TFEG TENSIONED ELEMENTS:

From design to implementation

Innsbruck, February 24th 2009

Ing. Valter Maria SANTORO - IGeS

I.Ge.S.
INGEGNERIA GEOTECNICA E STRUTTURALE snc
di VALTER MARIA SANTORO & C.

JobSoil
INNOVATION & RESEARCH

PREVISIONAL MODELS AND FIELD

TESTS RESULTS

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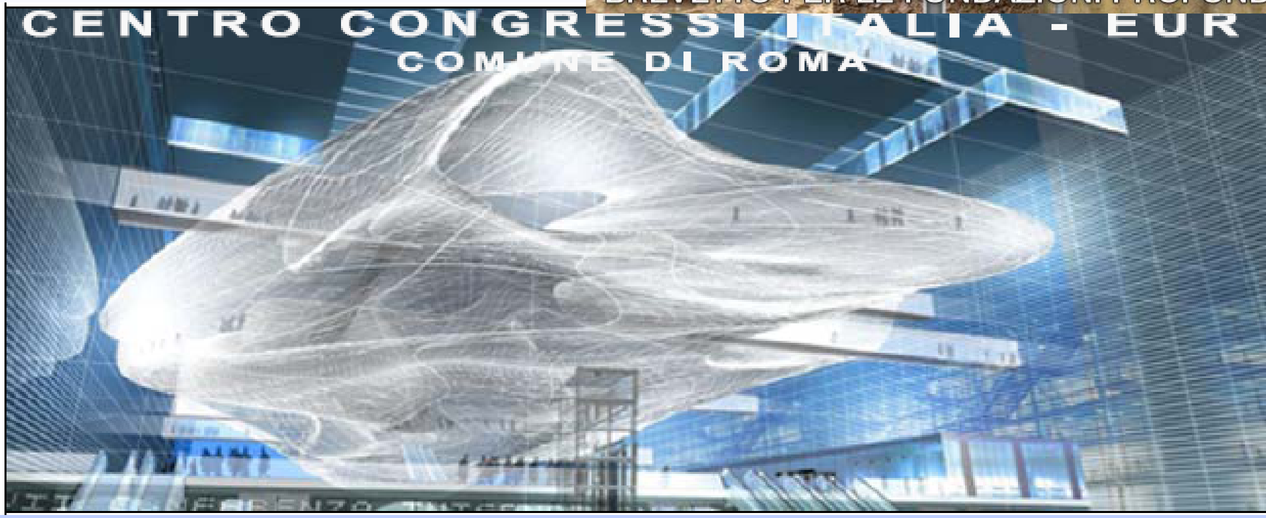
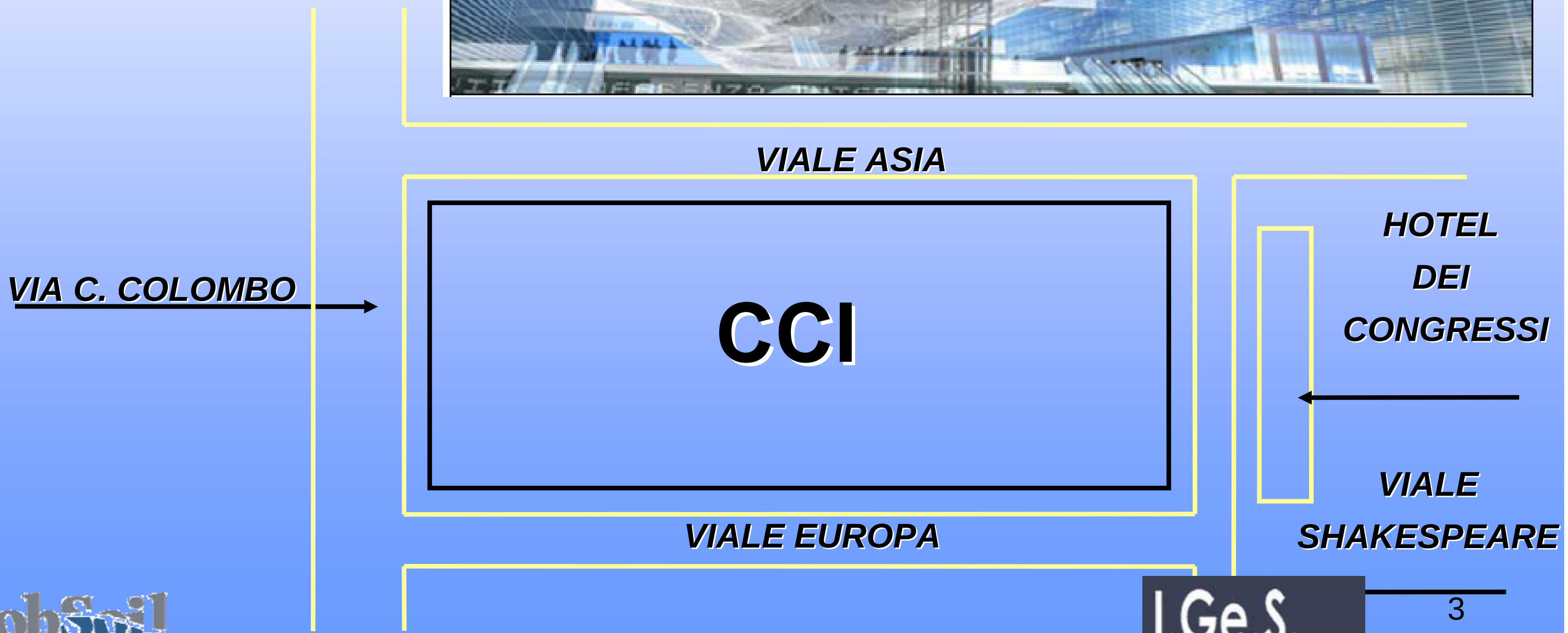
CASE HISTORY





GEOLOGY FEATURES

GENERAL DATA

- SITE: EUR DIRECTIONAL CENTER;
- ALTITUDE: 28M s.l.m.;
- MORFOLOGY: PLAIN;
- STABILITY: NO INSTABILITY EVIDENCE.

GEOLOGICAL FORMATIONS:

- RECENT FILL COVER (PRESENT);
- FLUVIO-LACUSTRINE FORMATION (TYRRENIAN);
- OLD TUFFS (MEDIUM PLEISTOCENE);
- FLUVIO-LACUSTRINE FORMATION (UPPER SICILIAN);
- CLAY, SILT, SAND AND GRAVEL COMPLEX (SICILIANO).

