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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

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PART 3 PROGRAMME LISTS FOR NEAR-FIELD TSUNAMI

PART 4 PROGRAMME LIST FOR FAR-FIELD TSUNAMI

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PART 1: SHALLOW WATER THEORY AND ITS DIFFERENCE SCHEME

CHAPTER 1: METHOD OF NUMERICAL SIMULATION

CHAPTER 2: TYPICAL PROGRAMMES

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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.

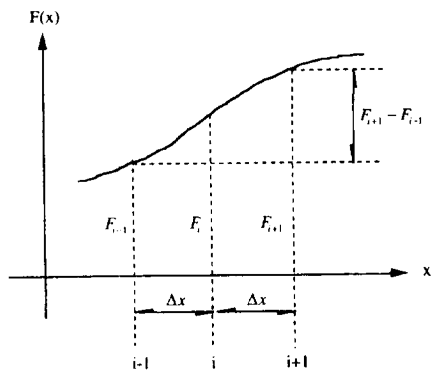


Figure 1-1. Central difference

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

The Taylor series expressions for $_{\text{IF-1}}$ and $_{\text{IF+1}}$ are

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

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

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

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

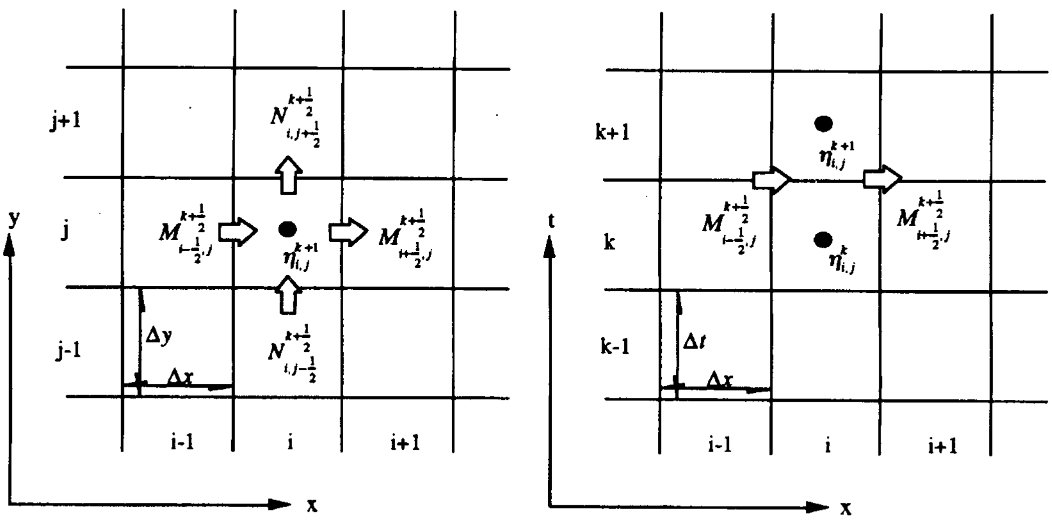


Figure 1-2. Arrangement of points for computation in the leap-frog method.

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

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

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.

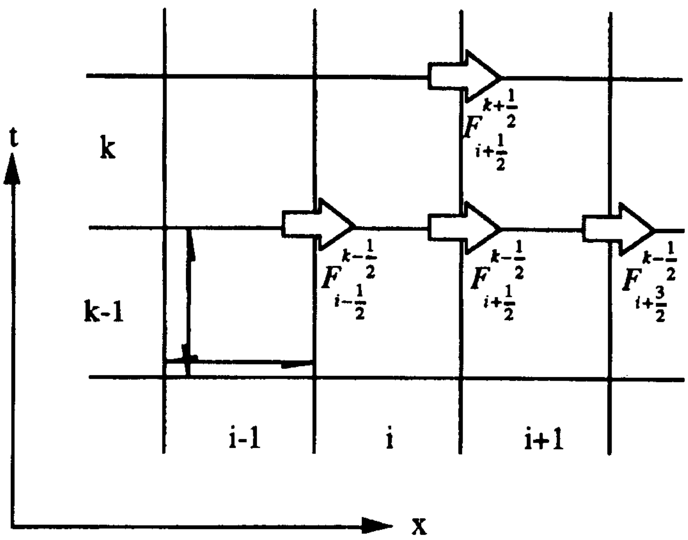


Figure 1-3. Arrangement of points for convection terms.

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

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

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

and with the backward difference

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

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.

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

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

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

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

where

$$M^{k-\frac{1}{2}}_{i+\frac{1}{2},j}\ \ge 0,\quad \lambda_{11}=0,\quad \lambda_{21}=1,\quad \lambda_{31}=-1$$
$$< 0,\quad \lambda_{11}=1,\quad \lambda_{21}=-1,\quad \lambda_{31}=0$$

$$N^{k-\frac{1}{2}}_{i+\frac{1}{2},j}\ \ge 0,\quad \nu_{11}=0,\quad \nu_{21}=1,\quad \nu_{31}=-1$$
$$< 0,\quad \nu_{11}=1,\quad \nu_{21}=-1,\quad \nu_{31}=0$$

$$M^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}\ \ge 0,\quad \lambda_{12}=0,\quad \lambda_{22}=1,\quad \lambda_{32}=-1$$
$$< 0,\quad \lambda_{12}=1,\quad \lambda_{22}=-1,\quad \lambda_{32}=0$$

$$N^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}\ \ge 0,\quad \nu_{12}=0,\quad \nu_{22}=1,\quad \nu_{32}=-1$$
$$< 0,\quad \nu_{12}=1,\quad \nu_{22}=-1,\quad \nu_{32}=0$$

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.,

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

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

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

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

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

$$\left\{\nu_{11}\frac{M^{k-\frac{1}{2}}_{i+\frac{1}{2},j+1}N^{k-\frac{1}{2}}_{i+\frac{1}{2},j+1}}{D^{k-\frac{1}{2}}_{i+\frac{1}{2},j+1}}+\nu_{21}\frac{M^{k-\frac{1}{2}}_{i+\frac{1}{2},j}N^{k-\frac{1}{2}}_{i+\frac{1}{2},j}}{D^{k-\frac{1}{2}}_{i+\frac{1}{2},j}}+\nu_{31}\frac{M^{k-\frac{1}{2}}_{i+\frac{1}{2},j-1}N^{k-\frac{1}{2}}_{i+\frac{1}{2},j-1}}{D^{k-\frac{1}{2}}_{i+\frac{1}{2},j-1}}\right\}-gD^{k}_{i+\frac{1}{2},j}\frac{\Delta t}{\Delta x}\left\{\eta^{k}_{i+1}\right.$$

$$\frac{1}{{}^{y}\mu^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}}\left[\left(1-{}^{y}\mu^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}\right)N^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}-\frac{\Delta t}{\Delta x}\left\{\lambda_{12}\frac{M^{k-\frac{1}{2}}_{i+1,j+\frac{1}{2}}N^{k-\frac{1}{2}}_{i+1,j+\frac{1}{2}}}{D^{k-\frac{1}{2}}_{i+1,j+\frac{1}{2}}}+\lambda_{22}\frac{M^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}N^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}}{D^{k-\frac{1}{2}}_{i,j+\frac{1}{2}}}+\lambda_{32}\frac{M^{k}_{i}}{}\right.\right.$$

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

where

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

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

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

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

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

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

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

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

and Eq.(37) is reduced to

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

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

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

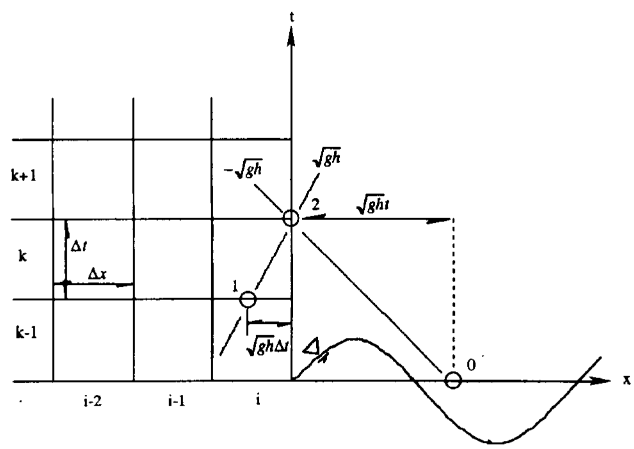


Figure 4. An offshore open boundary and characteristics when a simple harmonic wave train is propagating in the negative x direction.

