THE EFFECTIVENESS OF AN IMPACT ROLLER ON ALLUVIAL SANDY CLAYS[1]

T.R. Nash
4DGeotechcnics, Perth, WA

ABSTRACT

A new heavy haul railway embankment in the Pilbara region of Western Australia traversed an alluvial floodplain deposit that displayed sufficient dry strength but inadequate soil strength when saturated. The use of conventional ground improvement techniques for the design and construction of the embankment was assessed against the use of a dynamic impact roller. An impact roller trial was conducted to assess its effectiveness at increasing the soil density with the premise that an increase in density would increase the saturated strength of the soil. Trial results indicated that the impact roller generally increased the soil density to a depth of approximately 1m. However, when saturated, the strength of the modified soil remained unacceptably low as a heavy haul railway embankment foundation subgrade.

1 INTRODUCTION

During geotechnical investigations for a new heavy haul railway in the Pilbara region of Western Australia, alluvial soils associated with the Robe River floodplain were identified as being problematic as a rail embankment subgrade. In particular, a loss of strength with an increase of moisture conditions above natural levels was regarded as a significant issue with respect to embankment foundation preparation and design. Of the 46km of new rail embankment required for the project, approximately 14 km traversed these problematic fine alluvial deposits. Initial laboratory testing of this material indicated a fine grained sandy clay with a relatively high void ratio, collapse potential and a significant order of magnitude reduction in strength and bearing capacity when saturated.

During the project's feasibility stage without the aid of laboratory testing or sub surface information, 'remove and replace' ground improvement was assigned to sections of rail over the floodplain material in order to obtain an earthworks cost estimate. Following detailed investigations of the floodplain deposits, it was clear that these materials displayed high soil strengths at natural moisture levels (dry) with a substantial loss of strength when saturated (wet). This adverse soil behaviour combined with the cost of the ground improvement methods originally proposed for the 14 km of floodplain deposits lead to a reassessment of possible ground remediation options. In reviewing alternative ground improvement options, the use of a square impact roller was considered as a potential cost effective and appropriate solution to improve embankment foundation conditions. As impact rolling had not been utilised for this purpose on Pilbara rail projects in this soil type in the past to the best of our knowledge, and given the importance of maintaining rail operability, a detailed field impact roller trial was undertaken to determine the application's suitability.

This brief paper presents the geological context and composition of the floodplain deposits, provides details of the impact roller field trial and presents the trial results with a discussion on the expected versus actual results.

2 PROBLEMATIC SOIL AND BEHAVIOUR

2.1 GEOLOGICAL SETTING

Superficial floodplain deposits under review occur adjacent and generally parallel to the Robe River - a major drainage comprising a relatively narrow and well-defined channel (or several anastomosing channels) in the western Pilbara's Ashburton Plain. The Robe River headwaters are located in the Hamersley Ranges with the river draining in a westerly direction (Commander, 1994). The river is typical of major Pilbara river systems which generally only carry significant flows in response to cyclonic rainfall.

Geotechnical field investigations have confirmed a general geological profile of up to 15 m of coarse gravels and cobbles occupying the main river channel with finer sand, silt and clay overbank deposits becoming dominant distal to the main channel. The floodplain deposits were found to be up to 6 m thick in places but are typically 2-3 m thick at the site, overlying 2-3 m of cemented gravel, and form gently sloping to flat plains traversed by

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[1] This paper was presented at the 2010 Baden Clegg Award

second and third order streams which are subject to periodic inundation. The floodplain deposits can be weakly iron or calcite cemented and are interbedded with minor gravel lenses. Underlying the floodplain soils and cemented gravel is the Ashburton Formation basement rock comprising indurated quartz-mica schists (Williams, 1968). Patchy Gilgai deposits (expansive clays) are also found within the floodplain and rail corridor; Gilgai and other surficial deposits are not assessed in this paper.