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LITOSTRATIGRAPHY

- **GENERAL DATA**
- **N°8 CORE DRILLING BOREHOLES (depth 45- 50 m) S1-S8;**
- **375 m OF DRILLED SOIL;**
- **34 UNDISTURBED SAMPLES;**
- **69 SCPT DYNAMIC CONTINUOUS PENETRATION TESTS;**
- **20 LEFRANC PERMEABILITY IN SITU TESTS;**
- **8 PIEZOMETERS.**

- **A) SHALLOW FILL: sand and tuffs with brick debris (th=0.80 – 4.90 m);**
- **B) CLAYEY SILT AND SANDY SILTS: redeposited piroclastic clayey and sandy silts (th=4.50 m);**
- **C) PIROCLASTIC DEPOSITS: piroclastic vulcanic pozzolans and tuffs with sands (th=0.50- 1.10 m);**
- **D) CLAYEY SILTS. SILTY SANDS AND SANDS: lacustric clayey silst and clayey with sands (th=1.30- 7.90 m);**
- **E) SILTY CLAY AND CLAYEY SILT: silty clay (th=8.20-19.50);**
- **F) SANDS AND GRAVELS: silty sands and calcareous gravels (th=9.80-11.60m);**
- **G) BASE SLIGHTLY OVERCONSOLIDATED SILTY CLAYS**

FIRST PRE-EXCAVATION PHASE

WORK SITE ON SEPTEMBER 2008

WORK SITE ON SEPTEMBER 2008

TFEGGED TIE RODS – FIELD TEST

FIELD TEST

- ***PRE-TENSIONED TIE RODS 4 AND 6 0.6" STRAND;***
- ***PRIMARY (BINARY SEMENT) AND SECONDARY (CHEMICAL) SUB-VERTICAL INJECTIONS;***
- **SUB-HORIZONTAL SOIL NAILING;**
- **JET-GROUTING COLUMNS.**

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TIE ROD FIELD TESTS

TIE ROD	L - m	ANCHOR LEG - m	STRAND	HORIZ. INCLINATION
1A-1B-1C	23	8 - PR INJ	6	10°
1D	18	3 - TFEG	6	10°
2A-2B-2C	22	9 - PR INJ	8	30°
2D	16	3 - TFEG	8	30°

RESULTS AND POST-ANALYSIS

•***<u>RESULTS 1° TFEGGED TIE ROD</u>***

-**N° strand 0.6”= 6**

-**Pult-Pmax=1150 KN**

-**delta-Pmax= 74 mm**

-**Ll= 15.00 m**

-**Lleq= 11.50 m**

•***<u>RESULTS 2° TFEGGED TIE ROD</u>***

-**N° strand 0.6”= 8**

-**Pult-Pmax=1700 KN**

-**delta-Pmax= 87 mm**

-**Ll= 13.00 m**

-**Lleq= 12.21 m**

PRESS. INJECTED – 1 VALVE - TIE ROD FIELD TEST

- ***TIE ROD NO. 1***
- **Lfree= 13.00 m**

- Lanchor= 9.00 m

- α=10°

-N° strand 0.6”= 6

Φperf= 180 mm

- ***TIE ROD NO. 2***
- **Lfree= 13.00 m**

- Lanchor= 9.00 m

- α=30°

- N° strand 0.6”= 8

– Φperf= 180 mm

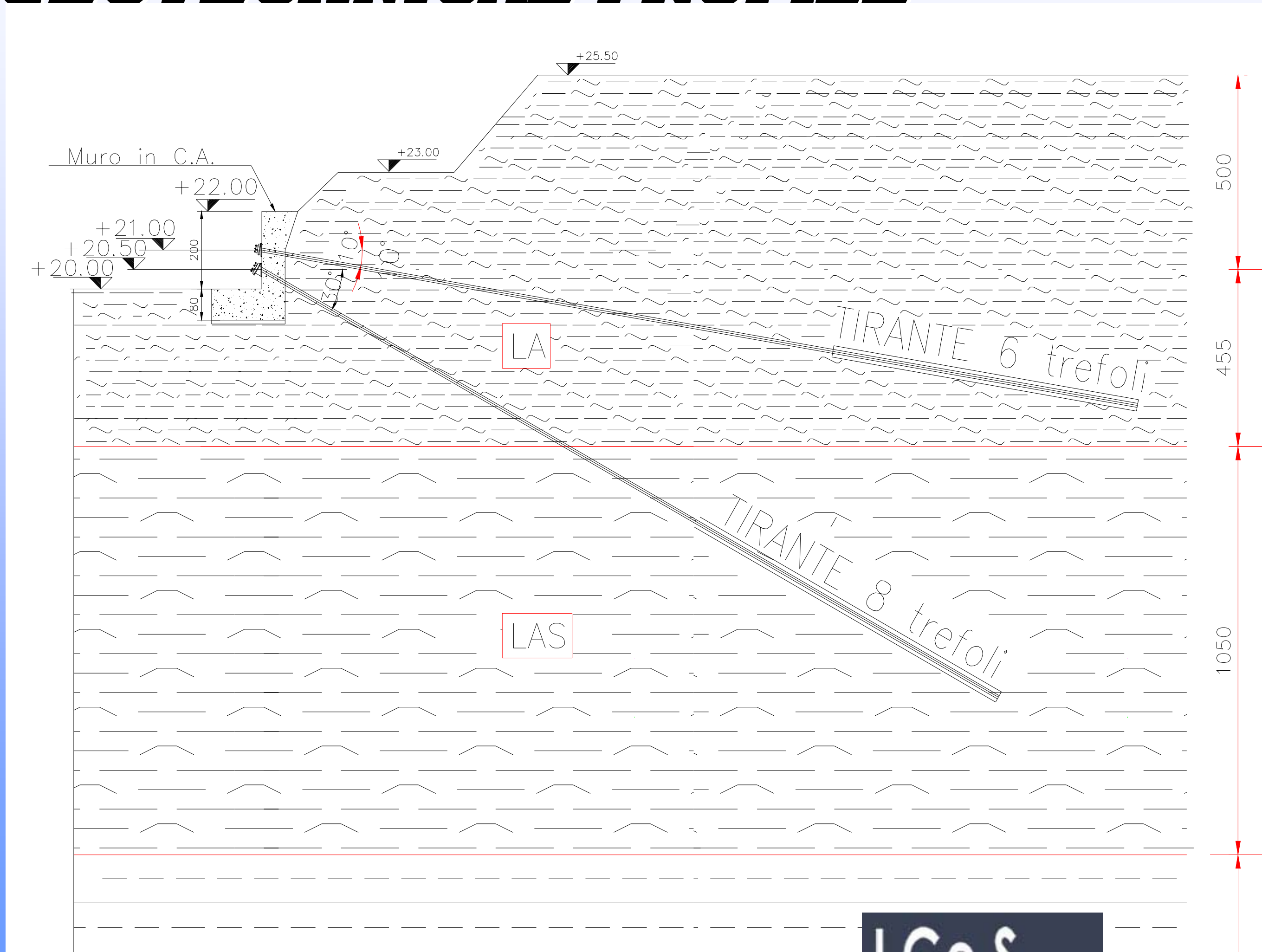
FIELD TEST GEOTECHNICAL PROFILE

- LA:

clayey silts

- LAS:

