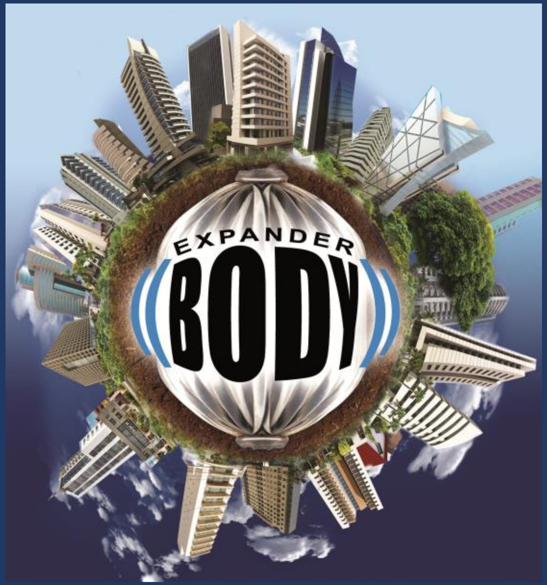
THE FUTURE OF DEEP FOUNDATIONS, TODAY

EXPANDER BODY ® TECHNOLOGY

SMART CELL® TECHNOLOGY



Mario Terceros H.

EXPANDER BODY INTERNATIONAL INC.

TOOLS USED TO DESIGN

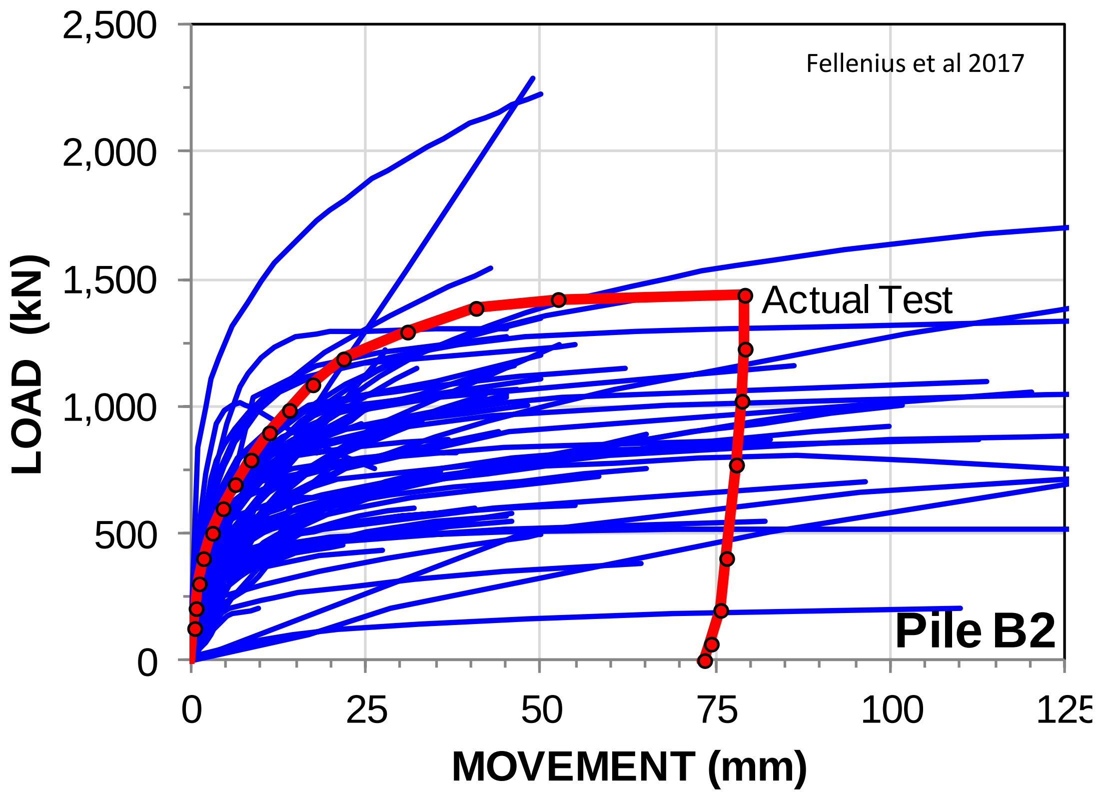
- **SOIL INVESTIGATION:** Conditions will differ between boreholes and therefore, the conditions assumed for the design can deviate from reality. (SPT, CPTu, DMT, PMT, Seismic, etc.)

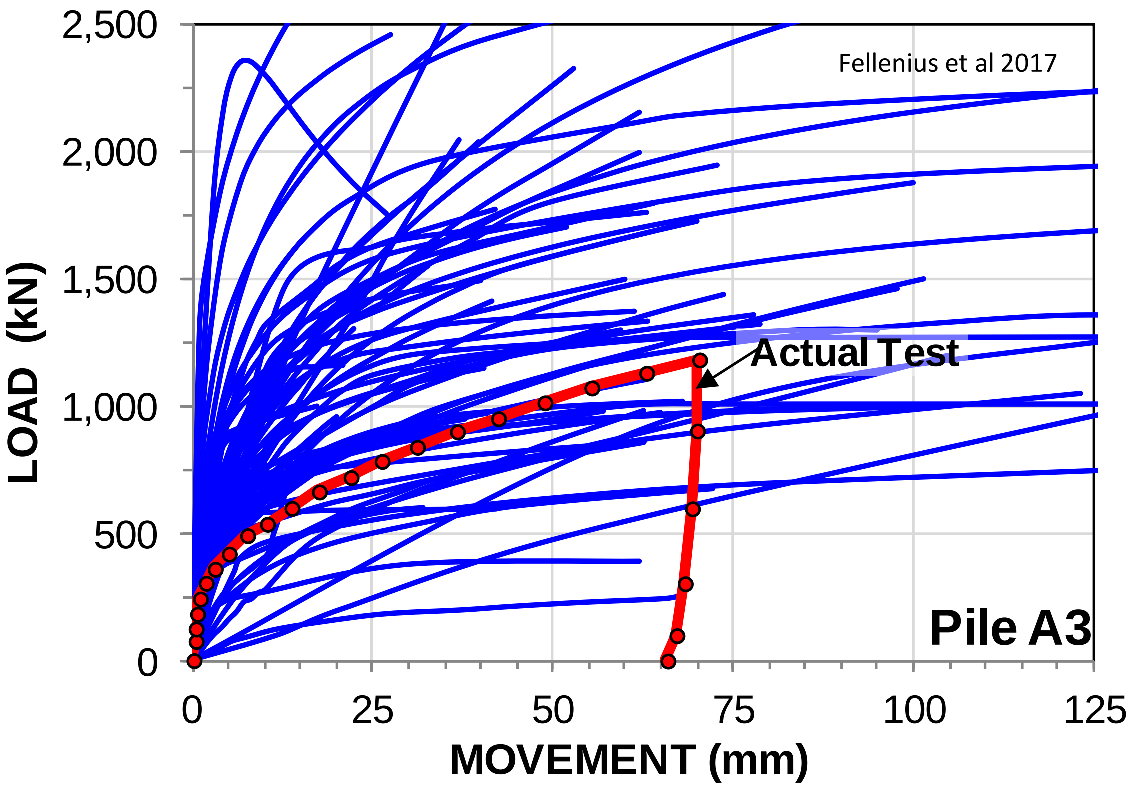
- **SOIL MODEL**: The soil model used for the design could be less than suitable for predicting the actual pile response. (From simple formulas to ***sophisticated*** mathematical models)

- **CONSTRUCTION METHODS**: The methods may affect the soil conditions, so the models applied will become less adequate. (Drilled, CFA, FDP, Driven, Vibrated, Pushed, etc.)

MAIN CONCERN

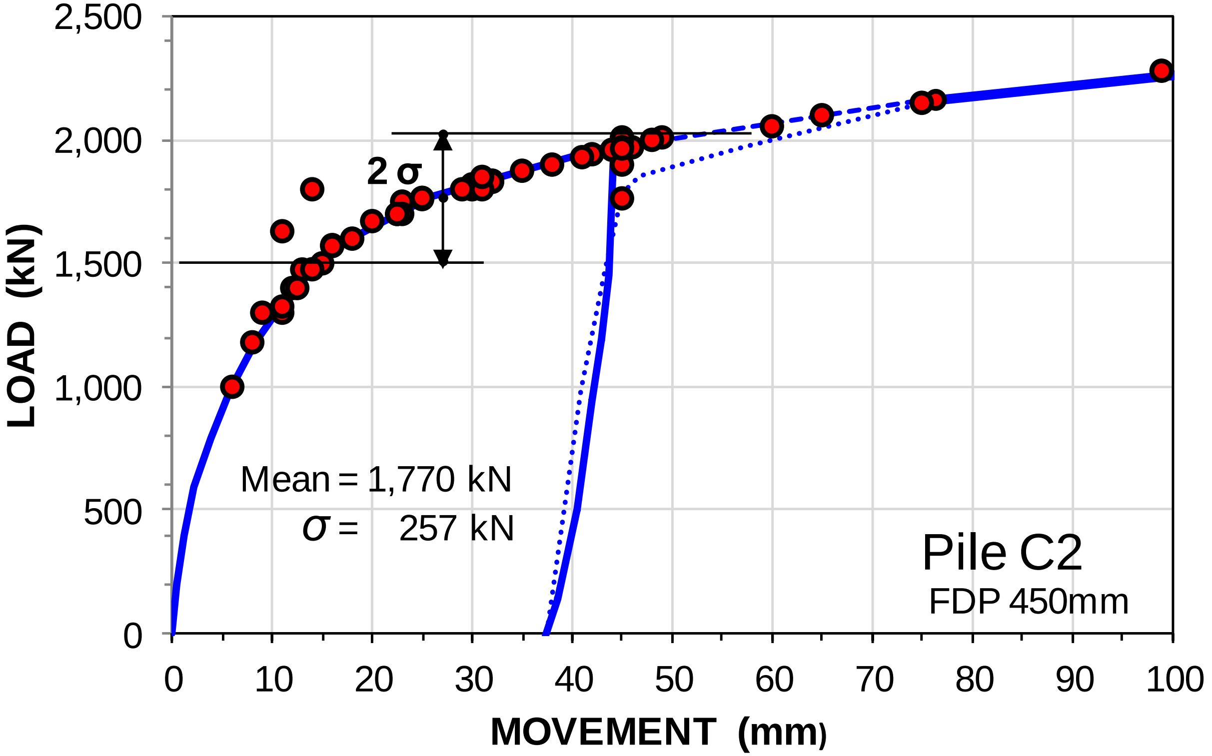
Is it possible to truly predict the response of a pile?

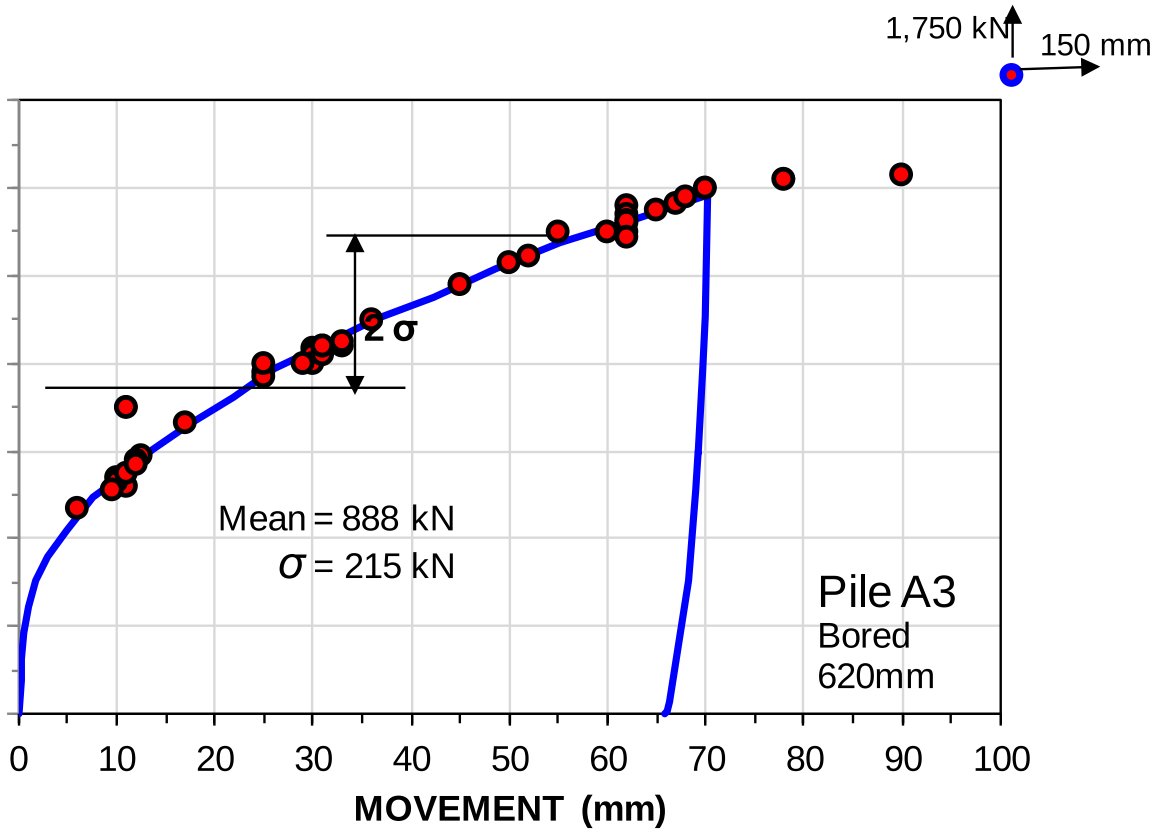




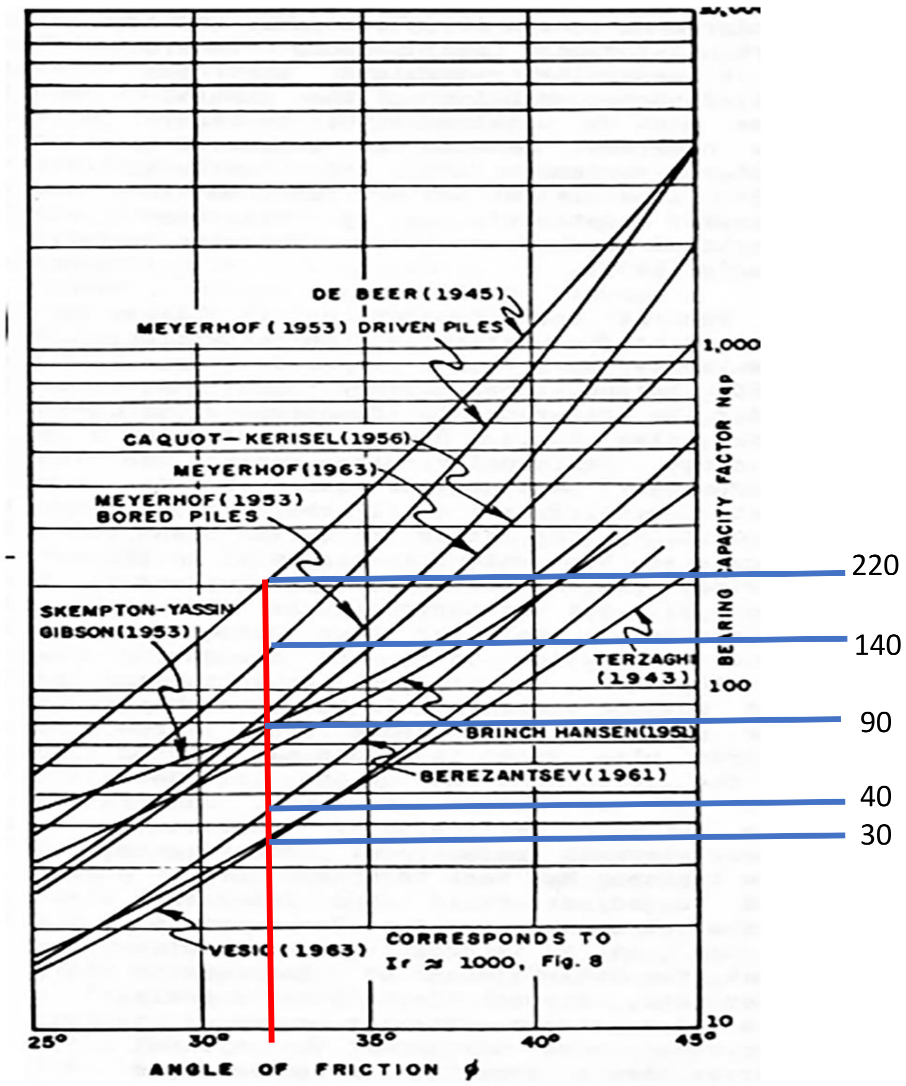
WHAT REALLY HAPPENS

Scatter of assessments of the load-movement curves: capacity (?)





ADDITIONAL COMMENTS



N_q values for toe resistance of driven piles according to different authors.

WHO IS RIGHT?

OR

IS THE MODEL WRONG?

What if we could have **RELIABLE** information **FOR EACH FOUNDATION UNIT?**

WHAT IS NEEDED FOR THAT PURPOSE?

- RELIABLE SYSTEMS, PROVIDING INFORMATION FOR EACH FOUNDATION UNIT

- HIGHER QUALTY CONTROL

- ECONOMICALLY COMPETITIVE SYSTEMS

1

WHAT IS THE EXPANDER BODY?

The Expander Body (EB), initially developed in Sweden, consists of a folded steel tube with a circular cross section.

It can be installed in the ground either **as an enlarged <u>pile</u> base or as a <u>soil anchor</u>**.

