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Design of Coal Storage Barns Using Reinforced Earth®

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Der Bau von Kohlespeichern mittels armierter Erdmassen
La construction de dépôts de charbon au moyen de masses de terre armées
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強化土を利用した石炭貯蔵庫の設計
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Der Bau von Kohlespeichern mittels armierter Erdmassen

Kohlehalden mit großem Speichervolumen, die durch steil geböschte Seitenwände begrenzt werden und bei denen die Rückladung durch Schwerkraftsabzug erfolgt, werden in immer stärkerem Maße als Zwischenlager bei Erzeugern und Verbrauchern eingesetzt. Derartige Zwischenlager bieten vielfältige wirtschaftliche Vorzüge beim Rückladen. Die Schwierigkeiten mit der Stabilität geböschter Seitenwände sind durch die Einführung »befestigter, armierter Erdmassen« überwunden worden. Diese Bauform erlaubt die technische und wirtschaftliche Erstellung derartiger Lagersysteme.

La construction de dépôts de charbon au moyen de masses de terre armées

Des haldes de charbon à grand volume de stockage, qui sont délimitées par des parois latérales à grande inclination et où la reprise au stock s'effectue par extraction à la pesanteur, sont utilisées de plus en plus comme entrepôts intermédiaires par les producteurs et les consommateurs. De tels entrepôts offrent de nombreux avantages économiques lors de la reprise au stock. Les difficultés de stabilité des parois latérales à grande inclination sont résolues par l'emploi de «masses de terre armées et consolidées». Cette forme de construction permet la production technique et économique de tels systèmes d'entrepôts.

La construcción de depósitos de carbón con masas de tierra afianzadas

Vaciaderos de carbón de gran volumen de depósito, los cuales están limitados por paredes laterales de gran ángulo de inclinación y con carga de retorno por gravitación son cada vez más utilizados como depósitos intermediarios, tanto como por productores como por consumidores. Tales depósitos intermediarios ofrecen múltiples ventajas económicas para la carga de retorno. Las dificultades con la estabilidad de las paredes laterales de gran ángulo de inclinación han sido resueltas con la introducción de «masas de tierra afianzadas». Esta forma de construcción permite la creación de tales sistemas de almacenaje tecnico-económicos.

Summary

The concept of large capacity gravity flow storage barns with steeply sloping interior sidewalls is coming into widespread use at various process and transportation interfaces of both producers and users. Such storage facilities with their high-volume discharge capability provide many economies in loadout operations. The difficulties with sloping sidewall stability as a barrier to their construction has been virtually eliminated by the use of Reinforced Earth, a design and construction system which responds favourably to the technical and economical requirements of this method of storage.

1. Introduction

Recently there have been many new developments in the field of coal handling and storage. These improvements have been brought about largely by the advent of the unit train, the construction of new mines with production potential of several million t/year and the requirements for abatement of environmental damage such as fugitive dust.

One of the innovations currently being incorporated into many mines is the *slot* or *barn storage* facility for live storage of large quantities of coal (Fig. 1).

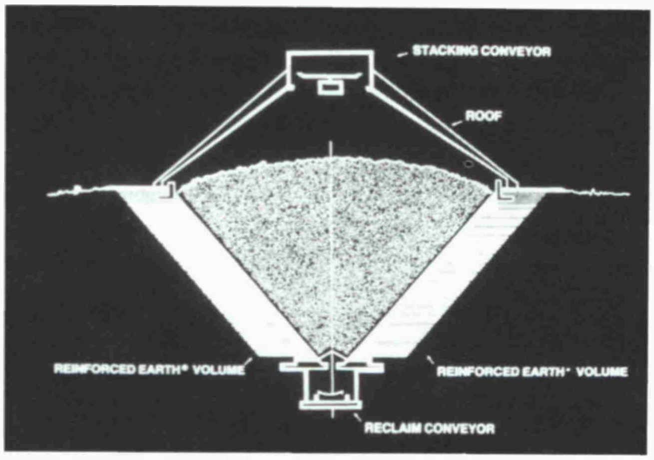

Fig. 1: Cross-section through a storage barn built using Reinforced Earth

Fig. 1 shows a cross-section through such a storage barn built using Reinforced Earth. Coal is loaded by an overhead stacking conveyor and is reclaimed by a conveyor running beneath the entire length of the barn. A roof protects the coal from moisture and prevents fugitive dust. Such structures, with capacities ranging from 22,000 to 100,000 t, have been constructed at mines and power plants.

