SYMPOSIUM : NUMERICS IN GEOTECHNICS & STRUCTURES

25 YEARS ZSOIL.PC

DATE :30-31.08.2010

Better ZSOIL, Better Geotechnical Analysis

——3D Numerical Analysis of A Building Under Construction Collapse in Shanghai

YIN JI [1,2]

Email:geofem@126.com

1.Shanghai Geotechnical Investigation & Design, co,.ltd.

2.GEOFEM

CONTENTS

- Overview
- Modeling
- Results
- Outlook

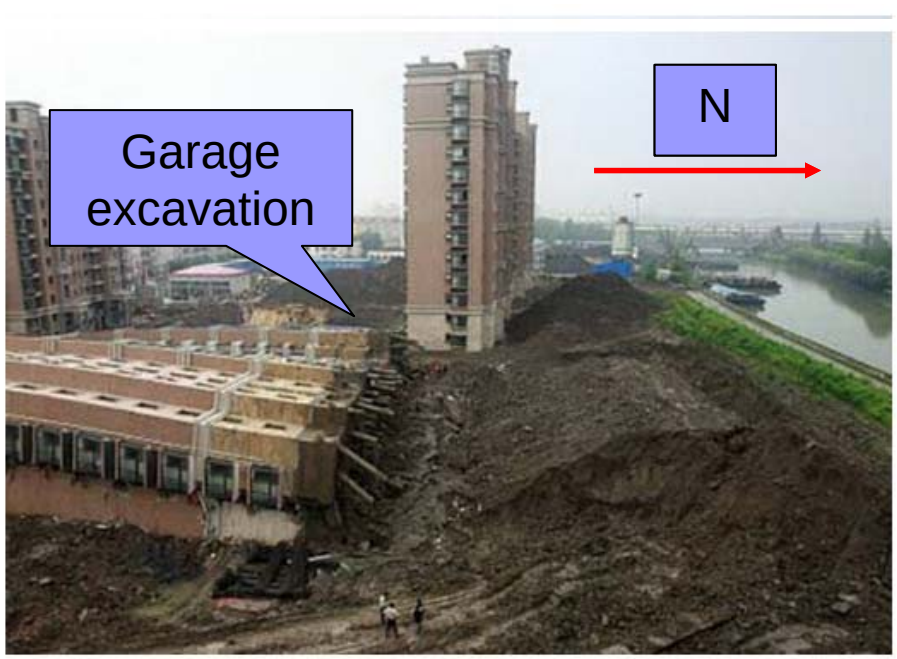
Overview

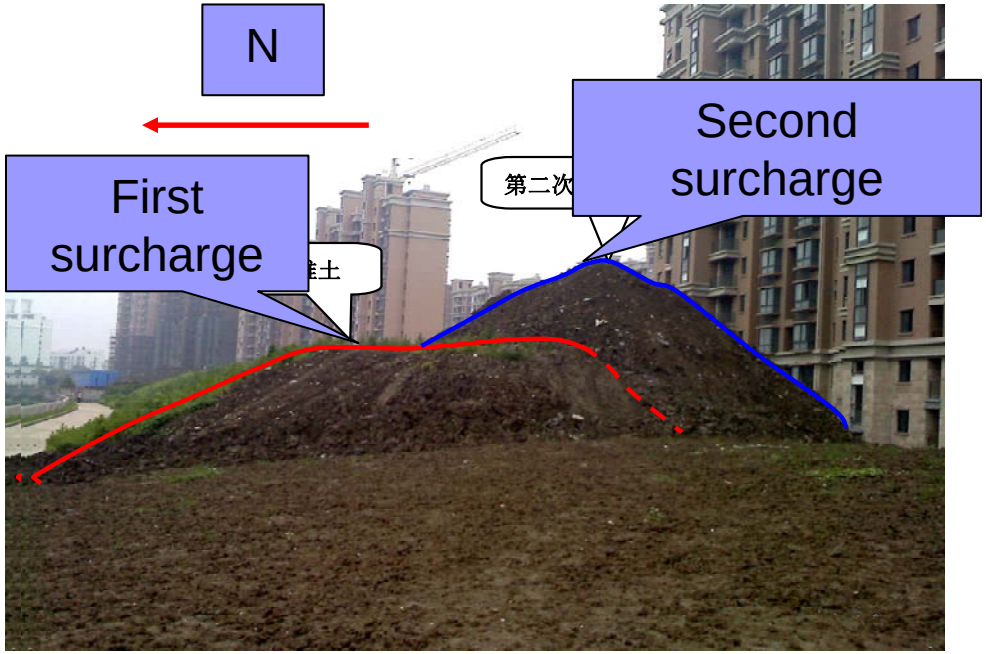
Some photos

- On June 27, 2009 at 5:30am local time, Block 7, one of the eleven 13-storey buildings of the apartment complex, collapsed killing one worker.
- As can be seen in the photo, the 13-story apartment building collapsed with just enough room to escape what would have been a far more destructive domino effect involving other structures in the 11-building complex.

Overview

Cause

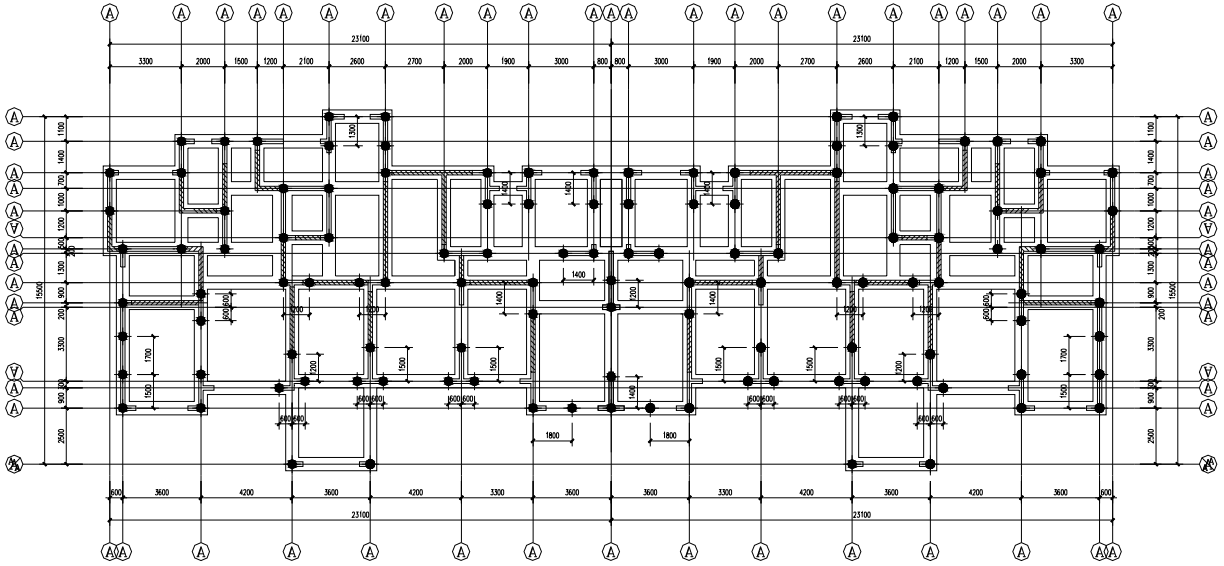




- The surcharge (backfill from underground garage excavation) on the north side of the building is considered the chief culprit
- And the underground garage excavation on the south side of the building is another important cause
- Other unfavorable factors : heavy rain just several hours before the accident

