*Proceedings of the 21st ICSMGE, Vienna, Austria, 14 – 19 June 2026. Pistrol, Adam & Schweiger (eds.)*
*Published by: ÖGG, Austrian Society for Geomechanics, Salzburg, Austria, ISBN 978-3-9503898-4-5*
*https://doi.org/10.53243/ICSMGE2026-1108*

# Global case studies in design and execution of Rigid Inclusions – a contractor's perspective

**Clemens Kummerer**
*Keller Grundbau GesmbH, Vienna, Austria, clemens.kummerer@keller.com*

Jonathan Daramalinggam
*Keller Asia-Pacific, Singapore*

Tanner Blackburn
*Keller North America, Hanover, Maryland, USA*

Thibaut Clauvelin
*Keller Grundbau GmbH, Dubai, United Arab Emirates*

Kenneth Kniss
*Keller North America, Charlotte, North Carolina, USA*

ABSTRACT: Rigid inclusions (RI) are an increasingly used ground improvement technique with applications in a wide range of geotechnical projects, from the foundation of single footings and slabs to large and high embankments. While their use is typically limited to static, vertical loading, with care they can be designed to work under dynamic or seismic loading conditions. The paper provides an overview of RIs as a ground improvement technique and compares them to other ground improvement techniques. The focus of the paper is the current state-of-practice for the design and construction of RI ground improvement solutions across the world. In Europe and in other countries that have adopted the Eurocodes, the introduction of the second generation of Eurocode (EC) 7, design rules have been improved and clarified. In USA, the codification of RI design is evolving, with several state and federal initiatives in progress. In many countries though, a standard design method for RIs is not yet established, resulting in project specific design situations. The paper addresses and reviews global design practice of RIs, including load transfer platforms (LTPs), based on examples from USA, Europe, the Middle East and Asia-Pacific. The second purpose of this paper is to briefly summarize proper execution practices for rigid inclusions, highlighting key lessons learned from the installation of the usually very slender, in many cases un-reinforced, RI elements. Case studies are presented showing the different kinds of structures that have been supported, different installation methods, the use of advanced design methods and quality control practices.

KEYWORDS: rigid inclusions, design, execution, quality control

## 1 INTRODUCTION

The first modern applications of rigid inclusions (RIs) appeared in the 1990's, though not necessarily with a full understanding of the system behaviour and design requirements. The first comprehensive guidelines on RIs were published in France in 2012 as the ASIRI program (IREX, 2012), with an English translation. This quickly became the international reference for the system.

RIs, even if often related to a screw displacement technique, are defined independently from the installation technique. They can be installed using displacement techniques or otherwise, and made of various materials (concrete, steel, timber, etc.). Typically (and in the first definition in the ASIRI guidelines), a load transfer platform (LTP) is used, made of soil, with or without treatment or reinforcement. The presence of the LTP is responsible for the typical mechanisms of negative skin friction in the upper part of the inclusions and positive skin friction and tip resistance (similar to pile foundations) below the so-called neutral plane (see Figure 1).

Since the ASIRI guideline, several local codes of practice and standards have been developed, and research initiatives have been initiated across the world.

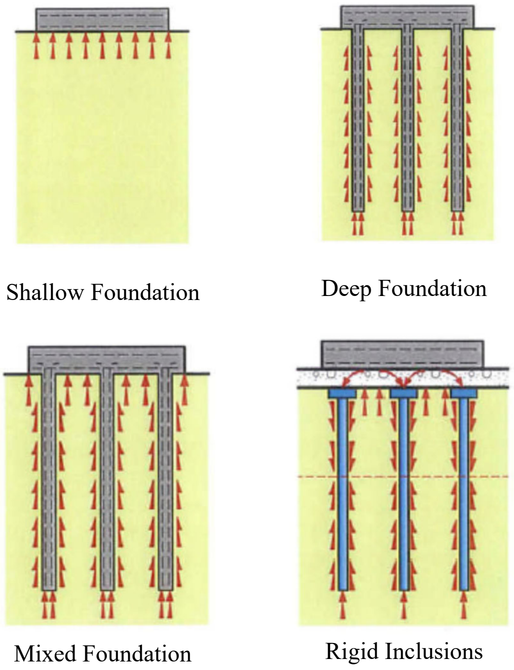


Figure 1. Types of foundations according to ASIRI (IREX, 2012)

One example of this is the ongoing ASIRI+ program, where the definition of RIs is extended to cases without an LTP. Also, many aspects not covered by the original ASIRI are being investigated with extensive field and laboratory testing, in particular dynamic and seismic loads, and reinforcement in LTP.

