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Compaction Grouting in Waste Rock

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SUMMARY A large mine structure is supported on a well founded concrete wall at one end and on deep mine waste fill at the other. When additional filling was carried out behind the structure substantial differential settlements were found to occur and a range of possible solutions is discussed. A penetration/compaction grouting method was successfully adopted but there were considerable difficulties in execution, principally due to problems of drilling in loose unstable soils containing very hard boulders.

After overcoming many unforeseen difficulties the supporting fill was successfully stabilized by grouting and the settlement of the structure halted for all practical purposes.

1 INTRODUCTION

An important part of a project to expand the production of iron ore from the Tom Price Mine to 46 million tonnes per annum was the modification of one of the two primary ore crushers. During the construction of an earthfill ramp substantial settlement at a maximum rate of 3 mm per day was observed to occur at the new feeder structure. It became clear within a few days that future operation of machinery within the structure would be affected and that immediate action had to be taken to ensure that commissioning of the $A400 million project was not delayed.

2 DESCRIPTION OF AREA

Tom Price is located in the Hamersley Iron Province in the Pilbara at about 22 degrees 45' South, 117 degrees 45' East. It is about 1000 km North of Perth, Western Australia.

The topography consists of steep and dramatic rocky hills rising to about 1100 - 1200 m above sea level, separated by relatively level plains 400 - 500 m below. The dry river courses on the plains are marked by mulga and river gums, but in the hills the spinifex and desert shrubs are sparse and stunted, and top soil is thin or absent.

The climate is semi arid, with a mean annual rainfall of 340 mm. Most of the rain occurs over relatively short periods, governed by cyclone activity.

The annual pan evaporation rate is about 3500 mm. The temperature range is wide with a January average daily maximum of 40 degrees and a July minimum of 8 degrees.

3 DESCRIPTION OF SITE

The tiphead structure is located on an extensive bank of mine waste fill on the northern slopes of Mount Tom Price. In this area the natural ground slopes vary from about 30 - 35 degrees near the crest to 20 degrees on the lower slopes. The total depth of fill measured above the valley floor is approximately 80 m.

Although the natural angle of repose of the fill is about 34 degrees some oversteepening had taken place both below and to the West of the structure where the gradients ranged up to 50 degrees. It was apparent that work was required to stabilise these steep slopes in addition to any work carried out at the tiphead.

There is a substantial depth of fill beneath the structure itself, varying from a minimum of 24 m to a maximum of more than 30 m measured vertically.

4 DESCRIPTION OF WORKS

4.1 General

The modifications to the primary crusher comprised the construction of a large tiphead structure which houses equipment to direct incoming ore to either the crusher or to the concentrator plant. Selection is made on size with the coarse material passing over vibrating grizzlies and screens into the crusher and the fines material falling through onto a conveyor belt.

The tiphead is a monolithic concrete structure which in addition to housing the dump hopper, grizzlies and screens also partially supports a large overhead travelling gantry crane, control buildings and dust collectors. An approach ramp of selected fine waste material provides access to the tiphead from the adjacent mine haul road.

The concrete structure consists of a 22.5 m square 1.5 m thick slab with two 6 m x 3 m "wings". The rear retaining wall is 17 m high and buttressed by the dump hopper walls. At the West side the base slab is supported on a 3.5 m thick blanket of selected fill overlying mine waste. The slab spans the loadout tunnel and is supported on the reinforced concrete wall of the existing crusher at the East end. The crusher itself is founded on bedrock. The foundation level of the structure is about 6 m below the original surface of the dump.

In addition to the loading applied to the foundations by the dead load of the structure, the approach ramp and from loaded trucks, the equipment when in operation was expected to impart intense vibrations to the structure and hence to the underlying rockfill.

A simplified cross section through the structure is given on Figure 1.

4.2 Foundation Material

The foundations of the tiphead structure rest on fill consisting mainly of shale, chert, goethite, and haematite, ranging from boulders of 2 - 3 m^3 to fine sand and clay slit. The average specific gravity of the coarser material is about 3.5. The fill had been placed in three ways:-

(a) Immediately beneath the foundation is a 3.5 m thick layer of 100 mm down, well graded angular rock with a fines content of about 20% and a plasticity index in the range 10 - 20%. It was compacted to a specified 85% modified density.

