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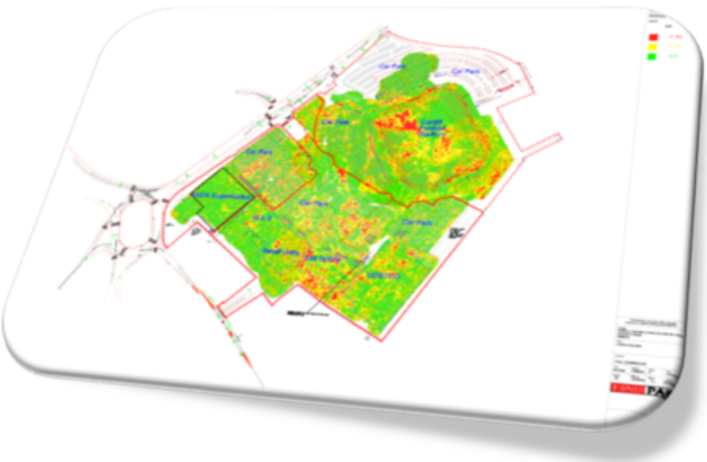
LANDPAC

USING THE LANDPAC CONTINUOUS IMPACT RESPONSE MEASUREMENT (CIR) SYSTEM AS A SITE VERIFICATION TOOL



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1. *Introduction*

High Energy Impact Compaction (HEIC) involves the transfer of compaction energy into the soil by means of the lifting and falling motion of non-circular rotating masses. The main features of this HEIC process include the following:

- *Relatively High Compaction Loads.*
- *Increased Depth of Influence compared to conventional roller compaction equipment.*
- *Vastly Improved Compaction Productivity.*

The deep ground improvement capabilities and the high rate of production of the HEIC equipment and technologies led to the need for a suitable measurement tool capable of verifying the ground improvement works being performed. The enhanced compaction capabilities of the Impact Compactors made traditional methods of specification and control generally inappropriate for use with the HEIC technology. The traditional approaches to compaction specification and control have the following limitations: -

- *an extremely small ratio between volume of material tested and that compacted (typically up to 1:100,000),*
- *lack of reliable correlation between laboratory and field compaction,*
- *poor reproducibility of results,*
- *long test duration, especially relative to the enhanced capabilities of HEIC*
- *difficulty in testing heterogeneous materials.*

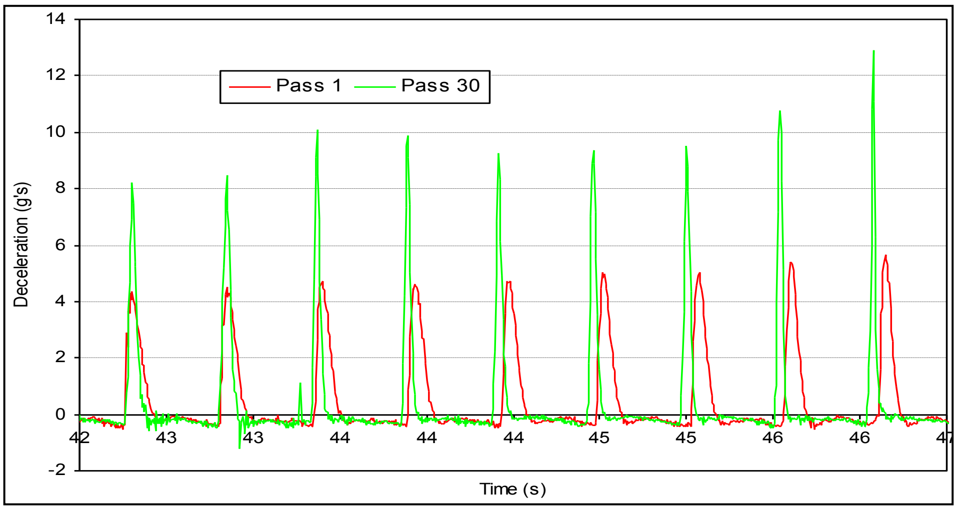
The Continuous Impact Response (CIR) system was developed by Landpac to overcome some of these limitations and to focus on the effective measurement of actual soil properties on works performed using HEIC.

