

# ENGINEERED IMPACT COMPACTION OF UN-ENGINEERED FILLS

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## ABSTRACT

Un-engineered fill sites are often characterised with variable and excessive settlement potential. Impact Compaction has been used extensively on sites of this nature as an economic alternative to the removal and replacement of the *in situ* fills as engineered fills. Impact compaction has in the past been applied simply with a pre-determined number of passes or a number of passes determined on site based on the average compaction settlement over large areas and visual observation by a geotechnical engineer. This technique provides only partial “engineered” fill, as the possibility of unidentified sub-surface deleterious material still presents some risk of adverse foundation performance which requires the use of conservative design parameters.

Innovative technologies have been developed that enable “Engineered” Impact Compacted fills that significantly reduce the risks associated with unidentified sub-surface deleterious material and spatial sub-grade variation. Case studies are presented where the reworking of un-engineered fills with “Engineered” impact compaction using innovative continuous impact response technology (CIR) and continuous induced settlement technology (CIS) allowed the use of slab-on-ground construction and upper level footings with more realistic design parameters.

## 1 INTRODUCTION

The poor load-carrying properties of many non-engineered fills have been associated with their heterogeneity (Hardie, 1999). The delineation of the sub-surface ground characteristics on un-engineered fill sites during geotechnical site investigations is often based on a limited number of test locations. The means of determining the soil parameters at these specific test locations are well established but are of little use without sufficient information of the spatial variation and heterogeneity of the site. With limited test locations on un-engineered fill sites the risk of unidentified areas with sub-surface deleterious material is high.

The use of Impact Compaction on un-engineered fill sites has previously relied on the visual observation of the Impact Compaction works to identify areas with deleterious sub-surface material. However, deleterious sub-surface material within typical footing stress zones does often not exhibit visual heave or surface deflection during Impact Compaction. Impact Compaction has been principally controlled with the monitoring of reduced compaction settlements during the compaction works on a grid with laser levelling systems or Total Station surveying systems. However, on sites with variable soils conditions, the measurement of compaction settlements at predetermined discrete grid locations does often not identify localized areas with higher compressibility that require additional compaction. Consequently foundation performance may be adversely affected by unidentified sub-surface deleterious or weak material or material with higher compressibility at localised areas.

**Engineered Impact Compaction** involves the application of Impact Compaction in an “engineered” manner with extensive GPS and computerised based monitoring and control of localised compaction settlement and soil response measurement. This allows the identification of localised areas with higher settlement compression and/or deleterious material within the stress zones. Impact Compaction applied in an “engineered” manner using extensive settlement and soil response monitoring provides the certifying geotechnical engineer with a much higher level of confidence and allows the use of slab-on-ground construction and upper level footings with realistic design parameters. Landpac Technologies has utilised innovative technologies such as Continuous Impact Response (CIR) and Continuous Induced Settlement (CIS) with Impact Compaction to provide Engineered Impact Compaction on un-engineered fill sites. These technologies provide continuous data in two dimensions in plan, on the sub-grade stiffness variations and on the compaction induced settlements.

2 CONTINUOUS IMPACT RESPONSE (CIR) TECHNOLOGY

2.1 DESCRIPTION

During Compaction the impact compactor drums (Figure 1) exert high dynamic loads on the sub-grade at regular intervals across the compaction area. The peak deceleration of the compactor drum is directly related to the resistance offered at contact resulting from the stiffness and shearing resistance of the material (B. Clegg 1980).

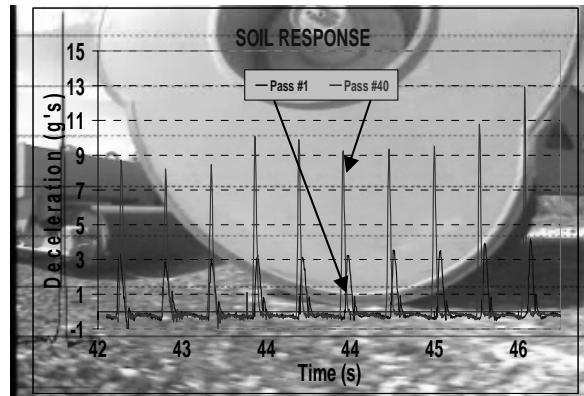


Figure 1: Peak Impact Drum Decelerations

As the sub-grade density and stiffness increase with compaction, the deceleration rates of the impact compactor drum also increase (Figure 2).

