

The Kogai Waste Dump A Case Study of the Observational Method

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Summary This paper describes the design and development of the Kogai waste dump using the Observational Method. The Kogai waste dump is an engineered structure located at the Porgera Gold Mine in Papua New Guinea. The main objective of the paper is to demonstrate through the example of Kogai that the Observational Method is valuable to many geotechnical projects, and to mine waste dump development in particular. The case history of the Kogai dump also highlights an innovative engineering solution that has allowed construction of a stable waste dump in an adverse geotechnical environment. "Lessons learned" from using the Observational Method for construction of the Kogai dump are also summarised.

Keywords: Observational Method, mine waste dump, Papua New Guinea

1 NOTATION AND UNITS

- tpd: metric tonnes per day
- Mt: million metric tonnes
- Bt: billion metric tonnes
- M7.0: Richter scale magnitude 7.0 earthquake.
- m/yr: metres per year

2 INTRODUCTION

The Observational Method is a systematic "learn-as-you-go" procedure developed by K. Terzaghi for applied soil mechanics. When correctly applied, the Observational Method is the ideal approach for the design and construction of mine waste dumps.

Located in the highlands of Papua New Guinea (see Figure 1), the Porgera Gold Mine has designed and developed the Kogai waste dump using the Observational Method. From the project inception, the Kogai waste dump was viewed as an "engineered" structure. This approach has allowed for informed risk taking, which is a necessary element in the mining industry for maximising cost effectiveness without compromising safety. Given the extreme conditions that exist at Porgera, the Observational Method was in fact essential to the development of a large stable waste dump.

A brief history of the Kogai waste dump since its inception in 1993 is presented herein. This case history highlights the use of the Observational Method to optimise an aggressive waste dump design based on performance, thereby minimising the cost to the mine development. Uncertainties in storage requirements and design parameters have been addressed, and will continue to be refined over the life of the mine. The conclusions and "lessons learned" from the continued successful development of the Kogai dump using the Observational Method are also summarised.

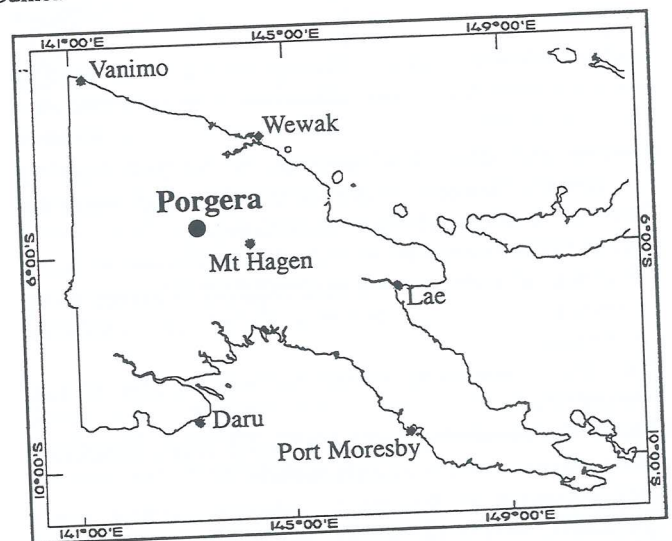


Figure 1: Location Plan

3. REVIEW OF OBSERVATIONAL METHOD

The Observational Method was well documented by R. Peck (1) as the 9th Rankine Lecture. This method is ideally suited to mine waste dump development due to the typically large foundations, where no practical amount of investigation can disclose all variations.

A brief summary of the essential steps is presented below, and has been tailored specifically for mine waste dumps:

1. Complete field, laboratory and office investigations sufficient for establishing the condition of the foundation and waste materials.
2. Assess the most probable conditions and the worst case deviations, and then determine the corresponding consequences in dump performance.
3. Establish the design of the waste dump based on the most probable conditions (a working hypothesis).

