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# Distinct element modeling of geosynthetic fabric containers

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ABSTRACT: An analysis technique entitled the Distinct Element Method (DEM) has been applied to simulate the behavior of Geosynthetic Fabric Containers (GFCs) filled with various materials (sand, mud, water, etc.) and used for a large variety of applications. This paper describes two of the ways in which the DEM has been used to simulate these behaviors. These simulations include: (a), the behavior of GFC's loaded in split hull bottom-dump scows (in which the simulation follows the filling and exiting of the GFC through the opening split hull, the fall through the water column, and the impact with the sea-floor); and (b), the behavior of water-filled GFC's which function as dams (including the use of internal baffles and other devices to prevent rolling). All of these DEM techniques provide for input properties in terms of common soil mechanics parameters and the output includes the prediction of fabric tensile forces.

## 1 INTRODUCTION

The purpose of this document is to give brief overviews of two Distinct Element Method computer programs (codes). The first code entitled ScowDropSim**,** is used to simulate the behavior of geosynthetic fabric containers (GFCs) which are placed in bottom dump (or similar type) scows, filled with dredged sediments, and then transported and dumped at the desired location**.** The second code simulates the behavior of impermeable fluid filled GFCs utilized to retain a pool of water. All the programs are FORTRAN based and include graphics based input and output. The codes are operational on a Personal Computer (PC).

## 2 DESCRIPTION OF SCOWDROPSIM.

During the mid 1970's, a new numerical modeling technique entitled the Distinct Element Method (DEM) was conceived at the University of Minnesota. The technique was developed under the sponsorship of the Corps of Engineers and the author served as a technical monitor during the study. Since that time the author has developed specialized DEM codes and has applied them to topics such as scour and transport of rock in channels, flow of materials in channel networks and to exploding debris effects. Recently, DEM analyses were conducted to examine the behavior of Geosynthetic Fabric Containers (GFCs) used at Marina Del Rey (1994), and New York Harbor (1995), and to simulate the filling of geosynthetic fabric tubes placed for shoreline protection in Chesapeake Bay (1995). This technique seeks the solution for the motion of distinct rigid bodies (e.g. rocks or soil particles) acted upon by applied and gravity forces. Each distinct element (particle) will, when isolated from other elements, follow Newton's law of motion (i.e. F=Ma). When the elements are in contact, forces between those elements are transferred via the use of mathematical springs (situated in the normal and shear directions at the point of contact) visualized to exist at their points of contact. In order to conduct a meaningful simulation of a GFC problem, the various components of the problem must be defined and characterized by distinct elements which have properties that mathematically mimic the prototype properties. Therefore, the dredged sediment contained within the GFC is represented by a large number of small disc-shaped elements, the scow is represented by special bar-shaped elements for which motions (due to scow opening) can be specified, and the GFC membrane is represented by a linkage of disc-shaped elements which are connected such that tensile forces between them may be maintained. Variable material properties and descriptive specifications which are considered by the present DEM formulation for GFCs, include,

1) Bulk specific gravity, $\gamma_B$, of the contents of the GFC
2) Angle of internal friction, φ, between sediment elements
3) Angle of friction, δ, between the scow and the GFC
4) Stiffness, k, of the GFC
5) Tensile strength (kn/m) of the GFC
6) Circumference (and lapping configuration) of the GFC
7) Rate and maximum width of scow opening
8) Elevation of ocean level with respect to scow.
9) Rate and amplitude of scow fore-to-aft pitch
10) Hydrodynamic drag coefficient on the GFC as it falls through the water column
11) Depth of ocean (for bottom impact response)

All simulations are formulated as a 2-D representation taken perpendicular to the long axis of the scow. Typically, the sequence of computations is as follows:

1) The discs representing the sediment (using a close packing arrangement) and the GFC membrane are placed within the boundary elements which describe the scow.
2) The ocean level is adjusted to reflect the draft of the scow and the bulk density of the sediment is set.
3) The DEM motion calculations are begun and the sediment elements are allowed to react with the GFC elements and the GFC elements with the scow wall boundary elements so as to establish equilibrium of forces. Total weights are used for the sediment elements above the ocean level and buoyant weights below.
4) The rate of scow opening and scow pitch parameters (period and amplitude) are specified and the GFC, acted on by gravity, begins to descend through the scow opening as it widens.
5) The computations continue and the GFC, if possible, squeezes through the scow opening and exits the scow.
6) The GFC, acted upon by velocity dependent hydrodynamic drag forces continues to fall through the water column and impacts the sea floor.
7) Following impact, the GFC continues to deform until reaching an at-rest shape on the sea floor.