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

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

where M_1 and η_1 are calculated by

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

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

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

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

This yields

$$u_2=u_1 \qquad or \qquad M^{k+\frac{1}{2}}_{i+\frac{1}{2},j}=M_1$$

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

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

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

where h_1 and h_2 are the water depths in front of and behind structure measured above the top of structure, and coefficients $\mu=0.35$ and $\mu'=2.6\mu$

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.

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

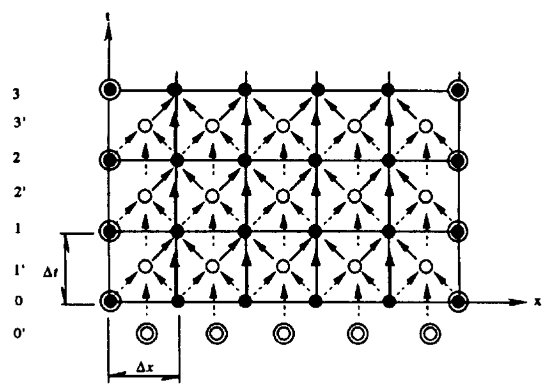
where Δt and Δx are the temporal and spatial grid lengths, and h_{max} is the maximum still water depth in a computation region. Approaching the shore, h_{max} becomes smaller, then a smaller Δx is selected to satisfy the CFL condition on keeping Δt constant. This is an ordinary way of how to select 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.



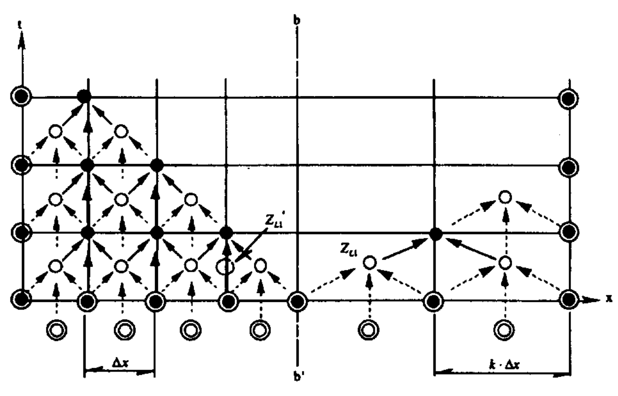


Figure 1-5. Computation procedure in the x-t plane, (A) if the spatial grid length is constant in the whole region, and (B) if two regions of different grid length are connected at the boundary b-b'.

(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.

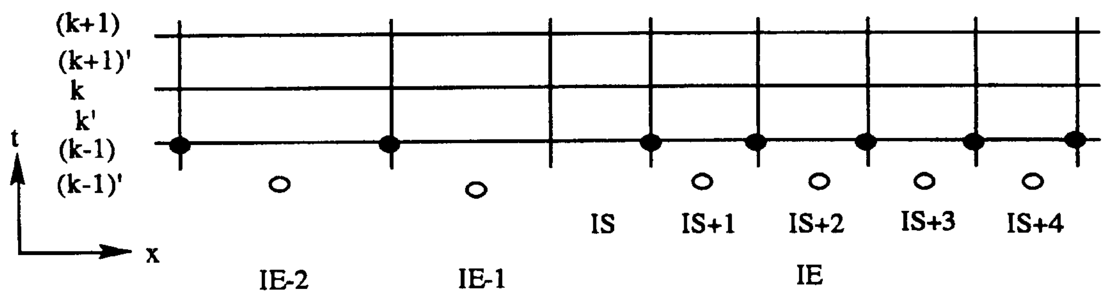


Figure 1-6(a). Details of computation continuation in the x-t plane in case of k = 3 and Δt =const. Open (filled) circles are points where the water level (discharge) is computed.

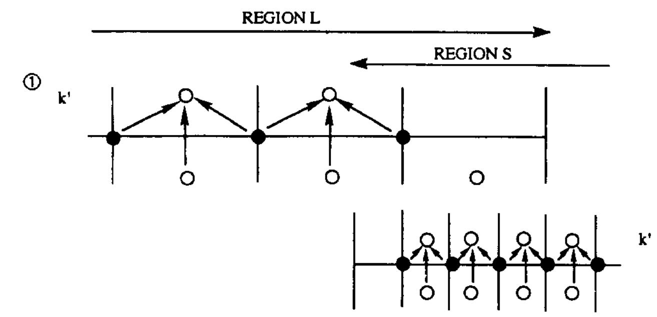


Figure 1-6(b). With the equation of continuity, $Z_S(I,K')$ and $Z_L(I',K')$ are computed. Suffixes $_S$ and $_L$ denote values in the region S of Δx and in the region L of $3\Delta x$

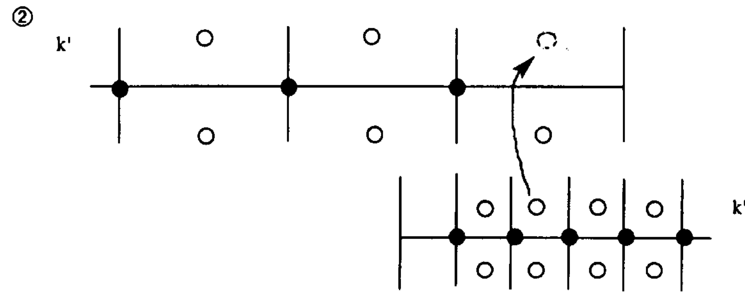


Figure 1-6(c). The water level $Z_L(IE,K')$ is set equal to $Z_S(IS+'',K')$

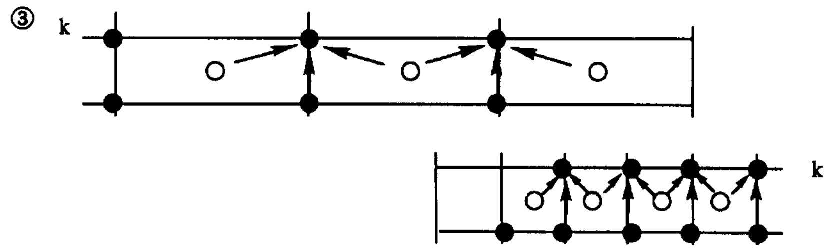


Figure 1-6(d). With the equation of motion, $M_S(I,K)$ and $M_L(I',K)$ are computed.

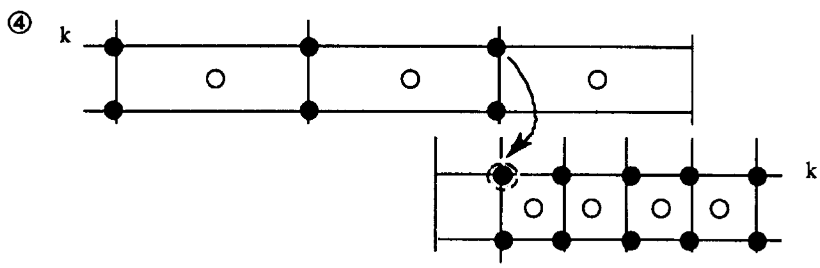


Figure 1-6(e). The water discharge $M_S(IS,K)$ is set to $M_L(IE-1,K)$

(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.

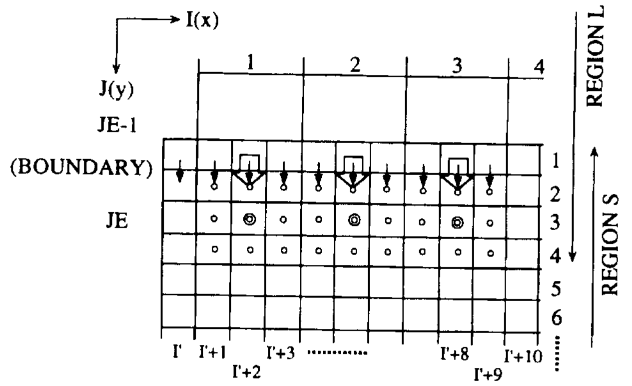


Figure 1-7. Continuation between two regions S and L in the (x,y-t) space, where k = 3 and Δt = const.