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These high volume surge bunkers generally are long and narrow structures built either above or below grade. The steeply sloping sidewalls form a V notch at the bottom below which a reclaim conveyor is situated. Coal is brought into the facility by several means including overhead traveling tripper-conveyors and is stacked evenly within the *slot*. By means of gravity and assisted by mechanical feeders in the reclaim gallery, the reclaim belt is loaded and coal is taken from storage at high rates of flow to support the rapid loading of unit trains or intermediate processing operations. For coal storage at power plants, the rapid loading and reclaim capability is necessary; and the barn storage concept has been incorporated here as well.

Some of the principle advantages of barn storage are listed as follows:

1. Discharge rates up to 4,000t/h provide improved transport equipment utilization through reduced loadout time.
2. The barn may be loaded rapidly.
3. By using a slot divided by transverse walls, coal may be segregated by type or size during loading and blended on the reclaim conveyor by selective withdrawal.
4. The slot is usually covered to keep out moisture, which improves handling characteristics.
5. The barn controls coal dust in compliance with environmental requirements.
6. Operating and maintenance costs are reduced by minimizing the number of men to operate the facility. No additional equipment is required.
7. Large storage volume per capital expenditure is obtained.
8. Slot structures can be founded in soil conditions unsuitable for silos.

Some difficulties have been experienced with the slot storage configuration, however, such as:

1. The tendency of coal to adhere initially to the sidewalls and empty from the center first, bringing the coal in the sidewalls down as a final movement.
2. Spontaneous combustion in some facilities that were not kept *live*.
3. Problems with slope stability and difficulties in the construction of the steeply sloping sidewalls. High groundwater tables can contribute to this.

The first two problems have been of an operational nature and are not attributed to the slot configuration. There is a tendency of coal to adhere even to vertical sided vessels and follow a *rathole*. The maintenance of a *live* state is the fundamental concern and is achieved by proper design of the sidewall angles, the selection of proper reclamation systems and just as importantly by regularly drawing down the facility.

2. Barn Storage Construction

To construct these slot storage facilites, several methods of slope stabilization have been employed since the first of these structures was built in the 1960s. One concept was simply to excavate a V slot in the ground and then to quickly cover the excavated slopes with a facing material, such as precast concrete or gunite. These methods were employed at Carbondale, Colorado, and Colstrip, Montana. Unfortunately, however, the stability of slopes at 45° or steeper is usually very marginal and of short term. Slopes cut into shales and sandstones encountered in typical coal mining sites are also subject to slaking and erosion from precipitation, snow melt and wind. Failures at the base of the slope were common during construction, and correction was difficult and expensive.

An improvement was the construction of a buttress of engineered fill, usually stabilized with lime or cement. The surface having been initially overbuilt, was trimmed and faced with gunite as a final step. This method of over-excavating and constructing the sidewalls with a stabilized, engineered fill was employed at Sarpy Creek, Montana, and at the Black Thunder Mine in Gillette, Wyoming. Gunite was used to finish the trimmed slopes. In early 1977, a new construction system, Reinforced Earth, was used to construct the end walls at the Black Thunder Mine. This system, incorporating an engineered reinforced embankment faced with precast concrete panels, was found to be uniquely suitable for the economical and speedy construction of these facilites (Fig. 2).

