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FIELD DEMONSTRATION PROJECT USING CLEAN COAL TECHNOLOGY BY-PRODUCTS

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ABSTRACT

The disposal of flue gas desulfurization (FGD) by-products has become a major concern as issues of emission cleansing and landfill costs continue to rise. Laboratory tests conducted in the Department of Civil Engineering at The Ohio State University have shown that the dry FGD by-products possess certain engineering properties which have been proven desirable in a considerable number of construction uses. As a follow on to the laboratory program, a field investigation into possible engineering uses of dry FGD wastes was initiated. In the work presented in this paper, FGD by-products were used to reconstruct the failed portion of a highway embankment. The paper presents the procedures used in the process and examines the stability of the repaired highway embankment.

Ohio State Highway 541 has suffered significant surface settlement and has exhibited features indicative of slope failure. FGD by-products were used to construct a continuous wall at the base of the embankment to prevent further slippage along an existing failure plane. The reconstructed slope is analyzed using an Intelligent Discussion Support System developed by the authors. The calculated factors of safety and the observed embankment performance give indications that the field demonstration project was a success. Long-term monitoring of embankment movement and water levels and quality are being performed since this is the best barometer of project performance. The completion of these experiments should lead to increased acceptance of these waste materials in various construction projects. Monetary

savings will be realized in the reduced disposal costs for the waste, as well as the reduced reliance on alternative engineering materials.

Introduction

The combustion of coal containing sulfur in U.S. power plants is thought to be one of the principal causes of acid rain in North America. The Clean Air Act of 1970 was passed as an attempt to reduce the environmental threat from sulfur released into the atmosphere. In addition to numerous other standards, this law established a permissible level for emissions of sulfur dioxide (SO_2) from coal fired power plants. Amendments in 1977 and in 1990 to the Act have considerably strengthened its provisions with respect to the allowable levels of atmospheric SO_2. Subsequently, many power plants have either opted to purchase low sulfur coal or to installing desulfurization systems. Typically, a desulfurization system works by injecting a reagent that combines with the sulfur to form a solid compound which can be collected prior to the atmospheric release of the exhaust gas (Bigham et al., 1992).

The most commonly encountered methods of desulfurization involve either wet scrubbers or dry scrubbers. In power plants with wet scrubbers, which are the more frequently used, the particulates in the exhaust stream are removed and the remaining gases are then mixed in a slurry with the reagent. The reaction of the SO_2 gas with the reagent creates a paste-like waste product which must be collected, dewatered, and eventually disposed of. In the dry scrubber process, the reagent may be mixed with the coal at any number of stages along the combustion process. It may be added to the coal prior to entering the furnace, sprayed on the coal while it is in the furnace, or it may be injected into the exhaust gas stream. The resulting solid waste product is collected and must be properly discarded. Current regulations treat the scrubber sludge from either process as a solid waste and require that it be deposited in a controlled landfill. Landfill costs vary from as low as $12/metric ton to as much as $35/metric ton, with prices surely to increase as regulations get more stringent and existing landfills reach capacity.

Because the volume of solid waste being produced is so great and because land filling is becoming a less attractive solution to all solid waste problems, a number of groups have sought to identify potential beneficial uses for the FGD by-products. Some of the more promising of these uses include such high volume applications as structural fills for highway embankments and ramps, backfills for retaining walls, and as the select material used in subbases and base courses for roadways.

Field Demonstration Project - Ohio State Route 541

Site History. Ohio State Route 541 runs approximately east to west between the towns of Coshocton to Mount Vernon. The portion of the highway studied in this project is an embankment about 15 meters high and 1000 meters long located just west of Coshocton in East Central Ohio. SR 541 has been a major thoroughfare in this part of the state for many years. The subject embankment which was constructed in 1966 was a realignment of the original highway designed to facilitate high speed travel by eliminating a series of sharp horizontal and vertical curves (ODOT Construction Plans, 1965). To minimize the vertical gradient and to ensure adequate roadway drainage, the 1000 meter realignment project required the construction of a large embankment involving a great deal of fill. A site map showing the location the project is presented as Figure 1.

