

Stamped features: creation of engineered structures in conceptual models

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ABSTRACT

Applying numerical modelling techniques to surface water bodies often requires the addition of man-made structures such as embankments or dredged shipping lanes to the natural bathymetric conditions. The application of the model may be to determine the specifications of these structures, such as size and location. Therefore, multiple variations of the structure must be evaluated. Interactive methods to easily create these structures in grids used by numerical models are presented that show great promise in reducing the time and effort required to consider multiple scenarios for modelling and management. The methods presented utilize a conceptual representation of the domain. Features in this conceptual model are used to derive grid elements for the numerical model. The resulting numerical models provide information for decision support based on multiple design considerations.

Key words | conceptual model, features, hydraulics, numerical modelling

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INTRODUCTION

Multidimensional numerical modelling has always required a significant amount of work to develop networks of grid cells or elements. When modelling natural regions of either surface water or groundwater, the use of a conceptual model (Jones & Richards 1994; Zundel & Jones 1996; Zundel *et al.* 1998; Nelson *et al.* 1999) has significantly decreased the cost involved in developing these geometric representations. Conceptual modelling uses GIS style entities to represent the domain and boundary conditions for the numerical model.

In the conceptual modelling approach, nodes, arcs and polygons (see Figure 1) are created to represent the location of natural features. For example, a node could locate a point source of flow or a location of particular interest. Arcs define important linear features in the numerical model. This includes both domain boundaries and interior details. Attributes assigned to the arc include the types of boundary conditions. Polygons delineate

the extents of the mesh as well as material zones and geometric property zones.

From the conceptual model, automated methods are used to fill the polygons with mesh elements or grid cells for application to a specific numerical method (EMRL 2000; Kuniandy & Lowther 1993). The algorithms extract bathymetry data for this network from observed scattered elevation data, regular digital terrain data, or existing numerical models.

Application of the finite element or finite volume method to surface water applications often requires the addition of engineered structures to modify the flow conditions. These structures include embankments for roadways, jetties, breakwaters, and levies. Other modelling applications may require creation of features such as deeper channels or borrow pits created by the movement of bed materials to another area. This paper presents an algorithm for the automatic creation of GIS entities

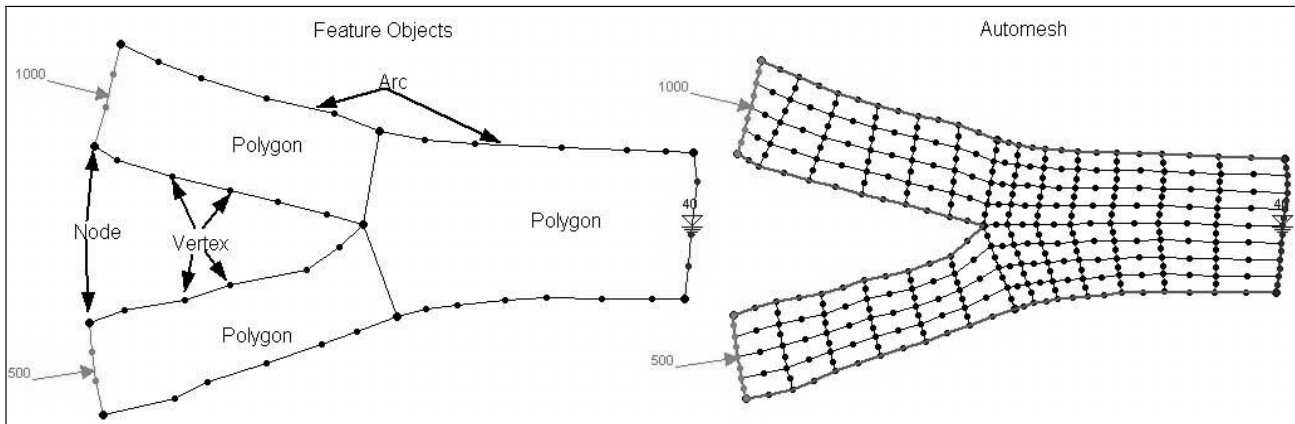


Figure 1 | Sample conceptual model and automatic mesh.

that represent man-made structures, and the subsequent representation in the numerical model. These structures are referred to as stamped features.

TYPES OF STAMPED FEATURES

Stamped features include two basic types, embankments/fills and channels/cuts. Both of these require the definition of attributes to define the shape of the feature. A later section describes the parameters that define these attributes in detail. In general terms, a feature consists of a flat feature area, a transition zone, and an end cap (see Figure 2).

