Técnicas de vibração profunda para tratamento de solos em obras marítimas

- **Enmanuel Carvajal Díaz**
  - *Keller Cimentaciones, S.L.U.*

KELLER

Organização

CPGT
Comissão Portuguesa de Geotecnia nos Transportes

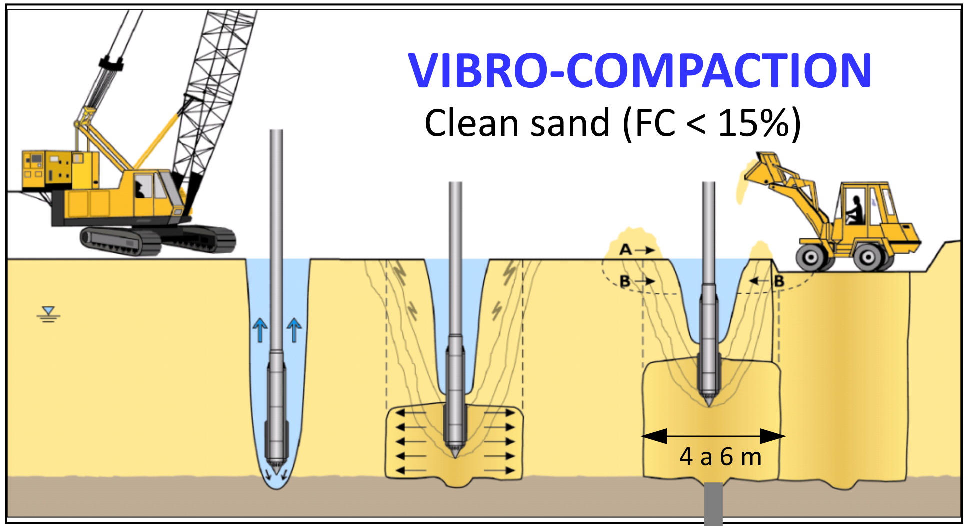
CPMT
COMISSÃO PORTUGUESA de MELHORAMENTO de TERRENOS

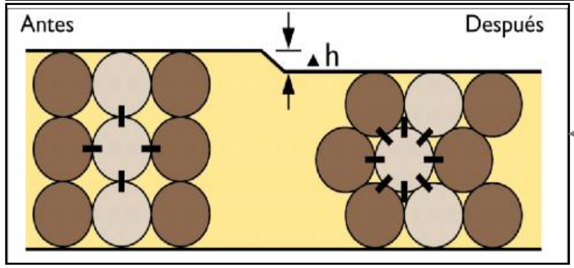
Sociedade Portuguesa de Geotecnia

APDL
ADMINISTRAÇÃO DOS PORTOS DOURO • LEIXÕES • VIANA

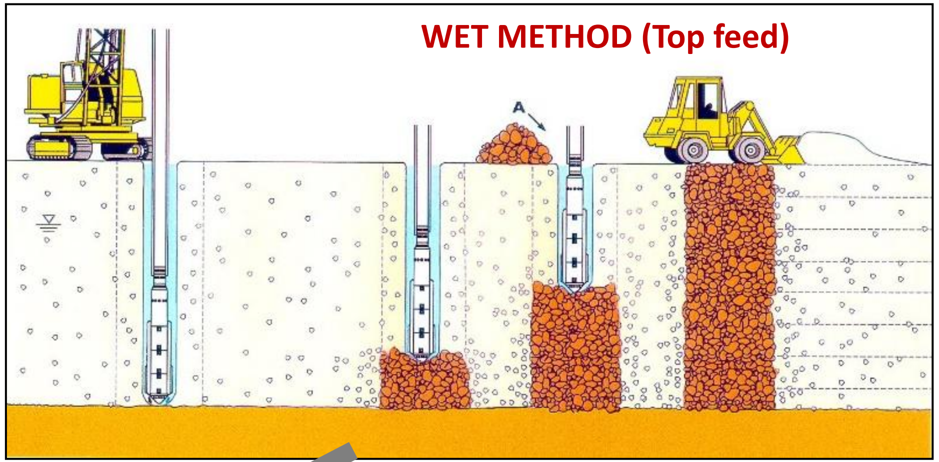
- **DEEP VIBRO TECHNIQUES**
- OFFSHORE WORKS
- LIQUEFACTION MITIGATION
- CASE HISTORIES
- CONCLUSIONS

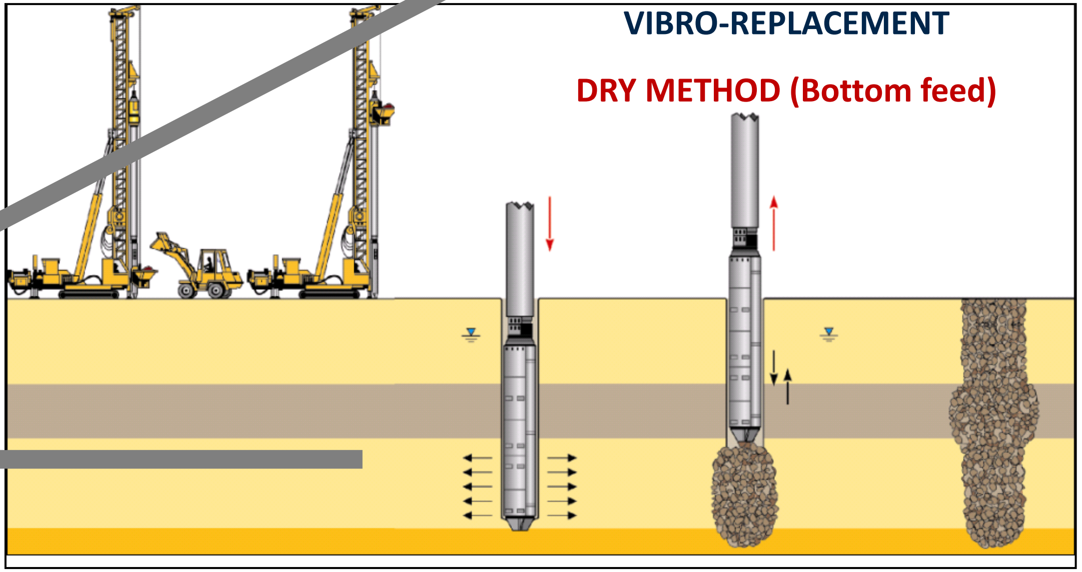
DEEP VIBRATORY TECHNIQUES



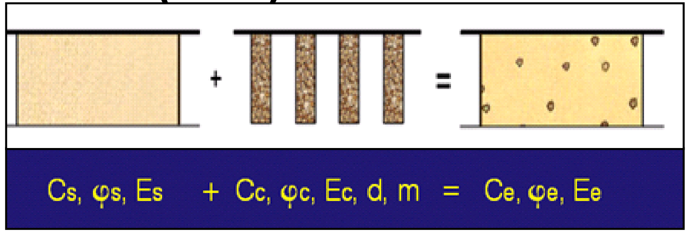


VIBRO-REPLACEMENT

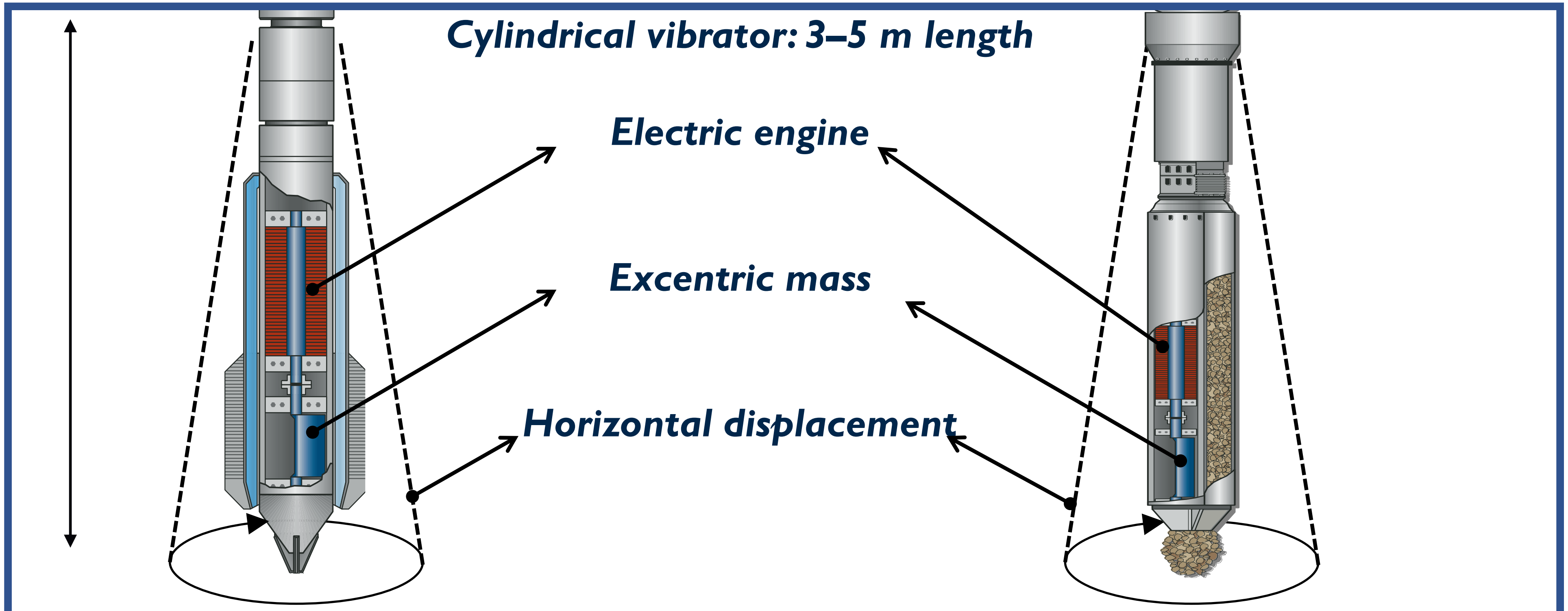




Priebe (1995)

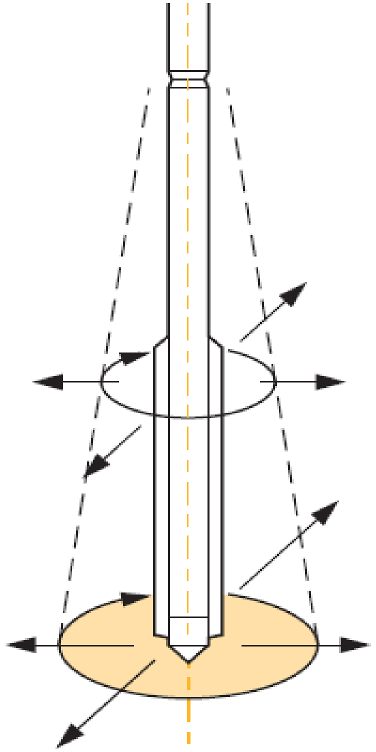


DEEP VIBRATORS



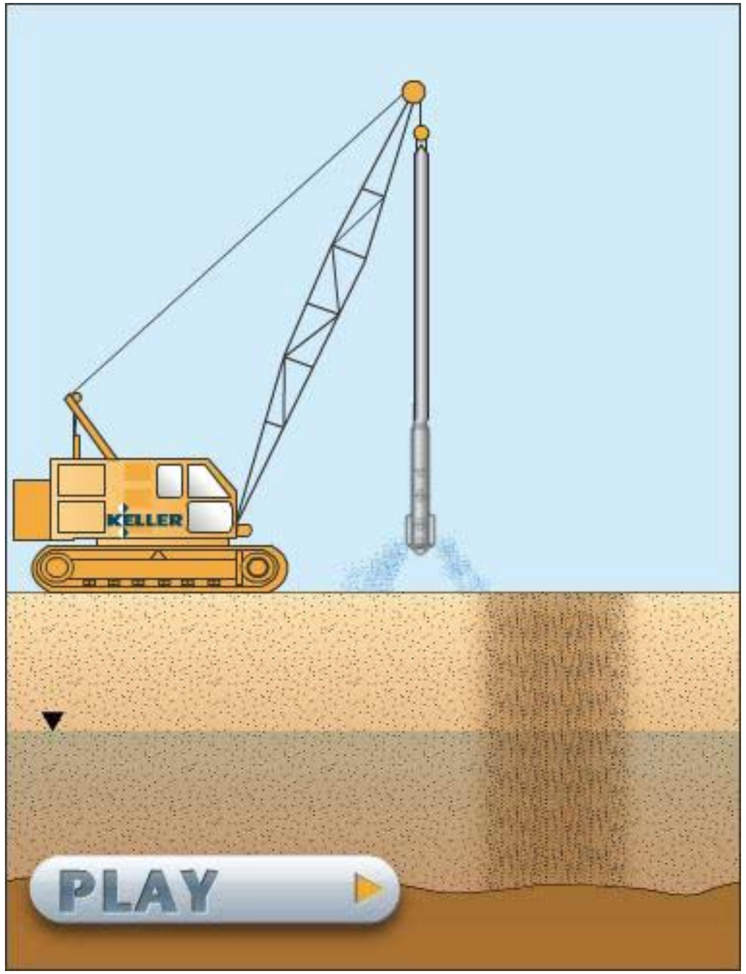
Gravel Top-feed
Vibro-Compaction
Vibro-Replacement (wet method)

Gravel Bottom-feed
Vibro-Replacement (dry method)



Vibrator motion

Vibrocompaction

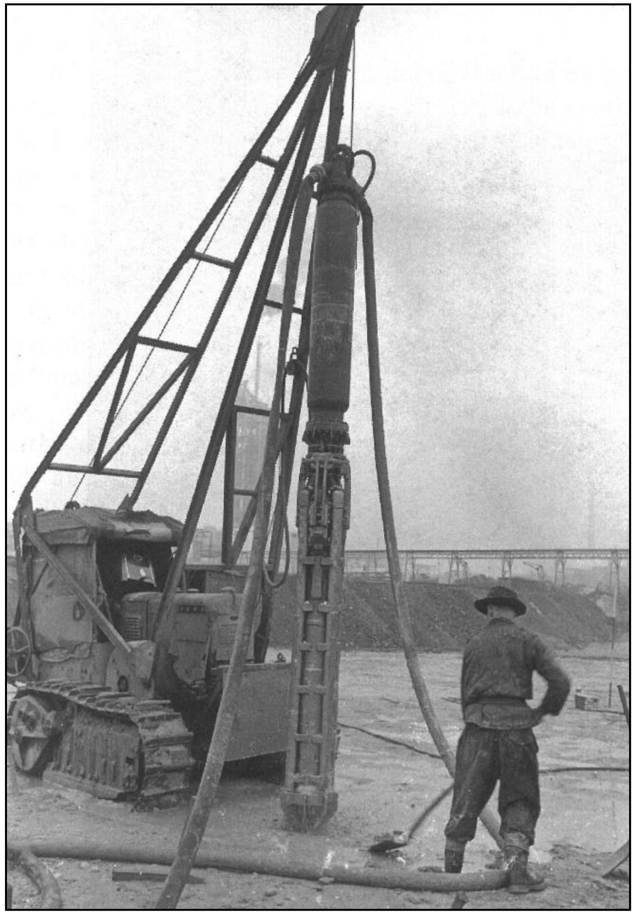


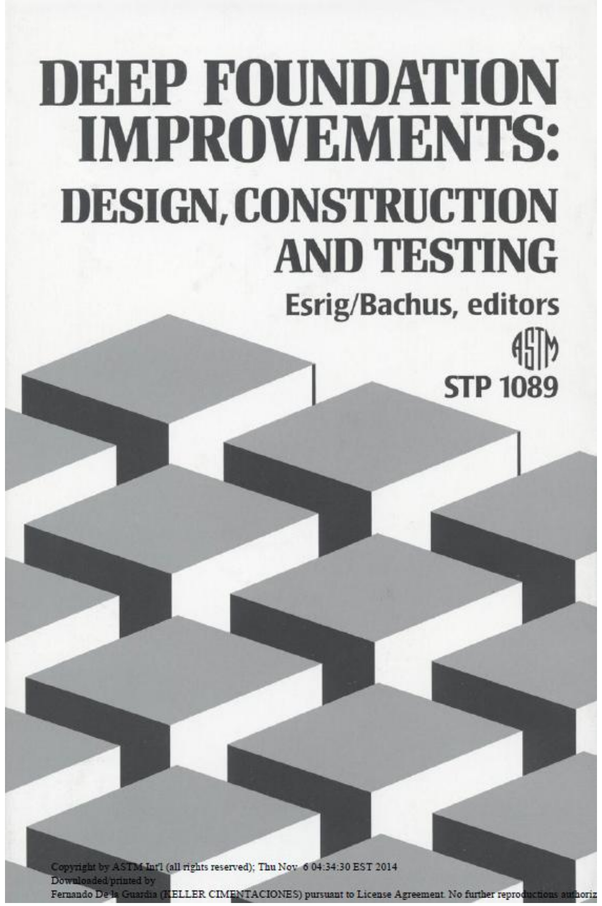
Vibroreplacement (Stone Columns)

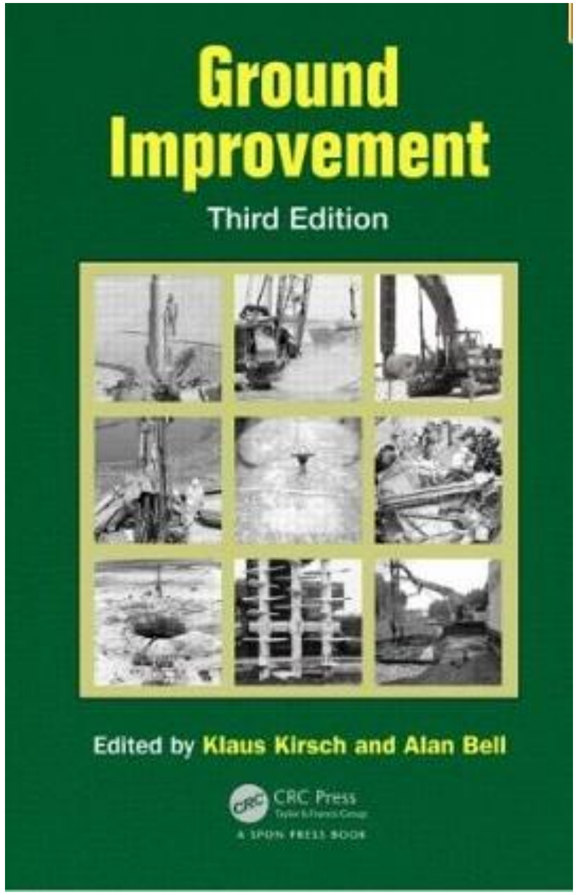
Vídeo disponível em: https://www.youtube.com/watch?v=vDe6Y8RoBIE