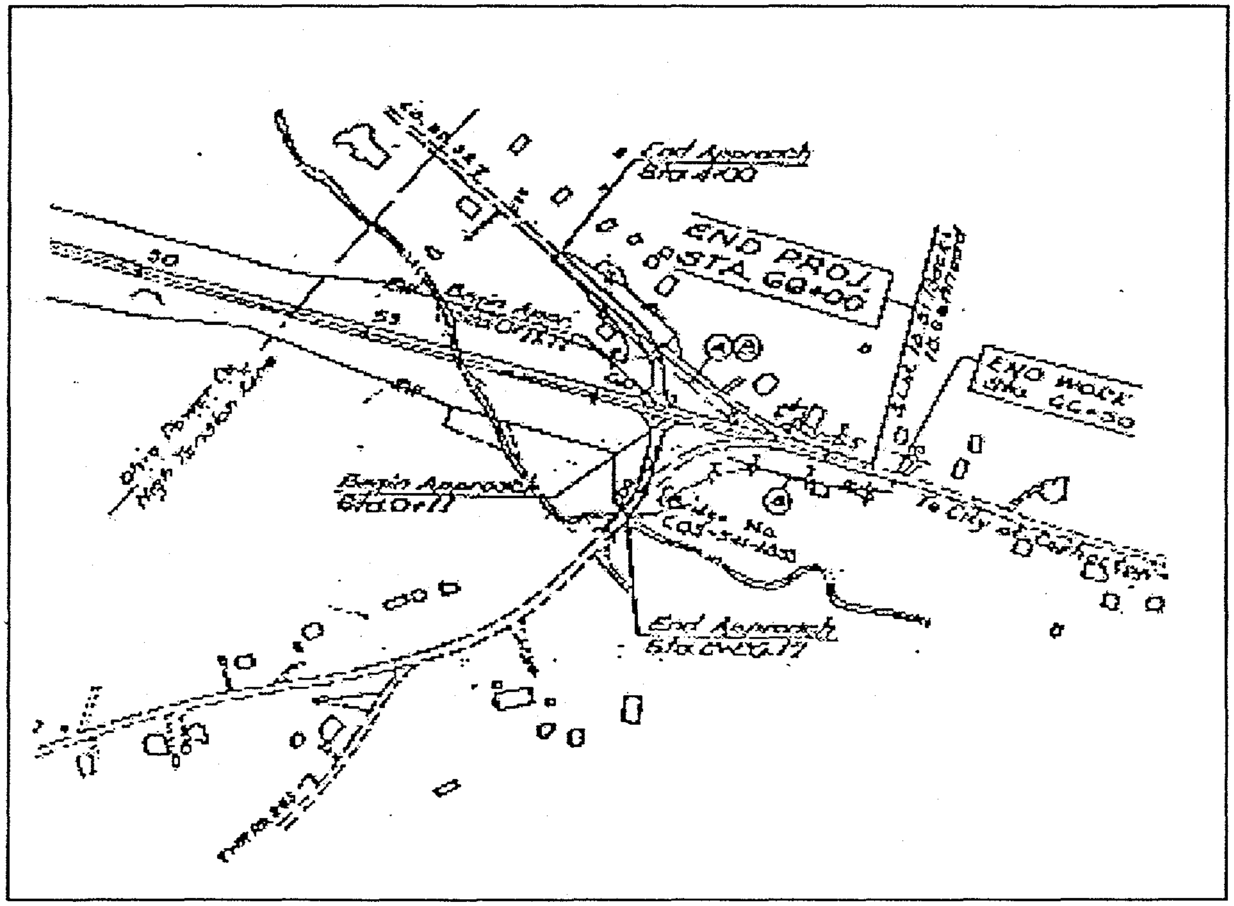

Figure 1. SR 541 site map showing station locations.

Ohio Department of Transportation (ODOT) records indicate there were no significant repairs made to the reconstructed section of SR541 during the first 20 years after the embankment was completed. However, by 1985, the northern half (west bound lanes) of road surface had visibly settled around Station 55+00. The settlement became progressively worse and was accompanied by some indications of a rotational slide. Reportedly, the north slope was covered by numerous scarps and there was evidence of soil upheaval at or near the base. In 1986, an ODOT repair crew attempted to correct the problem and prevent any further deterioration by digging a trench in the north shoulder for a distance of 25 meters lengthwise that was approximately 4 meters deep. Into the trench they drove a series of 8 meter long piles which they attached to the guardrail effectively creating a 25 meter long, 4 meter wide retaining wall. The trench was then backfilled and the asphalt road surface was repaired. Another trench was excavated on the south side of the roadway and a drain was installed to intercept surface and subsurface water associated with the adjacent hillside. The repair seemed to stop the sliding and nothing further was done to this section of highway for the next three years.