2. *How Continuous Impact Response (CIR) Measurement Works*

The new approach for testing and certification of ground improvement works using HEIC revolve around using conventional testing methods in conjunction with the CIR measurement system in order to be able to "verify" the ground improvement works over the entire site area. The preference in this approach is to use conventional testing methods that provide a direct measurement of the soil properties required for design purposes (strength and deformation) rather than a "proxy" such as soil density.

2.1 Landpac Impactometer

The heart of the CIR measurement system is the Landpac Impactometer. This impactometer employs an accelerometer, which is fitted to the axle between the two masses of the impact compactor. Deceleration is measured on a continuous basis during the operation of the impact compactor and the peak deceleration of the compaction masses is recorded at each impact. While the material being treated is still in a loose state, most of the initial compaction energy will lead to plastic deformation of the soil. At this stage, the soil has a soft response to the impact compaction loads applied and relatively low decelerations of the compaction masses are measured. Further compaction of the material results in an increased density and stiffness of the material and greater decelerations of the compaction masses are measured as the material moves towards the elastic state. The decelerations measured are in effect a direct measurement of the material's response to the "dynamic load" imparted by the impact compaction masses with each impact blow. The impactometer thus measures a "dynamic stiffness" of the material being treated by HEIC.



Example of BEFORE and AFTER decelerations measured.

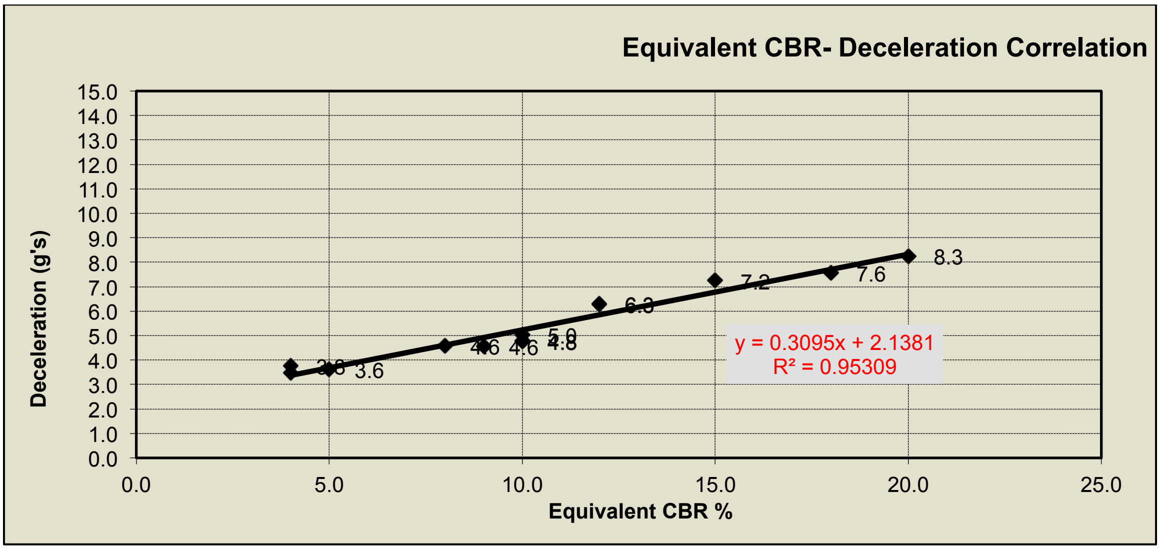
2.2 Use of GPS

The CIR measurement system employs a GPS receiver to locate the position of the impact roller. Each of the peak decelerations measured using the Landpac Impactometer is recorded relative to its position on site as determined by an integrated GPS receiver. It is thus possible to produce an accurate "map" of the deceleration values over the entire site.