## 2 RIGID INCLUSIONS AND OTHER GROUND IMPROVEMENT TECHNIQUES

Ground improvement techniques are generally aimed at modifying the compressive/shear strength, stiffness and permeability of an in-situ soil body by means of (a) consolidation, (b) chemical modification, (c) densification, and (d) reinforcement. RIs work by *reinforcement*.

Raju & Daramalinggam (2012) list 8 general factors that affect the choice of ground improvement technique (1) Suitability vis-à-vis in-situ soil, (2) technical compliance, (3) availability of appropriate QA and QC methods, (4) availability of materials, (5) time, (6) cost, (7) convenience vis-à-vis other construction activities, and (8) protection of the environment. With these factors in mind, we can readily conclude that while there is no one-size-fits-all ground improvement technique, the RI technique is nonetheless a very versatile “tool” in a geotechnical engineer’s problem-solving toolkit. For instance, it can be installed in a wide range of soils, allows significant improvements in load-settlement performance and tends to require only a limited quantity of material. It *complements* other ground improvement techniques (such as vibro stone columns, prefabricated vertical drains, dynamic compaction, and deep soil mixing), though its resistance to lateral actions is limited. Swift & Pearlman (2024) suggest that RIs occupy a wide spectrum of applications, generally sitting in between stone columns and conventional piles.

## 3 DESIGN OF RIGID INCLUSIONS

RIs are a well-established technique in some markets, but new in others. Levels of regulation and knowledge vary from market to market. All of this leads to significant differences in design approach across the world. Over time however, design practices tend to converge on minimum safe practices. independent of the presence or absence of official standards in new markets.

The first area of convergence is the design of *static vertical loads*. The key principle of RI design is the load transfer mechanism that governs the interaction between the different elements of the system, i.e., the structure, LTP, RI and native soil. Defining the stress distribution between the RI and the surrounding native soil along the entire reinforced depth is the first step of any RI design and is usually done by semi-analytical methods (IREX, 2012 and Bohn, 2015) or through numerical modelling. This allows designers to estimate the deformation below the structure and the maximum stress in the RI, which is required to verify the structural and geotechnical bearing capacities of the column. It is unwise to use the oversimplified method where the total load (or an arbitrarily defined proportion of the total load) is assigned to the RI. Though conservative in terms of bearing capacity, such methods tend to *underestimate* settlements and do not reflect the actual behaviour of the system.

In countries with experience in RI design and construction, the second aspect that is agreed upon is that RIs are sensitive lateral loading. Such loading can either come from the structure itself or an earthquake. For seismic loads, a design procedure implementing minimum safe practices was proposed in Clauvelin *et al.* (2024) while more advanced design principles are discussed in Gingery *et al.* (2018). Lateral loadings can also come from construction activities (construction equipment crawling over the RI, nearby excavation, etc.). To avoid damage, strict controls must be implemented during construction.

### 3.1 *Current design practice in Europe*

Current design practice in Europe is generally based on the ASIRI recommendations (IREX, 2012), with local adaptations. The concept involves structural verifications on the RI material as well as geotechnical verifications on the soil and on the inclusion part of the system. More details about the ASIRI design framework, and French and German guidelines and are given by Bohn (2015).

### 3.2 *Outlook design new Eurocode (EC) 7*

In the first generation of EC 7, limited guidance was given on ground improvement design. In the second generation, in particular in Part 3 of EN 1997 (EN 1997-3:2025), a clear framework is given for classifying and therefore designing ground improvement systems (Table 1). Rigid inclusions are classified as BII. As before, details for local application are defined in national annexes.

