EROSION COVER DESIGN FOR DISPOSAL SITES

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ABSTRACT

The dissipation of radon gases from uranium mill tailings piles is a major concern in the reclamation of existing tailings piles. In order to dissipate the gases before they escape into the atmosphere, the tailings will be covered with three to 10 feet of clays, silts, sands, or varying mixtures of the three. The type and thickness of material used will depend on the borrow material available in close proximity to the site as well as the physical properties of the material.

In the design of these radon barriers, it is extremely important that the integrity of the barrier be maintained for the design life of the facility (1000 years). Processes which threaten the integrity of the barrier are wind and water erosion resulting from flood inundation or on-site rainfall runoff, cracking of the soil due to differential settlement or desiccation, roots from plants or trees, and animals burrowing into the soil. In order to protect against potentially destructive erosional forces, a rock cover has been incorporated into the design.

The purpose of this paper is to present the design procedures that will be used for specifying rock erosion protection for the remedial action at the UMTRA Project sites, in order to have consistent designs from one site to another. These procedures have been adopted after a careful review of existing literature and design procedures.

INTRODUCTION

Design objectives for the UMTRA Project first became an issue in 1978 under Public Law 95-604 when responsibility for the remedial action of the inactive uranium mill tailings sites was placed on the Department of Energy (DOE). After an intensive research effort by the DOE, NRC, and EPA to develop standards, the EPA identified the major environmental and health problems associated with inactive uranium mill tailings sites and promulgated standards to be met by proposed remedial actions, which became effective March 7, 1983. The standards establish requirements for radiation protection, for protection of water quality, and for ensuring long-term containment and stability.

The release of radon gases from uranium mill tailings piles is a major concern in the stabilization of existing tailings piles. In order to reduce the concentration of Radon-222 to the atmosphere to acceptable levels, as determined by EPA regulations, the tailings will be covered with three to 10 feet of clays, silts, sands, or varying mixtures of the three. The type and thickness of material used will depend on the borrow material available in close proximity to the site and the physical properties of the material.

In the design of these radon barriers, it is extremely important that the integrity of the barrier be maintained for the design life of the facility (1000 years). Processes which threaten the integrity of the barrier are wind and water erosion, cracking of the soil due to differential settlement or desiccation, invasion of roots from plants or trees, and animals burrowing into the soil. In order to protect against these potentially destructive forces, a rock cover has been incorporated into the design. This paper describes the proposed procedures for specifying the maximum and minimum rock size and the grading of the material for the prevention of water erosion.

Depending on the erosive forces for a particular site, a single rock layer may be the proper size and gradation to meet the criteria for erosion protection and also serve as a filter for the radon barrier. However, at other sites it may be necessary to have one or more intermediate sand or gravel layers to protect against erosion of the radon barrier due to transport of soil particles through the rock cover during a storm event.

The design of a cover system that will be effective for a specific site requires the consideration of each of the following factors:

- Grain size of radon barrier.
- Grain size of available rock.
- Velocities of floods that come in contact with cover.
- Type of vegetative cover that will establish itself or will be established.
- Wind and water erosion factors.
- Infiltration requirements.
- Construction requirements.

The purpose of this paper is to set the design procedures that will be used for the remedial action at the UMTRA Project sites, in order to have consistent designs from one site to another. These procedures have been adopted after a careful review of existing literature and design procedures.

DESIGN METHODOLOGIES

Before one can design to the standards

established by the EPA, one must first decide on the methodologies that are available to solve the problem. In the case of the UMTRA Project sites, the criterion to use a design life of 1,000 years without planned maintenance presents a unique problem. In the design of earthen retention structures, it is generally assumed that routine maintenance will assure the continued operation of the facility.

Relating this to probability, using a probability of occurrence of 0.01 and a design life of 1,000 years, the required recurrence interval for design would be approximately 100,000 years. Clearly, there are no records available to define the methodologies needed to design for such a large recurrence interval. Also, there is no known way to extrapolate to 100,000 years or even 1,000 years based on only 50 or 100 years of record. Therefore, design methods must be adopted which incorporate conservatisms into the design. The design criteria for the stability of the UMTRA Project tailings piles due to erosive forces resulting from rainfall runoff across the top and down the sides of the stabilized embankment are based on the runoff from the localized Probable Maximum Precipitation (PMP). For flow occurring as a result of rainfall on the watershed above the stabilized embankment, the pile is designed to resist the runoff from the Probable Maximum Flood (PMF) as a result of the PMP. The PMP is the worst possible event that could occur as a result of a combination of the most severe meteorological conditions occurring over a watershed at the same time. Although no recurrence interval can be assigned to this event, it is felt by most surface-water hydrologists that the recurrence interval is in excess of 100,000 years.

