Intergovernmental
Oceanographic
Commission

Manuals and Guides

35

IUGG/IOC TIME PROJECT

NUMERICAL METHOD OF TSUNAMI SIMULATION WITH THE LEAP-FROG SCHEME

PART 1 SHALLOW WATER THEORY AND ITS DIFFERENCE SCHEME

PART 2 PROPAGATION IN THE OCEAN IN THE SPHERICAL CO-ORDINATES TSUNAMI-F1 AND ITS PROGRAMME LIST

by C. Goto and Y. Ogawa
Department of Civil Engineering
Faculty of Engineering
Tohoku University
Sendai 980-77 - Japan

Translated and prepared for the TIME PROJECT
by N. Shuto
Disaster Control Research Center
Faculty of Engineering
Tohoku University
Sendai 980-77 - Japan

PART 3 PROGRAMME LISTS FOR NEAR-FIELD TSUNAMI

PART 4 PROGRAMME LIST FOR FAR-FIELD TSUNAMI

by F. Imamura
Tohoku University
Sendai 980-77 - Japan

1997 UNESCO

SC-97/WS-37

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariats of UNESCO and IOC concerning the legal status of any country, territory, or its authorities, or concerning the delimitations of the frontiers of any country or territory.

For bibliographic purposes
this document should be cited as follows:

IUGG/IOC Time Project
IOC Manuals and Guides No. 35. UNESCO 1997
(English)

Published in 1997
by the United Nations Educational,
Scientific and Cultural Organization
7, place de Fontenoy, 75352 Paris 07 SP, France

Printed in UNESCO's Workshops

Printed in France

IUGG/IOC TIME PROJECT

PART 1: SHALLOW WATER THEORY AND ITS DIFFERENCE SCHEME

CHAPTER 1: METHOD OF NUMERICAL SIMULATION

CHAPTER 2: TYPICAL PROGRAMMES

CONTENTS

CHAPTER 1: METHOD OF NUMERICAL SIMULATION

Page

1.1 EQUATIONS AND DIFFERENCE SCHEMES 1

(1) Shallow Water Theory 1
(2) Difference Scheme and Stability 2

1.2 INITIAL CONDITIONS AND BOUNDARY CONDITIONS 9

(1) Initial Conditions 9
(2) Conditions for a Simple Harmonic Wave Train at an Offshore Open Boundary 9
(3) Open Boundary Conditions for Forced Inputs 12
(4) Open Boundary Conditions for Free Transmission 12
(5) Boundary Conditions at Run up Front 12
(6) Boundary Conditions at Water Overflows Structures 12

1.3 CONTINUATION OF REGIONS 12

(1) Necessity of Continuation of Regions in Numerical Computation 12
(2) Continuation of Regions of Different Δx 13
(3) Continuation of Regions of Different Δt 16

CHAPTER 2: TYPICAL PROGRAMMES

2.1 ASSUMPTIONS 1

2.2 CONSTRUCTION OF MAIN PROGRAMMES 1

(1) Specification Statement 1
(2) Input of Setting Value 3
(3) Setting of Initial Value 3
(4) Computation Repeated with Respect to Time 4

2.3 EXPLANATION OF SUB-ROUTINES 10

(1) DEPTH (Computation of Water Depth at Points for Discharge) 10
(2) SETZRO (Setting of Initial Conditions) 11
(3) CONTIN (Computation of the Equation of Continuity) 12
(4) JOINTZ (Connection of the Water Level in Space and Time) 14
(5) MOTION (Computation of the Equation of Motion) 16
(6) JOINTQ (Connection of the Water Discharge in Space and Time) 20
(7) CHANGE (Change of Data) 23

CHAPTER 1. METHOD OF NUMERICAL SIMULATION

1.1 EQUATIONS AND DIFFERENCE SCHEMES

(1) Shallow Water Theory

Water waves are classified into many types from a hydraulic point of view. This paper considers tsunamis, which are generated by the movement of sea bottom due to earthquakes. Tsunamis belong to long waves.

The theory of long waves is an approximate theory applicable to waves of small relative depth (the ratio of water depth to wave length), for which the vertical acceleration of water particles is negligible compared to the gravitational acceleration and the curvature of trajectories of water particles is sufficiently small. Consequently, the vertical motion of water particles has no effect on the pressure distribution. It is a good approximation that the pressure is hydrostatic. In addition, the horizontal velocity of water particles are vertically uniform.

Based upon these approximations, the motion of long waves is well expressed by the following shallow water theory.

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+g\frac{\partial \eta}{\partial x}+\frac{\tau_x}{\rho}=0$$

$$\frac{\partial \eta}{\partial t}+\frac{\partial[u(h+\eta)]}{\partial x}+\frac{\partial[v(h+\eta)]}{\partial y}=0$$

$$\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+g\frac{\partial \eta}{\partial y}+\frac{\tau_y}{\rho}=0$$

where x and y are horizontal coordinates, t time, h the still water depth, η the vertical displacement of water surface above still water level, u and v water particle velocities in the x- and y-directions, g the gravitational acceleration, and τ_x/ρ and τ_y/ρ bottom frictions in the x- and y-directions.

The bottom friction is expressed as follows, in an analogy to the uniform flow.

$$\frac{\tau_x}{\rho}=\frac{1}{2g}\frac{f}{D}u\sqrt{u^2+v^2} \quad , \quad \frac{\tau_y}{\rho}=\frac{1}{2g}\frac{f}{D}v\sqrt{u^2+v^2}$$

where D is the total water depth given by h + η and f is the friction coefficient. Without any detailed discussion of the value of the authors prefer to use Manning's roughness n which are familiar among civil engineers.

The friction coefficient f and Manning's roughness n are related by

$$n=\sqrt{\frac{fD^{1/3}}{2g}}$$

and, the bottom frictions are finally expressed by

$$\frac{\tau_x}{\rho}=\frac{gn^2}{D^{4/3}}u\sqrt{u^2+v^2} \quad , \quad \frac{\tau_y}{\rho}=\frac{gn^2}{D^{4/3}}v\sqrt{u^2+v^2}$$

throughout the present paper.

The next step is the introduction of discharge fluxes (M, N) in the x- and y-directions. M and N are related to u and v by the following expressions.

$$M=u(h+\eta)=uD \quad , \quad N=v(h+\eta)=vD$$

Integrating Eqs.(1) through (3) from sea bottom to water surface, the following shallow water theory is obtained for discharge fluxes M and N.

$$\frac{\partial \eta}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0$$

$$\frac{\partial M}{\partial t}+\frac{\partial}{\partial x}\left(\frac{M^2}{D}\right)+\frac{\partial}{\partial y}\left(\frac{MN}{D}\right)+gD\frac{\partial \eta}{\partial x}+\frac{gn^2}{D^{7/3}}M\sqrt{M^2+N^2}=0$$

$$\frac{\partial N}{\partial t}+\frac{\partial}{\partial x}\left(\frac{MN}{D}\right)+\frac{\partial}{\partial y}\left(\frac{N^2}{D}\right)+gD\frac{\partial \eta}{\partial y}+\frac{gn^2}{D^{7/3}}N\sqrt{M^2+N^2}=0$$

These equations are the fundamental equations used in the present paper.

The authors would not like to recommend the use of Eqs.(1) through (3) but the use of Eqs.(6) through (8). When discretized, the former set of equations sometimes does not satisfy the conservation of mass. This fact which is often disregarded becomes the source of large computation errors. On the other hand, the latter set of equations, Eqs.(6) through (8), has no defect in the conservation of mass, and it also satisfies the conservation of momentum fairly well.

(2) Difference Scheme and Stability

The leap-frog scheme used in the present paper is a central difference scheme with the truncation error of the second order.

Values of F(x) at discrete points with an spatial interval Δx are expressed as follows, on referring Figure 1.

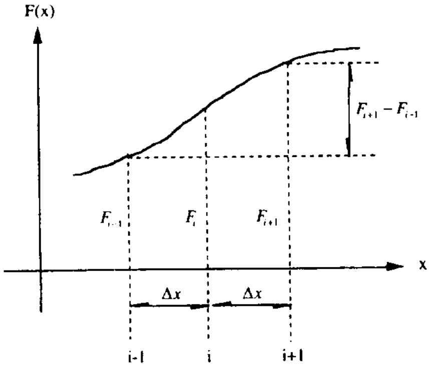


Figure 1-1. Central difference

$$F\{(i-1)\Delta x\}=F_{i-1}\ ,\ \ F(i\Delta x)=F_i\ ,\ \ F\{(i+1)\Delta x\}=F_{i+1}$$

The Taylor series expressions for $_{\mathrm{If-1}}$ and $_{\mathrm{If+1}}$ are

$$F_{i-1}=F_i-\Delta x\left.\frac{\partial F}{\partial x}\right|_i+\left.\frac{(\Delta x)^2}{2}\frac{\partial^2 F}{\partial x^2}\right|_i-\left.\frac{(\Delta x)^3}{6}\frac{\partial^3 F}{\partial x^3}\right|_i+\left.\frac{(\Delta x)^4}{24}\frac{\partial^4 F}{\partial x^4}\right|_i+O(\Delta x^5)$$

$$F_{i+1}=F_i+\Delta x\left.\frac{\partial F}{\partial x}\right|_i+\left.\frac{(\Delta x)^2}{2}\frac{\partial^2 F}{\partial x^2}\right|_i+\left.\frac{(\Delta x)^3}{6}\frac{\partial^3 F}{\partial x^3}\right|_i+\left.\frac{(\Delta x)^4}{24}\frac{\partial^4 F}{\partial x^4}\right|_i+O(\Delta x^5)$$

and the difference between the two Taylor series expressions yield a central difference of the first-order derivative as Eq.(9).

$$\left.\frac{\partial F}{\partial x}\right|_i = \frac{1}{2\Delta x}\left[F_{i+1} - F_{i-1}\right] + O(\Delta x^2)$$

Apply the above difference scheme to Eqs.(6) through (8). In order to make it easy to set the boundary conditions, the leap-frog scheme assumes that the computation point for η does not coincide with the computation point for M and N, as shown in Figure-2. In Figure1-2, suffixes (I, j, k) are used to express the spatial position (x, y) and the time t.

First, the equation of the continuity is approximated by a difference equation. With the central difference scheme, three terms in Eq.(6) are given by

$$\frac{\partial \eta}{\partial t} = \frac{1}{\Delta t}\left[\eta_{i,j}^{k+1} - \eta_{i,j}^{k}\right]$$

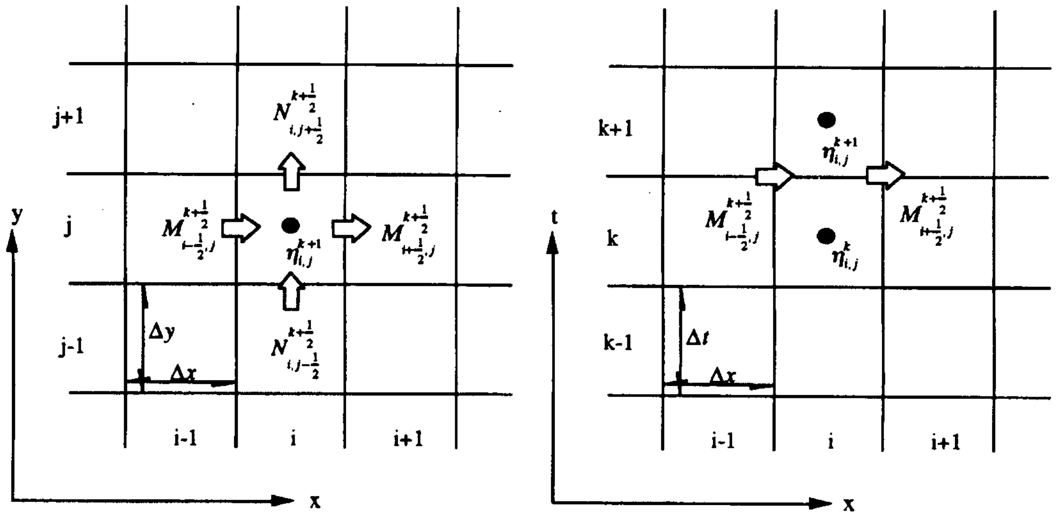

j+1
j
j-1
y
$N_{i,j+\frac{1}{2}}^{k+\frac{1}{2}}$
$M_{i-\frac{1}{2},j}^{k+\frac{1}{2}}$
$\eta_{i,j}^{k+1}$
$M_{i+\frac{1}{2},j}^{k+\frac{1}{2}}$
$N_{i,j-\frac{1}{2}}^{k+\frac{1}{2}}$
Δy
Δx
i-1
i
i+1
x
k+1
k
k-1
t
$\eta_{i,j}^{k+1}$
$M_{i-\frac{1}{2},j}^{k+\frac{1}{2}}$
$\eta_{i,j}^{k}$
$M_{i+\frac{1}{2},j}^{k+\frac{1}{2}}$
Δt
Δx
i-1
i
i+1
x

Figure 1-2. Arrangement of points for computation in the leap-frog method.

$$\frac{\partial M}{\partial x} = \frac{1}{\Delta x}\left| M_{i+\frac{1}{2},j}^{k+\frac{1}{2}} - M_{i-\frac{1}{2},j}^{k+\frac{1}{2}} \right|$$

$$\frac{\partial N}{\partial y} = \frac{1}{\Delta y}\left[N_{i,j+\frac{1}{2}}^{k+\frac{1}{2}} - N_{i,j-\frac{1}{2}}^{k+\frac{1}{2}} \right]$$

On assuming that values at k and k+1/2 time steps are known, the only unknown η(I, j, k+1) is solved by

$$\eta_{i,j}^{k+1} = \eta_{i,j}^{k} - \frac{\Delta t}{\Delta x}\left| M_{i+\frac{1}{2},j}^{k+\frac{1}{2}} - M_{i-\frac{1}{2},j}^{k+\frac{1}{2}} \right| - \frac{\Delta t}{\Delta y}\left| N_{i,j+\frac{1}{2}}^{k+\frac{1}{2}} - N_{i,j-\frac{1}{2}}^{k+\frac{1}{2}} \right|$$

Second, the equation of motion is approximated. Explanation consists of three parts; approximation of linear terms, approximation and stability of convection terms, and approximation of friction terms.

The linear equation of motion of in the x-direction is written as

$$\frac{\partial M}{\partial t}+gD\frac{\partial \eta}{\partial x}=0$$

A central difference at the point (I+1/2, j, k) yields the following equation for an unknown M(I+1/2, j, k-1/2)

$$M^{k+\frac{1}{2}}_{i+\frac{1}{2},j}=M^{k-\frac{1}{2}}_{i+\frac{1}{2},j}-gD^{k}_{i+\frac{1}{2},j}\frac{\Delta t}{\Delta x}\left[\eta^{k}_{i+1,j}-\eta^{k}_{i,j}\right]$$

where the total water depth D(I+1/2, j, k) is expressed by

$$D^{k}_{i+\frac{1}{2},j}=h_{i+\frac{1}{2},j}-\eta^{k}_{i+\frac{1}{2},j}=h_{i+\frac{1}{2},j}+\frac{1}{2}\left[\eta^{k}_{i+1,j}+\eta^{k}_{i,j}\right]$$

The similar manipulation yields the following difference equation for the linear equation of motion in the y-direction.

$$N^{k+\frac{1}{2}}_{i,j+\frac{1}{2}}=N^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}-gD^{k}_{i,j-\frac{1}{2}}\frac{\Delta t}{\Delta y}\left[\eta^{k}_{i,j+1}+\eta^{k}_{i,j}\right]$$

$$D^{k}_{i,j+\frac{1}{2}}=h_{i,j+\frac{1}{2}}+\eta^{k}_{i,j+\frac{1}{2}}=h_{i,j+\frac{1}{2}}\frac{1}{2}\left[\eta^{k}_{i,j+1}+\eta^{k}_{i,j}\right]$$

It is now possible to solve Eqs.(10), (12) and (14) simultaneously and obtain the solution of linear long waves. A comment is necessary to explain a difference between the original equations and Eqs.(12) and (14). The original equations of linear long waves uses h (still water depth), but Eqs.(12) and (14) use D (total water depth). If h is sufficiently larger then η, a linear computation with Eqs.(12) and (14) can yield reliable results, It should be kept in mind that this linear computation may become unstable if h is smaller than η.

In the leap-frog scheme, an upwind scheme is applied to the convection terms in order to make the computation stable. The reason why this scheme ensures the stability of computation is briefly explained by taking a simple convection equation in the following.

$$\frac{\partial F}{\partial t}+C\frac{\partial F}{\partial x}=0$$

Here, the coefficient C is the propagation velocity and is assumed constant. The arrangement of computation points in the leap-frog scheme requires the forward difference scheme for the first-order time derivative (see Figure-3). This yields

$$\frac{\partial F}{\partial t}=\frac{1}{\Delta t}\left[F^{k+\frac{1}{2}}_{i+\frac{1}{2}}-F^{k+\frac{1}{2}}_{i+\frac{1}{2}}\right]-\frac{\Delta t}{2}\frac{\partial^2 F}{\partial t^2}+O(\Delta t^2)$$

The central difference is applied to the space derivative.

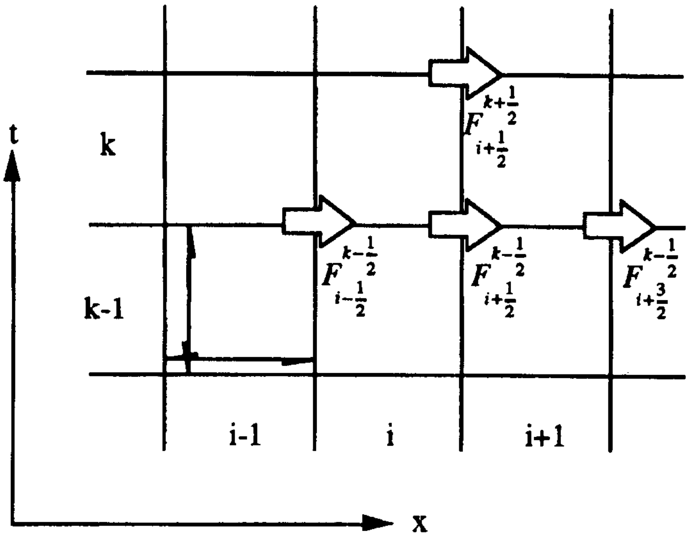

t
k
k-1
$F_{i+\frac{1}{2}}^{k+\frac{1}{2}}$
$F_{i-\frac{1}{2}}^{k-\frac{1}{2}}$
$F_{i+\frac{1}{2}}^{k-\frac{1}{2}}$
$F_{i+\frac{3}{2}}^{k-\frac{1}{2}}$
i-1
i
i+1
x

Figure 1-3. Arrangement of points for convection terms.

$$C\frac{\partial F}{\partial x}=\frac{C}{2\Delta x}\left[F_{i+\frac{3}{2}}^{k-\frac{1}{2}}-F_{i-\frac{1}{2}}^{k-\frac{1}{2}}\right]+O(\Delta x^{2})$$

As a result, the unknown F(I+1/2, k+1/2) is given by Eq.(17)

$$F_{i+\frac{1}{2}}^{k+\frac{1}{2}}=F_{i+\frac{1}{2}}^{k-\frac{1}{2}}-C\frac{\Delta t}{2\Delta x}\left[F_{i+\frac{3}{2}}^{k-\frac{1}{2}}-F_{i-\frac{1}{2}}^{k-\frac{1}{2}}\right]$$

Or, inversely speaking, the solution of Eq.(17) is implicitly equivalent the solution of Eq.(18) with an truncation error of $(\Delta x^2+\Delta y^2)$

$$\frac{\partial F}{\partial t}+\frac{\Delta t}{2}\frac{\partial^2 F}{\partial t^2}+C\frac{\partial F}{\partial x}=0$$

If the second-order derivative with respect to time is rewritten by using the following relationship,

$$\frac{\partial^2 F}{\partial t^2}=\frac{\partial}{\partial t}\left(-C\frac{\partial F}{\partial x}\right)=C^{2}\frac{\partial^2 F}{\partial x^2}$$

the solution of Eq.(18) is the same as the solution of the following diffusion equation in which the diffusion coefficient is negative.

$$\frac{\partial F}{\partial t}+C\frac{\partial F}{\partial x}=-\frac{\Delta t}{2}C^{2}\frac{\partial^2 F}{\partial t^2}$$

A negative diffusion works to collect round-off errors to lead to an instability. Therefore, Eq.(17) is an unstable difference scheme.

In order to obtain a stable scheme, the space derivative term is approximated either by a forward or by a backward difference. With the forward difference, we have

$$C\frac{\partial F}{\partial x}=\frac{C}{\Delta x}\left[F^{k-\frac{1}{2}}_{i+\frac{3}{2}}-F^{k-\frac{1}{2}}_{i+\frac{1}{2}}\right]-\frac{\Delta x}{2}C\frac{\partial^2 F}{\partial x^2}+O(\Delta x^2)$$

and with the backward difference

$$C\frac{\partial F}{\partial x}=\frac{C}{\Delta x}\left[F^{k-\frac{1}{2}}_{i+\frac{1}{2}}-F^{k-\frac{1}{2}}_{i-\frac{1}{2}}\right]+\frac{\Delta x}{2}C\frac{\partial^2 F}{\partial x^2}+O(\Delta x^2)$$

The corresponding differential equations we are going to solve are, within the truncation error of ($\Delta x^2+\Delta y^2$), for the forward difference

$$\frac{\partial F}{\partial t}+C\frac{\partial F}{\partial x}=-\frac{C}{2}(C\Delta t+\Delta x)\frac{\partial^2 F}{\partial x^2}$$

and for the backward difference

$$\frac{\partial F}{\partial t}+C\frac{\partial F}{\partial x}=\frac{C}{2}(-C\Delta t+\Delta x)\frac{\partial^2 F}{\partial t^2}$$

Therefore, in order to keep the virtual diffusion coefficient positive (or say, in order to ensure the stability of the computation), we have use the backward difference in case of positive C, and the forward difference in case of negative C, in addition to set $\Delta x/\Delta t \geq C$.

In other words, the difference should be taken in the direction of the flow. This is the reason why this scheme is called the upwind difference. It is usually said that the leap-frog scheme has the truncation error of the order of Δx^2. However, as long as the convection term concerns, the truncation error is of the order of Δx.

The convection terms in Eqs.(7) and (8) are expressed as follows with the upwind scheme mentioned above.

$$\frac{\partial}{\partial x}\left(\frac{M^2}{D}\right)=\frac{1}{\Delta x}\left[\lambda_{11}\frac{\left(M^{k-\frac{1}{2}}_{i+\frac{3}{2}j}\right)^2}{D^{k-\frac{1}{2}}_{i+\frac{3}{2}j}}+\lambda_{21}\frac{\left(M^{k-\frac{1}{2}}_{i+\frac{1}{2}j}\right)^2}{D^{k-\frac{1}{2}}_{i+\frac{1}{2}j}}+\lambda_{31}\frac{\left(M^{k-\frac{1}{2}}_{i-\frac{1}{2}j}\right)^2}{D^{k-\frac{1}{2}}_{i-\frac{1}{2}j}}\right]$$

$$\frac{\partial}{\partial y}\left(\frac{MN}{D}\right)=\frac{1}{\Delta y}\left[\nu_{11}\frac{M^{k-\frac{1}{2}}_{i+\frac{1}{2},j+1}N^{k-\frac{1}{2}}_{i+\frac{1}{2},j+1}}{D^{k-\frac{1}{2}}_{i+\frac{1}{2},j+1}}+\nu_{21}\frac{M^{k-\frac{1}{2}}_{i+\frac{1}{2},j}N^{k-\frac{1}{2}}_{i+\frac{1}{2},j}}{D^{k-\frac{1}{2}}_{i+\frac{1}{2},j}}+\nu_{31}\frac{M^{k-\frac{1}{2}}_{i+\frac{1}{2},j-1}N^{k-\frac{1}{2}}_{i+\frac{1}{2},j-1}}{D^{k-\frac{1}{2}}_{i+\frac{1}{2},j-1}}\right]$$

$$\frac{\partial}{\partial x}\left(\frac{MN}{D}\right)=\frac{1}{\Delta x}\left[\lambda_{12}\frac{M^{k-\frac{1}{2}}_{i+1,j+\frac{1}{2}}N^{k-\frac{1}{2}}_{i+1,j+\frac{1}{2}}}{D^{k-\frac{1}{2}}_{i+1,j+\frac{1}{2}}}+\lambda_{22}\frac{M^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}N^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}}{D^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}}+\lambda_{32}\frac{MN}{D}\frac{M^{k-\frac{1}{2}}_{i-1,j+\frac{1}{2}}N^{k-\frac{1}{2}}_{i-1,j+\frac{1}{2}}}{D^{k-\frac{1}{2}}_{i-1,j+\frac{1}{2}}}\right]$$

$$\frac{\partial}{\partial y}\left(\frac{N^2}{D}\right)=\frac{1}{\Delta y}\left[\nu_{12}\frac{\left(N^{k-\frac{1}{2}}_{i,j+\frac{3}{2}}\right)^2}{D^{k-\frac{1}{2}}_{i,j+\frac{3}{2}}}+\nu_{22}\frac{\left(N^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}\right)^2}{D^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}}+\nu_{32}\frac{\left(N^{k-\frac{1}{2}}_{i,j-\frac{1}{2}}\right)^2}{D^{k-\frac{1}{2}}_{i,j-\frac{1}{2}}}\right]$$

where

$$M^{k-\frac{1}{2}}_{i+\frac{1}{2},j}\begin{array}{llll}\geq 0, & \lambda_{11}=0, & \lambda_{21}=1, & \lambda_{31}=-1\\ < 0, & \lambda_{11}=1, & \lambda_{21}=-1, & \lambda_{31}=0\end{array}$$

$$N^{k-\frac{1}{2}}_{i+\frac{1}{2},j}\begin{array}{llll}\geq 0, & \nu_{11}=0, & \nu_{21}=1, & \nu_{31}=-1\\ < 0, & \nu_{11}=1, & \nu_{21}=-1, & \nu_{31}=0\end{array}$$

$$M^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}\begin{array}{llll}\geq 0, & \lambda_{12}=0, & \lambda_{22}=1, & \lambda_{32}=-1\\ < 0, & \lambda_{12}=1, & \lambda_{22}=-1, & \lambda_{32}=0\end{array}$$

$$N^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}\begin{array}{llll}\geq 0, & \nu_{12}=0, & \nu_{22}=1, & \nu_{32}=-1\\ < 0, & \nu_{12}=1, & \nu_{22}=-1, & \nu_{32}=0\end{array}$$

Next is the friction term. The friction term becomes a source of instability if it is decretized with an explicit scheme. The present authors use an implicit scheme; i.e.,

$$\frac{gn^2}{D^{7/3}}M\sqrt{M^2+N^2}=\frac{gn^2}{\left(D_{i+\frac{1}{2}j}^{k-\frac{1}{2}}\right)^{7/3}}\frac{1}{2}\left(M_{i+\frac{1}{2}j}^{k+\frac{1}{2}}+M_{i+\frac{1}{2}j}^{k-\frac{1}{2}}\right)\sqrt{\left(M_{i+\frac{1}{2}j}^{k-\frac{1}{2}}\right)^2+\left(N_{i+\frac{1}{2}j}^{k-\frac{1}{2}}\right)^2}$$

$$\frac{gn^2}{D^{7/3}}N\sqrt{M^2+N^2}=\frac{gn^2}{\left(D_{i,j+\frac{1}{2}}^{k-\frac{1}{2}}\right)^{7/3}}\frac{1}{2}\left(N_{i,j+\frac{1}{2}}^{k+\frac{1}{2}}+N_{i,j+\frac{1}{2}}^{k-\frac{1}{2}}\right)\sqrt{\left(M_{i,j+\frac{1}{2}}^{k-\frac{1}{2}}\right)^2+\left(N_{i,j+\frac{1}{2}}^{k-\frac{1}{2}}\right)^2}$$

As a summary of the present section, the set of differential equations is given by

$$\eta_{i,j}^{k+1}=\eta_{i,j}^{k}-\frac{\Delta t}{\Delta x}\left[M_{i+\frac{1}{2}j}^{k+\frac{1}{2}}-M_{i-\frac{1}{2}j}^{k+\frac{1}{2}}\right]-\frac{\Delta t}{\Delta y}\left[N_{i,j+\frac{1}{2}}^{k+\frac{1}{2}}-N_{i,j-\frac{1}{2}}^{k+\frac{1}{2}}\right]$$

$$\frac{1}{1+{}^{x}\mu_{i+\frac{1}{2}j}^{k-\frac{1}{2}}}\left[\left(1-{}^{x}\mu_{i+\frac{1}{2}j}^{k-\frac{1}{2}}\right)M_{i+\frac{1}{2}j}^{k-\frac{1}{2}}-\frac{\Delta t}{\Delta x}\left\{\lambda_{11}\frac{\left(M_{i+\frac{3}{2}j}^{k-\frac{1}{2}}\right)^2}{D_{i+\frac{3}{2}j}^{k-\frac{1}{2}}}+\lambda_{21}\frac{\left(M_{i+\frac{1}{2}j}^{k-\frac{1}{2}}\right)^2}{D_{i+\frac{1}{2}j}^{k-\frac{1}{2}}}+\lambda_{31}\frac{\left(M\right.}{D}\right.\right.$$

$$-\left\{\nu_{11}\frac{M_{i+\frac{1}{2}j+1}^{k-\frac{1}{2}}N_{i+\frac{1}{2}j+1}^{k-\frac{1}{2}}}{D_{i+\frac{1}{2}j+1}^{k-\frac{1}{2}}}+\nu_{21}\frac{M_{i+\frac{1}{2}j}^{k-\frac{1}{2}}N_{i+\frac{1}{2}j}^{k-\frac{1}{2}}}{D_{i+\frac{1}{2}j}^{k-\frac{1}{2}}}+\nu_{31}\frac{M_{i+\frac{1}{2}j-1}^{k-\frac{1}{2}}N_{i+\frac{1}{2}j-1}^{k-\frac{1}{2}}}{D_{i+\frac{1}{2}j-1}^{k-\frac{1}{2}}}\right\}-gD_{i+\frac{1}{2}j}^{k}\frac{\Delta t}{\Delta x}\left\{\eta_{i+1}^{k}\right.$$

$$\frac{1}{{}^{y}\mu_{i,j+\frac{1}{2}}^{k-\frac{1}{2}}}\left[\left(1-{}^{y}\mu_{i,j+\frac{1}{2}}^{k-\frac{1}{2}}\right)N_{i,j+\frac{1}{2}}^{k-\frac{1}{2}}-\frac{\Delta t}{\Delta x}\left\{\lambda_{12}\frac{M_{i+1,j+\frac{1}{2}}^{k-\frac{1}{2}}N_{i+1,j+\frac{1}{2}}^{k-\frac{1}{2}}}{D_{i+1,j+\frac{1}{2}}^{k-\frac{1}{2}}}+\lambda_{22}\frac{M_{i,j+\frac{1}{2}}^{k-\frac{1}{2}}N_{i,j+\frac{1}{2}}^{k-\frac{1}{2}}}{D_{i,j+\frac{1}{2}}^{k-\frac{1}{2}}}+\lambda_{32}\frac{M_{i}^{k}}{}\right.\right.$$

$$-\frac{\Delta t}{\Delta y}\left\{\nu_{12}\frac{\left(N_{i,j+\frac{3}{2}}^{k-\frac{1}{2}}\right)^2}{D_{i,j+\frac{3}{2}}^{k-\frac{1}{2}}}+\nu_{22}\frac{\left(N_{i,j+\frac{1}{2}}^{k-\frac{1}{2}}\right)^2}{D_{i,j+\frac{1}{2}}^{k-\frac{1}{2}}}+\nu_{32}\frac{\left(N_{i,j-\frac{1}{2}}^{k-\frac{1}{2}}\right)^2}{D_{i,j-\frac{1}{2}}^{k-\frac{1}{2}}}\right\}-gD_{i,j+\frac{1}{2}}^{k}\frac{\Delta t}{\Delta y}\left\{\eta_{i,j+1}^{k}-\eta_{i,j}^{k}\right\}\Bigg]$$

where

$$\mu\, x_{1\,i+\frac{1}{2}j}^{\,k-\frac{1}{2}}=\frac{1}{2}\frac{gn^2}{\left(D_{i+\frac{1}{2}j}^{k-\frac{1}{2}}\right)^2}\sqrt{\left(M_{i+\frac{1}{2}j}^{k-\frac{1}{2}}\right)^2+\left(N_{i+\frac{1}{2}j}^{k-\frac{1}{2}}\right)^2}$$

$$\mu y^{k-\frac{1}{2}}_{i,j+\frac{1}{2}} = \frac{1}{2}\frac{gn^2}{\left(D^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}\right)^2}\sqrt{\left(M^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}\right)^2+\left(N^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}\right)^2}$$

$$D^{k}_{i+\frac{1}{2},j} = \frac{1}{2}\left(D^{k}_{i+1,j}+D^{k}_{i,j}\right)=\frac{1}{2}\left(\eta^{k}_{i+1,j}+\eta^{k}_{i,j}\right)+h_{i+\frac{1}{2},j}$$

$$\begin{aligned} D^{k-\frac{1}{2}}_{i+\frac{1}{2},j} &= \frac{1}{4}\left(D^{k}_{i+1,j}+D^{k-1}_{i+1,j}+D^{k}_{i,j}+D^{k-1}_{i,j}\right) \\ &= \frac{1}{4}\left(\eta^{k}_{i+1,j}+\eta^{k-1}_{i+1,j}+\eta^{k}_{i,j}+\eta^{k-1}_{i,j}\right)+h_{i+\frac{1}{2},j} \end{aligned}$$

$$D^{k}_{i,j+\frac{1}{2}} = \frac{1}{2}\left(D^{k}_{i,j+1}+D^{k}_{i,j}\right)=\frac{1}{2}\left(\eta^{k}_{i,j+1}+\eta^{k}_{i,j}\right)+h_{i,j+\frac{1}{2}}$$

$$\begin{aligned} D^{k-\frac{1}{2}}_{i,j+\frac{1}{2}} &= \frac{1}{4}\left(D^{k}_{i,j+1}+D^{k-1}_{i,j+1}+D^{k}_{i,j}+D^{k-1}_{i,j}\right) \\ &= \frac{1}{4}\left(\eta^{k}_{i,j+1}+\eta^{k-1}_{i,j+1}+\eta^{k}_{i,j}+\eta^{k-1}_{i,j}\right)+h_{i,j+\frac{1}{2}} \end{aligned}$$

with λ and ν given by Eq.(23).

1.2 INITIAL CONDITIONS AND BOUNDARY CONDITIONS

(1) Initial Conditions

The present programme is only for tsunamis. No wind waves and tides are included. The still water level is given by tides and is assumed constant during the computation of tsunamis. This means that no motion is assumed up to the time k-1/2. Therefore, we set the initial conditions in sea as,

$$\eta^{k-1}_{i,j}\ ,\quad M^{k-\frac{1}{2}}_{i+\frac{1}{2},j}\ ,\quad N^{k-\frac{1}{2}}_{i,j+\frac{1}{2}} = 0$$

For Run up computation on land, the initial water level η(I, j, k-1) is equal to ground height $h_{i,j}$.

$$\eta^{k-1}_{i\ ,\ j} = -h_{i,j}$$

It should be kept in mind that values of h take negative sign on land.

(2) Conditions for a Simple Harmonic Waves Train at an Offshore Open Boundary

In the following, a method of input at an offshore boundary is given for a progressive sine wave train.

Actual motion of the water at the offshore boundary is not given by the sine wave but by a resultant of the advancing and receding sine wave trains. If the sine motion is given at the boundary, no reflected wave can pass through the boundary, and a forced oscillation is inevitably introduced. At the open boundary, it is necessary to allow the reflected wave freely pass the boundary and go out of the region of computation. This is easily solved if the method of characteristics is used at the boundary.

Consider first a one-dimensional case. The equations for linear long waves in a channel of constant depth are,

$$\frac{\partial u}{\partial t}+g\frac{\partial \eta}{\partial x}=0$$

$$\frac{\partial \eta}{\partial t}+h\frac{\partial u}{\partial x}=0$$

Equation (36) is reduced to

$$\frac{\partial u}{\partial t}+\sqrt{gh}\frac{\partial}{\partial x}\left(\sqrt{\frac{g}{h}}\eta\right)=0 ,$$

and Eq.(37) is reduced to

$$\frac{\partial}{\partial t}\left(\sqrt{\frac{g}{h}}\eta\right)+\sqrt{gh}\frac{\partial u}{\partial x}=0 ,$$

Addition and subtraction of the two equations yield

$$\left\{\frac{\partial}{\partial t}\pm\sqrt{gh}\frac{\partial}{\partial x}\right\}\left(u\pm\sqrt{\frac{g}{h}}\eta\right)=0$$

This leads to

$$u\pm\sqrt{\frac{g}{h}}\eta=Const, \quad on \quad \frac{dx}{dt}=\pm\sqrt{gh}$$

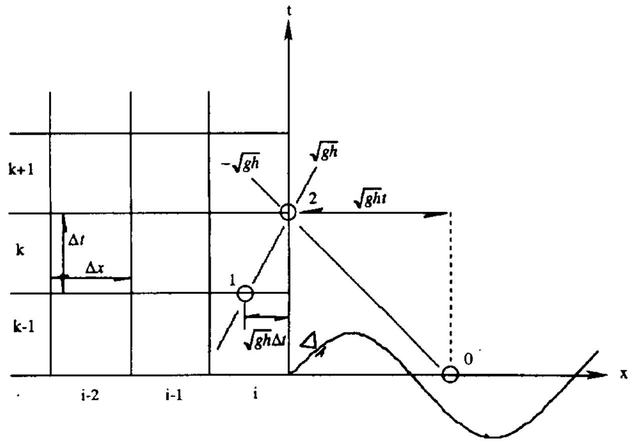


Figure 4. An offshore open boundary and characteristics when a simple harmonic wave train is propagating in the negative x direction.

Assume a simple harmonic wave train advancing in the negative x-direction having its front at x=x$_0$ at t=0. On referring Figure-4, equation (39) gives

$$u_2+\sqrt{\frac{g}{h}}\eta_2=u_1+\sqrt{\frac{g}{h}}\eta_1$$

along a positive characteristics, and

$$u_{2_2}-\sqrt{\frac{g}{h}}\eta_2=u_0-\sqrt{\frac{g}{h}}\eta_0$$

along a negative characteristics. The given wave train is propagating in the negative x-direction. It satisfies the following relationship between the horizontal water particle velocity u_0 and the water surface elevation η_0

$$u_0=-\sqrt{\frac{g}{h}}\eta_0$$

With this relationship substituted, Eq.(41) is reduced to

$$u_2-\sqrt{\frac{g}{h}}\eta_2=2u_0$$

and from Eqs.(40) and (41'), we have

$$u_2=u_0+\frac{1}{2}(u_1+\sqrt{\frac{g}{h}}\eta_1)$$

If we assume the incident wave train η_0 is given by

$$\eta_0=a\cdot\sin(k_0(x-x_0))$$

where k_0 is the wave number, then the corresponding water particle velocity is expressed by

$$u_0=a\sqrt{\frac{g}{h}}\sin(k_0(x-x_0))=a\sqrt{\frac{g}{h}}\sin(k_0\sqrt{gh}t)$$

Consequently, the value of u_2 at the boundary is composed of two parts as follows,

$$u_2=a\sqrt{\frac{g}{h}}\sin(k_0\sqrt{gh}t)+\frac{1}{2}(u_1+\sqrt{\frac{g}{h}}\eta_1)$$

where the first term on the right-hand side corresponds to the given incident wave train and the second term corresponds to the receding wave trains.

If Eq.(45) is rewritten in terms of water discharge, we have

$$M_{i+\frac{1}{2},j}^{k+\frac{1}{2}}=a\sqrt{gh}\sin(k_0\sqrt{gh}(k+\frac{1}{2})\Delta t)+\frac{1}{2}(M_1+\sqrt{gh}\eta_1)$$

where M_1 and η_1 are calculated by

$$M_1=\frac{1}{\Delta x}\left[\sqrt{gh}\Delta tM_{i-\frac{1}{2},j}^{k-\frac{1}{2}}+(\Delta x-\sqrt{gh}\Delta t)M_{i+\frac{1}{2},j}^{k-\frac{1}{2}}\right]$$

$$\eta_1=\frac{1}{\Delta x}\left[\frac{1}{2}(\sqrt{gh}\Delta t-\frac{\Delta x}{2})(\eta_{i-1,j}^{k}-\eta_{i-1,j}^{k-1})+\frac{1}{2}(\frac{3}{2}\Delta x-\sqrt{gh}\Delta t)(\eta_{i,j}^{k}-\eta_{i,j}^{k-1})\right]$$

Second, we consider a two-dimensional case in which the relationship of characteristics is, in principle, given on characteristic surface. In the present text, however, an extension of the one-dimensional case mentioned above is used. Different from a one-dimensional problem, the direction of wave propagation should be determined carefully. In general, the propagation direction of the incident waves is given and constant, and therefore negative characteristics have a constant direction. On the other hand, the direction of positive characteristics corresponding to the reflected waves may be different from that of the incident waves. The direction of positive characteristics is determined as the direction of he the resultant of M(I, j, k-1/2) and N(I, j, k-1/2).In this way, negative and positive characteristics should be computed with the same method as in the one-dimensional problem, on taking their propagation direction into consideration.

(3) Open Boundary Conditions for Forced Inputs

When the boundary condition itself is already composed of progressive and reflected waves, it is given with no modification at the boundary. There is no need to follow the method developed in the precedent subsection. No consideration is required to make the reflected wave freely pass the boundary. In case of a linear problem, either the displacement of water surface or discharge flux is used as the input at the boundary.

(4) Open Boundary Conditions for Free Transmission

A method is given to make waves in the computation region go outward freely passing through an open boundary. The characteristics relationship in (2) above is used. On referring Figure 3-4, at the boundary x=x$_0$, the relationships are

$$u_0=\eta_0=0 \ and \ u_1=\sqrt{g/h}\eta_1$$

This yields

$$u_2=u_1 \quad or \quad M_{i+\frac{1}{2},j}^{k+\frac{1}{2}}=M_1$$

In case of two-dimensional propagation, the boundary condition should be set in the same way as discussed above in (2).

(5) Boundary Conditions at Run up Fronts

Run up is taken into consideration only in nonlinear computations but not in linear computations.

Whether a computation cell is dry or submerged is judged in terms of the total water depth, as follows.

$D = h + \eta > 0$, then the cell is submerged, and
$\leq$, then the cell is dry.

A wave front is located between the dry and submerged cells. The discharge across the boundary between the two cells is computed if the ground height in the dry cell is lower than the water level in the submerged cell. In other cases, discharge is considered zero.

(6) Boundary Conditions When Water Overflows Structures

The Hom-ma formula is used when water overflows breakwaters and sea walls in the computation region. Discharge overflowing a structures is given by

$$Q=\mu h_1\sqrt{2gh_1} \ , \quad if \ h_2\leq\frac{2}{3}h_1$$

$$=\mu' h_1\sqrt{2g(h_1-h_2)} \ , \ if \ h_2>\frac{2}{3}h_1$$

where h$_1$ and h$_2$ are the water depths in front of and behind structure measured above the top of structure, and coefficients μ=0.35 and μ'=2.6μ

1.3 CONTINUATION OF REGIONS

(1) Necessity of Continuation of Regions in Numerical Computation

In the design of numerical computations for long waves such as storm surges and tsunamis, it is recommended to set an open sea boundary in the deep ocean where the boundary conditions can be accurately and easily given. In addition, in order to save the CPU time, also recommended are the proper use of linear and nonlinear theories according to the degree of non-linearity of the phenomena, and (2) coarse grids in the deep sea and fine grids in the near shore zone. These selection and use require the continuation of computation at the boundary of regions of different grid length.