Table 1. Classification of ground improvement according to the 2nd generation of EC 7 (EN 1997-3:2025)

| Class | A- Diffused | B - Discrete |
|---|---|---|
| I | **AI – Diffused with no measurable unconfined compressive strength**<br>The improved ground has an increased shear strength or stiffness higher than the original ground. The improved ground can be modelled as ground with improved properties | **BI- Discrete with non-rigid inclusions**.<br>Inclusions, installed in the ground, with higher shear capacity and stiffness compared to the surrounding ground. The unconfined compressive strength of the inclusion is not measurable. |
| II | **AII – Ground improvement sone with measurable unconfined compressive strength.**<br>The improved ground is modified from its original natural state, has a measurable unconfined compressive strength and is significantly stiffer than the surrounding ground. Usually, it comprises a composite of binder and ground. | **BII – Discrete with rigid inclusions**<br>Rigid inclusions, installed in the ground with unconfined compressive strength and significantly higher stiffness than the surrounding ground. The inclusions can be an engineered material such timber, concrete / grout or steel or a composite of binder and ground |

The main enhancements in the new EC7 are:

- A clear definition of RIs compared to piled raft foundations: RIs are *not* structurally connected to the slab or spread foundation (with or without LTP), whereas piles in piled rafts are structurally connected to the slab or spread foundation.
- The requirement to model *all* interactions happening in the RI system between structure, LTP, soil, inclusions and in particular, the load distribution between soil and column and the neutral plane.
- Geotechnical ULS verifications as an overall system, in line with all other geotechnical structures.

### 3.3 *Design in North America*

In contrast to Europe, the design and construction of RIs in North America is not typically governed by regulatory codes; although, a few states and cities within the U.S. have included RIs in their recent building codes, and an ASCE task force has been working to develop a foundation design standard that would include RI.

Designers must address geotechnical and structural resistance, following general and local standards of practice and must calculate element and system settlement accounting for soil structure interaction, including the load transfer platform. In most cases, element structural capacity is determined by methods used on other deep foundations, such as continuous flight auger piles, displacement auger piles, and bored piles, following accepted codes such as ACI (2025) and CSA (2024). The geotechnical resistance of a RI is determined based on soil engineering properties using accepted methods for determining side friction and tip resistance of RI. In Canada, the geotechnical resistance of the RI is determined based on the National Building Code of Canada (NRC, 2020), or local or provincial building codes. The allowable geotechnical resistance and load-deflection response are typically verified by single element compression load testing of individual elements or groups of elements.

Numerical analyses are typically used to adequately address the complexity of the interactions between loading, LTP, RI and soil as deformation occurs, and load is transferred to and from the RI. In North America, this analysis is typically conducted using commercially available software, such as Plaxis or FLAC.

When using RI in areas with significant seismic hazard conditions, designs are expected to account for the inertial and kinematic loading conditions. The inertial load of the structures supported by RI will impose additional lateral shear loading to the load transfer platform and the kinematic soil deformation (and resulting RI deformation) will impose additional structural forces within the individual RI. The seismically imposed stresses within the RI must be adequately addressed to ensure that the RI maintain structural strength and continuity (Gingery *et al*., 2018, Gingery & Humire, 2024; Hutabarat *et al*., 2026).

### 3.4 *Design in Asia-Pacific and the Middle East*

In the Asia-Pacific region, Australia has seen the fastest adoption of RIs thanks to its low seismicity, the wide availability of suitable rigs (usually small piling rigs), flexible national design regulations, and the relatively advanced approach to foundation design. Similar to the development of RIs in other parts of the world early projects were marked by occasional spectacular failures, usually related to lateral loadings or damage from follow-on construction activities.

In Australia, the industry has adopted design and construction approaches generally in line with ASIRI. However, terminology can vary. For instance, the Transport for NSW specification (TfNSW, 2021) uses the term “Concrete Injected Columns” to describe RIs. It refers to relevant Australian Standards and other TfNSW specifications. The specification is focused on construction and testing practices and makes only limited comments on design.

In Australia, most private developers do not specify RIs, but put out a general performance specification (total settlement, differential settlement, factor-of-safety, etc.) as part of the tender. Contractors are free to propose a suitable foundation scheme. Typically, design & construct contracts will include submission of a detailed design report, often independently reviewed by the owner’s consultants. For RIs, it is common for the design to be done in accordance with ASIRI, and any other relevant Australian Standards.

In Singapore, no national standard exists at the date of writing. The first project has been executed according to a prescriptive, project-specific guideline from the Maritime and Port Authority of Singapore (PSA, 2024). The guideline was prepared to be compliant with Singapore’s overarching national standards (EC7) and with reference to ASIRI. Because of the highly specific nature of this guideline, it remains to be seen how future projects will be specified. In any case, all such designs must be submitted for review centrally by the Building and Construction Authority.