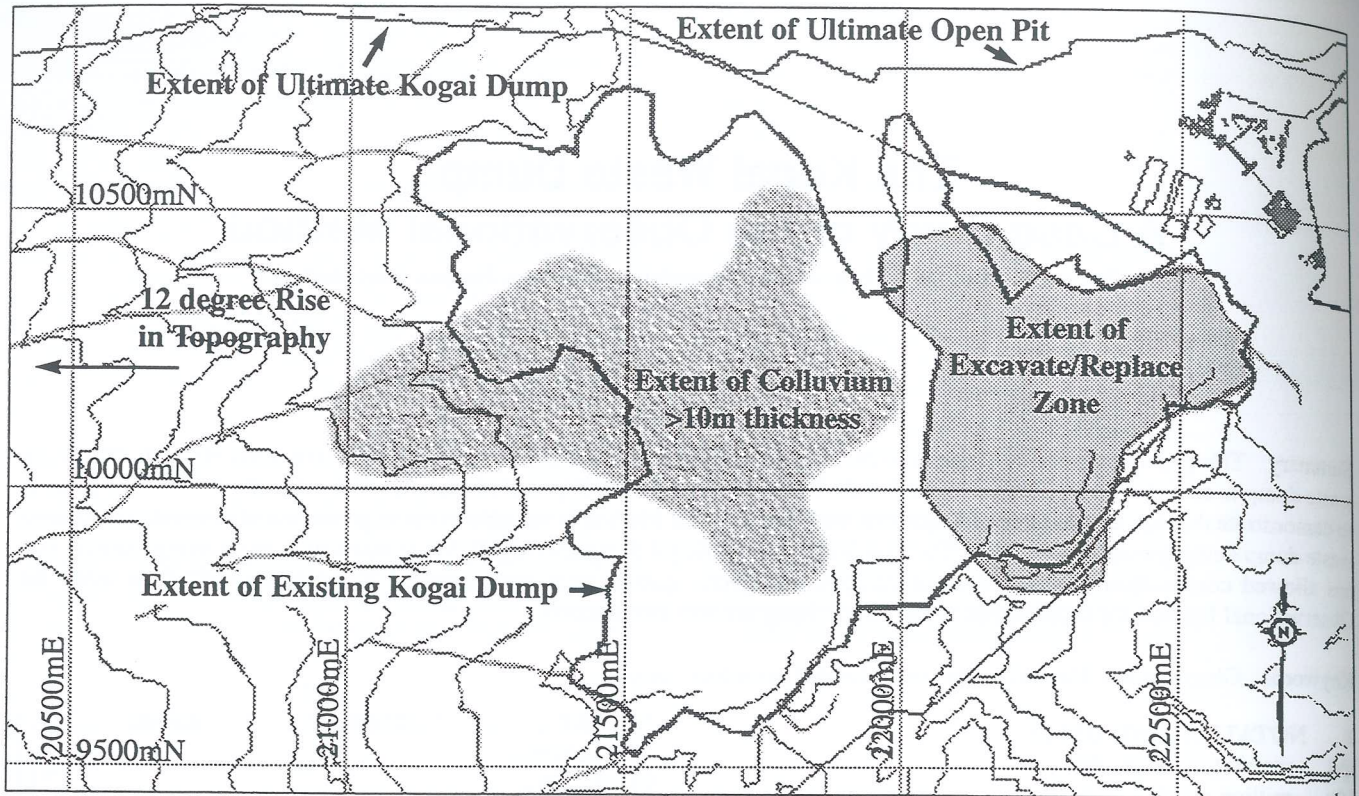


Figure 2: Kogai Dump

4. Define and select key quantities to be monitored as construction proceeds. Calculate the anticipated values for both the probable and worst case conditions.
5. As part of the design stage, identify the appropriate course of action or design modification required to handle every foreseeable serious deviation from the predicted performance.
6. Develop a monitoring system for measurement of key parameters.
7. Using the monitoring system, evaluate actual conditions during construction in a timely fashion.
8. Act according to the results collected; control waste placement, modify the design, and adjust the monitoring program as appropriate.

The above feedback loop which funnels the performance monitoring data back into design is essential to the correct application of the Observational Method. This allows the gaps in knowledge to gradually be closed, and the design modified during construction as necessary. As a result, great savings in time, money or risk reduction can be realised. The Observational Method must not be applied to a design which can't be modified during construction.

Unlike some civil engineering projects, waste dump development is typically stretched over several years of the mine life. This creates an ideal timeframe to collect data and experience to optimise the design and construction procedures, often without impacting production.

4 CASE STUDY - KOGAI WASTE DUMP

4.1 General Setting

The Porgera Gold Mine is located in the remote Enga Province, at the heart of the Papua New Guinea highlands.

