边界条件文件设置

infl.QBC：入口流量边界条件　　入口边界单元，边，垂向分层流量

```
1    1  10.001492  10.001492  10.001492  10.001492  10.001492
2    1  10.001492  10.001492  10.001492  10.001492  10.001492
  0.000000
  0.000388    0.000388
9999.000000
  0.000388    0.000388
```

入口流量（其他边界条件文件等同）

outl.EBC：出口边界条件　　出口边界单元，边

```
6321    3    6322    3    6323    3    6324    3
```

VIS.QBC：入口湍粘性系数边界条件

垂向分层湍粘性系数k, w (TKEQ, TDISSQ)

```
  0.000000
0.774126-138 0.903846-133 0.104336-127 0.119062-122 0.134289-117 0.149686-112 0.164865-107 0.179397-102
0.191994E-04 0.191994E-04 0.191994E-04 0.191994E-04 0.191994E-04 0.191994E-04 0.191994E-04 0.191994E-04
```

VIS.EBC：出口湍粘性系数边界条件　　垂向分层湍粘性系数k, w (TKEE, TDISSE)

Step 1：构建算例相似明渠流计算网格，通常入口网格宽度为两个网格宽。
Step 2：利用计算程序迭代，通过验证u^+, y^+获得稳定计算。
Step 3：修改真实算例边界条件。

RUN文件：计算信息设置

```
    YR     MO     DA     HR
  2005      5      1      0
     DTI        IRAMP IHOTSTART
   1.00E-3       1000      1000
    NSTEPS     IPRINT RESTART    TOR        ADVECT
   10000            1 COLD START BAROTROPIC NON-LINEAR
     BFRIC        ZOB      WFBC
 0.250E-02 0.100E-05       FUN1
UNIFORM        VISCON  SGSMODEL
CONSTANT   0.100E-00          1
HORIZON        HORCON     HPRNU
CONSTANT   0.300E-00 0.100E+01
VERTMIX        VERCON     UMOL      VPRNU
SSTMODEL   0.100E-00 0.100E-05 0.100E+01
COMPUTATIONAL HISTORY OUTPUT TIMES
        20        10
     50      100      150      200      250      300      350      400      450      500
    550      600      650      700      750      800      850      900      950     1000
AVERAGING INTERVAL FOR SKILL ASSESSMENT
       100     1000
LOCATION OF COMPUTED TIME SERIES ELEVATION ELEMENTS
    4
     11       51      101     201
LOCATION OF COMPUTED TIME SERIES CURRENT ELEMENTS
    4
     11       51      101     201
LOCATION OF COMPUTED TIME SERIES CROSSSECTIONAL FLUXES
    0
TIME VARIABLE BOUNDARY ELEVATION
 110
outl.EBC
TIME VARIABLE BOUNDARY VELOCITY
    0
TIME VARIABLE RIVER/DAM AND ONSHORE INTAKE/OUTFALL DISCHARGES
 110
infl.QBC
TIME VARIABLE OFFSHORE INTAKE/OUTFALL(DIFFUSER) DISCHARGES
    0
ASTROTIDE BOUNDARY
    0
```

时间步设置

保存步数

水位监测点

入口、出口边界

SETDOM：读取网格信息文件GRD&CUV

GRD文件

Grids and grid point depths and the topology of the meshes 文件信息
Vertical Segmentation_Sigma Levels (KB)
11 IKB
0.0
-0.100000
...... Z(K):垂向分层坐标[-1,0] → DZ(K):垂向单元高度Z(K)-Z(K+1)
DZR(K):1/DZ(K)
ZZ(K):垂向坐标0.5*[Z(K)+Z(K+1)]
DZZ(K):垂向单元高度ZZ(K)-ZZ(K+1)
-1.000000
Horizontal Segmentation Levels IJP
6561 IJP,IJP1:判断是否与头文件一致

0.0000000	0.0000000	0.200000	PXY(I,1), PXY(I,2), HP(I)
0.0000000	0.1000000	0.200000	

......

2	1	82	83
3	2	83	84
4	3	84	85

......

CUV文件

Detailed information of the cells 文件信息

6400 IJM,IJM1:判断是否与头文件一致

1 4 1 -999 2 1 KCELL,CELL_POLYGEN(K)

6481 -999 1 82 81 81 CELL_SIDE:边，临单元，端点

82 83 6482 2 83 2

-1.00000000000000 0.000000000000000E+000 0.000000000000000E+000

-1.00000000000000 1.00000000000000 0.100000000000000 CELL_CUV：坐标雅克比系数

......