clayey sandy silts



TFEGGED TIE RODS FIELD TEST

•***TIE ROD NO 1***

• **Lfree= 15.00 m**

- Lanchor= 3.00 m

- α=10°

-**N° strand 0.6”= 6**

-**Double MTFEGMP 88.9-3-160 tie tip – 4 sockets**

•***TIE ROD NO. 2°***

•**Lfree= 13.00 m**

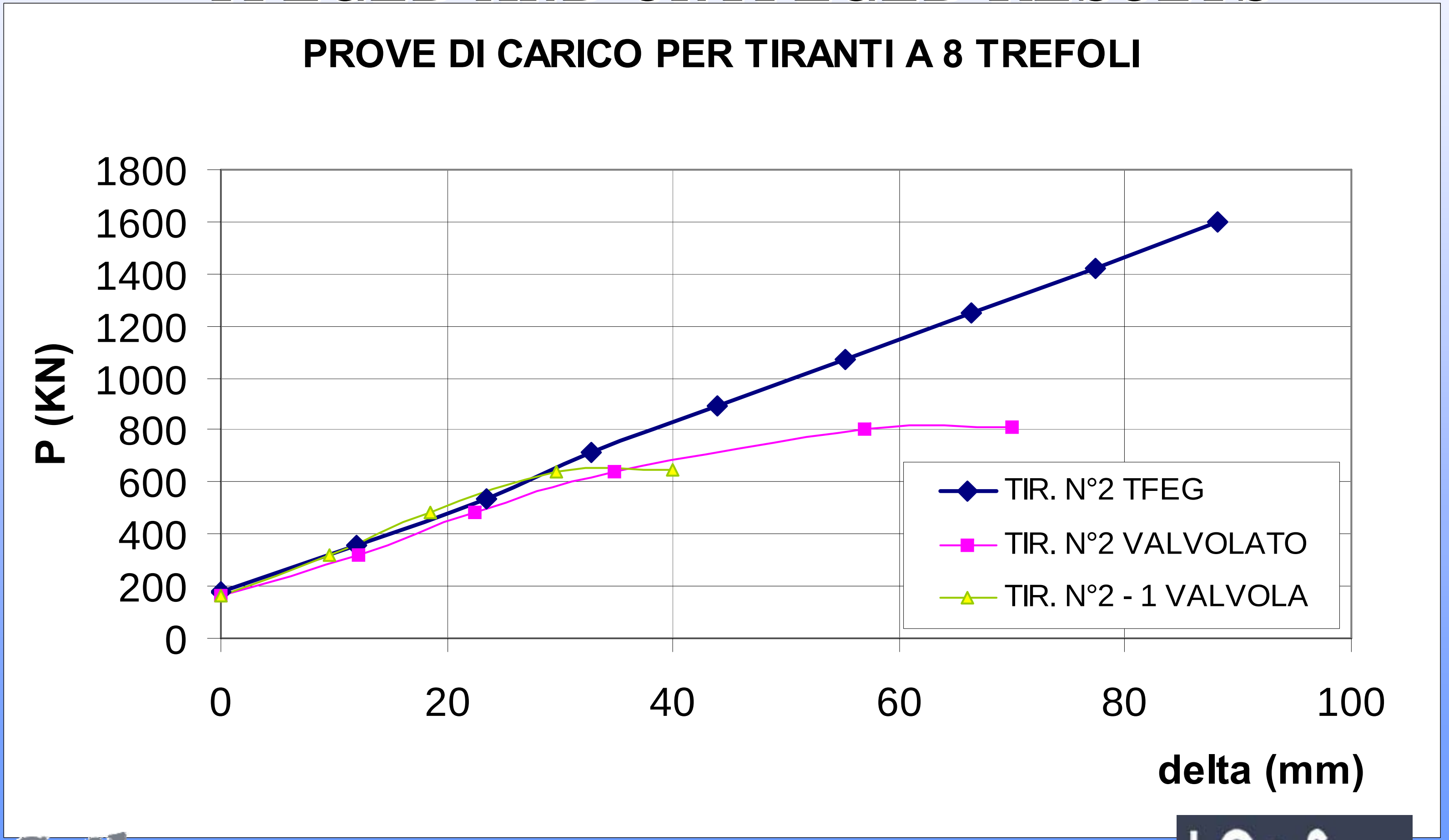
- Lanchor= 3.00 m

- α=30°

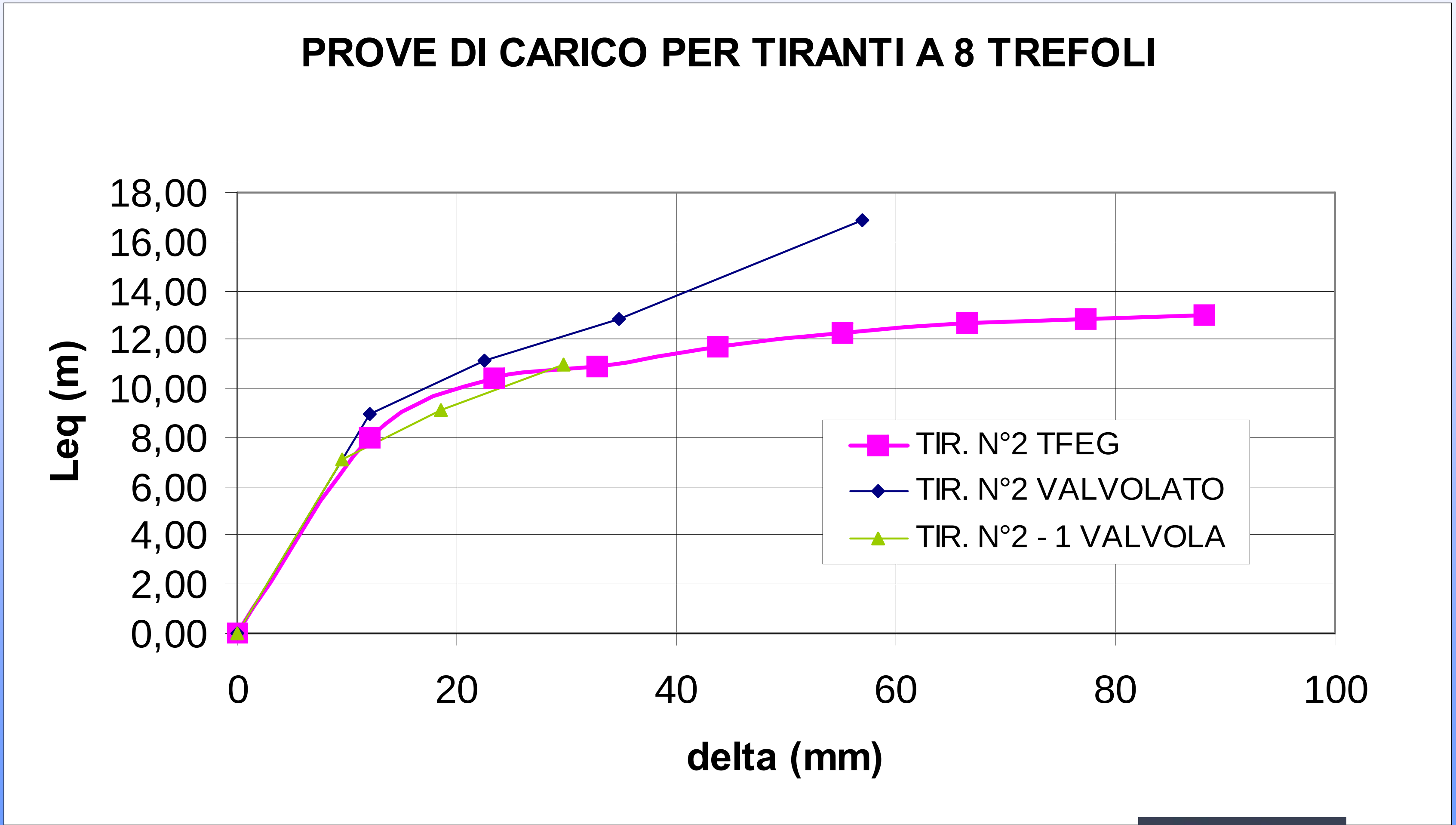
-**N° strand 0.6”= 8**

-**Double MTFEGMP 88.9-3-160 tie tip – 4 sockets**

TIE ROD FIELD TEST – COMPARISON BETWEEN TFEGED AND UNTFEGED RESULTS

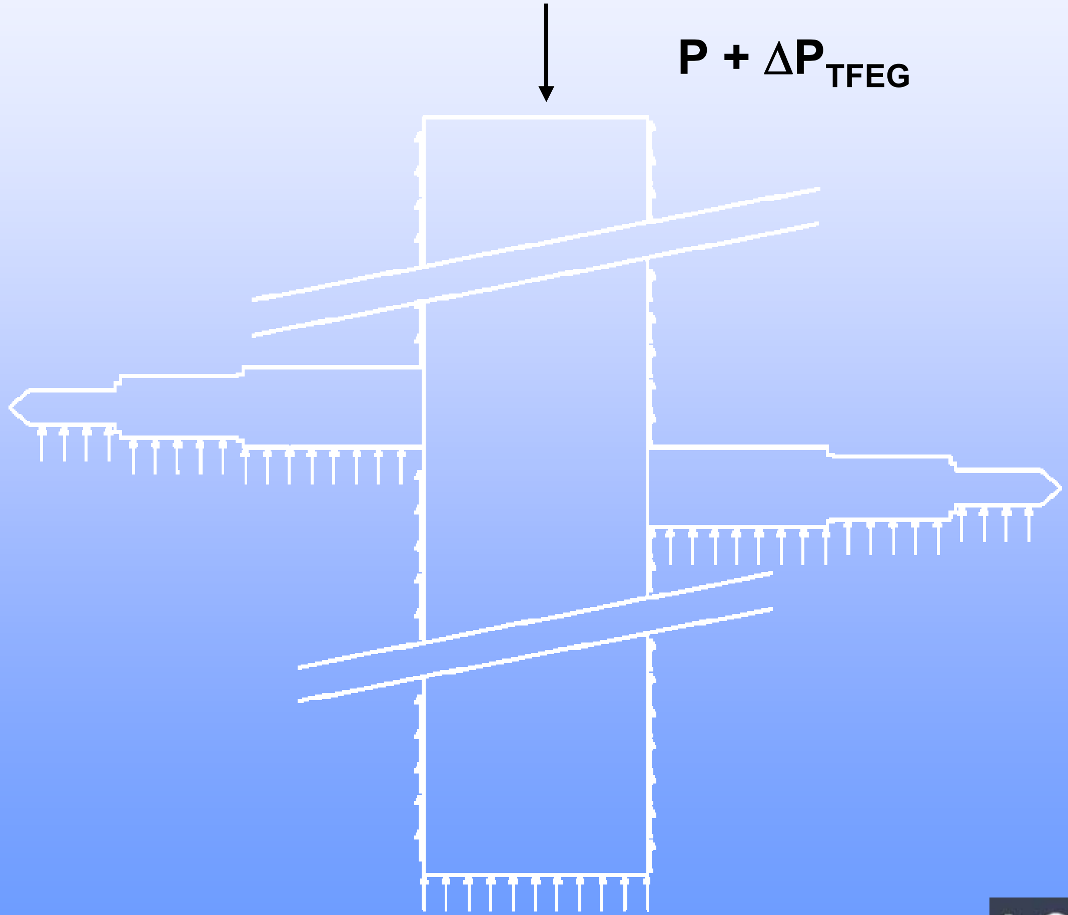


TIE ROD FIELD TEST – COMPARISON BETWEEN TFEGED AND UNTFEGED RESULTS