2.3 Correlations

In order to provide a meaningful measure of the ground improvement works performed using HEIC it is necessary to relate the decelerations that are measured by the CIR measurement system to an appropriate traditional engineering measurement suitable for the particular site. To do this, it is necessary to generate a direct correlation between the decelerations measured in the form of "g's" and an "equivalent" conventional testing method result.

During the performance of a trial on a representative section of the site, decelerations are recorded using the CIR measurement system and conventional testing, such as density, Cone Penetration Testing (CPT), Dynamic Cone Penetration (DCP), Plate Load Testing (PLT), Zone Load Testing (ZLT), or California Bearing Ratio (CBR), is conducted at specific points on the trial section. The decelerations that were measured and recorded by the CIR system at the specific points where the conventional tests were performed are then correlated back to the results of these conventionally measured engineering properties.



Typical Correlation Graph: Equiv CBR and Deceleration Correlation showing a 95% accuracy between CBRs derived from DCP results (measuring penetration rates) and the decelerations recorded with every impact.

2.4 Establishing Limits and Interpretation of Colours

With customer specification requirements on hand, it is possible to establish limits for the decelerations measured on site using the CIR measurement system.

Using the example of the correlation above:
Following the trial, the following may be identified:

- *any deceleration less than 4g's could be equated to a CBR of less than 5%, which could be identified in red and deemed unacceptable;*
- *decelerations of between 4g's and 7g's may be equivalent to a CBR between 5 and 15%, where the customer might like some additional testing to be done to verify level of acceptability, could be identified in yellow, and, finally,*
- *decelerations above 7g's, being greater than a CBR of 15%, would be acceptable and could be identified in green.*

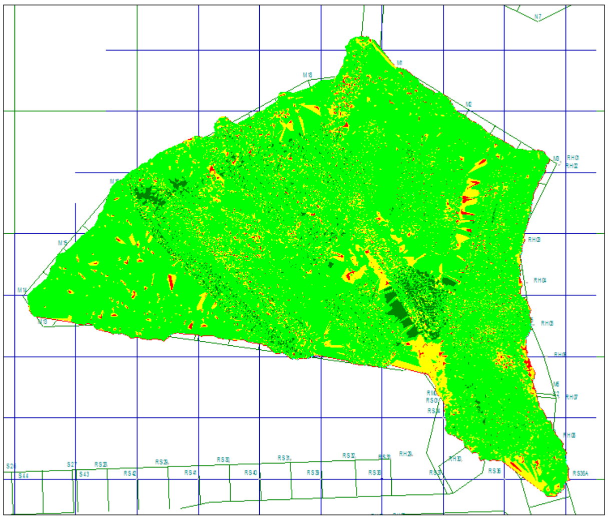
CIR Deceleration Value [g's]	Equiv. CBR [%]	Colour Coding
< 4.0	< 5	(red)
4.0-7.0	5.0 – 15.0	(yellow)
>7.0	>15	(green)

Typical Colour Coding Table.