Overview

Layout of foundation



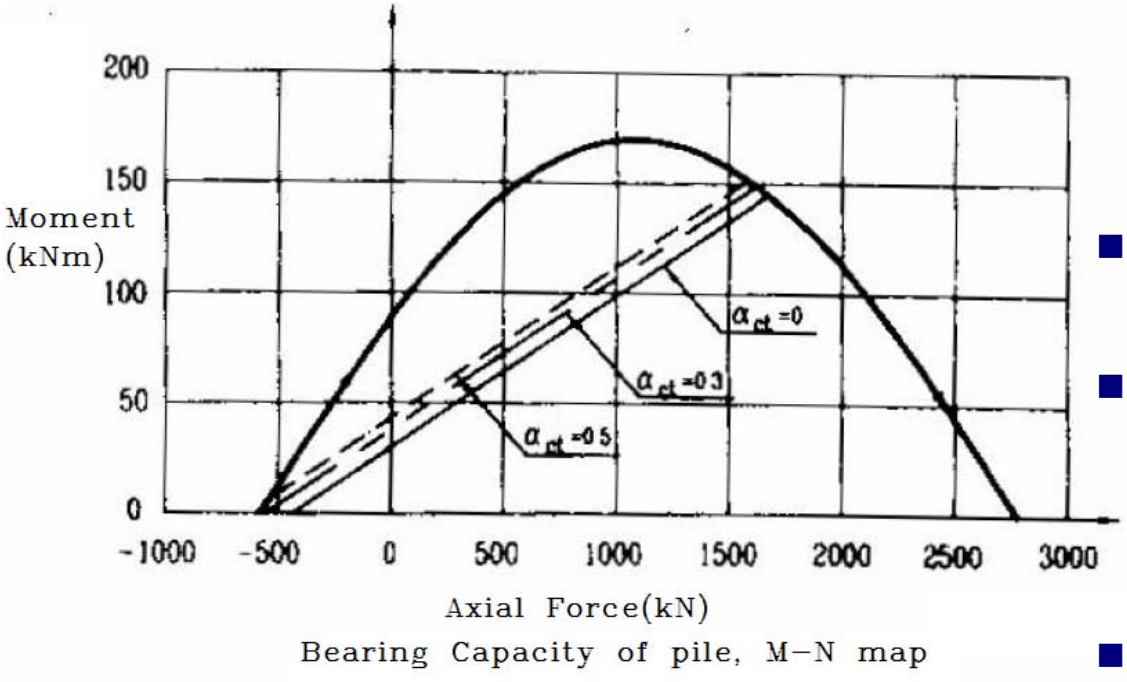
7#住宅桩位平面布置图

桩选型：⊕为PHC-AB400-80-33,未注明的桩均居轴线居中布置。

- The foundation style of the building is “Pile + Strip Foundation”, no raft
- About 118 Pre-stressed concrete pipe piles are used to support the building
- Pile type is PHC-AB-400-80-33(according to shanghai design code), Dia.=400mm,thickness=80mm, length=33m (11m+11m+11m, 2 welded joints)

Overview

Bearing capacity of pile

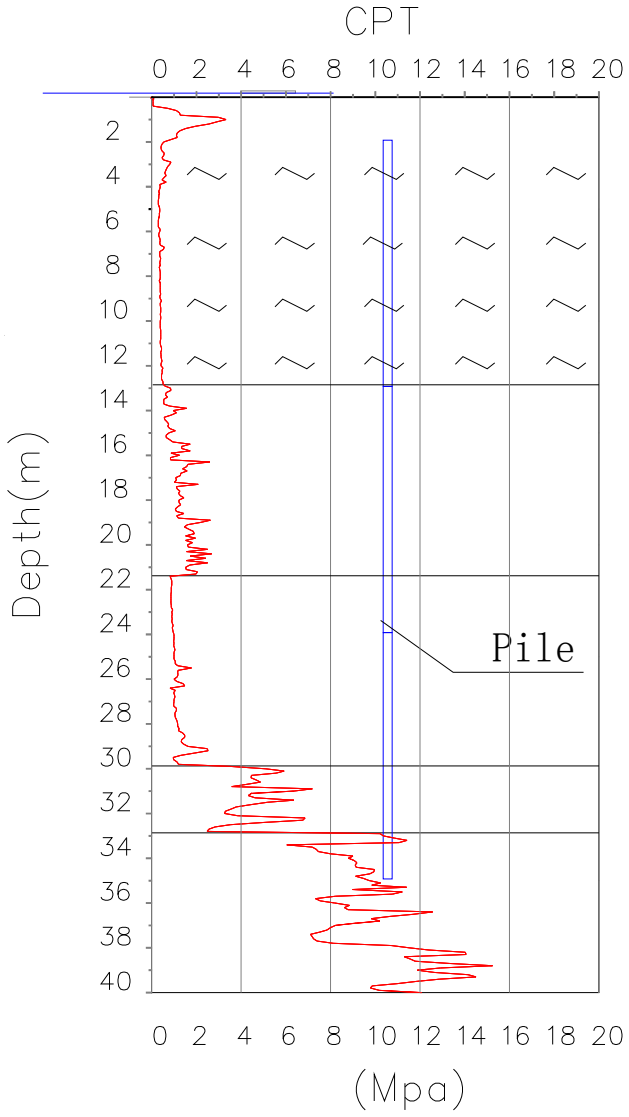


Bearing Capacity of pile, M–N map

- Bearing capacity of the PHC pile is described in this Scheme (according to DBJT08-92-2000, Shanghai Design Standards)
- Flexural capacity is coupled with the axial force
- For a pile at work (axial force 500kN~1500kN), its max. flexural capacity will be around 150kNm
- Joints are weak link. Their flexural capacity will be lower than 150kNm, if welding quality is not reliable

