# The use of Temporary Soil Anchors in Service Freeport Mine Irian Jaya, Indonesia

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## Abstract

**Located in the Sudirman Mountains of the Irian Jaya province of Indonesia, the Grasberg complex (also known as the Freeport Mine) is one of the largest gold and copper mining operations in the world. The rich copper ore was discovered in the area in 1936, and the Grasberg gold-bearing ore was discovered in 1988, this deposit has the largest gold reserves and the third-largest copper reserves in the world**

**The mine site is found at 2400m above sea level whilst the ore crusher plants are located at approximately 3760m above sea level. Freeport mines 78,000 tonne of ore per day.**

**Crusher plant no 6 was installed in 1997 and crusher no 7 in 2001. The plant was designed around 27m high vertical retained earth walls, and 36 meters high operating mine dump structures, allowing 200 tonnes dump trucks to tip the mined ore into the crushers located beneath the wall base.**

**After deterioration of the existing steel faced and the metal strip of the Reinforced Earth wall structures around the crusher plant a replacement retained earth walls where proposed. To allow the demolition and reconstruction of the new walls a temporary retaining wall constructed as a soil anchored piled wall was proposed. This paper considers the requirements of temporary soil anchors to retain the piled wall, their performance and monitoring needs.**

## Existing Reinforced Earth Wall Condition

Inspection of the Reinforced Earth walls in 2002 revealed that the fill material used mine cuttings and tailings in the wall construction, combined with acid water percolating into the backfill, had led to severe deterioration of the steel facing panel and of the buried tensile members essential to the sound structural behavior of the wall.

Continual monitoring of the walls by means of inclinometers and survey indicated substantial wall displacement and therefore determined the overall stability of the wall was compromised.

The risks related to potential failure were high (200T trucks working as closely as 3 meters from the edge of the wall) and therefore the decision was taken to stop all activities around the Crusher Plant dump slabs and to install a new Reinforced Earth walls around the crusher plant.

**Photo 1 – Freeport's Grasberg Mine**

## Remedial Solution

### Design Concept

A temporary anchored piled wall 45 meters long and 23 meters high was designed to allow the demolition and rebuilding of the Reinforced Earth walls 2, 3 and 4 that support the crusher 7 dump slabs, refer figure 1. The anchored piled wall consisted of 273mm dia grouted steel piles spaced at 750mm centers, the excavated face between the piles is stablised from erosion by a shotecrete facing, refer figure 2. The wall is retained by 7 rows of soil anchors inclined at alternative angles of 10 and 15 degrees to the horizontal. The anchors were connected to the wall by means of concrete waler at the top of the piled wall and steel walers at 3m vertical centers to the piles wall face. Whilst the top row of anchors had a design working load of 600kN at 3 meters spacing, the remaining 6 rows of anchors were designed to provide working loads of 1200kN at 1.5 meters spacing.

Altogether, a total of 130 anchors were included in the design. The anchors were provided with an adequate free length to ensure that the bond length was located outside of a line drawn at 45 degrees from the toe of the wall, or for the final row of anchors a minimum free length of 5 meters was respected.

Total anchor lengths ranged from 18 to 32 meters. Bond length of the anchors were to be installed in a mixture of granular fill and mine tailings with assumed friction angle of 40 degrees.
The wall had an expected design life of 12 months.

