Lizzi Lecture 2006

Performance of Seismic Retrofits with High Capacity Micropiles

Jiro Fukui

Public Works Research Institute, Japan

Topics

1. Introduction (Background of Research)
2. Joint Research
   A) Model test 1(horizontal loading tests of group piles)
   B) Static analysis for group piles (simulation analyses for the horizontal loading tests)
   C) Model test 2 (shaking table test of group piles)
3. Construction examples in Japan
4. Development in the future
5. Conclusion

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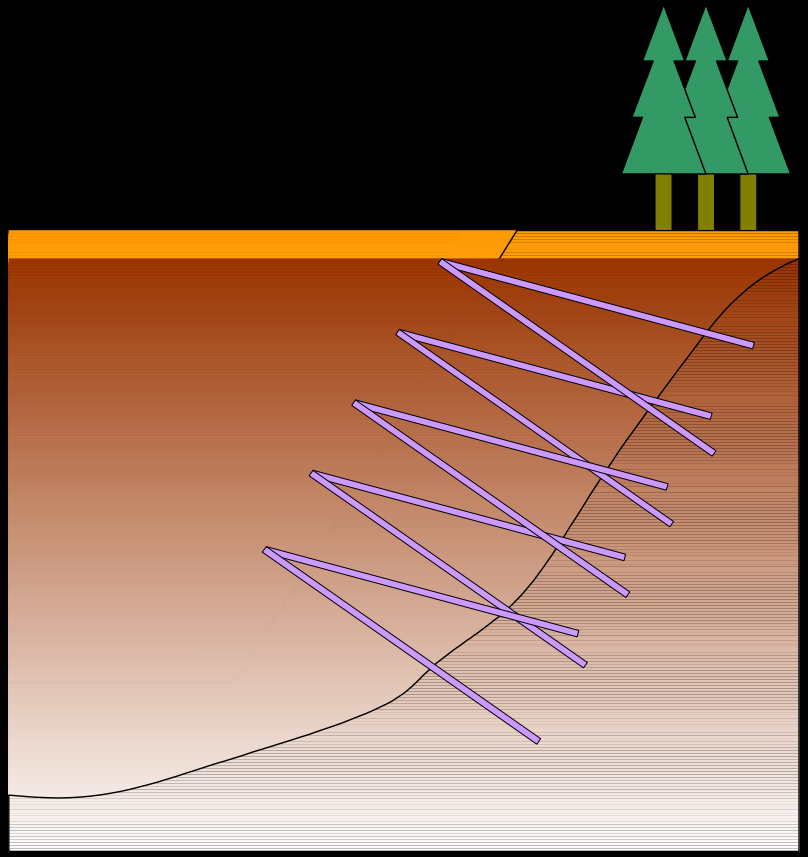
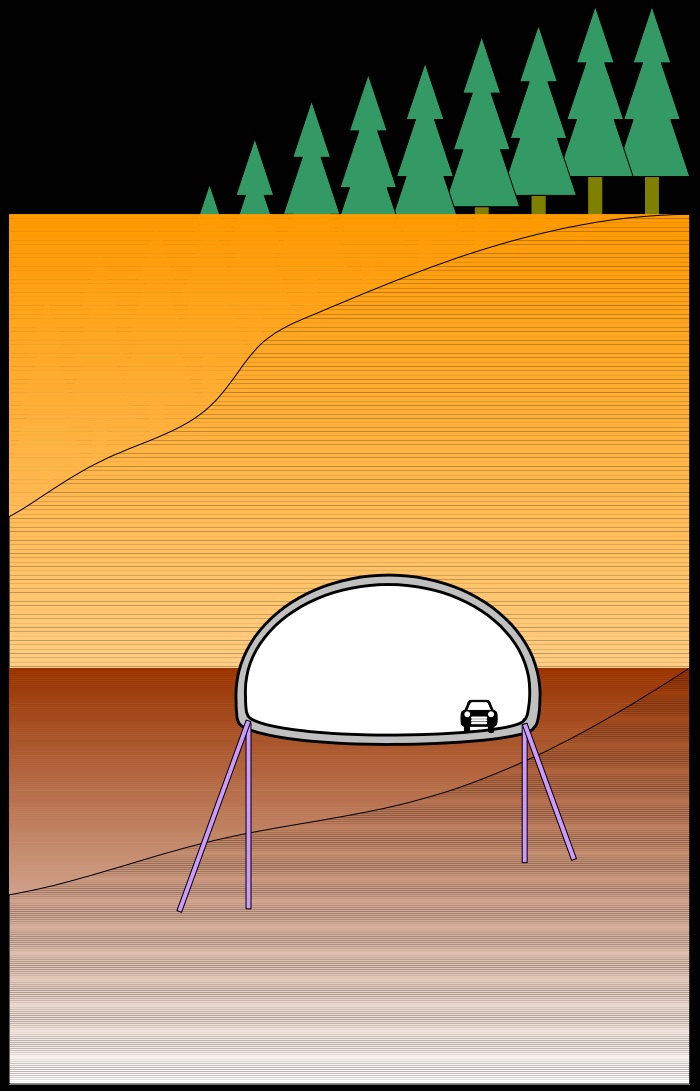
Application example past in Japan



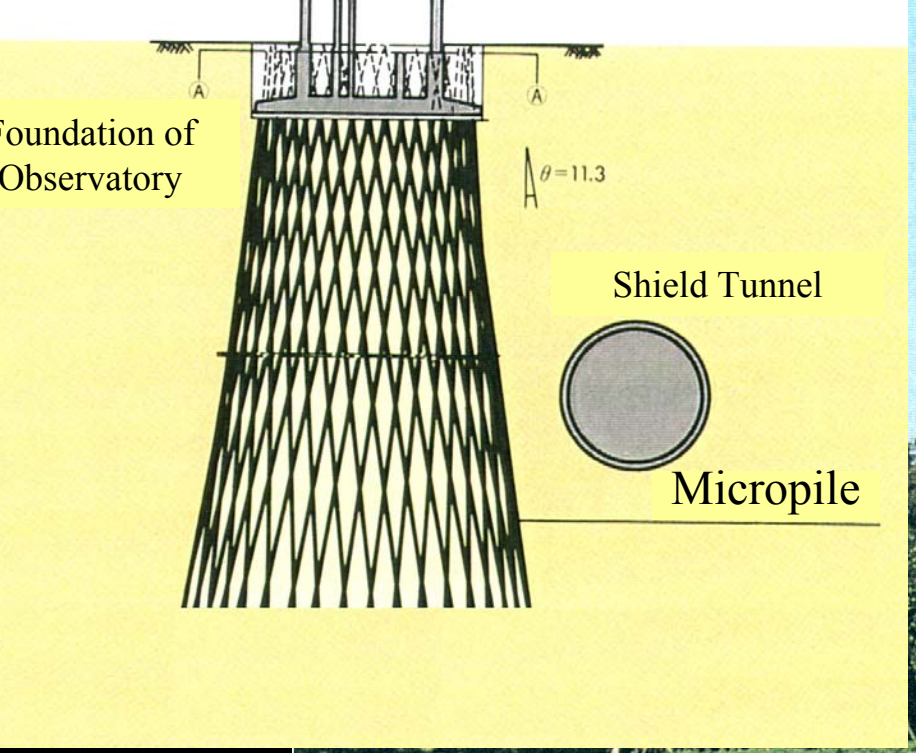
Slope Stabilization

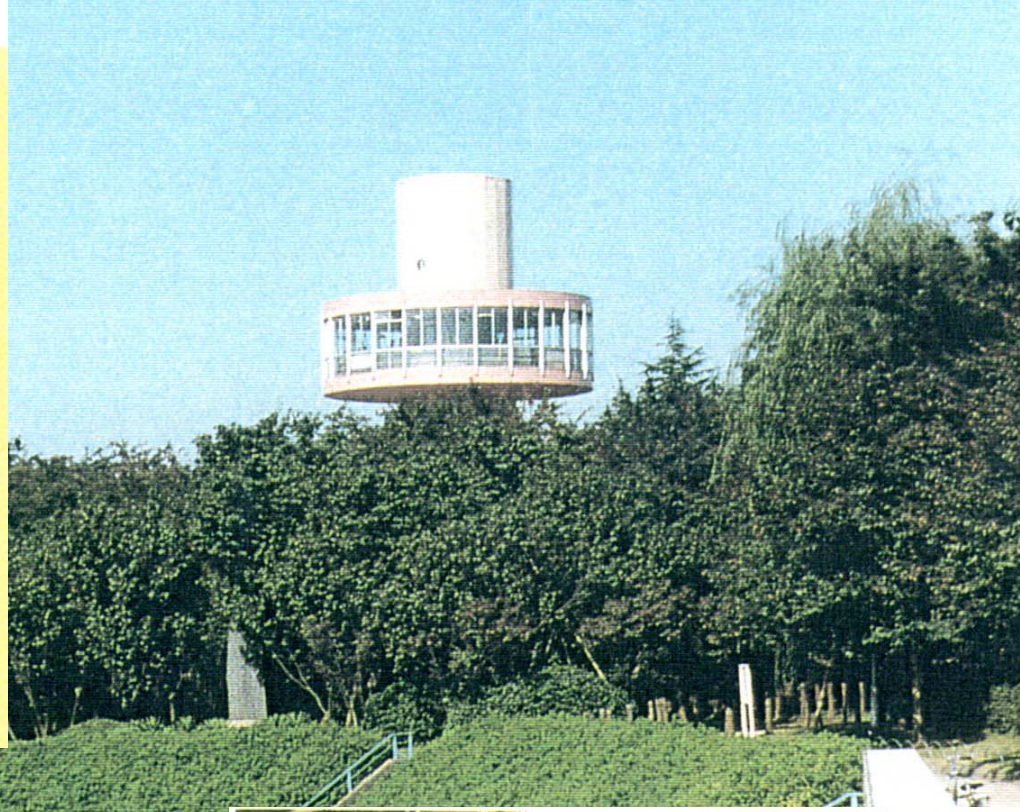


Tunnel leg reinforcement

Slope stabilization

Slope stabilization



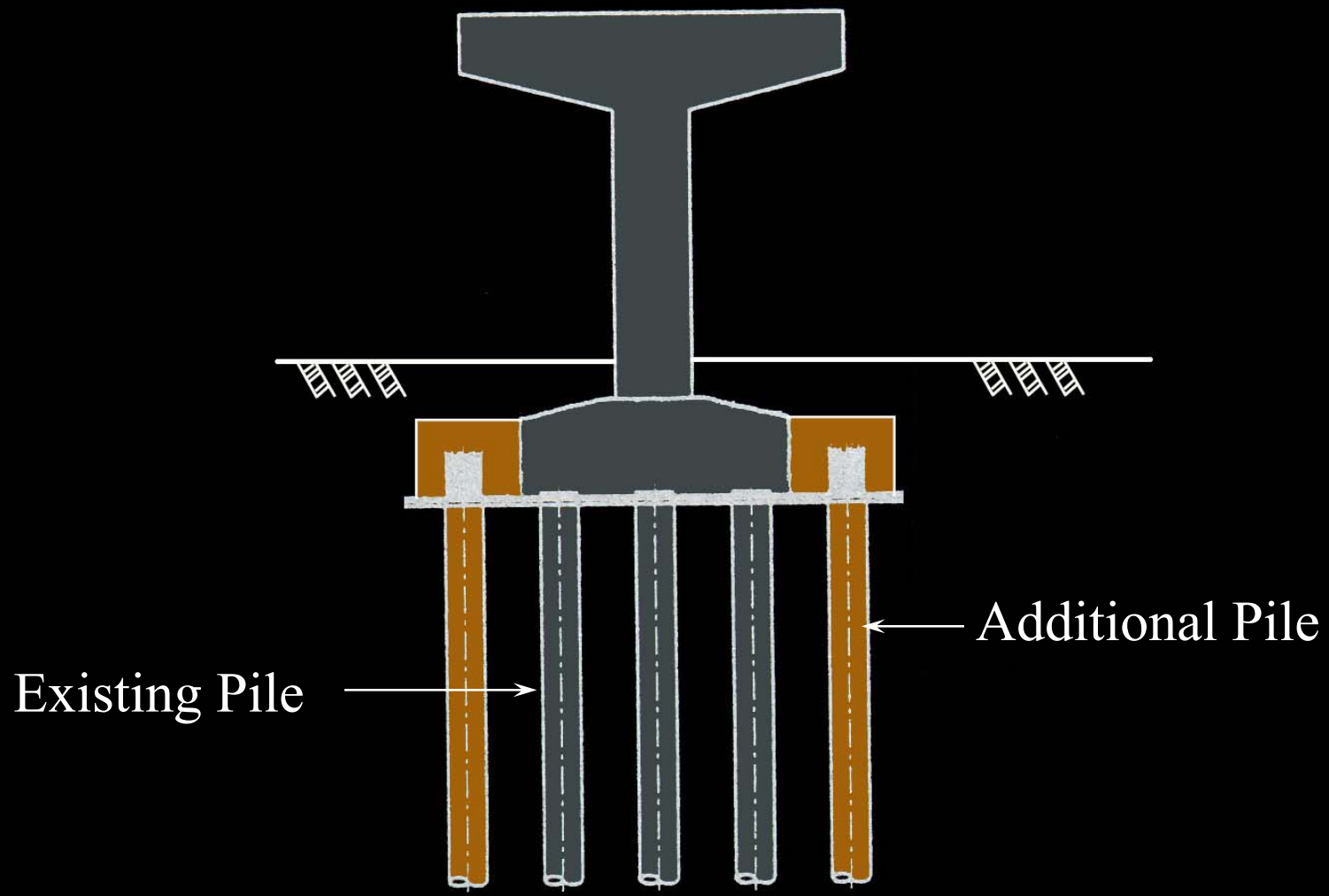


Underpinning of existing foundations

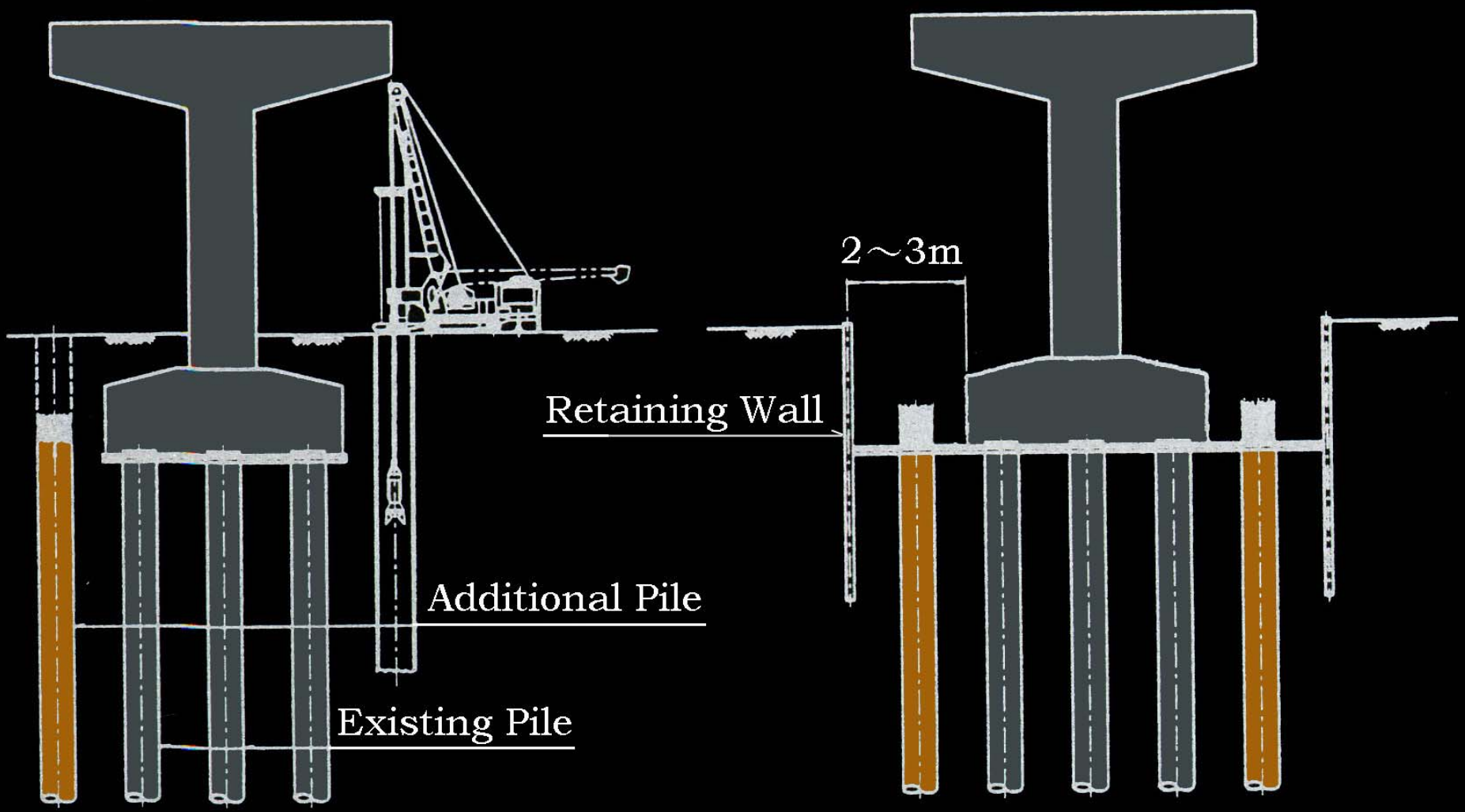
Hyogoken-nanbu EQ, 1995.1.17

Cracks on the cast-in-place concrete pile

Fall down of superstructure (Nishinomiya Br.)



Additional pile method



Construction procedure of additional pile method


Existing girder

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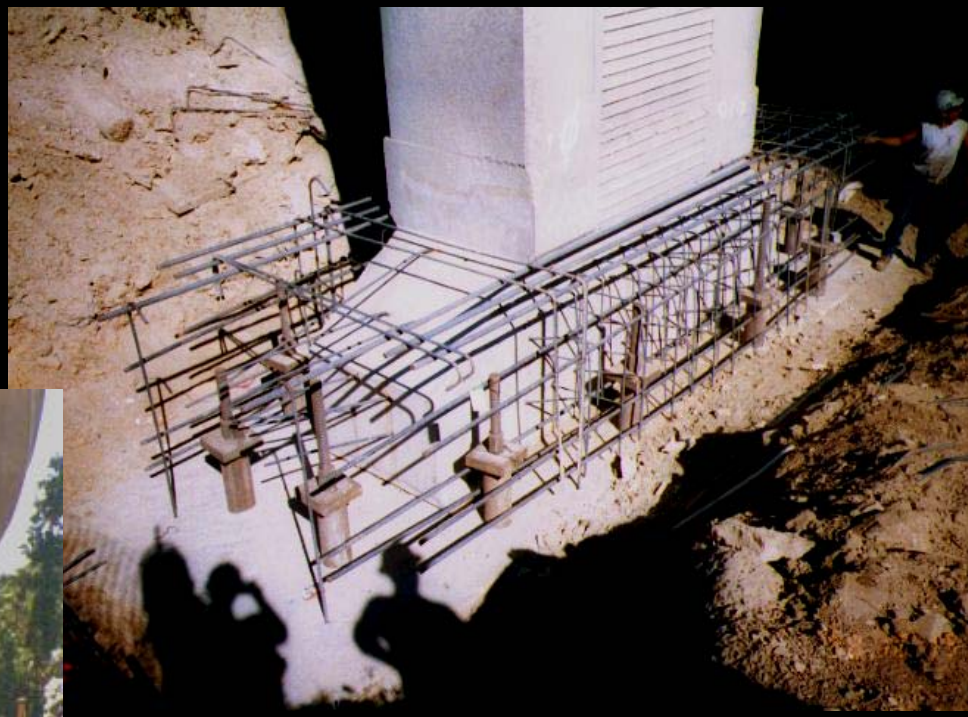
Joint Research on the Development of Seismic Retrofit Method for the Existing Bridge Foundation

Purpose :

- Development of new seismic retrofit method
- Establishment of design & construction manual

Research Period : 1999-2001



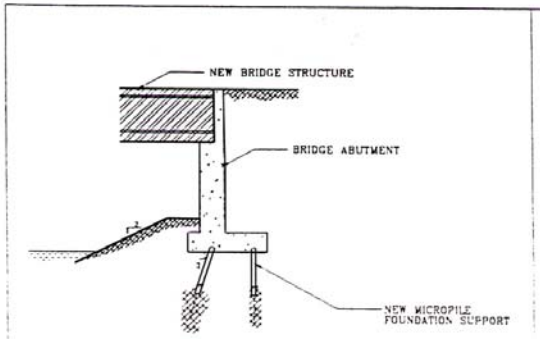
Utilization of micropile for seismic retrofit of foundation (USA)