A design based on the PMF impacts the proposed remedial action in two ways: (1) if the pile cannot be protected from the PMF due to geomorphic considerations then the pile must be relocated, and (2) wherever the pile is stabilized, it must resist the erosive forces of the water due to flow adjacent to the pile from drainage area runoff, and also due to on-pile runoff.

Erosion Protection Design Methodology

Erosion protection of cover material at the UMTRA Project tailings reclamation sites is controlled by the erosive forces associated with the Probable Maximum Precipitation (PMP) resulting in the Probable Maximum Flood (PMF) both on and adjacent to the tailings pile. Based on the PMF for a particular site, the erosion cover material can range from a coarse sand and gravel to large boulder riprap, depending on the size of storm, the size of the drainage basin, and the velocities associated with the runoff. Several procedures were investigated for calculating the required mean rock size needed to provide a stable rock slope during the PMF. Each procedure used one of three basic approaches: (1) critical velocity, (2) critical shear stress, and (3) lift and drag force mechanisms.

The critical velocity equations consider the impact of flowing water on the particles such that the material of a given size and weight is just able to move. Inherent in this approach is the lack of good definition of the bottom velocity and the difficulty in accurately measuring or predicting this velocity. Another difficulty in using this approach is determining the relationship between bottom velocity and average velocity.

The lift and drag force mechanism approach accounts for pressure differences caused by the gradient of the velocity. The pressure differences occur because of steep velocity gradient, where the velocity at the top surface of a particle at rest on a channel bottom is greater than zero, while the velocity at the bottom surface is zero.

The critical shear stress equations consider frictional drag of the flow on the particles and consider the fluid shear stress on a rock layer to the mean flow velocity. This approach is the best for the design of erosion protection in general and for the UMTRA Project sites because the mean cross-sectional velocities are most easily obtained.

The design method which is most applicable to the design of a rock blanket for erosion protection is the "Riprap Design with Safety Factors Method" developed for the Wyoming State Highway Department by Stevens et al. (1976)[1]. The theory and formulation of this method are not discussed as part of this paper since they are well documented in the published paper. This method is based on the theory of critical shear stress and allows more flexibility in design because the designer is able to choose the factor of safety needed for the design of a particular site and work through the analysis to determine the required rock size. This flexibility is particularly important when considering the conservatism associated with using the PMF as the design storm. As will be discussed in more detail in later sections, the best technique available for steep slopes is the method proposed by Stephenson (1979)[2], which is based on critical shear stress and empirical solutions developed from flume studies.

Riprap Design Parameters

Information needed to design riprap by the Safety Factors Method is:

- The angle of repose of rock to be used.
- The specific gravity of rock to be used.
- The slope of the bed or sideslope over which the rock will be placed.
- The velocity of flow over the rock to be used.
- The depth of flow over the rock to be used.

The angle of repose of a rock is dependent on the angularity and diameter of the rock and can vary from about 32 degrees to 42 degrees, with most rocks falling in the range of 34 to 37 degrees. This factor has a small effect on the final mean rock size and wherever data are not available a conservative estimate of 35 degrees is usually assumed.

The specific gravity of a rock is dependent on the mineralogy of the rock and usually varies from 2.5 to 2.8. Where data are not available, a conservative estimate of 2.6 is usually assumed.

The slope of the bed, and side and top slopes will vary and be part of the design. Typically, the top slope will be two to five percent and the sideslope will be 20 percent or less. The bed slope will be dependent on the topography.

The velocity (V) and depth of flow (Y) are related to the quantity of flow (Q) which occurs either on or adjacent to a stabilized tailings pile, the angle of the slope over which the flow occurs, and the roughness of the surface. The method used to calculate this quantity is somewhat controversial for rainfall on the pile itself. This controversy is centered on whether the flow across the top of the pile and down the sideslopes is in the form of sheet flow or whether there are flow concentrations which cause the quantity of flow per unit area to increase. The design concepts which have been implemented by the UMTRA Technical Assistance Contractor (TAC) will, in the case of a relocated, recompacted pile, be placed and graded in such a way that sheet flow over the pile will occur. At piles where excessive differential settlement is predicted to occur, an increase in the quantity of flow per unit area, due to some flow concentration, will be calculated based on the area over which the flow occurs and the area of differential settlement which would contribute to the increased flow.