Rugged limestone and sandstone peaks up to El. 4,000 m surround the Porgera valley, and active colluvium landslides blanket most of the valley floor. The peaks and colluvium slides are underlain by highly folded mudstone, which is the basal unit for the region. This complex geological setting combined with an average rainfall of over 3m/yr and recorded seismic activity of M7.0 has resulted in a very adverse geotechnical environment for mine development.

Underground mining of the Porgera gold deposit began in 1989 and development of the open pit commenced in 1991. Over the past 8 years, the open pit operation has expanded and now produces an average of 210,000tpd of waste, while the underground was decommissioned in 1997. Three waste dumps are currently used by operations, of which the Kogai stable waste dump is the primary facility for storage of competent waste material.

4.2 Investigation and Initial Design

The Kogai valley, located in the main Porgera valley, is immediately adjacent to the open pit (see Figure 2). The foundation ranges from colluvium and residual soils over 20m thick to fresh mudstone outcrops at the base of some active stream channels and local ridges. Five major creeks and associated tributaries flow through the valley. The original ground surface rises to the west at about 12 degrees.

In 1993, drilling, surface mapping, and geophysical methods were used to investigate the foundation conditions. The Observational Method was adopted, and the initial design was completed in 1994. The storage requirement of the dump, set at 160Mt over the life-of-mine (LOM), was determined from mine planning projections.

Based on the 1993 investigations, the most probable foundation conditions were ascertained and a design concept was developed. The main aspects of the design concept for Kogai were as follows:

- The colluvium would be excavated from the toe area of the dump to expose a more competent mudstone foundation.
- The dump would be constructed to abut into the ridges forming the sides of the Kogai valley, thereby maximising three-dimensional confinement.
- The dump would be constructed of competent waste only.
- The upper portion of the dump would be founded on colluvium and buttressed by the dump toe founded on mudstone.
- "Flow-through" drains of coarse, competent rock would be used to direct the creeks through the dump. An emergency southern perimeter ditch would also be included and the ultimate dump was to be graded to slope towards the perimeter channel.

Stability criteria were set at a factor of safety of 1.1 during construction, 1.3 for long term closure conditions, and less than 5m horizontal displacement under seismic loading (long term closure conditions). These criteria are lower than the conventionally used factors of safety for engineered waste dumps, which are virtually impossible to economically achieve given the combination of weak foundation materials, moderate ground slope, and slow pore pressure dissipation rates characteristic of the Porgera minesite.

The critical geotechnical parameters which governed stability of the dump were identified as follows:

- The strength of the mudstone and colluvium foundations under undrained and drained conditions.
- The thickness and extent of the colluvium.
- The dip and dip direction of bedding planes in the mudstone.
- The pore pressure response in the colluvium and the mudstone foundations.
- The level of saturation within the dump during construction and upon closure.
- The strength of the mine waste materials.

Limit equilibrium stability analyses were carried out using both the probable and worst case values for the above critical parameters. The critical mode of failure resulting in overall dump instability was shearing through the mudstone foundations in the toe buttress area. Potential mitigative actions ranged from revised dumping procedures to full cessation of dumping.

To better understand the foundation response to loading and quantify dump performance for comparison to the design intent, a monitoring program was developed and implemented. The program consisted of the following components, and is directed by the on-site senior geotechnical engineer:

- detailed mapping and point load testing of the exposed mudstone foundation after colluvium was stripped from the

toe buttress area.

- daily visual inspection of waste placement areas.
- regular full dump visual inspection, which is also required after extreme events.
- survey monuments on dump surface for movement measurement (waste and foundation together)
- inclinometers for separate measurement of movement in waste and foundation materials.
- shear strips in inclinometers after they become too warped for measurement with the inclinometer probe.
- piezometers and load cells in the foundation to measure pore pressure response due to loading.
- piezometers in the waste materials to measure the fluctuation of water within the dump, and the effectiveness of the flow through drains.

4.3 1994-1995 Construction

Construction of the access road for excavation of the colluvium in the toe area commenced in May 1994, after appropriate land negotiations were finalised. Almost 2Mt of colluvium was excavated from the toe buttress area, which was roughly 2500m² in size when completed in November 1995 (see Figure 2).

The exposed mudstone foundation was immediately mapped and backfilled with competent waste to prevent excessive weathering and strength reduction in the mudstone. This particular aspect of the development program was critical to prove the design assumption that the mudstone bedding was steeply dipping and a large-scale failure along bedding was not possible. Following external review, a second drilling program was also undertaken to assess the potential for a large deep-seated failure in the mudstone.

