CONVERTING UNCONTROLLED FILL SITES INTO CONTROLLED ENGINEERED FILLS THROUGH RAPID, COST-EFFECTIVE, AND QUANTIFIABLE IMPACT ROLLING

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ABSTRACT

Uncontrolled fill sites pose significant geotechnical challenges for future development due to uncertain material quality, compaction, and load-bearing capacity. Converting these sites into reliable, controlled engineered fills is essential to ensure structural performance and reduce long-term settlement or failure risks. This paper presents the use of Impact Rolling as a fast, cost-effective, and quantifiable ground improvement technique for reworking and validating uncontrolled fills and significantly increasing the value of the development site.

Impact Rolling applies high-energy, non-circular dynamic loads to the ground, promoting deep compaction and densification well beyond the reach of conventional rollers. It is particularly suited for heterogeneous fill materials, where traditional compaction methods may be ineffective. By integrating real-time Intelligent Compaction Measurement and in-situ validation tools such as the crawler based Dynamic Probing Super Heavy (DPSH) and portable Variable Energy Dynamic Cone Penetrometer (VEDP) strength profile and compaction control capability, site improvement is not only achieved but verified with quantifiable data.

A case study is presented to illustrate the transformation of problematic fill sites into compliant platforms suitable for construction or infrastructure use. Results highlight the method's ability to improve ground stiffness, reduce voids, and demonstrate uniformity—reducing the need for costly excavation and replacement. This approach offers a practical, low-risk solution for developers and engineers dealing with legacy or undocumented fill conditions.

Keywords: **Impact rolling, uncontrolled fill, controlled engineered fill, compaction control, land development, ground improvement, dynamic probing**

Introduction

Uncontrolled fill materials are often heterogeneous, poorly compacted, and typically contain a mix of material at variable moisture contents. These characteristics make them unsuitable for supporting structures without significant risk of differential settlement or structural failure. Conventional approaches such as full excavation and replacement or deep foundation systems are expensive and time-consuming. Impact Rolling offers a viable alternative for improving the engineering properties of such materials in place. By integrating real-time Intelligent Compaction Measurement and in-situ validation tools such as the Dynamic Probing Super Heavy (DPSH) and portable Variable Energy Dynamic Penetrometer (VEDP), strength profile and compaction control capability, site improvement is not only achieved but verified with quantifiable data.

What is Uncontrolled Fill

In-situ uncontrolled fills are deposits of soil or other materials that have been placed without engineering oversight or control and in some cases materials that have been placed with engineering oversight or control, but records are missing or not available. These fills can vary widely in their composition, including a mix of clay, silt, sand, gravel, or even waste materials, often with differing degrees of compaction, moisture content, and suitability for construction. A waste material example is demolition waste which could include concrete, brick, asphalt, and metals. The absence of compaction control during placement often results in uneven density and inconsistent engineering properties across the fill.

Such variability and unpredictability pose risks for construction projects, including differential settlement, poor load-bearing capacity, and increased susceptibility to erosion or liquefaction.

Conventional Approach to Uncontrolled Fill Sites

A conventional approach for converting uncontrolled fill sites into engineered fill sites typically involves excavation, replacement, and controlled compaction. The key steps include:

1. Excavation and Removal

   All existing uncontrolled fill is removed, especially if it's of unknown quality, poorly compacted, or contains unsuitable materials (e.g., debris, organics, or contaminants). Excavation often proceeds down to natural ground or competent material. In some cases, a relatively shallow 1-2m depth could be left in place for impact rolling and validation.

2. Site Assessment and Subgrade Preparation

   The exposed subgrade is inspected, tested (e.g., Dynamic Cone Penetrometer (DCP), Variable Energy Dynamic Penetrometer (VEDP) or Dynamic Probing Super Heavy (DPSH) instrumented penetrometers, Plate Load Testing) and, if necessary, stabilised or proof rolled. Groundwater and drainage conditions are managed to ensure stability.

3. Placement of Engineered Fill

   Clean, site won or imported material is placed in controlled lifts (typically 200–300 mm thick). Each lift is compacted using appropriate equipment (e.g., padfoot roller) to specified densities (typically 95% or 98% Standard Proctor).

4. Quality Assurance Testing

   In-situ density tests (nuclear gauge, or in some cases sand cone) are typically carried out. Geotechnical supervision and testing ensure fill meets design specifications. A proof roll may be carried out using a roller or other construction plant at nominated layers in some cases.

While effective, this process is time-consuming, costly, and generates significant waste and haulage, as well as noise and dust.

An Alternative Approach – Impact Rolling

Impact Rolling is increasingly favoured as a faster, more cost effective and sustainable alternative to the conventional remove and replace approach. Although not a new technique, Impact Rolling (Figure 1) has gained traction because of the emerging abilities to easily quantify improvement. By integrating real-time Intelligent Compaction Measurement on the Impact Rollers and in-situ validation tools with strength profile and compaction control capability, site improvement is achieved and verified with quantifiable data. Areas of differential response during rolling can identify soft spots or buried obstructions, which can then be targeted for additional treatment.



