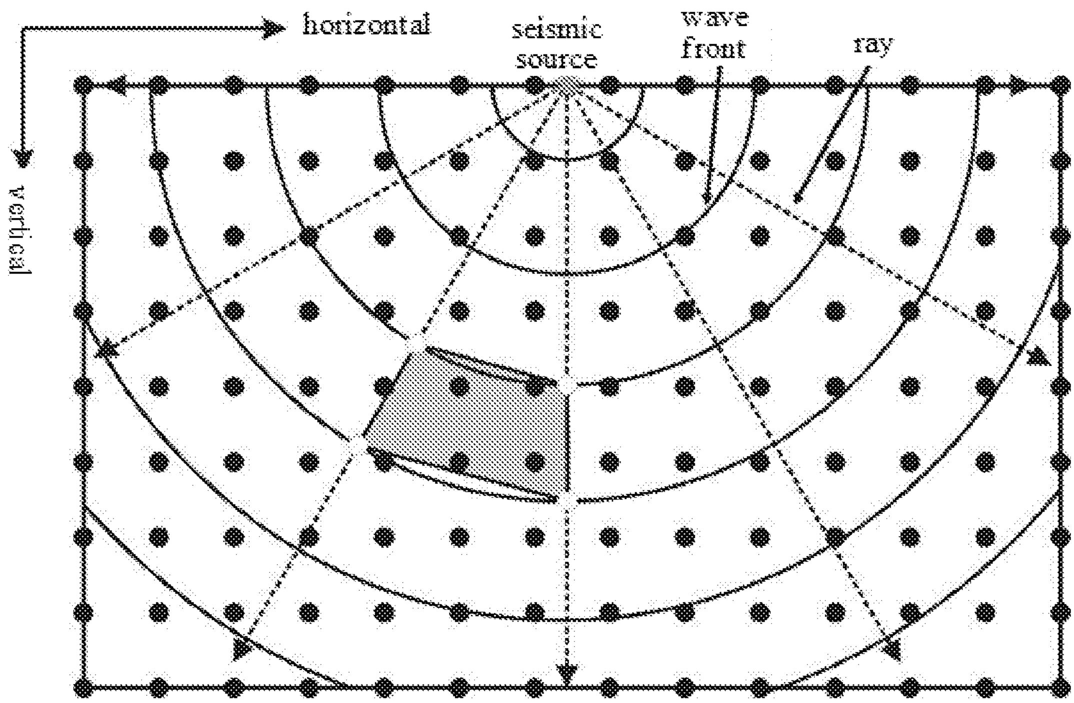
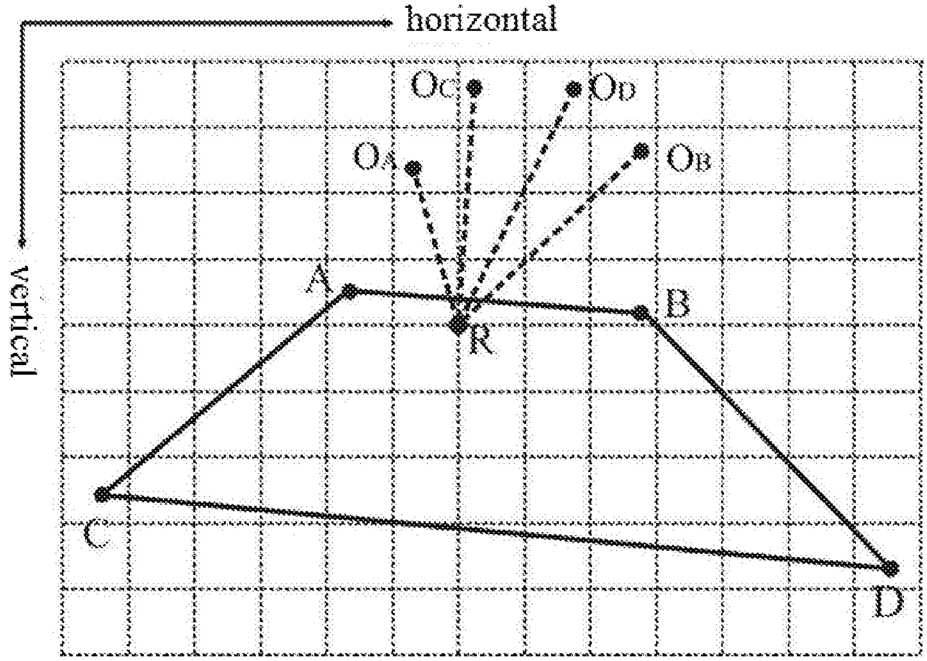
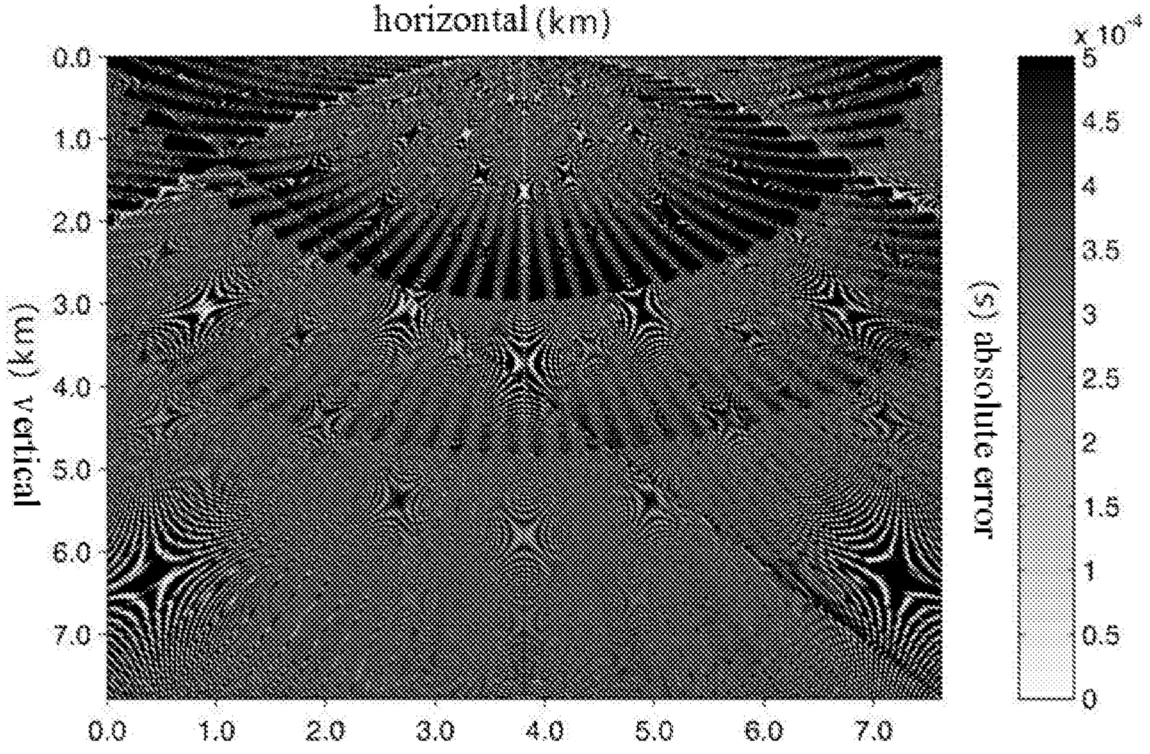