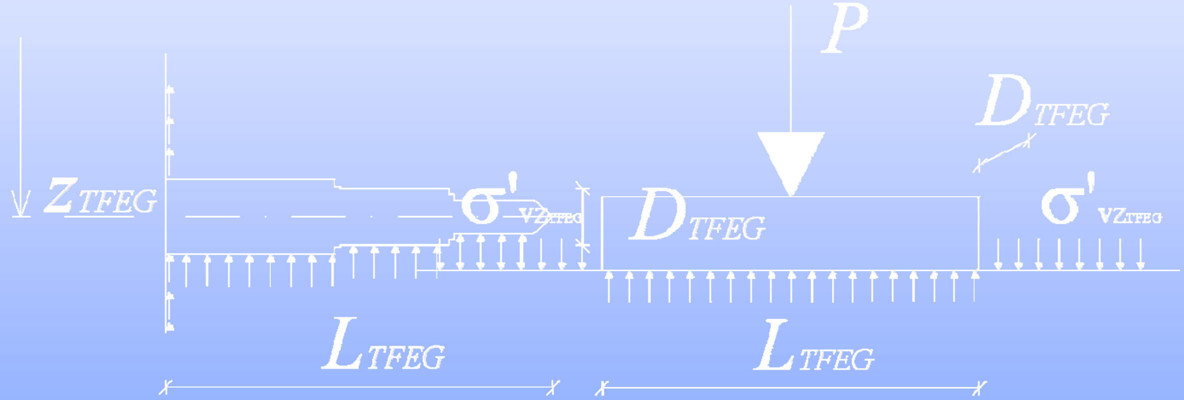
PREVISIONAL MODELS AND TESTS RESULTS FITTING

BEARING CAPACITY CONTRIBUTION



PREVISIONAL MODEL - FSE

TFEG SOCKET=SHALLOW FOUNDATION



Let us consider an **EQUIVALENT SHALLOW FOUNDATION** located at the socket depth z_{TFEG} with its horizontally projected surface

PREVISIONAL MODEL - FSE

The contribution to the bearing capacity can be compute with the classic Brinch – Hansen expression:

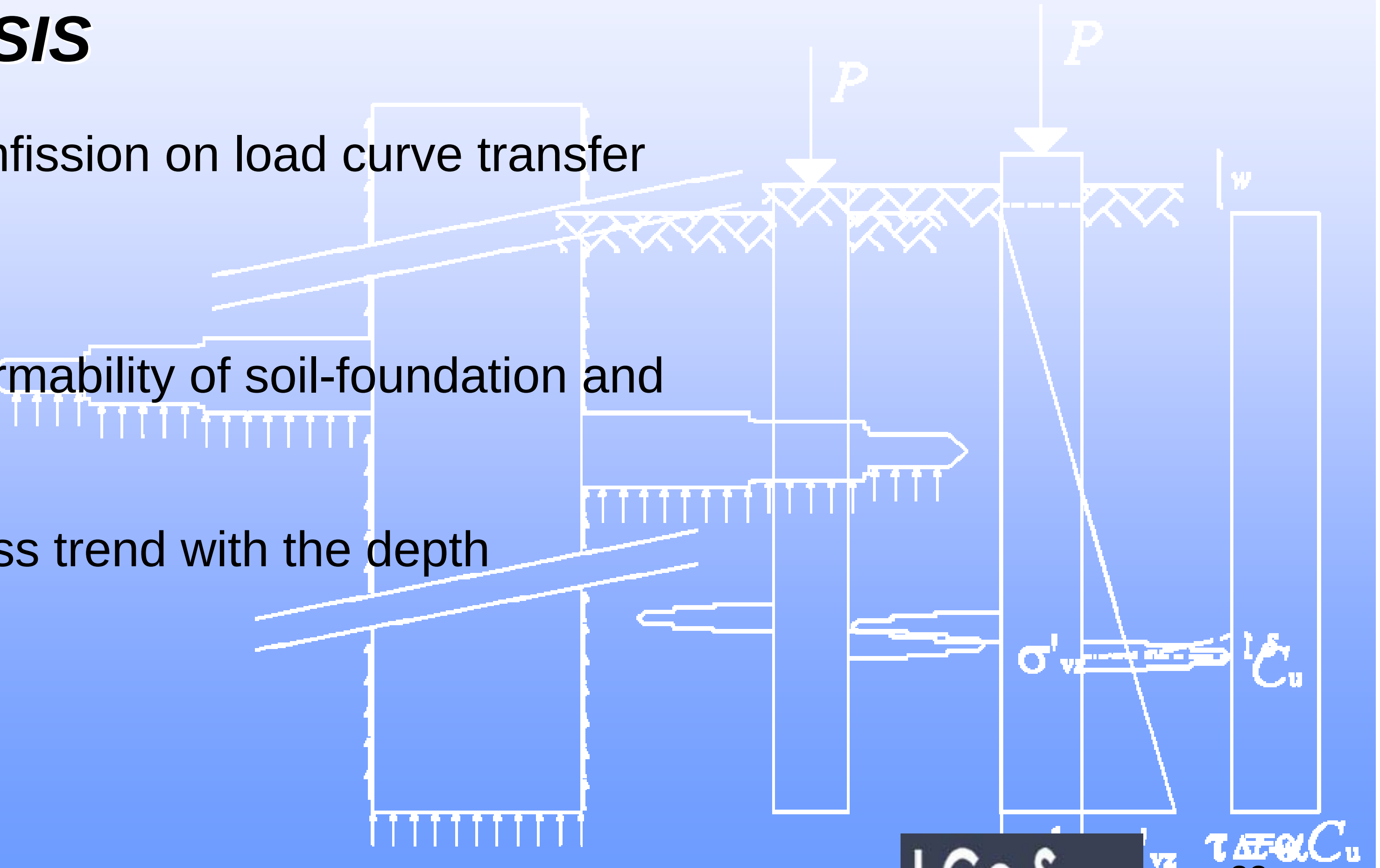
$$\Delta P = Q_{lim} = (N_q \sigma'_{vz_{TFEG}} + N_c c' + N_\gamma \gamma D_{TFEG}/2) A_{TFEG}$$