Figure 1 - Impact Roller (Landpac)

Principle of Impact Rolling (High Energy Impact Compaction - HEIC)

Impact rolling is a ground improvement technique that utilizes a heavy, non-circular 3,4 or 5 sided steel roller to compact soil by repeatedly impacting the ground at high speed, as shown in Figure 2. Impact Rollers are typically towed behind a heavy tractor at speeds of 10 – 16 km/h. The geometry of the roller induces a series of high-energy, vertical impacts as it rotates, transmitting dynamic loads deep into the ground. This process densifies the soil to depths from 1.5m to 4m, depending on the material and moisture condition and whether the material is pre-existing fill or freshly placed. A typical impact rolling process slow is shown in Figure 3.

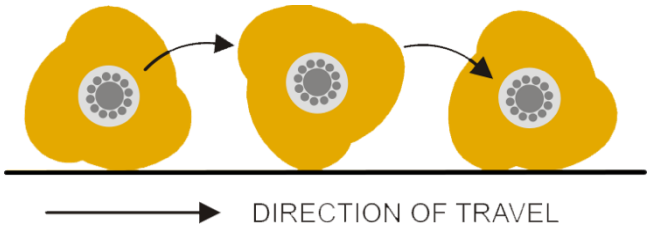


Figure 2 - Schematic of the Impact Rolling Concept

Site characterisation is a critical step in assessing suitability for impact rolling. Often, review of existing geotechnical data is sufficient. However, in some cases, intrusive testing (test pits, boreholes, DCP or instrumented penetrometers such as portable VEDP or the more robust crawler-based DPSH rigs) and laboratory testing are valuable in characterising materials and insitu density and moisture conditions. Field moisture content in relation to Standard Optimum Moisture Content (SOMC) is an important consideration as a guide to roller effectiveness. There can be limitations to the effectiveness of impact rolling and long-term fill performance if insitu moisture content is significantly outside the accepted range for controlled fill. This particularly applies to cohesive fill with higher moisture contents.

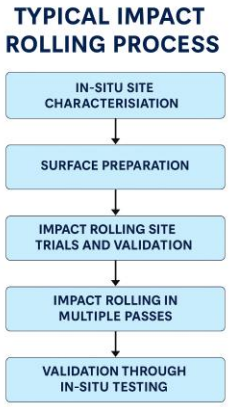


Figure 3 - Typical Impact Rolling Process Flow

Trials and their validation are often prudent and can include review of impact roller induced settlement heat maps and penetration tests using VEDP or heavier duty DPSH instrumented penetrometers. With included compaction interpretation software, VEDP and DPSH resistance plots enable a continuous Standard or Modified compaction profile over the depth of testing. Checks of VEDP or DPSH cone resistance with co-located nuclear densometer tests allows calibration with software compaction interpretation.

Final validation testing after impact rolling can be achieved using the same methodology used for trials, but on a grid assessed to provide appropriate statistical coverage.

Benefits of Impact Rolling for Uncontrolled Fill Sites

Impact Rolling is a cost-effective alternative to excavating and replacing unsuitable material.

- Rapid: Large areas and deeper layers can be treated in a short time compared to traditional excavation. The programme for the ground improvement works will be reduced.
- Reduced Disturbance: Contaminated material does not necessarily need to be disposed of offsite. It can be treated insitu.
- Cost-Effective: Significantly reduces the need for excavation, disposal, and importation of select fill.
- Quantifiable: Real-time data acquisition from roller response and follow-up full depth insitu testing allows for measurable quality assurance.
- Sustainable: Re-uses on-site material, reducing carbon footprint and transport-related impacts.

Case Study - Industrial Subdivision, Former Backfilled Quarry, Rural NSW

Multiple projects across Australia and internationally have demonstrated the effectiveness of impact rolling in converting uncontrolled fills. For example, a former quarry site in New South Wales was successfully treated and later developed into a commercial facility, with post-treatment deflections meeting engineering specifications.

Background

The client advised that the quarry had been backfilled around 2010 using material imported from a large basement excavation for a nearby shopping centre and that the fill had been placed quickly using a dozer and compactor to spread and compact. Reportedly, the operation had at times been unable to keep up with the rate at which fill was being delivered to site and hence layer thicknesses and roller passes were likely to have been variable. There had been no geotechnical supervision or testing during fill placement. Based on historical data and preliminary investigations, the fill was understood to be typically <3m to locally >6m deep. The volume of existing fill was estimated by others to be in the range of about 100,000-120,000 m^3 for the entire site.

GeoSmart Solutions was engaged to carry out a preliminary investigation of the existing fill to aid assessment of suitability for insitu remediation by impact rolling. Investigation methodology included Dynamic Probing Super Heavy (DPSH) soundings (Figure 4), soil sampling, Multi Analysis of Surface Waves (MASW), co-located nuclear densometer tests, and laboratory index tests.



Figure 4 - Dynamic Probing DPSH Testing (Geosmart Solutions)

Preliminary investigation findings relating to inherent material characteristics and suitability as engineered fill included:

- Existing fill assessed to be relatively consistent, comprising mainly low to medium plasticity Sandy Clay and minor Clayey Gravelly Sand, with Liquid Limit and Plasticity Index typically <50 and <40 respectively. Nuclear densometer testing recorded variable compaction above and below 98% Standard.