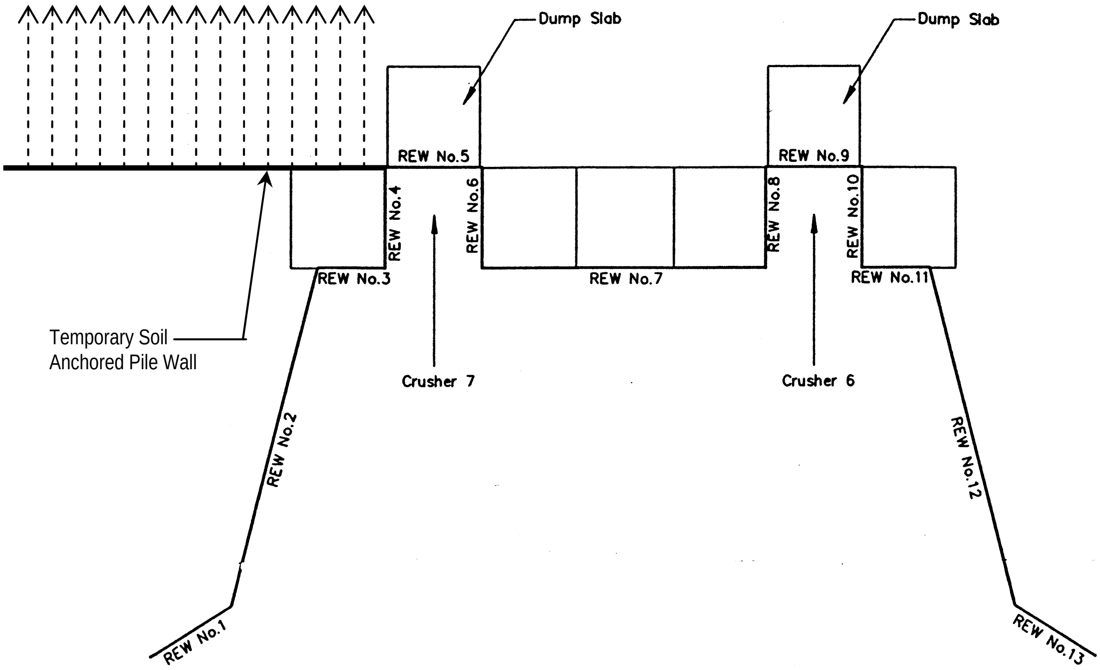


**Figure 1 Simplified plan view of Crusher Plant Wall layout**

## SBMA Concept

Due to the variable nature of the fill material and the relatively high anchor capacities, the soil anchor system, the Single Bore Multiple Anchors (SBMA) was proposed. This soil anchor system relies on the succession of small successive bond lengths rather than one unique longer bond length and has proven its effectiveness in numerous projects worldwide.

In consideration of the 12 month design life of the wall structure and the anchor founding conditions being highly aggressive due to acid ground water percolating the mine fill, the SBMA system provided additional robustness in its construction, the plastic encapsulation of the anchor free and bond lengths was seen as a significant advantage.

For the short term monitoring of the anchor it was considered acceptable to leave all anchors with long stands and uncapped, thus allowing the ability to load check and restress with simple stressing equipment rather than threaded stressing blocks and special lift off jacks. Access systems for high level anchor locations were considered using cherry picker baskets and crane support.