2.2 FLOODPLAIN SOILS

Laboratory testing and field classification generally identify the unsaturated floodplain deposits as a sandy clay (CL-CI), low to medium plasticity, red and brown, sand (35-50%) poorly graded fine grained, brown and red in colour, dry, very stiff to hard and alluvial in origin. Natural moisture contents are around 7-9% with a degree of saturation between 25% and 35% and void ratios between 0.7 and 0.8. *In situ* soil strengths are variable but generally very stiff to hard based on SPT values of 30-35. *In situ* density is around 1.6-1.8t/m^3, equivalent to density ratios of between 70 and 80 based on an average maximum modified dry density (MMDD) of 2.1 t/ m^3 (average OMC 13%). Laboratory CBR values of between 25-30% with the 4-day soaked CBR values reducing to less than 5% and as low as 2% at *in situ* densities (CBR values increasing slightly on tests done with increased compactive effort). Dynamic cone penetrometer tests (DCP) show a similar reduction from 5-6 mm/blow to >50 mm/blow when saturated. Soil collapse potential tests following ASTM D5333 on undisturbed push tube samples gave values between 2-9% with the majority around 5% which classifies the soil as 'trouble' to 'severe trouble' after Jennings and Knight (1975).

The Pilbara is a semi arid region with annual evaporation well in excess of annual rainfall and consequently for most of the year the floodplain materials are considered dry and display relatively high soil strengths. Periodically, cyclonic events and tropical lows produce localised intense rainfall events which may result in the Robe River flooding and inundating the adjacent floodplains. This inundation rapidly increases the moisture content of the floodplain deposits causing a dramatic loss of strength; it is this soil behaviour that controls the embankment foundation design. The soil characteristics and observed behaviour when wet are considered unsuitable as a heavy-haul railway embankment foundation.

A hypothesis was developed inferring that an increase in the floodplain soil density using an impact roller would remove the potential for volume change when wet and possibly increase the wet (saturated) soil strength. Additionally, the use of an impact roller would 'treat' the ground more efficiently and to greater depths than conventional compaction equipment. A trial to test this hypothesis was proposed.

3 TRIAL SETUP AND METHODOLOGY

The main objectives of the impact roller trial were to assess the vertical extent of the ground improvement achieved, impact roller operability, the optimum number of impact roller passes to achieve the maximum density, and to assess the improvement in field soil strengths after ground treatment.

Two trial areas with dimensions of 260 m x 50 m were established parallel to the rail alignment (T1 and T2). The trial locations were based on the close proximity to existing sub-surface geotechnical investigations and material that best represented the floodplain deposits. These two areas were further divided into three 60 m x 30 m cells (cell A - CA, cell B - CB and cell C - CC) each with a 20 m zone at either end to allow for impact roller manoeuvring between passes (Figure 1). Each cell was then prepared in a different manner: CA was ripped and watered, CB was ripped but no water was added throughout the trial and CC was the control cell with no ripping or water added. Baseline soil conditions for each cell were determined and included precise survey of the ground surface elevation, excavation of test pits to classify the soil and density profiling using the Nuclear Moisture-Density Method (NDM) and Dynamic Cone Penetrometer tests (DCP) at various depths. Water was added to cell CA at the start and throughout the trial using a 16 wheel water cart; the quantity of water added was not recorded.

The impact roller used in the trial was a BH-1300MS Square Impact Roller with a gross impact weight of 8.5 tonnes and an impact footprint of 1.3 m towed by a John Deere 8760 tractor. The roller was towed between 8 and 10 kph in a clockwise direction with a nominal 10% overlap of the impact weight. After three passes, the roller was moved to the adjacent cell to allow for surface surveying. Grading after 3 passes was also required to maintain a smooth working platform for the impact roller. Although the purpose of the grading was to remove local irregularities from the surface of each cell, this arguably influenced the surveying results as discussed later. A water cart was used to apply water to cell CA after every 3 passes of the impact roller. This entire process was repeated for a total of 24 passes.

Precise surface levelling of each cell was achieved using a Leica TCRA 1201 total station set up on a single station and using the same backsight to achieve the required vertical accuracy (0.005 m) and repeatability. The surface of each cell was baseline surveyed on a 10.0 m x 10.0 m grid pattern then surveyed after 3, 6, 9, 12, 18 and 24 passes prior to grading. Surveying required approximately 30 minutes which allowed enough time for the required light grade before the next three passes from the impact roller. This method resulted in a smooth continuous trial without interruption.