- Moisture content assessed to be within a range close to +/-2% from Standard Optimum Moisture Content (SOMC) targeted for controlled fill in AS3798-2007 *Guidelines on earthworks for commercial and residential developments.* SOMC was typically in the range of about 13-18%.
- No organic or other deleterious inclusions encountered at the tested locations, including at/close to the interpreted base of existing fill.
- Existing fill was assessed to be suitable as engineered fill provided it was sufficiently compacted. Landpac, the impact rolling contractor, reviewed the preliminary results and considered their heavy 3-sided impact roller (Figure 5) could be effective to depths down to about 4m.

The investigation demonstrated correlation between the assessment methods including:

- Strong correlation between conventional nuclear densometer compaction results and DPSH probe tip resistance values, with 98% Std assessed to be met with probe tip resistance values of 3.0 and 5.5 MPa respectively for the dominant Sandy CLAY and minor Clayey Gravelly SAND materials.
- Strong correlation between MASW S-Wave velocity and fill compaction condition, with a velocity above 200 m/s assessed to indicate a minimum 98% Standard.
- DPSH tip resistance assessed to achieve 98% Standard based on the Sol Solution database (adhering to Compaction Control NF-P 94-063) was in close agreement, but slightly higher at 4 MPa and 7 MPa for the dominant and minor materials encountered. These higher values were adopted for initial validation assessment, with recommendation that the lower site-specific correlation values be considered when assessing any apparent non-conformances.



Figure 5 - Impact Rolling of the Filled Quarry (Landpac)

Impact Rolling Methodology

Landpac were engaged to carry out impact rolling after the site earthworks contractor had carried out excavation to ensure a maximum 4m depth of existing fill based on depths interpreted from preliminary investigations. Impact rolling was initially carried out where the existing fill was generally <3m depth and then in areas where the targeted adjusted fill depth was a maximum 4m.

Settlement heat maps (Figure 6) were reviewed after intervals of typically 20-40 passes with a heavy, 3-sided impact roller.

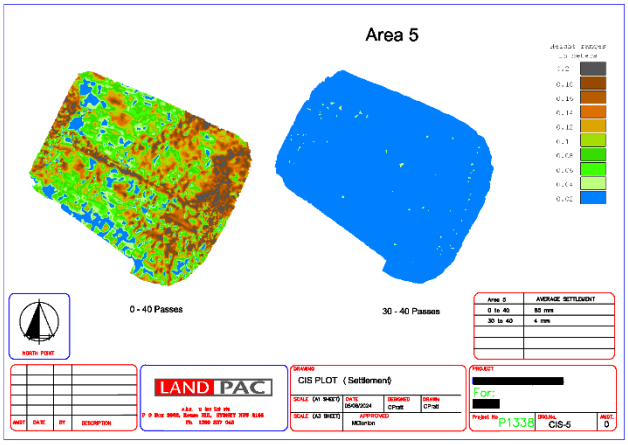


Figure 6 - Settlement Heat Map (Landpac)

GeoSmart Solutions (GSS) set out a test grid at typically 20-25m spacing in rolled areas and conducted DPSH instrumented dynamic probing soundings to assess achieved compaction.

Impact rolling, DPSH testing, borehole drilling and co-located nuclear densometer testing was an iterative process essentially continued until passing compaction was achieved, or no further compaction could be achieved.

When no passing compaction could be achieved, visual/tactile assessment of soils recovered from boreholes, nuclear densometer tests and associated laboratory compaction tests indicated Field Moisture Content (FMC) was generally at the wetter end of +/- 2.0% from SOMC. As the fill generally had detectable silt content, it was reasoned the fill materials were increasingly moisture sensitive at or above SOMC.

For areas where passing compaction could not be achieved by impact rolling, the earthworks contractor excavated, moisture conditioned, spread in layers of 300mm loose thickness, compacted and tested conventionally.

Testing Methodology and Results

As mentioned previously, validation cone resistance values based on interpretation using the vendor software and database were initially adopted. However, the progressively developed site-specific correlation based on co-located nuclear densometer tests within mostly low DPSH cone resistance anomalies was assessed to be reliable and statistically significant, and was adopted for compaction validation, as follows:

- 98% Standard, minimum tip resistance of 3.5 MPa within the tight insitu moisture regime of mostly +/- 1.0% from SOMC with the following exceptions:
  - 98% Standard, minimum tip resistance 2.0-2.2 MPa if sampling and/or testing confirmed field moisture content to be in the range of about 1.0% to slightly >2% wetter than SOMC (reflects that the site fill materials were assessed to be generally moisture sensitive due to silt content)
  - 98% Standard, for rare lower tip resistance values subject to a passing co-located nuclear densometer test

The basis for the above validation regime is shown in plotted DPSH tip resistance vs nuclear densometer density ratio in Figure 7, Figure 8 and Figure 9Error! Reference source not found..

