

Chapter 5

THE LOW-ORDER METHOD (ILOWHI=0)

This Chapter includes specific topics which are applicable when the low-order method is used, as in earlier versions of WAMIT. The essential features of this method are (a) the geometry of the body is represented by an ensemble of flat quadrilateral panels, or facets, and (b) the solutions for the velocity potential, and optionally for the source strength, are approximated by piecewise constant values on each panel.

The geometry of the body is specified in this case by a Geometric Data File (GDF) which includes the Cartesian coordinates of each vertex of each panel, listed sequentially. In addition the GDF file specifies the characteristic length ULEN used for nondimensionalization of outputs, the value of the gravitational acceleration constant GRAV in the same units of measurement, the number of panels NPAN, and two symmetry indices ISX, ISY, as described in Section 5.1. The syntax for data in this file follows the same requirements outlined for the generic input files in Chapter 3.

When the low-order method is used there are three options which can be used for special purposes. These include the source formulation, analysis of a body near one or two orthogonal vertical walls, and the analysis of bodies with thin elements such as damper plates or strakes.

When the source formulation is used, as described in Section 5.2, the solution is computed both for the velocity potential and for the equivalent source distribution which generates this potential. The source formulation must be used, in the low-order method, if the mean drift force and moment are evaluated by pressure integration, and more generally if the fluid velocity is required on the body surface.

The option to include one or two vertical walls, described in Section 5.3, is based on the method of images. The body geometry is specified in the usual manner by a GDF file, and the program automatically represents the image body (or bodies, if two walls are present).

If the body has thin elements, there are two possible approaches. The first is to panel both sides of these elements, with a finite thickness to separate the two sides. The disadvantage of this approach is that, as a general rule, the size of the panels must be comparable

to the thickness, and thus a very large number of small panels may be required to achieve accurate results. The second approach is to reduce the thickness to zero, and represent the corresponding elements of the body by special ‘dipole panels’. This approach is analogous to the thin-wing approximation in lifting-surface theory [21]. Version 6 permits the user to specify a set of dipole panels, as described in Section 5.4. This option facilitates the analysis of bodies with damper plates, strakes, and similar thin elements, without the need to use very large numbers panels or to artificially increase the thickness.

Starting in V6.2, the same extension is made for ILOWHI=1 and the users may specify dipole patches to represent thin structures as described in Section 6.10.

5.1 THE GEOMETRIC DATA FILE

In the low-order method the wetted surface of a body is represented by an ensemble of connected four-sided facets, or panels. The Geometric Data File contains a description of this discretized surface, including the body length scale, gravity, symmetry indices, the total number of panels specified, and for each panel the Cartesian coordinates x, y, z of its four vertices. A panel degenerates to a triangle when the coordinates of two vertices coincide. The order in which the panels are defined in the file is unimportant, but each panel must be described completely by a set of 12 real numbers (three Cartesian coordinates for each vertex) which are listed consecutively, with a line break between the last vertex of each panel and the first vertex of the next. The value of gravity serves to define the units of length, which apply to the body length scale, panel offsets, and to all related parameters in the other input files. The coordinate system x, y, z in which the panels are defined is referred to as the *body coordinate system*. The only restrictions on the body coordinate system are that it is a right-handed Cartesian system and that the z -axis is vertical and positive upward.

The name of the GDF file can be any legal filename accepted by the operating system, with a maximum length of 16 ASCII characters, **followed by the extension ‘.gdf’**.