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.

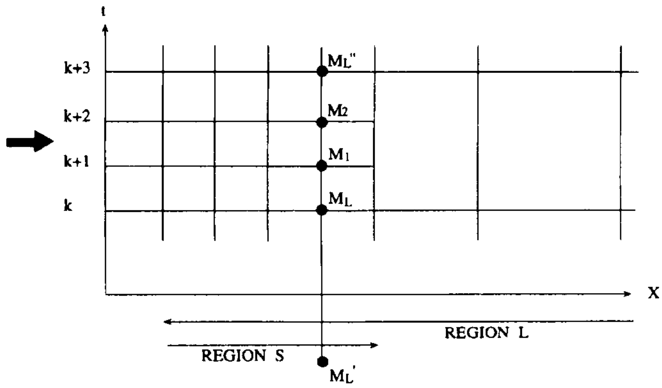


Figure 1-8. Computation continuation between two regions S and L in the x-t plane when Δt varies at the ration of 1:3.

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.

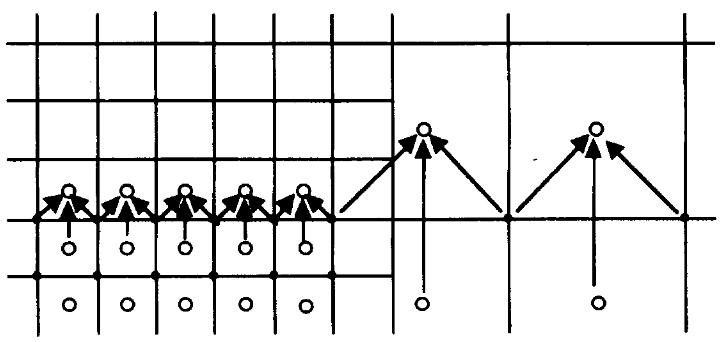


Figure 1-9(a). Details of computation continuation in the x-t plane, when Δt varies at the ratio of 1:3. Computation of the water level Z in the regions S and L, with the equation of continuity.

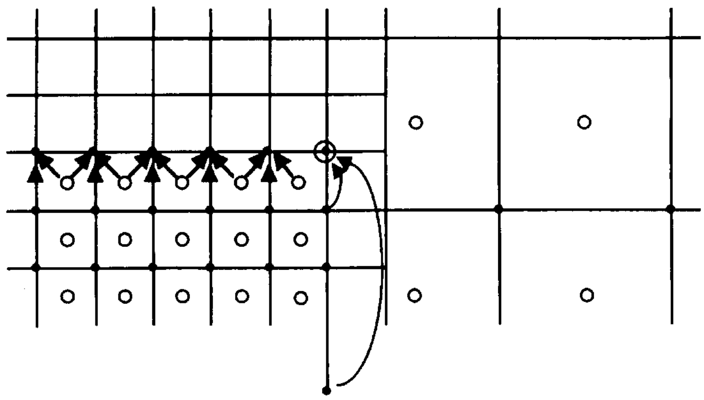


Figure 1-9(b). Computation of the water discharge M in the region S, with the equation of motion. An extrapolation in the region L to determine value of M at the boundary. Connection of the water discharge from the region L to the region S.

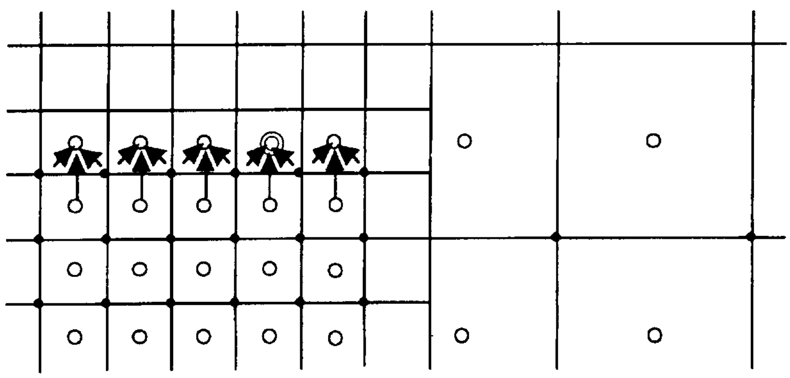


Figure 1-9(c). Computation of the water level Z in the region S, with the equation of continuity. Connection of the water level from the region S to the region L.

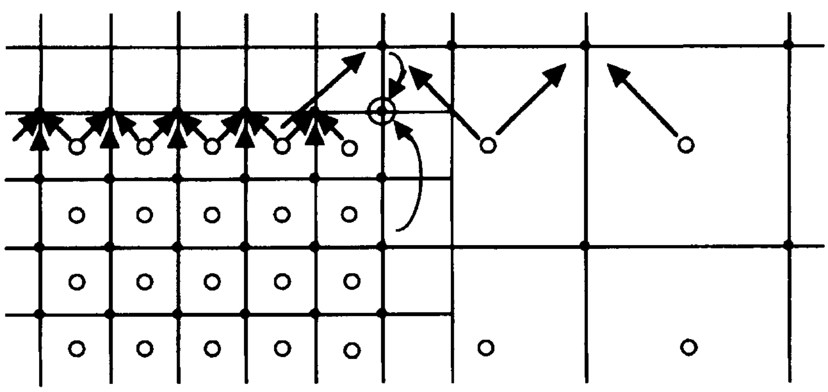


Figure 1-9(d). Computation of the water discharge M in the region S and L, with the equation of motion. An interpolation in the region L to determine values of M at the boundary. Connection of the water discharge from the region L to the region S.

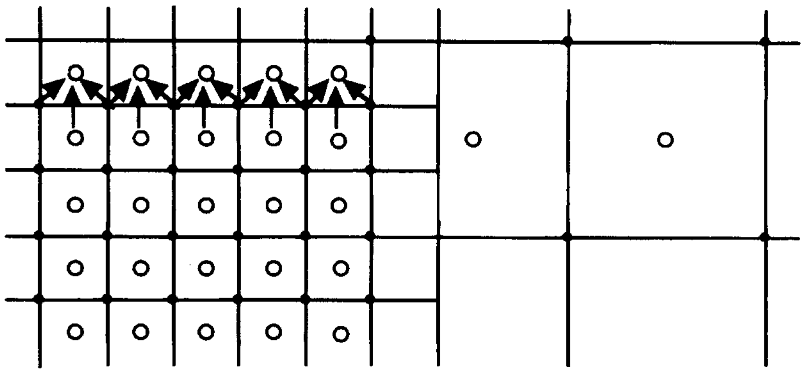


Figure 1-9(e). Computation of the water level Z in the region S, with the equation of continuity

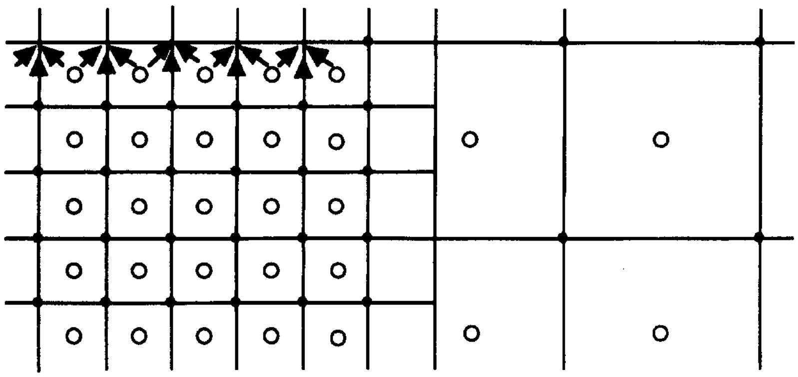


Figure 1-9(f). Computation of the water discharge M in the region S, with the equation of motion.

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.