Our equations belong to the wave equation, for which the CFL condition should be satisfied for stability of numerical computation.

$$\frac{\Delta x}{\Delta t}=\sqrt{2gh_{\max}}$$

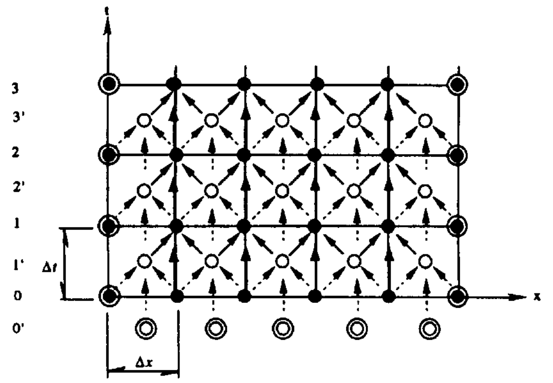
where Δt and Δx are the temporal and spatial grid lengths, and h_{max} is the maximum still water depth in a computation region. Approaching the shore, h_{max} becomes smaller, then a smaller Δx is selected to satisfy the CFL condition on keeping Δt constant. This is an ordinary way of how to select the temporal and spatial grids, if Run up is not included in simulations. If Run up is included, it is sometimes very hard to satisfy the CFL condition by changing only the spatial grid length. In this case, not only Δx but also Δt are changed in different computation regions.

Methods are given, in the following, to connect water level and discharge flux between regions of different temporal and spatial grid lengths, in order to carry out a computation continuously.

(2) Continuation of Regions of Different Δx

In a problem which is two-dimensional in space, three independent variables, x, y and t, should be taken into consideration. In the following, it is assumed that Δt is constant in any regions of different spatial grid length.

In section (a), a method of continuation and its importance is explained by taking a one-dimensional cases as an example. In section (b), a method of continuation is given for the spatially two-dimensional problem.



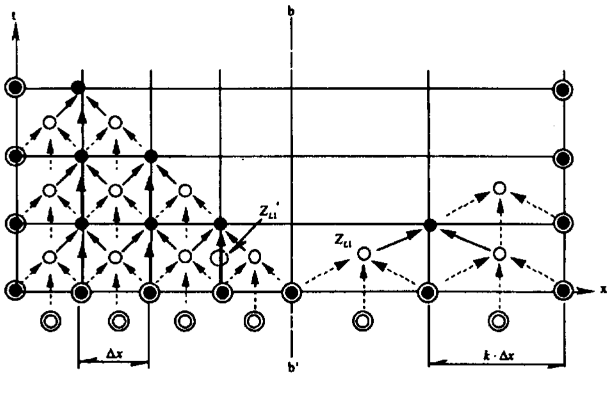


Figure 1-5. Computation procedure in the x-t plane, (A) if the spatial grid length is constant in the whole region, and (B) if two regions of different grid length are connected at the boundary b-b'.

(a) Continuation of Regions in the x-t plane

Figure 1-5 shows the process of computation in the x-t plane in a one-dimensional case. Arrows given by solid lines are for the computation of the discharge, and those by broken lines are for the computation of the water level. Numerals without prime on the t-axis correspond to the time step when the discharge is computed. Numerals with prime is for the computation of the water level. The discharge M^k is defined as the discharge at the positive x side of the computation cell(i,k).

Figure 1-5(A) is the mesh when Δx is constant in the whole region of computation. In order to begin the computation, values at points of double circles on boundaries should be known; they are, the water level Z at t=0' and the discharge M at t=0 as the initial condition, and either the discharge M at t=0 as the initial condition, and either the discharge or water level along x = 0 and x = nΔx as the boundary condition. If they are given, the water level Z_1 at t = 1' is calculated with the equation of continuity, then the discharge M_1 at t = 1 is obtained with the equation of motion. The same procedure is repeated to determine Z and M in the direction of time.

Figure 1-5(B) is a case of continuation of regions of different grid length. In the region S (of small grid length) to the left of the line b-b', the spatial grid length is Δx, and in the right region L (of larger grid length) the spatial grid length is larger and is equal to kΔx (k>1). The computation procedure in each region is the same as in the former case. However, if values are not calculated and not connected along the line, the region where the solution is given becomes narrower with the lapse of time as shown in Figure-5(B).

In order to obtain the solution in the whole x-t plane, the discharge should be known on the boundary b-b' first. This value of discharge can be calculated either in the region S or in the region L. Assume now that the discharge is calculated in the computation for the region L. In order to calculate the discharge at t = 1 on the line b-b', we need the value of the water level $Z_{L1'}$ at a point in the region S, the position of which is symmetric to the point for Z_{L1} in the region L with respect to the line b-b'. An interpolation may be used to determine $Z_{1'}$ from values obtained in the region S. However, in place of interpolation, the present authors recommend to set k be an odd number then the necessary value is already calculated in the computation in the region S.

In the authors' programme, they take the following assumptions are made.

(i) The ratio k is 3;
(ii) For connection of water level, the region L needs an extra cell in the region S beyond the line b-b';
(iii) In more general case than Figure-5(b), the region S needs an extra cell in the region L beyond the line b-b'.

Otherwise, when the direction of the x-axis is taken inversely to the case in Figure-5(B), values of discharge on the right boundary in the region S can not be calculated, because the point of computation for discharge is located on the left side of the computation cell.

In conclusion, the computation procedure for the continuation of region is summarized as shown in Figure-6 for a one-dimensional case.

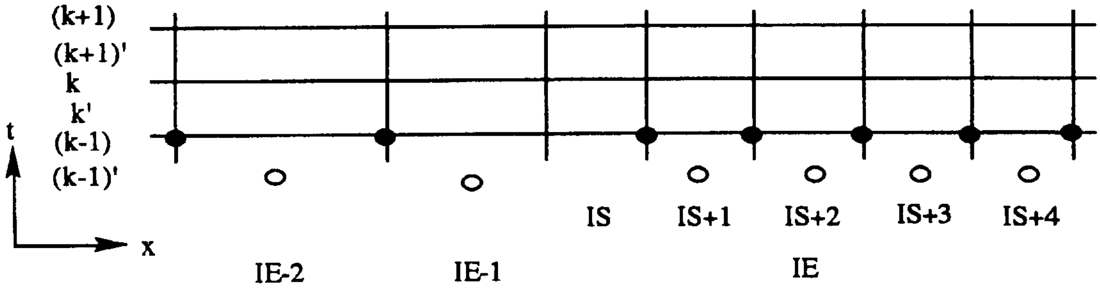


Figure 1-6(a). Details of computation continuation in the x-t plane in case of k = 3 and Δt =const. Open (filled) circles are points where the water level (discharge) is computed.

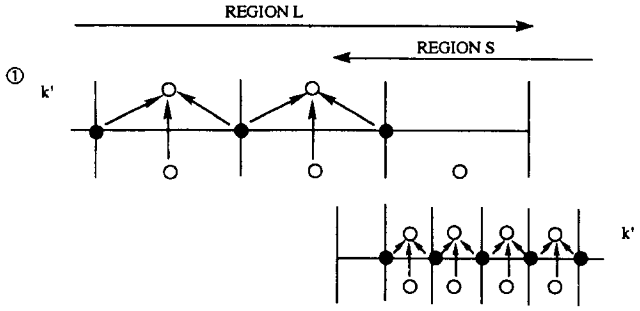


Figure 1-6(b). With the equation of continuity, $Z_S(I,K')$ and $Z_L(I',K')$ are computed. Suffixes $_S$ and $_L$ denote values in the region S of Δx and in the region L of $3\Delta x$

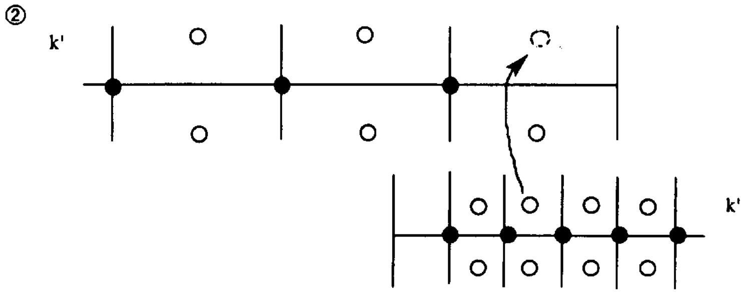


Figure 1-6(c). The water level $Z_L(IE,K')$ is set equal to $Z_S(IS+",K')$

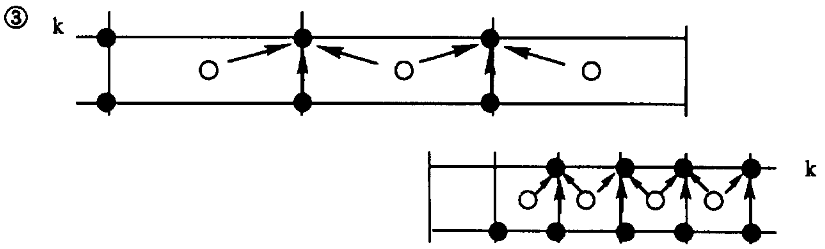


Figure 1-6(d). With the equation of motion, $M_S(I,K)$ and $M_L(I',K)$ are computed.

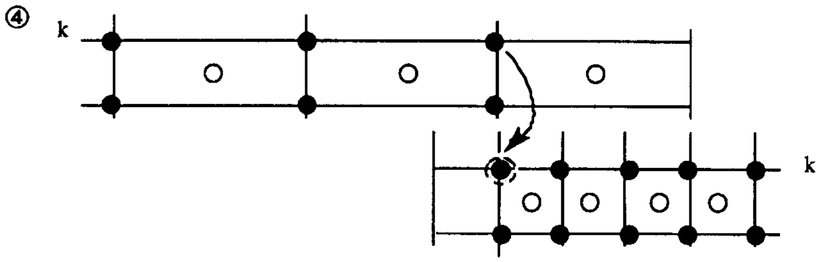


Figure 1-6(e). The water discharge $M_S(IS,K)$ is set to $M_L(IE-1,K)$

(b) Continuation of Region in the x, y-t Space

Discussion in the preceding section give the way of connection of values when a difference equation is solved across the boundary between two regions of different grid length.

(i) The water level in the region S in the neighborhood of the line b-b' is used in the computation in the region L.

(ii) The water discharge in the region L in the neighborhood of the line b-b' is used in the computation in the region S.

The method is explained for a two-dimensional case, on referring Figure-7 where circles are computation points for water level and arrows are those for discharge.

As for the water level, two methods are possible. Since k is taken equal to 3, when the region L is extended by an extra cell into the region S, this extra cell is composed of 9 small cells of the region S. The central point (marked by double circles in Figure-7) of the 9 cells is located at the central point of the extra cell.

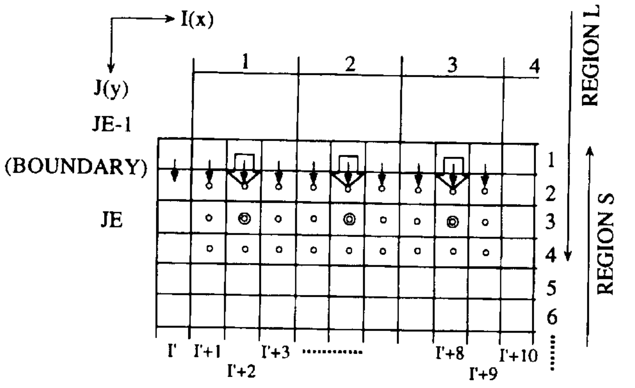


Figure 1-7. Continuation between two regions S and L in the (x,y-t) space, where k = 3 and Δt = const.

Therefore, we set

$$Z_L(1,JE) = Z_S(I'+2,3)$$

or, taking the mean value averaged over 9 cells, we have

$$Z_L(1,JE) = \frac{1}{9}\sum_{I'=I'+1}^{I'+3}\sum_{J'=2}^{4} Z_s(I',J')$$

Different from the water level, the connection of the water discharge requires either interpolation or extrapolation. Along the boundary between the regions L and S, discharges area connected as follows, on referring Figure-7.

(i) At points from (I'+2) to (I'+8) along the boundary, discharges are calculated by an interpolation. For example,

$$M_S(I'+3,1) = (2.0*M_L(1,JE-1) + 1.0*M_L(2,JE-1))/3.0$$

(ii) At other points, an interpolation is used if the region L still exists. For example, the discharge at the point (I'+10) on the boundary is given by,

$$M_S(I'+10,\ 1) = (1.0*M_L(3,JE-1) + 2.0*M_L(4,\ JE-1))/3.0$$

If the region L does not exist as the point I', an extrapolation is used. Then, we have

$$M_S(I',\ 1) = (5.0*M_L(1,JE-1) - 2.0*M_L(2,JE-1))/3.0$$

(3) Continuation of Regions of Different Δt

Assume that the time grid changes from 3Δt to Δt. Figure 1-8 shows the computation procedure in the x-t plane.

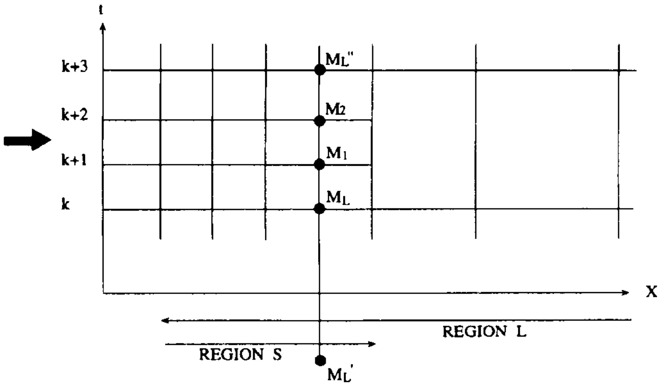


Figure 1-8. Computation continuation between two regions S and L in the x-t plane when Δt varies at the ration of 1:3.

As for the water level, values in the region S is used in the computation in the region L. This means that values are connected at the time step shown by an arrow in Figure 1-8; i.e., at the middle of 3 cells in the region S.

As for the discharge, values in the region L is used in the computation in the region S. Therefore, at each time step in the region S (at K, K+1,K+2, and so on), values of discharge such as M_1 and M_2 should be given.

Let M_L at time K and M_L'at time (K-3) be known. Then, M1 is calculated by an extrapolation.

The same extrapolation is applicable to M_2. However, an interpolation is preferable for M_2 in order to reduce numerical errors. For this interpolation, value of M_L" should be known beforehand at time (K+2).

Figure 1-9 shows the way of computation in detail.

A comment is added here that the position of time-region continuation is not necessarily the same as the position of space-region continuation.

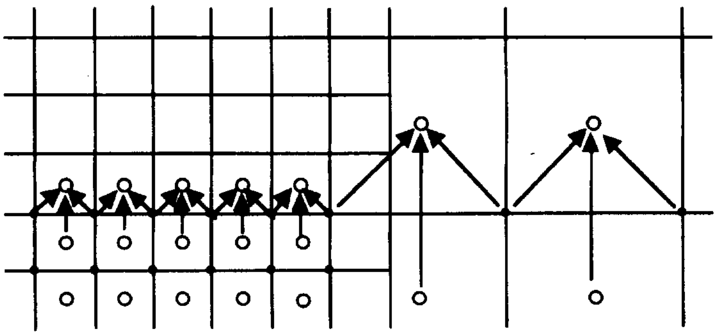


Figure 1-9(a). Details of computation continuation in the x-t plane, when Δt varies at the ratio of 1:3. Computation of the water level Z in the regions S and L, with the equation of continuity.

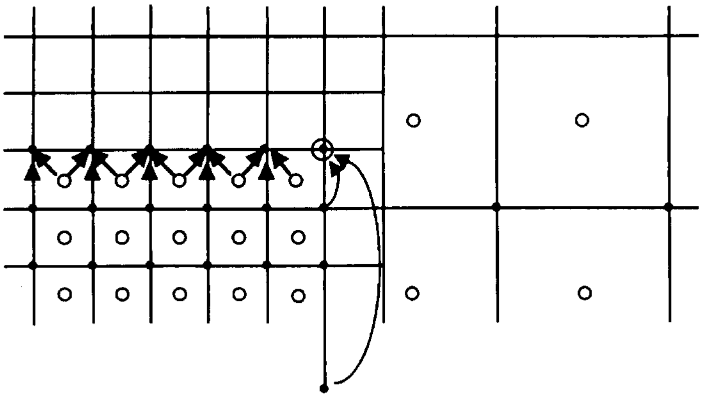


Figure 1-9(b). Computation of the water discharge M in the region S, with the equation of motion. An extrapolation in the region L to determine value of M at the boundary. Connection of the water discharge from the region L to the region S.

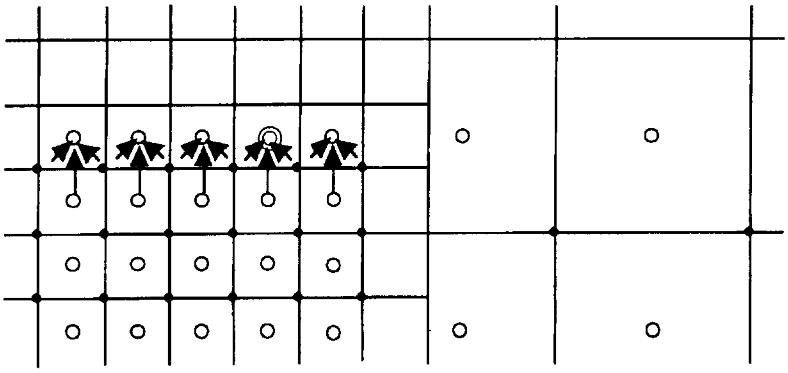


Figure 1-9(c). Computation of the water level Z in the region S, with the equation of continuity. Connection of the water level from the region S to the region L.

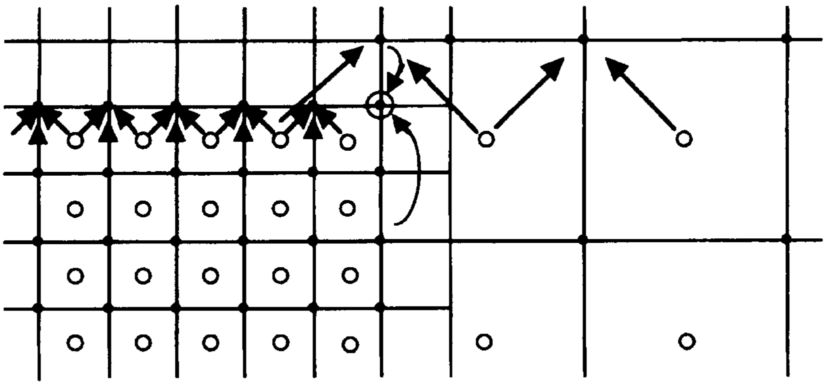


Figure 1-9(d). Computation of the water discharge M in the region S and L, with the equation of motion. An interpolation in the region L to determine values of M at the boundary. Connection of the water discharge from the region L to the region S.

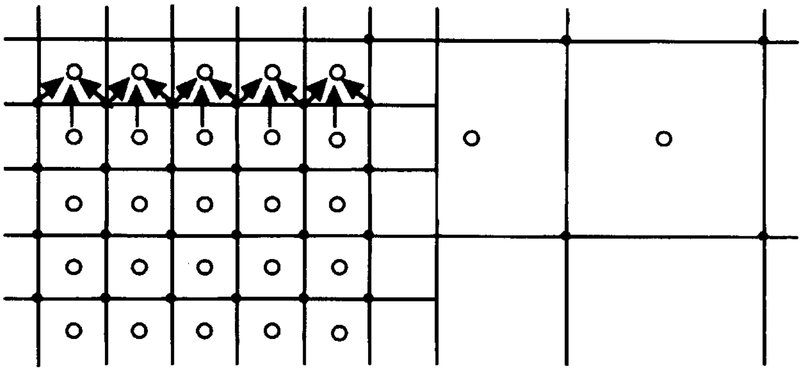


Figure 1-9(e). Computation of the water level Z in the region S, with the equation of continuity

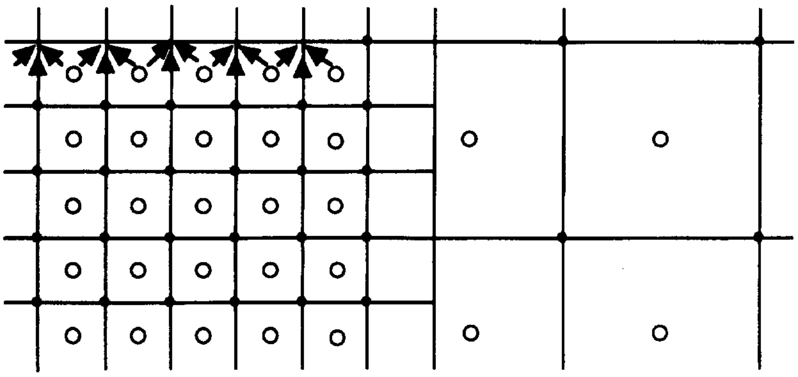


Figure 1-9(f). Computation of the water discharge M in the region S, with the equation of motion.

CHAPTER 2. TYPICAL PROGRAMMES

2.1 ASSUMPTIONS

The following three assumptions are made.

(1) The astronomical tide does not vary with respect to time throughout the tsunami computation. The still water level in the computation is set equal to the water level at the beginning of computation.

(2) Both the spatial and temporal grid lengths vary only at the ratio of 1:3:9: and so on, if the change of them is necessary.

(3) In the linear computation, no run up can be included, and therefore the computation is not carried out for the water depth shallower than 0.1cm, and vertical walls are set in place of the actual slope.

2.2 CONSTRUCTION OF MAIN PROGRAMMES

In order to make it easy to understand the flow of computation, the main programme is composed of calls of sub-programmes. For simplicity of explanation, we take a region of computation shown in Figure 2-1 as an example. The region is of a constant water depth, surrounded by vertical walls (shown by hatches) and has a small bay also bounded by vertical walls. The region is divided into three subregions, A, B and C, the spatial and temporal grid lengths of which vary as 9:3:1. In Table 2-1, letters used in the main and subroutines are summarized and explained. The main programme is given after Table 2-1 from page 30 to page 34. In the following, explanations and hints in programming are given, in the order of the flow in the main programme.

(1) Specification Statement

- REAL M and N should be stated.

- Declare, in each domains, three-dimensional arrays for Z, M, N, DZ, DM, and DN, and two-dimensional arrays for HZ, HM, HN, IR and IB. Declaration of BT(10) should not be missed (This will be explained later). Dimensions for space should be increased by one in order to include an extra row or column outside the domain under consideration, as shown in Figure 2-1. Otherwise, discharge on the boundary, or IB and IR maps (both of them will be explained later) are sometimes not definable, according to the way of selection of the I and J axes. Dimensions for time are always taken to be 2, because values are changed by a subroutine CHANGE.

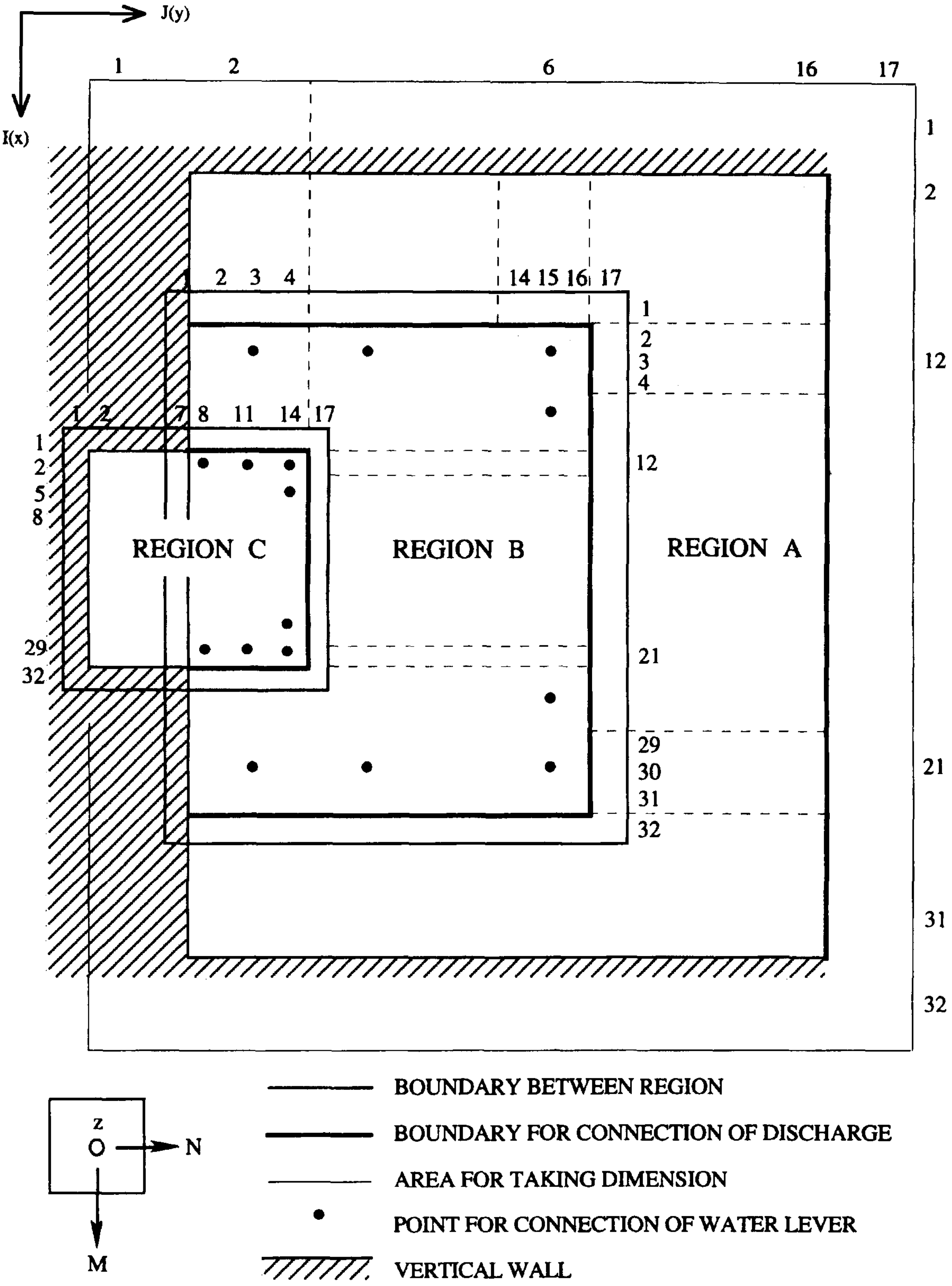


Figure 2-1: A model basin for explanation of the programme

(2) Input of Setting Values

- Values of DX, DT AND R(=DT/DX) should be input in every domains.

(3) Setting of Initial Value

(i) CALL DEPTH0

With this command, data of water depth HZ, IB and IR map are input in every domain. To build this subroutine for data input, the following points should be taken into consideration.

- Water depth

Read water depths HZ on hydrographic charts with the z-axis positive downwards.

- IB map (a two-dimensional array)

An IB map gives the method of computation and the existence of vertical walls. According to the following rule, positive integers of one or two figures are allotted to and input into every grid point in every domain.

The unit digit = 0, the computation is with the linear theory without the convection term.

The unit digit = 1, the computation is with the nonlinear theory with the convection term included.

The tenth digit = 1, the discharge flux M in the I-direction is zero, owing to the existence of a vertical wall.

The tenth digit = 2, the discharge flux N in the J-direction is zero, owing to the existence of a vertical wall.

The tenth digit = 3, the discharge fluxes M and N in the I- and J-directions are zero, owing to the existence of a vertical wall.

The tenth digit = 4, no computation.

For example (See Figure 2-1), if the computation in the domain A is carried out with the linear theory, the IB(I,J) is set as follows.

IB(I,J) = 10, for $1 \leq I \leq 31$ and $1 \leq J \leq 16$, because of the vertical wall.

IB(I,J) = 20, for $2 \leq I \leq 31$ and J = 1, because of the vertical wall.

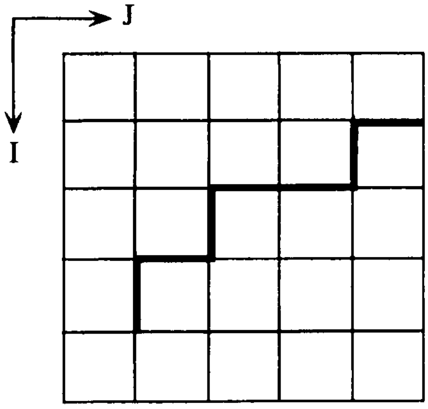
IB(I,J) = 40, for $12 \leq I \leq 20$ and $1 \leq J \leq 5$, the computation in the domain A is not necessary because it is carried out in the domain B.

IB(I,J) = 0, for other combination of I and J.

- IR map (a two-dimensional array)

This map shows the existence of such structures as sea walls of finite crown height. According to the following rule, positive integers of one or two figures are allotted to and input into every grid point in every domain.

The unit digit -------- assign the address I (=1~9) of BT(I), data of the crown height of sea walls.
No tenth digit -------- no sea wall.
The tenth digit = 1, there is a sea wall on the computation line of discharge M in the I-direction.
The tenth digit = 2, there is a sea wall on the computation line of discharge N in the J-direction.
The tenth digit = 3, there is a sea wall both on the computation lines of discharge M and N in the I- and J-directions.



0	0	0	0	11
0	0	11	31	0
0	31	0	0	0
21	0	0	0	0
0	0	0	0	0

Figure 2-2: An example of the IR map.

An example of IR map is shown in Figure 2.2 The thick line in Figure 2.2(a) is the axis of the sea wall. Figure.2.2(b) is the corresponding IR map. In BT(1), stored is the crown height of sea wall measured positive upward above still water level. Attention should be paid on the fact that the positive direction for the crown height is different from that for HZ, HM and HN.

(ii) CALL DEPTH

Water depths HM and HN at the point where the discharge is computed are calculated. A call statement is necessary for a computation domain.

(iii) CALL SETZRO

Initial values are set for Z, M, N and DZ, all of which are set equal to zero. A call statement is necessary for a computation domain.

(4) Computation Repeated with Respect to Time

(i) CALL CONTIN

The water depth Z at the next time step is computed with the equation of continuity. A call statement is necessary for a computation domain.

(ii) CALL JOINTZ

The water depth is connected between domains of different time and space grid lengths. A call statement is necessary for a line of connection. In Figure 2-1, six call statements are required in total :three call statements between the domain A and the domain B, and other three call statements between the domain B and the domain C.

(iii) CALL MOTION

The discharges M and N at the next time step is computed with the equation of motion. Discharges over sea walls is evaluated with the Hom-ma formula. A call statement is necessary for a commutation domain.

(iv) CALL BOUND

The conditions are input at the seaside boundary. Input data of a tsunami should be prepared, on referring Chapter 1, Section 1-1.

(v) CALL JOINTQ

The discharge is connected between domains of different time and space grid lengths. A call statement is necessary for a line of connection.

(vi) CALL OUTPUT

A subroutine is added at need, to output the computed results.

(vii) CALL CHANGE

Old data one time step before are changed with new data. For example, newly obtained Z(I, J, 2) replaces old data and become Z(I, J, 1) which is used in the next computation.

- Time Step Index

If the time step Δt varies from a domain to another, the computation procedures from (i) to (vii) mentioned above is not always carried out at every time step except in the domain of the smallest Δt. The time step at which the computation is carried out in the other domains should be controlled by introducing the "time step index". On referring Figure 1-9 and the subroutine given later in 2.3, the time step index is as follows in case of Figure 2-1.

KT in CONTIN, MOTION, CHANGE	1, 3, 9 in domains C, B and A, respectively.
KT in JOINTZ	3 in connection of domains C and B. 9 in connection of domains B and A.
KT1 and KT2 in JOINTQ	1 and 3 in connection of domains C and B. 3 and 9 in connection of domains B and A.

Table 2-1: Notations in the Main Programme

Notation	Type	Definition
Z	R (3-D array)	water level
M	R (3-D array)	discharge in the I-direction
N	R (3-D array)	discharge in the J-direction
DZ	R (3-D array)	total water depth at point for Z
DM	R (3-D array)	total water depth at point for M
DN	R (3-D array)	total water depth at point for N
HZ	R (2-D array)	still water depth at point for Z
HM	R (2-D array)	still water depth at point for M
HN	R (2-D array)	still water depth at point for N
IB	I (2-D array)	map of the selection of theory (linear of nonlinear, and the existence of vertical walls.
IR	I (2-D array)	map of the existence of structures
BT	R (1-D array)	crown height of structures
DX	R	space grid length
DT	R	time step length
R	R	ration DT / DX
GG	R	gravitational acceleration
PP	R	2 Pi
K	I	time step of the computation
K1	I	argument to call subroutines, taken as the same value as K
KE	I	the last time step
(KOUT)	I	time step for output procedure
(WP)	R	wave period
(WD)	R	water depth
(LL)	R	index for output
(LX)	R	index for output

Note: Suffixes A, B and C denotes domains. Notations in parentheses are used only in this programme

```
C
C        MAIN PROGRAMME
C
         REAL MA,NA,MB,NB,MC,NC
         DIMENSION ZA(32,17,2),MA(32,17,2),NA(32,17,2),DZA(32,17,2), &
         DMA(32,17,2),DNA(32,17,2),HZA(32,17),HMA(32,17),HNA(32,17) DIMENSION
         ZB(32,17,2),MB(32,17,2),NB(32,17,2),DZB(32,17,2), &
         DMB(32,17,2),DNB(32,17,2),HZB(32,17),HMB(32,17),HNB(32,17) DIMENSION
         ZC(32,17,2),MC(32,17,2),NC(32,17,2),DZC(32,17,2), &
         DMC(32,17,2),DNC(32,17,2),HZC(32,17),HMC(32,17),HNC(32,17) DIMENSION
         IRA(32,17),IRB(32,17),IRC(32,17) DIMENSION IBA(32,17),IBB(32,17),IBC(32,17) DIMENSION
         BT(10)
C
C        READ(5,*), DXC,DTC,WP,WD,KOUT
         DXC = 50.0
         DTC = 1.0
         WP = 600.0
         WD = 50.0
         KOUT = 5
         DXB=3.0*DXC
         DXA=3.0*DXB
         DTB=3.0*DTC
         OTA=3.0*DTB
         RA=DTA/DXA
         RB=DTB/DXB
         RC=DTC/DXC
         GG=9.8
         PP=6.283185
         KE=IFIX(2.0*WP/DTC)
         DO 20 I=1,10
         BT(I)=0.0
    20   CONTINUE
C
         CALL DEPTHO(32,17,HZA,IRA,IBA,WD,1)
         CALL DEPTHO(32,17,HZB,IRB,IBB,WD,2)
         CALL DEPTHO(32,17,HZC,IRC,IBC,WD,3)
C
         CALL DEPTH(32,17,HZA,HMA,HNA,BT,IRA)
         CALL DEPTH(32,17,HZB,HMB,HNB,BT,IRB)
         CALL DEPTH(32,17,HZC,HMC,HNC,BT,IRC)

         CALL SETZRO(32,17,ZA,MA,NA,DZA,HZA)
         CALL SETZRO(32,17,ZB,MB,NB,DZB,HZB)
         CALL SETZRO(32,17,ZC,MC,NC,DZC,HZC)
         LL=1
         LX=0
C
         DO 10 K=1,KE
         K1=K
         CALL CONTIN(32,17,2,31,2,16,ZA,MA,NA,DZA,HZA,RA,IBA,K1,9)
         CALL CONTIN(32,17,2;31,2,16,ZB,MB,NB,DZB,HZB,RB,IBB,K1,3)
         CALL CONTIN(32,17,2,31,2,16,ZC,MC,NC,DZC,HZC,RC,IBC,K1,1)
C
         CALL JOINTZ(32,17,32,17,ZB,ZA,DZB,DZA,12,12,2,6,3,3,K1,9,DXA,DXB)
         CALL JOINTZ(32,17,32,17,ZB,ZA,DZB,DZA,12,21,6,6,3,15,K1,9,DXA,DXB)
         CALL JOINTZ(32,17,32,17,ZB,ZA,DZB,DZA,21,21,2,6,30,3,K1,9,DXA,DXB)
C
         CALL JOINTZ(32,17,32,17,ZC,ZB,DZC,DZB,12,12,2,4,3,9,K1,3,DXB,DXC)
         CALL JOINTZ(32,17,32,17,ZC,ZB,DZC,DZB,12,21,4,4,3,15,K1,3,DXB,DXC)
         CALL JOINTZ(32,17,32,17,ZC,ZB,DZC,DZB,21,21,2,4,30,9,K1,3,DXB,DXC)
```

```
C
          CALL      MOTION(32,17,2,31,2,16,ZA,MA,NA,DZA,DMA,DNA,HZA,HMA,HNA,IRA,      &
          IBA,RA,0.0,DTA,K1,9)
          CALL      MOTION(32,17,2,31,2,16,ZB,MB,NB,DZB,DMB,DNB,HZB,HMB,HNB,IRB,      &
          IBB,RB,0.0,DTB,K1,3)
          CALL      MOTION(32,17,2,31,2,16,ZC,MC,NC,DZC,DMC,DNC,HZC,HMC,HNC,IRC,      &
          IBC,RC,0.0,DTC,K1,1)

C
          CALL BOUND(32,17,2,31,NA,ZA,WD,WP,DTA,DXA,K1,9)
C
          CALL JOINTQ(32,17,32,17,MA,MB,NA,NB,1,1,2,16,11,2,0,1,0,2, & K1,3,9,DXA,DXB)
          CALL JOINTQ(32,17,32,17,MA,MB,NA,NB,2,31,16,16,12,6,0,2,0,2, & K1,3,9,DXA,DXB)
          CALL JOINTQ(32,17,32,17,MA,MB,NA,NB,31,31,2,16,21,2,0,1,0,2, & K1,3,9,DXA,DXB)
          CALL JOINTQ(32,17,32,17,MB,MC,NB,NC,1,1,8,16,11,2,0,1,0,2, & K1,1,3,DXB,DXC)
          CALL JOINTQ(32,17,32,17,MB,MC,NB,NC,2,31,16,16,12,4,0,2,0,2, & K1,1,3,DXB,DXC)
          CALL JOINTQ(32,17,32,17,MB,MC,NB,NC,31,31,8,16,21,2,0,1,0,2, & K1,1,3,DXB,DXC)
C
          IF(MOD(K1,9).EQ.5) LL=LL+1
          IF(MOD(LL,KOUT).NE.0) GO TO 30
          IF(LL.EQ.LX) GO TO 30
C
          CALL OUTPUT(32,17,ZA,DZA,K1)
          CALL OUTPUT(32,17,ZB,DZB,K1)
          CALL OUTPUT(32,17,ZC,DZC,K1)
          WRITE(60,1000) K
     1000 FORMAT(10X,'K=',I5)
     30   CONTINUE
          LX=LL
C
          CALL CHANGE(32,17,ZA,MA,NA,DZA,K1,9)
          CALL CHANGE(32,17,ZB,MB,NB,DZB,K1,3)
          CALL CHANGE(32,17,ZC,MC,NC,DZC,K1,1)
C
     10   CONTINUE
C
          STOP
          END

          SUBROUTINE BOUND(IG,JG,IS,IE,N,Z,WD,WP,DT,DX,KK,KT)
          REAL N
          DIMENSION N(IG,JG,2),Z(IG,JG,2)
          GG=9.8
          PP=6.283185
          IF(KT.EQ.1) GO TO 200
          IF(MOD(KK,KT).NE.KT/2+1) RETURN
     200  CONTINUE
          DO 10 I=IS,IE
          CC=SQRT(GG*WD)
          XMM=(CC*DT*N(I,15,1)+(DX-CC*DT)*N(1,16,1))/DX
          ZZ2=(Z(I,15,2)+Z(I,15,1))*0.5
          ZZ1=(Z(I,16,2)+Z(I,16,1))*0.5
          ZZ=((CC*DT-0.5*DX)*ZZ2+(1.5*DX-CC*DT)*ZZ1)/DX
          EZ=-2.0*SIN(PP*FLOAT(KK)*DT/(WP*FLOAT(KT)))
          N(I,16,2)=CC*EZ+0.5*(XMM+CC*ZZ)
     10   CONTINUE
          RETURN
          END
```

```
      SUBROUTINE DEPTH (IG,JG,HZ,HM,HN,BT,IR)
      DIMENSION HZ(IG,JG),HM(IG,JG),HN(IG,JG)
      DIMENSION IR(IG,JG),BT(10)
      DO 10 I=1,IG
      DO 10 J=1,JG
      IF(I.EQ.IG) GO TO 11
      HM(I,J)=0.5*(HZ(I,J)+HZ(I+1,J))
      GO TO 12
11    HM(I,J)=HZ(I,J)
12    IF(J.EQ.JG) GO TO 13
      HN(I,J)=0.5*(HZ(I,J)+HZ(I,J+l))
      GO TO 10
13    HN(I,J)=HZ(I,J)
10    CONTINUE
      DO 14 I=1,IG
      DO 14 J=1,JG
      IRR=MOD(IR(I,J),10)
      IRM=IR(I,J)/10
      IF(IRM.EQ.0) GO TO 14
      IF(IRM.EQ.2) GO TO 15
      HM(I,J)=-BT(IRR)
      IF(IRM.EQ.1) GO TO 14
15    HN(I,J)=-BT(IRR)
14    CONTINUE
      RETURN
      END

      SUBROUTINE OUTPUT(IG,JG,Z,DZ,KK)
C
      DIMENSION LW(20),Z(IG,JG,2),DZ(lG,JG,2)
      WRITE(6,100) KK,(J,J=2,l6)
100   FORMAT(1H ,2X,'K=',I4,/,6X,15I4)
      IG1=IG-1
      JGl=JG-1
      DO 10 I=2,IG1
      DO 11 J=2,JG1
      LW(J)=0
      IF(DZ(I,J,2).GT.1.0E-4) LW(J)=IFIX(100.0*Z(I,J,2)+0.5)
11    CONTINUE
      WRITE(6,101) I,(LW(J).J=2,16)
101   FORMAT(1H ,I5,15I4)
10    CONTINUE
      RETURN
      END
```

2.3 Explanation of Subroutines

(1) DEPTH (Computation of the water depth at points for discharge)

Objective

The still water depth at points for discharge is calculated, based upon the still water depth at point for water depth. Information of the existence of structures from the map of breakwaters is also input.

Method of Connection

CALL DEPTH (IG, JG, HZ, HM, HN, BT, IR)

Parameter	Type	Content Before Calling the Subroutine	Content When Returned from the Subroutine
IG, JG	I	Indices of HZ,HM,HN and IR in the main programme	No change
HZ	R (2-D array) (JG, IG)	Still water depth	No change
HM	R (2-D array) (JG, IG)	No input	Still water depth at points for discharge in the I-direction
HN	R (2-D array) (JG, IG)	No input	Still water depth at points for discharge in the J-direction
BT	R (1-D array) (10)	Crown height of breakwaters	No change
IR	I (2-D array) (JG, IG)	Map of existence of breakwaters (integer of two figures)	No change

```
      SUBROUTINE DEPTH (IG,JG,HZ,HM,HN,BT,IR)
      DIMENSION HZ(IG,JG),HM(IG,JG),HN(IG,JG)
      DIMENSION IR(IG,JG),BT(10)
      DO 10 I=1,IG
      DO 10 J=1,JG
      IF(I.EQ.IG) GO TO 11
      HM(I,J)=0.5*(HZ(I,J)+HZ(I+1,J))
      GO TO 12
 11   HM(I,J)=HZ(I,J)
 12   IF(J.EQ.JG) GO TO 13
      HN(I,J)=0.5*(HZ(I,J)+HZ(I,J+l))
      GO TO 10
 13   HN(I,J)=HZ(I,J)
 10   CONTINUE
      DO 14 I=1,IG
      DO 14 J=1,JG
      IRR=MOD(IR(I,J),10)
      IRM=IR(I,J)/10
      IF(IRM.EQ.0) GO TO 14
      IF(IRM.EQ.2) GO TO 15
      HM(I,J)=-BT(IRR)
      IF(IRM.EQ.1) GO TO 14
 15   HN(I,J)=-BT(IRR)
 14   CONTINUE
      RETURN
      END
```

(2) SETZRO (Setting of initial condition)

Objective

Input of initial values of water level, water discharge, and total water depth at points for water level.

