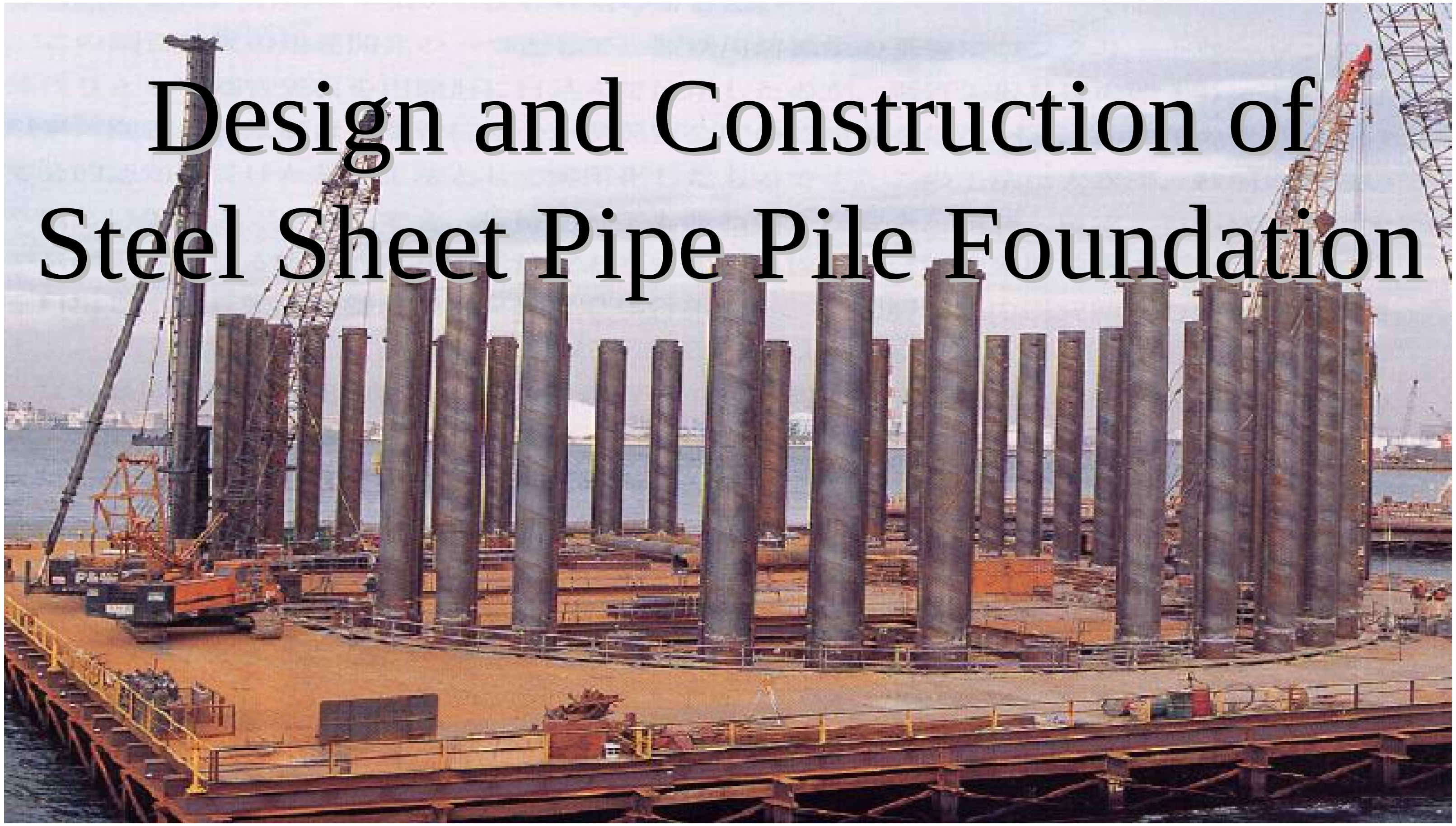
Design and Construction of Steel Sheet Pipe Pile Foundation



2007/10/4

Takeshi Katayama

Outline of the presentation

1. Outline of Steel Sheet Pipe Pile Foundation
2. Design of Steel Pipe Sheet Pile Foundation
3. Outline of Installation Methods
4. Projects in Japan
5. Advantage of Steel Pipe Wells Foundation
6. Topics Liquefaction, Corrosion, PC Well)
7. Conclusion

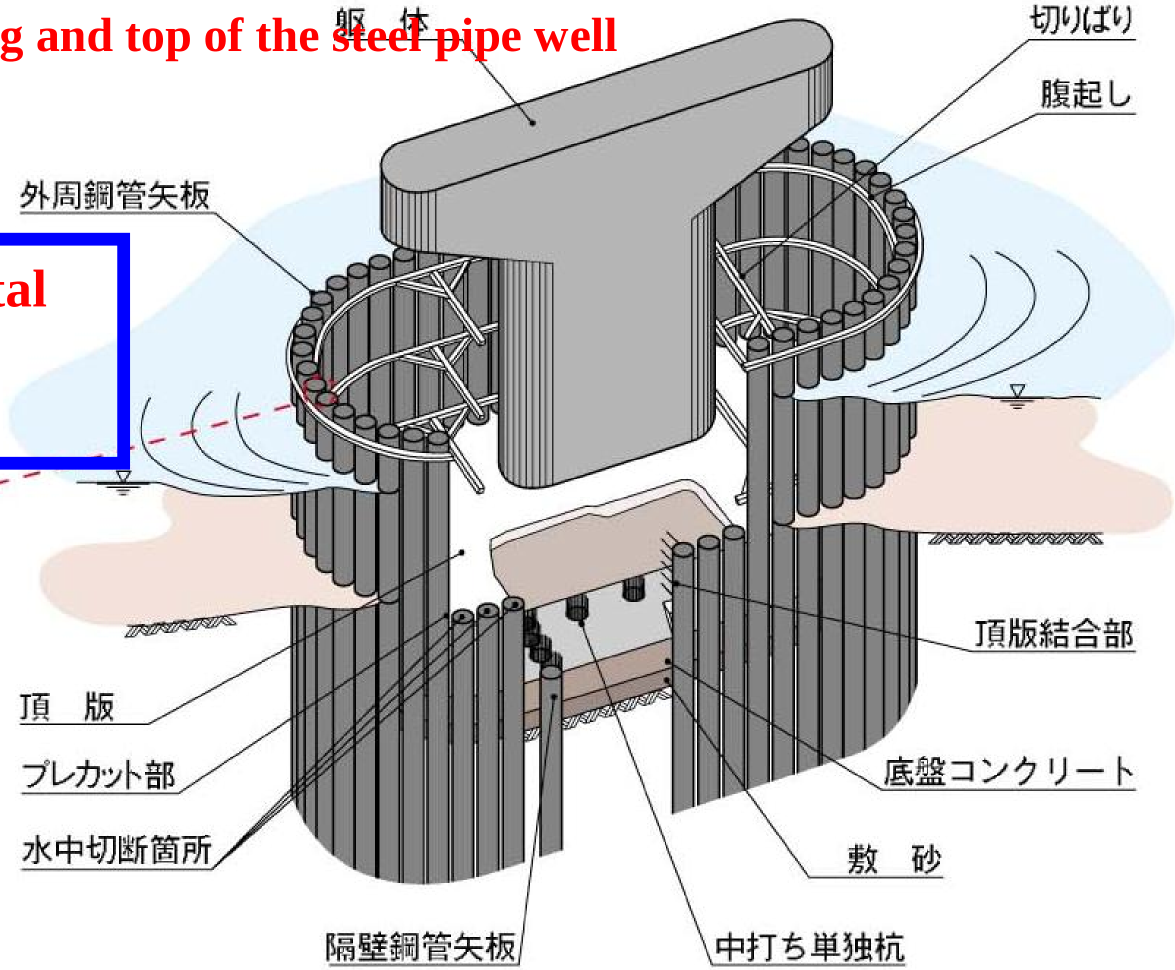
1.Outline of Steel Sheet Pipe Pile Foundation

.Closed with Circular,Rectangular or Oval shape

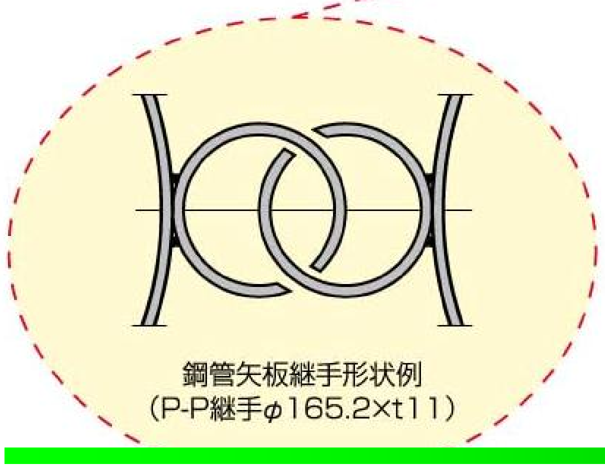
.Mortar injection inside joint to connect steel pipe sheet pile

.Rigid connection between footing and top of the steel pipe well

Foundation of large horizontal resistance and large bearing capacity



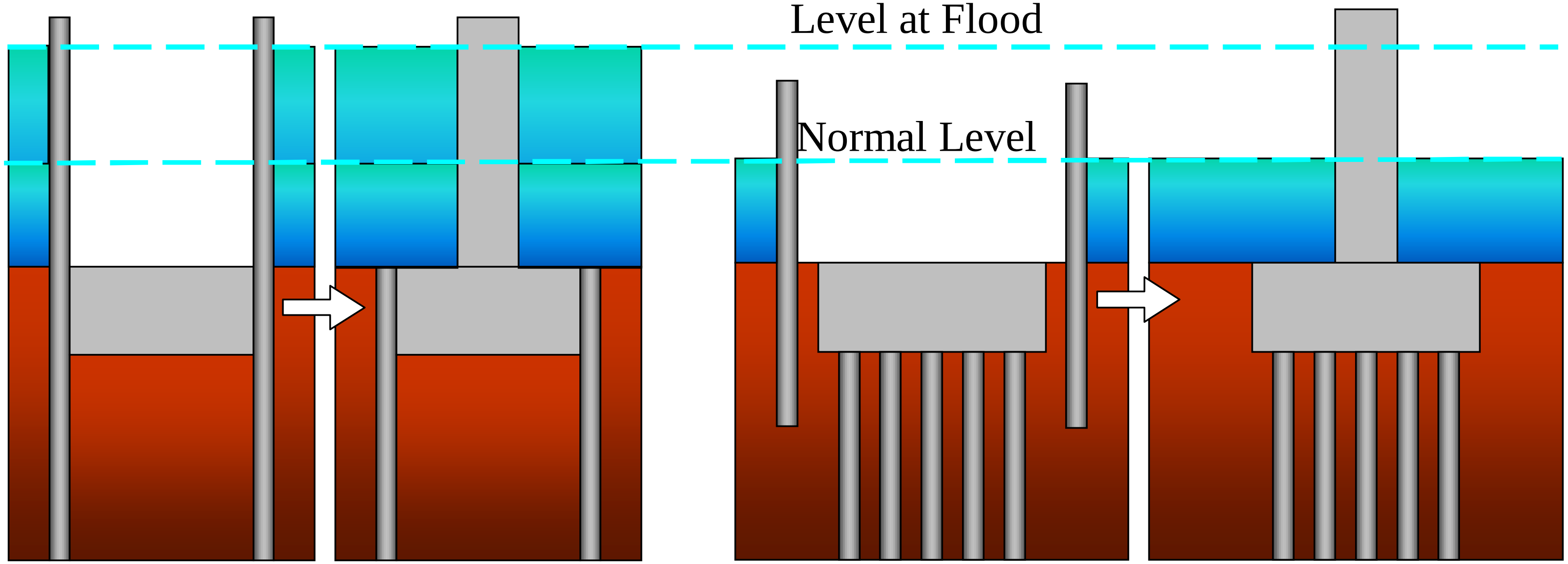
.Pipe-Pipe type interlocking joints




DATE : 30 - APRIL - 2005

Steel Sheet Pipe Pile Foundation

Thanh Tri Bridge Project



History of Steel Sheet Pipe Pile Foundation

.Development was started in around 1964

.First application for bridge foundation of Ishikari river mouth in 1969

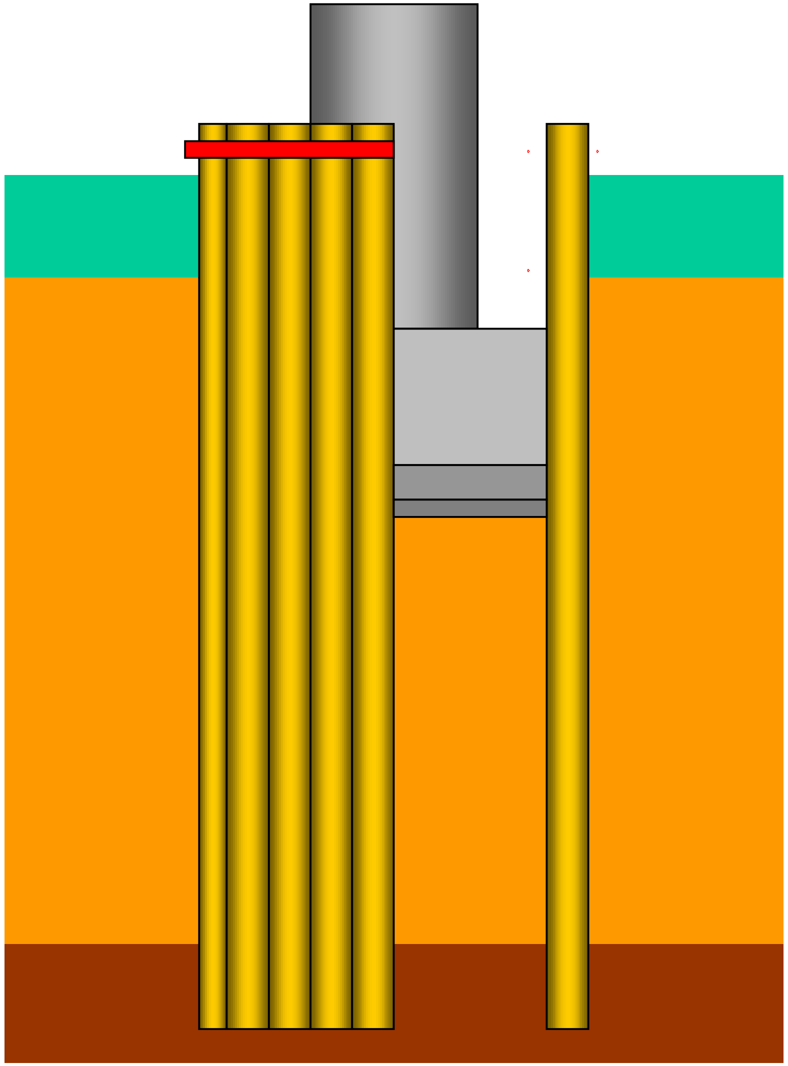
.From 1969

Five steel mill makers had started the research supported by Ministry of Construction

.In 1972,

.Guideline for design and construction of Steel Sheet Pipe Well] by research committee

2.Design of Steel Pipe Sheet Pile Foundation



Ordinary.Overwhelmingly Wind.Level 1 Earthquake

.Allowable Design methods)

Foundation stability	Temporary cofferdam
Force.Allowable	**Combined.Permanent**
Deformation.Allowable	**.Residual stress...a**

Level 2 Earthquake

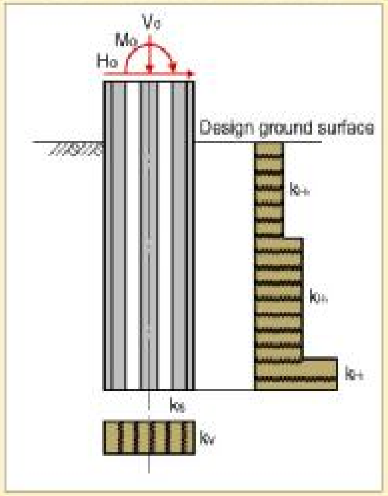
.Elasto-plastic method.

Check foundation stability

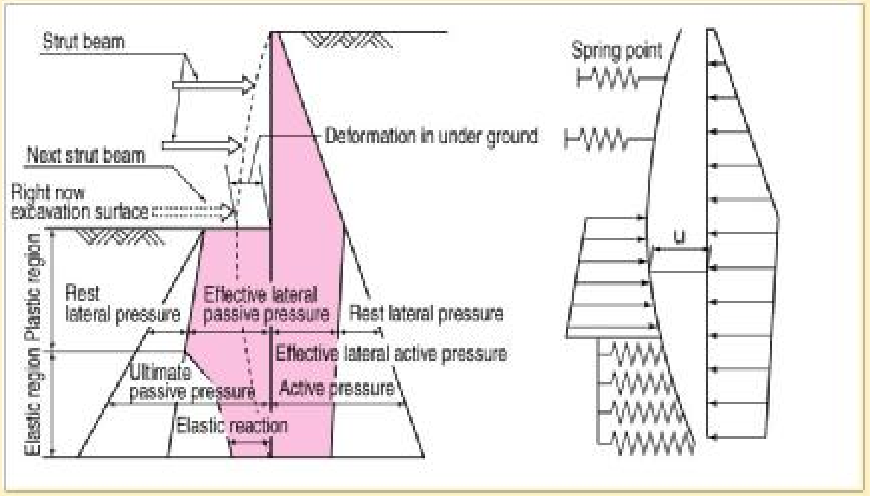
.Not foundation yielding.