(b) When the crusher was constructed in 1969, mine waste filling in the immediate vicinity was compacted to a specified 85% density, after removal of the large boulders.

(c) The remainder of the filling was end tipped and uncompacted. End tipping results in natural segregation, as the coarsest material tends to travel furthest downslope from the point of tipping. A typical section through a mine waste dump would show that there is a thick layer of large boulders at the base, with successive overlying layers of relatively uniformly sized and progressively finer material. Above these basal layers there is well graded material, with intercalated layers and lenses of single sized material, which vary widely in thickness. Particularly large assemblages of single sized material are produced in valley areas formed between adjacent areas of filling.

A typical section through a nearby filled bank showed layers of gravel and cobbles from 50 - 600 mm in thickness, separated by layers of finer material 600 mm or more thick. It is likely that the material under the structure is similar, although it was suspected that there might be an area near the crusher where oversize boulders were disposed of during early crusher operations. It is also believed that a valley situation exists under the West wall of the structure as evidenced by the high grout takes during remedial operations.

The bedrock at the base of the fill is Wittenoom Dolomite of the Hamersley Group. Of Proterozoic Age (2000 million years), this is partly a fine clastic and partly a chemical sedimentary deposit containing dolomite, chert and shale.

5 THE PROBLEM

5.1 General

By mid July 1978, 11 m of waste rock had been placed in the approach ramp fill area to the West of the structure. As the foundation of the building was constructed 6 m below original ground level, this represented an effective increase in the depth of overburden of 5 m. Settlement monitoring was carried out at a number of points and over a two week period, the average rate was recorded at about 2 mm/day, with a peak value of 5 mm in one day at one point.

The exact total settlement which had occurred at this stage is not known, but was probably of the order of 40 - 50 mm. As there was still a further 6.5 m of fill to be placed, it was clear that future operations of the plant could be prejudiced and work was stopped and further advice sought from ground engineering specialists.

When fill is deep, self weight is often the principal cause of long term settlement. With granular fills, the major component (primary compression) occurs almost immediately, and as a consequence most of the movement takes place during construction. Taking the primary compression settlement caused by the initial 5 m of filling as about 50 mm, the additional settlement due to a further 6.5 m of fill could have been expected to be about the same, giving a total primary settlement of 100 mm. However, significant further movements would continue to occur over a long period of time under conditions of constant stress and moisture content. With many fills, this further "creep" movement decreases with time and shows an approximately linear relationship when