Method of Connection

CALL SETZRO (IG, JG, Z, M, N, DZ, HZ)

Parameter	Type	Content Before Calling the Subroutine	Content When Returned from the Subroutine
IG, JG	I	Indices of Z, M, N, DZ and HZ in the main programme	No change
Z	R (3-D array) (JG, IG, 2)	No input	Initial water level
M	R (3-D array) (JG ,IG, 2)	No input	Initial discharge in the I-direction
N	R (3-D array) (JG ,IG, 2)	No input	Initial discharge in the J-direction
DZ	R (3-D array)	No input	Initial total water depth at point for
HZ	R (2-D array) (JG, IG)	Still water depth at point for water level	No change

```
      SUBROUTINE SETZRO (IG,JG,Z,M,N,DZ,HZ)
      REAL M,N
      DIMENSION Z(IG,JG,2),M(IG,JG,2),N(IG,JG,2)
      DIMENSION DZ(IG,JG,2),HZ(IG,JG)
      DO 10 K=1,2
      DO 10 I=1,IG
      DO 10 J=1,JG
      M(I,J,K)=0.0
      N(I,J,K)=0.0
      DZ(I,J,K)=HZ(I,J)
      IF(HZ(I,J).LT.1.0E-5) DZ(I,J,K)=0.0
      Z(I,J,K)=DZ(I,J,K)-HZ(I,J)
10    CONTINUE

      RETURN
      END
```

(3) CONTIN (Computation of the equation of continuity)

Objective

Cotation of the water level and total water depth at the next time step with the equation of continuity.

Method of Connection

CALL CONTIN (IG, JG, IS, IE, JS, JE, Z, M, N, DZ, HZ, R, IB, KK, KT)

Parameter	Type	Content Before Calling the Subroutine	Content When Returned from the Subroutine
IG, JG	I	Indices of Z, M, N, DZ and HZ in the main programme	No change
IS, IE	I	Co-ordinates of the start of imputation	No change
JS, JE	I	(IS, JS) and of end (IE, JE)	No change
Z	R (3-D array) (JG, IG, 2)	Water level given as Z(I, J, 2)=Z(I, J, 1)	Z(I, J, 2) newly computed
M	R (3-D array) (JG, IG, 2)	Discharge in the I-direction	No change
N	R (3-D array) (JG, IG, 2)	Discharge in the J-direction	No change
DZ	R (3-D array) (JG, IG, 2)	Total water depth at points for water level	DZ(I, J, 2) newly computed
HZ	R (2-D array) (JG, IG)	Still water depth at points for water level	No change
R	R	DT/DX; ratio of time-to-space grid length	No change
IB	I (2-D array) (JG, IG)	Map of the selection of theory (linear or nonlinear) and of the existence of vertical walls	No change
KK	I	Time step	No change
KT	I	Time step index	No change

```
      SUBROUTINE CONTIN (IG,JG,IS,IE,JS,JE,Z,M,N,DZ,HZ,R,IB, & KK,KT)
C
      REAL M,N
      DIMENSION Z(IG,JG,2),M(IG,JG,2),N(IG,JG,2),HZ(IG,JG)
      DIMENSION DZ(IG,JG,2),IB(IG,JG)
      DATA GX/1.0E-5/
      IF(KT.EQ.1)GO TO 200
      IF(MOD(KK,KT).NE.1)RETURN
  200 CONTINUE
      DO 10 I=IS,IE
      DO 10 J=JS,JE
      IF(IB(I,J).EQ.40) GO TO 11
      XM=0.0
      XN=0.0
      IF(I.NE.1)XM=M(I-1,J,2)
      IF(J.NE.1)XN=N(I,J-1,2)
      ZZ=Z(I,J,1)-R*(M(I,J,2)-XM+N(I,J,2)-XN)
      IF(ABS(ZZ).LT.1.0E-10)ZZ=0.0
      DD=ZZ+HZ(I,J)
      IF(DD.LT.GX) GO TO 11
      DZ(I,J,2)=DD
      Z(I,J,2)=ZZ
      GO TO 10
   11 DD = 0.0
      DZ(I,J,2)=DD
      Z(1,J,2)=DD-HZ(I,J)
   10 CONTINUE
      RETURN
      END
```

(4) JOINTZ (Connection of the water level in space and time)

Objective

Connection of the water level between computation domains of different Δx and Δt.

Method of Connection

CALL JOINTZ (IG1, JG1, IG2, JG2, Z1, Z2, DZ1, DZ2, IS, IE, JS, JE, ISS, JSS, KK, KT, DX1, DX2)

Parameter	Type	Content Before Calling the Subroutine	Content When Returned from the Subroutine
IG1, JG1	I	Indices of Z1 and DZ1 in the main programme	No change
IG2, JG2	I	Indices of Z2 and DZ2 in the main programme	No change
Z1	R (3-D array) (JG1, IG1, 2)	Water level in the sender (domain of fine grids)	No change
Z2	R (3-D array) (JG2,IG2,2)	Water level in the receiver (domain of coarse grids)	Values after connection
DZ!	R (2-D array) (JG1, IG1)	Water depth at points for water level in the sender	No change
DZ2	R (2-D array) (JG2, IG2)	Water depth at points for water level in the receiver	No change
IS, IE	I	Co-ordinates of the start of connection	No change
JS, JE	I	(IS, JS) and the end (IE, JE) in the receiver	No change
ISS, JSS	I	Co-ordinates of the start of connection in the sender	No change
KK	I	Time step	No change
KT	I	Time step index of the receiver	No change
DX1, DX2	R	Space grid length in the sender (DX1) and in the receiver (DX2)	No change

```
      SUBROUTINE      JOINTZ      (IG1,JG1,IG2,JG2,Z1,Z2,DZ1,DZ2,IS,IE,JS,JE,      &
      ISS,JSS,KK,KT,DX1,DX2)
      DIMENSION Z1(IG1,JG1,2),Z2(IG2,JG2,2)
      DIMENSION DZI(IG1,JG1,2),DZ2(IG2,JG2,2)
      IF(KT.EQ.1) GO TO 200
      IF(MOD(KK,KT).NE.KT/2+1)RETURN
200   CONTINUE
      DO 10 I=IS,IE
      DO 10 J=JS,JE
      IF(DX2-DX1) 20,21,20
20    II=ISS+3*(I-IS)
      JJ=JSS+3*(J-JS)
      GO TO 22
21    II=ISS+(I-IS)
      JJ=JSS+(J-JS)
22    Z2(I,J,2)=Z1(II,JJ,2)
      DZ2(I,J,2)=DZ1(II,JJ,2)
10    CONTINUE
      RETURN
      END
```

(5) MOTION (Computation of the equation of motion)

Objective

Computation of the water discharge at the next time step with the equation of motion.

Method of Connection

```
CALL MOTION (IG, JG, Z, M, N, DZ, DM, DN, HZ, HM, HN, IR, IB, R, FM, DT, KK, KT)
```

Parameter	Type	Content before calling the subroutine	Content when returned from the subroutine
JG, IG	I	Indices of Z, M, N, DZ, DM, DN, HZ, HM, HN, IR, IB, in the main programme	No change
Z	R (3-D array) (JG, IG, 2)	Water level	No change
M	R (3-D array) (JG, IG, 2)	Discharge in the I-direction given as M(I, J, 1)=M(I, J, 2)	M(I, J, 2) newly computed
N	R (3-D array) (JG, IG, 2)	Discharge in the j-direction given as N(I, J, 1)=N(I, J, 2)	N(I, J, 2) newly computed
DZ	R (3-D array) (JG, IG, 2)	Total water depth at points for water level	No change
DM	R (3-D array) (JG, IG, 2)	No need of input	Total water depth at points for M
DN	R (3-D array) (JG, IG, 2)	No need of input	No change
HZ	R (2-D array) (JG, IG)	Still water depth at points for water level	No change
HM	R (2-D array) (JG, IG)	Still water depth at points for M	No change
HN	R (2-D array) (JG, IG)	Still water depth at points for N	No change
IR	R (2-D array) (JG, IG)	Map of the existence of breakwaters (positive integer of two figures)	No change
IB	R (2-D array) (JG, IG)	Map of the selection of theory (linear or nonlinear) and of the existence of vertical walls (positive integer of two figures)	No change
R	R	DT/DX; RATIO of time-to-space grid length	No change
FM	R	Manning`s roughness in s/m$^{1/3}$	No change
DT	R	Time step length	
KK	I	Time step	
KT	I	Time step index	

```
      ROUTINEMOTION(IG,JG,IS,IE,JS,JE,Z,M,N,DZ,DM,DN,HZ,HM,HN, & IR,IB,R,FM,DT,KK,KT)
      REAL M,N
      DIMENSION Z(IG,JG,2),M(IG,JG,2),N(IG,JG,2)
      DIMENSION DZ(IG,JG,2),DM(IG,JG,2),DN(IG,JG,2)
      DIMENSION HZ(IG,JG),HM(IG,JG),HN(IG,JG)
      DIMENSION IR(IG,JC),IB(IG,JG)
      DATA GG,GX/9.8,1.0E-5/
      IF(KT.EQ.1)GO TO 200
      IF(MOD(KK,KT).NE.KT/2+1)RETURN
200   CONTINUE
      DO 10 I=IS,IE
      DO 10 J=JS,JE
      DMI=0.25*(Z(I,J,1)+Z(I,J,2)+Z(I+1,J,1)+Z(I+1,J,2))+HM(I,J)
      DM2=0.5*(Z(I,J,2)+Z(I+1,J,2))+HM(I,J)
      DNl=0.25*(Z(I,J,1)+Z(I,J,2)+Z(I,J+1,1)+Z(I,J+1,2))+HN(I,J)
      DN2=0.5*(Z(I,J,2)+Z(I,J+1,2))+HN(I,J)
      IF(DM1.LT.GX)DM1=0.0
      IF(DM2.LT.GX)DM2=0.0
      IF(DN1.LT.GX)DN1=0.0
      IF(DN2.LT.GX)DN2=0.0
      DM(I,J,1)=DM1
      DM(I,J,2)=DM2
      DN(I,J,1)=DN1
      DN(I,J,2)=DN2
l0    CONTINUE
      FN=0.5*DT*GG*FM**2
      DO 20 I=IS,IE
      DO 20 J=JS,JE
      IBB=IB(I,J)/10
      IBR=MOD(IB(I,J),10)
      IF(IBB.EQ.4)GO TO 20
      IF(IBB.EQ.1.0R.IBB.EQ.3)GO TO 30
      IF(I.EQ.IG)GO TO 30
      IRR=IR(I,J)/10
      IF(IRR.EQ.1.OR.IRR.EQ.3)GO TO 60
      IF(IBR.EQ.0)GO TO 33
      IF(DZ(I.J.2))31,31,32
31    IF(DZ(I+1,J,2))30,30,34
32    IF(DZ(I+1,J,2))35,35,36
34    IF(Z(I+1,J,2)+HZ(I,J))30,30,37
35    IF(Z(I,J,2)+HZ(I+1,J))30,30,38
36    DD=DM(I,J,2)
      GO TO 39
37    DD=0.5*(Z(I,J,2)+Z(I+1,J,2))+HZ(I,J)
      GO TO 39
38    DD=0.5*(Z(I,J,2)+Z(I+1,J,2))+HZ(I+1,J)
      GO TO 39
33    DD=HM(I,J)
       IF(DD.LT.0.1)GO TO 30
39    XNN=0.25*(N(I,J,1)+N(I+1,J,1)+N(I,J-1,1)+N(I+1,J-1,1))
      DF=DD
      IF(DF.LT.1.0E-2)DF=1.0E-2
      FF=FN*SQRT(M(I,J,1)**2+XNN**2)/DF**(7.0/3.0)
      IF(DD.LT.GX)GO TO 30
      XM=(1.0-FF)*M(I,J,1)-GG*R*DD*(Z(I+1,J,2)-Z(I,J,2))
      IF(IBR.EQ.0)GO TO 40
      IF(DM(I,J,1).LT.GX)GO TO 40
      IF(M(I,J,1)41,41,42
41    IF(DM(I+1,J,1).LT.GX)GO TO 40
      XM=XM-R*(M(I+1,J,1)**2/DM(I+1,J,1)-M(I,J,1)**2/DM(I,J,1))
      GO TO 43
42    IF(DM(I-1,J,1).LT.GX)CO TO 40
      XM=XM-R*(M(I,J,1)**2/DM(I,J,1)-M(I-1,J,1)**2/DM(I-1,J,1))
43    IF(XNN)44,44,45
44    XNE=0.25*(N(I,J+1,1)+N(I+1,J+1,1)+N(I,J,1)+N(I+1,J,1))
      IF(DM(I,J+1,1).LT.GX)GO TO 40
      XM=XM-R*(M(I,J+1,1)*XNE/DM(I,J+1,1) & -M(I,J,1)*XNN/DM(I,J,1))
      GO TO 40
45    XNE=0.25*(N(I,J-1,1)+N(I+1,J-1,1)+N(I,J-2,1)+N(I+1,J-2,1))
      IF(DM(I,J-1,1).GT.GX)GO TO 40
      XM=XM-R*(M(I,J,1)*XNN/DM(I,J,1) & -M(I,J-1,1)*XNE/DM(I,J-1,1))
40    XM=XM/(1.0+FF)
      IF(ABS(XM).LT.1.0E-10)XM=0.0
      M(I,J,2)=XM
      GO TO 100
30    M(I,J,2)=0.0
      GO TO 100
60    IRR=MOD(IR(I,J),10)
      Z1=Z(I,J,2)+HM(I,J)
      Z2=Z(I+1,J,2)+HM(I,J)
      ZZ=Z1
      ZX=Z2
      IF(Z1.GT.Z2)GO TO 61
      ZZ=Z2
      ZX=Z1
61    IF(ZZ.LT.GX)GO TO 30
      IF(ZZ*0.66667.LT.ZX)GO TO 62
      XM=1.55*ZZ**1.5
      GO TO 63
62    XM=4.029*ZX*SQRT(ZZ-ZX)
63    IF(Z2.GT.Z1)XM=-XM
      M(I,J,2)=XM
100   CONTINUE
      IF(IBB.GE.2)GO TO 130
      IF(J.EQ.JG)GO TO 130
      IRR=IR(I,J)/10
      IF(IRR.GE.2)GO TO 160
      IF(IBR.EQ.0)GO TO 133
      IF(DZ(I,J,2))131,131,132
131   IF(DZ(I,J+1,2))130,130,134
132   IF(DZ(I,J+1,2))135,135,136
134   IF(Z(I,J+1,2)+HZ(I,J))130,130,137
135   IF(Z(I,J,2)+HZ(I,J+1))130,130,138
136   DD=DN(I,J,2)
      GO TO 139
137   DD=0.5*(Z(I,J,2)+Z(I,J+1,2))+HZ(I,J)
      GO TO 139
138   DD=0.5*(Z(I,J,2)+Z(I,J+1,2))+HZ(I,J+1)
      GO TO 139
133   DD=HN(I,J)
      IF(DD.LT.0.1)GO TO 130
139   XMM=0.25*(M(I,J,1)+M(I,J+1,1)+M(I-1,J,1)+M(I-1,J+1,1))
      DF=DD
      IF(DF.LT.1.0E-2)DF=1.0E-2
      FF=FN*SQRT(N(I,J,1)**2+XMM**2)/DF**(7.0/3.0)
      IF(DD.LT.GX)GO TO 130
      XN=(1.0-FF)*N(I,J,1)-GG*R*DD*(Z(I,J+1,2)-Z(I,J,2))
      IF(IBR.EQ.0)GO TO 140
      IF(DN(I,J,1).LT.GX)GO TO 140
      IF(N(I,J,1))141,141,142
```

```
141  IF(DN(I,J+1,1).LT.GX)GO TO 140
     XN=XN-R*(N(I,J+1,1)**2/DN(I,J+1,1)-N(I,J,1)**2/DN(I,J,1))
     GO TO 143
142  IF(DN(I,J-1,1).LT.GX)GO TO 140
     XN=XN-R*(N(I,J,1)**2/DN(I,J,1)-N(I,J-1,1)**2/DN(I,J-1,1))
143  IF(XMM)144,144,145
144  XME=0.25*(M(I+1,J,1)+M(I+1,J+1,1)+M(I,J,1)+M(I,J+1,1))
     IF(DN(I+1,J,1).LT.GX)GO TO 140
     XN=XN-R*(N(I+1,J,1)*XME/DN(I+1,J,1) & -N(I,J,1)*XMM/DN(I,J,1))
     GO TO 140
145  XME=0.25*(M(I-1,J,1)+M(I-1,J+1,1)+M(I-2,J,1)+M(I-2,J+1,1))
     IF(DN(I-1,J,1).LT.GX)GO TO 140
     XN=XN-R*(N(I,J,1)*XMM/DN(I,J,1) & -N(I-1,J,1)*XME/DN(I-1,J,1))
140  XN=XN/(1.0+FF)
     IF(ABS(XN).LT.1.0E-10)XN=0.0
     N(I,J,2)=XN
     GO TO 20
130  N(I,J,2)=0.0
     GO TO 20
160  IRR=MOD(IR(I,J),10)
     Z1=Z(I,J,2)+HN(I,J)
     Z2=Z(I,J+1,2)+HN(I,J)
     ZZ=Z1
     ZX=Z2
     IF(Z1.GT.Z2)GO TO 161
     ZZ=Z2
     ZX=Z1
161  IF(ZZ.LT.GX)GO TO 130
     IF(ZZ*0.66667.LT.ZX)GO TO 162
     XN=1.55*ZZ**1.5
     GO TO 163
162  XN=4.029*ZX*SQRT(ZZ-ZX)
163  IF(Z2.GT.Z1)XN=-XN
     N(I,J,2)=XN
20   CONTINUE
     RETURN
     END
```

(6) JOINTQ (Connection of the water discharge in space and time)

Objective

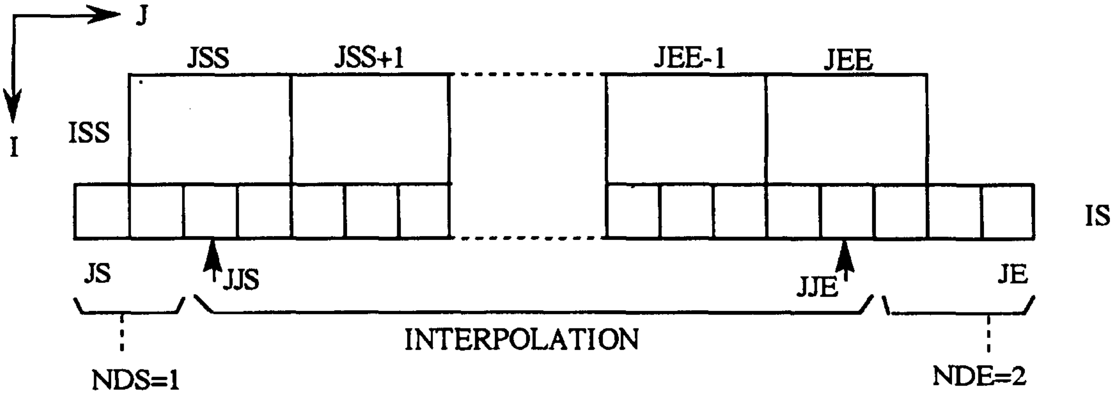
Connection of the water level between computation domains of different Δx and Δt.

Method of Connection

CALL JOINTQ (IG1, JG1, IG2, JG2, M1, M2, N1, N2, IS, IE, JS, JE, ISS, JSS, NDS, INS, NDE, INE, KK, KT1, KT2, DX1, DX2)

Parameter	Type	Content Before Calling the Subroutine	Content When Returned from the Subroutine
IG1, IG2	I	Indice of M1 and N1 in the main programme	No change
JG1, JG2	I	Indice of M2 and N2 in the main programme	No change
M1, N1	R (3-D array) (JG1, IG1, 2)	Discharge in the I-and J-directions in the sender (domain of coarse grids)	No change
M2, N2	R (3-D array) (JG2, IG2, 2)	Discharge in the I-and J-directions in the receiver (domain of fine grids)	Value after connection
IS, IE JS, JE	I	Co-ordinates of the start of connection (IS, JS) and the end (IE, JE) in the receiver	No change
ISS, JSS	I	Co-ordinates of the start of connection in the sender	No change
NDS, NDE	I	Number of extra grids at the start and end in the receiver	No change
INS, INE	I	Computation at the connection boundary; 1 for extrapolation and 2 for interpolation	No change
KK	I	Time step	No change
KT1, KT2	I	Time step index (1,3,9) (KT1<KT2)	No change
DX1, DX2	R	Space grid length in the sender (DX1) and in the receiver (DX2)	No change

Note: For the meanings of NDS and NDE, refer the following figure.



```
      SUBROUTINE JOINTQ(IG1,JG1,IG2,JG2,M1,M2,N1,N2,IS,IE, & JS, JE, ISS, JSS, NDS, INS,
      NDE, INE, KK, KT1, KT2, DX1, DX2)
      REAL M1,N1,M2,N2
      DIMENSION
      M1(IG1,JG1,2),M2(IG2,JG2,2),N1(IG1,JG1,2),N2(IG2,JG2,2)
      KY=KT1/2+1
      IF(KT1.EQ.1) GO TO 100
      IF(MOD(KK,KT1).NE.KY) RETURN
100   IF(IS.NE.IE) GO TO 200
      J3=NDS+1
      J4=NDE+1
      JJS=JS+J3
      JJE=JE-J4
      JEE=JSS+(JJE-JJS)/3
      DO 10 J=JS,JE
      IF(DX1-DX2) 51,50,51
51    IF(J.GE.JJS.AND.J.LE.JJE) GO TO 20
      IF(J.LT.JJS) GO TO 30
      IF(J.GT.JJE) GO TO 40
20    JF=JSS+(J-JJS)/3
      F=FLOAT(3-MOD(J-JJS,3))
      GO TO 60
30    IF(INS.EQ.2) GO TO 35
      JF=JSS
      F=3.0+FLOAT(JJS-J)
      GO TO 60
35    JF=JSS-1
      F=FLOAT(JJS-J)
      GO TO 60
40    IF(INE.EQ.2) GO TO 45
      JF=JEE-1
      F=FLOAT(JJE-J)
      GO TO 60
45    JF=JEE
      F=FLOAT(3-(J-JJE))
      GO TO 60
50    JF=J-(JS-JSS+NDS)
      F=3.0
60    XM2=(F*M1(ISS,JF,2)+(3.0-F)*M1(ISS,JF+1,2))/3.0
      XM1=(F*M1(ISS,JF,1)+(3.0-F)*M1(ISS,JF+1,1))/3.0
      IF(KT1.EQ.KT2) GO TO 101
      KX=MOD(KK,KT2)
      IF(KT1.EQ.1) GO TO 103
      IF(KX.EQ.KY) GO TO 102
      IF(KX.EQ.KY+2*KT1) GO TO 101
      GO TO 104
103   IF(KX.EQ.0) GO TO 101
      IF(KX.EQ.1) GO TO 102
104   M2(IS,J,2)=(2.0*XM2+XM1)/3.0
      GO TO 10
101   M2(IS,J,2)=XM2
      GO TO 10
102   M2(IS,J,2)=(4.0*XM2-XM1)/3.0
10    CONTINUE
      RETURN
200   I3=NDS+1
      I4=NDE+1
      IIS=IS+I3
      IIE=IE-I4
      IEE=ISS+(IIE-IIS)/3
      DO 70 I=IS,IE
      IF(DX1-DX2) 151,150,151
151   IF(I.GE.IIS.AND.I.LE.IIE) GO TO 120
      IF(I.LT.IIS) GO TO 130
      IF(I.GT.IIE) CO TO 140
120   IF=ISS+(I-IIS)/3
      F=FLOAT(3-MOD(I-IIS,3))
      GO TO 160
130   IF(INS.EQ.2) GO TO 135
      IF=ISS
      F=3.0+FLOAT(IIS-I)
      GO TO 160
135   IF=ISS-I
      F=FLOAT(IIS-I)
      GO TO 160
140   IF(INE.EQ.2) GO TO 145
      IF=IEE-I
      F=FLOAT(IIE-I)
      GO TO 160
145   IF=IEE
      F=FLOAT(3-(I-IIE))
      GO TO 160
150   IF=I-(IS-ISS+NDS)
      F=3.0
160   XN2=(F*N1(IF,JSS,2)+(3.0-F)*N1(IF+1,JSS,2))/3.0
      XN1=(F*N1(IF,JSS,1)+(3.0-F)*N1(IF+1,JSS,1))/3.0
      IF(KT1.EQ.KT2) GO TO 201
      KX=MOD(KK,KT2)
      IF(KT1.EQ.1) GO TO 203
      IF(KX.EQ.KY) GO TO 202
      IF(KX.EQ.KY+2*KT1) GO TO 201
      GO TO 204
203   IF(KX.EQ.0) GO TO 201
      IF(KX.EQ.1) GO TO 202
204   N2(I,JS,2)=(2.0*XN2+XN1)/3.0
      GO TO 70
201   N2(I,JS,2)=XN2
      GO TO 70
202   N2(I,JS,2)=(4.0*XN2-XN1)/3.0
70    CONTINUE
      RETURN
      END
```

(7) CHANGE (Change of dat)

Objective

Change the index of time index from 2 to 1, at every time step of computation.

Method of Connection

CALL CHANGE (IG, JG, Z, M, N, DZ, KK, KT).

Parameter	Type	Content Before Calling the Subroutine	Content When Returned from the Subroutine
IG, JG	I	Indices of Z,M,N and DZ and in the main programme	No change
Z	R (3-D array) (JG, IG, 2)	Water level	Z(I, J, 2) is equal to Z(I, J, 1)
M	R (3-D array) (JG, IG, 2)	Discharge in the I-direction	M(I, J, 2) is equal to M(I, J, 1)
N	R (3-D array) (JG, IG, 2)	Discharge in the I-direction	N(I, J, 2) is equal to N(I, J, 1)
DZ	R (3-D array) (JG, IG, 2)	Total water depth at points for water level	DZ(I, J, 2) is equal to DZ(I, J, 1)
KK	I	Time step	No change
KT	I	Time step index	No change

```
      SUBROUTINE  CHANGE (IG,JG,Z,M,N,DZ,KK,KT)
      REAL M,N
      DIMENSION Z(IG,JG,2),M(IG,JG,2),N(IG,JG,2),DZ(IG,JG,2)
      LL=MOD(KK,KT)
      LX=KT/2
      IF(LL.NE.0.AND.LL-LX.NE.0)RETURN
      DO 10 I=1,IG
      DO 10 J=1,JG
      IF(LL.NE.0) GO TO 11
      Z(I,J,1)=Z(I,J,2)
      DZ(I,J,1)=DZ(I,J,2)
 11   IF(LL-LX.NE.0)GO TO 10
      M(I,J,1)=M(I,J,2)
      N(I,J,1)=N(I,J,2)
 10   CONTINUE
      RETURN
      END
```

IUGG/IOC TIME PROJECT

PART 2. PROPAGATION IN THE OCEAN IN THE SPHERICAL CO-ORDINATES TSUNAMI-F1 AND ITS PROGRAMME LIST

CONTENTS

Page

1. INTRODUCTION 1

2. METHODS OF COMPUTATION 1

2.1 CO-ORDINATES AND AREA FOR COMPUTATION 1
2.2 GOVERNING EQUATIONS AND GRID LENGTH 2
2.3 INITIAL AND BOUNDARY CONDITIONS 4

3. TSUNAMI SIMULATION PROGRAMMES 5

3.1 AN EXAMPLE OF PROGRAMME 5
3.2 VARIABLES AND CONSTANTS IN TSUNAMI SIMULATION 6
3.3 SUBROUTINES IN TSUNAMI SIMULATION 6
3.4 VARIABLES AND CONSTANTS IN INITIAL PROFILE COMPUTATION 7

4. CONCLUDING REMARKS 8

1. INTRODUCTION

Numerical simulations of far-field tsunamis require longer CPU time and larger memory capacity than those of near-field tsunamis, because the computation covers wide areas. The long travel distance may yield dispersion of wave components, and therefore the physical dispersion term should be included; i.e. the equations of higher order approximation should be used. The long travel time yields an inevitable accumulation of numerical error. These factors suggest that the computation programme should be carefully designed.

In the present text, a method of simulation is explained. The linear long wave theory is expressed in the latitude-longitude co-ordinates. The equations are different. A method of setting initial and boundary conditions is stated. A process of computation is explained by an example. A method of output is given. In addition, variables, constants and subroutines are explained. This model is TUNAMI-F1 (Tohoku University's Numerical Analysis Model for Investigation of Far-field Tsunamis, 1).

When the linear theory is used, it is also easy to attain a high rate of vectorization even with the ordinary programming method. The present programme for transoceanic propagation is composed to fully utilize the vectorization ability of super computer. The rate of vectorization of higher than 99% is a result of elimination of both the IF-sentences in DO-groups and the division operation.

2. METHOD OF COMPUTATION

2.1 CO-ORDINATES AND AREA FOR COMPUTATION

For near field tsunamis, the Cartesian co-ordinate system is used, because areas included in simulations are not wide. On the other hand, in numerical simulations of far-field tsunamis which travel more than 1,000 km over the ocean, the polar co-ordinates should be used. As shown in Figure 1, the earth is considered as a sphere of radius R, covered by the latitude and longitude (θ,λ).

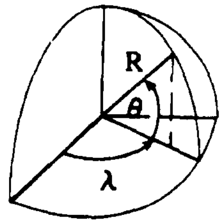


Figure 1. Spherical Co-ordinates

The area in computation is taken wide enough to simulate the whole process of the transoceanic propagation of such tsunamis as the 1960 Chilean tsunami and the 1964 Alaska tsunami. Figure 2 shows the area used in the present example. Since the figure is drawn in Mercator's projection, the length at high latitude in this map is different from the actual length. The map covers the area from

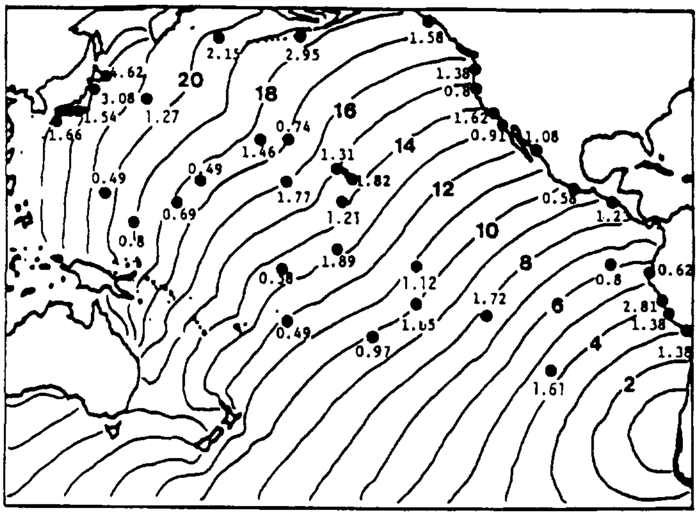


Figure 2. Area for Computation, and Propagation of the Chilean tsunami

S60° to N63° and from E120° to W70°. The water depth is given at every 5' in longitude and latitude. The space grid length of 10' is used in the computation. The total number of grids amounts to 1,020 x 738 = 752,760.

2.2 GOVERNING EQUATIONS AND GRID LENGTH

In computation of a far-field tsunami, the dispersion term becomes important because the long travel distance acts to disperse wave components. The linear Boussinesq equation which includes the physical dispersion term is considered appropriate to express this effect. In the following, another simple method is explained to replace the physical dispersion term by the numerical dispersion term which is inevitably resulted as the truncation error of a numerical scheme. This replacement is possible, if the grid length is appropriately selected. Then, the linear long wave theory of lower order of approximation becomes almost equivalent to the linear Boussinesq equation of higher order of approximation. In addition, due to this replacement, the CPU time and the computer memory are much saved.

The linear long wave theory is given by the following expression in the latitude-longitude co-ordinates.

$$\frac{\partial \eta}{\partial t}+\frac{1}{R\cos\theta}\left[\frac{\partial M}{\partial \lambda}+\frac{\partial}{\partial \theta}(N\cos\theta)\right]=0 \tag{1}$$

$$\frac{\partial M}{\partial t}+\frac{gh}{R\cos\theta}\frac{\partial \eta}{\partial \lambda}=fN \tag{2}$$

$$\frac{\partial N}{\partial t}+\frac{gh}{R}\frac{\partial \eta}{\partial \theta}=-fM \tag{3}$$

where η is the water level, M and N are discharge fluxes in the λ (along a parallel of latitude) and θ (along a circle of longitude) directions, g is the gravitational acceleration, and f ($2\omega\sin\theta$) is the Coriolis coefficient.

The leap-frog scheme is applied to obtain difference expressions of Eqs.(1) through (3). Then, we have

$$\frac{\eta_{j,m}^{n+\frac{1}{2}}-\eta_{j,m}^{n-\frac{1}{2}}}{\Delta t}+\frac{1}{R\cos\theta_m}\left[\frac{M^n_{j+\frac{1}{2},m}-M^n_{j-\frac{1}{2},m}}{\Delta\lambda}+\frac{N^n_{j,m+\frac{1}{2}}\cos\theta_{m+\frac{1}{2}}-N^n_{j,m-\frac{1}{2}}\cos\theta_{m-\frac{1}{2}}}{\Delta\theta}\right]=0 \tag{4}$$

$$\frac{M^{n+1}_{j+\frac{1}{2},m}-M^n_{j+\frac{1}{2},m}}{\Delta t}+\frac{gh_{j+\frac{1}{2},m}}{R\cos\theta_m}\frac{\eta_{j+1,m}^{n+\frac{1}{2}}-\eta_{j,m}^{n+\frac{1}{2}}}{\Delta\lambda}=fN' \tag{5}$$

$$\frac{N^{n+1}_{j+\frac{1}{2},m}-N^{n}_{j+\frac{1}{2},m}}{\Delta t}+\frac{gh_{j+\frac{1}{2},m}}{R\sin\theta_m}\frac{\eta^{n+\frac{1}{2}}_{j,m+1}-\eta^{n+\frac{1}{2}}_{j,m}}{\Delta\theta}=-fM' \qquad (6)$$

where

$$N'=\frac{1}{4}\left[N^{n}_{j+1,m+\frac{1}{2}}+N^{n}_{j+1,m-\frac{1}{2}}+N^{n}_{j,m+\frac{1}{2}}+N^{n}_{j,m-\frac{1}{2}}\right]$$

$$M'=\frac{1}{4}\left[M^{n}_{j+\frac{1}{2},m+\frac{1}{2}}+M^{n}_{j+\frac{1}{2},m}+M^{n}_{j-\frac{1}{2},m+1}+M^{n}_{j-\frac{1}{2},m}\right] \qquad (7)$$

The unkowns, η, M and N, are given by the following explicit expressions.

$$\eta^{n+\frac{1}{2}}_{j,m}=\eta^{n-\frac{1}{2}}_{j,m}-R_1\left[M^{n}_{j+\frac{1}{2},m}-M^{n}_{j-\frac{1}{2},m}+N^{n}_{j,m+\frac{1}{2}}\cos\theta_{m+\frac{1}{2}}-N^{n}_{j,m-\frac{1}{2}}\cos\theta_{m-\frac{1}{2}}\right] \qquad (8)$$

$$M^{n+1}_{j+\frac{1}{2},m}=M^{n}_{j+\frac{1}{2},m}-R_2\cdot h_{j+\frac{1}{2},m}\left[\eta^{n+\frac{1}{2}}_{j+1,m}-\eta^{n+\frac{1}{2}}_{j,m}\right]+R_3N' \qquad (9)$$

$$N^{n+1}_{j,m+\frac{1}{2}}=M^{n}_{j,m+\frac{1}{2}}-R_4\cdot h_{j,m+\frac{1}{2}}\left[\eta^{n+\frac{1}{2}}_{j+1,m}-\eta^{n+\frac{1}{2}}_{j,m}\right]+R_5M' \qquad (10)$$

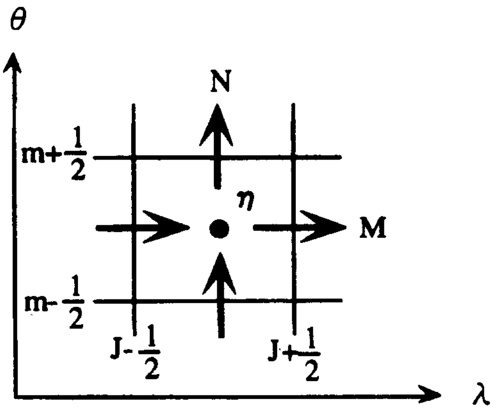


Figure 3. Computation Points for Water Level and Discharge

where R'$_n$s a re given as follows.

$$R_1=\Delta t/\left(R\cos\theta_m\Delta s\right)$$

$$R_2=g\Delta t/\left(R\cos\theta_m\Delta s\right)$$

$$R_3=2\Delta t\varpi\sin\theta_m$$

$$R_4=g\Delta t/\left(R\Delta s\right)$$

$$R_5=2\Delta t\varpi\sin\theta_{m+\frac{1}{2}} \qquad (11)$$

A point of computation is numbered as (j, m, n) in the (θ, λ, t) directions. The grid lengths are $(\Delta\theta, \Delta\lambda, \Delta t)$ In the present computation grid lengths in the latitude and longitude directions are taken equal: i.e. $\Delta s = \Delta\theta = \Delta\lambda$. The angular velocity of earth rotation is given by ω.

The spatial grid length is taken to be 10', and the time step interval is taken to be 20 seconds. This spatial grid length is selected to satisfy the condition that the Imamura number Im given below is nearly equal to unity, or in other words, the numerical and physical dispersion effects are nearly the same.

$$Im = \Delta x / 2h\sqrt{1-K^2} \qquad \textbf{(12)}$$

where K is the Courant number $(=(gh)^{1/2}\Delta t/\Delta x.)$ and h the mean water depth in the ocean under consideration. The time step interval is determined to satisfy the C.F.L. condition for the spatial grid length thus determined.

2.3 INITIAL AND BOUNDARY CONDITIONS

The initial condition, the vertical displacement of water surface is usually considered the same as the vertical displacement of sea bottom which is calculated with the Mansinha and Smylie method (1972), if fault parameters are given. When the actual vertical displacement of ground is available even though it is very rare, as in case of the 1964 Great Alaska earthquake, the better is to use this actual displacement. In case of a huge earthquake, other effects of dynamic fault motion such as the rise time and the rupture velocity may not be negligible. However, when the effect of a tsunami at a very remote place is studied, these dynamic factors are not influential.

The boundary condition on land is the perfect reflection. The velocity component (or, discharge flux component) normal to the land boundary is made equal to zero.

At the open sea boundary, the boundary condition is the free transmission. In terms of u the linear free transmission condition is,

$$\begin{aligned} \eta &= +\sqrt{h/g}\cdot && \textit{for advancing waves} \\ &= -\sqrt{h/g}\cdot u && \textit{for receding waves} \qquad \textbf{(13)} \end{aligned}$$

where η is the water level and u the velocity. In terms of water discharge Q, the condition is given as follows, on assuming that $\eta << h$.

$$\begin{aligned} \eta &= +Q/\sqrt{gh} && \textit{for advancing waves} \\ &= -Q/\sqrt{gh} && \textit{for receding waves} \qquad \textbf{(14)} \end{aligned}$$

Here, two judgements are necessary One is the evaluation of the discharge flux Q. Another is the judgement of the direction of wave propagation. On referring Figure 4, the resultant discharge flux is simply determined by

$$Q = \sqrt{\frac{(M_1+M_2)^2}{4} + N_2^2} \qquad \textbf{(15)}$$

wave propagation direction can be judged by the sign of N_2 in relation to the alignment of the open sea boundary.

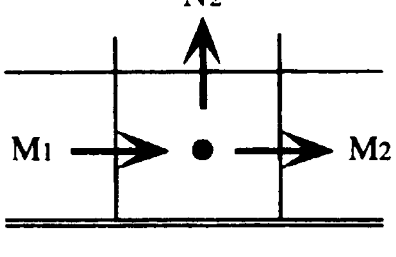


Figure 4. Distinction of Advancing and Receding Waves by the sign of N_2

2.4 FLOW CHART

In Figure 5, the flow of computation is shown with the names of subroutines, the details of which are described in Section 3.

3. TSUNAMI SIMULATION PROGRAMMES

3.1 AN EXAMPLE OF PROGRAMME

Attached are the programme sheets of TUNAMI-F1 applied to the 1990 Mariana tsunami, with brief explanations and comments. Pages 1 to 10 of the programme sheets are the tsunami simulation with the method describe above. Pages 11 to 13 are for the computation to determine the initial tsunami profile with the method given in the following subsection.

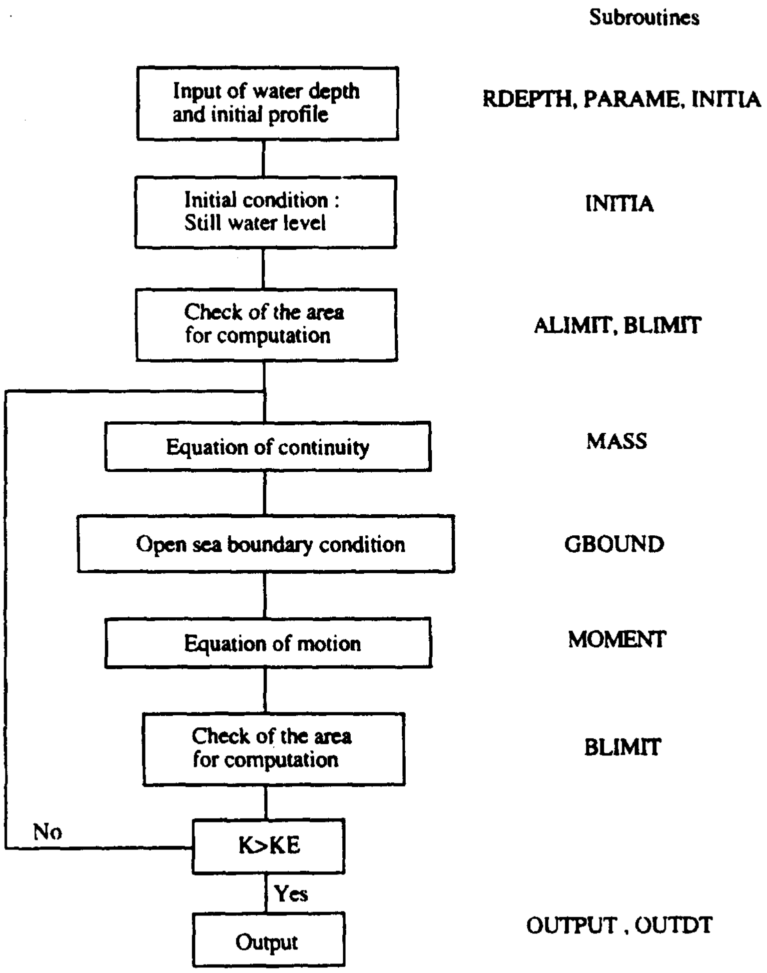

Subroutines
Input of water depth and initial profile
RDEPTH, PARAME, INITIA
Initial condition : Still water level
INITIA
Check of the area for computation
ALIMIT, BLIMIT
Equation of continuity
MASS
Open sea boundary condition
GBOUND
Equation of motion
MOMENT
Check of the area for computation
BLIMIT
No
K>KE
Yes
Output
OUTPUT, OUTDT

Figure 5. Flow Chart of the Computation

3.2 VARIABLES AND CONSTANTS IN TSUNAMI SIMULATION

Variables in the programme are;

Z: Water level.
M,N: Discharge flux.
H: Still water depth.
PZ: Time history of water level.
IP,JP: Co-ordinates of points for output of the history of water level.
V1,V2,V3,V4,V5,V6,V7: Working arrays for vector operation.