0.000000000000000E+000 1.00000000000000 5.000000000000000E-002 CXY(I,1)

5.000000000000000E-002 1.000000000000000E-002

CXY(I,2) AREA(I):单元面积

Detailed information of the edges

12960 IJE,IJE1:判断是否与头文件一致

1 1 -999 2 1 -1.0 KEDGE CFM:干湿边界

2 2 -999 3 2 -1.0 INDEX_EDGE,IEND_EDGE:临单元，端点

......

Detailed information of the points

6561 IJP,IJP1:判断是否与头文件一致

1 1 1 KPOINT POINT_CELL:顶点临单元数

2 2 1 2

3 2 2 3 INDEX_POINT

.....,

计算参数设定

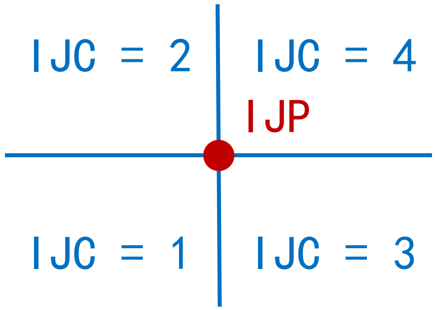
```
HS(I) = 0.5 * (HP(N1) + HP(N2))
HC(I) = (HP(CELL_SIDE(I,1,3))+HP(CELL_SIDE(I,2,3))+
    &   HP(CELL_SIDE(I,3,3))+HP(CELL_SIDE(I,4,3)))/4
DC(I) = HC(I) + EL(I)

DS(I) = HS(I) + EL(INDEX_EDGE(I,1,2))
ELFM(I) = EL(INDEX_EDGE(I,1,2))
ELFV(I) = ELFV(I) / RTOL
```

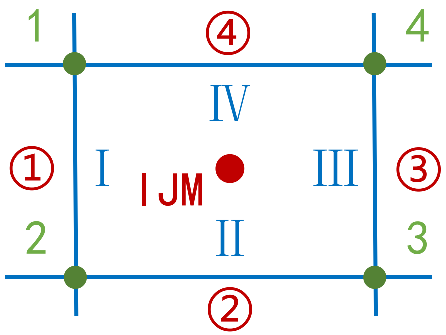
HS(IJE):边静水深，由边端点差值而来
HC(IJM):单元静水深，由单元顶点差值而来
DC(IJM):水深，静水深+自由表面水位变化

DS(IJE):边水深
ELFM(IJE):边水位
ELFV(IJP):顶点水位（权重差值） $RCOE = \frac{\omega_i}{\sum \omega_i}$

单元与网格点规则

INDEX_POINT(IJP,IJC)





ADVU, ADVV, ADVW：动量方程计算

x方向离散动量方程为例

动压项

$$\frac{q_{xi}^{n+1}-q_{xi}^{n}}{\Delta t}=\boxed{Fq_{xi}^{n}}-\boxed{gD\theta\left(\frac{\partial\zeta^{n+1}}{\partial x}\right)_i}-\boxed{gD(1-\theta)\left(\frac{\partial\zeta^{n}}{\partial x}\right)_i}-\boxed{\frac{D}{\rho_0}\left(\frac{\partial p_n^{n+1}}{\partial x}\right)_i}+\boxed{\left[\frac{\partial}{D\partial\sigma}\left(\frac{\nu_{tv}}{D}\frac{\partial q_x^{n+1}}{\partial\sigma}\right)\right]_i}$$

隐式项：水位梯度项。

显式项：对流扩散项、水位梯度项。对流扩散项由该模块求解得到。

对流项离散

$$\sum_{CS}\int_{\Delta A_i}\mathbf{n}_i\cdot(\rho\phi\mathbf{u})dA\approx\sum_{CS}\mathbf{n}_i\cdot(\rho\mathbf{u})\Delta A_i\phi_i=\sum_{CS}\boxed{F_i\phi_i}$$