In other Southeast Asian and South Asian countries (such as Indonesia and India), RI are usually proposed as value engineering alternatives to more traditional foundation solutions. As no central government agency exists for such reviews, designs are reviewed purely by the asset owners themselves. The quality of the reviews is therefore dependent on the experience of the local consulting engineers, and hence the designs themselves show significant variability. In several instances, the authors have noted designs that flout ASIRI guidelines, particularly in the use of RIs in seismic areas or under static lateral loading.

Similarly, in the Middle East, there are no national standards, and different government authorities are responsible for each sector (oil & gas, ports, utilities, buildings, etc.) Different guidelines and specifications are issued by the various authorities, and usually cover only geotechnical solutions that have historically dominated the market: piles on one side and ground improvement by compaction techniques on the other side. In the last 5 years however, RI emerged as a value engineering alternative, offering more economical and faster execution than piles while being able to carry higher load and achieving more stringent settlement requirements than common ground improvement methods. This quick increase in popularity meant that guidelines have not been updated, often leaving the acceptance of the design entirely to the discretion of the consultant and reviewer. This has sometimes led to inappropriate use of RIs. The authors have seen projects where RIs were treated as identical to piles, used to “mitigate liquefaction” or even as a “slope stabilization method.”

## 4 EXECUTION OF RIGID INCLUSIONS

### 4.1 *Working platforms & installation method*

Working platforms must be designed and constructed to safely carry all loads during the installation of RI. Given the slenderness of unreinforced RIs, the working platform has also the function to protect the head of the RI element from heavy construction traffic.

Multiple techniques can be used for the construction of rigid inclusion elements. The most common are inclusions made of grout or concrete installed by drilled-displacement or vibrated-tube methods. Also common are inclusions installed by vibro methods – grouted stone columns or vibro concrete columns. Less typical construction techniques include the use of driven steel, precast-concrete or timber elements, compaction grouting, jet grouting, and deep soil mixing. Depending on the design requirements and installation method, RI may be reinforced with bars or cages. RI elements are generally slender, with diameters typically ranging from 25 to 50 cm. The installation depth is typically up to 20 m, with exceptional cases being reported in excess of 30 m (Chang, 2019). Especially when using displacement methods, the installation effects on previously installed elements and on the working platform must be considered. An extensive overview can be found at Topolnicki & Kłosiński (2022).

### 4.2 *Formation & protection of rigid inclusions*

For RIs concreted in-situ, Larisch (2024) highlights that both workability and stability of the (pumped) concrete must be ensured and provides recommendations for both drilled and vibrated displacement systems. Care must then be taken not to damage the installed elements. Topolnicki & Kłosiński (2022) summarize various scenarios that might result in damaged RI elements. Figure 2 shows some of these scenarios.

- Heavy vehicles passing close to casted concrete elements can result in cracking. Site traffic management and RI reinforcement can be countermeasures.
- Displacement tools can introduce lateral displacement of adjacent elements resulting in excessive deformation. Moreover, vertical displacement of the working platform may exceed the tensile strength of the RI elements.
- Necking (or loss of integrity) can be caused by inadequate concrete flow or the "rebound" of the adjacent subsoil.

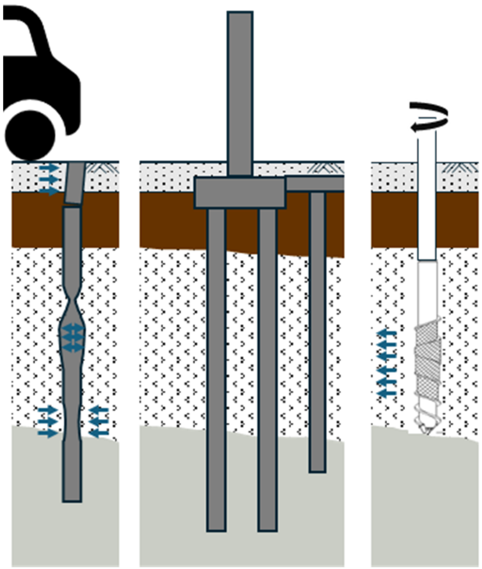
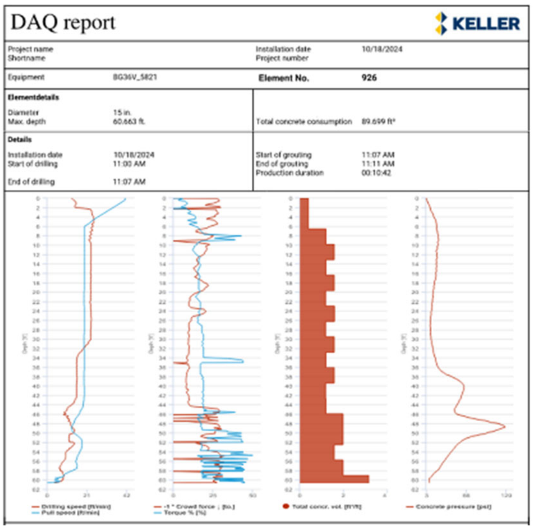