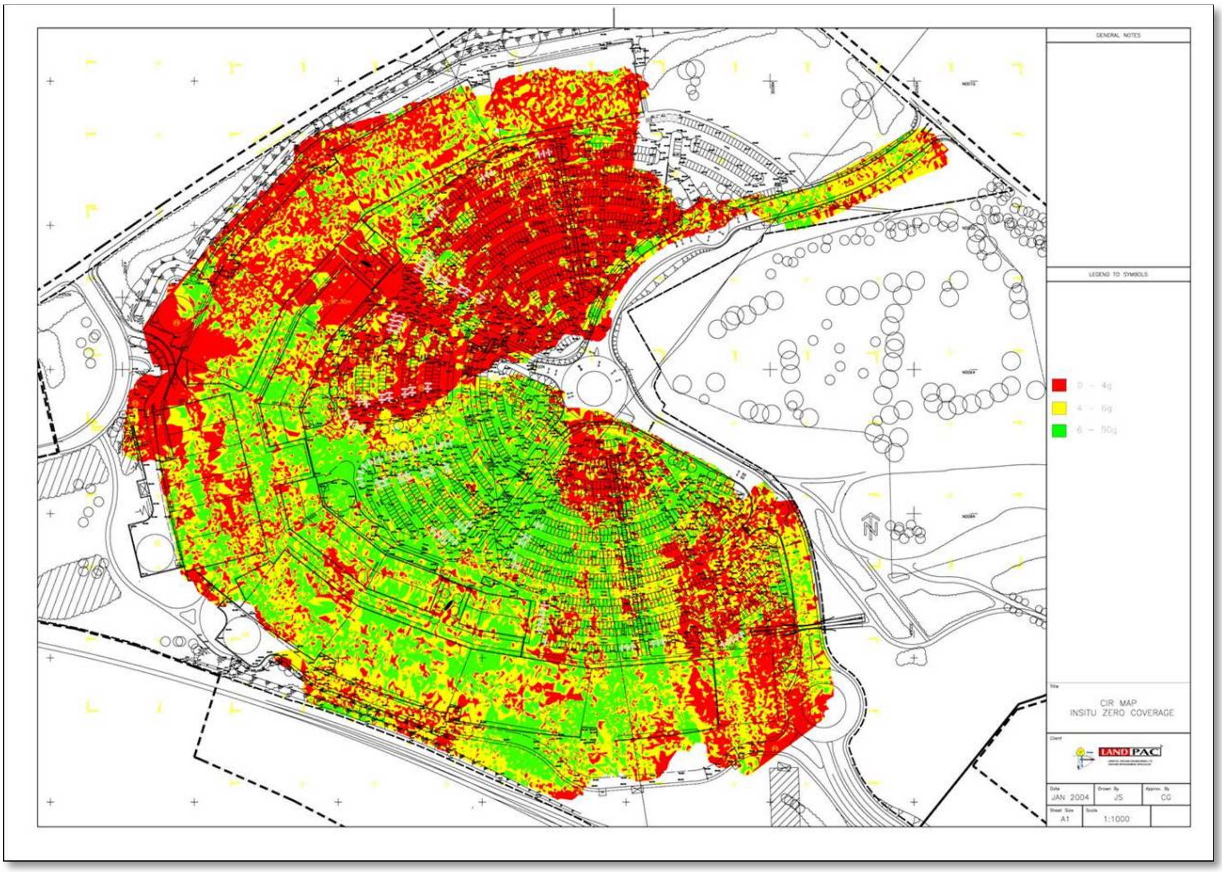
By using this colour coding and all of the measurements generated by the CIR measurement system, it is possible to generate coloured "maps" of the entire area being treated by HEIC. These maps then clearly identify the relative strength of the entire area and serve to highlight the following:

- *Green areas : these areas are likely to exceed engineering requirements of strength and stiffness and do not require any further conventional testing.*
- *Yellow Areas : these areas could need some further investigation with conventional testing to verify their acceptance relative to the engineering requirements.*
- *Red areas : these areas are likely to fall short of engineering requirements and would require specific investigation with conventional testing with a view to further ground improvement treatment or remediation if required.*

2.5 *Typical CIR Plots*



CIR Plot on a residential site.



CIR Plot on a commercial development.

3. Using CIR as a site Verification Tool

By using the CIR measurement system to identify the relative strength and stiffness of the material being treated, it is possible to focus the conventional tests in the relatively weaker areas. By ensuring that the relatively weaker areas conform to specification, it is then possible to use the CIR results to extrapolate the conventional test results over the entire site thereby increasing the certainty of the overall future performance of the compaction works.

This process can actually allow for a reduced level of conventional testing thereby reducing the cost of testing whilst still increasing the level of certainty of the test programme.

