The Koornfontein coal load-out facility

By P C DE LANGE and A C S SMITH

Synopsis
An alternative concept for the storage of washed coal prior to loading into unit trains was recently used at Koornfontein Colliery in the Hendrina district of the Eastern Transvaal. Reinforced earth (RE) was used for the construction of two slanted glory hole bunkers, one for storing power station smalls (PSS) coal and the other for storing low ash coal (LAC), from which a high capacity belt delivers the coal to a common load-out facility. Trains are loaded continuously at a rate of 4 000 t per hour. This paper reviews and describes the project with particular reference to the construction of the reinforced earth bunkers and their integration with a widely used and well proven locally designed flash rapid load-out station. The cost ratios of the facility are summarized and compared with alternative facilities. The conclusion reached is that the storage and loading solutions adopted have merit in terms of economy, speed, ease of construction and quality of product, and should be considered for intermediate storage capacities.

Samenvatting
'n Alternatiewe ontwerp vir die voorafberging van gewasse steenkool vir beskikbaarheid gedurende die spoedstasie daarvan in treinwaens is onlangs deur die Koornfontein-steenkoolmyn in die Oos-Transvaalse distrik van Hendrina gebruik. Die konsep behels 'n dubbel stel, omgekeerd-keelvormige kolkhoekige bunkers in siamese verbinding gekeur in die medium van gewapende grond (RE) vir die opberg van kragtasies (PSS) en lae as steenkool (LAC) sonder besoedeling van die een produk met die ander. 'n Hoë-kapasiteits-voorbou iewer die steenkool aan 'n gemeenskaplike laaste- sie waar treinwaens aaneenlopend gelaaí word teen 'n tempo van 4 000 t per uur. Die doel van hierdie verhandeling is die beskrywing en beskrywing van die projek met spesifieke verwysing na die konstruksie van die gewapende grond-bunkers en die integreer daarvan met die sisteem in geheel, waarvan 'n wel bekende plaslik ontwerpe automatisering spoedlaaisie een van die hoofelemente vorm. Die kosteverhoudings van die fasilititeit word opgesom en vergelyk met alternatiewe sisteme, en die gevolgtrekking hieruit dat daar 'n waarde in die gebruik van dit sisteem in terme van koste, spoed en gemak van oproting en kwaliteit van die eindproduk, en dat dit ongewen vergeden vir interoperere bergingskapasiteite, gesoek met spoedlaai van treine.

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This paper was submitted to independent referees for scrutiny prior to acceptance for publication.

Introduction
General
Washed coal at the Koornfontein Mine, produced by the heavy media separation (HMS) plant in two different product types, has to be transported to the load-out station where it is loaded onto trains for transportation to Richards Bay and ultimately to the export market. The load-out station is located approximately 115 km from the HMS plant.

A series of overland conveyors transports the coal to two storage bunkers, each with a nominal capacity of 17 000 t, where it is stored in bulk to enable successive rapid loading of trains.

When train loading from the selected stockpile takes place, the product is withdrawn by vibrating feeder and vibrating drawdown hoppers onto a common belt conveyor and conveyed to the rapid load-out station situated over the railway line. The load-out station is the proven ELB flash weighing system operating with only a nominal amount of surge capacity. A constant speed train-mover moves the train at the required speed through the load-out station during the filling cycle.

Client brief
The client brief at tender stage was to design and build a plant to store and automatically load two different products onto trains, without contamination of the products, while adhering to the loading tolerances for truck axle and train laid down by the South African Transport Services. The storage facility had to be capable of storing 12 700 t of each product with sufficient space allowance for possible future expansion of the storage capacity of the two stockpiles, an option that was taken up before completion of the facility, the storage capacity of both stockpiles being increased to 17 000 t. A further practical requirement for the proper performance of the total load-out system was the need for a free, uninterrupted flow of the stockpiled material onto the feeders without hang-ups or formation of stable pockets of dead material.

It was also a client requirement that the project be completed on a tight schedule of eight months from date of order to hot commissioning.

Schemes evaluated
Various schemes were evaluated, including the following:
1. Open stockpiles with stacking and reclaiming machines.
2. Large-capacity over-rail silos with direct train loading facilities.
3. Bunker-type stockpile with reclaim tunnel for fast reclaiming by gravitational means.