Figure 2. Possible damage scenarios for RI elements (simplified after Topolnicki & Kłosiński 2022).

### 4.3 *DAQ systems and Testing*

Data acquisition (DAQ) systems have been commonplace in the geotechnical construction industry since the early 2000s (NeSmith & NeSmith, 2006). Systems for drilled displacement piles and CFA piles are in use today and offer similar advantages for the rigid inclusions. The data collected (Fig. 3) is often used to establish termination depths and consequently the geotechnical capacity of the element.



DAQ report

KELLER

Project name
Shortname
Installation date 10/18/2024
Project number

Equipment BG36V_5821
**Element No. 926**

**Elementdetails**
Diameter 15 in.
Max. depth 60.663 ft.
Total concrete consumption 89.699 ft³

**Details**
Installation date 10/18/2024
Start of drilling 11:00 AM
End of drilling 11:07 AM
Start of grouting 11:07 AM
End of grouting 11:11 AM
Production duration 00:10:42

Figure 3. DAQ report showing the recommended RI installation data.

Monitoring the grouting or concreting procedure is just as critical, if not more so, than monitoring for the depth acceptance criteria. Even an element with unlimited geotechnical capacity is only as good as the structural capacity of the grout / concrete column, which can be reduced severely by necking and soil inclusions (Kniss & Riddle, 2024). Although both "open" and "closed" systems are used for RI construction, a closed system in which grout/concrete is pumped through a hollow stem and can maintain pressure throughout construction is the most common in practice.

Testing connects the design assumptions with the installation methods for the project. Because the RI system and its purpose are specific to each project, there is no one-size-fits-all test. However, four typical options are available for RI designers when specifying a test program:

- Full-scale/Area load test
- Plate load test on multiple elements with LTP
- Plate load test on single element with LTP
- Single-element test – no LTP.

The most common test is the static single-element load bearing and deformation control test with no LTP (single-element test). The single-element test is generally incorporated into the project QC plan, even when more complex tests are included in the test program. Although the load distribution is different from the actual loading through the LTP, the single-element test is used to less-directly confirm geotechnical capacity and load-deformation behaviour.

As discussed previously, the RI system usually includes an LTP. Where applicable, quality control of the LTP work must also be specified. Unlike installation of RI, this portion of the work is typically designed by the specialty contractor but constructed by an earthworks or foundation contractor. LTP construction is also affected by weather, engineering properties of the subgrade, and water levels. LTPs are subject to disturbance when excavations are left open for prolonged periods of time, and during construction of formwork. As a result, the authors strongly recommend thorough inspection, approval and documentation of subgrade preparation, LTP material placement, compaction and thickness by a qualified engineer. LTP testing and inspection procedures should be specific about test requirements and frequency.

## 5 CASE STUDIES

### 5.1 *Europe*

Figure 4. Aerial view from Lublin County Road extension project

Numerous RI projects have been delivered across Europe since the 1990s. A typical example of a large infrastructure project is the extension of a road in the Lubin County in Poland. Subsoil conditions involved clays and sand with weak soils up to a depth of about 11 m depth (Figure 4). In total, about 9,000 RI elements 300 mm in diameter were installed in a square grid arrangement of 2 m spacing. The elements were constructed as hybrid columns with a 2 m *gravel head*, to manage the lateral stresses close to the ground surface from other construction activities.