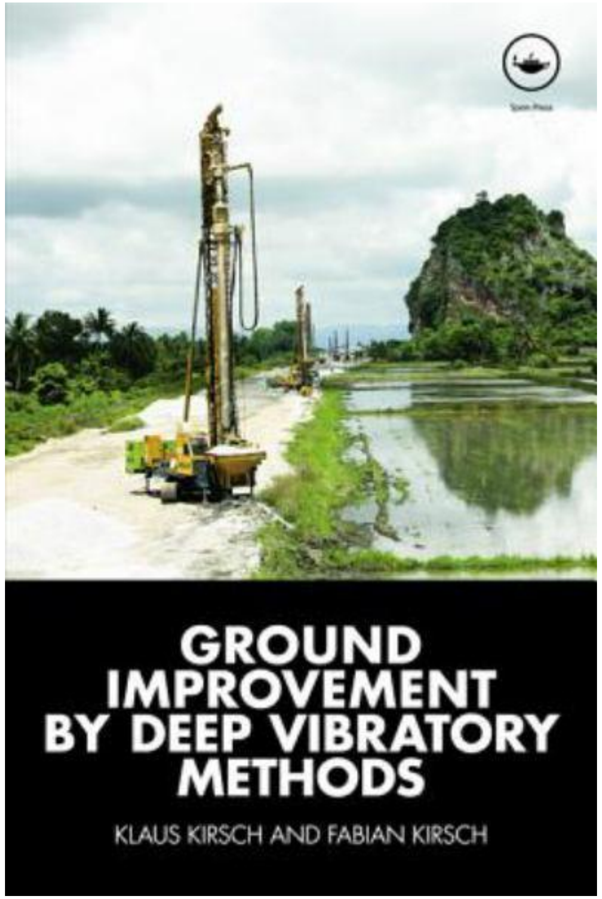
KELLER

LITERATURE: DEEP VIBRATORY TECHNIQUES









STANDARDS AND GUIDELINES

1. European Standard: BS EN 14731:2005

“Execution of special geotchnical Works – Ground treatment by Deep vibration”

(Equipment, Procedures, Materials, Qc/Qa)

BRITISH STANDARD

BS EN 14731:2005

Execution of special geotechnical works — Ground treatment by deep vibration

2. Guide: Design and Construction of Stone Columns (Vols. 1 y 2)

Federal Highway Administration USA (FHWA). 1983

2 volumes: Vol. 1 FHWA/RD-83/026 y Vol. 2 FHWA/RD-83/027

(Equipment, Procedures, Materials, Qc/Qa, Design, Examples)

DESIGN AND CONSTRUCTION OF STONE COLUMNS VOL. I

U.S. Department of Transportation

Federal Highway Administration

Research, Development, and Technology

Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101

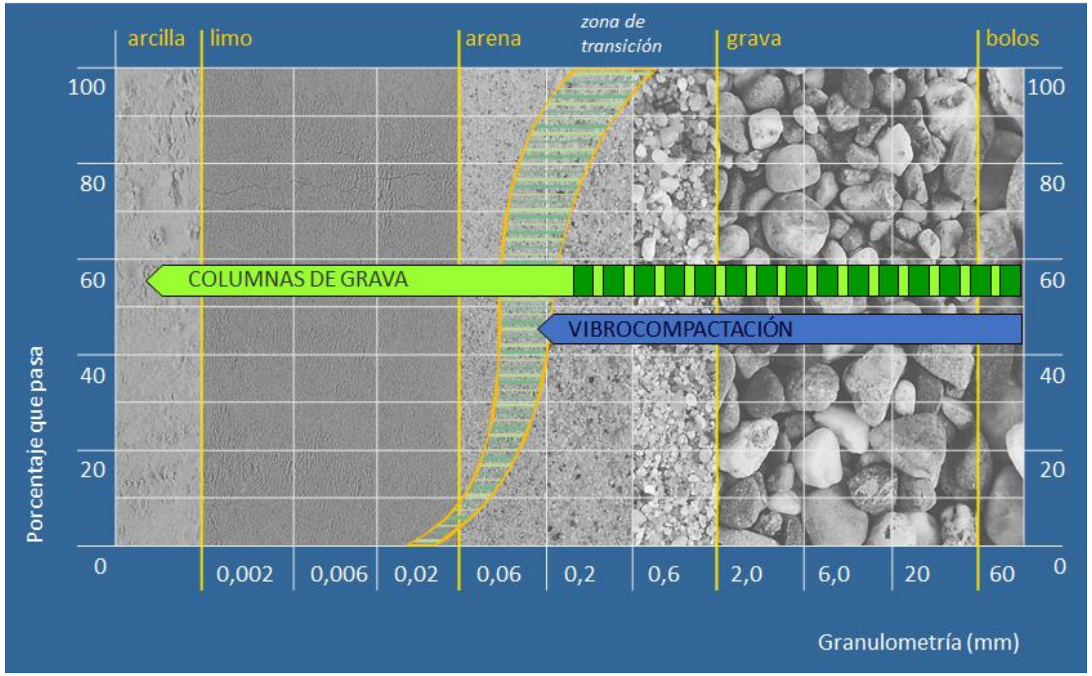
Report No. FHWA/RD-83/026

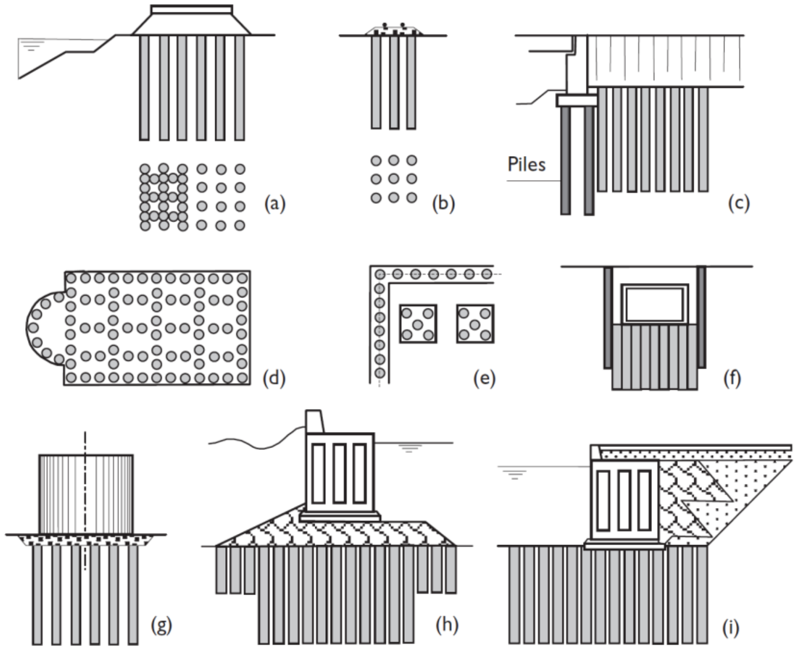
Final Report

December 1983

KELLER

IMPLEMENTATION



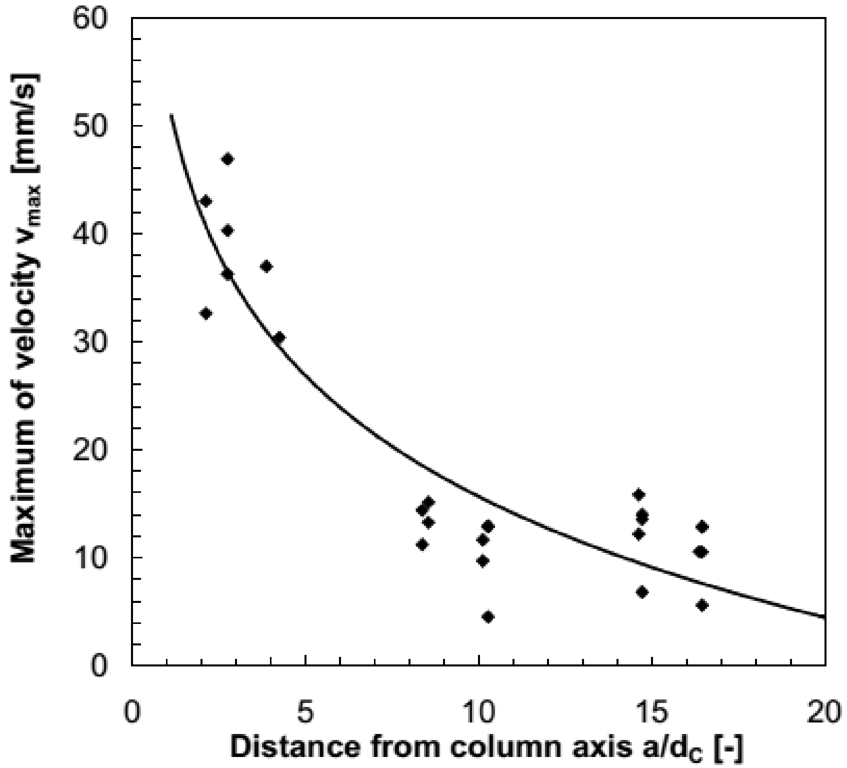


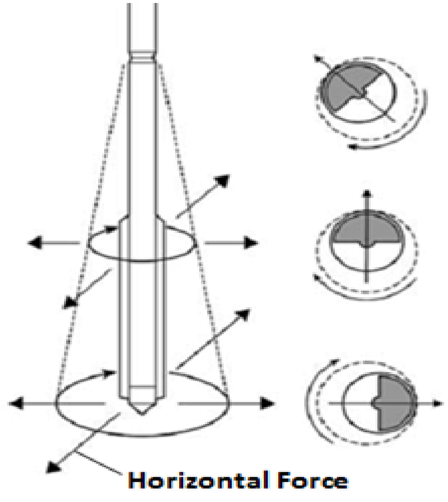
- Marine works. Near and offshore. Dykes and berths.
- Tanks, silos, large containers.
- Buildings, warehouses. Wind turbines, etc.
- Bearing Capacity
- Control of settlements. Acceleration of consolidation
- Liquefaction mitigation

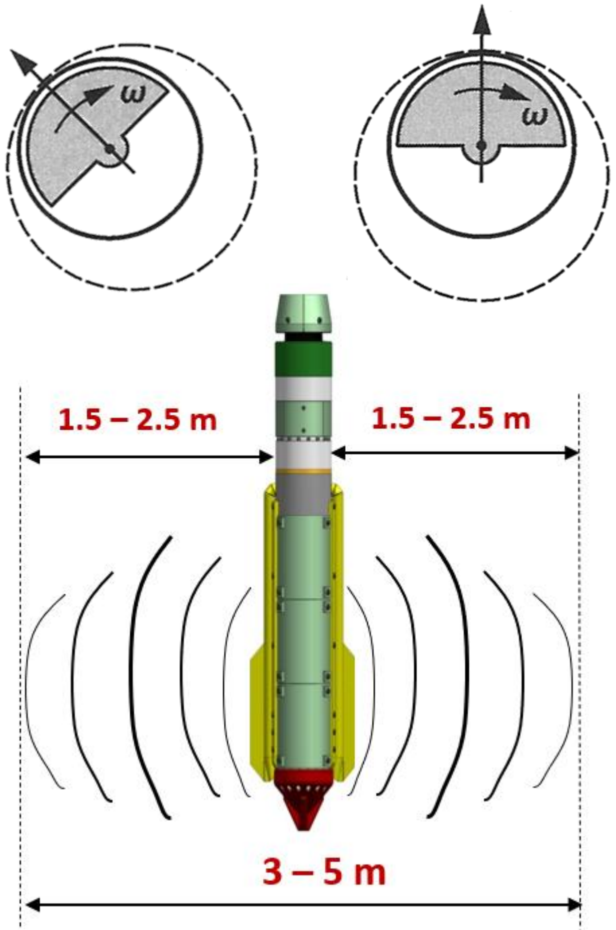
VIBROCOMPACTION

– High densification effect by:
  - Lateral displacement
  - Transferring high vibration energy

Freq. Hz	Amplitude mm	Horiz. Force kN	Weight kN	Diameter mm
25-60	6-50	150-700	15-45	300-500



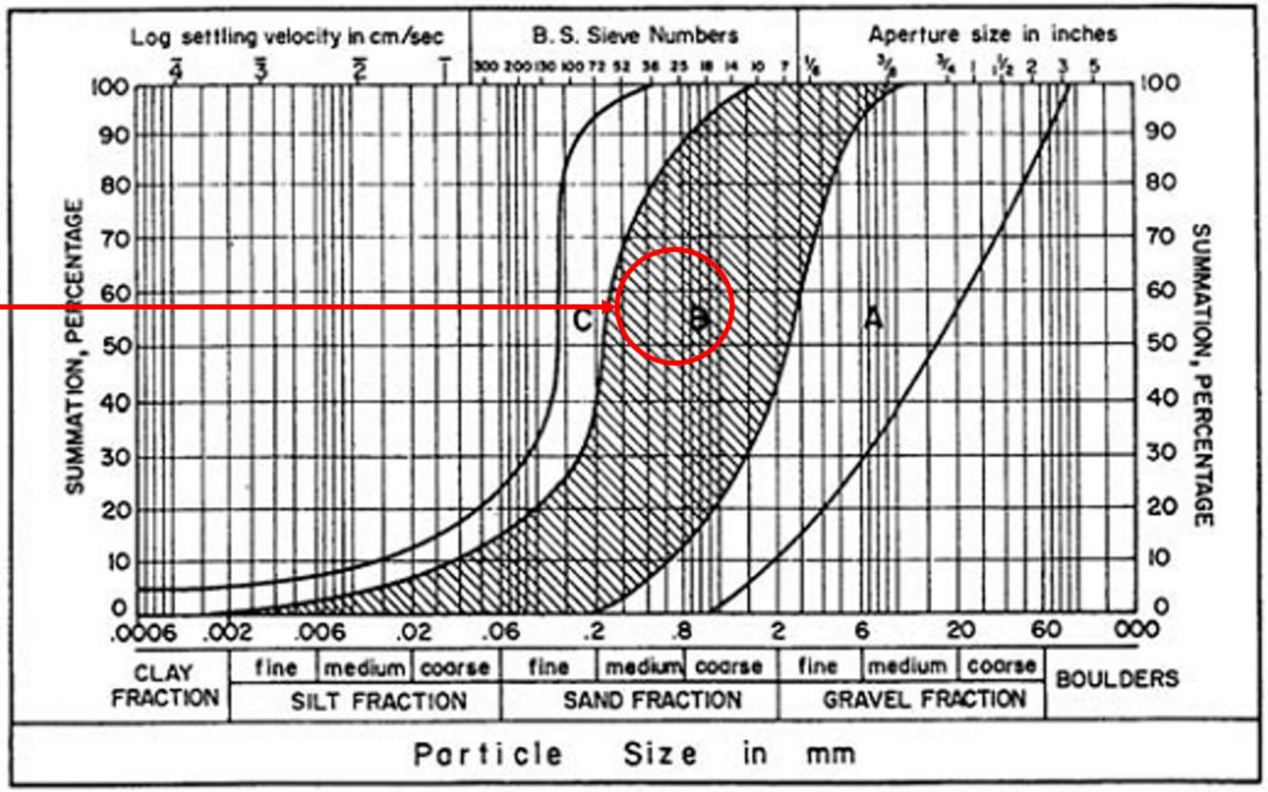




KELLER

VIBROCOMPACTION: Preliminary assessment

Suitable zone for Vibrocompaction treatment



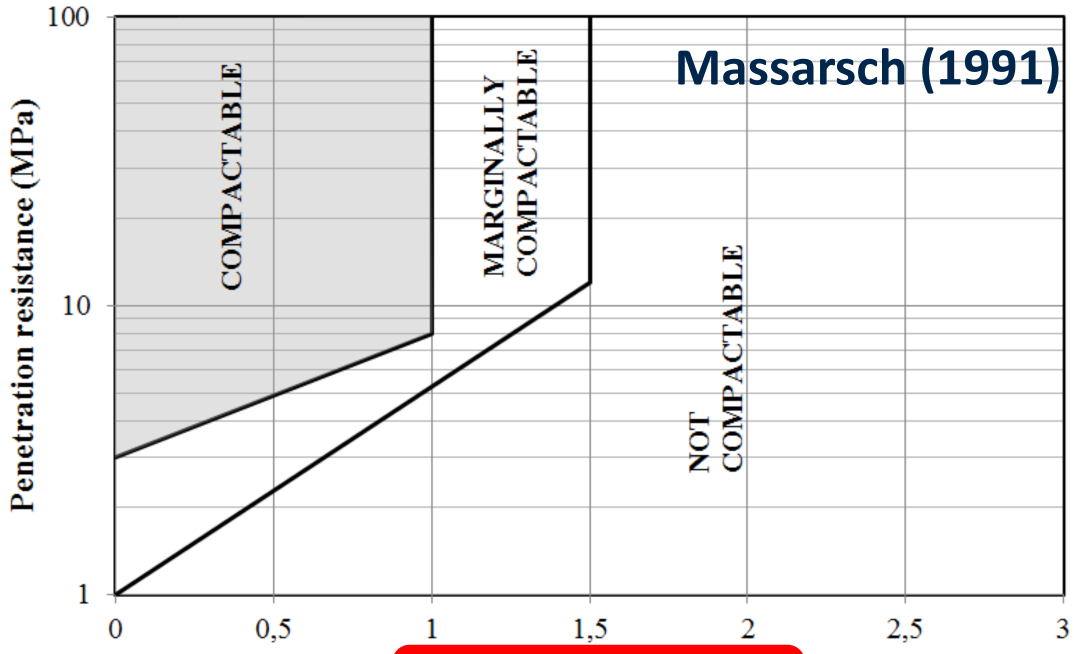
SUITBILITY NUMBER (Brown 1977)