By early 1989, it became apparent that the highway was again slipping. In that summer, ODOT engineers, realizing that the pile-supported retaining wall had failed to prevent the road surface from settling, ordered a more comprehensive repair. The excavation of the piles revealed how dramatic the embankment movement was. The base of the piles, which was eight meters below grade, had moved approximately two meters down slope for an equivalent angle of rotation of almost 20 degrees. The piles were removed and the embankment material was excavated to a depth of 13 meters below the road surface and replaced with select fill. The slope was brought back to its original condition (2:1 slope). Two drains were installed at the top of the embankment, to intercept a layer of water that was detected during the excavation process. These drains are still active, particularly after periods of heavy rainfall or snow melt (Newhart, 1994).

Figure 2. Landslide in the Northbound Shoulder of State Highway 541 West of Coshocton, Ohio

On 17 May 1993, the Department of Transportation was made aware that the road surface was again exhibiting signs indicative of another rotational slide. As before, at the base of the embankment there was a zone of earth flow and the slope had the rolling terrain typical of a series of rotational slides. The top of the slope was beginning to suffer significant settlement. By the end of the summer, the shoulder of the westbound lane had settled up to 1 meter and the scarp appeared to be progressing towards the center of the roadway. See Figure 2. Concurrently, the Civil Engineering Department at The Ohio State University was discussing with ODOT the possibility of utilizing dry FGD by-products in state highway construction and repairs and this project became the subject of the present study.

Embankment Repair. In the following presentation, the subject repair has been divided into two separate activities. The first activity was the excavation of the embankment and underlying natural soil. The second activity was the placement of the FGD by-product and the replacement of the excavated material.

As the repair crew began the excavation at the base of the embankment, a layer of moist grayish clayey-shale was exposed near the surface. After a few meters of excavation, the grayish soil was completely saturated. The elevation of the saturated layer seemed to coincide with the elevation of the original natural ground surface beneath the embankment (approximately 11 meters below the road level at Station 55+00). The weight of the vehicles operating on the soil caused it to pump, temporarily halting the operation while a trench was dug to find the source of the excess water. When the trench was approximately 2 meters deep, a spring was discovered. Water rushed out of the new opening for 15 minutes and eventually settled into a steady flow that continued for 3 weeks at a rate of approximately 1.5 - 2.0 l/s (Newhart, 1994). Due in large part the poor weather conditions at the site in the Fall of 1993, the excavation of the soil above the slip plane required approximately eight weeks. During that time the scarp at the head of the slide progressed across the highway so that by late November, the entire roadway had slipped and the total volume of material that had to be removed was approximately 9000 ^{m}. The long completion time of the excavation phase of the project can be attributed to the crew working only part time. This operation, as well as all other phases of the project, were conducted solely by personnel and equipment from ODOT's Special Projects Branch and from the Coshocton County Division. The bottom of the excavation was approximately 13 meters below the original road surface. At that elevation, the soil was a combination of exposed shale and a firm blue-gray shale clay. Approximately half this material was stockpiled on site to later be used in Phase 2. The balance of the soil, which was heavily saturated clay, was transported off-site (Newhart, 1994).

The replacement of the embankment material began with the installation of a geotextile filter and drain tile which were placed at the base of the hillside. The drain was located on the up-slope face of what was to be the FGD by-product buttress. The drain outlet empties into a stream and is near a culvert that runs underneath the highway at Station 54+00. The flow which has been relatively constant since the drain was installed, is approximately 0.5 l/s. From this, it may be hypothesized that the system is operating as intended and the drainage layer is preventing the water from reaching the FGD by-product. Water that does reach the retaining layer will likely find an alternate path, as the permeability of this material is often as low as 9.1×10^{-10} cm/sec (Bigham et al., 1992). Once the geotextile was in place, the crew began placing the dry FGD by-product, which had been stockpiled on site. Self loading scrapers, as shown in Figure 3, delivered the material to the excavation as bulldozers spread it evenly over an area 12 meters wide by 30 meters long. The first lift of approximately 60 cm, was placed and rolled at the end of the first day. The next morning, as the scrapers were delivering the FGD by-product for subsequent lifts, the drivers noticed that the vehicles were not leaving tire tracks on the surface. The Tidd ash was already strong enough that by the next morning, 40 metric ton scrapers could move freely over it without any noticeable settlement (Newhart, 1994). The FGD buttress was built up until the end of November, when approximately 4 to 5 meters of the material had been placed. It should be noted that there were no stringent controls on the depth of the lifts or on the quantity of water added. The amount of water added in the field far exceed the optimum water content as determined in the laboratory (Bigham et al., 1992). ODOT field personnel adjusted the size of the lifts and the amount of water added to suit the prevailing conditions. The important point to be addressed here is the material has a wide workable range and does not have to be treated with laboratory precision to yield excellent strength properties. Atop the FGD, the original embankment material was replaced throughout December in controlled lifts that ultimately totaled 3 to 4 meters.

