New foundations in Japan and recent pile researches in Kyoto University

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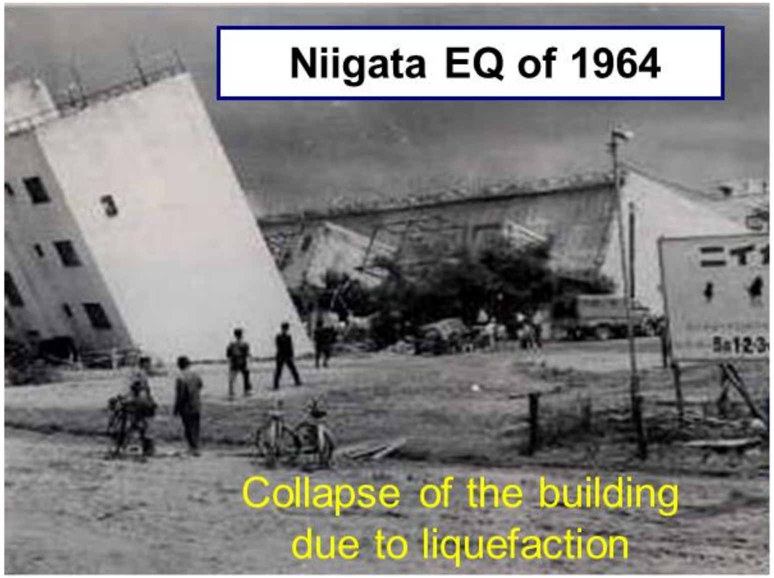
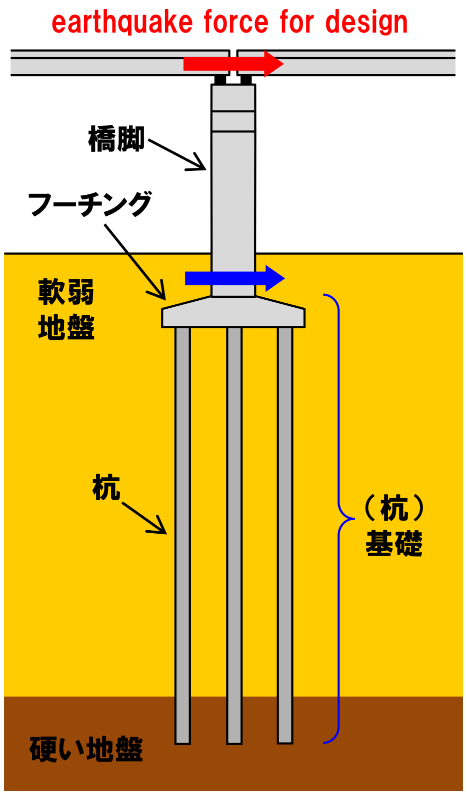


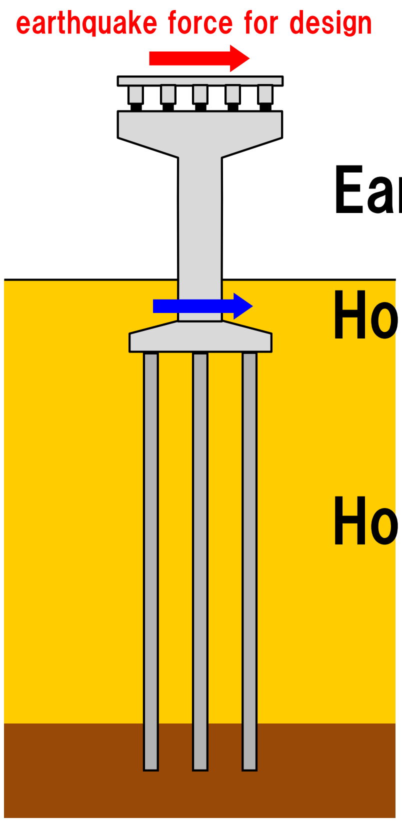
Contents

- Japanese design ideas of road bridge foundations
- New pile foundation in Japan
- Investigation of mechanical behavior of pile group

Seismic design for pier and foundation



路線直角方向から見た図



路線方向から見た図

Basic idea
for seismic design

Earthquake force for design

∧

Horizontal bearing capacity on pier

∧

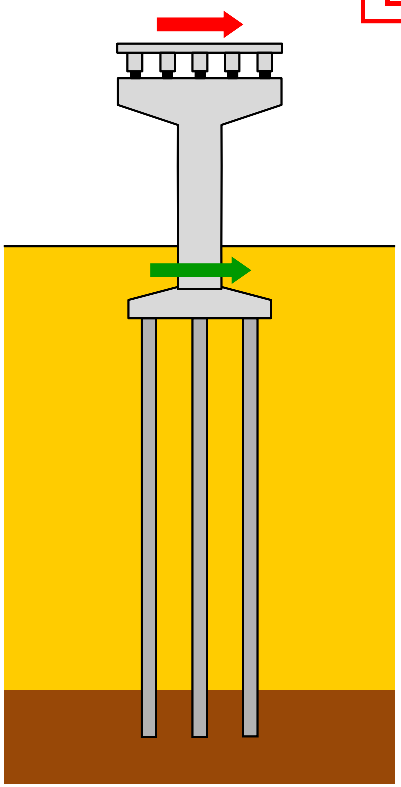
Horizontal bearing capacity on foundation

↓

No foundation failure

Needs of seismic reinforcement for existing foundations

Reinforcement for existing foundations



After Kobe earthquake

Earthquake force for design — Increase

∧

Stiffness of pier — Reinforcement of pier

∧

Horizontal bearing capacity on foundation — Reinforcement of foundation

Pandora's box

Advancement of numerical method

Combined calculation for upper structure and foundation

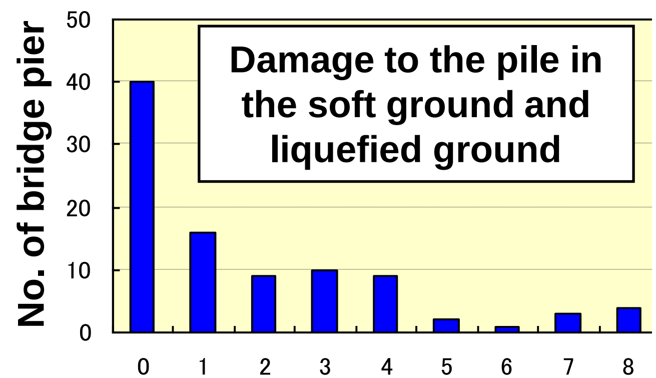
Needs of seismic reinforcement for existing foundations

Plastic deformation caused by the earthquake disaster

The Southern Hyogo prefecture EQ in 1995

Cracks generated in piles

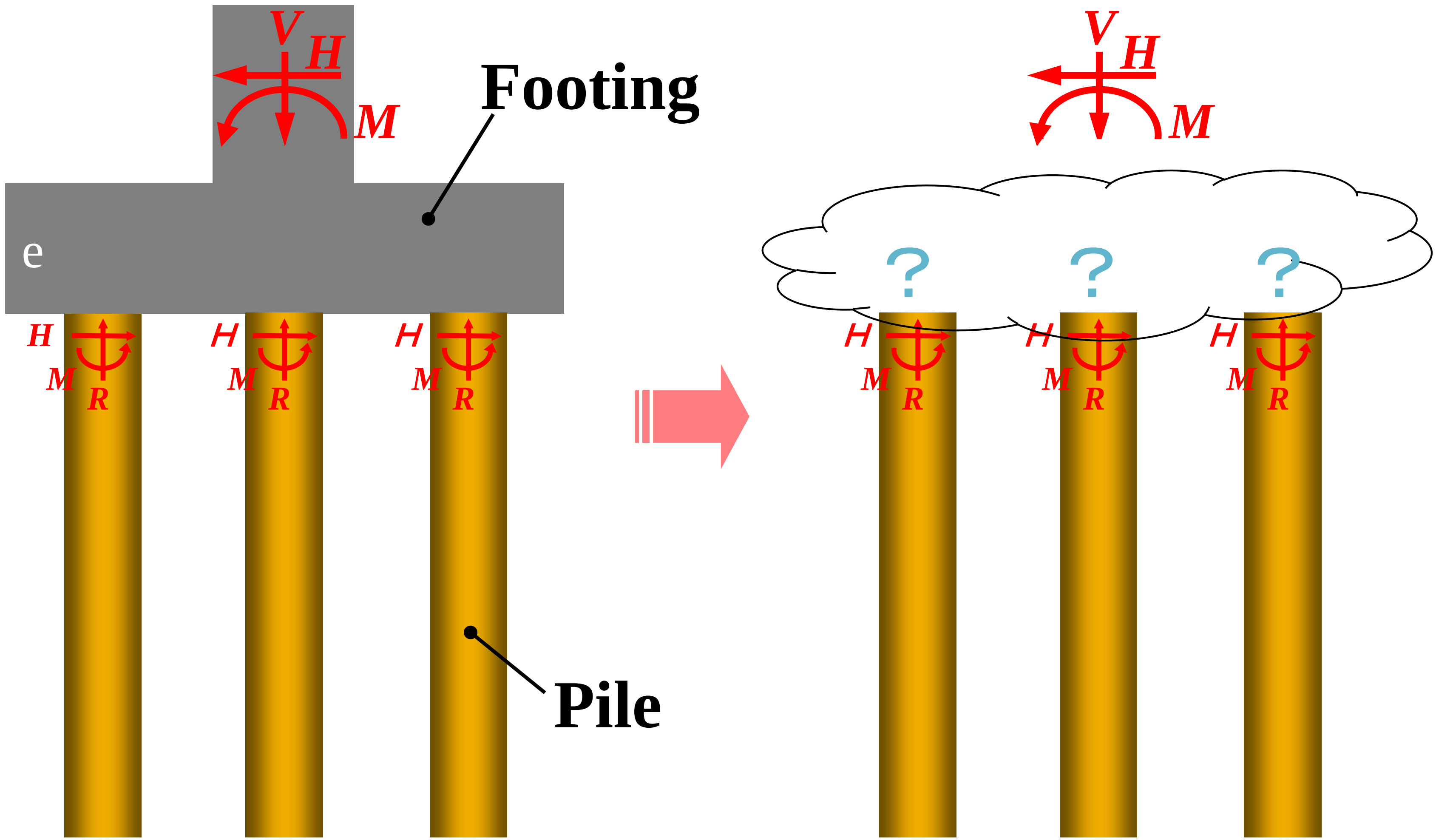
The 2011 off the Pacific coast of Tohoku EQ



Cumulative No. of pile damage found by the bore-hole camera investigation

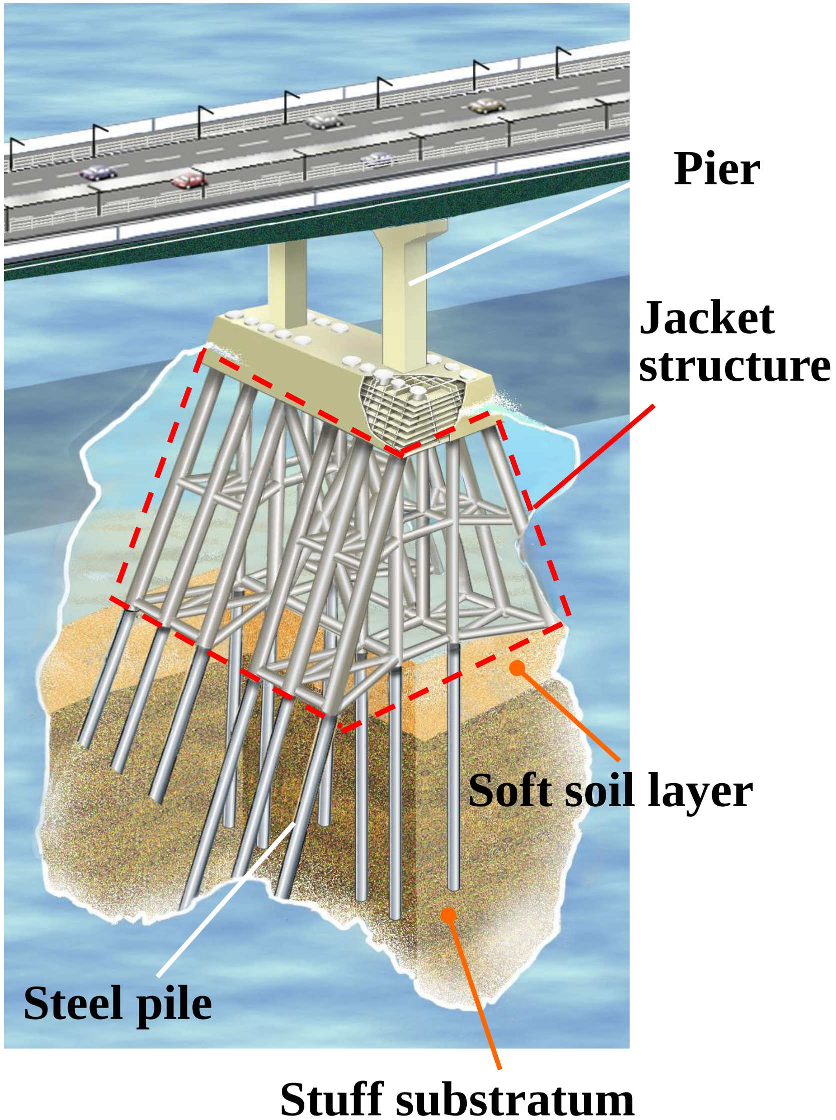
Based on the reports of restoration for foundation structures of Kobe line #3 by Hanshin Expressway

Why do we design a footing?