Physical site conditions, technical constraints, flexibility-constraints and economic factors in one way or another ruled out the first two schemes in favour of the third, and it was decided to proceed with the open bunker-type stockpiles with reclaim tunnel for fast reclaiming by a
high-capacity conveyor belt feeding the load-out station situated over the railway line. The system is totally automated and interlocked throughout to ensure reliable, uninterrupted loading to the specification.

Selection of bunker construction method

After having decided on the system and the conceptual arrangement of the storage facility, potential methods of construction of the bunkers were evaluated as follows:

1. Compacted fill suitably stabilized along the inside edges, shaped and covered with interlocking concrete blocks or lined with a nominally reinforced concrete layer.

2. Roller compacted concrete, cut and shaped during construction to form the bunkers, with common compacted fill forming the major cross-section of the embankment.

3. Reinforced earth.

These construction methods were evaluated from technical, cost, speed and practicality of construction viewpoints and the overall decision was made in favour of reinforced earth. In particular the RE provides a flexible bunker system that can accommodate anticipated settlements of the embankment both during and after construction.

Hopper geometry

For the type of plant under discussion it is important that sufficient material is available at the train loading point at all times during loading of a train.

Problems resulting from an erratic or unreliable flow of material from the storage facility are detrimental to the performance of the rapid load-out station and are unacceptable.

It is therefore essential that the geometry of storage hoppers be designed to meet the requirements of uninterrupted free flow and self-cleaning under all possible combinations of varying flow conditions.

The LAC and PSS coals were laboratory tested to determine the material's physical properties such as the internal and liner friction angles, effects of varying moisture contents, effects of consolidating pressures, etc., and from these results the flow characteristics of the material were established. These results were in turn used in the geometrical design of the bunkers. The hopper side slopes and valley angles were fixed at 46° and 45° respectively in order to ensure free-flowing and self-cleaning conditions.

Selection of site

The client had pre-fixed the basic set-out points at both battery limits and at the intermediate transfer point between the feed conveyors into the stockpile.

Because of the high cost of the high-capacity conveyor between the stockpile and load-out terminal against the relatively low cost of the stockpile feed conveyor, the distance between the stockpiles and load-out station was kept to the minimum commensurate with the mechanical design radius of curvature for the conveyor belt system as well as optimum reclaim tunnel and feeder arrangements and elevations under the stockpile.

General description

In its final form the stockpile consists of two 17 000 t storage bunkers constructed on top of a reclaim tunnel.

The two HMS products are sequentially conveyed on a belt conveyor up a gantry straddling the stockpiles and fed into the selected bunker from a fixed position above the bunker. During train loading the coal is reclaimed from the bunkers through drawdown hoppers by means of vibrating feeders onto a high-capacity belt conveyor inside the reclaim tunnel. The belt then carries the coal to the load-out station, from where it is loaded onto unit trains at a nominal rate of 4 000 tph.

The drawdown hoppers are not used during the normal course of operations, but only on occasion to loosen the material during extreme conditions of consolidation pressures, unfavourable moisture content and excessive fines content.

Fig 1 is a line diagram illustrating the arrangement of the plant.

Site conditions

The site slopes sharply towards the west. Fig 2 shows the contours of the natural ground and the superimposed storage facility.

Reclaim tunnel

The stockpile reclaim tunnel is of conventional design and construction, is 110 m long and has a typical cross-section of 4.8 m wide x 3.5 m high with a height increase to 5.5 m local to the feeder positions to accommodate the feeders and skirts. The tunnel roof elevation is at about the normal ground level and slopes at 2.2° directly under the stockpile to match the slope of the natural ground surface. The exit portion of the tunnel is curved in elevation to match the radius of curvature of the reclaim conveyor and hence minimizes the tunnel and conveyor lengths.

Drainage of the tunnel is by means of a 1 200 mm diameter concrete drain pipe from the back end of the tunnel. This pipe also serves as an escape tunnel as well as natural ventilation chamber.

There are three openings of 3 m diameter each in the tunnel roof under each stockpile to receive mechanically activated drawdown hoppers directly above the feeders.

Earth embankment and reinforced earth

History

In 1977 RE was used for the first time for the construction of coal slot storage facilities. These structures differ from conventional RE structures in the sense that the cladding elements are designed for sloping walls rather than vertical walls and that although they still perform their normal function when the facility is empty they double as a lining to the bunker when it contains coal.

Since 1977, 23 major RE slot storage or glory hole storage facilities have been constructed with total storage capacity in excess of 1 000 000 t. Prior to the Koornfontein project these facilities were built in the United States (19), South Africa (3), Australia (3) and Canada (1). Further facilities are under construction, including a 150 000 t facility in China.