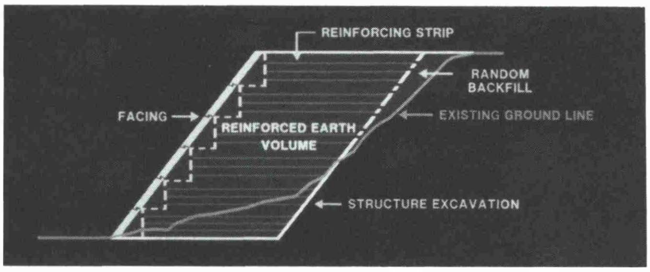

Fig. 2: Cross-section through a sloping Reinforced Earth structure

3. Reinforced Earth

Reinforced Earth is a composite material formed by the association of frictional soil and linear metallic reinforcements. It was originally conceived by French architect-engineer Henri Vidal.

In concept, Reinforced Earth is analogous to reinforced concrete. It is an economical means of improving the mechanical properties of a basic material, earth, by reinforcing that material with another, usually steel. For most projects, Reinforced Earth consists of a granular backfill such as silty sand, gravel, or quarry run rock reinforced with ribbed, horizontal layers within the backfill. Individual strip length, cross-sectional area and spacing depend upon stresses to be resisted. The resulting material behaves like a soil which has cohesion, the value of which is directly proportional to the tensile resistance provided by the reinforcements.

3.1 Design

Reinforced Earth theory is based on the proven hypothesis that an active Rankine state of stress exists within the reinforced volume. The earth pressures normally associated with this state of stress are taken in tension by the reinforcements. The basic mechanism affecting this stress transfer is friction between the soil and the reinforcements.

The forces to be resisted by the reinforcements at any level are determined using basic soil mechanics principles, taking into account all external loading, geostatic and hydrostatic forces as well as dynamic forces from moving or seismic loads. Then, the cross-sectional area of reinforcement necessary to resist those forces is calculated using normal working stresses for the reinforcement material. In addition, allowance is made for metal loss during the service life of the structure. Finally, the reinforcing strip length required to preclude a bond failure is determined. These calculations are repeated for each lift of reinforcements.

The external or general stability design procedures for Reinforced Earth structures are similar in most respects to those for other flexible gravity structures. Because of the width of a Reinforced Earth structure, however, factors of safety with respect to sliding at the base and overturning are greater than with traditional designs. Also, because of their ability to sustain substantial settlements without structural distress, Reinforced Earth structures can be designed for higher allowable bearing capacities than can traditional structures more susceptible to settlement damage.

3.2 Construction

The backfill/strip mass is known as the *reinforced volume.* A Reinforced Earth structure is built of this material and a facing system. The backfill is spread and compacted in lifts, and strips are placed at specified vertical spacing. The strips are bolted to the facing system, usually precast concrete panels, at the face of the reinforced volume. A structure constructed with this material behaves as a coherent gravity mass which exerts no concentrated stress on the foundation soil, distributes force evenly throughout the entire mass, and can withstand substantial differential settlement of underlying soil strata without loss of structural integrity.

For the sloping sidewalls of slot storage facilities, active earth pressures are of somewhat lower magnitude than those encountered in a vertical retaining wall. The length of reinforcing is roughly 1/3 the vertical height of the wall (Table 1).

Table 1: Initial proportioning of sloping Reinforced Earth walls

Height, ft	Strip Length, ft
0—25	14
25—40	17
40—85	20

The construction of a Reinforced Earth slot is a straightforward, repetitive operation requiring no special craft skills or equipment. The initial course of facing panels is set on the top of the reclaim tunnel after the embankment has been placed to this elevation. The granular backfill in the reinforced volume is spread and compacted, and then the first row of reinforcements is laid horizontally and bolted into place on the panels (Figs. 3 and 4). As subsequent rows of panels are set into place, the entire procedure is repeated until the desired height is reached. Regardless of height or length, each time a layer of panels, backfill and reinforcements is completed, the structures become internally stable. Trucks, scrapers, dozers, compactors and other equipment can drive on top of the structure while crews continue to work.