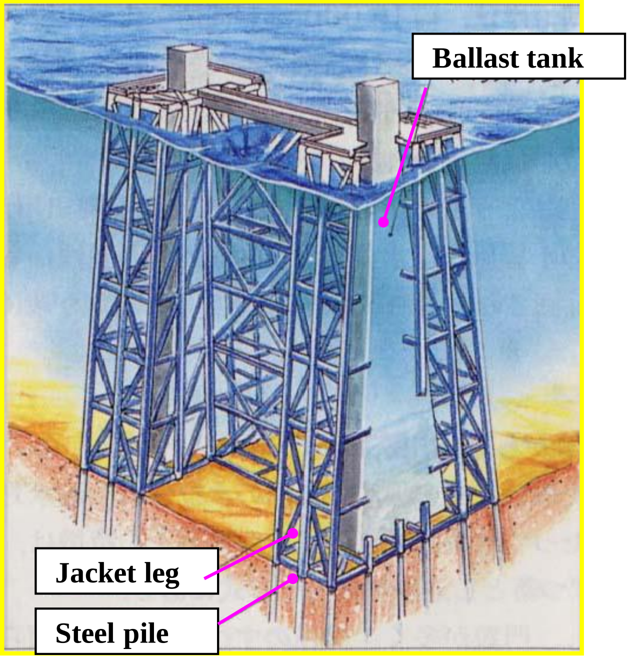
JACKET FOUNDATION WITH INCLINED PILES

Offshore pile foundations for roads

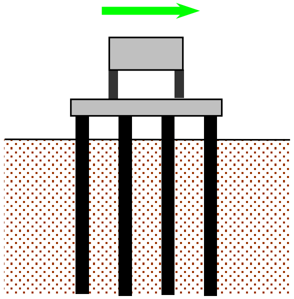


- **Jacket steel pile foundation with inclined piles**

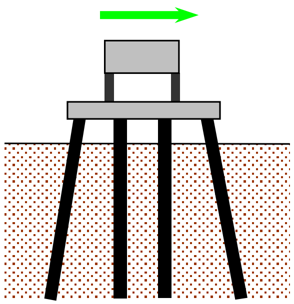
Not so heavy



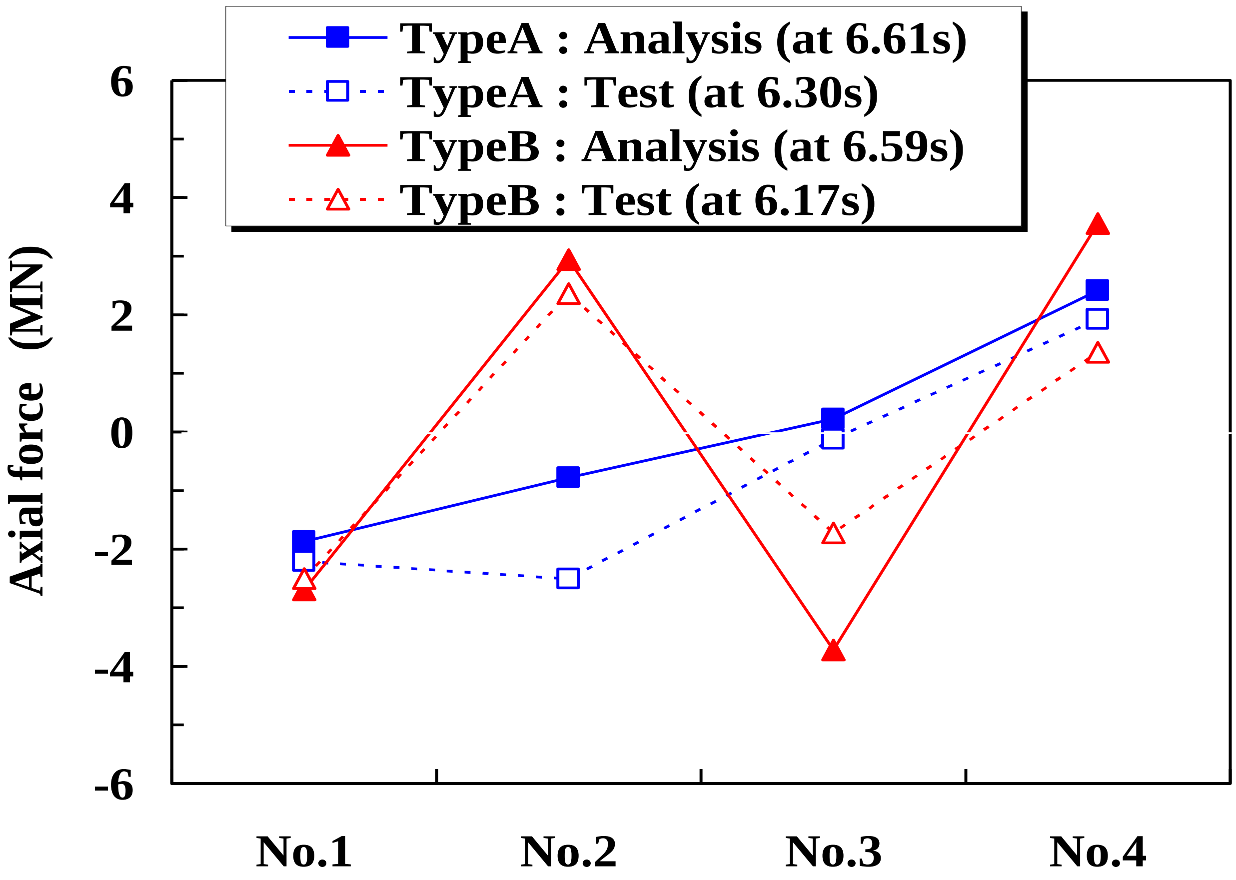
AXIAL LOAD DISTRIBUTION(STATIC)