The flat region represents either the top of the embankment or the bottom of the channel. The transition zone defines the sloped surface that transitions from the flat zone into the natural bathymetry zone. This transition zone degenerates into a line when vertical sidewalls are desired. The abutment or end type determines the shape of the end cap. The newly developed algorithm supports three options for end types with vertical walls and three options for end types with sloped walls.

Vertical wall end types

Newly created features default to having vertical walls because these require no bathymetric information. Three

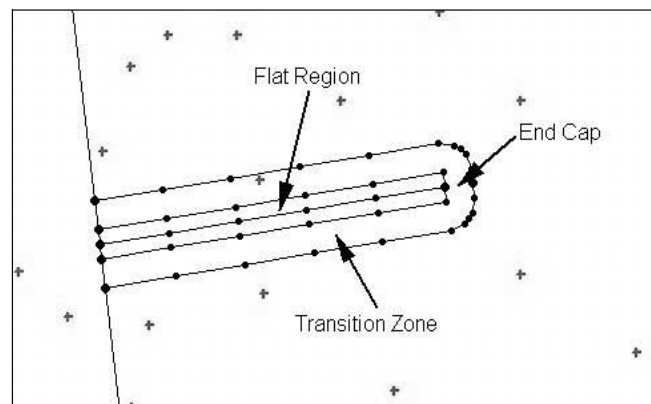


Figure 2 | The parts of a stamped feature.

end types have been tested. The end types for vertical walled features include square, rounded and wing walls. Figure 3 illustrates these three options.

Sloped wall end types

Sloped wall features include a region that transitions from the flat zone to natural bathymetry. Therefore, bathymetric data is required for these features. The three end types supported are illustrated in Figure 4.

The sloped transition region makes sloped wall features more complex than vertical wall features. It also opens up the possibility of more complex end types.

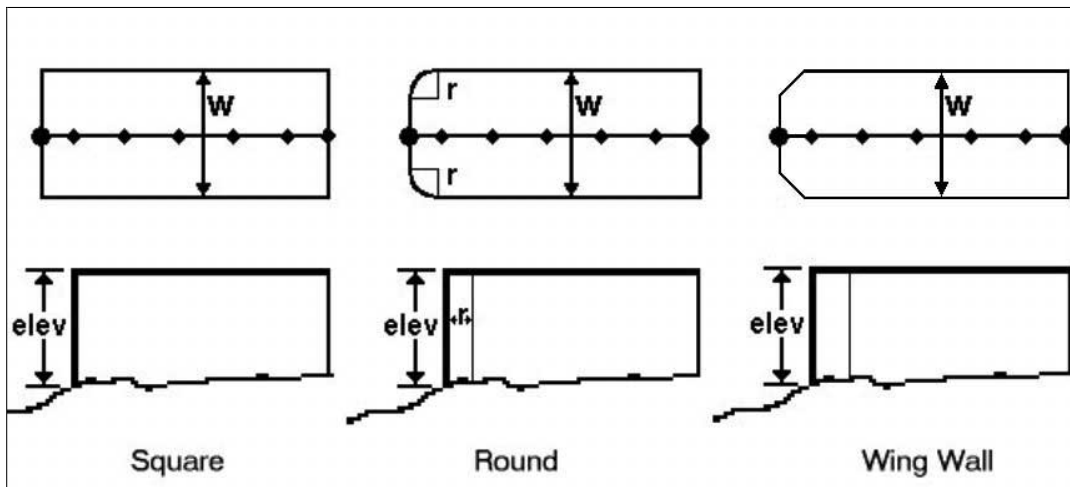


Figure 3 | Vertical wall end types—side and top views. The variables W , r and $elev$ represent the width of the flat zone (i.e. the width of the top of the embankment), the radius of curvature, and the elevation of the flat zone relative to a fixed datum, respectively.

PROCESS TO CREATE A STAMPED FEATURE

Three steps define the process of creating a stamped feature:

1. Creation of the centreline of the feature.
2. Assignment of the feature's attributes.
3. Generation of the additional GIS objects required to delineate the centreline of the feature.

The creation of the centreline is accomplished by the definition of a feature arc or feature arc group. This arc defines the geometric centre of the top of the embankment or the bottom of the channel. This feature may be an isolated arc that will become a desired breakwater, central portion of an embankment, or a channel connecting two regions of deeper water. It may also be connected to other conceptual features such as the bank or edge of the waterway being considered, as shown in Figure 5.

