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Design and Application of REINFORCED EARTH® Storage Slots

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Summary

The author reviews the properties of REINFORCED EARTH® in the construction of storage slots and holes. Examples are given of the increasing use of these structures in the storage of coal and attention is drawn to the suitability of the technique in the storage of other materials as shown by recent constructions. Significant economic advantages are claimed over alternative techniques.

1. Introduction

High-capacity, gravity-fed slot storage structures for coal, ores and other bulk commodities are finding increasing favor in the United States. Time and again, these bins have proven to have excellent operating characteristics and low labor, energy and equipment costs as compared with dead storage stockpiles.

The growing acceptance of slots, especially for coal storage, is also due to the use of REINFORCED EARTH® in building them. This technology has resolved the problems encountered with other construction methods, while significantly reducing the cost.

Slots are long, narrow bunkers, usually barn-covered, with steeply sloping walls that form a V-shaped cross-section. Built above or below grade, these structures often have lengths of more than 200 m. Those constructed to date have storage capacities of up to 113,500 metric tons.

The material to be stored enters the slot by overhead traveling tripper, shuttle conveyor or traveling stacker and descends to a reclaim gallery at the notch of the "V". From there the material is discharged at rates in excess of 3,600 t/h. Rotary plows or vibratory feeders in the gallery help load the reclaim belt.

Among the many benefits of slot storage for bulk materials are:

- The elimination of dead spots, vertical build-ups and freeze-ups in the stored material.
- Faster loading and reclaim rates, thus saving time and improving equipment utilization.
- A steady outflow from their large capacities is available in the face of irregular inflow.
- When covered with a barn-type roof, fugitive dust problems are mitigated and material is protected from deterioration and other effects of moisture.
- Slots are easily fitted with blending equipment to meet specific quality standards.
- Slots can be economically built on soil too poor to accommodate structures with more severe base loadings.

2. A Frictional Association

The Reinforced Earth technique has proven to be an ideal way to form the walls of storage slots. This construction system consists of galvanized steel reinforcing strips bolted to facing panels of precast concrete (Fig. 1). Horizontal rows

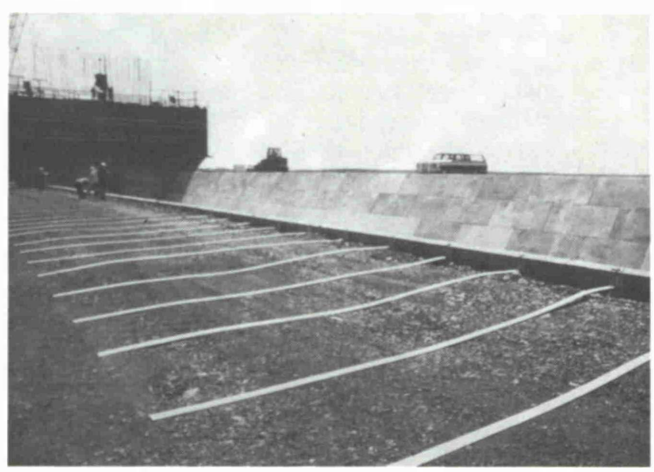

Fig. 1: Galvanized steel reinforcing strips are bolted in place to the REINFORCED EARTH inclined sidewalls

of strips are placed behind the wall in compacted, cohesionless fill, e.g., sand, gravel or crushed stone. Friction between the reinforcements and the elements of fill creates sufficient tensile stress in the strips to tie the entire mass together.

The result is a coherent gravity mass of great strength and stability that will resist external and internal forces, geostatic and hydrostatic pressures and dynamic forces from moving or seismic loads. By analogy to reinforced concrete, a Reinforced Earth structure strengthens one basic material, earth, by reinforcing it in the direction of greatest stress with another basic material, steel.

A Reinforced Earth slot is built using standard construction equipment and methods in a series of straightforward operations that are easily mastered even by inexperienced work crews. In building a slot, the first course of panels usually rests atop the side walls of the reclaim tunnel. Backfill is placed behind the panels to the level of the first row of tie strips which are embedded in the precast panel. After compacting the soil, reinforcing strips are laid down and bolted to the tie strips. A lift or lifts of backfill thick enough to reach the next level of tie strips is spread over the reinforcements and compacted.

The next layer of strips is then set in place and covered with another lift of fill. When the backfill reaches the top of the panels, another course is set in place. This repetitive sequence — involving panels, backfill, strips and more fill — continues until the desired height is reached. From 300 to 450 m² of panel surface area can usually be installed per 8 hour shift, although rates nearly double this have been achieved.