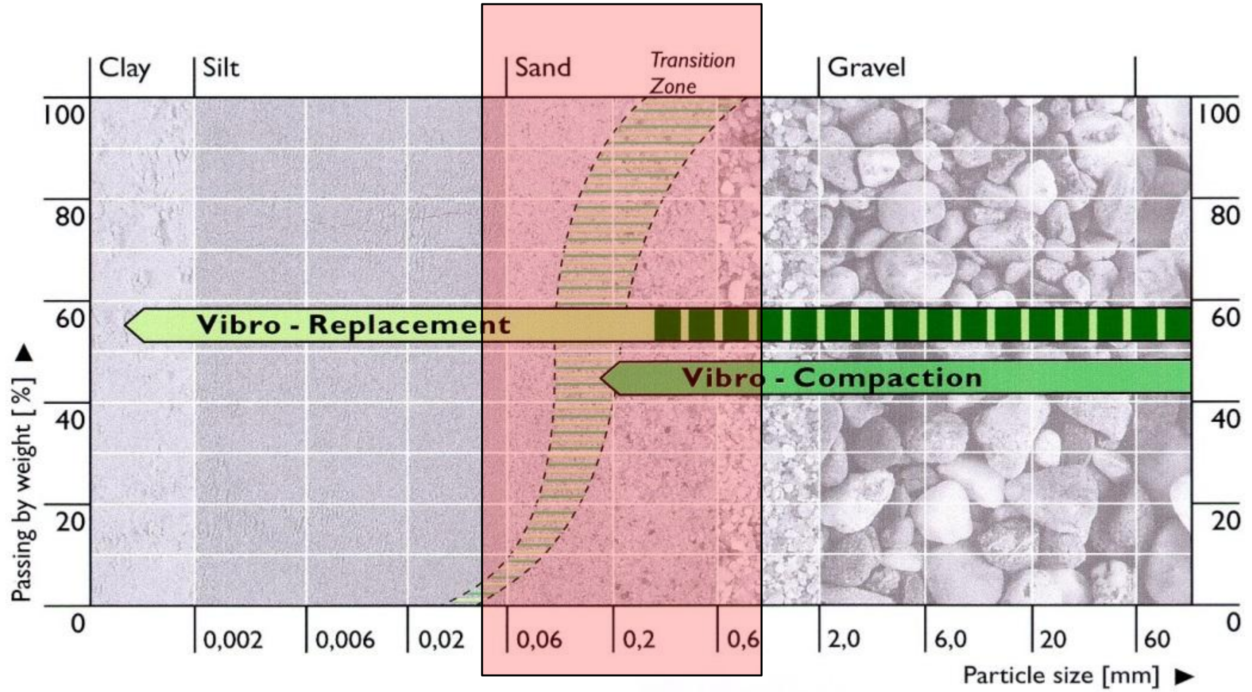
$$SN = 1.7 \cdot \sqrt{\left(\frac{3}{D_{50}^2} + \frac{1}{D_{20}^2} + \frac{1}{D_{10}^2}\right)}$$

Suitable soils for vibrocompaction
SN < 40 to 50 approx.