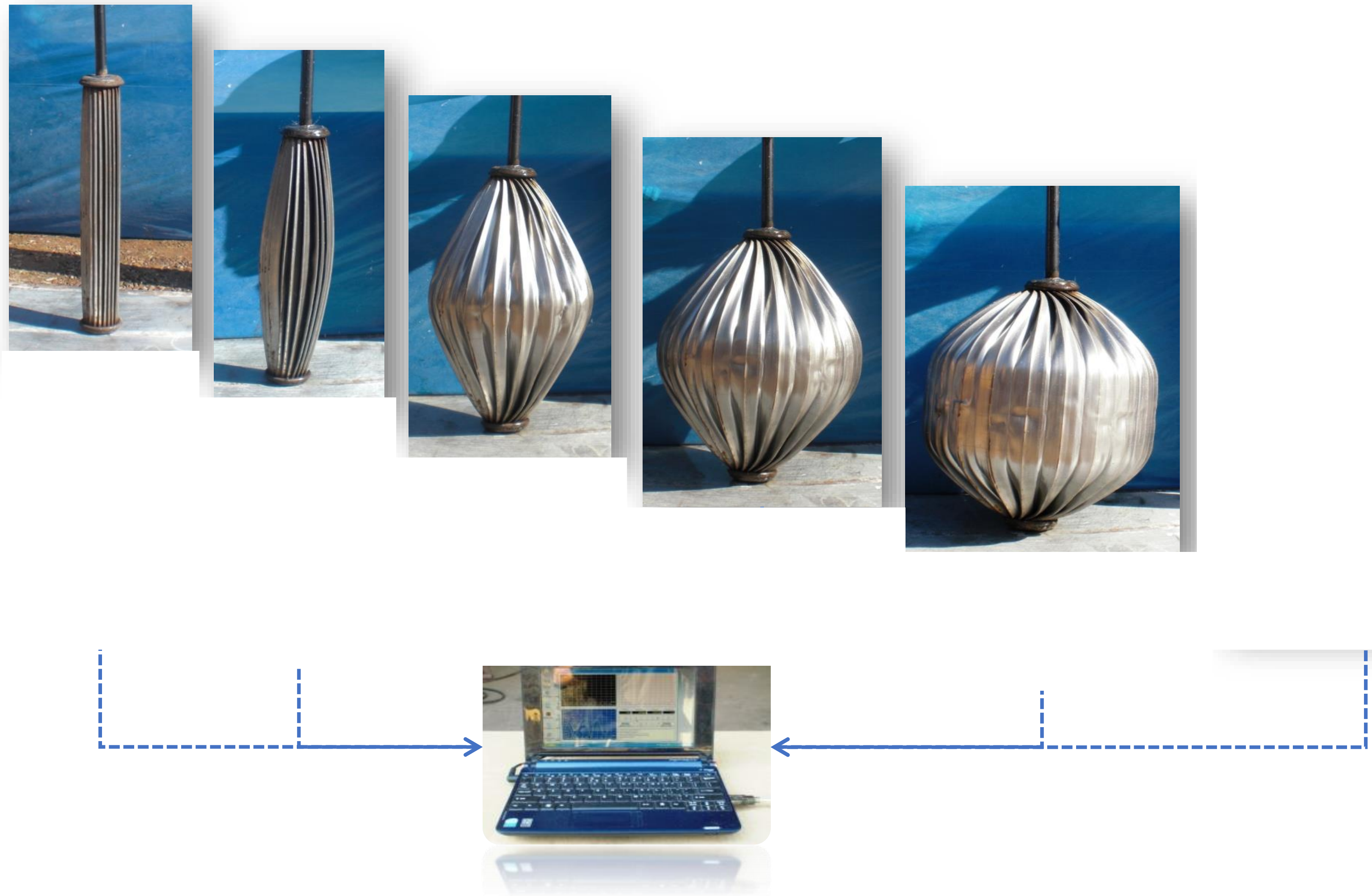
EXPANDER BODY PRIOR TO EXPANSION

EXPANSION PROCESS

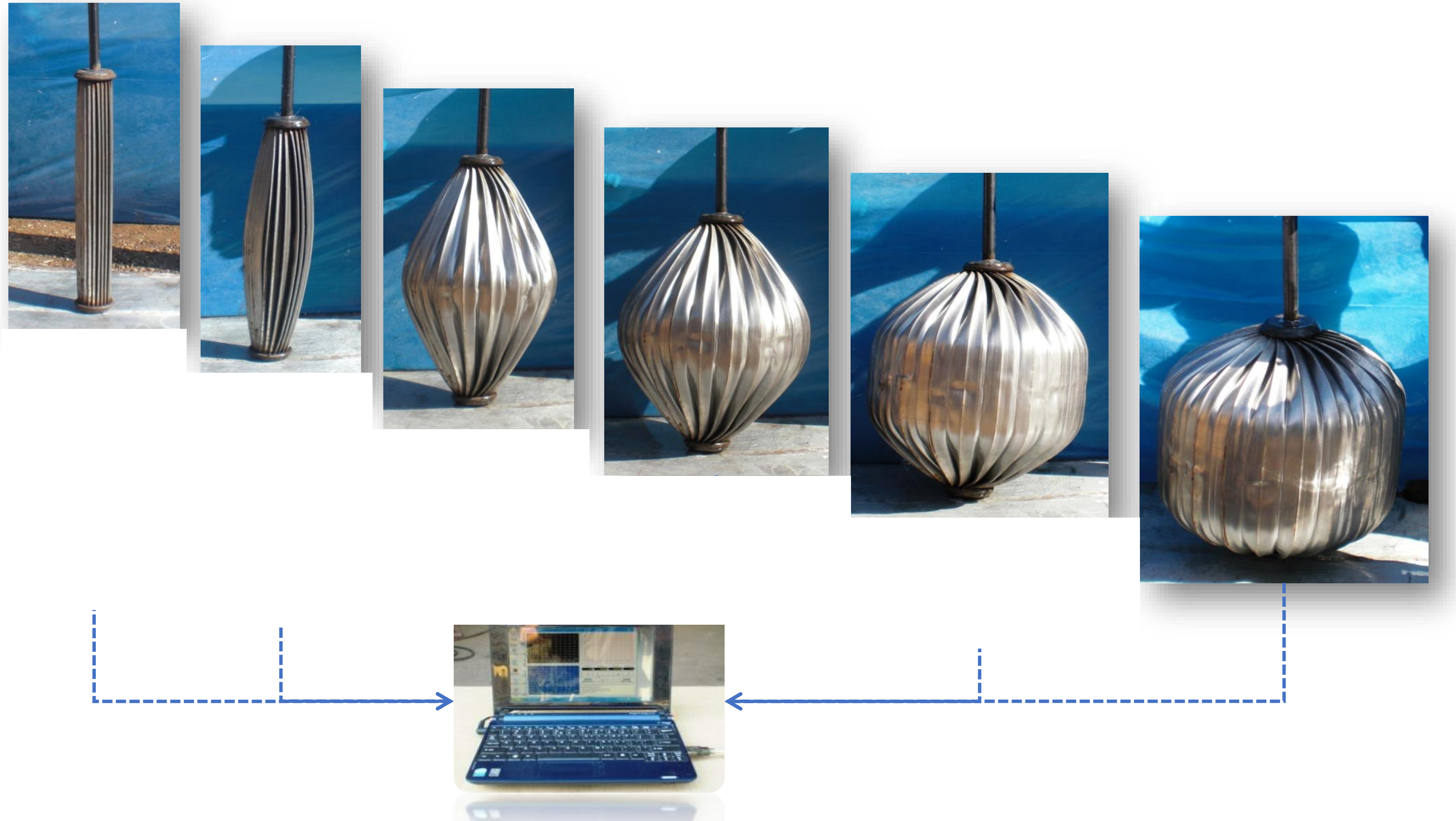
EXPANSION PROCESS

EXPANSION PROCESS

EXPANSION PROCESS

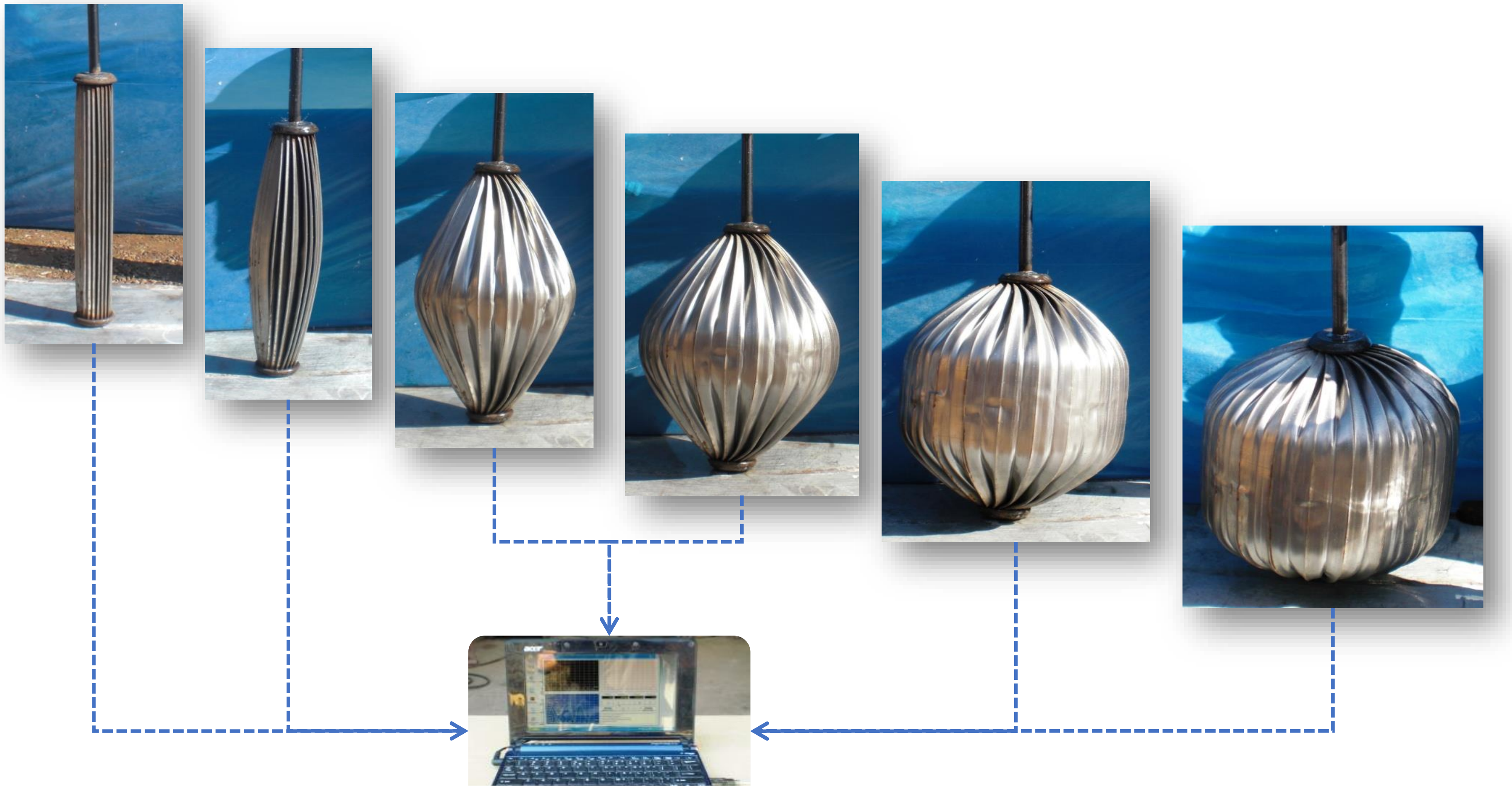


EXPANSION PROCESS



During the expansion, pressure and volume are recorded **electronically as well as manually.**

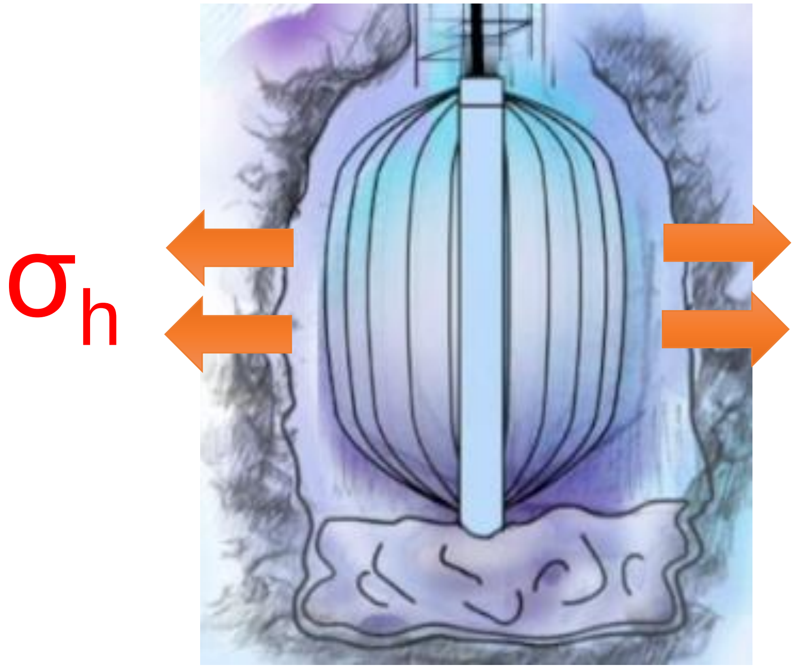
MONITORING OF EXPANSION PROCESS

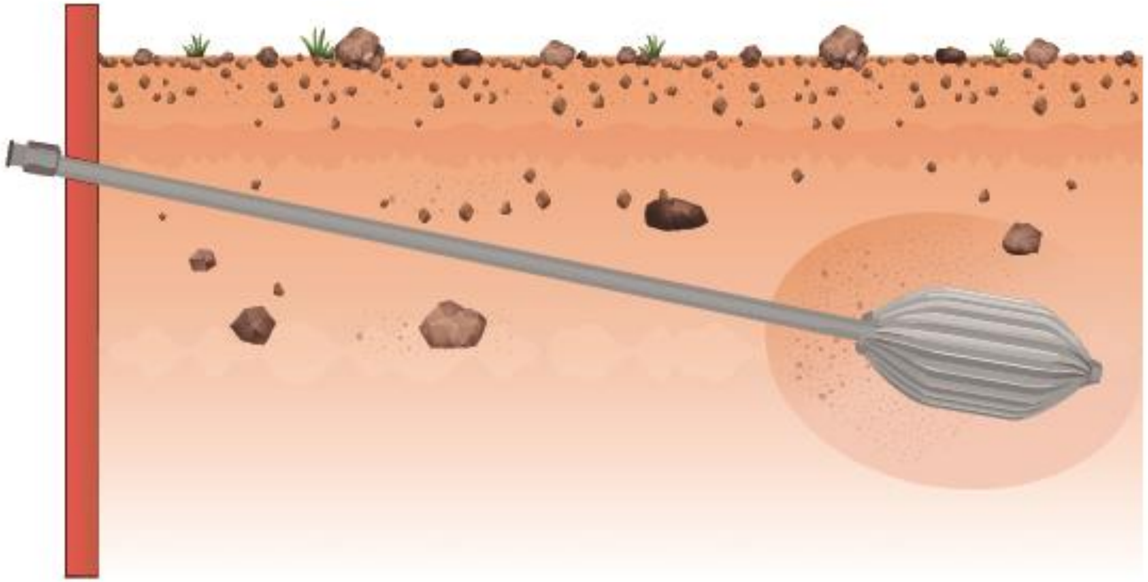


The EB is inflated by high-pressure injection of grout. **The result is an expanded,** water-tight, **high-strength,** steel “balloon”.

ABOUT THE EXPANDER BODY

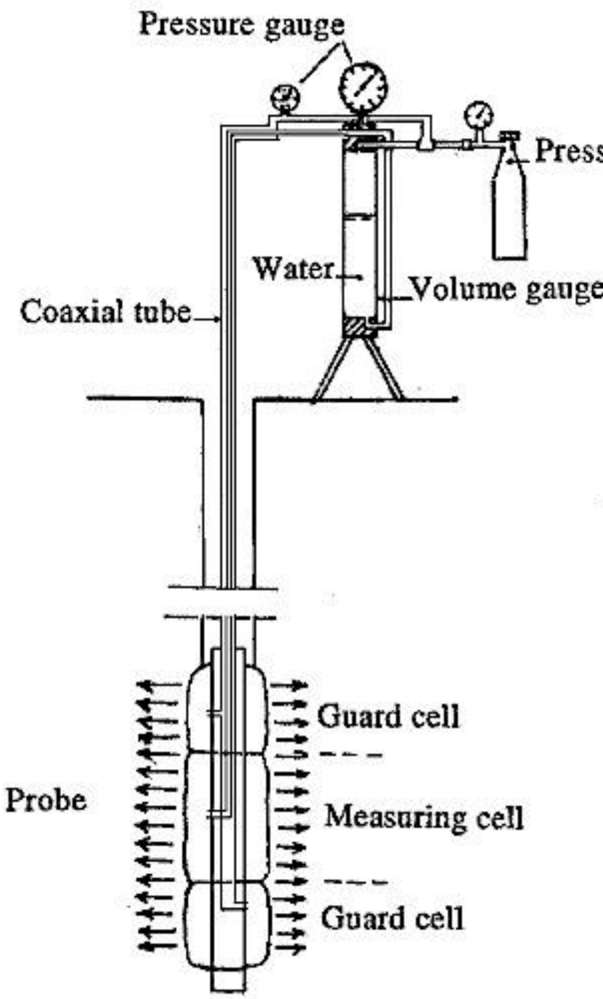
- During expansion, lateral stresses around the EB are increased, creating a **high passive earth pressure.**
- The inflation pressure, which is measured, reflects the σ_h at the EB.





EXPANDER BODY ACTS LIKE A PRESSUREMETER

- The Expander Body is similar to a **large-scale pressuremeter** and can be used as a soil testing device in each pile.
- By **recording the injected grout volume and expansion pressure**, the increase in soil stiffness and soil strength during inflation can be estimated. This information can be used to determine the toe capacity of a pile or an anchor.
- Based on a large number of pile and soil anchor applications, a **semi-empirical design method** was developed, which can be used to assess the toe response of piles and the pull-out resistance of soil anchors.



