CASE STUDY

Geotechnics of Utilizing Dredged Sediments as Structural Fill

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My remarks deal with the structural aspects of the use of dredged sediments as opposed to the environmental aspects. The case is a site in Elizabeth, New Jersey. It is probably one of the largest, if not the largest, site in New Jersey now using dredged sediments to prepare a site for a large shopping mall, which will have about 1.5 million ft^2 (139,500 m^2) in retail space. The project has been heavily supported locally and at the state level. The environmental permitting was not the most significant part of the site development. The owner prepared a risk assessment. That particular aspect of the use of dredged sediment in New Jersey is not regulated by the solid waste group, although it is being reviewed by the group. That is very important.

This is a 160-acre (64.8-ha) site that used to be a garbage disposal site. It is about 30 years old and is commonly referred to as the Kapkowski site. It was purchased about seven years ago by a Danish company, which prepared the site, and it is being developed now by an Ohio company. The original plan was to stabilize the garbage using a combination of deep dynamic compaction as well as preloading. These are not new technologies; they are well proven. The question was how to grade the site to make it suitable for construction. That is how the use of dredged sediment came to be considered.

Originally, the plan was to dike the whole site and pump the dredged material into the diked area—basically the traditional method used successfully by the U.S. Army Corps of Engineers (USACE) at many sites and just discussed by Wayne Young. But it would take a long time, maybe seven or eight years, for the material to consolidate and be suitable for construction. Some thought was given to accelerating the drainage by putting in drainage nets, so that each layer of the dredged material pumped would consolidate the one beneath it. However, there was a concern that the effluent from the consolidation process would have to be treated, increasing the cost of the project.

The last option was to stabilize the dredged sediments, again using a very old technology but with a new twist that involved mixing the dredged sediment with lime, cement, and fly ash. The old TRB literature mentions that organic soils are not suitable for stabilization. What that really means is, they are not suitable for stabilization at a reasonable cost. We are talking about fine-grained material, which has a relatively large percentage of organics, about 7 percent, maybe as much as 19 percent.

Regarding grain size, the data for a lot of samples from New York Harbor, New York Bay, Newark Bay, and Arthur Kill show there is not a wide range in the gradation of the material. Anywhere from 50 to 95 percent passes through the number 200 sieve, which is silt size, or very-fine-grained material, and quite a bit passes through the 2-micron size, or the so-called clay size, at which the material begins to exhibit clay-like properties.

For all practical purposes, all the material, whether from New York or Newark Bay, could be considered the same material; in any event, New York sediments come to Newark Bay. It is all the same.

From an engineering classification viewpoint, the samples are mostly elastic silt. For those of you not in the soil mechanics business, the liquid limit is the moisture content at which the material starts to flow. The higher the liquid limit, the weaker the material; the lower the limit, generally speaking, the stronger the material. The plasticity index is the difference between the liquid limit and the plastic limit. The plastic limit is the moisture content at which the material starts to break, which means it becomes very stiff and brittle. The lower the plastic limit, the stronger the material.

I mentioned the term "moisture content." I must caution that many groups have different definitions of moisture content, depending on the discipline involved. The way I am using it here, moisture content is the weight of water divided by the dry weight, which is the traditional geotechnical (or soil mechanics) definition. However, to the environmentalist, the moisture content is the weight of water divided by the total weight, which is wet weight. Thus, from an environmental standpoint, the moisture content of pure water is 100 percent, whereas from a soil mechanics structural viewpoint, the moisture content is infinity. There is also a third definition, the volumetric moisture content, which is the volume of water divided by the total volume. This definition is used by hydrogeologists.

That leads me to one comment about the NRC report. Right at the beginning, you should try to define which moisture content you are talking about. A wrong assumption about the meaning can be disastrous in contract documents, depending on which moisture content you are talking about.

Without stabilization, the material is very weak. The USACE data from 1994 for Newark Bay shows that the material has a very high void ratio and is very compressible, although less so than peat or, in general, phosphatic clay. In any event, when it is dredged and put on a barge, it has a mayonnaise-like consistency, which is very weak. The problem with it is not only environmental but also structural. You cannot handle it; you cannot drive on it; you cannot walk on it. The mobility is a major concern in trying to dispose of it for structural use to support a building.