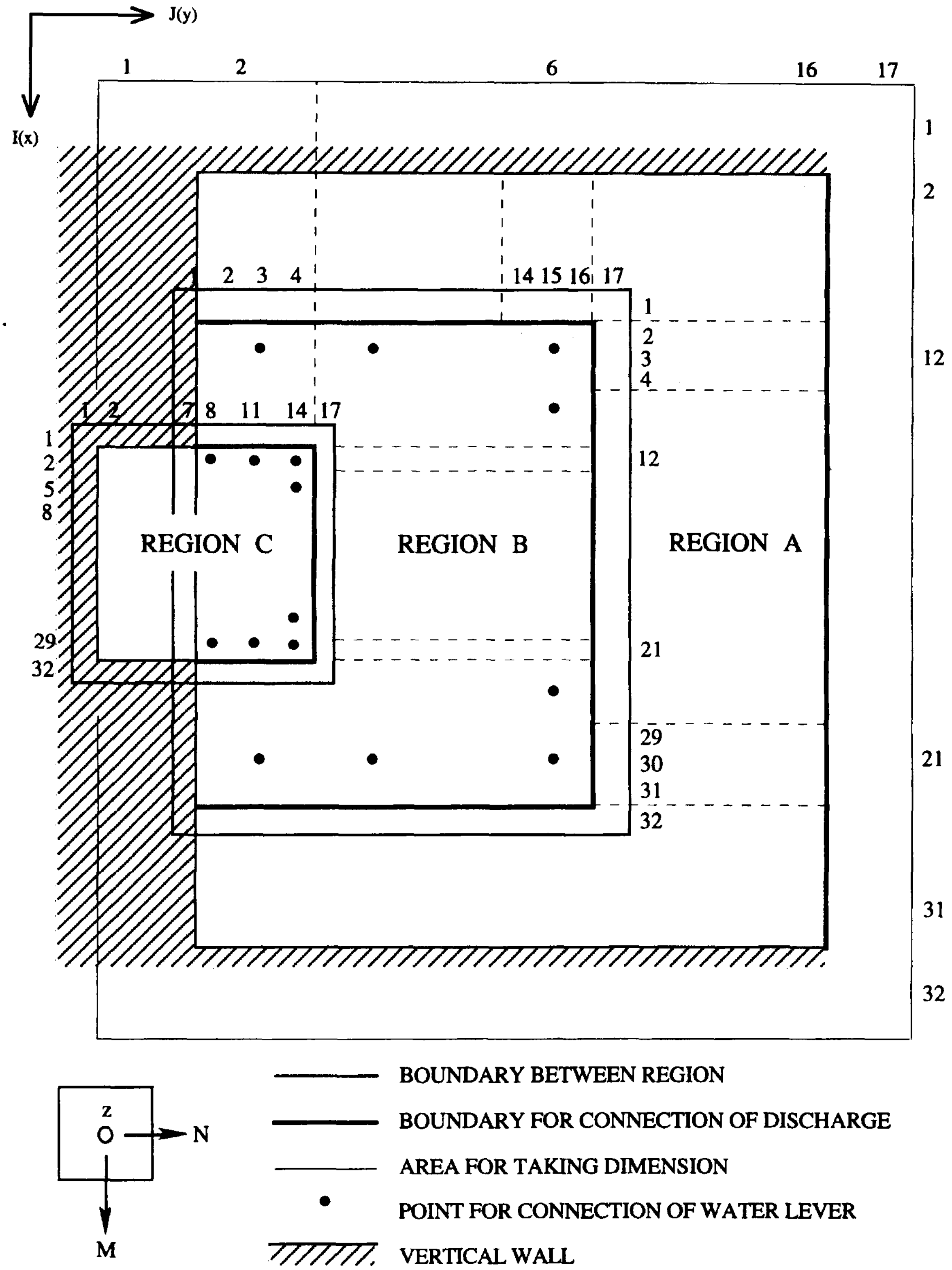


Figure 2-1: A model basin for explanation of the programme

(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.

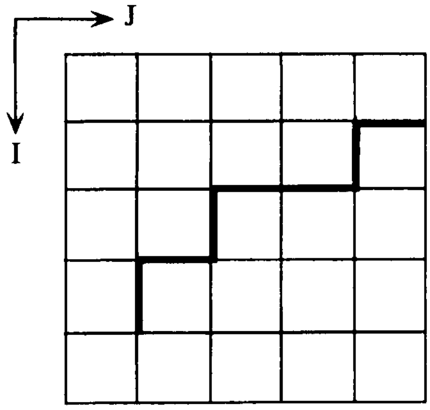
IB(I,J) = 40, for $12 \leq I \leq 20$ and $1 \leq J \leq 5$, the computation in the domain A is not necessary because it is carried out in the domain B.

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) <u>CALL DEPTH</u>

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) <u>CALL SETZRO</u>

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) <u>CALL CONTIN</u>

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) <u>CALL JOINTZ</u>

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) <u>CALL MOTION</u>

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) <u>CALL BOUND</u>

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

(v) <u>CALL JOINTQ</u>

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 i n 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

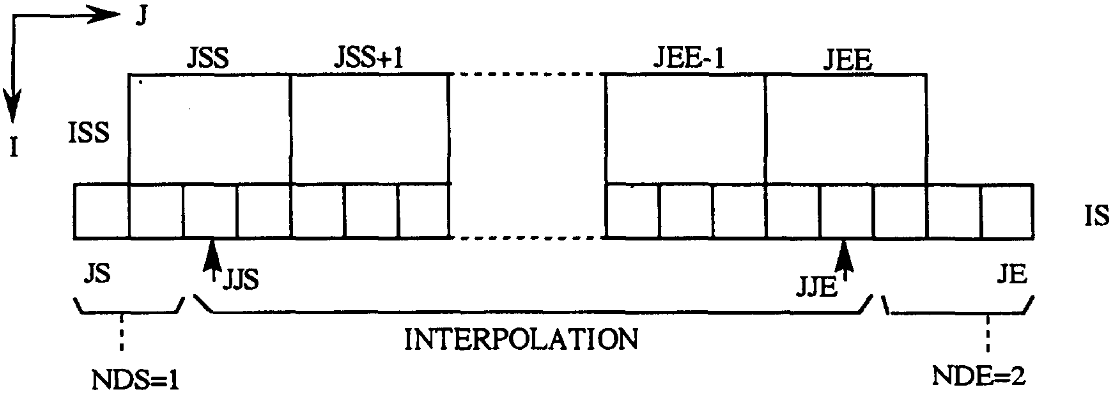
Connection of the water level between computation domains of different Δx and Δt.

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

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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).

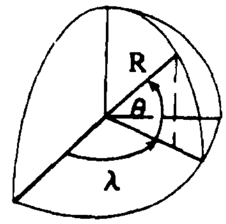


Figure 1. Spherical Co-ordinates

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

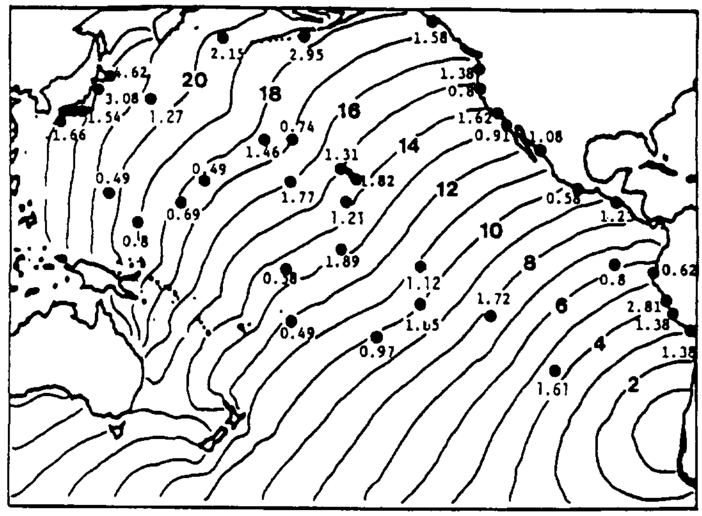


Figure 2. Area for Computation, and Propagation of the Chilean tsunami

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.

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

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

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

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

$$\frac{\eta^{n+\frac{1}{2}}_{j,m}-\eta^{n-\frac{1}{2}}_{j,m}}{\Delta t}+\frac{1}{R\cos\theta_m}\left[\frac{M^{n}_{j+\frac{1}{2},m}-M^{n}_{j-\frac{1}{2},m}}{\Delta\lambda}+\frac{N^{n}_{j,m+\frac{1}{2}}\cos\theta_{m+\frac{1}{2}}-N^{n}_{j,m-\frac{1}{2}}\cos\theta_{m-\frac{1}{2}}}{\Delta\theta}\right]=0 \qquad (4)$$

$$\frac{M^{n+1}_{j+\frac{1}{2},m}-M^{n}_{j+\frac{1}{2},m}}{\Delta t}+\frac{gh_{j+\frac{1}{2},m}}{R\cos\theta_m}\frac{\eta^{n+\frac{1}{2}}_{j+1,m}-\eta^{n+\frac{1}{2}}_{j,m}}{\Delta\lambda}=fN' \qquad (5)$$

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

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.