Another point which has lead to some confusion is the method of calculating the shear stress. The most common method adopted is to use Eq. (1).

$$\tau = \gamma_w RS \tag{1}$$

where

τ = Average shear stress acting on the wetted perimeter
γ_w = Unit weight of water
R = Hydraulic radius
S = Slope of bed

Another method for calculating the shear stress is to use Eq. (2), which takes into account the average velocity and the ratio of the depth of flow to mean rock size. The formulation includes the equation for Manning's "n" and one must be careful when using Eqs. (2) and (3) that Manning's "n" is checked and iterated for.

$$\tau = .3 \times V^2 / [3.4/\ln (12.21\ (Y/K))]^2 \tag{2}$$

where

V = Mean velocity (fps)
Y = Depth of flow (ft)
K = Mean rock size (ft)

If Eq. (1) is used to calculate the shear stress, the mean rock size is then calculated by Eq. (3).

$$K = 21 \times \tau/[(G_s - 1) \times 62.4 \times N] \tag{3}$$

If Eq. (2) is used to calculate the shear stress, the mean rock size is calculated by Eq. (4).

$$K = \tau/(N \times (G_s - 1) \times 32.2) \tag{4}$$

where

N = Stability number calculated from the formulations in the Safety Factors Method
G_s = Specific gravity of rock

This is an iterative process because one has to first assume a value of n and K to solve for the calculated K. If they are not equal, the iteration for n and K continues until they are equal. If Eq. (2) is used to calculate the shear stress, the formulation for 'n', Eq. (9), has been incorporated into the equations, necessitating the need to iterate for both n and K.

For the case of sheet flow, the quantity of flow (Q) is calculated by Eq. (5) which is derived from the equation Q = CIA:

$$Q = \frac{I \times L}{43{,}560} \tag{5}$$

where:

A = Area (L x W)
I = The maximum 1-hour intensity (inches)
L = The length of flow (feet)
W = Width of flow (feet)
C = Constant, assumed to equal 1.0

The maximum one-hour intensity is calculated by first determining the local PMP for the pile location and then determining the storm rainfall distribution using the appropriate Hydrometeorological Report (HMR) based on geographical locations. For most of the UMTRA Project sites, Hydrometeorological Report No. 49 is the most appropriate. Next, determine the time of concentration (t_c). This can be estimated by determining the largest length of flow, dividing that length by 2, and then dividing that length by the estimated flow velocity. Once t_c is determined, use this number as the most intense period of time for the PMP. Then using the appropriate HMR, extrapolate down to the correct interval increment to determine the incremental PMP rainfall amounts. The intensity I is then determined by the following formula:

$$I = (\mathrm{PMP})_{t_c} \times \frac{60}{t_c} \text{ (inches/hour)} \tag{6}$$

where:

$\mathrm{PMP}(t_c)$ = The incremental rainfall intensity for the time of concentration

t_c = Time of concentration

The depth of flow over the rock is then calculated using Manning's equation for sheet flow as shown in Eq. (7).

$$Y = \left[\frac{n \times Q}{1.486 \times S^{1/2}}\right]^{3/5} \tag{7}$$

where:

n = Manning's friction factor
Q = Quantity of flow (cfs)
S = Slope of bed, top slope, or sideslope (feet/feet)
Y = Depth of flow (feet)

The velocity of the flow (V) is then calculated from the results of Eqs. (5) and (7) by Eq. (8):

$$V = Q/A \text{ (fps)} \tag{8}$$

where:

V = Velocity (fps)
A = Y x unit width (ft^2)

One number which is critical to making the calculations is Manning's friction factor ('n'). This number is very subjective and is usually based on previous experience. Tables have been published which give values of 'n' for various types of vegetation. Most of these published values are for river beds or open channel flow and are difficult to apply to a tailings pile covered with rock and sparse vegetation.

Another method of calculating 'n' is by a formulation developed by the Corps of Engineers[4] which is related to the depth of flow and size of rock as shown by Eq. (9).

$$n = \frac{Y^{1/6}}{23.85 + 21.95 \log_{10}\ (Y/k)} \tag{9}$$

For some combinations of flow depth and rock size, this equation gives the value of 'n' that may be either too conservative or not conservative enough. Therefore, when using Eq. (9), a lower bound of 0.02 and an upper bound of 0.06 should be used.

Design Sequence

Once all of the design parameters have been calculated, they can be input into the equations for determining the mean diameter rock size. The Safety Factors Methods has four (4) sets of equations depending on the type of flow. These flow conditions are:

- o Nonhorizontal flow on a sideslope.
- o Horizontal flow on a sideslope.
- o Flow on a plane sloping bed.
- o Flow on a horizontal bed.