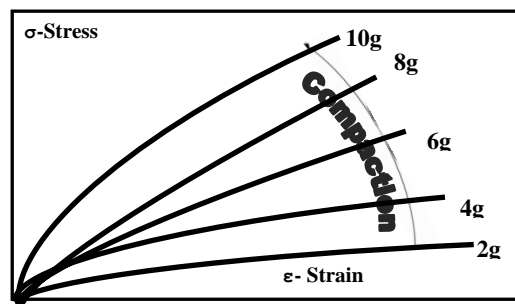


Figure 2: Illustration-Deceleration with Compaction

The CIR technology measures the deceleration rates of the impact drum assembly and records the location co-ordinates with integrated GPS technology (Figure 3). The measured g-values indicate the average sub-grade stiffness over the CIR zone of influence.

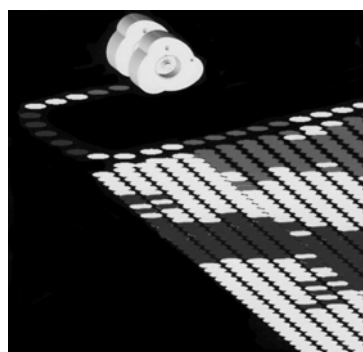


Figure 3: Illustration of recorded locations.

The recorded g-values and corresponding co-ordinates are imported onto site plans and colours are assigned to the range of g-values measured across the site (Figure 4). The CIR plots indicate the varying degrees of sub-grade stiffness across the site. Lower g-values on the CIR plot typically indicate weaker sub-surface materials.

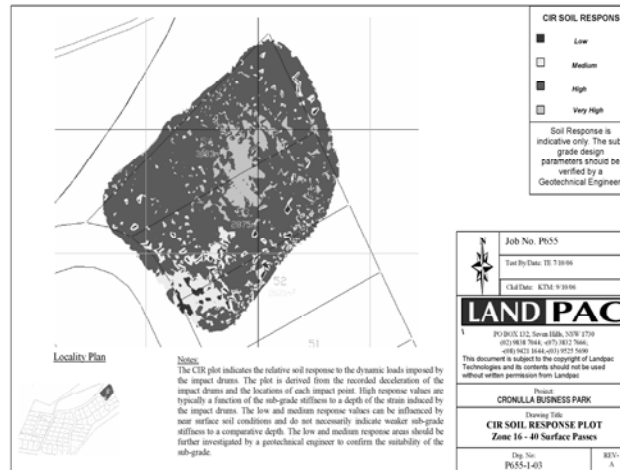


Figure 4: Example of CIR Plot.

2.2 CIR-ZONE OF INFLUENCE

Previous studies conducted (K. McCann 2007) have shown that there is a significant relationship between the CIR g-values and the soil strength to a depth of 2 m to 2.5 m (Figure 5).

The CIR zone of influence is governed principally by the depth and magnitude of strain induced in the sub-grade by the high dynamic loads exerted by the impact drum assembly. The induced strain is a function of the size and type of the Impact compactor used.

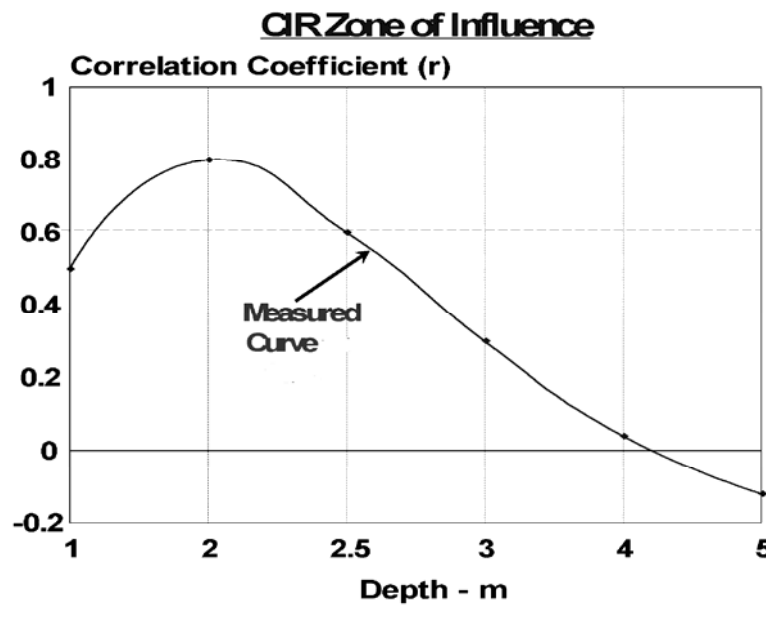


Figure 5: Correlation Curve.