A Digital Terrane Model (DTM) was created from the 10.0m survey grid. To determine the height difference between each compacted stage, the volume between the staged surface DTM and the base surface DTM was divided by the cell area which was fixed for each volume computation. The average height of the compacted cell surface at any one of the compaction stages could then be compared to the baseline surface.

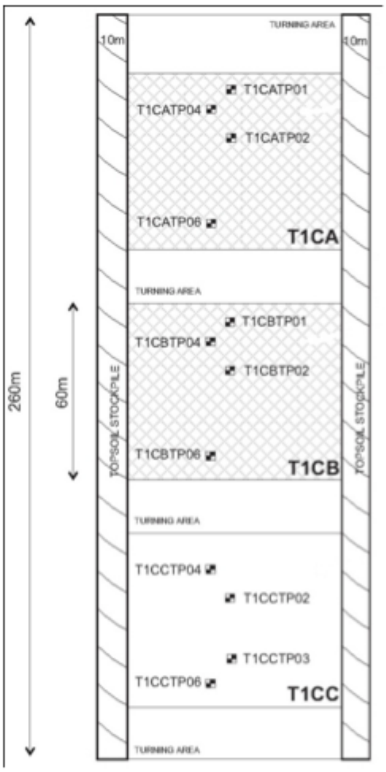

Figure 1: Field trial area layout for Trial Area 1. CA ripped and watered; CB ripped no water added; CC control cell no ripping or water added. Squares show excavated test pit and NDM testing locations.

Changes to the vertical soil density profile were measured via NDM tests to AS1289.5.8.1 using a Troxler Nuclear Surface Moisture-Density Gauge Model 20147 and, to a limited extent DCP testing to AS1289.6.3.2. Baseline NDM tests were conducted at 20.0 m centres down the middle of each cell establishing two vertical baseline density profiles per cell. NDM tests were performed at the surface, at 0.5 m and at 1.0 m depths as test pits were excavated (Figure 1) with care not to disturb the soil mass at the base of the test pit. After 24 passes of the impact roller, NDM tests were repeated adjacent to the initial test pits to assess the change in density as a result of impact rolling.

At the conclusion of the trial earth containment bunds were constructed with dimensions 4.0 m x 4.0 m x 0.2 m, filled with water and left for 24 hours after which test pits were excavated in the soaked areas to assess the extent of the vertical and horizontal water penetration. DCP tests were also carried out from the surface of the soaked areas to compare with the dry post-compaction results.

4 TRIAL RESULTS AND DISCUSSION

Surface levels for each cell after successive passes and relative to the baseline are shown graphically in Figure 2. As expected cells CA and CB show an initial increase in surface level due to ripping while the unripped cell CC showed an immediate reduction in surface level below baseline levels. Ripped and watered cells (CA) took between 10 and 15 passes to reduce to the baseline surface elevation after which they record a final level of between approximately 10 mm and 20 mm below baseline levels. Cell CB displayed a similar pattern to cells CA and recorded a similar final surface level of between approximately 10 mm and 25 mm. However, less passes were required to reach initial surface level of between 7 and 12 passes. Cell CC recorded a final surface of between 30 mm and 40 mm below the baseline level. Survey data also indicated that the majority of the settlement was achieved with 18 passes of the impact roller.

Settlement surveys recorded total reductions in surface elevation after 24 passes with the impact roller of between 10 mm and 40 mm. Overall, the generation of fine bulldust without the addition of water made it difficult to accurately assess surface settlements while accurate measurements could be obtained for these soils when conditioned throughout the trial. Although cell CC (not ripped or watered) for both trial areas showed the greatest decrease in surface level, the process of grading after 3 passes and the generation of the fine dust layer up to 0.5 m thick from the impact rolling are thought to have influenced the results. Settlements recorded for cell CC are therefore considered apparent settlements and may not reflect the actual reduction in volume. The development of a crust with the addition of water during the trial for cell CA increased the accuracy of settlement measurements as no bulldust was generated.