KELLER

VIBROCOMPACTION: Preliminary assessment

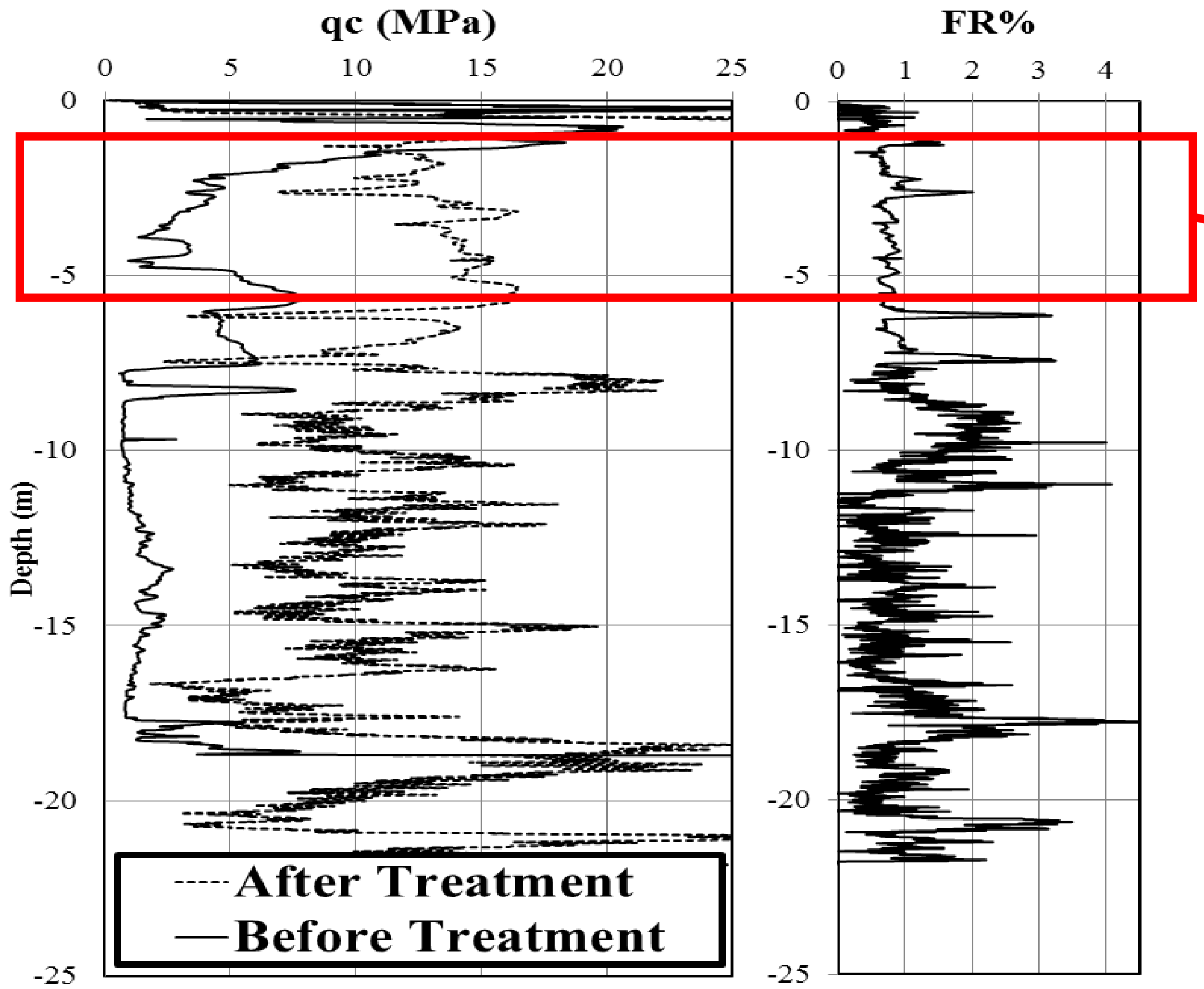


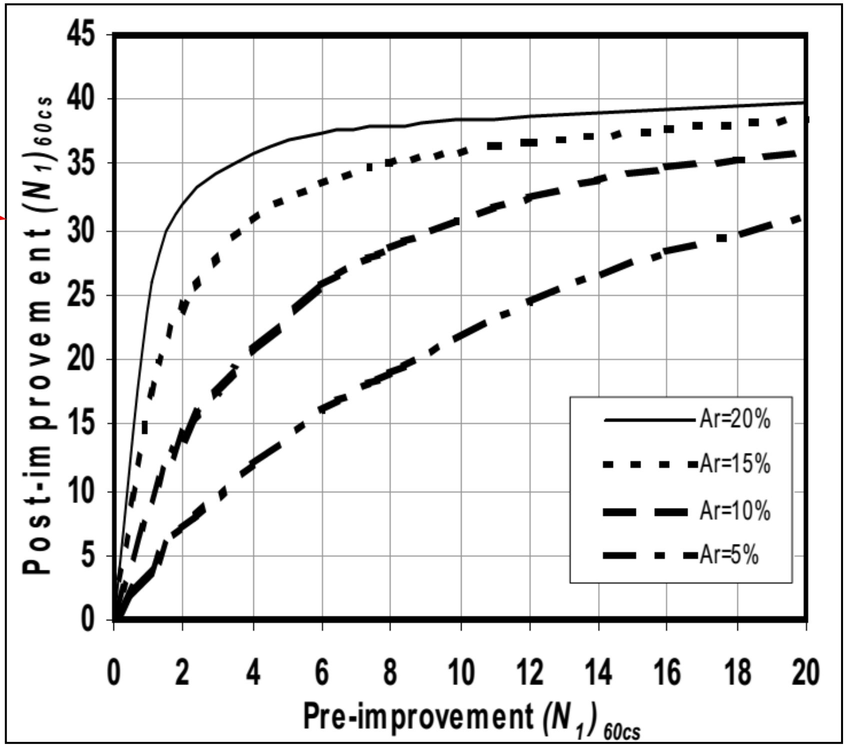


Indirect measurement of FC%

Fr% < 1,5 → Soil Behavior Index "Ic" < 2,05

VIBROCOMPACTION: Preliminary assessment

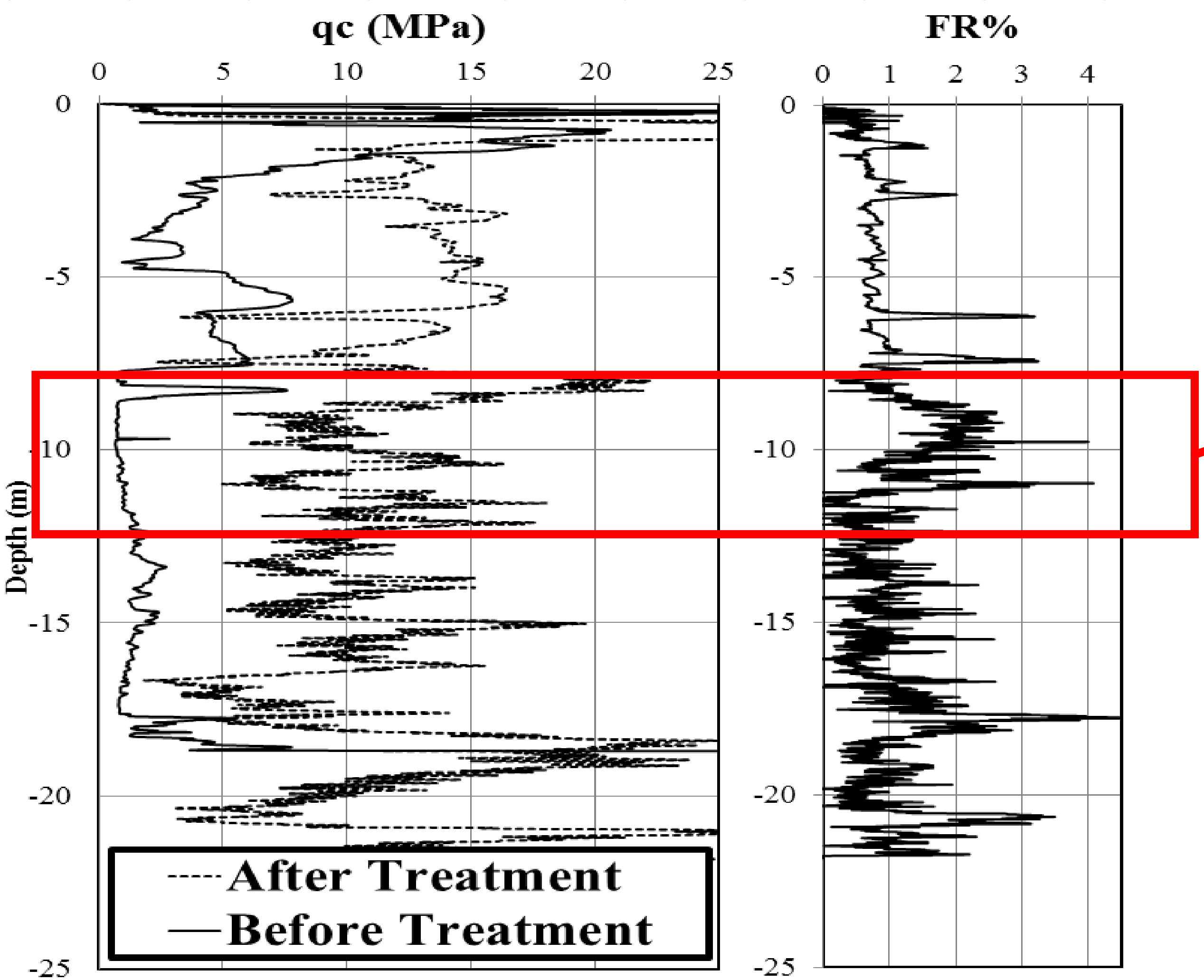


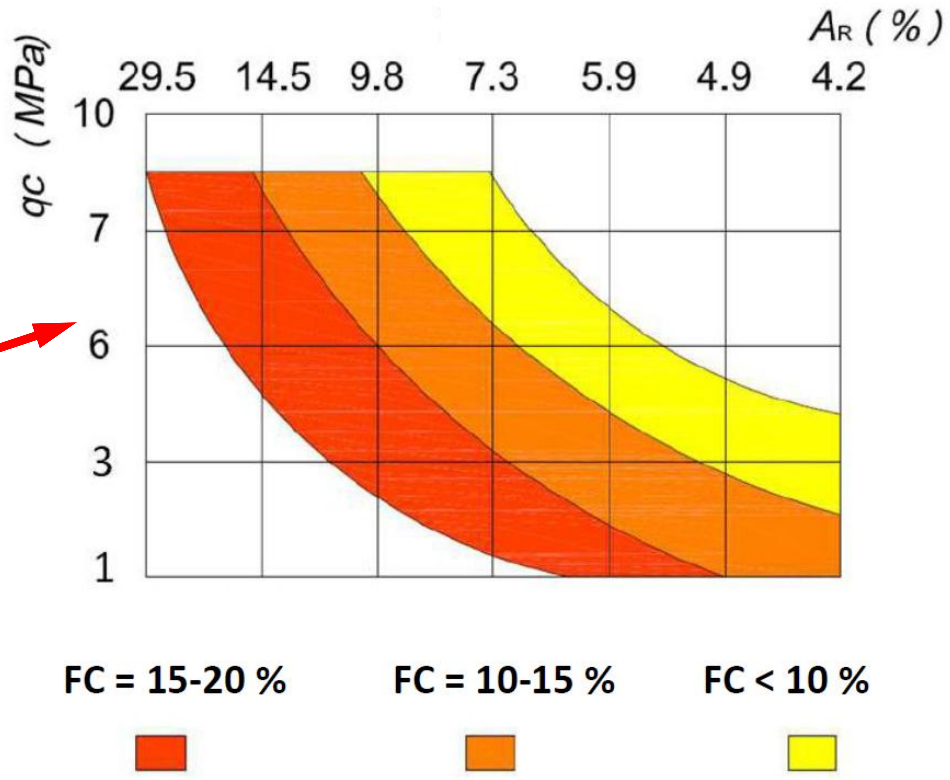


Báez (1995). Clean sand Vibroreplacement method

KELLER

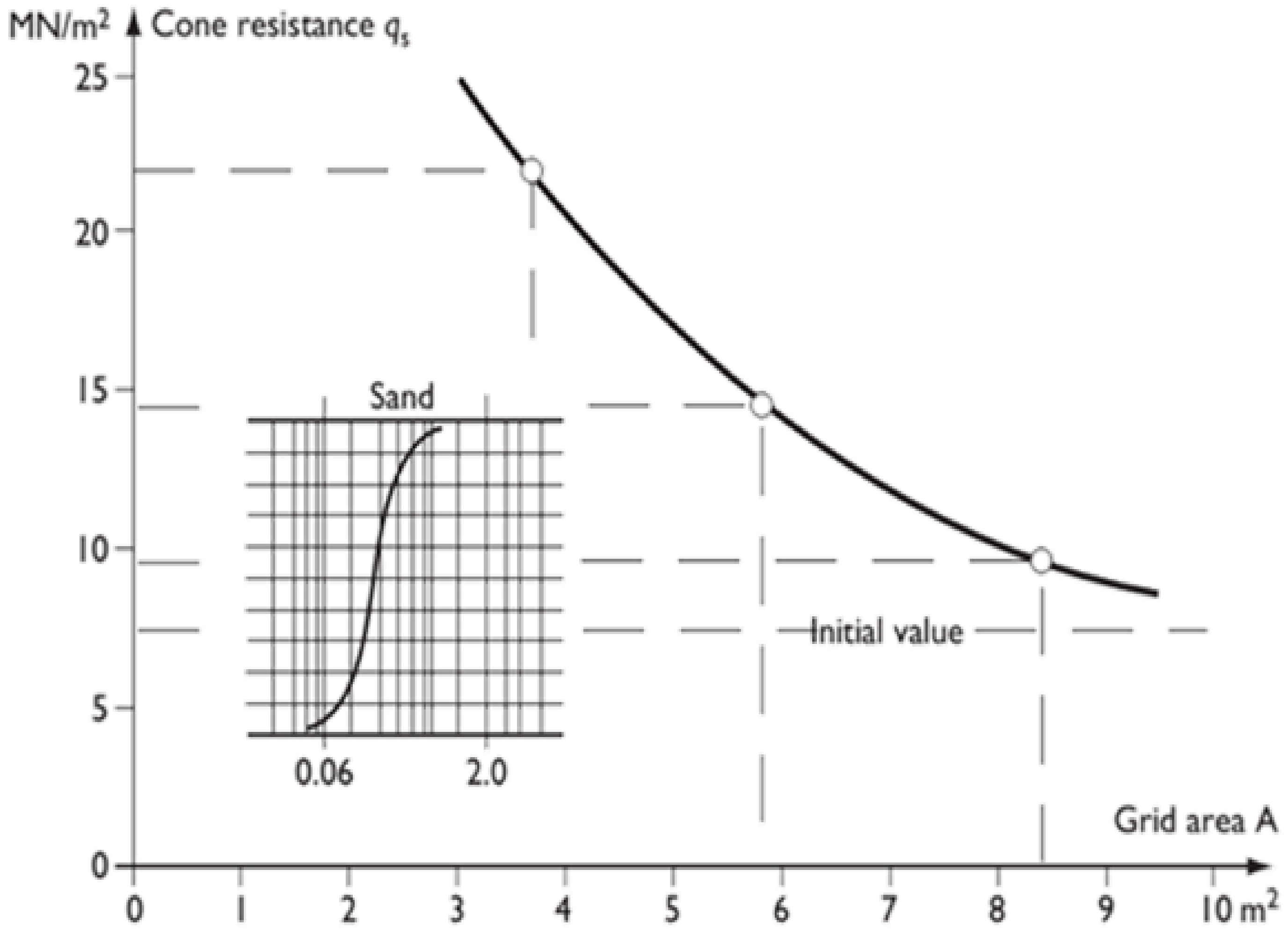
VIBROCOMPACTION: Preliminary assessment

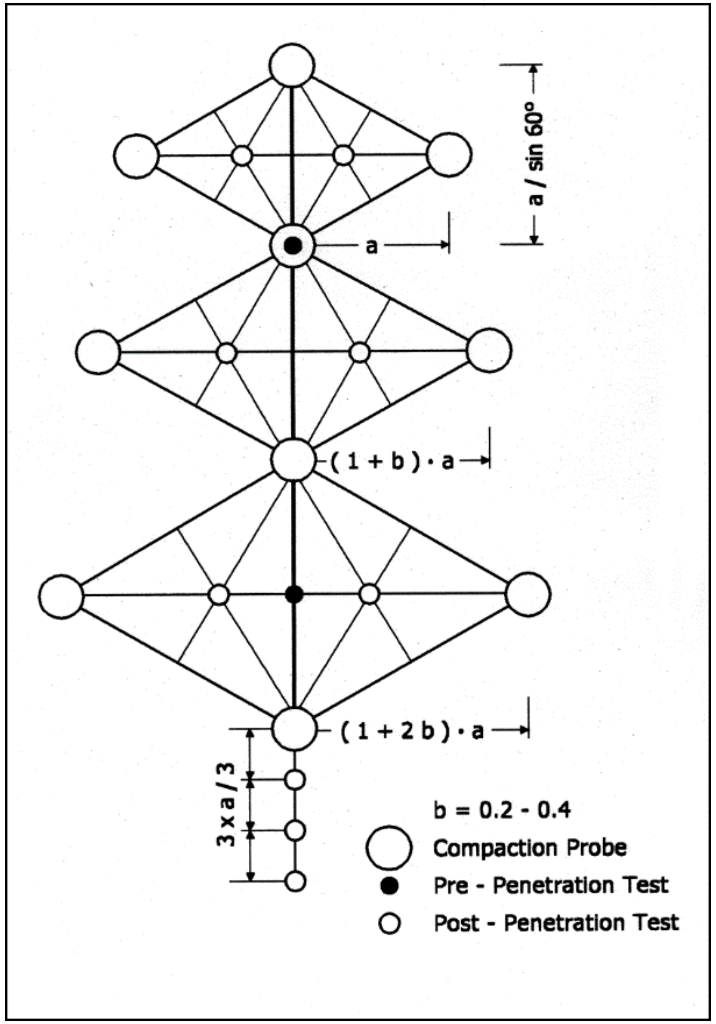




FHWA Guideline
Dobson and Slocombe (1982)

VIBROCOMPACTION: Field trails



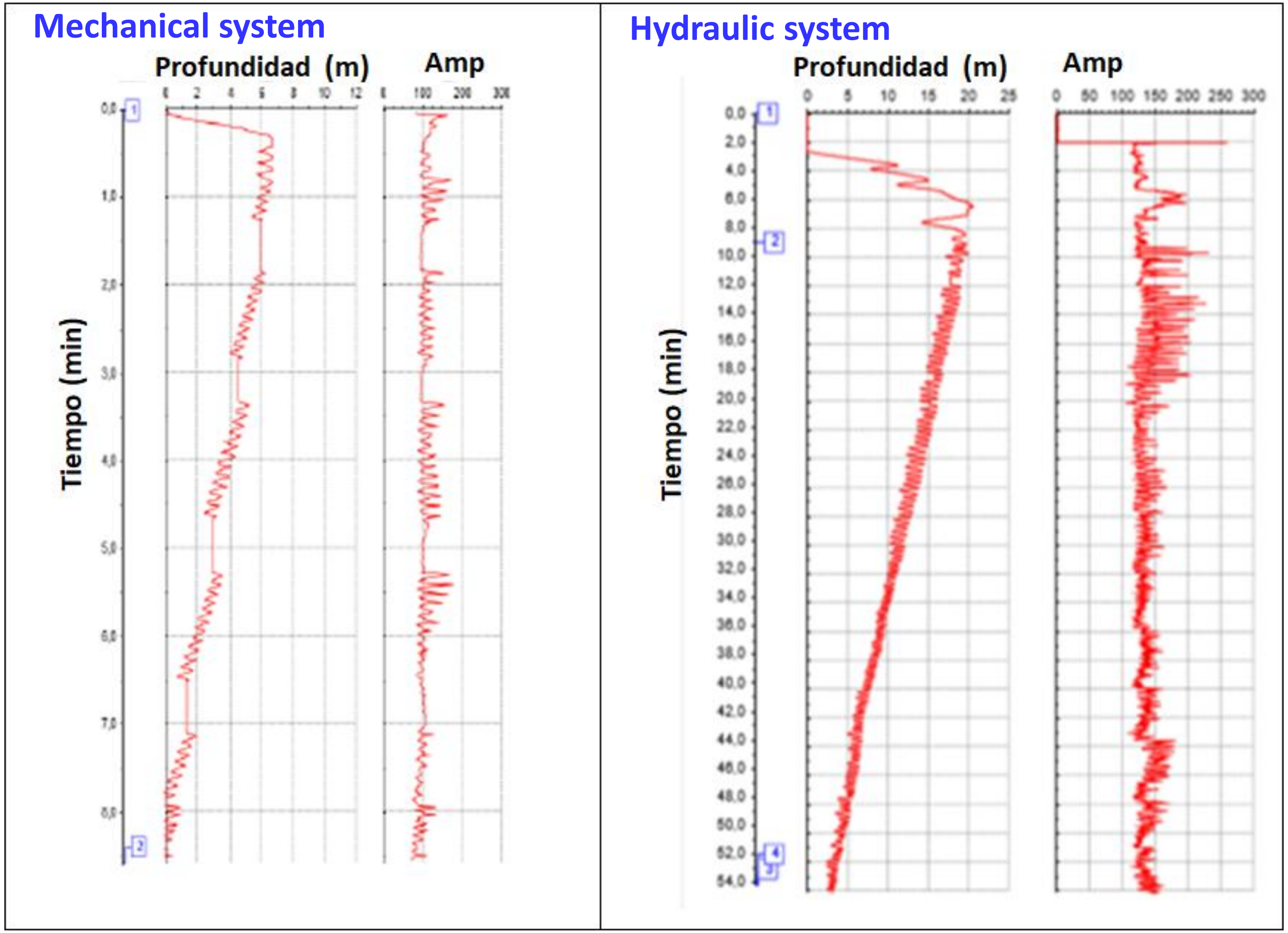


KELLER

VIBROCOMPACTION: Control system

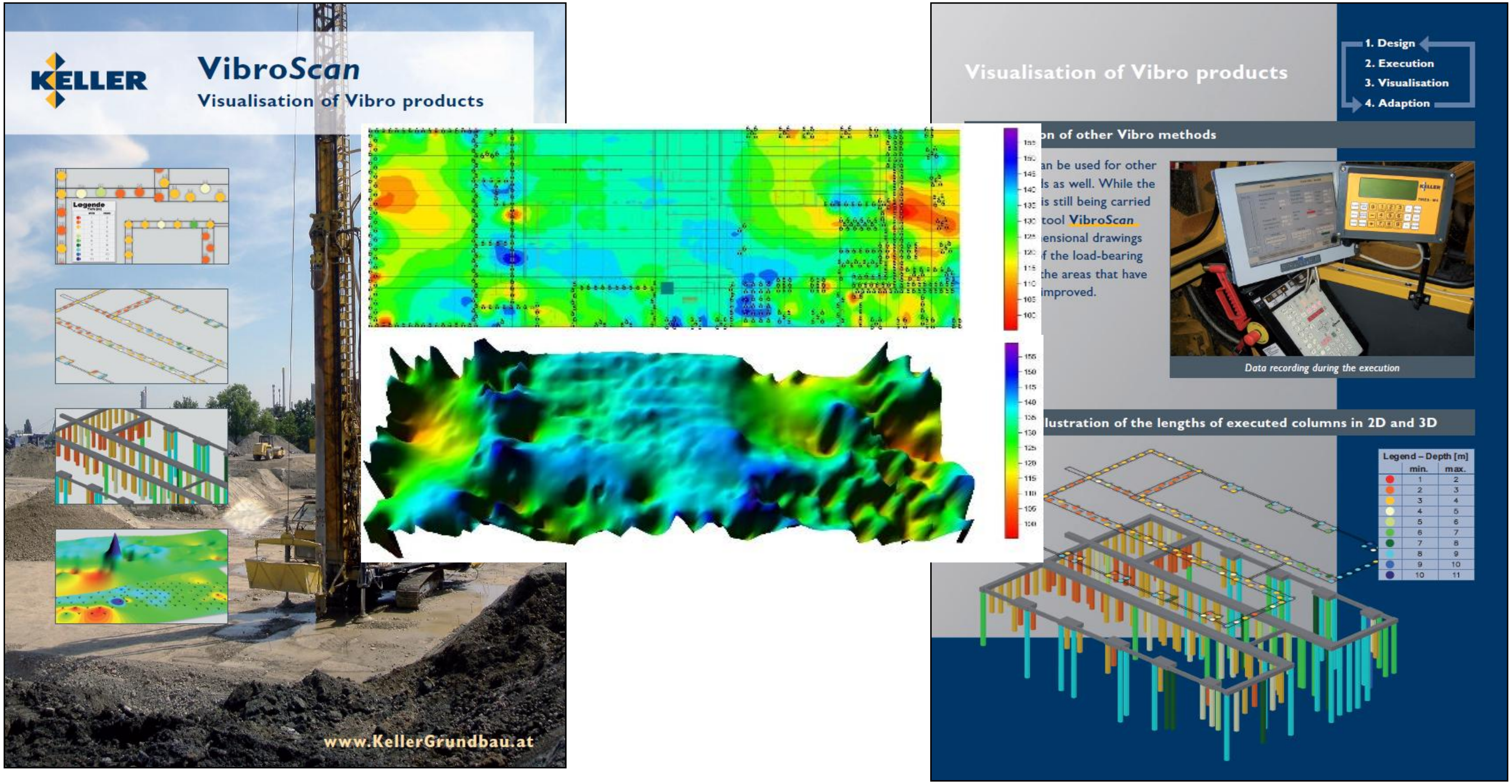
Gravel: Grain size distribution:

- 8 - 50 mm (Dry bottom feed)
- 25 - 75 mm (Wet top feed)
- Los Ángeles Abrasion test < 45 %
- Fines content less than 5% (silt)



KELLER

VIBROCOMPACTION: Control system

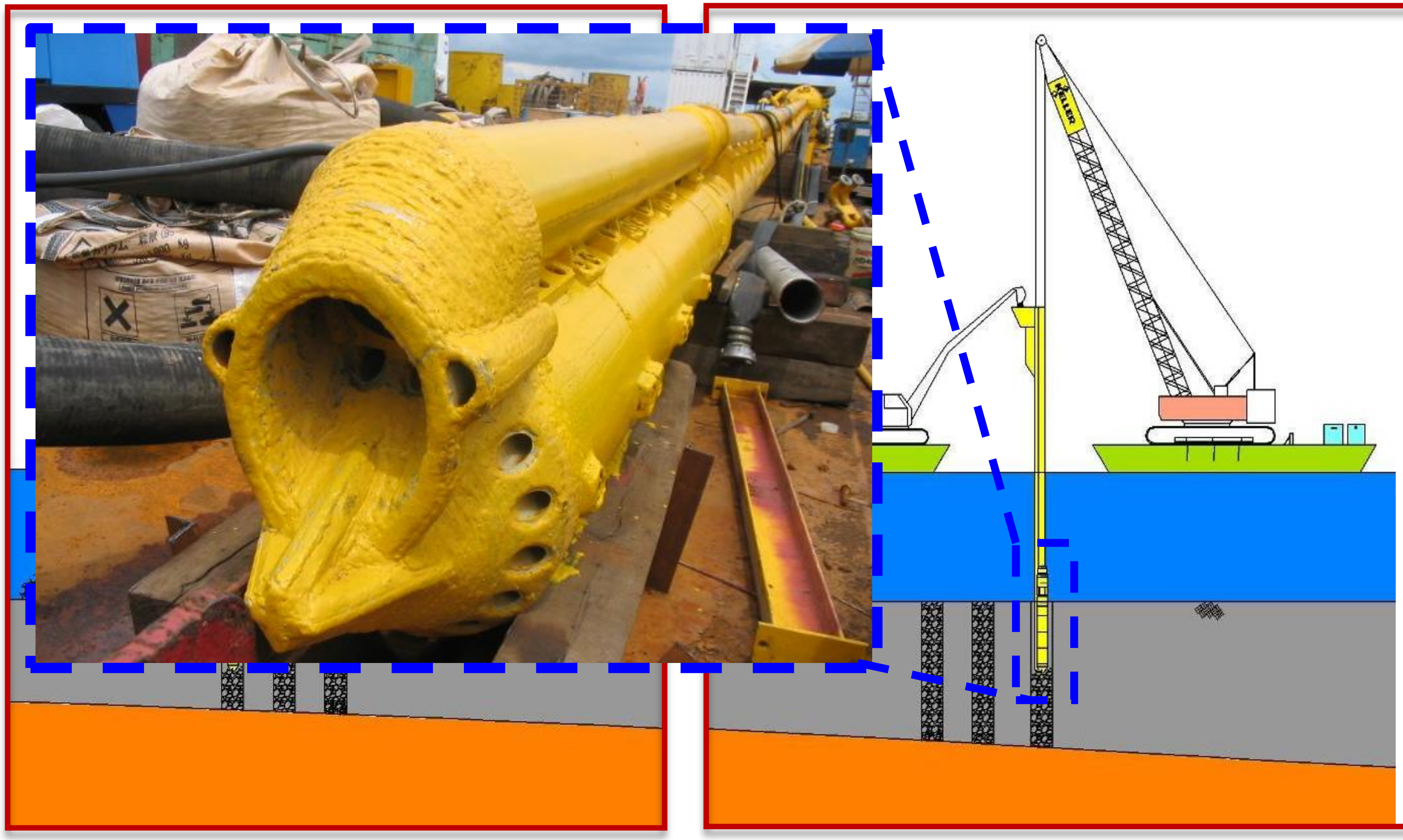


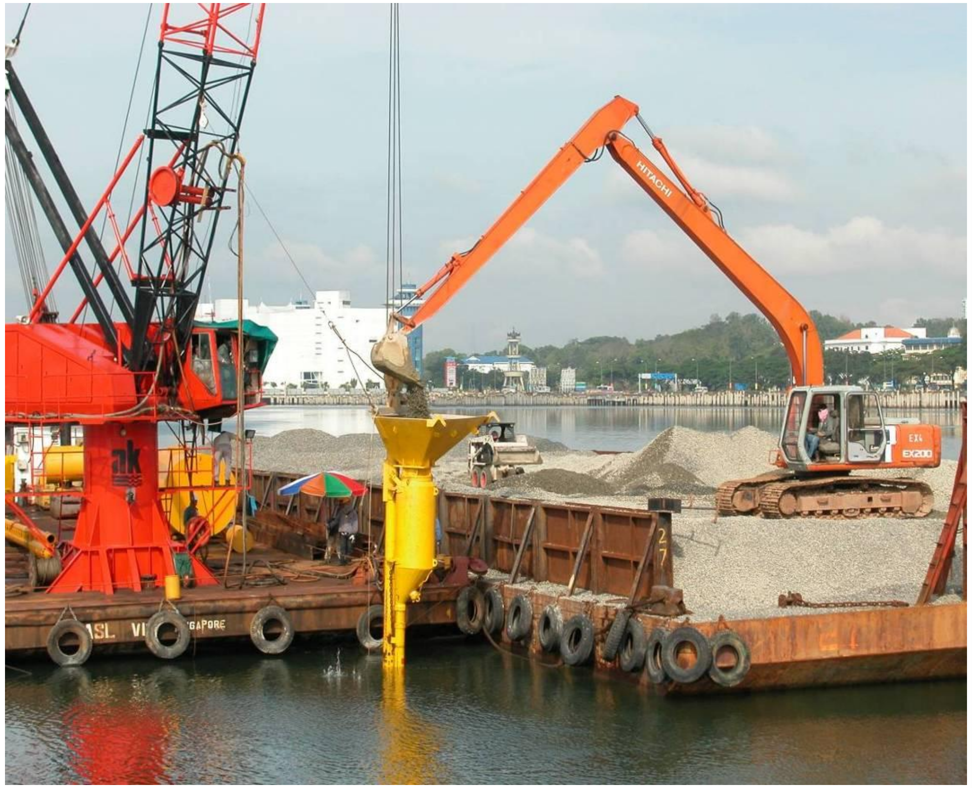
- DEEP VIBRO TECHNIQUES
- **OFFSHORE WORKS**
- LIQUEFACTION MITIGATION
- CASE HISTORIES
- CONCLUSIONS

