Guide for Stockpile Sizing Spreadsheet

As part of Task 4 of the project Salt Shed Design Template an Excel spreadsheet has been created to provide insights to users on how large various buildings would need to be to store a given quantity of salt. This document is intended as a guide in the use of the spreadsheet.

The spreadsheet does not provide precise sizing information, but it does provide an indication of how much salt can be stored in a given type of structure, of a given size. How much salt can actually be stored in a structure will depend on how the salt is loaded into the structure. If the salt is loaded from the top of the structure using a conveyer system, then it is a conservative assumption that the building will hold about 90% of its calculated maximum storage. If the salt is loaded by a front-end loader or equivalent (essentially being pushed or shoveled into the storage building), then it is a conservative assumption that the building will hold about 60% of its calculated maximum storage. These assumptions are used in the spreadsheet.

The spreadsheet has three tabs. The first provides a calculation of how much salt is stored in a conical pile of salt. This provides an initial "ballpark" estimate of the size of the building that might be required to store given amounts of salt. Two calculations are shown. The first calculates how many tons of salt can be stored in a conical pile of a given diameter. It also gives the height of the pile. The second calculates what size of cone is needed to store a given weight of salt. These calculations depend on two given assumptions about how salt sits in a pile.

> ASSUMPTION 1: The angle of repose of a conical pile of salt is 32°. This means that the angle between the sloping face of the salt pile and the horizontal is 32° as shown in figure 1.
>
> ASSUMPTION 2: The density of salt granules is approximately 80 lbs. per cubic foot.

Tab 1: "Conical Piles No Walls"

In calculating the values in the first tab, the height of the pile (designated as h) is given as a function of the width or diameter of the pile (designated as w) by this equation:

$$h = \left(\frac{w}{2}\right) \tan 32 \qquad (1)$$

The equation for the volume of a cone (V) is given by (using r for radius, which is half of the diameter, w):

$$V = \frac{1}{3}\pi r^2 h \qquad (2)$$

If we substitute in for r and h in terms of w, we get:

$$V = \frac{1}{3}\pi \left(\frac{w}{2}\right)^3 \tan 32 \qquad (3)$$

Which simplifies to:

$$V = \frac{1}{24}\pi w^3 \tan 32 \quad (4)$$

This can then be converted into tons of salt (denoted as W), using the density of salt given above (80 lbs per cubic foot) and taking 2,000 lbs per ton:

$$W = \frac{80}{(24\times 2000)}\pi w^3 \tan 32 \quad (5)$$

Equation 5 is used in option 1 of tab 1 (“Conical Piles No Walls”) to calculate the weight of stored salt in tons. The user supplies the width of the pile (w) in cell C7 in feet and the weight is returned in cell C12. The height of the salt pile (h) is given in terms of the width of the pile (w) in equation 1, and this is used to calculate the height of the pile in feet given in cell C13.

Option 2 in tab 1 takes a given weight of salt (in tons) supplied by the user in cell H7 and inverts equation 5 (shown in equation 6) to find the width or diameter of the pile (w) in feet, which is given in cell H12. The height of the pile is calculated using equation 1 as before and is given in cell H13.

$$w = \sqrt[3]{\frac{(24\times 2000)W}{80\pi \tan 32}} \quad (6)$$

Figure 1 shows the conical pile.