Design Procedure

1) Calculation of foundation stability



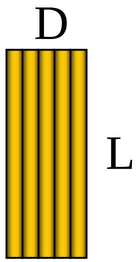
2) Temporary cofferdam calculation

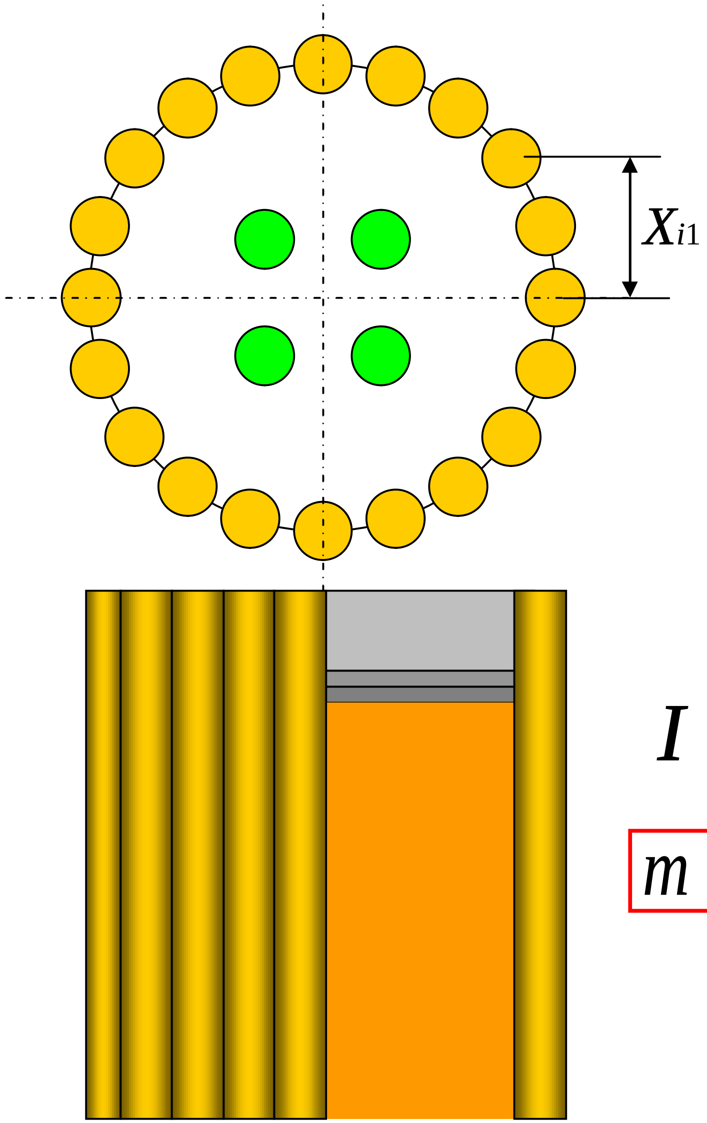


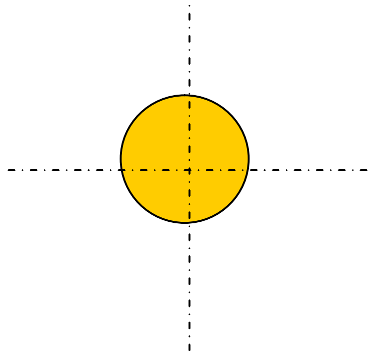
3) Check the combined stress between real action and residual stress

※Steel Pipe Well = Steel Pipe Sheet Pile

Beam Analysis Method



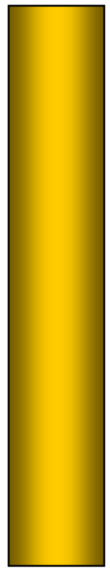




$$I=\sum I_{0i}+m\sum A_{0i}X_{i1}^{2}$$

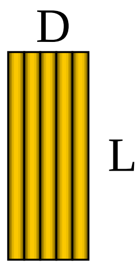
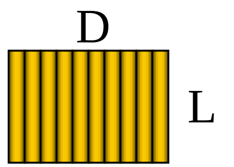
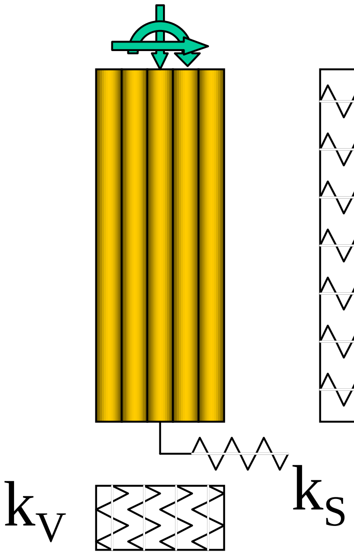
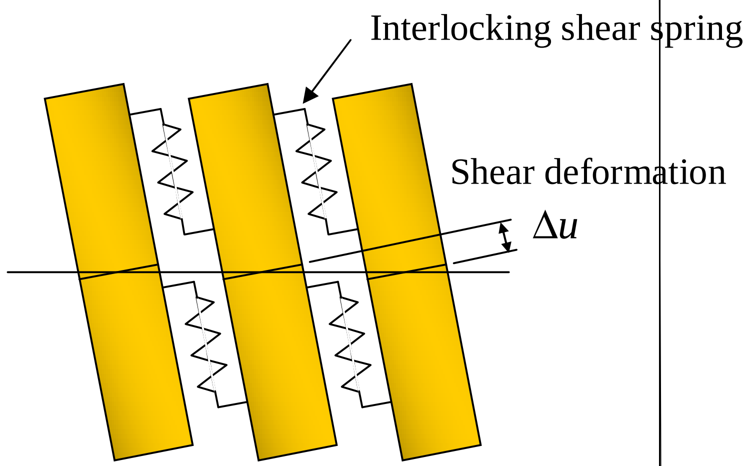
$$m=0.75$$

rigidity efficiency

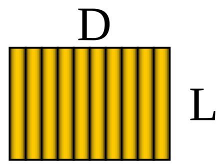


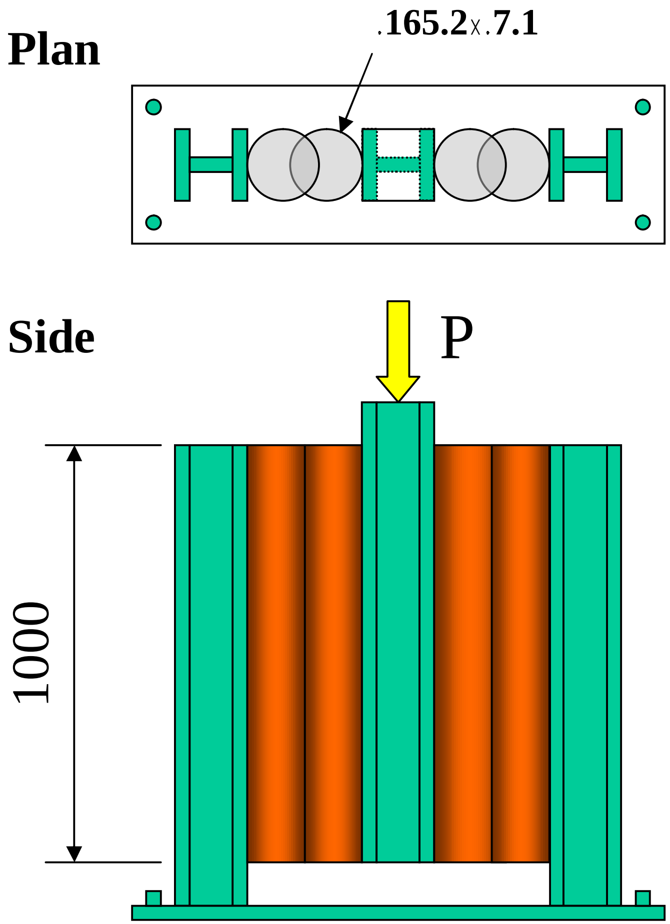
Choice of stability calculation model

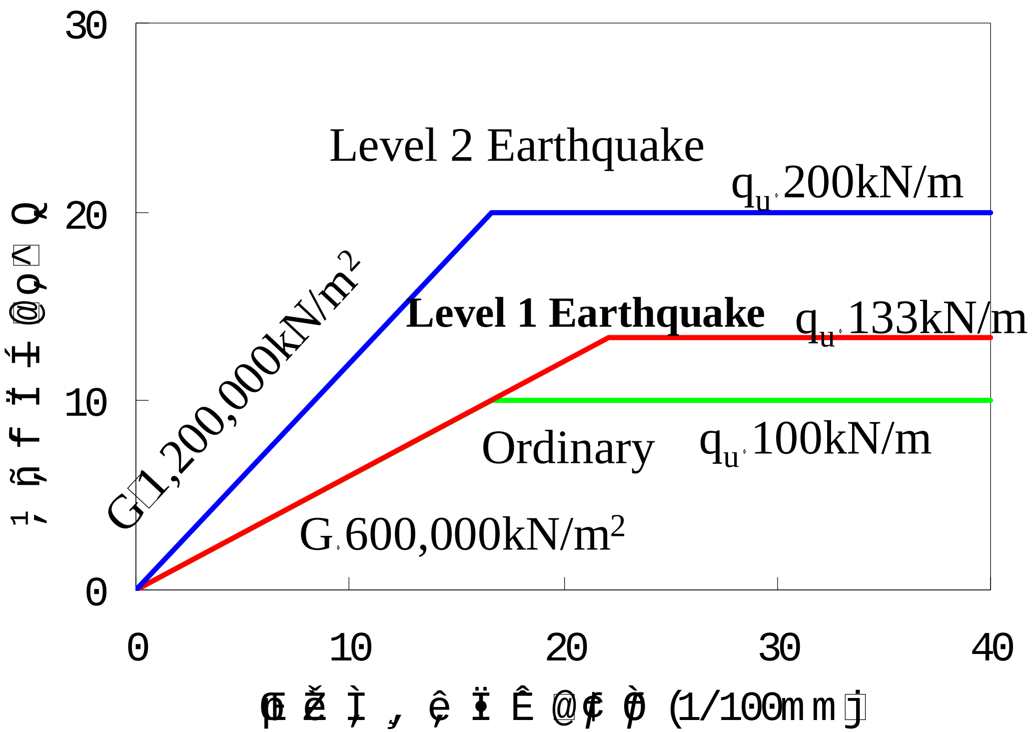
..Design concept of permanent main structure

Class	D . 30m and L/D . 1 and . Le . 1 	D . 30m or L/D . 1 or . Le . 1 
Method	beam on the elastic spring Analysis	With shear force transmission Imaged well beam Analysis
Model Figure		

Imaged Well beam Analysis with interlocking shear deformation







Interlocking Shear capacity test

Assumption of plane form

Bridge pier form

Circular, Rectangle, Ellipse

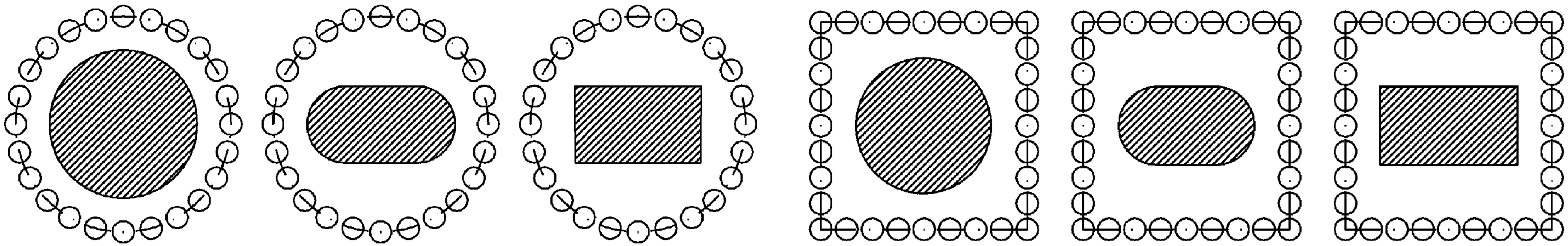
Assumption of plane form

Circular

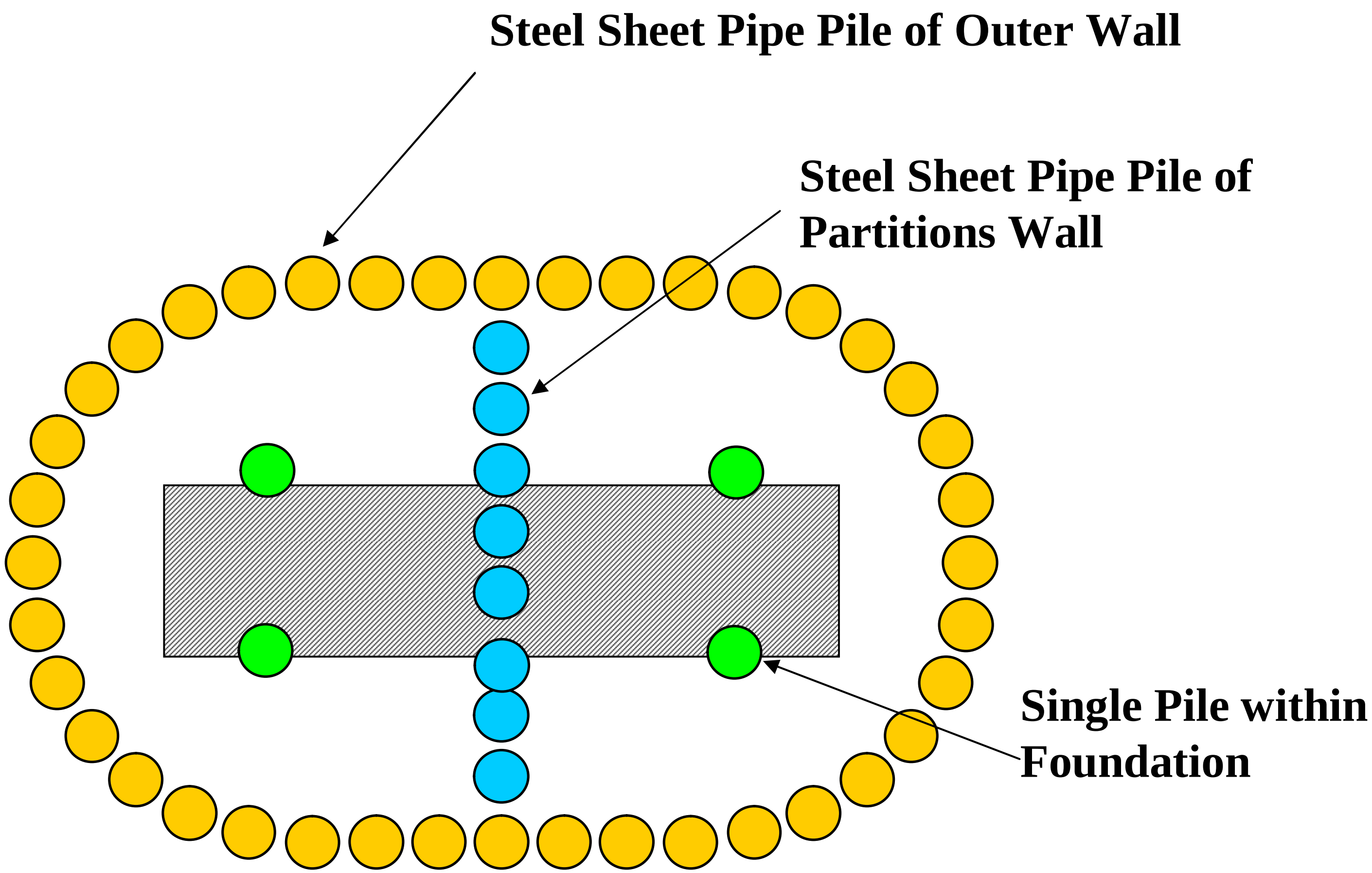
The optimal design

Circular

Rectangle



Example of steel sheet pipe pile arrangement



Assumption of steel pipe sheet pile size

The diameter is around 1000 mm and t/D is less than about 1.4 percent.

Thickness(mm)

22						○	○	○	○	○	○
21					○	○	○	○	○	○	○
20				○	○	○	○	○	○	○	○
19				○	○	○	○	○	○	○	○
18				○	○	○	○	○	○	○	○
17				○	○	○	○	○	○	○	○
16		○	○	○	○	○	○	○	○	○	○
15		○	○	○	○	○	○	○	○	○	
14		○	○	○	○	○	○	○	○		
13	○	○	○	○	○		○	○			
12	○	○	○	○			○				
11	○	○	○	○							
10	○	○	○								
9	○	○									
8	○										
7	○										
6											
	500	600	700	800	900	1000	1100	1200	1300	1400	1500

The diameter of a steel pipe sheet pile(mm)

Corrosion allowance

A corrosion allowance may be 1mm.