Overview

Borehole



Wmax=67.9%, e0=1.90, fa<50KPa
Ps＝0.35MPa, Su≤17KPa

③～④very soft clay

⑤1 clayey silt

⑤3 silty clay

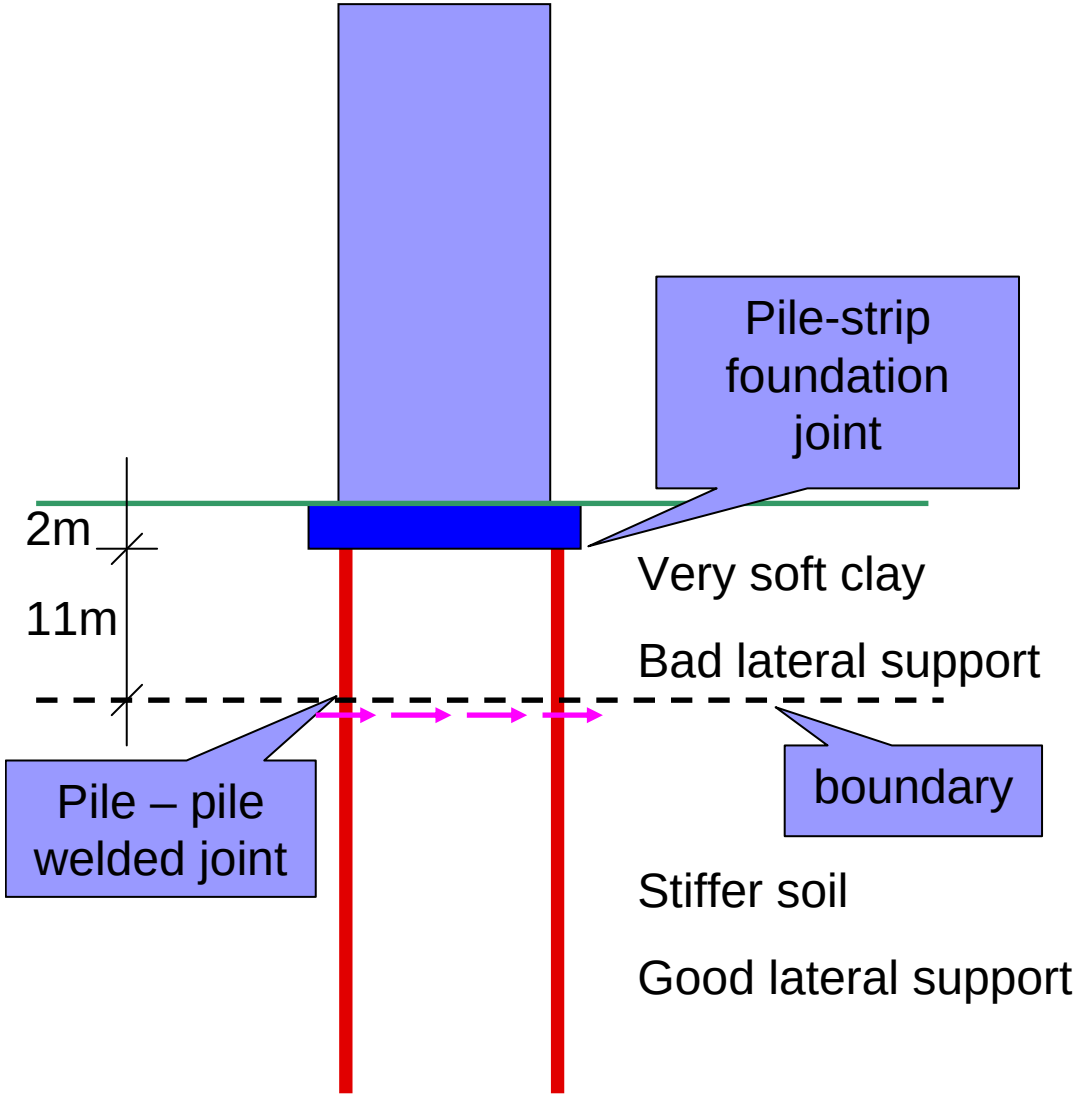
⑦1-1 clayey silt

⑦1-2 silt

- The soil from ground surface to 13m depth is very soft clay. Its engineering properties may be the worst in Shanghai.
- Max. void ratio :1.4,Bearing capacity : <50kPa
- Ps (CPT) < 0.35Mpa
- N (SPT) < 0.5
- E_{oed} < 1.5Mpa
- The soil from around 13~22m depth is stiffer than the upper soil, Ps >2.5Mpa