Another typical project is the construction of wind turbine generator foundations in France. Geotechnical investigations carried revealed a stratigraphy dominated by chalk, with compressible thicknesses varying between 6.0 and 15.0 m. No clear voids were detected. The foundation was built with rigid inclusions, 300 mm in diameter, with an LTP. Because of the sensitivity of this tall structure, design calculations were carried out using 3D finite element analysis (Figure 5), enabling a detailed assessment of the soil-structure-interaction against the performance criteria. The criteria included long-term vertical stiffness $K_v \geq 3.0$ MPa/m, dynamic moduli $E_{dyn} \geq 65$ MPa, and differential settlement ≤ 3 mm/m over 20 years.

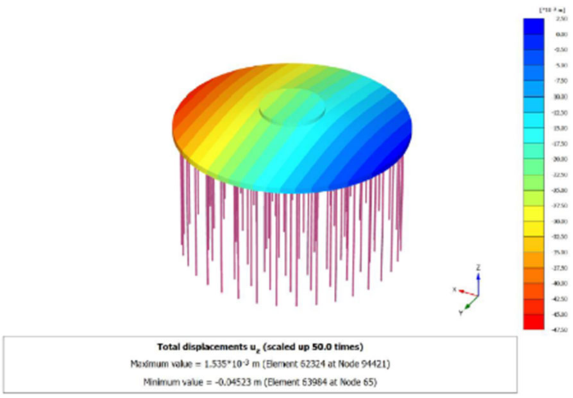


Figure 5. 3D finite element modelling of wind turbine foundation

## 5.2 *North America*

The use of rigid inclusions has become widely accepted in the United States as a cost-effective solution to support structures and embankments on sites with marginal, soft, compressible ground. RIs have been implemented effectively in the warehouse distribution, cold storage, data centre, industrial and manufacturing markets.

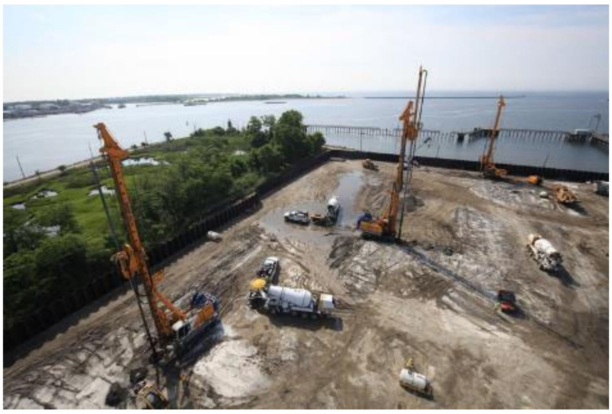


Figure 6. Rigid inclusions for energy facility on reclaimed soils

Mazzei et al. (2019) presents a case-history for an energy facility located in New England (Figure 6). The project involved construction of over 60 new structures and three fuel oil tanks ranging from 23 to 31m in diameter. Site grades were raised approximately 3m across the site to meet FEMA flood elevation standards. The project spanned 2.83 hectares, most of which was reclaimed land from nearby water bodies. The subsurface conditions are shown in Figure 7 below. The layers of thick, compressible soil were the primary concern for the owner's geotechnical engineer. RIs were selected to mitigate settlement of both the raise-in-grade fill and associated utilities, and proposed structures. The RI system was also designed to increase bearing capacity for the large tanks.

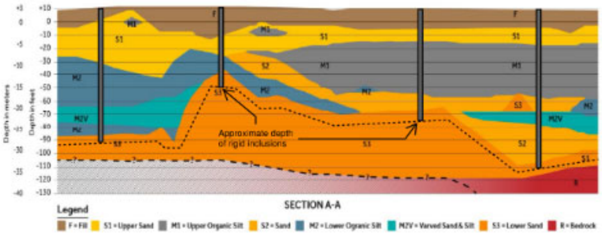


Figure 7. Geologic Section

This project was marked by an extensive testing program, which consisted of multiple single-element load tests and a full-scale load test program. The full-scale load test program showed the value of geotechnical instrumentation to check and verify the contractor's finite element analysis, for RI support of the raise-in-grade fill. A comparison of the interpreted strain gauge force development over time and force output from the FE analysis with depth is shown in Figure 8, confirming the level of the neutral plane.