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

$$M^{n+1}_{j+\frac{1}{2},m} = M^{n}_{j+\frac{1}{2},m} - R_2 \cdot h_{j+\frac{1}{2},m}\left[\eta^{n+\frac{1}{2}}_{j+1,m} - \eta^{n+\frac{1}{2}}_{j,m}\right] + R_3 N' \qquad (9)$$

$$N^{n+1}_{j,m+\frac{1}{2}} = M^{n}_{j,m+\frac{1}{2}} - R_4 \cdot h_{j,m+\frac{1}{2}}\left[\eta^{n+\frac{1}{2}}_{j+1,m} - \eta^{n+\frac{1}{2}}_{j,m}\right] + R_5 M' \qquad (10)$$

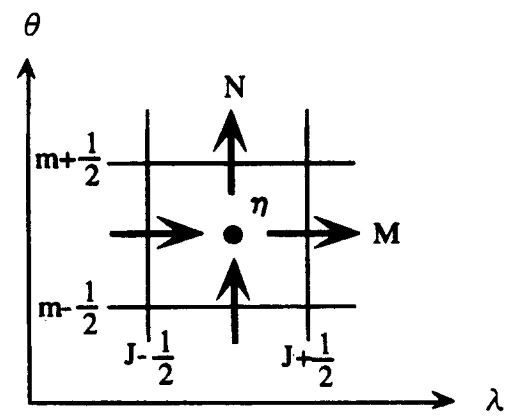


Figure 3. Computation Points for Water Level and Discharge

where R'_ns a re given as follows.

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

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

$$R_3 = 2\Delta t\bar{\omega}\sin\theta_m$$

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

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

A point of computation is numbered as (j, m, n) in the (θ, λ, t) directions. The grid lengths are ($\Delta\theta$, $\Delta\lambda$, Δt) 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.

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

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,

$$\eta = +\sqrt{h/g}\cdot \qquad \textit{for advancing waves}$$

$$= -\sqrt{h/g}\cdot u \qquad \textit{for receding waves} \qquad (13)$$

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 $\eta << h$.

$$\eta = +Q/\sqrt{gh} \qquad \textit{for advancing waves}$$

$$= -Q/\sqrt{gh} \qquad \textit{for receding waves} \qquad (14)$$

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

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

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

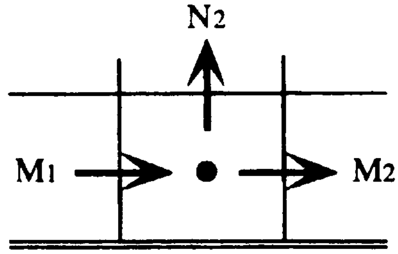


Figure 4. Distinction of Advancing and Receding Waves by the sign of N_2

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.

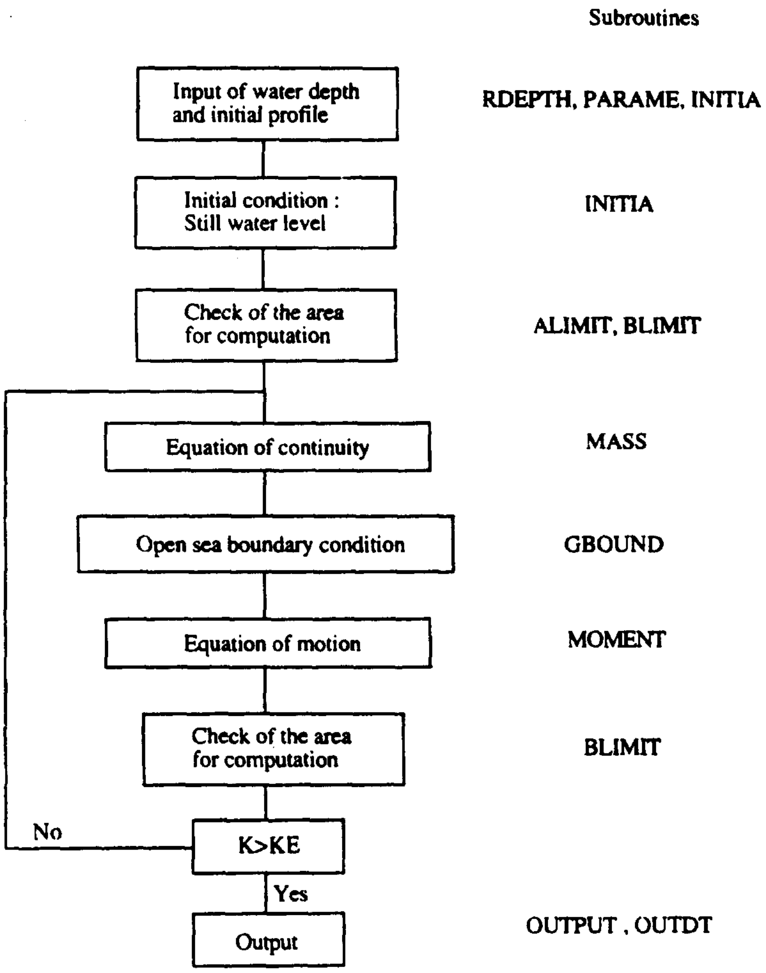


Figure 5. Flow Chart of the Computation

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.

$\bar{Y}0$, $\bar{X}0$: 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.

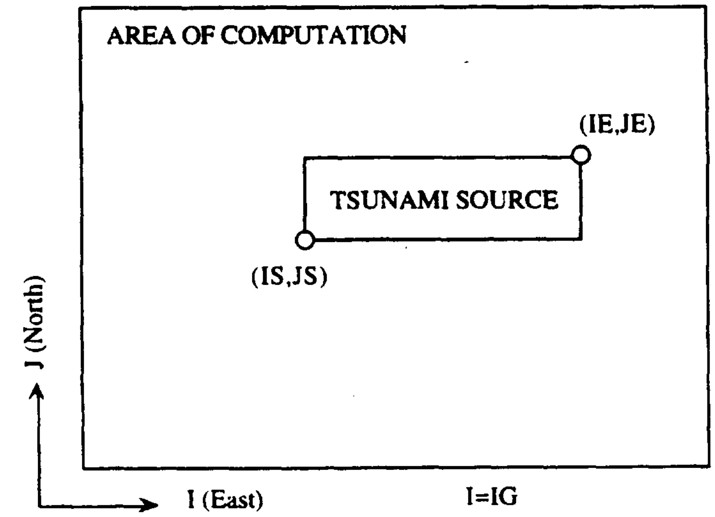


Figure 6. Co-ordinates in the Areas for Computation of Tsunami and Initial Profile

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.