INTERNATIONAL STANDARDS AND GUIDELINES

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 12699

December 2000

ICS 93.020

English version

Execution of special geotechnical work - Displacement piles

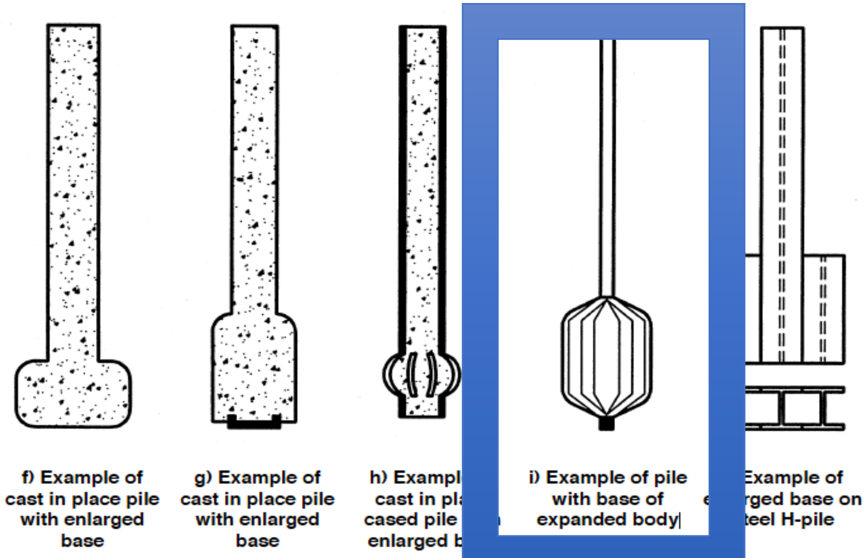
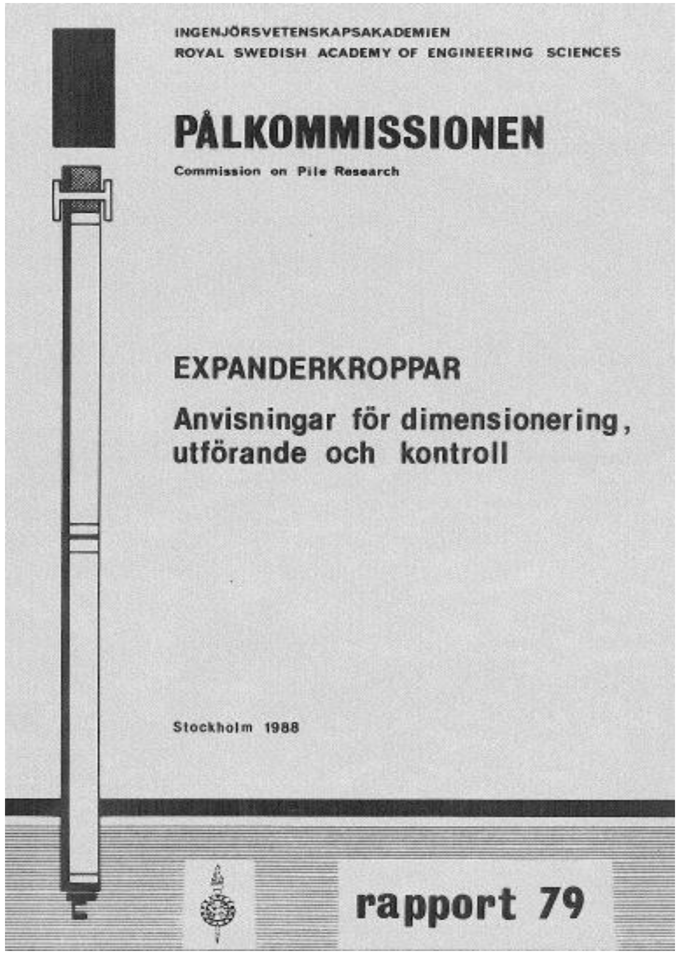
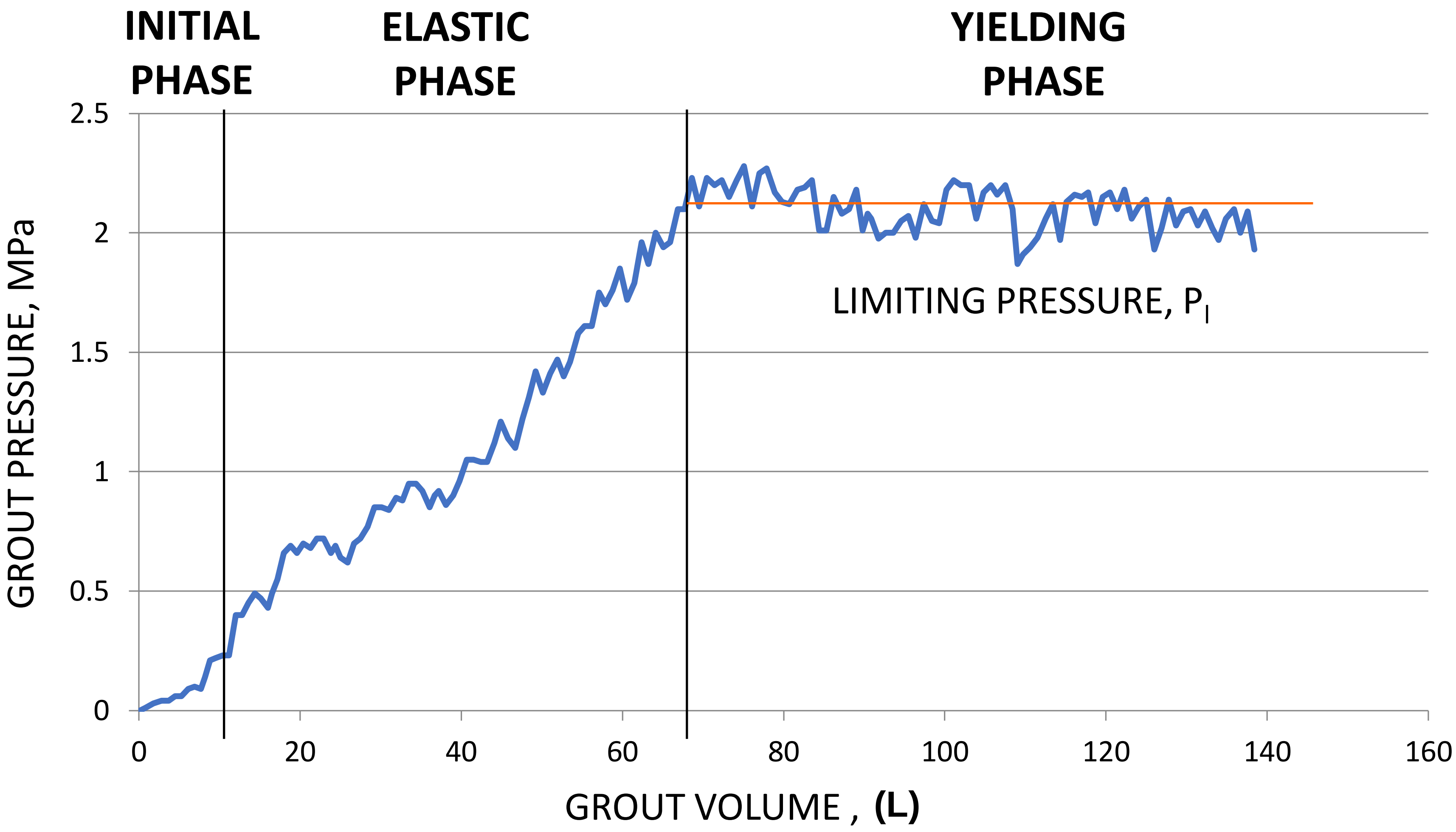


Figure A.2 — Exemples of shafts and bases of displacement piles

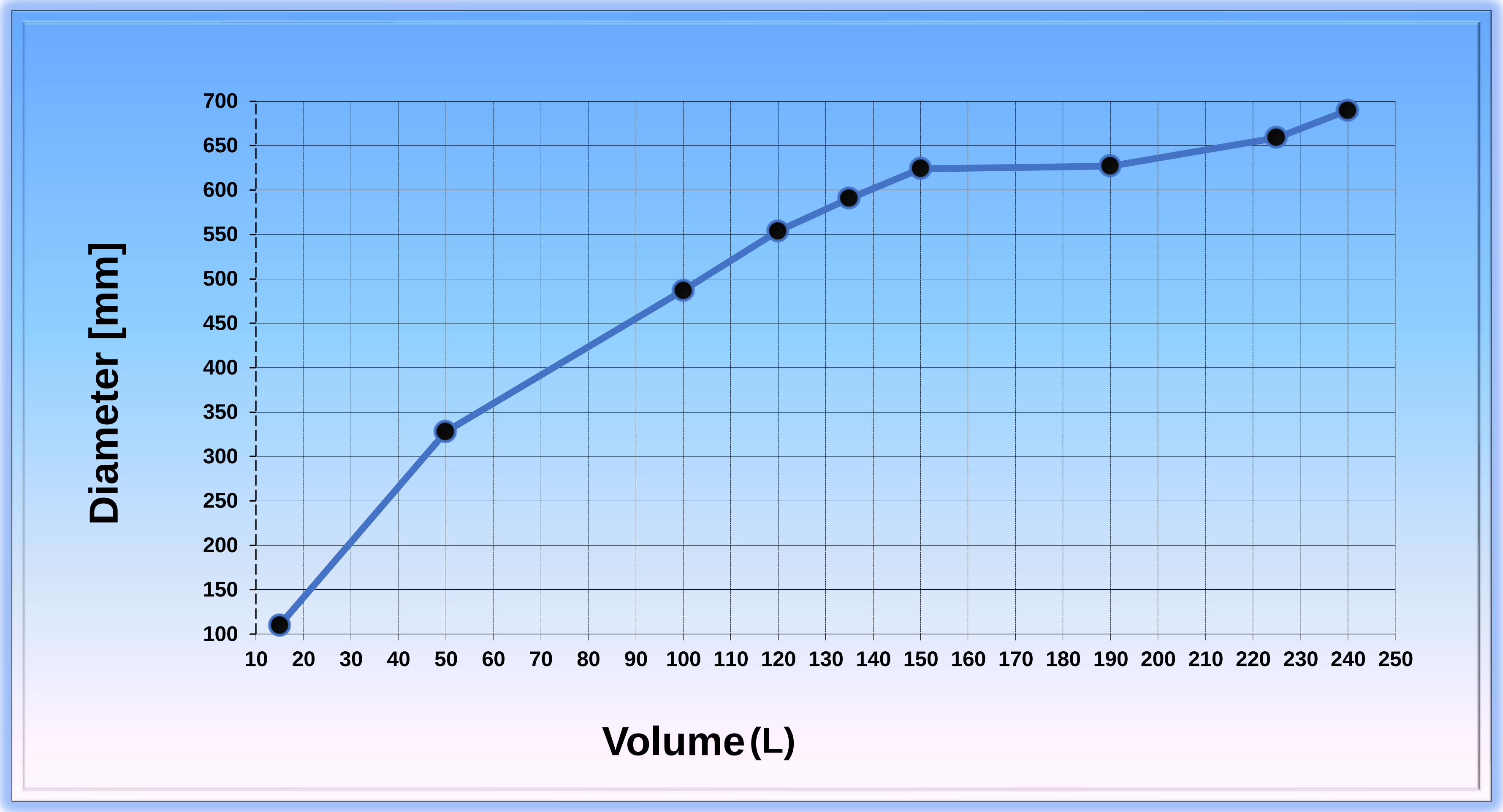


PRINCIPLE OF GROUT INJECTION IN EB

During the EB expansion, three typical injection phases can be identified:



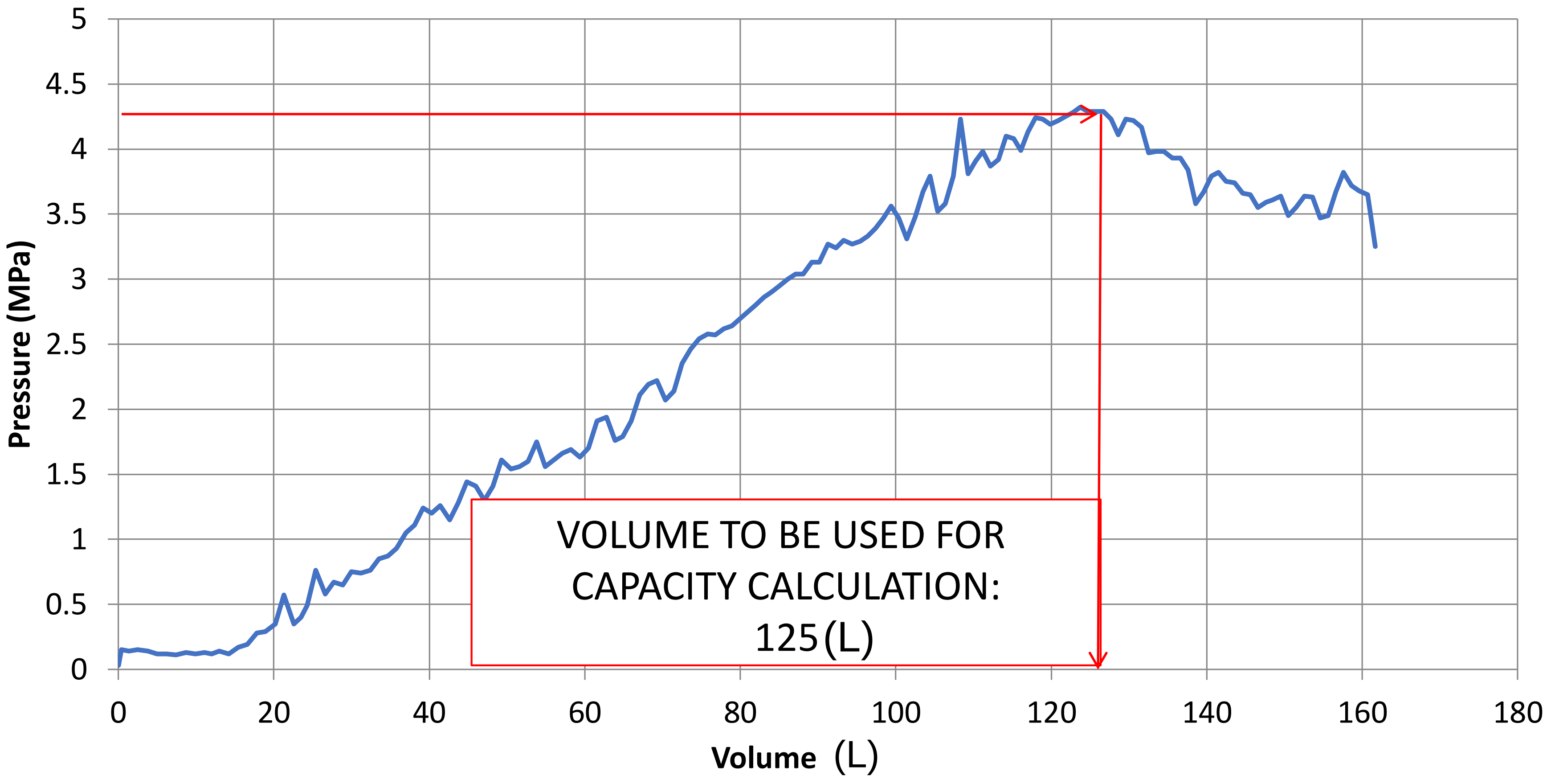
CALIBRATION CURVE FOR EACH SIZE OF EB



This curve, for each size of EB, allows to know the **actual diameter for each volume** of grout injected.