3 CONTINUOUS INDUCED SETTLEMENT (CIS) TECHNOLOGY

3.1 DESCRIPTION

One of the difficulties associated with the Impact Compaction of variable un-engineered fills is judging when sufficient compaction has been applied. With conventional compaction where soil is placed and compacted in thin consecutive layers, the compaction is usually controlled with density testing. With Impact Compaction the amount of compaction applied is usually controlled on site by measuring the compaction settlement between set numbers of passes. On homogeneous fills the desired number of passes can be determined by measuring compaction settlement on a trial area. However, on variable fill sites the selected trial area may not be representative of the remainder of the site and the compaction settlement in this instance should be measured across the whole compaction area.

The compaction settlement can be measured on a grid with laser leveling systems or Total Station surveying systems. However, on sites with variable soils conditions, the measurement of compaction settlements at predetermined discrete grid locations often does not identify localized areas with higher compressibility that require additional compaction.

CIS technology overcomes this deficiency by measuring, recording and determining the compaction settlement at approximately 2 m intervals between periodic numbers of passes (Figure 6). CIS technology utilises Differential GPS systems, consisting of a stationary base station and a kinematic rover, for performing on-the-run surveys of compaction sites and a proprietary software tool (Figure 7) that calculates the compaction settlement between two surface planes. Plots showing localised settlements are generated from the data (Figure 8).

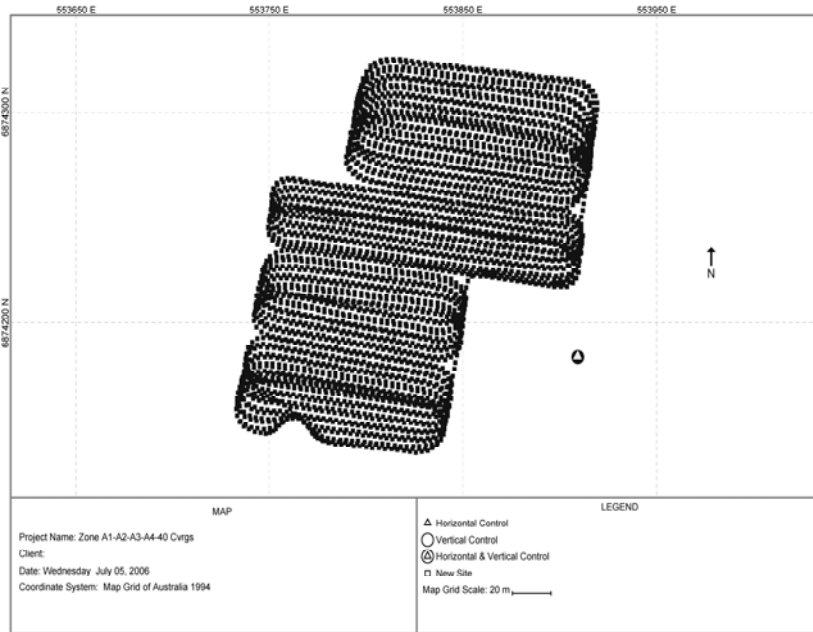


Figure 6: Settlement Observations on Compaction Area.