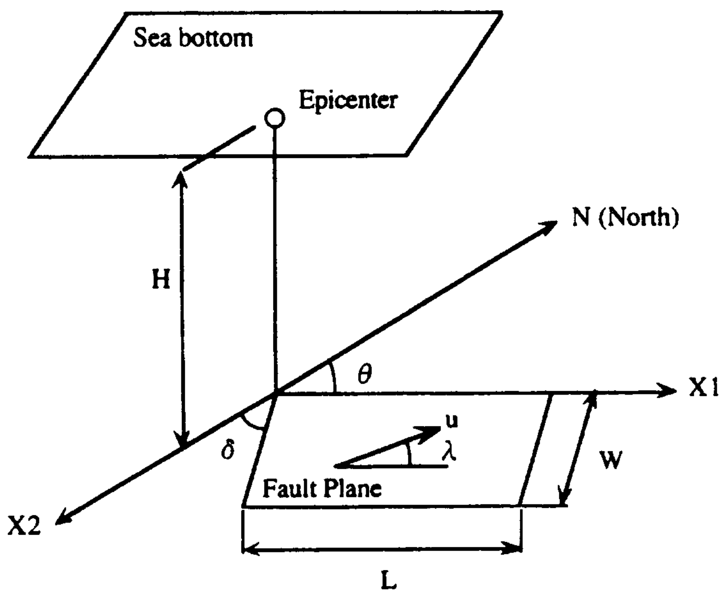


Figure 7. Fault Parameter

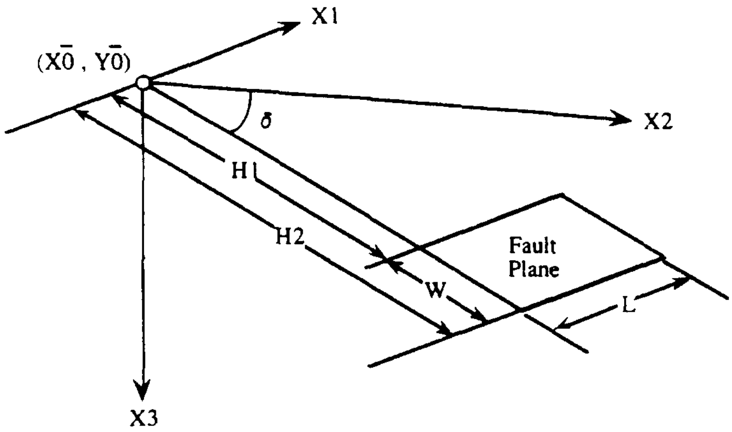


Figure 8 Plan of Fault Plane

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

```
      SUBROUTINE BLIMIT (IG,JG,IS,JS,IE,JE,Z)
C
      PARAMETER (GX=1.E-4)
      DIMENSION Z(IG,JG)
C
      IF(IS.EQ.2)GOTO 61
      L=0
      DO 10 J=JS,JE
      IF(ABS(Z(IS+2,J)).GT.GX)L=1
   10 CONTINUE
      IF(L.EQ.1)THEN
      IS=IS-1
      IF(IS.LE.2)IS=2
      ENDIF
   61 IF(IE.EQ.IG-1)GOTO 62
      L=0
      DO 20 J=JS,JE
      IF(ABS(Z(IE-2,J)).GT.GX)L=1
   20 CONTINUE
      IF(L.EQ.1)THEN
      IE=IE+1
      IF(IE.GE.IG-1)IE=IG-1
      ENDIF
   62 IF(JS.EQ.2)GOTO 63
      L=0
      DO 30 I=IS,IE
      IF(ABS(Z(I,JS+2)).GT.GX)L=1
   30 CONTINUE
      IF(L.EQ.1)THEN
      JS=JS-1
      IF(JS.LE.2)JS=2
      ENDIF
   63 IF(JE.EQ.JG-1)GOTO 64
      L=0
      DO 40 I=IS,IE
      IF(ABS(Z(I,JE-2)).GT.GX)L=1
   40 CONTINUE
      IF(L.EQ.1)THEN
      JE=JE+1
      IF(JE.GE.JG-1)JE=JG-1
      ENDIF
   64 RETURN
      END
C
```

Setting of the area for computation

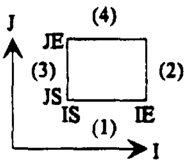
(Enlarge the area if water level is higher than GX(1.0E-4).)

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
```

Setting of the initial condition

```
      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
```

Still water level is assumed.

```
C
      CALL DEFORM (IG,JG,IS,JS,IE,JE,Z)
```

Input of the initial profile.

```
C
      DO 30 J=JS,JE
      DO 30 I=IS,IE
      IF(H(I,J).LT.0.)Z(I,J)=0.
   30 CONTINUE
```

Water level is set zero on land.

```
      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
```

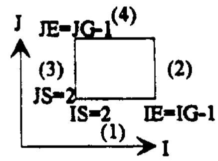
The area for computation is limited within the area of concern.

(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
      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 (1).

```
      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 (2).

```
      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 (3).

```
      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
```

Setting on the line (4).

```
      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
```

Computation of the equation of motion.

```
C
      SUBROUTINE MOMENT (IG,JG,IS,JS,IE,JE,
     &                   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
```

Computation of M.

```
      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)
      M(I,J)=M(I,J)-R2(I,J)*V1(I)+R3(I,J)*V2(I)
   10 CONTINUE
```

Computation of M along the boundary line.

```
      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
   16 M(I,JG)=M(I,JG)-R2(I,JG)*(Z(I+1,JG)-Z(I,JG))
      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
```

Computation of N.

```
      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)
      N(I,J)=N(I,J)-R4(I,J)*V1(I)-R5(I,J)*V2(I)
   20 CONTINUE
```

Computation of N along the boundary line.

```
      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
   26 N(IG,J)=N(IG,J)-R4(IG,J)*(Z(IG,J+1)-Z(IG,J))
      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. (SUBROUTINE OUTPUT)

Output of the spatial distribution of water level in the area for computation. (IF(MOD(KK,180)... to ENDIF)

Computation of the mean water level in each area of 2' x 2'. (DO 30 KY=1,100 to 40 CONTINUE)

Output of the mean water level on the display. (WRITE(6,400)... to WRITE(6,100)...)

```
      SUBROUTINE FILEOT (IG,JG,Z,M,N)
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
```

Output of the water level and discharge.

```
      SUBROUTINE MAX (IG,JG,IS,JS,IE,JE,Z,H,ZM,ZN)
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
```

Computation of the highest and lowest water levels.

```
      SUBROUTINE POINT (IG,JG,Z,KK,KC)
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
```

Output of the time histroy of water level.

```
      SUBROUTINE PROPA (IG,JG,IS,JS,IE,JE,Z,H,LF,KK)
      DIMENSION Z(IG,JG),H(IG,JG),LF(IG,JG)
      LK=KK/60+1
      GX=0.002
      IF(LK.LE.3)GX=0.02
      IF(LK.GT.3.AND.LK.LE.6)GX=0.005
      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)).GT.GX)LF(I,J)=LK
      ENDIF
      ELSE
      LF(I,J)=-9
      ENDIF
   10 CONTINUE
      RETURN
      END
C
      SUBROUTINE OUTDT (IG,JG,ZM,ZN,LK)
      DIMENSION ZM(IG,JG),ZN(IG,JG),LK(IG,JG)
      DO 20 I=1,IG
      DO 20 J=1,JG
      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,JG
C     WRITE(31,100)(ZM(I,J),I=1,IG)
C     WRITE(32,100)(ZN(I,J),I=1,IG)
      WRITE(33,200)(LK(I,J),I=1,IG)
   10 CONTINUE
C 100 FORMAT(20F6.3)
  200 FORMAT(40I3)
      RETURN
      END
C
```

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.

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

```
      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
```

Computation of the vertical displacement due to strike slip.