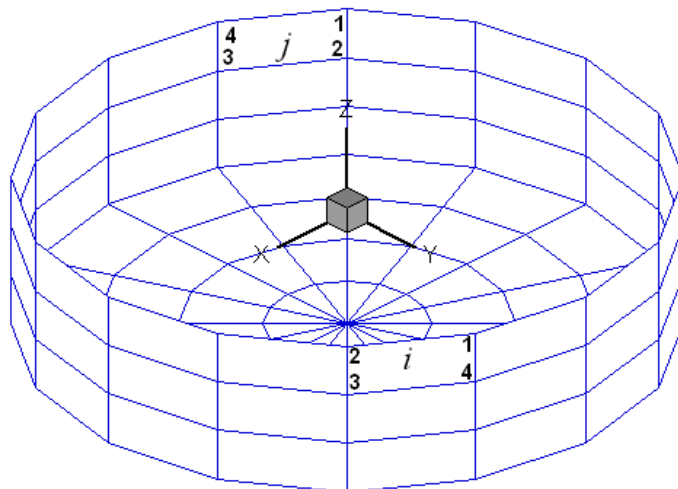


Figure 5.1: Discretization of a circular cylinder showing the convention for panel vertex numbering. The perspective view is from above the free surface, showing portions of the exterior and interior of the cylinder (lower and upper portions of the figure, respectively). The view of panel i is from the ‘wet side’, *inside* the fluid domain, so the vertex ordering appears *anti-clockwise*. The view of panel j is from the ‘dry side’ *outside* the fluid domain, so the vertex ordering appears *clockwise*.

The data in the GDF file can be input in the following form:

```

header
ULEN GRAV
ISX ISY
NPAN
X1(1) Y1(1) Z1(1) X2(1) Y2(1) Z2(1) X3(1) Y3(1) Z3(1) X4(1) Y4(1) Z4(1)
X1(2) Y1(2) Z1(2) X2(2) Y2(2) Z2(2) X3(2) Y3(2) Z3(2) X4(2) Y4(2) Z4(2)
.
.
.
. . . . . X4(NPAN) Y4(NPAN) Z4(NPAN)

```

Each line of data indicated above is input by a separate FORTRAN READ statement, hence line breaks between data must exist as shown. Additional line breaks between data shown above have no effect on the READ statement, so that for example the user may elect to place the twelve successive coordinates for each panel on four separate lines. (However the format used above is more efficient regarding storage and access time.)

Input data must be in the order shown above, with at least one blank space separating data on the same line.

The definitions of each entry in this file are as follows:

‘header’ denotes a one-line ASCII header dimensioned CHARACTER*72. This line is available for the user to insert a brief description of the file, with maximum length 72 characters.

ULEN is the dimensional length characterizing the body dimension. This parameter corresponds to the quantity L used in Chapter 4 to nondimensionalize the quantities output from WAMIT. ULEN can be input in any units of length, meters or feet for example, as long as the length scale of all other inputs is in the same units. ULEN must be a positive number, greater than 10^{-5} . An error return and warning statement are generated if the last restriction is not satisfied.

GRAV is the acceleration of gravity, using the same units of length as in ULEN. *The units of time are always seconds.* If lengths are input in meters or feet, input 9.80665 or 32.174, respectively, for GRAV.

ISX, ISY are the geometry symmetry indices which have integer values 0, +1. (A negative value is assigned when a vertical wall is present. This case is discussed in Section 5.3.) If ISX and/or ISY = 1, $x = 0$ and/or $y = 0$ is a geometric plane of symmetry, and the input data (panel vertex coordinates X,Y,Z and their total number NPAN) are restricted to one quadrant or one half of the body, namely the portion $x > 0$ and/or $y > 0$. Conversely, if ISX=0 and ISY=0, the complete submerged surface of the body must be represented by panels.

ISX = 1: The $x = 0$ plane is a geometric plane of symmetry.

ISX = 0: The $x = 0$ plane is not a geometric plane of symmetry.

ISY = 1: The $y = 0$ plane is a geometric plane of symmetry.

ISY = 0: The $y = 0$ plane is not a geometric plane of symmetry.

For all values of ISX and ISY, the (x, y) axes are understood to belong to the body system. The panel data are always referenced with respect to this system, even if walls or other bodies are present.

NPAN is equal to the number of panels with coordinates defined in this file, i.e. the number required to discretize a quarter, half or the whole of the body surface if there exist two, one or no planes of symmetry respectively.

X1(1), **Y1(1)**, **Z1(1)** are the (x, y, z) coordinates of vertex 1 of the first panel, **X2(1)**, **Y2(1)**, **Z2(1)** the (x, y, z) coordinates of the vertex 2 of the first panel, and so on. These are expressed in the same units as the length ULEN. The vertices must be numbered in the *counter-clockwise* direction when the panel is viewed from the fluid domain, as shown in Figure 3.1. The precise format of each coordinate is unimportant, as long as there is at least one blank space between coordinates, and the coordinates of the four vertices representing a panel are listed sequentially.