The formulation of the code follows a time marching scheme in which output from the code is delivered after selected time intervals. The DEM code produces graphical output of the positions of all of the elements at frequent time intervals. The output of the DEM code, for each selected time step, includes:

1) The forces (normal and shear) between the sediment elements.
2) The tensile (or compressive) forces between the elements comprising the GFC membrane.
3) The forces transmitted to the scow elements or ocean bottom elements.
4) The displacements (horizontal, vertical and rotational) of all elements comprising the simulation.
5) The velocities of each element.
6) The velocity and position of the centroid of the GFC.
7) The velocity and position of the top and bottom of the GFC.
8) The area of the GFC.
9) The hydrodynamic drag forces on the GFC.
10) The width of the scow opening

11) The length of fabric (the catenary length) extruding from the scow.

As the calculations are performed, the outputs listed above are stored in files on disc so that other display programs may retrieve them. These display programs may be used to produce good quality movie-like renditions and snapshots of the GFC behavior during scow exit, fall through the water column and sea floor impact. In addition, graphs may be prepared showing the values of the above listed items versus time.

The use of the DEM code to simulate the behavior of GFCs is two-fold. The first usage is to simulate the behavior using sediment and material property parameters which are believed to apply to the prototype and to then use the computed output from the code as a predictor of the prototype behavior. The second usage is to investigate the influence of changes in one or more of the system parameters so as to identify the ranges in which those parameters may vary without causing failure (seizure within the scow or excessive fabric strains) of the prototype deployment.

There are three modes of GFC failure which can be evaluated by this code. The first is failure caused by the seizure of the GFC within the scow. This type of failure occurred at Marina Del Rey and may have come into play during the 1995 GFC drop in New York Harbor. Simulations of these two drops with an earlier version of the DEM code indicated that seizure would occur. The second type of failure is rupture of the container due to excessive tensile strains in the fabric and seams during exit from the scow. This mode of failure probably occurred during the 1995 New York Harbor demonstration (and this mode was also indicated by DEM analysis). The third failure mode is rupture due to high tensile strains experienced by the fabric and seams upon ocean bottom impact. This type of failure probably occurred during the second (June, 1996) drop in the New York Harbor demonstration.

## 3 EXAMPLE OF SCOWDROPSIM SIMULATION

To illustrate the usage of the ScowDropSim code, the following set of 5 figures shows the sequence of events for a GFC exiting a bottom dump scow. Figure 1 shows the original placement of the GFC within the scow. The width of the scow hopper is 6.3 m, the depth of the hopper is 3.5 m and the draft of the loaded scow is 3.15 m. The circumference of the GFC is 15 m and the initial cross sectional area of the GFC is 12.4 m$^2$. The friction angle, $\varphi$, of the sand sediment was set to 30$^o$ and the friction angle of the GFC to the scow sides, $\delta$, was initially set at 24$^o$. The density of the sediment was set at 1.86 g/cc. The grid divisions shown on the plots are 0.61 m (2 ft). Figure 2 shows the situation after the scow has opened 1.9 m. The hinge point of the hopper rotation is indicated on the plots as the darkened circle located on the centerline of the drawings. Figure 3 shows that the GFC has seized within the scow even after the scow to GFC friction angle was lowered to 12$^o$ and the scow is fully opened to a width of 3 m.

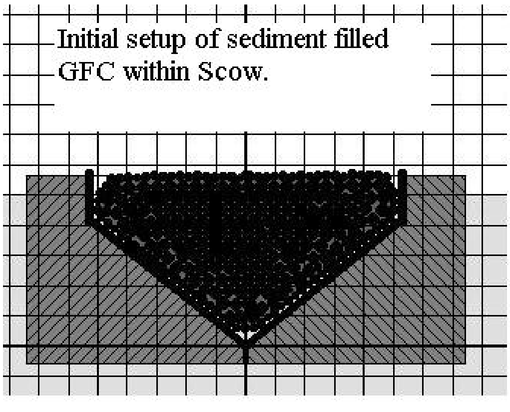


Figure 1. Initial setup of scow and GFC.