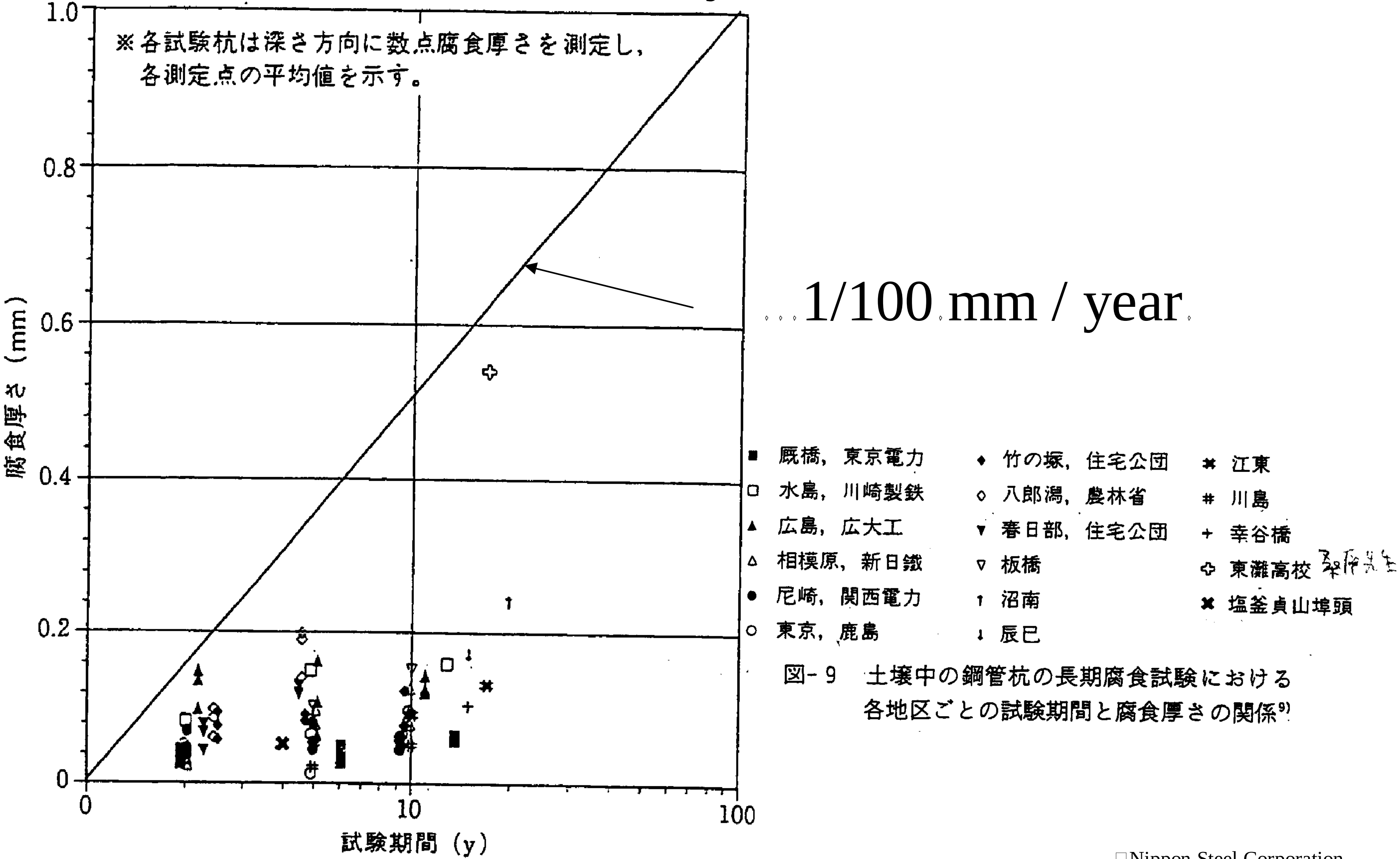
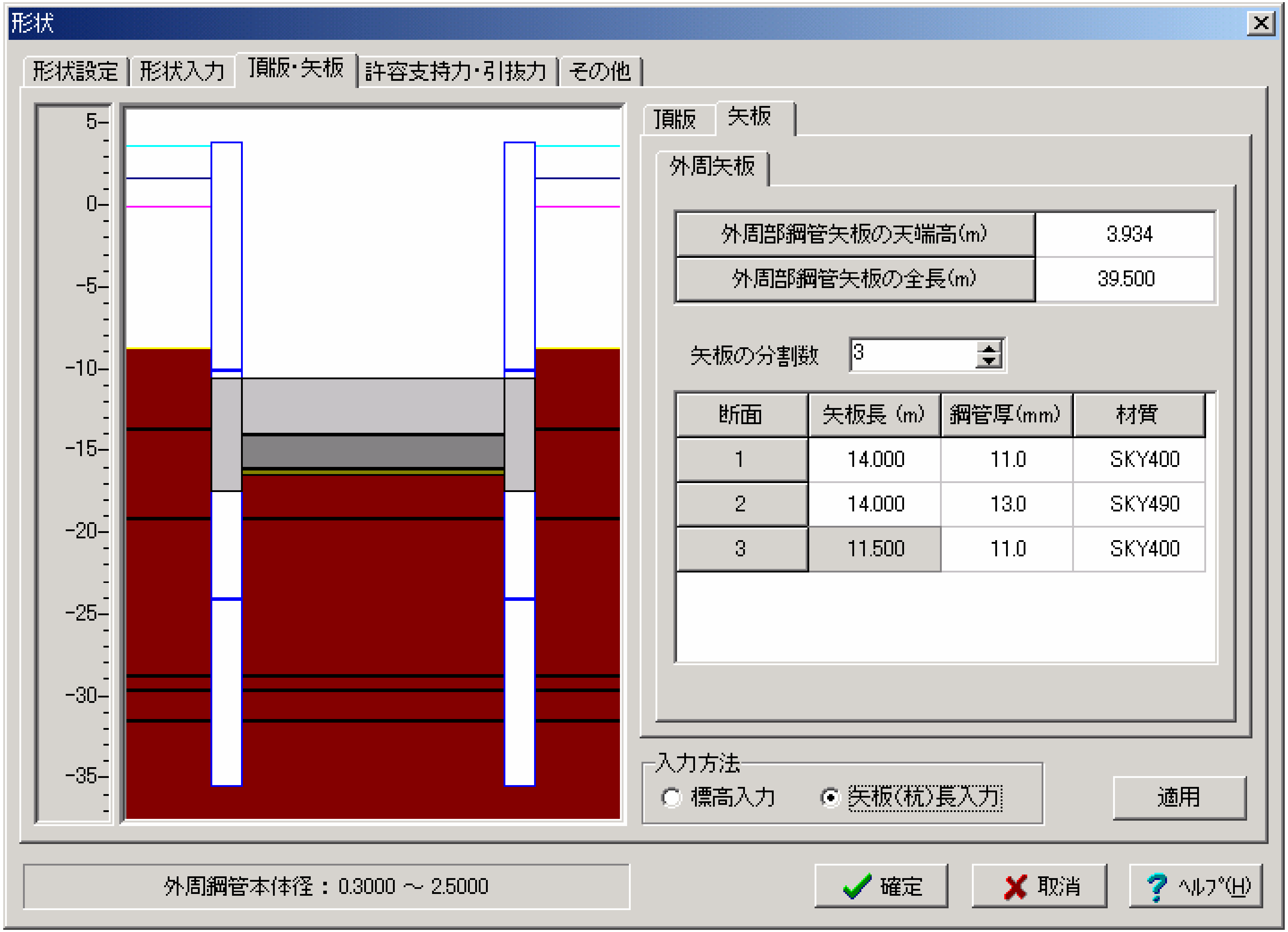


図-9　土壌中の鋼管杭の長期腐食試験における各地区ごとの試験期間と腐食厚さの関係[9)]

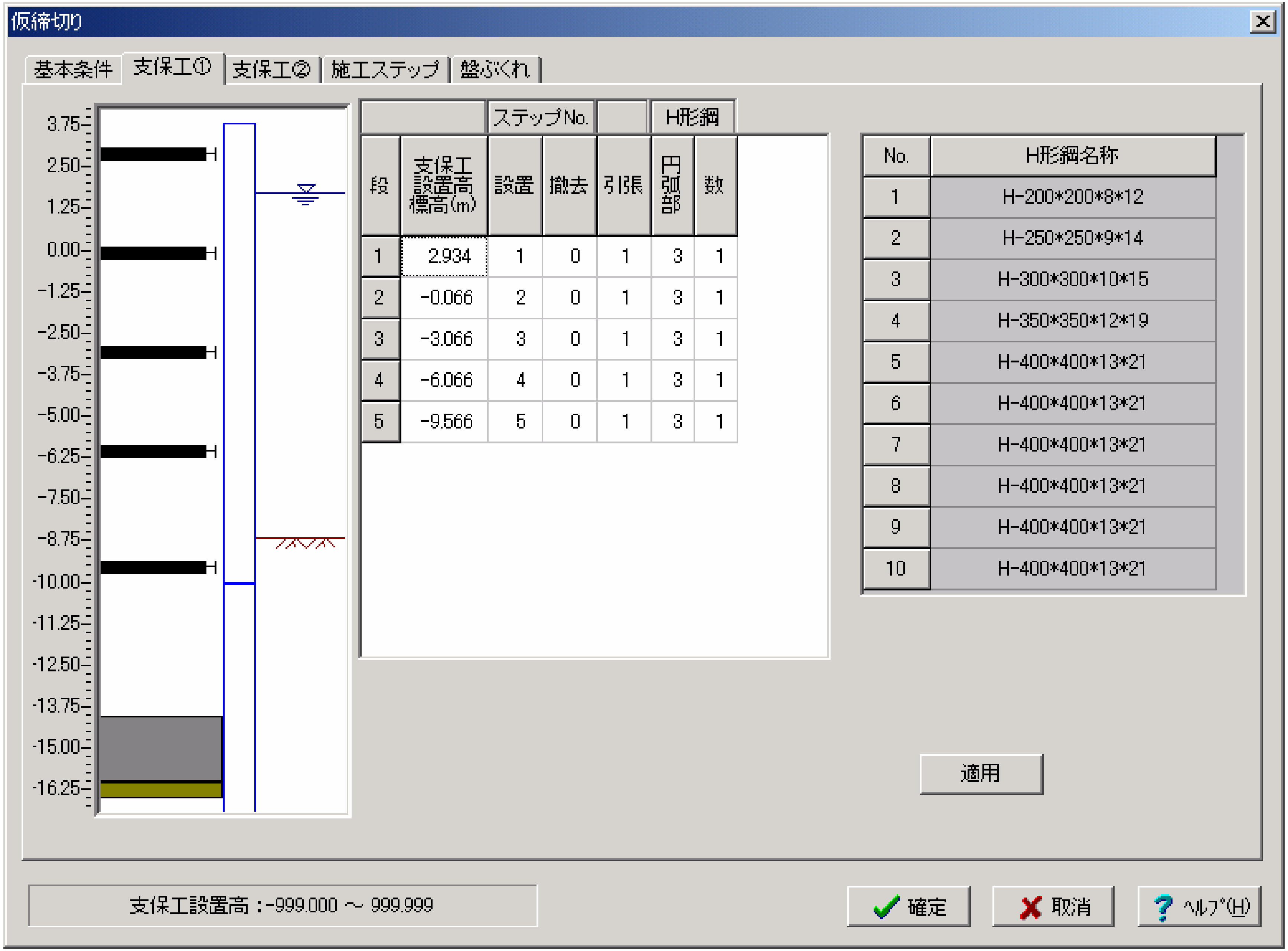

形状
形状設定
形状入力
頂版･矢板
許容支持力･引抜力
その他
5
0
-5
-10
-15
-20
-25
-30
-35
頂版
矢板
外周矢板
外周部鋼管矢板の天端高(m) 3.934
外周部鋼管矢板の全長(m) 39.500
矢板の分割数 3
断面 矢板長 (m) 鋼管厚(mm) 材質
1 14.000 11.0 SKY400
2 14.000 13.0 SKY490
3 11.500 11.0 SKY400
入力方法
標高入力
矢板(杭)長入力
適用
外周鋼管本体径：0.3000 ～ 2.5000
確定
取消
ヘルプ(H)

Temporary cofferdam calculation

1) A construction step is examined.

- Underwater digging
- Digging among the ground
- Combined use of underwater digging and digging among the ground

2)Examination of timbering


仮締切り
基本条件
支保工①
支保工②
施工ステップ
盤ぶくれ
3.75
2.50
1.25
0.00
-1.25
-2.50
-3.75
-5.00
-6.25
-7.50
-8.75
-10.00
-11.25
-12.50
-13.75
-15.00
-16.25
ステップNo.
H形鋼
段
支保工設置高標高(m)
設置
撤去
引張
円弧部
数
1 2.934 1 0 1 3 1
2 -0.066 2 0 1 3 1
3 -3.066 3 0 1 3 1
4 -6.066 4 0 1 3 1
5 -9.566 5 0 1 3 1
No.
H形鋼名称
1 H-200*200*8*12
2 H-250*250*9*14
3 H-300*300*10*15
4 H-350*350*12*19
5 H-400*400*13*21
6 H-400*400*13*21
7 H-400*400*13*21
8 H-400*400*13*21
9 H-400*400*13*21
10 H-400*400*13*21
適用
支保工設置高：-999.000 ～ 999.999
確定
取消
ﾍﾙﾌﾟ(H)

The check of a calculation result

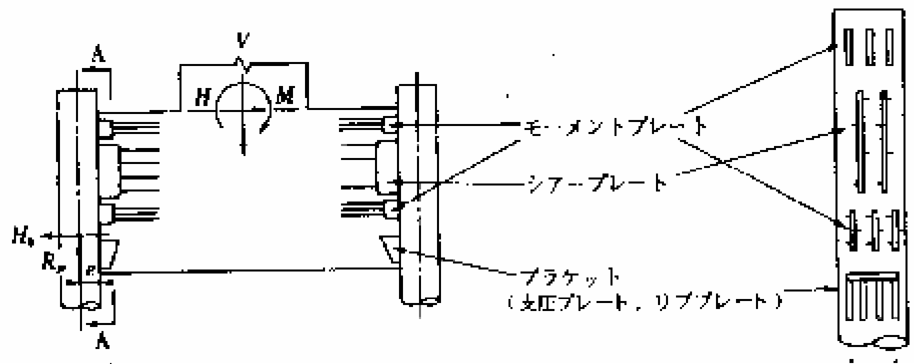
When displacement does not satisfy an acceptable value.
1) Board thickness is thickened.
2) A plane size is enlarged.
3) A diaphragm pile is adopted.

When stress intensity does not satisfy an acceptable value.
1) It changes into SKY490.
2) A plane size is enlarged.

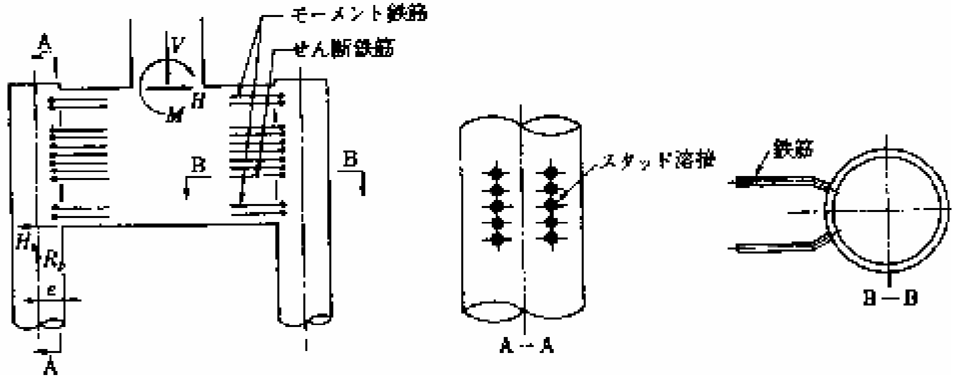
When bearing power does not satisfy an acceptable value.
1) Steel pipe sheet pile length is lengthened.
2) A inside single pile is adopted.