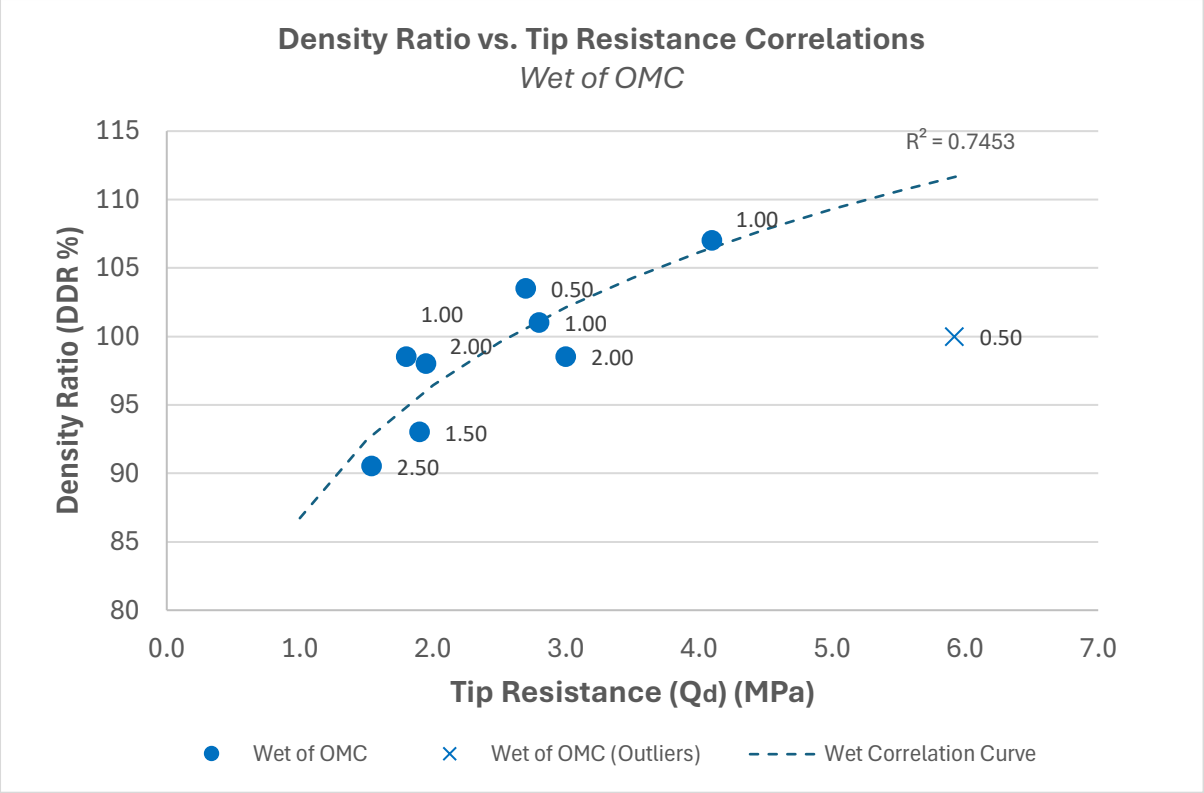


Figure 7 - Wet of OMC Correlation

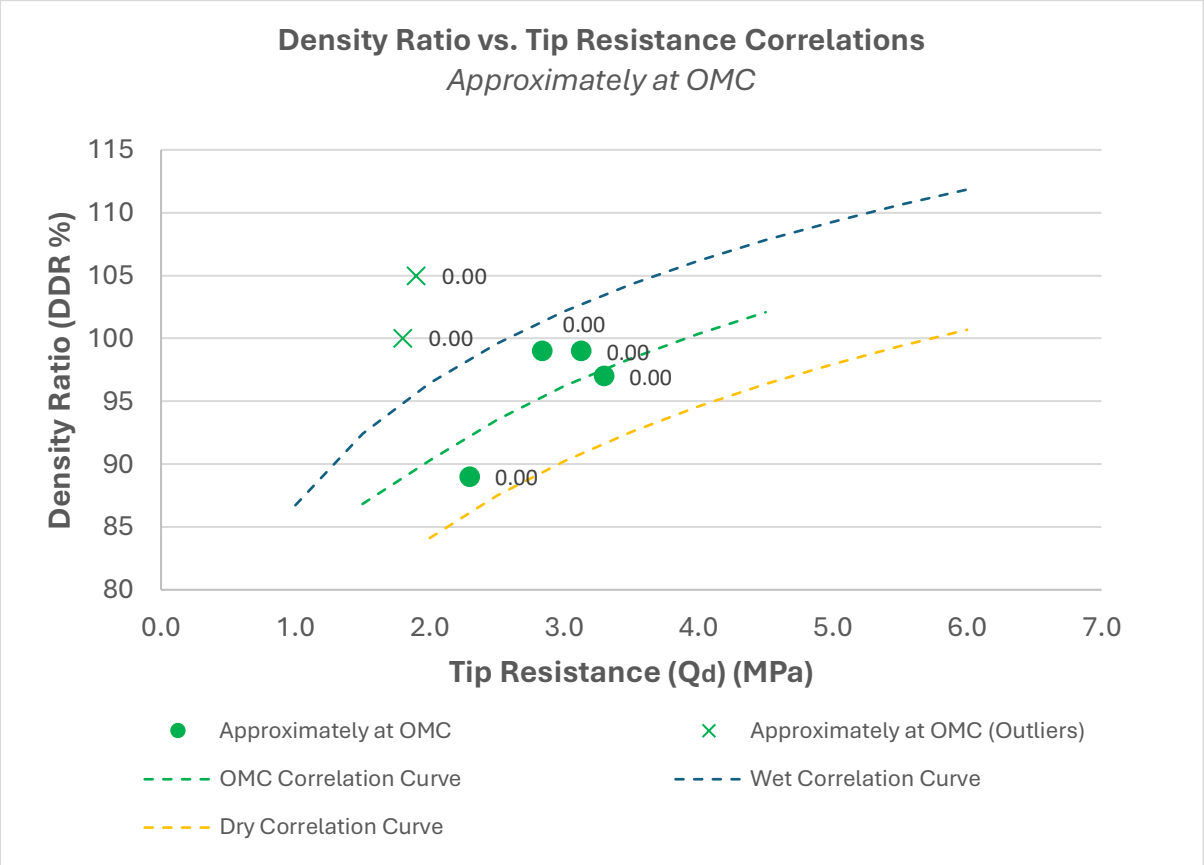


Figure 8 - Approximately at OMC

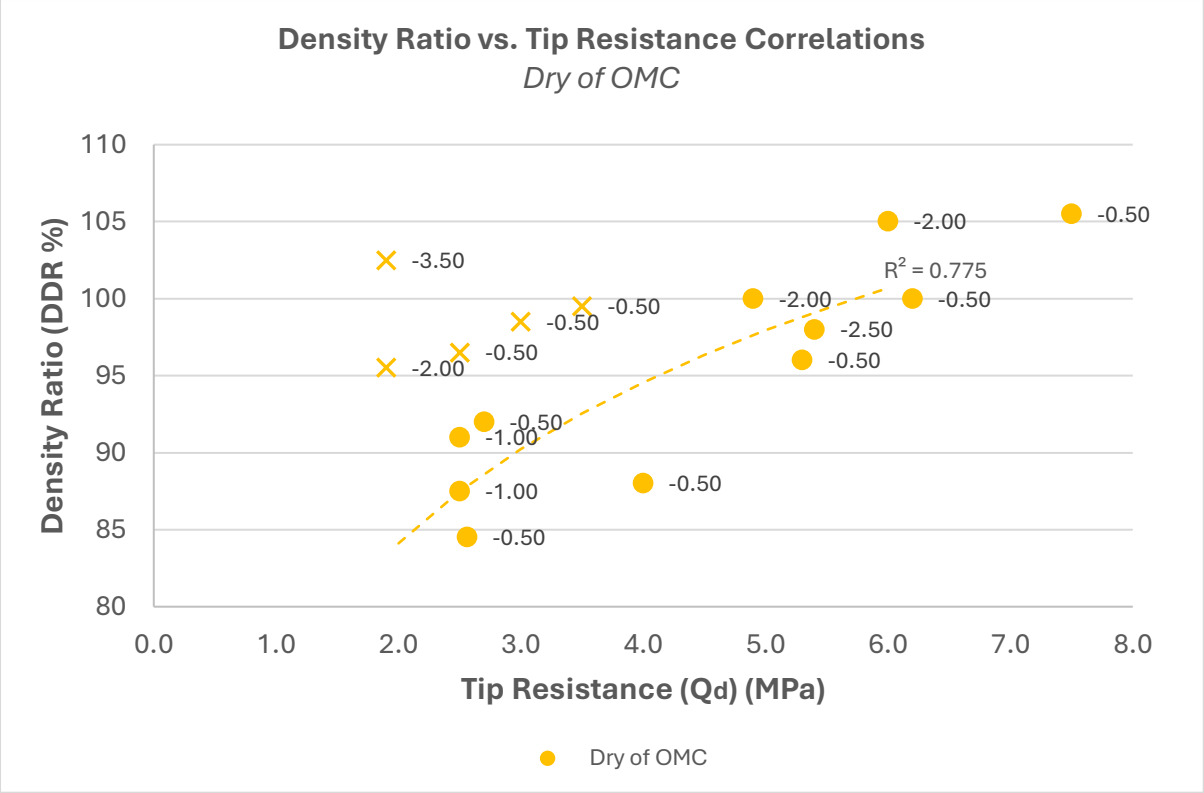


Figure 9 - Dry of OMC Correlation

At the completion of conventionally locally replaced, compacted and tested fill, the entire final fill surface was given 20 further impact roller passes aimed at achieving uniformity with areas of successfully impact rolled full depth fill. A further round of DPSH tests were then performed.

Discussion of Results

By the completion of fill placement to final levels, there were two independent data sets correlating DPSH tip resistance with density ratio, namely:

- Impact rolled fill: 19 nuclear densometer tests co-located exactly with targeted locations and depth intervals, as represented in Figure 7**Error! Reference source not found.**, **Figure 8** and Figure 9. The test pairs in this data set are very closely aligned in location and depth and on this basis is considered a reliable correlation. The nuclear densometer tests were deliberately targeted more to zones of low measured DPSH cone resistance but did include some targeted locations with passing compaction results as indicated by DPSH cone resistance.

- Replaced reworked fill: 118 compaction control tests carried out during conventional filling of areas where impact rolling was shown by DPSH testing not to meet the required compaction criteria. Compaction test locations as recorded by the testing authority and surveyed by the site earthworks contractor were not reliably recorded for each test but often by grid location proximity and layer/depth. Hence the correlation developed between DPSH tip resistance used filtered compaction results assessed to be located within a 2m and 5m radius of the DPSH grid points, based on the provided coordinates or nominated grid location, per Figure 10 and Figure 11. The correlations of this data set are assessed to be statistically robust, after ignoring obvious outliers assessed likely due to a mismatch in location/depth/material/moisture between DPSH cone resistance and paired compaction result. As would be expected, the scatter increases with offset radius from the DPSH test grid location, assessed to be due to variation in tested materials.