The strips themselves are 0.6 cm thick and, at the base of the slot, have lengths approximately one-third the vertical height of the structure. They tie into inclined panels 1.5 m high, 3 m wide and 13 cm thick made of 4,000 psi concrete.

Throughout construction, once each layer of fill has been placed and compacted, scrapers, bulldozers and other heavy equipment can operate directly on the structure.

3. The Early Slots

Slot storage structures were developed in the 1960s. The steeply sloping sidewalls of the first ones were excavated and then stabilized with a facing material, such as soil cement or gunite. Their walls suffered from slaking and erosion, and frequently proved unstable. "Pop-out" failures at the base of the slot often occurred during construction. These failures were difficult, time-consuming and expensive to correct.

An improved design used a buttress of engineered fill, usually stabilized with overbuilt lime or cement. The surface was then trimmed and faced with gunite. This design was also time-consuming to construct and spalling made it technically unreliable and expensive to maintain.

As a mechanically stabilized embankment with an incorporated facing, Reinforced Earth effectively buttresses the walls of storage slots. Not only does this technique exclude slope failure and spalling, it also speeds construction by eliminating guniting and slope trimming.

The method also allows work in the reclaim gallery to proceed while the walls are underway, for the Reinforced Earth structure is constructed from behind the facing panels. Reinforced Earth also works for a wide range of site conditions and constraints, especially where the foundation soil cannot support concrete silos.

Reinforced Earth slots are especially economical to erect. A cost analysis for the construction of a 20,900 ton slot compared this method with soil-cement stabilized berms. Reinforced Earth walls saved 22% in material and labor costs due to their speed of construction and the standardization and prefabrication of their components. In addition, their construction is nearly independent of weather conditions.

4. Coal Industry Standard

Since 1977 almost all coal storage slots built at mines and power stations in the United States have used Reinforced Earth technology. This amounts to nearly a half-million tons of capacity at thirteen sites.

4.1 Black Thunder Mine

Reinforced Earth walls were first used in a coal storage slot in mid-1977 to solve a knotty design problem. Sidewalls of soil-cement, lined with gunite, had been constructed for a 90,800 ton slot at the Black Thunder Mine near Gillette, Wyoming. The end walls were awaiting completion of the reclaim conveyors and transfer towers. The delay in end-wall erection meant that large amounts of trim would have to be removed from the bottom of the slot, a difficult and expensive task.

By using Reinforced Earth inclined end-walls, the project's designers were able to erect them concurrent with other work and do away with trimming. This cut months off the construction schedule.

4.2 Clovis Point Mine

The first slot storage facility with Reinforced Earth sidewalls was at Kerr-McGee Coal Corp.'s Clovis Point Mine in Wyoming (Fig. 1). Kerr-McGee chose Reinforced Earth because the soil at the site was too unstable to support concrete silos, which would have required pilings driven as deep as 60 m. A Reinforced Earth slot, because it distributes all forces evenly within its mass, eliminates stress concentrations in the foundation soil and thus needs no special foundation preparation.

The 20,900 ton capacity slot measures 85 m in length and 15 m in height from the top of the reclaim tunnel to ground level. Its walls taper from a width of 24 m at ground level to 6 m just above the reclaim gallery. An above-ground structure 12 m high houses the conveyor gallery. The end-walls were cast in-place.

Panels angled at 55° form the sloping walls of the structure. Reinforcing strips 6 m long and 8 cm wide tie into the panels. The strips are spaced 1.5 m horizontally and 0.5 m vertically.

Ungrouted, overlapping joints link adjacent panels horizontally. Loss of fine-grained backfill through the 2 cm joint opening is prevented by a polyurethane packing. Each panel sits on a cork cushion that eliminates concrete-to-concrete contact and allows some movement.

Coal enters the slot by reverse shuttle conveyor at rates up to 1,400 t/h. Fourteen vibrating feeders along the base of the slot aid the flow of coal to the reclaim area where a 1.8 m wide belt conveyor moves coal out of the slot at 3,600 t/h. At this rate, a 110 car, 10,000 ton capacity unit train can be loaded in as little as 2.5 hours. In its first two years of operation, this slot handled more than 5.9 million tons of coal.