There are two situations when panels lie on the free surface, and thus all four vertices are on the free surface: (1) the discretization of a structure which has zero draft over part or all of its submerged surface, and (2) the discretization of the interior free surface for the irregular frequency removal as described in Chapter 9. For the first case, where the panels are part of the physical surface, the panel vertices must be numbered in the counter-clockwise direction when the panel is viewed from the fluid domain as in the case of submerged panels. For the second case, where the panel is interior to the body and non physical, the vertices must be numbered in the *clockwise* direction when the panel is viewed from inside the structure (or in the *counter-clockwise* direction when the panel is viewed from above the free surface). Details of the discretization of the interior free surface are provided in Chapter 9.

Although the panels on the free surface are legitimate in these two special cases, a warning message is displayed by WAMIT when it detects panels with zero draft, which have four vertices on the free surface. This is to provide a warning to users for a possible error in the discretization other than the above two exceptional cases. The run continues in this case, without interruption. An error message is displayed with an interruption of the run when the panels have only three vertices on the free surface, unless two adjacent vertices are coincident. (The latter provision permits the analysis of a triangular panel with one side in the free surface.)

The three Cartesian coordinates of four vertices must always be input for each panel, in a sequence of twelve real numbers. Triangles are represented by allowing the coordinates of two adjacent vertices to coincide, as in the center bottom panels shown in Figure 3.1.

Two adjacent vertices are defined to be coincident if their included side has a length less than $ULEN \times 10^{-6}$. An error return results if the computed area of any panel is less than $ULEN^2 \times 10^{-10}$.

The input vertices of a panel do not need to be co-planar. WAMIT internally defines planar panels that are a best fit to four vertices not lying on a plane. However it is advisable to discretize the body so that the input vertices defining each panel lie close to a plane, in order to achieve good accuracy in the computed velocity potentials. An error message is printed if a panel has two intersecting sides. A warning message is printed if a panel is 'convex' (the included angle between two adjacent sides exceeds 180 degrees).

The origin of the body coordinate system may be on, above or below the free surface. The vertical distance of the origin from the free surface is specified in the Potential Control File. The same body-system is also used to define the forces, moments, and body motions. (See Chapter 5 regarding the change in reference of phase relations when walls are present.)

Only the wetted surface of the body should be paneled, and then only half or a quarter of it if there exist one or two planes of symmetry respectively. This also applies to bodies mounted on the sea bottom or on one or two vertical walls. The number of panels NPAN refers to the number used to discretize a quarter, half or the whole body wetted surface if two, one or no planes of symmetry are present respectively.

The displaced volume of the structure deserves particular discussion. Three separate algorithms are used to evaluate this quantity, as explained in Section 4.1. Except for the special case where the structure is bottom-mounted, the three evaluations (VOLX, VOLY, VOLZ) should be identical, but they will generally differ by small amounts due to inaccuracies in machine computation and, more significantly, to approximations in the discretization of the body surface.

For a bottom-mounted structure VOLZ is less than the true volume due to the missing panels in the bottom. In this case a substantial reduction should be observed for VOLZ, but VOLX and VOLY should be nearly equal. For the same reason, substantial differences may occur if a body is mounted in a vertical wall unless the origin of the body coordinates is in the plane of the wall. With these exceptions, substantial differences between the three volumes may indicate errors in the GDF input data.

A unique value of the displaced volume is required in computing the hydrostatic parameters, and in evaluating the body inertia for the motions of the freely-floating body. In these cases the displaced volume of fluid is based on the median (middle value of the three when ranked according to value) of VOLX, VOLY, and VOLZ. A warning message is displayed by WAMIT if the median volume is less than 10^{-30} .

■ A general-purpose pre-processor has been developed for preparation of GDF files, using the MultiSurf geometric modelling program.¹ The extended version of the MultiSurf interface introduced with WAMIT Version 6.4 includes the option to generate and output a low-order GDF file directly during a WAMIT run, following the procedure described in Section 6.7 and Appendix C.