The backfill is placed in lift thicknesses not exceeding 10 inch and is compacted to 95% of its maximum density as determined by the Standard Procter Test, ASTM D-698. Within 3 ft of the facing panels, compaction is achieved by using light mechanical tampers. Backfill is placed using the same heavy construction equipment and methods used in constructing other large embankments.

Fig. 3: Positioning of a panel in the early stages of construction

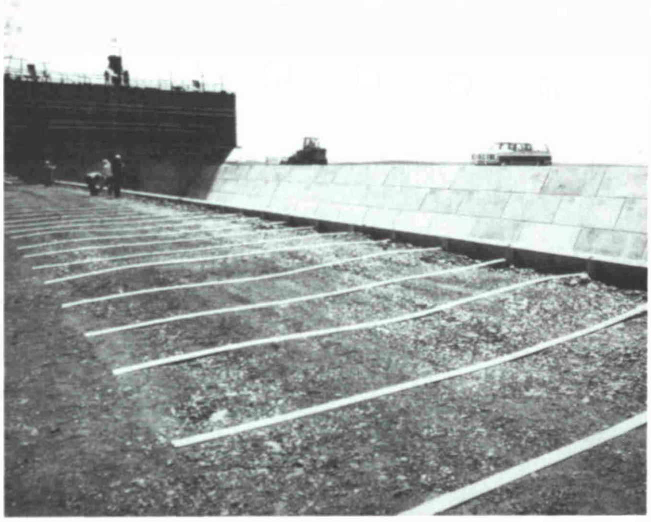

Fig. 4: After placement of the panels, layers of backfill are spread and compacted

The facing panels are precast prior to construction and transported to the project site for direct placement into the structure or temporary storage. The panel is a 5-ft by 10-ft modified double-tee section made of 4000-psi reinforced concrete (Fig. 5). The galvanized steel reinforcing strips conform to the minimum requirements of ASTM A-36 steel. Hot-dip galvanization after fabrication is to ASTM A-123.

Production rates in construction vary with the contractor's equipment spread and utilization, the overall magnitude of the embankment (behind the reinforced volume), and the complexity of the structure. The incorporation in design of cast-in-place concrete end walls, divider walls, building foundations and other apurtenances within the fill area tend to interrupt the placement of the sloping walls.

A typical construction rate for sloping walls is approximately 4 panels (200 ft^2) per hour, although at a recently completed project in Gillette, Wyoming, rates of more than 14 panels per hour were not uncommon. The use of Reinforced Earth rather than cast-in-place concrete for building vertical end walls contributed greatly to speeding the construction.

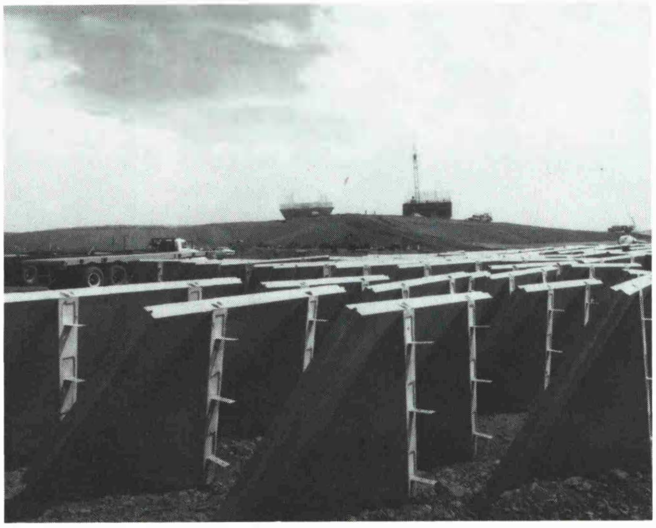

Fig. 5: Panels used as facing for Reinforced Earth structures are modified double-T section precast of 4000 lb/in² concrete

4. Coal Storage Projects

Sloping-wall Reinforced Earth structures have proven to be versatile solutions to bulk-storage problems. Not only does Reinforced Earth provide a standard design that eliminates uncertainties in quality control, material costs, construction cost-work estimates and scheduling, it is also adaptable to a variety of site constraints. For example, at sites where soil conditions are too poor to support storage silos, a Reinforced Earth slot can often be built because it imposes no concentrated stress on the foundation soil.