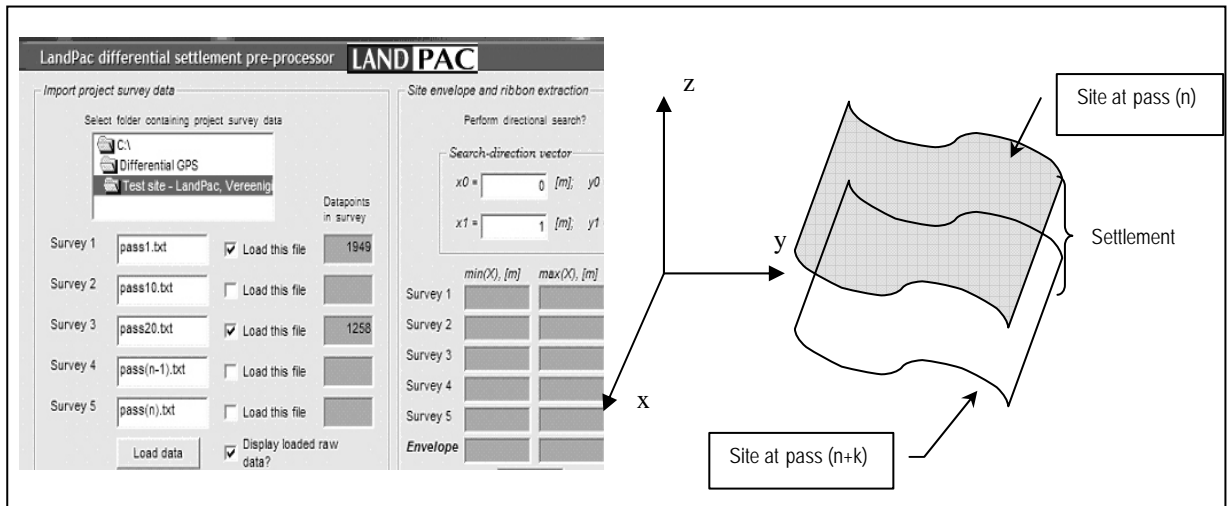


Figure 7: Software Tool used to calculate settlement.



Figure 8: Plot showing Compaction Settlement over 10 Passes

## 4 CASE STUDIES

### 4.1 CASE STUDY ONE – IDENTIFICATION OF WEAK SUB-SURFACE MATERIAL WITH CIR

#### 4.1.1 Site Description

The 20 ha site was located on the Kurnell Peninsular in Sydney. A large portion of the site was used for sand mining in the past and extensive backfilling had occurred. The site was characterised with up to 6 m of un-engineered loose sand fill with foreign material including building rubble/rubbish at various locations. The site was zoned industrial with the possibility of rezoning for residential use. Impact Compaction was applied with a Landpac 3-sided 135kJ (Kinetic Energy) Impact Compactor to compact the sand fill to 5 m depth to a medium density or higher to allow the support of warehouse type footings and slab with a 100 kPa bearing capacity slab design loading of 20 kPa respectively or residential footings in accordance with a Class 'M' or better site classification (AS2870).

The impact compaction was carried out in an engineered manner using CIR and CIS technology.

#### 4.1.2 CIR Monitoring

The CIR monitoring at the completion of the Impact Compaction indicated a predominantly high to very high response to the dynamic impact loads across all the compaction areas with the exception of localised low and medium response areas on a small portion of the site (Figure 9).

These areas were investigated further with Dynamic Penetrometer Testing (DCP) and Cone Penetrometer Testing (CPT) on site. The tests (Figure 10) confirmed the presence of weaker sub-surface material. Surface deflection or heave was not evident in this area during the impact compaction works. The weak material was excavated and backfilled with suitable fill.

The high soil response corresponds with the soil strength shown in CPT plots 16-1 and 16-2 (Figure 11).