Overview

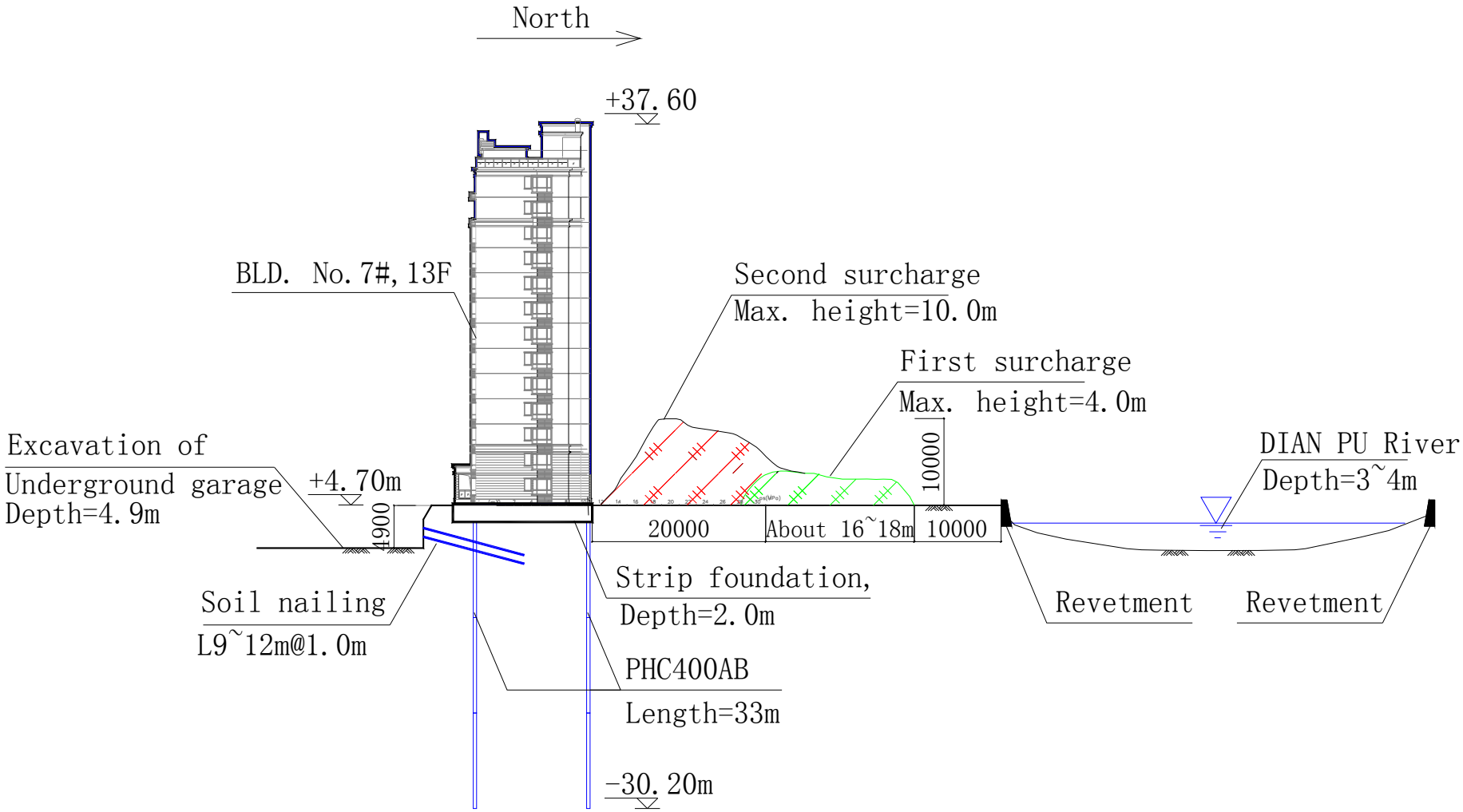
Soil and Pile



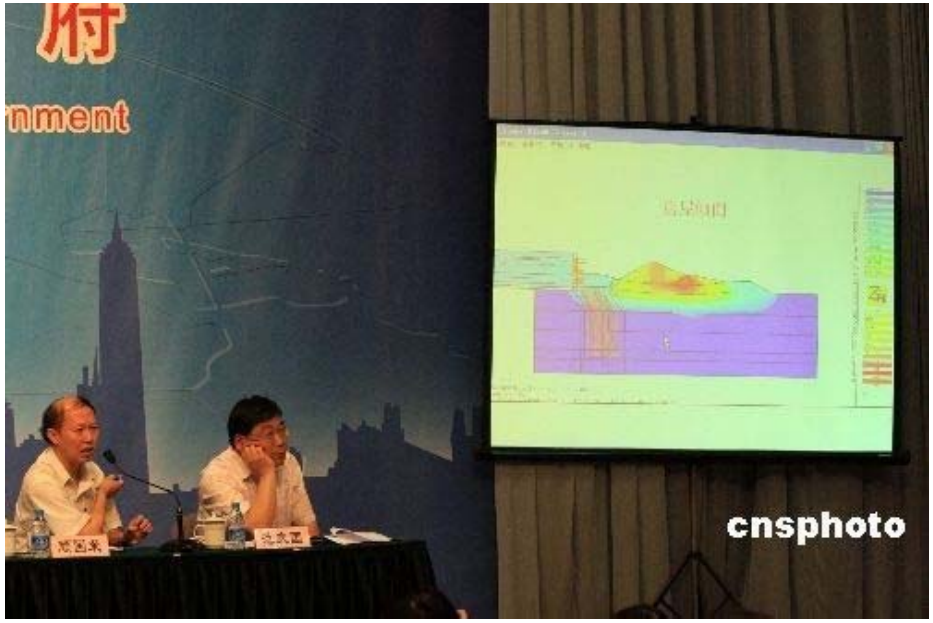
- The stiffness difference of the upper soil and lower soil is very huge. If we use CPT as the basis for judgment of soil stiffness, the lower soil is about 8 (2.5/0.35Mpa) times large than the upper soil.
- The large stiffness difference will cause large shear force and moment of piles near the boundary.
- The pile – pile welded joint (weak link) just situates near the boundary.
- The pile – strip foundation joint is also in the very soft clay.

Overview

Schematic diagram



Modeling
Software



- The government accident investigation expert group employed ZSOIL.PC(2D) to analyze the affect caused by the surcharge.
- The photo left shows an expert described the cause of the accident with contour map generated by ZSOIL.PC(2D) on Shanghai Municipal Government press conference
- ZSOIL.PC(3D) is employed to conduct the following analysis

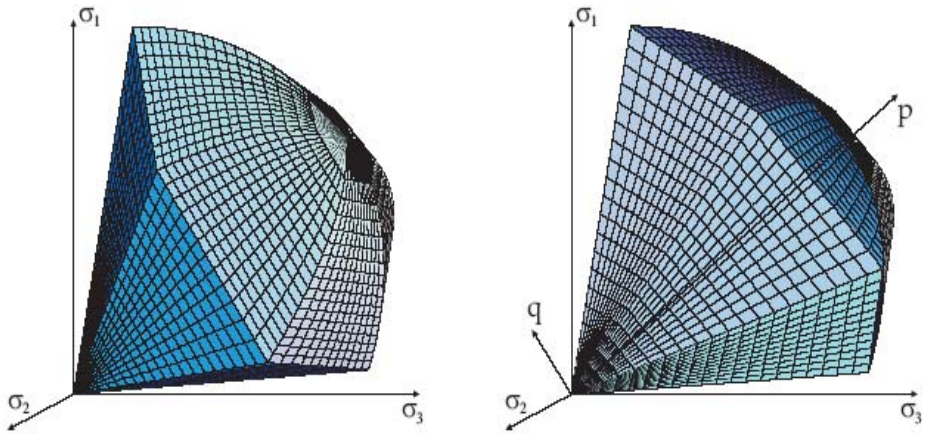
Modeling

Basic rules

Basic Rules for modeling : Realistic procedure, reasonably simplified FEM model, reliable parameters

Modeling

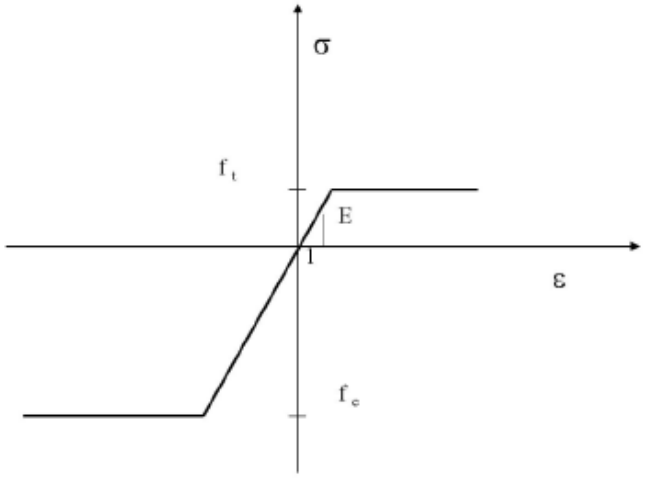
Soil constitutive model



- Hardening soil model with small strain stiffness(Benz,2007) is employed to simulate the stress-strain-strength relationship of shanghai soft clay.
- Cap yield surface + Hyperbolic shear yield surface can model the behavior of soil more accurate.