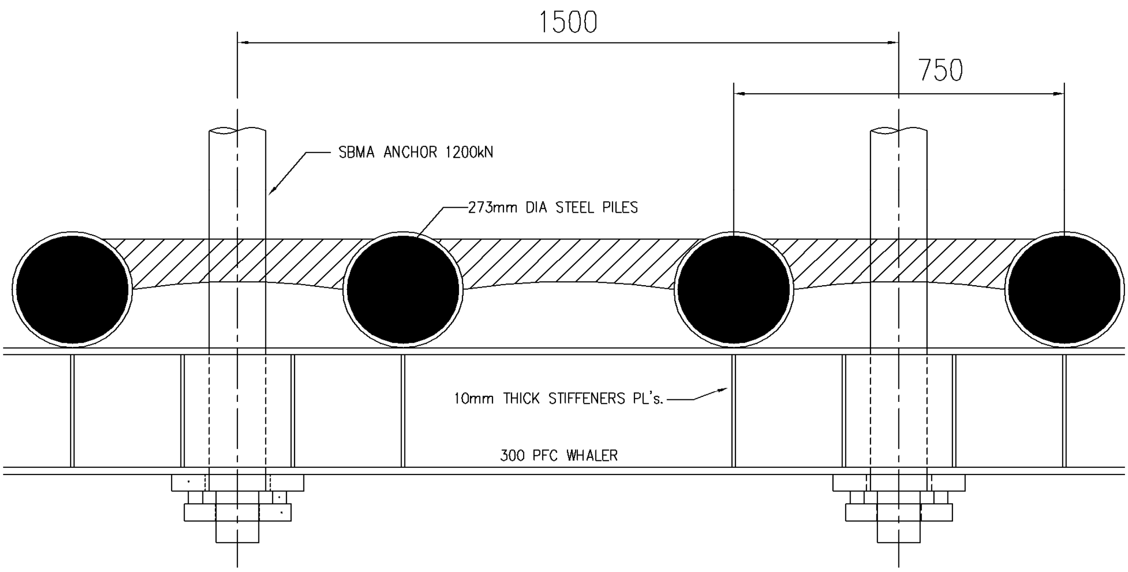


**Figure 2 Plan of Piled Wall**

The SBMA concept relies on the utilisation of successive short units, each behaving like a normal anchor but with a reduced load. The grout deformation induced by these reduced forces is thus lower which in turns reduces grout bursting and failure of the surrounding stratum. "Debonding" generally occurs progressively from the top of the anchor bond length and is due to the difference in elastic modulus between the grout and the ground. The field of displacement of these two materials being non compatible above a certain load there is therefore a strong benefit in distributing the total anchor load over a number of interfaces along the anchor bond length. Figure 3 illustrates how progressive "debonding" of a long single unit significantly reduces the total efficiency in load transfer or mobilised bond stress. However the succession of several independent short anchor units permits the mobilization of bond stress over the whole anchor bond length, resulting in a higher anchor capacity.

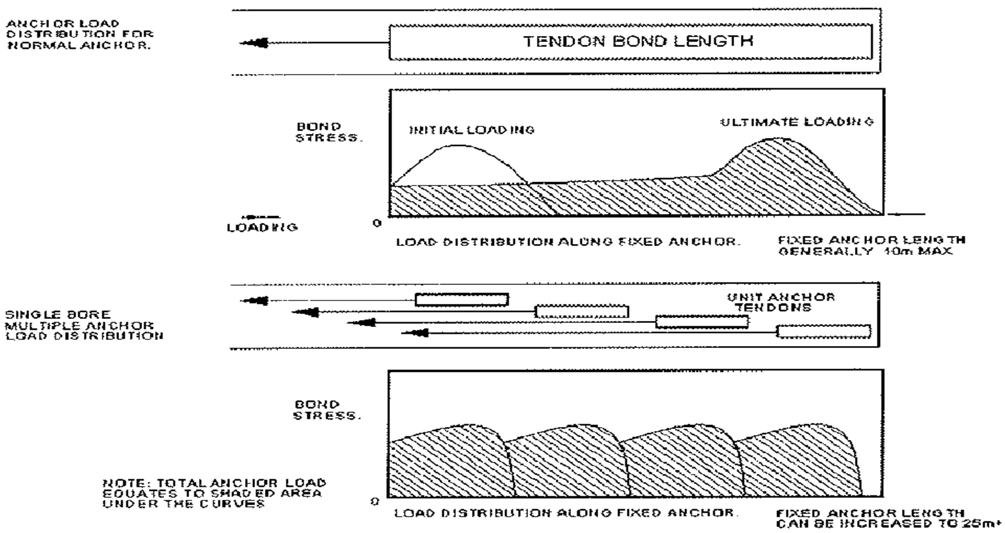


**Figure 3 Anchor Load Distribution – Conventional anchor vs SBMA**

According to multiple tests in the field and in laboratory evidence suggests that the bond stress varies with the anchor bond length according to the following relationship:

$$\tau = 1.6 * L^{-0.57} * \tau_{ult} \quad \text{(eq 1)}$$

With: L: anchor bond length

$\tau_{ult}$: ultimate bond length of a short fixed anchor (<2.3m)