¹AeroHydro, Inc., 54 Herrick Rd., Southwest Harbor, Maine 04679 USA 207-244-4100 (www.aerohydro.com)

5.2 USE OF THE SOURCE FORMULATION (ISOR=1)

This section describes the evaluation and use of the source strength, in the context of calculating the fluid velocity components on the body and the mean drift force and moment based on pressure integration in uni- and bi-directional waves.

In order to evaluate effectively the tangential components of the fluid velocity on the body (and hence the second-order mean pressure), the solution for the velocity potential based on Green's theorem is augmented if ISOR=1 by the corresponding solution for the source distribution on the body surface.

Setting the parameter ISOR=1 in the POT file or in the CONFIG.WAM file specifies that the source-distribution integral equation is solved in addition to the velocity-potential integral equation. Extended values are assigned to the option switches IOPTN(5), IOPTN(6), IOPTN(7) and IOPTN(9) in the FRC file, to control the evaluation of the fluid velocity on the body and the pressure-integrated drift force/moment, respectively. Explanations of the new output quantities and changes in input are explained in the following section. A brief description of the theory is provided in Section 12.5. (Further details are given in [10] and [26].)

Values of the horizontal drift force and vertical drift moment can be compared with the corresponding outputs evaluated using momentum conservation. In general the results obtained from integration of the second-order pressure will require a finer discretization on the body surface, particularly in the vicinity of sharp corners.

Body symmetries can be exploited to minimize computing time. Special attention must be given to the evaluation of the drift forces, since these are dependent on quadratic products of the first-order solution. For example, if the body has two planes of symmetry the vertical first-order exciting force and heave response can be evaluated simply by setting IRAD=-1, IDIFF=0, MODE(3)=1, and the remaining MODE indices equal to zero. This will not give the correct vertical drift force on the body, however, since the components of the diffraction potential and body motions which are odd functions of x and y have not been evaluated. In general the drift forces should be evaluated only after evaluating all components of the first-order potential, i.e. by setting IDIFF=1 for the stationary body and IRAD=1 and IDIFF=1 for the freely floating body in the POT file. [An example of a valid short cut exists if both the body geometry and the hydrodynamic flow field are symmetrical about a plane of symmetry; then it is not necessary to evaluate first-order potentials which are odd about that plane since these would vanish. For example, if the body is symmetrical about $y = 0$ and the incident-wave heading angle is either zero or 180° , the drift force and moment can be obtained by setting MODE(n)=0 for $n = 2, 4, 6$.]

To calculate the mean drift forces it is necessary to evaluate the runup or, equivalently, the velocity potential at the waterline. Since the program utilizes the velocity potentials at the centroids of the panels adjacent to the waterline for the runup, it is advisable to use panels with small vertical dimensions near the waterline.

In the Force Control File (FRC) extended options are assigned to IOPTN(5), IOPTN(6), IOPTN(7) and IOPTN(9), as follows (See also Section 3.3):

IOPTN(5) is the index used to specify whether the pressure and/or velocity are evaluated on the body boundary:

IOPTN(5) = 0: Do not output either the pressure or velocity.

IOPTN(5) = 1: Output the pressure only.

IOPTN(5) = 2: Output the velocity only (requires ISOR= 1).

IOPTN(5) = 3: Output both the pressure and the velocity (requires ISOR= 1).

IOPTN(6) is the index used to specify whether the pressure in the fluid and/or free surface elevation are evaluated.

IOPTN(6) = 0: do not output pressure and/or free-surface elevation

IOPTN(6) = 1: do output pressure and/or free-surface elevation by the potential formulation

IOPTN(6) = 2: do output pressure and/or free-surface elevation by the source formulation

IOPTN(7) is the index used to specify whether the velocity in the fluid is evaluated.

IOPTN(7) = 0: do not output fluid velocity in the fluid

IOPTN(7) = 1: do output fluid velocity in the fluid by the potential formulation

IOPTN(7) = 2: do output fluid velocity in the fluid by the source formulation

IOPTN(9) is the index used to specify whether the mean drift forces are evaluated from pressure integration:

IOPTN(9) = 0: do not evaluate the mean force and moment

IOPTN(9) = 1: do evaluate the mean force and moment for each wave heading (requires ISOR= 1).