U.S. Department of Transportation

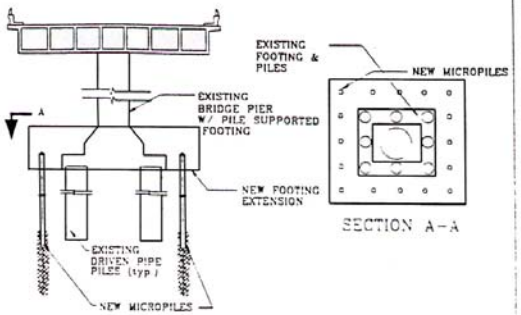
Federal Highway Administration

Priority Technologies Program

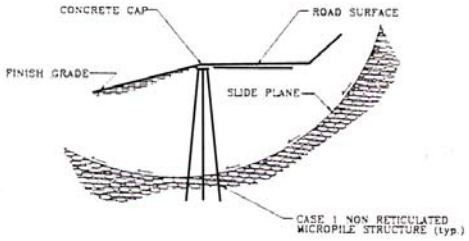
MICROPILE DESIGN AND CONSTRUCTION GUIDELINES



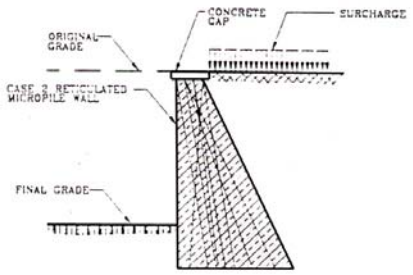
FOUNDATION SUPPORT



SEISMIC RETROFIT OF BRIDGES



SLOPE STABILIZATION



EARTH RETENTION

IMPLEMENTATION MANUAL

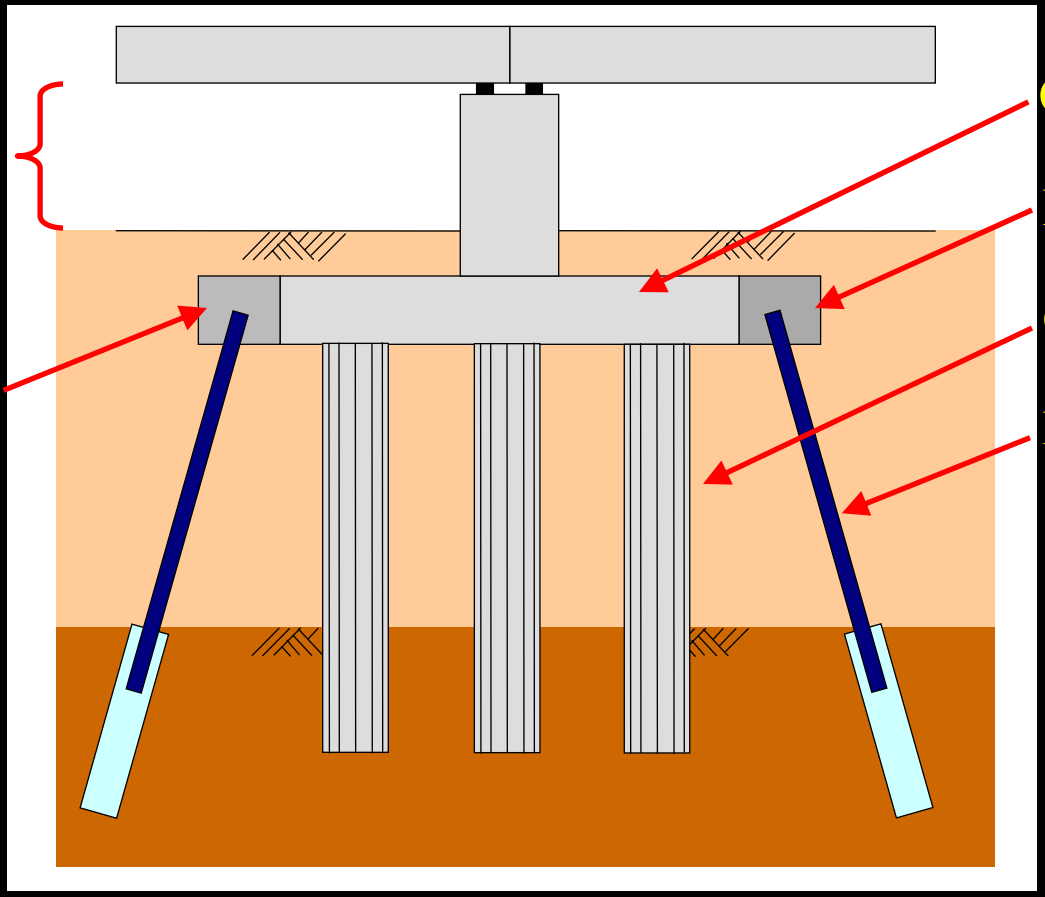
PUBLICATION NO. FHWA-SA-97-070

JUNE 1997

Retrofit method for existing bridge foundation by using micropiles

Execution at narrow Working Area

Small Enlargement of Footing & Small Excavation



Original Footing

Enlarged Footing

Original Pile

Micropile

Content of Joint research

- Loading test of High Capacity Micropile (vertical, horizontal)
- Horizontal loading test of group piles(existing piles & micropiles)
- Shaking table test of group piles
- Centrifuge loading test of group piles
- Analysis for group piles (simulation for the horizontal loading tests)
- Loading test of a connection part of pile head and footing
- Examination of design method for group piles
- Numerical analysis considering finite deformation of piles
- Examination of quality control & quality assurance by integrity test

Design and Construction Manual

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- Loading test of High Capacity Micropile (vertical, horizontal)
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Design and Construction Manual

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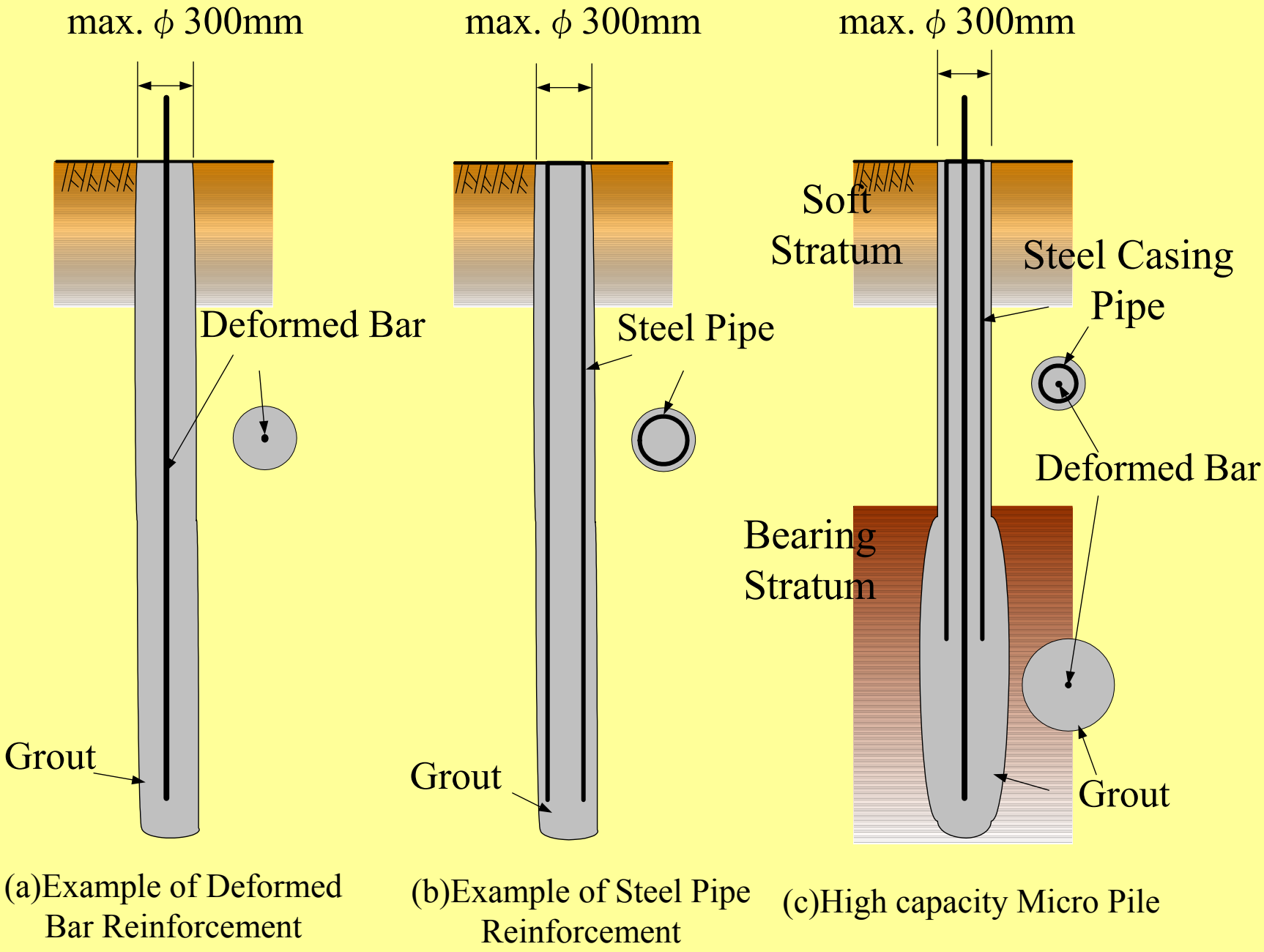


(a)Example of Deformed Bar Reinforcement

(b)Example of Steel Pipe Reinforcement

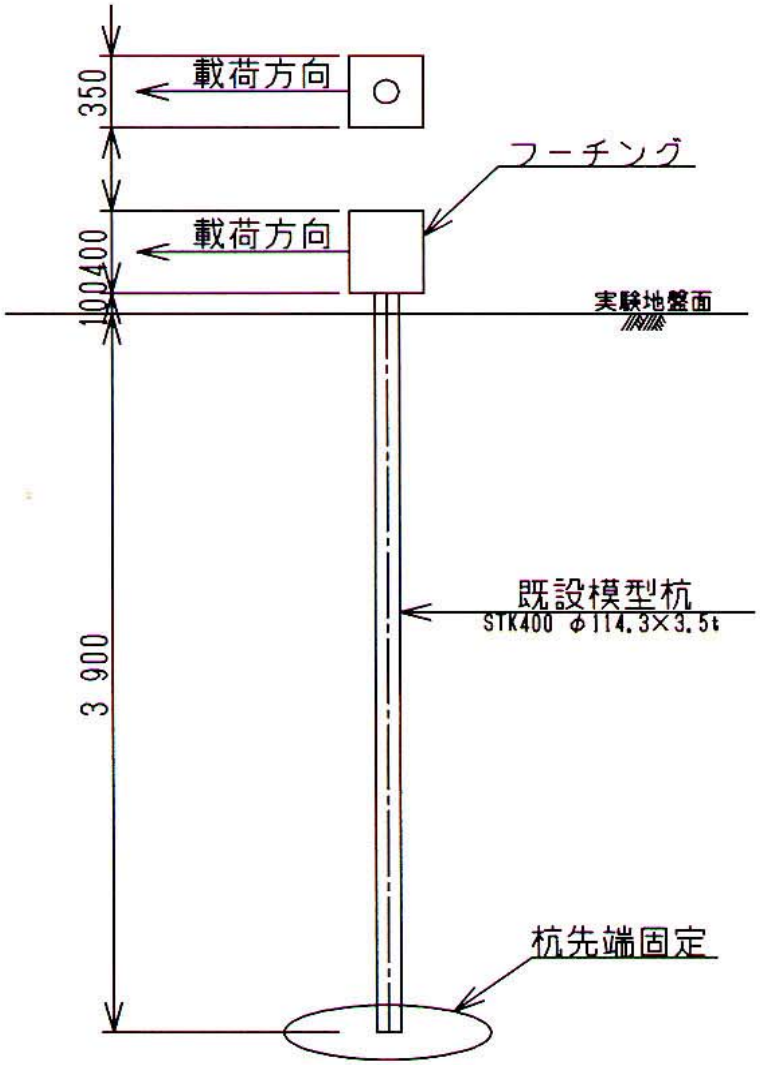
(c)High capacity Micro Pile

General form of Micropiles

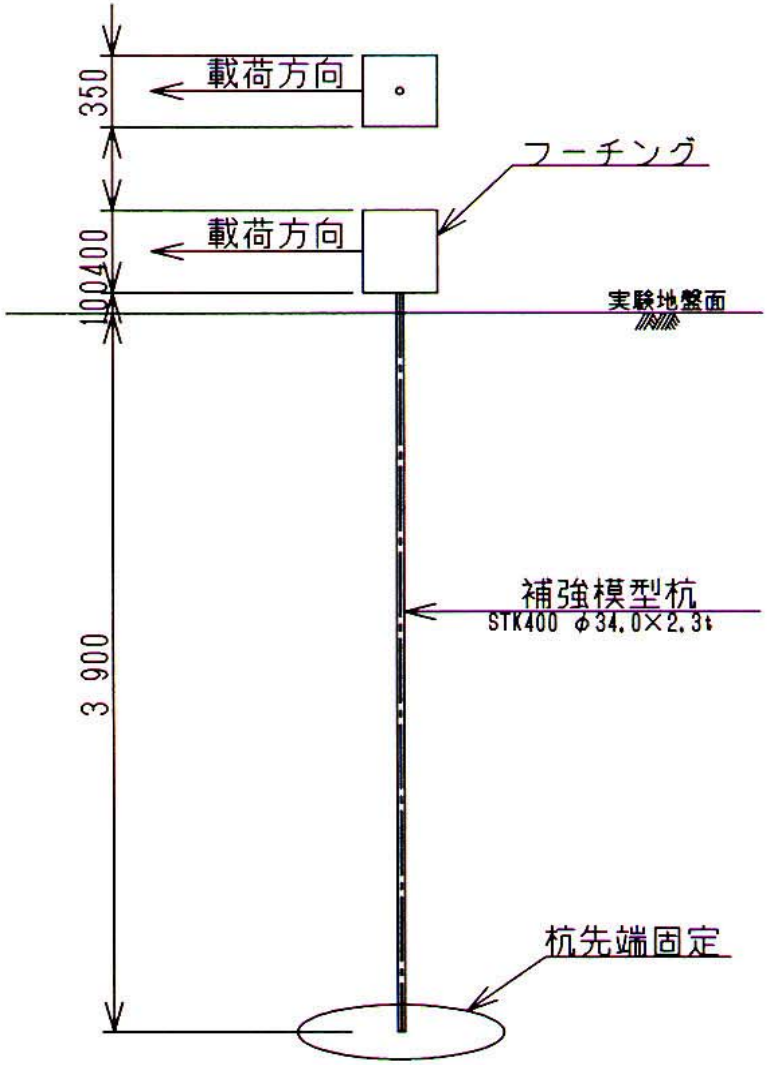
Cases of Horizontal Loading Tests

Case	Number of Piles	Spacing between Existing Piles Center and Micropiles Center (mm)	Inclination Angle of Micropiles (°)
1	Single Existing Pile	—	—
2	Single Micropile	—	—
3	4 Existing Piles	—	—
4	4 Existing Piles and 6 Micropiles	200	0
5	4 Existing Piles and 6 Micropiles	400	0
6	4 Existing Piles and 6 Micropiles	200	10
7	4 Existing Piles and 6 Micropiles	200	20

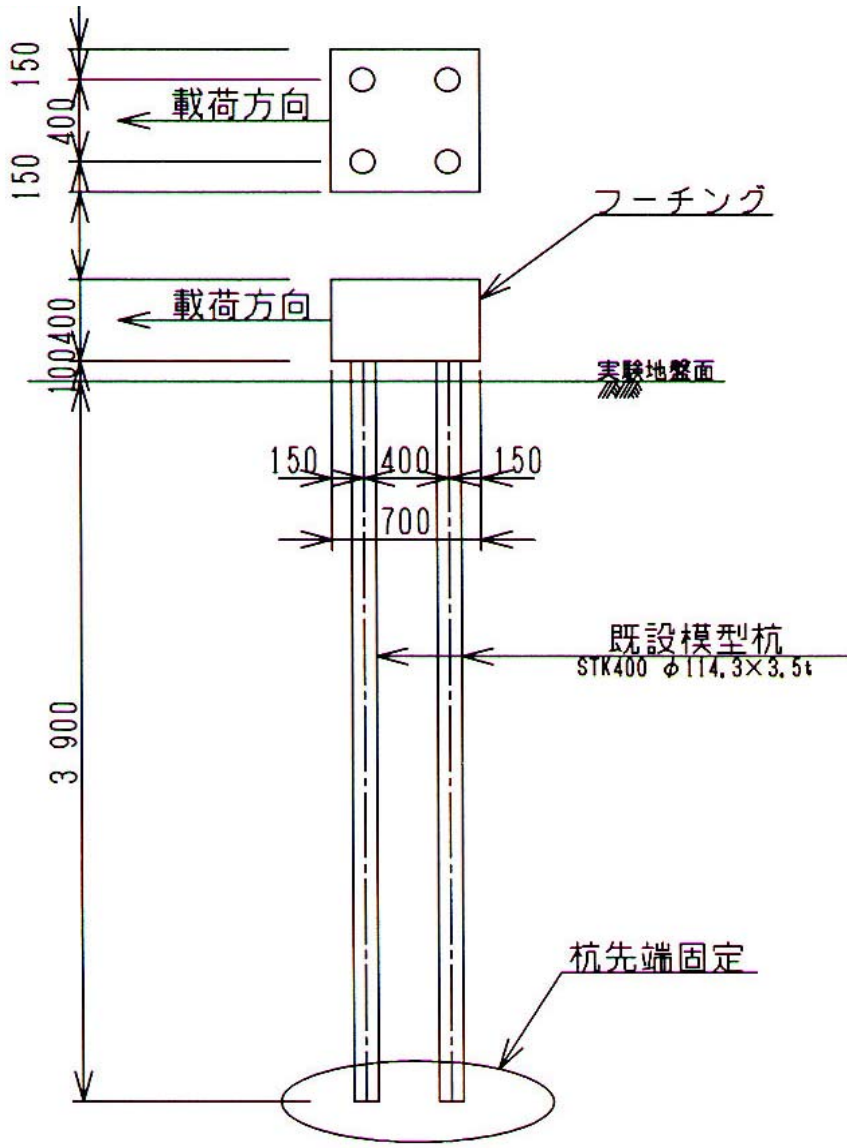
Case 1


350
載荷方向
フーチング
400
載荷方向
実験地盤面
既設模型杭
STK400 φ114.3×3.5t
3 900
杭先端固定

Case 2


350
載荷方向
フーチング
400
載荷方向
実験地盤面
補強模型杭
STK400 φ34.0×2.3t
3 900
杭先端固定

Case 3


150
400
150
載荷方向
フーチング
載荷方向
100
400
実験地盤面
150
400
150
700
既設模型杭
STK400 φ114.3×3.5t
3 900
杭先端固定

