DESIGNING SURFACE COVERS: AN APPROACH TO LONG-TERM WASTE SITE STABILIZATION

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ABSTRACT

The wide range of existing environmental conditions, potential contaminants and available cover materials at waste disposal sites requires site-specific designing of surface covers for effective long-term erosion resistance. This paper presents a systematic approach to designing surface covers for hazardous waste repositories that can be tailored to conditions at any site. The approach consists of three phases: 1) An assessment, during which the degree of required surface protection (erosion potential) is determined. 2) A preliminary design that integrates surface cover design with the need to minimize transport of contaminants 3) A final design, where the cost and effectiveness of the surface cover are determined.

INTRODUCTION

Soil placed over a containment system can provide a protective mantle if the soil is not lost by erosion. Vegetation is an attractive choice for controlling wind and water erosion since it is economical and self-renewing. In extremely arid regions, the attainable vegetative cover may not stabilize the surface layer adequately. In these areas, rock covers may be required. However, by limiting evapotranspiration, rock covers can permit the moisture content of the waste to increase.[1] An advantage of maintaining elevated moisture contents in overburden materials is reduced emanation of toxic gases such as radon in uranium mill tailings[2-3]. Excessive moisture accumulation, however, may result in drainage through the waste which increases the potential for groundwater contamination. Increased moisture may also affect the physical stability of the site[4].

The vegetation and rock surface covers discussed here are various combinations of plant types (grasses, forbs and shrubs) and/or thin layers of small to medium-sized rock or aggregates. These covers can be applied to protect portions of waste sites from the erosive forces of wind and rainfall events. Vegetative and rock covers are distinct from more massive riprap materials, which are used to protect areas that are likely to be subjected to flooding.

An approach for designing surface covers on a site-specific basis is necessary because of the wide range in climatic, edaphic, and topographic conditions existing at the various parts of the country where disposal sites are located as well as differences in waste characteristics. To develop a site-specific design re quires detailed site information combined with the proper techniques to evaluate the information. Following are discussions of 1) the basic elements involved with surface cover design and 2) an approach to designing site specific surface covers. The research is being performed at the Pacific Northwest Laboratory (PNL)[a] and is supported by the Department of Energy's Uranium Mill Tailings Remedial Action Program (UMTRAP). This method for designing surface covers is being developed specifically for inactive uranium mill tailings, but it is applicable to any type of buried waste facility.

BASIC ELEMENTS OF SURFACE COVER DESIGNS

Erosion

The type of surface cover used on a disposal site should be based on the expected type and severity of erosion. Excess protection will lead to unnecessary expense, while too little protection could result in failure to contain the waste material. However, surface covers should not be expected to correct or compensate for steep slopes or other physical/structural features that contribute to instability. For each site, an initial evaluation must identify the types of erosion likely to occur and the portion of the site to be impacted. Stabilization designs should be adequate to resist erosion from channeling, wind, and rainfall runoff processes as necessary. Where channel cutting is likely to occur, relatively massive riprap may be required for long-term stability. Portions of the site above projected flood stage will require stabilization from wind, rainfall and overland flow. For those sites where soil and climatic conditions are favorable, vegetation alone may be adequate to stabilize the surface. Where vegetation is likely to be inadequate, surfaces may require a covering of rock or a combination of rock/vegetation to control erosion.

Soil Moisture

Except in cases where the groundwater level occurs near the surface soil moisture dynamics within the waste are driven by input from precipitation and regulated by surface conditions. Expected surface conditions may range from a cover where vegetation is predominant, to rock-vegetation combinations, to a cover of total rock. At most western sites, potential evapotranspiration equals or exceeds precipitation. Under these conditions, no net accumulation of moisture in the soil/waste profile is expected because, normally, evaporation from the soil surface and transpiration by plants effectively remove the water that enters the soil as precipitation. Rock covers will cause increased infiltration and decreased evaporation[1]. Areas covered with rock will effectively capture more precipitation than adjacent areas without rocks. Thick rock covers can exclude

[a]Operated by Battelle Memorial Institute

plant growth for a number of years and contribute further to water accumulation in and percolation through the waste. Thin rock covers (rock mulches) that permit plant growth may make additional moisture (from increased infiltration and decreased evaporation) available to plants and thereby provide a more vigorous vegetative cover than would otherwise be available. The type of surface cover, then, will affect the moisture balance of the containment system.