Importantly, the two independent data set correlations are assessed to be similar.

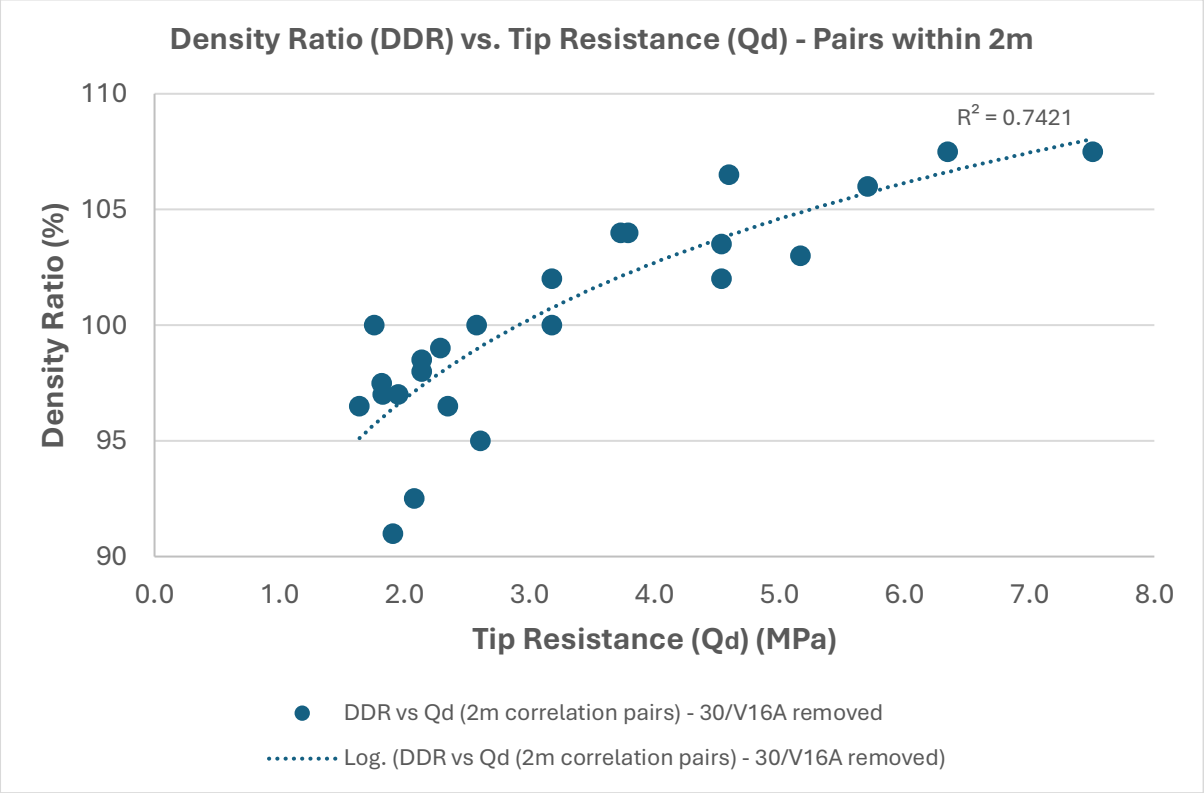


Figure 10 - Replacement Fill Statistical Correlation - Pairs within 2m - 30/V16A Removed