Modeling

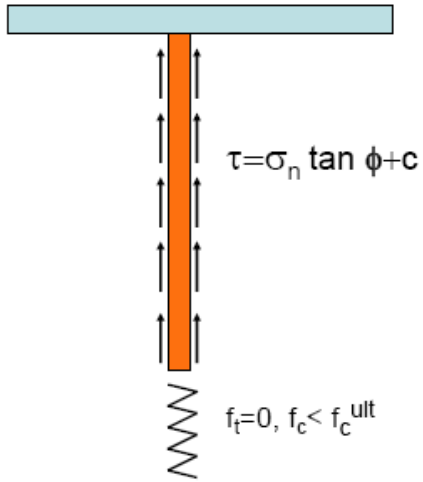
Structure model



Uni–axial elasto-plastic material model

- Strip foundation → beam element, with real section dimension
- Wall and shear wall, floor → one layer shell element, same thickness with the real structure member
- Advanced structure material setting → steel bar, core concrete, tension strength of concrete and steel bar, compression strength of concrete and steel bar …… →simulate the real situation

Modeling
Pile



- Pile → embedded pile element (since v2009), circular pipe section, real dimension
- Frictional (shear) interface + pile toe interface → simulate the real interaction between pile and soil
- Pile material → elasto-plastic beam, simulate the critical bearing capacity of piles
- Pile head is rigidly connected to the strip foundation, so the shear force, moment, and axial force can transfer from upper structure to piles, and vice versa

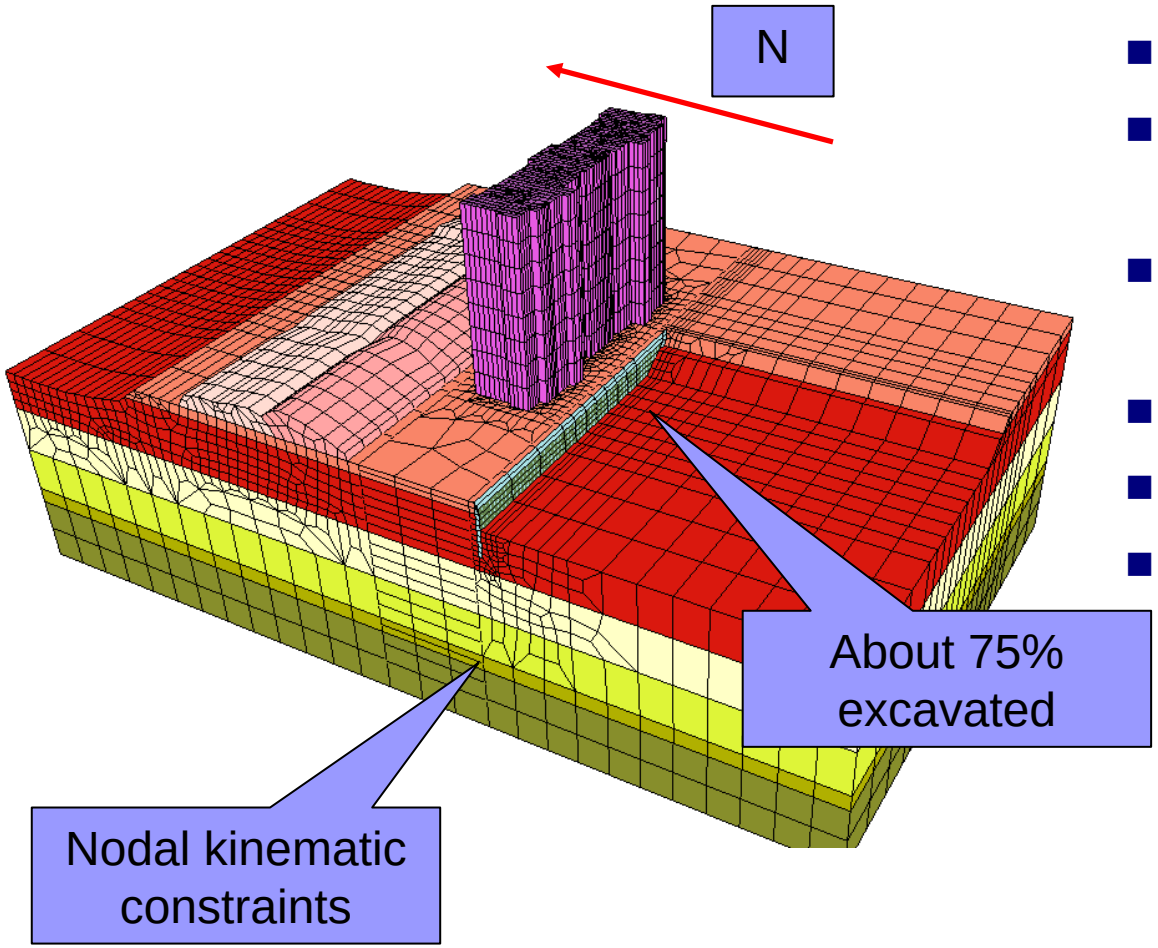
Modeling

Other elements

- Soil Nail → beam elements + nodal kinematic constraints
- Surcharge (soil) → elastic solid, weight of the backfill (18kN/m3) to simulate the surcharge
- Soil cement mixing pile, which is employed to support the underground garage excavation → solid, MC model
- Interface is set between soil cement mixing pile and soil