..Connection between steel pipe sheet pile and footing

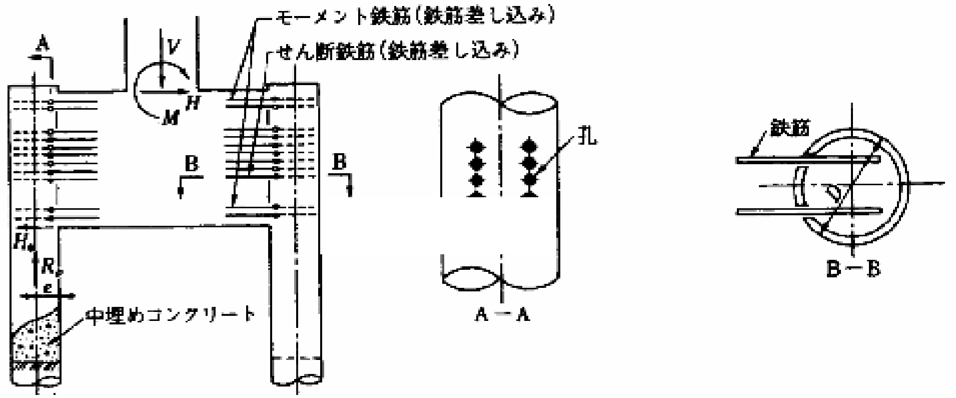
Plate and Bracket



Reinforcing Bar Stud

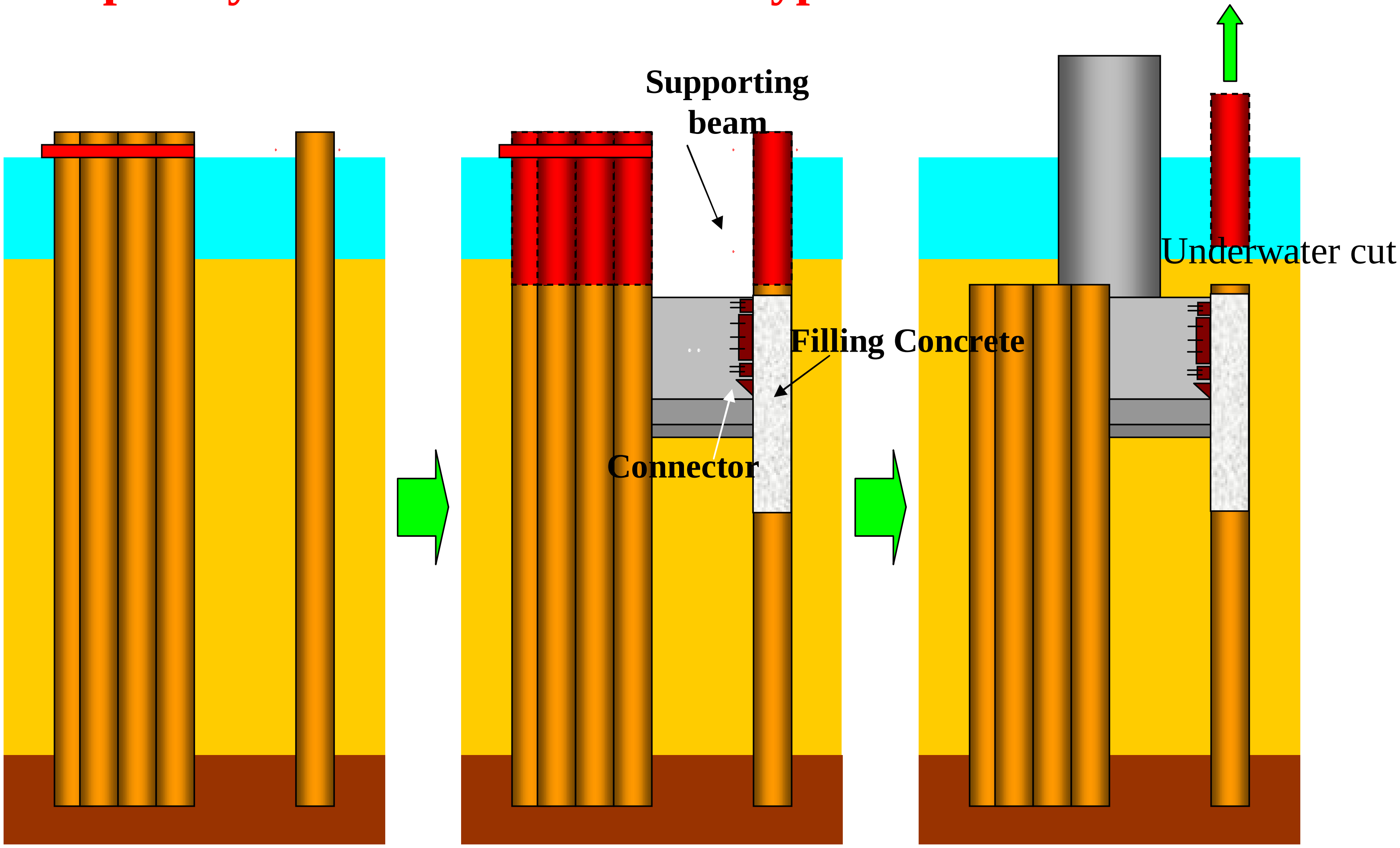


Inserting Reinforcing Bar



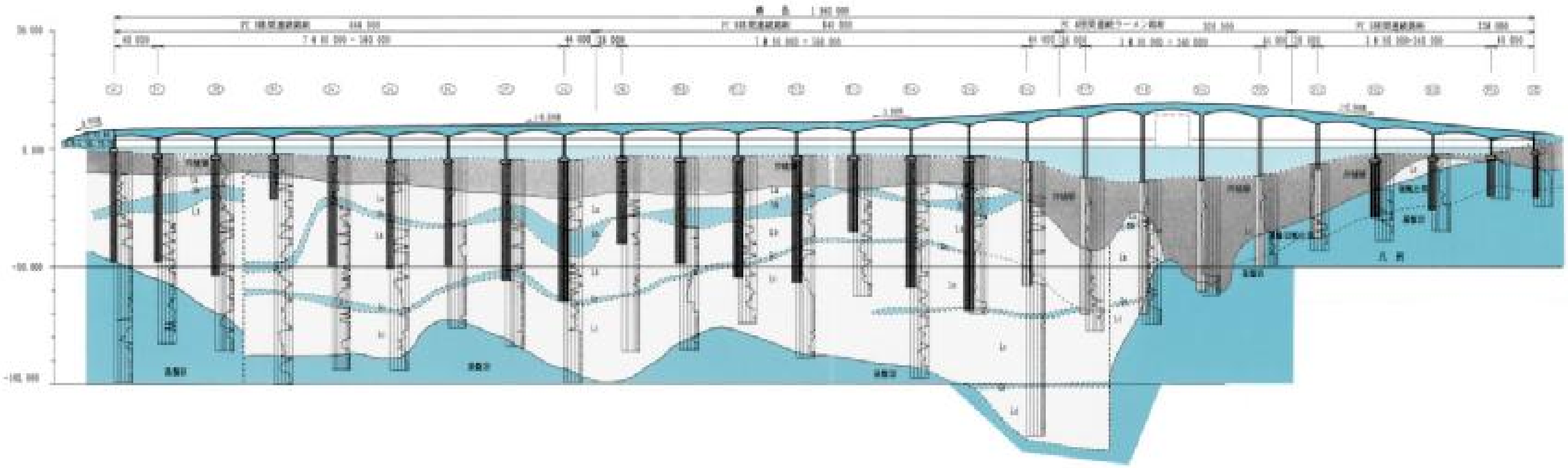
An Outline of Installation Methods

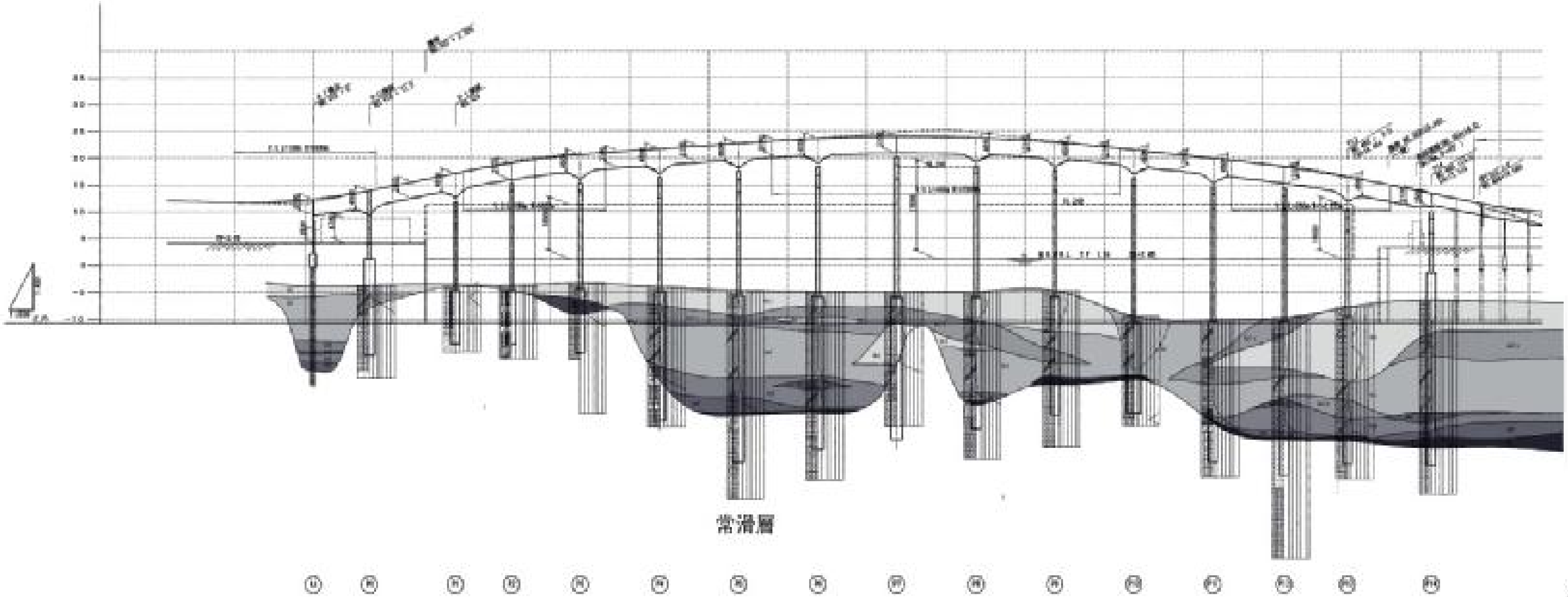
Temporary cofferdam/foundation type 90 of total construction



Kouri Ohashi

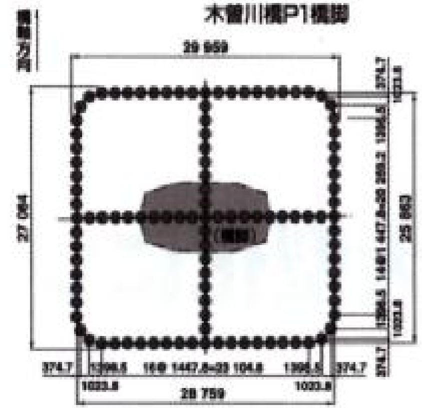
4. Projects in Japan



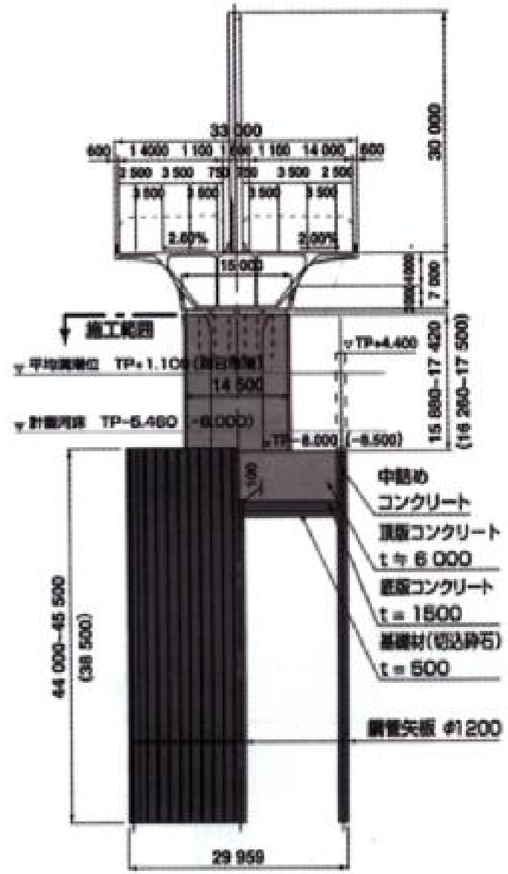

常滑層

木曽三川橋（木曽川橋・揖斐川橋）のイメージ
（提供：日本道路公団）

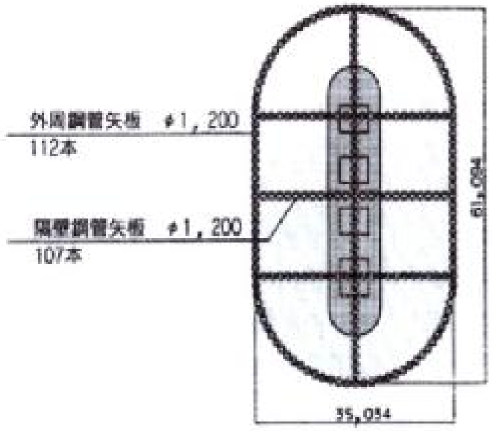
（提供：日本道路公団）

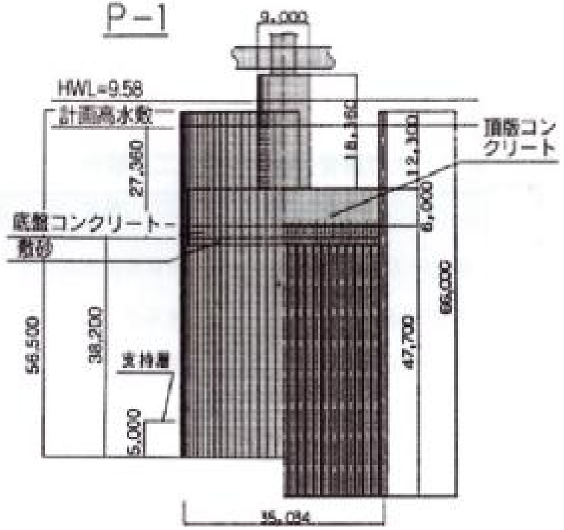


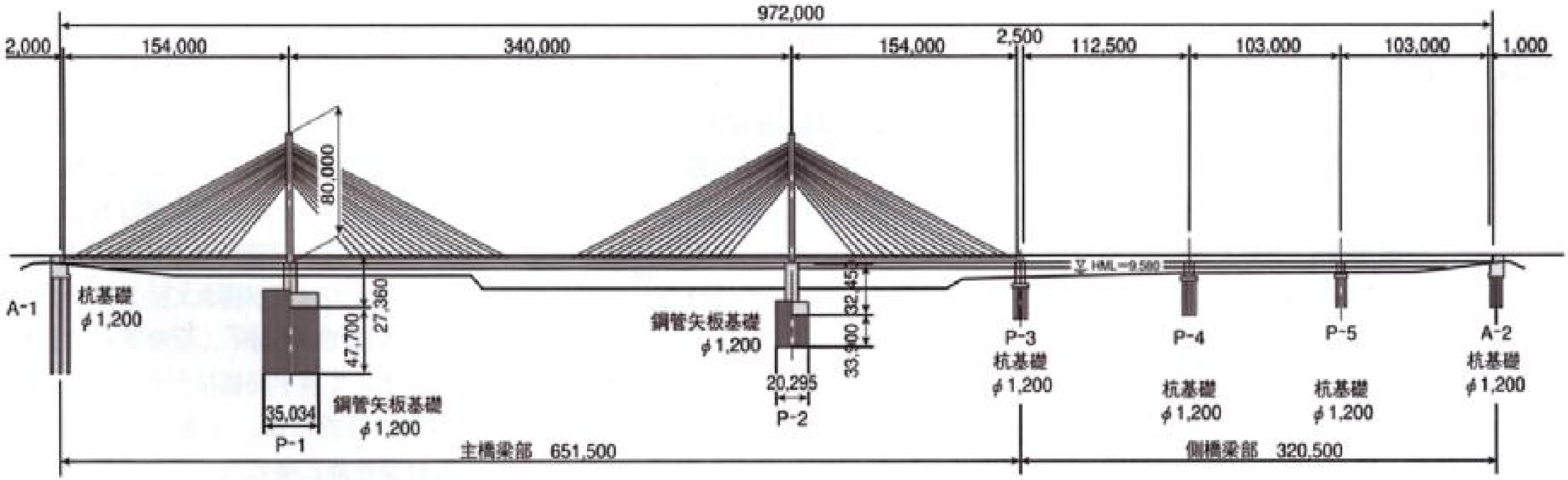
鋼管矢板配置図



橋脚正面図


外周鋼管矢板 φ1,200
112本
隔壁鋼管矢板 φ1,200
107本
61,034
35,034

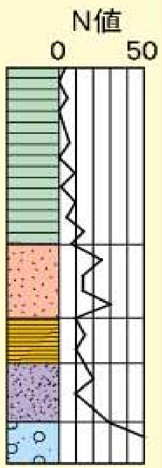
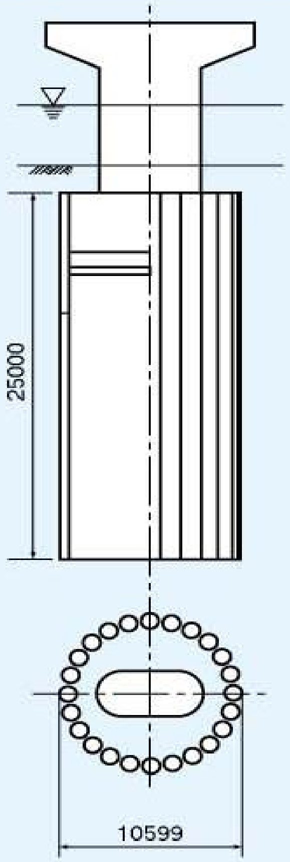
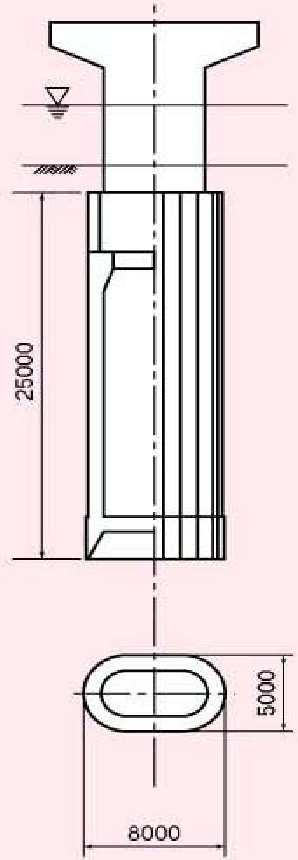

P−1
9,000
HWL=9.58
計画高水敷
頂版コンクリート
底盤コンクリート
敷砂
支持層
27,360
18,360
12,300
6,000
56,500
38,200
5,000
47,700
66,000
35,034