面通量(TVD scheme)

$$\phi_f=\phi_C+\frac{1}{2}\psi(r_f)(\phi_D-\phi_C),\quad r_f=\frac{(2\nabla\phi_C\cdot r_{CD})}{\phi_D-\phi_C}-1$$

```
UW = (U(I,K) + U(CELL_SIDE(I,J,2),K)) / 2
GRADX(I,K) = UW * CELL_CUV(I,J,7) * CELL_CUV(I,J,6)/AREA(I)      ∇xφc
GRADY(I,K) = UW * CELL_CUV(I,J,8) * CELL_CUV(I,J,6)/AREA(I)      ∇yφc

RF = 2.0 * GRADX(INDEX_EDGE(I,K,1),K) * (CXY(INDEX_EDGE(I,K,2),1) - CXY(INDEX_EDGE(I,K,1),1))+   rf
     2.0 * GRADY(INDEX_EDGE(I,K,1),K) * (CXY(INDEX_EDGE(I,K,2),2) - CXY(INDEX_EDGE(I,K,1),2))
QSUR(I,K) = Q(INDEX_EDGE(I,K,1),K) + 0.5 * FUNLIMTER(LIMTER,RF) *  (Q(INDEX_EDGE(I,K,2),K) -   φf
            Q(INDEX_EDGE(I,K,1),K))
UF(I,K) = HQ(CELL_SIDE(I,J,1),K) * CELL_CUV(I,J,6) * PORE_HF(CELL_SIDE(I,J,1),K) *        Fiφi
          (UN(CELL_SIDE(I,J,1),K) * CELL_CUV(I,J,7) + VN(CELL_SIDE(I,J,1),K) * CELL_CUV(I,J,8))
```

扩散项离散

$$\sum_{CS}\int_{\Delta A_i}\mathbf{n}_\mathbf{i}\cdot(\Gamma\nabla\phi)dA \approx \sum_{CS}\frac{\mathbf{n}\cdot\mathbf{n}}{\mathbf{n}\cdot\mathbf{e}_\xi}\cdot\frac{\phi_C-\phi_D}{\Delta\xi}\Gamma\Delta A_i + S_{D-cross} = \sum_{CS}\boxed{D_i(\phi_C-\phi_D)} + S_{D-cross}$$

由局部坐标计算

```
FLUX1 = (DISCOE(I,J,1) - DISCOE(I,J,8))* AAMF * (U(CELL_SIDE(I,J,2),K) - U(I,K)) *
         PORE_HF(CELL_SIDE(I,J,1),K)
FLUX2 = (DISCOE(I,J,7) - DISCOE(I,J,2)) * AAMF * (UV(CELL_SIDE(I,J,4),K) - UV(CELL_SIDE(I,J,3),K)) *
         PORE_HF(CELL_SIDE(I,J,1),K)
UF(I,K) = UF(I,K) + (FLUX1 + FLUX2) * DZ(K)
```

$$D_i(\phi_C-\phi_D)$$

UF即为对流扩散项计算结果，为显式项。
进一步合并水位梯度显式项：

$$gD(1-\theta)\left(\frac{\partial\zeta^n}{\partial x}\right)_i\Delta\sigma$$

```
UF(I,K) = UF(I,K) - GRAV * DC(I) * (1.0 - THITA) * DZ(K)* UFHYD(I) * PORE(I,K)
```

UF为本模块最终计算结果，进入ELTION计算。

ELTION：水位计算模块

计算水位需要利用连续性方程

$$\frac{\zeta_i^* - \zeta_i^n}{\Delta t} + \theta \sum_{k=1}^{KBM} \left(\frac{\partial q_x^*}{\partial x}\right)_{i,k} \Delta\sigma_k + (1-\theta) \sum_{k=1}^{KBM} \left(\frac{\partial q_x^n}{\partial x}\right)_{i,k} \Delta\sigma_k + \theta \sum_{k=1}^{KBM} \left(\frac{\partial q_y^*}{\partial y}\right)_{i,k} \Delta\sigma_k + (1-\theta) \sum_{k=1}^{KBM} \left(\frac{\partial q_y^n}{\partial y}\right)_{i,k} \Delta\sigma_k = 0.$$

离散连续性方程与离散动量方程可写成紧凑形式

$$\zeta_i^* + \boldsymbol{Z}_{1i} \left(\frac{\partial \boldsymbol{Q}_x^*}{\partial x}\right)_i + \boldsymbol{Z}_{1i} \left(\frac{\partial \boldsymbol{Q}_y^*}{\partial y}\right)_i = \zeta_i^n - \boldsymbol{Z}_{2i} \left(\frac{\partial \boldsymbol{Q}_x^n}{\partial x}\right)_i - \boldsymbol{Z}_{2i} \left(\frac{\partial \boldsymbol{Q}_y^n}{\partial y}\right)_i$$

$$\boxed{\boldsymbol{A}_{ix}^n \boldsymbol{Q}_{xi}^* = \boldsymbol{G}_{xi}^n - \boldsymbol{B}_i^n \left(\frac{\partial \zeta^*}{\partial x}\right)_i} \xrightarrow{\text{分步法}} \boxed{\mathbf{Q}_{\mathbf{xi}}^{*(2)} = -\mathbf{A}_{\mathbf{xi}}^{\mathbf{n}-1} \mathbf{B}_{\mathbf{i}}^{\mathbf{n}} \left(\frac{\partial \zeta^*}{\partial x}\right)_i}$$

