1 November 2013

Earthen Material Density/Volume States
Version 3.0

During mass earthwork operations, earthen materials such as soils and rock typically occur in three fundamental *density states*, each of which contractors need to recognize, account for, and convert volumes between. Each of those density states represents specific circumstances in which the material will be encountered or handled, and for which its volume typically needs to be determined. Business Center – HCE (BC-HCE) addresses the three material states noted and defined below.

Bank

The *bank* density state is that in which a material is found on the job site, or at an off-site borrow location, in its natural or present condition prior to excavation. That is commonly referred to as the material's *in situ* condition. The volume of that in situ material that is excavated in performing mass earthworks is referred to as the *bank cut* volume.

Loose

The *loose* density state is that which materials exhibit after being excavated and placed in an uncompacted (loose) state within a truck or other means of transportation or conveyance, or after being dumped into a stockpile. The volume occupied or expected to be occupied by a specific quantity of material in this state is referred to as its *loose haulage* volume.

Compacted

The *compacted* density state is that in which an earthen material exists after being placed into earth fill, and compacted to the specified density. The volume of material that results or that is expected to result after being placed into compacted earth fill is referred to as the *compacted* volume. BC-HCE's report may refer to this more descriptively as the *in-place, fully compacted volume*.

From the above explanations it should be clear that earthen materials are commonly found to be in a *bank density state* prior to their excavation, at which point they are in a *loose haulage state*, until being placed into a *compacted state*. In considering and quantifying the effort required to excavate, haul, place and compact earthen materials, the contractor may wish to be able to measure or predict the volumes associated with each of these material density states. He may wish to be able to do so for each material strata that is expected to be encountered, or for an anticipated representative average material, if subsurface conditions have not been sufficiently investigated.

In performing mass earthwork analyses, BC-HCE can compute earthen material volumes representing each of the above density states. For soil material in general, the relative volumes associated with each of those states can be represented as shown in Figure 1 below.

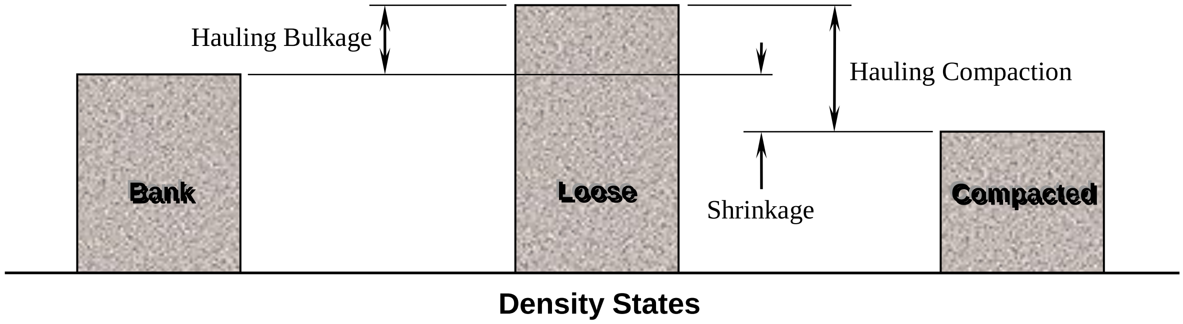

Figure 1 – Relative Volumes of the Three Earthen Material Density States

The differences in the volume of an earthen material as it exists in each of the above noted three density states depends on the particular material that is being excavated, hauled and placed into earth fill. Business Center - HCE-HCE allows the user to establish the density variation properties of each earthen material, which enable those volumes to be computed. Such properties are typically determined as a result of a geotechnical analysis of the materials that have been sampled from the site, typically through the process of performing soil borings.

Figure 2 below shows the properties that the user has defined for a hypothetical earthen material named *Clayey Fine Sand*, including its shrinkage, hauling bulkage and hauling compaction values. Note that those three properties can be entered either as multiplication factors or as percentages. They are entered as percentages in this example.