All arcs in a conceptual model can have attributes. The types of attributes depend on the specific capabilities of the numerical model being used. An arc may be used to represent a geometric feature in the mesh or a closed boundary of the domain, or it may be an open boundary, with parameters such as a flow rate or head value. In the case of stamped features, the modeller specifies the

attribute of the arc to be the centreline of a specific stamped feature and defines the following parameters (illustrated in a sample dialogue in Figure 6):

- feature type (embankment or channel)
- width of the flat zone (W)
- elevation of the flat zone ($elev$)
- slope of the side (zero slope indicates vertical sides) (Se)
- end type (as illustrated above)
 - radius of curvature for rounded/vertical wall (r)
 - wing wall angle for all wing walls (a)
 - wing wall width for vertical wall
 - end slope for sloped end (S)
- end cap orientation (default equal parallel to the bank if bank exists, perpendicular to end of centreline if no bank exists).

OVERVIEW OF THE ALGORITHM

The algorithm used to create the stamped feature includes these four steps:

1. create arcs that define the flat area of the feature,

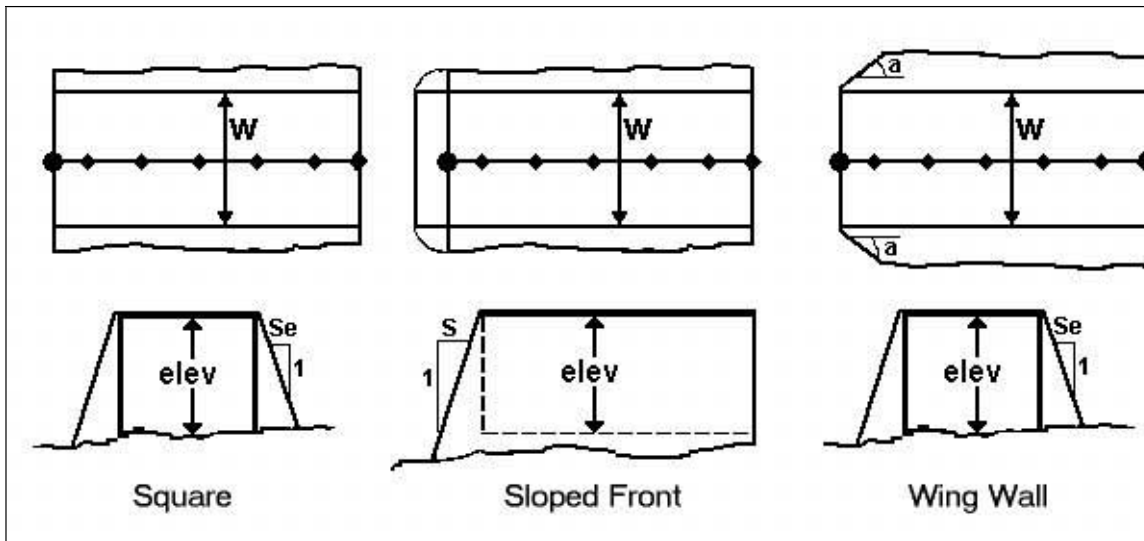


Figure 4 | Sloped wall end types. The variables Se , S and a represent the side slope run per unit rise, the end slope run per unit rise and the angle of the wing wall. Other variables are the same as in Figure 3.

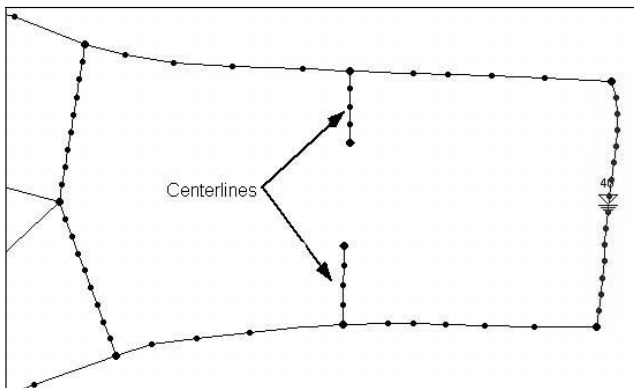


Figure 5 | Sample feature centerlines in a conceptual model.