Flow conditions 1, 2, and 4 are used when flood flow from the associated drainage area flows adjacent to the pile. Flow condition 3 is used for flow which occurs due to rainfall which falls on the pile and flows across the top and down the sideslopes.

Once the flow condition is determined, it is a simple calculation to determine the mean rock size (D_{50}) that will be required to protect against the PMF.

A critical ratio that is used in the calculations of the rock size is the depth of flow (Y) over the mean diameter of the rock (K). This ratio is very important in the calculation of the shear stress if Eq. (2) is used. As the ratio Y/K decreases below 1.0, the shear stress increases significantly for small changes in Y/K and once the ratio Y/K gets below 0.5, the formulation is no longer valid because the flow is no longer sheet flow but interstitial between the individual rock particles.

When determining the rock size for top slopes by the Safety Factors Method, using a safety factor of 1.0, it is recommended that the calculated mean diameter rock size (D_{50}) be actually used as the D_{30} size rock and that D_{50} be calculated accordingly. This method, as reported by Shen and Lu (1983),[5] will produce a layer equal to the layering that would evolve due to the self-armoring of the layers of rock during the degradation or erosion process when not all particles in a given grain size distribution are being transported with a given flow. Under this condition the median size (D_{50}) of the bed comes coarser and coarser. Therefore, by initially using the calculated D_{50} size rock as the specified D_{30} size rock, the natural process of self-armoring is eliminated, unless an event larger than the design event occurs.

As previously mentioned, a critical ratio in the design using the Safety Factors Methods is Y/K, because when the ratio is less than 0.5 the formulation is not valid. This will usually occur when the slopes are steeper than 10 percent and/or the flow (Q) is small. When this situation occurs, another method for determining the mean rock size needed for specific flow and slope characteristics is the method proposed by Stephenson (1979)[2] which was derived for steep slopes. The input parameters for this method are the following:

- o Quantity of flow (cfs) (Q).
- o Angle of slope (θ).
- o Constant (C) (varies from 0.22 to 0.27).
- o Specific gravity of rock to be used (G_s).
- o Angle of repose of rock to be used (ϕ).
- o Porosity of rock fill (related to density) (p).

This formulation is based on the work originally done by Olivier (1967)[6]. This work included research in which a flume was constructed with different size rock layers and different slope angles (two percent to 20 percent) and was tested to determine the failure of various size rocks under different flow and slope conditions.

Based on this work, a formulation for which all rock slopes would not fail was derived. This formulation is shown as Eq. (10).

$$K = \left[\frac{Q(\tan\theta)^{7/6} p^{1/6}}{Cg^{1/2}\,[(1-p)(G_s-1)\,\mathrm{Cos}\,\theta\,(\tan\phi - \tan\theta)]^{5/3}}\right]^{2/3} \quad (10)$$

We feel that this method, although empirical, is more appropriate for flow on the steep sideslopes because it accounts for interstitial flow (flow within the rock layers) and the Safety Factors Method does not. However, the Safety Factors Method could be used if an accurate determination of the amount of interstitial flow could be calculated. This would reduce the depth of flow and therefore the shear stress. This reduction in shear stress would result in a smaller rock size than would be calculated, ignoring interstitial flow.

When Stephenson's method is used, it is not necessary to specify the D_{50} size rock as the D_{30} size rock since the formulation is conservative and includes a safety factor on the order of 1.2 to 1.8.

FILTER REQUIREMENTS AND DESIGN

When designing the cover system, one must evaluate the need for a filter layer between the radon barrier and the erosion protection layer. Most of the research into the need for a filter and design criteria is over 20 years old and varies somewhat. The most widely accepted design criteria for filters are shown in Eqs. (11), (12), and (13).

$$\frac{D_{15}\text{filter}}{D_{85}\text{soil}} < 5 \qquad \text{Stability Criterion} \qquad (11)$$

$$5 < \frac{D_{15}\text{filter}}{D_{15}\text{soil}} < 40 \qquad \text{Permeability Criterion} \qquad (12)$$

$$\frac{D_{50}\text{filter}}{D_{50}\text{soil}} \leq 25 \qquad \text{Separation Criterion} \qquad (13)$$

It has also been suggested at times that Eq. (13) be modified as shown in Eq. (14).

$$12 < \frac{D_{50}\text{filter}}{D_{50}\text{soil}} < 58 \qquad (14)$$

Recent studies by Sherard et al.[7,8] have shown that Eq. (11) is conservative, has a built-in factor of safety between 1.5 and 2.0, and is supported by experimental data.