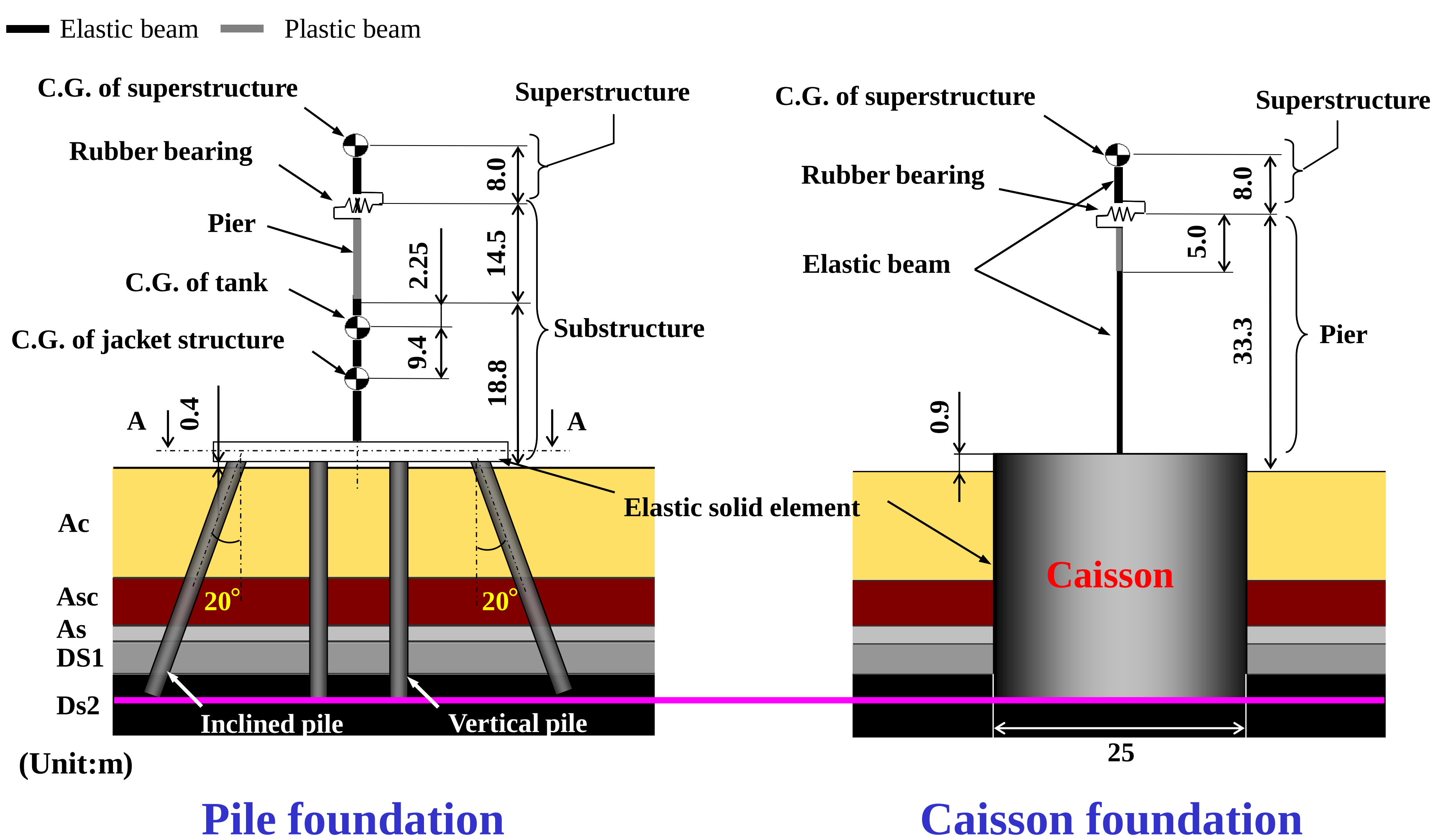
Type A



Type B



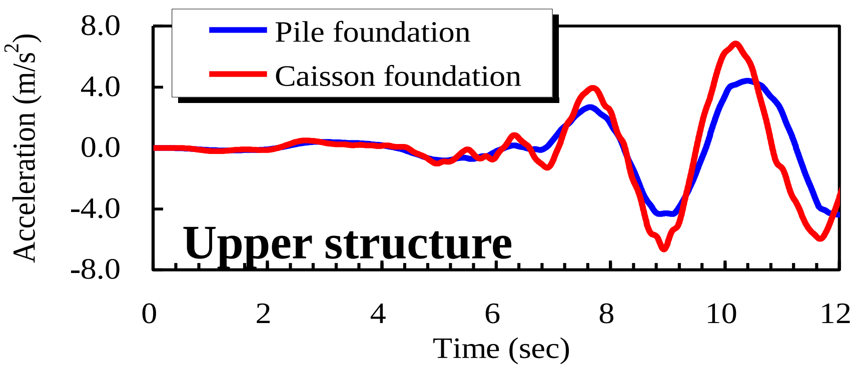
Pile foundation and caisson foundation

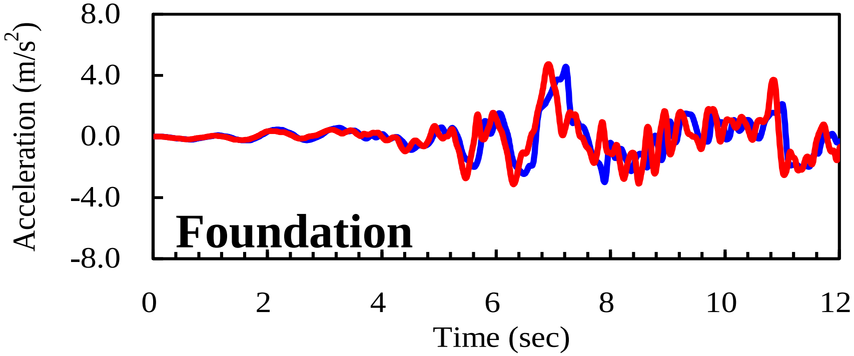


＜Remarks＞ C.G.: Center of gravity

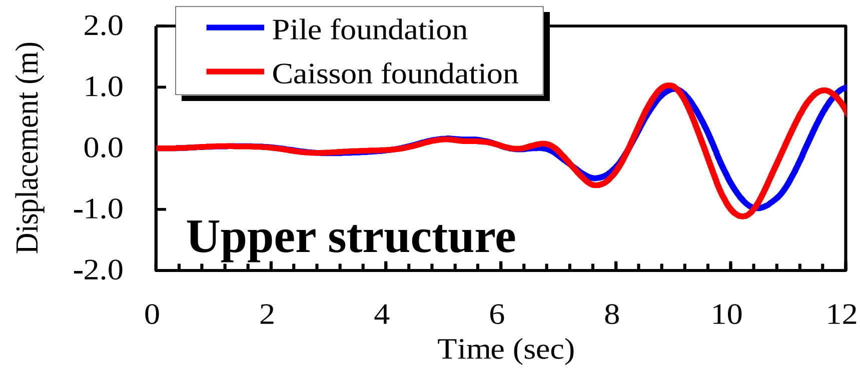
Response for acceleration and displacement

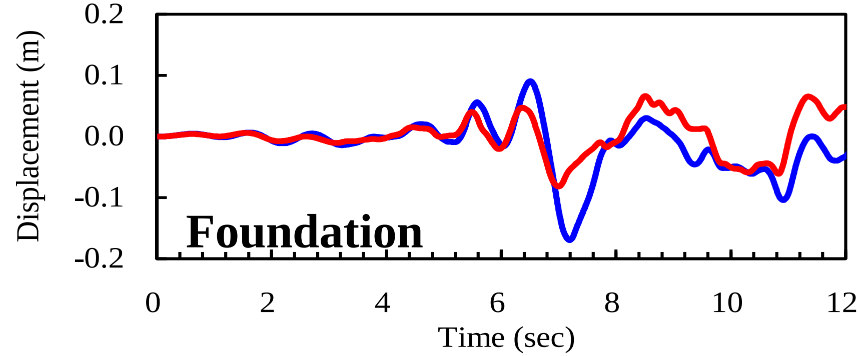
Acceleration





Displacement



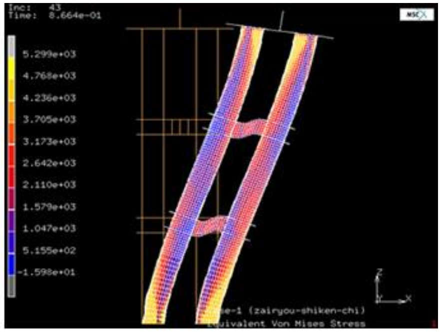


Shaking table test and numerical simulation on seismic performance of a bridge column integrated by multiple steel pipes with directly-connected piles

Koichi Isobe (Hokkaido University)
H. Sugiyama, M. Shinohara, H. Kobayashi (Hanshin Expressway)
Y. Sawamura, Y. Mitsuyoshi, M. Kimura (Kyoto University)

Introduction

□Development of "Integrated column by multiple steel pipes" (2004)



- A bridge column integrated by 4 steel pipes and multiple shear panels interconnecting the pipes has been proposed.
- It is designed based on damage control concept, in which the vertical load is supported by the steel pipes and the lateral load is adjunctively supported by shear links.
- Shear panels are made of low yield stress steel and have hysteretic energy dissipation properties.
- It intends to lead seismic damage into shear panels and enables early recovery by replacing only panels.

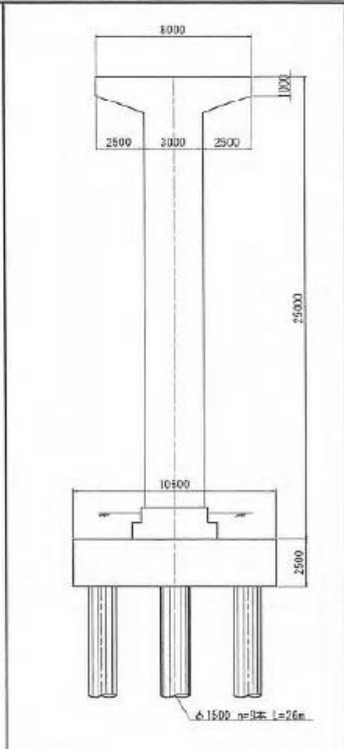
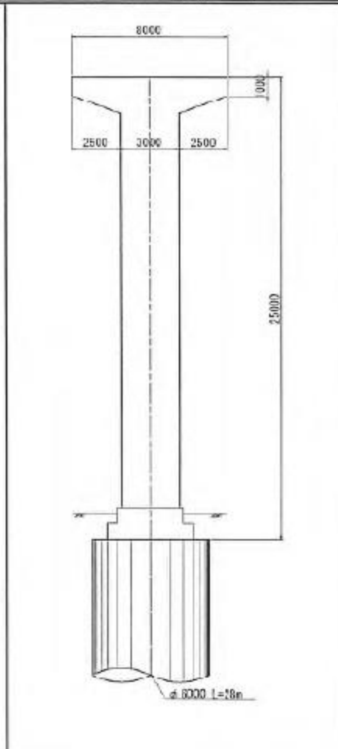
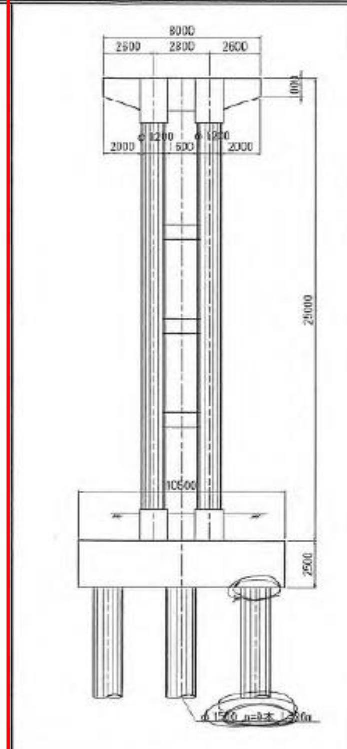
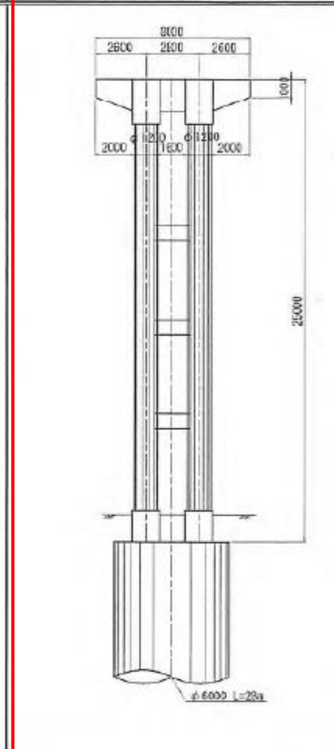
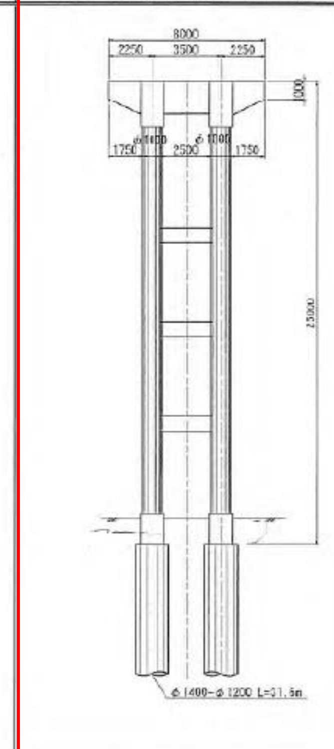
Introduction

□Development of "Integrated column by multiple steel pipes" (2004)

NO Anchor frame

- Budget-pleasing prefabricated material (ready-made spiral steel pipes) are used.
- Anchor frame is NOT necessary unlike a conventional steel pier structure.
- Reduce 30% of construction cost
- Reduce construction time
- Rapid transportation open

Cost analysis

	鋼製橋脚	鋼製橋脚	鋼管集成橋脚	鋼管集成橋脚	鋼管集成橋脚
	場所打ち杭（φ1500×9本）	ケーソン基礎（φ6000）	場所打ち杭（φ1500×9本）	ケーソン基礎（φ6000）	パイルベント基礎（φ1400−1200×4本）
構造図					
工事金額 橋脚	86,800 （千円）	86,800 （千円）	64,000 （千円）	64,000 （千円）	47,250 （千円）
工事金額 基礎工	40,030 （千円）	62,330 （千円）	40,030 （千円）	62,330 （千円）	34,600 （千円）
工事金額 合計	126,830 （千円）	149,130 （千円）	104,030 （千円）	126,330 （千円）	[illegible]1,850 （千円）
比率	[illegible]	(1.82)	(1.27)	[illegible]	[illegible]
比率	(1.0[illegible])	(1.1[illegible])	(0.8[illegible])	([illegible]0)	(0.[illegible]5)
備考					柱−杭接合工費は除く