**Photo 2 – Piled wall after anchor installation third row**

## Freeport's Soil Anchor proposal

Design of the production anchors was substantiated by a test anchor program which allowed an accurate estimate of the available bond shear stress at the interface of the grout and the in-situ fill material found in the bond zone. The test anchor program also included proving the drill method and the groutablility of the fill material in the anchor zone

A single anchor unit of 2.5m length was manufactured with 3 x 15.7mm dia strands given an ultimate strand capacity of 800kN, a proving test regime concluded that at a load of 600kN(.75% GUTS) no failure of the anchor unit was detected.

To accommodate project requirements SBMA anchors manufactured 3 and 6 units of 2.5 meters length which could mobilise working loads of 200kN per unit, providing the 600kN and 1200kN working load production anchors. Each unit were designed with two 15.7mm strands given an ultimate strand capacity of 560kN per unit.

The use of post-grouting system (tube-a-manchette) and end of casing grouting techniques to make provision for likely "grout-flow-away" situations as were experienced during the initial grouting trials was recommended for the production anchors. These techniques increase the maximum shear stress than can be mobilized in a given soil or fill.

### Anchor installation

Anchor installation commenced in January 2004. The anchors were installed in successive rows with maximum excavation steps of 3.5 meters. Anchors where manufactured on site, a rotary percussive drill formed a 152mm dia cased hole, anchors where installed through the casing and as the casing was withdrawn the end of casing grouting techniques where effected.

All anchors received a post grouting treatment at 24 hours after primary grouting. Acceptance anchor testing was completed 5 to 8 days after primarily grouting and after the grout strength had attained a minimum 30 Mpa compressive strength. After a complete row of anchors at a given level were installed and successfully stressed, the successive excavation to the next anchor bench could occur. Due to short term nature of the structure, anchor strand which where left long for ease of restressing were protected from surface corrosion with a grease film.

The installation of all anchors was completed within a time frame of 4 months.

**Photo 3 – Piled wall after excavation of fourth bench**

## Piled wall performance

A maximum allowable wall deflection of 50mm at the top waler beam was to be respected allowing for maximum anchor loads of 1200kN to 1420kN and maximum bending moments in the wall of 70 to 142KNm whilst the maximum axial force was 750 to 980 kN.

During anchor installation, partial excavation phase after benching and at the fully excavated condition, the wall was monitored with survey points on the capping beam and wall face and with inclinometers installed behind the wall. All survey points where recorded and related to the expected design deflections.

After completion of the wall excavation to the final level, the survey points and inclinometers where measured at 2 weekly intervals throughout the 12 month life of the wall.

The wall performed within the acceptable tolerances of the design and consequently, for all 130 no anchors, there was no requirement for subsequent load monitoring or restressing after initial anchor lock of load.

Procedures that had been developed for access to all anchor positions and the consequential safe working methods for jack handling and stressing were never implemented.

The wall was decommissioned in October 2004 after the construction of the replacement Reinforced Earth wall 2, 3 and 4.

**Photo 4 - Freeport Mine anchored piled wall to Crusher 7 Dump Slab**

## Conclusions

Temporary soil anchors used in retaining wall construction require consideration of their performance in terms of their environment and the wall stability criteria. If a detailed control of wall movements combining survey and inclinometers are engaged and the structure performs within the design limits, then the need for load monitoring can be relaxed in the short term. However, methods and procedures that will allow effective accesses to high level anchor positions for load monitoring and restressing should be provided as part of the specialist anchoring works.

The Freeport project environment and the site conditions provided demanding logistical and engineering challenges which allowed established anchoring methods and practices to be adopted in this unique location.

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## Acknowledgements

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