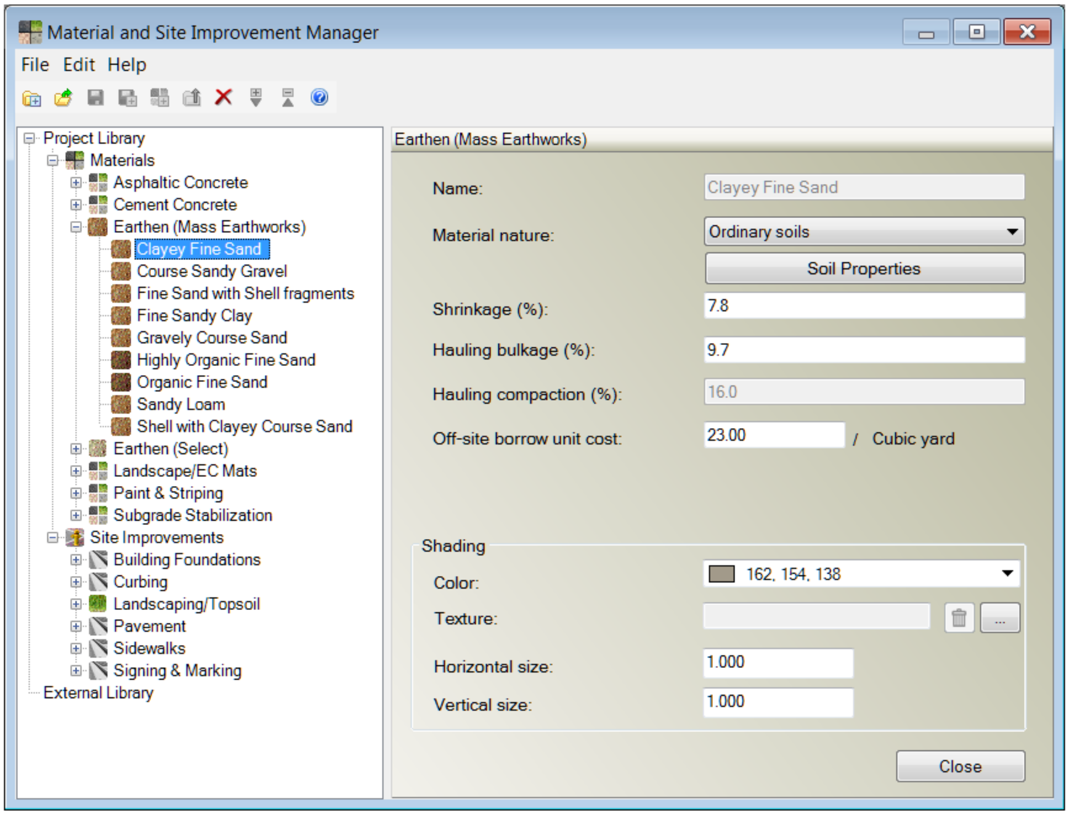

Figure 2 – Earthen Material Properties

In Figure 2, a *shrinkage* value of 7.8% has been entered. The corresponding multiplication factor is 0.922. Referring again to Figure 1, the shrinkage factor is used to compute the difference in volume between the bank density state and the compacted density state. That is, as a specific sample of an in situ material is excavated, placed into earth fill, and compacted to the specified density, it is expected to be reduced in volume by 7.8%. The compacted volume that can be satisfied by the volume of in situ material that is excavated can therefore be computed by multiplying the bank cut volume by a factor of 0.922.

Figure 2 indicates that that same material has a *hauling bulkage* value of 9.7%, the equivalent multiplication factor for which is 1.097. Referring again to Figure 1, the hauling bulkage factor is used to compute the difference in volume between the bank density and loose density states. That is, as the in situ material is excavated and placed in a loose state, it is expected to increase in volume by 9.7%. The loose haulage volume can be computed by multiplying the bank cut volume by a factor of 1.097. This volume allows the user to determine, for example, the number of dump trucks of a particular capacity, which will be needed to haul the material from where it is excavated to where it will be placed into fill or stockpiled.

Note that by specifying either two of the applicable factors, the third can be calculated. So, in Figure 2, the *hauling compaction* value has been computed from the user entered shrinkage and hauling bulkage factors. The hauling compaction value is indicated as 16.0%, where the corresponding multiplication factor is 0.840. Figure 1 shows that the hauling compaction factor is used to compute the difference in volume between the loose and compacted density states. That is, as the loose material is placed into earth fill and compacted to the specified density, it is expected to be reduced in volume by 16.0%. The compacted volume can then be computed by multiplying the loose haulage volume by a factor of 0.840. That factor therefore allows one to compute the compacted volume that can be satisfied by a stockpile of a particular volume, or how many truck loads in the loose state will be required to achieve a particular compacted volume.

In performing an earthwork analysis, BC-HCE will typically compute and report the following volumes for a particular earthen material.

Available Bank Cut

This is the computed volume of material to be excavated, as measured in its in situ bank density state. Where space is at a premium in a report, this volume may be referred to simply as the *Bank Cut*. This is therefore simply the cut volume, as computed between the two surfaces on which cut/fill volumes are being based.

Loose Haulage

This is the loose haulage volume that is expected to be occupied by the above noted *available bank cut* material. It is computed by multiplying that cut volume by the material's hauling bulkage factor. It is noted that hauling bulkage factors should be considered as rough estimates, due to the lack of a need for specificity as to what constitutes a loose condition, and the inability to maintain the material at a specific density while being transported or stockpiled.

Compacted Fill Supplied

This represents the amount of in-place, fully compacted earth fill that can be produced by the above noted bank cut volume. Where space is at a premium in a report, this volume may be referred to simply as the *Fill Supplied*. It is determined by multiplying the related *available bank cut* volume by the material's shrinkage factor. It is noted that the shrinkage factor for a material, as resulting from the application of a specified compactive effort, can be determine in the laboratory with precision, making that factor and a measured or computed bank cut volume preferred in computing the related compacted volume. Nevertheless, the amount of compacted fill that can be supplied by a stockpile or a certain number of truck loads of loose material can be estimated by multiplying that loose haulage volume by the material's hauling compaction factor.

Compacted Fill Required

This is the computed volume of material to be placed into earth fill, as measured in its fully compacted bank fill density state. Where space is at a premium in a report, this volume may be referred to simply as the *Fill Required*. This is therefore simply the fill volume, as computed between the two surfaces on which cut/fill volumes are being based.

Compacted Excess/Deficit

The compacted excess or deficit is obtained by subtracting the above noted *compacted fill required* from the *compacted fill supplied*, thereby yielding a net material volume in its specified, in-place, fully compacted density state. If the difference is a positive number, there is an excess of material available on site, and it represents the compacted in place volume to be wasted (either hauled offsite, or disposed of on site if sufficient latitude is provided). If the difference is negative, then there is a deficit and that difference represents the in place, compacted volume of material to be borrowed (hauled in from an offsite source).

Loose Waste/Borrow

This number represents the expected loose haulage volume of the excess material to be wasted to an offsite location, or that of the deficit to be borrowed from an offsite location. In either case, it allows the user to estimate the number of truck loads required, based on a loose haulage volume.

In performing an earthwork analysis, if subsurface earthen material strata have been defined within the project file, BC-HCE can address the volumes associated with each stratum, and with a designated offsite borrow material, if applicable. In the absence of such data, the user will be able to designate a particular native earthen material and a borrow material, if applicable, based on which the above noted volumes will be computed.