The constituent materials

Common backfill: The embankment is built according to standard earthwork norms and the backfill material used had to conform to these. At Koornfontein 70 000 m³ of the locally available sandy hillwash soil and 80 000 m³ of burnt shale and coal discard from the Koornfontein waste dump were used.

RE backfill: A 700 mm thick laterite layer situated within the locally avail-
able sandy hillwash was used as RE backfill at Koornfontein. 30 000 m$^3$ was required. Fig 3 gives the mechanical and chemical criteria for RE backfill and the properties of the laterite used at Koornfontein.

**RE cladding:** 140 mm thick 30 MPa precast concrete cladding elements were used. Buttresses were cast into the back of the panel in order to present it to the work at its specified slope of 46°. Galvanized tie strips, onto which the reinforcing strips were bolted, were cast into the back of the buttresses. The prime purpose of the buttresses is to facilitate the erection. (Fig 4).

**RE reinforcing strips:** Reinforcing strips were bolted onto the tie strips.

The connection is by means of a 12 mm diameter Grade 8.8 high tensile bolt in double shear. The strips are hot-rolled mild steel with 40 mm $\times$ 5 mm and 60 mm $\times$ 5 mm sections and have ribs formed on them during the hot-rolling process to increase their adherence capability in the fill material. (Fig 5).

**Joining materials:** Resin-bonded cork planks were placed between the panels in the horizontal 'fishlap' joints. Polyurethane foam was pushed into the earth face of the vertical joints, which are also of the 'fishlap' type and are normally 10 mm thick.

At Koornfontein 20 mm thick cork planks were used for the lower third and 10 mm thick planks for the upper two-thirds of the horizontal joints.

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**Fig 2:** Site layout

**Fig 3:** General specification for RE backfill and properties of backfill used at Koornfontein

<table>
<thead>
<tr>
<th>pH</th>
<th>RE - SPEC</th>
<th>KOORNFONTEIN LATERITE</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>5 - 10</td>
<td>5.4</td>
</tr>
<tr>
<td>Resistivity</td>
<td>$&gt;$ 1000 ohm cm</td>
<td>6500 ohm cm</td>
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<tr>
<td>Grading</td>
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The valley angles had a relatively large, 135 mm gap between the cladding elements that was filled with dry pack concrete as late in the construction as possible.

**Drainage**

In open stockpiles the runoff water from the coal pile, after saturation by rain, needs to be considered. This water would be aggressive and would increase the corrosion rate of the RE reinforcing strips should it seep through the cladding element joints and reach the strips. The cladding is either sealed to prevent this water from entering the mass or a drainage layer is placed behind the panels.

Initially the Koornfontein facility was not to be covered with a roof and all joints were sealed with polysulphide. The large potential order of movement at the valley angle joints presented some difficulty. Instead of trying to seal the joint, a crack is allowed to develop between the edge of the RE cladding and the dry-pack concrete. A galvanized steel backing plate, flownet and filter cloth provide a backup drainage system behind the valley angles. Should post-construction movement take place, polluted water is then returned to the coal pile by this system (Fig 6).

The top surface of the embankments are covered with a 150 mm thick, mesh-reinforced, curved slab with the appropriate expansion joints laid on a 200 micron PVC sheet and sloping into three catchment boxes from where stormwater is taken down the side slopes in 600 mm diameter concrete pipes into the site surface drainage system. Energy absorption (silling) boxes are built midway downslope in the sloping pipes. Sloping sides of the embankments are covered with selected topsoil and grassed to preclude surface gouging during rains.

**External stability**

The external stability is checked by slip circle analysis as shown in Fig 8. A failure circle cannot pass through the reinforcing strips, but rather is forced behind and beneath the structure. It is, however, possible for a failure line to pass between layers of reinforcing strips and this possibility is also checked. The stability of the common embankment fill is treated in a similar fashion.

**Durability**

An RE structure is designed to meet a required service life. For coal storage facilities this is usually assumed to be 70 years. This means that after at least 70 years has elapsed then the stresses in the reinforcing strips will, for the first time, have reached the design working stresses. The structure will then still have many years before it finally reaches the ultimate end of its life.