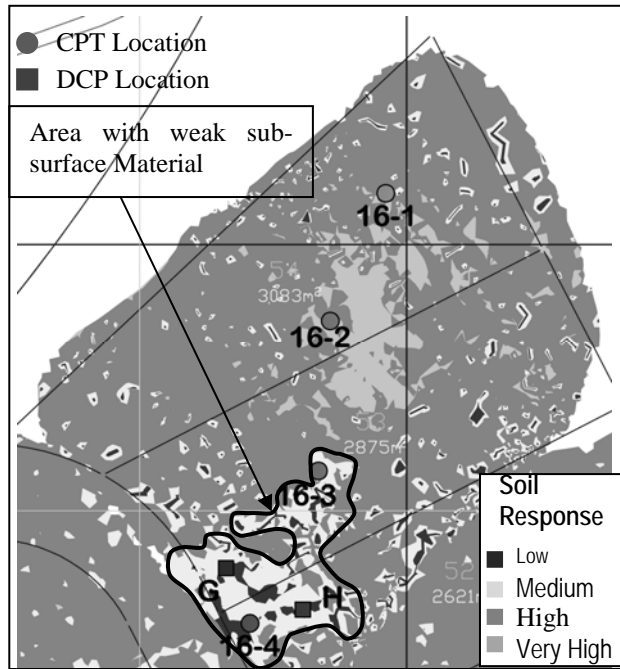


Figure 9: CIR Plot

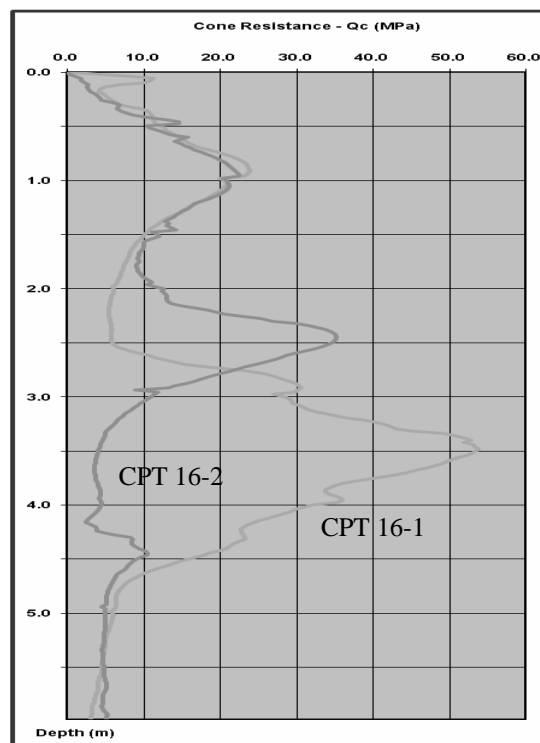


Figure 10: CPT's - Low/Medium Response Area.

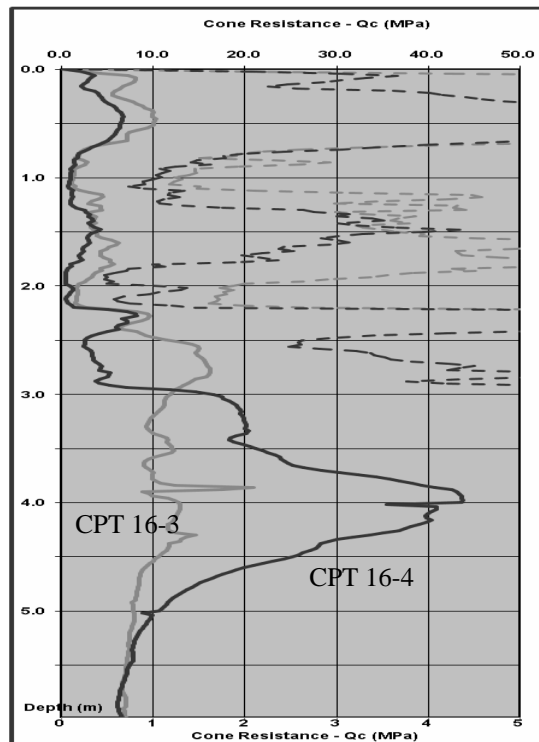


Figure 11: CPT's-High Response Area

The CIR monitoring provided a means of control during the compaction works and confirmed that the whole of the sub-grade on the areas compacted was compacted to a relatively uniform level and that the sub-grade was suitable for the required footing bearing capacities and site classification. The post compaction testing was also located across the site using the CIR plots. Rather than inadvertently only testing the more competent areas tests were also located on areas with an indicated lower stiffness.

**4.2 CASE STUDY TWO – CIR & CIS MONITORING ON VARIABLE FILL**

**4.2.1 Site Description**

The 7 ha site was located in Barrow-in-Furness south of the Lakes District in England. The site was characterised with predominantly dredged oceanic Sands with localised Silty/Clay soils. Two storey office complexes were constructed on the site. A Landpac 3-sided 135kJ (Kinetic Energy) Impact Compactor was used to compact up to 5 metres of un-engineered fill.

**4.2.2 CIR and CIS Monitoring**

The average compaction settlement on the whole compaction area indicated that compaction settlements had been reduced to acceptable levels between 30 to 40 passes (Table 1). However, the CIS plots (Figure 12) and monitoring data indicated over a portion of the compaction area an unacceptable average of 32 mm compaction settlement between 30 to 40 passes whilst the eastern corner area had an average of 6mm compaction settlement.

Table 1: Compaction Settlement Results.