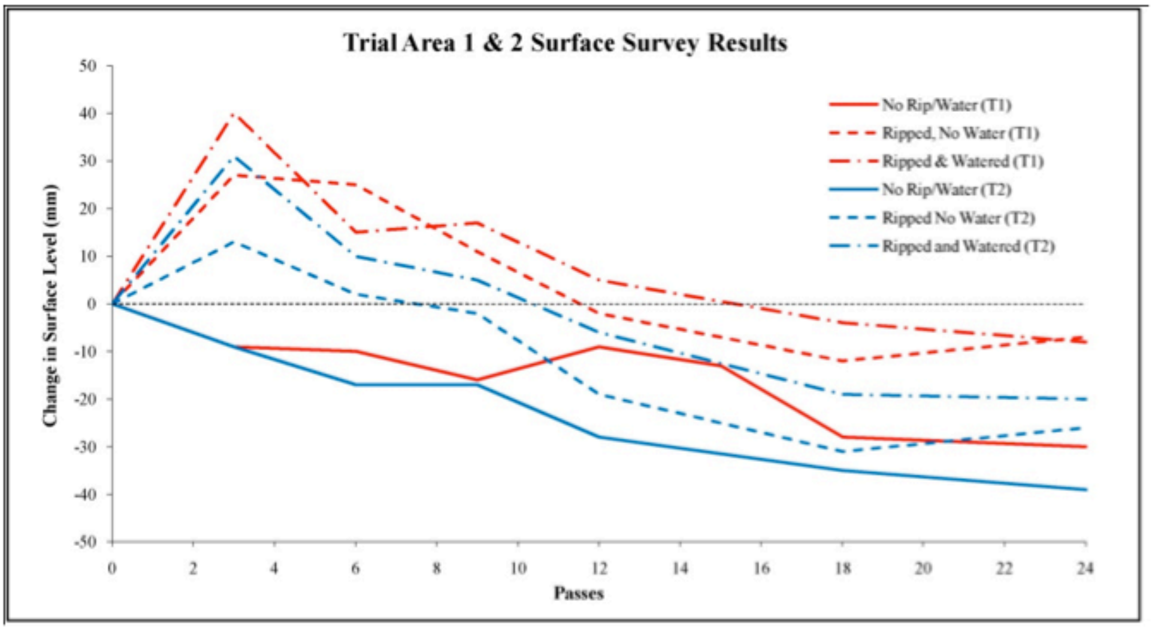

Figure 2: Recorded surface settlements for T1 and T2. Horizontal dotted line represents the baseline surface level.

NDM density ratio results obtained at 0.0, 0.5 and 1.0 m depth intervals relative to laboratory MMDD values for 0 and 24 passes for T1 and T2 are presented graphically in Figure 3. The density ratios presented are the average of two vertical density profiles conducted per cell.

T1 baseline NDM densities show a general increase in density with depth. Ripping with water applied throughout the trial shows the greatest increase in density after 24 passes while the control cell with no ripping or added water shows a negligible increase after 24 passes. The ripped cell with no water added throughout the trial shows an increase in density after 24 passes but not as significant as cell CA.

T2 baseline NDM density readings are somewhat mixed showing a drop in the *in situ* density from surface to 0.5 m depth then stabilising or increasing to 1.0 m depth. The control cell CC shows a large increase in density from 0.5 m depth after 24 passes but a slight decrease at the surface after 24 passes which may be attributed to disturbance at the surface by the impact roller process. Cell CB results from Figure 3 also show a shift to the right and arguably a more uniform density profile to 1.0 m depth. CA shows the largest increase in density ratio at the surface with slight increases in density from 0.5 m depths. The large increase at the surface is attributed to the formation of a surface crust between 50mm and 100 mm thick that formed during the trial.

NDM tests used to identify changes in density with depth were generally successful at measuring changes. However, care is required to not disturb the ground when excavating to the test depths. This may account for inconsistencies in density readings particularly for TA2. As far as possible NDM tests were conducted on ground which was deemed to be undisturbed.