972,000
2,000
154,000
340,000
154,000
2,500
112,500
103,000
103,000
1,000
80,000
HWL=9.580
A-1
杭基礎
φ1,200
27,360
47,700
35,034
P-1
鋼管矢板基礎
φ1,200
鋼管矢板基礎
φ1,200
32,450
33,900
20,295
P-2
P-3
杭基礎
φ1,200
P-4
杭基礎
φ1,200
P-5
杭基礎
φ1,200
A-2
杭基礎
φ1,200
主橋梁部 651,500
側橋梁部 320,500

美原大橋側面図

5.Comparison

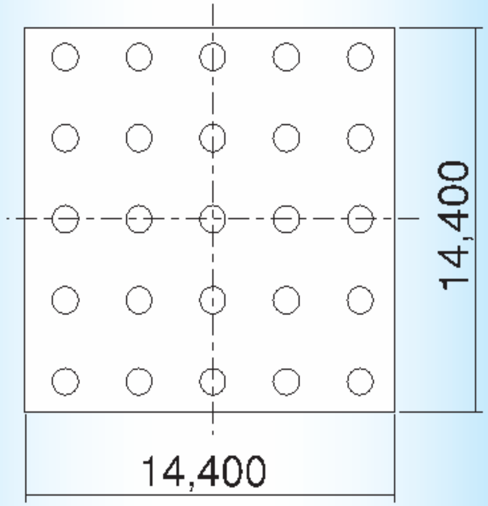
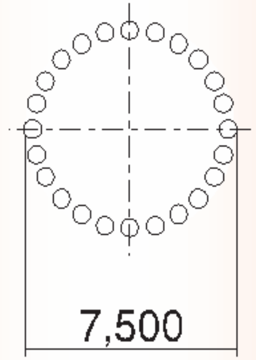
Comparison with Caisson

Soil	Steel Pipe Sheet Pile	Pneumatic Caisson
		
Period	6 months	9 months
Cost	1.00	1.09

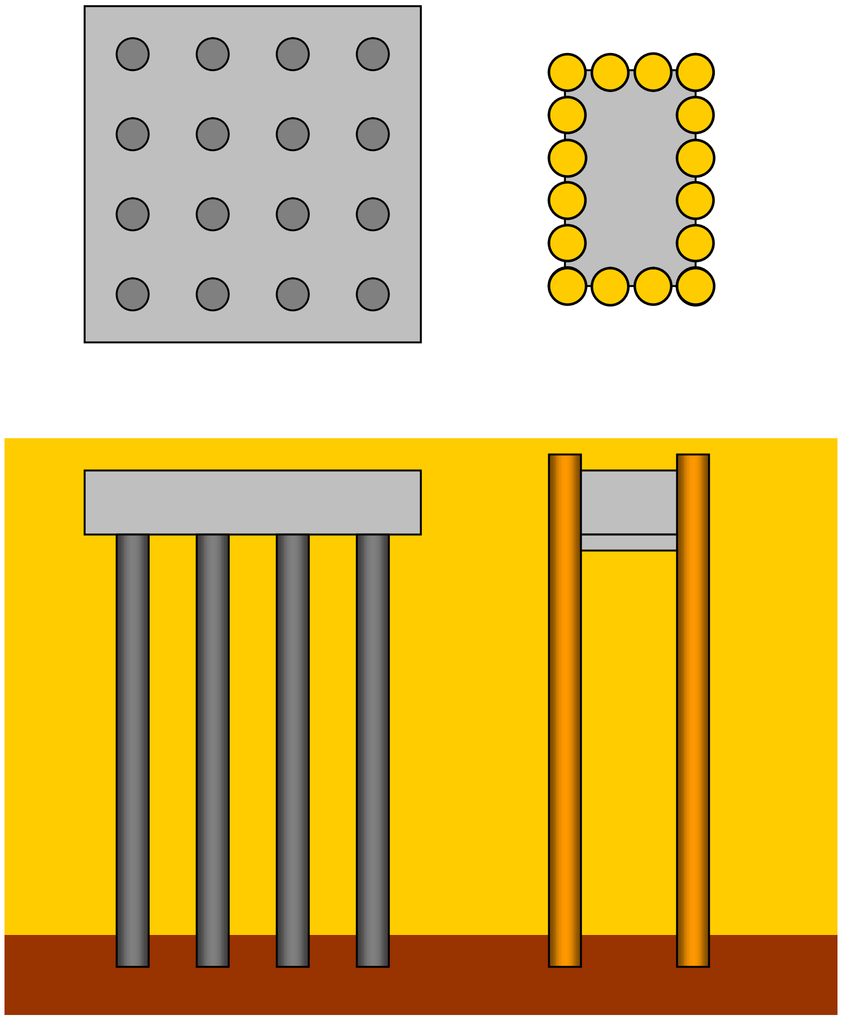
Comparison with Cast-in-place Pile

Item	Cast-in-place Concrete	Steel Pipe Sheet Pile
Application to Deep Foundation	Excavation and concrete placing inside the deep holes is becoming difficult	Possible up to 80m - long piles
Application to Deep-Water	Temporary cofferdam is needed	Used for both foundations and temporary cofferdam
Size of Foundation	Larger	Smaller because of high rigidity
Quality Control	Careful control is needed to spread concrete fully inside the pile holes	Bearing capacity can be confirmed while driving
Construction Period	Longer Temporary cofferdam and excavation	Shorter Driven rapidly, Used also as temporary cofferdam
Construction Cost	Depends on design and site conditions.	More economic in case of deep foundations under deep water.
Environmental Influence	Disposal of waste water and removed soil is more.	Disposal of waste water and removed soil is less.

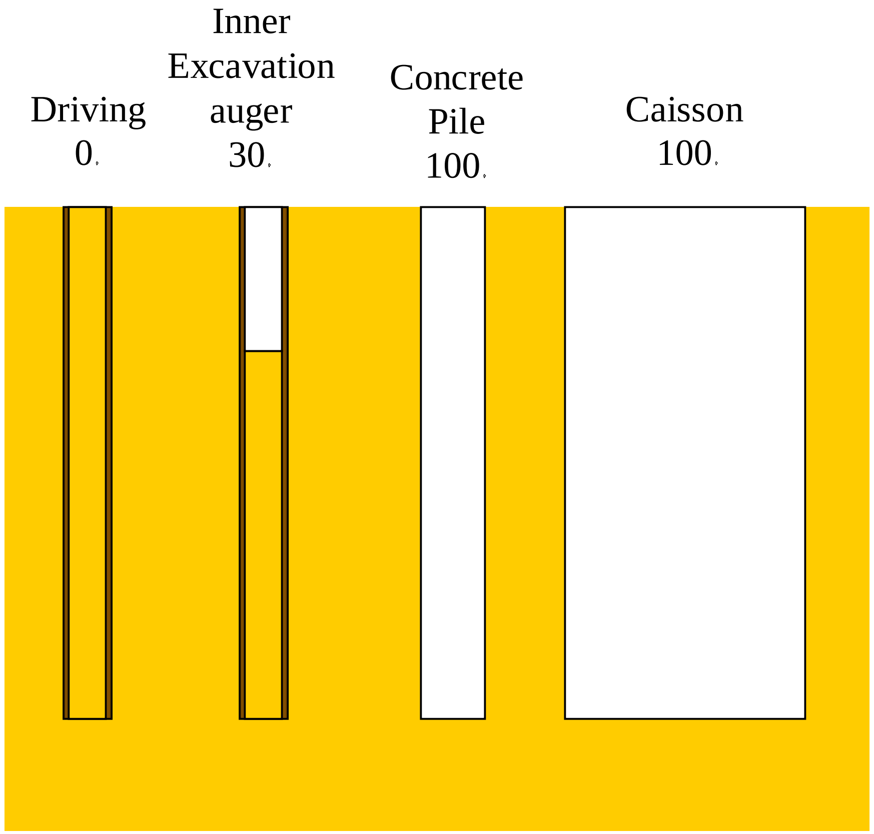
Example in Some Case

Soil	Cast-in-place Pile	Steel Pipe Sheet Pile
		
Area	$207.4m^2$	$44.2m^2$
Occupied	Foundation + Cofferdam	Foundation
Excavation	$1{,}296.0m^3$ ※	$132.6m^3$
Cost	**1.1**	**1.0**

Environmentally Friendly construction method



Soil Excavation of the pile volume



6. Technical Topics

1) Liquefaction
2) How to consider Corrosion
3) Comparison between Steel Sheet Pipe Piles Foundations and PC Well

Special Topics: Liquefaction

1) Liquefaction

A) Saturated loose sandy soil tend to liquefy during an earthquake , causing to structure

- Loose sandy soil mainly located in shore line and river
- High ground water level

B) Mechanics of Liquefaction

Soil is composed of soil itself, water and air

a) Earthquake cause shear motion

b) Shear motion cause the over pore water pressure

c) Soil is like liquid

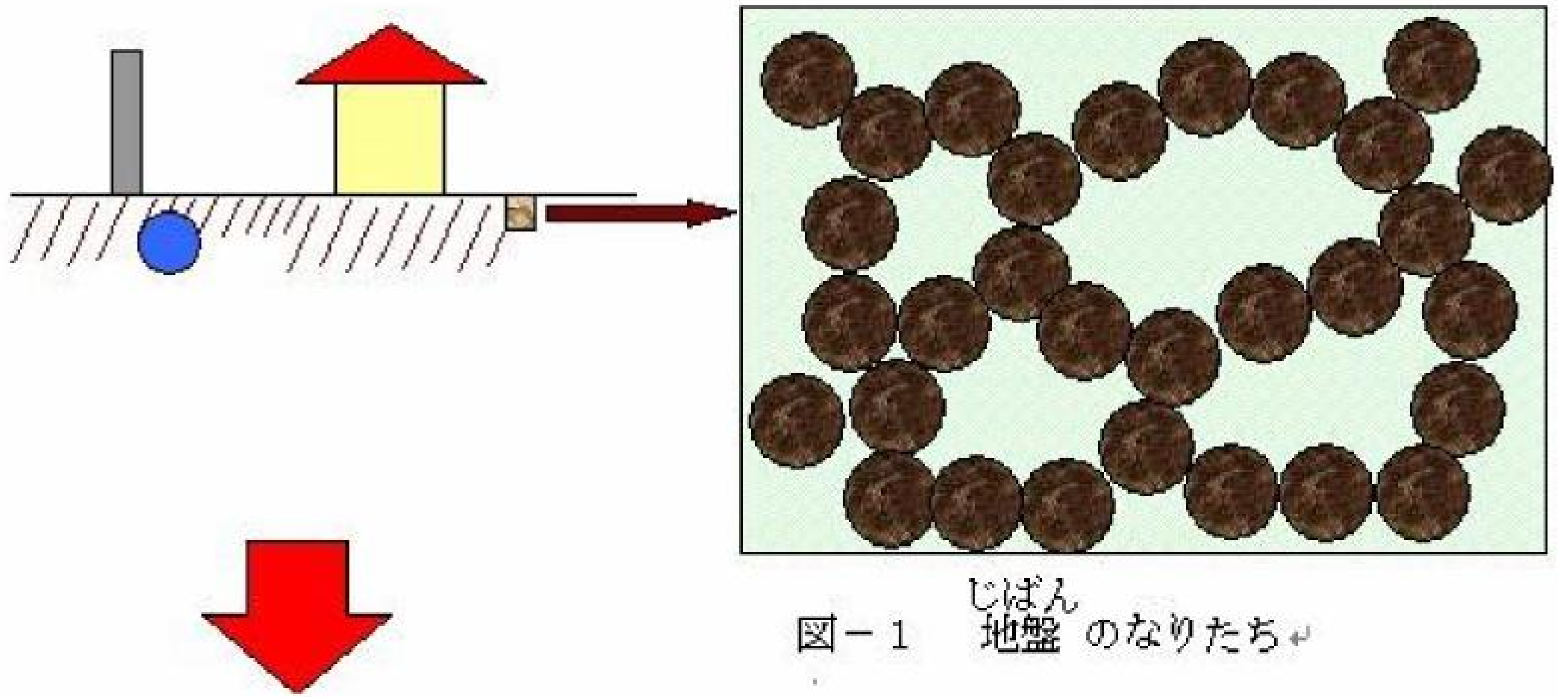
d) Structure heavier than water may sunk

e) Structure lighter than water may float

Mechanism of Liquefaction

Soil in Usual condition

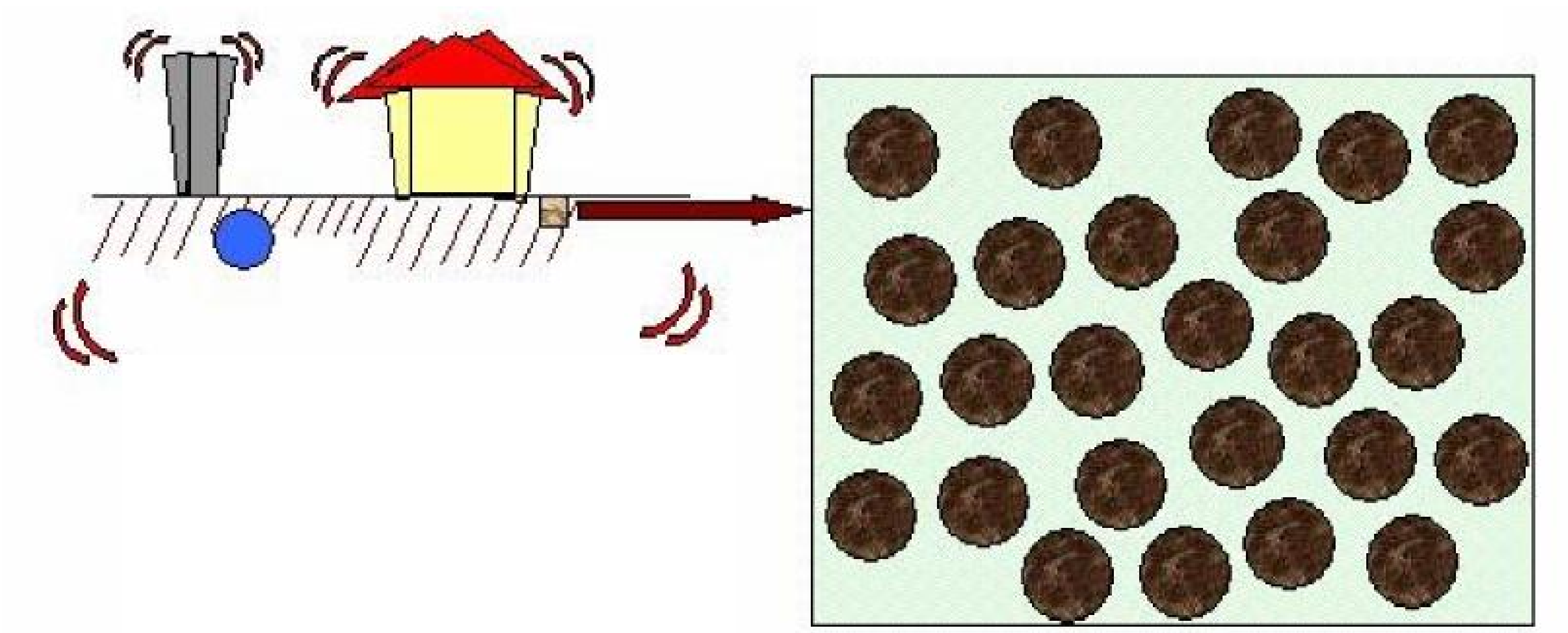
Component of the soil touch each other and other space is full with water



Mechanism of Liquefaction。

Soil Behavior in time of earthquake

Soil particle is floated in the ground water due to over water stress



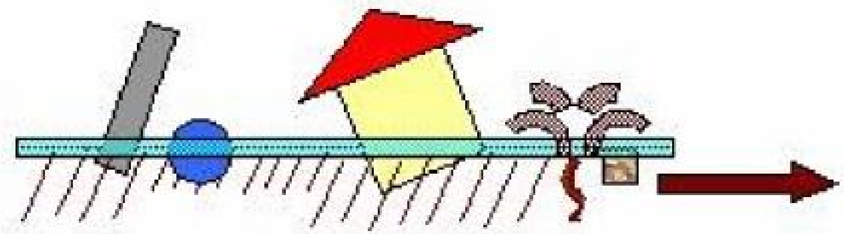
図－2　液状化した地盤（じばん）

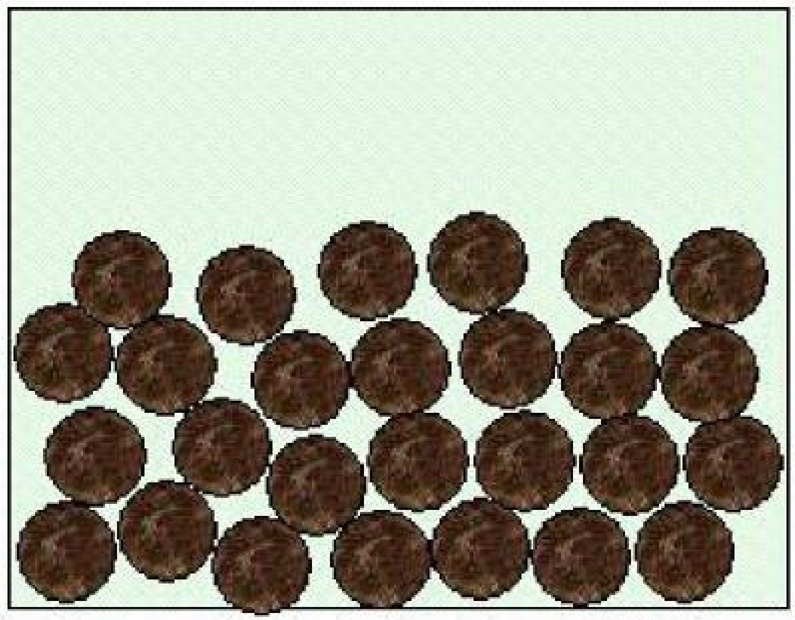
Mechanisms of Liquefaction

Soil ground after Liquefaction

Each particle of the soil shall be sunk , Water flow up to the soil surface

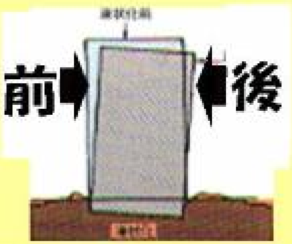
Water contained of sand may flow up to the surface