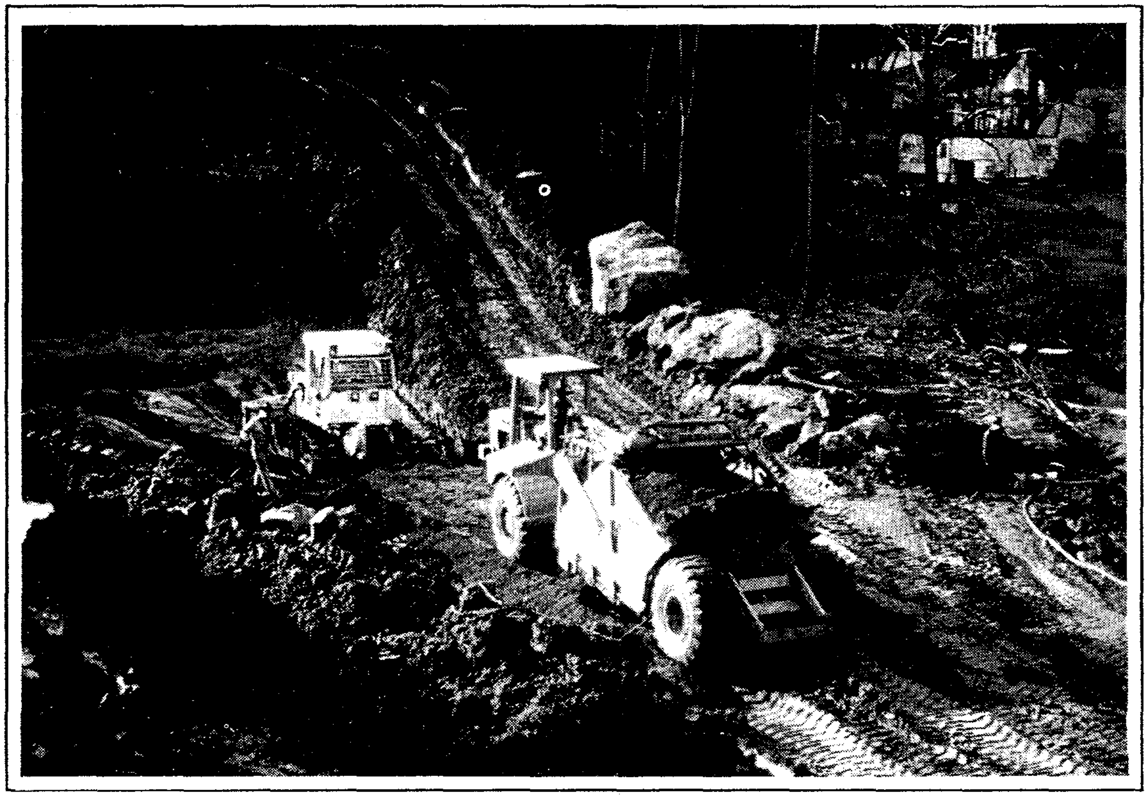

Figure 3. Construction of the FGD Buttress

A second source of moisture was detected during reconstruction of the embankment at an elevation of 6 meters below the original road surface. Additional excavation exposed another potential trapped aquifer and two additional drains were installed using the same procedures as before. To strengthen the embankment another FGD layer that extended from the center of the road to within 2 meters of the leading edge of the original embankment was placed at this elevation. This FGD layer measured 1 meter in depth, 10 meters in width, and 20 meters in length. The top of the layer is approximately 5 meters below the original roadway surface.

To bring the embankment from this level up the final 5 meters, a grayish-brown clay shale was hauled from a borrow area two miles west of the construction site. This material has strength properties significantly higher than the original embankment material (Appendix). The base course of the repaired area was brought back to original grade in early February and the FGD by-product was mixed with aggregate to form a temporary wearing course which is shown in Figure 4. The road opened to traffic in March 1994.