IOPTN(9) = 2: do evaluate the mean force and moment for all combinations of the wave headings (requires ISOR= 1).

The non-dimensional fluid velocity is evaluated in vector form with respect to the global coordinate system at the centroid of each panel. The non-dimensional definition of the fluid velocity is given in Section 4.7.

Three coordinate systems are used in the analysis of the second order mean forces and moments. The first is the global coordinate system (an inertial coordinate system) whose origin should be on the free-surface with the vertical axis positive upward. The phases of time-harmonic quantities in WAMIT are defined with respect to the phase of the incident wave at the origin of the global coordinate system. The second coordinate system is the body-fixed coordinate system. The position and orientation of this coordinate system at rest are defined relative to the global coordinates by the input array XBODY (see Chapter 3). The third coordinate system, introduced to provide additional flexibility in the mean-force analysis, is the inertial coordinate system which coincides with the body-fixed coordinate system at rest. This third system is illustrated in Section 12.5, Figure 12.2.

The non-dimensional definitions of mean drift forces and moments are defined as in Section 4.8. Typical outputs are provided in Test03 described in the Appendix (Section A.3). The following features should be noted in the output:

- i) On the line showing the number of iterations required for the solution, the second number inside the parenthesis indicates the maximum number of iterations required for the solution of the linear system for the evaluation of the source strength.
- ii) The components of the fluid velocity on the body surface are defined in reference to the global coordinate system.
- iii) The three drift force and moment components evaluated by momentum conservation are defined with reference to the axes of the **global coordinate system**.
- iv) The six components of the drift force and moment evaluated by pressure integration are defined with reference to the axes of the **body coordinate system at rest** (O of Figure 12.2). Also listed in the OUT file, in the two right columns, are the components of the moment vector defined with respect to the **body-fixed coordinate system** (o of Figure 12.2).

The format of the numerical output files is given in Section 4.9.

5.3 BODY NEAR VERTICAL WALLS

WAMIT includes the option to account for images of the body in the presence of one vertical wall, or two vertical walls which intersect at a right angle. The method described here is restricted to the low-order method (ILOWHI=0). A more general method, introduced in WAMIT V6.4 and described in Section 10.9, is recommended in all cases except where compatibility with earlier versions is required.

Figure 5-2 defines two coordinate systems, one fixed on the body and the other on the wall. The axes of the former are denoted by (x, y, z) and those of the latter by (X, Y, Z) . In the presence of wall(s), the global coordinate system defined in Section 3.1 must coincide with the wall coordinate system as defined in Figure 5-2. Only one body may be analyzed in the presence of walls (NBODY=1). The drift force and moment cannot be evaluated by momentum integration.

In the GDF file the panels are defined as in Section 5.1, in terms of the body coordinate system. Negative values (-1, -2) are assigned to the symmetry indices **ISX**, **ISY** in place of the conventional corresponding values (0, 1) to indicate the presence of either one or two walls, as follows:

ISX = -1 or -2: The $X = 0$ plane is a plane wall.

ISY = -1 or -2: The $Y = 0$ plane is a plane wall.

If ISX or ISY is assigned the value -1, no local plane of symmetry is assumed and the body must be represented completely (or half of it must be represented in the case where the complementary plane of symmetry is specified). Conversely, if the body has a local plane of symmetry $x = 0$ and/or $y = 0$, ISX and/or ISY can be assigned the value -2, with panels defined in the GDF file only for the portion of the body where $x \geq 0$ and/or $y \geq 0$. For example, ISX = -2, ISY = 0 signify that a wall is present on the $X = 0$ plane and that the body is symmetric about the local $x = 0$ plane. In this case only the half of the body needs to be discretized by the input panels. When ISX = 1, ISY = -2, a wall is present on the $Y = 0$ plane and the body has two local planes of symmetry.

In the Potential Control File the vector **XBODY(1),XBODY(2),XBODY(3)** specifies the dimensional (X, Y, Z) coordinates of the origin of the body-fixed coordinate system relative to wall system, in the units of the length ULEN. **XBODY(4)** is the angle in degrees formed by the body x -axis and the X -axis of the wall system, as defined in Figure 5-2. The values of the incident wave heading angles **BETA** are defined with respect to the positive X -axis.