Number of Passes	0	10	20	30	40	50	60	70
Maximum (mm)	0	237	311	342	358	384	407	406
Average (mm)-Total	0	95	150	186	205	233	261	265
Average (mm)-Incremental	0	95	55	36	19	28	18	4

Reduced Compaction Area

The CIR monitoring data indicated a reduction of the soil response probably due to excess pore pressures over the eastern corner area from 30-40 passes (Figure 13). The CIR and CIS data had therefore indicated that sufficient

compaction had been applied to the eastern corner of the compaction area. Further compaction on the area outside of the eastern corner area was carried out until uniform settlement refusal was achieved over this area. The further compaction resulted in an average compaction settlement of 60 mm and a reduction of the compaction settlement over the last 10 passes to similar levels to that on the eastern corner area.

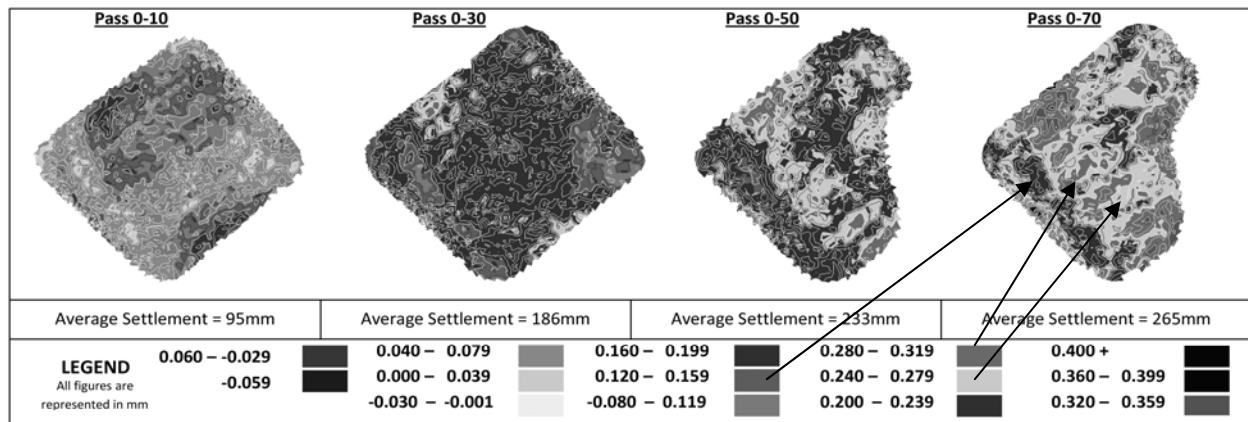


Figure 12: CIS Plots.

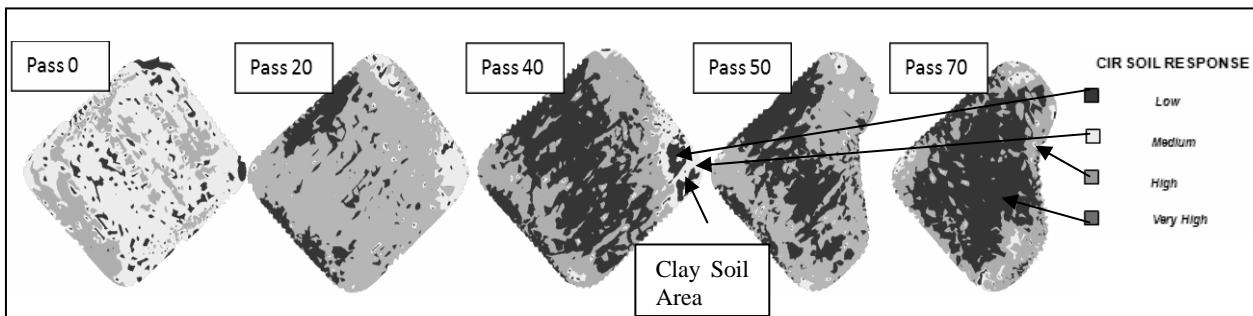


Figure 13: CIR Plots.

### 4.3 CASE STUDY THREE – IDENTIFICATION OF SUB-SURFACE DELETERIOUS MATERIAL WITH CIR

#### 4.3.1 Site Description

The site was located adjacent to Duck Creek in Auburn, Sydney. A detergent factory was previously located on the site. The site was reported as having 1-2.5 m of un-engineered fill with underlying residual firm to stiff Clays. The site was developed with ten industrial units approximately 25 x 25 metres each on a site area of approximately 2 ha.