STONE COLUMNS OFFSHORE

Gravel Bed Method

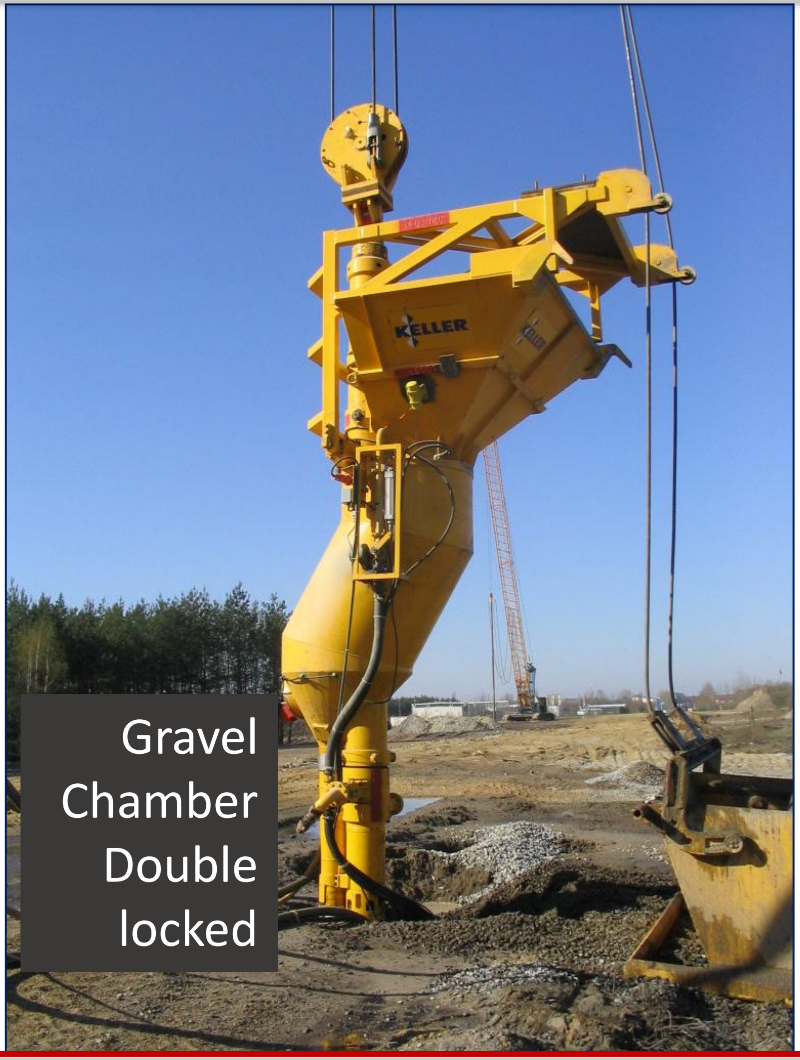
Alpha-Mechanic System (Bottom-feed)





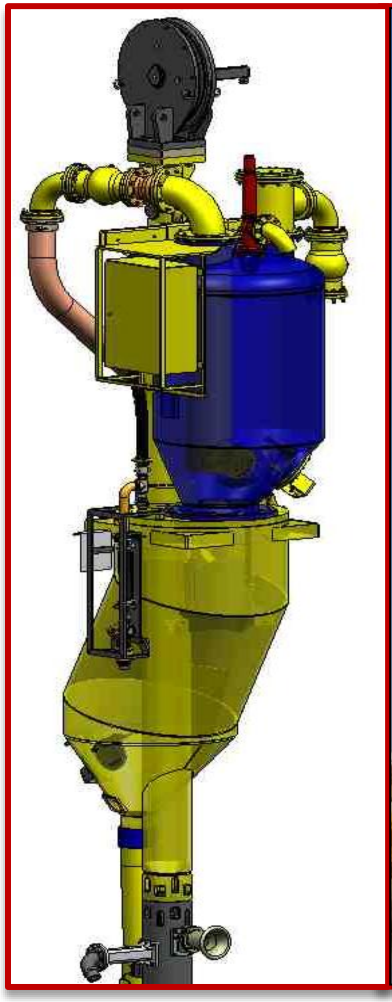
STONE COLUMNS OFFSHORE

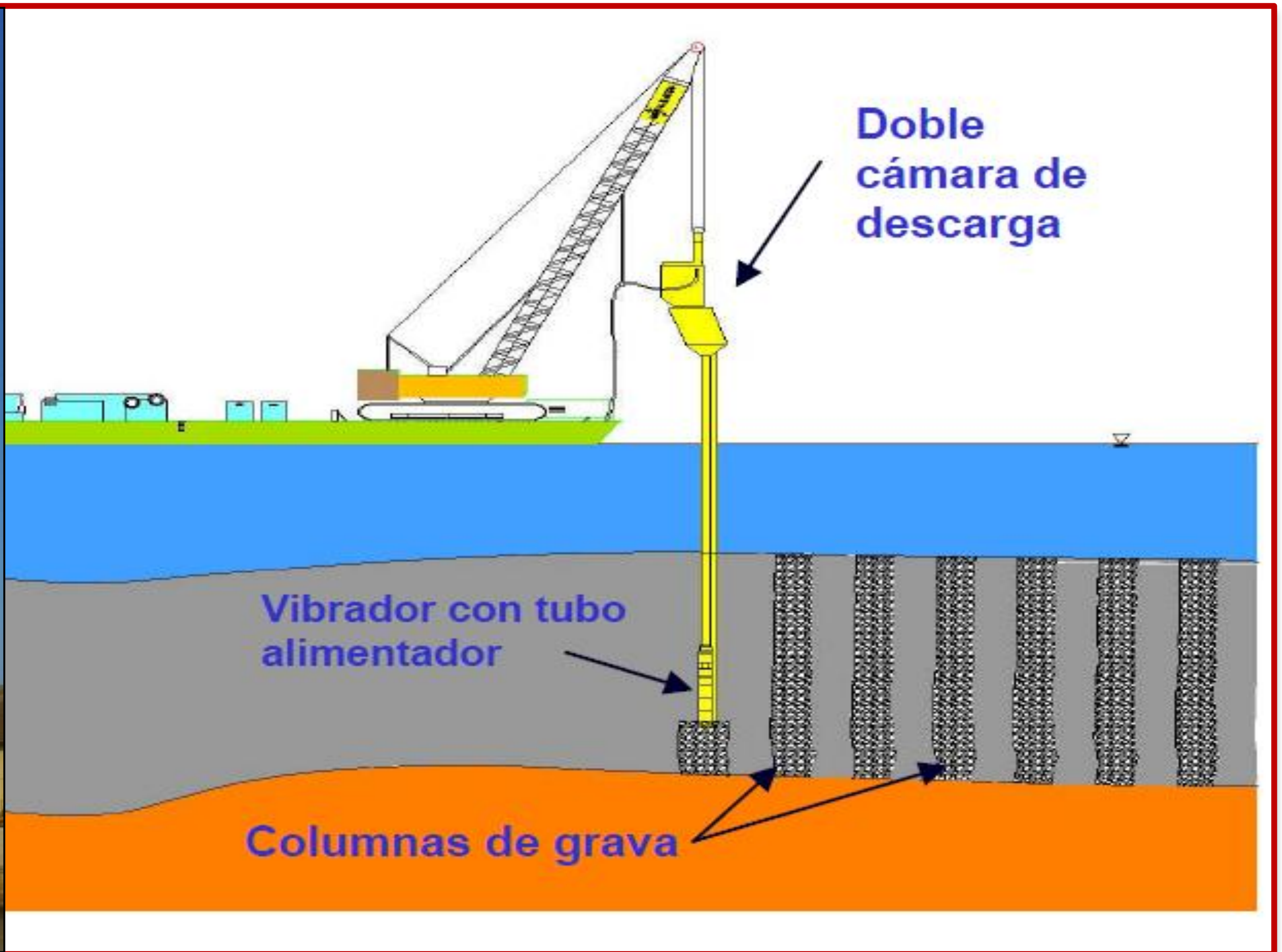
Alpha-Mechanic System (Bottom-feed)



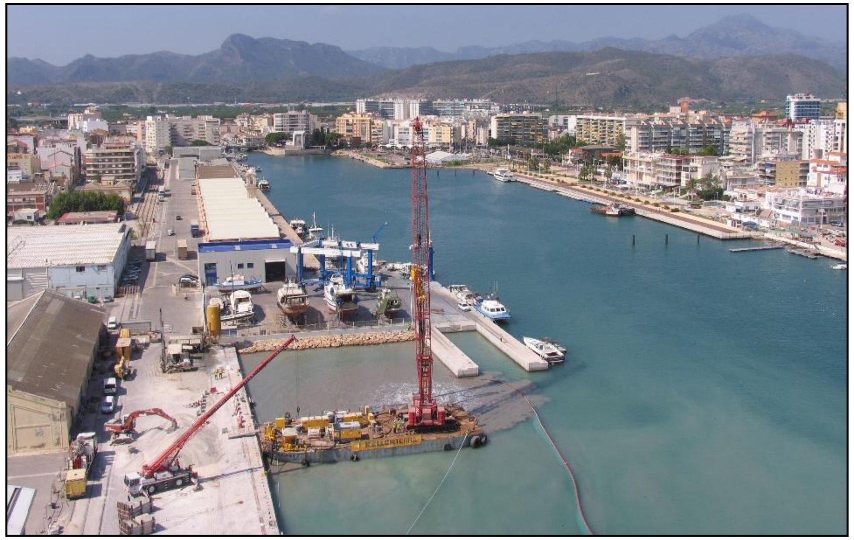
STONE COLUMNS OFFSHORE

Alpha-Hydraulic System (Bottom-feed)





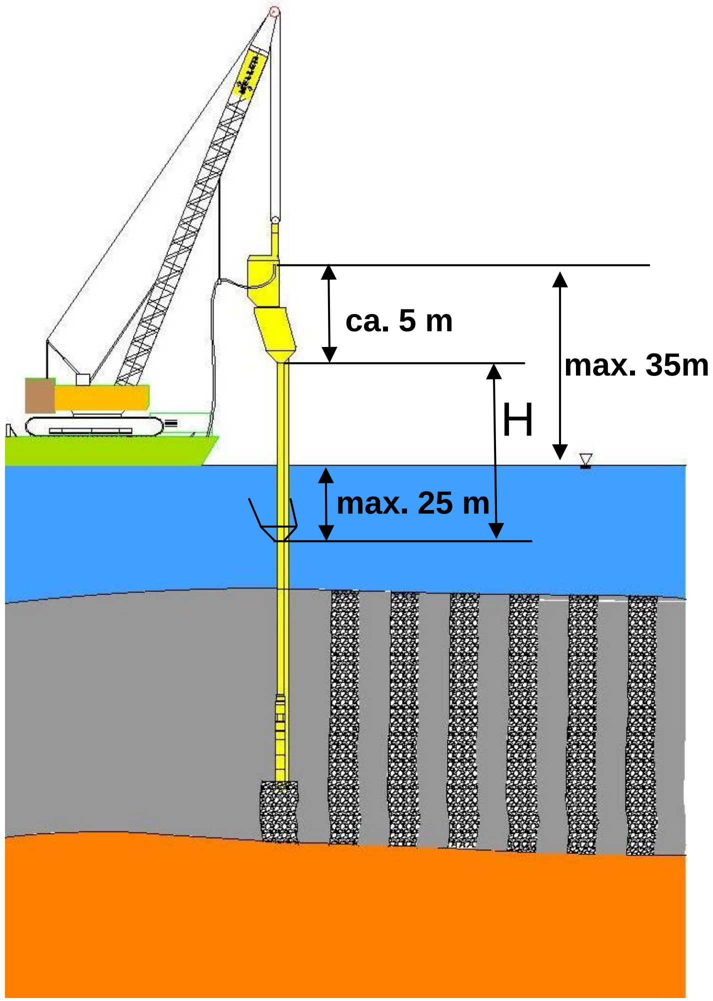
STONE COLUMNS OFFSHORE



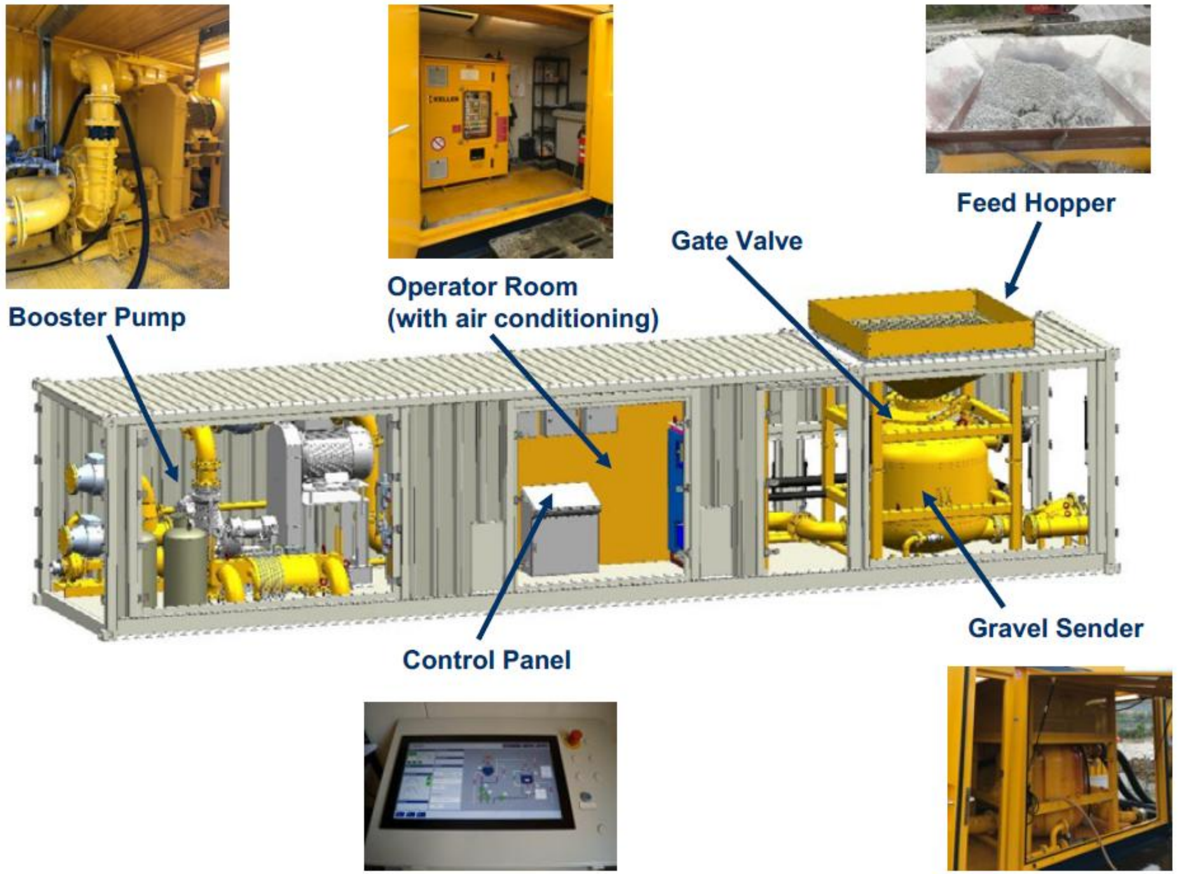
KELLER

STONE COLUMNS OFFSHORE: S-Alpha hydraulic Dive

- Completely submersible, and possible immersion depth up to 25m
- Compact set of main components in one container allowing easy assembly and disassembly
- Continuous gravel feeding
- Optimization of cranes and barges
- Productivity / performance 35-40% higher (30 – 40 lm/hr)



