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INTRODUCTION

The DIFID (DIsposal From an Instantaneous Dump) model provides forecasts of the distribution of dredged sediment at an open water disposal site after its release from a barge or hopper dredge (Johnson, 1987). In the DIFID model, the dredged sediment forms an ellispodal cloud on the disposal site floor. It collapses and spreads radially while simultaneously being translated over the floor of the disposal site by the effects of ambient currents and any uniform, regional slope. For this computation, the floor of the disposal site can slope in only one direction. The DIFID model is not designed to account for the effects of local slopes on the spread of dredged sediment over the disposal site. The model cannot include in its forecast the effect of pre-existing mounds, berms, or irregular pits on the spread of the dredged sediment although the special case of disposal into a rectangular pit can be accommodated (Johnson, 1987).

Local slopes can be prevalent features of well-used disposal sites, however, and an approach for anticipating their effects is discussed here in the context of the DIFID model. This approach is based on changes in the energy density of the collapsing cloud. The symmetry required by the DIFID model and unresolved internal distributions of material and momentum within the cloud impose substantial constraints on calculating the effects of local slopes. Nevertheless, a calculation can be done as a perturbation of the basic DIFID forecast. When the calculated perturbation is small, it provides an indication of the effects of local slopes. If the calculated perturbation is large, the DIFID model is probably inappropriate for the given situation.

BACKGROUND: THE ENERGETICS APPROACH

In general, as the cloud of dredged sediment collapses and spreads over the floor of the disposal site, its center of mass lowers transforming its potential energy into kinetic energy. It can also gain energy by the entrainment of kinetic energy with the ambient water. All this energy is lost eventually through friction and the deposition of sediment until all motion ceases and the sediment from the cloud is in place on the disposal site floor. Over sloping ground, additional energy is lost in doing the work required to lift the could up a slope, or additional energy can be gained by moving downslope.

Although an energy balance does not provide insight into specific hydrodynamic mechanisms, it has been useful in investigations of the downslope motion of turbidity currents. The concept of an "internal slope" (i.e., the gain in potential energy due to the lowering of the center of mass during spreading) was used by Kuenen (1952) in estimating the characteristics of the Grand Banks turbidity currents. A similar approach was used by Hsu (1975) and Kersey and Hsu (1976) to calculate the range of density currents traveling down a slope. For density currents in which the difference in density was due to salinity, they could calculate a critical slope at which the frictional dissipation was exactly balanced by the energy gained in moving downslope. At the critical slope a saline density

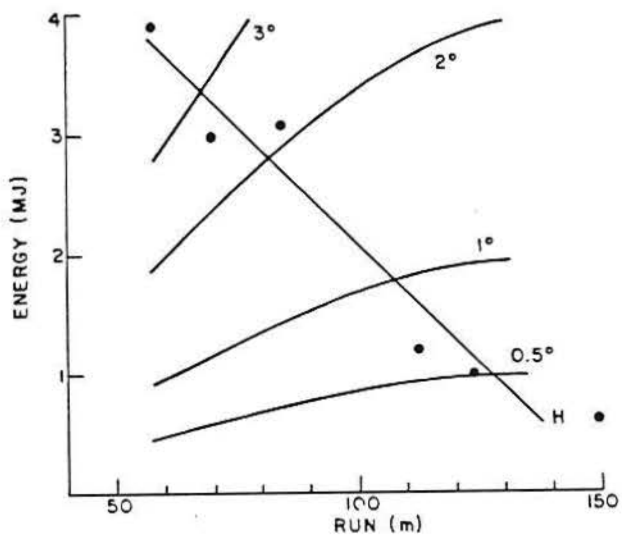

Figure 1. Total energy H in the surge measured as a function of the position of the surge front. The curved lines (labeled 0.5°, 1°, 2°, and 3°) represent the work required to move the surge up the indicated slope. The intersection of a curve with H marks the maximum travel of the surge of that slope.

current would move downslope indefinitely with no change in velocity or thickness. The density current would grow thinner when traveling down sub-critical slopes and thicken on supercritical slopes (i.e., energy in excess of that needed to replace the frictional losses and maintain a constant velocity was stored as potential energy by thickening the flow or raising its center of mass). As I will discuss later, this effect has implications for the DIFID results in the presence of local slopes.