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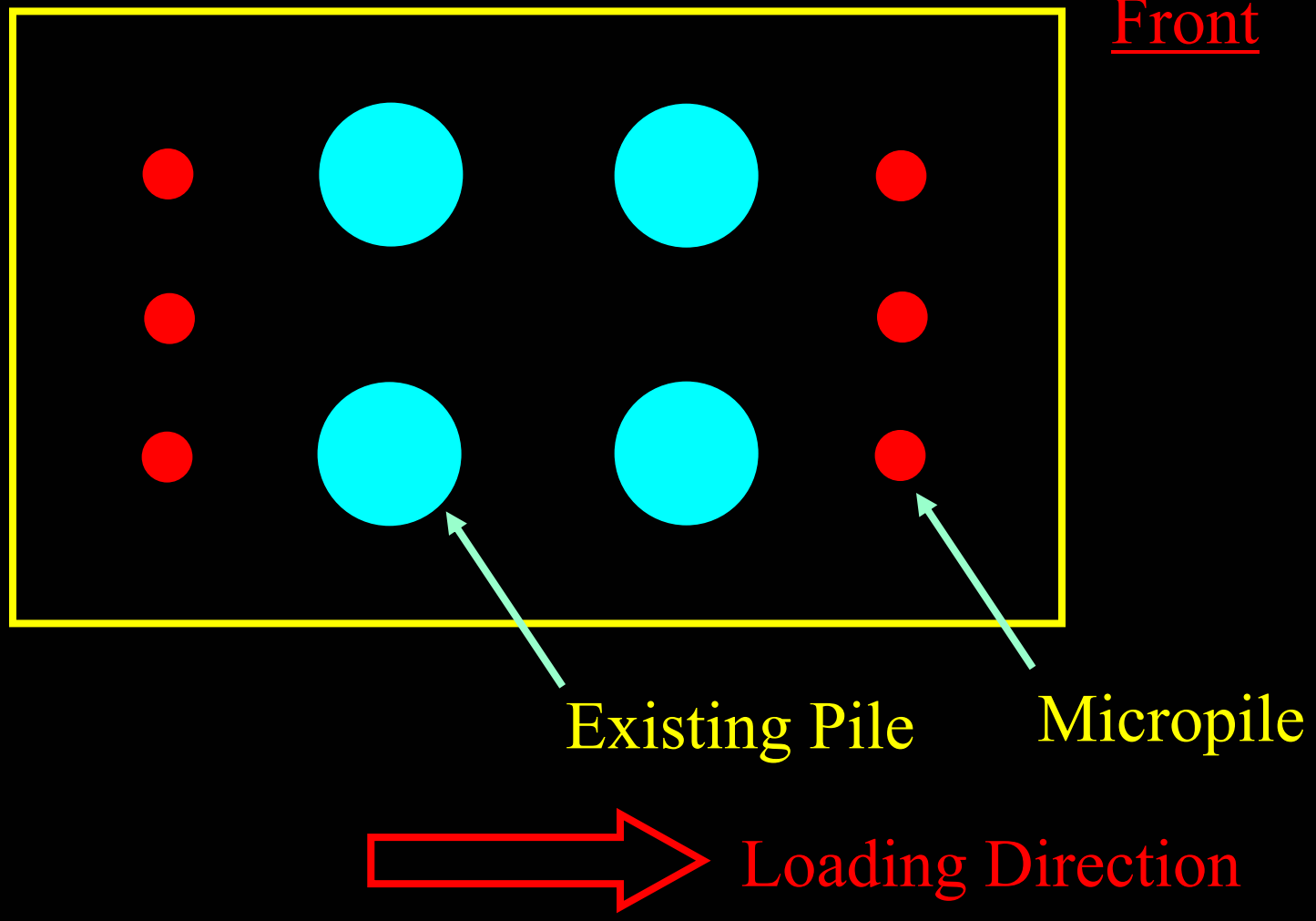
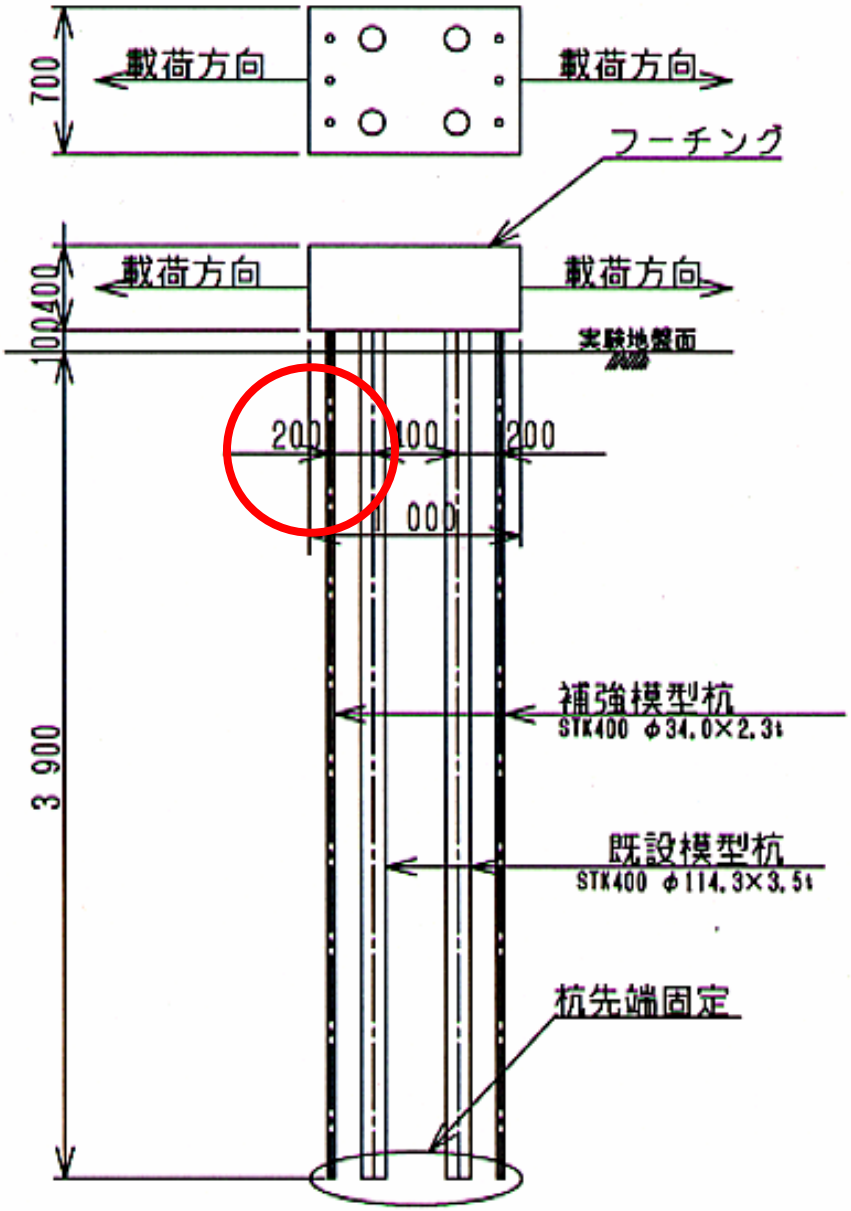
6	4 Existing Piles and 6 Micropiles	200	10
7	4 Existing Piles and 6 Micropiles	200	20

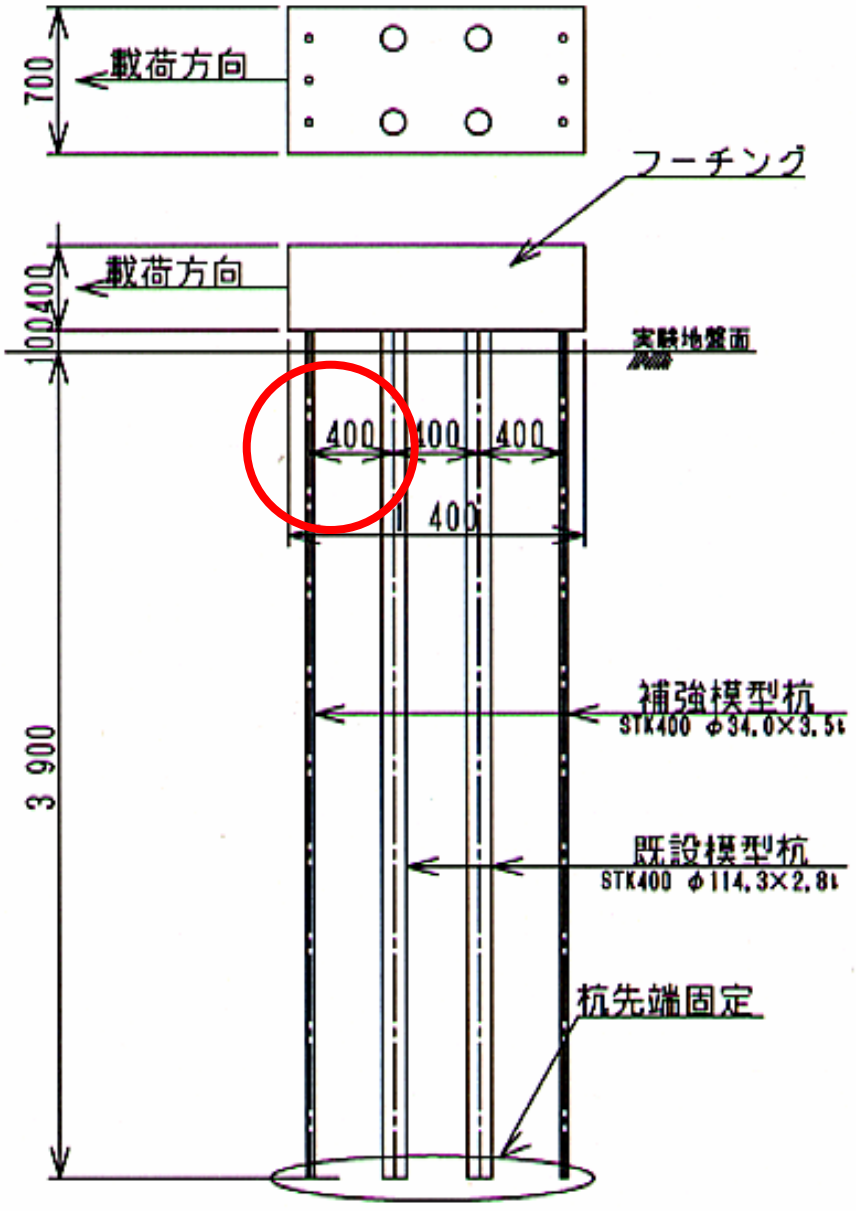


Arrangement of piles (Case 4 - 7)

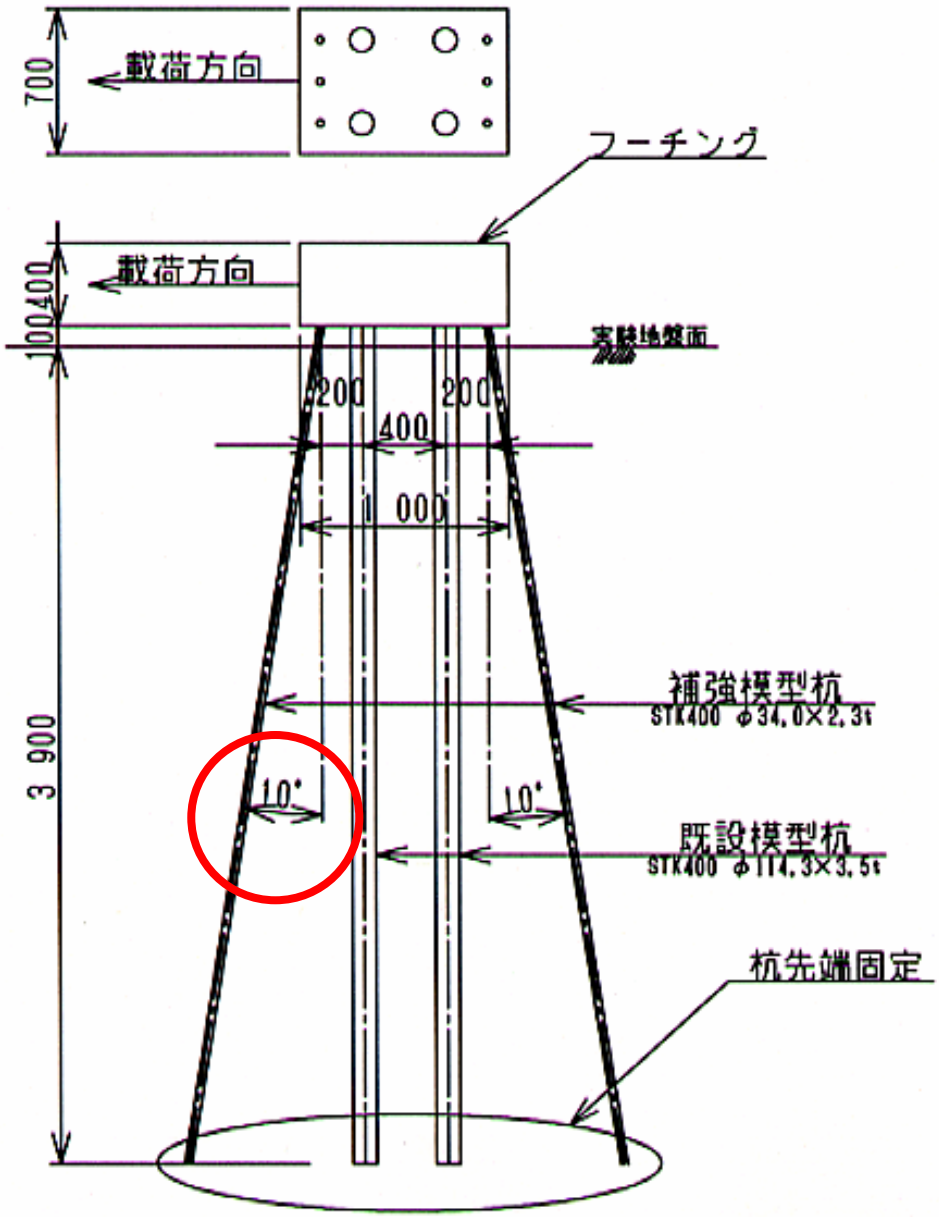
Case 4


700
載荷方向
載荷方向
フーチング
400
100
載荷方向
載荷方向
実験地盤面
200
100
200
000
3 900
補強模型杭
STK400 φ34.0×2.3t
既設模型杭
STK400 φ114.3×3.5t
杭先端固定

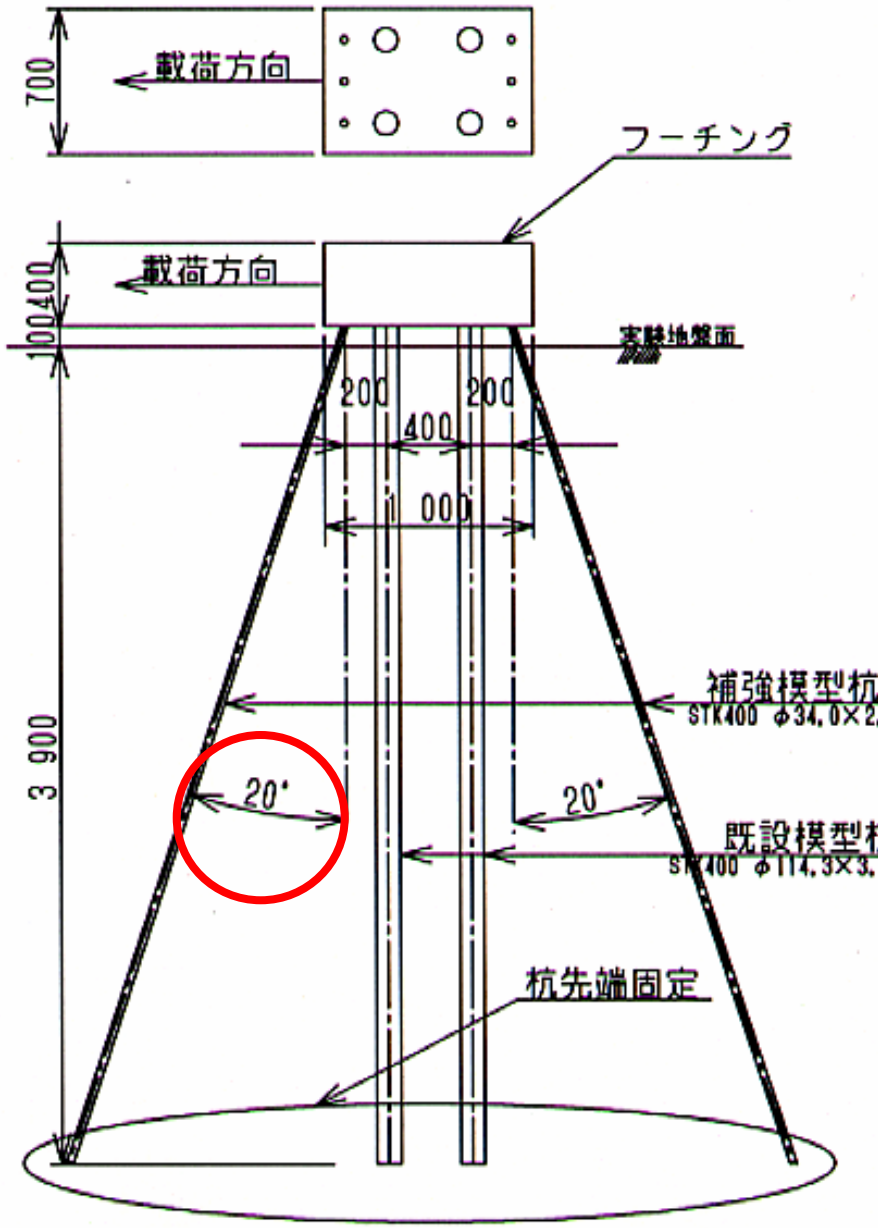
Case 5


700
載荷方向
フーチング
400
100
載荷方向
実験地盤面
400
400
400
400
3 900
補強模型杭
STK400 φ34.0×3.5t
既設模型杭
STK400 φ114.3×2.8t
杭先端固定

Case 6

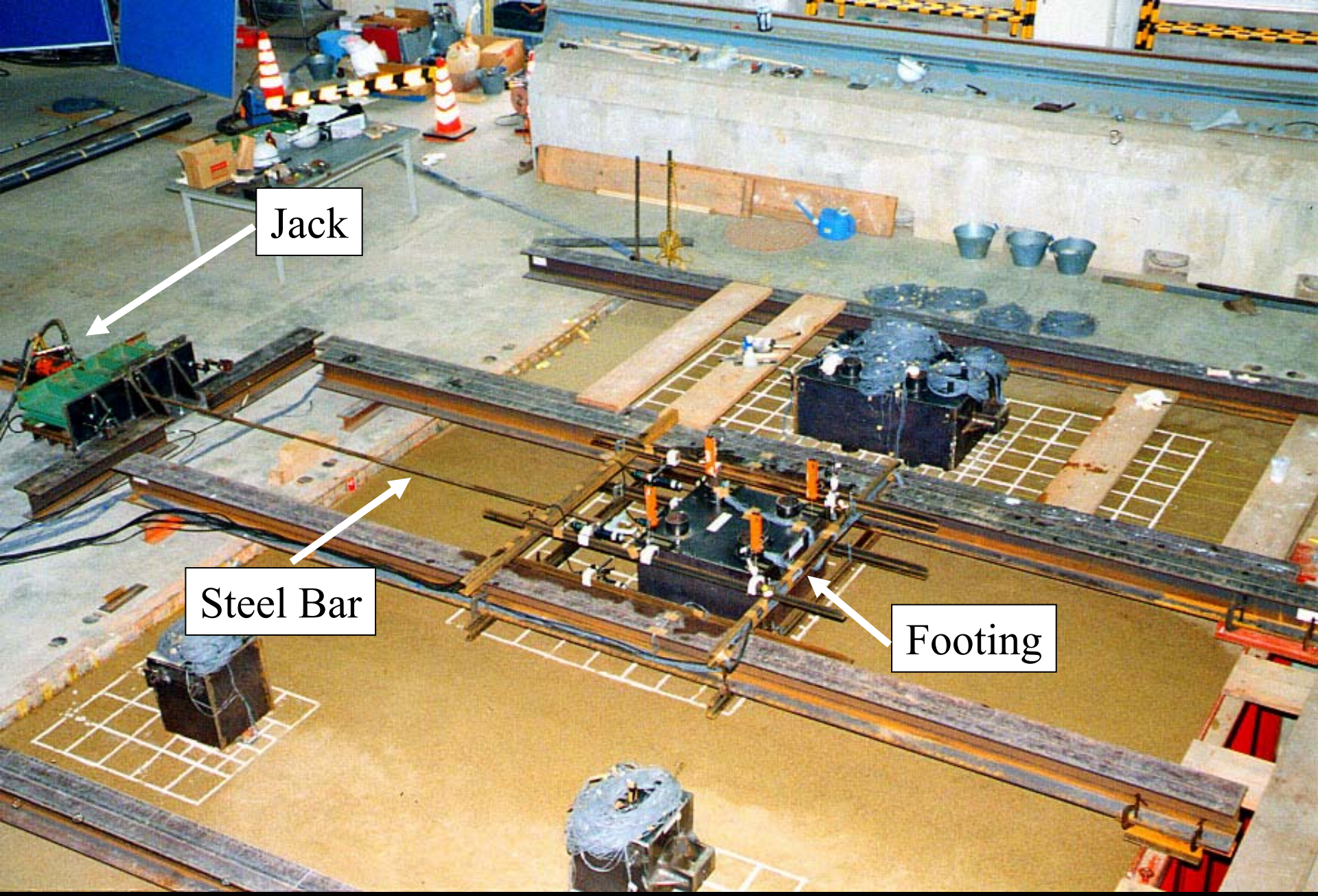

700
載荷方向
フーチング
100
400
載荷方向
実験地盤面
200
200
400
1 000
補強模型杭
STK400 φ34.0×2.3t
3 900
10°
10°
既設模型杭
STK400 φ114.3×3.5t
杭先端固定