Computation of the vertical displacement due to dip 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
```
□

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

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```
*#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)
```

```
      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)
      Z(I,J,1)=US+UD
      Z(I,J,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
      END
C
      SUBROUTINE ZMAX(IF,JF,Z,ZM)
      DIMENSION Z(IF,JF),ZM(IF,JF)
C
      DO 10 I=1,IF
       DO 10 J=1,JF
        IF(ZM(I,J).LT.Z(I,J))ZM(I,J)=Z(I,J)
   10 CONTINUE
      RETURN
      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
```

```
C
C ***** EXCHANGE FOR LAST STEP DATA TO NEXT STEP DATA *****
C
      SUBROUTINE CHANGE(IF,JF,Z,M,N,D)
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
      DIMENSION D(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)
        D(I,J,1)=D(I,J,2)
   10 CONTINUE
      RETURN
      END
C
C ******* INPUT OF BOUNDARY DATA (WATER LEVEL) *******
C
      SUBROUTINE DATA(NN,B)
      DIMENSION B(1800,14)
      DO 10 K=1,1800
       READ(NN)(B(K,J),J=1,14)
   10 CONTINUE
      RETURN
      END
C
C ************* OUTPUT OF DATA *****************
C
      SUBROUTINE OUT3(NN,IF,JF,ZM)
      DIMENSION ZM(IF,JF)
      DO 10 I=1,IF
       WRITE(NN)(ZM(I,J),J=1,JF)
   10 CONTINUE
      RETURN
      END
C
C ********* OUTPUT OF WATER LEVE;L & DISCHARGE **********
C
      SUBROUTINE OUT1(NN,IF,JF,Z,M,N,DM,DN,H)
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2),H(IF,JF)
      DIMENSION DM(IF,JF,2),DN(IF,JF,2)
      DIMENSION VEL(200,200,2)
      DATA GX/1.0E-3/
      DO 20 J=2,JF
       DO 20 I=2,IF
        IF(H(I,J).LT.-9.9)GOTO 21
        UU=0.0
        VV=0.0
        IF(DM(I,J,1).GT.GX)UU=M(I,J,1)/DM(I,J,1)
        IF(DN(I,J,1).GT.GX)VV=N(I,J,1)/DN(I,J,1)
        UUU=0.0
        VVV=0.0
        IF(DM(I-1,J,1).GT.GX)UUU=M(I-1,J,1)/DM(I-1,J,1)
        IF(DN(I,J-1,1).GT.GX)VVV=N(I,J-1,1)/DN(I,J-1,1)
        VEL(I,J,1)=0.5*(UU+UUU)
        VEL(I,J,2)=0.5*(VV+VVV)
        GOTO 20
   21   VEL(I,J,1)=0.0
        VEL(I,J,2)=0.0
   20 CONTINUE
       DO 30 I=1,IF
        WRITE(NN)(Z(I,J,1),J=1,JF)
        WRITE(NN)(VEL(I,J,1),J=1,JF)
        WRITE(NN)(VEL(I,J,2),J=1,JF)
   30 CONTINUE
      RETURN
      END
C
      SUBROUTINE OUT2(NN,IF,JF,Z,M,N,ZZ)
      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)
```

```
      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 MASS(IA,JA,ZA,MA,NA,HA,DA,TA,LP,1)
      CALL MASS(IB,JB,ZB,MB,NB,HB,DB,TB,LP,1)
      CALL MASS(IC,JC,ZC,MC,NC,HC,DC,TC,LP,1)
      CALL MASS(ID,JD,ZD,MD,ND,HD,DD,TD,LP,1)
      RETURN
      END
C
      SUBROUTINE CJNZ
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)
      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 BOUT(IA,JA,ZA,MA,LP,1)
      CALL JNZ(IA,JA,IB,JB,ZA,ZB,HB,LAB,1110,LP,1)
      CALL JNZ(IB,JB,IC,JC,ZB,ZC,HC,LBC,1110,LP,1)
      CALL JNZ(IC,JC,ID,JD,ZC,ZD,HD,LCD,1110,LP,1)
      RETURN
      END
C
      SUBROUTINE CMMNT
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)
      LP=1
      CALL MMNT(IA,JA,ZA,MA,NA,HA,DA,TA,LP,1)
      CALL MMNT(IB,JB,ZB,MB,NB,HB,DB,TB,LP,1)
      CALL MMNT(IC,JC,ZC,MC,NC,HC,DC,TC,LP,1)
      CALL MMNT(ID,JD,ZD,MD,ND,HD,DD,TD,LP,1)
      RETURN
      END
C
      SUBROUTINE CJNQ
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)
      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
```

```
C         DO 30 JJ=JS,JE
C           IF(H(II,JJ).GT.0.)THEN
        IF(H(I,J).GT.0.)THEN
C           L=L+1
C           S=S+Z(II,JJ,2)
C           ENDIF
C      30 CONTINUE
C        IF(L.GE.2)THEN
C         S=S/L
          S=Z(I,J,2)
          KMM=11+INT(S/0.2)
          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
       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
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,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)
```

```
        CALL UDCAL(X1,X2,X3,0.,H2,E*DL,G3)
        CALL UDCAL(X1,X2,X3,0.,H1,E*DL,G4)
        US=(F1-F2-F3+F4)*DS/(12.0*A)
        UD=(G1-G2-G3+G4)*DD/(12.0*A)
        Z(I,J,1)=US+UD
        Z(I,J,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
```

IUGG/IOC TIME PROJECT

PART 4. PROGRAMME LIST FOR FAR-FIELD TSUNAMI

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

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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)
```

```
C
C ----- PARAMETERS FOR CONNECTION ------
C
      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/
C
      LP=1 ; DO WHILE (LP.LE.16)
      CALL MASS2 (IA,JA,ZA,MA,NA,RA1,RA6,LP,8)
      CALL MASS2 (IB,JB,ZB,MB,NB,RB1,RB6,LP,4)
      CALL MASS3 (IC,JC,ZC,MC,NC,HC,DC,TC,LP,4)
      CALL MASS3 (ID1,JD1,ZD1,MD1,ND1,HD1,DD,TD,LP,4)
      CALL MASS3 (ID2,JD2,ZD2,MD2,ND2,HD2,DD,TD,LP,4)
      CALL MASS3 (ID3,JD3,ZD3,MD3,ND3,HD3,DD,TD,LP,4)
      CALL MASS3 (ID4,JD4,ZD4,MD4,ND4,HD4,DD,TD,LP,4)
      CALL MASS3 (ID5,JD5,ZD5,MD5,ND5,HD5,DD,TD,LP,4)
      CALL MASS3 (IE1,JE1,ZE,ME,NE,HE,DE,TE,LP,2)
C      CALL MASS3 (IF1,JF1,ZF,MF,NF,HF,DF,TF,LP,1)
C
      CALL JNZOA (LP,16)
      CALL JNZ (IA,JA,IB,JB,ZA,ZB,HB,LAB,1101,LP,8)
      CALL J2Z (IB,JB,IC,JC,ZB,ZC,HC,LBC,1111,LP,4)
      CALL J2Z (IC,JC,ID1,JD1,ZC,ZD1,HD1,LD1,1111,LP,4)
      CALL J2Z (IC,JC,ID2,JD2,ZC,ZD2,HD2,LD2,1101,LP,4)
      CALL J2Z (IC,JC,ID3,JD3,ZC,ZD3,HD3,LD3,0110,LP,4)
      CALL J2Z (IC,JC,ID4,JD4,ZC,ZD4,HD4,LD4,1110,LP,4)
      CALL J2Z (IC,JC,ID5,JD5,ZC,ZD5,HD5,LD5,0110,LP,4)
      CALL JNZ (ID1,JD1,IE1,JE1,ZD1,ZE,HE,LDE,1011,LP,4)
C      CALL JNZ (IE1,JE1,IF1,JF1,ZE,ZF,HF,LEF,1011,LP,2)
C
      IF(LP.EQ.16) CALL MMNT1 (IS,JS,IE,JE)
      CALL MMNT2 (IA,JA,ZA,MA,NA,RA2,RA3,RA4,RA5,LP,8)
      CALL MMNT2 (IB,JB,ZB,MB,NB,RB2,RB3,RB4,RB5,LP,4)
      CALL MMNT3 (IC,JC,ZC,MC,NC,HC,DC,TC,LP,4)
      CALL MMNT3 (ID1,JD1,ZD1,MD1,ND1,HD1,DD,TD,LP,4)
      CALL MMNT3 (ID2,JD2,ZD2,MD2,ND2,HD2,DD,TD,LP,4)
      CALL MMNT3 (ID3,JD3,ZD3,MD3,ND3,HD3,DD,TD,LP,4)
      CALL MMNT3 (ID4,JD4,ZD4,MD4,ND4,HD4,DD,TD,LP,4)
      CALL MMNT3 (ID5,JD5,ZD5,MD5,ND5,HD5,DD,TD,LP,4)
      CALL MMNT3 (IE1,JE1,ZE,ME,NE,HE,DE,TE,LP,2)
C      CALL MMNT3 (IF1,JF1,ZF,MF,NF,HF,DF,TF,LP,1)
C
      CALL JNQOA (LP,8)
      CALL JNQ (IA,JA,IB,JB,MA,NA,MB,NB,HB,LAB,1101,LP,4)
      CALL JNQ (IB,JB,IC,JC,MB,NB,MC,NC,HC,LBC,1111,LP,4)
      CALL JNQ (IC,JC,ID1,JD1,MC,NC,MD1,ND1,HD1,LD1,1111,LP,4)
      CALL JNQ (IC,JC,ID2,JD2,MC,NC,MD2,ND2,HD2,LD2,1101,LP,4)
      CALL JNQ (IC,JC,ID3,JD3,MC,NC,MD3,ND3,HD3,LD3,0110,LP,4)
      CALL JNQ (IC,JC,ID4,JD4,MC,NC,MD4,ND4,HD4,LD4,1110,LP,4)
      CALL JNQ (IC,JC,ID5,JD5,MC,NC,MD5,ND5,HD5,LD5,0110,LP,4)
      CALL JNQ (ID1,JD1,IE1,JE1,MD1,ND1,ME,NE,HE,LDE,1011,LP,2)
C      CALL JNQ (IE1,JE1,IF1,JF1,ME,NE,MF,NF,HF,LEF,1011,LP,1)
C
      CALL CHANG (IA,JA,ZA,MA,NA,LP,8)
      CALL CHANG (IB,JB,ZB,MB,NB,LP,4)
      CALL CHANG (IC,JC,ZC,MC,NC,LP,4)
      CALL CHANG (ID1,JD1,ZD1,MD1,ND1,LP,4)
      CALL CHANG (ID2,JD2,ZD2,MD2,ND2,LP,4)
      CALL CHANG (ID3,JD3,ZD3,MD3,ND3,LP,4)
      CALL CHANG (ID4,JD4,ZD4,MD4,ND4,LP,4)
      CALL CHANG (ID5,JD5,ZD5,MD5,ND5,LP,4)
      CALL CHANG (IE1,JE1,ZE,ME,NE,LP,2)
C      CALL CHANG (IF1,JF1,ZF,MF,NF,LP,1)
      LP=LP+1 ; ENDDO
C
      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
```