Another relevant effect is that of the energy balance in maintaining sediment in suspension as developed by Bagnold (1962). In steady state, the energy gained as the mass moves downslope might be devoted to maintaining the suspended sediment load through the replenishment of turbulent energy. At some critical slope, the energy gained is equal to the energy required to maintain the suspension. In this case, a turbidity current might transport an unlimited amount of sediment downslope indefinitely. In application to the DIFID model, energy gained in moving down local slopes could be translated into an inhibition of the deposition of sediment from the cloud.

Energy considerations have been applied to dredged sediment disposal (Bokuniewicz, 1985). Observations of discharges in the Great Lakes were used to calculate an energy budget of a radially symmetric cloud of dredged sediment spreading over the floor of a disposal site. The empirical rate of dissipation of the total energy in the collapsing cloud can be used to forecast its behavior over local slopes in special cases. For a radially symmetric cloud centered on the apex of a right circular cone, the rate of energy dissipation could be balanced by the rate of gain of energy as the cloud moved down the sides of the cone if the side slopes were about 0.05 or 3°. In this case, the cloud should run off the cone without diminishing its speed or depositing its sediment. In a similar manner, the behavior of a collapsing cloud at the center of a right-conical pit can be forecast. Figure 1 shows empirical values of the total energy in a collapsing cloud as a function of its radius. The line labeled H helps to define the trend of decreasing energy. The superimposed curves (labeled 0.5°, 1°, 2°, and 3°) indicate the amount of work that would be needed to lift the cloud up various slopes. The intersection of each of these curves with the line H, therefore, is the furthest distance that the cloud could expand up a given conical slope. This general approach could be applied in the context of the DIFID model but several important features of the model proscribe the way in which the energy calculations can be handled. These are described in the next section.

RELEVANT CHARACTERISTICS OF THE DIFID MODEL

First, the model assumes that the footprint of the collapsing cloud remains an ellipse with semi-major axes, B and C. Radial symmetry (B=C) can, of course, be accommodated but it would be a special case; the energy calculations cannot be based on the assumption of radial symmetry. On the other hand, the predictions based on the energy calculations cannot invalidate the geometry assumed in DIFID. The collapsing cloud must remain essentially an ellispsoid so that the basic DIFID calculations can proceed on this condition. In practical terms, this means that the influence of local slopes cannot be so great as to fragment the cloud or even to substantially distort its ellipsoidal shape. At this stage there is no a priori way to decide when the energy-based modifications are appropriate but the magnitude of any differences relative to the same calculations in the absence of local topography must be used as a guide. (It is interesting that the height distribution of the top of the cloud does not seem to be critical to the DIFID calculations as long as the elevation of the center of mass is known at each time step. The energy calculations might be used, therefore, to change the shape of the top surface of the cloud.)

Second, it seems to be assumed in the DIFID model that the suspended sediment is well mixed within the cloud. Only the average mass of the cloud is calculated and when particles settle the remaining particles are redistributed uniformly throughout the remaining volume. As a result, any modification of the DIFID results supplied by the energy calculations in one time step will be distributed uniformly before the next time step. Physically, this translates into an assumption of intense turbidity mixing within the cloud.

Third, the center of mass of the cloud is allowed to translate both down the regional slope and in the direction of the ambient water velocities. This means that the energy calculation must be done at each time step for every cell in the spatial grid. (Fortunately, the DIFID model contains a subroutine, TRNSPT, that "computes the location from which a particle occupying a grid point at the current time came" (Johnson, 1987). The size of the grid cell, therefore, limits the resolution of the local bathymetry. Changes in slope that do not span at least one cell must be treated as roughness elements affecting the bottom friction if their influence is included in the calculations at all.

STRUCTURE OF A SUBROUTINE FOR ENERGY CONSIDERATIONS

At the end of each time step, an energy subroutine would be called and for each grid point, the following values would be transferred into the subroutine (or calculated initially):

1. the x and z coordinates of the center of mass, E(1) and E(3).
2. the grid spacing, DX and time step, DT.
3. the total mass of the cloud E(4).
4. a buoyancy-corrected, effective mass of the cloud CM* E(4).
5. the X- and Z- speeds of the centroid of the cloud (VV and WW).
6. the water depth at each grid point, DEPC(N,M).
7. the total mass (or concentration of particles) in each settling class along with their appropriate settling velocities.
8. the total volume of the cloud, VOLUME.
9. the volume of solids of each grain size in the cloud (E (13), E(14), E(12+NS)) and their corresponding settling velocities VFALL(1) .... VFALL(NS).