Case 7

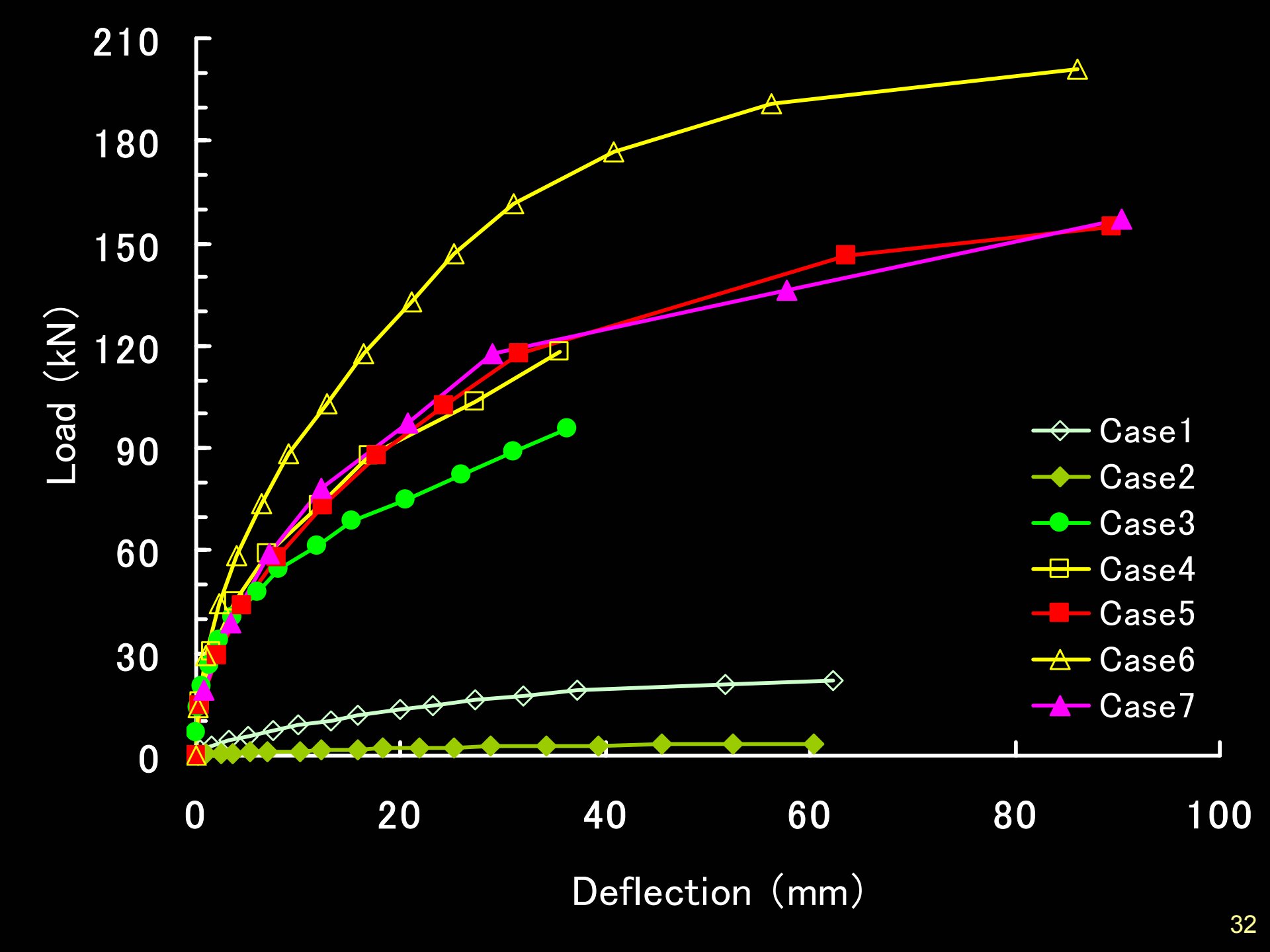

700
載荷方向
フーチング
100
400
載荷方向
実験地盤面
200
200
400
1 000
補強模型杭
3 900
20°
20°
杭先端固定

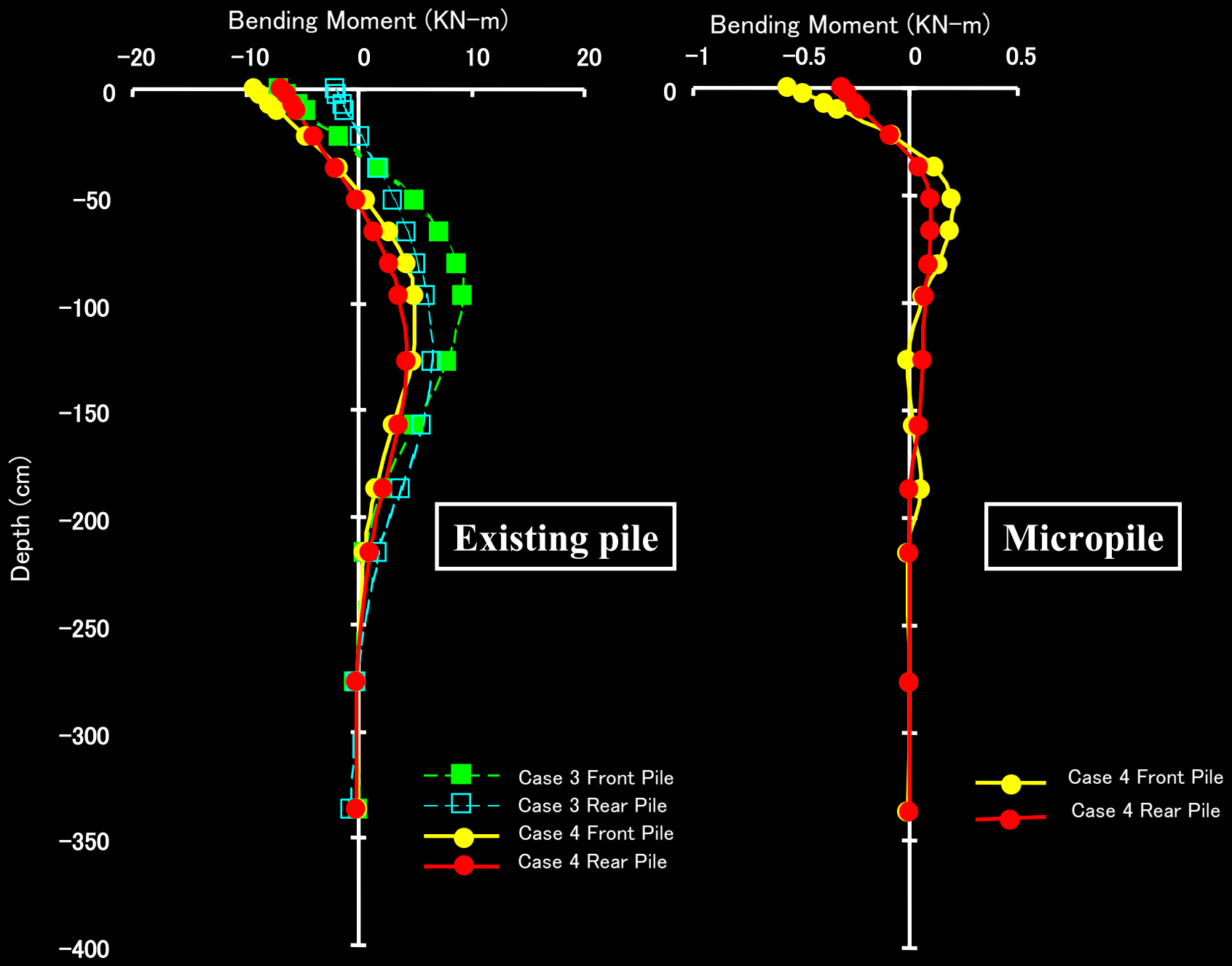
Dimensions of Piles

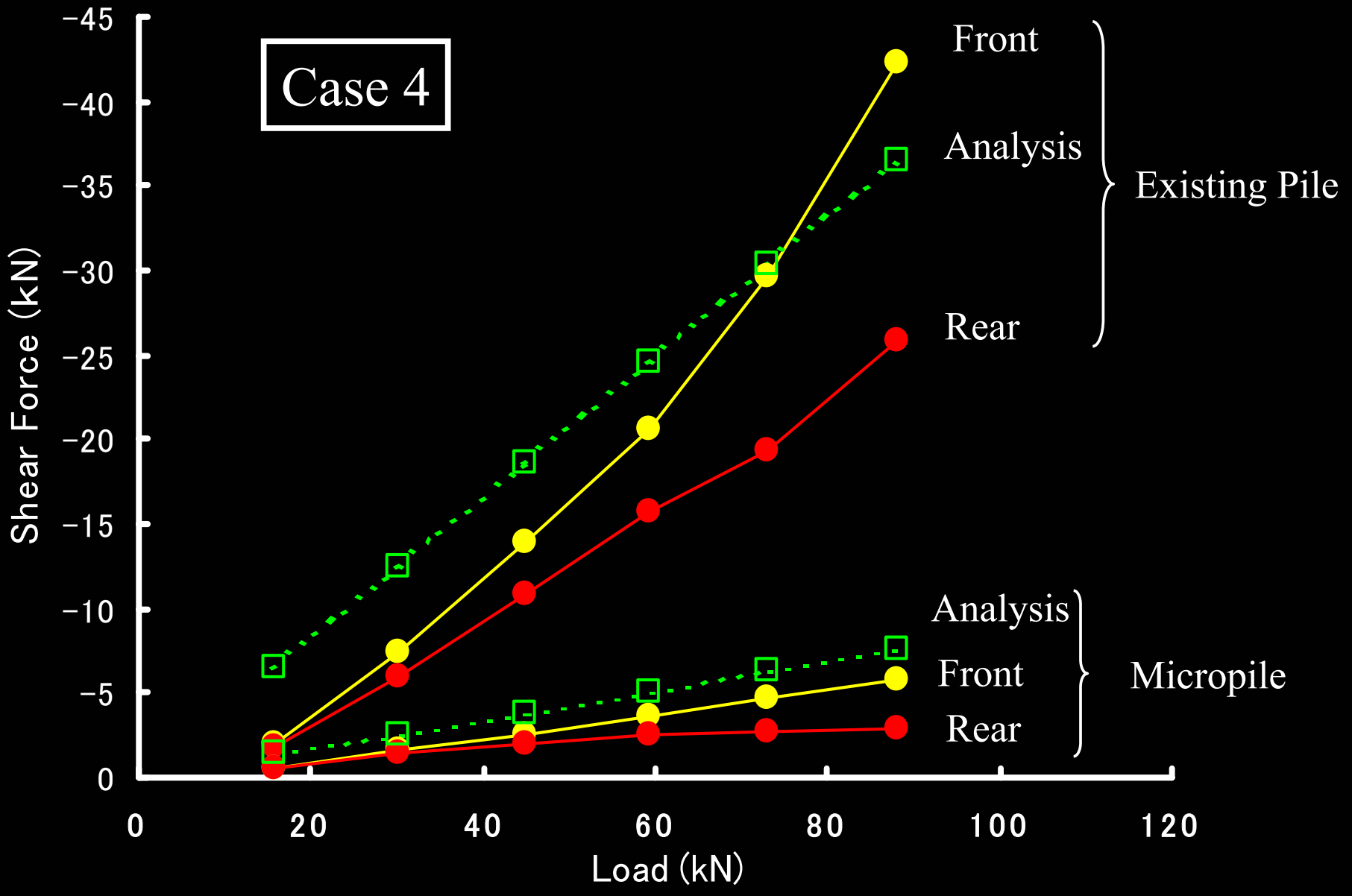
	Diameter (mm)	Thickness (mm)	Sectional Area (cm^2)	Moment of Inertia (cm^4)
Existing Pile	114.3	3.5	12.18	187.0
Micropile	34.0	2.3	2.291	2.89



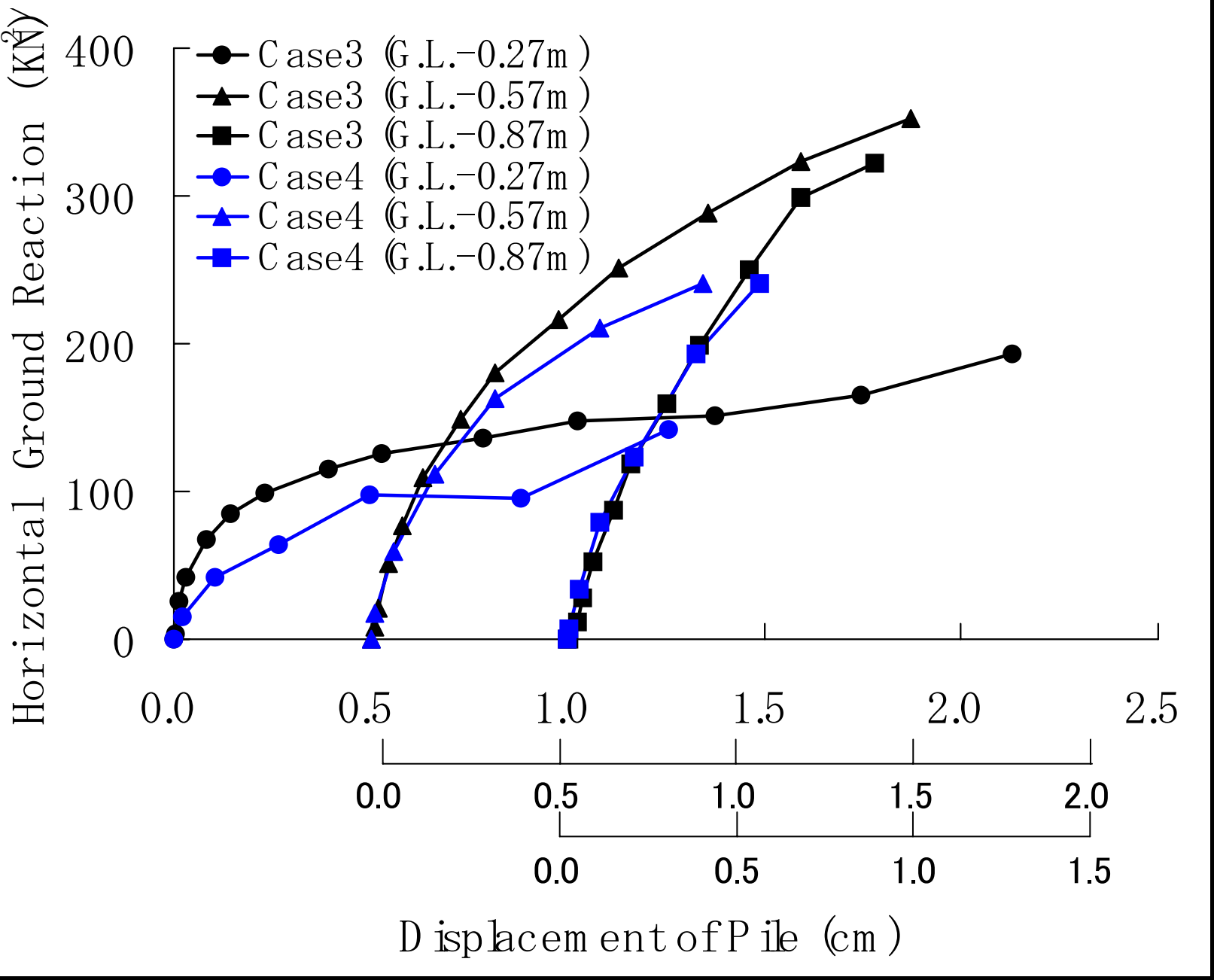
Loading Test for Case 3


210
180
150
120
90
60
30
0
Load (kN)
0
20
40
60
80
100
Deflection (mm)
Case1
Case2
Case3
Case4
Case5
Case6
Case7


Bending Moment (KN-m)
-20
-10
0
10
20
0
-50
-100
-150
-200
-250
-300
-350
-400
Depth (cm)
Existing pile
Case 3 Front Pile
Case 3 Rear Pile
Case 4 Front Pile
Case 4 Rear Pile
Bending Moment (KN-m)
-1
-0.5
0
0.5
Micropile
Case 4 Front Pile
Case 4 Rear Pile



Distribution of Shear Force



Horizontal ground reaction - Displacement Curve

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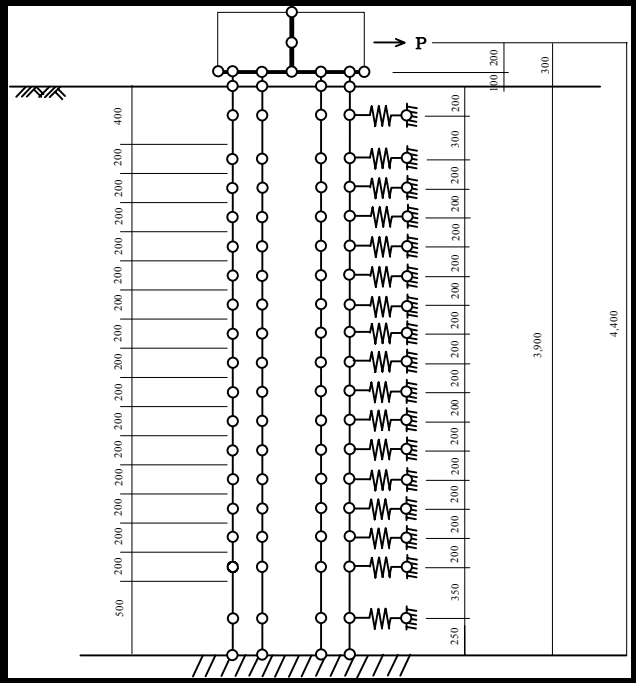
To Study the Design Method of Group Piles with Different Diameter Piles….

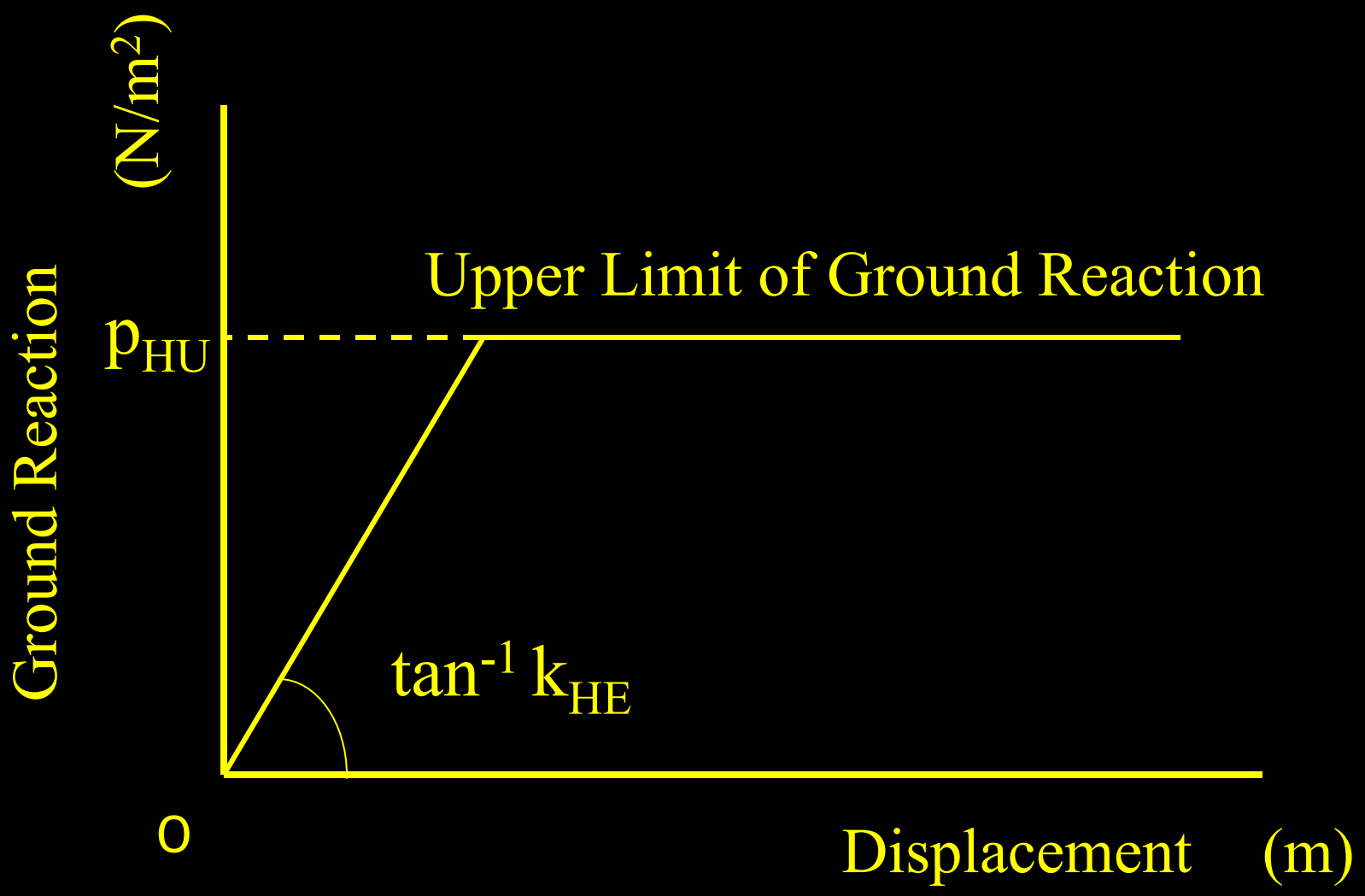
→ Simulation Analyses for Loading Tests by Ductility Design Method