Figure 4. Completed Reconstruction of the SR 541 Embankment

The instrumentation of the slope and an analysis of the measurements made is expected to continue over the next three years. To date, water measurements to study pH, total dissolved solids (TDS), total alkalines, hydroxide alkalines, SO_4^{2-} and Cl^- have been made. No significant differences have been observed in the pre-construction and post-construction values and the differences that have been noted fall within an accepted range of normal stream fluctuations. gauges.

Slope Stability Analysis

The failure of the SR 541 slope can most likely be attributed to an increase over time of the amount of water present in the embankment soils. Loss of soil strength that can be attributed to the absorption of water and the development of increased pore water pressure has been shown to be a likely cause of slope instability. Slope stability analyses were performed on the embankment profile at conditions just before the slip occurred. The material properties used in the analysis are presented in Table 1. The computer program PC STABL (Lovell, 1988) was used to perform the appropriate calculations. In its normal analtyical mode, PC STABL generates a series of potential failure surfaces, each with a calculated factor of safety after all of the necessary geometric and soil data are input. However, the program also allows the user to specify a particular failure surface from which a corresponding factor of safety can be calculated. This proved to be useful when comparing the factors of safety for similar failure surfaces before and after the installation of the FGD sections. Furthermore, as the program allows for heterogeneous soils systems, anisotropic soil strength properties, excess pore water pressure due to shear, and static ground water tables, actual field conditions usually do not need to be oversimplified, (Kim, 1994).

Table 1.
Typical Soil Properties

Material	Unit Weight (kN/m^3) Moist/Saturated	Cohesion (kPa)	Friction Angle (deg)
Soil above top FGD	18.2 / 19.8	48	30
Fill	18.3 / 20.4	19.1	20
Natural Soil	18.3 / 20.4	38.2	0

Figure 5 shows the most critical failure surface with respect to the original embankment configuration and the estimated location of the water table. This computed failure surface, with a calculated factor of safety of 0.96 (failure is imminent when the factor of safety approaches 1.0), is nearly identical to the one that actually occurred.

In a second analysis, the weak soil near the base of the slide was replaced by compacted FGD ash. The water table in this calculation was left at its original elevation assumed for the failed section discussed in the previous paragraph, but was quickly lowered once it made contact with the drainage material adjacent to the FGD by-product buttress. Water not intercepted by the filter is assumed to go around the buttress and exit at either the eastern or western edges of the slope. The program is limited to two-dimensional analysis, therefore the water table was simply lowered to the bottom edge of the buttress and maintained at that elevation. Figures 6 and 7 depict the profile of the embankment with the FGD by-product layers included. In Figure 6 the critical surface has been forced out of the FGD and as a result is a much shallower circle with a calculated minimum factor of safety of nearly ten. In Figure 7 the original failure surface shown in Figure 4 was specified for the reconstructed embankment and a new Factor of Safety was calculated which clearly much greater than as likely failure surfaces are now forced out of the FGD by-product.

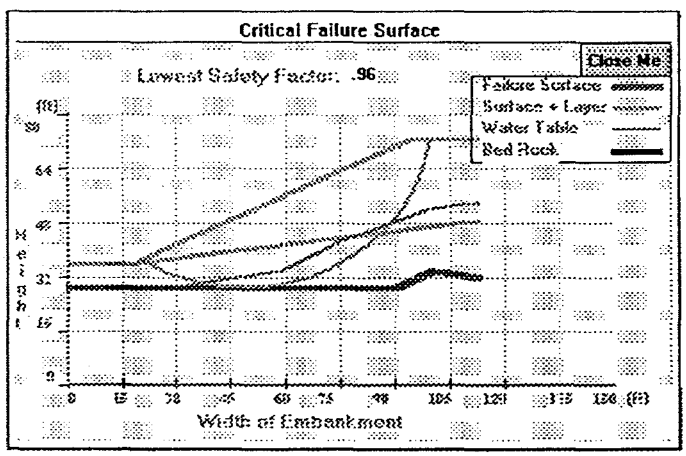

Figure 5. SR 541 Embankment, critical failure surfaces.