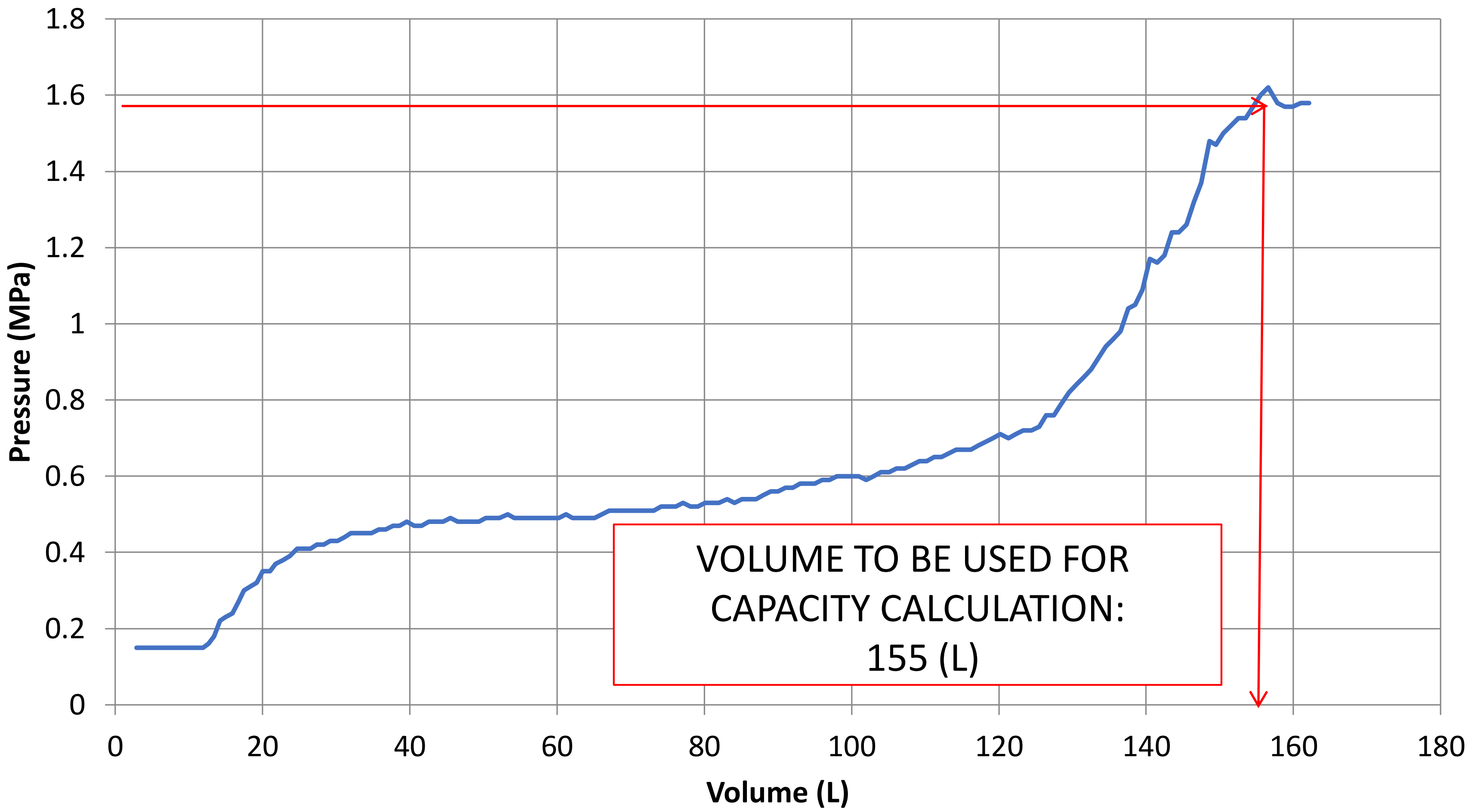
HOW TO CREATE THE CALIBRATION CURVES

MONITORING & QUALITY CONTROL



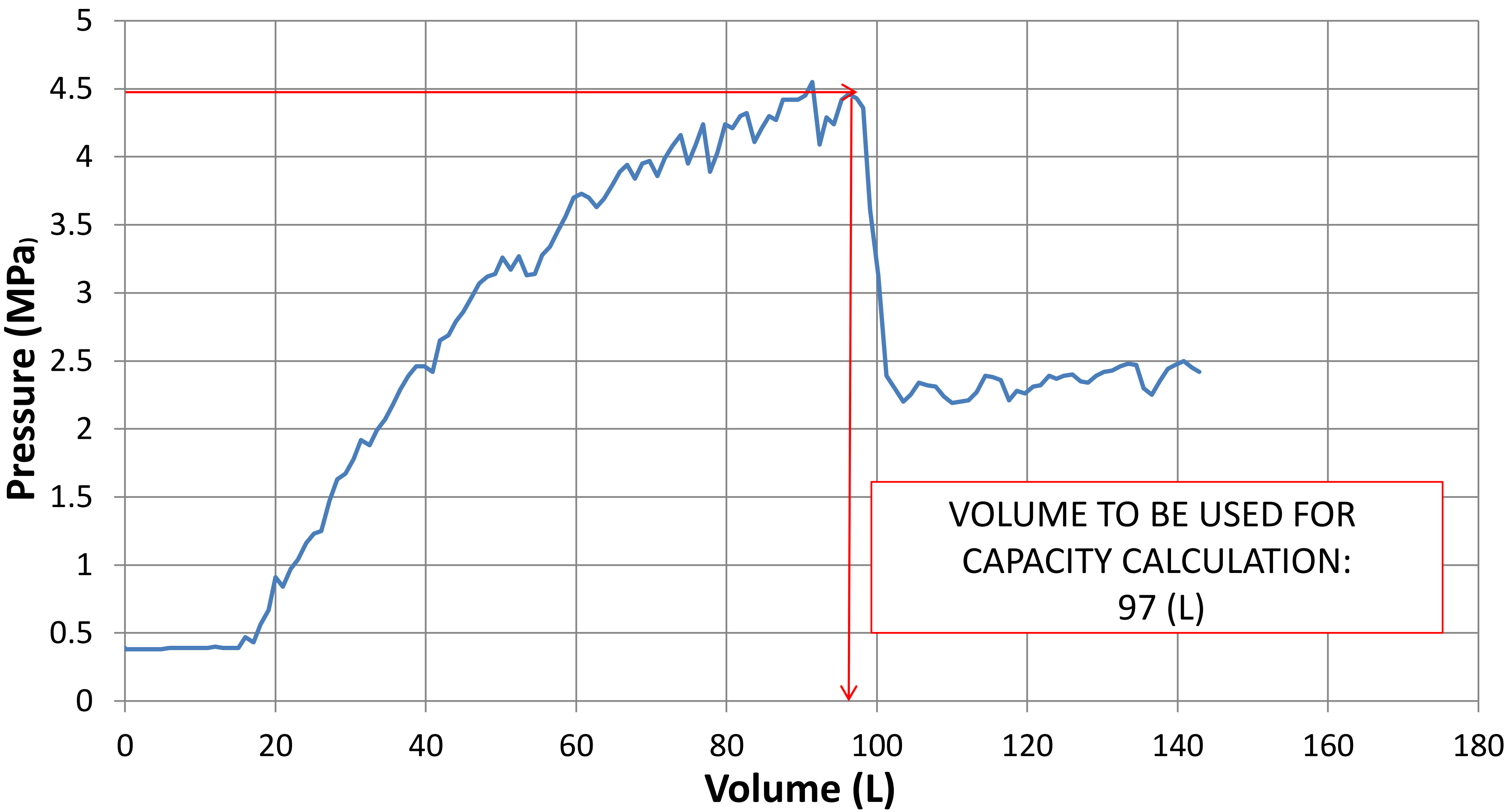
Typical grouting curve in medium dense sandy soil

MONITORING & QUALITY CONTROL



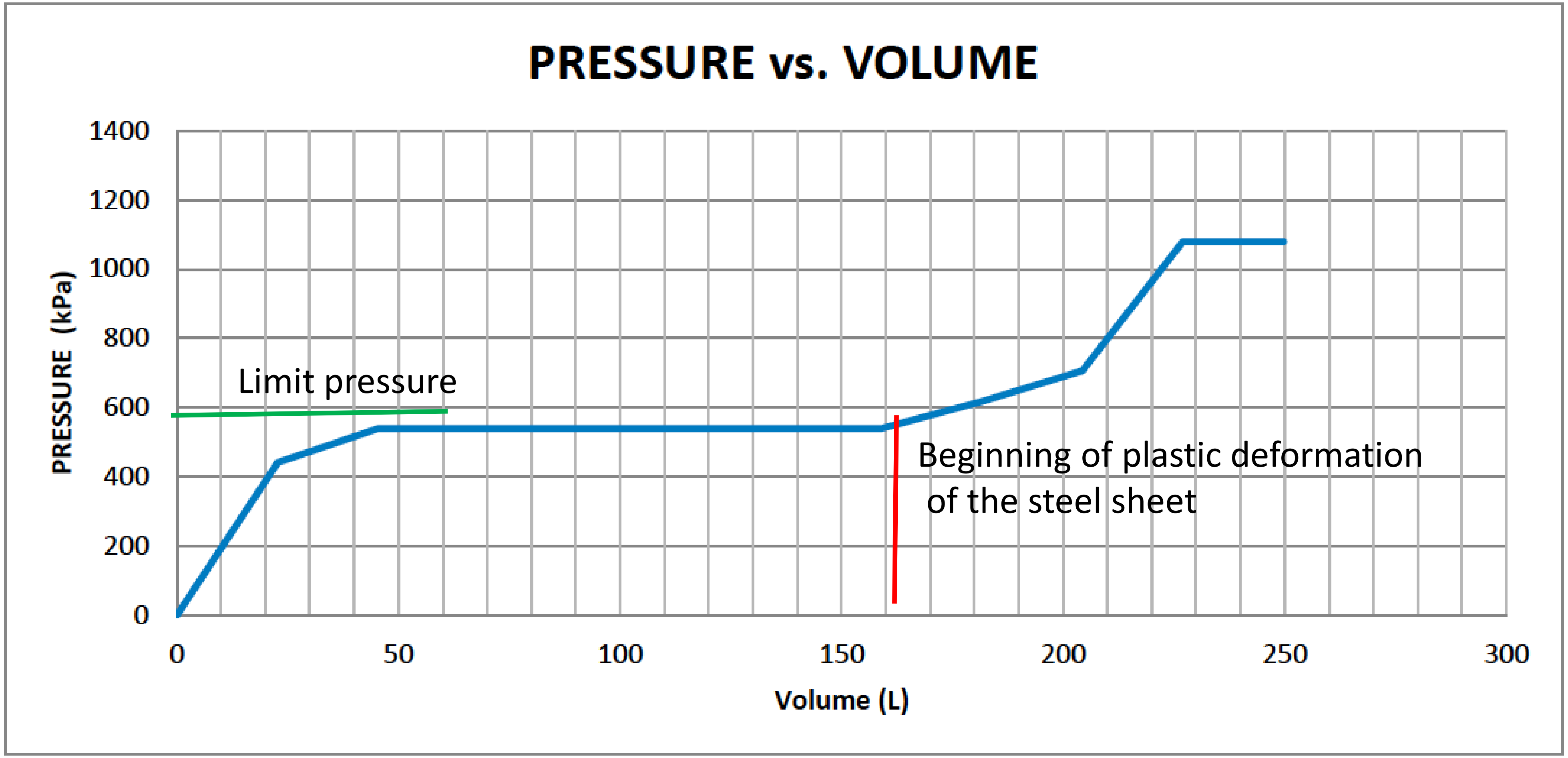
Typical grouting curve in loose sandy soil. Note that the maximum pressure **in loose sand** is significantly lower than in a medium dense sand.

MONITORING & QUALITY CONTROL



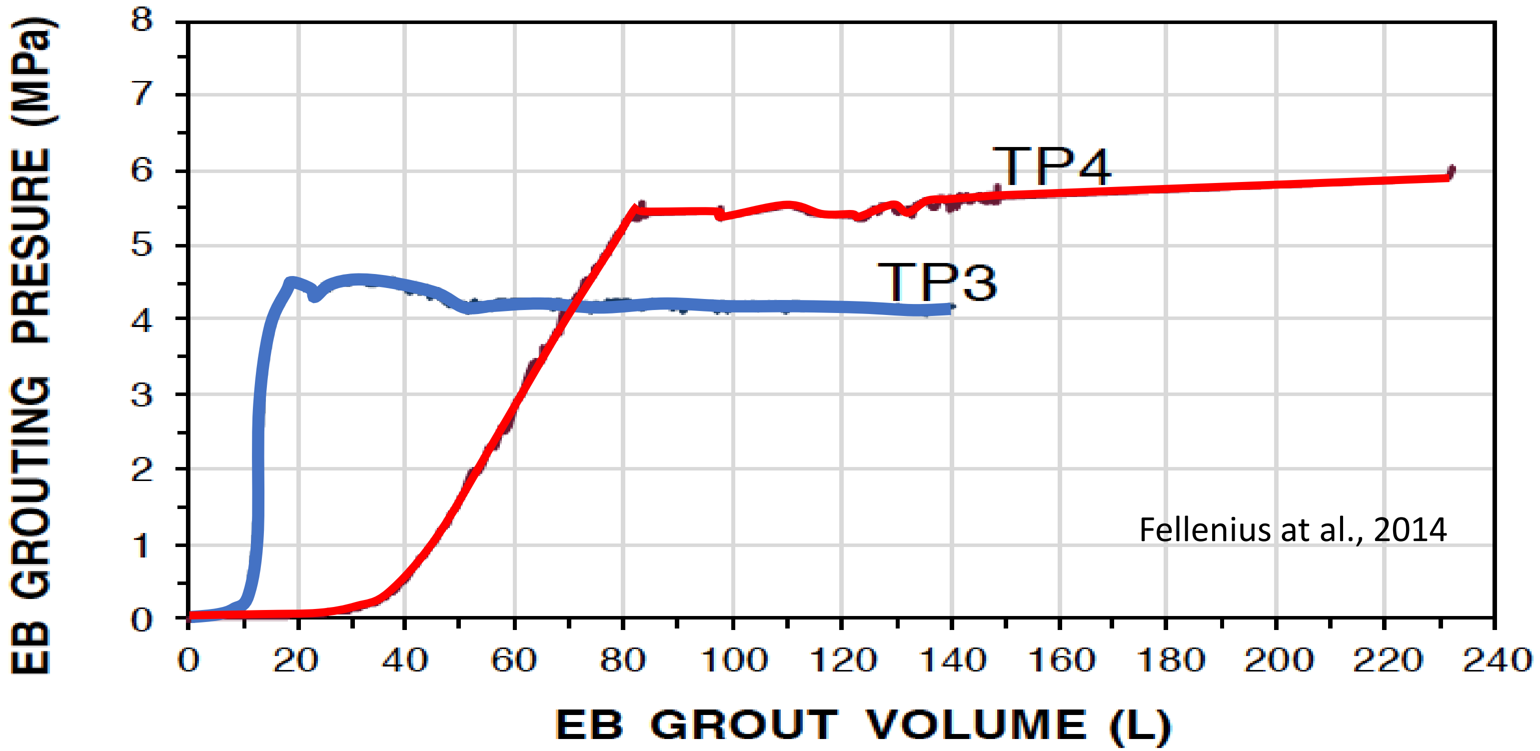
Leakage of grout during EB inflation before full expansion - or potential damage – can be detected by monitoring. The diameter used for the design of each pile can be adapted based on monitoring results.

MONITORING & QUALITY CONTROL



Typical grouting curve in soft clay

INFLUENCE OF INSTALLATION PROCESS ON SHAPE OF INJECTION CURVE



- Blue curve (TP3) is from an EB installed **at base** of Full Displacement pile (FDP).
- Red curve (TP4) is from an EB installed **at the toe** of a drilled pile constructed under bentonite. The initial soil stiffness is **softer** because the drilled pile may have decompressed the surrounding soil and had debris at the pile toe. **(The FDP leaves no debris and compresses the surrounding soil).**

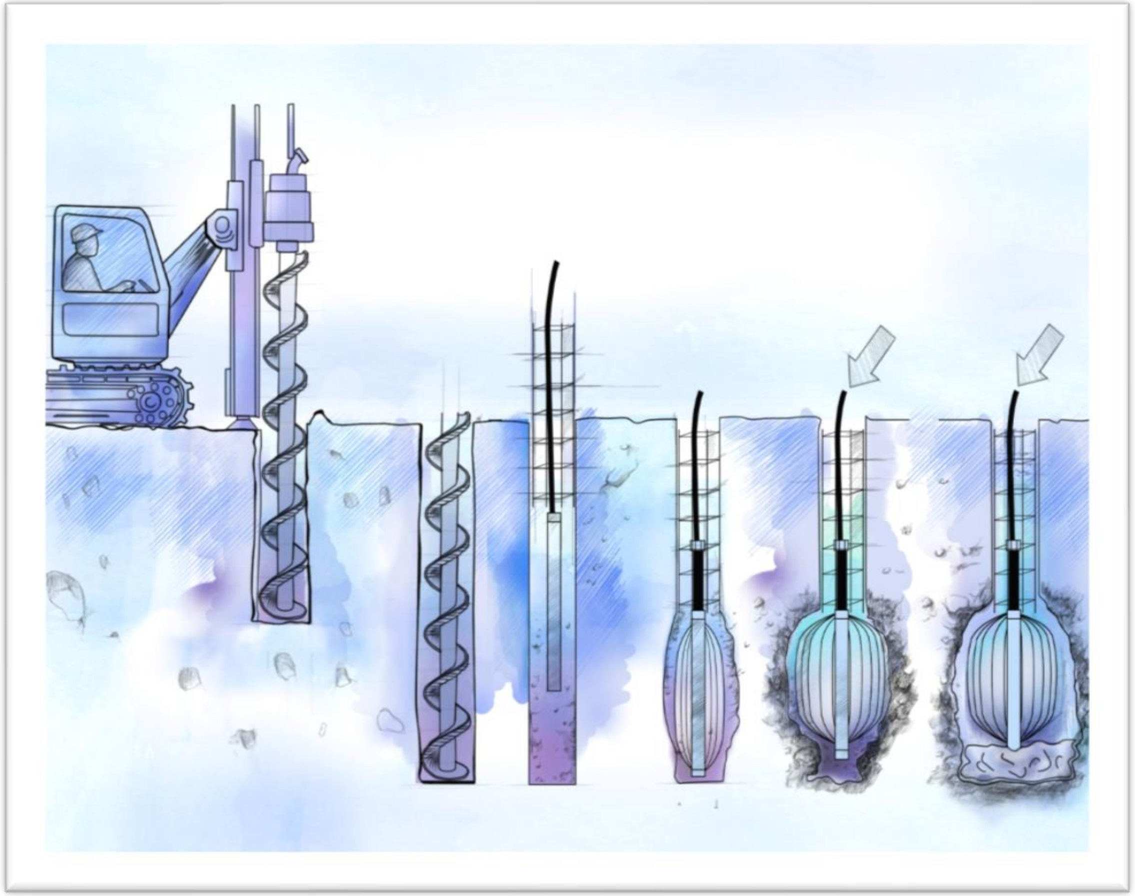
EXPANDER BODY TYPES

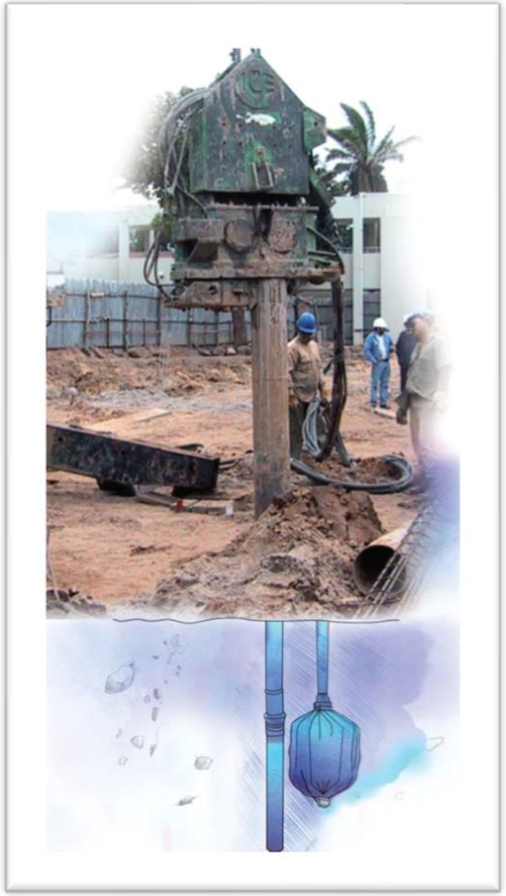
Model	Length prior to expansion	Length after expansion	Diameter of expanded body	Base Area	Surface Area	Maximum Volume
	m	m	m	m^2	m^2	m^3
EB 310	1.0	0.96	0.3	0.07	0.90	0.94
EB 410	1.0	0.86	0.4	0.13	1.10	0.11
E 610	1.0	0.76	0.6	0.28	1.43	0.21
EB 612	1.2	0.96	0.6	0.28	1.83	0.27
EB 615	1.5	1.26	0.6	0.28	2.38	0.36
EB 815	1.5	1.26	0.6	0.50	3.17	0.63
EB 820	2.0	1.76	0.8	0.50	4.42	0.88

- Typically, the **EB 600** series is used in **sandy soils.**
- The **EB 800** series was developed for **clayey soils** but now is also used in sandy soils.
- A new type, the **EB 310,** has been successfully used in **stiff soils, cemented sands, and soft rocks**.
- A new model, the **EB 1220, Ø1,20** m has also been introduced.