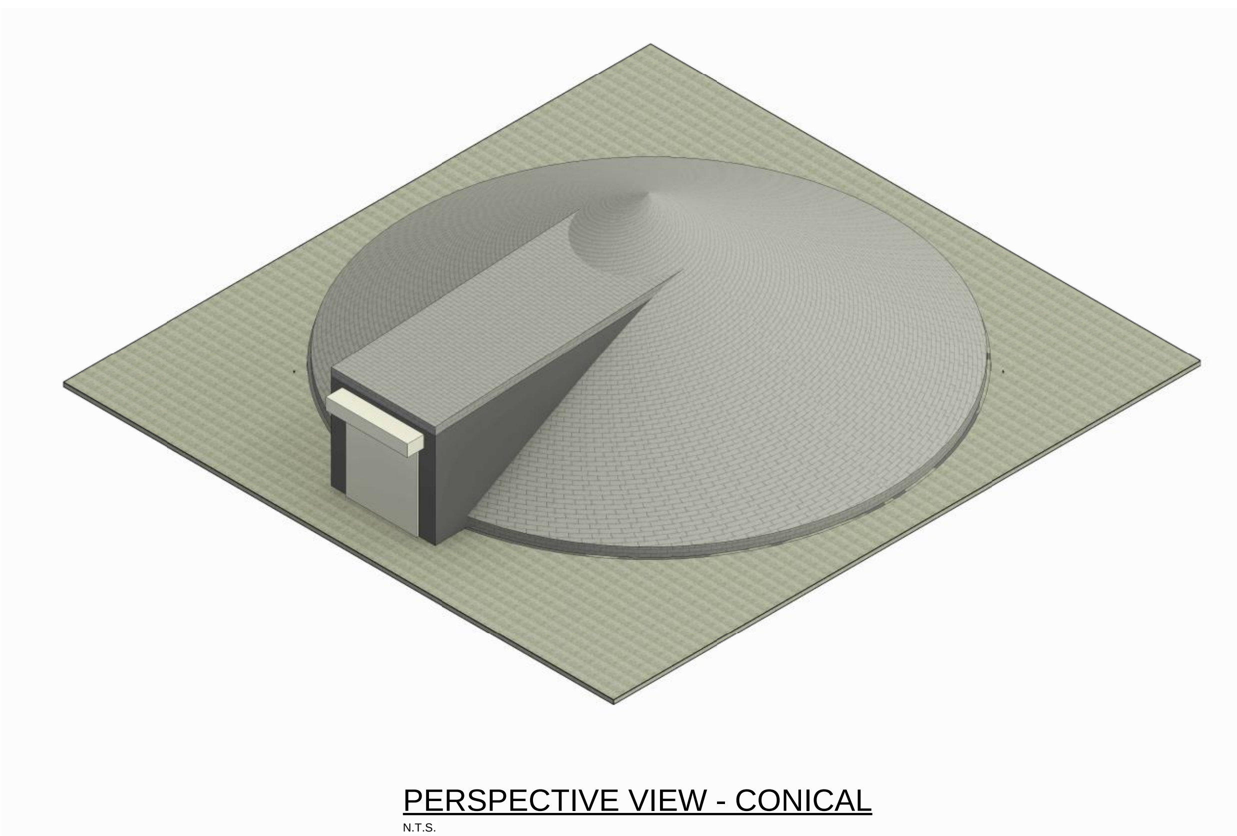

Figure 1: Perspective view of the conical pile.

Tab 2: “Storage in Conical Building”

This set of values is derived from the amount of salt that can be stored in a conical building with vertical side walls as depicted in figure 2. Prior to any calculations, a suitable value must be entered into cell F4 for the height of the walls (entered in units of feet and designated as h_w in the equations below).

From this point, the user has two sets of calculations available. Option 1 is for a building loaded with a conveyer system which assumes (see above) that 90% of the total available storage can be utilized. Option 2 is for a building loaded with a front-end loader or equivalent which assumes that 60% of the total available storage can be utilized.

To calculate the salt stored in a conical building of a given diameter (w in feet – this value is provided by the user in cell C11 for option 1 and cell H11 for option 2) the volume of a cylinder of diameter w and height h_w is found and then added to the volume of the cone of diameter w and with angle of repose 32° as given in equation 4. This volume (in cubic feet) is then converted into tons of salt by multiplying by the density of granular salt (80 lbs per cubic foot) and dividing by the number of pounds in a ton. This gives the following equation for the weight of salt stored in a conical building of diameter w feet and with wall height h_w feet:

$$W = \frac{80}{2000}\left[\frac{\pi w^2}{4} h_w + \frac{1}{24}\pi w^3 \tan 32\right] \tag{7}$$

The solutions in the two options are then obtained by multiplying the value obtained in equation 7 by 0.9 and 0.6 respectively, giving the salt stored in a conical structure with a conveyer system in cell C15 and in a structure without a conveyer system in cell H15. The height of the salt pile is simply the sum of the height of the wall (provided by the user in cell F4) plus the height of the cone on top of the pile (calculated using equation 1 as before) and is provided in cells C16 and H16 respectively.