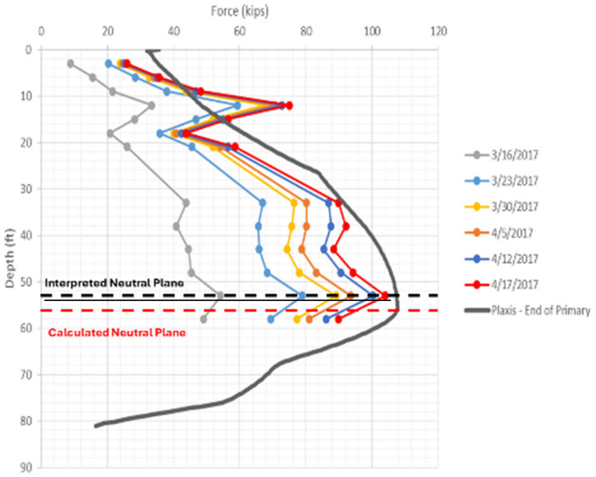


Figure 8. Interpreted strain gauge force development over time and force output from FE analysis with depth from full-scale load test.

## 5.3 *Middle East*

The main challenge for a data centre project in the Middle East was high bearing pressure requirements (200 to 250 kPa) on large footings (up to 5 x 5 m) combined with loose, liquefiable sand. Although the location has low seismicity, there has been the local authorities significantly raised the requirement for factor of safety (> 1.50 - 2.0) for seismic design. Because of this stringent requirement, Keller proposed a *combined solution* consisting of Vibro compaction (VC) to densify the loose liquefiable soil and RIs (Figure 9) to further support foundation load and reduce settlements to within allowable limits. The densification from VC offered the advantage of optimizing the

RI grid spacing and diameter, but a CFA-type tool had to be used instead of the usual displacement auger.

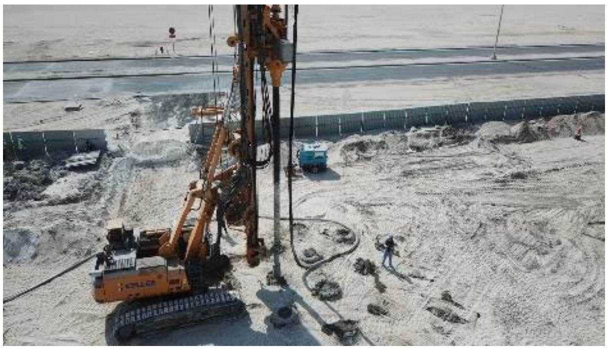


Figure 9: Installation of rigid inclusions

Given that this was the first major project in the area and that design was not covered in the government guidelines, Keller performed a detailed design exercise in conjunction with the structural designer. This involved a 3D finite element geotechnical model (Figure 10) with loading from structural columns, accurate foundation layout and individual RI elements. The load-settlement results from the geotechnical model were then used as input in the structural model to confirm that deformations and stresses were in good agreement. This allowed to confirm that the initial bearing pressure requirements were overestimated, and that further optimization was possible.

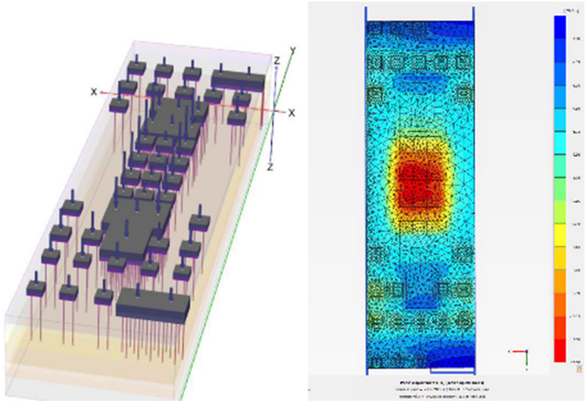


Figure 10. 3D finite element analysis

## 6 CONCLUSIONS

RI systems are versatile products offered by specialty geotechnical contractors, but they are also one of the most complicated to design and construct. The product offers benefits for many soil conditions and can extend the benefits of ground improvement beyond the limits previously associated with other ground improvement technologies. RI design has been enhanced by the introduction of numerical analyses and research conducted by both academia and practitioners. Construction quality for RIs and LTPs has historically been a challenge for the industry. However, driven by codes, standards and guidelines (such as ASIRI) well-considered QA/QC procedures, augmented by existing tools like data acquisition is raising the quality of construction. Ultimately however, the authors believe that specialist contractors should lead product application through responsible design practices, a focus on quality, and innovation.