2. assign an elevation to all nodes and vertices on the flat area arcs,
3. create arcs that define the transition zone of the feature (if required),
4. create arcs that define the end cap zone (if required).

Step 1—The flat area

The flat area of the feature consists of a topologically rectangular region surrounding the centreline arc. The

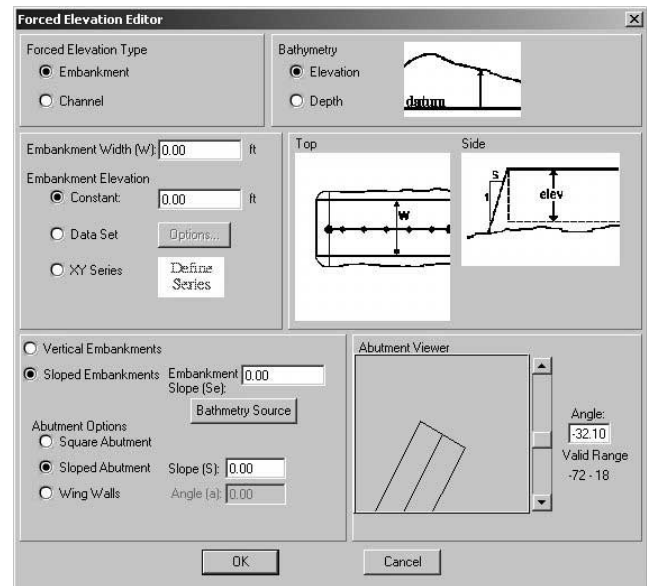


Figure 6 | Stamped feature attributes.

algorithm generates the sides of this rectangular region by offsetting the centreline at each vertex or node by half of the embankment width in each direction. The perpendicular direction is computed from the average of the two segments connected to any vertex or node (see Figure 7). These offset centreline arcs define the edge of the stamped

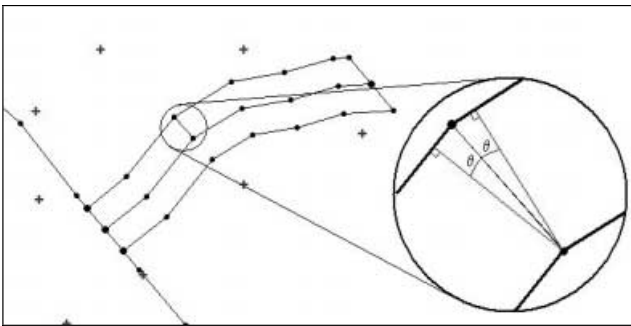


Figure 7 | Perpendicular direction from the centreline point.

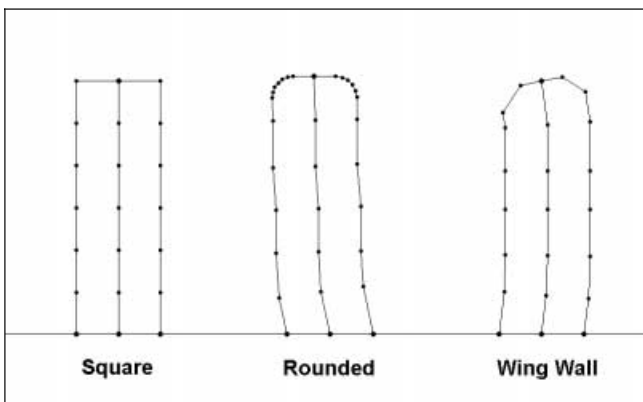


Figure 8 | Vertical walled embankment end modifications.

feature and will be referred to as flat edge arcs. To complete the ends of the flat rectangular region, the algorithm computes the intersection of the edge arcs with the bank or edge of water arcs if they exist. In the case of a free feature end, the defined end direction defines the orientation of the end of the rectangle.

The free end of the flat area requires modification if vertical sides with rounded or wing wall corners are specified (Figure 8). For rounded corners, the algorithm inserts a new vertex every 15° around the curve. For wing wall corners, it inserts two new vertices to cut in the wing wall.