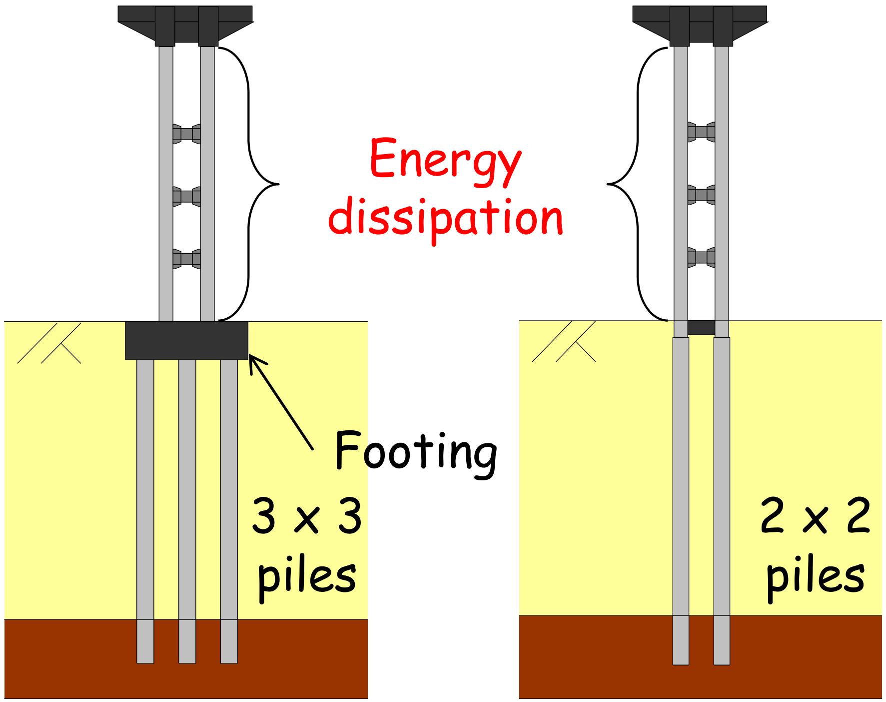
1.00 1.18 0.82 1.00 0.65

Pile group

Integrated column by multiple steel pipes

Introduction

☐Proposal of "Steel pipe pile foundation" for integrated column



Conventional
GP foundation with Footing

Way-out
Directly connected without Footing

- Each pipe of the column is supported by a directly connected steel pile without a footing
- Maybe rational & reasonable foundation structure for "A bridge column integrated column by multiple steel pipes"
- Not impair the ability of the integrated column structure
- Reduce inertia force and sectional force at the connected area between piles and column
- Reduce the cost of footing and the number of piles
- Can employ the pile foundation in narrow construction conditions

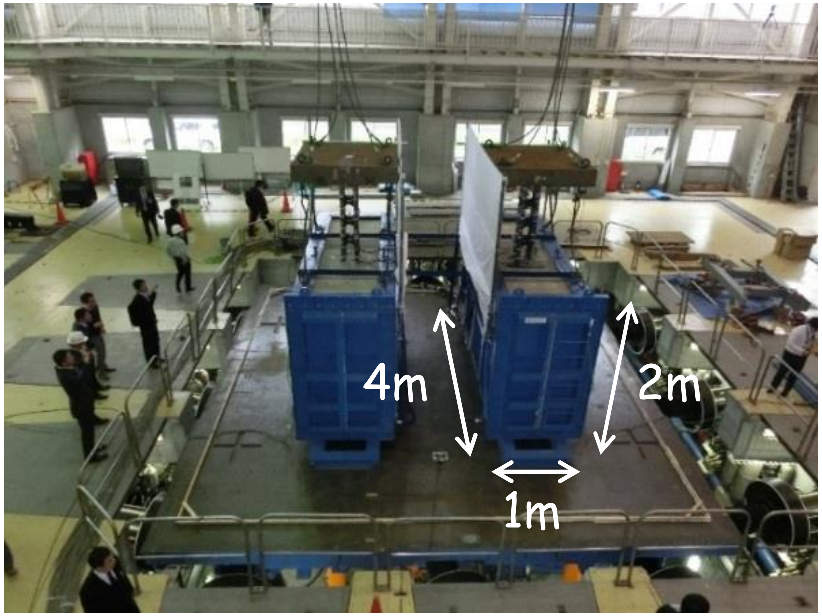
Purpose of Study

□Shaking table test and Numerical simulation

- To compare the both seismic performance (footing type vs footing-less type)
  - Axial force acting at pile heads
  - Lateral displacement at a pier top and pile heads
  - Cross sectional force acting in a bridge column and piles
- To confirm the yield order of the member for the proposed structure
- To check the behavior of the proposed structure in liquefiable sand
- To identify the structural issues of the proposed type
- To cross-check analytical model by simulating the model tests

Outline of Shaking table test

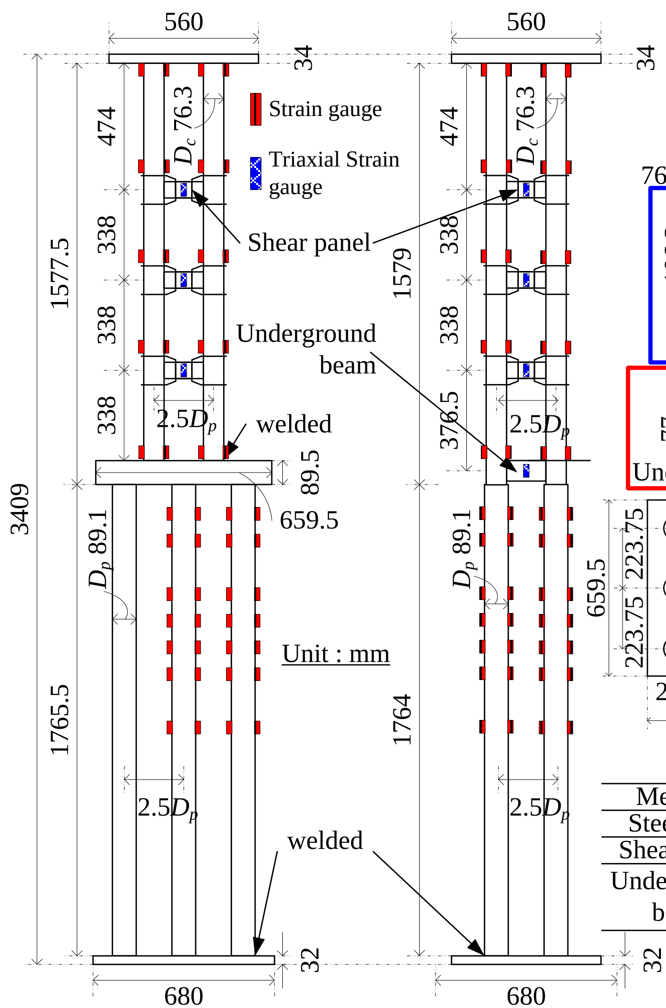
□Shaking table and Large-scale rigid box with tempered glass



- Public Works Research Institute in Tsukuba
- Large-scale 3-dimensional shaking table
- Table size: 8m x 8m
- Box size: 4m (W) x 1m (L) x 2m (H)
- See the ground through the tempered glass

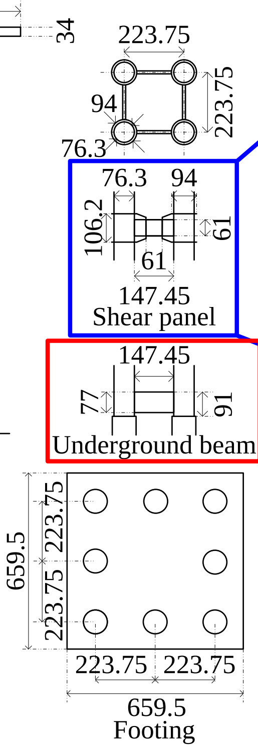
Outline of Shaking table test

□Detail of the model used in the tests



Footing type

Footing-less



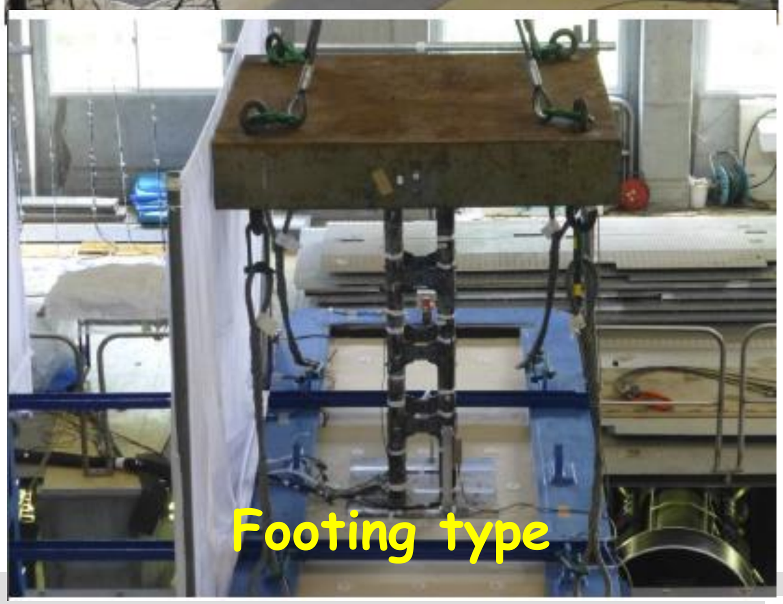
Member	Material
Steel pipe	STK400
Shear panel	LY225
Underground beam	SS400