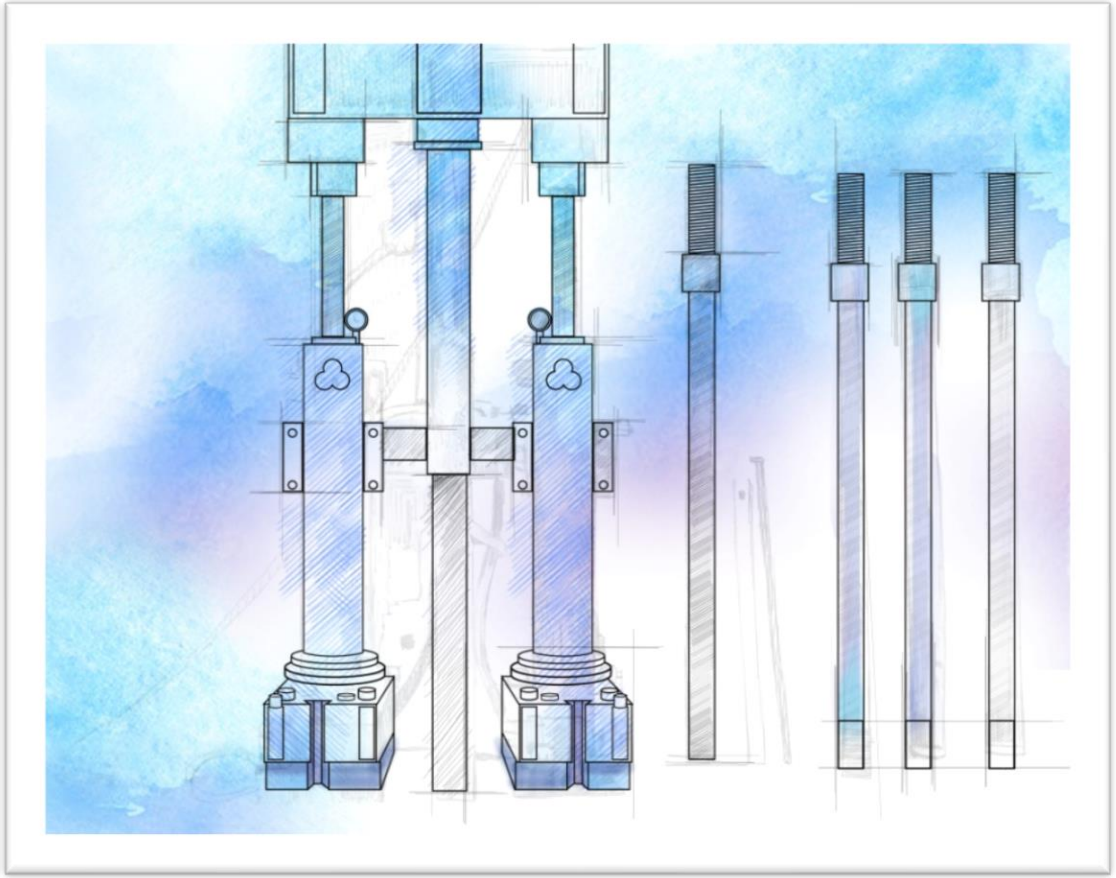
INSTALLATION OF THE EXPANDER BODY

As the cross section is small, several methods can be used for the installation.





INSTALLATION OF THE EXPANDER BODY



COMMON PILE TYPES IN COMBINATION WITH THE EB

Partial Displacement Auger pile with EB achieves higher shaft resistance than regular CFA and high toe resistances.

Full displacement auger pile (FDP) with EB achieves high shaft and toe resistances.

EXPANDER BODY PILES TYPICAL REPORT

PROJECT: TORRE CALACOTO

EBI PILES REPORT

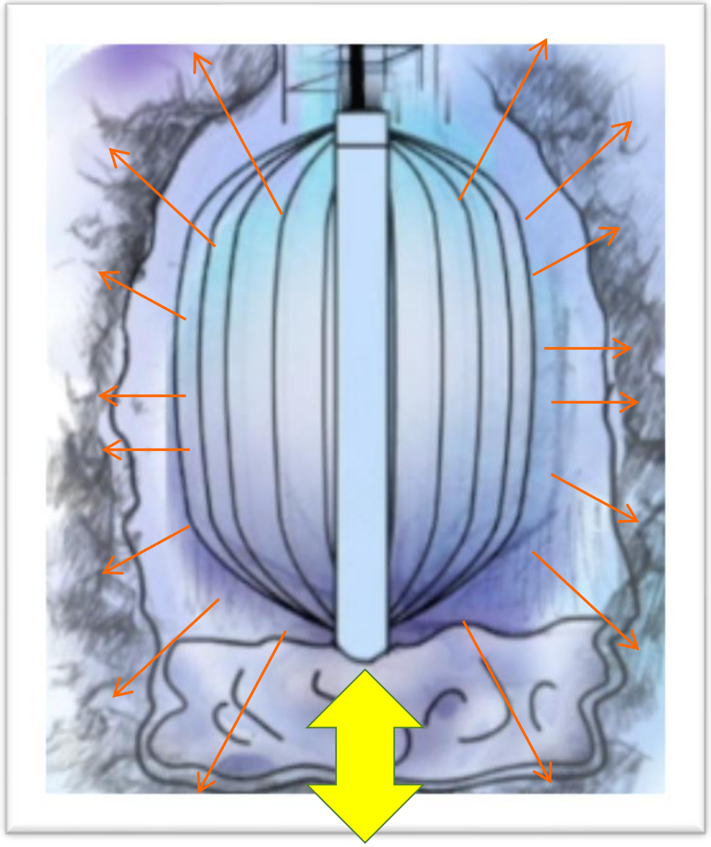
incotec
INGENIERÍA Y CONSTRUCCIÓN

CAP CODE	PILE	TIPO	SHAFT LENGTH (m)	SHAFT DIAMETER (m)	INJECTION PRESSURE (MPA)	INJECTION VOLUMEN (l)	INYECCION DE FONDO PRESION (kg/cm2)	INYECCION DE FONDO VOLUME (l)	SERVICE RESISTANCE SHAFT RESISTANCE (kN)	SERVICE RESISTANCE EBI FRICTION (KN)	SERVICE RESISTANCE EBI TOE (KN)	SERVICE RESISTANCE TOTAL (kN)	EBI EQUIVALENT DIAMETER(mm)	AREA (sq m)	DESIGN SERVICE LOAD (kN)	MAX. LOAD PER CAP (kN)	REAL RESISTANCE PER CAP (kN)
CA3	**1**	**1**	14.60	0.50	2.44	280.20	3.59	70.00	764.45	559.67	1,129.79	2,453.92	788.71	0.49	1,500.00		
CA3	**2**	**1**	14.60	0.50	4.04	85.00			764.45	466.21	333.47	1,564.13	397.29	0.12	1,500.00		
																3,000.00	**4,018.05**
CB2	**1**	**1**	14.60	0.50	1.71	280.80			764.45	391.44	556.36	1,712.26	789.44	0.49	1,500.00		
CB2	**2**	**1**	14.60	0.50	5.39	280.00			764.45	1,236.85	1,755.78	3,757.08	788.46	0.49	1,500.00		
CB2	**3**	**1**	14.60	0.50	4.39	279.90			764.45	1,006.71	1,428.85	3,200.01	788.34	0.49	1,500.00		
CB2	**4**	**1**	14.60	0.50	2.73	281.50	4.04	70.30	764.45	628.14	1,270.81	2,663.40	790.29	0.49	1,500.00		
																6,000.00	**11,332.76**
CB3	**1**	**1**	14.60	0.50	2.45	280.40	4.33	70.20	764.45	562.60	1,203.26	2,530.32	788.95	0.49	1,500.00		
CB3	**2**	**1**	14.60	0.50	5.10	280.30			764.45	1,170.90	1,662.93	3,598.28	788.83	0.49	1,500.00		
CB3	**3**	**1**	14.60	0.50	3.23	280.60			764.45	740.65	1,052.36	2,557.46	789.19	0.49	1,500.00		
CB3	**4**	**1**	14.60	0.50	1.44	280.90	4.47	71.00	764.45	330.66	887.24	1,982.35	789.56	0.49	1,500.00		
CB3	**5**	**1**	14.60	0.50	2.28	280.40	4.25	70.50	764.45	524.05	1,141.04	2,429.55	788.95	0.49	1,500.00		
																7,500.00	**13,097.96**
CB4	**1**	**1**	14.60	0.50	1.41	280.10	4.89	70.70	764.45	323.82	916.16	2,004.44	788.58	0.49	1,500.00		
CB4	**2**	**1**	14.60	0.50	2.70	280.30			764.45	619.17	879.36	2,262.99	788.83	0.49	1,500.00		
CB4	**3**	**1**	14.60	0.50	3.92	110.00			764.45	529.47	442.74	1,736.66	464.44	0.17	1,500.00		
CB4	**4**	**1**	14.60	0.50	1.50	280.50	5.24	70.60	764.45	343.30	976.78	2,084.53	789.07	0.49	1,500.00		
CB4	**5**	**1**	14.60	0.50	2.59	281.70	5.93	71.20	764.45	595.91	1,401.62	2,761.98	790.53	0.49	1,500.00		
																7,500.00	**10,850.60**
CC2	**1**	**1**	14.60	0.50	1.51	280.40	4.12	70.10	764.45	345.77	875.68	1,985.91	788.95	0.49	1,500.00		
CC2	**2**	**1**	14.60	0.50	2.56	280.70	5.20	70.00	764.45	586.50	1,318.81	2,669.76	789.32	0.49	1,500.00		
CC2	**3**	**1**	14.60	0.50	3.22	130.00		-	764.45	482.31	446.82	1,693.58	514.56	0.21	1,500.00		
CC2	**4**	**1**	14.60	0.50	2.80	280.90	5.47	80.02	764.45	643.40	1,425.15	2,833.00	789.56	0.49	1,500.00		
CC2	**5**	**1**	14.60	0.50	1.54	281.40	2.91	70.00	764.45	353.66	774.73	1,892.84	790.17	0.49	1,500.00		
CC2	**6**	**1**	14.60	0.50	2.60	281.00	5.21	70.10	764.45	597.34	1,335.53	2,697.32	789.68	0.49	1,500.00		
																9,000.00	**13,772.42**
CD2	**1**	**1**	14.60	0.50	2.06	280.40	2.96	70.30	764.45	471.74	946.34	2,182.53	788.95	0.49	1,500.00		
CD2	**2**	**1**	14.60	0.50	2.56	280.90	3.22	70.80	764.45	588.52	1,137.13	2,490.11	789.56	0.49	1,500.00		
CD2	**3**	**1**	14.60	0.50	2.68	280.30	4.57	72.40	764.45	614.82	1,299.70	2,678.97	788.83	0.49	1,500.00		
CD2	**4**	**1**	14.60	0.50	2.97	280.90	3.42	70.00	764.45	681.75	1,288.32	2,734.53	789.56	0.49	1,500.00		
CD2	**5**	**1**	14.60	0.50	3.14	281.20	4.62	70.40	764.45	720.20	1,455.46	2,940.11	789.93	0.49	1,500.00		
CD2	**6**	**1**	14.60	0.50	4.34	145.00	2.58	70.20	764.45	694.10	928.17	2,386.72	550.05	0.24	1,500.00		
																9,000.00	**15,412.96**

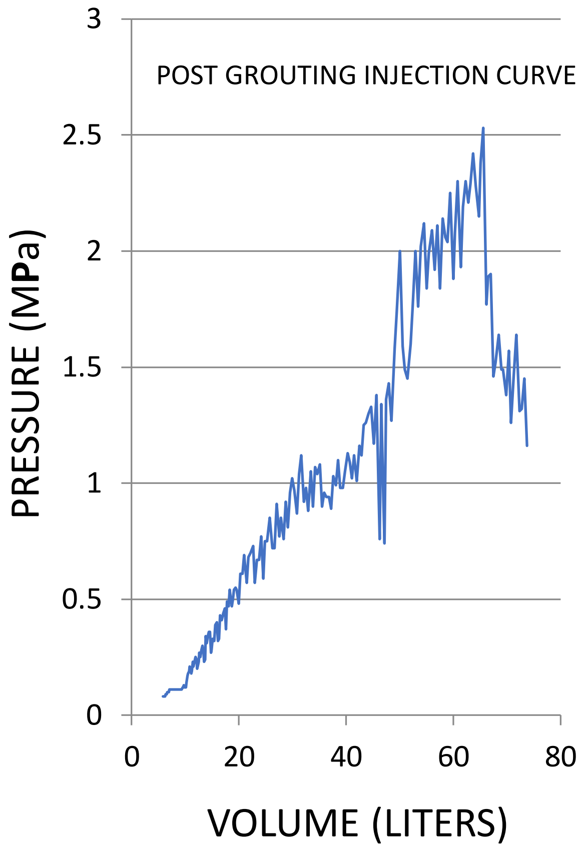
POST- GROUTING OF EB

- During the expansion, the EB shortens, which induces tension in the shaft and lifts the EB base, which may soften the soil at the EB base.

- To counteract this effect, the soil below the EB is post-grouted, thus, **increasing the pile toe stiffness** and providing **quality assurance**.



POST- GROUTING OF EB



Similar to the expansion-grouting, **the post-grouting below and around the EB is monitored** to verify the improvement effect.

POST- GROUTING OF EB

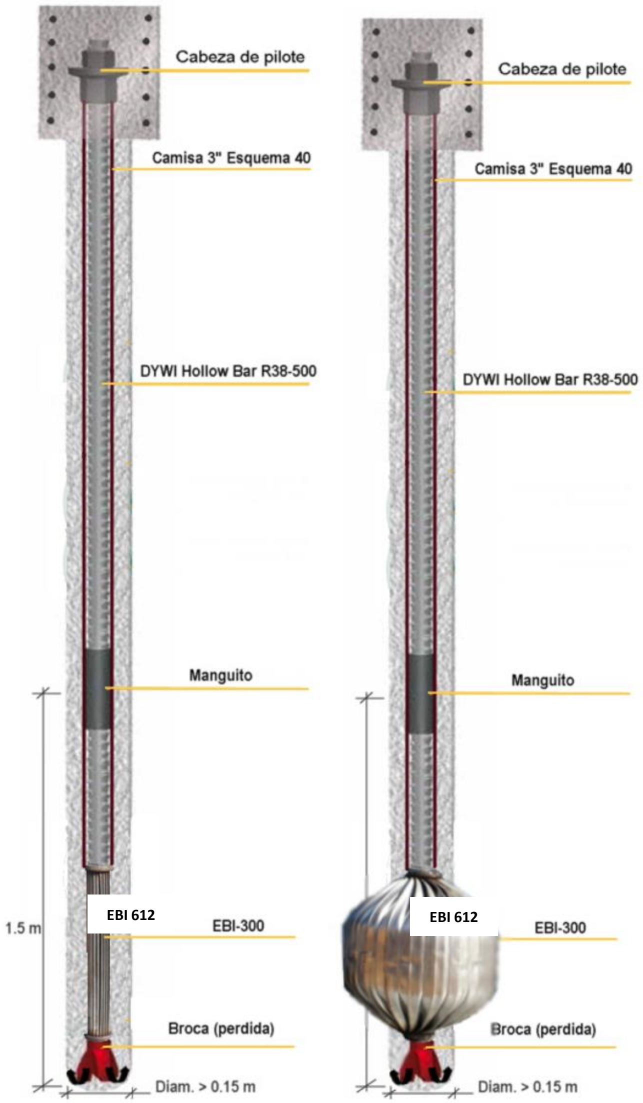
EXHUMED EB WITH POST- GROUTING

RECENT ADVANCES

SELF BORING EXPANDER BODY:

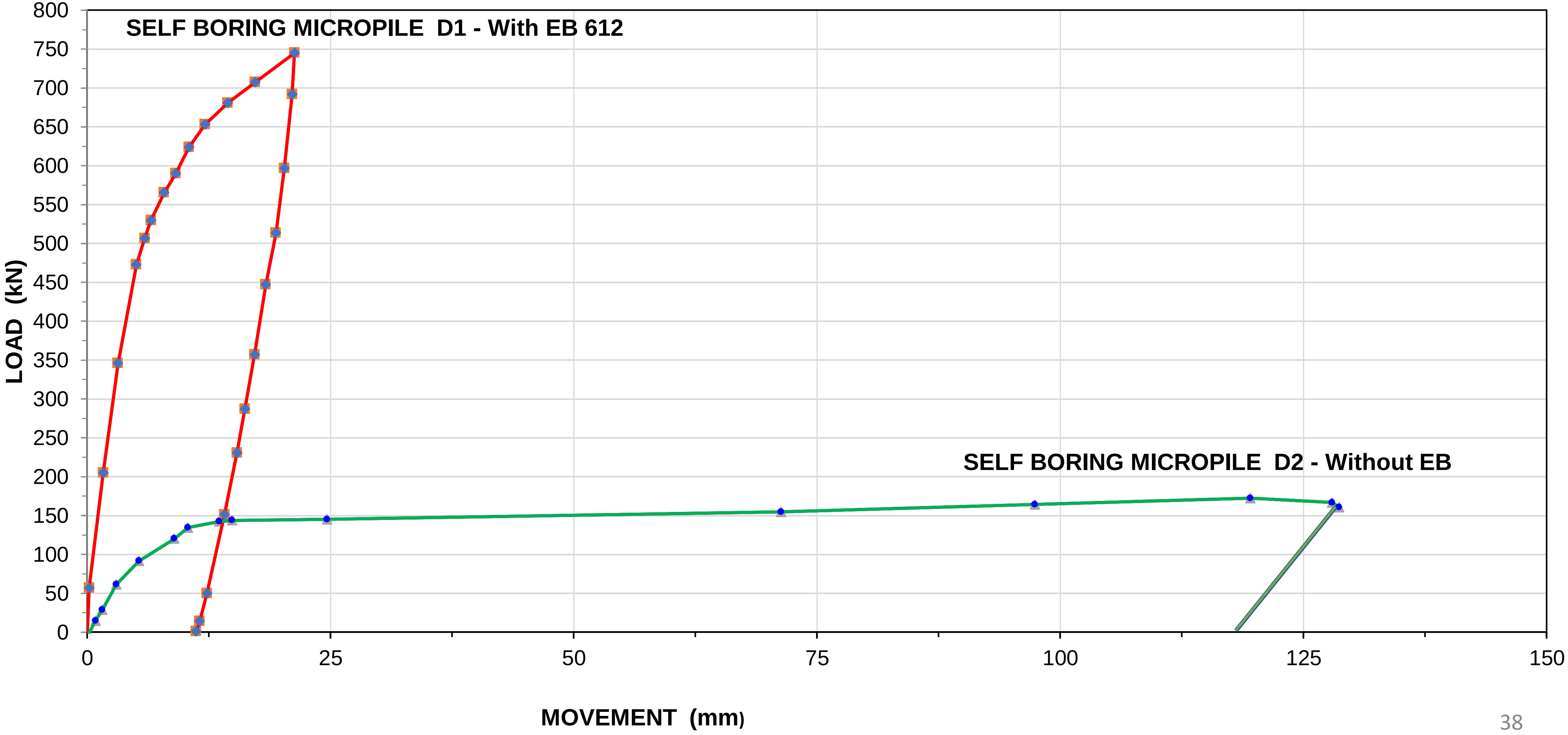
- The micro pile is installed in one operation.
- It is a perfect solution for underpinning, working in limited access areas, or when only small equipment is available.