Step 2—Flat area elevations

The newly created flat edge arcs need elevations to complete the definition of the flat area. Three elevation options are provided: constant, scatter set, and xy series. For

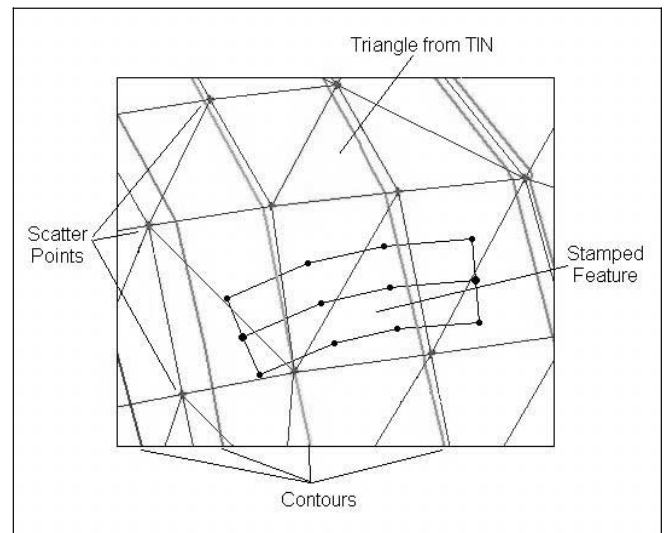


Figure 9 | TIN with contours under stamped feature.

constant elevation the algorithm assigns the value to all of the nodes and vertices. Similarly, for the scatter set option, the algorithm interpolates an elevation from the selected scatter set at each of the nodes and vertices in the flat area. The xy series option requires the definition of a curve of elevation values versus distance along the feature. The elevation is assigned at each node and vertex by computing the distance between the node or vertex and the beginning of the stamped feature. The elevation corresponding to this distance is then assigned to the vertex.

The process described in the previous two steps creates a flat area. This completes the algorithm for vertical sided stamped features. In order to create stamped features with sloped sides, the algorithm requires a representation of the natural bathymetry. This usually consists of a series of data points that form a triangulated irregular network or TIN (Jones *et al.* 1990; Nelson *et al.* 1999). Figure 9 shows the vertical walled stamped feature overlaid on a TIN. The contours of bathymetry from the TIN are displayed as grey lines.

Step 3—The transition zone

The transition zone of a stamped feature consists of the region where the elevation transitions from the specified

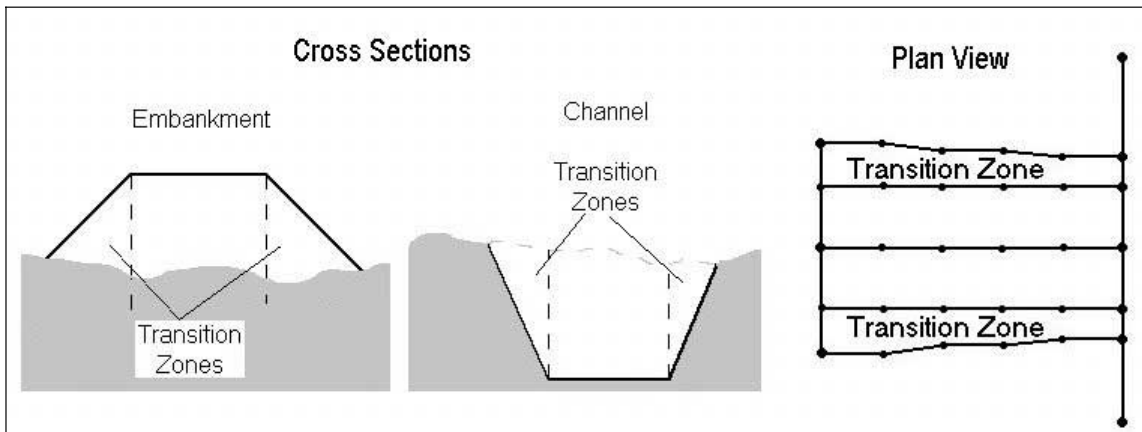


Figure 10 | Transition zone illustrations.