Modeling

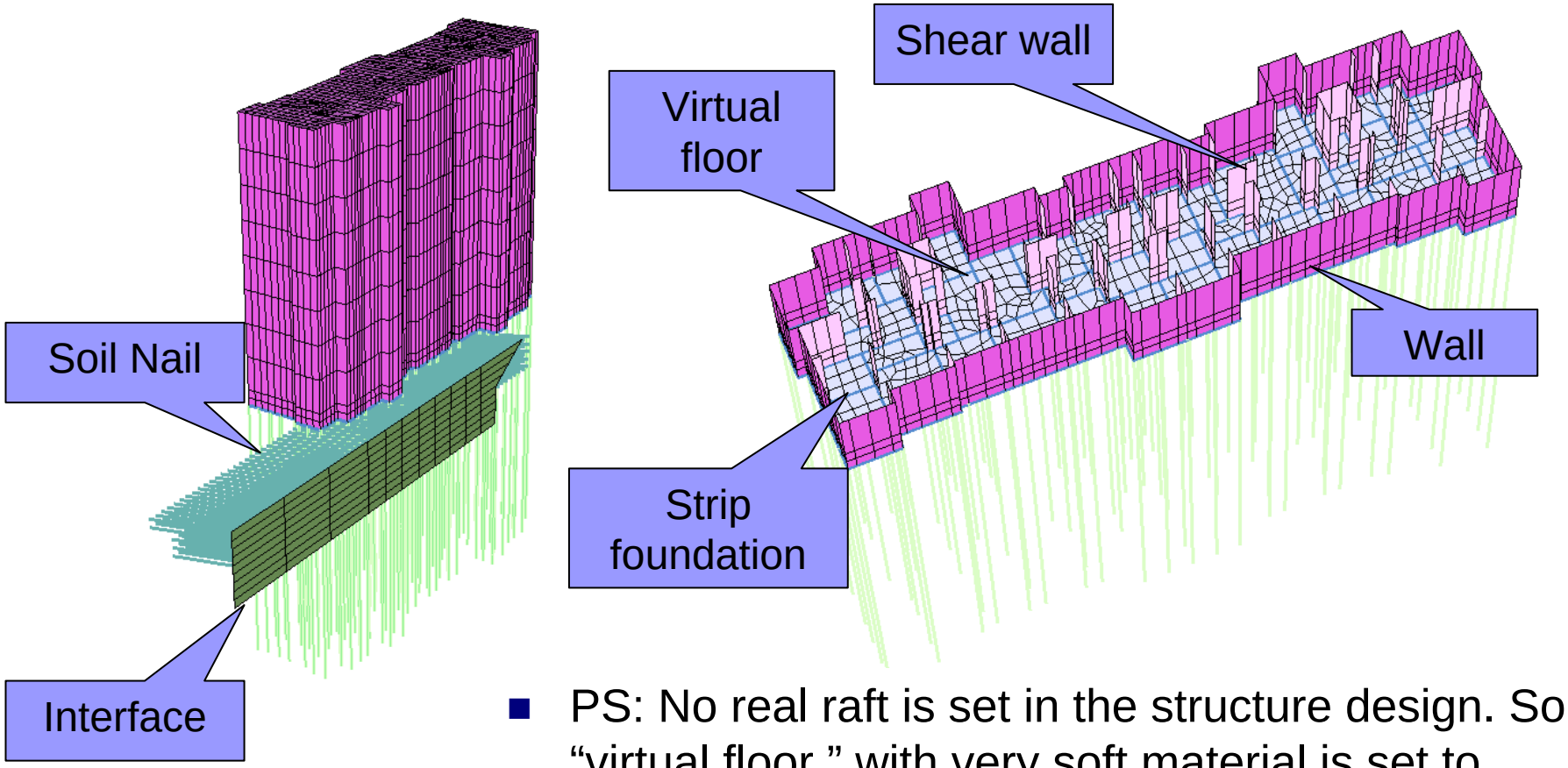
Overall FEM model



- Number of node : 47941
- Number of continuum element :35919
- Number of single layer shell : 8839
- Number of beam : 1618
- Number of contact : 99
- Number of kinematic constraints : 4005

Modeling

Structure FEM model



- PS: No real raft is set in the structure design. So “virtual floor ” with very soft material is set to connect the shear wall and beam well

Modeling

Calculation stage

- Stage 0: Initial state, corresponding to time=0
- Stage 1: Activate piles, foundation, upper structure, corresponding to time=0 ~5
- Stage 2: Activate first surcharge, corresponding to time=5 ~10
- Stage 3: Support and excavate the underground garage, corresponding to time=6 ~12
- Stage 4: Activate second surcharge, corresponding to time=10 ~25
- PS: To model the actual construction stage , Stage 4 starts when stage 3 is still unloading(by control EXF and LTF).