ANEXO 1



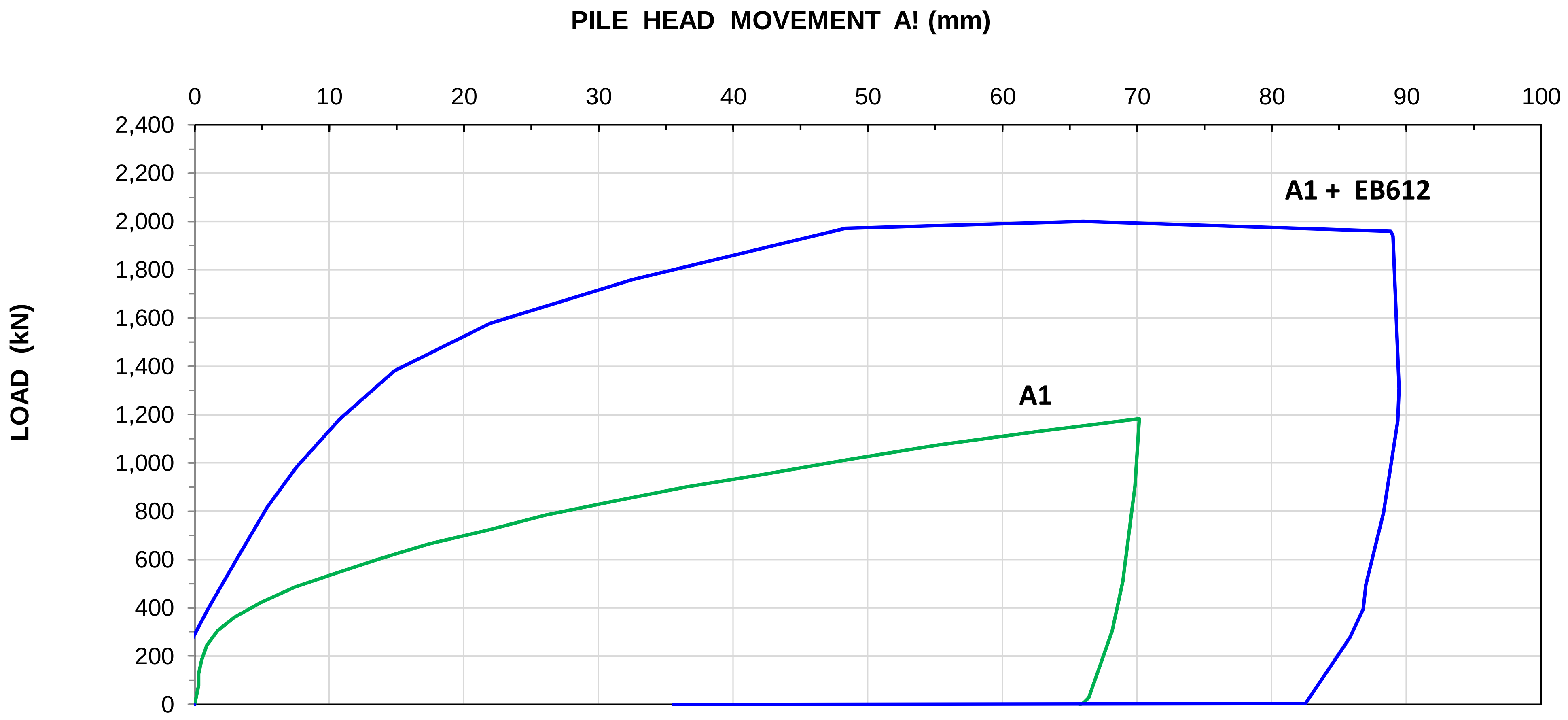
SOME LOADING TESTS CURVES

LOADING TESTS FOR MICROPILES WITH AND WITHOUT SELF BORING EB

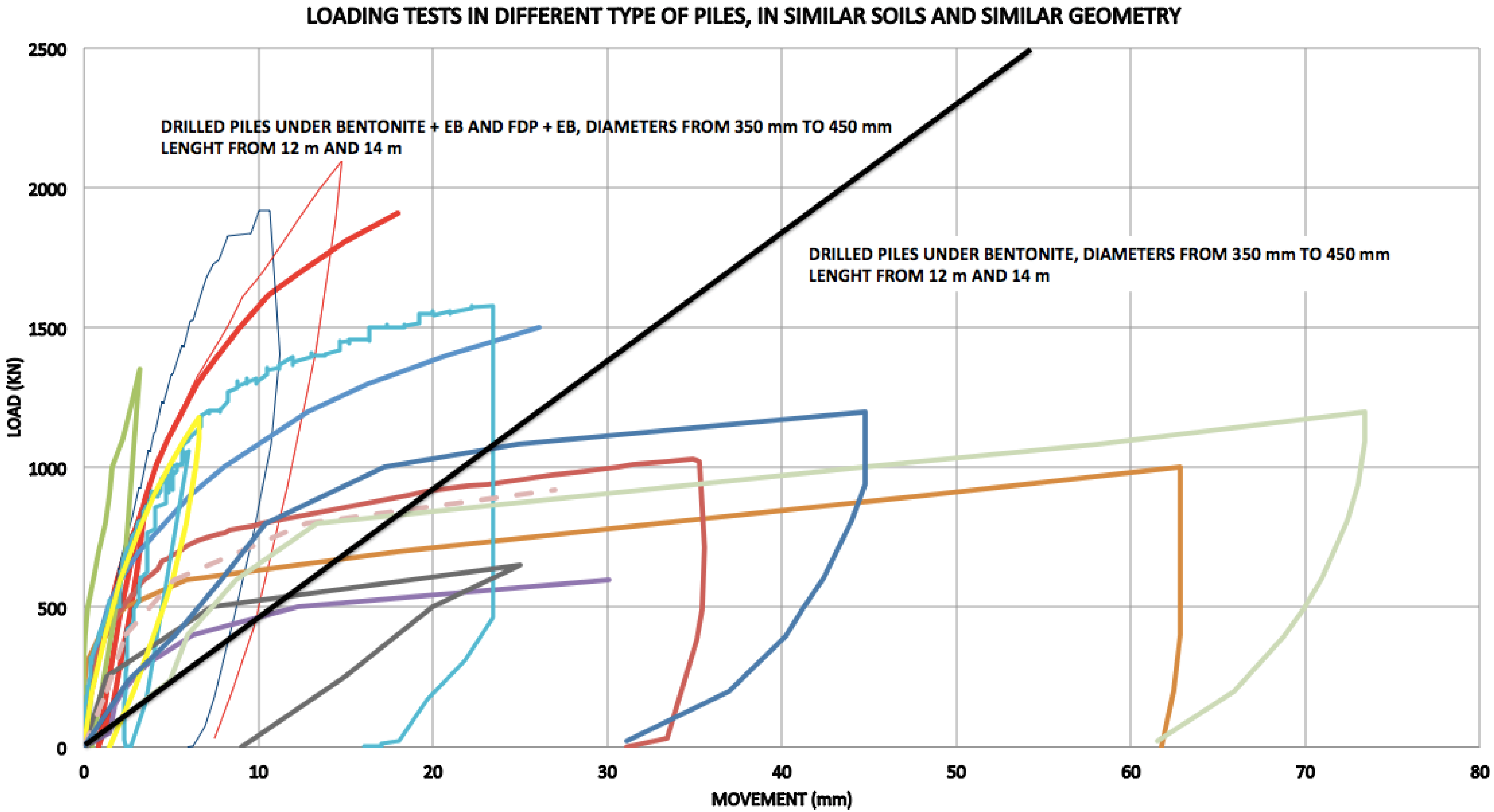


LOADING TEST: DRILLED SHAFT IN SILTY SAND

SHAFT 450 mm IN DIAMETER, L=9 m. EB 612

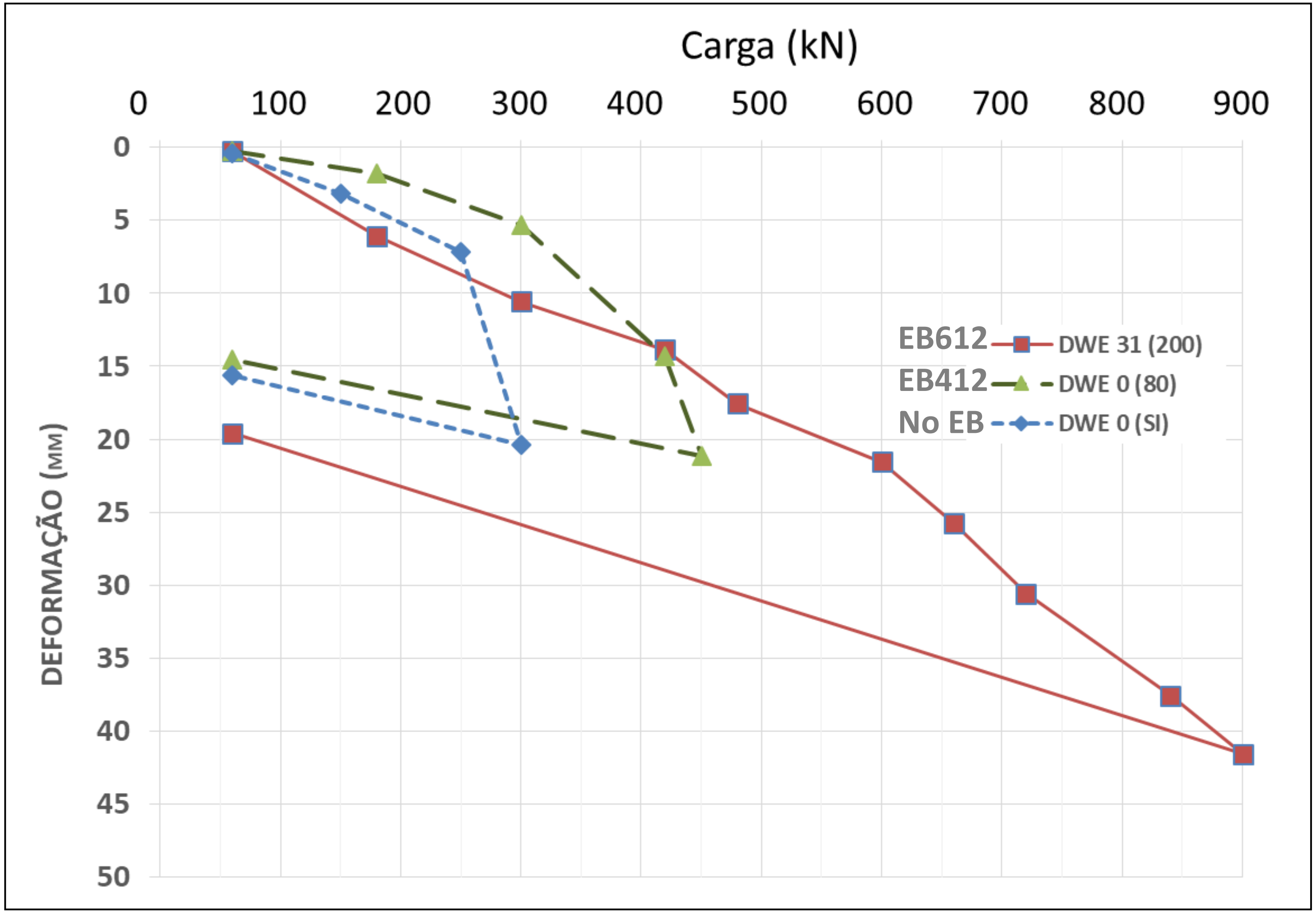


LOADING TESTS CURVES FOR PILES IN SANDS



ANCHORS

LOADING TEST: TIEBACKS IN COLLAPSABLE CLAY



GENERAL LIMITATIONS

1.- Typically, the higher service loads are limited to about 5000 kN for piles in very dense sands and 500 mm shaft.

2.- In sands, the minimum service load is around 250 kN, usually larger, therefore the EB is not competitive for lower loads in sands.

GENERAL ADVANTAGES

1.- Each EB performs a **soil investigation** with information about soil condition, soil type and stiffness. It can be used in all the types of soils. Also, the toe resistance increases dramatically, both in piles and anchors.

2.- Important economical savings, between 15% and 60% compared with traditional systems. It can be installed with any system.

3.- Shorter construction time. Up to 60% of time saving per resisted ton.

4.- High production. More than 20 EBs per shift, depending on the installation method.

5.- The carbon print per service ton is **much smaller** than in other systems.

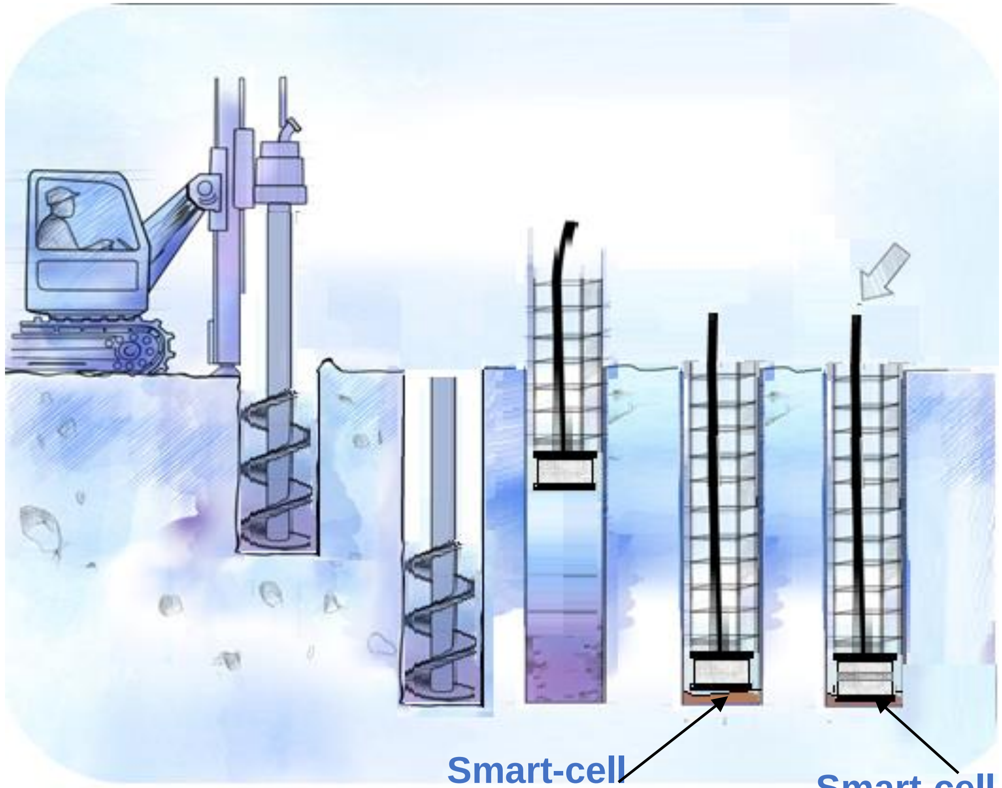
BETTER QUALITY CONTROL, PRICE AND TIME.