4. Advantages and Limitations of the CIR Measurement System

Some of the advantages of using the Continuous Impact Response system are as follows:

- *Accurate identification of weaker areas allowing for directed emphasis on the areas requiring added improvement.*
- *Immediate availability of results allowing for quicker decision making without delay to compaction works.*
- *Quality Control during compaction.*
- *Quality Assurance on final pass, with results used as part of the certification process.*
- *Verification of the entire site.*
- *Quick and inexpensive measurement.*
- *Direct correlated measurement of soil properties.*
- *Ability to control a site from a remote location.*
- *Greatly reduce the risk relative to the verification of soil properties during the compaction process.*

Notwithstanding these many advantages that the CIR Measurement System has to offer, it is important to note that there are a couple of limitations with the system that need to be constantly kept in mind. The important limitations that must always be considered are as follows:

- *Although the HEIC process can often lead to a compaction depth of influence of more than 2metres below the surface, it must be noted that the CIR measurement system is only considered to be an accurate measurement tool for the resultant ground improvement to a depth of 1.5metres to 2metres (dependent upon the material type). The CIR measurement system can, as a general rule, be accurately correlated to engineering properties measured using conventional testing techniques for depths of up to 2metres, but the reliability of the system to accurately measure ground strength falls away at depths beyond 2metres.*

- *Because the CIR measurement system is based upon the measurement of the deceleration of the impact compaction masses as they impart a blow of energy to the ground being treated, the accuracy of the measured ground response is influenced by the state of the material at the surface. If the material at the surface is particularly "soft" for a reason not related to the actual ground improvement being performed, then the CIR measured result can be "negatively influenced". This problem is encountered in cases where the surface is particularly muddy or where the surface material is very "powdery". Care just needs to be taken to ensure that such conditions are taken into account should they be encountered. This problem is best resolved by removing the "soft material" to ensure improved accuracy of the CIR measurement results.*

4. Some Typical Questions and Answers relating to the CIR Measurement System

- ***Q: How often should you be verifying the correlations?***
  A: *There is no fixed setting for this but it is well understood that as material conditions change, this may have an effect on the decelerations recorded. If it is known that the material condition has changed on site, it is advised to perform a few conventional tests to verify the accuracy of the correlations. Should the material be consistent, it remains advisable to verify the correlations from time to time. This is generally done when weaker areas need to be verified; the data collected can be used for correlation verification.*

- ***Q: Do you still need to perform conventional testing?***
  A: *CIR can be used to reduce the testing regime considerably but it is still advisable to perform conventional tests to verify the accuracy of the correlations. Conventional testing would still be required in sections that have been identified as not meeting specification by CIR.*

- ***Q: What engineering properties can you correlate to?***
  A: *Generally, CIR results can be correlated to most engineering properties, including density, Cone Penetration Testing (CPT), Dynamic Cone Penetration (DCP), Plate Load Testing (PLT), Zone Load Testing (ZLT), and California Bearing Ratio (CBR).*

- ***Q: What is the best engineering property to use for correlation purposes?***
  A: *They're all usable except that with some, additional tests may be required for a more accurate correlation. This is generally the case with density results. CPT results (measuring Qc values) and DCP results (measuring penetration rates and/or equivalent CBRs) are generally easily correlated.*

- ***Q:* Is one correlation trial sufficient for an entire site?**
  A: *Provided that the material is of a similar nature over the entire site, then one correlation would suffice (this correlation can be verified using CIR measurements and conventional test results during the site operations phase). If however, there are areas on the site that have materials that differ significantly, then it is necessary to perform a correlation trial on a representative section for each material type. In such cases, it is important to ensure that the CIR results during compaction operations are processed using the correct correlation relative to the material type of the area being measured.*

- ***Q:* Can you use in-situ compaction correlations on thick layerworks compaction, both using an impact roller for compaction?**
  A: *No. Separate trials must be conducted in order to establish two series of limits for control purposes.*

- ***Q:* Is CIR an absolute measurement?**
  A: *No. A deceleration measurement in itself has no meaningful value to a civil or geotechnical engineer. That is why it needs to be correlated to an engineering property that is well understood. A result of 6 g's doesn't mean much, but if 6 g's is equivalent to a CBR of 25% up to 2metres below the surface, then it is better understood.*