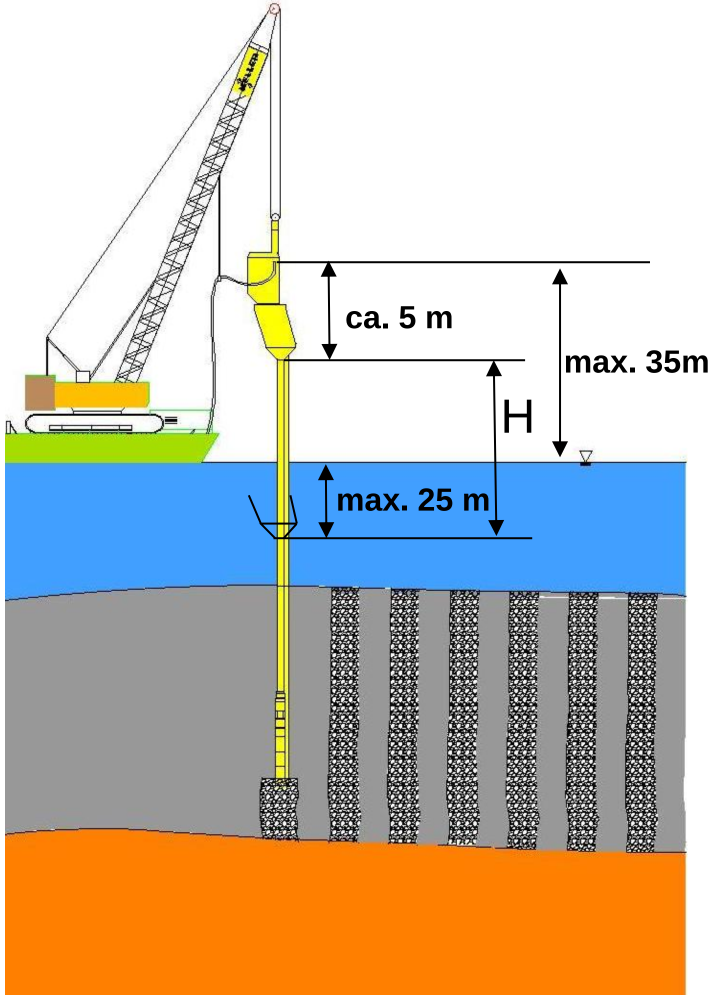
Main components

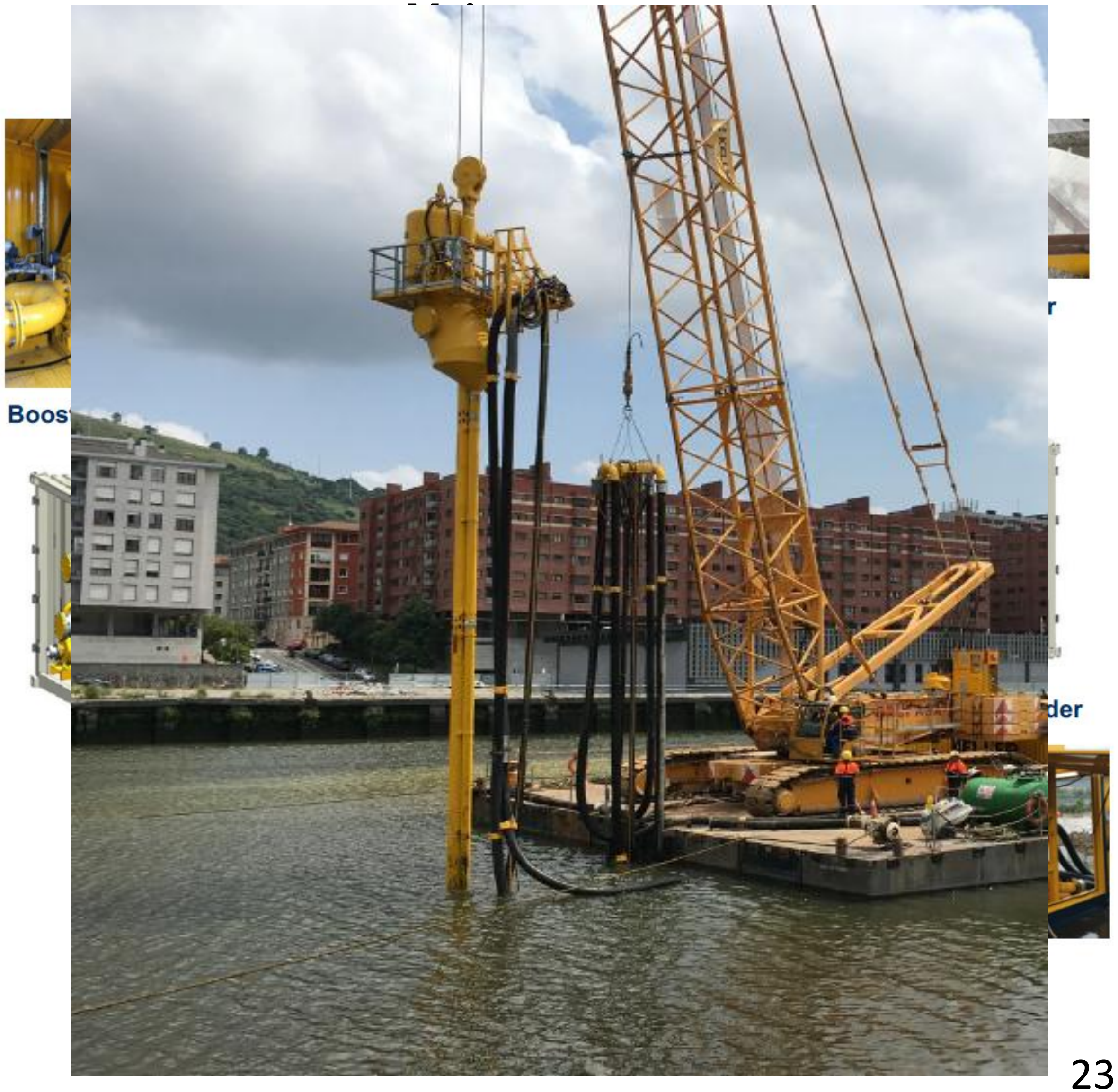


KELLER

STONE COLUMNS OFFSHORE: S-Alpha hydraulic Dive

- Completely submersible, and possible immersion depth up to 25m
- Compact set of main components in one container allowing easy assembly and disassembly
- Continuous gravel feeding
- Optimization of cranes and barges
- Productivity / performance 35-40% higher (30 – 40 lm/hr)



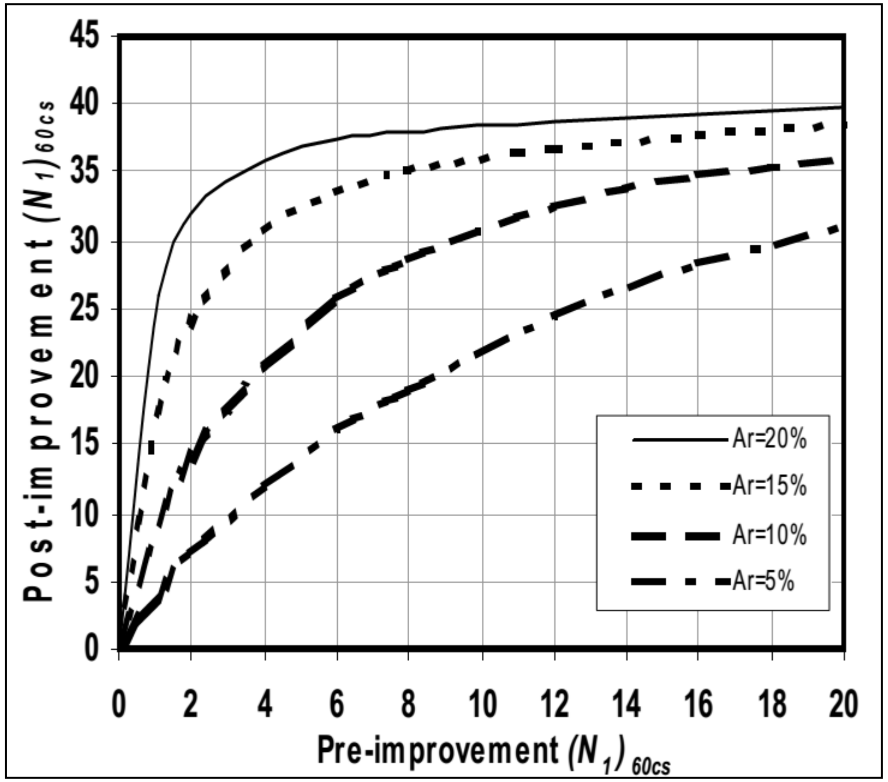


KELLER

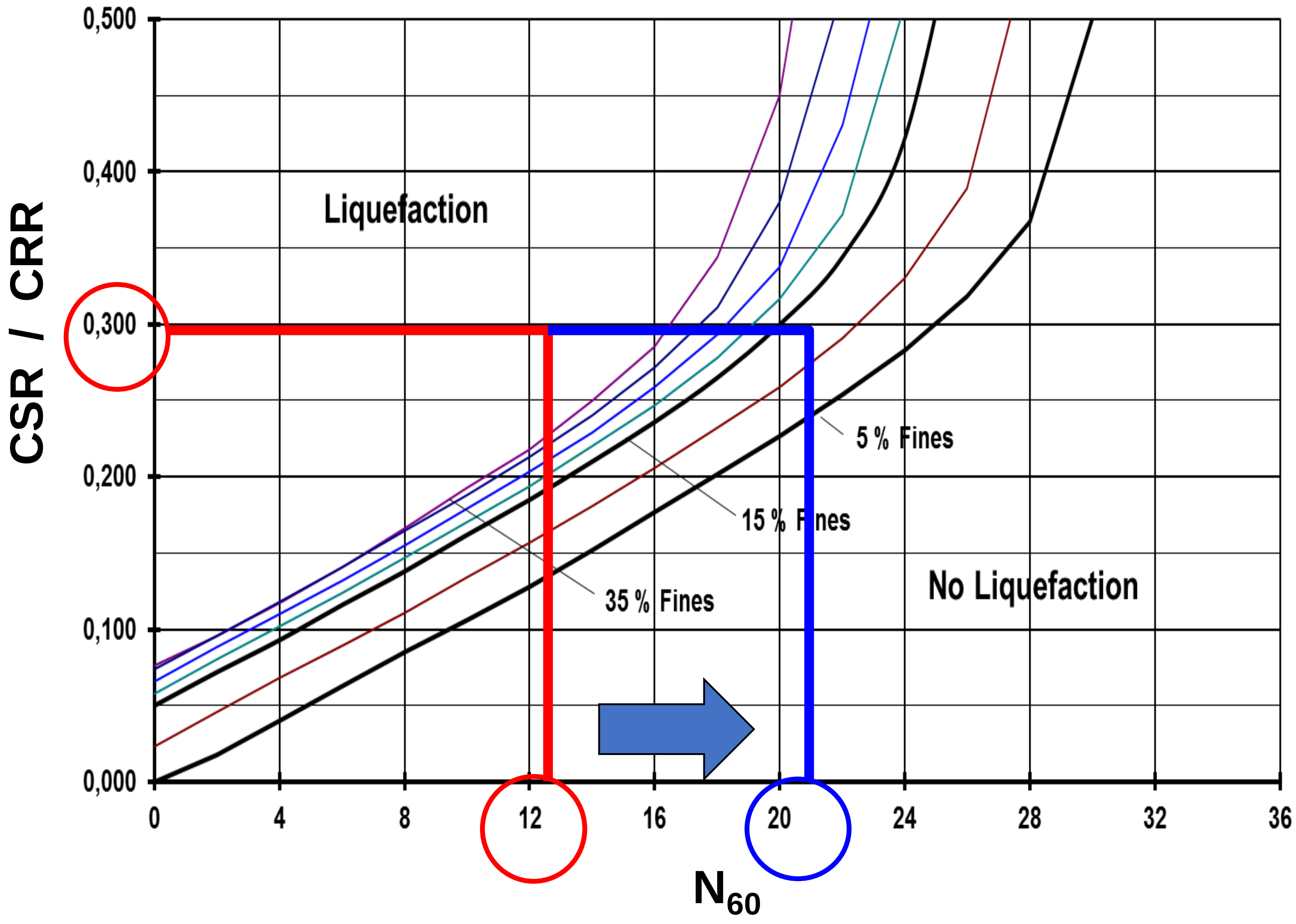
- DEEP VIBRO TECHNIQUES
- OFFSHORE WORKS
- **LIQUEFACTION MITIGATION**
- CASE HISTORIES
- CONCLUSIONS

LIQUEFACTION MITIGATION

Densification effect → Increase cyclic resistance – CRR (Báez 1995)



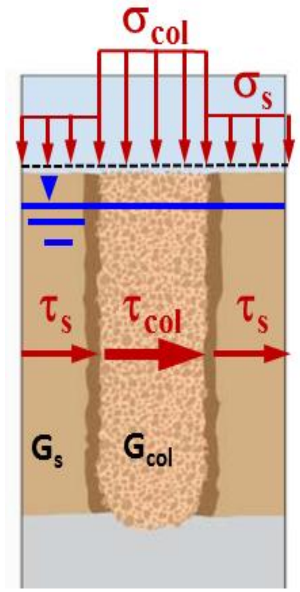
Báez (1995) Vibroreplacement

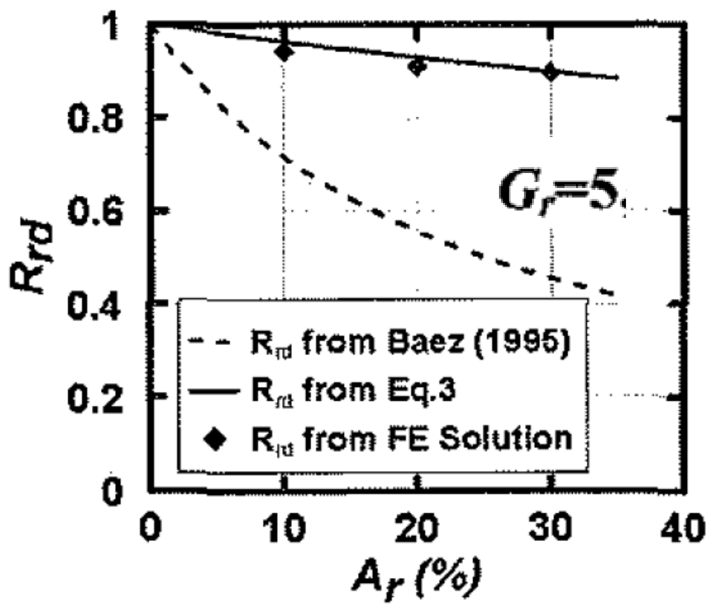


LIQUEFACTION MITIGATION

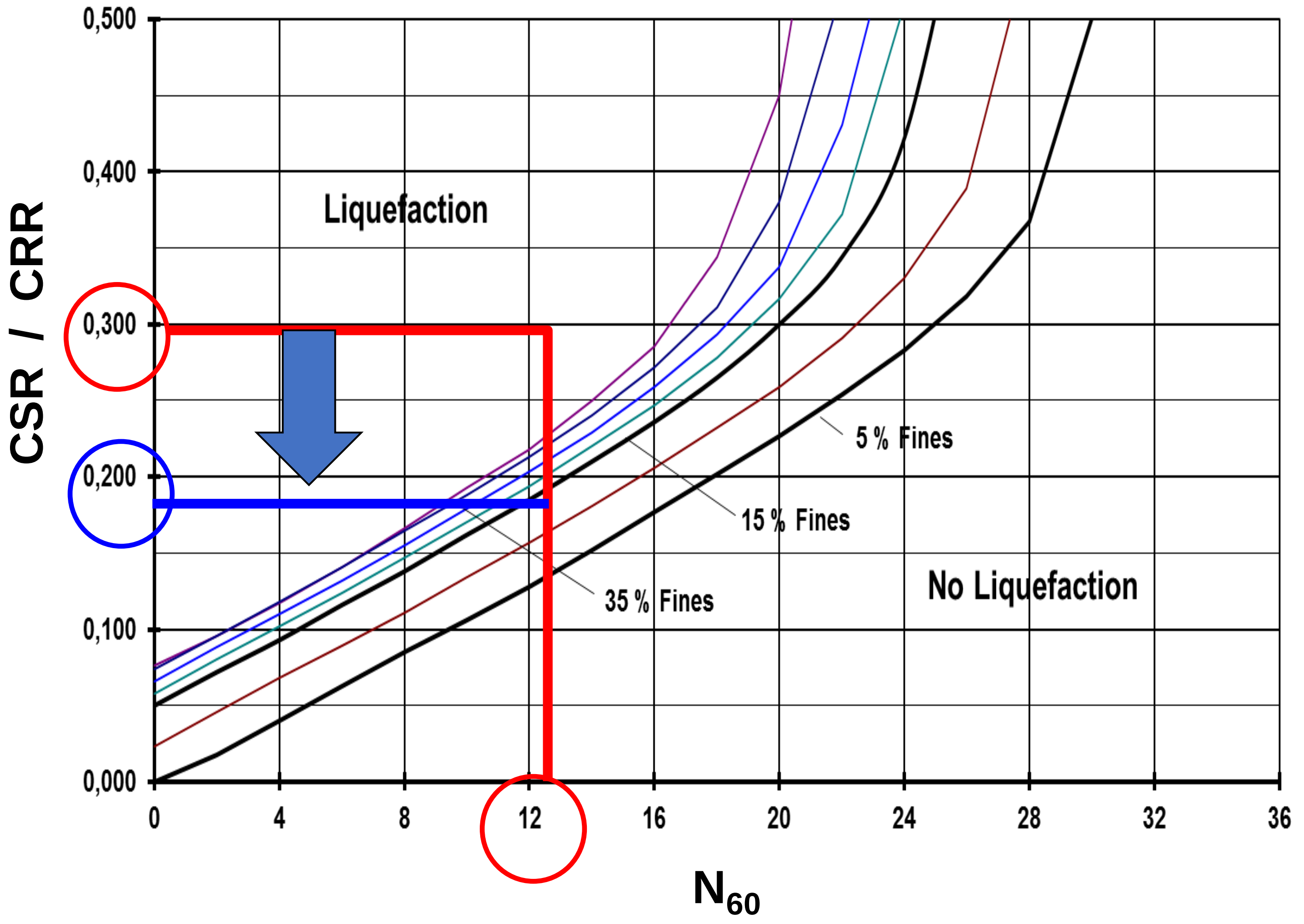
Densification effect → Increase cyclic resistance – CRR (Báez 1995)

Reinforcement effect →Reduced the induced shear stress– CSR (Priebe 1995)





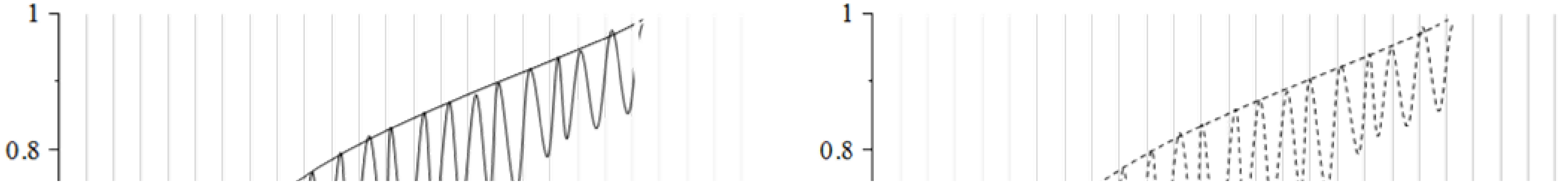
Reinforcement effect
Rayamajhi et al. (2012)



LIQUEFACTION MITIGATION

Densification effect → Increase cyclic resistance – CRR (Báez 1995)
Reinforcement effect →Reduced the induced shear stress– CSR (Priebe 1995)
Drainage effect → Rapid dissipation of PWP during the earthquake (Seed y Booker 1976)