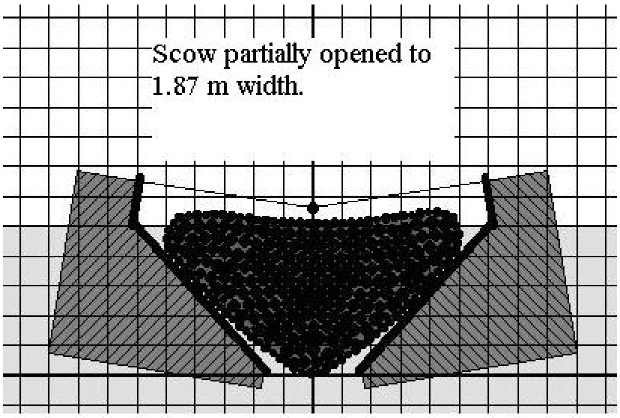


Figure 2. Intermediate stage of GFC release from scow.

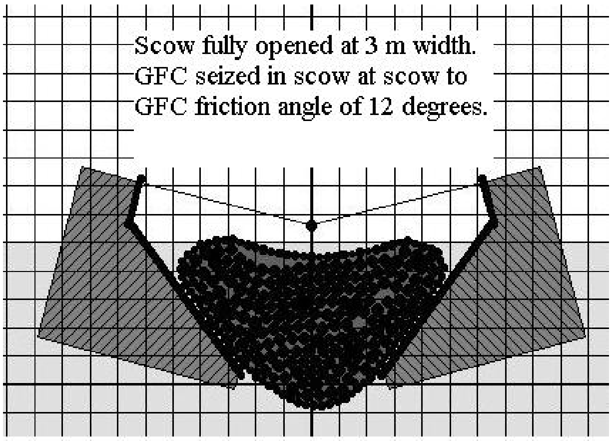


Figure 3. GFC seizure in scow at GFC to scow friction angle of 12$^o$.

Finally, after lowering the scow to GFC friction angle to 8$^o$, the GFC exits the scow as shown in Figure 4. The simulation may be continued to investigate the impact of the GFC with the ocean bottom as shown in Figure 5. The sediment friction angle of 30$^o$ led to a final "at-rest" GFC height of 2.72 m.

## 4 DESCRIPTION OF FLUID FILLED BARRIER TUBES WITH THE "GAP" CODE

A DEM code entitled "GAP" was developed to simulate the behavior of fluid filled GFCs (or tubes). This program is similar to the ScowDropSim code; the major difference being that it is presumed that the interior of the tube is filled with a saturated fluid rather than sediment elements. That is, within a tube the outward fluid pressure acting on a tube element is presumed to be given as $\gamma d$ (where $\gamma$ is the fluid density and, d, is the vertical distance from the topmost portion of the tube and the location of the element) plus an additional excess pressure, $p_o$. Therefore, at any point within the tube there exists a constant piezometric pressure governed by $p_o$. Similarly, if an external pool exists, the effect of that pool is to cause a similar pressure acting inward to the tube. It is also presumed that the tubes are impermeable (or that the tube inflow equals the outflow). Figure 6 shows a

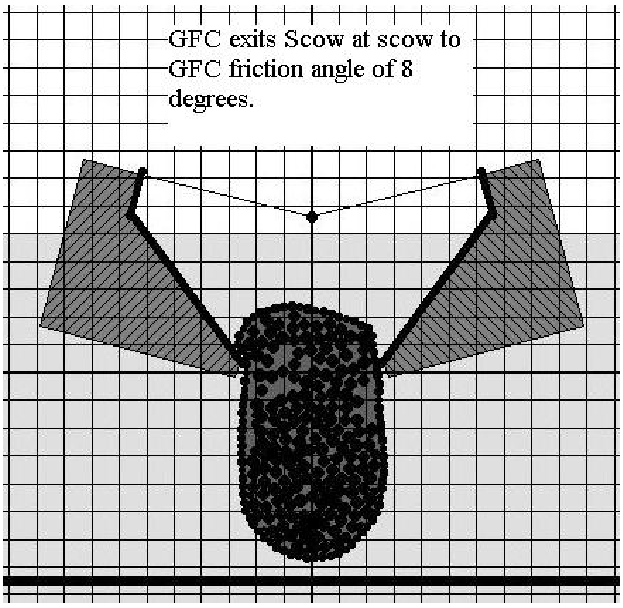


Figure 4. GFC exit scow at sufficiently low friction angle.