*We would like to acknowledge Michal Topolnicki and Cecilia Bohn for their contribution and support for this paper.*

## 7 REFERENCES

American Concrete Institute (2025). Building Code Requirements for Structural Concrete (ACI 318-25) and Commentary. *Farmington Hills, MI: American Concrete Institute.*

Bohn, C. (2015). Serviceability and safety in the design of rigid inclusions and combined pile-raft foundations. *PhD thesis, Technical University Darmstadt and University Paris-Est.*

Canadian Standards Association (2024). Design of Concrete Structures (CSA A23.3:24). *Mississauga, ON: CSA Group.*

Chang, N. (2019). Ground improvement using rigid inclusions in Durban soft clay: A South African case study. *Proc. of the 17th African Regional Conference on Soil Mechanics and Geotechnical Engineering.* 7-9 October 2019, Cape Town, p. 757-762.

Clauvelin, T., Chang N. & Daramalinggam, J. (2024). Design of rigid inclusions in seismic conditions. *Proceedings of the 8th International Conference on Earthquake Geotechnical Engineering*, Japanese Geotechnical Society Special Publication, p. 918-923. https://doi.org/10.3208/jgssp.v10.OS-14-02.

EN 1997-3:2025. (2025). *Eurocode 7 – Geotechnical design – Part 3: Geotechnical structures*.

Gingery, J.R., Blackburn, J.T. & Shao, L. (2018). “Toward understanding the seismic performance of rigid inclusions,” *Deep Foundations Institute 43rd Annual Conference*, October 24-27, 2018, Anaheim, CA.

Gingery, J.R. & Humire, F. (2024). Flexural behavior of rigid inclusions and implications for seismic performance. *ASCE Geotechnical Frontiers Conf.*, Louisville, KY, March 2-5, 2025.

Hutabarat, D., Gingery, J.R. & Humire, F. (2026). Nonlinear simulation of the seismic performance of unreinforced and fiber-reinforced rigid inclusions in soft soil site. DRAFT submitted to *ASCE Geotechnical Frontiers Conference*, Salt Lake City, Utah, March 9-12, 2026.

IREX (Institut pour la Recherche et l’Expérimentation en Génie civil). (2012). *Recommendations of the French national project on rigid inclusions ASIRI.* Operation of the civil and urban engineering network, France.

Kniss, K. & Riddle, C. (2024). Quality Programs for Rigid Inclusions and Load Transfer Platforms. *Proceedings of 34th Central Pennsylvania Geotechnical Conference*, Hershey, PA, October 30-November 1, 2024.

Larisch, M.D. (2024). Concrete for Rigid Inclusions—Potential Risks and Their Mitigation Strategies. In: Rujikiatkamjorn, C., Xue, J., Indraratna, B. (eds.), *Proceedings of the 5th Int. Conference on Transportation Geotechnics (ICTG)*, Volume 8. ICTG 2024. Lecture Notes in Civil Engineering, vol 409. Springer, Singapore.

Mazzei, D., Kniss, K., Elsaid, F., & Zhang, Y. (2019). Rigid Inclusions Ground Improvement for a New Energy Facility: Design, Construction, and Full-Scale Embankment Load Testing and Results. *Proceedings of Geo-Congress (GSP 309),* Philadelphia, PA, pp 101-114.

National Research Council of Canada (2020). *National Building Code of Canada 2020.* Ottawa, ON: Canadian Commission on Building and Fire Codes.

NeSmith, W.M. & NeSmith, W.M. (2006). Anatomy of a Data Acquisition System for Drilled Displacement Piles. *Proceedings from GeoCongress 2006: Geotechnical Engineering in the Information Technology Age,* Atlanta, GA, February 2006.

Port of Singapore Authority (2024). Guideline for Rigid Inclusion Foundation System for Container Yards.

Raju, V.R. & Daramalinggam, J. (2012). Ground improvement: principles and applications in Asia. *Ground Improvement 165*, pp. 65-76.

Swift, S.S. & Pearlman, S.L. (2024). Rigid Inclusions: A spectrum of applicability, *IFCEE 2024*, ASCE, pp. 315- 325.

Topolnicki, M. & Kłosiński, B. (2022). *Recommendations for Ground Improvement with Rigid Inclusions – Design, Execution and Control* (in Polish), PWN, ISBN 978-83-01-22578-0.

Transport for NSW (2021). *Specification D&C R225 Concrete Injected Columns.* Transport for New South Wales, Australia.