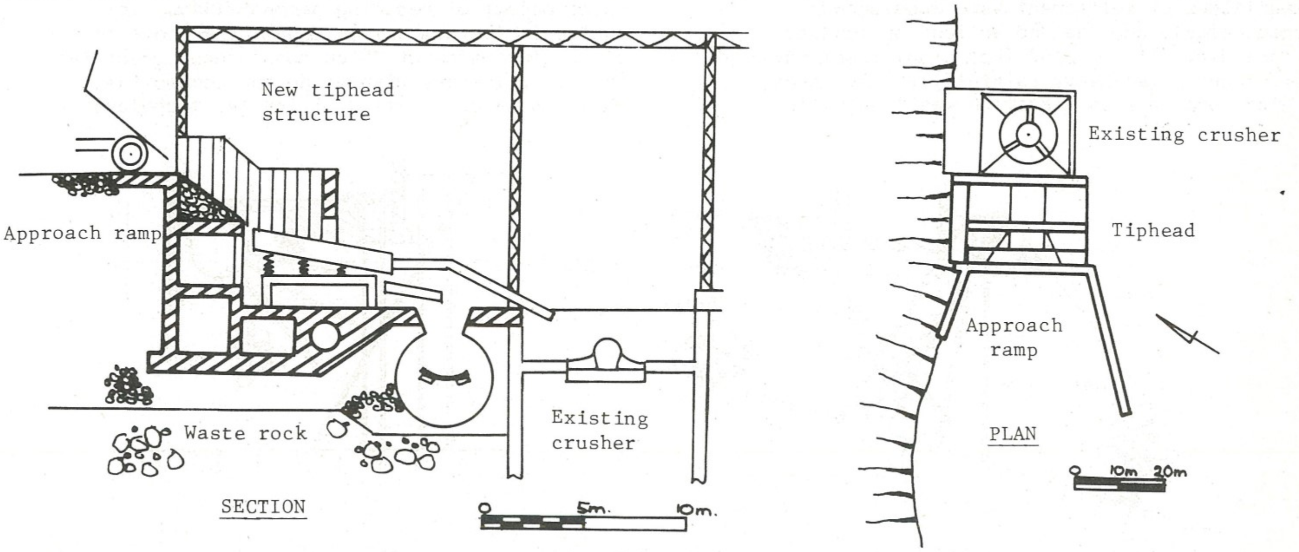

Figure 1 - Tiphead structure

plotted against the logarithm of elapsed time. Using a log 10 cycle, similar amounts of movement would be anticipated between 1 month and 10 months as between 10 and 100 months.

With uncompacted rock backfill, typical quoted figures are in the range of 0.5 - 1% of fill thickness in one log cycle. With a fill thickness of 16 m, this would indicate movement of the order of 180 mm per log cycle.

However, these figures assume constant effective stress and moisture content. Inundation can cause "collapse compression" of 2-5%, or more, and vibration is a common cause of dramatic settlements.

While drainage would prevent inundation, it would not prevent an increased moisture content after heavy rain, which would lead, in turn, to greater settlement. In addition there was a risk that excessive settlement might occur due to the effects of the operation of the heavy machinery imparting vibration to the structure.

5.2 Possible Remedial Works

Time was tight, and one of the requirements of any remedial work was to minimise interference with other activities. These activities included:-

i) Ore crushing by the existing primary crusher which continued during the construction period.

ii) Erection of the superstructure and facilities, involving a variety of disciplines.

iii) Installation of the vibrating screens.

Four courses of action were considered:-

5.2.1 To take no special action.

This concept often has much to commend it, inasmuch as it demands a reassessment of fundamental design criteria.

It was calculated that a "best figure" settlement of around 250 mm over a three year period could be expected. The worst case would result in far greater settlements. Such magnitudes of settlement were considered unacceptable and the "no action" option was discarded. It is noted that significant movement did occur after heavy rainfall, as discussed later, and intense vibration was transmitted to the structure from the grizzlies.

5.2.2 To provide underpinning to solid rock

An underpinning scheme could have completely halted all settlement and would have provided a satisfactory technical solution. However installation of piers would have been difficult and expensive and the five and a half months available for redesign, tendering and construction was not sufficient.

5.2.3 Reduce loading

Replacement of the ramp fill with a suspended structure would have reduced the magnitude of final settlement but would not have stopped movements occuring due to water saturation and vibration. Construction would have been difficult, lengthy, expensive, and would have interfered with work on the main structure.

5.2.4 Grouting

Grouting had the merits of speed of mobilisation and completion, and of minimum interference with other construction activities. Only drilling equipment would operate close to the structure and the grout mixing stations, pumps and supplies would be kept at a distance.

It was recognized that cement grout would not penetrate the fine material in the fill but by using high pressure techniques the fine material could be precompressed. Movement of the fine material into the voids could be halted and there would be a future option to raise the structure back to design levels. Further treatment of the fine materials by chemical grouting could be used to reduce creep settlement.

The most important factor, though, was speed of completion as it was anticipated that initial work would be carried out in a few weeks. An experienced local contractor had grouting plant available and agreed to an immediate start. Grouting was accepted as the only viable option.

6 DESCRIPTION OF WORK

Conventional penetration grouting involves the use of a very fluid grout to fill voids, joints and fractures in rock, or pore spaces in soil, with the usual object of reducing permeability. In contrast, the compaction grouting process consists of the intrusion of thick consistency grout into the soil, thereby displacing and compacting it. In this case a combination of the two techniques was