Coefficients are;

ZM: Highest water level.
ZN: Lowest water level.
LF: Arrival time in hour.
R1,R2,R3,R4,R5,R6: Coefficients given by Eq.(11), and R6 = $\cos \theta_{m+1/2}$
C1= $\theta_{m+1/2}$ in radian.
C2= θ_m in radian.
C3= $\theta_{m-1/2}$ in radian.
C4= h : Water depth.

Constants are;

GG: Gravitational acceleration.
PP: Circular constant π (= 3.1415926).
R: Radius of the Earth.

The computation is controlled by the following conditions.

IG,JG: Size of the area for computation in longitude and latitude.
FL: Latitude of the southernmost end of the area for computation.
IS,JS,IE,JE: Area where the tsunami exists and the computation is carried out.
DS,DT: Grid length in minute, and time step length in second.
KS,KE: Time steps of beginning and end of the computation.
NG: Number of spatial points where the time history of water level is output.
KC: Time step length in outputting the time history of water level.
KD: Time step length to output spatial wave profiles.

3.3 SUBROUTINES IN TSUNAMI SIMULATION

Subroutines indicated in Figure 5 are as follows.

RDEPTH: Data input of water depth.
PARAME: Setting of parameters required in vectorized computation.
INITIA: Input of the initial condition and the initial profile.
ALIMIT: Making the area of computation be within the area under consideration.
BLIMINT: Enlargement of the area of computation as the tsunami propagates.
OUTPUT: Output and display of the spatial distribution of water level at an instant.
CLOCK: Time from the beginning of the computation, special for a NEC SX-1.
MASS: Computation of the equation of continuity.
GBOUND: Open sea, boundary condition.
MOMENT: Computation of the equation of motion.
MAX: Check of the highest and lowest water level.
POINT: Output of the time history of water level at the point (IP, JP).
PROPA: Output of the tsunami arrival time in hour.
OUTDT: Output of the highest and lowest water levels, and the arrival time.
FILEOT: Output of the water level and the discharge flux.

3.4 VARIABLES AND CONSTANTS IN INITIAL PROFILE COMPUTATION

The vertical displacement of sea bottom is calculated with the Mansinha and Smylie method (1972), and is assumed equal to the tsunami initial profile with no modification of hydraulic effect because the horizontal size of the initial profile is sufficiently large compared to the water depth at the tsunami source.

In the attached programme sheets, the subroutine DEFORM is used to calculate the initial tsunami profile from the given fault parameters.

Variables in the programme are, on referring Figs. 7 through 9;

DX: Grid length in meter for the Cartesian co-ordinates.
DR: Grid length in degree for the spherical co-ordinates.
H: Depth of a corner of the fault plane in meter.
D: Dislocation of the upper plane (u) in meter.
DL: Dip angle (8) in degree
TH: Strike angle (O) in degree measured clockwise from north.
RD: Direction of dislocation (A) in degree.
L: Length of fault plane in meter.
W: Width of fault plane in meter.
Y0, X0: Co-ordinate of the origin in the area for tsunami computation.

$\overline{\mathrm{Y0}}$, $\overline{\mathrm{X0}}$: Co-ordinate of the origin of the fault plane.

Constants are;

A: Circular constant π (= 3.1415926).
RR: Radius of the earth (= 6.37E + 6 (m)).
E: = 1.7453E - 3(m).

3.5 SUBROUTINES IN INITIAL PROFILE COMPUTATION

Subroutines are;

DEFORM: Computation of the initial profile.
USCAL: Computation of the vertical displacement due to the strike slip component.
UDCAL: Computation of the vertical displacement due to the dip slip component.

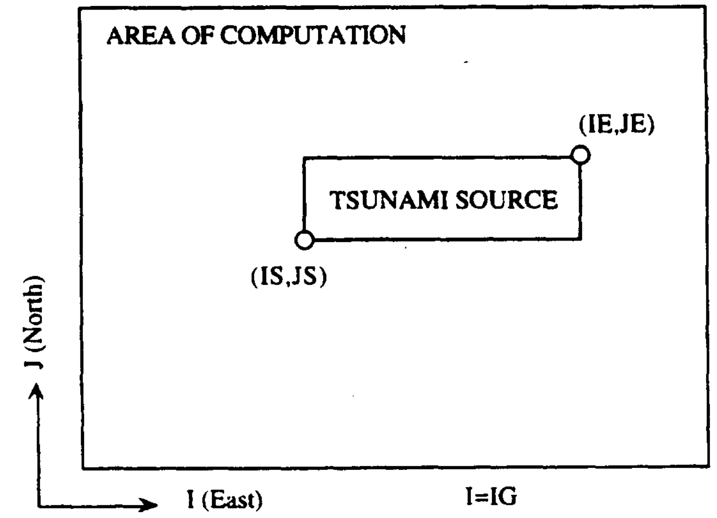


Figure 6. Co-ordinates in the Areas for Computation of Tsunami and Initial Profile

4. CONCLUDING REMARKS

In addition to TUNAMI-F1, the Disaster Control Research Center, Tohoku University provides four programs.

TUNAMI-F2 is for the simulation of a far-field tsunami, combining the transoceanic propagation and the detailed simulation in coastal water with the linear long wave equations.

For a near-field tsunami, there are three programs.

The first is TUNAMI-N1, with the linear theory with constant spatial grid length. The authors recommend to begin with this programme, because it is easy to understand programs. Reader may refer "NUMERICAL METHOD OF TSUNAMI SIMULATION WITH THE LEAP-FROG SCHEME" written by Goto and Ogawa, and translated by Shuto.

The second is TUNAMI-N2, with the linear theory in deep sea and with the shallow water theory in shallow sea and on land with constant grid length in the whole region. The run up can be computed with this programme.

The third is TUNAMI-N3, in which the spatial grid length varies from coarse grids in deep sea to fine grids in shallow sea. The linear long wave theory is used.

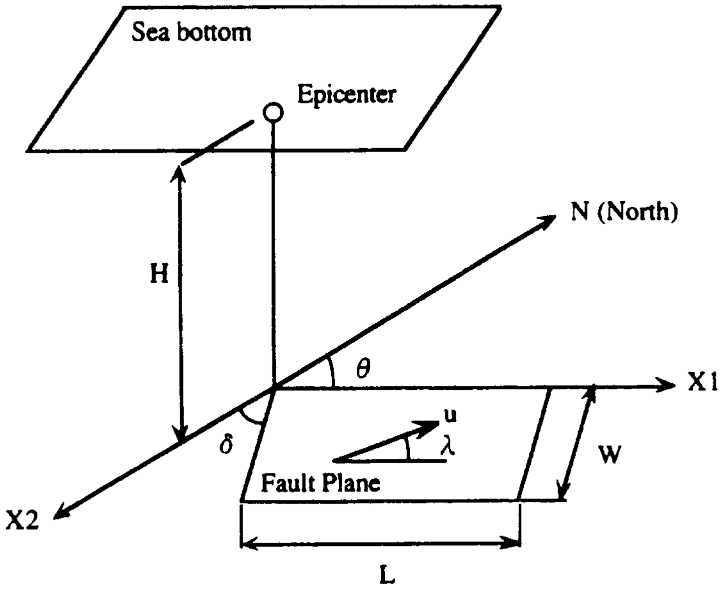


Figure 7. Fault Parameter

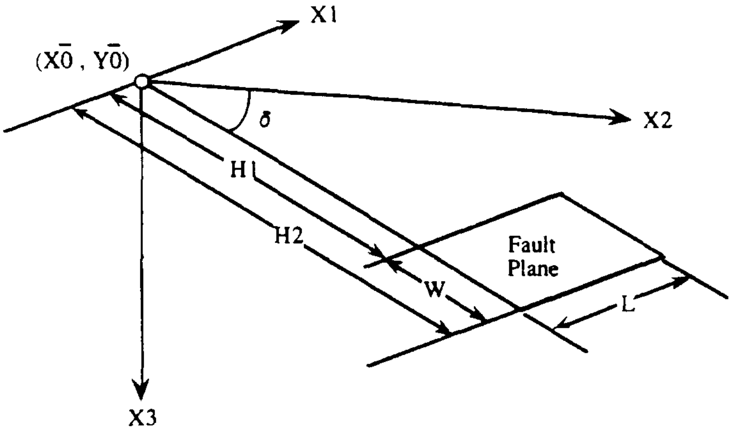


Figure 8 Plan of Fault Plane

Figure 9. Fault Plane in Three Dimensions

```
C
C     *************** TUNAMI-F1 ****************
C        Tohoku University's Numerical-Analysis Model
C            for Investigation of tsunami
C             Far-field Tsunami version
C
C             1990 MARIANA  TSUNAMI (DX=5')
C            --- LINEAR LONG WAVE THEORY ----
C                 NUMERICAL EXPERIMENT
C                                           91.4.11
C
      PARAMETER (IG=480,JG=600)
      PARAMETER (DS=5.,DT=10.)
      PARAMETER (KS=1,KE=360*10,KD=360*2,KC=1)
C
      REAL M,N
      DOUBLE PRECISION TS,TE,TD
      DIMENSION Z(IG,JG),M(IG,JG),N(IG,JG),H(IG,JG)
      DIMENSION R1(IG,JG),R2(IG,JG),R3(IG,JG)
      DIMENSION R4(IG,JG),R5(IG,JG),R6(JG)
      DIMENSION C1(IG),C2(JG),C3(IG),C4(JG)
      DIMENSION V1(JG),V2(JG),V3(JG),V4(JG),V5(JG)
      DIMENSION ZM(IG,JG),ZN(IG,JG),LF(IG,JG)
C
      CALL RDEPTH (IG,JG,H)
      WRITE(6,255)
  255 FORMAT(1H1,5X,"READ DEPTH OK!")
      CALL PARAME (IG,JG,IR,JR,ID,JD,DS,DT,
     &             R1,R2,R3,R4,R5,R6,C1,C2,C3,C4,
     &             V1,V2,V3,V4,V5,H)
      CALL INITIA (IG,JG,IR,JR,ID,JD,
     &             Z,M,N,H)
      CALL ALIMIT (IG,JG,IS,JS,IE,JE,IR,JR,ID,JD)
      CALL BLIMIT (IG,JG,IS,JS,IE,JE,Z)
C     CALL OUTPUT (IG,JG,IS,JS,IE,JE,0,KD,Z,H)
      CALL CLOCK (TS)
      DO 20 K=KS,KE
      KK=K  ; IF(MOD(KK,50).EQ.0)WRITE(6,*)KK
      CALL MASS (IG,JG,IS,JS,IE,JE,
     &             Z,M,N,R1,R6)
      CALL GBOUND (IG,JG,IS,JS,IE,JE,
     &             Z,M,N,C1,C2,C3,C4)
      CALL MOMENT (IG,JG,IS,JS,IE,JE,
     &             Z,M,N,R2,R3,R4,R5,
     &             V1,V2)
      CALL OUTPUT (IG,JG,IS,JS,IE,JE,KK,KD,Z,H)
      CALL BLIMIT (IG,JG,IS,JS,IE,JE,Z)
C
      CALL MAX (IG,JG,IS,JS,IE,JE,Z,H,ZM,ZN)
      CALL POINT (IG,JG,Z,KK,KC)
      CALL PROPA (IG,JG,IS,JS,IE,JE,Z,H,LF,KK)
C
   20 CONTINUE
      CALL OUTDT (IG,JG,ZM,ZN,LF)
      CALL CLOCK (TE) ; TD=TE-TS
      WRITE(6,*)KK,TD
      STOP
      END
C
```

Data and initial condition input

Main program

Main computation

Output of computed results

```
      SUBROUTINE RDEPTH (IG,JG,H) ------ Input of water depth
C
      DIMENSION H(IG,JG)
C
      DO 10 J=1,JG
      READ(20,100)(H(I,J),I=1,IG)
  100 FORMAT(20F6.1)
   10 CONTINUE
      RETURN
      END
C
      SUBROUTINE PARAME (IG,JG,IR,JR,ID,JD,DS,DT, ----- Setting of parameters
     &                  R1,R2,R3,R4,R5,R6,C1,C2,C3,C4,
     &                  V1,V2,V3,V4,V5,H)
C
      PARAMETER (GG=9.8)
      PARAMETER (FL=0.0,PP=3.1415926)
      PARAMETER (R=6.37E+6,WW=7.2722E-5)
      PARAMETER (IS=240,JS=120,IE=360,JE=240)
C
      DIMENSION R1(IG,JG),R2(IG,JG),R3(IG,JG),R4(IG,JG),R5(IG,JG)
      DIMENSION R6(JG),C1(IG),C2(JG),C3(IG),C4(JG)
      DIMENSION V1(JG),V2(JG),V3(JG),V4(JG),V5(JG)
      DIMENSION H(IG,JG)
C
      IR=IS
      JR=JS
      ID=IE
      JD=JE
      PX=PP/180.
      DX=R*(DS/60.)*PX
      RR=DT/DX
      RS=0.5*GG*RR
      RT=0.5*DT*WW
      DO 10 J=1,JG
      C2(J)=(FL+(DS*J-0.5*DS)/60.)*PX            Setting of C1 and C2
      C4(J)=(FL+DS*J/60.)*PX
   10 CONTINUE
      DO 11 J=1,JG
      R6(J)=COS(C2(J))
      V1(J)=RR/R6(J)
      V2(J)=RS/R6(J)
      V3(J)=RT*SIN(C2(J))                        Setting of C3 and R6
      V4(J)=RS
      V5(J)=RT*SIN(C4(J))
   11 CONTINUE
      DO 12 J=1,JG
      C4(J)=0.
      DO 12 I=1,IG                               Setting of C4
      IF(H(I,J).GT.C4(J))C4(J)=H(I,J)
   12 CONTINUE
```

```
      DTMIN=1.E+20
      DXMAX=0.
      DXMIN=1.E+20
      DO 13 J=1,JG
      DXM=DX*R6(J)
      DTM=SQRT((1./(GG*C4(J)))/(1./DX**2+1./DXM**2))
      IF(DXM.GT.DXMAX)DXMAX=DXM
      IF(DXM.LT.DXMIN)DXMIN=DXM
      IF(DTM.LT.DTMIN)DTMIN=DTM
   13 CONTINUE
      WRITE(6,110)DX,DXMAX,DXMIN,DTMIN
      DO 20 J=1,JG
      DO 20 I=1,IG
      R1(I,J)=0.
      R2(I,J)=0.
      R3(I,J)=0.
      R4(I,J)=0.
      R5(I,J)=0.
   20 CONTINUE
      DO 30 J=1,JG
      DO 30 I=1,IG
      IF(H(I,J).LT.0.)GOTO 30
      R1(I,J)=V1(J)
      IF(I.NE.IG)THEN
      IF(H(I+1,J).LT.0.)GOTO 31
      R2(I,J)=V2(J)*(H(I,J)+H(I+1,J))
      R3(I,J)=V3(J)
      ELSE
      R2(I,J)=V2(J)*H(I,J)*2
      R3(I,J)=V3(J)
      ENDIF
   31 IF(J.NE.JG)THEN
      IF(H(I,J+1).LT.0.)GOTO 30
      R4(I,J)=V4(J)*(H(I,J)+H(I,J+1))
      R5(I,J)=V5(J)
      ELSE
      R4(I,J)=V4(J)*H(I,J)*2
      R5(I,J)=V5(J)
      ENDIF
   30 CONTINUE
      DO 41 I=1,IG
   41 C1(I)=0.
      DO 42 I=1,IG
   42 IF(H(I,1).GT.0.)C1(I)=1./SQRT(GG*H(I,1))
      DO 43 J=1,JG
   43 C2(J)=0.
      DO 44 J=1,JG
   44 IF(H(1,J).GT.0.)C2(J)=1./SQRT(GG*H(1,J))
      DO 45 I=1,IG
   45 C3(I)=0.
      DO 46 I=1,IG
   46 IF(H(I,JG).GT.0.)C3(I)=1./SQRT(GG*H(I,JG))
      DO 47 J=1,JG
   47 C4(J)=0.
      DO 48 J=1,JG
   48 IF(H(IG,J).GT.0.)C4(J)=1./SQRT(GG*H(IG,J))
      RETURN
  110 FORMAT(1H ,"DX,DXMAX,DXMIN,DTMIN=",2X,4E12.4)
      END
C
```

Max. and min. of DX
Min. of DT=DX'/$(gh)^{1/2}$

Setting of R1 through R5

Setting of coefficients used at the open sea boundary

```
2080       SUBROUTINE BLIMIT (IG,JG,IS,JS,IE,JE,Z)
2090C
2100       PARAMETER (GX=1.E-4)
2110       DIMENSION Z(IG,JG)
2120C
2130       IF(IS.EQ.2)GOTO 61
2140       L=0
2150       DO 10 J=JS,JE
2160       IF(ABS(Z(IS+2,J)).GT.GX)L=1
2170    10 CONTINUE
2180       IF(L.EQ.1)THEN
2190       IS=IS-1
2200       IF(IS.LE.2)IS=2
2210       ENDIF
2220    61 IF(IE.EQ.IG-1)GOTO 62
2230       L=0
2240       DO 20 J=JS,JE
2250       IF(ABS(Z(IE-2,J)).GT.GX)L=1
2260    20 CONTINUE
2270       IF(L.EQ.1)THEN
2280       IE=IE+1
2290       IF(IE.GE.IG-1)IE=IG-1
2300       ENDIF
2310    62 IF(JS.EQ.2)GOTO 63
2320       L=0
2330       DO 30 I=IS,IE
2340       IF(ABS(Z(I,JS+2)).GT.GX)L=1
2350    30 CONTINUE
2360       IF(L.EQ.1)THEN
2370       JS=JS-1
2380       IF(JS.LE.2)JS=2
2390       ENDIF
2400    63 IF(JE.EQ.JG-1)GOTO 64
2410       L=0
2420       DO 40 I=IS,IE
2430       IF(ABS(Z(I,JE-2)).GT.GX)L=1
2440    40 CONTINUE
2450       IF(L.EQ.1)THEN
2460       JE=JE+1
2470       IF(JE.GE.JG-1)JE=JG-1
2480       ENDIF
2490    64 RETURN
2500       END
2510C
```

Setting of the area for computation

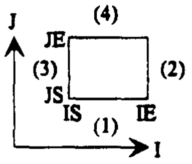
(Enlarge the area if water level is higher than GX(1.0E-4).)

Enlargement in (1) direction.

Enlargement in (2)irection.

Enlargement in (3) direction.

Enlargement in (4) direction.



```
      SUBROUTINE INITIA (IG,JG,IS,JS,IE,JE,
     &                  Z,M,N,H)
C
      REAL M,N
      DIMENSION Z(IG,JG),M(IG,JG),N(IG,JG),H(IG,JG)
C
      DO 10 J=1,JG
      DO 10 I=1,IG
      Z(I,J)=0.
      M(I,J)=0.
      N(I,J)=0.
   10 CONTINUE
C
      CALL DEFORM (IG,JG,IS,JS,IE,JE,Z)
C
      DO 30 J=JS,JE
      DO 30 I=IS,IE
      IF(H(I,J).LT.0.)Z(I,J)=0.
   30 CONTINUE
      RETURN
      END
C
      SUBROUTINE ALIMIT (IG,JG,IS,JS,IE,JE,IR,JR,ID,JD)
C
      IS=IR-1
      JS=JR-1
      IE=ID+1
      JE=JD+1
      IF(IS.LE.2)IS=2
      IF(JS.LE.2)JS=2
      IF(IE.GE.IG-1)IE=IG-1
      IF(JE.GE.JG-1)JE=JG-1
      WRITE(6,100)IS,JS,IE,JE
      RETURN
  100 FORMAT(1H ,"IS=",I5,2X,"JS=",I5,2X,"IE=",I5,2X,"JE=",I5)
      END
C
```

Setting of the initial condition

Still water level is assumed.

Input of the initial profile.

Water level is set zero on land.

The area for computation is limited within the area of concern.

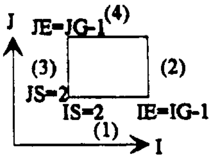
(ALIMIT is not necessary.
BLIMIT given below is sufficient)

Computation of the equation of continuity.

```
      SUBROUTINE MASS (IG,JG,IS,JS,IE,JE,Z,M,N,R1,R6)
C
      REAL M,N
      DIMENSION Z(IG,JG),M(IG,JG),N(IG,JG)
      DIMENSION R1(IG,JG),R6(JG)
C
      DO 10 J=JS,JE
      DO 10 I=IS,IE
      Z(I,J)=Z(I,J)-R1(I,J)*(M(I,J)-M(I-1,J))
     &           -R1(I,J)*(N(I,J)*R6(J)-N(I,J-1)*R6(J-1))
   10 CONTINUE
      DO 20 J=JS,JE
      DO 20 I=IS,IE
      IF(ABS(Z(I,J)).LT.1.0E-5)Z(I,J)=0.0
   20 CONTINUE
      RETURN
      END
C
```

Setting of the open sea boundary condition.

```
      SUBROUTINE GBOUND (IG,JG,IS,JS,IE,JE,
     &                  Z,M,N,C1,C2,C3,C4)
C
      REAL M,N
      DIMENSION Z(IG,JG),M(IG,JG),N(IG,JG)
      DIMENSION C1(IG),C2(JG),C3(IG),C4(JG)
C
```



Setting on the line (1).

```
      IF(JS.LE.2)THEN
      DO 10 I=2,IG-1
      Z(I,1)=SQRT(N(I,1)**2
          &+0.25*(M(I,1)+M(I-1,1))**2)*C1(I)
   10 IF(N(I,1).GT.0.)Z(I,1)=-Z(I,1)
      ENDIF
```

Setting on the line (2).

```
      IF(IS.LE.2)THEN
      DO 20 J=2,JG-1
      Z(1,J)=SQRT(M(1,J)**2
          &+0.25*(N(1,J)+N(1,J-1))**2)*C2(J)
C     IF(Z(1,J).GT.1.0)Z(1,J)=1.0
C     IF(Z(1,J).LT.-1.0)Z(1,J)=-1.0
   20 IF(M(1,J).GT.0.)Z(1,J)=-Z(1,J)
      ENDIF
```

Setting on the line (3).

```
      IF(JE.GE.JG-1)THEN
      DO 30 I=2,IG-1
      Z(I,JG)=SQRT(N(I,JG-1)**2
          &+0.25*(M(I,JG)+M(I,JG-1))**2)*C3(I)
      IF(N(I,JG-1).LT.0.)Z(I,JG)=-Z(I,JG)
   30 CONTINUE
C
      ENDIF
```

Setting on the line (4).

```
      IF(IE.GE.IG-1)THEN
      DO 40 J=2,JG-1
      Z(IG,J)=SQRT(M(IG-1,J)**2
          &+0.25*(N(IG,J)+N(IG,J-1))**2)*C4(J)
   40 IF(M(IG-1,J).LT.0.)Z(IG,J)=-Z(IG,J)
      ENDIF
      Z(1,1)=SQRT(M(1,1)**2+N(1,1)**2)*C1(1)
      IF(N(1,1).GT.0.0)Z(1,1)=-Z(1,1)
      Z(IG,1)=SQRT(M(IG-1,1)**2+N(IG,1)**2)*C1(IG)
      IF(N(IG,1).GT.0.0)Z(IG,1)=-Z(IG,1)
      Z(1,JG)=SQRT(M(1,JG)**2+N(1,JG-1)**2)*C3(1)
      IF(N(1,JG-1).LT.0.0)Z(1,JG)=-Z(1,JG)
      Z(IG,JG)=SQRT(M(IG-1,JG)**2+N(IG,JG-1)**2)*C3(IG)
      IF(N(IG,JG-1).LT.0.0)Z(IG,JG)=-Z(IG,JG)
      RETURN
      END
```

```
C
      SUBROUTINE MOMENT (IG,JG,IS,JS,IE,JE, ---   Computation of the equation of motion.
     &                   Z,M,N,R2,R3,R4,R5,
     &                   V1,V2)
C
      REAL M,N
      DIMENSION Z(IG,JG),M(IG,JG),N(IG,JG)
      DIMENSION R2(IG,JG),R3(IG,JG),R4(IG,JG),R5(IG,JG)
      DIMENSION V1(JG),V2(JG)
C
      DO 10 J=JS,JE
      DO 10 I=IS,IE
      V1(I)=Z(I+1,J)-Z(I,J)
      V2(I)=N(I,J-1)+N(I,J)+N(I+1,J-1)+N(I+1,J)          Computation of M.
      M(I,J)=M(I,J)-R2(I,J)*V1(I)+R3(I,J)*V2(I)
   10 CONTINUE
      IF(JS.LE.2)THEN
      DO 15 I=1,IG-1
   15 M(I,1)=M(I,1)-R2(I,1)*(Z(I+1,1)-Z(I,1))
      ENDIF
      IF(JE.GE.JG-1)THEN
      DO 16 I=1,IG-1                                     Computation of M along
   16 M(I,JG)=M(I,JG)-R2(I,JG)*(Z(I+1,JG)-Z(I,JG))       the boundary line.
      ENDIF
      IF(IS.LE.2)THEN
      DO 17 J=1,JG
   17 M(1,J)=M(1,J)-R2(1,J)*(Z(2,J)-Z(1,J))
      ENDIF
C
      DO 20 J=JS,JE
      DO 20 I=IS,IE
      V1(I)=Z(I,J+1)-Z(I,J)
      V2(I)=M(I-1,J)+M(I,J)+M(I-1,J+1)+M(I,J+1)          Computation of N.
      N(I,J)=N(I,J)-R4(I,J)*V1(I)-R5(I,J)*V2(I)
   20 CONTINUE
      IF(IS.LE.2)THEN
      DO 25 J=1,JG-1
   25 N(1,J)=N(1,J)-R4(1,J)*(Z(1,J+1)-Z(1,J))
      ENDIF
      IF(IE.GE.IG-1)THEN
      DO 26 J=1,JG-1                                     Computation of N along
   26 N(IG,J)=N(IG,J)-R4(IG,J)*(Z(IG,J+1)-Z(IG,J))       the boundary line.
      ENDIF
      IF(JS.LE.2)THEN
      DO 27 I=1,IG
   27 N(I,1)=N(I,1)-R4(I,1)*(Z(I,2)-Z(I,1))
      ENDIF
C
      RETURN
      END
C
```

```
      SUBROUTINE OUTPUT (IG,JG,IS,JS,IE,JE,KK,KD,Z,H)
C
      PARAMETER (GX=1.E-4)
      DIMENSION Z(IG,JG),H(IG,JG)
      DIMENSION KW(100),KM(23)
C
      DATA KM/1HJ,1HI,1HH,1HG,1HF,1HE,1HD,1HC,
     &       1HB,1HA,1H.,1H1,1H2,1H3,1H4,1H5,
     &       1H6,1H7,1H8,1H9,1H0,1H*,1H /
      IF(KK.EQ.0)GOTO 120
C     IF(MOD(KK,180).EQ.0.AND.KK.LE.360*4)THEN
C     WRITE(26,102)IS,JS,IE,JE
C 102 FORMAT(4I10)
C     DO 15 J=JS,JE
C     WRITE(26,101)(Z(I,J),I=IS,IE)
C 101 FORMAT(20F6.3)
C  15 CONTINUE
C     ENDIF
  120 IF(MOD(KK,KD).NE.0)RETURN
      WRITE(6,410)KK,(KI,KI=120,160,10)
      DO 30 KY=1,100
      KJ=100-KY+1
      J1=6*(KJ-1)+1
      J2=J1+5
      DO 40 KI=1,80
      I1=6*(KI-1)+1
      I2=I1+5
      L=0
      S=0.
      DO 41 J=J1,J2
      DO 41 I=I1,I2
      IF(H(I,J).GT.0.)THEN
      L=L+1
      S=S+Z(I,J)
      ENDIF
   41 CONTINUE
      IF(L.GE.20)THEN
      S=S/L
      KMM=11+INT(S/0.02)
      IF(KMM.GT.21)KMM=21
      IF(KMM.LT.1)KMM=1
      IF(ABS(S).LT.GX)KMM=23
      ELSE
      KMM=22
      ENDIF
      KW(KI)=KM(KMM)
   40 CONTINUE
      JK=(KY+1)/2
      WRITE(6,400)JK,(KW(I),I=1,80)
   30 CONTINUE
      WRITE(6,100)KK,IS,JS,IE,JE
      RETURN
  100 FORMAT(1H ,"K=",I5,2X,"IS,JS,IE,JE=",4I5)
  400 FORMAT(1H ,I3,2X,80A1)
  410 FORMAT(1H1,/,2X,"MAP AT K=",I5,//,3X,4I20)
      END
C
```

Output of the spatial distribution of water level.

Output of the spatial distribution of water level in the area for computation.

Computation of the mean water level in each area of 2' x 2'.

Output of the mean water level on the display.

```
      SUBROUTINE FILEOT (IG,JG,Z,M,N)---  Output of the water level and discharge.
C
      REAL M,N
      DIMENSION Z(IG,JG),M(IG,JG),N(IG,JG)
C
      DO 10 J=1,JG
      WRITE(25,100)(Z(I,J),I=1,IG)
      WRITE(25,100)(M(I,J),I=1,IG)
      WRITE(25,100)(N(I,J),I=1,IG)
   10 CONTINUE
  100 FORMAT(10E12.5)
      RETURN
      END
C
      SUBROUTINE MAX (IG,JG,IS,JS,IE,JE,Z,H,ZM,ZN)---  Computation of the highest
                                                       and lowest water levels.
C
      DIMENSION Z(IG,JG),H(IG,JG),ZM(IG,JG),ZN(IG,JG)
      DO 10 I=IS,IE
      DO 10 J=JS,JE
      IF(H(I,J).LT.0.0)GOTO 10
      IF(ZM(I,J).LT.Z(I,J))ZM(I,J)=Z(I,J)
      IF(ZN(I,J).GT.Z(I,J))ZN(I,J)=Z(I,J)
   10 CONTINUE
      RETURN
      END
C
      SUBROUTINE POINT (IG,JG,Z,KK,KC)---  Output of the time histroy of water level.
C
      DIMENSION Z(IG,JG)
      IF(MOD(KK,KC).NE.0)RETURN
      WRITE(24,100)Z(211,405),Z(252,417),
               &Z(249,417),Z(246,418),
               &Z(219,415),Z(238,419),
               &Z(237,397),Z(266,325),
               &Z(133,377),Z(92,315),
               &Z(50,292),
               &Z(480,339),Z(382,89),
               &Z(480,231),Z(269,161)
  100 FORMAT(15F9.5)
      RETURN
      END
C
```

```
4650       SUBROUTINE PROPA (IG,JG,IS,JS,IE,JE,Z,H,LF,KK)
4660       DIMENSION Z(IG,JG),H(IG,JG),LF(IG,JG)
4670       LK=KK/60+1
4680       GX=0.002
4690       IF(LK.LE.3)GX=0.02
4700       IF(LK.GT.3.AND.LK.LE.6)GX=0.005
4710       DO 10 I=IS,IE
4720       DO 10 J=JS,JE
4730       IF(H(I,J).GT.0.0)THEN
4740       IF(LF(I,J).EQ.0)THEN
4750       IF(ABS(Z(I,J)).GT.GX)LF(I,J)=LK
4760       ENDIF
4770       ELSE
4780       LF(I,J)=-9
4790       ENDIF
4800    10 CONTINUE
4810       RETURN
4820       END
4830C
```

Check of the arrival time.

Travel time at present.

Give the travel time to a point, if the water level at the point exceeds 1cm.

```
4840       SUBROUTINE OUTDT (IG,JG,ZM,ZN,LK)
4850       DIMENSION ZM(IG,JG),ZN(IG,JG),LK(IG,JG)
4860       DO 20 I=1,IG
4870       DO 20 J=1,JG
4880       ZN(I,J)=ZM(I,J)-ZN(I,J)
4890       IF(ZN(I,J).GT.100.0)ZN(I,J)=100.0
4900       IF(ZM(I,J).GT.100.0)ZM(I,J)=100.0
4910    20 CONTINUE
4920       DO 10 J=1,JG
4930C      WRITE(31,100)(ZM(I,J),I=1,IG)
4940C      WRITE(32,100)(ZN(I,J),I=1,IG)
4950       WRITE(33,200)(LK(I,J),I=1,IG)
4960    10 CONTINUE
4970C 100 FORMAT(20F6.3)
4980  200 FORMAT(40I3)
4990       RETURN
5000       END
5010C
```

Output of the highest and lowest water level, and the arrival time.

```
      SUBROUTINE DEFORM(IG,JG,IS,JS,IE,JE,Z)
      REAL L
      PARAMETER (DX=15.0E+3,DR=5.0)
      PARAMETER (A=3.141592,B=4.848E-06,RR=6.37E+6,E=1.7453E-2)
      PARAMETER (HH=1.0E+3,D=1.2,DL=45.0,TH=10.0,RD=-90.0)
      PARAMETER (L=100.0E+3,W=50.0E+3)
      PARAMETER (YO=10.0,XO=140.0)
      PARAMETER (Y0=15.4,X0=147.3)
      DIMENSION Z(IG,JG)
      XL=A*RR*(X0-XO)*COS(E*YO)/180.0 ; YL=A*RR*(Y0-YO)/180.0
      H1=HH/SIN(E*DL)        ; H2=HH/SIN(E*DL)+W
      DS=D*COS(E*RD)         ; DD=D*SIN(E*RD)
      WRITE(6,*)XL,YL,H1,H2,DS,DD
      DO 10 I=1,IE-IS+1
      DO 10 J=1,JE-JS+1
C      XX=DX*(I-1) ; YY=DX*(J-1)
      YY=A*RR*DR*(J-1)/(60.0*180)
      XX=A*RR*DR*(I-1)*COS(E*(YO+DR*(J-1)/60.0))/(60.0*180)
      X1=(XX-XL)*SIN(E*TH)+(YY-YL)*COS(E*TH)-L/2.0
      X2=(XX-XL)*COS(E*TH)-(YY-YL)*SIN(E*TH)+HH/TAN(E*DL)
      X3=0.0
      CALL USCAL (X1,X2,X3, L/2.,H2,E*DL,F1)
      CALL USCAL (X1,X2,X3, L/2.,H1,E*DL,F2)
      CALL USCAL (X1,X2,X3,-L/2.,H2,E*DL,F3)
      CALL USCAL (X1,X2,X3,-L/2.,H1,E*DL,F4)
      CALL UDCAL (X1,X2,X3, L/2.,H2,E*DL,G1)
      CALL UDCAL (X1,X2,X3, L/2.,H1,E*DL,G2)
      CALL UDCAL (X1,X2,X3,-L/2.,H2,E*DL,G3)
      CALL UDCAL (X1,X2,X3,-L/2.,H1,E*DL,G4)
      US=(F1-F2-F3+F4)*DS/(12.0*A)
      UD=(G1-G2-G3+G4)*DD/(12.0*A)
      IF=I+IS-1  ; JF=J+JS-1
      Z(IF,JF)=US+UD
 10   CONTINUE
      RETURN
      END

C
```

Computation of the initial profile

Computations of parameters. Refer Figs.8 and 9.

Co-ordinates transform between (X,Y) and (X1,Y1).

Vertical displacement due to strike slip

Vertical displacement due to dip slip

```
5390      SUBROUTINE USCAL (X1,X2,X3,C,CC,DP,F)---
5400      REAL K
5410C
5420      SN=SIN(DP)    ; CS=COS(DP)
5430      C1=C ; C2=CC*CS ; C3=CC*SN
5440      R=SQRT((X1-C1)**2+(X2-C2)**2+(X3-C3)**2)
5450      Q=SQRT((X1-C1)**2+(X2-C2)**2+(X3+C3)**2)
5460      R2=X2*SN-X3*CS
5470      R3=X2*CS+X3*SN
5480      Q2=X2*SN+X3*CS
5490      Q3=-X2*CS+X3*SN
5500      H=SQRT(Q2**2+(Q3+CC)**2)
5510      K=SQRT((X1-C1)**2+Q2**2)
5520      A1=LOG(R+R3-CC)
5530      A2=LOG(Q+Q3+CC)
5540      A3=LOG(Q+X3+C3)
5550      B1=1+3.0*(TAN(DP))**2
5560      B2=3.0*TAN(DP)/CS
5570      B3=2.0*R2*SN
5580      B4=Q2+X2*SN
5590      B5=2.0*R2**2*CS
5600      B6=R*(R+R3-CC)
5610      B7=4.0*Q2*X3*SN**2
5620      B8=2.0*(Q2+X2*SN)*(X3+Q3*SN)
5630      B9=Q*(Q+Q3+CC)
5640      B10=4.0*Q2*X3*SN
5650      B11=(X3+C3)-Q3*SN
5660      B12=4.0*Q2**2*Q3*X3*CS*SN
5670      B13=2.0*Q+Q3+CC
5680      B14=Q**3*(Q+Q3+CC)**2
5690      F=CS*(A1+B1*A2-B2*A3)
5700     & +B3/R+2*SN*B4/Q-B5/B6+(B7-B8)/B9+B10*B11/Q**3-B12*B13/B14
5710      RETURN
5720      END
5730C
```

Computation of the vertical displacement due to strike slip.

```
      SUBROUTINE UDCAL (X1,X2,X3,C,CC,DP,F)
      REAL K
C
      SN=SIN(DP)  ; CS=COS(DP)
      C1=C ; C2=CC*CS ; C3=CC*SN
      R=SQRT((X1-C1)**2+(X2-C2)**2+(X3-C3)**2)
      Q=SQRT((X1-C1)**2+(X2-C2)**2+(X3+C3)**2)
      R2=X2*SN-X3*CS
      R3=X2*CS+X3*SN
      Q2=X2*SN+X3*CS
      Q3=-X2*CS+X3*SN
      H=SQRT(Q2**2+(Q3+CC)**2)
      K=SQRT((X1-C1)**2+Q2**2)
      A1=LOG(R+X1-C1)
      A2=LOG(Q+X1-C1)
      B1=Q*(Q+X1-C1)
      B2=R*(R+X1-C1)
      B3=Q*(Q+Q3+CC)
      D1=X1-C1  ; D2=X2-C2  ; D3=X3-C3
      D4=X3+C3  ; D5=R3-CC  ; D6=Q3+CC
      T1=ATN(D1*D2,(H+D4)*(Q+H))
      T2=ATN(D1*D5,R2*R)
      T3=ATN(D1*D6,Q2*Q)
      F=SN*(D2*(2*D3/B2+4*D3/B1-4*C3*X3*D4*(2*Q+D1)/(B1**2*Q))
     &  -6*T1+3*T2-6*T3)
      &+CS*(A1-A2-2*(D3**2)/B2
     &  -4*(D4**2-C3*X3)/B1-4*C3*X3*D4**2*(2*Q+X1-C1)/(B1**2*Q))
      &+6*X3*(CS*SN*(2*D6/B1+D1/B3)-Q2*(SN**2-CS**2)/B1)
      RETURN
      END
C
      REAL FUNCTION ATN (AX,AY)
      DATA GX/1.0E-6/
      AAX=ABS(AX) ; AAY=ABS(AY)
      P=AX*AY
      IF(AAX.LE.GX.AND.AAY.LE.GX)GOTO 10
      SR=ATAN2(AAX,AAY)
      ATN=SIGN(SR,P)
      RETURN
   10 WRITE(6,100)AX,AY
  100 FORMAT(1H ,"ATAN --   AX=",E15.7,2X,"AY=",E15.7)
      ATN=0.2
      RETURN
      END
```

Computation of the vertical displacement due to dip slip.