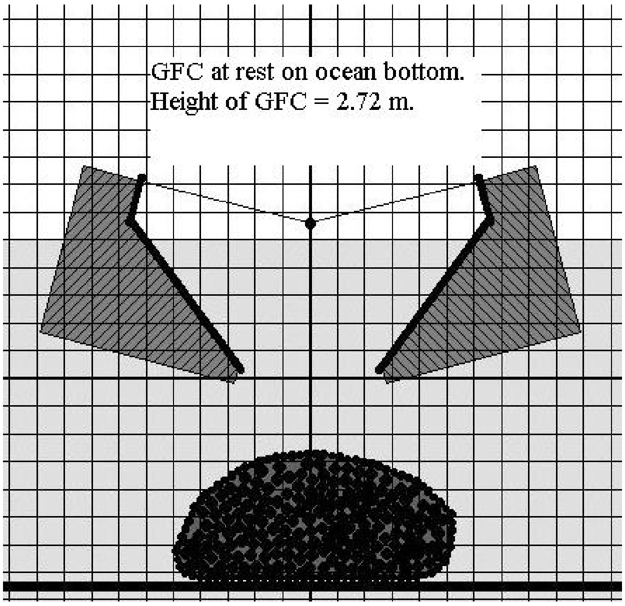


Figure 5. Final configuration of GFC on ocean floor.

water filled tube of 12 m circumference inflated to a height of 2m. This tube also contains two longitudinal membranes (or baffles) which are untensioned at the 2 m height. The purpose of the baffled tube is to act as a barrier to the flow of water. If the tube were not baffled or secured in some fashion, the application of an unbalanced pool water load on either side of the tube would result in a rolling of the tube and the tube could not function as an effective water barrier.

The computation of the excess pressure within the tube, $p_o$, required to result in a given tube circumference and height is not a trivial exercise. However, there is an equation and graphical procedure (Den Hartog, 1952) which does describe the shape of a fluid filled flexible membrane in which there exists a non zero pressure at the top of the membrane and for which the tension force in the membrane is constant. For a sausage shaped tube like membrane, the equation is:

$$R = T / p$$

where R is the local radius of curvature of the tube, T is the uniform tension force in the membrane and p is the pressure ($p_o + \gamma d$). Since the pressure at the top center of the tube is known to be $p_o$, and the tension force, T, is given, the radius at the top center of the tube is known. Then, a graphical solution may be used to compute the tube radii as one proceeds downward from the top. After this procedure has been carried out, the complete shape of the tube is then known (i.e. the height, circumference and area of the tube). A computer program entitled SOFFTWIN has been developed by the author to perform these graphical solutions. If the tension force, T, and the excess pressure, $p_o$, is given, a single pass graphical solution gives the required result. However, if the tube circumference and height is given, the SOFFTWIN code performs iterative schemes to find which T and $p_o$ will yield the given parameters. SOFFTWIN is formulated so that any combination of two parameters involving T, $p_o$, circumference, area or height may be specified and the remaining are computed. Figure 7 shows a SOFFTWIN computation for the given 12 m circumference and the 2 m height of tube. The SOFFTWIN code computes that an excess pressure head of 0.217 m of water is required to inflate the 12 m circumference tube to a height of 2 m. That is, the piezometric level is 0.217 m above the top of the tube (or 2.217 m).