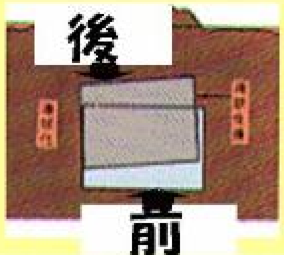
図－３　液状化した地盤（じばん）

Damages due to Liquefaction

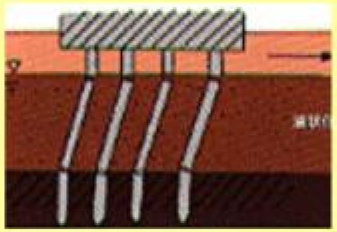


基礎の支持力低下
による沈下、傾斜

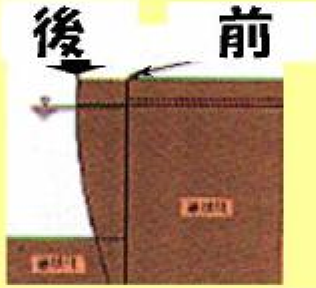
盛土の沈下・変形



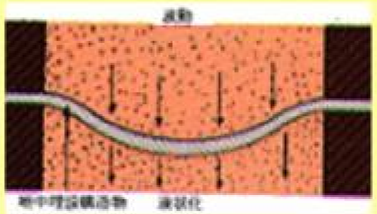
地盤の浮力による
浮き上がり



地盤の永久変形による
杭基礎の被害



主働土圧の増大
受動土圧の減少等
による変形



地盤の永久変形による
地中埋設構造物の被害

Soil condition to consider the liquefaction

In Sand of alluvable layer which has followings three conditions, liquefaction may occur

- Ground water level is high (Within 10m from ground surface) and Saturated loose sandy subsoil lie within 20m from ground surface
- FC less than 35% or

  Ip is less than 15%(Even more than 35%)
- D_{50}(the grain size corresponding to 50%) is less than 10mm and D_{10} is less than 1mm

Ratio of dynamic shear strength to shear stress

□□□ □ □ □

where

□□□Resisting ratio to liquefaction

□ Dynamic shear stress ratio

□ □1max□ σ’□

□ Shear stress ratio in time of earthquake

□ □max□ σ’□

σ□’□Effective stress

τ1max □Repeated shear stress□Repeated number=20□

τmax□Maximum shear stress

When □□□ □ Liquefaction occur

How to use FL

FL□ □ □	□ □□ □ □ □ □ □ □ □ (m)	□ □ □ □ □ □			
		□ □0.3		0.3□ □	
		□ □ 1□ □ □	□ □ 2□ □ □	□ □ 1□ □ □	□ □ 2□ □ □
FL□ 1/3	0□ □ 10	1/6	0	1/3	1/6
	10□ □ 20	2/3	1/3	2/3	1/3
1/3□ FL□ 2/3	0□ □ 10	2/3	1/3	1	2/3
	10□ □ 20	1	2/3	1	2/3
2/3□ FL□ 1	0□ □ 10	1	2/3	1	1
	10□ □ 20	1	1	1	1

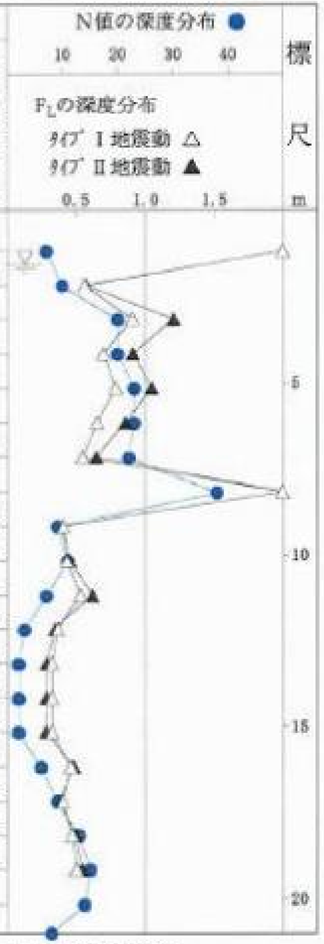
Design figure must be reduced based on FL and R

Example of prediction of liquefaction

件名： 上ノ加江　　ボーリングNo.： A　　地盤標高： 0 m　　地下水位：GL-1.56 m

地層深度 (m)	層厚 (m)	γ_t (kN/m3)	γ_{sat} (kN/m3)	γ' (kN/m3)	計算深度 (m)	N値	σ_v (kN/m2)	σ_v' (kN/m2)	F_c (%)	P_c (%)	I_p	D_{50} (mm)	D_{10} (mm)	計算式の種別
					1.15	7	20.70	20.70	12.6			4.631	0.043	G
					2.15	10	39.29	33.39	12.6			4.631	0.043	G
					3.15	20	58.29	42.39	12.6			4.631	0.043	G
					4.15	20	77.29	51.39	12.6			4.631	0.043	G
					5.15	23	96.29	60.39	12.6			4.631	0.043	G
					6.15	23	115.29	69.39	12.6			4.631	0.043	G
					7.15	22	134.29	78.39	12.6			4.631	0.043	G
8.50	8.50	18.00	19.00	9.00	8.15	38	153.29	87.39	12.6			4.631	0.043	G
					9.15	9	172.29	96.39	28.8			0.129	0.046	S
10.50	2.00	18.00	19.00	9.00	10.15	11	191.29	105.39	28.8			0.129	0.046	S
					11.15	7	210.29	114.39	74.9			0.016	0.001	S
					12.15	3	229.29	123.39	74.9			0.016	0.001	S
					13.15	2	248.29	132.39	74.9			0.016	0.001	S
					14.15	2	267.29	141.39	74.9			0.016	0.001	S
					15.15	2	286.29	150.39	74.9			0.016	0.001	S
					16.15	6	305.29	159.39	74.9			0.016	0.001	S
17.60	6.50	18.00	19.00	9.00	17.15	9	323.69	167.79	38.7			0.110	0.004	S
					18.15	13	338.69	172.79	38.7			0.110	0.004	S
					19.15	15	353.69	177.79	38.7			0.110	0.004	S
					20.15	14	368.69	182.79	38.7			0.110	0.004	S
21.30	4.30	14.00	15.00	6.00	21.15	8	383.69	187.79	38.7			0.110	0.004	S

計算深度 (m)	タイプI地震動 (C_z = 1.00, K_{hc0} = 0.40, K_{hc} = 0.40) R	L	F_L	低減係数 D_E	タイプII地震動 (C_z = 1.00, K_{hc0} = 0.60, K_{hc} = 0.60) R	L	F_L	低減係数 D_E
1.15	****	****	****	1	****	****	****	1
2.15	0.256	0.456	0.561	1/3	0.387	0.683	0.566	2/3
3.15	0.474	0.524	0.905	1	0.949	0.786	1.207	1
4.15	0.392	0.564	0.695	1	0.771	0.846	0.911	1
5.15	0.462	0.589	0.786	1	0.925	0.883	1.048	1
6.15	0.393	0.603	0.652	2/3	0.775	0.905	0.856	1
7.15	0.334	0.612	0.546	2/3	0.592	0.918	0.645	2/3
8.15	2.042	0.616	3.315	1	4.084	0.924	4.421	1
9.15	0.250	0.617	0.406	1/3	0.375	0.925	0.405	2/3
10.15	0.268	0.615	0.436	2/3	0.417	0.923	0.452	2/3
11.15	0.325	0.612	0.530	2/3	0.566	0.919	0.616	2/3
12.15	0.223	0.608	0.366	2/3	0.313	0.912	0.343	2/3
13.15	0.194	0.602	0.322	1/3	0.254	0.903	0.281	1/3
14.15	0.192	0.596	0.322	1/3	0.249	0.894	0.279	1/3
15.15	0.189	0.588	0.322	1/3	0.245	0.883	0.278	1/3
16.15	0.269	0.581	0.463	2/3	0.419	0.871	0.481	2/3
17.15	0.232	0.573	0.404	2/3	0.332	0.860	0.386	2/3
18.15	0.270	0.571	0.473	2/3	0.421	0.856	0.492	2/3
19.15	0.286	0.567	0.504	2/3	0.462	0.861	0.542	2/3
20.15	****	****	****	*	****	****	****	*
21.15	****	****	****	*	****	****	****	*
P_L			34.01				27.71	
C_{NL}			1.00				1.00	
沈下量			0.60				0.58	



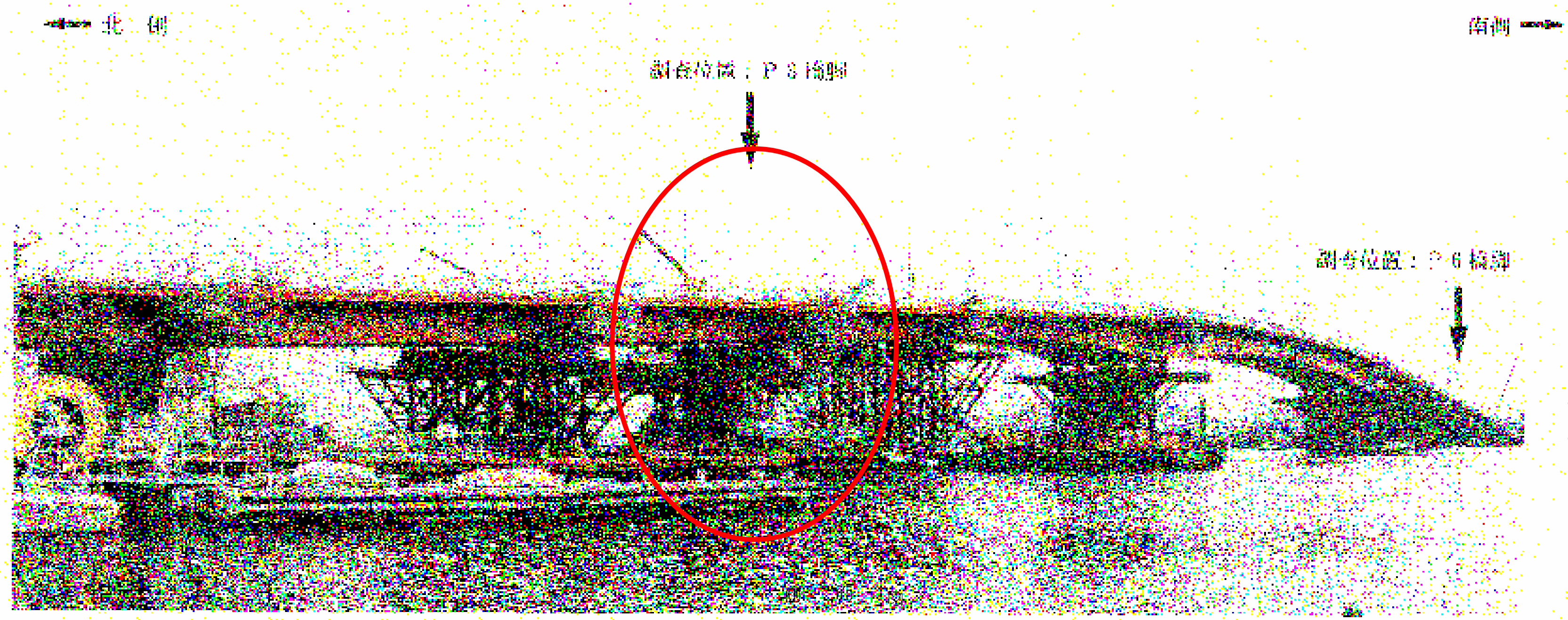
対象土層条件　Fc≦35%またはFc>35%の場合Ip≦15
D50≦10mmかつD10≦1mm

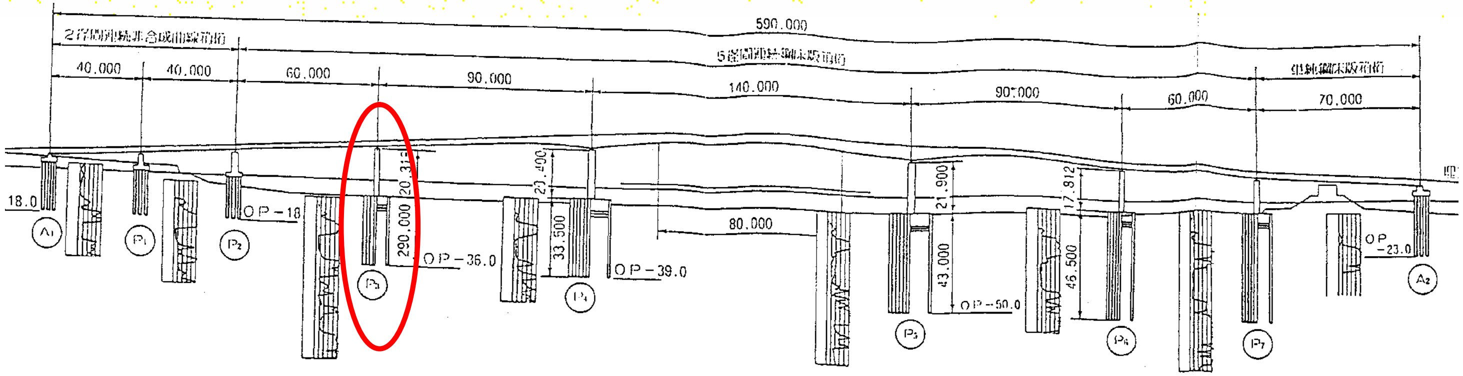
地震時せん断応力比の深さ方向の低減係数　γd = 1.0 − 0.015X

式の種別
S：砂質土
G：礫質土

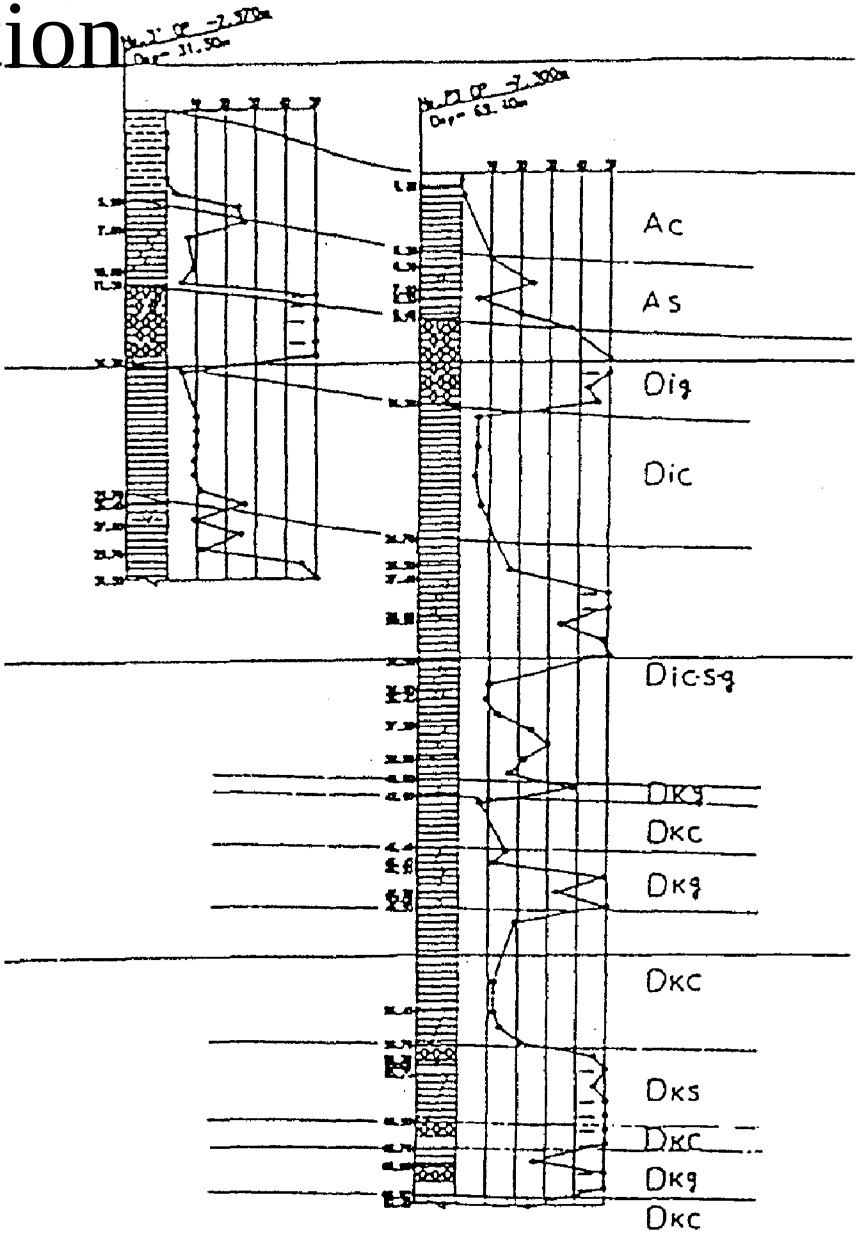
P_Lによる補正係数C_{NL}
$P_L \leq 5$　:C_{NL} = 0
$5 < P_L \leq 20$:C_{NL} = (0.2 P_L − 1) / 3
$20 < P_L$　:C_{NL} = 1