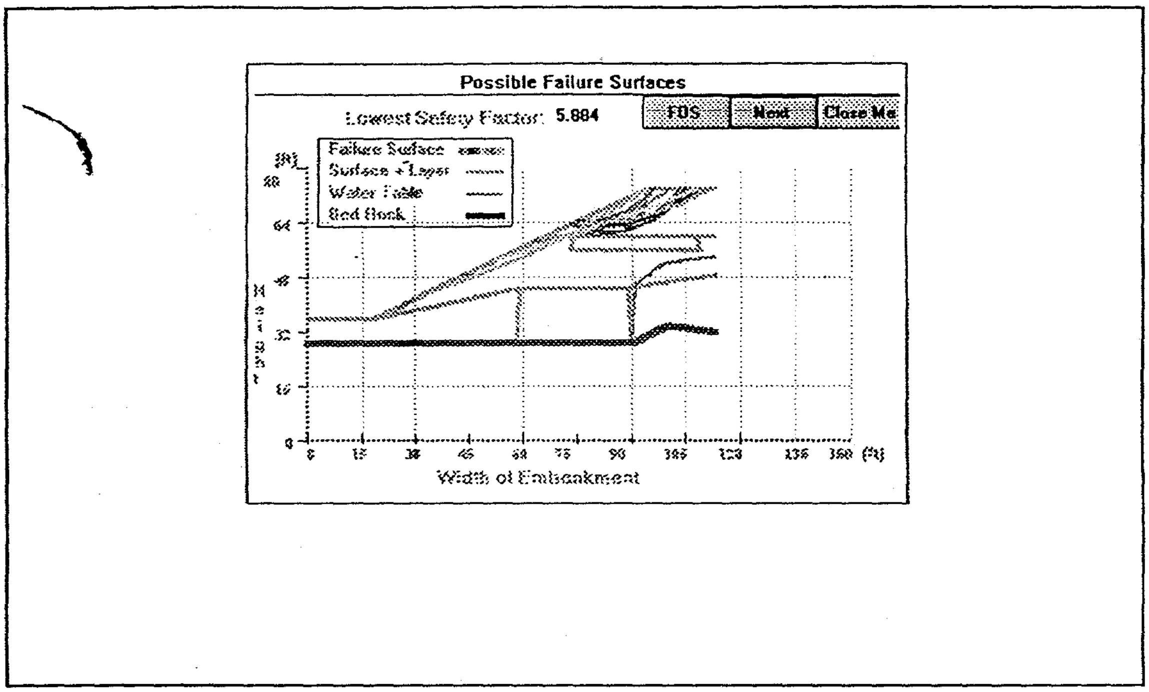

Figure 6. SR 541 Embankment with FGD By-product, critical failure surfaces.

SUMMARY AND CONCLUSIONS

U.S. power plants are producing over 18.1 million metric tons of coal combustion waste annually (Taha, 1993), and this number is expected to double as the provisions of the 1990 Clean Air amendment take full effect (Taha, 1993). The Department of Energy estimates that the amount of solid waste generated over the life of one 500 MW power plant would fill a 200 hectare disposal pond to a depth of 12.2 meters (U.S. Department of Energy, 1992). Numbers of this magnitude justify the need to find alternatives to land filling the waste associated with the FGD process.

It has been shown how one dry FGD by-product can be successfully incorporated into a highway construction program. In this project a PFBC by-product demonstrated high strengths ease of installation and although early in its design life, no significant change in the environment of the surroundings. The installation procedures followed made it clear that no special equipment or training is necessary. Results reinforce the point that extra caution above that required on any construction project is not required when working with this material and its excellent strength properties and workability are suited for field modifications. We hope that the visibility and success of the SR 541 highway project leads to the increased acceptance of FGD waste as a viable construction material as further, and more creative uses, for this product are developed.

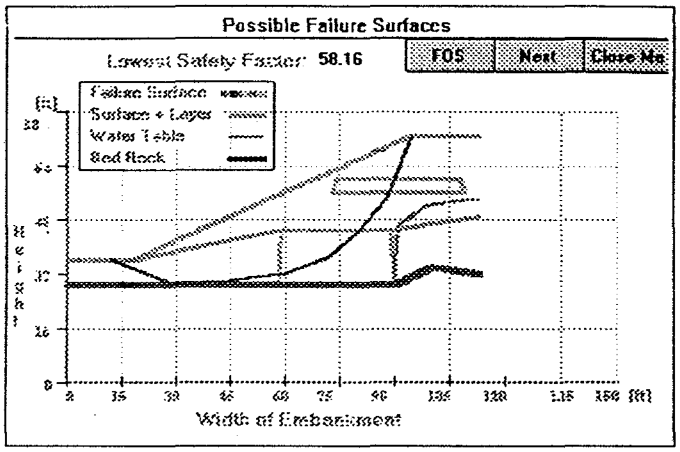

Figure 7. Factor of Safety for Failure Surface Passing Through FGD Buttress

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