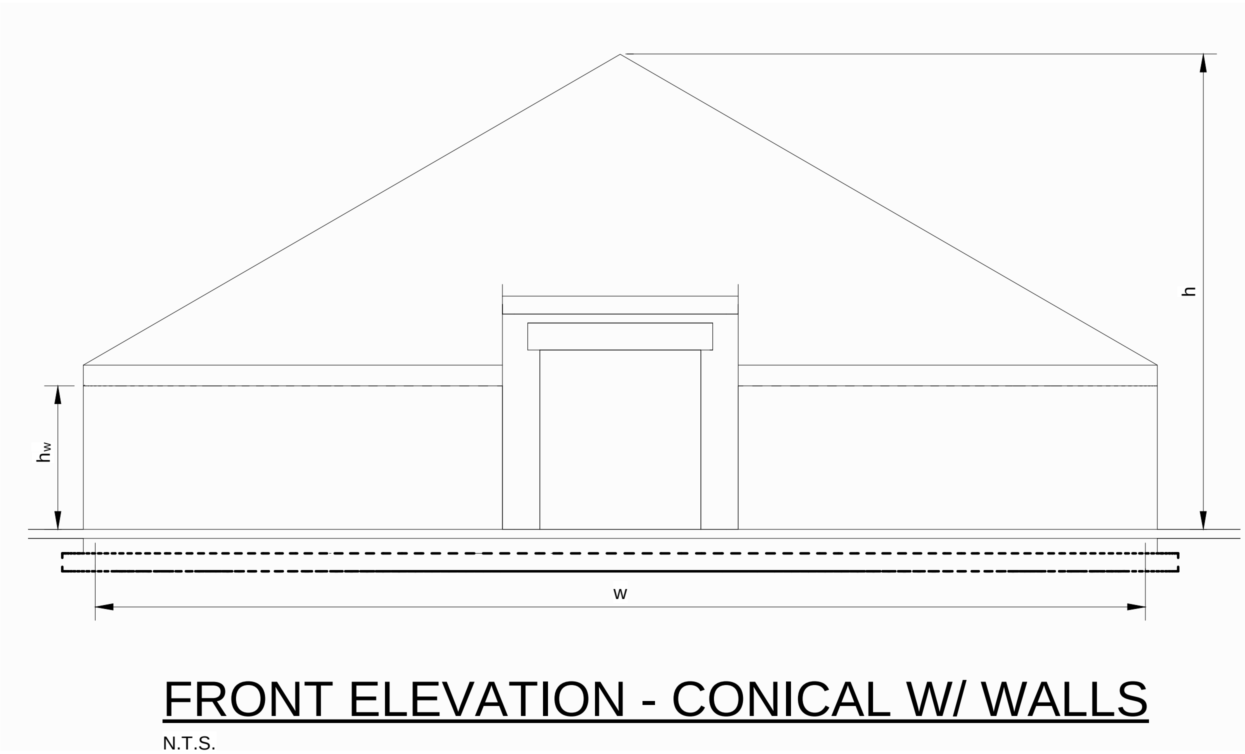

Figure 2: Conical Building with Vertical Walls

Tab 3: "Storage in Rectangular Building"

This set of values is derived from the amount of salt that can be stored in a rectangular building with vertical sidewalls as depicted in figure 3 (a and b). It is assumed that the salt will form a shape with rounded ends and a prismatic central section as shown in figure 3. Key input variables for the calculations are the height of the building walls (h_w) entered in feet in cell E4, and the aspect ratio of the building (the ratio of the building length to its width – designated as A_r) entered in cell E6. The aspect ratio should be at least 2.0 (that is, the length should be twice the width as a minimum). The total length of the building (L) is given as:

$$L = wA_r \tag{8}$$

As in tab 2, the user has two sets of calculations available. Option 1 is for a building loaded with a conveyer system which assumes (see above) that 90% of the total available storage can be utilized. Option 2 is for a building loaded with a front-end loader or equivalent which assumes that 60% of the total available storage can be utilized.

The building width, w, (in feet) is entered by the user in cell C11 for option 1 and H11 for option 2. Different widths can be assigned for each option as needed by the user, since this allows the user to compare the size of building needed to store a given salt amount with a conveyer system, with the size of building needed to store that same salt amount without a conveyer system.

The volume of salt stored in the building is calculated by "breaking" the salt stored into two parts – the ends of the pile are assumed to be approximately semi-conical (so the two ends together will make a cone), while the center of the pile is a prismatic shape, with a triangular cross section placed upon a rectangular base (again, as shown in figure 3). Using this representation, the weight of salt stored in the ends of the pile is the same as in a conical building of diameter w feet as given in equation 7. To this is added the weight of the salt stored in the prismatic part of the pile. To calculate this, we first estimate the length of the prismatic section (*l*) as shown here:

$$l = w(A_r - 1.0) \tag{9}$$

Using this, and the height of the walls (h_w) previously entered, as well as the height of the triangular cross-section pile of salt on top of the rectangular base as calculated using equation 1 (h) we can calculate the volume of the prismatic section of the pile (V_p) as:

$$V_p = wl\left(h_w + \frac{h}{2}\right) \tag{10}$$

As discussed above, equation 7 provides the weight of the salt stored in the semi-conical ends of the pile, and we can add this to the weight of salt stored in the prismatic central section of the pile to obtain the total weight stored in the pile (W), as shown here:

$$W = \frac{80}{2000}\left[wl\left(h_w + \frac{w \tan 32}{4}\right) + \pi\left\{\frac{h_w w^2}{4} + \frac{0.3125w^3}{24}\right\}\right] \tag{11}$$