The RE backfill is selected to comply with mechanical and chemical criteria. After analysis of available corrosion data and results of ongoing research programmes and monitoring of existing structures, the corrosion rate of galvanized steel in RE backfill is now reasonably well known. Once adequate factors of safety are applied, a sacrificial thickness of reinforcing strip is allocated to ensure the required service life. The galvanizing of the strip tends to even out the corrosion in the early years since the zinc acts as cathodic protection for the steel. The products of corrosion of the zinc tend to form a relatively insoluble gange around the strips, which leads to a slowing-down of the corrosion rate with time, even once the zinc has disappeared.

**Internal stability**

Since an RE mass behaves as a coherent, gravity structure, it is proportioned first to resist forces of sliding and overturning. The internal stability is then analysed by subjecting the structure to a number of loading conditions.

The vertical stress in the mass at each level of reinforcing strips is calculated, taking into account the internal and applied loads. An earth pressure coefficient is used to determine the horizontal stresses at these levels. These horizontal forces are assumed to be transferred through friction to the reinforcing strips. The density and size of the strips, taking into account the service life requirements, are then determined.

The locus of maximum tension of the reinforcing strips divides the structure into an active zone, where the earth with its cladding lands to pull the reinforcing strips out of the earth, and a resistant zone in which the RE backfill holds the reinforcing strips back in the mass.

It is necessary to check that sufficient area of reinforcing strip is available in the resistant zone to mobilize the frictional forces in the mass and to provide an adequate factor of safety under all loading conditions with respect to adherence.

This analysis is, in practice, calculated for a number of loading conditions.

In order to allow the RE mass at Koornfontein to settle relative to the reclaim tunnel, the lowermost part of the mass consists of RE with vertical cladding elements placed on either side of the reclaim tunnel. These cladding elements sit on compressible cork at the point where they meet the tunnel. In situ concrete is then required in front of the vertical cladding to lead the coal on the 46° slope to the openings at the top of the tunnel.

A 50 mm polystyrene plank was placed between the cladding elements and the in situ concrete to allow both horizontal and vertical movement of the RE mass relative to the tunnel both during and after construction. This in situ concrete at the tunnel and RE interface can be and was substantially poured at an early stage of the construction. The gap
between the early-poured in situ concrete and the lowermost RE sloping panel was filled with dry-pack concrete towards the end of the RE construction. This detail also incorporates a flexible horizontal joint. Fig 7 illustrates the interface between the RE and the tunnel.

Fig 8 illustrates the RE structure analysed at Koornfontein. The locus of maximum tension, active and passive zones and stability considerations are shown on the sketch.

The gantry loads are transmitted down through the columns into the RE mass and the embankment. Where these loads are accepted by the RE, an extra layer of reinforcing strips is placed beneath the column foundation to improve the bearing capacity of the backfill locally.

**Erection of the RE**

The placing of panels, backfilling behind the panels and fixing of the reinforcing strips to the panels are systematic operations that require attention to be given to the planning of the work process in order to achieve optimum labour and plant utilization. All construction took place from the back of the panels, leaving the way clear for simultaneous completion of the reclaim tunnel, installation of mechanical equipment in the reclaim tunnel and sealing of joints. An average erection rate of 90 m² of completed RE per day was achieved at Koornfontein.

Both the RE backfill and the common backfill was compacted to 93 per cent MOD AASHTO. Special care was taken in the compaction of the backfill immediately behind the panels, for which mechanical stampers were used.

**Increase in capacity**

The civil construction of the stockpile was about 75 per cent complete when the client found it necessary to increase the capacity of the stockpiles to the maximum possible within the limits of the already completed civil and mechanical design and construction, which at that stage were well advanced in respect of fabrication and erection.

Utilizing the free space of ±3 m originally allowed between the tip of the stockpile and the underside of the conveyor gantries meant overflowing of the glory hole perimeters, which was not acceptable. Furthermore, owing to construction and stability considerations the 3 m wide flat ridge around the glory holes on top of the embankment could not be reduced, which precluded a simple height increase of the embankment. The result was that a 2 m high reinforced concrete wall had to be constructed around the full perimeter of each stockpile on top of the embankment to retain the coal.

The design had to be reviewed for the new conditions in terms of overall as well as local element stability. Accurate volume checks have been carried out on a computervision CADD system. (Fig 9).

The final capacity was increased at nominal cost, from 12 700 t to 17 000 t for each stockpile, and is an indication of the flexibility of the medium of construction. Fig 10 is an aerial view of the stockpiles, taken before construction of the 2 m high reinforced concrete wall.