$$\Delta P = Q_{lim} = (\sigma_{vz_{TFEG}} + N_c c_u) A_{TFEG}$$

PREVISIONAL MODEL - FSE

HYPOTHESIS

- no influence of infission on load curve transfer law
- no effect of deformability of soil-foundation and of the socket
- linear shear stress trend with the depth



PREVISIONAL MODEL - FSE

Hypothesis are generally conservative:

1) The approch does imply failure lines stpping at the center line of the socket

1) Plane strain proble, unlikely the reality.

1) We do not take into account of the increase of density state of the soil after the infissione

IF WE APPLY THE FSE MODEL TO THE CASE OF THE TIE RODS ABOVE, WE CAN ONLY ACHIEVE AN INCREASE OF 10% OF THE BEARING CAPACITY, INSTEAD OF THE 200%!

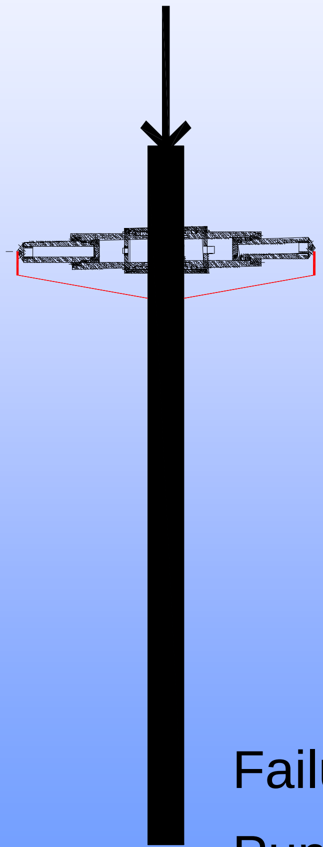
→ WE NEED TO BUILD UP AN ALTERNATIVE FAILURE PATTERN MODEL