horizontal
seismic source
wave front
ray
vertical

Fig. 2



horizontal
vertical
OC
OD
OA
OB
A
B
R
C
D

Fig. 3



horizontal (km)
vertical (km)
absolute error (s)
x 10-4
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0

Fig. 4

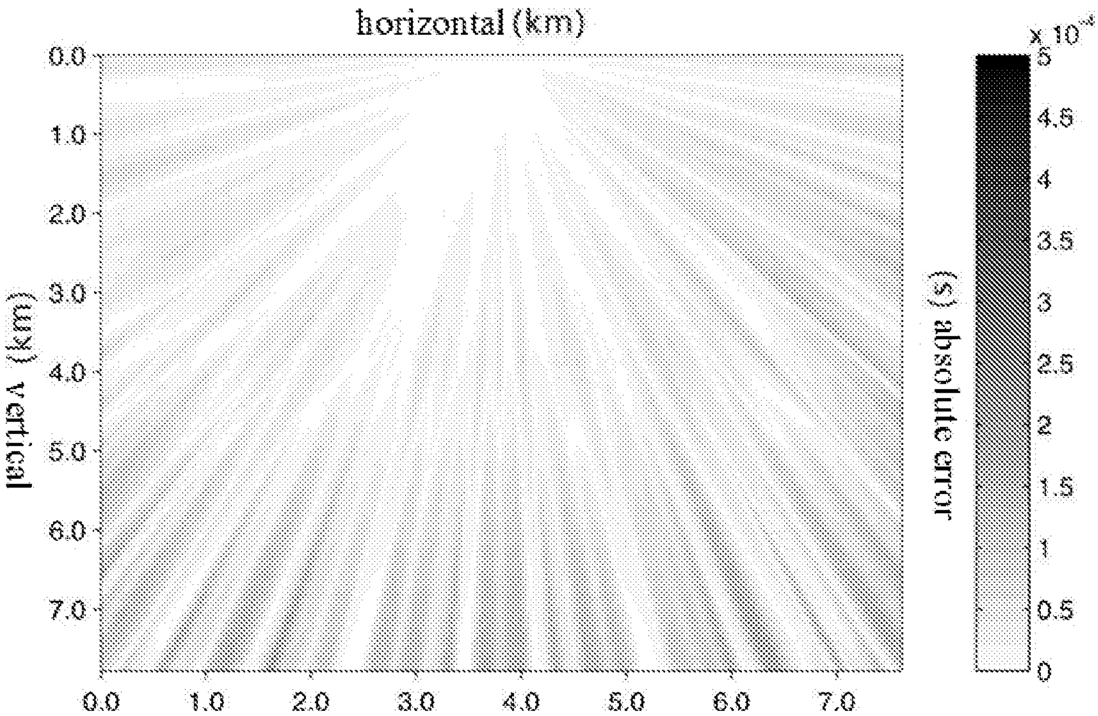

horizontal (km)
vertical (km)
absolute error (s)
x 10^-4
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5

Fig. 5

Abstract

2-D Seismic Travel Time Calculation Method Based on Virtual Source Wavefront Construction

The invention discloses a 2-D seismic travel time calculation method based on virtual source wavefront construction. The seismic travel time calculation method comprises the following steps of reading in relevant parameters and a velocity model; tracing rays in different directions from a seismic source by using a Runge-Kutta method, and inserting new rays during ray tracing according to relevant judgement conditions in the ray tracing process; dividing a calculation space into a plurality of wavefront quadrilaterals through discrete points on adjacent rays and adjacent wave front surfaces; finding grid points in the wavefront quadrilaterals; calculating the travel time of the grid point in each of the wavefront quadrilaterals by a virtual source method; and completing the calculation of the travel time of the grid points in all wavefront quadrilaterals. Through adoption of the virtual source method, during calculation of the travel time of the grid points in the wavefront quadrilaterals of the invention, the calculation precision of the travel time of the grid points is improved, and a high-precision seismic travel time calculation method based on wavefront construction is realized.

Fig. 1