Since 1977, eleven structures have been constructed using the Reinforced Earth system. Information on these structures is given in Table 2. Several of these projects are discussed below.

4.1 Black Thunder Mine and Clovis Point Mine

In mid-1977, the sidewalls of a 100,000-t capacity slot at Black Thunder Mine near Gillette, Wyoming, had been constructed using soil-cement stabilization with a gunite lining. Endwall construction had been delayed, however, until completion of the reclaim conveyor and transfer towers. This delay would have meant building and trimming the endwalls late in the construction sequence and would have required the removal of a large amount of trim material from the bottom of the slot.

The use of Reinforced Earth solved this construction problem because all work could be done from behind the facing, leaving the bottom of the slot open for the installation of the reclaim conveyor. Fig. 6 shows one of the Reinforced Earth endwalls.

A second project, also in Wyoming, became the first use of Reinforced Earth sidewalls. Project engineers selected Reinforced Earth over soil-cement with gunite lining at Kerr-McGee's Clovis Point Mine because they could accurately predict material costs and construction rates, and because all Reinforced Earth construction was done outside the trench itself, workmen installed the reclaim splitter and conveyor equipment at the same time the sidewalls were being built.

Fig. 6: Endwall construction for the 100,000 t storage barn at Black Thunder Mine

During design, engineers considered using silos, because the 23,000-t capacity was well within the economic range for silos. Soil conditions were so poor, however, that the deep foundations for silos would have been prohibitively expensive. Hence the decision to use a slot. Fig. 4 shows the slot at Clovis Point under construction, and Fig. 7 shows the completed facility.

Fig. 7: Aerial view of coal storage facility at Clovis Mine in Wyoming

4.2 Cordero Mine

In March of 1979, Sun Energy Development Company began a $ 21 million expansion of its Cordero Mine 22 miles southeast of Gillette, Wyoming. A key element in the

Table 2: Storage structures using sloping Reinforced Earth walls

Facility	Owner	Location	Tonnage	Slope Angle	Description
Black Thunder Mine	ARCO	Gillette, WY	100,000 (coal)	50	Lime stabilized sidewalls RE endwalls Cast-in-place divider walls
East Gillette # 16 Mine	Kerr-McGee	Gillette, WY	23,000 (coal)	55	RE sidewalls Cast-in-place endwalls
Coyote Station	Otter Tail Power	Beulah, ND	23,000 (coal)	55	RE sidewalls & wingwalls Cast-in-place endwalls
Pawnee Generating Station	Public Service Company of CO	Brush, CO	60,000 (coal)	60	RE sidewalls & wingwalls Cast-in-place endwalls & divider walls
Cordero Mine	Sunedco	Gillette, WY	100,000 (coal)	55	RE sidewalls & endwalls
Kyanite Mine	Kyanite Mining Corporation	Dillwyn, VA	30,000 (kyanite) (# 1)	55	RE sidewalls
Marissa Mine	Peabody Coal Co.	Marissa, IL	30,000 (coal)	55	RE glory hole
Antelope Valley Station	Basin Electric	Beulah, ND	50,000 (coal)	65	RE sidewalls & wingwalls Cast-in-place endwalls
Prairie Hill Mine	Assoc. Electric Cooperative	Moberly, MO	20,000 (coal)	52	RE sidewalls RE endwalls
Kyanite Mine	Kyanite Mining Corporation	Dillwyn, VA	27,000 (kyanite) (# 2)	55	RE sidewalls RE endwalls
Keenesburg Mine	Adolph Coors Company	Keenesburg, CO	35,000 (coal)	52	RE glory hole

expansion is a 100,000-t capacity storage barn. Coal will go from the secondary crusher to the barn for storage, then into existing silos used to load trains.