Non-Linear Model

- Ground Properties
- Flexural Rigidity of Piles



Model of Transverse Resistance of Ground



Transverse Resistance Characteristics of Ground

$k_{HE} = a_k b_k k_H$

$p_{HU} = a_p b_p p_U$

a_k, a_p : Correction Factors of a Single Pile

b_k, b_p : Correction Factors of Group Piles

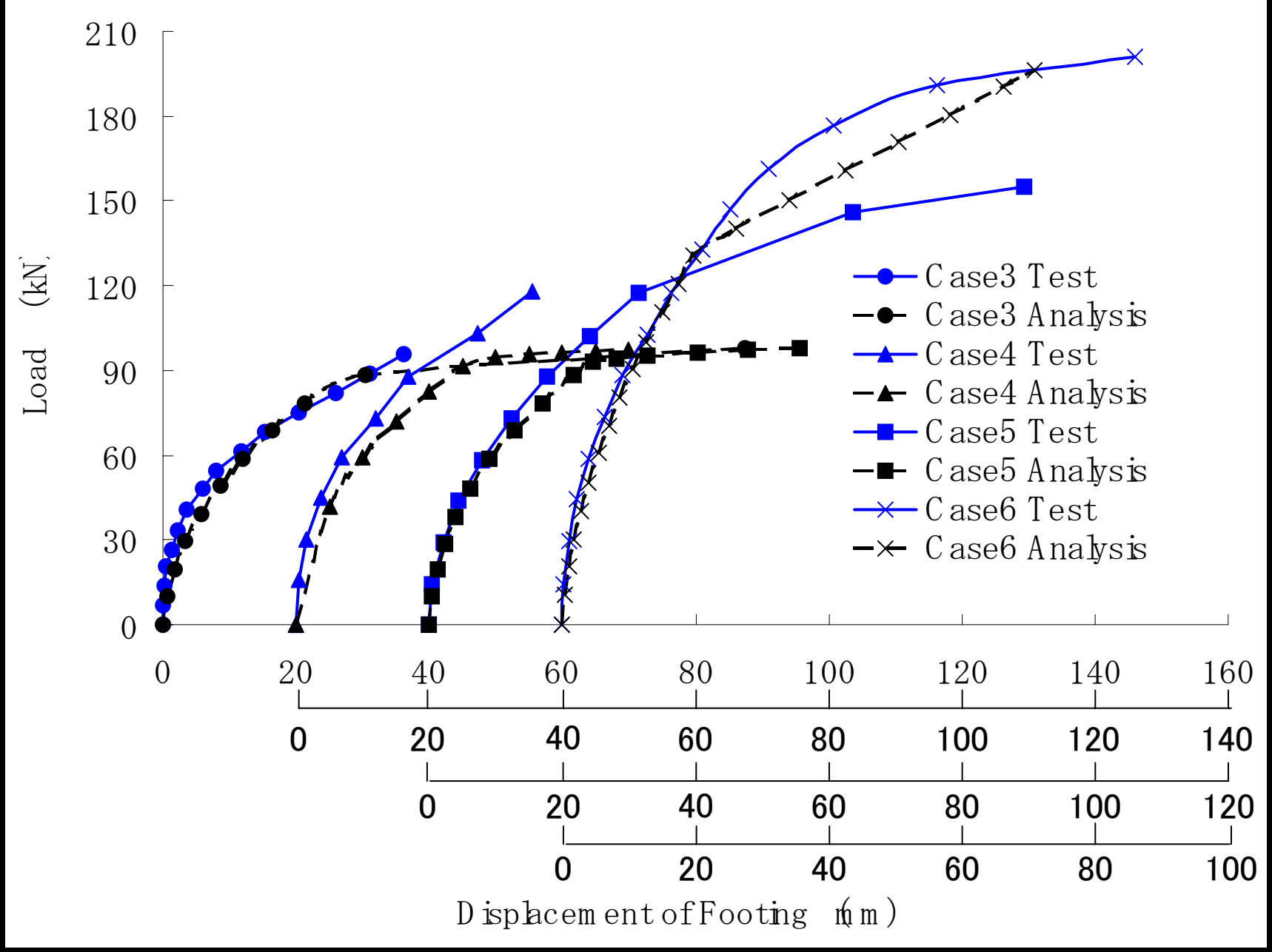
To consider the group effects…

$a_k b_k = 1$

a_p (Cray Ground) = 1.0

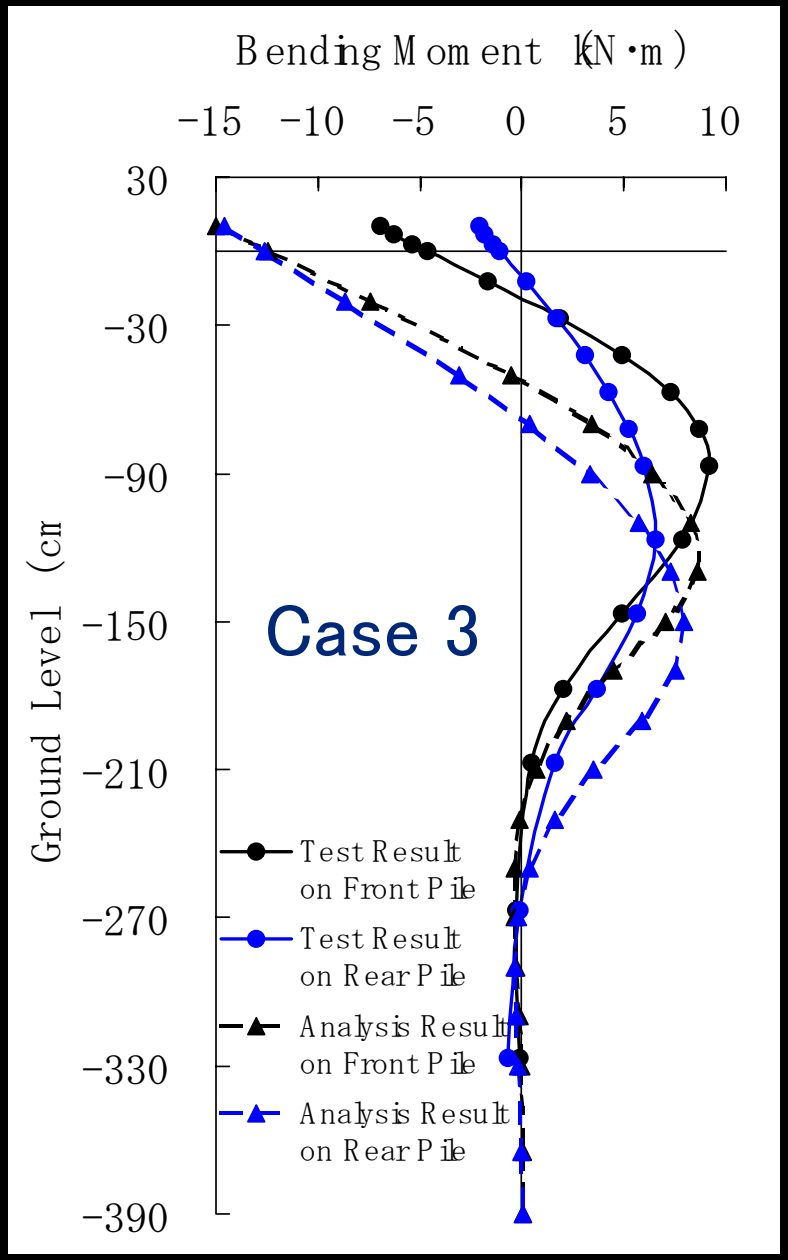
$a_p b_p$(Sandy Ground) = S/D ($\leqq 3$)

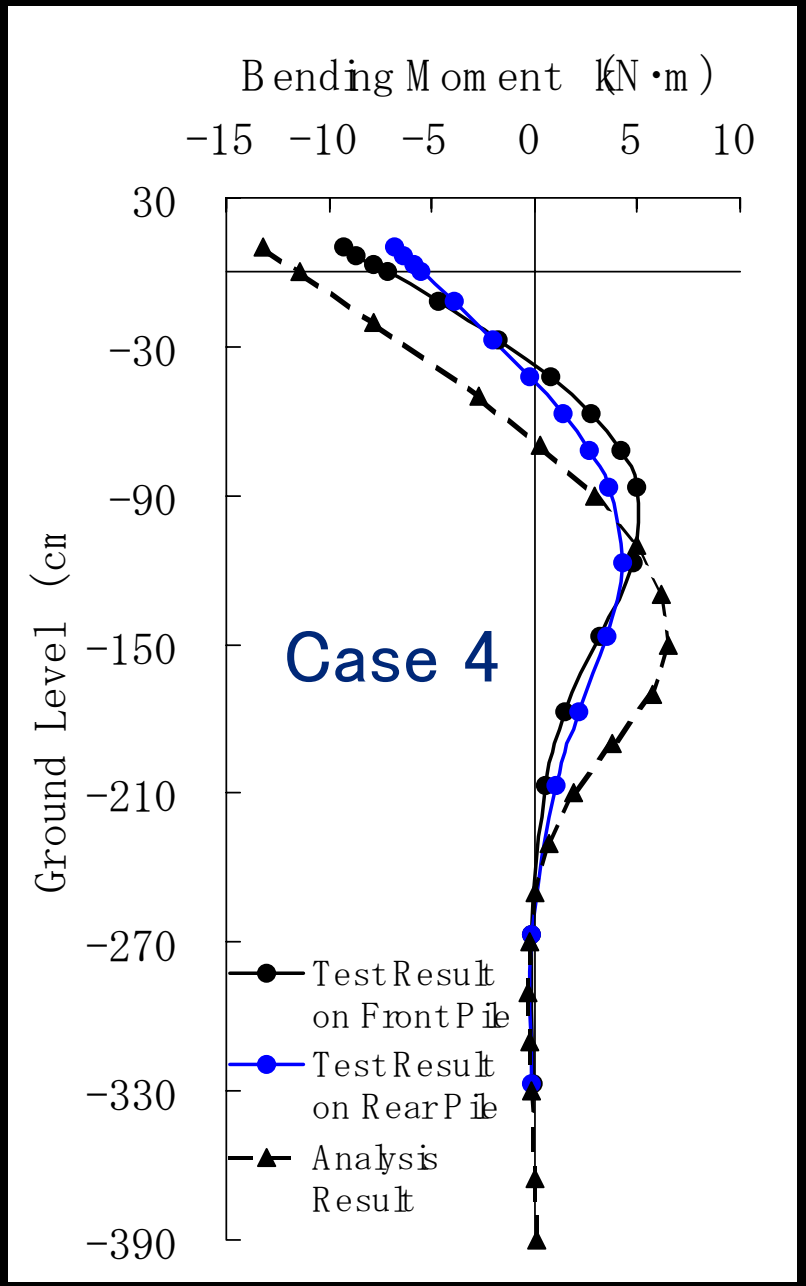
To consider the group effects of trailing piles…



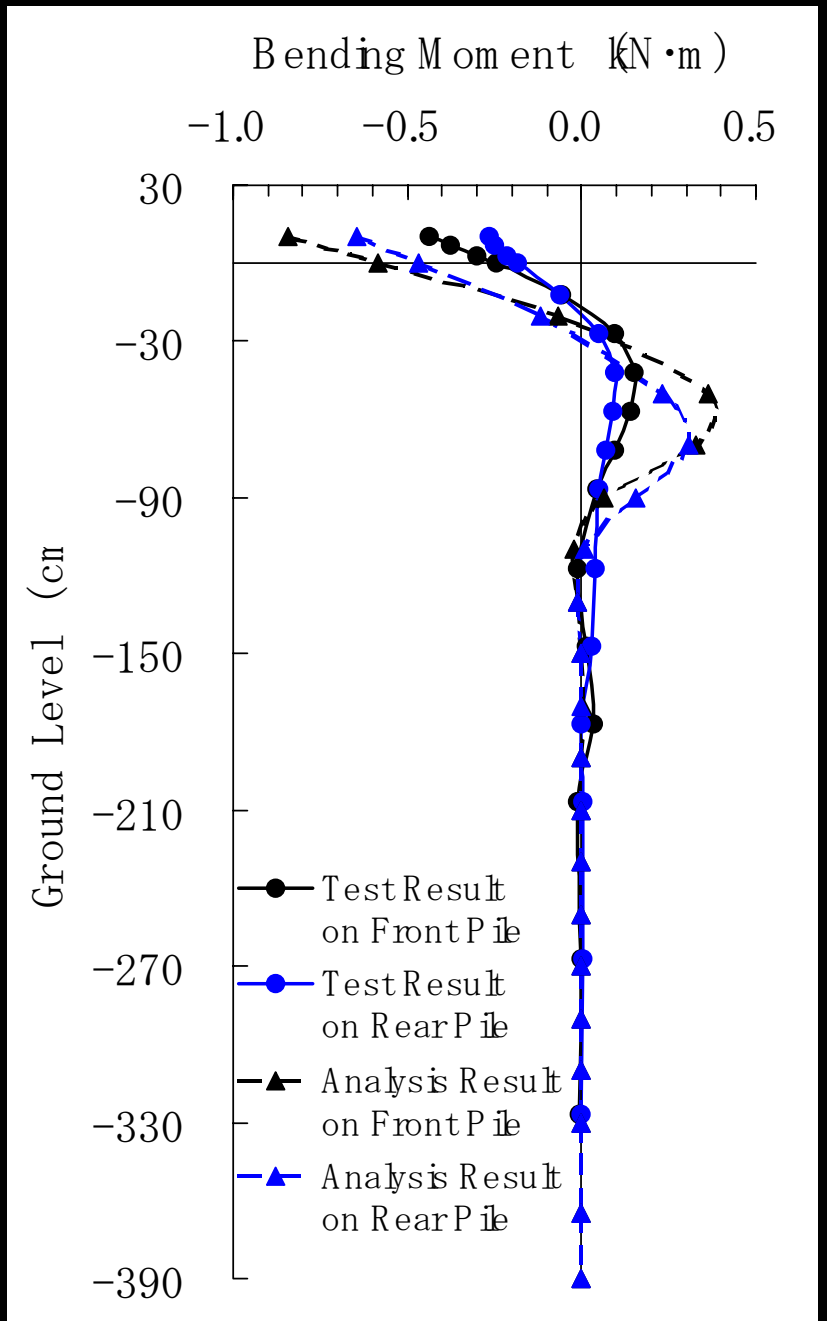
Load – Displacement Curve

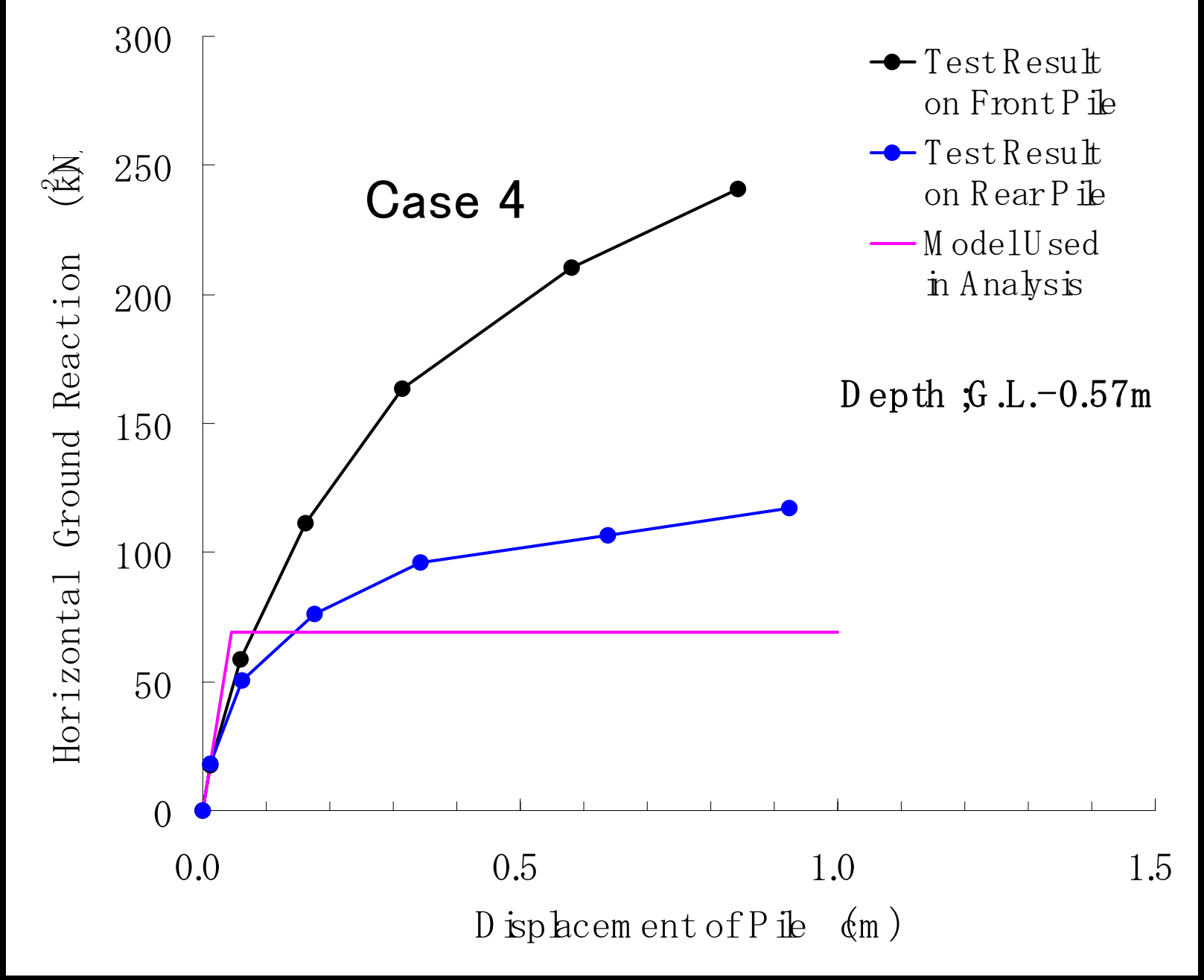
Bending Moment of Existing Piles in Case 3 and Case 4





Bending Moment on Micropiles in Case 4





Horizontal ground reaction - Displacement Curve

Summaries of horizontal loading tests & analysis

- Results of horizontal loading tests
  - Micropiles have a large reinforcement for existing foundation.
  - Spacing between existing pile and micropile has little effect on reinforcement.
  - Inclination of micropiles increase horizontal resistance of existing foundation.
- Results of simulation analyses
  - Ductility design method for new foundation is available to retrofitting design with some modification.

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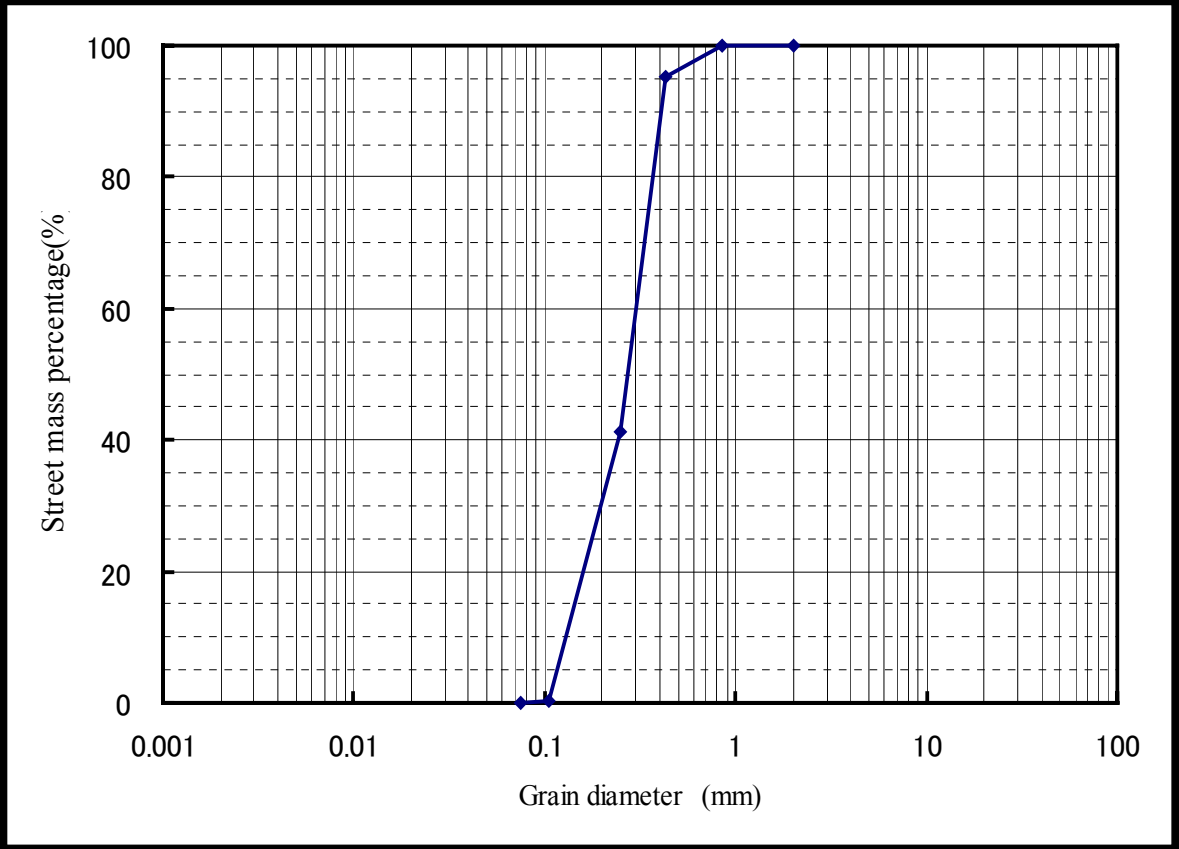
Shear soil container