```
      REAL M,N
      PARAMETER (GX=1.E-4)
      PARAMETER (IO=1020,JO=738)
      COMMON /XX/ Z(IO,JO,2),M(IO,JO,2),N(IO,JO,2)
      IF(IS.EQ.2)GOTO 61
      L=0
      DO 10 J=JS,JE
      IF(ABS(Z(IS+2,J,2)).GT.GX)L=1
   10 CONTINUE
      IF(L.EQ.1)THEN
      IS=IS-1
      IF(IS.LE.2)IS=2
      ENDIF
   61 IF(IE.EQ.IO-1)GOTO 62
      L=0
      DO 20 J=JS,JE
      IF(ABS(Z(IE-2,J,2)).GT.GX)L=1
   20 CONTINUE
      IF(L.EQ.1)THEN
      IE=IE+1
      IF(IE.GE.IO-1)IE=IO-1
      ENDIF
   62 IF(JS.EQ.2)GOTO 63
      L=0
      DO 30 I=IS,IE
      IF(ABS(Z(I,JS+2,2)).GT.GX)L=1
   30 CONTINUE
      IF(L.EQ.1)THEN
      JS=JS-1
      IF(JS.LE.2)JS=2
      ENDIF
   63 IF(JE.EQ.JO-1)GOTO 64
      L=0
      DO 40 I=IS,IE
      IF(ABS(Z(I,JE-2,2)).GT.GX)L=1
   40 CONTINUE
      IF(L.EQ.1)THEN
      JE=JE+1
      IF(JE.GE.JO-1)JE=JO-1
      ENDIF
   64 RETURN
      END
C
      SUBROUTINE MASS1 (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)
      DO 10 J=JS,JE
      DO 10 I=IS,IE
      Z(I,J,2)=Z(I,J,1)-R1(I,J)*(M(I,J,1)-M(I-1,J,1))
      &  -R1(I,J)*(N(I,J,1)*R6(J)-N(I,J-1,1)*R6(J-1))
   10 CONTINUE
      DO 20 J=JS,JE
      DO 20 I=IS,IE
      IF(ABS(Z(I,J,2)).LT.1.0E-5)Z(I,J,2)=0.0
   20 CONTINUE
      RETURN
      END
C
      SUBROUTINE MASS2 (IF,JF,Z,M,N,R1,R6,LP,LT)
C
      REAL M,N
      DIMENSION Z(IF,JF,2),M(IF,JF,2),N(IF,JF,2)
      DIMENSION R1(IF,JF),R6(IF)
      IF(MOD(LP,LT).NE.0)RETURN
      DO 10 J=2,JF
      DO 10 I=2,IF
      Z(I,J,2)=Z(I,J,1)-R1(I,J)*(M(I,J,1)-M(I-1,J,1))
      &  -R1(I,J)*(N(I,J,1)*R6(J)-N(I,J-1,1)*R6(J-1))
   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
```

```
      Z(1,J,2)=SQRT(M(1,J,1)**2
        &+0.25*(N(1,J,1)+N(1,J-1,1))**2)*C2(J)
      IF(Z(1,J,2).GT.1.0)Z(1,J,2)=1.0
      IF(Z(1,J,2).LT.-1.0)Z(1,J,2)=-1.0
   20 IF(M(1,J,1).GT.0.)Z(1,J,2)=-Z(1,J,2)
      ENDIF
      IF(JE.GE.JO-1)THEN
      DO 30 I=2,IO-1
      Z(I,JO,2)=SQRT(N(I,JO-1,1)**2
        &+0.25*(M(I,JO,1)+M(I,JO-1,1))**2)*C3(I)
   30 IF(N(I,JO-1,1).LT.0.)Z(I,JO,2)=-Z(I,JO,2)
      ENDIF
      IF(IE.GE.IO-1)THEN
      DO 40 J=2,JO-1
      Z(IO,J,2)=SQRT(M(IO-1,J,1)**2
        &+0.25*(N(I,JO,1)+N(I,JO-1,1))**2)*C4(J)
   40 IF(M(IO-1,J,1).LT.0.)Z(IO,J,2)=-Z(IO,J,2)
      ENDIF
      Z(1,1,2)=SQRT(M(1,1,1)**2+N(1,1,1)**2)*C1(1)
      IF(N(1,1,1).GT.0.0)Z(1,1,2)=-Z(1,1,2)
      Z(IO,1,2)=SQRT(M(IO-1,1,1)**2+N(IO,1,1)**2)*C1(IO)
      IF(N(IO,1,1).GT.0.0)Z(IO,1,2)=-Z(IO,1,2)
      Z(1,JO,2)=SQRT(M(1,JO,1)**2+N(1,JO-1,1)**2)*C3(1)
      IF(N(1,JO-1,1).LT.0.0)Z(1,JO,2)=-Z(1,JO,2)
      Z(IO,JO,2)=SQRT(M(IO-1,JO,1)**2+N(IO,JO-1,1)**2)*C3(JO)
      IF(N(IO,JO-1,1).LT.0.0)Z(IO,JO,2)=-Z(IO,JO,2)
      RETURN
      END
C
      SUBROUTINE JNZOA (LP,LT)
C
      REAL M,MA,N,NA
      PARAMETER (IO=1020,JO=738,IA=76,JA=76)
      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)
      COMMON /HA/ HA(IA,JA)
      IF(MOD(LP,LT).NE.0)RETURN
C
      II=ISL ; JJ=JSL ; I1=ISS ; J1=JSS
      DO WHILE (II.LE.IEL)
      S=0.0 ; L=0
      IE=I1+2 ; IF(IE.GE.IES)IE=IES
      DO 10 I=I1,IE
      DO 10 J=J1,J1+2
      IF(HA(I,J).GT.0.0)THEN
      S=S+0.5*(ZA(I,J,1)+ZA(I,J,2))
      L=L+1 ; ENDIF
   10 CONTINUE
      IF(L.GE.1)THEN
      Z(II,JJ,2)=S/L  ; ELSE
      Z(II,JJ,2)=0.0  ; ENDIF
      II=II+1 ; I1=I1+2
      IF(MOD(II,2).EQ.1)I1=I1+1
      ENDDO
C
      II=IEL ; JJ=JSL ; I1=IES-2 ; J1=JSS
      DO WHILE (JJ.LE.JEL)
      S=0.0 ; L=0
      JE=J1+2 ; IF(JE.GE.JES)JE=JES
      DO 20 I=I1,I1+2
      DO 20 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
   20 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
C
```

```
      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
```

```
      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).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,J).LT.0.0)MY(I,J,2)=0.0
      J=J+1
      ENDDO ; ENDIF
      RETURN ; END
C
      SUBROUTINE COUT (KK,KD)
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 /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 /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)
     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
```