Pore pressure ratio, $\mathbf{r_u = u_g / \sigma`_v}$



XV Buenos Aires 2015
CONGRESO PANAMERICANO DE MECÁNICA DE SUELOS E INGENIERÍA GEOTÉCNICA

Liquefaction mitigation by soil improvement with vibro stone columns

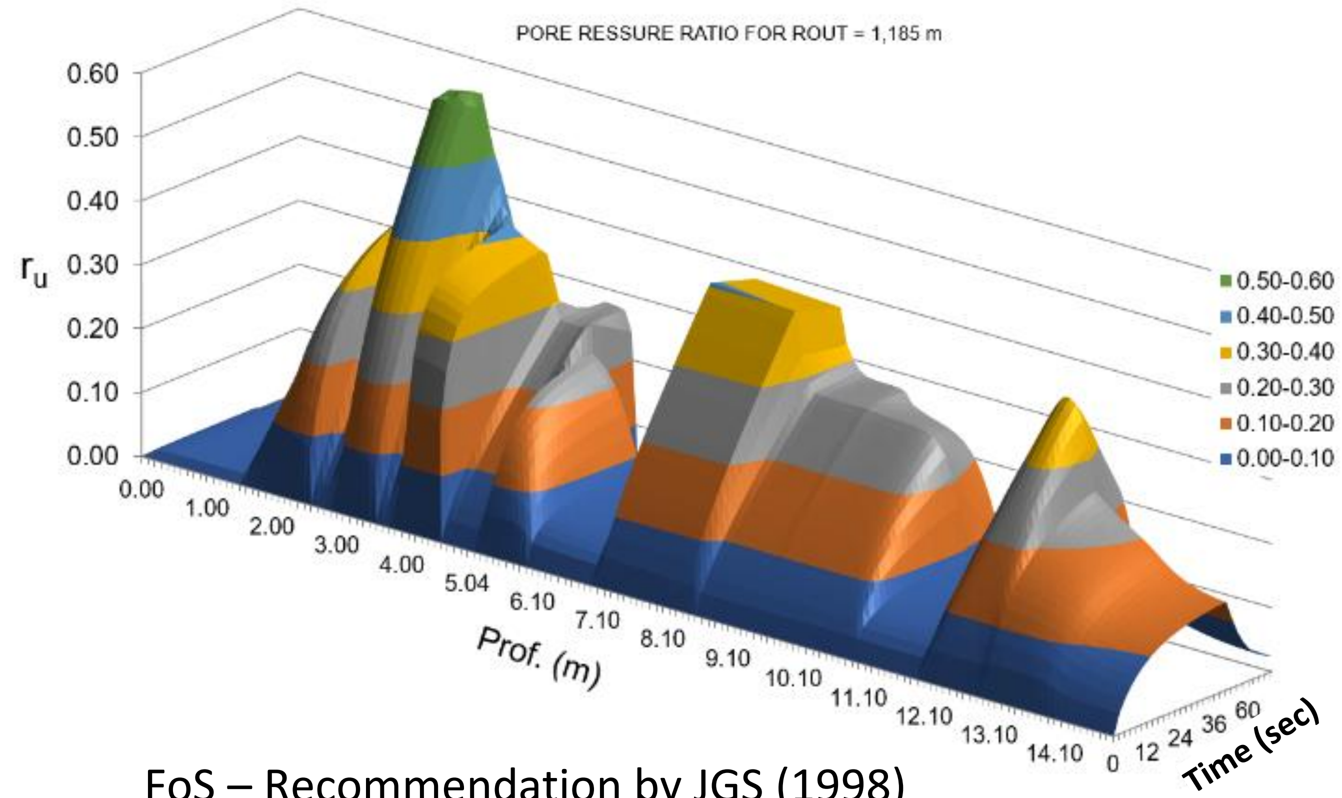
Enmanuel CARVAJAL DÍAZ[a,1], Goran VUKOTIĆ[a] and Daniel MARTÍNEZ OVIEDO[b]

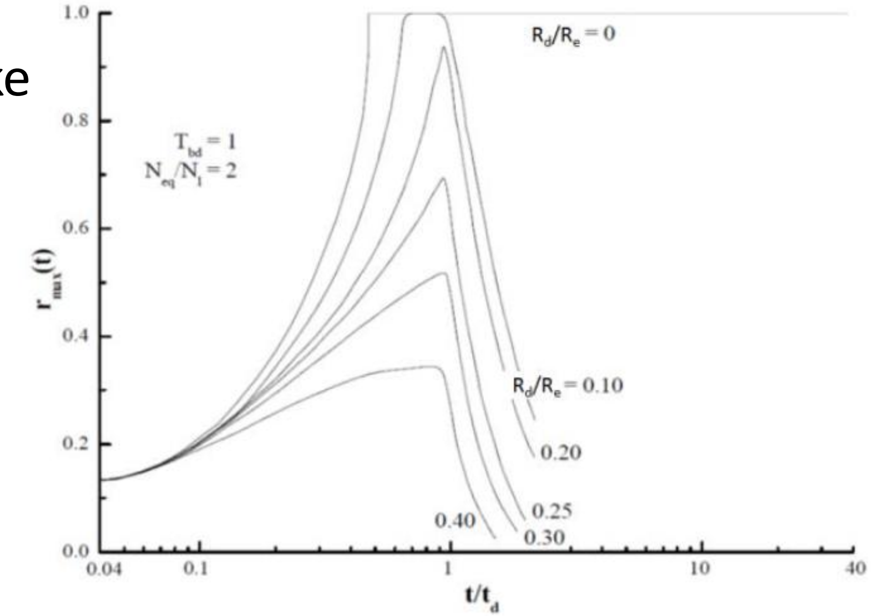
[a] *Keller Cimentaciones, S.L.U., Madrid, Spain.*
[b] *Keller Cimentaciones de Latinoamérica, S.A. de C.V., México D.F., México.*

KELLER

LIQUEFACTION MITIGATION

Drainage effect → Rapid dissipation of PWP during the earthquake

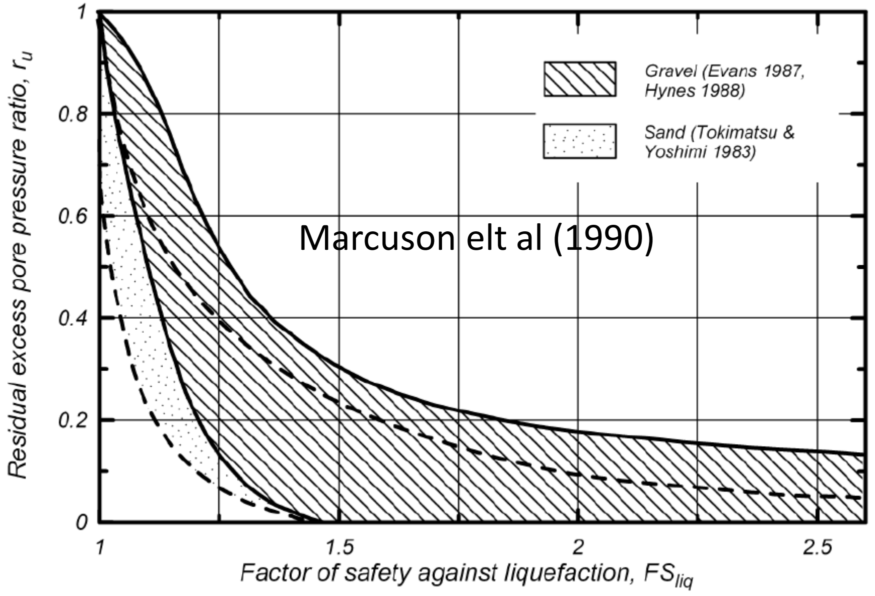




FoS – Recommendation by JGS (1998)

With → n = 4 to 10 …. For practical implementation, n = 7

$$r_u = F_L^{-n} \quad (\text{for } F_L > 1)$$



Marcuson elt al (1990)

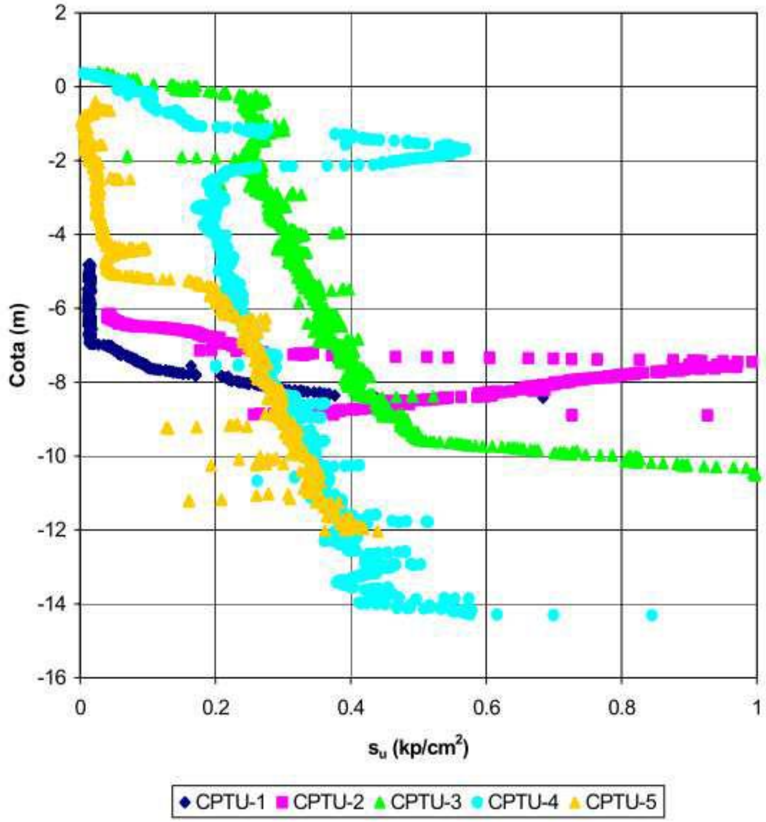
- DEEP VIBRO TECHNIQUES
- OFFSHORE WORKS
- LIQUEFACTION MITIGATION
- **CASE HISTORIES**
- CONCLUSIONS

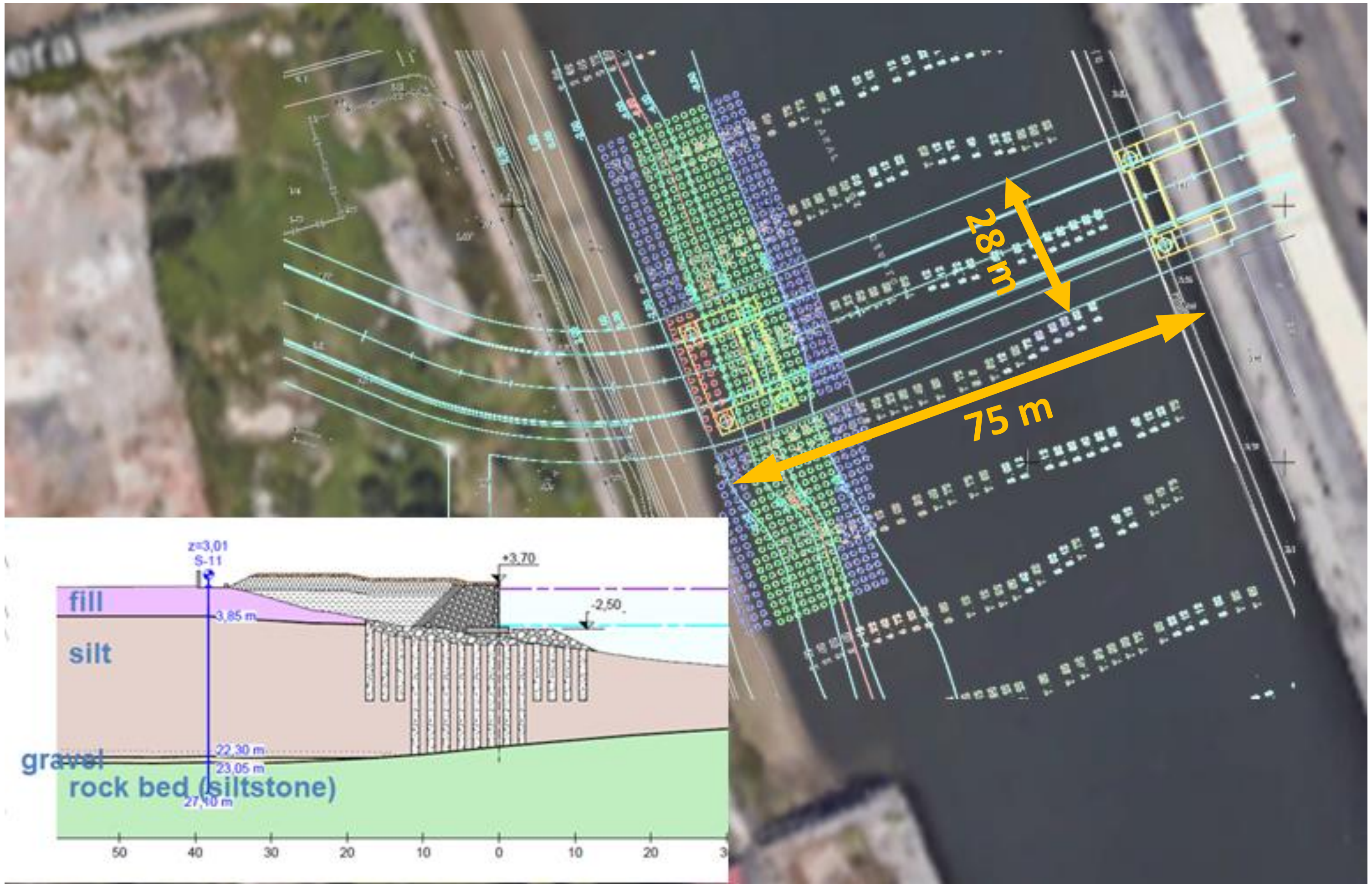
STONE COLUMNS OFFSHORE: San Ignacio Bridge, Bilbao (Spain)

KELLER

STONE COLUMNS OFFSHORE: San Ignacio Bridge, Bilbao (Spain)

- Stone columns by **S-Alpha hydraulic Dive**
- Reinforcement of soft and low plastic silt deposit for the West abutment and adjacent embankments up to 18-15 m below the seabed.



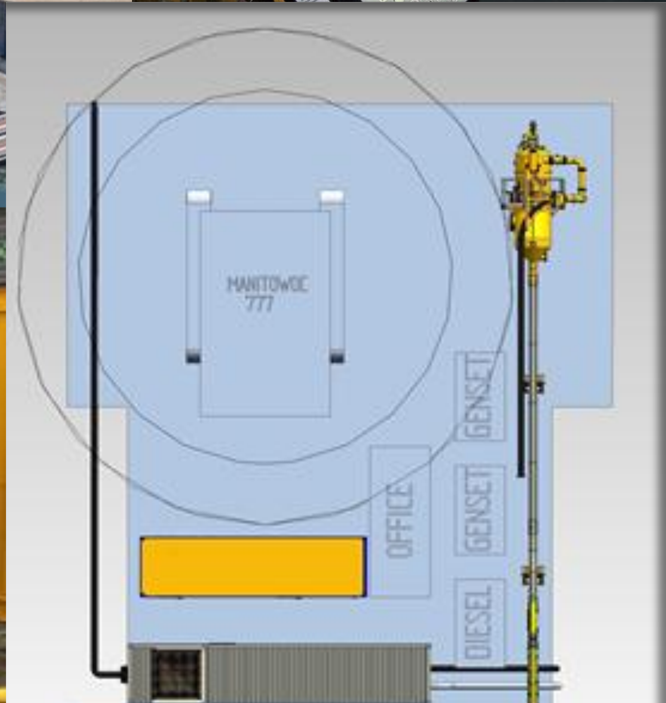


KELLER


KELLER

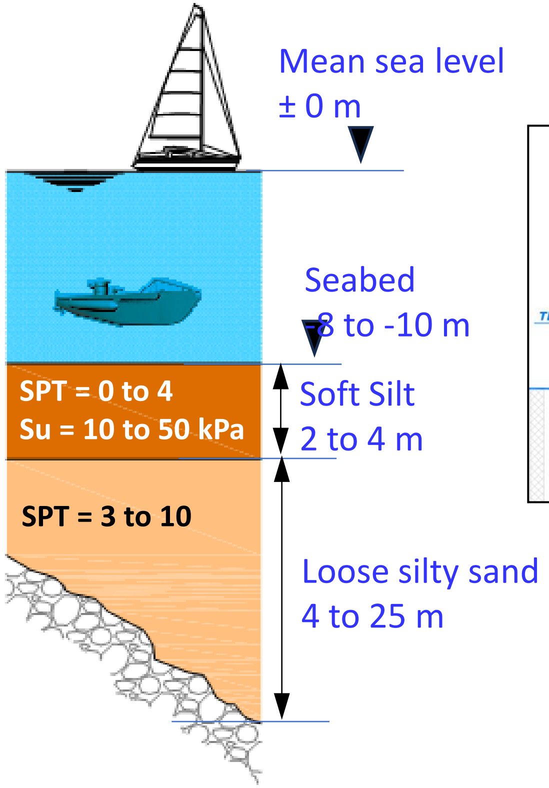

KELLER
TMES-M4

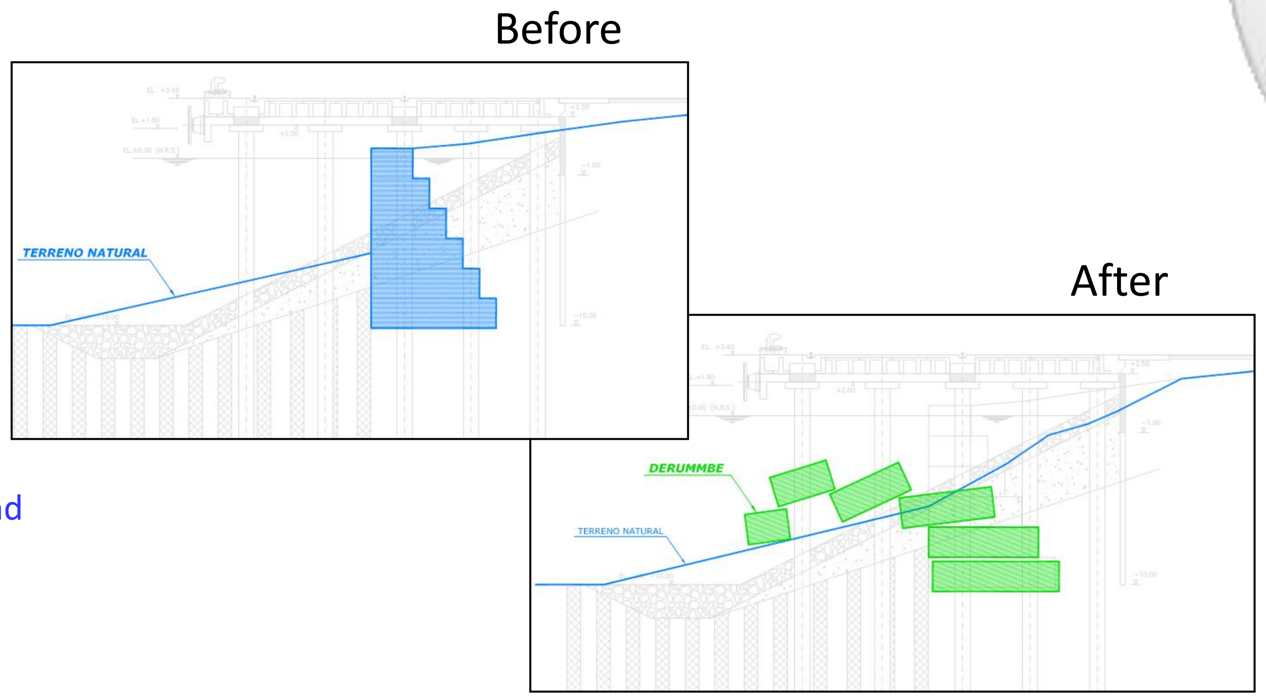

KELLER
KELLER


MANITOWOC
777
GENSET
GENSET
OFFICE
DIESEL

STONE COLUMNS OFFSHORE: Asmar port (Chile)