These observations suggest that the surface area covered with riprap or thick rock cover be minimized at sites where additional water flowing through the waste zone might contribute to groundwater contamination. Areas with vegetation or rock mulches and vegetation should be maximized for the same reason.

Plant and Animal Intrusion

The effectiveness of containment systems is affected by plant growth and animal activity. The penetration of plant roots into waste can cause the release of contaminants into the environment. Burrowing activity of mammals and invertebrates promotes contaminant escape. Hakonson[5] discovered up to two miles of pocket gopher tunnels over a low-level waste burial site at Los Alamos National Laboratory. Vogel[6] reported that prairie dogs construct their mounds in a way that promotes wind-induced ventilation through their tunnels. This activity over a waste site could increase the emanation of toxic gases. Tunnel systems created by small mammals, ants and decomposing plant roots may also enhance the passage of surface water through earthen covers and into wastes. Burrowing, digging and similar action of animals reduces soil structure and results in an accumulation of more easily erodible soil on the surface[7-8]. A continuation of this process over several years will "feed" natural erosional processes by wind and water and thereby reduce the cover thickness over the waste site.

Design of the surface cover can affect the kinds of plants and animals associated with tailings piles. Soil characteristics such as texture and amount of rock can affect vegetation composition[9 10 11], and consequently, root distribution. Vegetation type and soil properties affect the species of burrowing rodents in an area[12-13-14]. Control of plant and animal activity is possible by the proper design of surface covers and subsurface barriers[15].

Integration of System Components

Soil moisture is the common link between the components of a containment system. The amount of moisture in the soil affects the attenuation of toxic gases by earthen materials[3]. The design of effective liners depends on knowing the amount and rate of water passing through the waste. Calculations of leachate movement will require information on water input via precipitation. The amount and depth of soil moisture will affect the growth of plant roots, and may influence the need for intrusion barriers. Hence, understanding the factors affecting soil moisture is critical to designing effective containment systems.

Optimization

It is obvious that containment system designs will involve a number of trade-offs. Increase the amount of soil moisture to reduce toxic gas flux and increase the chance of biotic intrusion. Reduce the erosion potential by thickening rock covers and increase the amount of water in the system --- and so on. Optimization of system components will be a vital part of containment design. Because soil moisture is a factor in the functioning of all components, the ability to regulate the amount of moisture in the system allows a greater range of design options. Sufficient knowledge of how surface covers affect soil moisture dynamics may make it possible to engineer surface covers that maintain a desired amount of moisture. Control of soil moisture is conceivable by a proper mix of rock and vegetation in the surface cover. The depth to which roots penetrate may be controlled through proper placement of a root barrier. For example, maximum cover moisture could be achieved by placing thick rock layers on the surface to reduce evapotranspiration and by placing a root barrier close to the surface to prevent roots from extracting moisture from the lower portions of the cover. In this way, precipitation quickly infiltrates beyond the rooting zone and can only be lost by drainage. Minimal soil moisture could be achieved by maximizing vegetative cover and root development to extract the water. Combinations of rock, vegetation, and biobarriers can result in the control of soil moisture as desired.

Risks

Assessments of risk related to particular methods of surface stabilization will play an important role in designing covers. The appropriate level of risk will vary from site to site as will the elements of that risk. Stabilization designs must reflect real concerns but they must be practical in terms of cost and application methods. The costs associated with maximum assurance of long-term stability may be prohibitive, while practical designs are likely to have some risk of failure. The risks associated with surface stabilization involve: 1) excess moisture percolating through the waste with the potential for contaminant leaching in to groundwater or 2) failure of the protective cover and subsequent disruption of the containment system, which would allow escape of contaminants into the environment. Vegetative and rock covers are both subject to failure for basically different reasons.