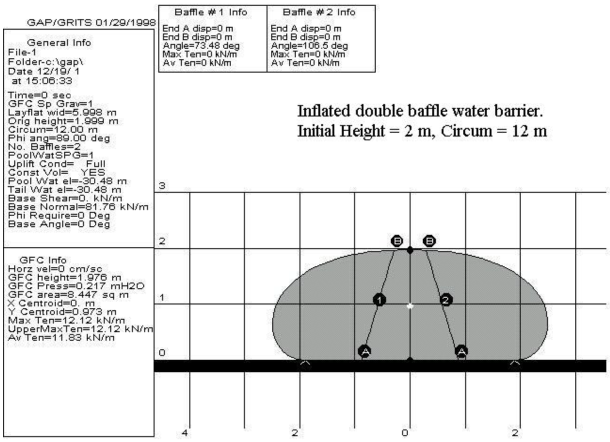
The GAP code contains a SOFFTWIN routine which permits the computation of an internal excess pressure consistent with the selected tube circumference and original tube height. This permitted the result shown in Figure 6. Figure 8 shows the application of a 1.5 m pool (75% of the pool height) on the left side of the tube (before the computation of the effect of that pool). In these computations it was presumed that an uplift pressure equal to the total pool height existed beneath the entire tube to ground contact. This is a very conservative assumption, but, for design purposes it is probably warranted. A linear uplift assumption (where the uplift varies linearly from full pool height at the upstream ground contact to the tail water level at the downstream contact) is probably more likely. Figure 9 shows the tube after the pool load has caused the tube to rotate to the position shown. The two internal baffles restrain the tube from rolling. The tube is stable as regards rolling at this 1.5 m pool height. The GAP code computes the required friction angle, $\varphi$, (the coefficient of friction, $\mu$ is given as $\mu = \tan(\varphi)$ to prevent sliding. In this situation the required friction angle is $22.26^\circ$. Notice that the centroid of the tube (the small white dot) has displaced downstream a distance of almost 1 m. The top of the tube has also risen in height to 2.218 m. The internal excess pressure head in the tube has also increased to 0.309 m of water (from 0.217 m at the outset). After the tube is initially inflated, it is generally required that the tube preserves its volume as it deforms under the application of external loads. In practice, these tubes are generally sealed after the first inflation. The constant volume requirement is achieved by an algorithm to manipulate the excess pressure head. That is, if the tube is tending to decrease in volume, the excess pressure is increased, and vice versa. The constant volume requirement is quite necessary for a meaningful simulation. Figure 10 shows that the tube is also stable (as regards rolling) at a pool height of 1.75 m (87.5% of the pool height). However, the height of the tube has increased to 2.39 m and the friction angle required to prevent sliding has increased to $35.65^\circ$. At a pool height of 2 m (100% of the original tube height), the tube rolls completely over as shown in Figure 11.

## 5 ACKNOWLEDGEMENTS

Special thanks to T.C. Mirafi Corporation, Pendergrass, GA, for data provided for the ScowDropSim code and to HydroSolutions, Houston, TX, for water barrier data.

## 6 REFERENCE

Den Hartog, J.P. 1952. *Advanced Strength of Materials,* Dover Publications, Inc., New York.



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Date 12/19/ 1
 at 15:06:33

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Base Angle=0 Deg

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GFC Press=0.217 mH2O
GFC area=8.447 sq m
X Centroid=0. m
Y Centroid=0.973 m
Max Ten=12.12 kN/m
UpperMaxTen=12.12 kN/m
Av Ten=11.83 kN/m
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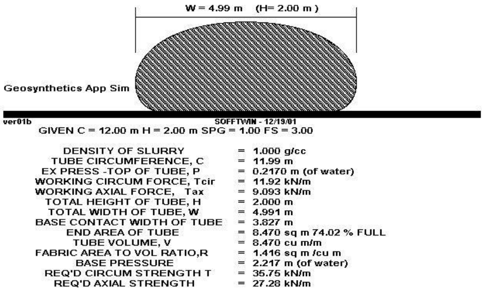
Inflated double baffle water barrier.
Initial Height = 2 m, Circum = 12 m

Figure 6. Initial condition of double baffle water barrier tube.

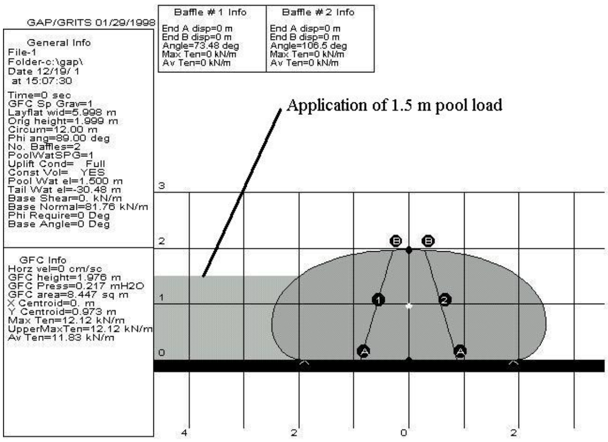


```
W = 4.99 m    (H= 2.00 m )

Geosynthetics App Sim
ver01b                    SOFFTWIN - 12/19/01
GIVEN C = 12.00 m H = 2.00 m SPG = 1.00 FS = 3.00

      DENSITY OF SLURRY            =  1.000 g/cc
    TUBE CIRCUMFERENCE, C          =  11.99 m
   EX PRESS -TOP OF TUBE, P        =  0.2170 m (of water)
  WORKING CIRCUM FORCE, Tcir       =  11.92 kN/m
  WORKING AXIAL FORCE,   Tax       =  9.093 kN/m
    TOTAL HEIGHT OF TUBE, H        =  2.000 m
    TOTAL WIDTH OF TUBE, W         =  4.991 m
  BASE CONTACT WIDTH OF TUBE       =  3.827 m
       END AREA OF TUBE            =  8.470 sq m 74.02 % FULL
       TUBE VOLUME, V              =  8.470 cu m/m
  FABRIC AREA TO VOL RATIO,R       =  1.416 sq m /cu m
        BASE PRESSURE              =  2.217 m (of water)
   REQ'D CIRCUM STRENGTH T         =  35.75 kN/m
    REQ'D AXIAL STRENGTH           =  27.28 kN/m
```

Figure 7. SOFFTWIN solution for initial condition.