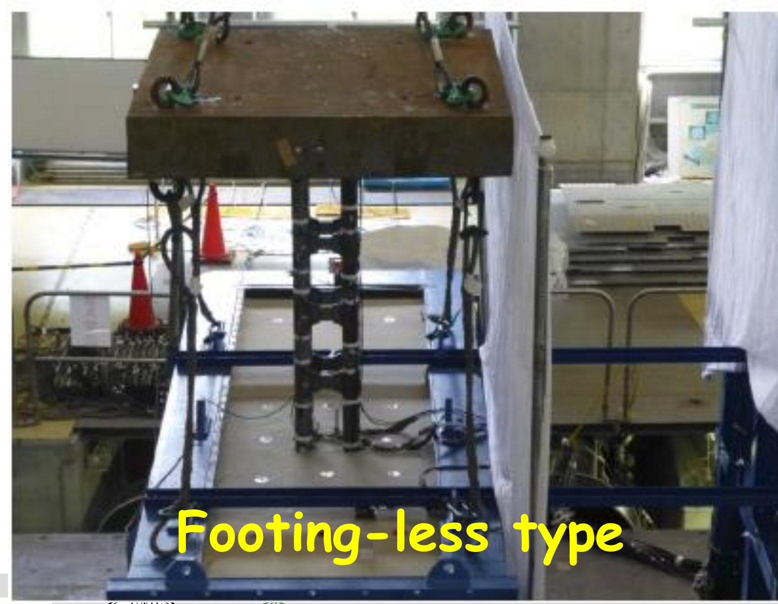
Shear panels

Underground beam

HOKKAIDO UNIVERSITY

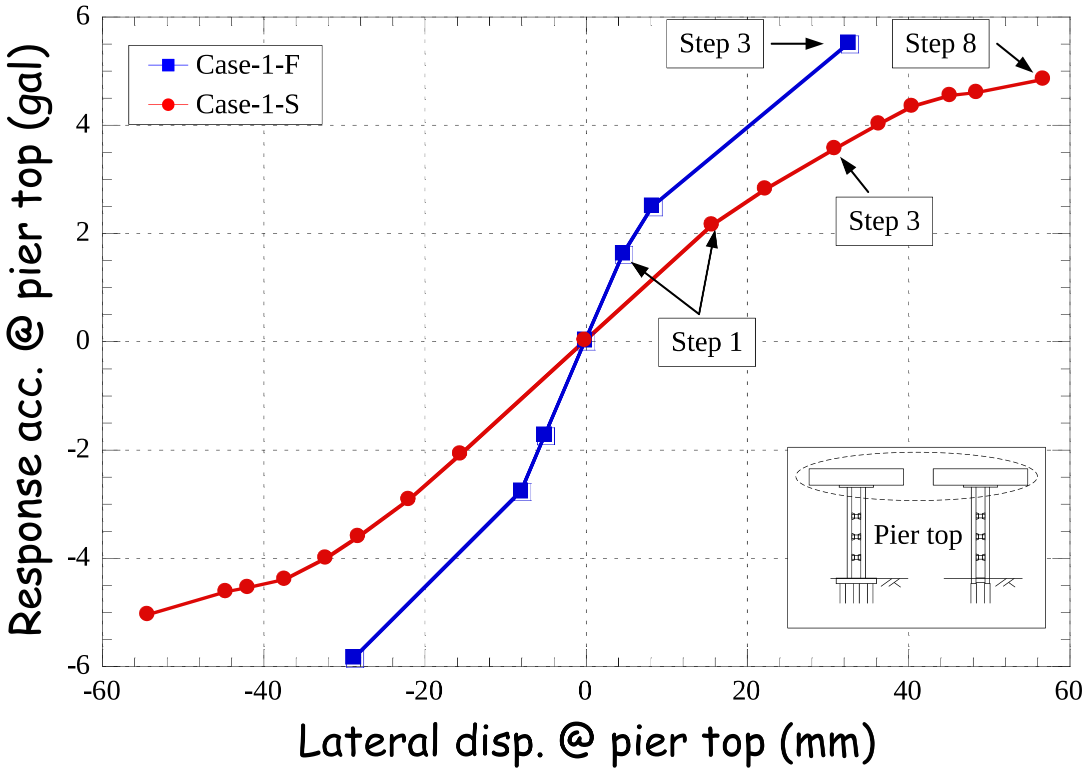
Outline of Shaking table test





Results of Shaking table test Dry sand

☐Response acceleration vs lateral displacement @ pier top

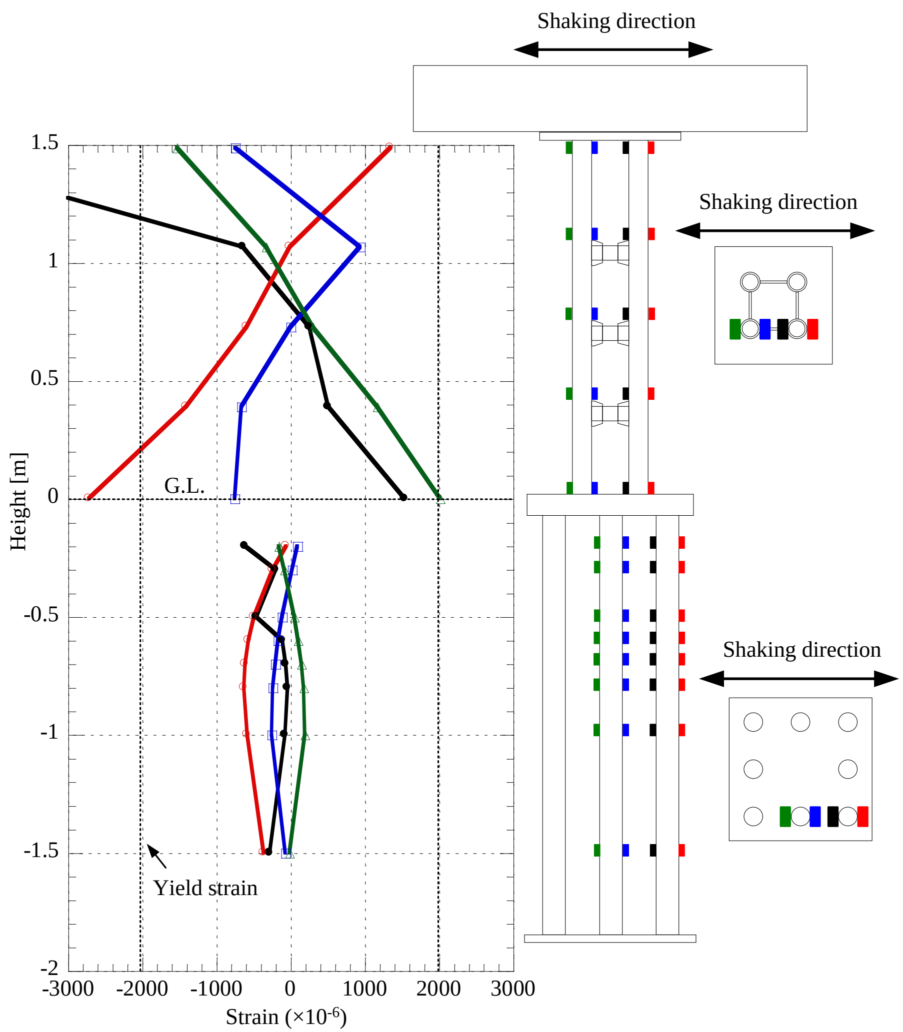


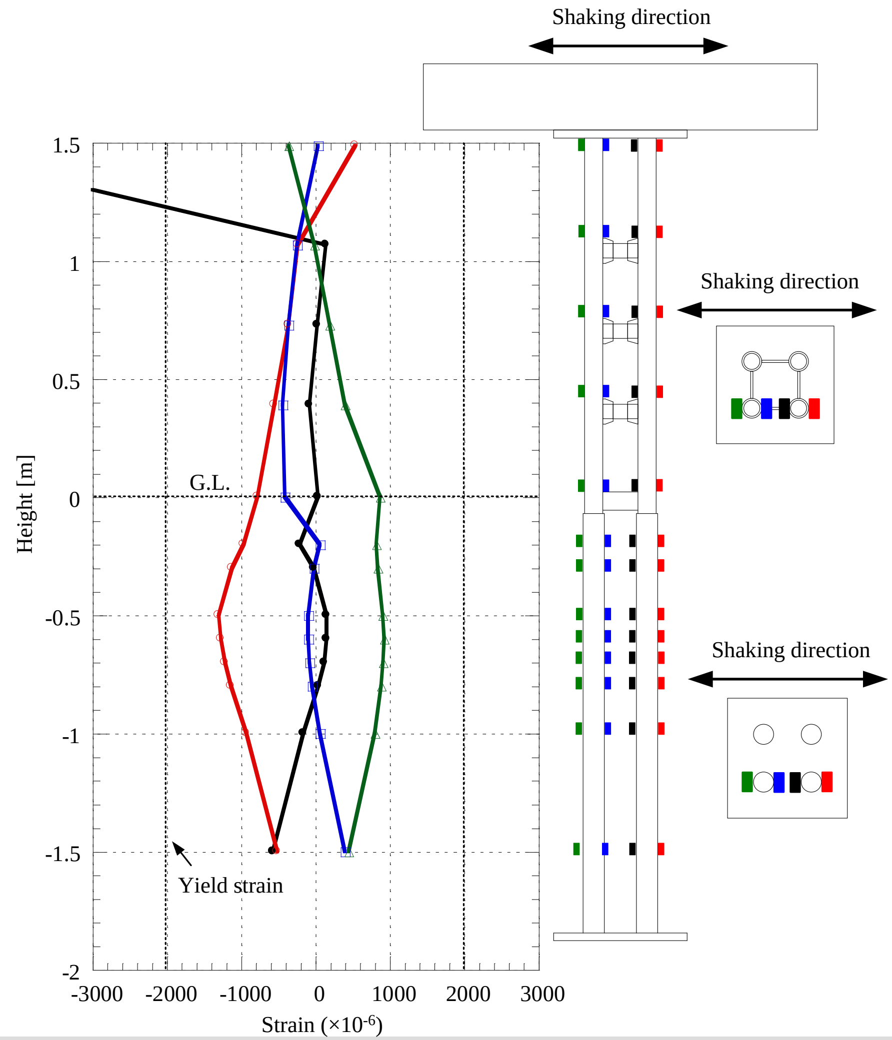
Input wave acc.
(1) 0.5 m/s²
(2) 1.0 m/s²
(3) 1.5 m/s²
(4) 2.0 m/s²
(5) 2.5 m/s²
(6) 3.0 m/s²
(7) 3.5 m/s²
(8) 5.0 m/s²

- The stiffness of Case-1-F (D-F) is bigger than that of Case-1-S (D-S).
- Case-1-F yields at earlier stage than Case-1-S.
- Response acceleration and lateral displacement for Case-1-F increase rapidly and brittle deformation is observed.

Results of Shaking table test

□Strain on the structure at Step 3





Results of Shaking table test

□Damage process of the member

	フーチングを有する杭基礎（Case-1-F）					杭基礎一体型 (Case-1-S)					
	せん断パネル			鋼管		せん断パネル			地中梁	鋼管	
加振No. (最大入力加速度)	上段	中段	下段	柱	杭	上段	中段	下段		柱	杭
第1加振 (0.5 m/sec^2)	(a)								(a)		
第2加振 (1.0 m/sec^2)	(b)										
第3加振 (1.5 m/sec^2)	(c)										
第4加振 (2.0 m/sec^2)											
第5加振 (2.5 m/sec^2)											
第6加振 (3.0 m/sec^2)											
第7加振 (3.5 m/sec^2)											
第8加振 (5.0 m/sec^2)									(b)		

せん断パネル: 弾性 / 塑性 / 面外変形

柱・杭（鋼管）: 弾性 / 塑性 / 塑性の可能性あり

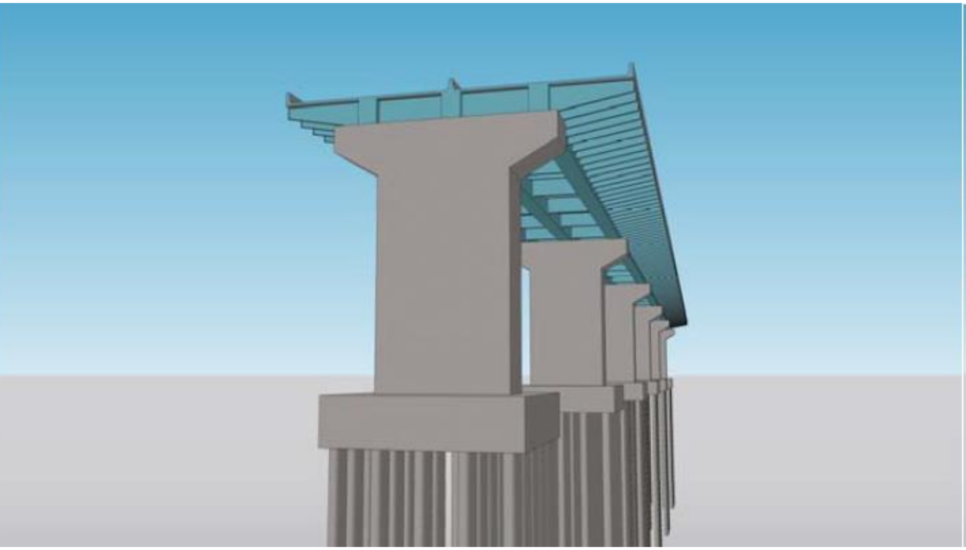
- The proposed substructure (Case-1-S) have advantages of strain reduction of column by strain descentralization at footing point.
- It has high seismic performance and high toughness if the conditions are right in view of the fact that the main member (columns and piles) holds a large residual strength after yielding of the shear panels.