代入离散连续性方程求解

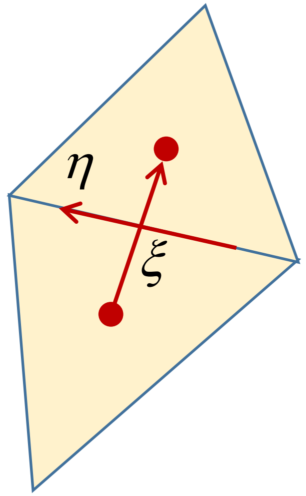
$$\zeta_i^* - \boldsymbol{Z}_{1i} \left\{\frac{\partial}{\partial x}\left[\boldsymbol{A}^{n-1} \boldsymbol{B}^n \left(\frac{\partial \zeta^*}{\partial x}\right)\right]\right\}_i - \boldsymbol{Z}_{1i} \left\{\frac{\partial}{\partial y}\left[\boldsymbol{A}^{n-1} \boldsymbol{B}^n \left(\frac{\partial \zeta^*}{\partial y}\right)\right]\right\}_i = BB_i$$

利用高斯积分定理并离散，在局部坐标系下得到

$$\zeta_i^* \Delta s_i - \boldsymbol{Z}_{1i} \sum_{s=1}^{NS} \frac{\boldsymbol{A}_i^{n-1} \boldsymbol{B}_i^n}{J_{is}} \left\langle \boxed{\frac{\partial \zeta^*}{\partial \xi}} y\eta - \frac{\partial \zeta^*}{\partial \eta} y\xi \right\rangle_{is}^f \cos\alpha_{is} \Delta l_{is} - \boldsymbol{Z}_{1i} \sum_{n=1}^{NS} \frac{\boldsymbol{A}_i^{n-1} \boldsymbol{B}_i^n}{J_{is}} \left\langle \frac{\partial \zeta^*}{\partial \eta} x\xi - \frac{\partial \zeta^*}{\partial \xi} x\eta \right\rangle_{is}^f \sin\alpha_{is} \Delta l_{is} = \langle BB_i \rangle$$

$$AP_i \zeta_i^* - \sum_{s=1}^{NS} AP_{is} \zeta_{is}^* = \langle \widetilde{B}_i \rangle$$

$$\boxed{\frac{\zeta_{is}^* - \zeta_i^*}{\Delta \xi}}$$



首先对系数矩阵赋值

```
ZZZ1(K) = DTI * THITA * DZ(K)
ZZZ2(K) = DTI * (1.0 - THITA) * DZ(K)
```

$$Z_{1i} = [\Delta t\theta\Delta\sigma_1, \cdots, \Delta t\theta\Delta\sigma_k, \cdots, \Delta t\theta\Delta\sigma_{KBM}]$$

$$Z_{2i} = [\Delta t(1-\theta)\Delta\sigma_1, \cdots, \Delta t(1-\theta)\Delta\sigma_k, \cdots, \Delta t(1-\theta)\Delta\sigma_{KBM}]$$

```
BBBB(K) = GRAV * DC(I) * DTI * THITA * DZ(K)* PORE_HF(I,K)
```

$$B_i = [gD_i^n\Delta t\theta\Delta\sigma_1, \cdots, gD_i^n\Delta t\theta\Delta\sigma_k, \cdots, gD_i^n\Delta t\theta\Delta\sigma_{KBM}]^{\mathrm{T}}$$

分步计算

```
USTAR(I,K) = USTAR(I,K) + AAAA(K,J) * (UF(I,J) - BBBB(J) * TTTTX * AREA(I))
```

$$\mathbf{Q}_{\mathbf{xi}}^{*(1)} = \mathbf{A}_{\mathbf{xi}}^{\mathbf{n}-1}\mathbf{G}_{\mathbf{i}}^{\mathbf{n}}$$