The solutions in the two options are then obtained by multiplying the value obtained in equation 11 by 0.9 and 0.6 respectively, giving the salt stored in a conical structure with a conveyer system in cell C16 and in a structure without a conveyer system in cell H16. The height of the salt pile is simply the sum of the height of the wall (provided by the user in cell F4) plus the height of the cone on top of the pile (calculated using equation 1 as before) and is provided in cells C17 and H17 respectively.

Figure 3a: Perspective View of Elongated Conical Building

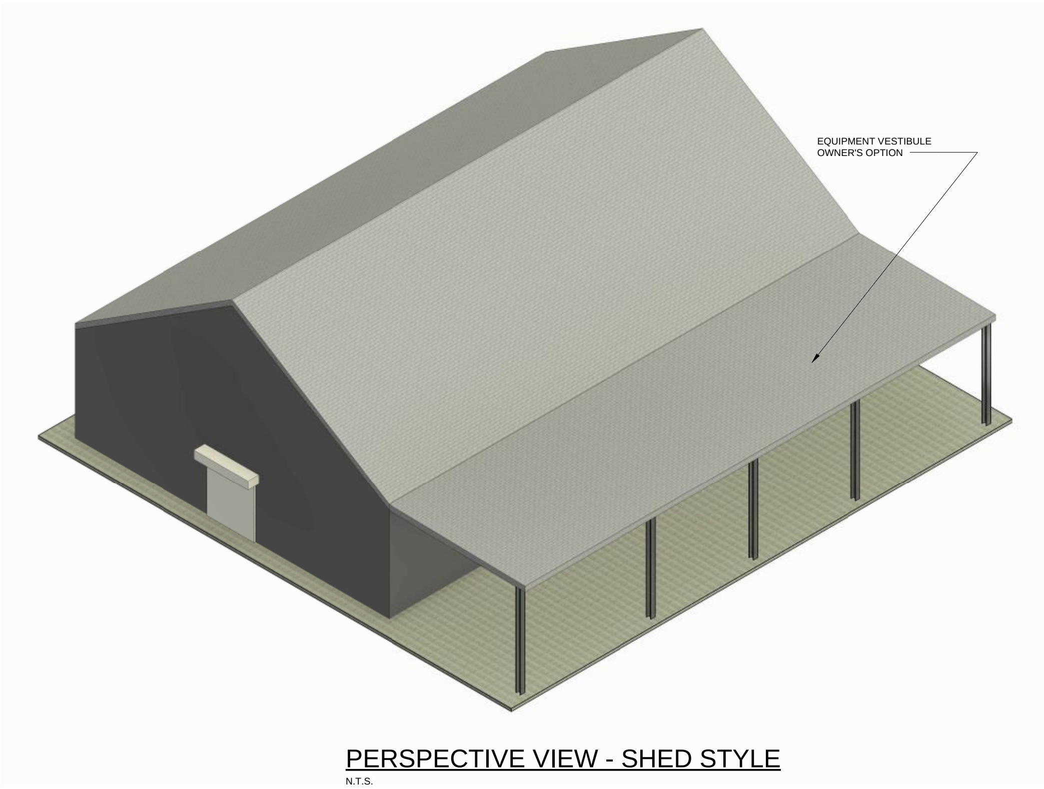

Figure 3b: Perspective View of Rectangular Shed Style Building

Using the Spreadsheet Tool

The purpose of the tool is to provide an estimate of how much salt can be stored in a given size of structure. Users may choose to employ the tool as they wish, but the following is offered as a general guide to how the tool might be used by an agency interested in sizing a salt storage facility.

Step 1: Starting Estimates

Let's suppose that an agency needs a facility that can store 12,000 tons of salt (which is based upon their five year average of salt use at the location where the new facility will be placed). With this number in mind, the user might go to the first tab (Conical Piles No Walls) and input the desired storage (12,000 tons in this example) into cell H7 (this is under option 2). The output for this is shown in Figure 4.