Vegetation can be diminished by grazing, fire or climatic change. Of these, grazing poses the most serious threat, but the use of plant species that are resistant to grazing or unpalatable can reduce the problem. Fire can burn off the vegetation, but if fire-tolerant plant species are used, fire effects on the cover will likely be minimal[16]. Fire-tolerant plants typically resume normal growth within a year of the fire, and even though the above-ground parts are lost until the next growing season, the root systems remain intact and stabilize the soil surface. Long-term drying could reduce the vegetative cover, but it would concurrently reduce the risk of water erosion. A change toward a wetter climate would increase the vegetative cover, which might then provide more protection. Clearly, perturbations resulting from climatic change are the most difficult to ascertain. Simulation models may provide the best estimates of alterations in erosion patterns resulting from long-term climatic change.

Rock covers present another set of risks. These include the problems associated with increasing moisture in the waste, human disturbance, fire, salt accumulation and climatic change. By placing rocks on the surface to prevent erosion, evaporation and run-off are reduced. If enough rocks are placed on the surface, plant cover (and transpiration) will be reduced. The net result will be increased moisture in the waste and possible leaching. Whether or not the increase in moisture poses a greater risk than increased erosion (if the rocks are not used) remains a site-specific question. Aside from flood damage, mass wasting probably poses the most serious threat to waste site stability[4-17]. The effects of the added weight of rock covers and increased moisture in the overburden may contribute to mass wasting.

Another major risk involved with rock covers (especially riprap) is removal of stones by humans. Archeologists are familiar with the removal and subsequent use of rock building materials by later generations unfamiliar with the purpose of a structure[18]. Many Roman ruins have had stones removed for use as building materials by later generations. Some burial mounds constructed by the North American Indians originally had rock covers. European settlers who later dominated the land removed the stones to build fences and buildings. Waste sites with elaborately engineered rock covers in areas where little rock is available would be prime targets for disturbance once institutional control is lost.

Burning of vegetation growing on rock covers can seriously reduce rock durability if the rocks are strongly heated[19]. The disintegration of rock by salt action is one of the most potent and rapid weathering processes[19]. If rock covers are placed on overburden containing salt or if salts from wastes rise to the surface, rock covers could be adversely affected. Extensive chemical weathering of rock is related to elevated moisture and high temperatures, and may be accelerated by high levels of organic acids produced by vegetation[20]. If rock covers are used in humid areas, or if future climates are wetter, survivability of rock covers will be reduced.

AN APPROACH TO DESIGNING SURFACE COVERS

Climate, soil, and topographic conditions must be considered in conjunction with the revegetation potential and the availability of rock material at a given site. As a basis for design planning and for determining research needs, we have constructed a decision tree (Figure 1). The decision tree outlines the process of gathering site information necessary for designing a surface stabilization plan and for evaluating the effects of the surface cover on the containment system. The degree of erosion protection is determined by calculating the expected maximum erosive forces acting on the various portions of the site using erosion models and design flood analysis.

The decision tree shows the process of designing surface covers as having three phases: The first, or assessment phase, involves collecting the appropriate site information in order to construct a preliminary surface cover design (phase two). The preliminary surface design will describe the general type of cover necessary to prevent erosion damage. This general surface cover design can be combined with preliminary designs of the other components of the containment system to produce a conceptual site design. After a conceptual design has been formulated, phase three begins. During phase three, an optimization procedure results in a final site-specific surface cover design. A brief discussion of the steps involved will illustrate the procedure.

Phase one consists of evaluating site conditions. For a given site, data on climate, soils, topography and vegetation are collected. The long-term vegetative potential of the site may then be determined by evaluating existing vegetative cover on soils that are available and desirable for use at the site. Over the long-term, vegetation on the covered waste can be expected to resemble that in the surrounding area where soils and topography are similar. Using physical characteristics of the site, soil properties, local climatic data and expected vegetative cover, erosion models may be used to predict the consequences of erosion events with and wtihout vegetative covers.