求解水位方程系数

```
COES(I) = ZZZ1(K) * AAAA(K,J) * BBBB(J) * PORE_HF(I,K)
CS(I,J) = COES(CELL_SIDE(I,J,1)) * (DISCOE(I,J,1) - DISCOE(I,J,8))
CP(I) = CP(I) + CS(I,J)
CB(I) = -CB(I) + ZZZ2(K) * TEMP(K) + AREA(I) * EL(I) * PORE_AVE
TEMP(K) = PORE_HF(CELL_SIDE(I,J,1),K) * CELL_CUV(I,J,6) *
          ((USTAR(IL,K) + USTAR(IR,K)) / 2 * CELL_CUV(I,J,7) +
           (VSTAR(IL,K) + VSTAR(IR,K)) / 2 * CELL_CUV(I,J,8))
```

$$\mathbf{Z}_{\mathbf{1i}}\mathbf{A}_{\mathbf{xi}}^{\mathbf{n}-1}\mathbf{B}_{\mathbf{i}}^{\mathbf{n}}$$

$$\mathbf{AP}_{is}$$

$$\mathbf{AP}_{i}$$

$$\langle BB_i \rangle$$

$$\mathbf{Q}_{\mathbf{xi}}^{*} = \boxed{\mathbf{A}_{\mathbf{xi}}^{\mathbf{n}-1}\mathbf{G}_{\mathbf{i}}^{\mathbf{n}}} - \mathbf{A}_{\mathbf{xi}}^{\mathbf{n}-1}\mathbf{B}_{\mathbf{i}}^{\mathbf{n}}\left(\frac{\partial\zeta^*}{\partial x}\right)_i$$

$$\int_{CS} BB_i dS \approx \zeta_i^n \Delta S_i - Z_{1i}\sum_{is}\left\langle\frac{\partial q^n}{\partial x}\right\rangle_{is}\cos\alpha\Delta l_{is} - Z_{2i}\sum_{is}\left\langle\frac{\partial q^n}{\partial y}\right\rangle_{is}\sin\alpha\Delta l_{is}$$

所有系数求解完毕，使用双共轭梯度法即可求解水位方程。水位变量**ELF(I)**。

PROV：流速计算模块

同样把离散动量方程写成紧凑形式

$$\boldsymbol{A}_{ix}^{n}\boldsymbol{Q}_{xi}^{*}=\boldsymbol{G}_{xi}^{n}-\boldsymbol{B}_{i}^{n}\left(\frac{\partial\zeta^{*}}{\partial x}\right)_{i}$$

在分步求解过程中，求解水位模块已经完成了部分计算，即：

```
USTAR(I,K) = USTAR(I,K) + AAAA(K,J) * (UF(I,J) - BBBB(J) * TTTTX * AREA(I))
```

$$\boldsymbol{A}_{ix}^{n}\boldsymbol{Q}_{xi}^{*}=\boldsymbol{G}_{xi}^{n}$$

接下来只需计算后半部分

$$\boldsymbol{A}_{ix}^{n}\boldsymbol{Q}_{xi}^{*}=-\boldsymbol{B}_{i}^{n}\left(\frac{\partial\zeta^{*}}{\partial x}\right)_{i}$$

```
BU = WIX(I,J) * (ELF(CELL_SIDE(I,J,2)) - ELF(I))
BV = WIY(I,J) * (ELF(CELL_SIDE(I,J,2)) - ELF(I))
U(I,K) = U(I,K) - AAAA(K,J) * BBBB(J) * BU
V(I,K) = V(I,K) - AAAA(K,J) * BBBB(J) * BV
```

$$\left(\frac{\partial\zeta^{*}}{\partial x}\right)_{i}\quad\left(\frac{\partial\zeta^{*}}{\partial y}\right)_{i}$$

$$\mathbf{A}_{\mathbf{xi}}^{\mathbf{n}}=\left[\ldots,\ -\Delta t\left(\frac{\nu_t}{\Delta\sigma\cdot D^2}\right)_{k-1},\ \Delta\sigma-2\Delta t\left(\frac{\nu_t}{\Delta\sigma\cdot D^2}\right)_{k},\ -\Delta t\left(\frac{\nu_t}{\Delta\sigma\cdot D^2}\right)_{k+1},\ \ldots\right]$$

最后合并分步求解的结果即可得到流速解

```
U(I,K) = U(I,K) + USTAR(I,K)
V(I,K) = V(I,K) + VSTAR(I,K)
```

U(I,K),V(I,K)为一个时间步最终解（如考虑动压还需进一步求解）