□

IUGG/IOC TIME PROJECT

PART 3. PROGRAMME LISTS FOR NEAR-FIELD TSUNAMI

TUNAMI-N1: LINEAR THEORY WITH CONSTANT GRIDS

TUNAMI-N2: LINEAR THEORY IN DEEP SEA, SHALLOW WATER THEORY IN SHALLOW SEA AND RUNUP ON LAND WITH CONSTANT GRIDS

TUNAMI-N3: LINEAR THEORY WITH VARYING GRIDS

CONTENTS

Page

TUNAMI-N1: LINEAR THEORY WITH CONSTANT GRIDS 1

TUNAMI-N2: LINEAR THEORY IN DEEP SEA, SHALLOW WATER THEORY IN SHALLOW SEA AND RUNUP ON LAND WITH CONSTANT GRIDS 7

TUNAMI-N3: LINEAR THEORY WITH VARYING GRIDS 16

```
*#RUN : IAP OPT=2 F=/SNRK/MM2.7(02)
C
C   *************** TUNAMI-N1 ****************
C     Tohoku University's Numerical-Analysis Model
C        for Investigation of tsunami
C         Near-field Tsunami version
C
C       1968 TOKACHI-OKI EARTHQUAKE TSUNAMI
C         USING BY LINEAR LONG WAVE THEORY
C
C              CODED  BY
C
C         F.IMAMURA, TOHOKU UNIV., JAPAN
C
C                       1991.6.25
C
C     Z; WATER SURFACE LEVEL   M,N; WATER DISCHARGE
C     H; STILL WATER DEPTH      ZD; TOTAL WATER DEPTH
C  IF,JF; DIMENSION          DX,DT; SPATIAL GRID & TIME STEP SIZE
C     G; GRAVITATIONAL ACCES.  KL; TOTAL TIME STEP
C  IP,JP; POSITION OF OUTPUT POINT
C  I0,J0; ORIGIN OF EPICENTER
C
      REAL M,N
      PARAMETER(IF=260,JF=180,I0=111,J0=188)
      PARAMETER(DX=2700.0,DT=5.0,G=9.8,KD=1,KL=360)
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2),H(IF,JF)
      DIMENSION ZM(IF,JF),ZD(IF,JF),IH(IF,JF)
C      DIMENSION IP(16),JP(16),PZ(16)
C      DATA IP/62,76,86,96,104,114,124,132,142,152,162,172,182
C     &     ,192,202,212/
C      DATA JP/60,60,62,66,72,76,80,84,88,86,80,78,78,78,80,78/
C
      R=DT/DX ; KK=0
C
C ********* INITIAL CONDITION *************
C
      CALL DEPTH(IF,JF,H,IH)
      CALL INTL(IF,JF,Z,M,N)
      CALL DEFORM(IF,JF,Z,I0,J0,DX)
C      CALL OUT6 (IF,JF,Z,H,KK)
      CALL PTIME(CT1)
C
C ********* MAIN CALCULATION *************
C
      DO 10 K=1,KL
       KK=K
       IF(MOD(KK,10).EQ.0)WRITE(6,*)KK
       CALL MASS(IF,JF,Z,M,N,H,R,ZD)
       CALL OPEN(IF,JF,Z,M,N,H)
       CALL MOMENT(IF,JF,Z,M,N,H,R,G)
       CALL ZMAX(IF,JF,Z,ZM)
C       CALL OUT3 (IF,JF,16,Z,IP,JP,PZ)
       IF(MOD(K,50).NE.0)GOTO 20
       CALL OUT6(IF,JF,Z,H,KK)
C       CALL OUT1 (IF,JF,Z)
   20  CALL CHANGE(IF,JF,Z,M,N)
   10 CONTINUE
C
C      CALL OUT66 (IF,JF,ZM,H)
C      CALL OUT11 (IF,JF,ZM)
      CALL PTIME(CT2)
      CT=CT2-CT1
      WRITE(6,100)CT
  100 FORMAT(1H ,3X,"CPU TIME =",E12.4)
      STOP
      END
C
C ******** READ DEPTH DATA *********************
C
      SUBROUTINE DEPTH(IF,JF,H,IH)
C
```

```
      DIMENSION H(IF,JF),IH(IF,JF)
      L=JF/10+1
      IF(MOD(JF,10).EQ.0)L=L-1
      DO 10 LL=1,L
       J1=10*(LL-1)+1
       J2=J1+9
       IF(J2.GT.JF)J2=JF
       DO 10 I=1,IF
        READ(2,100)(IH(I,J),J=J1,J2)
  100   FORMAT(5X,10I5)
        DO 10 J=J1,J2
         H(I,J)=FLOAT(IH(I,J))
         IF(IH(I,J).GT.0.0.AND.IH(I,J).LT.500)H(I,J)=500.0
   10 CONTINUE
      RETURN
      END
C
C ********* INITIAL CONDITION **************
C
      SUBROUTINE INTL(IF,JF,Z,M,N)
C
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
      DO 10 K=1,2
       DO 10 J=1,JF
        DO 10 I=1,IF
         Z(I,J,K)=0.0
         M(I,J,K)=0.0
         N(I,J,K)=0.0
   10 CONTINUE
      RETURN
      END
C
C ********** MASS CONSERVATION **************
C
      SUBROUTINE MASS(IF,JF,Z,M,N,H,R,ZD)
C
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2),H(IF,JF)
      DIMENSION ZD(IF,JF)
      DATA GX/1.0E-10/
      DO 10 J=2,JF
       DO 10 I=2,IF
        IF(H(I,J).LT.0.0)GO TO 10
        ZZ=Z(I,J,1)-R*(M(I,J,1)-M(I-1,J,1)+N(I,J,1)-N(I,J-1,1))
        ZZ=ZZ+ZD(I,J)
        IF(ABS(ZZ).LT.GX)ZZ=0.0
        Z(I,J,2)=ZZ
   10 CONTINUE
      RETURN
      END
C
C *********** MOMENTUM CONSERVATION *****************
C
      SUBROUTINE MOMENT(IF,JF,Z,M,N,H,R,G)
C
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2),H(IF,JF)
      DATA GX/1.0E-10/
      DO 10 J=1,JF
       DO 10 I=1,IF
        IF(I.EQ.IF)GOTO 20
        IF(H(I,J).LT.0.0)GO TO 10
        IF(H(I+1,J).LT.0.0)GO TO 20
        HM=0.5*(H(I,J)+H(I+1,J))
        XM=M(I,J,1)-G*R*HM*(Z(I+1,J,2)-Z(I,J,2))
        IF(ABS(XM).LT.GX)XM=0.0
        M(I,J,2)=XM
   20   IF(J.EQ.JF)GOTO 10
        IF(H(I,J+1).LT.0.0)GO TO 10
        HN=0.5*(H(I,J)+H(I,J+1))
        XN=N(I,J,1)-G*R*HN*(Z(I,J+1,2)-Z(I,J,2))
```

```
          IF(ABS(XN).LT.GX)XN=0.0
          N(I,J,2)=XN
   10 CONTINUE
      RETURN
      END
C
C ****** OUTPUT OF COMPUTED RESULTS ON THE DISPLAY *******
C
      SUBROUTINE OUT6(IF,JF,Z,H,K)
C
      DIMENSION KM(46),LW(140),Z(IF,JF,2)
      DIMENSION H(IF,JF)
      DATA KM/1H*,1HW,1HV,1HU,1HT,1HS,1HR,1HP,1HO,1HN,1HM,1HL,1HK,1HJ,
     & 1HI,1HH,1HG,1HF,1HE,1HD,1HC,1HB,1HA,1H.,1H1,1H2,1H3,1H4,1H5,1H6,
     & 1H7,1H8,1H9,1H0,1H.,1H-,1H+,1H/,1H#,1H$,1H%,1H&,1H=,1H?,1H(,1H)/
      WRITE(6,100)K
  100 FORMAT(1H ,2X,"K=",I4,/)
      WRITE(6,200)(J,J=10,70,10)
  200 FORMAT(1H ,4X,7I10)
      DO 10 I=1,130
        DO 30 J=1,90
          II=2*(I-1)+1
          JJ=2*(J-1)+1
          ZZZ=0.0
          DO 999 IX=II,II+1
            DO 999 JX=JJ,JJ+1
              ZZZ=ZZZ+0.25*Z(IX,JX,2)
              IF(H(IX,JX).LT.0.0)GOTO 998
  999     CONTINUE
          KKM=24
          IF(ZZZ.GT.0.0)KKM=IFIX((ZZZ+0.05)/0.1)+24
          IF(ZZZ.LT.0.0)KKM=IFIX((ZZZ-0.05)/0.1)+24
          IF(KKM.LT.2)KKM=2
          IF(KKM.GT.46)KKM=46
          LW(J)=KM(KKM)
          GOTO 30
  998     LW(J)=KM(1)
   30   CONTINUE
        WRITE(6,110)I,(LW(J),J=1,70)
  110   FORMAT(1H ,I3,1X,90A1)
   10 CONTINUE
      RETURN
      END
C
C *********** OUTPUT OF DATA *************
C
      SUBROUTINE OUT1(IF,JF,Z)
      DIMENSION Z(IF,JF,2)
      DO 10 I=1,IF
        WRITE(4)(Z(I,J,2),J=1,JF)
   10 CONTINUE
      RETURN
      END
C
      SUBROUTINE OUT3(IF,JF,IM,Z,IP,JP,PZ)
      DIMENSION Z(IF,JF,2),IP(IM),JP(IM),PZ(IM)
      DO 10 I=1,IM
        II=IP(I)
        JJ=JP(I)
        PZ(I)=Z(II,JJ,2)
   10 CONTINUE
      WRITE(3)(PZ(I),I=1,IM)
      RETURN
      END
C
C *********** OPEN BOUNDARY CONDITION *************
C
      SUBROUTINE OPEN(IF,JF,Z,M,N,H)
C
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2),H(IF,JF)
      DO 10 KK=1,2
      J=1
      IF(KK.EQ.2)J=JF
      DO 10 I=2,IF
       IF(H(I,J).LT.0.0)GO TO 10
       CC=SQRT(9.8*H(I,J))
       UU=0.5*ABS(M(I,J,2)+M(I-1,J,2))
       IF(J.EQ.1)UU=SQRT(UU**2+N(I,J,2)**2)
       IF(J.EQ.JF)UU=SQRT(UU**2+N(I,J-1,2)**2)
       ZZ=UU/CC
       IF(J.EQ.1.AND.N(I,J,2).GT.0.0)ZZ=-ZZ
       IF(J.EQ.JF.AND.N(I,J-1,2).LT.0.0)ZZ=-ZZ
       Z(I,J,2)=ZZ
  10 CONTINUE
     DO 20 KK=1,2
      I=1
      IF(KK.EQ.2)I=IF
      DO 20 J=2,JF
       IF(H(I,J).LT.0.0)GO TO 20
       CC=SQRT(9.8*H(I,J))
       UU=0.5*ABS(N(I,J,2)+N(I,J-1,2))
       IF(I.EQ.1)UU=SQRT(UU**2+M(I,J,2)**2)
       IF(I.EQ.IF)UU=SQRT(UU**2+M(I-1,J,2)**2)
       ZZ=UU/CC
       IF(I.EQ.1.AND.M(I,J,2).GT.0.0)ZZ=-ZZ
       IF(I.EQ.IF.AND.M(I-1,J,2).LT.0.0)ZZ=-ZZ
       Z(I,J,2)=ZZ
  20 CONTINUE
    RETURN
    END
C
C *** EXCHANGE FOR LAST STEP DATA TO NEXT STEP DATA *****
C
    SUBROUTINE CHANGE(IF,JF,Z,M,N)
C
    REAL M,N
    DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
    DO 10 J=1,JF
     DO 10 I=1,IF
      Z(I,J,1)=Z(I,J,2)
      M(I,J,1)=M(I,J,2)
      N(I,J,1)=N(I,J,2)
  10 CONTINUE
    RETURN
    END
C
C
C *** CALCULATOIN FOR INITIAL TSUNAMI SOURCE ******
C        (= SEA BOTTOM DEFORMATION)
C
C    RR; RADIUS OF EARTH
C    L ; FAULT LENGTH,     W ; FAULT WIDTH
C    TH; DIP DIRECTION,    DL; DIP ANGLE
C    RD; SLIP ANGLE        D ; DISLOCATION
C    HH; DEPTH
C
    SUBROUTINE DEFORM(IF,JF,Z,I0,J0,DX)
    REAL L
    PARAMETER(A=3.141592,B=4.848E-06,RR=6.37E+6,E=1.7453E-2)
    PARAMETER(L=188.2E+3,W=92.0E+3,TH=145.0,DL=20.0)
    PARAMETER(RD=148.0,D=3.2,HH=1.0E+3)
    DIMENSION Z(IF,JF,2)
    XL=DX*(I0-1) ; YL=DX*(J0-1) ; H1=HH/SIN(E*DL)
    H2=HH/SIN(E*DL)+W ; DS=D*COS(E*RD) ; DD=D*SIN(E*RD)
    DO 10 I=1,IF
     DO 10 J=1,JF
      XX=DX*(I-1) ; YY=DX*(J-1)
      X1=(XX-XL)*SIN(E*TH)+(YY-YL)*COS(E*TH)-L/2.0
      X2=(XX-XL)*COS(E*TH)-(YY-YL)*SIN(E*TH)+HH/TAN(E*DL)
      X3=0.0
      CALL USCAL(X1,X2,X3,L/2.,H2,E*DL,F1)
      CALL USCAL(X1,X2,X3,L/2.,H1,E*DL,F2)
      CALL USCAL(X1,X2,X3,-L/2.,H2,E*DL,F3)
```

```
2890        CALL USCAL(X1,X2,X3,-L/2.,H1,E*DL,F4)
2900        CALL UDCAL(X1,X2,X3,L/2.,H2,E*DL,G1)
2910        CALL UDCAL(X1,X2,X3,L/2.,H1,E*DL,G2)
2920        CALL UDCAL(X1,X2,X3,-L/2.,H2,E*DL,G3)
2930        CALL UDCAL(X1,X2,X3,-L/2.,H1,E*DL,G4)
2940        US=(F1-F2-F3+F4)*DS/(12.0*A)
2950        UD=(G1-G2-G3+G4)*DD/(12.0*A)
2960        Z(I,J,1)=US+UD
2970        Z(I,J,2)=US+UD
2980  10 CONTINUE
2990     RETURN
3000     END
3010C
3020     SUBROUTINE USCAL(X1,X2,X3,C,CC,DP,F)
3030     REAL K
3040C
3050     SN=SIN(DP) ; CS=COS(DP) ; C1=C ; C2=CC*CS ; C3=CC*SN
3060     R=SQRT((X1-C1)**2+(X2-C2)**2+(X3-C3)**2)
3070     Q=SQRT((X1-C1)**2+(X2-C2)**2+(X3+C3)**2)
3080     R2=X2*SN-X3*CS
3090     R3=X2*CS+X3*SN
3100     Q2=X2*SN+X3*CS
3110     Q3=-X2*CS+X3*SN
3120     H=SQRT(Q2**2+(Q3+CC)**2)
3130     K=SQRT((X1-C1)**2+Q2**2)
3140     A1=LOG(R+R3-CC)
3150     A2=LOG(Q+Q3+CC)
3160     A3=LOG(Q+X3+C3)
3170     B1=1+3.0*(TAN(DP))**2
3180     B2=3.0*TAN(DP)/CS
3190     B3=2.0*R2*SN
3200     B4=Q2+X2*SN
3210     B5=2.0*R2**2*CS
3220     B6=R*(R+R3-CC)
3230     B7=4.0*Q2*X3*SN**2
3240     B8=2.0*(Q2+X2*SN)*(X3+Q3*SN)
3250     B9=Q*(Q+Q3+CC)
3260     B10=4.0*Q2*X3*SN
3270     B11=(X3+C3)-Q3*SN
3280     B12=4.0*Q2**2*Q3*X3*CS*SN
3290     B13=2.0*Q+Q3+CC
3300     B14=Q**3*(Q+Q3+CC)**2
3310     F=CS*(A1+B1*A2-B2*A3)+B3/R+2*SN*B4/Q-B5/B6+(B7-B8)/B9+B10*B11/
3320    & Q**3-B12*B13/B14
3330     RETURN
3340     END
3350C
3360     SUBROUTINE UDCAL(X1,X2,X3,C,CC,DP,F)
3370     REAL K
3380C
3390     SN=SIN(DP) ; CS=COS(DP) ; C1=C ; C2=CC*CS ; C3=CC*SN
3400     R=SQRT((X1-C1)**2+(X2-C2)**2+(X3-C3)**2)
3410     Q=SQRT((X1-C1)**2+(X2-C2)**2+(X3+C3)**2)
3420     R2=X2*SN-X3*CS
3430     R3=X2*CS+X3*SN
3440     Q2=X2*SN+X3*CS
3450     Q3=-X2*CS+X3*SN
3460     H=SQRT(Q2**2+(Q3+CC)**2)
3470     K=SQRT((X1-C1)**2+Q2**2)
3480     A1=LOG(R+X1-C1)
3490     A2=LOG(Q+X1-C1)
3500     B1=Q*(Q+X1-C1)
3510     B2=R*(R+X1-C1)
3520     B3=Q*(Q+Q3+CC)
3530     D1=X1-C1 ; D2=X2-C2 ; D3=X3-C3 ; D4=X3+C3 ; D5=R3-CC ; D6=Q3+CC
3540     T1=ATN(D1*D2,(H+D4)*(Q+H))
3550     T2=ATN(D1*D5,R2*R)
3560     T3=ATN(D1*D6,Q2*Q)
3570     F=SN*(D2*(2*D3/B2+4*D3/B1-4*C3*X3*D4*(2*Q+D1)/(B1**2*Q))
3580    & -6*T1+3*T2-6*T3)+CS*(A1-A2-2*(D3**2)/B2-4*(D4**2-C3*X3)/
3590    & B1-4*C3*X3*D4**2*(2*Q+X1-C1)/(B1**2*Q))+6*X3*(CS*SN*(2*D6/B1+D1/
3600    & B3)-Q2*(SN**2-CS**2)/B1)
```

```
3610      RETURN
3620      END
3630C
3640      REAL FUNCTION ATN(AX,AY)
3650      DATA GX/1.0E-6/
3660      AAX=ABS(AX) ; AAY=ABS(AY)
3670      P=AX*AY
3680      IF(AAX.LE.GX.AND.AAY.LE.GX)GOTO 10
3690      SR=ATAN2(AAX,AAY)
3700      ATN=SIGN(SR,P)
3710      RETURN
3720   10 WRITE(6,100)AX,AY
3730  100 FORMAT(1H ,"ATAN --    AX=",E15.7,2X,"AY=",E15.7)
3740      ATN=0.2
3750      END
3760C
3770      SUBROUTINE ZMAX(IF,JF,Z,ZM)
3780      DIMENSION Z(IF,JF),ZM(IF,JF)
3790C
3800      DO 10 I=1,IF
3810        DO 10 J=1,JF
3820          IF(ZM(I,J).LT.Z(I,J))ZM(I,J)=Z(I,J)
3830   10 CONTINUE
3840      RETURN
3850      END
```

```
*#RUN : IAP OPT=2 F=/SNRK/GD-MK(10) F=/SNRK/GD-BT1(11);
*#            F=/SNRK/TBN-MYK(12)
C
C  ************** TUNAMI-N2 ****************
C    Tohoku University's Numerical-Analysis Model
C       for Investigation of tsunami
C        Near-field Tsunami version
C
C      FOR 1896 MEIJI SANTRIKU TSUNAMI
C        AT MIYAKO BAY (DX=50M)
C        WITH SHALLOW WATER THEORY
C      INCLUDING EFFECTS OF RUNUP AND STRUCTURES
C
C                         1991.1.25
C             BY
C
C      F.IMAMURA, TOHOKU UNIV., JAPAN
C
C     Z; WATER SURFACE LEVEL   M,N; WATER DISCHARGE
C  HM,HN; STILL WATER DEPTH AT POINT OF WATER DISCHARGE
C  DM,DN; TOTAL WATER DEPTH AT POINT OF WATER DISCHARGE
C    HZ; STILL WATER DEPTH      ZD; TOTAL WATER DEPTH
C  IF,JF; DIMENSION PARAME    DX,DT; SPATIAL GRID & TIME STEP SIZE
C     G; GRAVITATIONAL ACCES.  KL; TOTAL TIME STEP
C    IR; MAP OF WAVE-BRAKER     BT; HEIGHT OF WAVE-BRAKER
C  IP,JP; POSITION OF OUTPUT POINT
C    ZM; MAXIMUM WATER LEVEL
C
      REAL M,N
      PARAMETER(IF=170,JF=150)
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2),HZ(IF,JF)
      DIMENSION DZ(IF,JF,2),DM(IF,JF,2),DN(IF,JF,2)
      DIMENSION HM(IF,JF),HN(IF,JF),B(1800,14),ZM(IF,JF)
      DIMENSION IP(13),JP(13),PZ(13)
      DIMENSION IR(IF,JF),BT(10)
      DATA IP/14,27,50,62,78,114,123,144,144,132,116,102,85/
      DATA JP/73,80,79,78,79,52,40,48,72,71,78,85,103/
      DATA BT/5.26,6.70,8.0,5.5,6.0,10.0,10.0,10.0,10.0,10.0/
      G=9.8 ; DX=50.0 ; DT=1.0 ; R=DT/DX
      KL=5400
C
C ********* INITIAL CONDITION *************
C
      CALL READ(10,11,IF,JF,HZ,IR)
      CALL DATA(12,B)
      CALL HMN(IF,JF,HZ,HM,HN,IR,BT)
      CALL INTL(IF,JF,Z,M,N,DZ,HZ)
      CALL PTIME(CT1)
C
C ********* MAIN CALCULATION *************
C
      DO 10 K=1,KL
       KK=K
       CALL NLMASS(IF,JF,Z,M,N,DZ,HZ,R)
       CALL BNC(IF,JF,Z,B,2,101,150,KK,DT)
       CALL NLMMT(IF,JF,Z,M,N,DZ,DM,DN,HZ,HM,HN,R,DT,0.025,IR)
       CALL MAX(IF,JF,Z,ZM)
       IF(MOD(K,30).NE.0)GOTO 20
       CALL POINT(17,IF,JF,13,Z,IP,JP,PZ)
       CALL OUT1(15,IF,JF,Z,M,N,DM,DN,HZ)
       CALL OUT6(IF,JF,Z,HZ,KK)
   20  CALL CHANGE(IF,JF,Z,M,N,DZ)
   10 CONTINUE
      CALL OUT3(16,IF,JF,ZM)
C      CALL OUT4 (18,IF,JF,Z,M,N,HZ,ZM)
      CALL PTIME(CT2)
      CT=CT2-CT1
      WRITE(6,180)CT
  180 FORMAT(1H ,3X,"CPU TIME=",E12.4)
      STOP
      END
C
```

```
C ******** READ DEPTH DATA *********************
C
      SUBROUTINE READ(N1,N2,IF,JF,HZ,IR)
      DIMENSION HZ(IF,JF),IR(IF,JF)
      L=IF/10
      IF(MOD(IF,10).NE.0)L=L+1
      DO 10 LL=1,L
       I1=10*(LL-1)+1
       I2=I1+9
       IF(I2.GE.IF)I2=IF
       DO 10 J=1,JF
         READ(N1,100)(HZ(I,JF-J+1),I=I1,I2)
         READ(N2,200)(IR(I,JF-J+1),I=I1,I2)
  100    FORMAT(5X,10F5.1)
  200    FORMAT(4X,10I5)
   10 CONTINUE
      RETURN
      END
C
C ********** INITIAL CONDITION **************
C
      SUBROUTINE INTL(IF,JF,Z,M,N,D,H)
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
      DIMENSION H(IF,JF),D(IF,JF,2)
      DO 10 K=1,2
       DO 10 J=1,JF
        DO 10 I=1,IF
         Z(I,J,K)=0.0
         M(I,J,K)=0.0
         N(I,J,K)=0.0
         D(I,J,K)=H(I,J)
         IF(H(I,J).GT.0.0) GOTO 10
         D(I,J,K)=0.0
         Z(I,J,K)=-H(I,J)
   10 CONTINUE
      RETURN
      END
C
C  ****** CAL. OF WATER DEPTH AT POINT OF DISCHARGE ********
C
      SUBROUTINE HMN(IF,JF,HZ,HM,HN,IR,BT)
      DIMENSION HZ(IF,JF),HM(IF,JF),HN(IF,JF),IR(IF,JF),BT(10)
      DO 10 J=1,JF
       DO 10 I=1,IF
        IF(I.EQ.IF)GOTO 11
        HM(I,J)=0.5*(HZ(I,J)+HZ(I+1,J))
        GOTO 12
   11    HM(I,J)=HZ(I,J)
   12    IF(J.EQ.JF)GOTO 13
        HN(I,J)=0.5*(HZ(I,J)+HZ(I,J+1))
        GOTO 10
   13    HN(I,J)=HZ(I,J)
   10 CONTINUE
      DO 20 I=1,IF
       DO 20 J=1,JF
        IRR=MOD(IR(I,J),10)
        IRM=IR(I,J)/10
        IF(IRM.EQ.0) GOTO 20
        IF(IRM.EQ.2) GOTO 22
        HM(I,J)=-BT(IRR)
        IF(IRM.EQ.1) GOTO 23
   22    HN(I,J)=-BT(IRR)
   23    IF(IRM.EQ.2) GOTO 24
        IF(HM(I,J).GT.HZ(I,J))HM(I,J)=HZ(I,J)
        IF(HM(I,J).GT.HZ(I+1,J))HM(I,J)=HZ(I+1,J)
        IF(IRM.EQ.1) GOTO 20
   24    IF(HN(I,J).GT.HZ(I,J))HN(I,J)=HZ(I,J)
        IF(HN(I,J).GT.HZ(I,J+1))HN(I,J)=HZ(I,J+1)
   20 CONTINUE
      RETURN
      END
```

```
C
C ******** MASS CONSERVATION ***********
C
      SUBROUTINE NLMASS(IF,JF,Z,M,N,DZ,HZ,R)
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
      DIMENSION DZ(IF,JF,2),HZ(IF,JF)
      DATA GX,GY/1.0E-5,1.0E-10/
      DO 10 J=2,JF
       DO 10 I=3,IF
        IF(HZ(I,J).LT.-9.9)GOTO 11
        XM=0.0
        XN=0.0
        IF(I.NE.1)XM=M(I-1,J,1)
        IF(J.NE.1)XN=N(I,J-1,1)
        ZZZ=Z(I,J,1)-R*(M(I,J,1)-XM+N(I,J,1)-XN)
        IF(ABS(ZZZ).LT.GY)ZZZ=0.0
        DD=ZZZ+HZ(I,J)
        IF(DD.LT.GX)GOTO 11
        DZ(I,J,2)=DD
        Z(I,J,2)=ZZZ
        GOTO 10
 11      DD=0.0
        DZ(I,J,2)=DD
        Z(I,J,2)=DD-HZ(I,J)
 10 CONTINUE
      RETURN
      END
C
C *********** MOMENTUM CONSERVATION *****************
C
      SUBROUTINE NLMMT(IF,JF,Z,M,N,DZ,DM,DN,HZ,HM,HN,R,DT,FM,IR)
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
      DIMENSION DZ(IF,JF,2),DM(IF,JF,2),DN(IF,JF,2)
      DIMENSION HZ(IF,JF),HM(IF,JF),HN(IF,JF),IR(IF,JF)
      DATA GG,GX/9.8,1.0E-5/
C
C       ------ CAL. OF TOTAL DEPTH AT POINT OF DISCHARGE -------
C
      DO 10 I=2,IF
       DO 10 J=2,JF
        IRR=IR(I,J)/10
        IF(IRR.EQ.1.OR.IRR.EQ.3)GO TO 11
        DM2=0.5*(DZ(I,J,2)+DZ(I+1,J,2))
        DM1=0.25*(DZ(I,J,2)+DZ(I,J,1)+DZ(I+1,J,2)+DZ(I+1,J,1))
        GO TO 12
 11      IF(DZ(I,J,1))13,13,14
 13      IF(DZ(I+1,J,1))15,15,16
 14      IF(DZ(I+1,J,1))17,17,18
 16      IF(Z(I+1,J,1)+HM(I,J))15,15,19
 17      IF(Z(I,J,1)+HM(I,J))15,15,20
 18      IF(Z(I,J,1)+HM(I,J))21,21,22
 21      IF(Z(I+1,J,1)+HM(I,J))15,15,19
 22      IF(Z(I+1,J,1)+HM(I,J))20,20,23
 15      DM2=0.0
        DM1=0.0
        GO TO 12
 19      DM2=Z(I+1,J,1)+HM(I,J)
        DM1=DM2
        GO TO 12
 20      DM2=Z(I,J,1)+HM(I,J)
        DM1=DM2
        GO TO 12
 23      DM2=0.5*(Z(I,J,1)+Z(I+1,J,1))+HM(I,J)
        DM1=DM2
 12      IF(IRR.GE.2)GO TO 112
        DN2=0.5*(DZ(I,J,2)+DZ(I,J+1,2))
        DN1=0.25*(DZ(I,J,2)+DZ(I,J,1)+DZ(I,J+1,2)+DZ(I,J+1,1))
        GO TO 24
 112      IF(DZ(I,J,1))113,113,114
 113      IF(DZ(I,J+1,1))115,115,116
 114    IF(DZ(I,J+1,1))117,117,118
 116    IF(Z(I,J+1,1)+HN(I,J))115,115,119
 117    IF(Z(I,J,1)+HN(I,J))115,115,120
 118    IF(Z(I,J,1)+HN(I,J))121,121,122
 121    IF(Z(I,J+1,1)+HN(I,J))115,115,119
 122    IF(Z(I,J+1,1)+HN(I,J))120,120,123
 115    DN2=0.0
      DN1=0.0
      GO TO 24
 119    DN2=Z(I,J+1,1)+HN(I,J)
      DN1=DN2
      GO TO 24
 120    DN2=Z(I,J,1)+HN(I,J)
      DN1=DN2
      GO TO 24
 123    DN2=0.5*(Z(I,J,1)+DZ(I,J+1,1))+HN(I,J)
      DN1=DN2
  24    IF(DM1.LT.GX)DM1=0.0
      IF(DM2.LT.GX)DM2=0.0
      IF(DN1.LT.GX)DN1=0.0
      IF(DN2.LT.GX)DN2=0.0
      DM(I,J,1)=DM1
      DM(I,J,2)=DM2
      DN(I,J,1)=DN1
      DN(I,J,2)=DN2
  10 CONTINUE
C
C  ------- CAL. OF LINEAR TERMS (X-DIRECTION) -------
C
    FN=0.5*DT*GG*FM**2
    DO 200 I=2,IF
     DO 200 J=2,JF
      IF(HZ(I,J).LT.-8.1)GO TO 200
      IF(I.EQ.IF)GO TO 30
      IRR=IR(I,J)/10
      IF(IRR.EQ.1.OR.IRR.EQ.3)GO TO 60
      IF(HM(I,J).LT.-8.1)GO TO 30
      IF(DZ(I,J,2))31,31,32
  31    IF(DZ(I+1,J,2))30,30,34
  32    IF(DZ(I+1,J,2))35,35,36
  34    IF(Z(I+1,J,2)+HZ(I,J))30,30,37
  35    IF(Z(I,J,2)+HZ(I+1,J))30,30,38
  36    DD=DM(I,J,2)
      GO TO 39
  37    DD=Z(I+1,J,2)+HZ(I,J)
      GO TO 39
  38    DD=Z(I,J,2)+HZ(I+1,J)
  39    XNN=0.25*(N(I,J,1)+N(I+1,J,1)+N(I,J-1,1)+N(I+1,J-1,1))
      DF=DD
      IF(DF.LT.1.0E-2)DF=1.0E-2
      FF=FN*SQRT(M(I,J,1)**2+XNN**2)/DF**(7.0/3.0)
      IF(DD.LT.GX)GO TO 30
      XM=(1.0-FF)*M(I,J,1)-GG*R*DD*(Z(I+1,J,2)-Z(I,J,2))
C
C ----- CAL. OF NON-LINEAR TERMS (CONVECTION TERMS) ------
C
      IF(I.LE.6.OR.J.LE.6)GO TO 40
      IF(DM(I,J,1).LT.GX)GO TO 40
      IF(M(I,J,1))41,41,42
  41    IF(DM(I+1,J,1).LT.GX)GO TO 40
      IF(DZ(I+2,J,2).LT.GX)GO TO 40
      IF(DZ(I+1,J,2).LT.GX)GO TO 40
      IF(IR(I+1,J)/10.EQ.1.OR.IR(I+1,J)/10.EQ.3)GO TO 1001
      XM=XM-R*(M(I+1,J,1)**2/DM(I+1,J,1)-M(I,J,1)**2/DM(I,J,1))
      GO TO 43
1001    XM=XM-R*(-M(I,J,1)**2/DM(I,J,1))
      GO TO 43
  42    IF(DM(I-1,J,1).LT.GX)GO TO 40
      IF(DZ(I-1,J,2).LT.GX)GO TO 40
      IF(DZ(I,J,2).LT.GX)GO TO 40
      IF(IR(I-1,J)/10.EQ.1.OR.IR(I-1,J)/10.EQ.3)GO TO 1002
      XM=XM-R*(M(I,J,1)**2/DM(I,J,1)-M(I-1,J,1)**2/DM(I-1,J,1))
      GO TO 43
 1002  XM=XM-R*(M(I,J,1)**2/DM(I,J,1))
   43  IF(XNN)44,44,45
   44  XNE=0.25*(N(I,J+1,1)+N(I+1,J+1,1)+N(I,J,1)+N(I+1,J,1))
      IF(DM(I,J+1,1).LT.GX)GO TO 40
      IF(DZ(I,J+1,2).LT.GX)GO TO 40
      IF(DZ(I,J+2,2).LT.GX)GO TO 40
      IF(DZ(I+1,J+1,2).LT.GX)GO TO 40
      IF(DZ(I+1,J+2,2).LT.GX)GO TO 40
      IF(IR(I,J)/10.GE.2.OR.IR(I+1,J)/10.GE.2)GO TO 40
      XM=XM-R*(M(I,J+1,1)*XNE/DM(I,J+1,1)-M(I,J,1)*XNN/DM(I,J,1))
      GO TO 40
   45  XNE=0.25*(N(I,J-1,1)+N(I+1,J-1,1)+N(I,J-2,1)+N(I+1,J-2,1))
      IF(DM(I,J-1,1).LT.GX)GO TO 40
      IF(DZ(I,J-2,2).LT.GX)GO TO 40
      IF(DZ(I,J-1,2).LT.GX)GO TO 40
      IF(DZ(I+1,J-1,2).LT.GX)GO TO 40
      IF(DZ(I+1,J-2,2).LT.GX)GO TO 40
      IF(IR(I,J-1)/10.GE.2.OR.IR(I+1,J-1)/10.GE.2)GO TO 40
      XM=XM-R*(M(I,J,1)*XNN/DM(I,J,1)-M(I,J-1,1)*XNE/DM(I,J-1,1))
   40  XM=XM/(1.0+FF)
      IF(ABS(XM).LT.1.0E-10)XM=0.0
C
C  ------ LIMITING OF DISCHARGE -------
C
      IF(XM.GT.7.0*DD)XM=7.0*DD
      IF(XM.LT.-7.0*DD)XM=-7.0*DD
      M(I,J,2)=XM
      GO TO 100
   30  M(I,J,2)=0.0
      GO TO 100
C
C  ------ CAL. OF DISCHARGE OF OVERFLOW ------
C
   60  Z1=Z(I,J,2)+HM(I,J)
      Z2=Z(I+1,J,2)+HM(I,J)
      ZZZ=Z1
      ZX=Z2
      IF(Z1.GT.Z2)GO TO 61
      ZZZ=Z2
      ZX=Z1
   61  IF(ZZZ.LT.GX)GO TO 30
      IF(ZZZ*0.66667.LT.ZX)GO TO 62
      XM=1.55*ZZZ**1.5
      GO TO 63
   62  XM=4.029*ZX*SQRT(ZZZ-ZX)
   63  IF(Z2.GT.Z1)XM=-XM
      M(I,J,2)=XM
  100  CONTINUE
C
C  ------- CAL. OF LINEAR TERMS (Y-DIRECTION) -------
C
      IF(J.EQ.JF)GO TO 130
      IRR=IR(I,J)/10
      IF(IRR.GE.2)GO TO 160
      IF(HN(I,J).LT.-8.1)GO TO 130
      IF(DZ(I,J,2))131,131,132
  131  IF(DZ(I,J+1,2))130,130,134
  132  IF(DZ(I,J+1,2))135,135,136
  134  IF(Z(I,J+1,2)+HZ(I,J))130,130,137
  135  IF(Z(I,J,2)+HZ(I,J+1))130,130,138
  136  DD=DN(I,J,2)
      GO TO 139
  137  DD=Z(I,J+1,2)+HZ(I,J)
      GO TO 139
  138  DD=Z(I,J,2)+HZ(I,J+1)
  139  XMM=0.25*(M(I,J,1)+M(I,J+1,1)+M(I-1,J,1)+M(I-1,J+1,1))
      DF=DD
      IF(DF.LT.1.0E-2)DF=1.0E-2
      FF=FN*SQRT(N(I,J,1)**2+XMM**2)/DF**(7.0/3.0)
      IF(DD.LT.GX)GO TO 130
      XN=(1.0-FF)*N(I,J,1)-GG*R*DD*(Z(I,J+1,2)-Z(I,J,2))
```

```
C
C ----- CAL. OF NON-LINEAR TERMS (CONVECTION TERMS) ------
C
      IF(I.LE.6.OR.J.LE.6)GO TO 140
      IF(DN(I,J,1).LT.GX)GO TO 140
      IF(N(I,J,1))141,141,142
 141    IF(DN(I,J+1,1).LT.GX)GO TO 140
      IF(DZ(I,J+2,2).LT.GX)GO TO 140
      IF(DZ(I,J+1,2).LT.GX)GO TO 140
      IF(IR(I,J+1)/10.GE.2)GO TO 1003
      XN=XN-R*(N(I,J+1,1)**2/DN(I,J+1,1)-N(I,J,1)**2/DN(I,J,1))
      GO TO 143
 1003    XN=XN-R*(-N(I,J,1)**2/DN(I,J,1))
      GO TO 143
 142    IF(DN(I,J-1,1).LT.GX)GO TO 140
      IF(DZ(I,J-1,2).LT.GX)GO TO 140
      IF(DZ(I,J,2).LT.GX)GO TO 140
      IF(IR(I,J-1)/10.GE.2)GO TO 1004
      XN=XN-R*(N(I,J,1)**2/DN(I,J,1)-N(I,J-1,1)**2/DN(I,J-1,1))
      GO TO 143
 1004    XN=XN-R*(N(I,J,1)**2/DN(I,J,1))
 143    IF(XMM)144,144,145
 144    XME=0.25*(M(I+1,J,1)+M(I+1,J+1,1)+M(I,J,1)+M(I,J+1,1))
      IF(DN(I+1,J,1).LT.GX)GO TO 140
      IF(DZ(I+1,J,2).LT.GX)GO TO 140
      IF(DZ(I+2,J,2).LT.GX)GO TO 140
      IF(DZ(I+1,J+1,2).LT.GX)GO TO 140
      IF(DZ(I+2,J+1,2).LT.GX)GO TO 140
      IF(IR(I,J)/10.EQ.1)GO TO 140
      IF(IR(I,J+1)/10.EQ.1.OR.IR(I,J+1)/10.EQ.3)GO TO 140
      XN=XN-R*(N(I+1,J,1)*XME/DN(I+1,J,1)-N(I,J,1)*XMM/DN(I,J,1))
      GO TO 140
 145    XME=0.25*(M(I-1,J,1)+M(I-1,J+1,1)+M(I-2,J,1)+M(I-2,J+1,1))
      IF(DN(I-1,J,1).LT.GX)GO TO 140
      IF(DZ(I-2,J,2).LT.GX)GO TO 140
      IF(DZ(I-2,J+1,2).LT.GX)GO TO 140
      IF(DZ(I-1,J,2).LT.GX)GO TO 140
      IF(DZ(I-1,J+1,2).LT.GX)GO TO 140
      IF(IR(I-1,J)/10.EQ.1.OR.IR(I-1,J)/10.EQ.3)GO TO 140
      IF(IR(I-1,J+1)/10.EQ.1.OR.IR(I-1,J+1)/10.EQ.3)GO TO 140
      XN=XN-R*(N(I,J,1)*XMM/DN(I,J,1)-N(I-1,J,1)*XME/DN(I-1,J,1))
 140    XN=XN/(1.0+FF)
      IF(ABS(XN).LT.1.0E-10)XN=0.0
C
C ------ LIMITING OF DISCHARGE -------
C
      IF(XN.GT.7.0*DD)XN=7.0*DD
      IF(XN.LT.-7.0*DD)XN=-7.0*DD
      N(I,J,2)=XN
      GO TO 200
 130    N(I,J,2)=0.0
      GO TO 200
C
C ------ CAL. OF DISCHARGE OF OVERFLOW ------
C
 160    Z1=Z(I,J,2)+HN(I,J)
      Z2=Z(I,J+1,2)+HN(I,J)
      ZZZ=Z1
      ZX=Z2
      IF(Z1.GT.Z2)GO TO 161
      ZZZ=Z2
      ZX=Z1
 161    IF(ZZZ.LT.GX)GO TO 130
      IF(ZZZ*0.66667.LT.ZX)GO TO 162
      XN=1.55*ZZZ**1.5
      GO TO 163
 162    XN=4.029*ZX*SQRT(ZZZ-ZX)
 163    IF(Z2.GT.Z1)XN=-XN
      N(I,J,2)=XN
 200 CONTINUE
    RETURN
    END
```

```
4330C
4340C ***** EXCHANGE FOR LAST STEP DATA TO NEXT STEP DATA *****
4350C
4360      SUBROUTINE CHANGE(IF,JF,Z,M,N,D)
4370      REAL M,N
4380      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
4390      DIMENSION D(IF,JF,2)
4400      DO 10 J=1,JF
4410       DO 10 I=1,IF
4420        Z(I,J,1)=Z(I,J,2)
4430        M(I,J,1)=M(I,J,2)
4440        N(I,J,1)=N(I,J,2)
4450        D(I,J,1)=D(I,J,2)
4460   10 CONTINUE
4470      RETURN
4480      END
4490C
4500C ******* INPUT OF BOUNDARY DATA (WATER LEVEL) *******
4510C
4520      SUBROUTINE DATA(NN,B)
4530      DIMENSION B(1800,14)
4540      DO 10 K=1,1800
4550       READ(NN)(B(K,J),J=1,14)
4560   10 CONTINUE
4570      RETURN
4580      END
4590C
4600C  *************  OUTPUT OF DATA ******************
4610C
4620      SUBROUTINE OUT3(NN,IF,JF,ZM)
4630      DIMENSION ZM(IF,JF)
4640      DO 10 I=1,IF
4650       WRITE(NN)(ZM(I,J),J=1,JF)
4660   10 CONTINUE
4670      RETURN
4680      END
4690C
4700C ********* OUTPUT OF WATER LEVE;L & DISCHARGE **********
4710C
4720      SUBROUTINE OUT1(NN,IF,JF,Z,M,N,DM,DN,H)
4730      REAL M,N
4740      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2),H(IF,JF)
4750      DIMENSION DM(IF,JF,2),DN(IF,JF,2)
4760      DIMENSION VEL(200,200,2)
4770      DATA GX/1.0E-3/
4780      DO 20 J=2,JF
4790       DO 20 I=2,IF
4800        IF(H(I,J).LT.-9.9)GOTO 21
4810        UU=0.0
4820        VV=0.0
4830        IF(DM(I,J,1).GT.GX)UU=M(I,J,1)/DM(I,J,1)
4840        IF(DN(I,J,1).GT.GX)VV=N(I,J,1)/DN(I,J,1)
4850        UUU=0.0
4860        VVV=0.0
4870        IF(DM(I-1,J,1).GT.GX)UUU=M(I-1,J,1)/DM(I-1,J,1)
4880        IF(DN(I,J-1,1).GT.GX)VVV=N(I,J-1,1)/DN(I,J-1,1)
4890        VEL(I,J,1)=0.5*(UU+UUU)
4900        VEL(I,J,2)=0.5*(VV+VVV)
4910        GOTO 20
4920   21    VEL(I,J,1)=0.0
4930         VEL(I,J,2)=0.0
4940   20 CONTINUE
4950      DO 30 I=1,IF
4960        WRITE(NN)(Z(I,J,1),J=1,JF)
4970        WRITE(NN)(VEL(I,J,1),J=1,JF)
4980        WRITE(NN)(VEL(I,J,2),J=1,JF)
4990   30 CONTINUE
5000      RETURN
5010      END
5020C
5030      SUBROUTINE OUT2(NN,IF,JF,Z,M,N,ZZ)
5040      REAL M,N
```

```
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2),ZZ(IF,JF,3)
      DO 10 I=1,IF
       DO 10 J=1,JF
        ZZ(I,J,1)=Z(I,J,2)
        ZZ(I,J,2)=M(I,J,2)
        ZZ(I,J,3)=N(I,J,2)
    10 CONTINUE
      DO 20 L=1,3
       DO 20 I=1,IF
        WRITE(NN)(ZZ(I,J,L),J=1,JF)
    20 CONTINUE
      RETURN
      END
C
C ****** OUTPUT OF COMPUTED RESULTS ON THE DISPLAY *******
C
      SUBROUTINE OUT6(IF,JF,Z,H,K)
      DIMENSION KM(47),LW(120),Z(IF,JF,2)
      DIMENSION H(IF,JF)
      DATA KM/1H ,1HW,1HV,1HU,1HT,1HS,1HR,1HP,1HO,1HN,1HM,1HL,1HK,1HJ,
     & 1HI,1HH,1HG,1HF,1HE,1HD,1HC,1HB,1HA,1H*,1H1,1H2,1H3,1H4,1H5,1H6,
     & 1H7,1H8,1H9,1H0,1H,,1H-,1H+,1H/,1H#,1H$,1H%,1H&,1H=,1H?,1H(,1H),
     & 1H./
      WRITE(6,110)K
  110 FORMAT(//1H ,2X,"K=",I5)
      LLL=JF/120+1
      IF(MOD(JF,120).EQ.0)LLL=LLL-1
      DO 100 L=1,LLL
       J1=120*(L-1)+1
       J2=J1+119
       IF(J2.GT.JF)J2=JF
       JX=J1+9