Obviously, there is a correlation between the organic content and the specific gravity. For very fibrous peat, the specific gravity is about 1.4. The material from Newark Bay, New York Bay, Arthur Kill, and New York Harbor typically has about 7 percent organic content by the American Society for Testing and Materials definition. To determine the organic content, you burn the material at very high temperature and measure the weight before and after. You occasionally find very high organic content, on the order of 15 percent. This is important, because we found that organic material hydrates more slowly than does inorganic material when mixed with cement and lime. The organic content basically inhibits hydration. This affects how long you have to wait before you start handling the material. This is not something new. It was reported in the literature in the early 1950s that, if you have high organic content, even in trace amounts, the strength will be very low because there will be less hydration.

In stabilizing the material with cement and lime, the key is to have enough lime to form a gel. These days, lime is very expensive. The material used as a stabilizer for the Elizabeth project is cement and fly ash. Cement is much cheaper than lime. At some point early in the project they used lime kiln dust, which has some lime, but not much. The key to the stabilization of the material is to maintain a high pH. That is not a new finding. That was found in the early 1950s in work at Louisiana State University and other institutions. If you maintain a pH of 12.4 or close to 12, then you get high strength after hydration.

If the material has a high organic content, then it has a tendency to absorb calcium ions. That does not leave much calcium for the hydration. There is a correlation between the strength and the absorption of calcium ions. If you have very low absorption, which means less organic content, then you have higher strength. That is very important in the stabilization of the dredged material. Obviously the material has to be strong enough to support the pavement of the parking areas for the shopping mall as well as access roads.

A variety of mixtures can be used. One has 20 percent lime kiln dust; another has 20 percent cement kiln dust; others have 7 to 8 percent cement; and still another has about 8 percent cement and 12 percent fly ash. You get different behavior based on what mix you use. The important thing is to be as close to the optimal density as possible, and not too far off the optimal moisture content. If you are too far off, then you have lower strength. If the material is too wet, then you cannot compact it and you have low strength; if it is too dry, then, when the material gets inundated, it just collapses if it is compacted. You have to strike a balance.

Looking at compaction for these mixes under different levels of energy (the standard energy is about 12,400 ft-lbf/ft or 600 kN-m/m), none of the densities is good enough. In the range of a dry density of 60 lb/ft^3 (973 kg/m^3), the material simply collapses when you saturate it. Even if you use only 95 percent of the standard energy, the standard density is not good enough to maintain a stable material for structural support. We also found that, as the material waits before you try to compact it, it takes more and more energy to compact it. The permeability of the material is quite low. In a way, this is good, because it will be more difficult for the water to go through. On the other hand, if it is fine grained, then it could crack very easily.

Consolidation curves show that the material is not very compressive but is well compacted. Up to a certain point, it exhibits the properties of overconsolidated soil. If you are below 3 or 4 tons/ft^2 (27 to 39 tonne/m^2) of bearing, then you have relative compressibility for the stabilized material of different mixes. Once you go beyond that, it will act as ordinary material.

It is very simple to normalize all these data into a meaningful form that can be used by the designer. We use a parameter called normalized density, or the density to which you compact the material divided by the optimal density and multiplied by the normalized moisture content (which is the optimal moisture divided by the moisture content to which you compact it). The higher the number, the greater the strength of the material. A preliminary design chart can be made to assess what type of strength you could expect based on a certain density and moisture content.

The same data can be plotted in the California bearing ratio (CBR), which is the standard test comparing the penetration resistance of the material to the penetration resistance of strong material such as crushed stone. The minimum CBR they can use for structural purposes is 10 percent; anything below that is no good. You can get some idea of the CBR if you have the moisture content.

In many compacted fill applications for conventional material, engineers use a nuclear density gauge to figure out the wet density in situ and the moisture content. We found out that the nuclear density gauge underestimates the moisture content of the material and therefore overestimates the dry density. Thus, a big lesson learned from this project is: Do not use a nuclear density gauge to measure the moisture content. Compared to a dry density value obtained using the most reliable sand density cone, a nuclear gauge overestimates by up to 20 percent, which, for structural purposes, could be a very serious difference indeed.

After it is mixed and placed for compaction, the material looks like ordinary structural fill. Again, I must caution that, based on most highway specifications, it does not fit the grain size requirement. Furthermore, with regard to the negative aspects of this material, it has a very low tolerance for frost-and-thaw cycles; we have to cover it with 2 to 3 ft (.6 to .9 m) of sand or non-frost-susceptible material. It is also somewhat expensive. In addition, it is quite corrosive. But that is not a big limitation because, with the concrete technology we have now, we can mitigate against high sulfates and chlorides and bury it in concrete.

The dredged material in a compacted state is performing very well. We have lots of data to show that it has a field CBR of over 10 percent, and that the unconfined compressive strength could be well above 20 or 30 lb/in.^{2} (138 to 207 kPa).