Results of experiments from the research have shown that the D_{15} size of the soil (Eq. (12)) has no significant influence on the properties of a filter. Additionally, experiments on silts and clays as the base soils show that the D_{15}/D_{15} ratio commonly exceeded 1000 for successful tests.

The criterion shown in Eqs. (13) and (14) has also been found to be unsupported by theory or experimental results. The research by Sherard et al.

recommends that Eq. (11) continue to be used and that Eqs. (12), (13), and (14) be abandoned.

Therefore, it is recommended that Eq. (11) be used as the criterion for all filters. This criterion can be relaxed in some instances for a clay with a high plasticity or if there are fairly low flow gradients. In addition to the above criterion, the following requirements for a graded filter should be met.

- The filter material should pass the three-inch sieve for minimizing particle segregation and bridging during placement. Smaller maximum particle sizes may be specified if practical. Also, filters must not have more than five percent minus the No. 200 mesh sieve, to prevent excessive movement of fines in the filter.
- The gradation curves of the filter and the base material should be approximately parallel in the range of the finer sizes, because the stability and proper function of protective filters depends upon skewness of the gradation curve of the filter towards the fines, giving support to the fines in the base material. Additionally, the material should be reasonably well graded throughout the in-place layer thickness.
- The minimum thickness of the layer should be six inches in order to facilitate ease of construction during placement.

When a rock blanket is to be used over a filter, the rock used should be essentially equidimensional, well graded in size, with a maximum size equal to the blanket thickness to about one-tenth of the blanket thickness. The rock blanket should also meet the filter criteria of Eq. (11) so that the filter material does not migrate through the voids in the rock. The thickness of the rock layer should not be less than the spherical diameter of the upper limit of D_{100} rock or less than 1.5 times the spherical diameter of the upper limit of D_{50} rock, whichever is greater.

When a rock blanket is to be used on a sideslope and flow will be horizontal to the slope, scour at the toe will most likely occur. To prevent the scour, which could cause failure of the rock blanket, it is recommended that a shallow trench be excavated at the toe of the slope and that the trench be backfilled with the same rock blanket material. As a rule of thumb, the depth of the trench should be at least two times the thickness of the blanket and the width of the trench should be twice the depth.[9]

CONVERSIONS FROM ENGLISH TO SI UNITS

Since the equations used in this paper are more commonly recognized in their English units form, they have been left as such and the following table provided to convert to SI units.

feet per second x 0.3049 = meters per second
feet x 0.3049 = meters
cubic feet per second x 0.0283 = cubic meters per second
square feet x 0.0929 = square meters
inches per hour x 0.3937 = centimeters per hour

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REFERENCES

1. Stevens et al. (M. A. Stevens, D. B. Simons, and G. L. Lewis), 1976. "Safety Factors for Riprap Protection," in American Society of Civil Engineers Journal of Hydraulic Engineering (1976).
2. Stephenson, David, Rockfill in Hydrologic Engineering, Elsevier Scientific Publishing Company, New York, New York (1979).
3. Hansen et al. (E. M. Hansen, Francis K. Schwarz, and John T. Riedel), Probable Maximum Precipitation Estimates, Colorado River and Great Basin Drainages, Hydrometeorological Report No. 49, prepared by the National Weather Service, Office of Hydrology, for the U.S. Department of Commerce and U.S. Department of the Army, Silver Spring, Maryland (1977).
4. COE (U.S. Army Corps of Engineers), Engineering and Design, Hydraulic Design of Flood Control Channels, EM 1110-2-1601, Office of the Chief of Engineers, Washington, D.C. (1970).
5. Shen, H. S., and J. Y. Lu, "Development and Prediction of Bed Armoring," in American Society of Civil Engineers Journal of Hydraulic Engineering (1983).
6. Olivier, "Through and Overflow Rockfill Dams - New Design Techniques," in Proceedings of ICS, published in Rockfill Hydraulic Engineering, Elsevier Scientific Publishing Company, New York, New York (1967).
7. Sherard et al. (J. L. Sherard, L. P. Dunnigan, and J. R. Talbot), "Basic Properties of Sand and Gravel Filters," in American Society of Civil Engineers Journal of Geotechnical Engineering (1984).
8. Sherard et al. (J. L. Sherard, L. P. Dunnigan, and J. R. Talbot), "Filters for Silts and Clays," in American Society of Civil Engineers Journal of Geotechnical Engineering (1984).
9. B. Keshian, M. Bone, and T. Schruben, "Design of Erosion Protection for Long-Term Stability," Proceedings of the Seventh Annual Symposium on Management of Uranium Mill Tailings, Low Level Waste, and Hazardous Waste, Colorado State University, Fort Collins, Colorado (1985).