An important detail to note is the definition of the incident-wave amplitude and its physical interpretation. The 'incident-wave' is defined as the incoming wave component prior to reflection from the wall(s), and A is the corresponding amplitude. After reflection the resulting wave field, in the absence of the body, is an oblique standing wave with

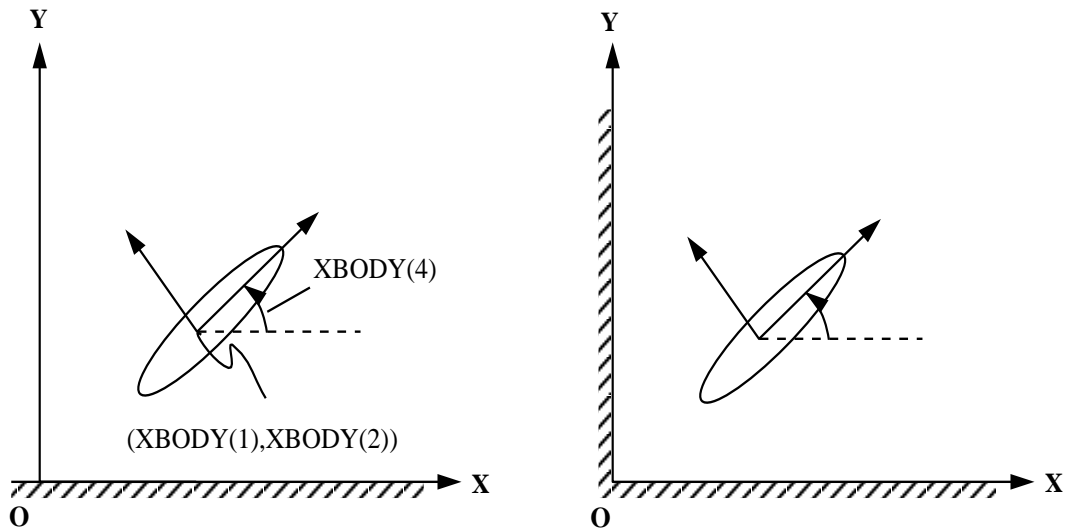


Figure 5.2: Definition sketch of coordinates

maximum free-surface elevation $2A$. In the special case $\beta = 0$ the incident wave propagates parallel to the wall, without a distinct reflected component, but the physical amplitude of this wave is $2A$. Some consequences of this definition are noted in the comparison of Test Runs 04 and 19 (see Sections A.4 and A.19).

In the Force Control File the array IOPTN is unchanged from the definitions in Section 3.3. Since momentum integration cannot be used to determine the mean drift force and moment, IOPTN(8)=1 is ignored. IOPTN(9) is used in the normal manner to evaluate the drift force and moment from pressure integration. The Haskind wave heading angles **BETAH** are defined with respect to the walls in the same manner as the array BETA above. The coordinates of field points **XFIELD** where the pressure, wave elevation, and velocity are evaluated, are defined as in Section 3.3 relative to the wall-mounted system.

The incident-wave velocity potential is defined relative to the wall-mounted coordinate

system. Consequently, the phases of the exciting forces, motions, hydrodynamic pressure and field velocity induced by the incident wave are understood relative to the incident-wave elevation at $X = Y = 0$. In addition the fluid velocity vector components are given with respect to the wall-mounted coordinate system.

The other definitions of output quantities in Chapter 4 are unchanged.

5.4 BODIES WITH THIN SUBMERGED ELEMENTS

In Version 6 an extension has been developed to analyze bodies which consist partially (or completely) of elements with zero thickness. These elements are represented by panels in the same manner as conventional body panels (Section 5.1). Figure 5-3 shows a typical example of a floating spar with thin helical strakes. This structure is analyzed in Test Run 09, described in the Appendix (Section A.9).