Survey of the Nishinomiya Ohashi Bridge affected by the Great Hanshin Earthquake of1995

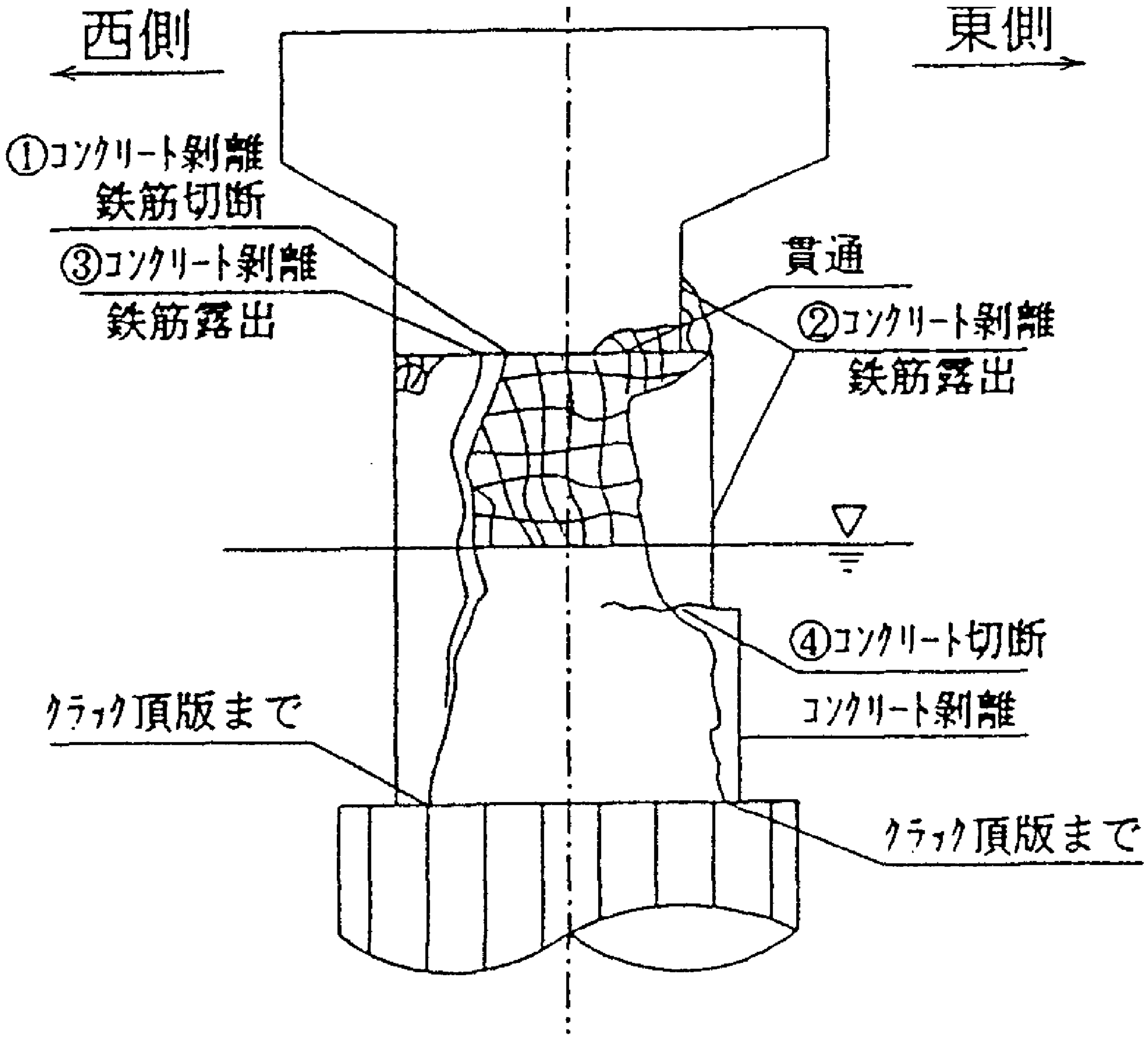




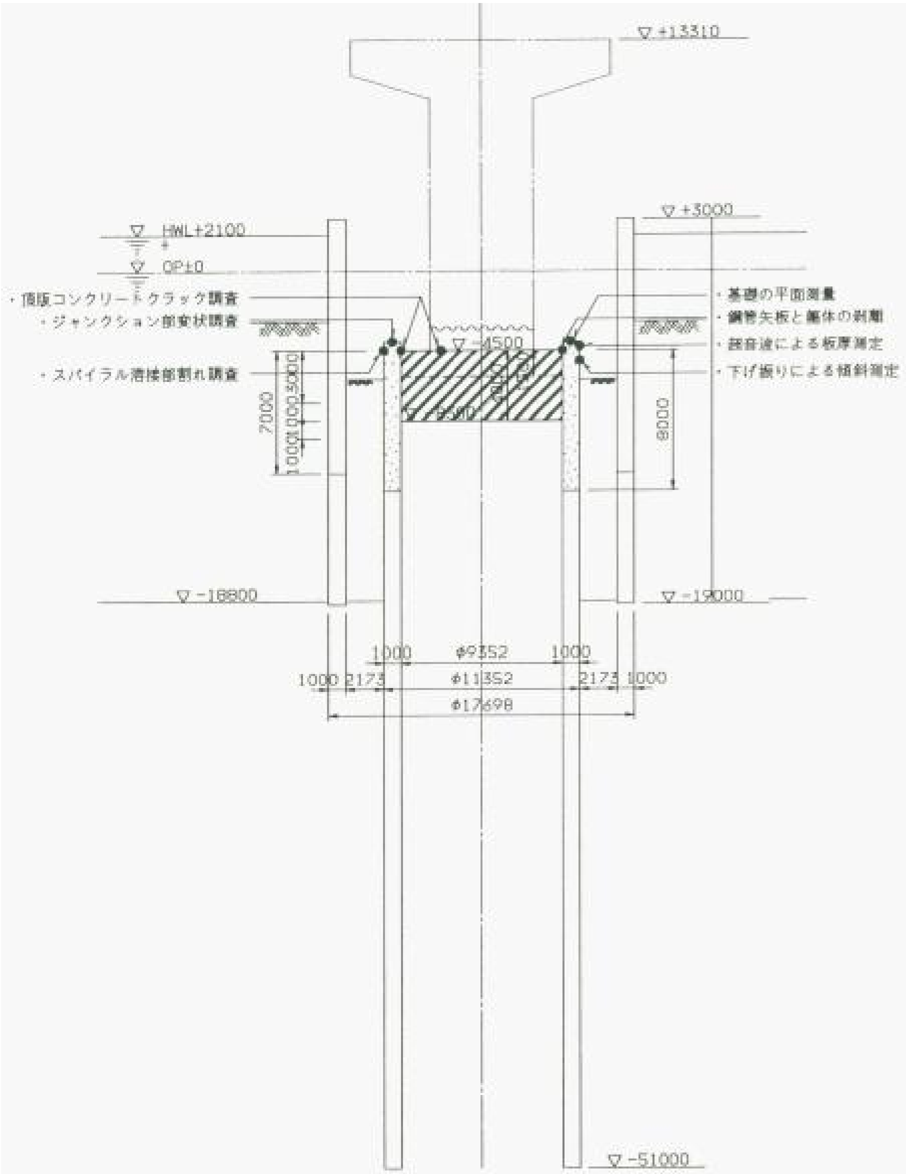
Soil Condition



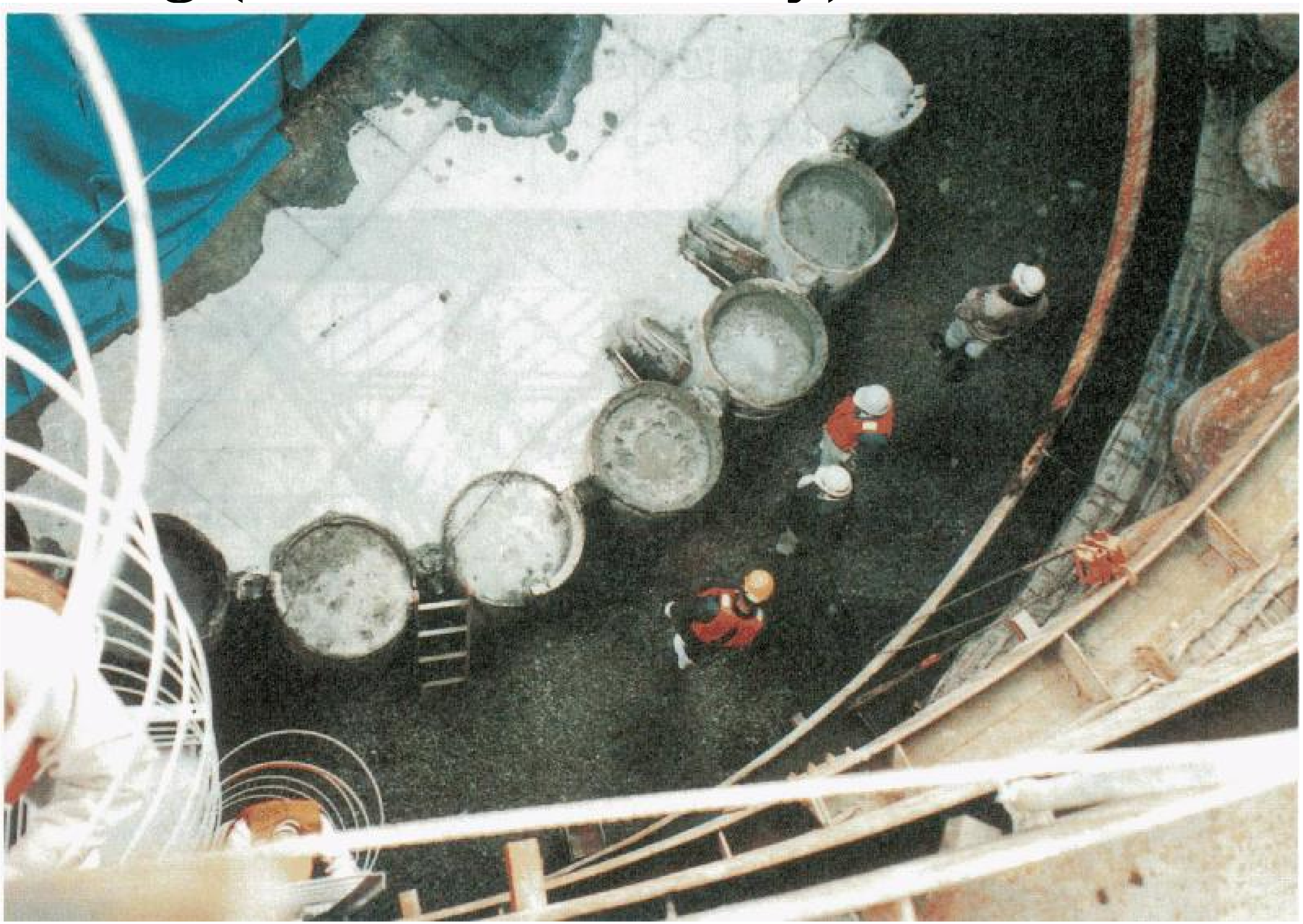
Damage of the Bridge Pier



Examine the steel sheet pipe pile foundation



◊ To check the occurrence of footing concrete cracking (Excavation survey)



To check the interlocking joints

To check the connecting methods between steel sheet pipe pile and footing conceret

Results of investigation

- There is no damage on footing concrete, connection methods (Plate – Bracket methods) and in between.
- There is no drawback on the interlocking
- Welding on spirals steel pipe piles and on site connecting welding is very good after earthquake
- There is no drawback on welding portion of plates on to the steel pipe sheet piles

Steel Pipe sheet pile foundation has high seismic resistance

Establishment of Corrosion-protection Design Methods for Steel Structure and Future Development in Japan

JISF

Southeast Asia Steel Structure Seminar 2005

Hiromasa NAKANO

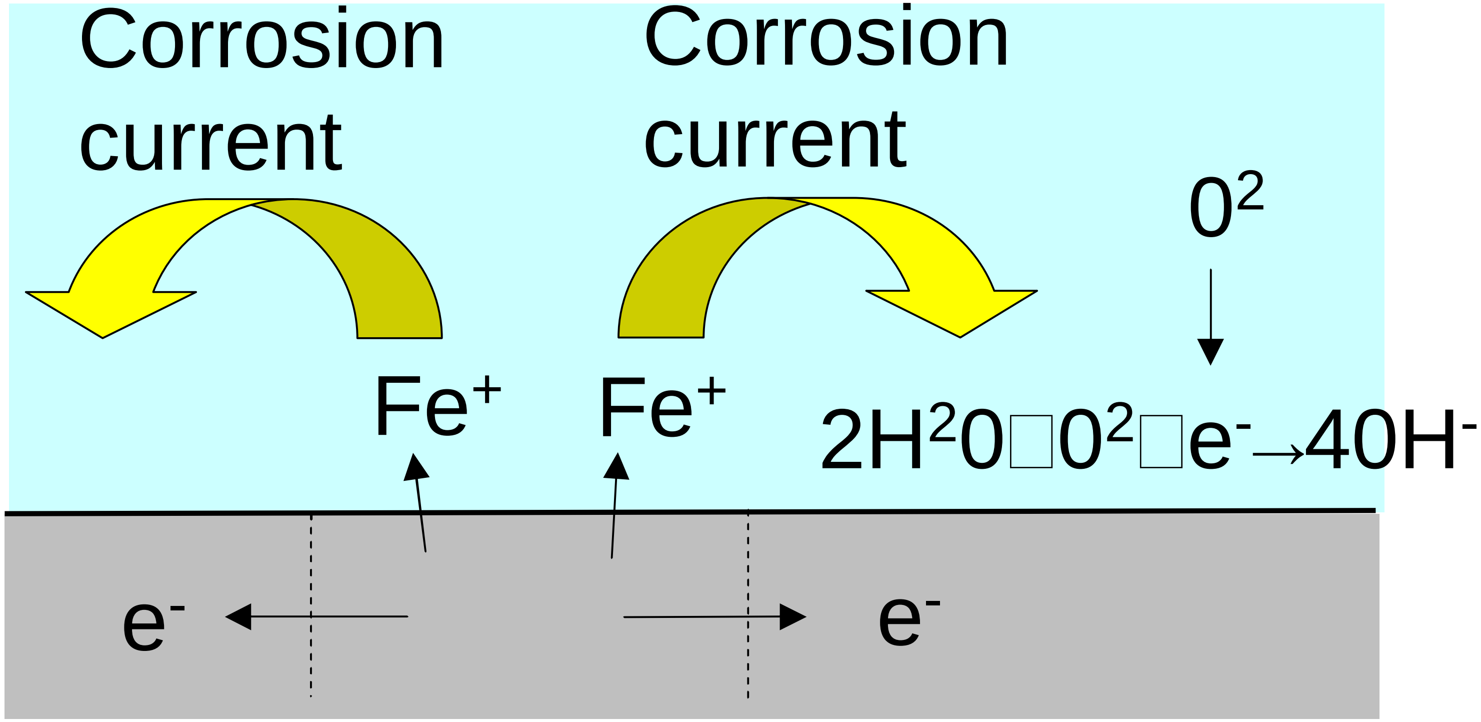
Suitomo Metal Industries

Outline of Presentation

- **Current state of corrosion protection**
  - Port and harbor steel structure
    - Mechanisms in seawater environment
    - Corrosion protection method
    - Research
  - Substructure
    - Mechanisms in underground environment
    - Corrosion protection method
    - Research
- **Future of corrosion protection**