**Introduction of roof cover**

Shortly after the increase in capacity, the first coal was loaded into the stockpile. It was found that on windy days and as a result of the high free drop of coal into the stockpile, a significant deflection of the coal stream into the bunkers was taking place with the fines fraction being blown outside the perimeter of the storage area. In addition it had been found that the increase in moisture content from the ingress of rainwater into the

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**Fig 7:** Details of RE interface with reclaim tunnel

**Fig 8:** RE at Koornfontein — geometry and basic mechanics

**Fig 9:** Simulation of fully loaded coal profile
coal during heavy rain was not conducive to smooth reclamation of the product from the bunker discharge ports. In order to counter these problems the client decided to construct a roof cover over the stockpiles.

The solution adopted consists of three main pin base portal frames across the width of each of the two elliptical stockpiles, two main portals across the length, four hip rafters and eight semi-hip rafters forming two identical semi-conical covers.

The frames are supported on foundations along the inside top edges of the bunker embankments and had to be keyed into the RE fill material in order to develop sufficient resistance to overturning and sliding forces.

Erection of the steel structure posed some problems with respect to crane positioning and reach and certain activities had to be rescheduled in order to facilitate erection of the steelwork without damage to other parts of the structure.

Cost analysis

The cost of the facility in 1985 rands was as follows:

Civil work:
- Clearing of site
- Excavation for and construction of the reclaim tunnel
- Construction of the earth embankments and the RE bunkers
- RE retaining wall at the top of the bunkers and the roof support pads
- Conveyor and gantry foundations
  \[ \text{R 67/t} \ (1 \text{tonne of coal stored}) \]

Mechanicals:
- Feed conveyor system
- Reclaim conveyor and feeder system
- Flask load-out station
  \[ \{ \text{R 54/t} \} \]

Roof cover:
- \[ \text{R 22/t} \]

Total cost of the load-out facility:
- \[ \text{R143/t} \]

The sloping nature of the site required the use of an additional 70 000 m² of backfill, which cost approximately R6/t. The polysulphide sealing of the RE bunker, which proved unnecessary owing to the late decision to put a roof on the facility, contributed another R2/t to the cost. This indicates that the overall cost could be reduced to R135/t.

Comparison with silos

In order to store 34 000 t of coal, two 17 000 t silos were required. To our knowledge the largest dual purpose coal-storage/train-loading silos previously built in South Africa had a capacity of the order of 12 000 t to 15 000 t. An estimate of the cost of the silo load-out facility is as follows:

Civil works for silo situated directly on top of the railway lines:
- \[ \text{R120/t} \]

Total cost of load-out facility with mechanicals but excluding feed conveyor system:
- \[ \text{R156/t} \]

Comparison with stacker reclaimers

In order to compare the load-out facility at Koornfontein with stacker reclaimers, not only the capital cost but also the operating and maintenance costs need to be considered.

Stacker reclaimers are generally more economical for larger storage capacities than that considered at Koornfontein.

Programme

Civil construction for the facility started in mid-May 1985 and was completed at the end of October 1985. Most of the structural, mechanical and electrical construction activities were carried out in parallel with the civil construction, enabling commissioning of the whole facility in mid-October 1985.

Of interest is the fact that once the reclaim tunnel had been constructed, installation of the mechanical and electrical equipment could proceed at the same time as construction of the earth and RE embankments.

Conclusion

The rapid load-out facility at Koornfontein adequately satisfies all technical criteria and requirements. The facility has proved to be cost-effective and its construction has met stringent programme requirements.

The RE at Koornfontein provided a flexible bunker and was easily built to specification. The rapid construction of the RE contributed towards the timeous overall completion of the facility.

This type of load-out facility can provide a cost-effective solution for storage capacities ranging between those below which silos are more economical and above which stacker reclaimer systems are most cost-effective.

Discussion on papers

Written discussion on the papers in this issue will be accepted until 31 December 1987. This, together with the authors’ replies, will be published in the May 1988 issue of The Civil Engineer in South Africa, or later. For the convenience of overseas contributors only, the closing date for discussion will be extended to 31 January 1988.

Discussion must be sent to the Secretaries of the SAICE.

Such written discussion must be submitted in duplicate, should be in the first person present tense and should be typed in double spacing. It should be as short as possible and should not normally exceed 500 words in length. It should also conform to the requirements laid down in the ‘Notes on the preparation of papers’ as published in the October 1983 issue of The Civil Engineer in South Africa.

Whenever reference is made to the above papers this publication should be referred to as The Civil Engineer in South Africa and the volume and date given thus: Civ Engr S Afr, Vol 29, No 6, 1987.