Laboratory Settlement Testing to determine Settling Characteristics of Fine Crushed Rock

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Summary
A major infrastructure project proposed to place crushed rock into an existing freshwater reservoir. A range of laboratory investigations was undertaken to determine settling characteristics of the crushed rock, establish TSS-turbidity relationship, assess effectiveness of flocculation and to determine the critical particle size that remains in suspension after a certain period of time. Settlement rates were ascertained from the critical particle size analysis. The tests were used to inform the numerical modelling, reference design and the Environmental Impact Statement for the project. The suite of tests could be amended to inform design and environmental assessment of dredging, sea disposal and land reclamation projects.

Keywords: Reclamation, dredging, turbidity, working with nature.

Introduction

A major infrastructure project currently under construction in Australia proposed the excavation of tunnels and underground caverns, which were to be excavated using a combination of Tunnel Boring Machines (TBMs) and drill and blast (D&B) techniques. A significant quantity of surplus spoil will be produced by the underground excavations.

During preparation of the reference design and Environmental Impact Statement (EIS), a number of options to dispose of the crushed rock were considered, including subaqueous placement below minimum operating level within the two existing freshwater reservoirs. The preferred disposal option was further developed during the detailed design phase of the project.

To inform the reference design and EIS, a number of laboratory-based investigations were undertaken to assess the settling performance of fine crushed samples of rock that would be encountered from nine different geological formations.

Outcomes from these investigations were used to inform numerical modelling of the fate of fine crushed rock placed in the reservoirs. The tests also informed the reference design and EIS.

Scope of Investigation

The scope of work for the laboratory investigations comprised four detailed tests which were undertaken for each geological formation, including:

1. Column test to establish TSS-turbidity relationship, based on recommendations outlined in the US Army Corps of Engineers guidelines “Improved Methods for Correlating Turbidity and Suspended Solids for Monitoring” [1]. The column test were undertaken using large settling columns to minimise the ‘wall effects’ of the column sides on settling behaviour. The settling columns had a diameter of 200mm and an overall height of 2000 mm.

2. Settlement test to determine the settling behaviour of crushed rock. Surface placement and placement of crushed rock through a fall pipe were considered. The test was undertaken in large settling column. The fall pipe was 75mm diameter with the end of the fall pipe typically 500mm below the water surface. However, alternate configurations were also trialled.

3. Flocculation trial to assess whether a chemical flocculant would assist (accelerate) settling performance.

4. Critical particle size analysis to determine the maximum particle size remaining in suspension. The test was undertaken in 1L glass cylinders with samples extracted using a pipette. Particle size was determined using the Mastersizer 2000, which uses a laser to determine the size of particles in a dispersant (fluid).

All tests were undertaken using water from the proposed reservoir. The geological formations were crushed using a ring mill. The sample was sieved using a 250μm sieve screen and split into sub samples using a riffle splitter box. The quantity of sediment in each test varied between 47.5g (column test) and 5g (critical particle size analysis).

Results

Following completion of the laboratory tests, the following was concluded:

1. Once fine crushed rock enters the water column, a portion of the finer particles remain in suspension for extended periods, in the order of several weeks (possibly longer).

2. TSS-turbidity correlations for the geological formations were similar for most samples and turbidity equivalent to a TSS concentration of 50mg/L varied between 43 NTU (Nephelometric Turbidity Units) and 68 NTU as shown in Figure 1. Crushed rock was generally light grey, with the exception of Test 6, which comprised orange-red crushed rock. Resultant turbidity equivalent to a TSS concentration of 50mg/L was 102 NTU for this sample.

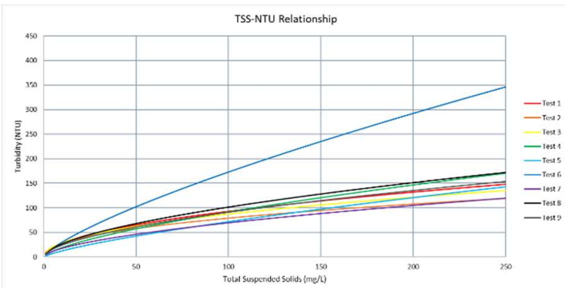

Figure 1: Trendline of best fit through datasets - Power Function.

3. The flocculation trial indicated that alum (aluminium sulfate) is effective in clarifying the water and reducing turbidity in the water column. It should be noted that the particular chemical flocculant selected for the test was somewhat arbitrary and it was not proposed for use during placement of rock in the reservoirs.

4. After 15 minutes, the maximum particle size in suspension varied between 15μm to 37μm reducing to 2.5μm to 6μm after 24 hours. As expected, the particle size distribution was coarser at depth. An example from a geological formation (Test 8) is shown in Figure 2.

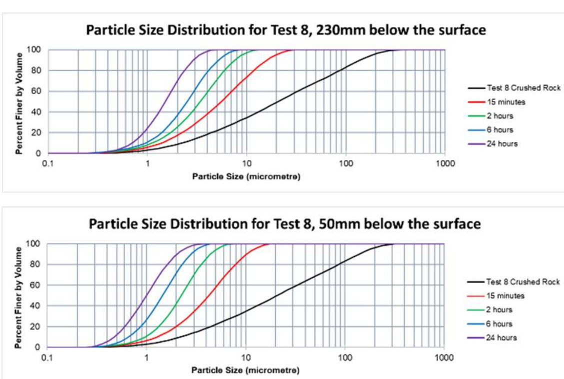

Figure 2: Particle size distribution with varying depth from the water surface.

5. Settling velocities determined from the critical particle size analysis were slower than those predicted by Stokes Law as shown in Figure 3. There are a number of assumptions that underpin Stokes Law, which do not always hold true for the settlement of particles.

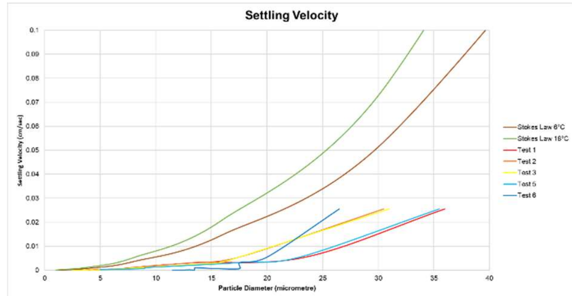

Figure 3: Settling velocity calculated from the critical particle size analysis.

Additional testing on the sensitivity of key parameters was conducted on crushed rock from a single geological formation. Key findings from the sensitivity testing were that settlement performance is sensitive to:

1. The length of a fall pipe, with longer fall pipes resulting in significantly lower surface turbidity levels; and,

2. Temperature fluctuations, where a variation in water temperature was observed to result in an increase in surface turbidity. The increase in surface turbidity is hypothesized to be a result of convection currents within the settling columns.

Conclusion

Seawater, encountered in most dredging and reclamation projects, is a natural flocculant. A supplementary test was undertaken to assess settlement characteristics of crushed rock in seawater. Compared to freshwater, seawater resulted in lower TSS remaining within the water column after placement of crushed rock.

The suite of tests could be amended to inform design and environmental assessment of dredging, sea disposal and land reclamation projects particularly where similar excavation methods (i.e. drill and blast or cutter heads) are required.

References

[1] Thackston, E.L. and Palermo M.R, (2000), Improved methods for the correlation of turbidity and suspended solids for monitoring, DOER Technical Notes Collection (ENDC TN-DOER-E8), U.S. Army Research and Development Centre, Vicksburg, MS.