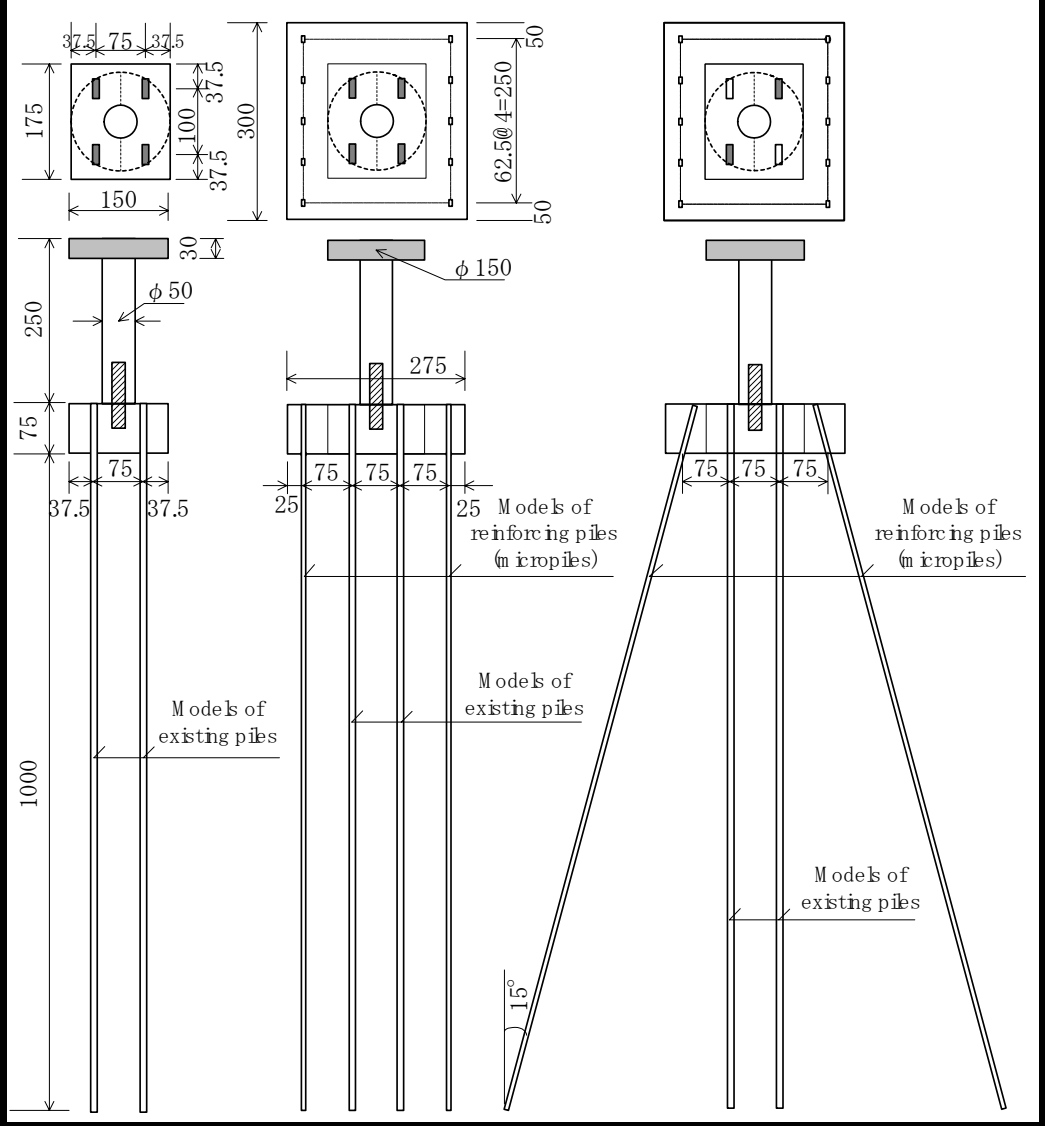
Properties of sand

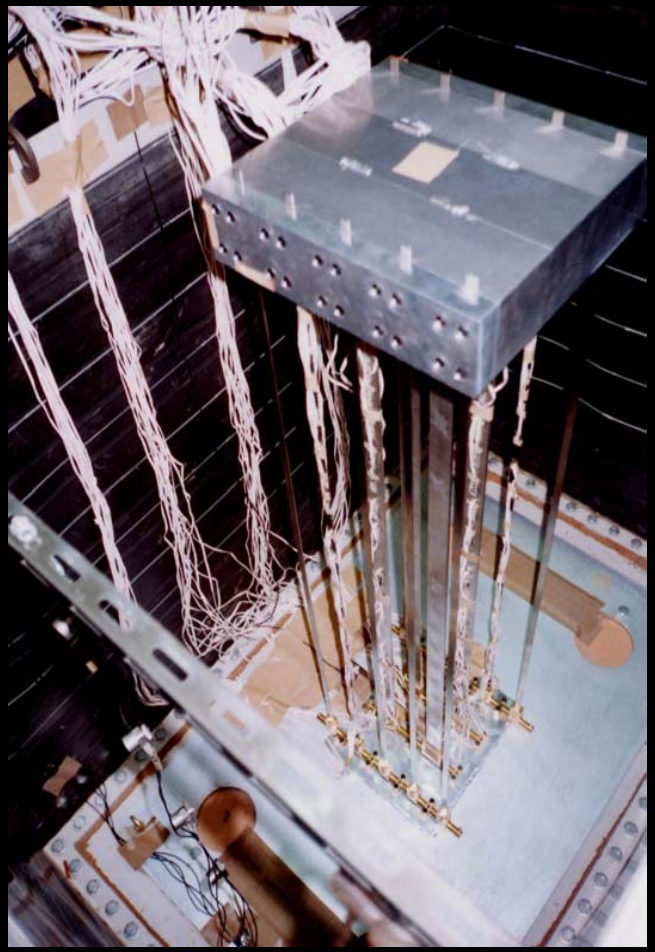
Physical properties

Density of soil particle	ρ_s	2.699 g/cm^3
Grin size distribution	Gravel content	0%
	Sand content	100.00%
	Silt content	0.00%
	Clay content	0.00%
	Uniformity coefficient	2.31
	Curvature coefficient	1.03
Maximum dry density	$\rho_{d\ max}$	1.694 g/cm^3
Minimum dry density	$\rho_{d\ min}$	1.396 g/cm^3



Gradation curve of the Hamaoka sand



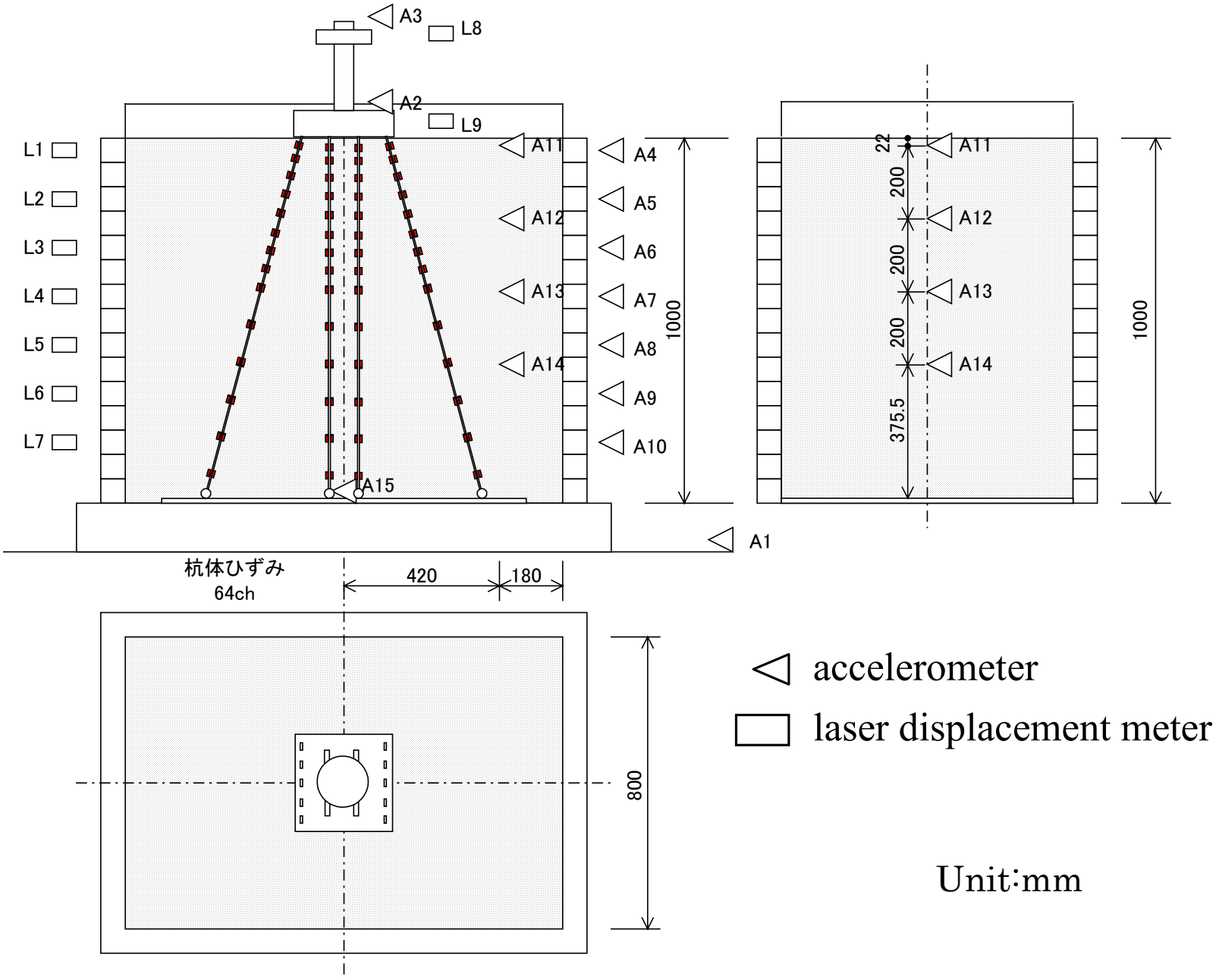


Existing pile

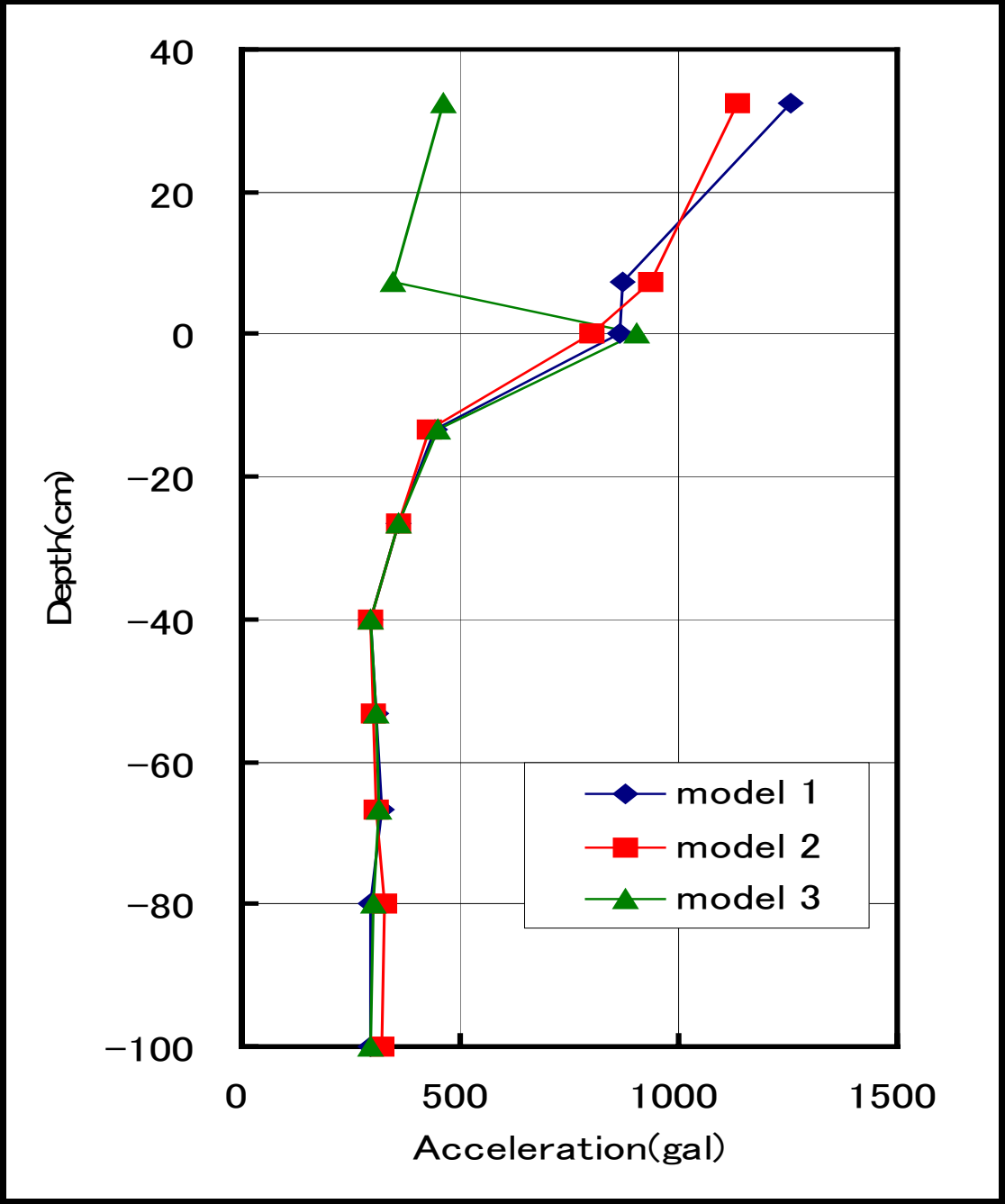
Existing pile with micropile (vertical)

Existing pile with micropile (inclined)

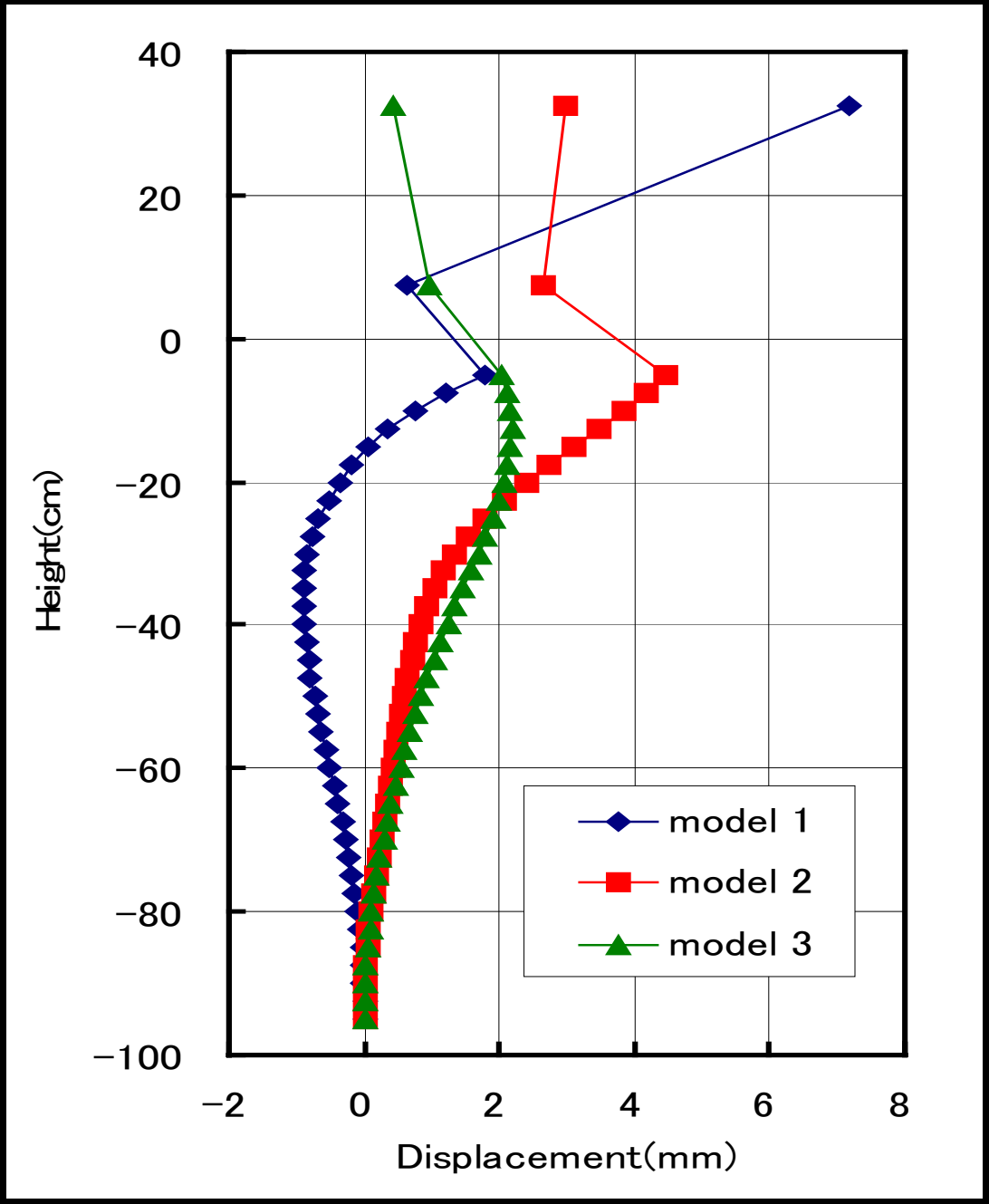
Outline of the model



The locations of the measuring points



The maximum acceleration response



The displacements of the existing pile and bridge pier

Summaries of shaking table tests

- The dynamic response characteristics of the foundation reinforced with micropiles are proved free from problems.
- Micropiles are effective in reinforcing the existing foundation.
- Inclined micropiles can decrease the response of the existing foundation.

Design & Construction Manual for Seismic Retrofit Method for the Existing Bridge Foundation

CHAPTER 3 EXECUTION METHOD

3.1 Execution process

The standard execution process of HMP consists of boring, installation of core bars, grout mixing, initial injection, pressure injection, reinsertion of HMP steel pipes, and treatment of pile head. The execution of a single HMP shall, in principle, be a continuous work from the beginning of boring to the reinsertion of HMP steel pipes.

[Explanation]

Figure-C 3.1.1 shows the standard HMP execution process, and Figure-C 3.1.2 is the outline of the execution process.

The process from the beginning of the boring until the reinsertion of HMP steel pipes must be, in principle, a continuous work, because it is difficult to insert and remove HMP steel pipes if the boring work is interrupted. In addition, because the quality of hardened grout will be poor if the ground injection work is interrupted.

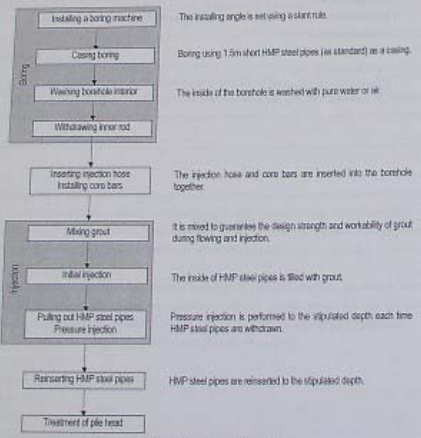


Figure-C 3.1.1 HMP Execution Process

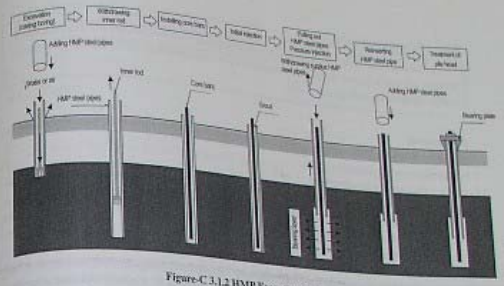


Figure-C 3.1.2 HMP Execution Process

3.2 Major machinery and equipment

The execution machinery and equipment used to execute HMP shall be selected appropriately accounting for the working environment conditions at the execution site, surrounding environment conditions, and economic factors.

[Explanation]

Table-C 3.2.1 shows the standard execution machinery and equipment used to execute HMP. The specifications in the table are standard sample. Therefore, special machinery and equipment must be selected according to the working environment and ground conditions.