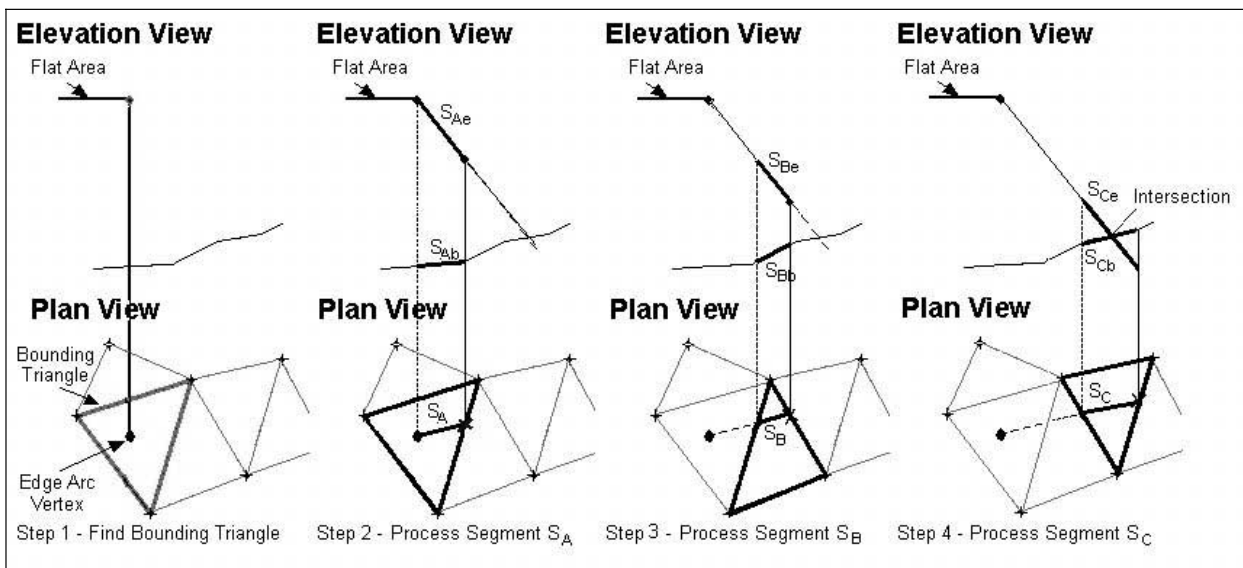


Figure 11 | TIN traversal to define extents of transition zone.

flat zone elevation to the elevation in the bathymetric data (see Figure 10).

In order to create the transition zone, two intersection arcs are defined as offsets from the flat area edge arcs (described in step 1). The algorithm to create these intersection arcs creates one vertex on the intersection arc for each vertex on the flat edge arc by finding the intersection point between a line extended in the perpendicular direction from the flat edge arc down the embankment

slope with the bathymetric data. Figure 11 illustrates the process.

Starting at a vertex on the flat edge arc, the algorithm finds the triangle from the bathymetric data that contains the point (see Figure 11 Step 1). Proceeding in the perpendicular direction from the flat edge arc to the first triangle edge in the TIN defines the line segment S_A in the plan view. The projection of this line segment on the embankment is line S_{Ae} and the projection on the bathymetric

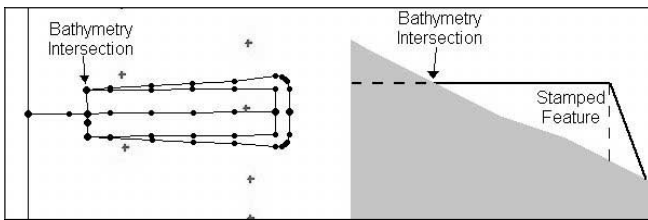


Figure 12 | Intersection of bathymetry and flat zone.

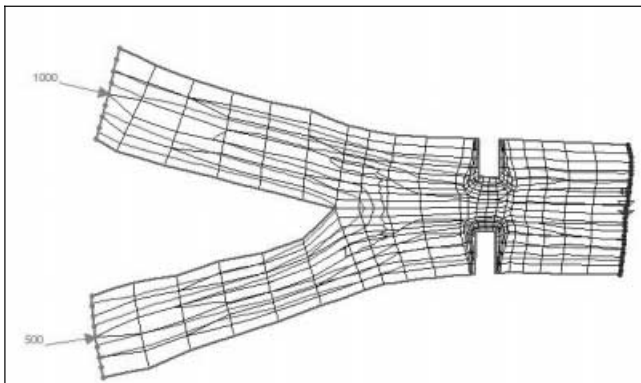


Figure 13 | Stamped feature represented in elements with bathymetry contours.

data is line S_{Ab} . If S_{Ae} and S_{Ab} do not intersect then line segment S_B is defined by continuing through the adjacent triangle in the bathymetric data (see Figure 11 Step 3). Again a check is made to see if line segment S_{Be} intersects S_{Bb} . If not, the process repeats for the next adjacent triangle. As can be seen in the example defined by Figure 11 Step 4, line segment S_{Ce} intersects S_{Cb} . Once the intersection is found a vertex is inserted into the intersection arc and the process is repeated for the next vertex on the flat edge. For edge points that lie on a bank arc, the TIN is traversed along the bank.