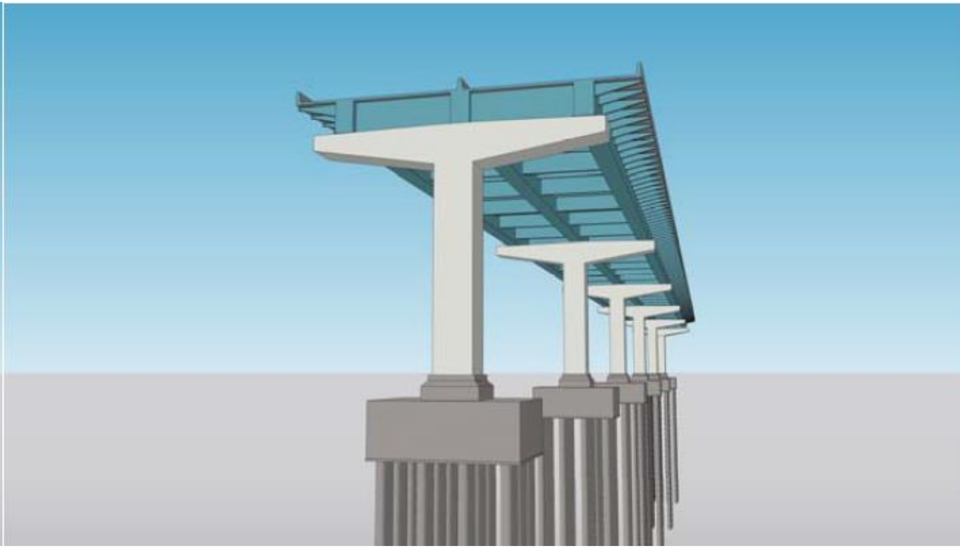
Summary for model tests

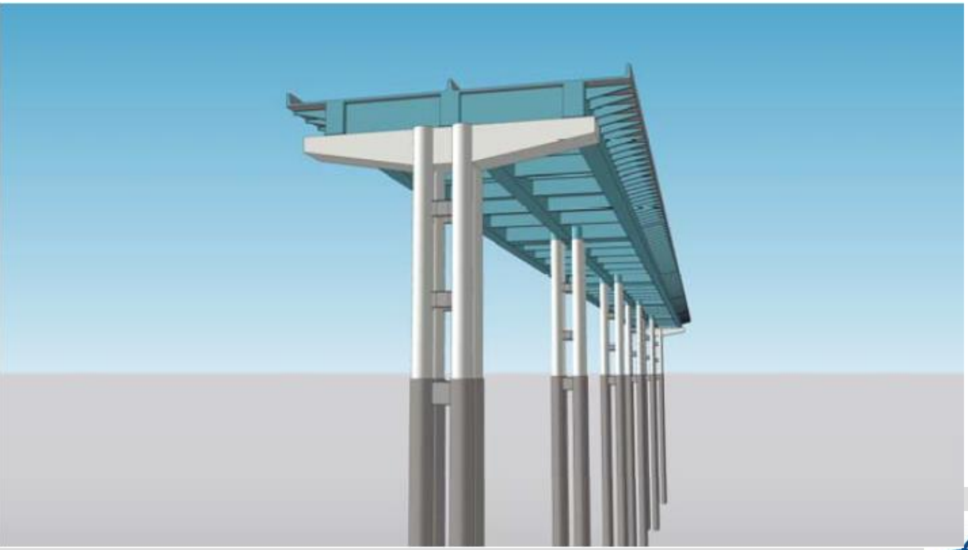
- Based on the fact that the main members such as the columns and piles yield after the shear panels (secondary member) yield, the proposed structure has a damage control performance by energy absorption due to plastic deformation of the shear panels.

- In particular, S-type has high seismic performance because the main member (columns and piles) holds a large residual strength even after yielding of the shear panels.

My new pile foundations





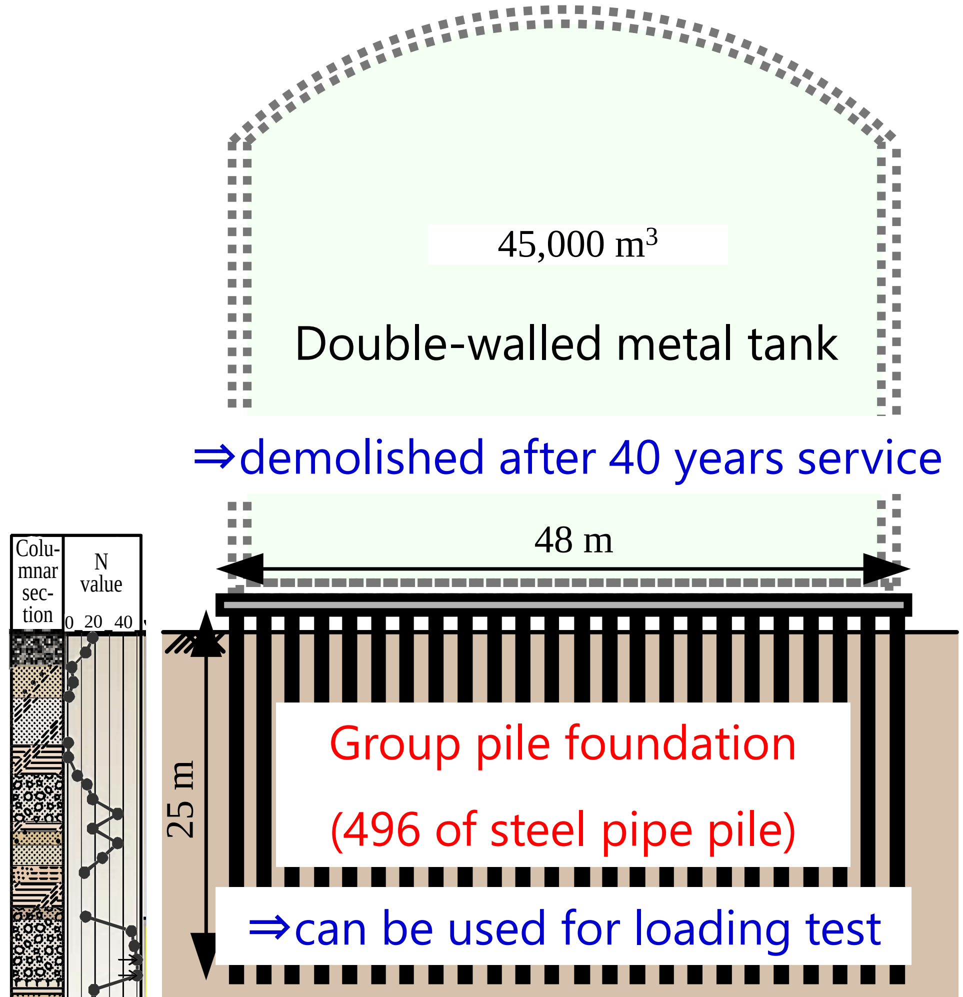


5.2 LNG receiving terminal and LNG tank

LNG receiving terminal

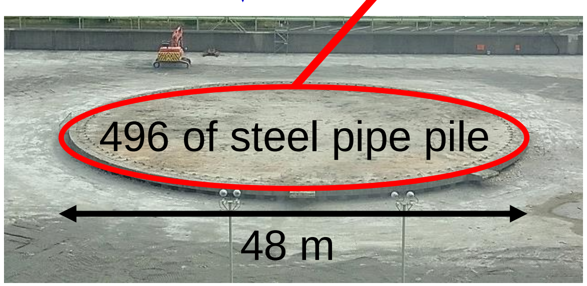
LNG tank

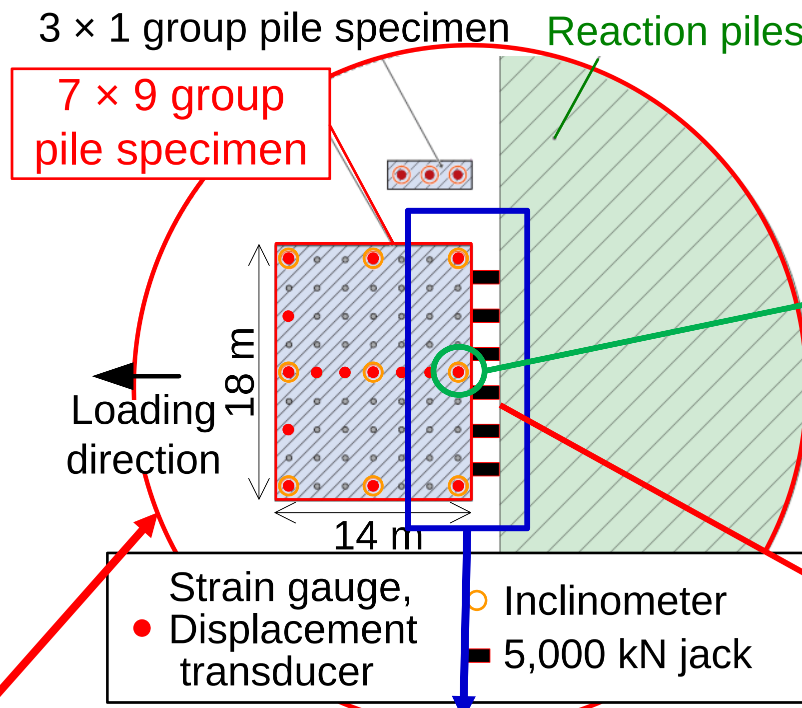
LNG tank need enough stability even if earthquake

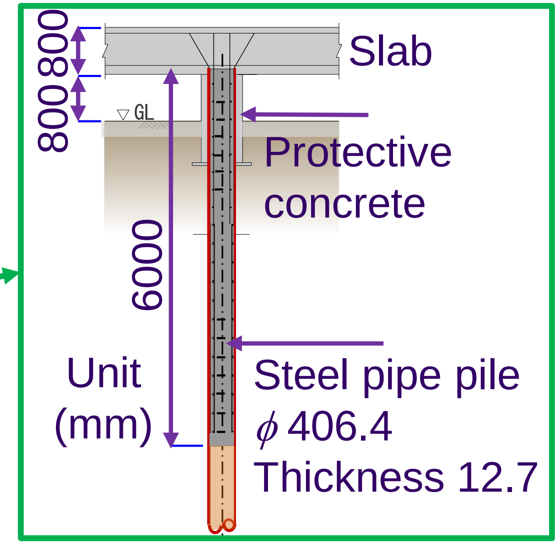


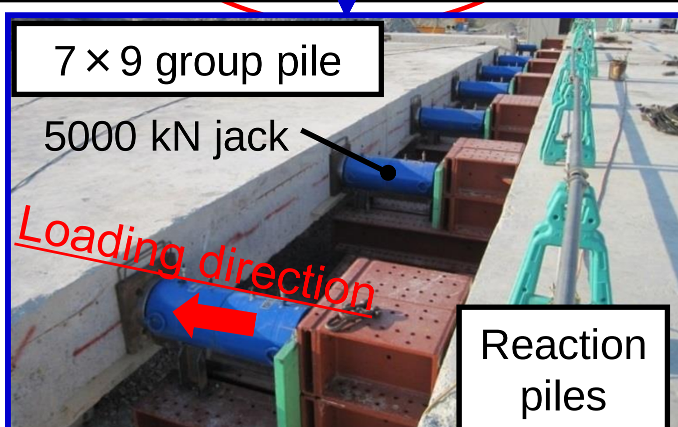
5.3 Experimental condition

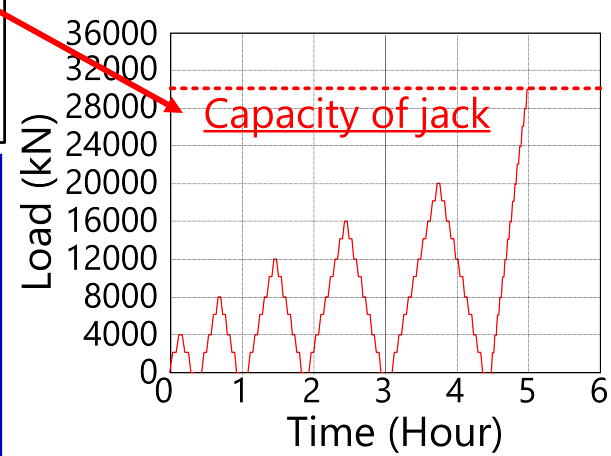
demolished after
40 years service





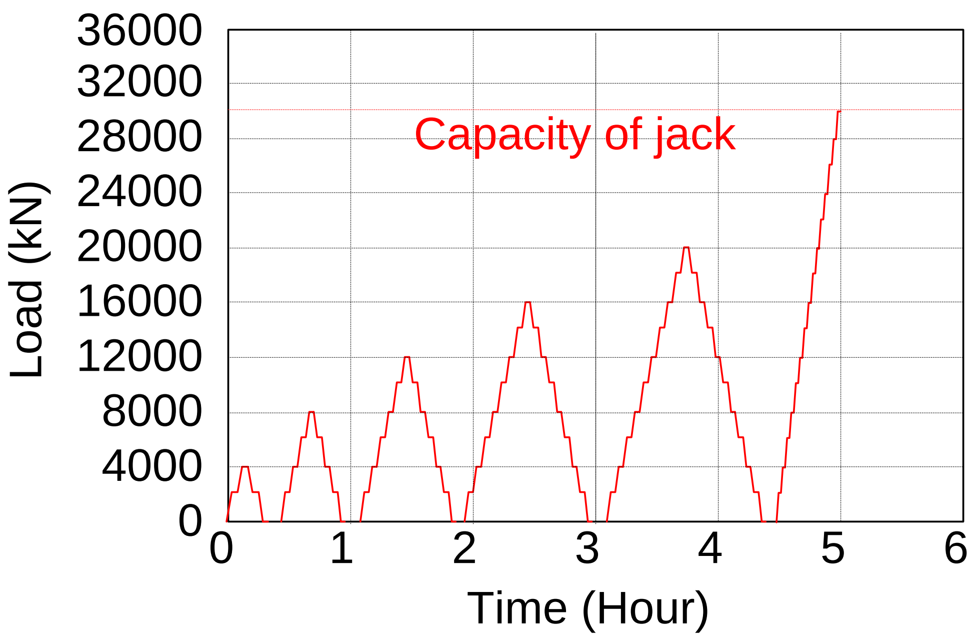






⇒Prediction FEM analysis to decide max. load

5.3 Experimental conditions



⇒ How to decide max. load?