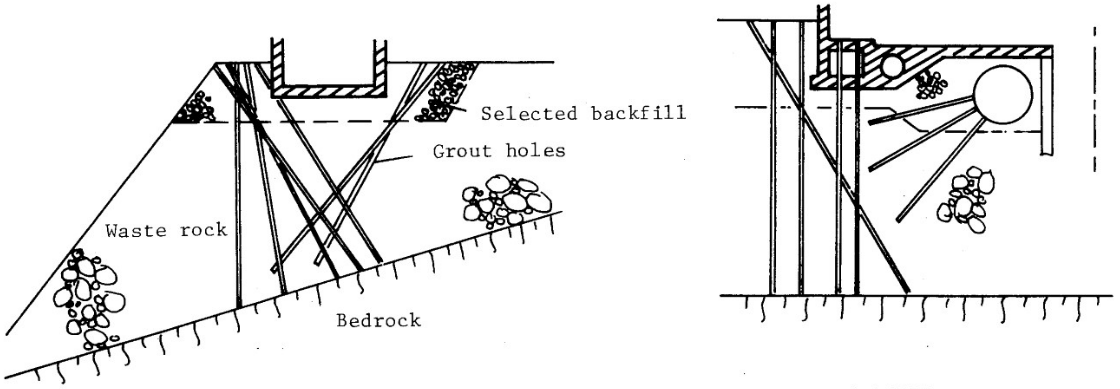

Figure 2 - Grout hole layout

adopted.

To limit the extent of the treatment zone, a confining grout curtain, or barrier zone, was required prior to advancing pressure grout treatment progressively under the structure. This was carried out by drilling a line of primary holes at 4 m centres on the North and West sides of the structure and tremieing in the grout under gravity. When the holes had been sufficiently advanced, a line of secondary holes was drilled between the primaries and similarly treated.

The unit grout acceptance, (that is, the quantity of grout used per metre run of drill hole) was carefully monitored. A significant reduction in acceptance was taken to indicate that saturation had been achieved.

It is preferable to adopt upstage grouting techniques in loose fills if possible, as, by stabilizing the base of the formation first, settlement caused by the weight of grout and by moisture penetration is minimised. Due to the particular ground conditions at Tom Price this technique did not prove practicable and downstage grouting was adopted. The nominal stage length was 3 m with shorter stages being used when substantial voids were encountered.

Under normal circumstances if the grout curtain is completed before commencing pressure injection subsequent analysis of grout acceptance is made more reliable. In this case installation of the curtain was slow and pressure grouting was started when the curtain was about 10 m below the proposed pressure grouting level.

To avoid interference with construction operations treatment was mainly carried out from outside the structure. A simplified layout of the holes is shown in Figure 2. On the North side of the structure a single row of vertical curtain holes was constructed first, followed by a further single row of holes at 70°, one at 57° and two at 45°. On the West side a double row of curtain holes was established followed by a single row at 65°, under the structure. In all cases grout acceptances in primary and secondary holes were closely monitored. When grouting from outside the structure had been completed, a series of holes was drilled from an access-way within the structure and from the loadout tunnel under the East of the structure.

In the early part of the operation, there was a shortage of materials and very thin mixes were used to obtain maximum yield. By the time the first large voids had been encountered sand was available, and, when acceptance rates were high, 2:1:1 sand cement mixes were used. Where acceptance rates were very high rapid setting agents were added to the sanded mixes, and injection was carried out intermittently in quantities of 0.5 to 1 m^3. Twenty minutes to half an hour was allowed to elapse between successive injections to allow the grout to set. In some cases this intermittent injection was carried on for 3-4 days before the voids were filled.

The inclined pressure injection holes were cased with water pipe to a depth of up to 18 m to prevent "break back" under the high pressures used. In general about 1 m^3 of thin lubricating grout was injected followed by thicker grouts at 1:1 and 0.8:1 water cement ratio. Injection pressures were taken up to a maximum of 6000 kPa and the holes sealed off when refusal was reached.

A total of 62,500 sacks of cement was used in the operation, at an average rate of up to 1,400 sacks per day in the early stages, reducing to 400-500 sacks per day during pressure grouting. The 4000 m^3 of fluid grout injected represented about 23% of the estimated treated volume of 17,000 m^3.

7 EQUIPMENT

7.1 Drills

Drilling the mine waste was always the difficult part of the operation due to the combination of loose fine material and hard boulders, the high voids content, and the high rock strengths. Compressed air driven rotary percussion crawler drills were used for the most part, but use was also made of a large truck mounted Schramm 140 mm down the hole hammer exploration unit and an NQ wire line diamond drill.

The ideal drill stage length was 3 m, but due to air loss it was not always possible to achieve this. Air loss difficulties became greater with increasing depth, particularly beyond 30 m as the high particle S.G. meant that the cuttings could not always be carried back to the surface. Biodegradable foam was used to assist with cuttings return.