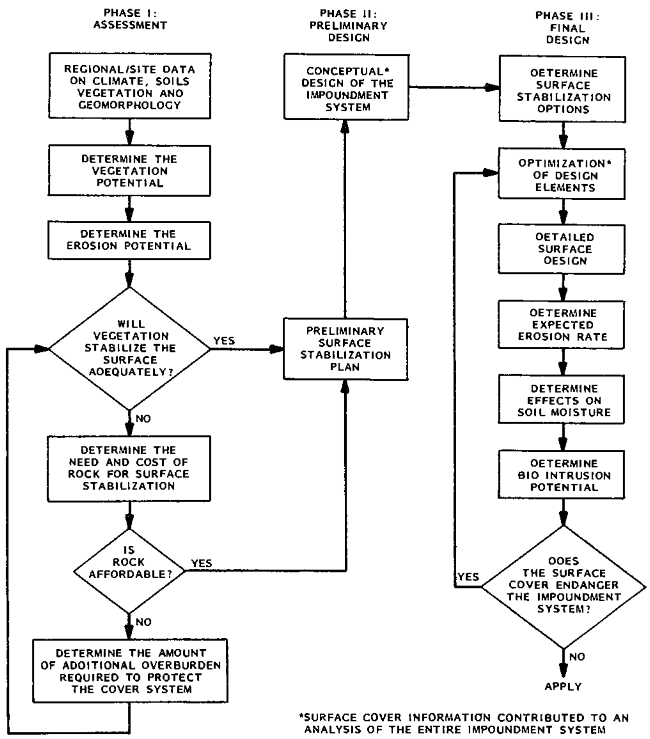

Fig. 1. Decision Tree for Designing Inactive Mill Tailings Surface Covers

Based on the calculated erosion rates and criteria for stability, the adequacy of vegetation for surface protection can be judged. If vegetation is considered adequate, a preliminary revegetation plan is produced. If vegetation is judged to be inadequate for long-term erosion control on all or parts of the site, other means must be used to control erosion. The recommended next step is to determine the need and cost of suitable rock for covering the entire site or portions of the site exposed to high erosion rates. Some types of rock can be very effective in reducing erosion, but they may not be available locally. The cost of using rock covers is heavily dependent on the distance the rock must be hauled. At some distance rock may no longer be affordable.

If rock cover is feasible, a preliminary design using rock or a combination of rock and vegetative covers can be produced. If suitable rock is not available, the use of additional overburden, greater amounts or better quality topsoil, or recontouring may reduce erosion rates; once these options are determined, erosion potential is recalculated and again the adequacies of vegetation as a surface cover are evaluated. This process may require several iterations before a preliminary plan is produced.

The preliminary surface stabilization plan is intended to provide information and alternatives for surface cover design to those designing other portions of the containment system. The product of this interaction is a conceptual design consisting of viable alternatives for surface covers and the other components of the containment system. The alternatives are expressed qualitatively and represent a "first cut" at a design based on existing knowledge.

The third phase of the design process begins by quantifying the alternatives for surface stabilization available for the site. The cost and effectiveness of the alternatives are optimized in conjunction with other containment system components to arrive at a final design plan. Before the final design can be applied, impacts of surface stablization design on the functioning of the entire system must be evaluated in detail. Erosion rates are determined using site specifications. Effects of surface covers on soil moisture should be determined, taking barrier and liner designs into account. The risk, and possible effects of biointrusion resulting from the proposed surface cover must be evaluated at this time. If the consequences of surface cover design do not jeopardize the functioning of the system based on the above evaluations, the design can be finalized. If the surface cover does jeopardize the functioning of the system, then alternative designs must be considered. Again, several iterations of this process may be necessary.

The major benefit of the decision tree approach is the flexibility it allows in designing surface covers. It does not specify types and amounts of cover material. This approach requires only that designs provide adequate surface erosion control and not jeopardize the containment of toxic waste by promoting biotic transport or accelerating water transport. Adequate erosion control is, logically, that which is required to keep the protective layer intact for the design life of the containment system. A surface cover, therefore, can be any combination of soil, rock and vegetation that is effective and economical.

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