       WRITE(6,200)(J,J=JX,J2,10)
  200  FORMAT(1H ,4X,12I10)
       DO 90 I=1,IF
        DO 80 J=J1,J2
         KKM=24
         IF(Z(I,J,2).GT.0.0)KKM=IFIX((Z(I,J,2)+0.50)/1.0)+24
         IF(Z(I,J,2).LT.0.0)KKM=IFIX((Z(I,J,2)-0.50)/1.0)+24
         IF(KKM.LT.2)KKM=2
         IF(KKM.GT.46)KKM=46
         IF(H(I,J).LT.0.0)KKM=1
         LW(J)=KM(KKM)
   80    CONTINUE
        WRITE(6,101)I,(LW(LL),LL=J1,J2)
  101    FORMAT(1H ,I3,1X,120A1)
   90  CONTINUE
  100 CONTINUE
      RETURN
      END
C
C     ********* CHECK OF MAXIMUM VALUE ***********
C
      SUBROUTINE MAX(IF,JF,Z,ZM)
      DIMENSION Z(IF,JF,2),ZM(IF,JF)
      DO 10 I=2,IF
       DO 10 J=2,JF
        IF(ZM(I,J).LT.Z(I,J,2))ZM(I,J)=Z(I,J,2)
   10 CONTINUE
      RETURN
      END
C
      SUBROUTINE BNC(IF,JF,Z,B,ISS,JSS,JES,KK,DT)
      DIMENSION Z(IF,JF,2),B(1800,14),BC(14)
      KT=(KK-1)*DT
      K1=KT/3+1
      IF(K1+1.GE.1800)K1=1799
      K2=MOD(KT,3)
      DO 10 J=1,14
   10 BC(J)=(K2*B(K1+1,J)+(3-K2)*B(K1,J))/3.0
      DO 20 J=JSS+2,JES-2
       JX=J-(JSS+1)
```

```
         JJ=JX/4+1
         JY=2*MOD(JX,4)+1
         Z(ISS,J,2)=(JY*BC(JJ+1)+(8-JY)*BC(JJ))/8.0
   20 CONTINUE
       Z(ISS,JSS,2)=BC(1)
       Z(ISS,JSS+1,2)=BC(1)
       Z(ISS,JES-1,2)=BC(14)
       Z(ISS,JES,2)=BC(14)
       RETURN
       END
C
C ******** OUTPUT OF WATER LEVEL TIMEHISTORIES *********
C
       SUBROUTINE POINT(NN,IF,JF,IM,Z,IP,JP,PZ)
       DIMENSION Z(IF,JF,2),IP(IM),JP(IM),PZ(IM)
       DO 10 I=1,IM
         II=IP(I)
         JJ=JP(I)
         PZ(I)=Z(II,JJ,2)
   10 CONTINUE
       WRITE(NN)(PZ(I),I=1,IM)
       RETURN
       END
C
C *********** OUTPUT OF LAST STEP DATA **************
C
       SUBROUTINE OUT4(NN,IF,JF,Z,M,N,H,ZM)
       REAL M,N
       DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2),H(IF,JF)
       DIMENSION ZM(IF,JF,3)
       DO 10 I=1,IF
         WRITE(NN)(Z(I,J,2),J=1,JF)
         WRITE(NN)(M(I,J,2),J=1,JF)
         WRITE(NN)(N(I,J,2),J=1,JF)
         WRITE(NN)(H(I,J),J=1,JF)
         DO 20 K=1,3
   20   WRITE(NN)(ZM(I,J,K),J=1,JF)
   10 CONTINUE
       RETURN
       END
C
C *********** INPUT OF LAST STEP DATA **************
C
       SUBROUTINE INDATA(NN,IF,JF,Z,M,N,H,ZM)
       REAL M,N
       DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2),H(IF,JF)
       DIMENSION ZM(IF,JF,3)
       DO 10 I=1,IF
         READ(NN)(Z(I,J,1),J=1,JF)
         READ(NN)(M(I,J,1),J=1,JF)
         READ(NN)(N(I,J,1),J=1,JF)
         READ(NN)(H(I,J),J=1,JF)
         DO 20 K=1,3
   20   READ(NN)(ZM(I,J,K),J=1,JF)
   10 CONTINUE
       RETURN
       END
```

```
*#RUN : IAP OPT=2 F=/SNRK/JP-MYK(10)
C
C  *************** TUNAMI-N3 ****************
C     Tohoku University's Numerical-Analysis Model
C        for Investigation of tsunami
C         Near-field Tsunami version
C
C      1896 SANRIKU TSUNAMIS NEAR MIYAKO BAY
C        --- LINEAR LONG WAVE THEORY ----
C            NUMERICAL EXPERIMENT
C                           91.7.25
C                  BY
C
C         F.IMAMURA, TOHOKU UNIV.
C
C
      REAL MA,NA,MB,NB,MC,NC,MD,ND
      DOUBLE PRECISION T1,T2,T3
      PARAMETER(IA=90,JA=130,IB=37,JB=85)
      PARAMETER(IC=43,JC=163,ID=61,JD=73)
      PARAMETER(DA=5400,DB=1800,DC=600,DD=200)
      PARAMETER(TA=3.0,TB=3.0,TC=3.0,TD=3.0)
      PARAMETER(KS=1,KE=1000,KD=200,KC=3)
      COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
      COMMON /HA/ HA(IA,JA)
      COMMON /XB/ ZB(IB,JB,2),MB(IB,JB,2),NB(IB,JB,2)
      COMMON /HB/ HB(IB,JB)
      COMMON /XC/ ZC(IC,JC,2),MC(IC,JC,2),NC(IC,JC,2)
      COMMON /HC/ HC(IC,JC)
      COMMON /XD/ ZD(ID,JD,2),MD(ID,JD,2),ND(ID,JD,2)
      COMMON /HD/ HD(ID,JD)
C
C ******** INITIAL CONDITION *********
C
      CALL CDEPTH
      WRITE(6,*)"DATA OK"
      CALL CINTL
      WRITE(6,*)"INITIAL OK"
      CALL OUTPUT(IA,JA,ZA,HA,1,1,1)
C       CALL COUT  (0,KD)
      CALL CLOCK(T1)
C
C ******** MAIN CALCULATION ********
C
      DO 10 K=KS,KE
       KK=K
       CALL CMASS
       CALL CJNZ
       CALL CMMNT
       CALL CJNQ
       CALL COUT(KK,KD)
       CALL CCHNG
   10 CONTINUE
      CALL CLOCK(T2)
      T3=T2-T1
      WRITE(6,*)KK,T3
      STOP
      END
C
      SUBROUTINE CDEPTH
C
      PARAMETER(IA=90,JA=130,IB=37,JB=85)
      PARAMETER(IC=43,JC=163,ID=61,JD=73)
      COMMON /HA/ HA(IA,JA)
      COMMON /HB/ HB(IB,JB)
      COMMON /HC/ HC(IC,JC)
      COMMON /HD/ HD(ID,JD)
      DIMENSION LAB(4),LBC(4),LCD(4)
      DATA LAB/27,44,38,71/
      DATA LBC/12,11,25,64/
      DATA LCD/16,79,35,102/
C
```

```
      NN=10
      DO 10 I=1,IA
   10 READ(NN,100)(HA(I,J),J=1,JA)
      DO 20 I=1,IB
   20 READ(NN,100)(HB(I,J),J=1,JB)
      DO 30 I=1,IC
   30 READ(NN,100)(HC(I,J),J=1,JC)
      DO 40 I=1,ID
   40 READ(NN,100)(HD(I,J),J=1,JD)
  100 FORMAT(10F8.1)
C
C ****** CAHNGE OF DEPTH DATA ********
C
      CALL CHH(IA,JA,IB,JB,HA,HB,LAB,1110)
      CALL CHH(IB,JB,IC,JC,HB,HC,LBC,1110)
      CALL CHH(IC,JC,ID,JD,HC,HD,LCD,1110)
      RETURN
      END
C
      SUBROUTINE CINTL
C
      REAL MA,NA,MB,NB,MC,NC,MD,ND
      PARAMETER(IA=90,JA=130,IB=37,JB=85)
      PARAMETER(IC=43,JC=163,ID=61,JD=73)
      PARAMETER(DA=5400,DB=1800,DC=600,DD=200)
      PARAMETER(TA=3.0,TB=3.0,TC=3.0,TD=3.0)
      COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
      COMMON /HA/ HA(IA,JA)
      COMMON /XB/ ZB(IB,JB,2),MB(IB,JB,2),NB(IB,JB,2)
      COMMON /HB/ HB(IB,JB)
      COMMON /XC/ ZC(IC,JC,2),MC(IC,JC,2),NC(IC,JC,2)
      COMMON /HC/ HC(IC,JC)
      COMMON /XD/ ZD(ID,JD,2),MD(ID,JD,2),ND(ID,JD,2)
      COMMON /HD/ HD(ID,JD)
C
      DO 100 L=1,2
        DO 10 J=1,JA
          DO 10 I=1,IA
            ZA(I,J,L)=0.0 ; MA(I,J,L)=0.0 ; NA(I,J,L)=0.0
   10     CONTINUE
        DO 20 J=1,JB
          DO 20 I=1,IB
            ZB(I,J,L)=0.0 ; MB(I,J,L)=0.0 ; NB(I,J,L)=0.0
   20     CONTINUE
        DO 30 J=1,JC
          DO 30 I=1,IC
            ZC(I,J,L)=0.0 ; MC(I,J,L)=0.0 ; NC(I,J,L)=0.0
   30     CONTINUE
        DO 40 J=1,JD
          DO 40 I=1,ID
            ZD(I,J,L)=0.0 ; MD(I,J,L)=0.0 ; ND(I,J,L)=0.0
   40     CONTINUE
  100 CONTINUE
C
      IS=20 ; JS=20 ; IE=90 ; JE=120
      CALL DEFORM(IA,JA,IS,JS,IE,JE,ZA,DA)
C
      RETURN
      END
C
      SUBROUTINE CMASS
C
      REAL MA,NA,MB,NB,MC,NC,MD,ND
      PARAMETER(IA=90,JA=130,IB=37,JB=85)
      PARAMETER(IC=43,JC=163,ID=61,JD=73)
      PARAMETER(DA=5400,DB=1800,DC=600,DD=200)
      PARAMETER(TA=3.0,TB=3.0,TC=3.0,TD=3.0)
      COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
      COMMON /HA/ HA(IA,JA)
      COMMON /XB/ ZB(IB,JB,2),MB(IB,JB,2),NB(IB,JB,2)
      COMMON /HB/ HB(IB,JB)
      COMMON /XC/ ZC(IC,JC,2),MC(IC,JC,2),NC(IC,JC,2)
```

```
1450     COMMON /HC/ HC(IC,JC)
1460     COMMON /XD/ ZD(ID,JD,2),MD(ID,JD,2),ND(ID,JD,2)
1470     COMMON /HD/ HD(ID,JD)
1480     LP=1
1490     CALL MASS(IA,JA,ZA,MA,NA,HA,DA,TA,LP,1)
1500     CALL MASS(IB,JB,ZB,MB,NB,HB,DB,TB,LP,1)
1510     CALL MASS(IC,JC,ZC,MC,NC,HC,DC,TC,LP,1)
1520     CALL MASS(ID,JD,ZD,MD,ND,HD,DD,TD,LP,1)
1530     RETURN
1540     END
1550C
1560     SUBROUTINE CJNZ
1570C
1580     REAL MA,NA,MB,NB,MC,NC,MD,ND
1590     PARAMETER(IA=90,JA=130,IB=37,JB=85)
1600     PARAMETER(IC=43,JC=163,ID=61,JD=73)
1610     PARAMETER(DA=5400,DB=1800,DC=600,DD=200)
1620     PARAMETER(TA=3.0,TB=3.0,TC=3.0,TD=3.0)
1630     COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
1640     COMMON /HA/ HA(IA,JA)
1650     COMMON /XB/ ZB(IB,JB,2),MB(IB,JB,2),NB(IB,JB,2)
1660     COMMON /HB/ HB(IB,JB)
1670     COMMON /XC/ ZC(IC,JC,2),MC(IC,JC,2),NC(IC,JC,2)
1680     COMMON /HC/ HC(IC,JC)
1690     COMMON /XD/ ZD(ID,JD,2),MD(ID,JD,2),ND(ID,JD,2)
1700     COMMON /HD/ HD(ID,JD)
1710     DIMENSION LAB(4),LBC(4),LCD(4)
1720     DATA LAB/27,44,38,71/
1730     DATA LBC/12,11,25,64/
1740     DATA LCD/16,79,35,102/
1750     LP=1
1760     CALL BOUT(IA,JA,ZA,MA,LP,1)
1770     CALL JNZ(IA,JA,IB,JB,ZA,ZB,HB,LAB,1110,LP,1)
1780     CALL JNZ(IB,JB,IC,JC,ZB,ZC,HC,LBC,1110,LP,1)
1790     CALL JNZ(IC,JC,ID,JD,ZC,ZD,HD,LCD,1110,LP,1)
1800     RETURN
1810     END
1820C
1830     SUBROUTINE CMMNT
1840C
1850     REAL MA,NA,MB,NB,MC,NC,MD,ND
1860     PARAMETER(IA=90,JA=130,IB=37,JB=85)
1870     PARAMETER(IC=43,JC=163,ID=61,JD=73)
1880     PARAMETER(DA=5400,DB=1800,DC=600,DD=200)
1890     PARAMETER(TA=3.0,TB=3.0,TC=3.0,TD=3.0)
1900     COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
1910     COMMON /HA/ HA(IA,JA)
1920     COMMON /XB/ ZB(IB,JB,2),MB(IB,JB,2),NB(IB,JB,2)
1930     COMMON /HB/ HB(IB,JB)
1940     COMMON /XC/ ZC(IC,JC,2),MC(IC,JC,2),NC(IC,JC,2)
1950     COMMON /HC/ HC(IC,JC)
1960     COMMON /XD/ ZD(ID,JD,2),MD(ID,JD,2),ND(ID,JD,2)
1970     COMMON /HD/ HD(ID,JD)
1980     LP=1
1990     CALL MMNT(IA,JA,ZA,MA,NA,HA,DA,TA,LP,1)
2000     CALL MMNT(IB,JB,ZB,MB,NB,HB,DB,TB,LP,1)
2010     CALL MMNT(IC,JC,ZC,MC,NC,HC,DC,TC,LP,1)
2020     CALL MMNT(ID,JD,ZD,MD,ND,HD,DD,TD,LP,1)
2030     RETURN
2040     END
2050C
2060     SUBROUTINE CJNQ
2070C
2080     REAL MA,NA,MB,NB,MC,NC,MD,ND
2090     PARAMETER(IA=90,JA=130,IB=37,JB=85)
2100     PARAMETER(IC=43,JC=163,ID=61,JD=73)
2110     COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
2120     COMMON /HA/ HA(IA,JA)
2130     COMMON /XB/ ZB(IB,JB,2),MB(IB,JB,2),NB(IB,JB,2)
2140     COMMON /HB/ HB(IB,JB)
2150     COMMON /XC/ ZC(IC,JC,2),MC(IC,JC,2),NC(IC,JC,2)
2160     COMMON /HC/ HC(IC,JC)
```

```
      COMMON /XD/ ZD(ID,JD,2),MD(ID,JD,2),ND(ID,JD,2)
      COMMON /HD/ HD(ID,JD)
      DIMENSION LAB(4),LBC(4),LCD(4)
      DATA LAB/27,44,38,71/
      DATA LBC/12,11,25,64/
      DATA LCD/16,79,35,102/
      LP=1
      CALL JNQ(IA,JA,IB,JB,MA,NA,MB,NB,HB,LAB,1110,LP,1)
      CALL JNQ(IB,JB,IC,JC,MB,NB,MC,NC,HC,LBC,1110,LP,1)
      CALL JNQ(IC,JC,ID,JD,MC,NC,MD,ND,HD,LCD,1110,LP,1)
      RETURN
      END
C
      SUBROUTINE CCHNG
C
      REAL MA,NA,MB,NB,MC,NC,MD,ND
      PARAMETER(IA=90,JA=130,IB=37,JB=85)
      PARAMETER(IC=43,JC=163,ID=61,JD=73)
      PARAMETER(TA=3.0,TB=3.0,TC=3.0,TD=3.0)
      COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
      COMMON /HA/ HA(IA,JA)
      COMMON /XB/ ZB(IB,JB,2),MB(IB,JB,2),NB(IB,JB,2)
      COMMON /HB/ HB(IB,JB)
      COMMON /XC/ ZC(IC,JC,2),MC(IC,JC,2),NC(IC,JC,2)
      COMMON /HC/ HC(IC,JC)
      COMMON /XD/ ZD(ID,JD,2),MD(ID,JD,2),ND(ID,JD,2)
      COMMON /HD/ HD(ID,JD)
      LP=1
      CALL CHANG(IA,JA,ZA,MA,NA,LP,1)
      CALL CHANG(IB,JB,ZB,MB,NB,LP,1)
      CALL CHANG(IC,JC,ZC,MC,NC,LP,1)
      CALL CHANG(ID,JD,ZD,MD,ND,LP,1)
      RETURN
      END
C
C
      SUBROUTINE MASS(IF,JF,Z,M,N,H,DX,DT,LP,LT)
C
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
      DIMENSION H(IF,JF)
      IF(MOD(LP,LT).NE.0)RETURN
      DO 10 J=2,JF
        DO 10 I=2,IF
          IF(H(I,J).GT.0.0)THEN
            Z(I,J,2)=Z(I,J,1)-DT/DX*(M(I,J,1)-M(I-1,J,1)+N(I,J,1)-N(I,
     &      J-1,1))
          ELSE
            Z(I,J,2)=0.0
          ENDIF
   10 CONTINUE
      DO 20 J=2,JF
        DO 20 I=2,IF
          IF(ABS(Z(I,J,2)).LT.1.0E-5)Z(I,J,2)=0.0
   20 CONTINUE
      RETURN
      END
C
      SUBROUTINE MMNT(IF,JF,Z,M,N,H,DX,DT,LP,LT)
C
      REAL M,N
      PARAMETER(GG=9.8)
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
      DIMENSION H(IF,JF)
      IF(MOD(LP,LT).NE.0)RETURN
      DO 10 J=2,JF-1
        DO 10 I=2,IF-1
          HH=0.5*(H(I,J)+H(I+1,J))*GG*DT/DX
          IF(HH.GT.0.0)THEN
            M(I,J,2)=M(I,J,1)-HH*(Z(I+1,J,2)-Z(I,J,2))
          ELSE
            M(I,J,2)=0.0
```

```
           ENDIF
       10 CONTINUE
          DO 20 J=2,JF-1
           DO 20 I=2,IF-1
             HH=0.5*(H(I,J)+H(I,J+1))*GG*DT/DX
             IF(HH.GT.0.0)THEN
              N(I,J,2)=N(I,J,1)-HH*(Z(I,J+1,2)-Z(I,J,2))
             ELSE
              N(I,J,2)=0.0
             ENDIF
       20 CONTINUE
C
          DO 16 I=1,IF-1
           HH=0.5*(H(I,JF)+H(I+1,JF))*GG*DT/DX
           IF(HH.GT.0.0)THEN
            M(I,JF,2)=M(I,JF,1)-HH*(Z(I+1,JF,2)-Z(I,JF,2))
           ELSE
            M(I,JF,2)=0.0
           ENDIF
       16 CONTINUE
          DO 26 J=1,JF-1
           HH=0.5*(H(IF,J)+H(IF,J+1))*GG*DT/DX
           IF(HH.GT.0.0)THEN
            N(IF,J,2)=N(IF,J,1)-HH*(Z(IF,J+1,2)-Z(IF,J,2))
           ELSE
            N(IF,J,2)=0.0
           ENDIF
       26 CONTINUE
          RETURN
          END
C
          SUBROUTINE BOUT
C
          REAL MA,NA
          PARAMETER(IA=90,JA=130)
          COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
          COMMON /HA/ HA(IA,JA)
          DO 10 KK=1,2
           J=2
           IF(KK.EQ.2)J=JA
           DO 10 I=3,IA
            IF(HA(I,J).LT.0.0)GOTO 10
            CC=SQRT(9.8*HA(I,J))
            UU=0.5*ABS(MA(I,J,2)+MA(I-1,J,2))
            IF(J.EQ.2)UU=SQRT(UU**2+NA(I,J,2)**2)
            IF(J.EQ.JA)UU=SQRT(UU**2+NA(I,J-1,2)**2)
            ZZ=UU/CC
            IF(J.EQ.2.AND.NA(I,J,2).GT.0.0)ZZ=-ZZ
            IF(J.EQ.JA.AND.NA(I,J-1,2).LT.0.0)ZZ=-ZZ
            ZA(I,J,2)=ZZ
       10 CONTINUE
          DO 20 KK=1,2
           I=2
           IF(KK.EQ.2)I=IA
           DO 20 J=3,JA
            IF(HA(I,J).LT.0.0)GOTO 20
            CC=SQRT(9.8*HA(I,J))
            UU=0.5*ABS(NA(I,J,2)+NA(I,J-1,2))
            IF(I.EQ.2)UU=SQRT(UU**2+MA(I,J,2)**2)
            IF(I.EQ.IA)UU=SQRT(UU**2+MA(I-1,J,2)**2)
            ZZ=UU/CC
            IF(I.EQ.2.AND.MA(I,J,2).GT.0.0)ZZ=-ZZ
            IF(I.EQ.IA.AND.MA(I-1,J,2).LT.0.0)ZZ=-ZZ
            ZA(I,J,2)=ZZ
       20 CONTINUE
          RETURN
          END
C
          SUBROUTINE CHH(IX,JX,IY,JY,HX,HY,L0,BCHK)
C
          INTEGER BCHK,CHK
          DIMENSION HX(IX,JX),HY(IY,JY),L0(4)
```

```
C
      ISS=2 ; JSS=2 ; IES=IY ; JES=JY ; ISL=L0(1) ; JSL=L0(2)
      IEL=L0(3) ; JEL=L0(4)
      CHK=BCHK
      KB=CHK/1000
      IF(KB.EQ.1)THEN
       CHK=CHK-1000
       II=ISL ; JJ=JSL ; I1=ISS ; J1=JSS
       DO WHILE(I1+2.LE.IES)
        S=0.0 ; L=0
        DO 10 I=I1,I1+2
         DO 10 J=J1,J1+2
          IF(HY(I,J).GT.0.0)THEN
           S=S+HY(I,J)
           L=L+1
          ENDIF
10       CONTINUE
        IF(L.GE.5)THEN
         HX(II,JJ)=S/L
        ENDIF
        II=II+1 ; I1=I1+3
       ENDDO
      ENDIF
C
      KB=CHK/100
      IF(KB.EQ.1)THEN
       CHK=CHK-100
       II=IEL ; JJ=JSL ; I1=IES-2 ; J1=JSS
       DO WHILE(J1+1.LE.JES)
        S=0.0 ; L=0
        DO 20 I=I1,I1+2
         DO 20 J=J1,J1+2
          IF(HY(I,J).GT.0.0)THEN
           S=S+HY(I,J)
           L=L+1
          ENDIF
20       CONTINUE
        IF(L.GE.5)THEN
         HX(II,JJ)=S/L
        ENDIF
        JJ=JJ+1 ; J1=J1+3
       ENDDO
      ENDIF
C
      KB=CHK/10
      IF(KB.EQ.1)THEN
       CHK=CHK-10
       II=ISL ; JJ=JEL ; I1=ISS ; J1=JES-2
       DO WHILE(I1+2.LE.IES)
        S=0.0 ; L=0
        DO 30 I=I1,I1+2
         DO 30 J=J1,J1+2
          IF(HY(I,J).GT.0.0)THEN
           S=S+HY(I,J)
           L=L+1
          ENDIF
30       CONTINUE
        IF(L.GE.5)THEN
         HX(II,JJ)=S/L
        ENDIF
        II=II+1 ; I1=I1+3
       ENDDO
      ENDIF
C
      IF(CHK.EQ.1)THEN
       II=ISL ; JJ=JSL ; I1=ISS ; J1=JSS
       DO WHILE(J1+2.LE.JES)
        S=0.0 ; L=0
        DO 40 I=I1,I1+2
         DO 40 J=J1,J1+2
          IF(HY(I,J).GT.0.0)THEN
           S=S+HY(I,J)
           L=L+1
          ENDIF
   40    CONTINUE
        IF(L.GE.5)THEN
         HX(II,JJ)=S/L
        ENDIF
        JJ=JJ+1 ; J1=J1+3
       ENDDO
      ENDIF
      RETURN
      END
C
      SUBROUTINE JNZ(IX,JX,IY,JY,ZX,ZY,HY,L0,BCHK,LP,LT)
C
      INTEGER BCHK,CHK
      DIMENSION ZX(IX,JX,2),ZY(IY,JY,2)
      DIMENSION HY(IY,JY),L0(4)
      IF(MOD(LP,LT).NE.0)RETURN
      ISS=2 ; JSS=2 ; IES=IY ; JES=JY ; ISL=L0(1) ; JSL=L0(2)
      IEL=L0(3) ; JEL=L0(4)
      CHK=BCHK
      KB=CHK/1000
      IF(KB.EQ.1)THEN
       CHK=CHK-1000
       II=ISL ; JJ=JSL ; I1=ISS ; J1=JSS
       DO WHILE(I1+2.LE.IES)
        S=0.0 ; L=0
        DO 10 I=I1,I1+2
         DO 10 J=J1,J1+2
          IF(HY(I,J).GT.0.0)THEN
           S=S+ZY(I,J,2)
           L=L+1
          ENDIF
   10    CONTINUE
        IF(L.GE.5)THEN
         ZX(II,JJ,2)=S/L
        ELSE
         ZX(II,JJ,2)=0.0
        ENDIF
        II=II+1 ; I1=I1+3
       ENDDO
      ENDIF
C
      KB=CHK/100
      IF(KB.EQ.1)THEN
       CHK=CHK-100
       II=IEL ; JJ=JSL ; I1=IES-2 ; J1=JSS
       DO WHILE(J1+1.LE.JES)
        S=0.0 ; L=0
        DO 20 I=I1,I1+2
         DO 20 J=J1,J1+2
          IF(HY(I,J).GT.0.0)THEN
           S=S+ZY(I,J,2)
           L=L+1
          ENDIF
   20    CONTINUE
        IF(L.GE.5)THEN
         ZX(II,JJ,2)=S/L
        ELSE
         ZX(II,JJ,2)=0.0
        ENDIF
        JJ=JJ+1 ; J1=J1+3
       ENDDO
      ENDIF
C
      KB=CHK/10
      IF(KB.EQ.1)THEN
       CHK=CHK-10
       II=ISL ; JJ=JEL ; I1=ISS ; J1=JES-2
       DO WHILE(I1+2.LE.IES)
        S=0.0 ; L=0
        DO 30 I=I1,I1+2
```

```
         DO 30 J=J1,J1+2
          IF(HY(I,J).GT.0.0)THEN
           S=S+ZY(I,J,2)
           L=L+1
          ENDIF
 30      CONTINUE
        IF(L.GE.5)THEN
         ZX(II,JJ,2)=S/L
        ELSE
         ZX(II,JJ,2)=0.0
        ENDIF
        II=II+1 ; I1=I1+3
       ENDDO
      ENDIF
C
      IF(CHK.EQ.1)THEN
       II=ISL ; JJ=JSL ; I1=ISS ; J1=JSS
       DO WHILE(J1+2.LE.JES)
        S=0.0 ; L=0
        DO 40 I=I1,I1+2
         DO 40 J=J1,J1+2
          IF(HY(I,J).GT.0.0)THEN
           S=S+ZY(I,J,2)
           L=L+1
          ENDIF
 40      CONTINUE
        IF(L.GE.5)THEN
         ZX(II,JJ,2)=S/L
        ELSE
         ZX(II,JJ,2)=0.0
        ENDIF
        JJ=JJ+1 ; J1=J1+3
       ENDDO
      ENDIF
      RETURN
      END
C
      SUBROUTINE JNQ(IX,JX,IY,JY,MX,NX,MY,NY,HY,L0,BCHK,LP,LT)
C
      INTEGER BCHK,CHK
      REAL MX,NX,MY,NY
      DIMENSION MX(IX,JX,2),NX(IX,JX,2),HY(IY,JY)
      DIMENSION MY(IY,JY,2),NY(IY,JY,2),L0(4)
      IF(MOD(LP,LT).NE.0)RETURN
      ISS=2 ; JSS=2 ; IES=IY ; JES=JY ; ISL=L0(1) ; JSL=L0(2)
      IEL=L0(3) ; JEL=L0(4)
      CHK=BCHK
      KB=CHK/1000
      IF(KB.EQ.1)THEN
       CHK=CHK-1000
       I=ISS ; J=JSS-1 ; II=ISL-1 ; JJ=JSL-1
       DO WHILE(I.LE.IES)
        SI=(I-ISS+2)/3.0
        IS=IFIX(SI) ; DI=SI-IS ; II=IS+ISL-1
        NY(I,J,2)=(1-DI)*NX(II,JJ,2)+DI*NX(II+1,JJ,2)
        IF(HY(I,J+1).LT.0.0)NY(I,J,2)=0.0
        I=I+1
       ENDDO
      ENDIF
C
      KB=CHK/100
      IF(KB.EQ.1)THEN
       CHK=CHK-100
       I=IES ; J=JSS ; II=IEL ; JJ=JSL-1
       DO WHILE(J.LE.JES)
        SJ=(J-JSS+2)/3.0
        JS=IFIX(SJ) ; DJ=SJ-JS ; JJ=JS+JSL-1
        MY(I,J,2)=(1-DJ)*MX(II,JJ,2)+DJ*MX(II,JJ+1,2)
        IF(HY(I,J).LT.0.0)MY(I,J,2)=0.0
        J=J+1
       ENDDO
      ENDIF
```

```
C
      KB=CHK/10
      IF(KB.EQ.1)THEN
        CHK=CHK-10
        I=ISS ; J=JES ; II=ISL-1 ; JJ=JEL
        DO WHILE(I.LE.IES)
          SI=(I-ISS+2)/3.0
          IS=IFIX(SI) ; DI=SI-IS ; II=IS+ISL-1
          NY(I,J,2)=(1-DI)*NX(II,JJ,2)+DI*NX(II+1,JJ,2)
          IF(HY(I,J).LT.0.0)NY(I,J,2)=0.0
          I=I+1
        ENDDO
      ENDIF
C
      IF(CHK.EQ.1)THEN
        I=ISS-1 ; J=JSS ; II=ISL-1 ; JJ=JSL-1
        DO WHILE(J.LE.JES)
          SJ=(J-JSS+2)/3.0
          JS=IFIX(SJ) ; DJ=SJ-JS ; JJ=JS+JSL-1
          MY(I,J,2)=(1-DJ)*MX(II,JJ,2)+DJ*MX(II,JJ+1,2)
          IF(HY(I+1,J).LT.0.0)MY(I,J,2)=0.0
          J=J+1
        ENDDO
      ENDIF
      RETURN
      END
C
      SUBROUTINE COUT(KK,KD)
C
      REAL MA,NA,MB,NB,MC,NC,MD,ND
      PARAMETER(IA=90,JA=130,IB=37,JB=85)
      PARAMETER(IC=43,JC=163,ID=61,JD=73)
      COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
      COMMON /HA/ HA(IA,JA)
      COMMON /XB/ ZB(IB,JB,2),MB(IB,JB,2),NB(IB,JB,2)
      COMMON /HB/ HB(IB,JB)
      COMMON /XC/ ZC(IC,JC,2),MC(IC,JC,2),NC(IC,JC,2)
      COMMON /HC/ HC(IC,JC)
      COMMON /XD/ ZD(ID,JD,2),MD(ID,JD,2),ND(ID,JD,2)
      COMMON /HD/ HD(ID,JD)
      CALL OUTPUT(IA,JA,ZA,HA,KK,KD,1)
      CALL OUTPUT(IB,JB,ZB,HB,KK,KD,2)
      CALL OUTPUT(IC,JC,ZC,HC,KK,KD,3)
      CALL OUTPUT(ID,JD,ZD,HD,KK,KD,4)
      RETURN
      END
C
      SUBROUTINE OUTPUT(IF,JF,Z,H,KK,KD,CHR)
C
      INTEGER CHR
      PARAMETER(GX=1.E-2)
      DIMENSION Z(IF,JF,2),H(IF,JF)
      DIMENSION KW(100),KM(23)
      CHARACTER NAME(4)*10
      DATA KM/1HJ,1HI,1HH,1HG,1HF,1HE,1HD,1HC,1HB,1HA,1H.,1H1,1H2,1H3,
     & 1H4,1H5,1H6,1H7,1H8,1H9,1H0,1H*,1H /
      NAME(1)="A REGION"
      NAME(2)="B REGION"
      NAME(3)="C REGION"
      NAME(4)="D REGION"
      IF(MOD(KK,KD).NE.0)RETURN
      WRITE(6,450)NAME(CHR)
  450 FORMAT(1H ,/,10X,A10)
      IN=IF/20
      WRITE(6,410)KK,(KI,KI=20,IN*20,20)
      DO 10 J=JF,1,-1
        JS=J-1 ; JE=J
        IF(JS.LE.0)JS=1
        DO 20 I=1,IF
C         IS=2*I-1 ; IE=IS+1 ; IF(IE.GE.IF)IE=IF
C         S=0.0 ; L=0
C           DO 30 II=IS,IE
```

```
6490C       DO 30 JJ=JS,JE
6500C        IF(H(II,JJ).GT.0.)THEN
6510      IF(H(I,J).GT.0.)THEN
6520C        L=L+1
6530C        S=S+Z(II,JJ,2)
6540C        ENDIF
6550C     30 CONTINUE
6560C      IF(L.GE.2)THEN
6570C       S=S/L
6580        S=Z(I,J,2)
6590        KMM=11+INT(S/0.2)
6600        IF(KMM.GT.21)KMM=21
6610        IF(KMM.LT.1)KMM=1
6620        IF(ABS(S).LT.GX)KMM=23
6630      ELSE
6640        KMM=22
6650      ENDIF
6660      KW(I)=KM(KMM)
6670  20  CONTINUE
6680     II=IF
6690     WRITE(6,400)J,(KW(I),I=1,II)
6700  10 CONTINUE
6710    RETURN
6720  400 FORMAT(1H ,I3,2X,100A1)
6730  410 FORMAT(1H ,/,2X,"MAP AT K=",I5,//,6X,11I10)
6740    END
6750C
6760C
6770    SUBROUTINE CHANG(IF,JF,Z,M,N,LP,LT)
6780C
6790    REAL M,N
6800    DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
6810    IF(MOD(LP,LT).NE.0)RETURN
6820    DO 10 J=1,JF
6830     DO 10 I=1,IF
6840      Z(I,J,1)=Z(I,J,2)
6850      M(I,J,1)=M(I,J,2)
6860      N(I,J,1)=N(I,J,2)
6870  10 CONTINUE
6880    RETURN
6890    END
6900C
6910    SUBROUTINE FILEOT(IF,JF,Z,M,N)
6920C
6930    REAL M,N
6940    DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
6950C
6960    DO 10 J=1,JF
6970     WRITE(25,100)(Z(I,J,2),I=1,IF)
6980     WRITE(25,100)(M(I,J,2),I=1,IF)
6990     WRITE(25,100)(N(I,J,2),I=1,IF)
7000  10 CONTINUE
7010  100 FORMAT(10E12.5)
7020    RETURN
7030    END
7040C
7050    SUBROUTINE MAX(IF,JF,IS,JS,IE,JE,Z,H,ZM,ZN)
7060C
7070    DIMENSION Z(IF,JF,2),H(IF,JF),ZM(IF,JF),ZN(IF,JF)
7080    DO 10 I=IS,IE
7090     DO 10 J=JS,JE
7100      IF(H(I,J).LT.0.0)GOTO 10
7110      IF(ZM(I,J).LT.Z(I,J,2))ZM(I,J)=Z(I,J,2)
7120      IF(ZN(I,J).GT.Z(I,J,2))ZN(I,J)=Z(I,J,2)
7130  10 CONTINUE
7140    RETURN
7150    END
7160C
7170    SUBROUTINE POINT(IF,JF,Z,NG,PZ,IP,JP,KK,KC)
7180C
7190    DIMENSION Z(IF,JF,2),PZ(NG),IP(NG),JP(NG)
7200C
```

```
      IF(MOD(KK,KC).NE.0)RETURN
      DO 10 K=1,NG
        PZ(K)=Z(IP(K),JP(K),2)
   10 CONTINUE
      WRITE(24,100)(PZ(K),K=1,NG)
  100 FORMAT(10F7.3)
      RETURN
      END
C
      SUBROUTINE PROPA(IF,JF,IS,JS,IE,JE,Z,H,LF,KK)
C
      DIMENSION Z(IF,JF,2),H(IF,JF),LF(IF,JF)
C
      LK=KK/180+1
      DO 10 I=IS,IE
        DO 10 J=JS,JE
          IF(H(I,J).GT.0.0)THEN
            IF(LF(I,J).EQ.0)THEN
              IF(ABS(Z(I,J,2)).GT.0.01)LF(I,J)=LK
            ENDIF
          ELSE
            LF(I,J)=-9
          ENDIF
   10 CONTINUE
      RETURN
      END
C
      SUBROUTINE OUTDT(IF,JF,ZM,ZN,LK)
      DIMENSION ZM(IF,JF),ZN(IF,JF),LK(IF,JF)
      DO 20 I=1,IF
        DO 20 J=1,JF
          ZN(I,J)=ZM(I,J)-ZN(I,J)
          IF(ZN(I,J).GT.100.0)ZN(I,J)=100.0
          IF(ZM(I,J).GT.100.0)ZM(I,J)=100.0
   20 CONTINUE
      DO 10 J=1,JF
        WRITE(31,100)(ZM(I,J),I=1,IF)
        WRITE(32,100)(ZN(I,J),I=1,IF)
        WRITE(33,200)(LK(I,J),I=1,IF)
   10 CONTINUE
  100 FORMAT(20F6.3)
  200 FORMAT(40I3)
      RETURN
      END
C
      SUBROUTINE DEFORM(IO,JO,IS,JS,IE,JE,Z,DX)
      REAL L
      PARAMETER(A=3.141592,B=4.848E-06)
      PARAMETER(RR=6.37E+6,E=1.7453E-2)
      PARAMETER(HH=1.0E+3,D=12.5,DL=20.0,TH=156.0,RD=58.0)
      PARAMETER(L=210.0E+3,W=50.0E+3)
      PARAMETER(YO=37.0,XO=139.67)
      PARAMETER(Y0=40.9,X0=143.3)
      DIMENSION Z(IO,JO,2)
      XL=A*RR*(X0-XO)*COS(E*YO)/180.0 ; YL=A*RR*(Y0-YO)/180.0
      H1=HH/SIN(E*DL) ; H2=HH/SIN(E*DL)+W ; DS=D*COS(E*RD)
      DD=D*SIN(E*RD)
      WRITE(6,*)XL,YL,H1,H2,DS,DD
      DO 10 I=IS,IE
        DO 10 J=JS,JE
          XX=DX*(I-1) ; YY=DX*(J-1)
C           YY=A*RR*DR*(J-1)/(60.0*180)
C           XX=A*RR*DR*(I-1)*COS(E*(YO+DR*(J-1)/60.0))/(60.0*180)
          X1=(XX-XL)*SIN(E*TH)+(YY-YL)*COS(E*TH)
          X2=(XX-XL)*COS(E*TH)-(YY-YL)*SIN(E*TH)+HH/TAN(E*DL)
          X3=0.0
          CALL USCAL(X1,X2,X3,L,H2,E*DL,F1)
          CALL USCAL(X1,X2,X3,L,H1,E*DL,F2)
          CALL USCAL(X1,X2,X3,0.,H2,E*DL,F3)
          CALL USCAL(X1,X2,X3,0.,H1,E*DL,F4)
          CALL UDCAL(X1,X2,X3,L,H2,E*DL,G1)
          CALL UDCAL(X1,X2,X3,L,H1,E*DL,G2)
```

```
7930        CALL UDCAL(X1,X2,X3,0.,H2,E*DL,G3)
7940        CALL UDCAL(X1,X2,X3,0.,H1,E*DL,G4)
7950        US=(F1-F2-F3+F4)*DS/(12.0*A)
7960        UD=(G1-G2-G3+G4)*DD/(12.0*A)
7970        Z(I,J,1)=US+UD
7980        Z(I,J,2)=US+UD
7990   10 CONTINUE
8000      RETURN
8010      END
8020C
8030      SUBROUTINE USCAL(X1,X2,X3,C,CC,DP,F)
8040      REAL K
8050C
8060      SN=SIN(DP) ; CS=COS(DP) ; C1=C ; C2=CC*CS ; C3=CC*SN
8070      R=SQRT((X1-C1)**2+(X2-C2)**2+(X3-C3)**2)
8080      Q=SQRT((X1-C1)**2+(X2-C2)**2+(X3+C3)**2)
8090      R2=X2*SN-X3*CS
8100      R3=X2*CS+X3*SN
8110      Q2=X2*SN+X3*CS
8120      Q3=-X2*CS+X3*SN
8130      H=SQRT(Q2**2+(Q3+CC)**2)
8140      K=SQRT((X1-C1)**2+Q2**2)
8150      A1=LOG(R+R3-CC)
8160      A2=LOG(Q+Q3+CC)
8170      A3=LOG(Q+X3+C3)
8180      B1=1+3.0*(TAN(DP))**2
8190      B2=3.0*TAN(DP)/CS
8200      B3=2.0*R2*SN
8210      B4=Q2+X2*SN
8220      B5=2.0*R2**2*CS
8230      B6=R*(R+R3-CC)
8240      B7=4.0*Q2*X3*SN**2
8250      B8=2.0*(Q2+X2*SN)*(X3+Q3*SN)
8260      B9=Q*(Q+Q3+CC)
8270      B10=4.0*Q2*X3*SN
8280      B11=(X3+C3)-Q3*SN
8290      B12=4.0*Q2**2*Q3*X3*CS*SN
8300      B13=2.0*Q+Q3+CC
8310      B14=Q**3*(Q+Q3+CC)**2
8320      F=CS*(A1+B1*A2-B2*A3)+B3/R+2*SN*B4/Q-B5/B6+(B7-B8)/B9+B10*B11/
8330     & Q**3-B12*B13/B14
8340      RETURN
8350      END
8360C
8370      SUBROUTINE UDCAL(X1,X2,X3,C,CC,DP,F)
8380      REAL K
8390C
8400      SN=SIN(DP) ; CS=COS(DP) ; C1=C ; C2=CC*CS ; C3=CC*SN
8410      R=SQRT((X1-C1)**2+(X2-C2)**2+(X3-C3)**2)
8420      Q=SQRT((X1-C1)**2+(X2-C2)**2+(X3+C3)**2)
8430      R2=X2*SN-X3*CS
8440      R3=X2*CS+X3*SN
8450      Q2=X2*SN+X3*CS
8460      Q3=-X2*CS+X3*SN
8470      H=SQRT(Q2**2+(Q3+CC)**2)
8480      K=SQRT((X1-C1)**2+Q2**2)
8490      A1=LOG(R+X1-C1)
8500      A2=LOG(Q+X1-C1)
8510      B1=Q*(Q+X1-C1)
8520      B2=R*(R+X1-C1)
8530      B3=Q*(Q+Q3+CC)
8540      D1=X1-C1 ; D2=X2-C2 ; D3=X3-C3 ; D4=X3+C3 ; D5=R3-CC ; D6=Q3+CC
8550      T1=ATN(D1*D2,(H+D4)*(Q+H))
8560      T2=ATN(D1*D5,R2*R)
8570      T3=ATN(D1*D6,Q2*Q)
8580      F=SN*(D2*(2*D3/B2+4*D3/B1-4*C3*X3*D4*(2*Q+D1)/(B1**2*Q))
8590     & -6*T1+3*T2-6*T3)+CS*(A1-A2-2*(D3**2)/B2-4*(D4**2-C3*X3)/
8600     & B1-4*C3*X3*D4**2*(2*Q+X1-C1)/(B1**2*Q))+6*X3*(CS*SN*(2*D6/B1+D1/
8610     & B3)-Q2*(SN**2-CS**2)/B1)
8620      RETURN
8630      END
8640C
```

```
      REAL FUNCTION ATN(AX,AY)
      DATA GX/1.0E-6/
      AAX=ABS(AX) ; AAY=ABS(AY)
      P=AX*AY
      IF(AAX.LE.GX.AND.AAY.LE.GX)GOTO 10
      SR=ATAN2(AAX,AAY)
      ATN=SIGN(SR,P)
      RETURN
   10 WRITE(6,100)AX,AY
  100 FORMAT(1H ,"ATAN --    AX=",E15.7,2X,"AY=",E15.7)
      ATN=0.2
      RETURN
      END
```