Impact Compaction was applied with a Landpac 5-sided 65kJ (Kinetic Energy) to allow the support of warehouse type footings with a 150 kPa bearing capacity and provide a slab design loading of 20 kPa on the southern units with suspended slabs and building structures over a riparian area on the northern half of the north units.

The impact compaction was carried out in an engineered manner using CIR and CIS technology.

#### 4.3.2 CIR Monitoring

The CIR monitoring indicated weaker sub-grade areas in the vicinity of the south-eastern unit (Figure 14). Dynamic Cone Penetrometer tests and trench excavation (Figure 15) confirmed that there was a weak alluvial soil layer at approximately 1.2 m depth on the north-west corner of the unit dipping away to the north. This material was excavated below the respective footing areas and backfilled with mass concrete to the underside of the footing.

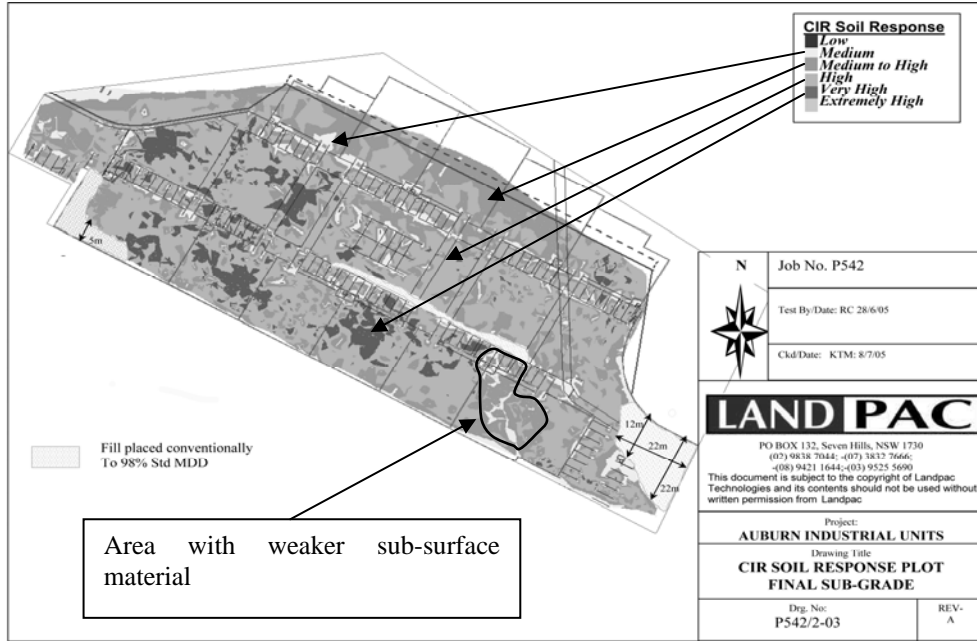


Figure 14: CIS Plot.



Figure 15: Excavation to East of Unit showing weak Clay layer.

Surface deflection or heave was not evident in this area during the impact compaction works.

The CIR monitoring identified and recorded areas with sub-surface weaker material. Integration with the site layout drawing enabled appropriate treatment of the various areas with respect to the specific structures in those areas

### 5 CONCLUSION

The case studies illustrate that CIR technology identifies sub-surface weak or deleterious material on un-engineered fills which could adversely affect footing performance and that CIS technology provides a more reliable means of controlling the amount of compaction applied on variable fill sites. The case studies also show that the visual observation of the ground response during the impact compaction of un-engineered fills is not a reliable indicator of the presence of sub-surface weak or deleterious material.

The use of CIR and CIS technology with the impact compaction of un-engineered fills provides reliable means for the engineering of un-engineered fills for the use of upper level footings and slab-on-ground construction and alleviates the need for removal or partial removal and replacement of un-engineered fill materials.

## 6 REFERENCES

- Hardie, T. (1999). *Brownfield sites: Foundations on fill*. Report BGS/Ground Board, Institution of Civil Engineers, United Kingdom
- Clegg, B. (1980). *An Impact Soil Test as Alternative to California Bearing Ratio*. 3<sup>rd</sup> ANZ Geomechanics Conference, Wellington, New Zealand, May 1980: 225-230
- McCann, K.T. and Schofield, N. (2007). *Innovative Methods in the In-situ Determination of Design Parameters on Heterogeneous Sites Subject To Ground Treatment Using Deep Impact Compaction*