4.3 Cordero Mine

To accomodate increased production from the expansion of its Cordero mine in Wyoming, Sun Energy Development Company built a 90,800 ton barn-covered slot using inclined sidewalls and vertical end-walls of Reinforced Earth (Fig. 2). The walls were completed in just two months. Construction rates averaged 900 m² per day because of a particularly efficient backfill operation and because all but a small section

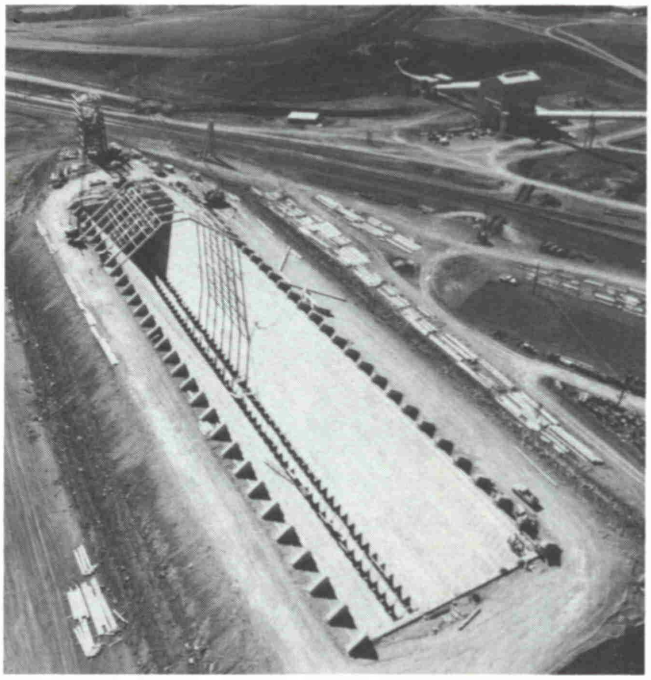

Fig. 2: Barn-covered slot built by SUNDECO fot its Cordero Mine at Gillette, Wyoming

of the vertical end-walls used Reinforced Earth, thus eliminating the delays of cast-in-place construction.

4.4 Great Plains Gasification Plant

The largest Reinforced Earth coal bunker to date will be completed this year for the Great Plains Coal Gasification Plant near Beulah, North Dakota (Fig. 3). The facility, which

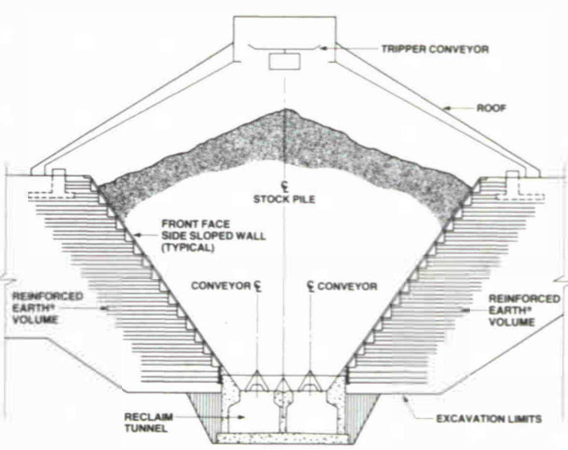

Fig. 3: Biggest barn-convered coal storage slot to date under construction at the Great Plains Coal Gasification Plant at Beulah, North Dakota

will store 113,500 tons of lignite for conversion to clean-burning gas, is 231 m long, 21 m deep and 38 m wide at the top. Partially set above ground, its width decreases to 10.5 m just above twin reclaim tunnels. An overhead conveyor suspended from an A-frame roof discharges coal into the slot. Rotary plows and conveyor belts in the reclaim tunnels move coal from storage to the plant.

4.5 Labadie Power Station

In a variant of the V-shaped bunker, Union Electric Company constructed a *one-sided-slot* at its Labadie, Missouri, power station as part of a facility for blending high- and low-sulfur coal (Fig. 4). Low-sulfur coal unloaded from unit trains by a

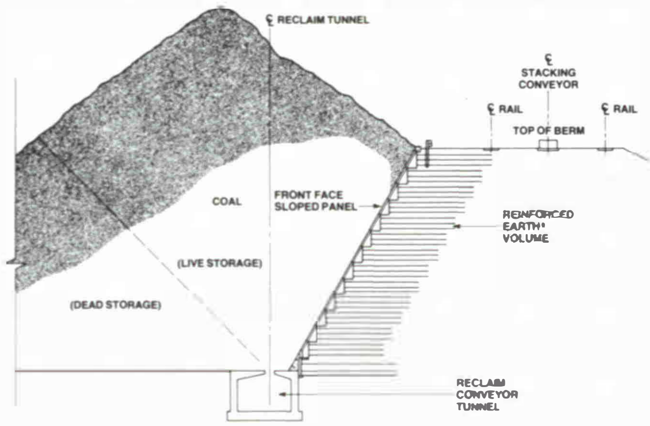

Fig. 4: Stacker-berm coal storage scheme for Union Electric Company's Labadie Generating Station

rail-mounted traveling stacker is discharged from the top of an 18 m high, 158 m long Reinforced Earth berm. Coal slides down the 60 degree incline to a 45,450 ton live storage pile above the reclaim tunnel.