Table-C 3.2.1 Sample of Standard Execution Machinery and Equipment

Work category	Name	Specifications	Quantity	Remarks
Boring	Boring machine	Motor about 110PS	1 unit	Rotary percussion double-wall pipe method
	Water feed pump	15kW	1 unit	Ejection rate 300L/min
	Water tank	5, 10m^3	Necessary number	For pure water, for slurry
	Sand pump	5.5kW	Necessary number	
	Pipe extractor		1 unit	Used as necessary
Injection	Grout mixer	11kW	1 unit	Vertical or two tank horizontal type
	Grout pump	15kW	1 unit	Ejection rate 300L/min
	Water meter		1 unit	
	Flow meter		1 unit	Used as necessary
Common	Compressor		1 unit	
	Crane	Lifting capacity 4.9 to 25t	1 unit	
	Engine driven generator	Approx. 45, 100kVA	1 unit	Used as necessary

Contents of Design & Construction Manual for Seismic Retrofit Method for the Existing Bridge Foundation

- Part 1 : General
- Part 2 : Design
  - Chapter 1 : General
  - Chapter 2 : Material
  - Chapter 3 : Surveys
  - Chapter 4 : General Instructions
  - Chapter 5 : General Instructions for Seismic Retrofit
  - Chapter 6 : Elastic Design for Ordinary time and Level Earthquake
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- Part 3 : Construction
  - Chapter 1 : General
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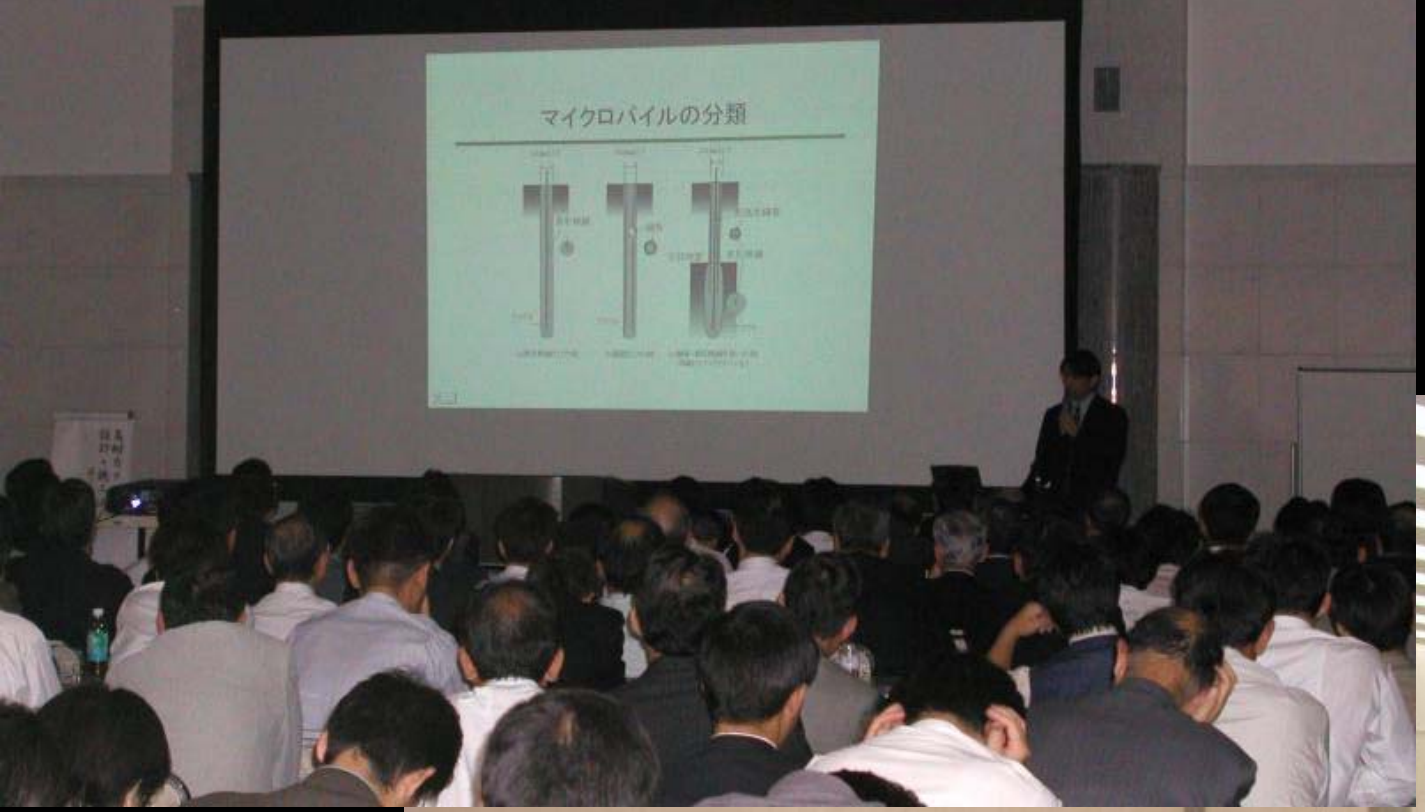
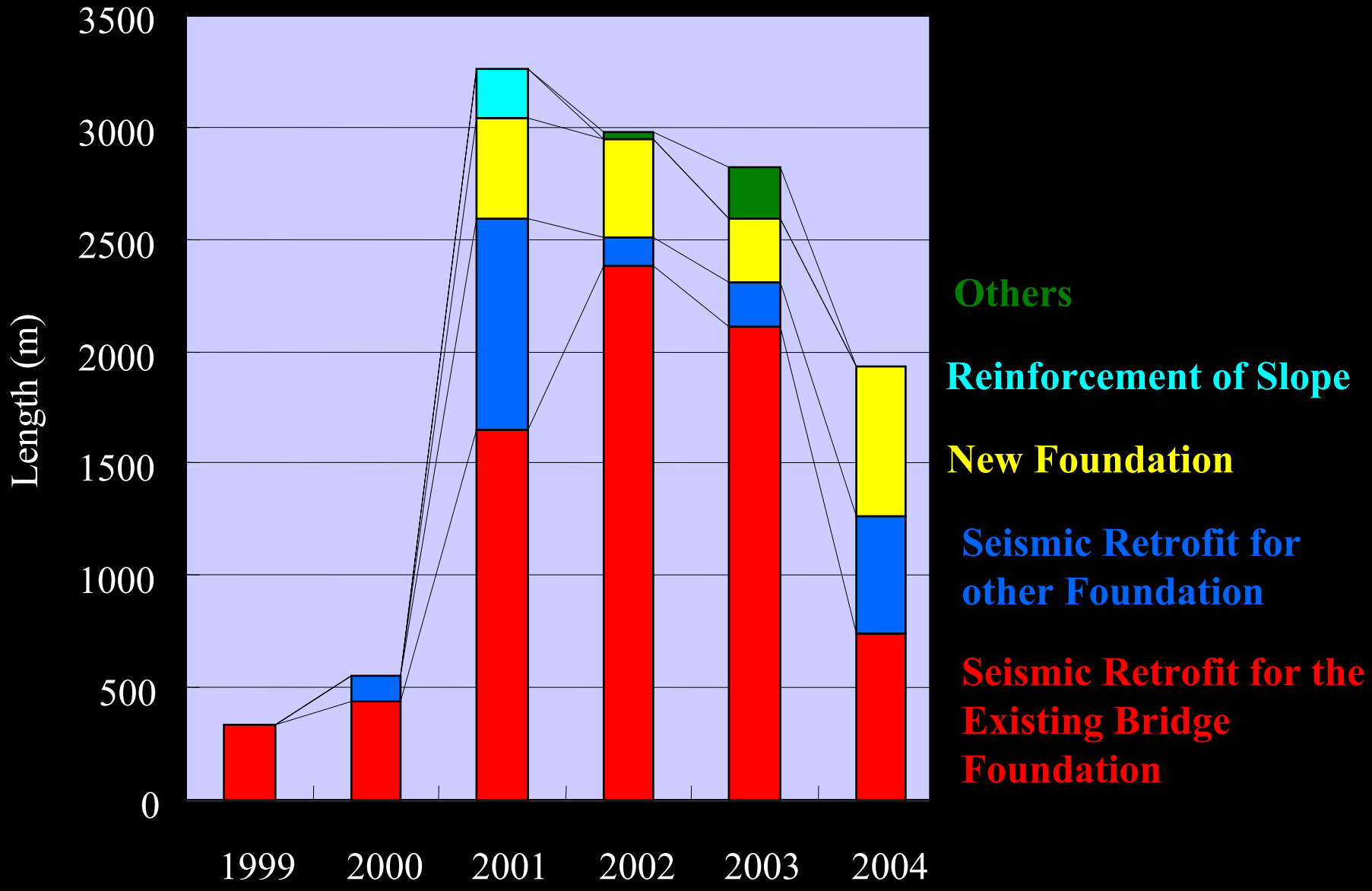
  - Chapter 3 : Quality Control & Quality Assurance



Lecture on the Design & Construction Manual

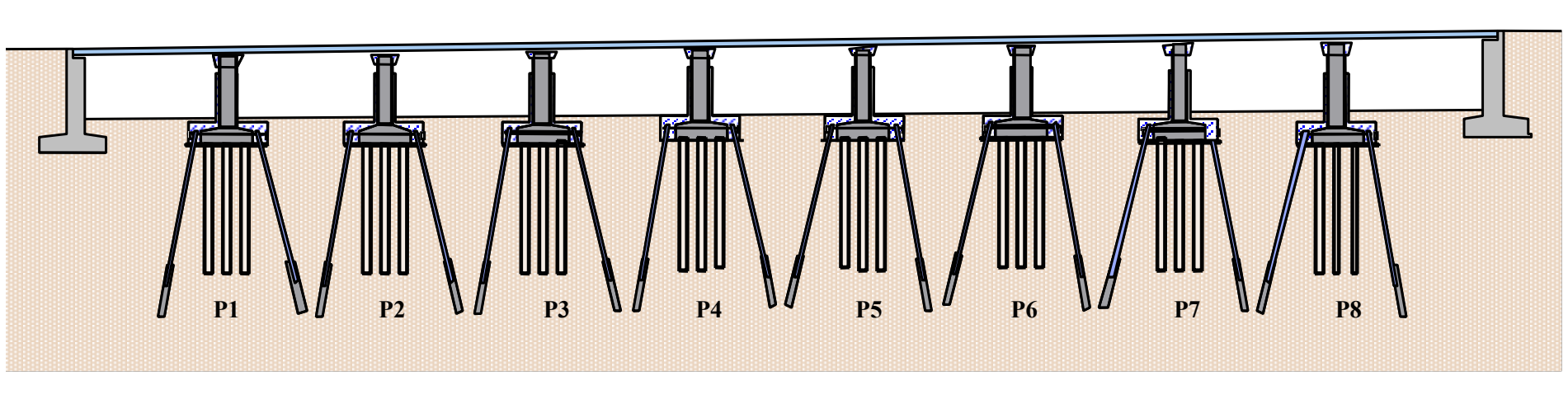
Topics

1. Introduction (Background of Research)
2. Joint Research
   A) Model test 1(horizontal loading tests of group piles)
   B) Static analysis for group piles (simulation analyses for the horizontal loading tests)
   C) Model test 2 (shaking table test of group piles)
3. Construction examples in Japan
4. Development in the future
5. Conclusion



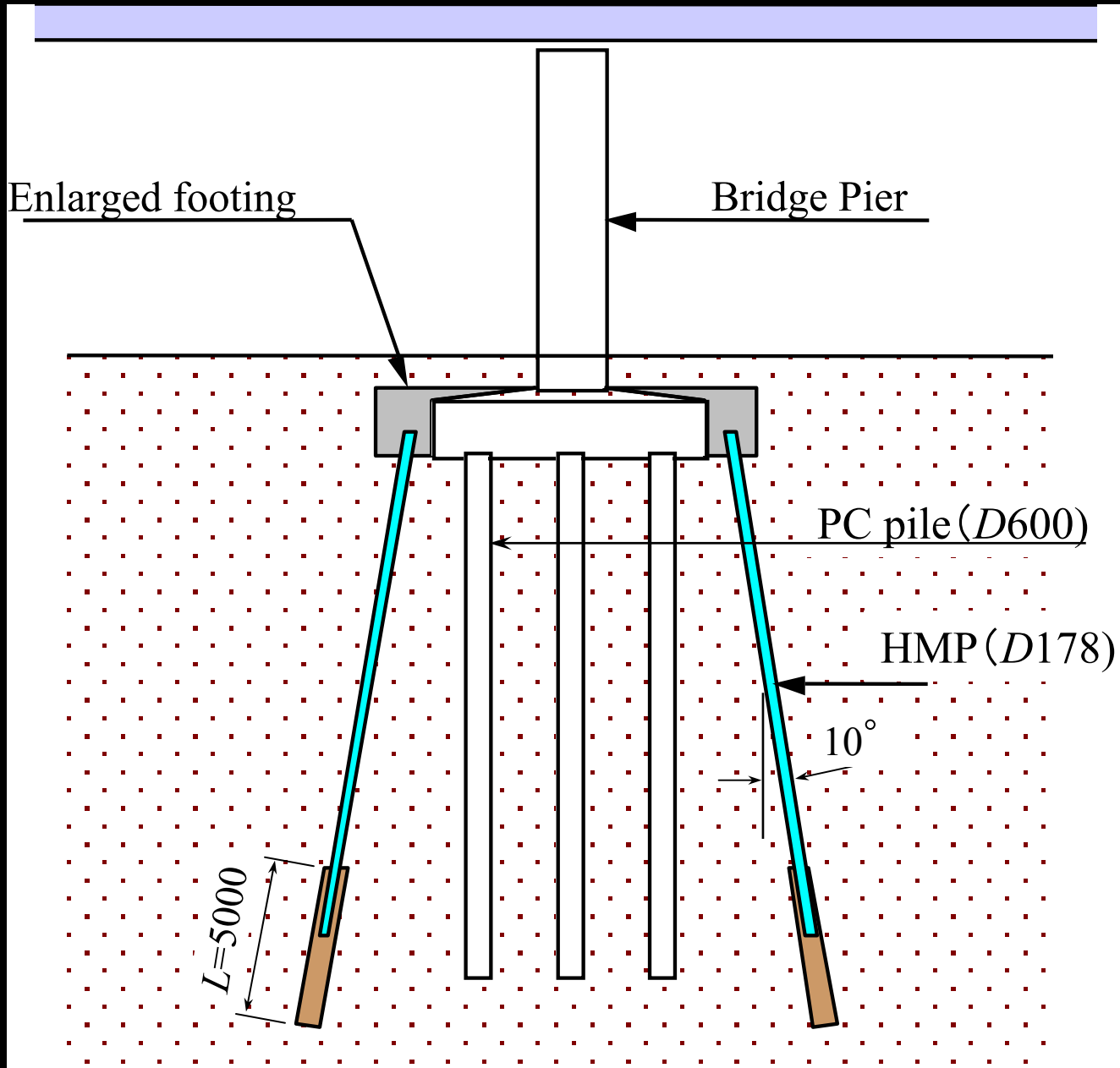
Application of HMP

Construction Example 1 (Highway Bridge)



Name of Bridge : RYUSENJI Viaduct
Construction period : Oct., 2001 - Mar., 2003
Number of micropiles : 95 piles (L=12.8 - 14.3m)
Total length of micropiles : 2418m

Construction Example 1 (Highway Bridge)



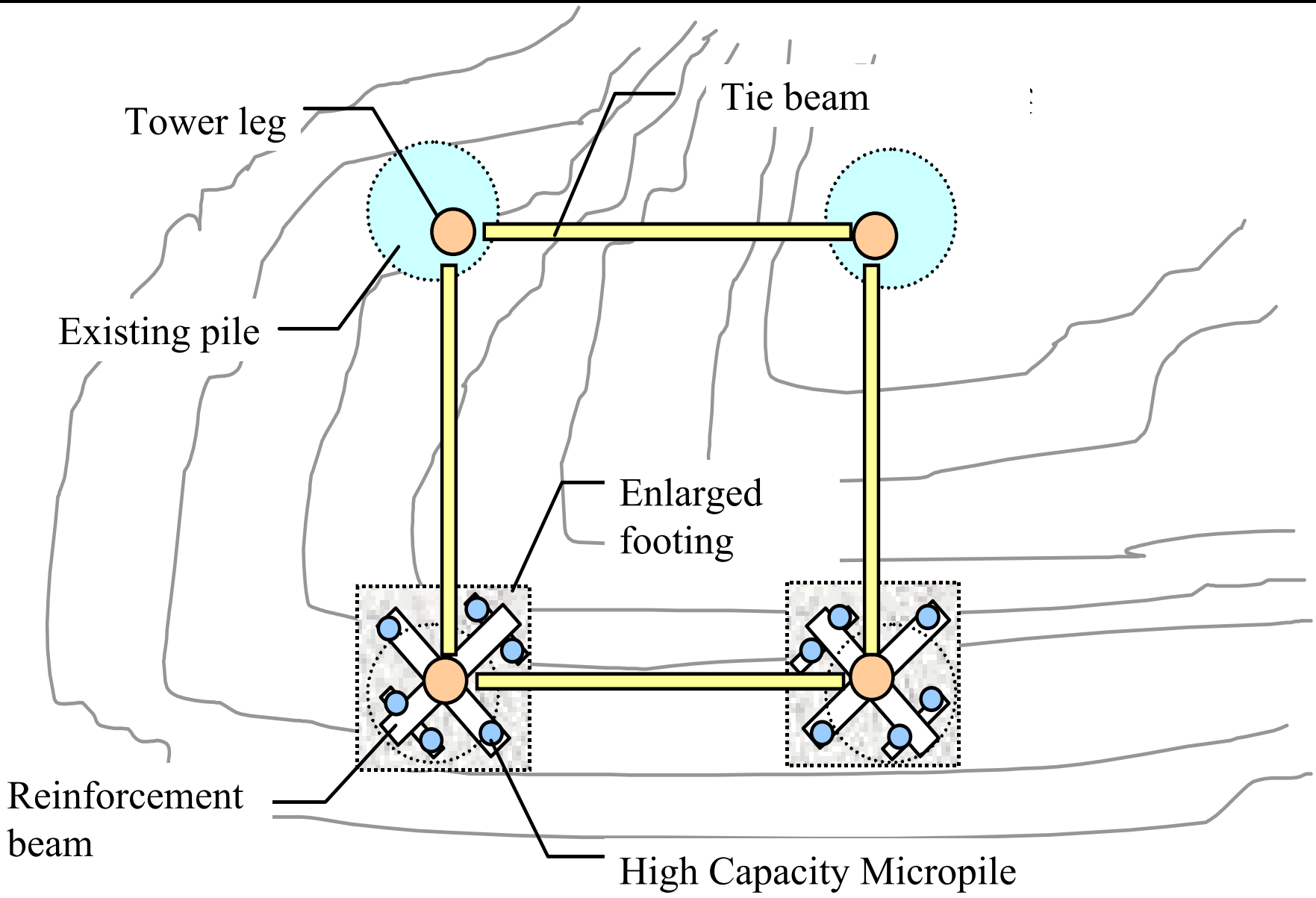
Construction Example 1 (Highway Bridge)

Construction Example 1 (Highway Bridge)

Construction Example 2 (Electric Pylon)

Construction Example 2 (Electric Pylon)

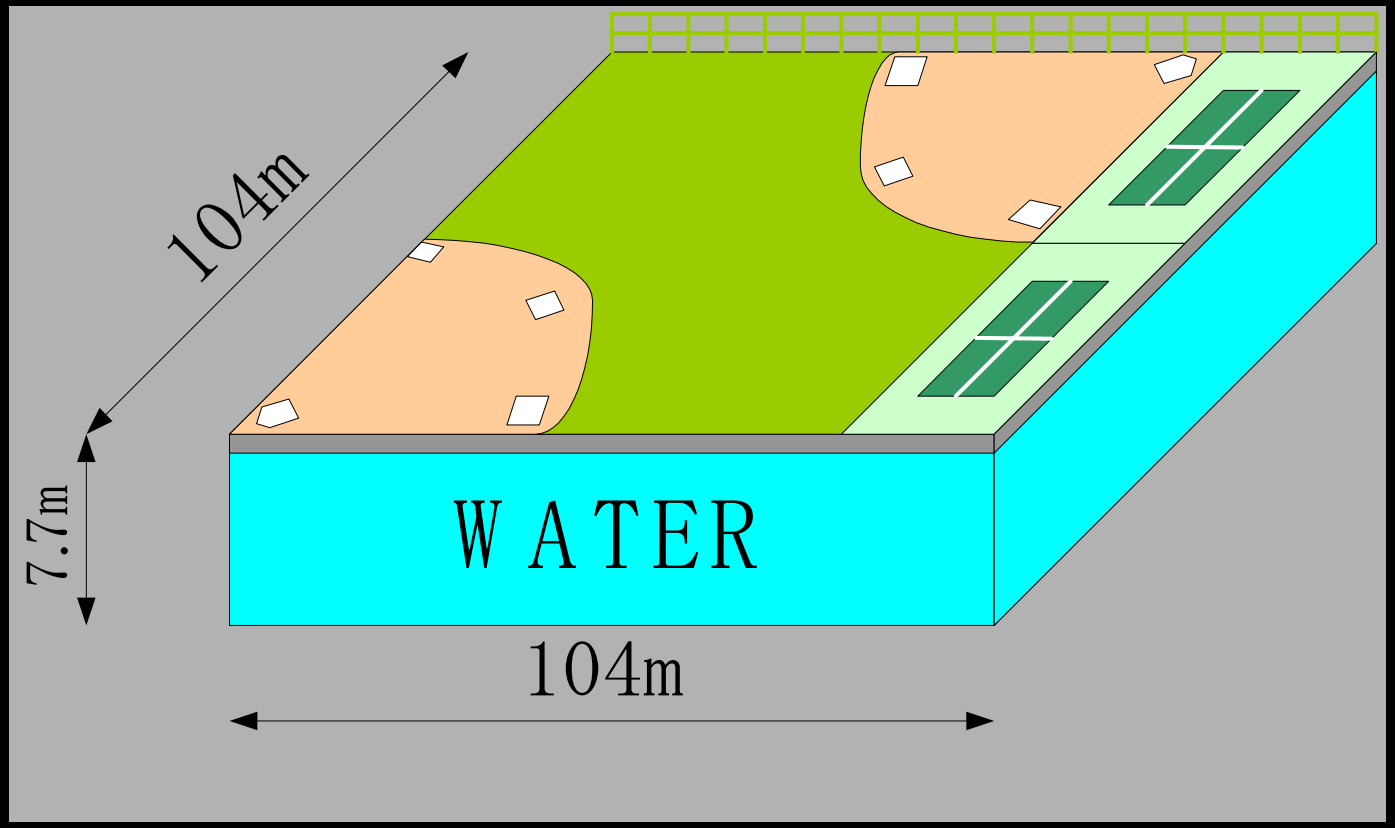
Construction Example 2 (Electric Pylon)