FAIURE PATTERNS

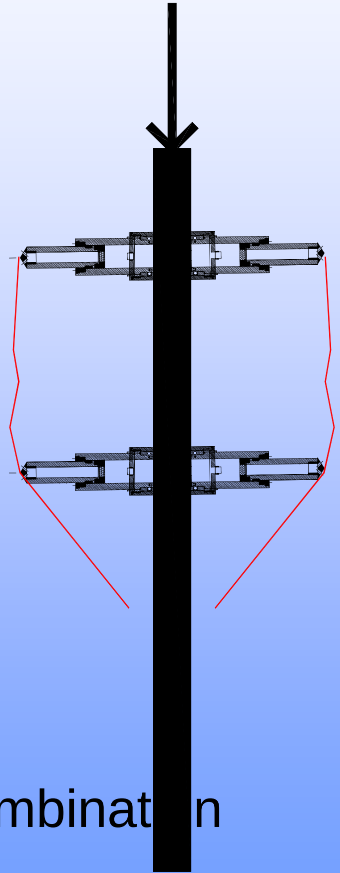
Failure: Punching down

P

FSE

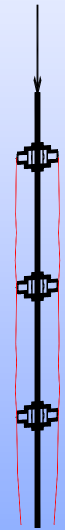


P FSE-CFAp



Failure: Cylindrical
CFAp

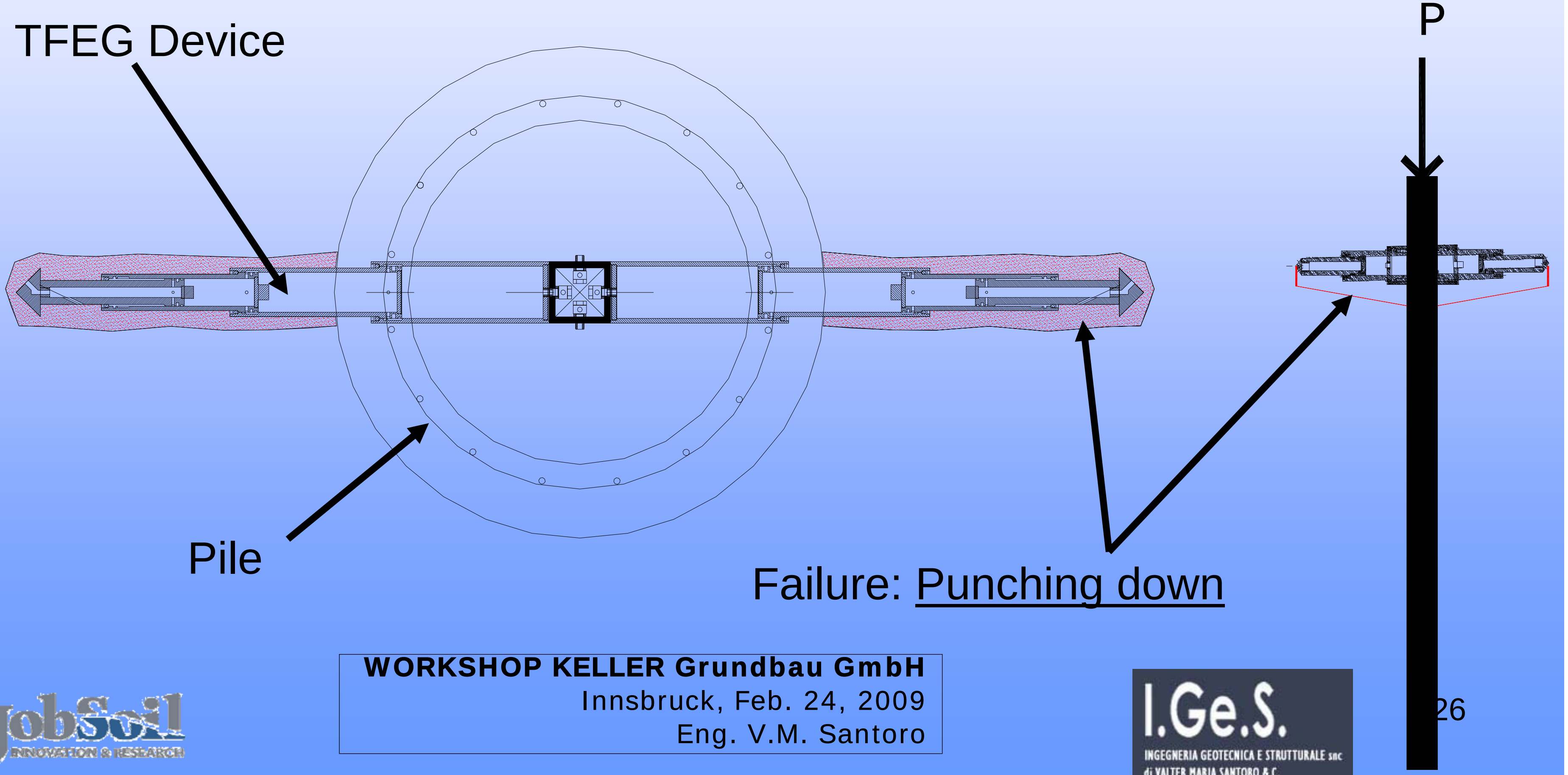
P



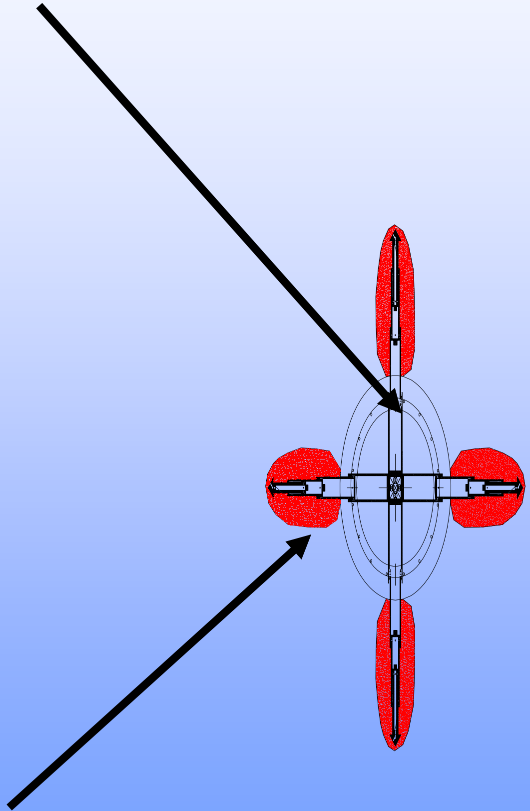
Failure: Failure Combinat n

Punching +Cylindrical

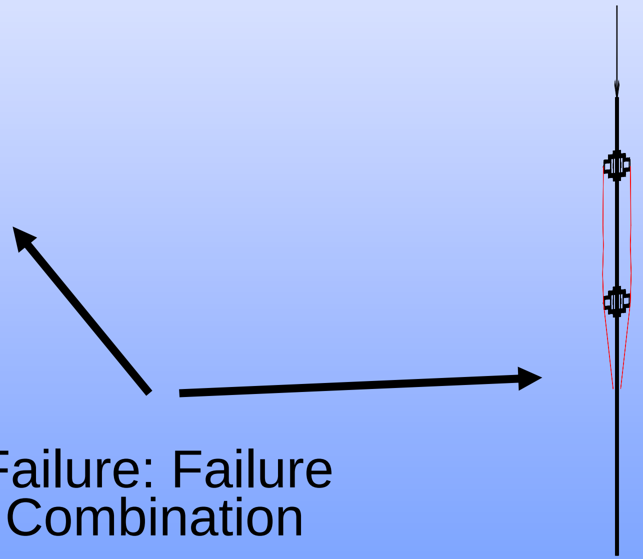
FAIURE PATTERNS



TFEG Device



Pile

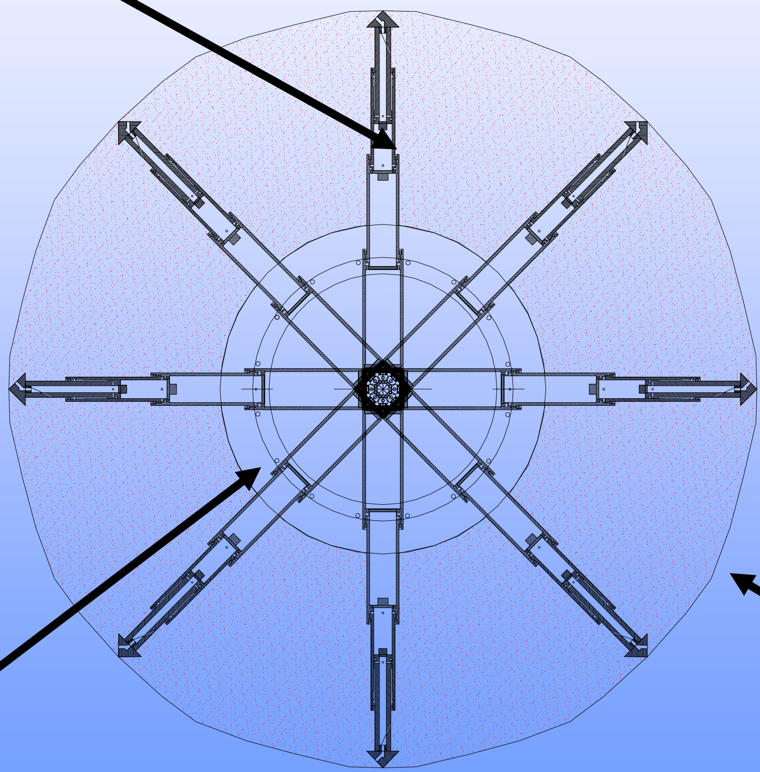


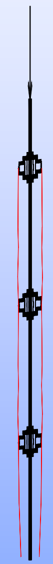
Failure: Failure Combination

Punching +Cylindrical

FAIURE PATTERNS

TFEG Device





Failure: Cylindrical

Pile

SHEAR STRENGTH CAPACITYOF THE TIE ROD-SOIL COMPLEX

•CONVENTIONAL APPROACH

Failure surface runs at the soil-grout interface, so that the available shear strength is:

$Cu^* = \alpha x Cu$ con $\alpha = 0.60$

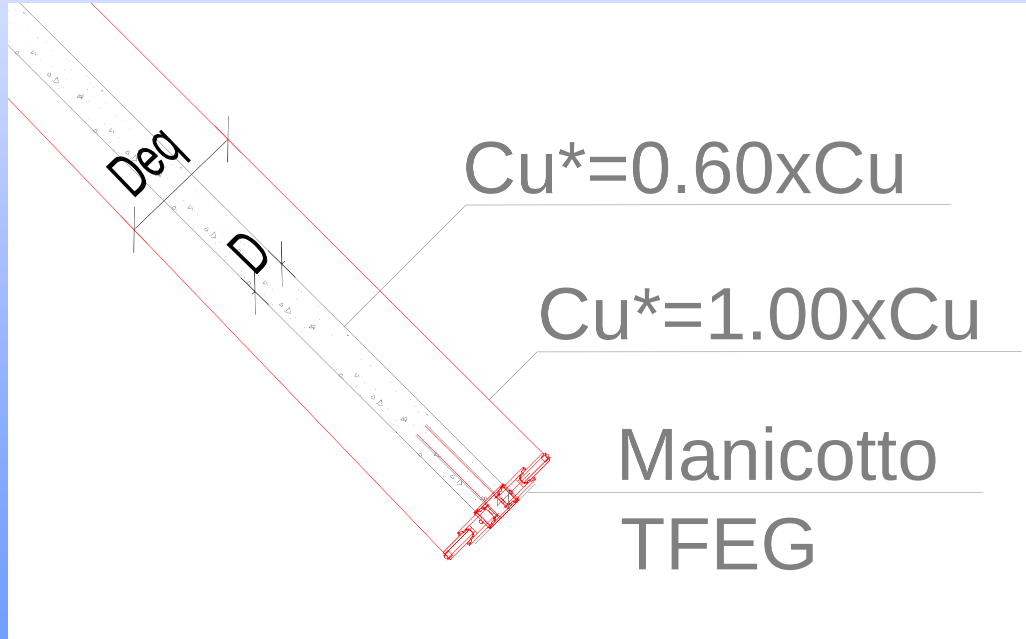
•*SOIL SHEAR STRENGTH*

Undrained cohesion Cu[KPa]

•*CYLINDRICAL APPROACH*

Failure surface runs within the soil volume, so that the available shear strength is:

$Cu^* = \alpha x Cu$ con $\alpha = 1.00$



BACK ANALYSIS

FIELD TEST – TIE ROD NO. 1

•***RESULTS TIE ROD NO. 1***

•**N° strand 0.6”= 6**

-**Pult-Pmax=1150 KN**

-**delta-Pmax= 74 mm**

-**Lcil-eq= 7.15 m**

Cylindrical Failure Approach

Deq-tfeg=0.51 m

•***RESULTS TIE ROD NO. 2°***

-**N° strand 0.6”= 8**

-**Pult-Pmax=1700 KN**

-**delta-Pmax= 87 mm**

-**Lcil-eq= 10.57 m**

Undrained Cohesion

Cu=100 KPa

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BACK ANALYSIS

FIELD TEST – TIE ROD NO. 2

- **RESULTS TIE ROD NO. 1°**

-N° strand 0.6”= 6

-Pult-Pmax=815 KN

-delta-Pmax= 74 mm

-Ll= 15 m

-Deq= 1.20 m

- **RESULTS TIE ROD NO. 2°**

-N° strand 0.6”= 8

-Pult-Pmax=1700 KN

-delta-Pmax= 87 mm

-Ll= 13 m

-Deq= 1.80 m

Cylindrical Failure Approach

Lcyl=Lf

Undrained Cohesion

Cu=100 KPa

TIE ROD FIELDS - CONLUSIONS

-**<u>BACK-ANALYSIS</u>:**

-**Tensile capacity of TFEG tie rod based on FSE – equivalent shallow foundation – method leads to an excessive underestimation of the actual performance, so that it appears too conservative;**

-**The CFAp – Cylindrical Failure Approach – model, based on the mobilisation of the shear strength along surface crossing the soil body leads to a more realistic estimation of the bearing capacity of the tie rod-soil complex;**

- TFEG Tie rod load-displacement curves show a more or less linear trend, a higher stiffness, and an ultimate capacity higher than the correspondent of conventional tie rods.

- Higher equivalent length of CFAp model for 8 strand tie rod is linked to the higher structural capaciti of the steel cross section, but probably also to the higher stresses available into the soil at higher depths (partially drained shear conditions).

THE S. GIULIANO DI PUGLIA TUNNEL – MOLISE - ITALY

SHEET MICROPILE TFEGGED TIE RODS

GEOLOGICAL PATTERN

CONNECTION MOTORWAY BETWEEN:

TAPPINO-RICCIA-COLLETORTO-SAN GIULIANO DI PUGLIA

AND

S. CROCE DI MAGLIANO - S.S. N°87 ROADWAY

STRATIGRAPHY

- **LAYER 1 (0-15 m)**

SILTY-SANDY CLAY ALTERNATE TO SANDSTONE AND MARLY SANDSTONE SCALES

- **LATYER 2 (15 – 25 m)**

MARLY CLAY ALTERNATE TO SILTY SANDY LEVELS, MARL AND LIMESTONE MARLS

ELEMENTI TESI CON TECNOLOGIA TFEG

Ing. Valter Maria SANTORO

TIE ROD DRILLING

WORKSHOP KELLER Grundbau GmbH
Innsbruck, Feb. 24, 2009
Eng. V.M. Santoro

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tfeg

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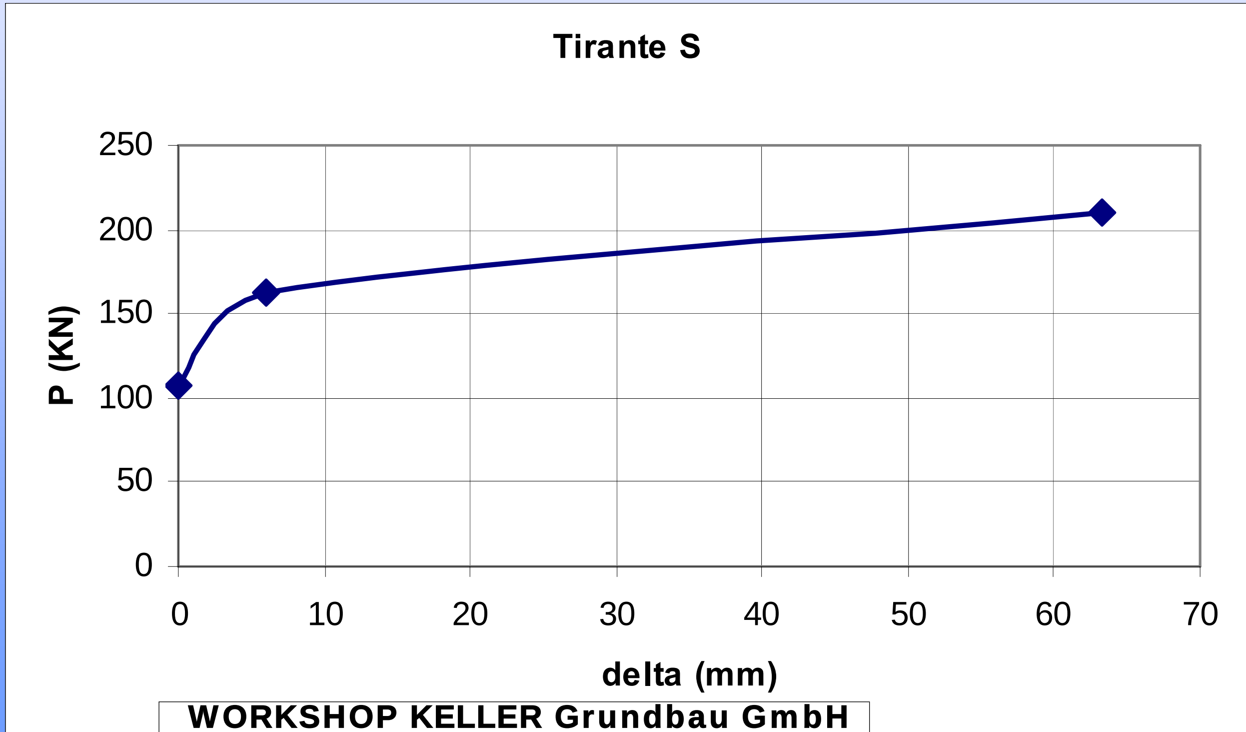
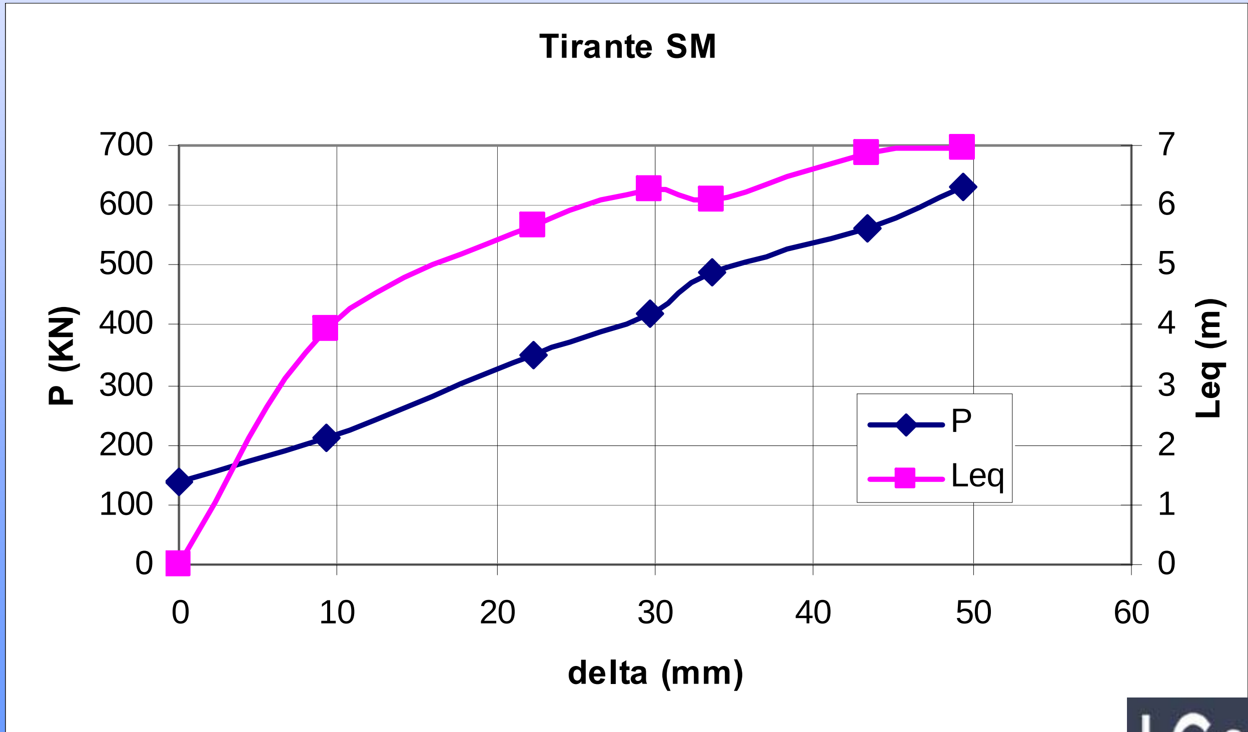
TIE ROD FIELD TESTS

• ***LOAD TEST ON UNTFEGGED TIE ROD – TIE ROD S***



TIE ROD FIELD TEST

- ***LOAD TEST ON TFEGGED TIE ROD – TIE ROD SM***



TIE ROD FIELD TEST

•COMPARISON BETWEEN LOAD-DISPLACEMENT GRAPHS

•Load test on SM tie rod stopped for safety reasons – Ultimate tensile load results higher than 700 KN

TIE ROD FIELD TEST

LOAD TEST BACK ANALYSIS FOR TIE ROD SM

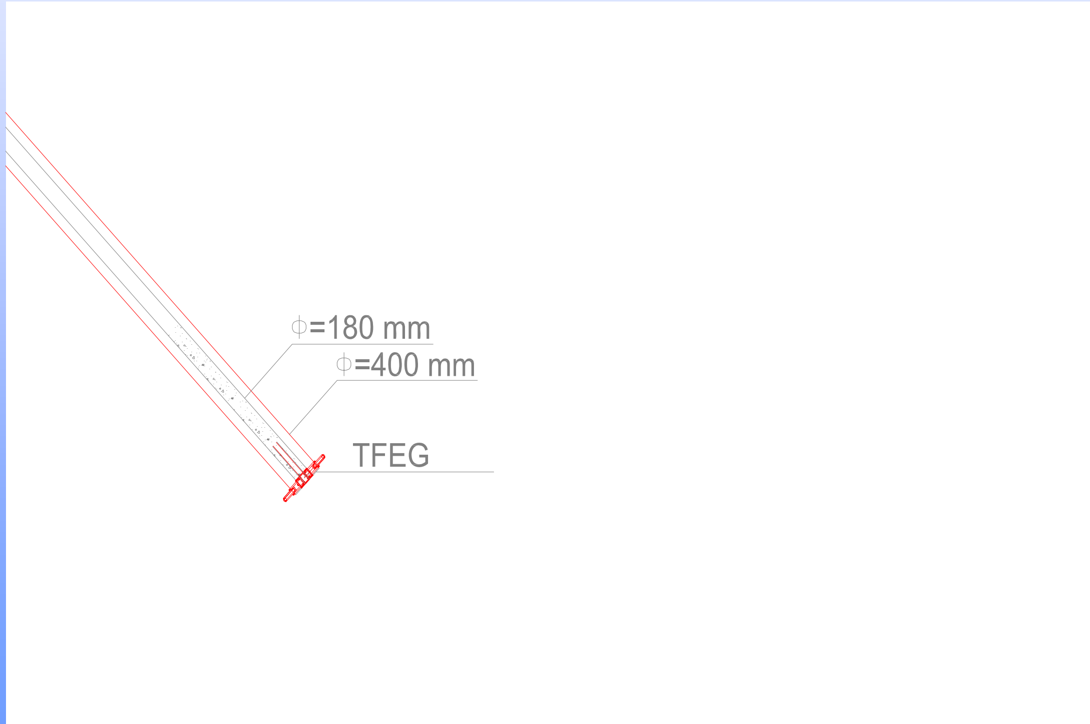
With the following geotechnical parameters:

- **Cu= 100 KPa** — **coesione non drenata**
- **R= 700 KN** — **carico di rottura**
- **Lb=6 m** — **lunghezza del bulbo equivalente**

- **Assumendo una forma cilindrica della superficie di rottura, il suo diametro risulta di 400 mm, largamente superiore al diametro di perforazione, pari a 180 mm. Considerando che il TFEG espanso ha un diametro di inviluppo di 414.50 mm il risultato della back analysis risulta compatibile con il sopra descritto meccanismo di rottura.**

SPERIMENTAZIONE SU TIRANTI

SUPERFICIE DI ROTTURA PRISMATICA CON TFEG : Φ=400 mm



FIELD TEST RESULTS
FIRST CONCLUSIONS

Notwithstanding the failure was not reached out, it is possibile to state that the evaluation of the bearing cvapacity based on the simple sum of the untfegged tie rod and the socket as shallow foundation can not be accepted – It looks like yoo much conservative.

An alternative failure pattern model based on the CFAp can be assumed. It assures the increase of the dimensions of the failure surface and also the higher mobilization of the available strength capacity into the foundation soil

The overall capacity gain results even in a 200% increase, still in a elastic conditions

THANK YOU FOR YOUR ATTENTION