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Circum=12.00 m
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Uplift Cond=   Full
Const Vol=   YES
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Tail Wat el=-30.48 m
Base Shear=0. kN/m
Base Normal=81.76 kN/m
Phi Require=0 Deg
Base Angle=0 Deg

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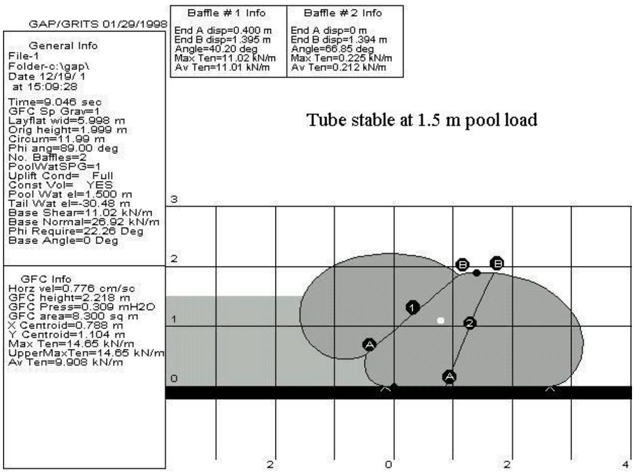
GFC Press=0.217 mH2O
GFC area=8.447 sq m
X Centroid=0. m
Y Centroid=0.973 m
Max Ten=12.12 kN/m
UpperMaxTen=12.12 kN/m
Av Ten=11.83 kN/m
```

Application of 1.5 m pool load

Figure 8. Application of 1.5 m pool height.



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Y Centroid=1.104 m
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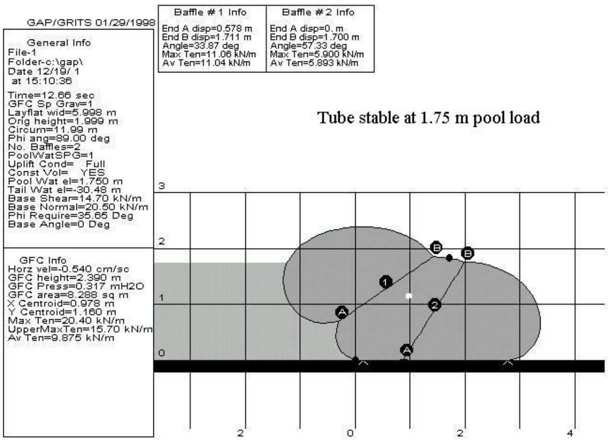
Tube stable at 1.5 m pool load

Figure 9. Baffles provide rolling stability at 1.5 m pool.



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Date 12/19/ 1
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Y Centroid=1.160 m
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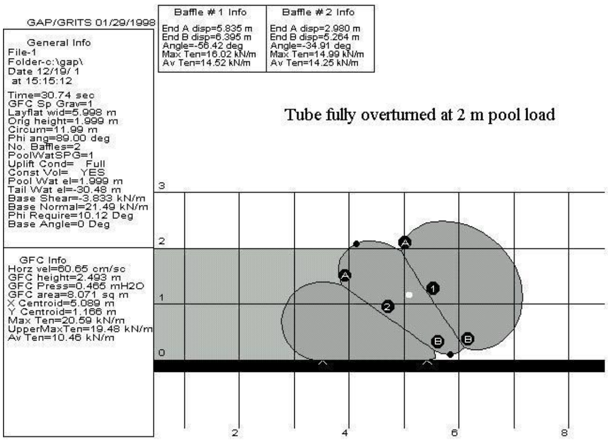
Tube stable at 1.75 m pool load

Figure 10. Stability maintained at 1.75 m pool.



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Tube fully overturned at 2 m pool load

Figure 11. Tube completely overturning at 2 m pool.