Construction Example 2 (Electric Pylon)

Construction Example 3 (Water service plant)

Construction Example 3 (Water service plant)



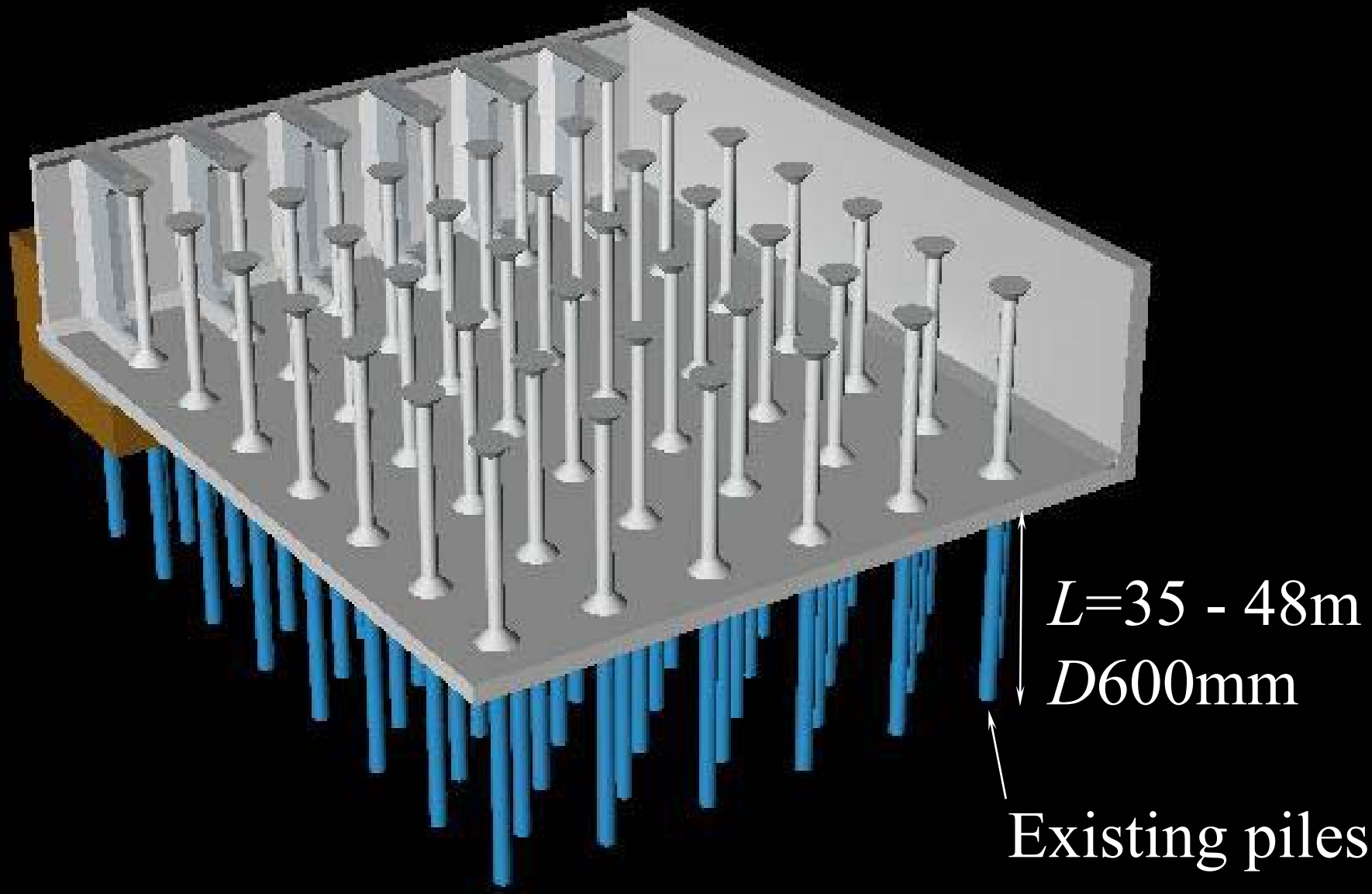
Name of plant : Kameido Water service plant

height : 7.7m

Width : 104m x 104m

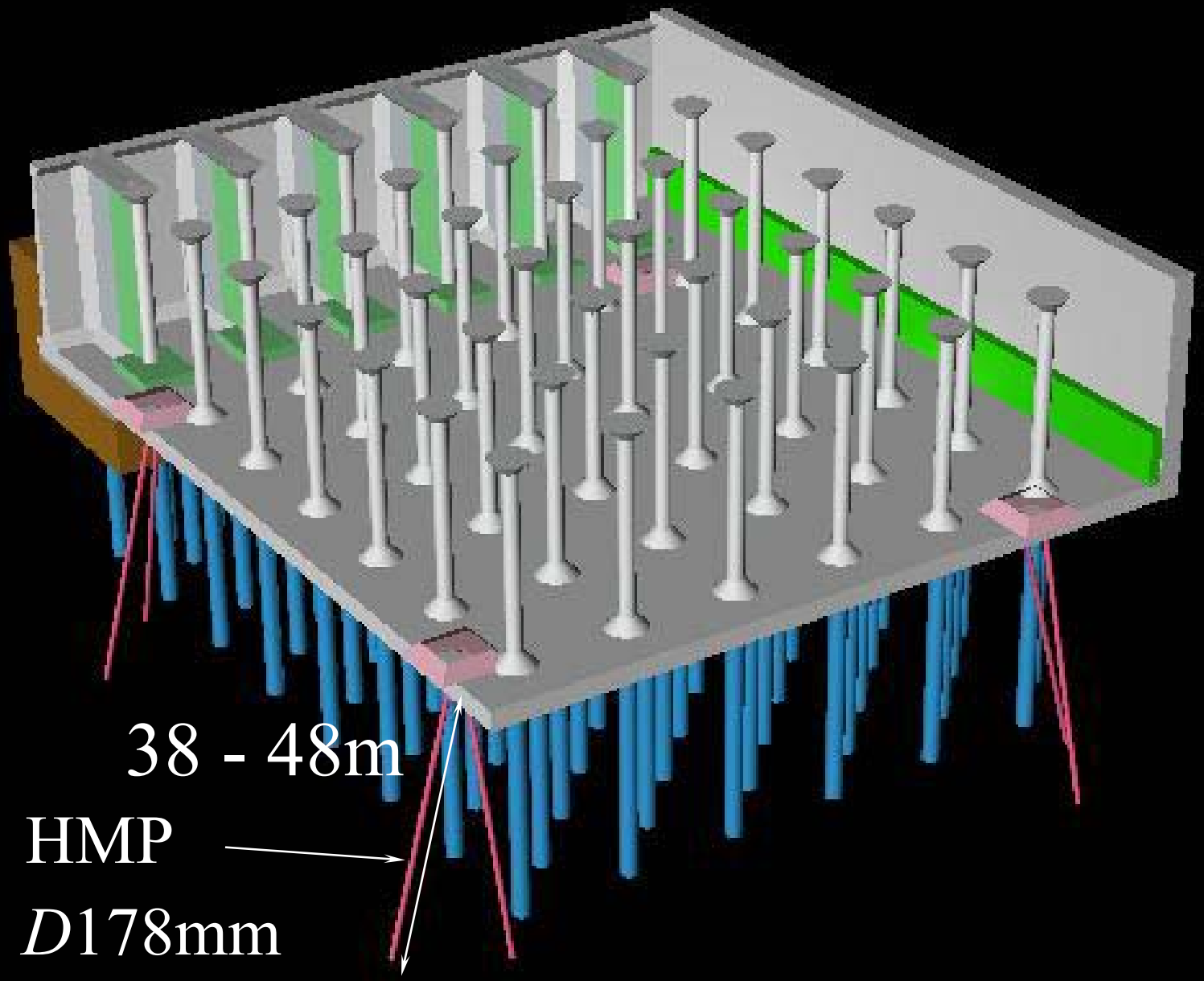
Volume : 60,000m^3

Construction Example 3 (Water service plant)



- The number of existing piles are 1696.

Construction Example 3 (Water service plant)



Construction Example 3 (Water service plant)

Construction Example 3 (Water service plant)

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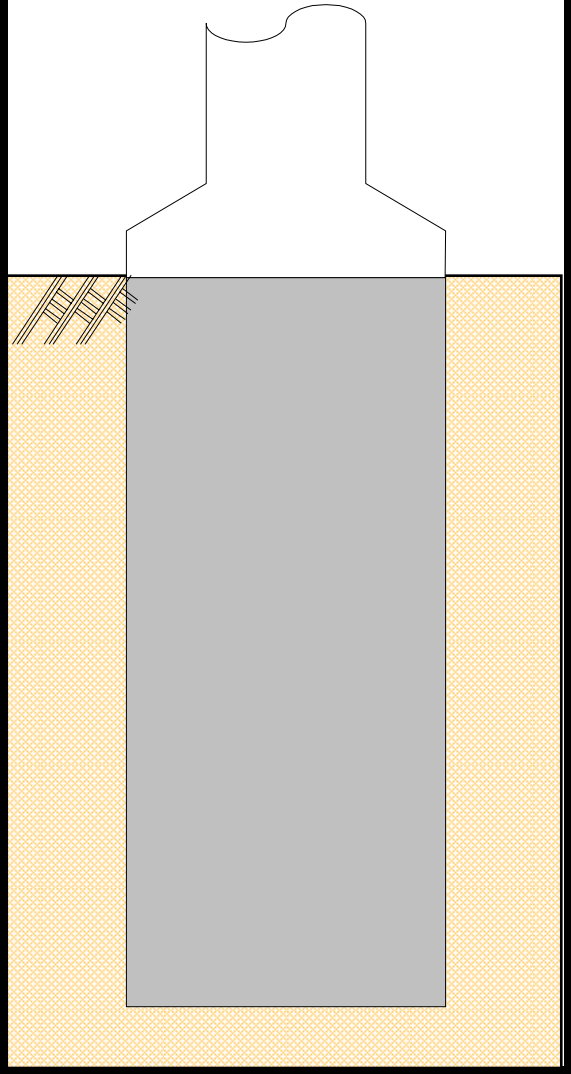
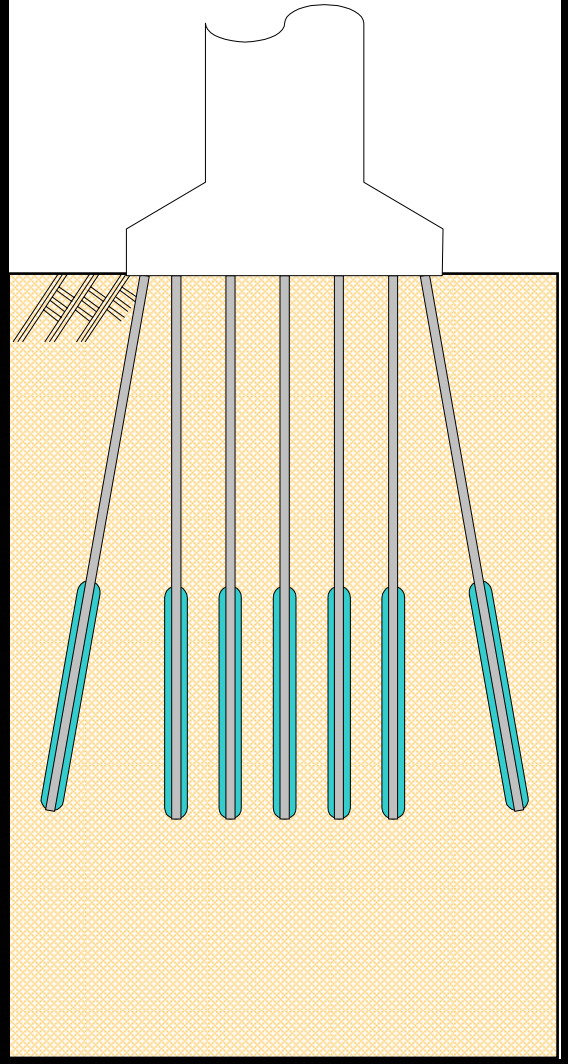


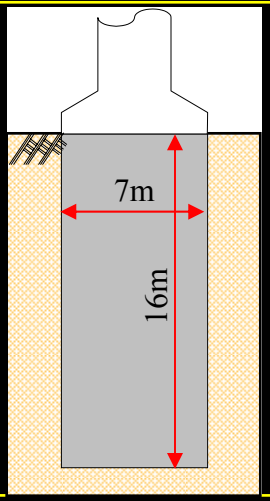
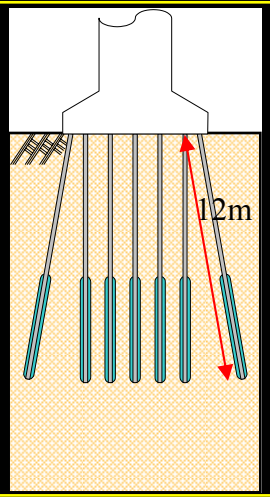
Caisson Type Pile



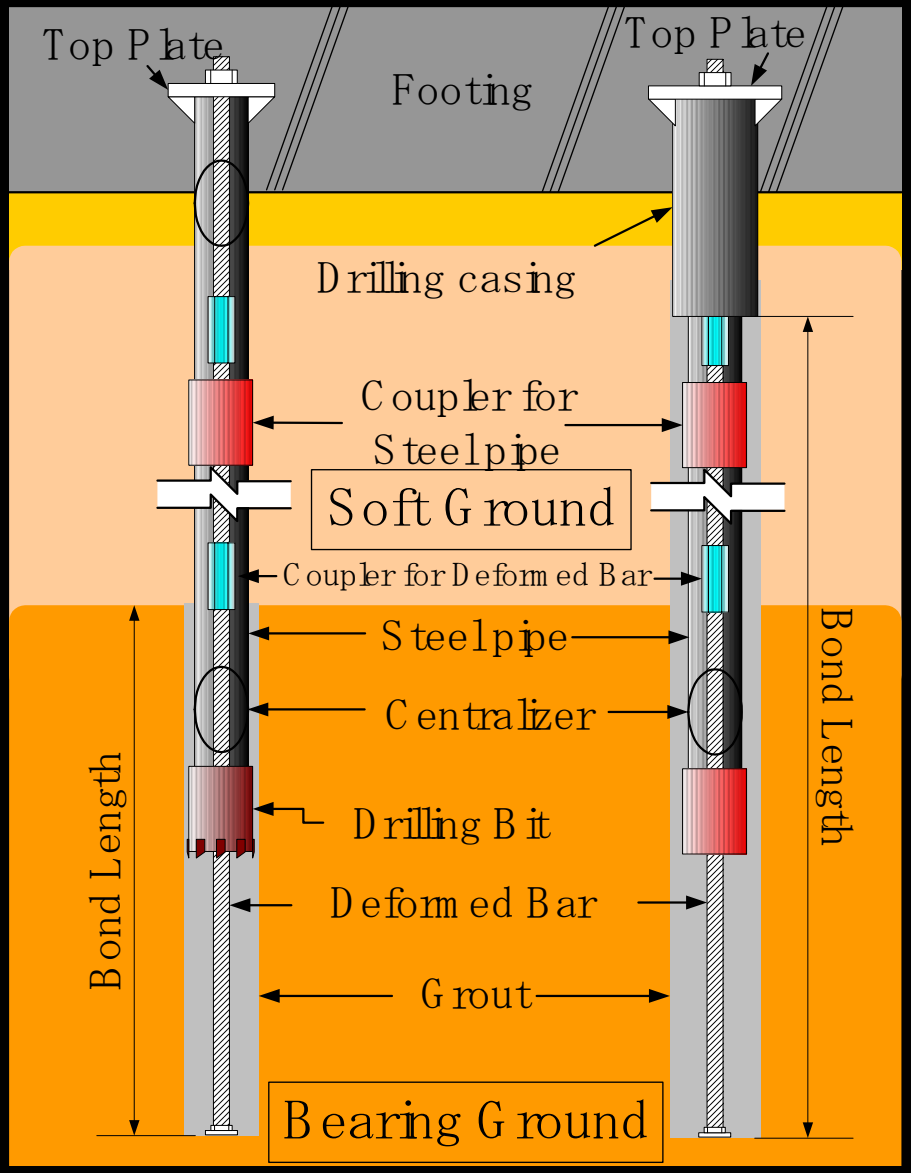
Micropile

Application of new Foundation

Effect when HMP is applied to new foundation

		Caisson Type Pile	Micropile
Structure			
		Φ7m@16m @1 piece	Φ0.17m@12m @49 pieces
Amount of digging(m^3)		615	115
Economy	materials	39%	43%(+4%)
	labor	43%	21%(-22%)
	machine	6%	22%(+16%)
	incidental facilities	12%	4%(-8%)
	Total	100%	90%(-10%)

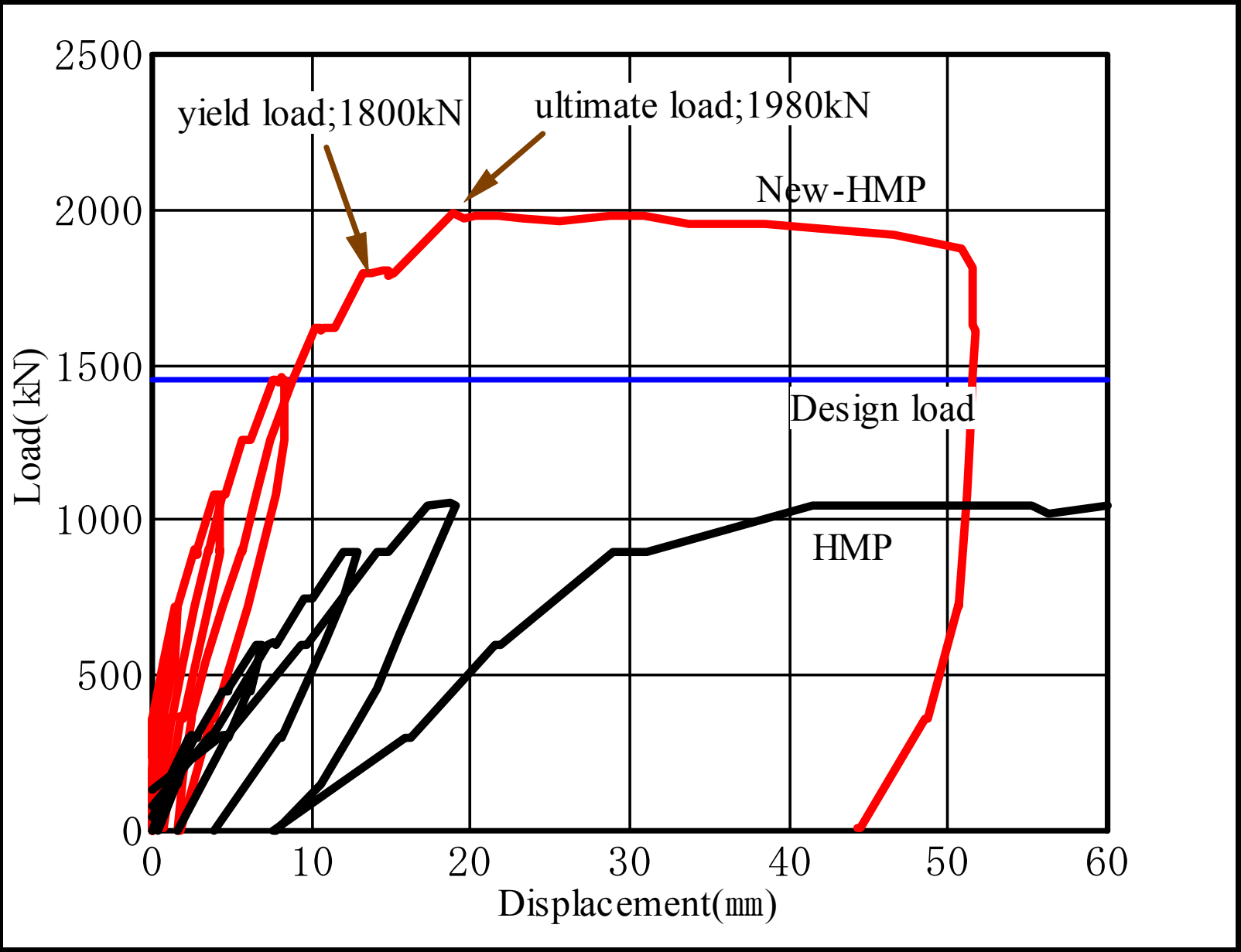
Improvement of HMP



Standard New Type

- New Type HMP
  - Diameters are larger than standard HMP.
  - Total length is a bond length.

Pull-out test of new type HMP



Pull-out test of new type HMP

Application of NEW-HMP for Overpass

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Award of excellent new civil engineering technology (2005.7.20)

Thank you for your kind attention!!