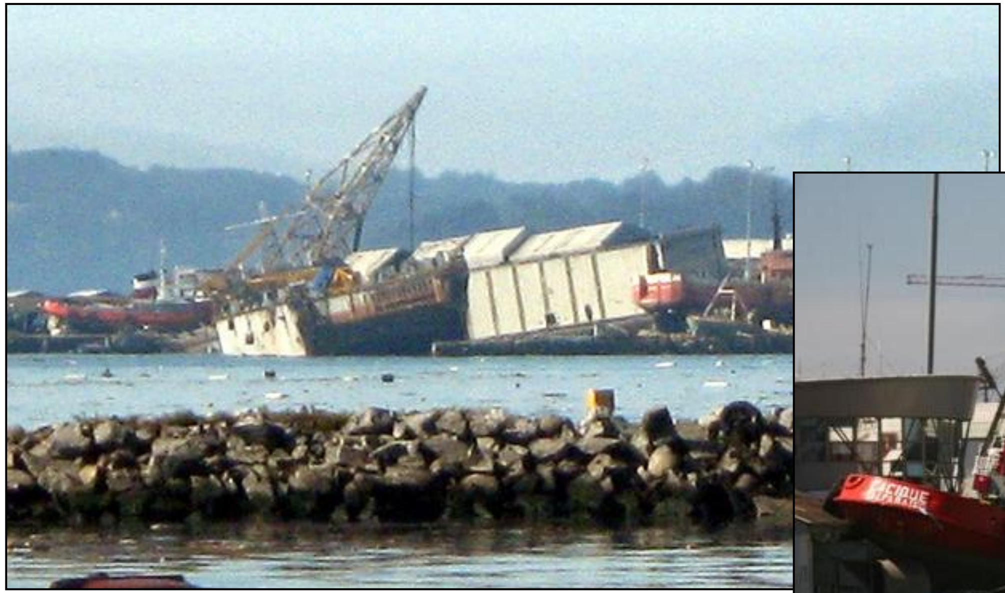
- Concepción bay, Talcahuano (Chile)
- Earthquake and tsunami of 27-Feb-2010, with Mw = 8,8
- General rebuilt and construction of new wharf with 750 m length supported by piles; including the creation of deeper seabed Depth to accommodate new generation ships.

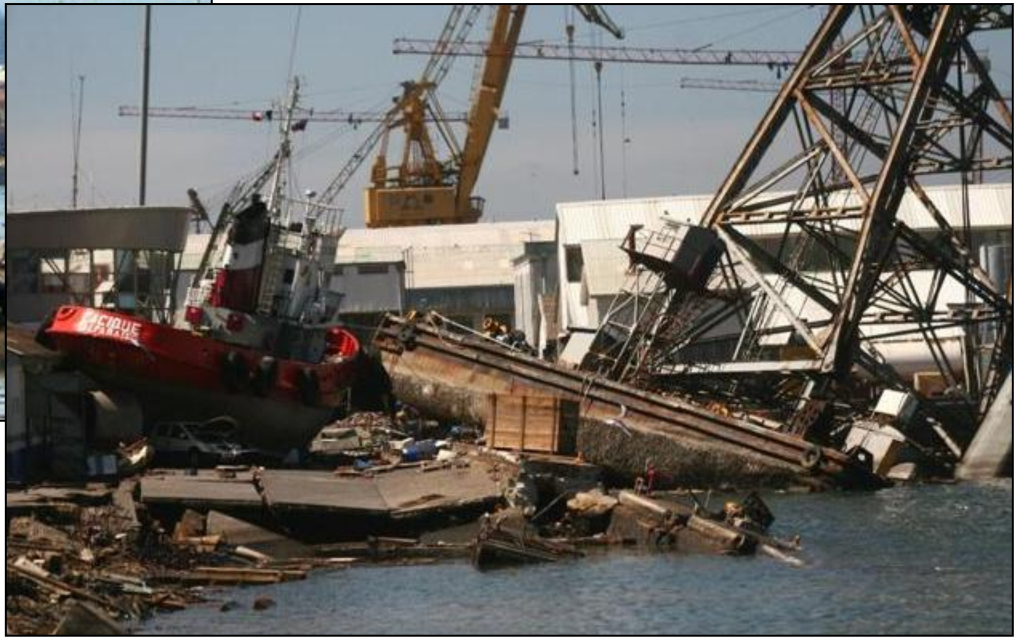




STONE COLUMNS OFFSHORE: Asmar port (Chile)

- Concepción bay, Talcahuano (Chile)
- Earthquake and tsunami of 27-Feb-2010, with Mw = 8,8
- General rebuilt and construction of new wharf with 750 m length supported by piles; including the creation of deeper seabed Depth to accommodate new generation ships.

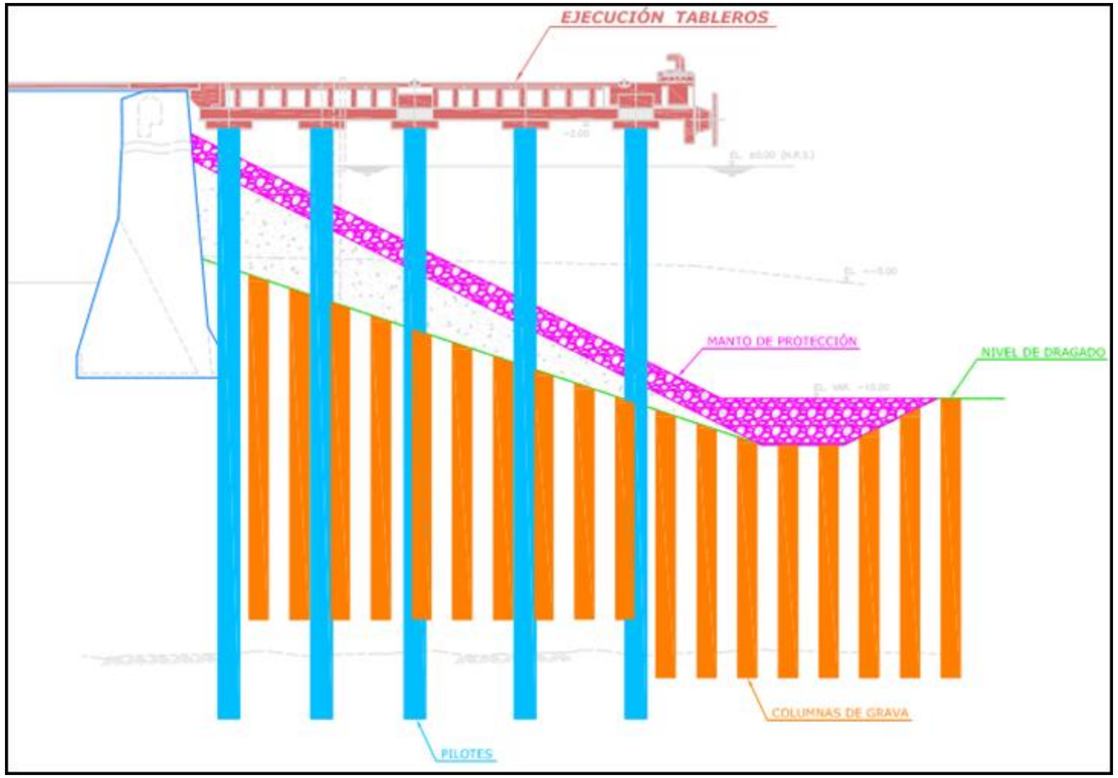




KELLER

STONE COLUMNS OFFSHORE: Asmar port (Chile)

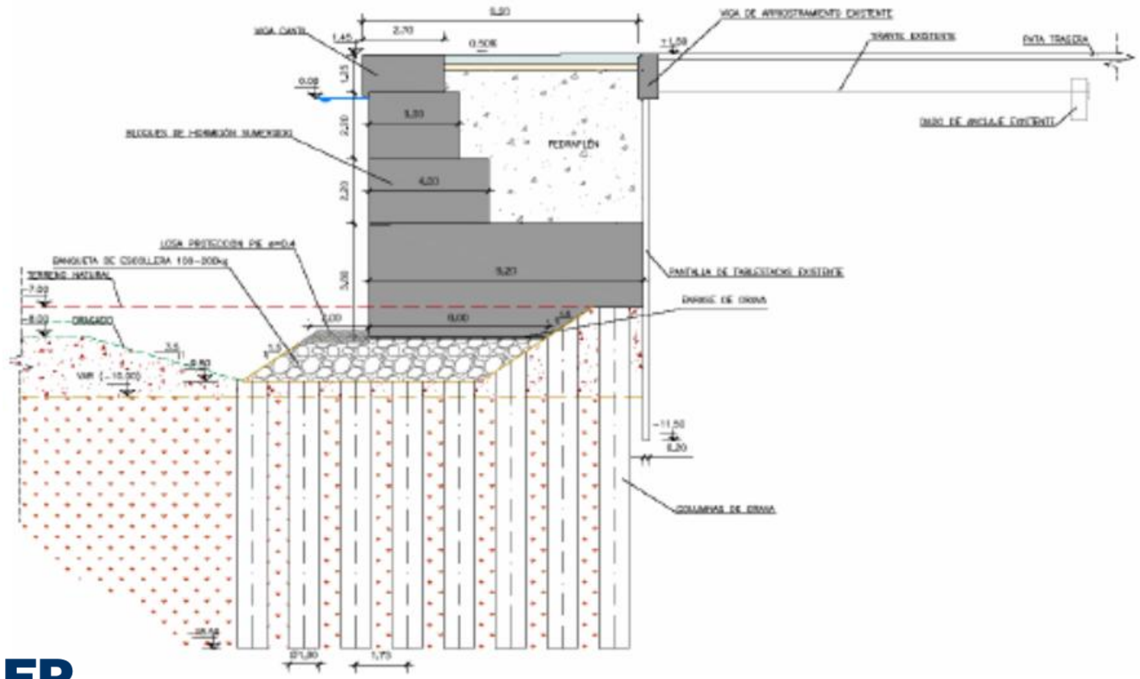
- Vibro Stone columns – S-Alpha hydraulic system
- Triangular grid pattern – Column spacing = 2,3 to 2,8 m
- Treatment Depth = 12 to 35 m from the barge
- Column diameters = 0,7 to 1,20 m
- Total quotation of 95000 lm of Stone columns,



KELLER

STONE COLUMNS OFFSHORE: Gandia port, Valencia (Spain)

- Support of new wharf
- S-Alpha system mechanic
- More than 10,000 lm of stone columns
- 17 meters deep (10 m + 7 m)
- Ø1.1 m diameter, average estimation



VIBROCOMPACTION OFFSHORE: Palm Jumeirah, Dubái (UAE)

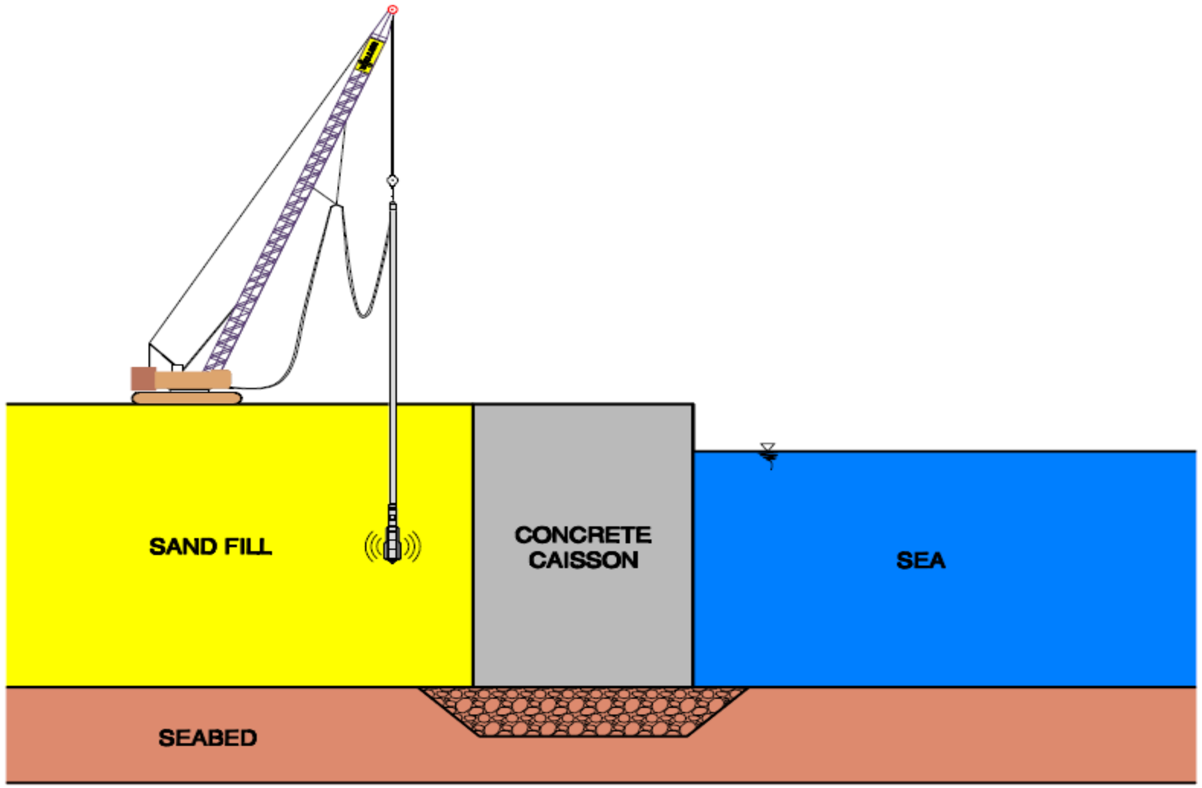
Large land reclamation→A total of 636,000 m2 of **Vibro Compaction**

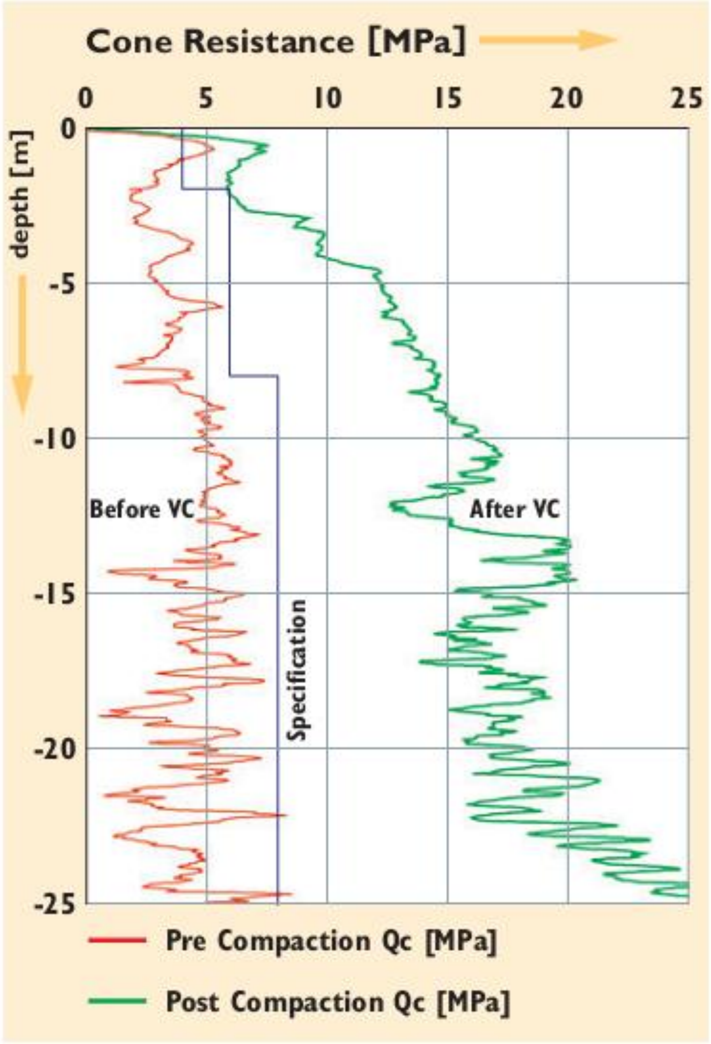
KELLER

VIBROCOMPACTION OFFSHORE: Pasir Panjang (Singapur)

- Compaction of hydraulic fills for terminal of containers (Phases 1 and 2)
- Total sandy fills compacted:

10 millions m3 (Land) and 2 millions m3 (Marine)





KELLER

- DEEP VIBRO TECHNIQUES
- OFFSHORE WORKS
- LIQUEFACTION MITIGATION
- CASE HISTORIES
- **CONCLUSIONS**

CONCLUSIONS

- Deep Vibratory Techniques have been implemented successfully in numerous projects worldwide for both onshore and offshore works. For improvement of Bearing Capacity, Settlement and Consolidation.

- Vibrocompaction and/or Vibroreplacement (Stone columns) are very effective solution for liquefaction mitigation.

- Benefits of the "S-Alpha hydraulic Dive" system for offshore vibro stone columns:
  - Completely submersible, and possible immersion depth up to 25m
  - Compact set of main components in one container allowing easy assembly and disassembly
  - Continuous gravel feeding (Hydraulic system)
  - Optimization of cranes and barges
  - Productivity / performance 35-40% higher (30 – 40 lm/hr)

- Control System: Computer system for data acquisition and processing of each column, with continuous recording many parameter: the duration of execution, depth, gravel consumption and the intensity of energy consumed for the control of gravel compaction

Antonio Cristovao
antonio.cristovao@keller.com

Paulo Matos
paulo.matos@keller.com

Pedro Barros
pedro.barros@keller.com

KELLER