It is very difficult
to calculate the load
to see ultimate behavior of
63 of group pile foundation

3D elasto-plastic FEM analysis

= Simulating group pile effect
elast-plastic approximate solution

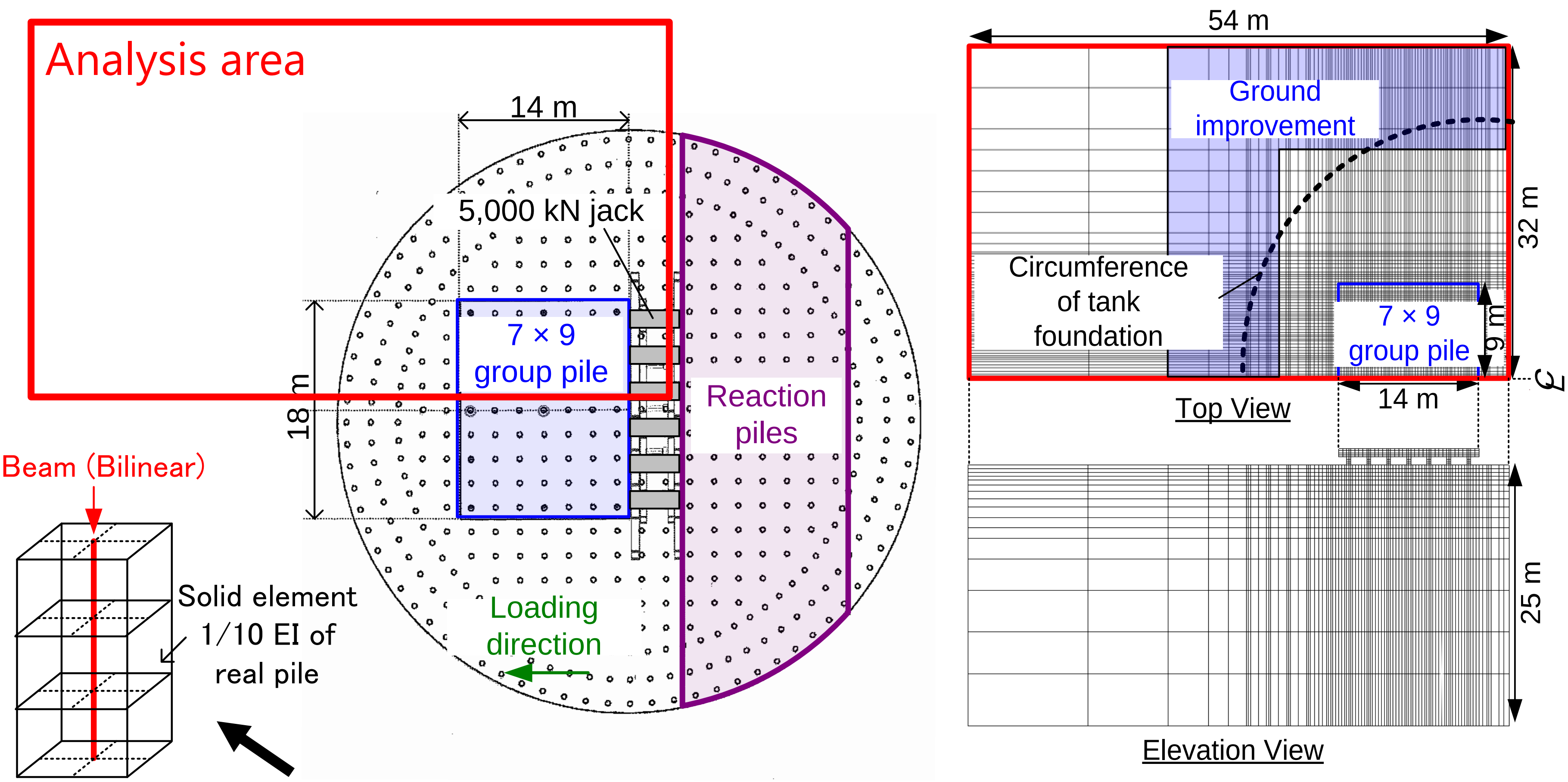
⇒ Conducted prediction analysis
to decide max. load

Unidirectional multiple-cycle
multiple-step loading (6 cycle)

Max. load is decided to 30,000 kN

5.4 Prediction analysis condition

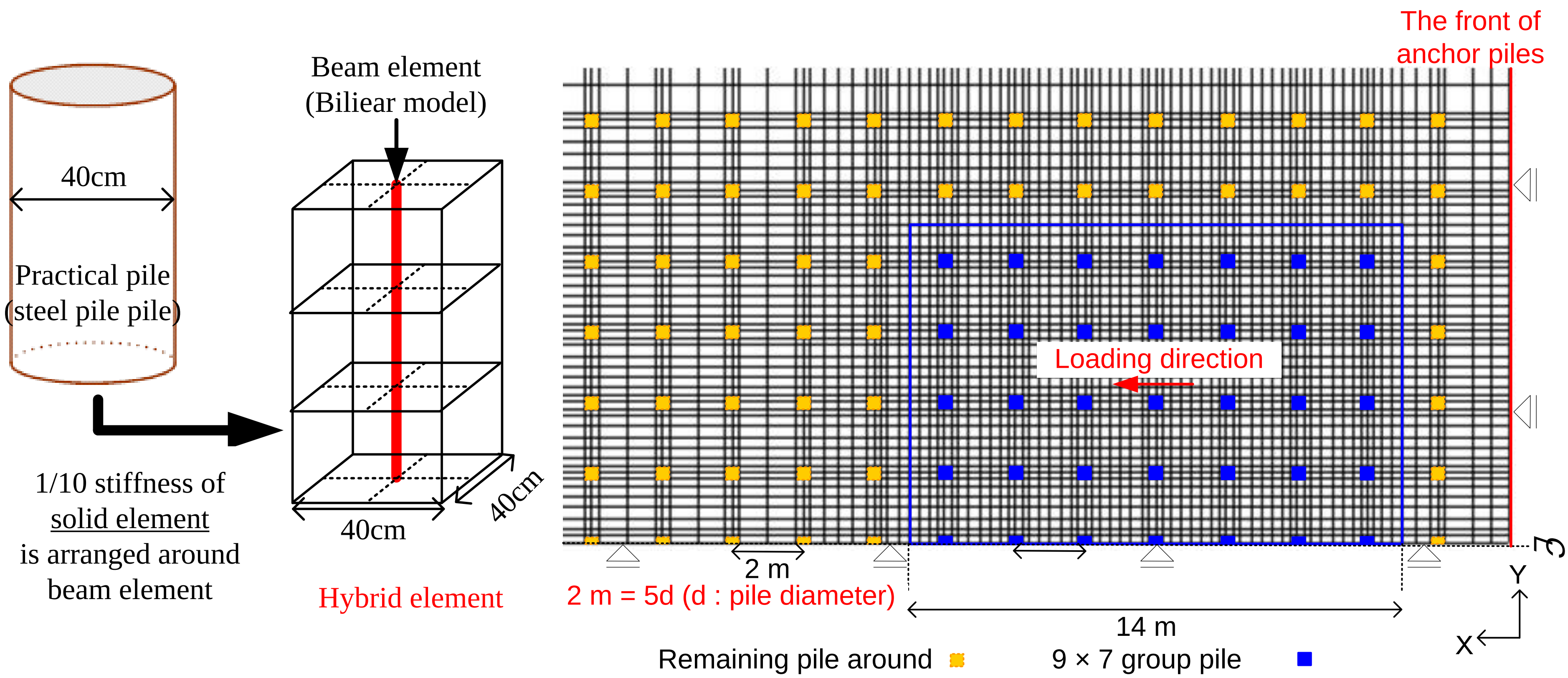
Prediction analysis by 3 dimensional elasto-plastic FEM



Pile : Hybrid model (Bilinear)

Ground : Subloading t_{ij} model

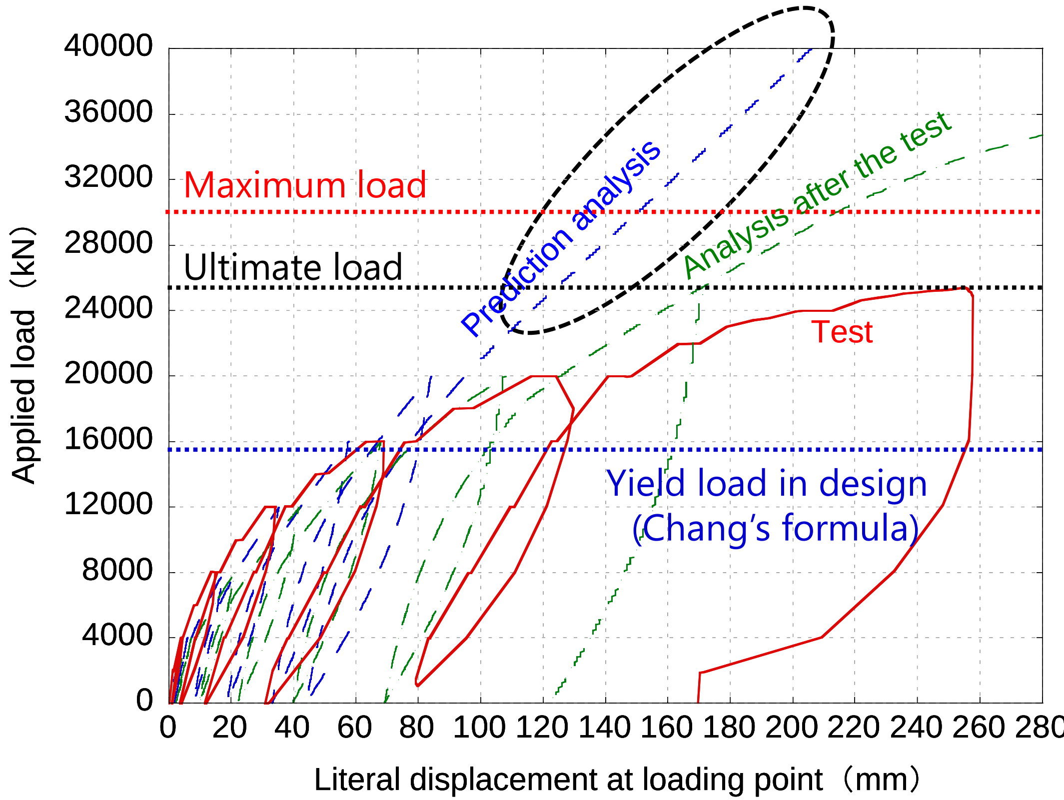
5.4 Prediction analysis model

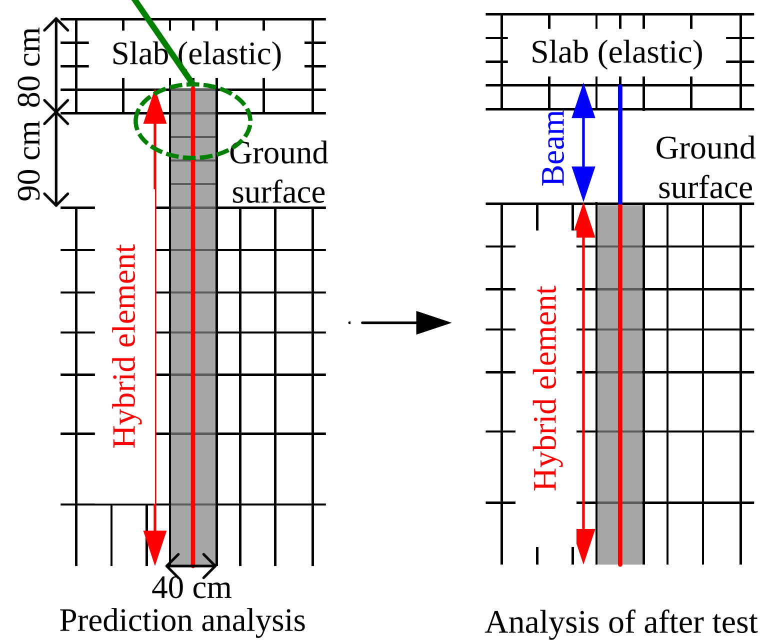


Pile group effect depend on L/d

Only beam element model overestimate pile spacing L and pile group effect is misesteemed