Option 2: What diameter to store a given weight of salt	
Input Section	
Weight of Salt Stored (in tons)	12000
Output Section	
Diameter of Conical Pile (in feet)	**154.2**
Height of Pile (in feet)	**48.2**

Figure 4: Output of the First Step

The cone to store this much material is about 155 feet in diameter. Of course, there is no wall around this pile, which will likely reduce the parameter somewhat. So the next step is to investigate whether a conical structure would allow the desired amount of salt to be stored within a reasonable footprint.

Step2: Conical Footprint

The user now proceeds to the second tab (Storage in Conical Building). Two initial choices must be made. First, what height of wall would be suitable in your conical building. Ten feet is a reasonable number to begin with, but this can be adjusted as needed. If the required wall height to store the needed salt exceeds 20 feet then it is likely not feasible. The wall height is entered into cell F4.

The second initial choice is whether salt will be stored with or without a conveyer system. A conveyer system allows much more efficient usage of the available storage space but the initial capital costs for such a system may not be feasible.

For the purpose of this example, we will assume a conveyer system is available, then we will run a parallel computation to see how large a building would be needed if no conveyer system was used. In other words, we will do our initial calculations in the Option 1 box, then a comparative calculation in the Option 2 box.

In the Option 1 box, we enter our initial estimate of the building diameter into cell C11. In step 1 we found that a conical pile needed to be about 155 feet in diameter to store 12,000 tons of salt, so that is a good starting point. As figure 5 shows, this gives us a salt storage of about 17,700 tons – rather more than we need.

Option 1: How Much Weight Stored for a Given Diameter Pile (assuming conveyer used so 90% efficient storage)	
Input Section	
Diameter of Pile (in feet)	155
Output Section	
Weight of Salt Stored (in tons)	17761
Height of Building (in feet)	58.4375

Figure 5: Salt stored in a conical structure.

Clearly, we do not need such a large structure. We can enter in different values of pile diameter in cell C11 until we get close to 12,000 tons stored. Doing this (see figure 6) we find that a diameter of 134 feet is sufficient to store 12,000 tons, in a facility with a conveyer system.

Option 1: How Much Weight Stored for a Given Diameter Pile (assuming conveyer used so 90% efficient storage)	
Input Section	
Diameter of Pile (in feet)	134
Output Section	
Weight of Salt Stored (in tons)	12164
Height of Building (in feet)	51.875

Figure 6: Diameter of conical structure to store 12,000 tons.

As discussed above, we can conduct a parallel calculation for a structure without a conveyer system, using option 2, and entering the pile diameter into cell H11. As can be seen in figure 7, we would need a conical building 156 feet in diameter (and with a 10 foot vertical wall) to store 12,000 tons of salt if we did not have a conveyer system.

Option 2: How Much Weight Stored for a Given Diameter Pile (Assuming no conveyer so 60% efficient storage)	
Input Section	
Diamter of Pile (in feet)	156
Output Section	
Weight of Salt Stored (in tons)	12041
Height of Building (in feet)	58.75

Figure 7: Size of Conical Building with no Conveyer System

Step 3: Rectangular Footprint

When considering a building with a rectangular footprint, the aspect ratio (the length of the building divided by its width) must be specified as well as the wall height. The spreadsheet requires that the aspect ratio (entered in cell E6 under the third tab "Storage in Rectangular Building") have a value of at least 2.

Continuing our example of storing 12,000 tons of salt, we may consider both the conveyer equipped option (option 1) and the building without a conveyer (option 2). As figure 8 shows, using a wall height of 10 feet and an aspect ration of 4, the conveyer equipped building would be 68 feet wide and 272 feet long.

Option 1: How Much Weight Stored for a Given Width of Building (assuming conveyer so 90% efficient storage)	
Input Section	
Width of Building (ft)	68
Output Section	
Length of Building (in feet)	272
Weight of Salt Stored (in tons)	12075
Height of Salt Pile (in feet)	31.3

Figure 8: Rectangular Building Footprint with Conveyer.

In contrast, if no conveyer system is available, then option 2 shows us (see figure 9) that the building would be 80 feet wide and 320 feet long.

Option 2: How Much Weight Stored for a Given Width of Building (Assuming no conveyer so 60% efficient storage)	
Input Section	
Width of Building (ft)	80
Output Section	
Length of Building (in feet)	320
Weight of Salt Stored (in tons)	12082
Height of Salt Pile (in feet)	35.0

Figure 9: Rectangular Building Footprint without Conveyer.

In any specific situation, the details of the available facility footprint will drive the selection of building shape, aspect ratio, wall height, and so forth. However, the spreadsheet tool provides a useful initial analysis tool to investigate the options in a broad sense.