In accordance with the Observational Method, the initial design was re-evaluated and no design modifications were considered necessary based on the additional mudstone mapping and strength testing data.

Survey monuments, inclinometers, and load test sites in the mudstone were installed progressively as the toe buttress area was constructed. Daily visual inspections were also carried out and feedback from the monitoring program was given to the engineering and operations staff, which focused in particular on quality control of waste material type and surface water control. No serious deviations from expected performance occurred during this construction period.

A formal qualitative risk assessment was also completed in 1995 to complement the design work already completed.

4.4 1996-1997 Construction and Design Optimisation

4.4.1 1996 Design Optimisation

Due to continued exploration, the size of the open pit had substantially increased by 1996 and approximately 460Mt of competent waste storage was required (see Figure 3). The question arose whether the toe buttress founded on mudstone would have to be extended to provide the additional storage capacity.

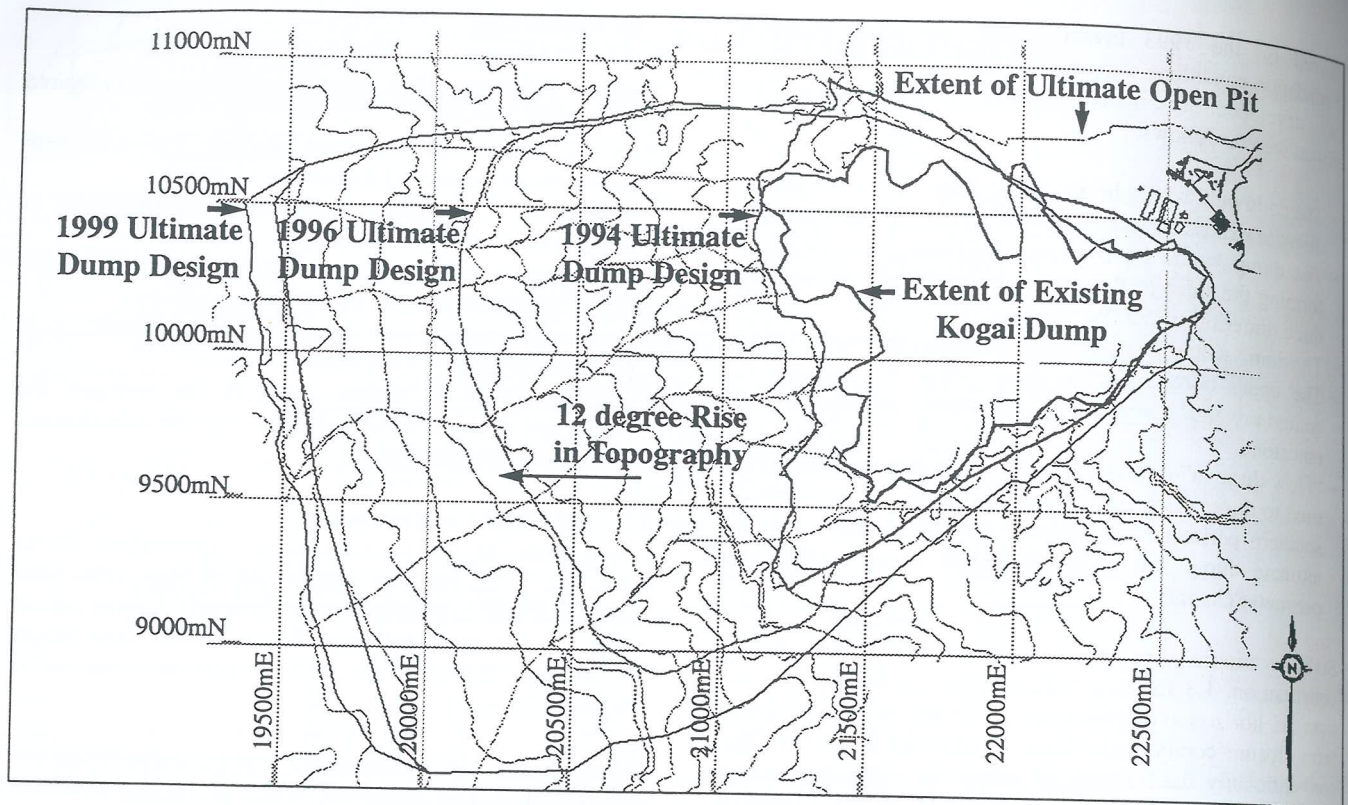


Figure 3: Kogai Dump Optimisations 1994, 1996, 1999

A conceptual optimisation of the Kogai dump was completed in 1996 using all of the investigation and monitoring data collected since construction began. The optimisation process complied with the principles of the Observational Method, and used a mixed team of on-site staff, external consultants, and academic professionals.