Because of an efficient backfill operation, and because there were no obstacles such as cast-in-place concrete endwalls or diaphragm walls to contend with, construction went very rapidly. The use of Reinforced Earth for construction of vertical endwalls, such as those at Cordero, greatly facilitates construction. The average production rate at Cordero was 3000 ft² of wall surface per day. The entire slot was completed in just two months.

Fig. 8 shows some of the intricate endwall geometry at Cordero. By using Reinforced Earth, the forming, concrete placement, curing and form stripping were eliminated, except in one small section. Fig. 9 shows the completed slot.

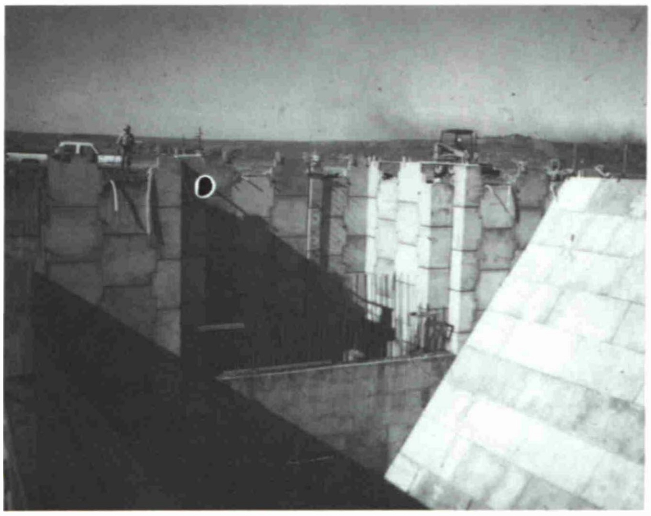

Fig. 8: View of one endwall at Cordero Mine

Fig. 9: Aerial view of 100,000 t storage slot at Cordero Mine

4.3 Pawnee Power Plant

At the Public Service Company of Colorado's new Pawnee Power Plant, construction of a 60,000-t barn required that the building of the Reinforced Earth sidewalls accommodate the simultaneous construction of cast-in-place concrete endwalls and interior diaphragm walls. While the Reinforced Earth construction proceeded in one section, workers and equipment were able to operate directly on all unfinished sections.

The diaphragm walls allow the segregation within the barn of different qualities of coal; in this case they are to be separated according to BTU content. By selective withdrawal, the coal can later be blended on the reclaim belt. Figs. 10—12 show the Pawnee project during construction.

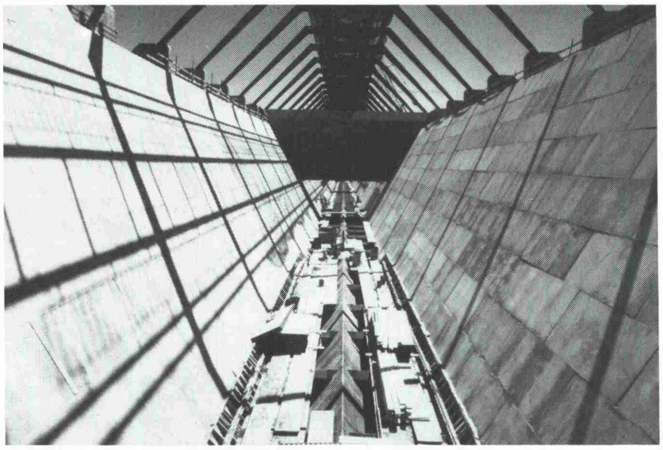

Fig. 10: 60,000 t slot at Pawnee Power Plant is divided by diaphragm walls into three sections