Test pits excavated into the soaked areas on improved ground after 24 impact roller passes indicated that the visible vertical saturation fronts were quite uniform in all three cells ranging in depth from 0.35 m to 0.45 m after 24 hours. Horizontal seepage outside of the soaked areas was negligible.

Few DCP results were available for assessing changes in soil strength. Where tested on *in situ* soil at natural moisture contents, most encountered refusal at less than 0.25 m depth requiring >50 blows to achieve this depth. DCP tests conducted in the soaked areas (post impact rolling) recorded 25 mm to 50 mm per blow to about 150 mm depth then increasing to refusal generally just beyond the saturation front. DCP testing was not a practical method to assess changes to soil strength in this material due to the apparatus limitations when used on very stiff soils, but was effective at indicating the significant loss of modified soil strengths at elevated moisture contents.

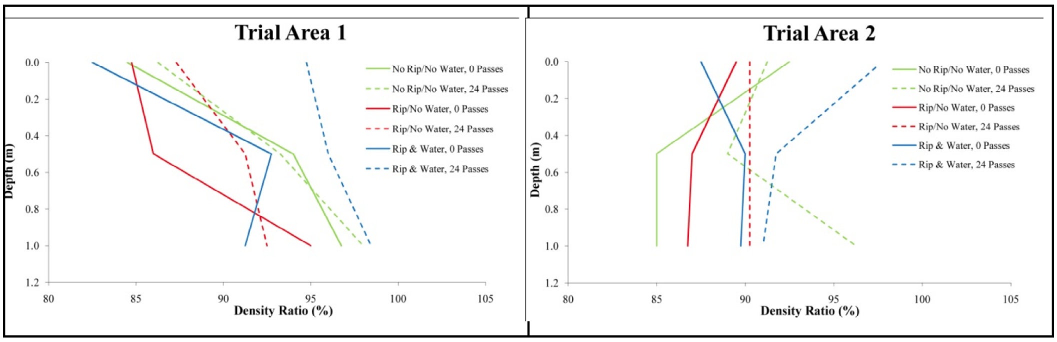

Figure 3: NDM measurements from surface, 0.0 m, 0.5 m and 1.0 m depths for T1 and T2 (Ripped and watered = CA; Ripped, no water added = CB; No ripping, no water added = CC).

5 CONCLUSIONS

The impact roller was generally successful at increasing density ratios to at least 1 m with most types of prepared soil and arguably produced a more uniform density profile with depth. Conditioning the soil through deep ripping with the application of water between impact rolling passes was the most effective method to produce the greatest increase in density. Precise surface surveying was effective in tracking changes to surface levels in ripped and watered ground where a 'crust' could form but is not considered effective when excessive dust is generated. NDM tests used to track changes in density ratio was effective however care is required not to disturb the soil mass during excavations to allow testing at depth. Ground improvement by increasing the density with an impact roller did not significantly improve the saturated soil strength as shown by DCP tests in the saturated floodplain material after 24 passes with the impact roller. This is also confirmed by the soaked CBR results which indicated a significant loss of soil strength when wet.

Ultimately for this project, the trial outlined the fact that by remoulding floodplain materials and applying compactive energy by way of the BH-1300MS Square Impact Roller, the saturated soil strengths were not improved sufficiently to warrant use of this method. Given the proximity to the Robe River, the embankment will be subject to inundation during flood events therefore limiting moisture access into the foundation material was considered to be the critical aspect for foundation design. The ultimate foundation concept adopted for the rail embankment over floodplain soils followed the principals of Emery, Masterson and Caplehorn (2003) for pavement design which was essentially maintaining soil strengths by keeping the subgrade in a dry state. For this rail project, final foundation preparation involved removal of the subgrade to a vertical depth of 0.3 m beneath the embankment footprint and 4.0 m beyond the toe, and replacement with a locally sourced engineered fill of low permeability. Good drainage was also required in the hydrological design to minimise the time floodwater stands against the embankment. This design has to date been successfully implemented with trains actively operating.

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