IUGG/IOC TIME PROJECT

PART 4. PROGRAMME LIST FOR FAR-FIELD TSUNAMI

TUNAMI-F2: LINEAR THEORY FOR PROPAGATION IN THE OCEAN AND COASTAL WATERS

CONTENTS

Page

TUNAMI-F2: LINEAR THEORY FOR PROPAGATION IN THE OCEAN AND COASTAL WATERS 1-23

```
C
C  *************** TUNAMI-F2 ****************
C    Tohoku University's Numerical-Analysis Model
C       for Investigation of tsunami
C        Far-field Tsunami version
C
C         1960 CHILEAN  TSUNAMI (DX=10')
C            OHMA VERSION 1.2
C                          91.7.25
C
C                 BY
C
C           F.IMAMURA, TOHOKU UNIV.
C
C    Z; WATER SURFACE LEVEL   M,N;WATER DISCHARGE
C    DX; GRID LENGTH
C
      REAL M,N,MA,NA,MB,NB,MC,NC,ME,NE,MF,NF
      REAL MD1,ND1,MD2,ND2,MD3,ND3,MD4,ND4,MD5,ND5
      DOUBLE PRECISION T1,T2,T3
      PARAMETER (IO=1020,JO=738,IA=76,JA=76)
      PARAMETER (IB=136,JB=136,IC=154,JC=307)
      PARAMETER (ID1=28,JD1=55,ID2=55,JD2=40)
      PARAMETER (ID3=37,JD3=31,ID4=13,JD4=40)
      PARAMETER (ID5=46,JD5=40)
      PARAMETER (IE1=34,JE1=67,IF1=46,JF1=58)
      PARAMETER (DO=10.0,DA=4.0,DB=1.33,DC=833)
      PARAMETER (DD=278.0,DE=93.0,DF=31.0)
      PARAMETER (TO=20.0,TA=10.0,TB=5.0,TC=5.0)
      PARAMETER (TD=5.0,TE=2.5,TF=1.25)
      PARAMETER (KS=1,KE=180*32,KD=180*2,KC=3)
      DATA IS,JS,IE,JE/961,61,1020,180/
      COMMON /XX/ Z(IO,JO,2),M(IO,JO,2),N(IO,JO,2)
      COMMON /HH/ H(IO,JO)
      COMMON /RR/ R1(IO,JO),R2(IO,JO),R3(IO,JO),
     &R4(IO,JO),R5(IO,JO),R6(IO)
      COMMON /CC/ C1(IO),C2(IO),C3(IO),C4(IO)
      COMMON /VV/ V1(IO),V2(IO),V3(IO),V4(IO),V5(IO)
      COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
      COMMON /HA/ HA(IA,JA)
      COMMON /RA/ RA1(IA,JA),RA2(IA,JA),RA3(IA,JA),
     &RA4(IA,JA),RA5(IA,JA),RA6(IA)
      COMMON /XB/ ZB(IB,JB,2),MB(IB,JB,2),NB(IB,JB,2)
      COMMON /HB/ HB(IB,JB)
      COMMON /RB/ RB1(IB,JB),RB2(IB,JB),RB3(IB,JB),
     &RB4(IB,JB),RB5(IB,JB),RB6(IB)
      COMMON /XC/ ZC(IC,JC,2),MC(IC,JC,2),NC(IC,JC,2)
      COMMON /HC/ HC(IC,JC)
      COMMON /XD1/ ZD1(ID1,JD1,2),MD1(ID1,JD1,2),
     &ND1(ID1,JD1,2),HD1(ID1,JD1)
      COMMON /XD2/ ZD2(ID2,JD2,2),MD2(ID2,JD2,2),
     &ND2(ID2,JD2,2),HD2(ID2,JD2)
      COMMON /XD3/ ZD3(ID3,JD3,2),MD3(ID3,JD3,2),
     &ND3(ID3,JD3,2),HD3(ID3,JD3)
      COMMON /XD4/ ZD4(ID4,JD4,2),MD4(ID4,JD4,2),
     &ND4(ID4,JD4,2),HD4(ID4,JD4)
      COMMON /XD5/ ZD5(ID5,JD5,2),MD5(ID5,JD5,2),
     &ND5(ID5,JD5,2),HD5(ID5,JD5)
      COMMON /XE/  ZE(IE1,JE1,2),ME(IE1,JE1,2),
     &NE(IE1,JE1,2),HE(IE1,JE1)
      COMMON /XF/  ZF(IF1,JF1,2),MF(IF1,JF1,2),
     &NF(IF1,JF1,2),HF(IF1,JF1)
```

```
C
C ******** INITIAL CONDITION *********
C
      CALL RDEPTH
      CALL PARAME
      CALL INITIA (IS,JS,IE,JE)
C      CALL COUT   (0,KD)
      CALL CLOCK  (T1)
C
C  ******** MAIN CALCULATION ********
C
      DO 10 K=KS,KE
      KK=K
C
C ******** TRANSOCEANIC PROPAGATION *******
C
      CALL MASS1 (IS,JS,IE,JE)
      CALL BOUND (IS,JS,IE,JE)
      CALL LIMIT (IS,JS,IE,JE)
C
C ******** CAL. NEAR NORTH JAPAN ************
C
      IF(IS.LE.121.AND.JE.GE.592)THEN
      CALL CAL   (IS,JS,IE,JE,KK) ; ELSE
      CALL MMNT1 (IS,JS,IE,JE)    ; ENDIF
      CALL COUT  (KK,KD)
      CALL CHANGE
   10 CONTINUE
      CALL CLOCK (T2) ; T3=T2-T1
      WRITE(6,*)KK,T3
      STOP  ; END
C
C ********* CAL. NEAR NORTH JAPAN ********
C
C
      SUBROUTINE CAL (IS,JS,IE,JE,KK)
C
      REAL M,N,MA,NA,MB,NB,MC,NC,ME,NE,MF,NF
      REAL MD1,ND1,MD2,ND2,MD3,ND3,MD4,ND4,MD5,ND5
      PARAMETER (IO=1020,JO=738,IA=76,JA=76)
      PARAMETER (IB=136,JB=136,IC=154,JC=307)
      PARAMETER (ID1=28,JD1=55,ID2=55,JD2=40)
      PARAMETER (ID3=37,JD3=31,ID4=13,JD4=40)
      PARAMETER (ID5=46,JD5=40)
      PARAMETER (IE1=34,JE1=67,IF1=46,JF1=58)
      PARAMETER (DC=833.0,DD=278.0,DE=93.0,DF=31.0)
      PARAMETER (TC=5.0,TD=5.0,TE=2.5,TF=1.25)
      COMMON /XX/ Z(IO,JO,2),M(IO,JO,2),N(IO,JO,2)
      COMMON /HH/ H(IO,JO)
      COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
      COMMON /HA/ HA(IA,JA)
      COMMON /RA/ RA1(IA,JA),RA2(IA,JA),RA3(IA,JA),
             &RA4(IA,JA),RA5(IA,JA),RA6(IA)
      COMMON /XB/ ZB(IB,JB,2),MB(IB,JB,2),NB(IB,JB,2)
      COMMON /HB/ HB(IB,JB)
      COMMON /RB/ RB1(IB,JB),RB2(IB,JB),RB3(IB,JB),
             &RB4(IB,JB),RB5(IB,JB),RB6(IB)
      COMMON /XC/ ZC(IC,JC,2),MC(IC,JC,2),NC(IC,JC,2)
      COMMON /HC/ HC(IC,JC)
      COMMON /XD1/ ZD1(ID1,JD1,2),MD1(ID1,JD1,2),
             &ND1(ID1,JD1,2),HD1(ID1,JD1)
      COMMON /XD2/ ZD2(ID2,JD2,2),MD2(ID2,JD2,2),
             &ND2(ID2,JD2,2),HD2(ID2,JD2)
      COMMON /XD3/ ZD3(ID3,JD3,2),MD3(ID3,JD3,2),
             &ND3(ID3,JD3,2),HD3(ID3,JD3)
      COMMON /XD4/ ZD4(ID4,JD4,2),MD4(ID4,JD4,2),
             &ND4(ID4,JD4,2),HD4(ID4,JD4)
      COMMON /XD5/ ZD5(ID5,JD5,2),MD5(ID5,JD5,2),
             &ND5(ID5,JD5,2),HD5(ID5,JD5)
      COMMON /XE/  ZE(IE1,JE1,2),ME(IE1,JE1,2),
             &NE(IE1,JE1,2),HE(IE1,JE1)
      COMMON /XF/  ZF(IF1,JF1,2),MF(IF1,JF1,2),
             &NF(IF1,JF1,2),HF(IF1,JF1)
      DIMENSION PD(14)
```

```
1370C
1380C ----- PARAMETERS FOR CONNECTION ------
1390C
1400    DIMENSION LAB(4),LBC(4),LDE(4),LEF(4)
1410    DIMENSION LD1(4),LD2(4),LD3(4),LD4(4),LD5(4)
1420    DATA LAB/5,20,49,64/
1430    DATA LBC/6,33,74,134/
1440    DATA LD1/60,144,68,161/
1450    DATA LD2/35,182,52,194/
1460    DATA LD3/90,133,101,142/
1470    DATA LD4/114,103,117,115/
1480    DATA LD5/122,23,136,35/
1490    DATA LDE/11,19,21,40/
1500    DATA LEF/14,26,28,44/
1510C
1520    LP=1 ; DO WHILE (LP.LE.16)
1530    CALL MASS2 (IA,JA,ZA,MA,NA,RA1,RA6,LP,8)
1540    CALL MASS2 (IB,JB,ZB,MB,NB,RB1,RB6,LP,4)
1550    CALL MASS3 (IC,JC,ZC,MC,NC,HC,DC,TC,LP,4)
1560    CALL MASS3 (ID1,JD1,ZD1,MD1,ND1,HD1,DD,TD,LP,4)
1570    CALL MASS3 (ID2,JD2,ZD2,MD2,ND2,HD2,DD,TD,LP,4)
1580    CALL MASS3 (ID3,JD3,ZD3,MD3,ND3,HD3,DD,TD,LP,4)
1590    CALL MASS3 (ID4,JD4,ZD4,MD4,ND4,HD4,DD,TD,LP,4)
1600    CALL MASS3 (ID5,JD5,ZD5,MD5,ND5,HD5,DD,TD,LP,4)
1610    CALL MASS3 (IE1,JE1,ZE,ME,NE,HE,DE,TE,LP,2)
1620C     CALL MASS3 (IF1,JF1,ZF,MF,NF,HF,DF,TF,LP,1)
1630C
1640    CALL JNZOA (LP,16)
1650    CALL JNZ (IA,JA,IB,JB,ZA,ZB,HB,LAB,1101,LP,8)
1660    CALL J2Z (IB,JB,IC,JC,ZB,ZC,HC,LBC,1111,LP,4)
1670    CALL J2Z (IC,JC,ID1,JD1,ZC,ZD1,HD1,LD1,1111,LP,4)
1680    CALL J2Z (IC,JC,ID2,JD2,ZC,ZD2,HD2,LD2,1101,LP,4)
1690    CALL J2Z (IC,JC,ID3,JD3,ZC,ZD3,HD3,LD3,0110,LP,4)
1700    CALL J2Z (IC,JC,ID4,JD4,ZC,ZD4,HD4,LD4,1110,LP,4)
1710    CALL J2Z (IC,JC,ID5,JD5,ZC,ZD5,HD5,LD5,0110,LP,4)
1720    CALL JNZ (ID1,JD1,IE1,JE1,ZD1,ZE,HE,LDE,1011,LP,4)
1730C     CALL JNZ (IE1,JE1,IF1,JF1,ZE,ZF,HF,LEF,1011,LP,2)
1740C
1750    IF(LP.EQ.16) CALL MMNT1 (IS,JS,IE,JE)
1760    CALL MMNT2 (IA,JA,ZA,MA,NA,RA2,RA3,RA4,RA5,LP,8)
1770    CALL MMNT2 (IB,JB,ZB,MB,NB,RB2,RB3,RB4,RB5,LP,4)
1780    CALL MMNT3 (IC,JC,ZC,MC,NC,HC,DC,TC,LP,4)
1790    CALL MMNT3 (ID1,JD1,ZD1,MD1,ND1,HD1,DD,TD,LP,4)
1800    CALL MMNT3 (ID2,JD2,ZD2,MD2,ND2,HD2,DD,TD,LP,4)
1810    CALL MMNT3 (ID3,JD3,ZD3,MD3,ND3,HD3,DD,TD,LP,4)
1820    CALL MMNT3 (ID4,JD4,ZD4,MD4,ND4,HD4,DD,TD,LP,4)
1830    CALL MMNT3 (ID5,JD5,ZD5,MD5,ND5,HD5,DD,TD,LP,4)
1840    CALL MMNT3 (IE1,JE1,ZE,ME,NE,HE,DE,TE,LP,2)
1850C     CALL MMNT3 (IF1,JF1,ZF,MF,NF,HF,DF,TF,LP,1)
1860C
1870    CALL JNQOA (LP,8)
1880    CALL JNQ (IA,JA,IB,JB,MA,NA,MB,NB,HB,LAB,1101,LP,4)
1890    CALL JNQ (IB,JB,IC,JC,MB,NB,MC,NC,HC,LBC,1111,LP,4)
1900    CALL JNQ (IC,JC,ID1,JD1,MC,NC,MD1,ND1,HD1,LD1,1111,LP,4)
1910    CALL JNQ (IC,JC,ID2,JD2,MC,NC,MD2,ND2,HD2,LD2,1101,LP,4)
1920    CALL JNQ (IC,JC,ID3,JD3,MC,NC,MD3,ND3,HD3,LD3,0110,LP,4)
1930    CALL JNQ (IC,JC,ID4,JD4,MC,NC,MD4,ND4,HD4,LD4,1110,LP,4)
1940    CALL JNQ (IC,JC,ID5,JD5,MC,NC,MD5,ND5,HD5,LD5,0110,LP,4)
1950    CALL JNQ (ID1,JD1,IE1,JE1,MD1,ND1,ME,NE,HE,LDE,1011,LP,2)
1960C     CALL JNQ (IE1,JE1,IF1,JF1,ME,NE,MF,NF,HF,LEF,1011,LP,1)
1970C
1980    CALL CHANG (IA,JA,ZA,MA,NA,LP,8)
1990    CALL CHANG (IB,JB,ZB,MB,NB,LP,4)
2000    CALL CHANG (IC,JC,ZC,MC,NC,LP,4)
2010    CALL CHANG (ID1,JD1,ZD1,MD1,ND1,LP,4)
2020    CALL CHANG (ID2,JD2,ZD2,MD2,ND2,LP,4)
2030    CALL CHANG (ID3,JD3,ZD3,MD3,ND3,LP,4)
2040    CALL CHANG (ID4,JD4,ZD4,MD4,ND4,LP,4)
2050    CALL CHANG (ID5,JD5,ZD5,MD5,ND5,LP,4)
2060    CALL CHANG (IE1,JE1,ZE,ME,NE,LP,2)
2070C     CALL CHANG (IF1,JF1,ZF,MF,NF,LP,1)
2080    LP=LP+1 ; ENDDO
2090C
2100    IF(KK.GE.180*22.AND.MOD(KK,3).EQ.0)THEN
```

```
      PD(1)=ZD1(24,39,2)  ; PD(2)=ZD1(22,43,2)
      PD(3)=ZD1(19,42,2)  ; PD(4)=ZD1(13,14,2)
      PD(5)=ZD1(10,7,2)   ; PD(6)=ZD2(41,16,2)
      PD(7)=ZD2(35,19,2)  ; PD(8)=ZD2(39,23,2)
      PD(9)=ZD2(18,39,2)  ; PD(10)=ZD3(6,25,2)
      PD(11)=ZD3(26,7,2)  ; PD(12)=ZD4(4,27,2)
      PD(13)=ZD5(22,4,2)  ; PD(14)=ZD5(32,6,2)
      WRITE(30,100)(PD(LL),LL=1,14)
  100 FORMAT(7F8.3)
      ENDIF
C
      RETURN ; END
C
C ******* READ DEPTH DATA *******
C
      SUBROUTINE RDEPTH
C
      REAL MD1,ND1,MD2,ND2,MD3,ND3,MD4,ND4,MD5,ND5
      REAL ME,NE,MF,NF
      PARAMETER (IO=1020,JO=738,IA=76,JA=76)
      PARAMETER (IB=136,JB=136,IC=154,JC=307)
      PARAMETER (ID1=28,JD1=55,ID2=55,JD2=40)
      PARAMETER (ID3=37,JD3=31,ID4=13,JD4=40)
      PARAMETER (ID5=46,JD5=40)
      PARAMETER (IE1=34,JE1=67,IF1=46,JF1=58)
      COMMON /HH/ H(IO,JO)
      COMMON /HA/ HA(IA,JA)
      COMMON /HB/ HB(IB,JB)
      COMMON /HC/ HC(IC,JC)
      COMMON /XD1/ ZD1(ID1,JD1,2),MD1(ID1,JD1,2),
     &        ND1(ID1,JD1,2),HD1(ID1,JD1)
      COMMON /XD2/ ZD2(ID2,JD2,2),MD2(ID2,JD2,2),
     &        ND2(ID2,JD2,2),HD2(ID2,JD2)
      COMMON /XD3/ ZD3(ID3,JD3,2),MD3(ID3,JD3,2),
     &        ND3(ID3,JD3,2),HD3(ID3,JD3)
      COMMON /XD4/ ZD4(ID4,JD4,2),MD4(ID4,JD4,2),
     &        ND4(ID4,JD4,2),HD4(ID4,JD4)
      COMMON /XD5/ ZD5(ID5,JD5,2),MD5(ID5,JD5,2),
     &        ND5(ID5,JD5,2),HD5(ID5,JD5)
      COMMON /XE/  ZE(IE1,JE1,2),ME(IE1,JE1,2),
     &        NE(IE1,JE1,2),HE(IE1,JE1)
      COMMON /XF/  ZF(IF1,JF1,2),MF(IF1,JF1,2),
     &        NF(IF1,JF1,2),HF(IF1,JF1)
      DIMENSION LAB(4),LBC(4),LDE(4),LEF(4)
      DIMENSION LD1(4),LD2(4),LD3(4),LD4(4),LD5(4)
      DATA LAB/5,20,49,64/
      DATA LBC/6,33,74,134/
      DATA LD1/60,144,68,161/
      DATA LD2/35,182,52,194/
      DATA LD3/90,133,101,142/
      DATA LD4/114,103,117,115/
      DATA LD5/122,23,136,35/
      DATA LDE/11,19,21,40/
      DATA LEF/14,26,28,44/
      DO 10 J=1,JO
   10 READ(20,900)(H(I,J),I=1,IO)
      DO 20 J=1,JA
   20 READ(21,900)(HA(I,J),I=1,IA)
      DO 30 J=1,JB
   30 READ(22,900)(HB(I,J),I=1,IB)
      DO 40 J=1,JC
   40 READ(23,900)(HC(I,J),I=1,IC)
      DO 51 J=1,JD1
   51 READ(24,900)(HD1(I,J),I=1,ID1)
      DO 52 J=1,JD2
   52 READ(24,900)(HD2(I,J),I=1,ID2)
      DO 53 J=1,JD3
   53 READ(24,900)(HD3(I,J),I=1,ID3)
      DO 54 J=1,JD4
   54 READ(24,900)(HD4(I,J),I=1,ID4)
      DO 55 J=1,JD5
   55 READ(24,900)(HD5(I,J),I=1,ID5)
      DO 60 J=1,JE1
   60 READ(25,900)(HE(I,J),I=1,IE1)
```

```
      DO 70 J=1,JF1
   70 READ(26,900)(HF(I,J),I=1,IF1)
C
  900 FORMAT(20F6.1)
      DO 101 J=1,JD1
      DO 101 I=1,ID1
      IF(HD1(I,J).LT.0.0)THEN ; HD1(I,J)=-90.0
      ELSE ; IF(HD1(I,J).LT.10.0)HD1(I,J)=10.0
      ENDIF
  101 CONTINUE
      DO 102 J=1,JD2
      DO 102 I=1,ID2
      IF(HD2(I,J).LT.0.0)THEN ; HD2(I,J)=-90.0
      ELSE ; IF(HD2(I,J).LT.10.0)HD2(I,J)=10.0
      ENDIF
  102 CONTINUE
      DO 103 J=1,JD3
      DO 103 I=1,ID3
      IF(HD3(I,J).LT.0.0)THEN ; HD3(I,J)=-90.0
      ELSE ; IF(HD3(I,J).LT.10.0)HD3(I,J)=10.0
      ENDIF
  103 CONTINUE
      DO 104 J=1,JD4
      DO 104 I=1,ID4
      IF(HD4(I,J).LT.0.0)THEN ; HD4(I,J)=-90.0
      ELSE ; IF(HD4(I,J).LT.10.0)HD4(I,J)=10.0
      ENDIF
  104 CONTINUE
      DO 105 J=1,JD5
      DO 105 I=1,ID5
      IF(HD5(I,J).LT.0.0)THEN ; HD5(I,J)=-90.0
      ELSE ; IF(HD5(I,J).LT.10.0)HD5(I,J)=10.0
      ENDIF
  105 CONTINUE
C
      DO 110 J=1,JE1
      DO 110 I=1,IE1
      IF(HE(I,J).LT.0.0)THEN ; HE(I,J)=-90.0
      ELSE ; IF(HE(I,J).LT.10.0)HE(I,J)=10.0
      ENDIF
  110 CONTINUE
      DO 120 J=1,JF1
      DO 120 I=1,IF1
      IF(HF(I,J).LT.0.0)THEN ; HF(I,J)=-90.0
      ELSE ; IF(HF(I,J).LT.10.0)HF(I,J)=10.0
      ENDIF
  120 CONTINUE
C
C ****** CAHNGE OF DEPTH DATA ********
C
      CALL CHH (IA,JA,IB,JB,HA,HB,LAB,1101)
      CALL CHH (IB,JB,IC,JC,HB,HC,LBC,0101)
      CALL CHH (IC,JC,ID1,JD1,HC,HD1,LD1,1111)
      CALL CHH (IC,JC,ID2,JD2,HC,HD2,LD2,1101)
      CALL CHH (IC,JC,ID3,JD3,HC,HD3,LD3,0110)
      CALL CHH (IC,JC,ID4,JD4,HC,HD4,LD4,1110)
      CALL CHH (IC,JC,ID5,JD5,HC,HD5,LD5,0110)
      CALL CHH (ID1,JD1,IE1,JE1,HD1,HE,LDE,1011)
      CALL CHH (IE1,JE1,IF1,JF1,HE,HF,LEF,1011)
      RETURN
      END
C
C ******** PARAMETERS FOR VECTOR OPERATION *******
C
      SUBROUTINE PARAME
      PARAMETER (GG=9.8)
      PARAMETER (FO=-60.,FA=38.5,FB=39.7,PP=3.1415926)
      PARAMETER (R=6.37E+6,WW=7.2722E-5)
      PARAMETER (IO=1020,JO=738,IA=76,JA=76)
      PARAMETER (IB=136,JB=136,IC=154,JC=307)
      PARAMETER (DO=10.0,DA=4.0,DB=1.33)
      PARAMETER (TO=20.0,TA=10.0,TB=5.0)
      COMMON /HH/ H(IO,JO)
      COMMON /RR/ R1(IO,JO),R2(IO,JO),R3(IO,JO),
           &R4(IO,JO),R5(IO,JO),R6(IO)
      COMMON /CC/ C1(IO),C2(IO),C3(IO),C4(IO)
      COMMON /VV/ V1(IO),V2(IO),V3(IO),V4(IO),V5(IO)
      COMMON /HA/ HA(IA,JA)
      COMMON /RA/ RA1(IA,JA),RA2(IA,JA),RA3(IA,JA),
           &RA4(IA,JA),RA5(IA,JA),RA6(IA)
      COMMON /HB/ HB(IB,JB)
      COMMON /RB/ RB1(IB,JB),RB2(IB,JB),RB3(IB,JB),
           &RB4(IB,JB),RB5(IB,JB),RB6(IB)
C
      PX=PP/180.
      DX=R*(DO/60.)*PX
      RR=TO/DX
      RS=0.5*GG*RR
      RT=0.5*TO*WW
      DO 10 J=1,JO
      C1(J)=(FO+(DO*J-0.5*DO)/60.)*PX
      C2(J)=(FO+DO*J/60.)*PX
   10 CONTINUE
      DO 11 J=1,JO
      C3(J)=COS(C1(J))
      V1(J)=RR/C3(J)
      V2(J)=RS/C3(J)
      V3(J)=RT*SIN(C1(J))
      V4(J)=RS
      V5(J)=RT*SIN(C2(J))
      R6(J)=C3(J)
   11 CONTINUE
      DO 12 J=1,JO
      C4(J)=0.
      DO 12 I=1,IO
      IF(H(I,J).GT.C4(J))C4(J)=H(I,J)
   12 CONTINUE
      DO 15 J=1,JO
      DO 15 I=1,IO
      IF(H(I,J).LT.0.)GOTO 15
      R1(I,J)=V1(J)
      IF(I.NE.IO)THEN
      IF(H(I+1,J).LT.0.)GOTO 16
      R2(I,J)=V2(J)*(H(I,J)+H(I+1,J))
      R3(I,J)=V3(J)
      ELSE
      R2(I,J)=V2(J)*H(I,J)*2
      R3(I,J)=V3(J)
      ENDIF
   16 IF(J.NE.JO)THEN
      IF(H(I,J+1).LT.0.)GOTO 15
      R4(I,J)=V4(J)*(H(I,J)+H(I,J+1))
      R5(I,J)=V5(J)
      ELSE
      R4(I,J)=V4(J)*H(I,J)*2
      R5(I,J)=V5(J)
      ENDIF
   15 CONTINUE
      DO 17 I=1,IO
   17 C1(I)=0.
      DO 18 I=1,IO
   18 IF(H(I,1).GT.0.)C1(I)=1./SQRT(GG*H(I,1))
      DO 19 J=1,JO
   19 C2(J)=0.
      DO 20 J=1,JO
   20 IF(H(1,J).GT.0.)C2(J)=1./SQRT(GG*H(1,J))
      DO 21 I=1,IO
   21 C3(I)=0.
      DO 22 I=1,IO
   22 IF(H(I,JO).GT.0.)C3(I)=1./SQRT(GG*H(I,JO))
      DO 23 J=1,JO
   23 C4(J)=0.
      DO 24 J=1,JO
   24 IF(H(IO,J).GT.0.)C4(J)=1./SQRT(GG*H(IO,J))
C
      DX=R*(DA/60.)*PX
      RR=TA/DX
      RS=0.5*GG*RR
   RT=0.5*TA*WW
   DO 30 J=1,JA
   CC1=(FA+(DA*J-0.5*DA)/60.)*PX
   CC2=(FA+DA*J/60.)*PX
   CC3=COS(CC1)
   V1(J)=RR/CC3
   V2(J)=RS/CC3
   V3(J)=RT*SIN(CC1)
   V4(J)=RS
   V5(J)=RT*SIN(CC2)
   RA6(J)=CC3
 30 CONTINUE
   DO 32 J=1,JA
   DO 32 I=1,IA
   IF(HA(I,J).LT.0.)GOTO 32
   RA1(I,J)=V1(J)
   IF(I.NE.IA)THEN
   IF(HA(I+1,J).LT.0.)GOTO 33
   RA2(I,J)=V2(J)*(HA(I,J)+HA(I+1,J))
   RA3(I,J)=V3(J)
   ELSE
   RA2(I,J)=V2(J)*HA(I,J)*2
   RA3(I,J)=V3(J)
   ENDIF
 33 IF(J.NE.JA)THEN
   IF(HA(I,J+1).LT.0.)GOTO 32
   RA4(I,J)=V4(J)*(HA(I,J)+HA(I,J+1))
   RA5(I,J)=V5(J)
   ELSE
   RA4(I,J)=V4(J)*HA(I,J)*2
   RA5(I,J)=V5(J)
   ENDIF
 32 CONTINUE
C
   DX=R*(DB/60.)*PX
   RR=TB/DX
   RS=0.5*GG*RR
   RT=0.5*TB*WW
   DO 40 J=1,JB
   CC1=(FB+(DB*J-0.5*DB)/60.)*PX
   CC2=(FB+DB*J/60.)*PX
   CC3=COS(CC1)
   V1(J)=RR/CC3
   V2(J)=RS/CC3
   V3(J)=RT*SIN(CC1)
   V4(J)=RS
   V5(J)=RT*SIN(CC2)
   RB6(J)=CC3
 40 CONTINUE
   DO 42 J=1,JB
   DO 42 I=1,IB
   IF(HB(I,J).LT.0.)GOTO 42
   RB1(I,J)=V1(J)
   IF(I.NE.IB)THEN
   IF(HB(I+1,J).LT.0.)GOTO 43
   RB2(I,J)=V2(J)*(HB(I,J)+HB(I+1,J))
   RB3(I,J)=V3(J)
   ELSE
   RB2(I,J)=V2(J)*HB(I,J)*2
   RB3(I,J)=V3(J)
   ENDIF
 43 IF(J.NE.JB)THEN
   IF(HB(I,J+1).LT.0.)GOTO 42
   RB4(I,J)=V4(J)*(HB(I,J)+HB(I,J+1))
   RB5(I,J)=V5(J)
   ELSE
   RB4(I,J)=V4(J)*HB(I,J)*2
   RB5(I,J)=V5(J)
   ENDIF
 42 CONTINUE
   RETURN ; END
C
   SUBROUTINE INITIA  (IS,JS,IE,JE)
C
```

```
      REAL M,N,MA,NA,MB,NB,MC,NC,ME,NE,MF,NF
      REAL MD1,ND1,MD2,ND2,MD3,ND3,MD4,ND4,MD5,ND5
      PARAMETER (IO=1020,JO=738,IA=76,JA=76)
      PARAMETER (IB=136,JB=136,IC=154,JC=307)
      PARAMETER (ID1=28,JD1=55,ID2=55,JD2=40)
      PARAMETER (ID3=37,JD3=31,ID4=13,JD4=40)
      PARAMETER (ID5=46,JD5=40)
      PARAMETER (IE1=34,JE1=67,IF1=46,JF1=58)
      COMMON /XX/ Z(IO,JO,2),M(IO,JO,2),N(IO,JO,2)
      COMMON /HH/ H(IO,JO)
      COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
      COMMON /XB/ ZB(IB,JB,2),MB(IB,JB,2),NB(IB,JB,2)
      COMMON /XC/ ZC(IC,JC,2),MC(IC,JC,2),NC(IC,JC,2)
      COMMON /XD1/ ZD1(ID1,JD1,2),MD1(ID1,JD1,2),
             &ND1(ID1,JD1,2),HD1(ID1,JD1)
      COMMON /XD2/ ZD2(ID2,JD2,2),MD2(ID2,JD2,2),
             &ND2(ID2,JD2,2),HD2(ID2,JD2)
      COMMON /XD3/ ZD3(ID3,JD3,2),MD3(ID3,JD3,2),
             &ND3(ID3,JD3,2),HD3(ID3,JD3)
      COMMON /XD4/ ZD4(ID4,JD4,2),MD4(ID4,JD4,2),
             &ND4(ID4,JD4,2),HD4(ID4,JD4)
      COMMON /XD5/ ZD5(ID5,JD5,2),MD5(ID5,JD5,2),
             &ND5(ID5,JD5,2),HD5(ID5,JD5)
      COMMON /XE/  ZE(IE1,JE1,2),ME(IE1,JE1,2),
             &NE(IE1,JE1,2),HE(IE1,JE1)
      COMMON /XF/  ZF(IF1,JF1,2),MF(IF1,JF1,2),
             &NF(IF1,JF1,2),HF(IF1,JF1)
C
      DO 200 L=1,2
      DO 10 J=1,JO ; DO 10 I=1,IO
      Z(I,J,L)=0.0 ; M(I,J,L)=0.0 ; N(I,J,L)=0.0
   10 CONTINUE
      DO 20 J=1,JA ; DO 20 I=1,IA
      ZA(I,J,2)=0.0 ; MA(I,J,L)=0.0 ; NA(I,J,L)=0.0
   20 CONTINUE
      DO 30 J=1,JB ; DO 30 I=1,IB
      ZB(I,J,L)=0.0 ; MB(I,J,L)=0.0 ; NB(I,J,L)=0.0
   30 CONTINUE
      DO 40 J=1,JC ; DO 40 I=1,IC
      ZC(I,J,L)=0.0 ; MC(I,J,L)=0.0 ; NC(I,J,L)=0.0
   40 CONTINUE
      DO 51 J=1,JD1 ; DO 51 I=1,ID1
      ZD1(I,J,L)=0. ; MD1(I,J,L)=0. ; ND1(I,J,L)=0.
   51 CONTINUE
      DO 52 J=1,JD2 ; DO 52 I=1,ID2
      ZD2(I,J,L)=0. ; MD2(I,J,L)=0. ; ND2(I,J,L)=0.
   52 CONTINUE
      DO 53 J=1,JD3 ; DO 53 I=1,ID3
      ZD3(I,J,L)=0. ; MD3(I,J,L)=0. ; ND3(I,J,L)=0.
   53 CONTINUE
      DO 54 J=1,JD4 ; DO 54 I=1,ID4
      ZD4(I,J,L)=0. ; MD4(I,J,L)=0. ; ND4(I,J,L)=0.
   54 CONTINUE
      DO 55 J=1,JD5 ; DO 55 I=1,ID5
      ZD5(I,J,L)=0. ; MD5(I,J,L)=0. ; ND5(I,J,L)=0.
   55 CONTINUE
      DO 60 J=1,JE1 ; DO 60 I=1,IE1
      ZE(I,J,L)=0. ; ME(I,J,L)=0. ; NE(I,J,L)=0.
   60 CONTINUE
      DO 70 J=1,JF1 ; DO 70 I=1,IF1
      ZF(I,J,L)=0. ; MF(I,J,L)=0. ; NF(I,J,L)=0.
   70 CONTINUE
  200 CONTINUE
C
      CALL DEFORM (IO,JO,IS,JS,IE,JE,Z)
      DO 110 J=JS,JE ; DO 110 I=IS,IE
      IF(H(I,J).LT.0.)Z(I,J,1)=0.
  110 CONTINUE
      RETURN
      END
C
      SUBROUTINE CHH (IX,JX,IY,JY,HX,HY,L0,BCHK)
C
      INTEGER BCHK,CHK
      DIMENSION HX(IX,JX),HY(IY,JY),L0(4)
C
      ISS=2    ; JSS=2    ; IES=IY   ; JES=JY
      ISL=L0(1) ; JSL=L0(2) ; IEL=L0(3) ; JEL=L0(4)
      CHK=BCHK
      KB=CHK/1000
      IF(KB.EQ.1)THEN
      CHK=CHK-1000
      II=ISL ; JJ=JSL ; I1=ISS ; J1=JSS
      DO WHILE (I1+2.LE.IES)
      S=0.0 ; L=0
      DO 10 I=I1,I1+2
      DO 10 J=J1,J1+2
      IF(HY(I,J).GT.0.0)THEN
      S=S+HY(I,J)
      L=L+1 ; ENDIF
   10 CONTINUE
      IF(L.GE.5)THEN
      HX(II,JJ)=S/L  ; ENDIF
      II=II+1 ; I1=I1+3
      ENDDO   ; ENDIF
C
      KB=CHK/100
      IF(KB.EQ.1)THEN
      CHK=CHK-100
      II=IEL ; JJ=JSL ; I1=IES-2 ; J1=JSS
      DO WHILE (J1+1.LE.JES)
      S=0.0 ; L=0
      DO 20 I=I1,I1+2
      DO 20 J=J1,J1+2
      IF(HY(I,J).GT.0.0)THEN
      S=S+HY(I,J)
      L=L+1 ; ENDIF
   20 CONTINUE
      IF(L.GE.5)THEN
      HX(II,JJ)=S/L  ; ENDIF
      JJ=JJ+1 ; J1=J1+3
      ENDDO   ; ENDIF
C
      KB=CHK/10
      IF(KB.EQ.1)THEN
      CHK=CHK-10
      II=ISL ; JJ=JEL ; I1=ISS ; J1=JES-2
      DO WHILE (I1+2.LE.IES)
      S=0.0 ; L=0
      DO 30 I=I1,I1+2
      DO 30 J=J1,J1+2
      IF(HY(I,J).GT.0.0)THEN
      S=S+HY(I,J)
      L=L+1 ; ENDIF
   30 CONTINUE
      IF(L.GE.5)THEN
      HX(II,JJ)=S/L  ; ENDIF
      II=II+1 ; I1=I1+3
      ENDDO   ; ENDIF
C
      IF(CHK.EQ.1)THEN
      II=ISL ; JJ=JSL ; I1=ISS ; J1=JSS
      DO WHILE (J1+2.LE.JES)
      S=0.0 ; L=0
      DO 40 I=I1,I1+2
      DO 40 J=J1,J1+2
      IF(HY(I,J).GT.0.0)THEN
      S=S+HY(I,J)
      L=L+1 ; ENDIF
   40 CONTINUE
      IF(L.GE.5)THEN
      HX(II,JJ)=S/L  ; ENDIF
      JJ=JJ+1 ; J1=J1+3
      ENDDO  ; ENDIF
      RETURN ; END
C
      SUBROUTINE LIMIT (IS,JS,IE,JE)
C
```

```
6550     REAL M,N
6560     PARAMETER (GX=1.E-4)
6570     PARAMETER (IO=1020,JO=738)
6580     COMMON /XX/ Z(IO,JO,2),M(IO,JO,2),N(IO,JO,2)
6590     IF(IS.EQ.2)GOTO 61
6600     L=0
6610     DO 10 J=JS,JE
6620     IF(ABS(Z(IS+2,J,2)).GT.GX)L=1
6630  10 CONTINUE
6640     IF(L.EQ.1)THEN
6650     IS=IS-1
6660     IF(IS.LE.2)IS=2
6670     ENDIF
6680  61 IF(IE.EQ.IO-1)GOTO 62
6690     L=0
6700     DO 20 J=JS,JE
6710     IF(ABS(Z(IE-2,J,2)).GT.GX)L=1
6720  20 CONTINUE
6730     IF(L.EQ.1)THEN
6740     IE=IE+1
6750     IF(IE.GE.IO-1)IE=IO-1
6760     ENDIF
6770  62 IF(JS.EQ.2)GOTO 63
6780     L=0
6790     DO 30 I=IS,IE
6800     IF(ABS(Z(I,JS+2,2)).GT.GX)L=1
6810  30 CONTINUE
6820     IF(L.EQ.1)THEN
6830     JS=JS-1
6840     IF(JS.LE.2)JS=2
6850     ENDIF
6860  63 IF(JE.EQ.JO-1)GOTO 64
6870     L=0
6880     DO 40 I=IS,IE
6890     IF(ABS(Z(I,JE-2,2)).GT.GX)L=1
6900  40 CONTINUE
6910     IF(L.EQ.1)THEN
6920     JE=JE+1
6930     IF(JE.GE.JO-1)JE=JO-1
6940     ENDIF
6950  64 RETURN
6960     END
6970C
6980     SUBROUTINE MASS1 (IS,JS,IE,JE)
6990C
7000     REAL M,N
7010     PARAMETER (IO=1020,JO=738)
7020     COMMON /XX/ Z(IO,JO,2),M(IO,JO,2),N(IO,JO,2)
7030     COMMON /HH/ H(IO,JO)
7040     COMMON /RR/ R1(IO,JO),R2(IO,JO),R3(IO,JO),
7050              &R4(IO,JO),R5(IO,JO),R6(IO)
7060     DO 10 J=JS,JE
7070     DO 10 I=IS,IE
7080     Z(I,J,2)=Z(I,J,1)-R1(I,J)*(M(I,J,1)-M(I-1,J,1))
7090     &  -R1(I,J)*(N(I,J,1)*R6(J)-N(I,J-1,1)*R6(J-1))
7100  10 CONTINUE
7110     DO 20 J=JS,JE
7120     DO 20 I=IS,IE
7130     IF(ABS(Z(I,J,2)).LT.1.0E-5)Z(I,J,2)=0.0
7140  20 CONTINUE
7150     RETURN
7160     END
7170C
7180     SUBROUTINE MASS2 (IF,JF,Z,M,N,R1,R6,LP,LT)
7190C
7200     REAL M,N
7210     DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
7220     DIMENSION R1(IF,JF),R6(IF)
7230     IF(MOD(LP,LT).NE.0)RETURN
7240     DO 10 J=2,JF
7250     DO 10 I=2,IF
7260     Z(I,J,2)=Z(I,J,1)-R1(I,J)*(M(I,J,1)-M(I-1,J,1))
7270     &  -R1(I,J)*(N(I,J,1)*R6(J)-N(I,J-1,1)*R6(J-1))
7280  10 CONTINUE
```

```
      DO 20 J=2,JF
      DO 20 I=2,IF
      IF(ABS(Z(I,J,2)).LT.1.0E-5)Z(I,J,2)=0.0
   20 CONTINUE
      RETURN
      END
C
      SUBROUTINE MASS3 (IF,JF,Z,M,N,H,DX,DT,LP,LT)
C
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
      DIMENSION H(IF,JF)
      IF(MOD(LP,LT).NE.0)RETURN
      DO 10 J=2,JF
      DO 10 I=2,IF
      IF(H(I,J).GT.0.0)THEN
      Z(I,J,2)=Z(I,J,1)-DT/DX*(M(I,J,1)-M(I-1,J,1)
      &                +N(I,J,1)-N(I,J-1,1))
      ELSE
      Z(I,J,2)=0.0
      ENDIF
   10 CONTINUE
      DO 20 J=2,JF
      DO 20 I=2,IF
      IF(ABS(Z(I,J,2)).LT.1.0E-5)Z(I,J,2)=0.0
   20 CONTINUE
      RETURN ; END
C
      SUBROUTINE MMNT1 (IS,JS,IE,JE)
C
      REAL M,N
      PARAMETER (IO=1020,JO=738)
      COMMON /XX/ Z(IO,JO,2),M(IO,JO,2),N(IO,JO,2)
      COMMON /HH/ H(IO,JO)
      COMMON /RR/ R1(IO,JO),R2(IO,JO),R3(IO,JO),
             &R4(IO,JO),R5(IO,JO),R6(IO)
      COMMON /VV/ V1(IO),V2(IO),V3(IO),V4(IO),V5(IO)
      DO 10 J=JS,JE
      DO 10 I=IS,IE
      V1(I)=Z(I+1,J,2)-Z(I,J,2)
      V2(I)=N(I,J-1,1)+N(I,J,1)+N(I+1,J-1,1)+N(I+1,J,1)
      M(I,J,2)=M(I,J,1)-R2(I,J)*V1(I)+R3(I,J)*V2(I)
   10 CONTINUE
      IF(JS.LE.2)THEN
      DO 15 I=1,IO-1
   15 M(I,1,2)=M(I,1,1)-R2(I,1)*(Z(I+1,1,2)-Z(I,1,2))
      ENDIF
      IF(JE.GE.JO-1)THEN
      DO 16 I=1,IO-1
   16 M(I,JO,2)=M(I,JO,1)-R2(I,JO)*(Z(I+1,JO,2)-Z(I,JO,2))
      ENDIF
      IF(IS.LE.2)THEN
      DO 17 J=1,JO
   17 M(1,J,2)=M(1,J,1)-R2(1,J)*(Z(2,J,2)-Z(1,J,2))
      ENDIF
C
      DO 20 J=JS,JE
      DO 20 I=IS,IE
      V1(I)=Z(I,J+1,2)-Z(I,J,2)
      V2(I)=M(I-1,J,1)+M(I,J,1)+M(I-1,J+1,1)+M(I,J+1,1)
      N(I,J,2)=N(I,J,1)-R4(I,J)*V1(I)-R5(I,J)*V2(I)
   20 CONTINUE
      IF(IS.LE.2)THEN
      DO 25 J=1,JO-1
   25 N(1,J,2)=N(1,J,1)-R4(1,J)*(Z(1,J+1,2)-Z(1,J,2))
      ENDIF