Many benefits were realised as a result of the optimisation based on performance data. In particular, the likely average values and ranges of the critical parameters were refined using the field performance data. Also, it was concluded on a conceptual level that the dump capacity could be expanded without additional excavation and replacement of colluvium. The latter outcome was achieved by modifying the waste dump geometry behind the design toe buttress to eliminate internal dump failure through the upper colluvium foundation.

4.4.2 1996 Construction

By the start of 1996, the excavate/replace zone was complete and waste placement directly onto a colluvium foundation commenced. Towards the end of 1996, significant deformations occurred over colluvium foundations. The movements were attributed to:

- the lack of adequate buttressing by the toe, which was underbuilt compared to design due to the presence of ore stockpiles.
- high pore pressure generation in the colluvium due to rapid loading.

Additional survey monuments were immediately installed adjacent to tension cracks to track the rate of deformation. The rate of dumping over colluvium foundations was

significantly reduced, and the toe buttress area was reinforced with additional waste placement. Dump construction proceeded normally following the above modifications.

Flaws in application of the Observational Method were evident both in lack of adequate monitoring and feedback into design modification to proactively minimise the deformations. Also, no instrumentation was installed to measure colluvium pore pressure dissipation after movements had stabilised, and post-failure documentation or back analysis was lacking.

4.5 1998-1999 Construction and Optimisation

From 1996 to 1999, the ultimate open pit had again expanded, and up to 1.1Bt of competent waste storage will be required over the LOM which will cover about 6km² (see Figure 3). For reference, the dump configuration as of mid 1999 is also shown in Figure 3.

Unlike 1996, a very detailed optimisation was undertaken in 1999. All monitoring data collected since initial construction was used to re-evaluate the critical parameters. In particular, additional data collected from dump deformations that occurred in early 1999 over the same area affected in 1996 was utilised.

With the expansion of the pit, the interaction between the pit and the dump was also evaluated. The optimisation process strictly complied with the principles of the Observational Method, and both on-site staff and external consultants were involved in the process.

The study concluded that a 1.1Bt dump was feasible, provided the excavate/replace was extended to the north. This design

modification was necessary given the deep colluvium upstream of this area. Priorities for future monitoring were identified and included additional data collection for defining pore pressure generation and dissipation in the colluvium and recording of dump saturation levels.

5 CONCLUSIONS AND "LESSONS LEARNED"

The Observational Method is the ideal approach for waste dump development: if not applied, only two options remain as stated by Terzaghi in 1915:

"...either to adopt an excessive factor of safety, or else to make assumptions in accordance with general average experience. ...The first method is wasteful; the second is dangerous."

Proper application of the Observational Method will be critical for continued safe and economic development of the Kogai engineered waste dump over the LOM. Further open pit optimisations will undoubtedly influence both the future storage requirements and the interaction between the ultimate pit and the dump.

With such adverse geotechnical conditions and low operating factors of safety for Kogai, vigilance in monitoring and design modifications can not be relaxed without incurring significant risk. Close cooperation between geotechnical engineering, mine engineering, and operations staff with full support by management is essential.

From the case study of the Kogai stable dump presented in this paper, several more general conclusions or "lessons learned" can also be gleaned. They are applicable to a wide range of geotechnical engineering projects that can benefit from the use of the Observational Method:

- Many engineers may instinctively apply several aspects of Observational Method to geotechnical projects. However, unless the observations are a part of a conscious and systematic program containing all essential steps, adverse outcomes can result. Many case histories will attest to this, where the absence of an essential step in the Observational Method has led to failure.
- When applying the Observational Method, constant stewardship by personnel fully cognisant of the design

assumptions and historical development is an absolute necessity. A gap in the continuity of this knowledge caused by staff turnover must be avoided through overlap and proper documentation. Significant risks could otherwise be incurred.

- Sufficient human and material resources for maintaining an adequate monitoring program must be available.
- The Observational Method is best used when more than one qualified engineer is involved in identifying the critical parameters, potential failure modes, and suitable monitoring program. There is no substitute for experience, making the involvement of senior engineers invaluable.

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