Coal either is shifted from live storage to a 1.36 million ton dead storage pile alongside the reclaim tunnel or is sent directly to the 2,300 MW boilers. The dead storage pile supports the opposite side of the live storage sector. A conveyor in a second tunnel, below and perpendicular to the reclaim tunnel, carries the coal to another conveyor where it is blended with high-sulfur coal before going to the boilers.

The berm sits on an old ash pond, which may cause the berm to settle up to 6.6 m. Reinforced Earth was chosen for this site because it resists the stress of foundation settlement.

4.6 Glory Holes

In an extension of its use in storage slots, sloping Reinforced Earth walls have been used to construct "glory hole"-type storage facilities. These structures are inverted, conical polygons used for live coal storage. An overhead conveyor feeds coal into the center of the hole from which it is metered to a reclaim conveyor.

One such structure stores coal near Marissa, Illinois, where material from several local mines travels by overland conveyor to an eight-sided glory hole, which acts as a surge pile to compensate for the differences between mining and processing rates (Fig. 5). The 27,200 ton capacity hole tapers to a 9.15 m throat from a ground level diameter of 60 m. A vibrating feeder below the throat discharges coal onto a conveyor that goes to a processing plant.

A glory hole built by Coors Energy Company at its Keenesburg Mine in Colorado, provides 18,000 tons of live storage in the delivery system between the crushers and truck loadout. A 2.5 m diameter lowering well at the center minimizes dust generation and supports a loading conveyor. A cast-in-place buttressed parapet atop the structure increases storage volume and supports the roof.

Fig. 5: "Glory-hole" type structures, built as octagonal inverted cones, are used as surge piles for nearby coal mines

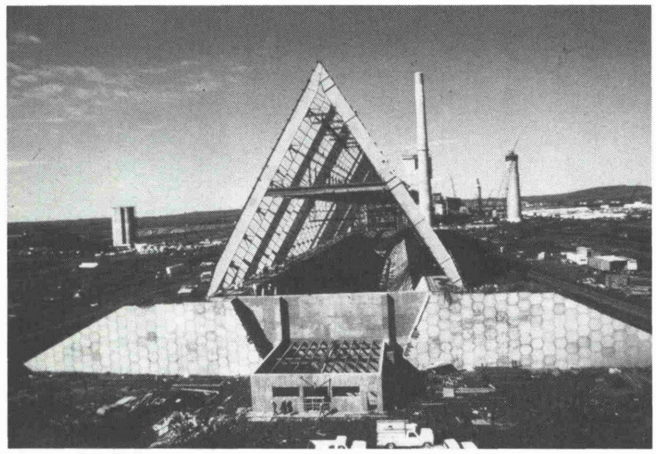

Fig. 6: A-framed roof covers 46,000 ton slot built by Basin Electric at its Antelope Valley Station near Beulah, North Dakota. Its inclined (65°) sidewalls and wingwalls are built of REINFORCED EARTH

4.7 Other Mining Applications

In non-coal applications, two Reinforced Earth barn-covered slots were built for Kyanite Mining Corporation's mine in Dillwyn, Virginia: one with 27,200 ton capacity for wet, impure kyanite and the other with 24,500 ton capacity to store dry kyanite. Both structures have sidewalls sloping at 55 degrees and vertical endwalls of Reinforced Earth.

The 27,200 ton slot was built over an existing 38 m long reclaim tunnel, which was almost totally rebuilt for the project. The structure consists of 18.3 m high sidewalls and 12.2 m high end-walls. This slot stores a kyanite/iron mixture containing 6% free moisture, which is the output of a froth flotation process that removes sand from the crushed ore.

The mixture then passes through a rotary drier and a magnetic separator. The resultant fine sand-like product is stored in the slightly smaller slot for eventual pneumatic bagging. This structure is 14.6 m high.

5. Conclusion

The use of large slot storage structures made of REINFORCED EARTH® is well-established in the United States. This is especially true in the coal and power industries, where such slots have become the technology of choice due to their tough, reliable facing, stability on poor soils, and construction and operational cost effectiveness (Figs. 6 & 7). These structures also perform well for other minerals and bulk commodities, as demonstrated by the two Reinforced Earth slots built to store kyanite.

Fig. 7: Public Service Company of Colorado's Pawnee Generating Station has a 33,000-ton barn-covered slot with Reinforced Earth inclined (60°) sidewalls and vertical wingwalls. The structure, located at Brush, Colorado, has cast-in-place divider walls which accommodate coal blending during reclaim.