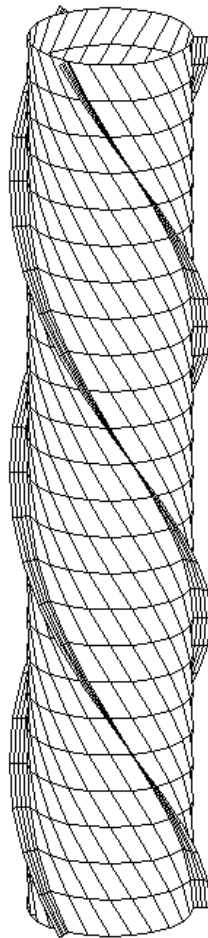


Figure 5.3: Perspective view of a floating spar with three helical strakes, showing the conventional panels on the spar and dipole panels on the strakes.

The velocity potential on the zero-thickness elements is represented by dipoles alone, with no corresponding sources. The panels are referred to as ‘dipole panels’. Since both sides of the dipole panels adjoin the fluid, the order of the vertex coordinates shown in Figure 5-1 (clockwise or counter-clockwise) is irrelevant.

- In Version 6.4 two alternatives are provided to identify the dipole panels. The first, used in earlier versions including Version 6.3, identifies the dipole panels entirely in the GDF file. The second alternative, introduced in Version 6.4, identifies the indices of the dipole panels in the CFG file as explained in Section 3.7. The second alternative is recommended except in cases where compatibility is required with earlier versions of WAMIT, or with earlier input files.

- In the first alternative where only the GDF file is used, the dipole panels must be included separately, after the conventional panels which represent the remainder of the body surface (and also the interior free surface, if IRR=1). The format of the GDF file is as follows:

```
header
ULEN GRAV
ISX ISY
NPANC
X1(1) Y1(1) Z1(1) X2(1) Y2(1) Z2(1) X3(1) Y3(1) Z3(1) X4(1) Y4(1) Z4(1)
X1(2) Y1(2) Z1(2) X2(2) Y2(2) Z2(2) X3(2) Y3(2) Z3(2) X4(2) Y4(2) Z4(2)
.
.
. . . . . X4(NPANC) Y4(NPANC) Z4(NPANC)
NPAND
X1(1) Y1(1) Z1(1) X2(1) Y2(1) Z2(1) X3(1) Y3(1) Z3(1) X4(1) Y4(1) Z4(1)
X1(2) Y1(2) Z1(2) X2(2) Y2(2) Z2(2) X3(2) Y3(2) Z3(2) X4(2) Y4(2) Z4(2)
.
.
. . . . . X4(NPAND) Y4(NPAND) Z4(NPAND)
```

Here NPANC is the number of conventional panels, NPAND is the number of dipole panels, and NPAN=NPANC+NPAND is the total number of panels in the GDF file. The first part of the GDF file, ending with the line which includes X4(NPANC), is identical to a conventional GDF file for the same body without the dipole panels. The remainder of the file, starting with NPAND, defines the dipole panels which represent the zero-thickness elements.

- In the second alternative, the indices of the dipole panels are defined in the CFG file by including one or more lines starting with ‘NPDIPOLE=’, followed by the indices or ranges of indices of the dipole panels, as explained in Section 3.7. In this case the format of the GDF file is as explained for the case without dipole panels in Section 5.1, and the parameter NPAN is the total number of panels including both conventional and dipole types. The dipole panels may be located arbitrarily within the array of all panels.

- The same alternatives can be extended to multiple bodies, with dipole panels specified for some or all of the bodies, following the procedure described in Chapter 7. It is possible to use different alternatives for different bodies, with the dipole panels identified in the GDF for some bodies and in the CFG for other bodies.

The source formulation cannot be used if dipole panels are included. Thus the fluid velocity on the body cannot be evaluated, and the mean drift force/moment can only be evaluated by the momentum method. An error message is output and the run is terminated if ISOR=1 with dipole panels specified in the GDF file.

- It is possible to analyze bodies which consist entirely of zero-thickness elements, by setting NPANC=0 in the first alternative method or by including the line 'NPDIPOLE=(1 nn)' in the CFG file, where nn=NPAN is the same integer value input in the GDF file.

A symmetry plane can be used when there are flat thin elements represented by dipole panels on the plane of symmetry. As an example, when a keel on the centerplane $y = 0$ is represented by dipole panels, either the port or starboard side of the vessel can be defined in the GDF file with ISY=1