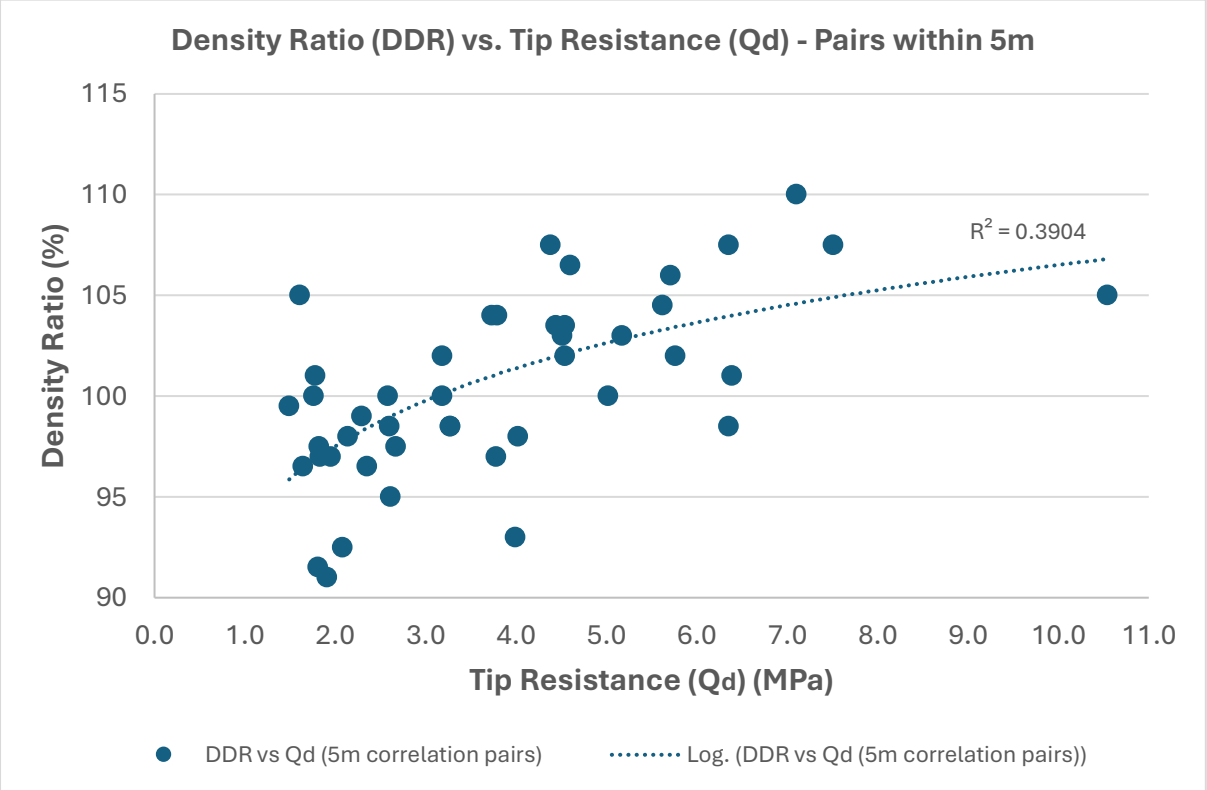


Figure 11 - Replacement Fill Statistical Correlation - Pairs within 5m

The smaller 19-point correlation dataset was adopted for validation testing. Of the 19 paired tip resistance and nuclear densometer results, qd = 3.5 MPa successfully predicted compaction outcomes in 18 cases, with only one anomaly where a very low laboratory density ratio value raised questions. Importantly, no systemic bias was observed, giving confidence in the reliability of the approach.

Based on the above, DPSH tip resistance qd of 3.5 MPa (Figure 12) was assessed to be a reliable pass/fail predictor, requiring engineering assessment to demonstrate that lower values still represent a compaction pass for the limited range of materials and insitu moisture conditions for existing and reworked fills at this site. Most of the low tip resistance anomalies when checked by targeted nuclear densometer tests were pass results, with insitu moisture generally 0.5% or more wetter than SOMC.

Further, subsequent laboratory testing confirmed that field assessment of insitu moisture by an experienced engineer can be reliable for the purpose of accepting lower passing tip resistance for layers/zones of higher insitu moisture.

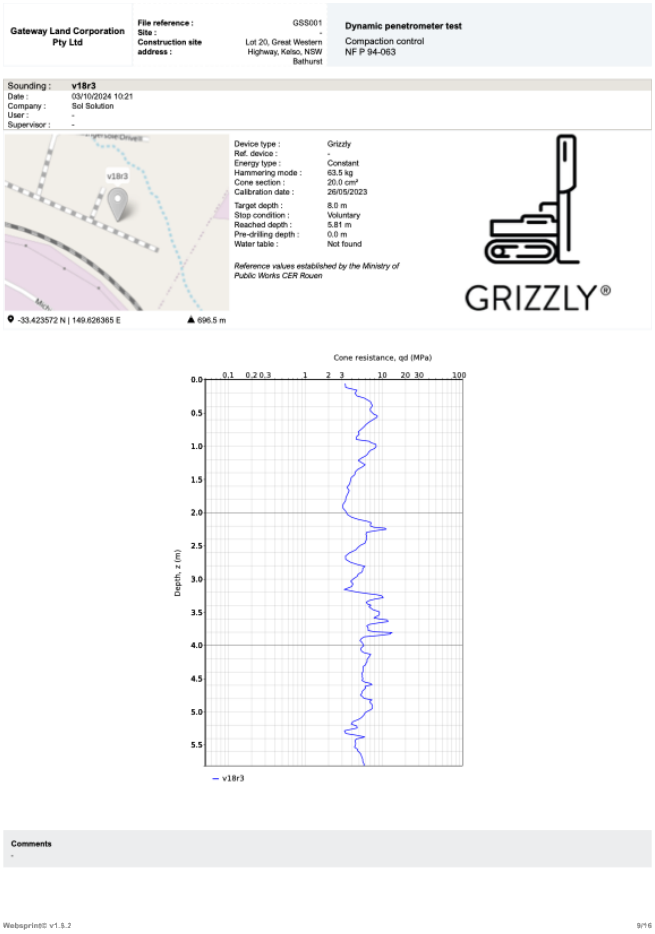


Figure 12 - DPSH Sounding Plot with Compaction Control NF-P 94-063

Fill Validation

Dynamic Probing Super Heavy (DPSH) testing at 25 grid locations covered an aggregate of about 85 column metres. The graphical DPSH plots are continuous with depth, and represent 285 subintervals of 300mm, which is the depth normally covered by a single nuclear densometer test. The DPSH tests cover both impact rolled and conventional compacted fill, for which there were also 118 nuclear densometer tests. There is good consistency between two compaction methods and two data sets assessing insitu compaction.