Step 4—The end cap zone

Additional considerations in creating the intersection arcs occur for the sloped end, or wing wall options. Creation of the sloped end follows the process used for the sloped sides by sloping away from the end of the flat zone at a specified slope. The circular corners are created by sloping from the corner point of the flat zone at 30°, 45° and 60°

measured perpendicular from the sloped end. The slope at each of these directions comes from an interpolation of the side slope and the end slope. This will create a smooth rounded corner between the end slope and the side slope.

The sloped wing wall abutment is created similar to the sloped side abutments; however, the corner points of the face are sloped back towards the bank at the wing wall angle. The remaining vertices are then created as the standard sloped sides.

SPECIAL CONSIDERATIONS

Several cases exist which cause difficulties to the algorithm described in the previous section. The two principal cases are described in this section. The first case includes situations where the top elevation of a feature designed to be an embankment drops below the natural bathymetry or the bottom elevation of a channel rises above the natural bathymetry. This is referred to as a cut/fill transition. The second case occurs when newly created arcs, which represent the stamped feature, intersect other arcs in the conceptual model or have self-intersections. This case is referred to as feature overlap.

Cut/fill transitions

When the elevation of the flat zone of a stamped feature intersects the natural bathymetry, the cut/fill transition problem exists. Figure 12 illustrates this case. When this occurs, the intersection between the flat zone and the bathymetry must be computed. This intersection will form a curve that may run perpendicular to the centreline (as shown) or may run through the flat zone parallel to the centreline for a region.

The first difficulty is determining what the extents of the stamped feature should be. One option would be to create a fill in the area where the feature is above the bathymetry, and a cut in the area where the feature is below. Another option would be to keep only one of these zones. The decision on whether to automatically change or specify only cutting or filling for a single feature should

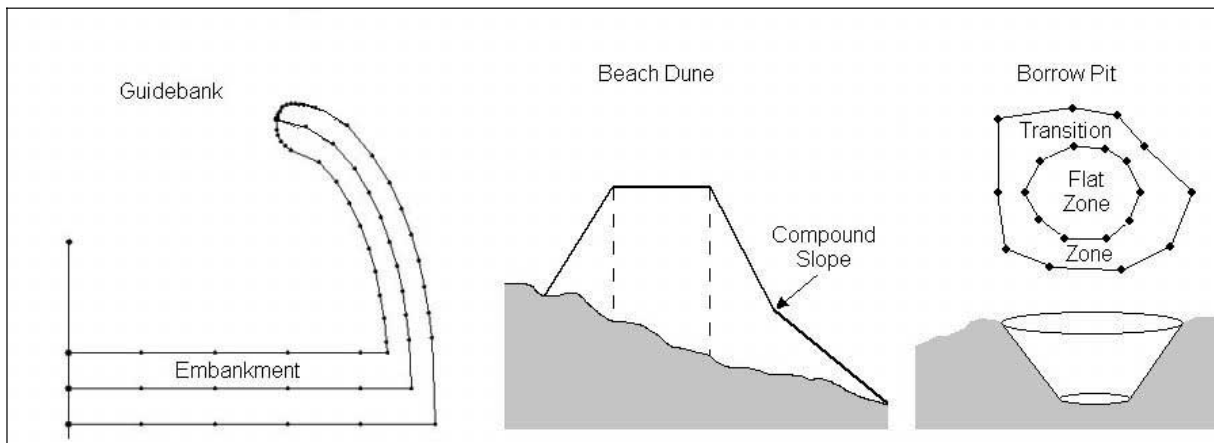


Figure 14 | Guidebanks, beach dunes and borrow pit applications.

be decided based on the specific application. The applications of this algorithm are for hydrodynamic models, therefore automatic transitions are not anticipated and have not been developed as a part of the algorithm. For example, if a channel is being cut into the bathymetry at a specified elevation and the natural bathymetry drops below the elevation of the channel, the elevation at this portion of the channel would follow the natural bathymetry. Therefore the feature should include only the cut zone. However, if the feature were defining a continuous level, such as a roadway, an automatic change from cut to fill would be desired.