Within the subroutine the following calculation would be done for each cell:

1. The thickness of the cloud (or, if the thickness is allowed to change non-uniformly, it would be imported from the last time step). For the ellipsoid the thickness would be:

```
THICKNESS(M,N) = SQRT((1.0-((X(N,M) - E(1))/B)**2
                 -((Z(N,M) - E(3))/C) **2)/A
```

2. the potential energy density in that cell

```
PE(N,M) =  CM * E(4) * G * 0.5 * THICKNESS(N,M)/VOLUME
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3. the speed, SPEED(N,M), of the cloud in each cell which would include both the speed of translation, SQRT(VV*VV + WW*WW) and a component due to the collapse. From which the kinetic energy density could be calculated as

```
KE(N,N) = 0.5 * E(4) * SPEED(N,M)**2/VOLUME
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4. The total energy density, HAMILTONIAN(N,M), at each grid location as PE(N,M) + KE(N,M)

5. The total energy density would be compared to the energy density required to raise the grid element of the cloud from its last grid point to its present position (or the energy density gained as it fell from its elevation at the last grid point to its present grid point).

```
WORK(N,M) = CM * E(4) * G * DELTAH(N,M)
          * THICKNESS(N,M) * DX * DX/VOLUME
```

For each parcel the cumulative amount of work associated with that parcel as it travels through each time step, CUMWORK(N,M), must be saved.

6. the energy density that would be required to maintain the existing suspended load in suspension. This calculation must be done for each size class but only the total is needed. The

total number of size classes is NS and, in DIFID, the total volume of solids in a specified grain size is E(13), E(14) ... E(12 + NS). The volume concentration at each time step is SS(ISTEP, 1) = E(13)/VOLUME and so forth, while the corresponding settling speed is VFALL(1) and so forth. Therefore, the power density needed to support that size fraction at each grid cell is

PSS(K) = CM * E(12 + K)/VOLUME * 2.6 * G * VFALL(K)

and the total energy density (TOTPSS) required to support this sediment in suspension for each time step is

TOTPSS = (PSS(1) + PSS(2) + ... + PSS(NS)) * DT

HOW CAN THE ENERGY CALCULATIONS BE USED IN THE DIFID MODEL

Now comes the tricky part. Ideally, the energy gained or lost in each grid cell should be translated into a change in velocity (offsetting frictional losses), a change in height and/or an inhibition of settling. However, neither the DIFID formulation or the energy consideration allow this to be done since they do not distribute the energy among the full range of hydrodynamic processes. To do this a numerical model would need to be developed to solve the Navier-Stokes equations in the presence of suspended sediment including the conservation of energy. Such a formulation would be restricted to ellipsoidal, or even unfragmented, clouds but would be an entirely different model from DIFID and computationally very intense. As a result, deciding how to use the energy considerations within the context of the DIFID model is problematical.

In one perspective, once the total work done in moving any parcel over the bathymetry along its path, CUMWORK(N,M), is equal to the instantaneous sum of its potential and kinetic energy, HAMILTONIAN(N,M) it should continue to exist as part of the cloud. This is the general equivalent of the approach shown in Figure 1 but it cannot be allowed to occur, however, since that would leave "holes" in the cloud that could not be handled in the subsequent DIFID calculations.

The assumption that the cloud is continually well-mixed, however, provides a physical reason why this should not happen. As the energy is preferentially depleted from one cell new energy would be mixed into it by turbulent exchange. With this rationale, the proper comparison would be between the total potential and kinetic energy of the cloud at any time step and the total work done in moving all parcels over the local bathymetry. When these two quantities are equal, the calculation should stop. On the other hand, if the total work done is negative (i.e., energy has been gained in moving over the local bathymetry), then the calculation should continue regardless of other criterion used in DIFID to stop the processes.

Alternatively, there may be a reasonable way to use the energy supplied or lost at each cell due to travel over the bathymetry to adjust the model results before the next time step. Since the basic shape of the cloud must remain ellipsoidal, the following assumptions might be made:

1. Gains or losses of energy due to travel over local bathymetry do not affect the cloud's velocity structure.
2. As energy is gained, the first effect is to inhibit the deposition of sediment in the same proportion as the

ratio of the change in energy over a time step to the work required to support the suspended load. When that ratio becomes 1, there is no deposition. When it exceeds 1, the excess energy goes into increasing the thickness of the cloud in the cell (i.e., raising its center of mass).

3. As energy is lost, the cloud thins according (and deposition is automatically enhanced as particles are concentrated).

It is probably premature to explore these options further here before experimental calculations are done to examine the feasibility of doing the energy calculations during the DIFID runs and gaining some experience concerning the character of the energy balance for a variety of scenarios.

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