2

PRE-LOAD, PRE-DEFORMATION CELLS FOR CAISSONS – SMART-CELL

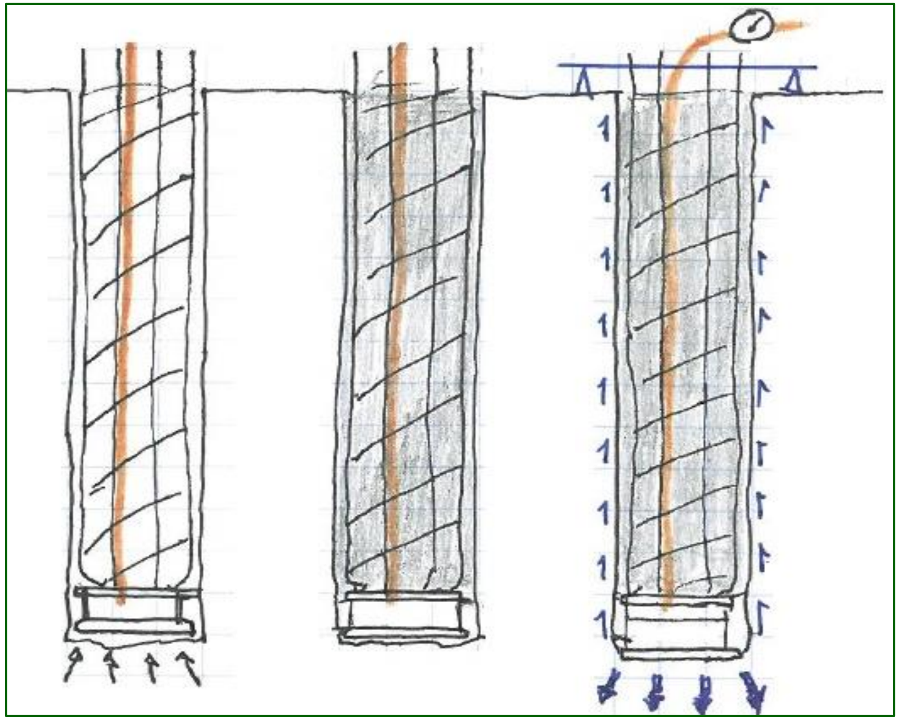
GENERAL ASPECTS

After pile construction, the toe-box is expanded by injecting grout, which pushes the toe-box bottom into the soil at (below) the pile toe, compressing and stiffening it. This process includes measuring pressures and grout volumes.



Smart-cell
before expansion

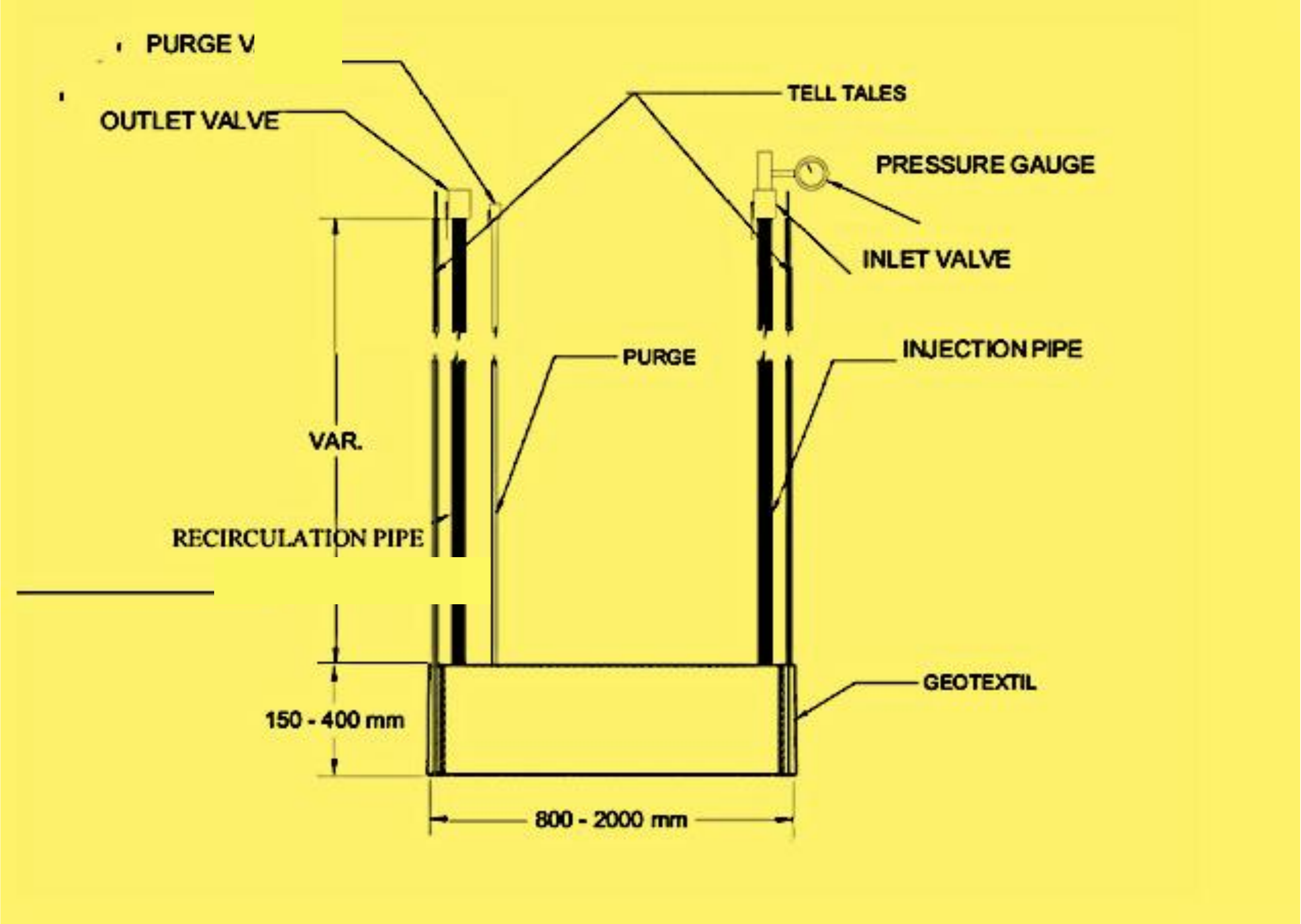
Smart-cell
after expansion



Smart-cell
before expansion

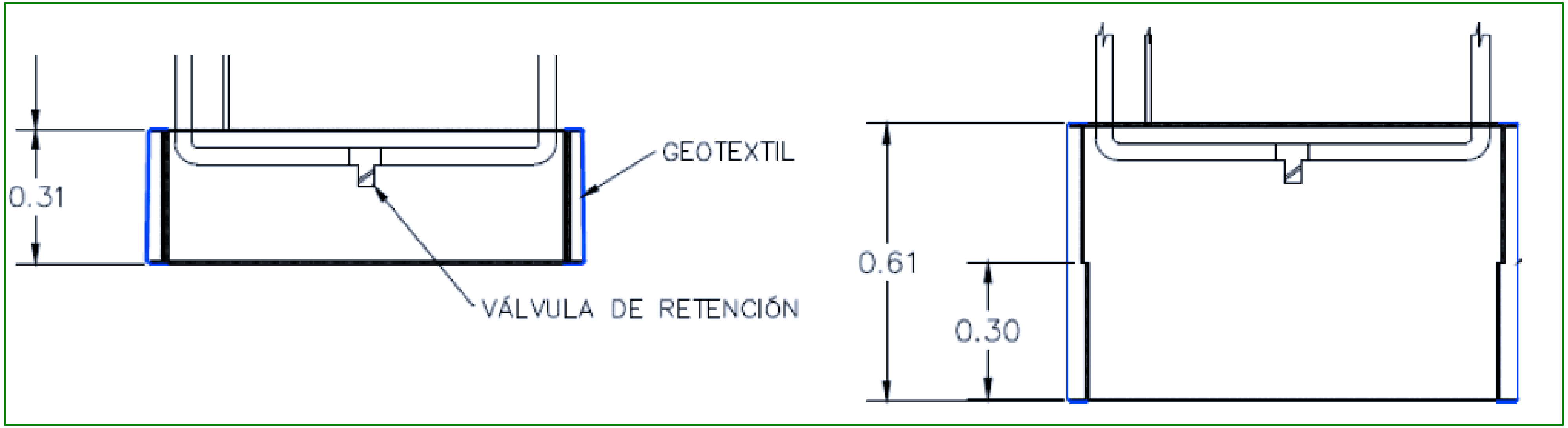
Smart-cell
after expansion

TOE BOX SCHEME



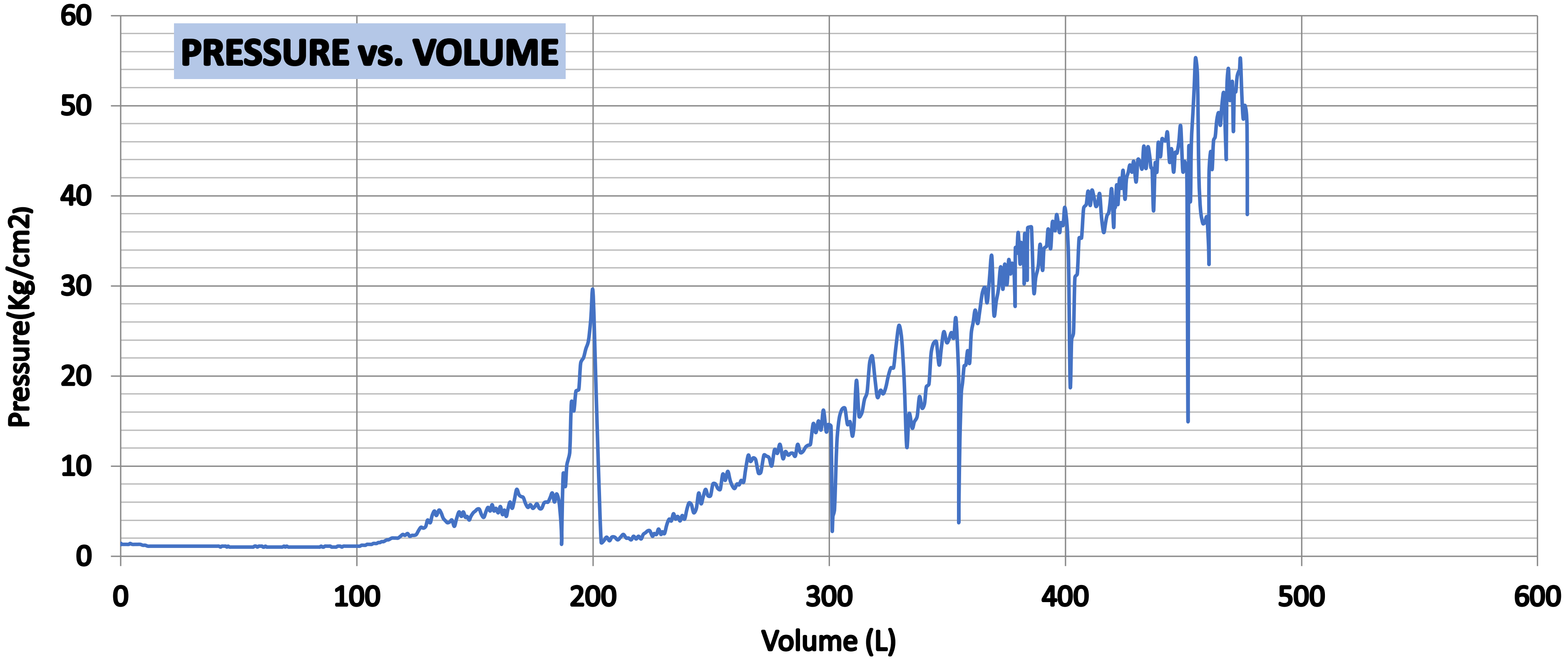
TELL TALES

TOE BOX



GENERAL ASPECTS

The expansion of toe-box acts is similar to performing a bidirectional cell test because during the process, several parameters are recorded: pressure, volume, toe movement and head movement to provide data for post-construction—as is—analysis. N.B. **of every pile**!



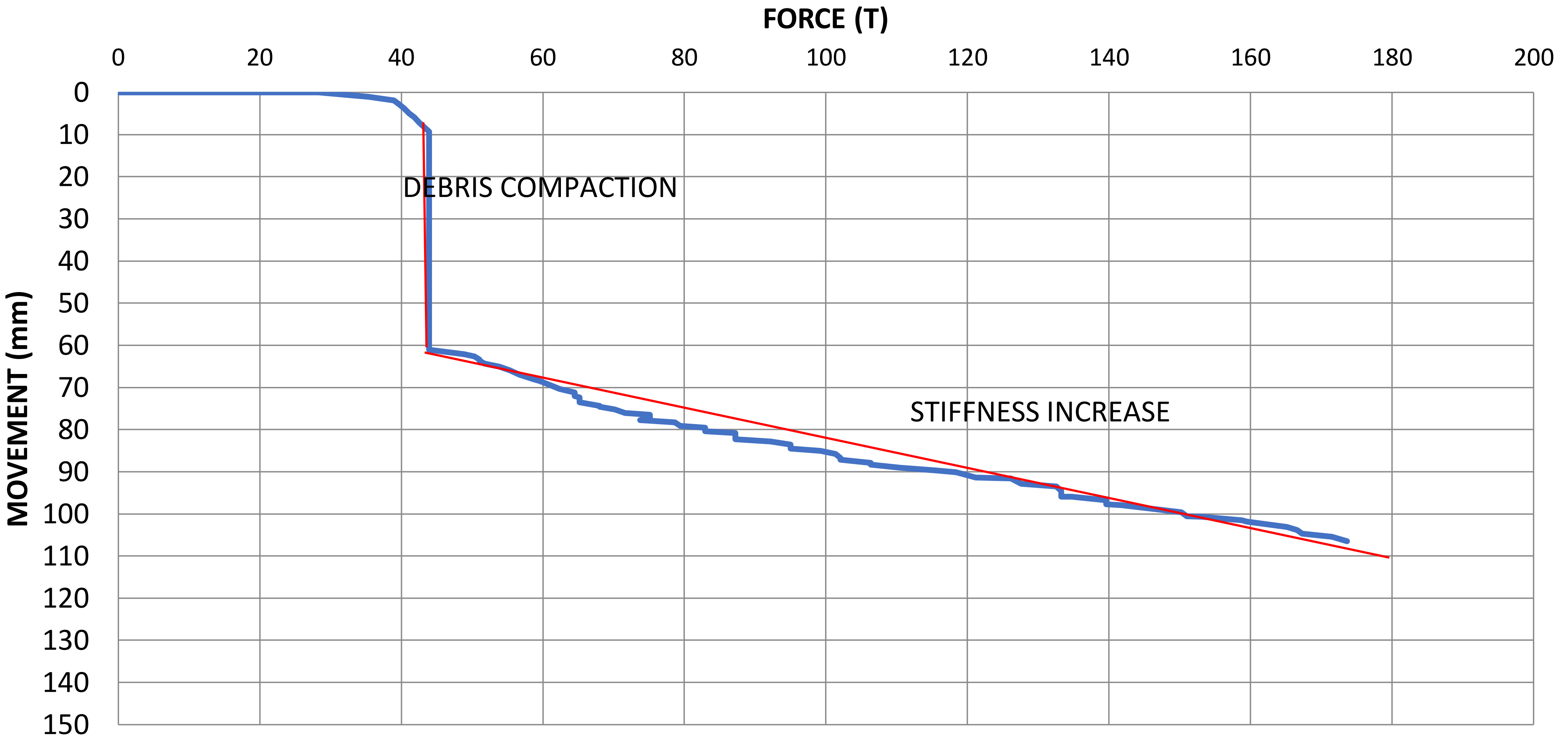
Graph of measured pressure vs. injected grout volume

GENERAL ASPECTS

TYPICAL CURVE FORCE VS. TOE MOVEMENT.

"Force" is a measured pressure times the cross sectional area of the toe-box.

THE CHANGE OF STIFFNESS IS PRESENTED



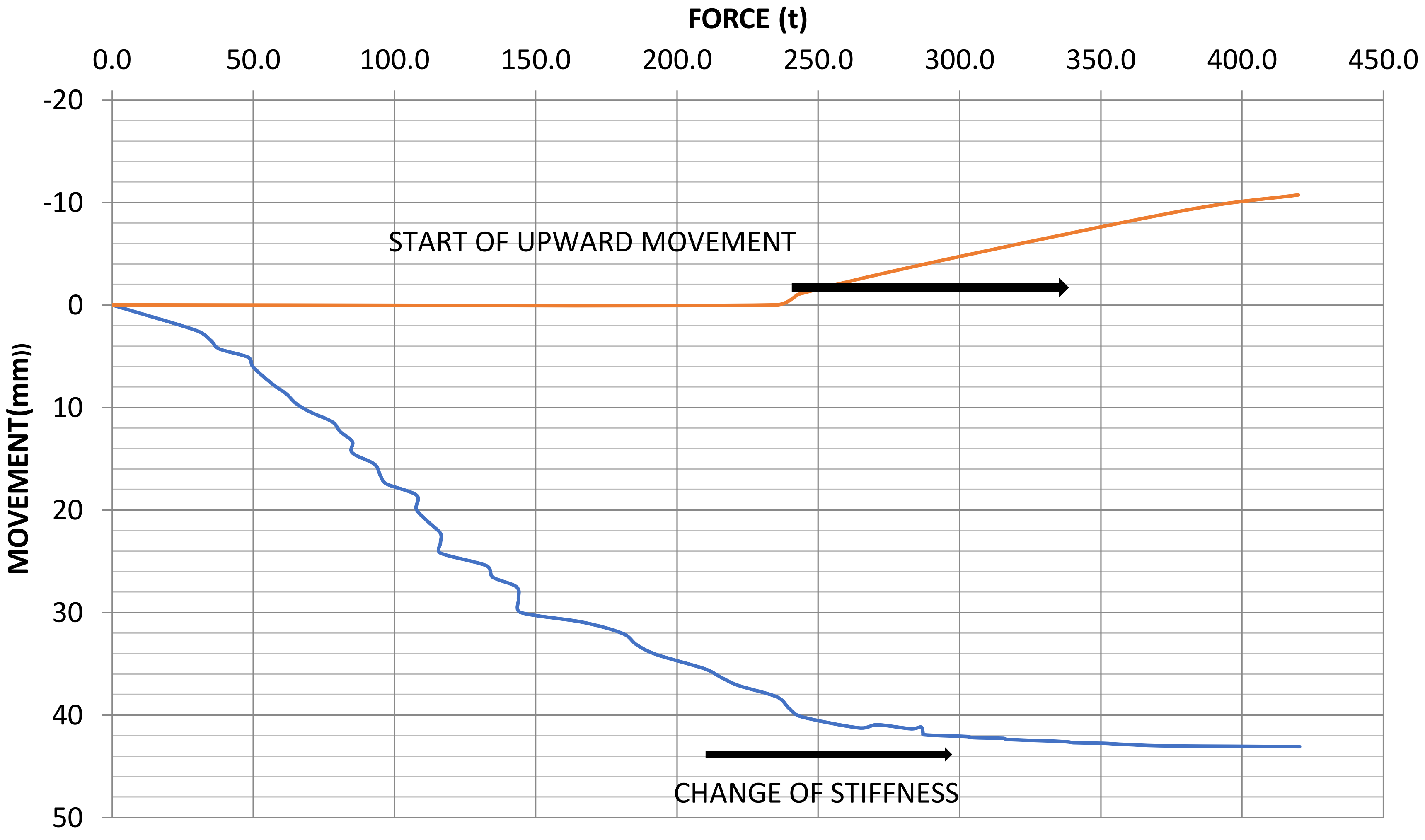
CAISSON (bored pile):
Ø1,500 mm
L = 22m

MAX. INJECTION PRESSURE:
25 kg/cm² (2,50 MPa)

TOTAL MOBILIZED
LOAD : 3,500 kN

GENERAL ASPECTS

TYPICAL CURVE FORCE VS. TOE MOVEMENT
THE CHANGE OF STIFFNESS AND HEAD MOVEMENT IS PRESENTED



CAISSON: Ø150 CM
L = 22m

MAX. INJECTION
PRESSURE: 55 Kg/cm2

TOTAL MOBILIZED
LOAD: 840 TN

QUALITY SYSTEM

- Although the capacity of a pile should be defined prior to the installation of the toe box, during the expansion (injection of grout) the pressure, volume, and movements (toe and head) are measured, giving the resistance parameters of **<u>each</u>** pile/caisson.