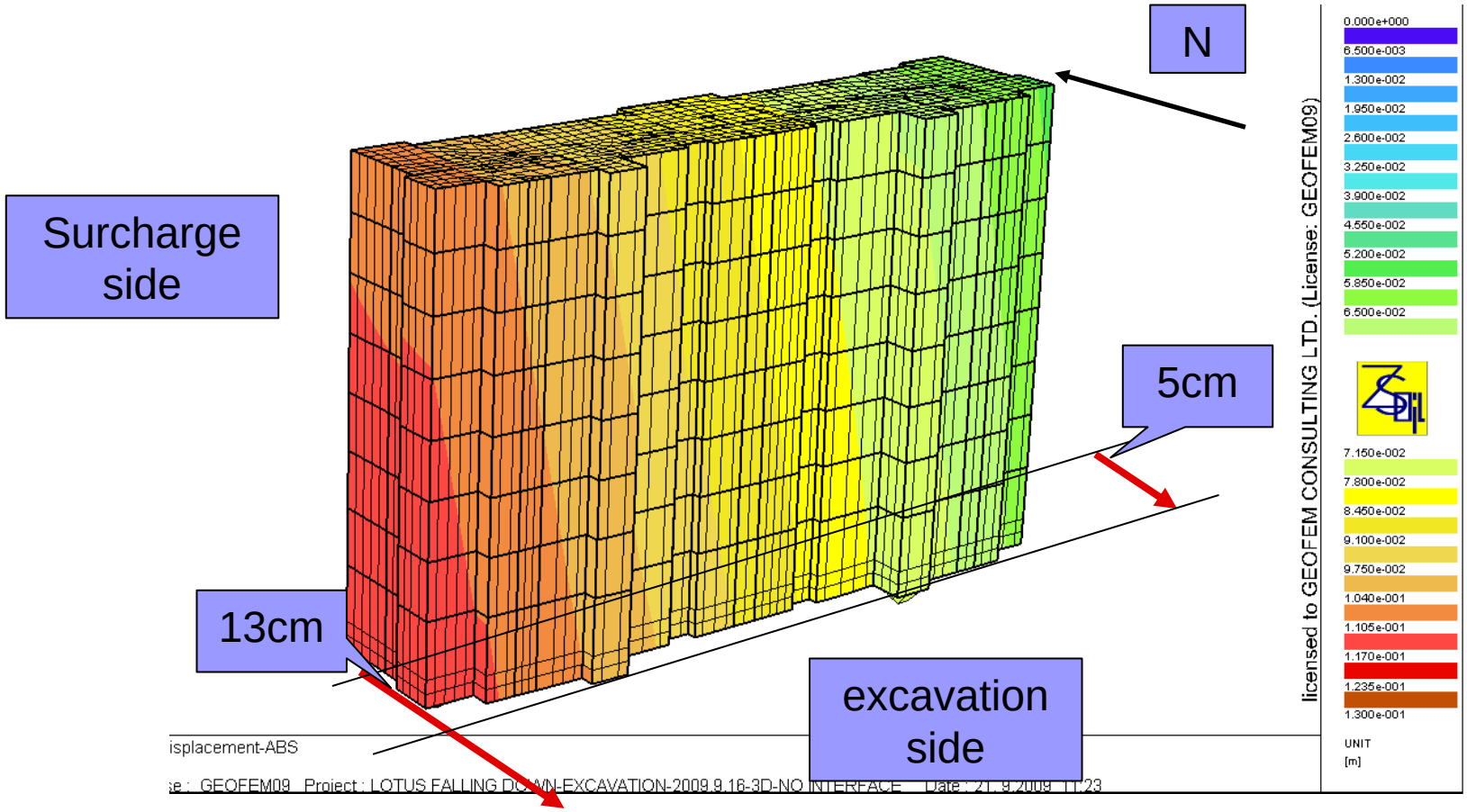
Modeling

Special problem

- The permeability of the soft clay in shanghai is very small (10e-7cm/s), so the loading (surcharge) procedure could be regarded as “undrained loading ”
- “Undrained” strength and deformation parameters should be used
- Loading and unloading function is assumed to be linear style
- Problem type is “deformation”, excess pore pressure generated by surcharge is not considered