      IF(IE.GE.IO-1)THEN
      DO 26 J=1,JO-1
   26 N(IO,J,2)=N(IO,J,1)-R4(IO,J)*(Z(IO,J+1,2)-Z(IO,J,2))
      ENDIF
      IF(JS.LE.2)THEN
      DO 27 I=1,IO
   27 N(I,1,2)=N(I,1,1)-R4(I,1)*(Z(I,2,2)-Z(I,1,2))
      ENDIF
      RETURN ; END
C
      SUBROUTINE MMNT2 (IF,JF,Z,M,N,R2,R3,R4,R5,LP,LT)
C
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
      DIMENSION R2(IF,JF),R3(IF,JF),R4(IF,JF),
           &R5(IF,JF)
      IF(MOD(LP,LT).NE.0)RETURN
      DO 10 J=2,JF-1
      DO 10 I=2,IF-1
      M(I,J,2)=M(I,J,1)-R2(I,J)*(Z(I+1,J,2)-Z(I,J,2))
     &+R3(I,J)*(N(I,J-1,1)+N(I,J,1)+N(I+1,J-1,1)+N(I+1,J,1))
      N(I,J,2)=N(I,J,1)-R4(I,J)*(Z(I,J+1,2)-Z(I,J,2))
     &+R5(I,J)*(M(I-1,J,1)+M(I,J,1)+M(I-1,J+1,1)+M(I,J+1,1))
   10 CONTINUE
C
      DO 16 I=1,IF-1
   16 M(I,JF,2)=M(I,JF,1)-R2(I,JF)*(Z(I+1,JF,2)-Z(I,JF,2))
      DO 26 J=1,JF-1
   26 N(IF,J,2)=N(IF,J,1)-R4(IF,J)*(Z(IF,J+1,2)-Z(IF,J,2))
      RETURN  ; END
C
      SUBROUTINE MMNT3 (IF,JF,Z,M,N,H,DX,DT,LP,LT)
C
      REAL M,N
      PARAMETER (GG=9.8)
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
      DIMENSION H(IF,JF)
      IF(MOD(LP,LT).NE.0)RETURN
      DO 10 J=2,JF-1
      DO 10 I=2,IF-1
      HH=0.5*(H(I,J)+H(I+1,J))*GG*DT/DX
      IF(HH.GT.0.0)THEN
      M(I,J,2)=M(I,J,1)-HH*(Z(I+1,J,2)-Z(I,J,2))
      ELSE ; M(I,J,2)=0.0 ; ENDIF
   10 CONTINUE
      DO 20 J=2,JF-1
      DO 20 I=2,IF-1
      HH=0.5*(H(I,J)+H(I,J+1))*GG*DT/DX
      IF(HH.GT.0.0)THEN
      N(I,J,2)=N(I,J,1)-HH*(Z(I,J+1,2)-Z(I,J,2))
      ELSE ; N(I,J,2)=0.0 ; ENDIF
   20 CONTINUE
C
      DO 16 I=1,IF-1
      HH=0.5*(H(I,JF)+H(I+1,JF))*GG*DT/DX
      IF(HH.GT.0.0)THEN
      M(I,JF,2)=M(I,JF,1)-HH*(Z(I+1,JF,2)-Z(I,JF,2))
      ELSE ; M(I,JF,2)=0.0 ; ENDIF
   16 CONTINUE
      DO 26 J=1,JF-1
      HH=0.5*(H(IF,J)+H(IF,J+1))*GG*DT/DX
      IF(HH.GT.0.0)THEN
      N(IF,J,2)=N(IF,J,1)-HH*(Z(IF,J+1,2)-Z(IF,J,2))
      ELSE ; N(IF,J,2)=0.0 ; ENDIF
   26 CONTINUE
      RETURN  ; END
C
      SUBROUTINE BOUND (IS,JS,IE,JE)
C
      REAL M,N
      PARAMETER (IO=1020,JO=738)
      COMMON /XX/ Z(IO,JO,2),M(IO,JO,2),N(IO,JO,2)
      COMMON /HH/ H(IO,JO)
      COMMON /CC/ C1(IO),C2(IO),C3(IO),C4(IO)
      IF(JS.LE.2)THEN
      DO 10 I=2,IO-1
      Z(I,1,2)=SQRT(N(I,1,1)**2
         &+0.25*(M(I,1,1)+M(I-1,1,1))**2)*C1(I)
   10 IF(N(I,1,1).GT.0.)Z(I,1,2)=-Z(I,1,2)
      ENDIF
      IF(IS.LE.2)THEN
      DO 20 J=2,JO-1
```

```
8770     Z(1,J,2)=SQRT(M(1,J,1)**2
8780        &+0.25*(N(1,J,1)+N(1,J-1,1))**2)*C2(J)
8790     IF(Z(1,J,2).GT.1.0)Z(1,J,2)=1.0
8800     IF(Z(1,J,2).LT.-1.0)Z(1,J,2)=-1.0
8810   20 IF(M(1,J,1).GT.0.)Z(1,J,2)=-Z(1,J,2)
8820     ENDIF
8830     IF(JE.GE.JO-1)THEN
8840     DO 30 I=2,IO-1
8850     Z(I,JO,2)=SQRT(N(I,JO-1,1)**2
8860        &+0.25*(M(I,JO,1)+M(I,JO-1,1))**2)*C3(I)
8870   30 IF(N(I,JO-1,1).LT.0.)Z(I,JO,2)=-Z(I,JO,2)
8880     ENDIF
8890     IF(IE.GE.IO-1)THEN
8900     DO 40 J=2,JO-1
8910     Z(IO,J,2)=SQRT(M(IO-1,J,1)**2
8920        &+0.25*(N(I,JO,1)+N(I,JO-1,1))**2)*C4(J)
8930   40 IF(M(IO-1,J,1).LT.0.)Z(IO,J,2)=-Z(IO,J,2)
8940     ENDIF
8950     Z(1,1,2)=SQRT(M(1,1,1)**2+N(1,1,1)**2)*C1(1)
8960     IF(N(1,1,1).GT.0.0)Z(1,1,2)=-Z(1,1,2)
8970     Z(IO,1,2)=SQRT(M(IO-1,1,1)**2+N(IO,1,1)**2)*C1(IO)
8980     IF(N(IO,1,1).GT.0.0)Z(IO,1,2)=-Z(IO,1,2)
8990     Z(1,JO,2)=SQRT(M(1,JO,1)**2+N(1,JO-1,1)**2)*C3(1)
9000     IF(N(1,JO-1,1).LT.0.0)Z(1,JO,2)=-Z(1,JO,2)
9010     Z(IO,JO,2)=SQRT(M(IO-1,JO,1)**2+N(IO,JO-1,1)**2)*C3(JO)
9020     IF(N(IO,JO-1,1).LT.0.0)Z(IO,JO,2)=-Z(IO,JO,2)
9030     RETURN
9040     END
9050C
9060     SUBROUTINE JNZOA (LP,LT)
9070C
9080     REAL M,MA,N,NA
9090     PARAMETER (IO=1020,JO=738,IA=76,JA=76)
9100     PARAMETER (ISS=2,JSS=2,IES=76,JES=76)
9110     PARAMETER (ISL=121,JSL=592,IEL=150,JEL=621)
9120     COMMON /XX/ Z(IO,JO,2),M(IO,JO,2),N(IO,JO,2)
9130     COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
9140     COMMON /HA/ HA(IA,JA)
9150     IF(MOD(LP,LT).NE.0)RETURN
9160C
9170     II=ISL ; JJ=JSL ; I1=ISS ; J1=JSS
9180     DO WHILE (II.LE.IEL)
9190     S=0.0 ; L=0
9200     IE=I1+2 ; IF(IE.GE.IES)IE=IES
9210     DO 10 I=I1,IE
9220     DO 10 J=J1,J1+2
9230     IF(HA(I,J).GT.0.0)THEN
9240     S=S+0.5*(ZA(I,J,1)+ZA(I,J,2))
9250     L=L+1 ; ENDIF
9260   10 CONTINUE
9270     IF(L.GE.1)THEN
9280     Z(II,JJ,2)=S/L  ; ELSE
9290     Z(II,JJ,2)=0.0  ; ENDIF
9300     II=II+1 ; I1=I1+2
9310     IF(MOD(II,2).EQ.1)I1=I1+1
9320     ENDDO
9330C
9340     II=IEL ; JJ=JSL ; I1=IES-2 ; J1=JSS
9350     DO WHILE (JJ.LE.JEL)
9360     S=0.0 ; L=0
9370     JE=J1+2 ; IF(JE.GE.JES)JE=JES
9380     DO 20 I=I1,I1+2
9390     DO 20 J=J1,JE
9400     IF(HA(I,J).GT.0.0)THEN
9410     S=S+0.5*(ZA(I,J,1)+ZA(I,J,2))
9420     L=L+1 ; ENDIF
9430   20 CONTINUE
9440     IF(L.GE.1)THEN
9450     Z(II,JJ,2)=S/L  ; ELSE
9460     Z(II,JJ,2)=0.0  ; ENDIF
9470     JJ=JJ+1 ; J1=J1+2
9480     IF(MOD(JJ,2).EQ.0)J1=J1+1
9490     ENDDO
9500C
```

```
      II=ISL ; JJ=JSL ; I1=ISS ; J1=JSS
      DO WHILE (JJ.LE.JEL)
      S=0.0 ; L=0
      JE=J1+2 ; IF(JE.GE.JES)JE=JES
      DO 30 I=I1,I1+2
      DO 30 J=J1,JE
      IF(HA(I,J).GT.0.0)THEN
      S=S+0.5*(ZA(I,J,1)+ZA(I,J,2))
      L=L+1 ; ENDIF
   30 CONTINUE
      IF(L.GE.1)THEN
      Z(II,JJ,2)=S/L  ; ELSE
      Z(II,JJ,2)=0.0  ; ENDIF
      JJ=JJ+1 ; J1=J1+2
      IF(MOD(JJ,2).EQ.0)J1=J1+1
      ENDDO
      RETURN ; END
C
      SUBROUTINE JNZ (IX,JX,IY,JY,ZX,ZY,HY
               &,L0,BCHK,LP,LT)
C
      INTEGER BCHK,CHK
      DIMENSION ZX(IX,JX,2),ZY(IY,JY,2)
      DIMENSION HY(IY,JY),L0(4)
      IF(MOD(LP,LT).NE.0)RETURN
      ISS=2    ; JSS=2    ; IES=IY    ; JES=JY
      ISL=L0(1) ; JSL=L0(2) ; IEL=L0(3) ; JEL=L0(4)
      CHK=BCHK
      KB=CHK/1000
      IF(KB.EQ.1)THEN
      CHK=CHK-1000
      II=ISL ; JJ=JSL ; I1=ISS ; J1=JSS
      DO WHILE (I1+2.LE.IES)
      S=0.0 ; L=0
      DO 10 I=I1,I1+2
      DO 10 J=J1,J1+2
      IF(HY(I,J).GT.0.0)THEN
      S=S+0.5*(ZY(I,J,1)+ZY(I,J,2))
      L=L+1 ; ENDIF
   10 CONTINUE
      IF(L.GE.5)THEN
      ZX(II,JJ,2)=S/L  ; ELSE
      ZX(II,JJ,2)=0.0  ; ENDIF
      II=II+1 ; I1=I1+3
      ENDDO   ; ENDIF
C
      KB=CHK/100
      IF(KB.EQ.1)THEN
      CHK=CHK-100
      II=IEL ; JJ=JSL ; I1=IES-2 ; J1=JSS
      DO WHILE (J1+1.LE.JES)
      S=0.0 ; L=0
      DO 20 I=I1,I1+2
      DO 20 J=J1,J1+2
      IF(HY(I,J).GT.0.0)THEN
      S=S+0.5*(ZY(I,J,1)+ZY(I,J,2))
      L=L+1 ; ENDIF
   20 CONTINUE
      IF(L.GE.5)THEN
      ZX(II,JJ,2)=S/L  ; ELSE
      ZX(II,JJ,2)=0.0  ; ENDIF
      JJ=JJ+1 ; J1=J1+3
      ENDDO   ; ENDIF
C
      KB=CHK/10
      IF(KB.EQ.1)THEN
      CHK=CHK-10
      II=ISL ; JJ=JEL ; I1=ISS ; J1=JES-2
      DO WHILE (I1+2.LE.IES)
      S=0.0 ; L=0
      DO 30 I=I1,I1+2
      DO 30 J=J1,J1+2
      IF(HY(I,J).GT.0.0)THEN
      S=S+0.5*(ZY(I,J,1)+ZY(I,J,2))
      L=L+1 ; ENDIF
   30 CONTINUE
      IF(L.GE.5)THEN
      ZX(II,JJ,2)=S/L  ; ELSE
      ZX(II,JJ,2)=0.0  ; ENDIF
      II=II+1 ; I1=I1+3
      ENDDO   ; ENDIF
C
      IF(CHK.EQ.1)THEN
      II=ISL ; JJ=JSL ; I1=ISS ; J1=JSS
      DO WHILE (J1+2.LE.JES)
      S=0.0 ; L=0
      DO 40 I=I1,I1+2
      DO 40 J=J1,J1+2
      IF(HY(I,J).GT.0.0)THEN
      S=S+0.5*(ZY(I,J,1)+ZY(I,J,2))
      L=L+1 ; ENDIF
   40 CONTINUE
      IF(L.GE.5)THEN
      ZX(II,JJ,2)=S/L  ; ELSE
      ZX(II,JJ,2)=0.0  ; ENDIF
      JJ=JJ+1 ; J1=J1+3
      ENDDO  ; ENDIF
      RETURN ; END
C
      SUBROUTINE J2Z (IX,JX,IY,JY,ZX,ZY,HY
     &,L0,BCHK,LP,LT)
C
      INTEGER BCHK,CHK
      DIMENSION ZX(IX,JX,2),ZY(IY,JY,2)
      DIMENSION HY(IY,JY),L0(4)
      IF(MOD(LP,LT).NE.0)RETURN
      ISS=2    ; JSS=2    ; IES=IY    ; JES=JY
      ISL=L0(1) ; JSL=L0(2) ; IEL=L0(3) ; JEL=L0(4)
      CHK=BCHK
      KB=CHK/1000
      IF(KB.EQ.1)THEN
      CHK=CHK-1000
      II=ISL ; JJ=JSL ; I1=ISS ; J1=JSS
      DO WHILE (I1+2.LE.IES)
      S=0.0 ; L=0
      DO 10 I=I1,I1+2
      DO 10 J=J1,J1+2
      IF(HY(I,J).GT.0.0)THEN
      S=S+ZY(I,J,2)
      L=L+1 ; ENDIF
   10 CONTINUE
      IF(L.GE.5)THEN
      ZX(II,JJ,2)=S/L  ; ELSE
      ZX(II,JJ,2)=0.0  ; ENDIF
      II=II+1 ; I1=I1+3
      ENDDO   ; ENDIF
C
      KB=CHK/100
      IF(KB.EQ.1)THEN
      CHK=CHK-100
      II=IEL ; JJ=JSL ; I1=IES-2 ; J1=JSS
      DO WHILE (J1+1.LE.JES)
      S=0.0 ; L=0
      DO 20 I=I1,I1+2
      DO 20 J=J1,J1+2
      IF(HY(I,J).GT.0.0)THEN
      S=S+ZY(I,J,2)
      L=L+1 ; ENDIF
   20 CONTINUE
      IF(L.GE.5)THEN
      ZX(II,JJ,2)=S/L  ; ELSE
      ZX(II,JJ,2)=0.0  ; ENDIF
      JJ=JJ+1 ; J1=J1+3
      ENDDO   ; ENDIF
C
      KB=CHK/10
      IF(KB.EQ.1)THEN
      CHK=CHK-10
      II=ISL ; JJ=JEL ; I1=ISS ; J1=JES-2
      DO WHILE (I1+2.LE.IES)
      S=0.0 ; L=0
      DO 30 I=I1,I1+2
      DO 30 J=J1,J1+2
      IF(HY(I,J).GT.0.0)THEN
      S=S+ZY(I,J,2)
      L=L+1 ; ENDIF
   30 CONTINUE
      IF(L.GE.5)THEN
      ZX(II,JJ,2)=S/L  ; ELSE
      ZX(II,JJ,2)=0.0  ; ENDIF
      II=II+1 ; I1=I1+3
      ENDDO   ; ENDIF
C
      IF(CHK.EQ.1)THEN
      II=ISL ; JJ=JSL ; I1=ISS ; J1=JSS
      DO WHILE (J1+2.LE.JES)
      S=0.0 ; L=0
      DO 40 I=I1,I1+2
      DO 40 J=J1,J1+2
      IF(HY(I,J).GT.0.0)THEN
      S=S+ZY(I,J,2)
      L=L+1 ; ENDIF
   40 CONTINUE
      IF(L.GE.5)THEN
      ZX(II,JJ,2)=S/L  ; ELSE
      ZX(II,JJ,2)=0.0  ; ENDIF
      JJ=JJ+1 ; J1=J1+3
      ENDDO  ; ENDIF
      RETURN ; END
C
      SUBROUTINE JNQOA
C
      REAL M,MA,N,NA
      PARAMETER (IO=1020,JO=738,IA=76,JA=76)
      PARAMETER (DO=10.0,DA=4.0)
      PARAMETER (ISS=2,JSS=2,IES=76,JES=76)
      PARAMETER (ISL=121,JSL=592,IEL=150,JEL=621)
      COMMON /XX/ Z(IO,JO,2),M(IO,JO,2),N(IO,JO,2)
      COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
      I=ISS ; J=JSS-1 ; II=ISL-1 ; JJ=JSL-1
      DO WHILE(I.LE.IES)
      SI=(I-ISS+1.75)*DA/DO
      IS=IFIX(SI) ; DI=SI-IS ; II=IS+ISL-1
      NA(I,J,2)=(1-DI)*N(II,JJ,2)+DI*N(II+1,JJ,2)
      I=I+1
      ENDDO
C
      I=IES ; J=JSS ; II=IEL ; JJ=JSL-1
      DO WHILE(J.LE.JES)
      SJ=(J-JSS+1.75)*DA/DO
      JS=IFIX(SJ) ; DJ=SJ-JS ; JJ=JS+JSL-1
      MA(I,J,2)=(1-DJ)*M(II,JJ,2)+DJ*M(II,JJ+1,2)
      J=J+1
      ENDDO
C
      I=ISS-1 ; J=JSS ; II=ISL-1 ; JJ=JSL-1
      DO WHILE(J.LE.JES)
      SJ=(J-JSS+1.75)*DA/DO
      JS=IFIX(SJ) ; DJ=SJ-JS ; JJ=JS+JSL-1
      MA(I,J,2)=(1-DJ)*M(II,JJ,2)+DJ*M(II,JJ+1,2)
      J=J+1
      ENDDO
      RETURN ; END
C
      SUBROUTINE JNQ (IX,JX,IY,JY,MX,NX,MY,NY
     &,HY,L0,BCHK,LP,LT)
C
      INTEGER BCHK,CHK
      REAL MX,NX,MY,NY
      DIMENSION MX(IX,JX,2),NX(IX,JX,2),HY(IY,JY)
      DIMENSION MY(IY,JY,2),NY(IY,JY,2),L0(4)
      IF(MOD(LP,LT).NE.0)RETURN
```

```
11730    ISS=2    ; JSS=2    ; IES=IY    ; JES=JY
11740    ISL=L0(1) ; JSL=L0(2) ; IEL=L0(3) ; JEL=L0(4)
11750    CHK=BCHK
11760    KB=CHK/1000
11770    IF(KB.EQ.1)THEN
11780    CHK=CHK-1000
11790    I=ISS ; J=JSS-1 ; II=ISL-1 ; JJ=JSL-1
11800    DO WHILE(I.LE.IES)
11810    SI=(I-ISS+2)/3.0
11820    IS=IFIX(SI) ; DI=SI-IS ; II=IS+ISL-1
11830    NY(I,J,2)=(1-DI)*NX(II,JJ,2)+DI*NX(II+1,JJ,2)
11840    IF(HY(I,J).LT.0.0)NY(I,J,2)=0.0
11850    I=I+1
11860    ENDDO ; ENDIF
11870C
11880    KB=CHK/100
11890    IF(KB.EQ.1)THEN
11900    CHK=CHK-100
11910    I=IES ; J=JSS ; II=IEL ; JJ=JSL-1
11920    DO WHILE(J.LE.JES)
11930    SJ=(J-JSS+2)/3.0
11940    JS=IFIX(SJ) ; DJ=SJ-JS ; JJ=JS+JSL-1
11950    MY(I,J,2)=(1-DJ)*MX(II,JJ,2)+DJ*MX(II,JJ+1,2)
11960    IF(HY(I,J).LT.0.0)MY(I,J,2)=0.0
11970    J=J+1
11980    ENDDO ; ENDIF
11990C
12000    KB=CHK/10
12010    IF(KB.EQ.1)THEN
12020    CHK=CHK-10
12030    I=ISS ; J=JES ; II=ISL-1 ; JJ=JEL
12040    DO WHILE(I.LE.IES)
12050    SI=(I-ISS+2)/3.0
12060    IS=IFIX(SI) ; DI=SI-IS ; II=IS+ISL-1
12070    NY(I,J,2)=(1-DI)*NX(II,JJ,2)+DI*NX(II+1,JJ,2)
12080    IF(HY(I,J).LT.0.0)NY(I,J,2)=0.0
12090    I=I+1
12100    ENDDO ; ENDIF
12110C
12120    IF(CHK.EQ.1)THEN
12130    I=ISS-1 ; J=JSS ; II=ISL-1 ; JJ=JSL-1
12140    DO WHILE(J.LE.JES)
12150    SJ=(J-JSS+2)/3.0
12160    JS=IFIX(SJ) ; DJ=SJ-JS ; JJ=JS+JSL-1
12170    MY(I,J,2)=(1-DJ)*MX(II,JJ,2)+DJ*MX(II,JJ+1,2)
12180    IF(HY(I,J).LT.0.0)MY(I,J,2)=0.0
12190    J=J+1
12200    ENDDO ; ENDIF
12210    RETURN ; END
12220C
12230    SUBROUTINE COUT (KK,KD)
12240C
12250    REAL M,N,MA,NA,MB,NB,MC,NC,ME,NE,MF,NF
12260    REAL MD1,ND1,MD2,ND2,MD3,ND3,MD4,ND4,MD5,ND5
12270    PARAMETER (IO=1020,JO=738,IA=76,JA=76)
12280    PARAMETER (IB=136,JB=136,IC=154,JC=307)
12290    PARAMETER (ID1=28,JD1=55,ID2=55,JD2=40)
12300    PARAMETER (ID3=37,JD3=31,ID4=13,JD4=40)
12310    PARAMETER (ID5=46,JD5=40)
12320    PARAMETER (IE1=34,JE1=67,IF1=46,JF1=58)
12330    COMMON /XX/ Z(IO,JO,2),M(IO,JO,2),N(IO,JO,2)
12340    COMMON /XA/ ZA(IA,JA,2),MA(IA,JA,2),NA(IA,JA,2)
12350    COMMON /HA/ HA(IA,JA)
12360    COMMON /XB/ ZB(IB,JB,2),MB(IB,JB,2),NB(IB,JB,2)
12370    COMMON /HB/ HB(IB,JB)
12380    COMMON /XC/ ZC(IC,JC,2),MC(IC,JC,2),NC(IC,JC,2)
12390    COMMON /HC/ HC(IC,JC)
12400    COMMON /XD1/ ZD1(ID1,JD1,2),MD1(ID1,JD1,2),
12410           &ND1(ID1,JD1,2),HD1(ID1,JD1)
12420    COMMON /XD2/ ZD2(ID2,JD2,2),MD2(ID2,JD2,2),
12430           &ND2(ID2,JD2,2),HD2(ID2,JD2)
12440    COMMON /XD3/ ZD3(ID3,JD3,2),MD3(ID3,JD3,2),
12450           &ND3(ID3,JD3,2),HD3(ID3,JD3)
12460    COMMON /XD4/ ZD4(ID4,JD4,2),MD4(ID4,JD4,2),
            &ND4(ID4,JD4,2),HD4(ID4,JD4)
      COMMON /XD5/ ZD5(ID5,JD5,2),MD5(ID5,JD5,2),
            &ND5(ID5,JD5,2),HD5(ID5,JD5)
      COMMON /XE/  ZE(IE1,JE1,2),ME(IE1,JE1,2),
            &NE(IE1,JE1,2),HE(IE1,JE1)
      COMMON /XF/  ZF(IF1,JF1,2),MF(IF1,JF1,2),
            &NF(IF1,JF1,2),HF(IF1,JF1)
      IF(KK.LT.180*26)RETURN
C      CALL OUTPUT1 (KK,KD)
      CALL OUTPUTQ (KK,KD)
      CALL OUTPUT3 (IA,JA,ZA,HA,KK,KD,1)
      CALL OUTPUT2 (IB,JB,ZB,HB,KK,KD,2)
      CALL OUTPUT2 (IC,JC,ZC,HC,KK,KD,3)
      CALL OUTPUT3 (ID1,JD1,ZD1,HD1,KK,KD,4)
      CALL OUTPUT3 (ID2,JD2,ZD2,HD2,KK,KD,5)
      CALL OUTPUT3 (ID3,JD3,ZD3,HD3,KK,KD,6)
      CALL OUTPUT3 (ID4,JD4,ZD4,HD4,KK,KD,7)
      CALL OUTPUT3 (ID5,JD5,ZD5,HD5,KK,KD,8)
      CALL OUTPUT3 (IE1,JE1,ZE,HE,KK,KD,9)
      CALL OUTPUT3 (IF1,JF1,ZF,HF,KK,KD,10)
      RETURN ; END
C
      SUBROUTINE OUTPUT1 (KK,KD)
C
      REAL M,N
      PARAMETER (IO=1020,JO=738)
      PARAMETER (GX=1.E-2)
      COMMON /XX/ Z(IO,JO,2),M(IO,JO,2),N(IO,JO,2)
      COMMON /HH/ H(IO,JO)
      DIMENSION KW(100),KM(23)
      DATA KM/1HJ,1HI,1HH,1HG,1HF,1HE,1HD,1HC,
     &       1HB,1HA,1H.,1H1,1H2,1H3,1H4,1H5,
     &       1H6,1H7,1H8,1H9,1H0,1H*,1H /
      IF(MOD(KK,KD).NE.0)RETURN
      WRITE(6,410)KK,(KI,KI=130,289,20)
      DO 30 KY=1,60
      KJ=60-KY+1
      J1=12*(KJ-1)+1
      J2=J1+11
      DO 40 KI=1,85
      I1=12*(KI-1)+1
      I2=I1+11
      L=0  ; S=0.
      DO 41 J=J1,J2
      DO 41 I=I1,I2
      IF(H(I,J).GT.0.)THEN
      L=L+1  ; S=S+Z(I,J,2)
      ENDIF
   41 CONTINUE
      IF(L.GE.60)THEN
      S=S/L
      KMM=11+INT(S/0.1)
      IF(KMM.GT.21)KMM=21
      IF(KMM.LT.1)KMM=1
      IF(ABS(S).LT.GX)KMM=23
      ELSE
      KMM=22
      ENDIF
      KW(KI)=KM(KMM)
   40 CONTINUE
      JK=2*KJ-60
      WRITE(6,400)JK,(KW(I),I=1,85)
   30 CONTINUE
      RETURN
  400 FORMAT(1H ,I3,2X,85A1)
  410 FORMAT(1H1,/,2X,"MAP AT K=",I5,//,6X,11I10)
      END
C
      SUBROUTINE OUTPUT2 (IF,JF,Z,H,KK,KD,CHR)
C
      INTEGER CHR
      PARAMETER (GX=1.E-2)
      DIMENSION Z(IF,JF,2),H(IF,JF)
      DIMENSION KW(100),KM(23)
      CHARACTER NAME(10)*10
      DATA KM/1HJ,1HI,1HH,1HG,1HF,1HE,1HD,1HC,
     &       1HB,1HA,1H.,1H1,1H2,1H3,1H4,1H5,
     &       1H6,1H7,1H8,1H9,1H0,1H*,1H /
      NAME(1)="A REGION"
      NAME(2)="B REGION"
      NAME(3)="C REGION"
      NAME(4)="D1 REGION"
      NAME(5)="D2 REGION"
      NAME(6)="D3 REGION"
      NAME(7)="D4 REGION"
      NAME(8)="D5 REGION"
      NAME(9)="E REGION"
      NAME(10)="F REGION"
      IF(MOD(KK,KD).NE.0)RETURN
      WRITE(6,450)NAME(CHR)
  450 FORMAT(1H ,/,10X,A10)
      IN=IF/20
      WRITE(6,410)KK,(KI,KI=20,IN*20,20)
      DO 10 J=JF,1,-2
      JS=J-1 ; JE=J ; IF(JS.LE.0)JS=1
      DO 20 I=1,IF/2
      IS=2*I-1 ; IE=IS+1 ; IF(IE.GE.IF)IE=IF
      S=0.0 ; L=0
      DO 30 II=IS,IE
      DO 30 JJ=JS,JE
      IF(H(II,JJ).GT.0.)THEN
      L=L+1
      S=S+Z(II,JJ,2)
      ENDIF
   30 CONTINUE
      IF(L.GE.2)THEN
      S=S/L
      KMM=11+INT(S/0.5)
      IF(KMM.GT.21)KMM=21
      IF(KMM.LT.1)KMM=1
      IF(ABS(S).LT.GX)KMM=23
      ELSE
      KMM=22
      ENDIF
      KW(I)=KM(KMM)
   20 CONTINUE
      II=IF/2
      WRITE(6,400)J,(KW(I),I=1,II)
   10 CONTINUE
      RETURN
  400 FORMAT(1H ,I3,2X,100A1)
  410 FORMAT(1H ,/,2X,"MAP AT K=",I5,//,6X,11I10)
      END
C
      SUBROUTINE OUTPUT3 (IF,JF,Z,H,KK,KD,CHR)
C
      INTEGER CHR
      PARAMETER (GX=1.E-2)
      DIMENSION Z(IF,JF,2),H(IF,JF)
      DIMENSION KW(100),KM(23)
      CHARACTER NAME(10)*10
      DATA KM/1HJ,1HI,1HH,1HG,1HF,1HE,1HD,1HC,
     &       1HB,1HA,1H.,1H1,1H2,1H3,1H4,1H5,
     &       1H6,1H7,1H8,1H9,1H0,1H*,1H /
      NAME(1)="A REGION"
      NAME(2)="B REGION"
      NAME(3)="C REGION"
      NAME(4)="D1 REGION"
      NAME(5)="D2 REGION"
      NAME(6)="D3 REGION"
      NAME(7)="D4 REGION"
      NAME(8)="D5 REGION"
      NAME(9)="E REGION"
      NAME(10)="F REGION"
      IF(MOD(KK,KD).NE.0)RETURN
      IN=IF/10 ; JN=JF/10
      WRITE(6,450)NAME(CHR)
  450 FORMAT(1H ,/,10X,A10)
```

```
      WRITE(6,410)KK,(KI,KI=10,100,10)
      DO 10 J=JF,1,-1
      IE=IF ; IF(IE.GE.100)IE=100
      DO 20 I=1,IE
      IF(H(I,J).GT.0.0)THEN
      KMM=11+INT(Z(I,J,2)/0.5)
      IF(KMM.GT.21)KMM=21
      IF(KMM.GT.21)KMM=21
      IF(KMM.LT.1)KMM=1
      IF(ABS(Z(I,J,2)).LT.GX)KMM=23
      ELSE
      KMM=22
      ENDIF
      KW(I)=KM(KMM)
   20 CONTINUE
      WRITE(6,400)J,(KW(I),I=1,IE)
   10 CONTINUE
      RETURN
  400 FORMAT(1H ,I3,2X,100A1)
  410 FORMAT(1H ,/,2X,"MAP AT K=",I5,//,6X,11I10)
      END
C
      SUBROUTINE OUTPUTQ (KK,KD)
C
      REAL M,N
      PARAMETER (GX=1.E-2)
      PARAMETER (IO=1020,JO=738)
      COMMON /XX/ Z(IO,JO,2),M(IO,JO,2),N(IO,JO,2)
      COMMON /HH/ H(IO,JO)
      DIMENSION KW(100),KM(23)
      DATA KM/1HJ,1HI,1HH,1HG,1HF,1HE,1HD,1HC,
     &        1HB,1HA,1H.,1H1,1H2,1H3,1H4,1H5,
     &        1H6,1H7,1H8,1H9,1H0,1H*,1H /
      IF(MOD(KK,KD).NE.0)RETURN
      IS=101 ; IE=200 ; JS=581 ; JE=630
      WRITE(6,410)KK,(KI,KI=100,200,10)
      DO 10 J=JE,JS,-1
      DO 20 I=1,100
      JJ=J ; II=I+100
      IF(H(II,JJ).GT.0.0)THEN
      KMM=11+INT(Z(II,JJ,2)/0.1)
      IF(KMM.GT.21)KMM=21
      IF(KMM.GT.21)KMM=21
      IF(KMM.LT.1)KMM=1
      IF(ABS(Z(II,JJ,2)).LT.GX)KMM=23
      ELSE
      KMM=22
      ENDIF
      KW(I)=KM(KMM)
   20 CONTINUE
      WRITE(6,400)J,(KW(I),I=1,100)
   10 CONTINUE
      RETURN
  400 FORMAT(1H ,I3,2X,100A1)
  410 FORMAT(1H ,///,2X,"MAP AT K=",I5,/,6X,11I10)
      END
C
      SUBROUTINE CHANGE
C
      REAL M,N
      PARAMETER (IO=1020,JO=738)
      COMMON /XX/ Z(IO,JO,2),M(IO,JO,2),N(IO,JO,2)
      DO 10 J=1,JO
      DO 10 I=1,IO
      Z(I,J,1)=Z(I,J,2)
      M(I,J,1)=M(I,J,2)
      N(I,J,1)=N(I,J,2)
   10 CONTINUE
      RETURN ; END
C
      SUBROUTINE CHANG (IF,JF,Z,M,N,LP,LT)
C
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
      IF(MOD(LP,LT).NE.0)RETURN
      DO 10 J=1,JF
      DO 10 I=1,IF
      Z(I,J,1)=Z(I,J,2)
      M(I,J,1)=M(I,J,2)
      N(I,J,1)=N(I,J,2)
   10 CONTINUE
      RETURN ; END
C
      SUBROUTINE FILEOT (IF,JF,Z,M,N)
C
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
C
      DO 10 J=1,JF
      WRITE(25,100)(Z(I,J,2),I=1,IF)
      WRITE(25,100)(M(I,J,2),I=1,IF)
      WRITE(25,100)(N(I,J,2),I=1,IF)
   10 CONTINUE
  100 FORMAT(10E12.5)
      RETURN
      END
C
      SUBROUTINE MAX (IF,JF,IS,JS,IE,JE,Z,H,ZM,ZN)
C
      DIMENSION Z(IF,JF,2),H(IF,JF),ZM(IF,JF),ZN(IF,JF)
      DO 10 I=IS,IE
      DO 10 J=JS,JE
      IF(H(I,J).LT.0.0)GOTO 10
      IF(ZM(I,J).LT.Z(I,J,2))ZM(I,J)=Z(I,J,2)
      IF(ZN(I,J).GT.Z(I,J,2))ZN(I,J)=Z(I,J,2)
   10 CONTINUE
      RETURN
      END
C
      SUBROUTINE POINT (IF,JF,Z,NG,PZ,IP,JP,KK,KC)
C
      DIMENSION Z(IF,JF,2),PZ(NG),IP(NG),JP(NG)
C
      IF(MOD(KK,KC).NE.0)RETURN
      DO 10 K=1,NG
      PZ(K)=Z(IP(K),JP(K),2)
   10 CONTINUE
      WRITE(24,100)(PZ(K),K=1,NG)
  100 FORMAT(10F7.3)
      RETURN
      END
C
      SUBROUTINE PROPA (IF,JF,IS,JS,IE,JE,Z,H,LF,KK)
C
      DIMENSION Z(IF,JF,2),H(IF,JF),LF(IF,JF)
C
      LK=KK/180+1
      DO 10 I=IS,IE
      DO 10 J=JS,JE
      IF(H(I,J).GT.0.0)THEN
      IF(LF(I,J).EQ.0)THEN
      IF(ABS(Z(I,J,2)).GT.0.01)LF(I,J)=LK
      ENDIF
      ELSE
      LF(I,J)=-9
      ENDIF
   10 CONTINUE
      RETURN
      END
C
      SUBROUTINE OUTDT (IF,JF,ZM,ZN,LK)
      DIMENSION ZM(IF,JF),ZN(IF,JF),LK(IF,JF)
      DO 20 I=1,IF
      DO 20 J=1,JF
      ZN(I,J)=ZM(I,J)-ZN(I,J)
      IF(ZN(I,J).GT.100.0)ZN(I,J)=100.0
      IF(ZM(I,J).GT.100.0)ZM(I,J)=100.0
   20 CONTINUE
```

```
      DO 10 J=1,JF
      WRITE(31,100)(ZM(I,J),I=1,IF)
      WRITE(32,100)(ZN(I,J),I=1,IF)
      WRITE(33,200)(LK(I,J),I=1,IF)
   10 CONTINUE
  100 FORMAT(20F6.3)
  200 FORMAT(40I3)
      RETURN
      END
C
      SUBROUTINE DEFORM (IO,JO,IS,JS,IE,JE,Z)
      REAL L
      PARAMETER (DR=10.0)
      PARAMETER (A=3.141592,B=4.848E-06)
      PARAMETER (RR=6.37E+6,E=1.7453E-2)
      PARAMETER (HH=53.0E+3,D=24.0,DL=10.0,TH=10.0,RD=90.0)
      PARAMETER (L=800.0E+3,W=200.0E+3)
      PARAMETER (YO=-50.0,XO=280.0)
      PARAMETER (Y0=-46.0,X0=284.0)
      DIMENSION Z(IO,JO,2)
      XL=A*RR*(X0-XO)*COS(E*YO)/180.0 ; YL=A*RR*(Y0-YO)/180.0
      H1=HH/SIN(E*DL)  ; H2=HH/SIN(E*DL)+W
      DS=D*COS(E*RD)   ; DD=D*SIN(E*RD)
      WRITE(6,*)XL,YL,H1,H2,DS,DD
      DO 10 I=1,IE-IS+1
      DO 10 J=1,JE-JS+1
C       XX=DX*(I-1) ; YY=DX*(J-1)
      YY=A*RR*DR*(J-1)/(60.0*180)
      XX=A*RR*DR*(I-1)*COS(E*(YO+DR*(J-1)/60.0))/(60.0*180)
      X1=(XX-XL)*SIN(E*TH)+(YY-YL)*COS(E*TH)-L/2.0
      X2=(XX-XL)*COS(E*TH)-(YY-YL)*SIN(E*TH)+HH/TAN(E*DL)
      X3=0.0
      CALL USCAL (X1,X2,X3, L/2.,H2,E*DL,F1)
      CALL USCAL (X1,X2,X3, L/2.,H1,E*DL,F2)
      CALL USCAL (X1,X2,X3,-L/2.,H2,E*DL,F3)
      CALL USCAL (X1,X2,X3,-L/2.,H1,E*DL,F4)
      CALL UDCAL (X1,X2,X3, L/2.,H2,E*DL,G1)
      CALL UDCAL (X1,X2,X3, L/2.,H1,E*DL,G2)
      CALL UDCAL (X1,X2,X3,-L/2.,H2,E*DL,G3)
      CALL UDCAL (X1,X2,X3,-L/2.,H1,E*DL,G4)
      US=(F1-F2-F3+F4)*DS/(12.0*A)
      UD=(G1-G2-G3+G4)*DD/(12.0*A)
      II=I+IS-1  ; JJ=J+JS-1
      Z(II,JJ,1)=US+UD
      Z(II,JJ,2)=US+UD
   10 CONTINUE
      RETURN
      END
C
      SUBROUTINE USCAL (X1,X2,X3,C,CC,DP,F)
      REAL K
C
      SN=SIN(DP)   ; CS=COS(DP)
      C1=C ; C2=CC*CS ; C3=CC*SN
      R=SQRT((X1-C1)**2+(X2-C2)**2+(X3-C3)**2)
      Q=SQRT((X1-C1)**2+(X2-C2)**2+(X3+C3)**2)
      R2=X2*SN-X3*CS
      R3=X2*CS+X3*SN
      Q2=X2*SN+X3*CS
      Q3=-X2*CS+X3*SN
      H=SQRT(Q2**2+(Q3+CC)**2)
      K=SQRT((X1-C1)**2+Q2**2)
      A1=LOG(R+R3-CC)
      A2=LOG(Q+Q3+CC)
      A3=LOG(Q+X3+C3)
      B1=1+3.0*(TAN(DP))**2
      B2=3.0*TAN(DP)/CS
      B3=2.0*R2*SN
      B4=Q2+X2*SN
      B5=2.0*R2**2*CS
      B6=R*(R+R3-CC)
      B7=4.0*Q2*X3*SN**2
      B8=2.0*(Q2+X2*SN)*(X3+Q3*SN)
      B9=Q*(Q+Q3+CC)
      B10=4.0*Q2*X3*SN
      B11=(X3+C3)-Q3*SN
      B12=4.0*Q2**2*Q3*X3*CS*SN
      B13=2.0*Q+Q3+CC
      B14=Q**3*(Q+Q3+CC)**2
      F=CS*(A1+B1*A2-B2*A3)
     &+B3/R+2*SN*B4/Q-B5/B6+(B7-B8)/B9+B10*B11/Q**3-B12*B13/B14
      RETURN
      END
C
      SUBROUTINE UDCAL (X1,X2,X3,C,CC,DP,F)
      REAL K
C
      SN=SIN(DP)  ; CS=COS(DP)
      C1=C ; C2=CC*CS ; C3=CC*SN
      R=SQRT((X1-C1)**2+(X2-C2)**2+(X3-C3)**2)
      Q=SQRT((X1-C1)**2+(X2-C2)**2+(X3+C3)**2)
      R2=X2*SN-X3*CS
      R3=X2*CS+X3*SN
      Q2=X2*SN+X3*CS
      Q3=-X2*CS+X3*SN
      H=SQRT(Q2**2+(Q3+CC)**2)
      K=SQRT((X1-C1)**2+Q2**2)
      A1=LOG(R+X1-C1)
      A2=LOG(Q+X1-C1)
      B1=Q*(Q+X1-C1)
      B2=R*(R+X1-C1)
      B3=Q*(Q+Q3+CC)
      D1=X1-C1  ; D2=X2-C2  ; D3=X3-C3
      D4=X3+C3  ; D5=R3-CC  ; D6=Q3+CC
      T1=ATN(D1*D2,(H+D4)*(Q+H))
      T2=ATN(D1*D5,R2*R)
      T3=ATN(D1*D6,Q2*Q)
      F=SN*(D2*(2*D3/B2+4*D3/B1-4*C3*X3*D4*(2*Q+D1)/(B1**2*Q))
        &  -6*T1+3*T2-6*T3)
     &+CS*(A1-A2-2*(D3**2)/B2
     &-4*(D4**2-C3*X3)/B1-4*C3*X3*D4**2*(2*Q+X1-C1)/(B1**2*Q))
     &+6*X3*(CS*SN*(2*D6/B1+D1/B3)-Q2*(SN**2-CS**2)/B1)
      RETURN
      END
C
      REAL FUNCTION ATN (AX,AY)
      DATA GX/1.0E-6/
      AAX=ABS(AX) ; AAY=ABS(AY)
      P=AX*AY
      IF(AAX.LE.GX.AND.AAY.LE.GX)GOTO 10
      SR=ATAN2(AAX,AAY)
      ATN=SIGN(SR,P)
      RETURN
   10 WRITE(6,100)AX,AY
  100 FORMAT(1H ,"ATAN --    AX=",E15.7,2X,"AY=",E15.7)
      ATN=0.2
      RETURN
      END
```