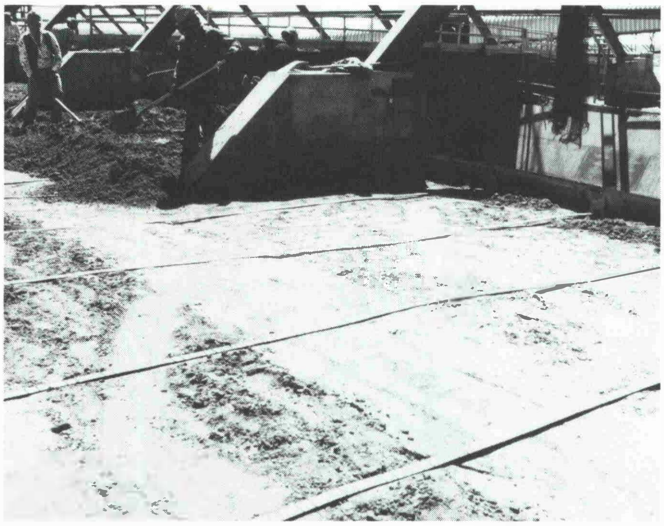

Fig. 11: Spreading backfill around the footings for the roof bents at the Pawnee slot

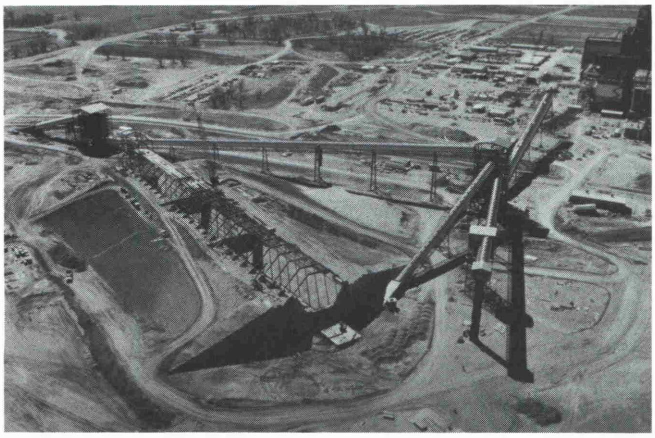

Fig. 12: Aerial view of Pawnee Power Plant under construction

4.4 Marissa Mine

A recently completed structure in Illinois demonstrates the versatility of Reinforced Earth. Rather than linear *slot* structure, Peabody Coal Company selected a conical *glory hole* for live coal storage for its Marissa mines. Because of higher predictability of performance and cost, Peabody selected Reinforced Earth over a soil-cement gunite-lining alternative.

Coal from several local mines travels by overland conveyor belt to the glory hole, which is actually eight sloping Reinforced Earth walls tapering to a 30-ft opening underground. At that opening, a vibrating feeder loads the coal onto a conveyor which moves the coal to the surface, then overland to a processing and storage plant.

The glory hole acts as a surge pile to compensate for differences between mining rates and loadout rates. It has a capacity of 30,000 t, yet uses only a small area (Fig. 13).

Fig. 13: Aerial view of the Glory Hole in Marissa, Illinois

5. Construction Schedule

In part because the components of a Reinforced Earth structure are prefabricated and in part because the construction procedure is simple and repetitive and requires no special skills, equipment or previous experience, the construction is extremely rapid, with construction of 1000—1500 ft^2 of wall surface per day about average. Rates twice that have been achieved. A comparison between the construction schedules of a hypothetical 36,000-t capacity slot using Reinforced Earth versus the schedule for a slot using soil-cement shows that the Reinforced Earth construction is 130 working days shorter than that for soil-cement.

6. Comparative Costs

Because of the ease and speed of construction, standardization and prefabrication of construction materials, relative insensitivity to weather conditions etc., Reinforced Earth is economical. A 1978 cost analysis comparing the estimated costs of building a 36,000 t slot using Reinforced Earth with the estimated costs of using soil-cement stabilized berm with troweled gunite facing showed Reinforced Earth to be 26 % less expensive. Percentage cost comparison for facilities completed in 1980 indicate total construction costs to be in the order of $110/t of material stored for structures in the range of 30,000 to 60,000 t.