The second difficulty arises because the sloped transition zone needs to intersect with the flat zone, and for the case of no automatic change the flat zone requires modification to include the smaller domain. The algorithm handles this case by creating an additional arc and inserting it where the flat zone intersects the natural bathymetry. The transition zones connect into this arc. The remainder of the flat zone is no longer created. The left portion of Figure 12 shows the arc created at the bathymetry intersection. To the left of this intersection, the centreline remains, but there is no flat region.

Arc intersections and overlaps

The conceptual model can become corrupt if arcs overlap without intersecting or if duplicate arcs exist. Therefore,

we need to check for cases in which the created stamped feature arcs overlap other features in the conceptual model. A specific case occurs when the elevation of the bank arcs is the same as the elevation of the flat region of the feature stamp. When this occurs, the algorithm intersects the flat region with the bathymetry and creates an arc that overlays the banks. This causes a problem with the definition of the feature stamp, as two arcs are in the same location. Intersecting the newly created feature stamp arcs with the bank arcs and other internal arcs in the conceptual model eliminates this problem. Nodes are added at intersection points and any duplicate arcs are removed.

CONVERTING TO A FINITE ELEMENT MESH

The conceptual model is only the first step of performing a numerical analysis. In order to be effective the stamped features must assist in the creation of a geometric network that incorporates the feature into the natural conditions surrounding the feature. This is accomplished in two different ways. The first is the guidance for network regions provided by the stamped feature polygons. By defining the shape of the stamped feature in the conceptual model, the algorithm has assisted the modeller in laying out the elements that will fill the separate regions (Fugal 2000;

Gonzales 2000). The second is the source of bathymetry from the feature. The polygons created in the stamped feature creation process derive their bathymetry from the definition of the stamped feature and thereby the elevations of the feature become part of the resulting mesh or grid (see Figure 13).

POTENTIAL REFINEMENTS

This paper presents a new tool for creating networks for numerical models that integrate potential man-made modifications into natural bathymetry for modelling purposes. The application of stamped features provides a flexible means of modelling embankments and channels of just about any shape with minimal effort. However, several additional options are possible and are worthy of future consideration (see Figure 14). Guidebanks or spur dikes at the entrance to a bridge opening, construction of beach dune profiles with compound slopes, and analysis of borrow pits are examples of three such options which are under consideration.

CONCLUSION

The use of conceptual modelling to automatically create numerical models that conform to user specifications will result in a shift of effort from model creation to model application and interpretation. The ability to incorporate

engineered structures into the conceptual model, and thereby into the numeric model, provides a valuable tool that allows a numerical modeller to consider more design possibilities with less effort and cost.

REFERENCES

- EMRL 2000 *SMS v7.0 Reference Manual*. Environmental Modeling Research Laboratory, Brigham Young University, Provo, UT.
- Fugal, A. L. 2000 *Two-Dimensional Finite Element Density Meshing*. Masters Thesis, Brigham Young University, Provo, Utah.
- Gonzales, D. S. 2000 *An Automatic Finite Element Mesh Generation Method: The Adaptive Rectangular Coons Patch*. Masters Thesis, Brigham Young University, Provo, Utah.
- Jones, N. L., Wright, S. G. & Maidment, D. R. 1990 Watershed delineation with triangle based terrain models. *ASCE J. Hydraul. Engng.* **116** (10), 1252–1251.
- Jones, N. L. & Richards, D. R. 1994 A comprehensive modeling environment. *International Conference on Hydroinformatics* (ed. A. Verwey, A. W. Minns, V. Babovic & C. Maksimovic), pp. 317–322. A. A. Balkema, Rotterdam, The Netherlands.
- Kuniansky, E. L. & Lowther, R. A. 1993 Finite-element mesh generation from mappable features. *Int. J. Geog. Inf. Syst.* **7**(5), 395–405.
- Nelson, E. J., Jopnes, N. L. & Berrett, R. J. 1999 Adaptive tessellation method for creating tins from GIS data. *ASCE J. Hydrol. Engng.* **7**(5), 2–9.
- Zundel, A. K., Fugal, A. L., Jones, N. L. & Demirbilek, Z. 1998 Automatic definition of two-dimensional coastal finite element domains. *International Conference on Hydroinformatics* (ed. V. Babovic & L. C. Larsen), pp. 693–700 A. A. Balkema, Rotterdam, The Netherlands.
- Zundel, A. K. & Jones, N. L. 1996 An integrated surface water modeling system. *International Conference on Hydroinformatics* (ed. A. Muller), pp. 231–237. A. A. Balkema, Rotterdam, The Netherlands.