- An additional important aspect is that the shape of the injected element is known.

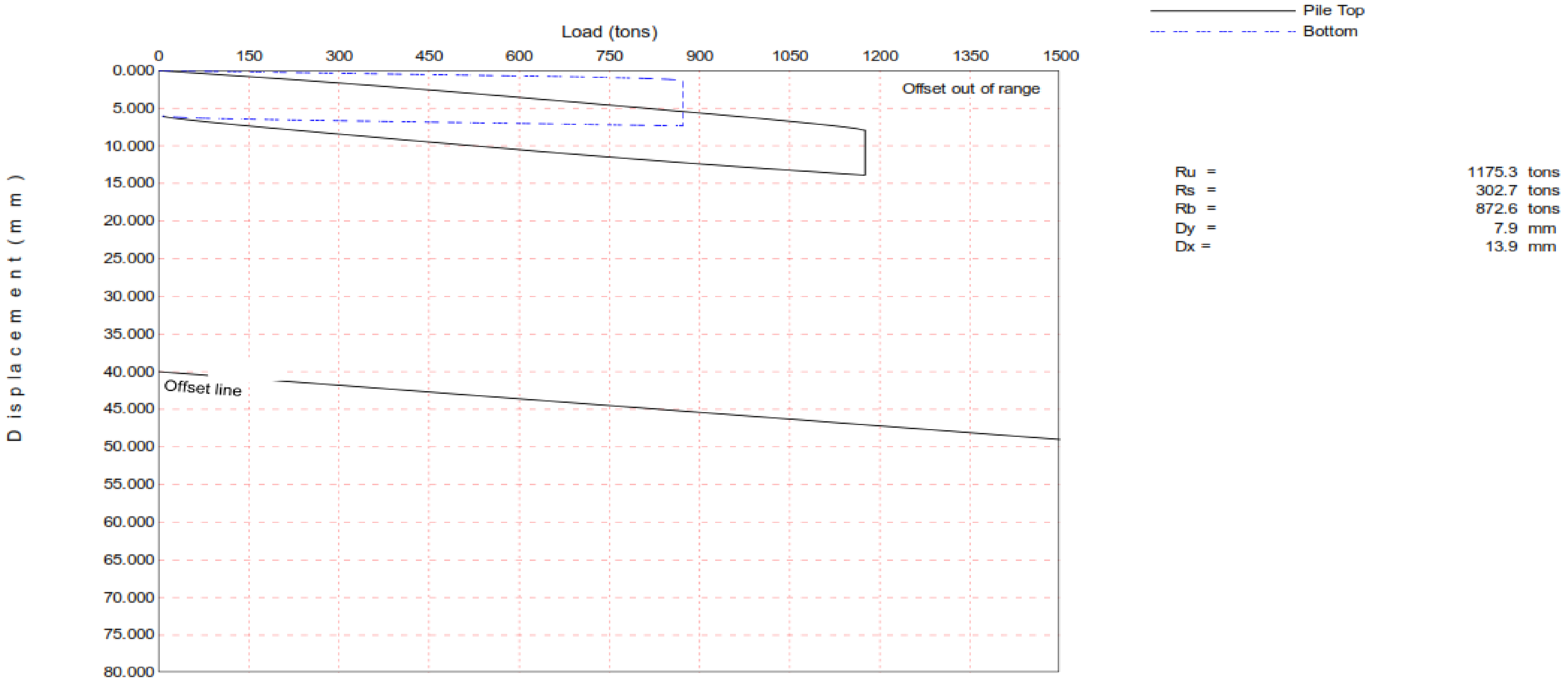
DYMANIC LOAD TEST

- The following graphs show the results of two dynamic load tests (dlt) performed on two caissons 5m apart.

- The first has a toe box and second does not. The test employed a 15 t falling weight at 1.8 m free fall

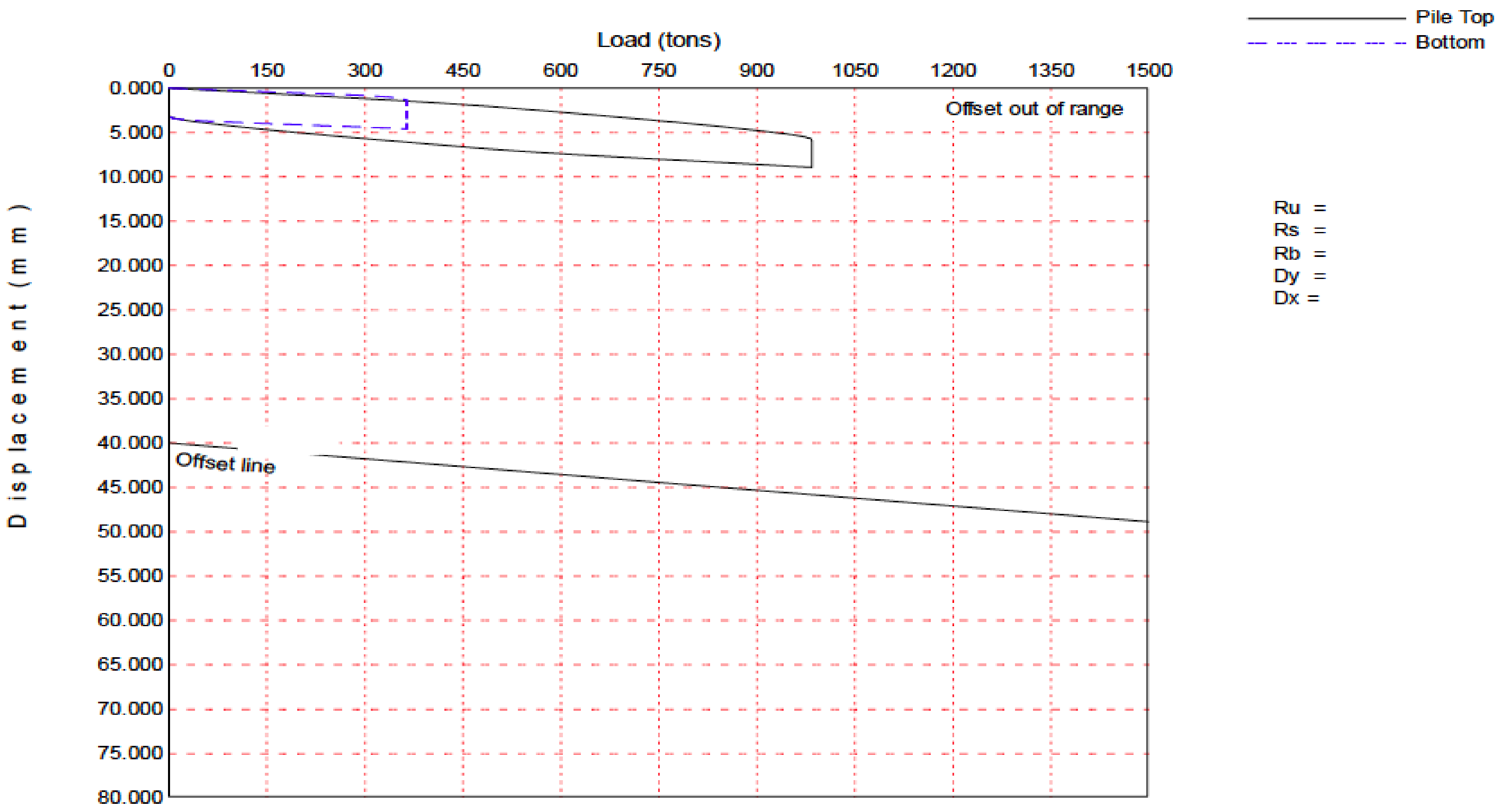
DYNAMIC LOAD TEST

CAISSON Ø 1200 mm, L=22 m **WITH TOE BOX**



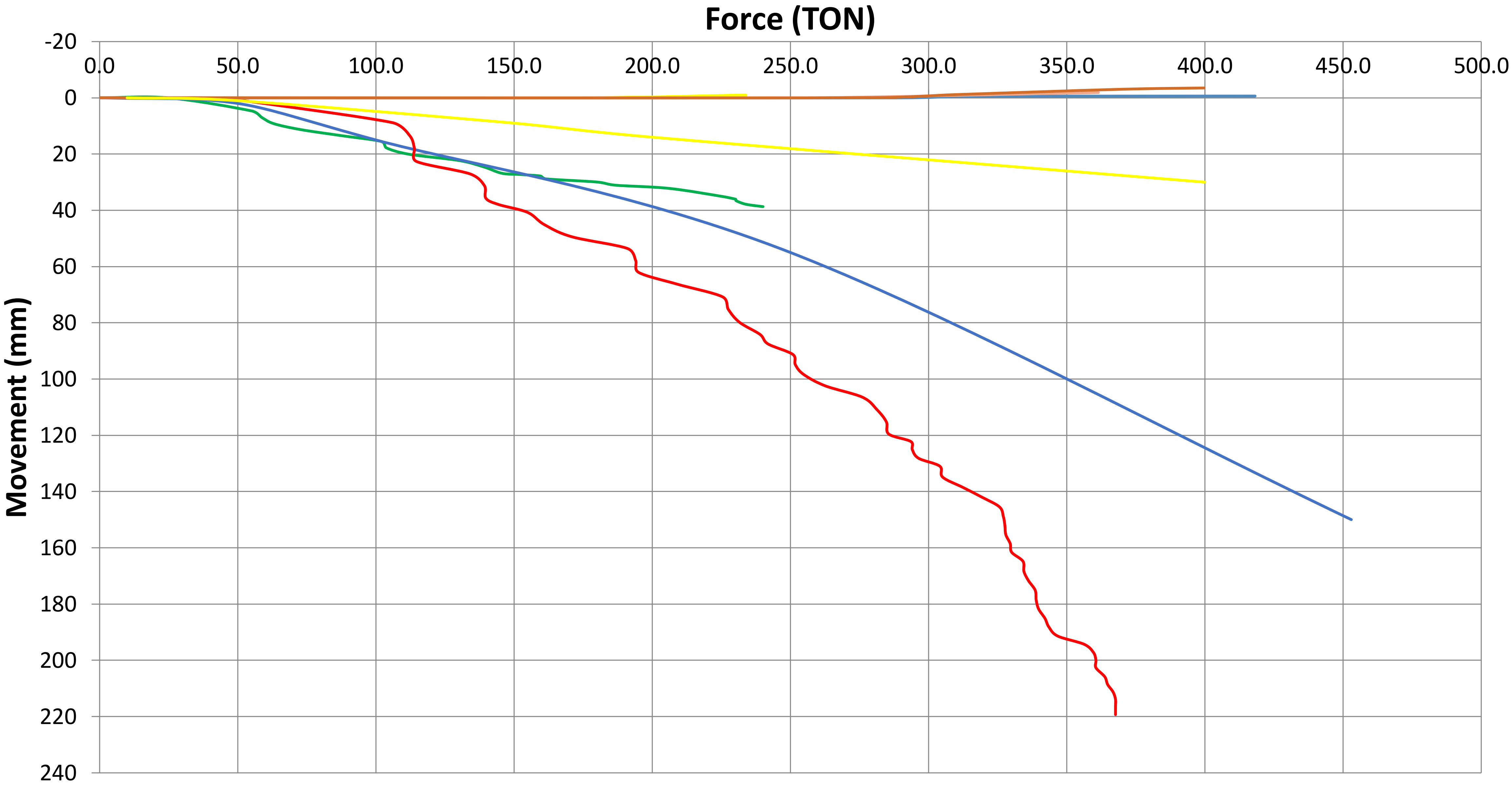
DYNAMIC LOAD TEST

CAISSON Ø 1200 mm, L=22 m **WITHOUT TOE BOX**



Ru =	984.3	tons
Rs =	620.0	tons
Rb =	364.3	tons
Dy =	5.9	mm
Dx =	8.9	mm

FORCE VS. MOVEMENT



BENEFITS

COST

- ✓ Cost reduction per ton
- ✓ Length of the caisson capacity increased

TIME

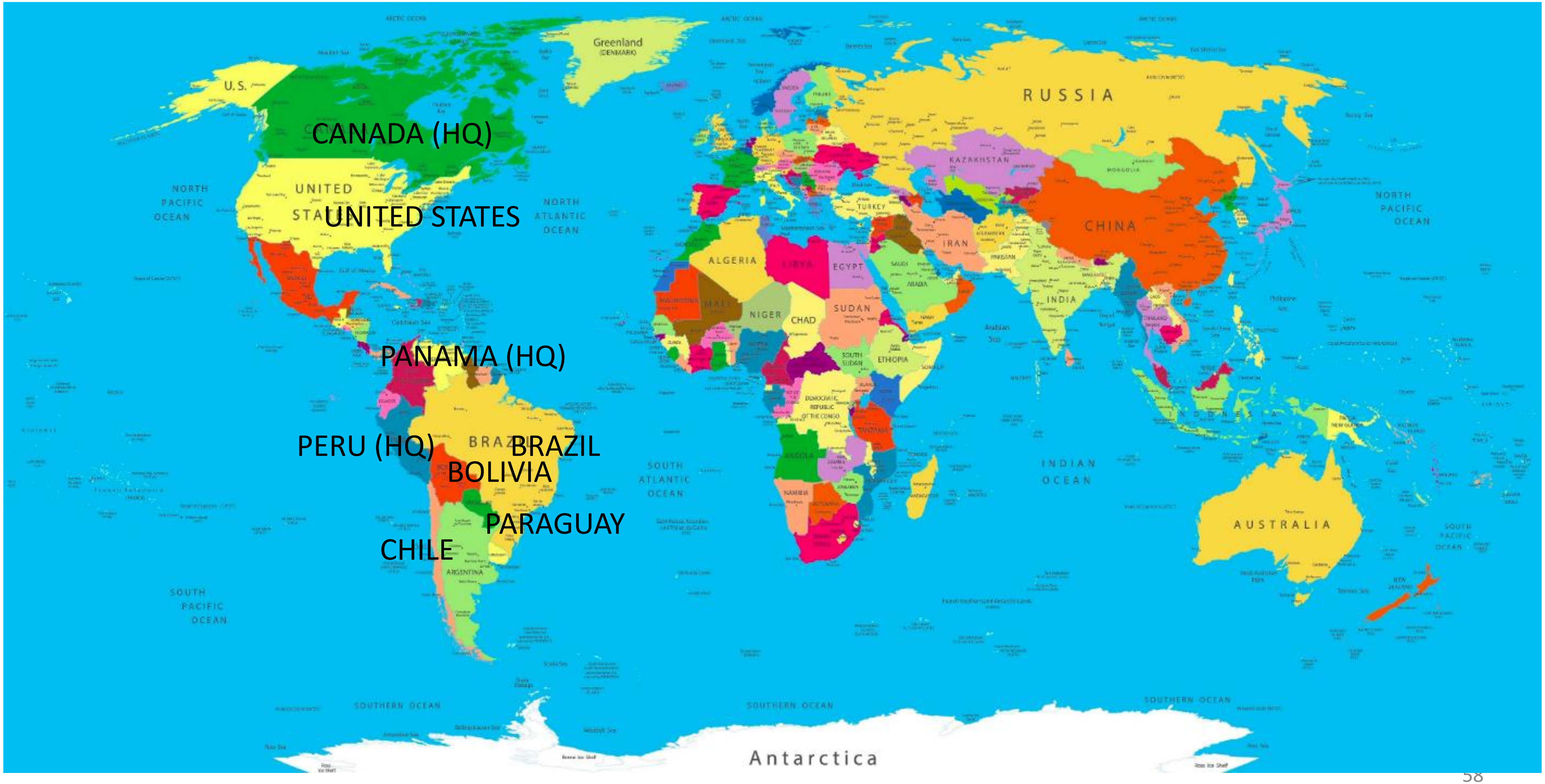
- ✓ The total construction time is reduced because the number of elements or its

QUALITY

- ✓ All processes are elect
- ✓ With the information possible to know the capacity of each caisson/pile.
- ✓ It remediates the disturbances introduced by the construction process

rilled shafts with
mm

WHERE ARE WE NOW?



WHERE ARE WE PLANNING TO BE IN 2020?

THANK YOU TAIWAN!