Because the loose fine mine waste offered little lateral stability, the drill bits were deflected to one side or the other. This meant that a drill re-entering a hole may not follow the same path and it was common to find new voids at the same level on several successive occasions, particularly as the holes became deeper. For example, one hole was drilled to depths of between 30 and 40 m on several successive occasions (i.e. 30, 36, 30, 31, 41, 34, 41, 30 and 40 m) and accepted significant quantities of grout on each occasion. This problem was common to both the crawler and the diamond drills.

7.2 Mixers

Three single bag colloidal mixers were used as larger units were not available. Their small capacity and inability to handle heavily sanded mixes effectively restricted production rates. Some mixing was also carried out at a central batching plant and the grout transferred in a transit mixer.

7.3 Pumps

Single and two stage Mono and piston pumps were used for grouting. These were capable of pressures of 400, 800 and 6000 kPa respectively.

7.4 Small Plant

For the most part, site fabricated mechanical packers were used. A simple screw arrangement was used to expand a heavy rubber sleeve. These were chained to the casing to prevent them being blown out under pressure. Down the hole packers were easily damaged by sharp pieces of rock and were seldom used. Pressure gauges gave continual problem due to failure of the seals in the gauge savers. The problem was never resolved and the gauges were regarded as expendable.

8 SETTLEMENT

Daily monitoring of settlement was carried out during the grouting programme and intermittent measurements made thereafter. For comparison purposes during grouting, levels were taken at two points about 15 and 30 m from the structure. For long term monitoring two points were established at a distance of 80 m from the structure. Settlement records during and after grouting are shown on Figure 3.

During initial filling in July 1978 a maximum daily movement of 5 mm was recorded. This rate dropped to about .5 mm per day after 10 days and then increased to about 1.2 mm per day 8 days after grouting had started as a result of the weight of the grout and the introduction of water. Unseasonal heavy rain, in excess of 84mm, occurred from 3rd - 6th August after several months of dry weather. On the first day run off water from the mine haul road found its way to the structure and two "sink holes" developed on the South side. An estimated 250 m^3 of water ran under the structure before diversion bunds could be erected, and the settlement rate quickly rose to an average of 2.6 mm per day.

Rates fell gradually to about 0.5 mm per day at the end of September and continued at this rate during October. In November 43,000 m^3 of fill were placed and compacted to stabilise nearby slopes, and this caused an immediate increase to about 1.5 mm per day. However, at a reference point remote from the structure, the rate rose to 13.5 mm per day indicating that the grouting had caused very substantial reductions in settlement rates.

A settlement/log time plot shows that the structure is continuing to settle at a reducing rate, somewhere in the range of 10-20 mm per log cycle. The total movement is presently about 240 mm.

9 CONCLUSIONS

Although the work took longer and used a larger quantity of grout than originally estimated, the end result would appear to have been successful. The overall cost of the work was high but nevertheless it is considered that it was still well below that of any of the options. Recent settlement records show that only a very slight movement of the structure has occurred since the grouting was completed.

10 ACKNOWLEDGEMENT

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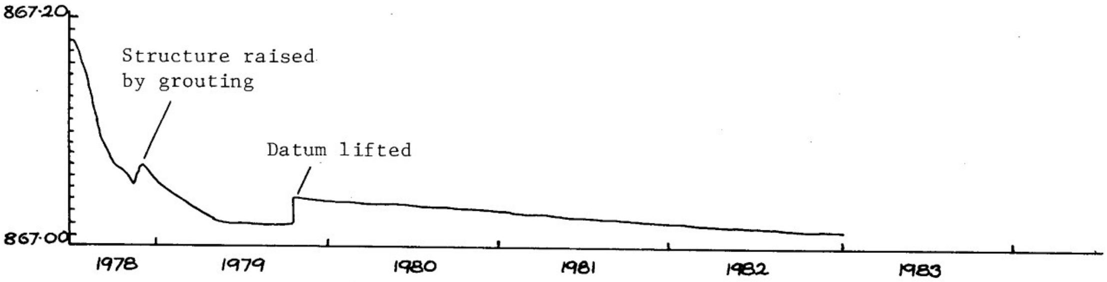

Figure 3 - Settlement plot