Results

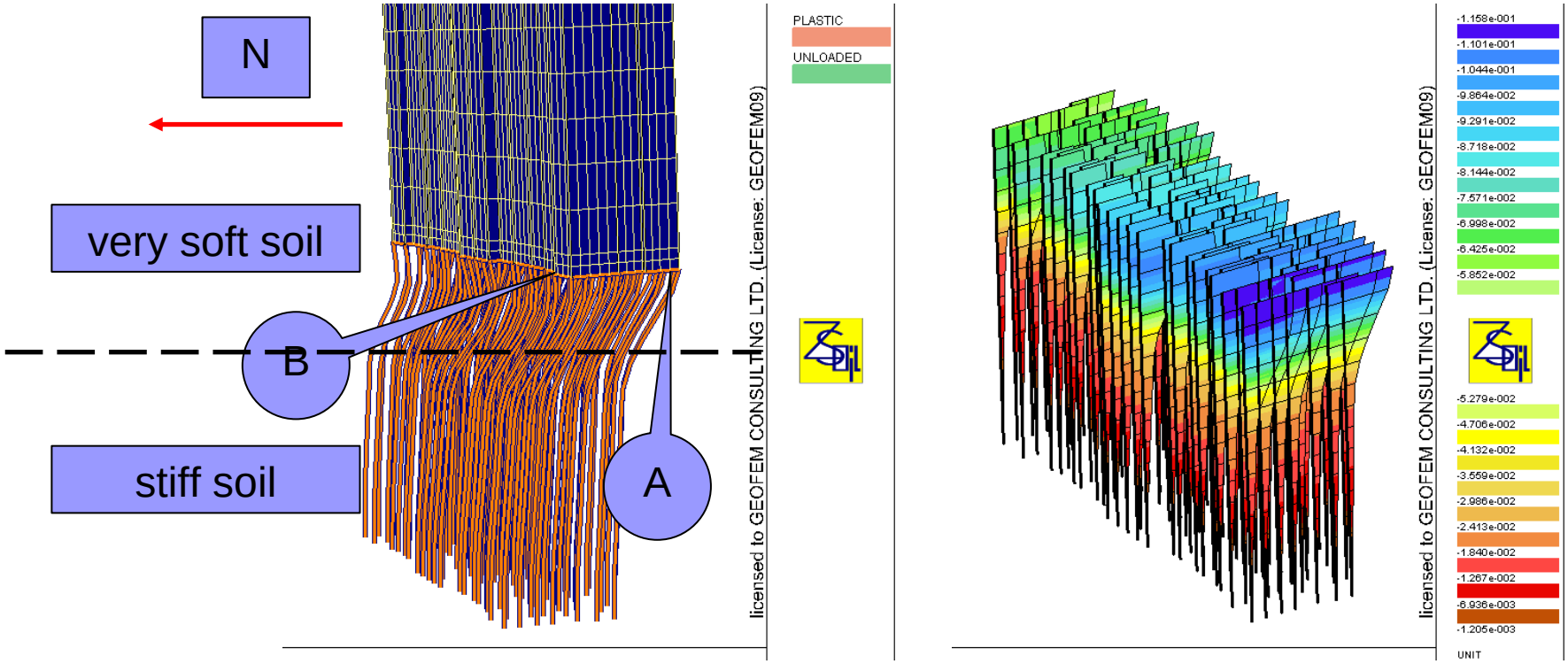
Displacement of the building



Max. Disp-ABS=13cm, Min. Disp-ABS=5cm, δ=8cm

Results

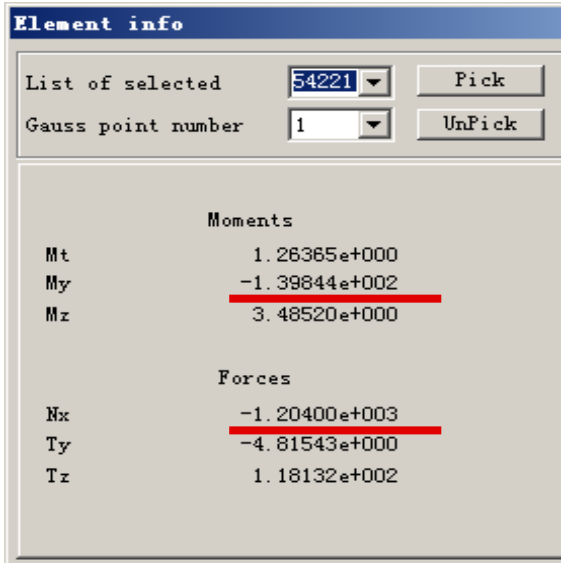
Displacement of the building

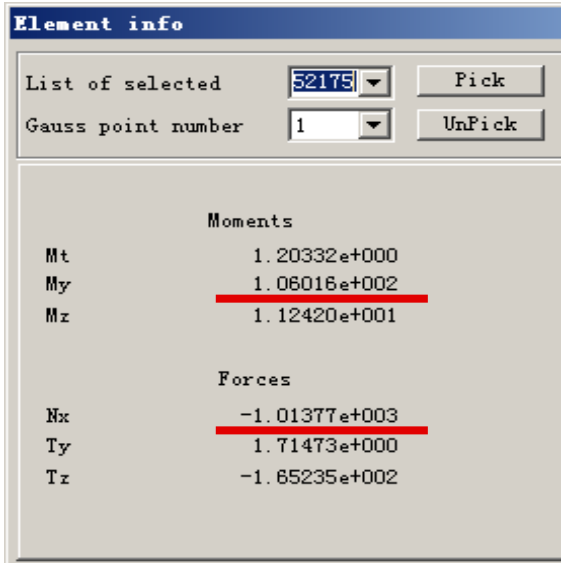


- Displacement of piles: Max. 11.6cm
- Pay attention to the deformation shape of the piles

Results

Internal force of piles

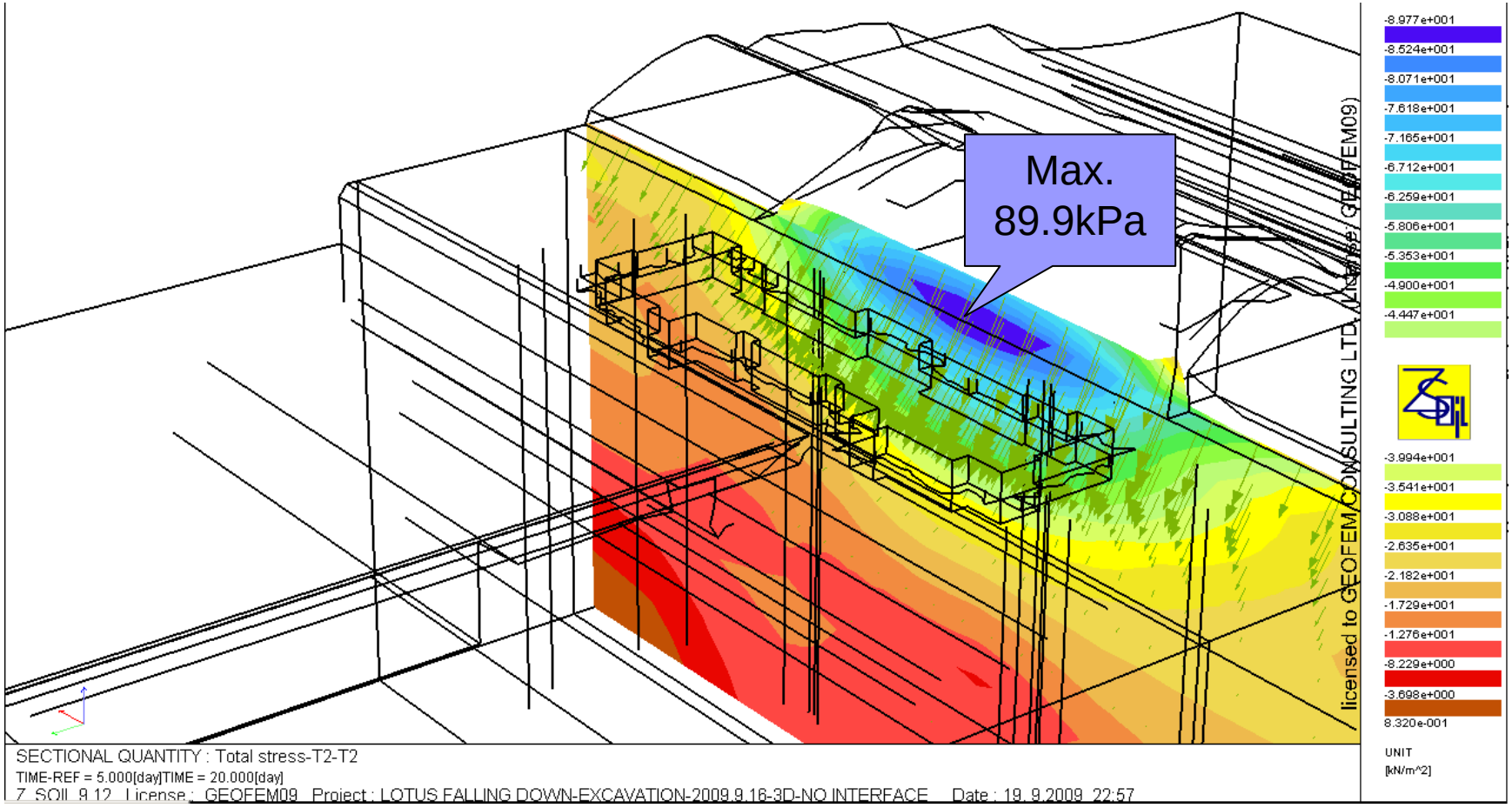




- Internal force combination of the most “dangerous” pile
- Pile A: My=139.8kNm, Nx=1200kN
- Pile B: My=106kNm, Nx=1014kN
- It seems Pile A is more dangerous than Pile B, and Pile A is more likely to break.
- If Pile A break first, the building will fall down to the south side (underground garage excavation side). This is consistent with the actual situation .

Results

Lateral force caused by surcharge



- Extra normal earth pressured exerted on the section

Results

Lateral force caused by surcharge

- According to the contour map, the extra earth pressure on the section is 30~90kPa, and the average is 60kPa
- The depth affected by the surcharge is about 11m, the extra earth force exerted on the section is 60kPa×11m=660kN/m
- The width of the building is about 45m, so the total extra earth force will be 660kN/m×45m=29700kN
- The strength of the very soft soil is very low, so most of the extra lateral load will be sustained by piles, for example 70%
- 29700×0.7/118=176.1kN ＞ shear strength of each pile

Results
Movie

- building.avi

Outlook

Improvements

- “deformation + flow” analysis should be used to evaluate the effect of excess pore pressure
- Post failure effect of soil and structure (pile) element

The content presented in this paper is my individual viewpoint only.

YIN JI

Email:geofem@126.com