DPSH tip resistance of 3.5 MPa was adopted as the pass/fail value for 98% Standard compaction within both the impact rolled fill and the conventionally placed reworked fill areas where impact rolling had not been effective. Exceptions include lower q_d values can be ignored when nuclear densometer tests confirm compaction and based on test data, a lower q_d value of 2.0-2.2 MPa may be adopted as passing 98% Standard compaction when testing or sampling confirm FMC to be about 1% or slightly wetter of SOMC.

Based on the above, six site-specific conditions were developed to validate the Dynamic Probing soundings as meeting compaction of 98% Standard for impact rolled fill and conventionally placed reworked fill. The site-specific conditions were as follows:

1. Meets 3.5 MPa over the full test depth
2. Meets 3.5 MPa over the full test depth, with supporting nuclear densometer results
3. Meets 3.5 MPa averaged over the full test depth, with no thin layers <2.0-2.2 MPa
4. Meets 3.5 MPa averaged over the full test depth, with supporting nuclear densometer results where <3.5MPa
5. Meets 3.5 MPa averaged over the full test depth, and wetter Field Moisture Content (FMC) supports lower 2.0-2.2 MPa for passing compaction
6. Does not meet 3.5 MPa, but compaction confirmed by nuclear densometer results

The six conditions noted above, whilst site specific for this project, are based on transferable assumptions, logic and process. These include a validation tip resistance value can be derived for a tight range of insitu moisture content, consider calibration/check nuclear densometer and moisture variation results in relation to derived validation tip resistance values, consider lower validation tip resistance for slightly over-wet insitu moisture content values, field estimates of insitu moisture variation by an experienced geotechnical engineer can be used for validation provided there is good agreement with actual laboratory results where available, averaging minor layers of indicated under-compaction with significant layers of over-compaction is practical (*see Note 1 below*), passing nuclear densometer results over-ride low indicated tip resistance (potentially for reasons of subtle material and/or insitu moisture changes).

Note 1: This is exactly what happens over the typically 300mm depth for a nuclear densometer test, where the upper part of a layer might be over-compacted and the lower part of a layer might be under-compacted, which is not uncommon as layer thickness increases.

Closing Comments

The report prepared by GeoSmart Solutions covered both the impact rolled and locally reworked fill and was accepted by the local Council as meeting the requirement for 98% Standard compaction. A relatively small number of reworked fill results that achieved <98% Standard were satisfactorily handled as minor non-conformances due to also having DPSH results. Associated testing indicated that the fill met or closely met the generally accepted insitu moisture specification of +/- 2.0% from SOMC.

The report opined the remediated site was suitable for industrial building development subject to the following:

1. Engineering design based on review of the report and additional geotechnical investigations that may be recommended by project design engineers.
2. Consideration of the potential for differential settlement where building development on the site straddles natural and filled ground.

Combining impact rolling with a practical means to assess the profile of achieved compaction over the full fill depth has been made possible with innovative insitu testing equipment now available.

For this case study, when reviewing settlement heat maps, it was possible to differentiate when minimal incremental settlement was also associated with under compaction of problem materials, in this case moisture sensitive material at higher insitu moisture content.

For this case study, there were assessed to be the following benefits:

- Practical: enormous volumes of materials didn't have to be excavated, stockpiled and reworked conventionally
- Economic: cost savings
- Sustainable: Reduced fuel usage and emissions
- Collaboration: between regulatory bodies, developers and designers to achieve "fit for purpose" fill remediated insitu in accordance with sound engineering principles.

On paper, cost savings appear compelling. The author was not privy to costings for the case study site however, has considered an example 3m depth of existing fill over a regular shaped area of 1 hectare (30,000m^3 of fill). Based on author experience, an efficient bulk earthworks operation using multiple scrapers to excavate to stockpile and then working with compactors to replace as controlled fill in 300mm thick layers is likely to take 10-12 days at an estimated cost about \$8-10/m^3. That time and cost could easily double if restricted site area required reworking in smaller sublots to allow space for initial stockpiling.

Again, based on author experience, impact rolling using a 3 sided impact roller operating at an average but sub-optimal speed of 8km/hr could complete 50-60 passes within 4-5 days at an estimated cost of about \$3-5/m^3, although that cost could easily double if impact rolling identified say 20% of the area in need of localised excavate and replace remedial works.

The fuel savings too are apparent, a single all terrain tractor for an impact rolling operation of up to 5 days, verses multiple scrapers and compactors for a conventional excavate and replace operation of up to 12 days.

Prior detailed site investigation should be able to identify fills suited to impact rolling before committing to the operation.

Conclusion

Impact Rolling is a proven, efficient, and quantifiable method to upgrade uncontrolled fill sites into structurally sound, engineered fills. Its adoption allows previously marginal land to be repurposed for infrastructure development, providing economic, environmental, and engineering benefits. Impact rolling is most effective in granular and mixed fills and may be less effective in very soft clays or organic-rich soils. Pre-screening for insitu moisture conditions, buried services or contamination are essential for safe and effective application. As demand for developable land increases, especially in urban and peri-urban areas, impact rolling and the associated performance validation techniques will play a key role in land reclamation and site readiness strategies.

Acknowledgements

The authors would like to acknowledge:

- GeoSmart Solutions team for data collection and analysis - Zev Gilmour, Stefano Pirrello and Peter Caffi
- Landpac team for settlement heat maps and collaborative approach - Chris Pratt