5.5 Results ~Load-displacement~





Even high load, remain stiffness ⇒not reasonable

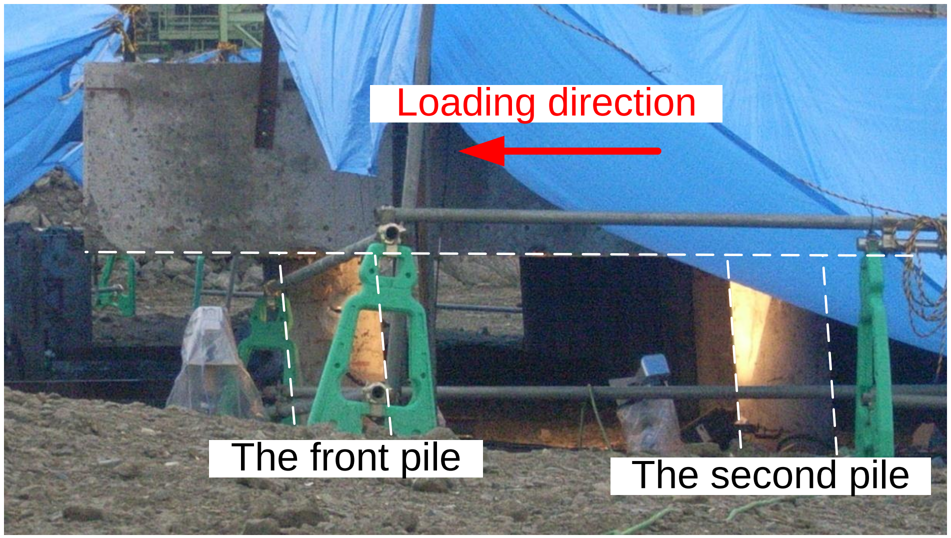
Actually, ultimate load was lower (25400 kN)

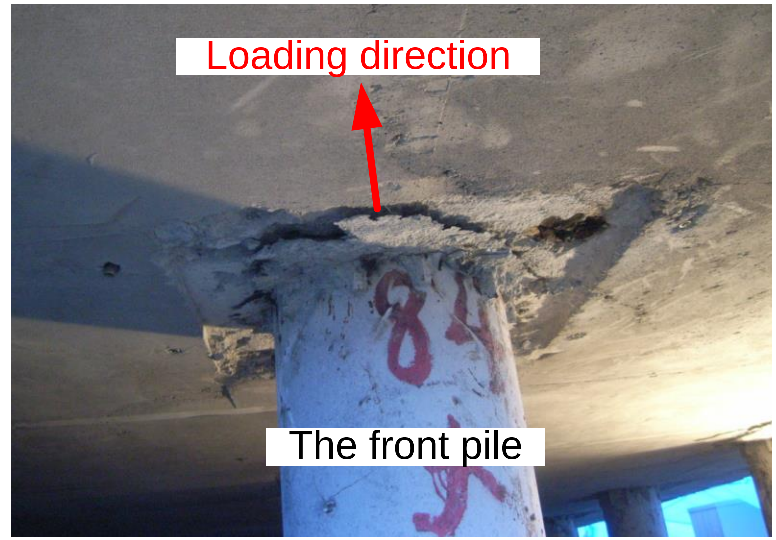
⇒ductile deformation over yield load in design

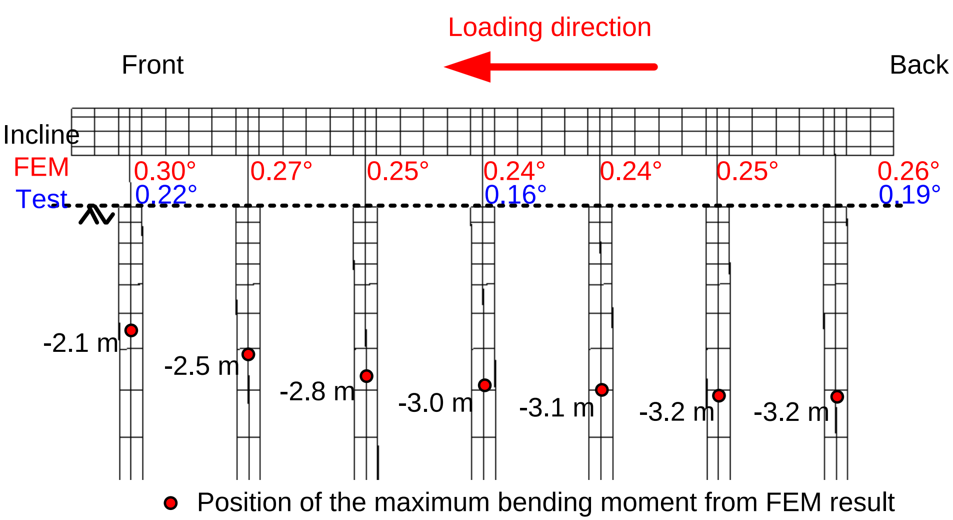
Simulate accurately at initial phase but not after yield

Plastic behavior simulated

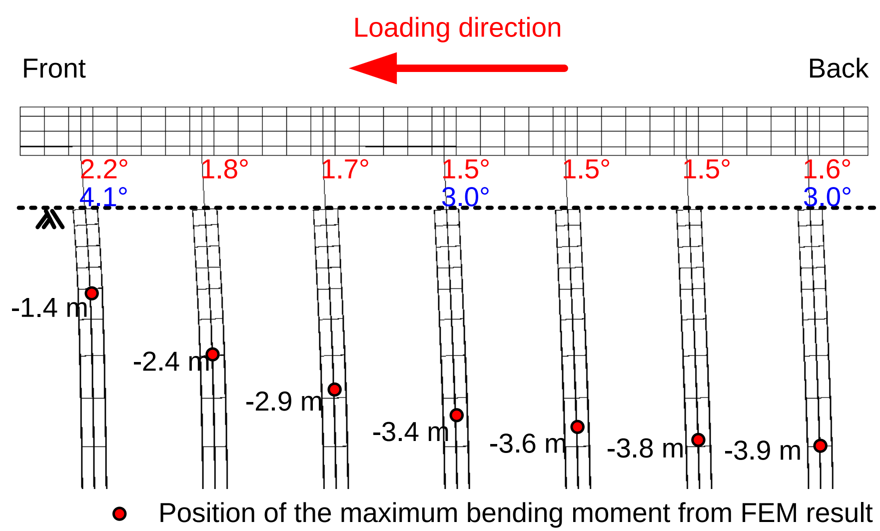
5.5 Results ~deformation of group pile~





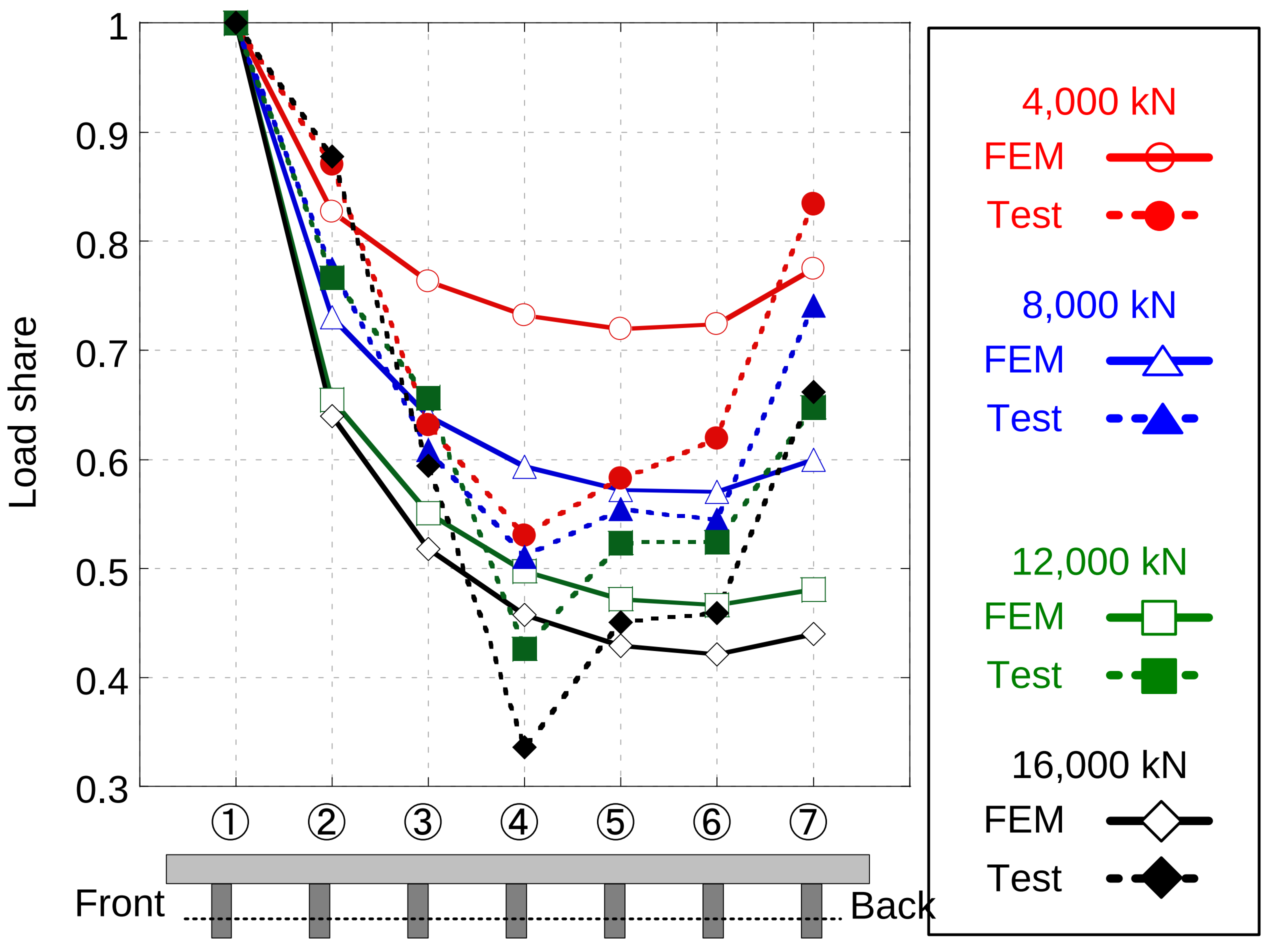


8,000 kN applied



25,400 kN applied

5.5 Results ~Load share of each pile~



Middle or back pile share small load

According to increase of load load share decrease

Large group pile effect generate in spite of L/d = 5

⇒ over 0.9 load share 3×1 group pile L/d = 5

Specific to large scale group pile