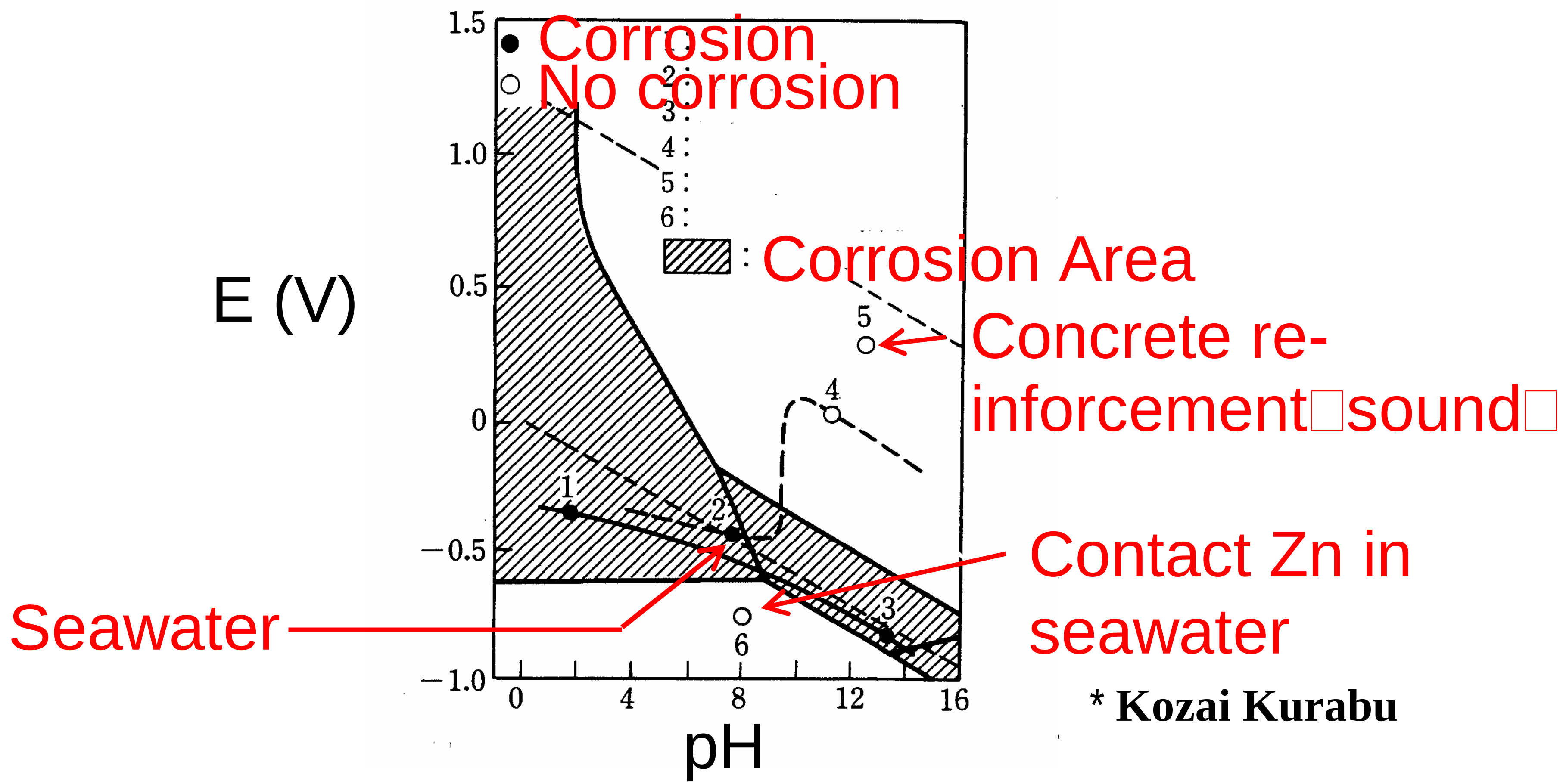
Mechanisms of Corrosion

- **Schematic diagram of local cell**



Mechanisms of Corrosion

- **Chemical equilibrium phase***



*** Kozai Kurabu**

Mechanisms of Corrosion

- **Corrosion types**
  - General Corrosion
    - Nearly uniform corrosion loss
  - Local Corrosion
    - Corrosion in which deep corrosion occurs in specified sections

Mechanisms of Corrosion

- **Underground corrosion of steel pipe piles**
  - Environment
    - Not uniform contrast to atmosphere and seawater → local cell
  - Characteristic
    - Difficult to occur local corrosion
      - Driven in vertically without disturbing the soil
    - Corrosion rate tend to decrease as time lapses
      - Corrosion products remain attached

Corrosion Protection Methods

- **Steel pipe pile**

  Bridge substructure, Building foundation

  - Usual environment
    - Anticipate corrosion

      1mm … Based on long-term survey
    - Not necessary for inner surface
  - Unusual environment

    ex. Seawater, Repeat dry and wet, etc.
    - Countermeasure must be taken

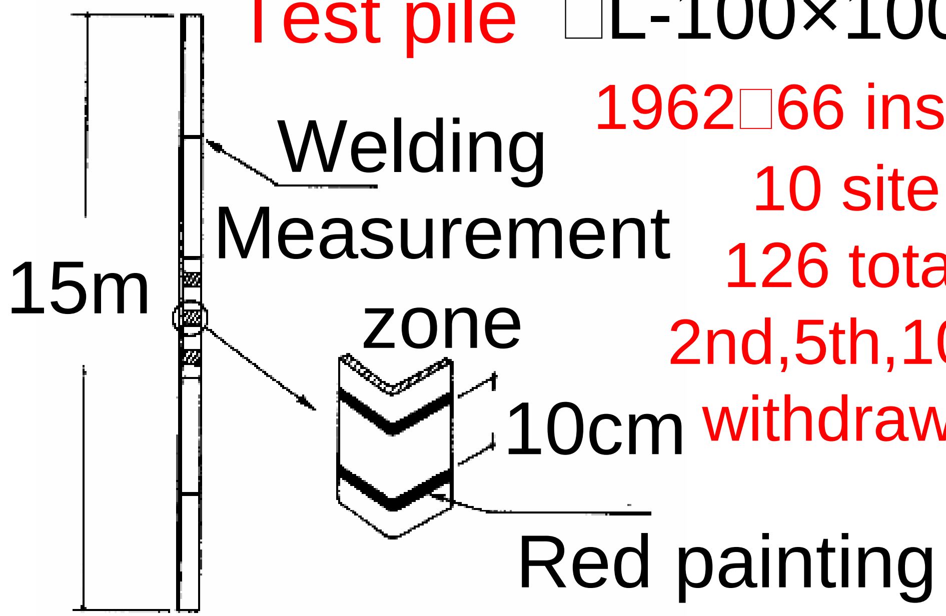
Research of Corrosion

* Kozai Kurabu

- **Research by Dr. OSAKI ***

Prominent among surveys that constitute the basis of anticipate corrosion

Test pile □L-100×100



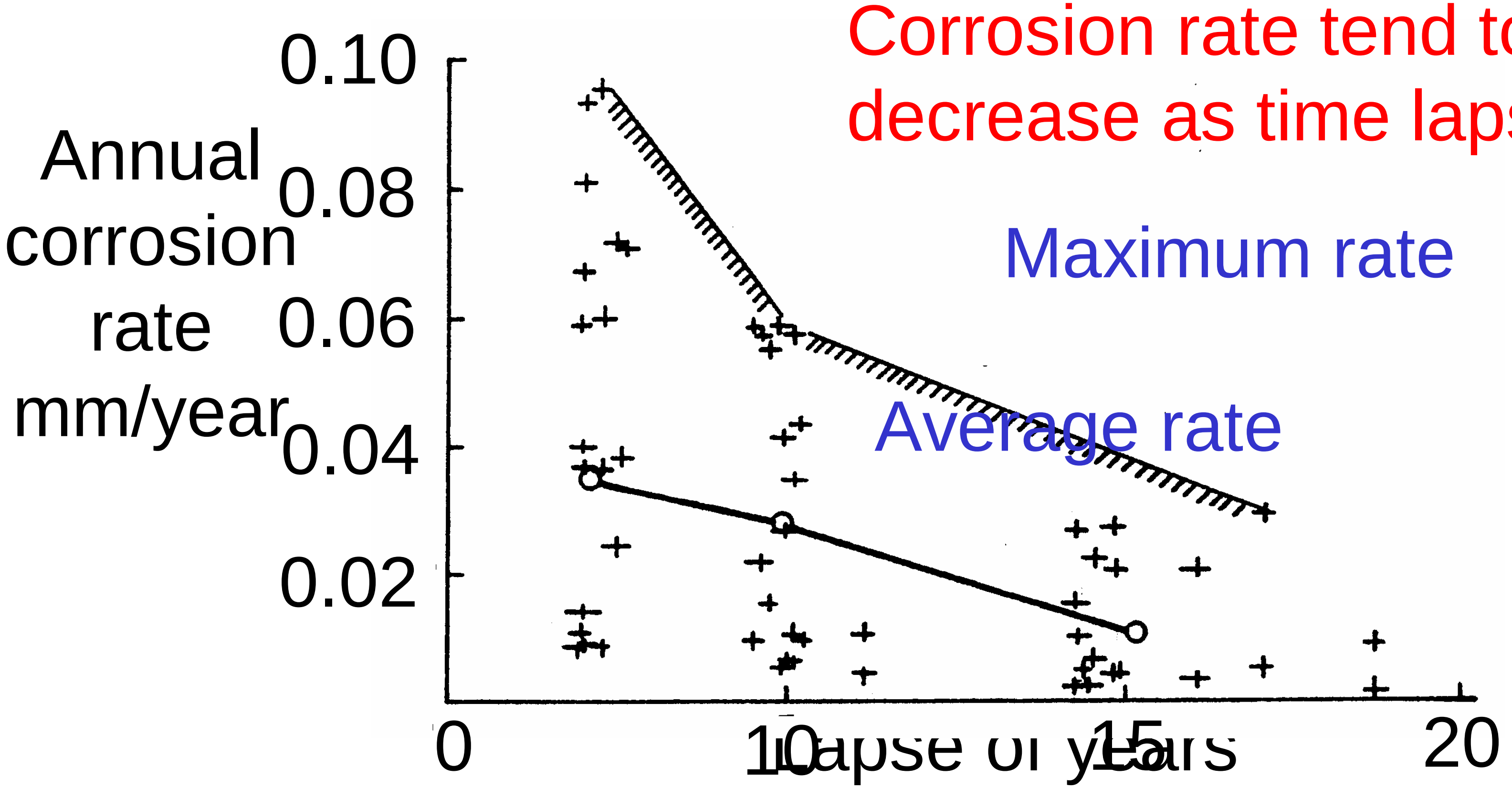
1962□66 installed
10 site
126 total
2nd,5th,10th withdrawn

Research of Corrosion

*** Kozai Kurabu**

- **Research by Dr. OSAKI ***

Corrosion rate tend to decrease as time lapses



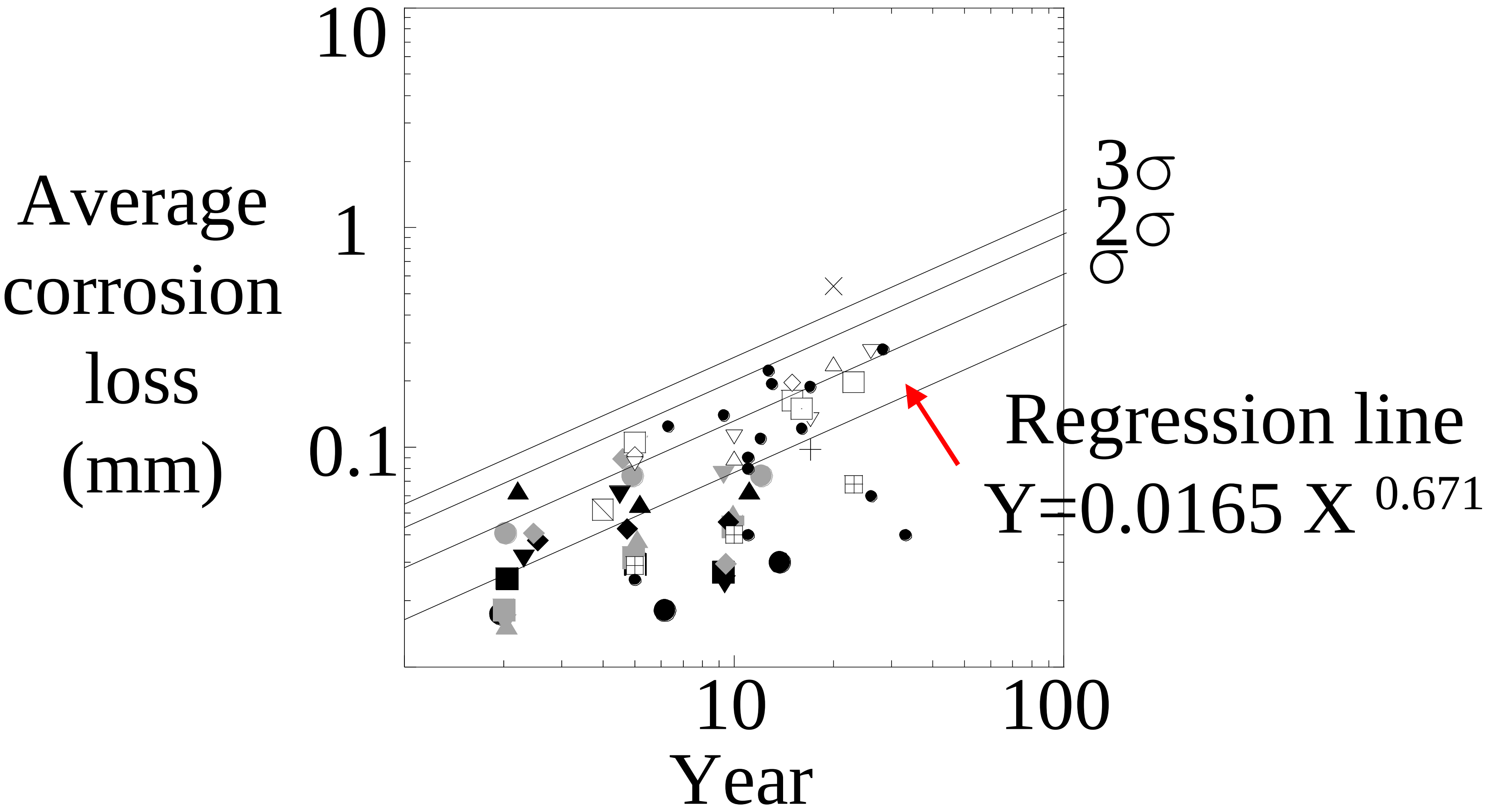
Research of Corrosion

- **Statistical examination based on subsequent survey**

	site	data
Pipe pile	9	18
Sheet pile	14	14
L	10	30
Total	33	62

Research of Corrosion

- **Result of statistical examination**



PC Well

- Diameter from 1.6m to 8.0m
- Construction:

An open-end cylindrical structure made of concrete is produced on the ground and gradually sunk by eliminating earth out of the cylinder interior , until it reaches a specified bearing layer.

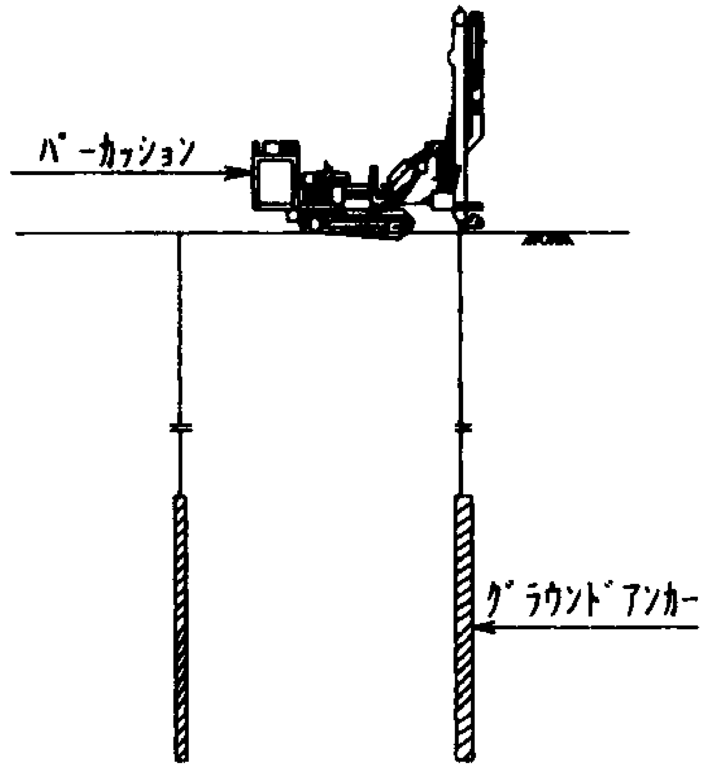
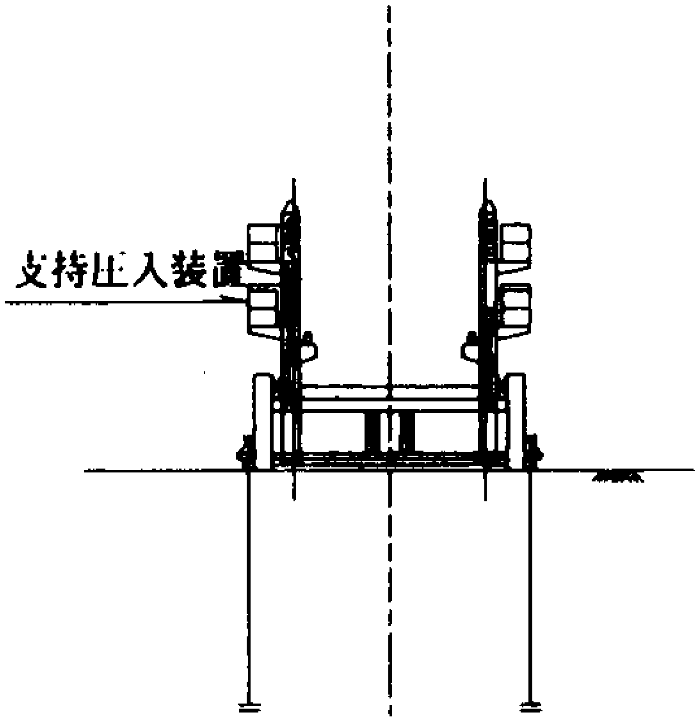
- Standard of PC Well Unit :

Diameter : from 1.6m to 4.0m

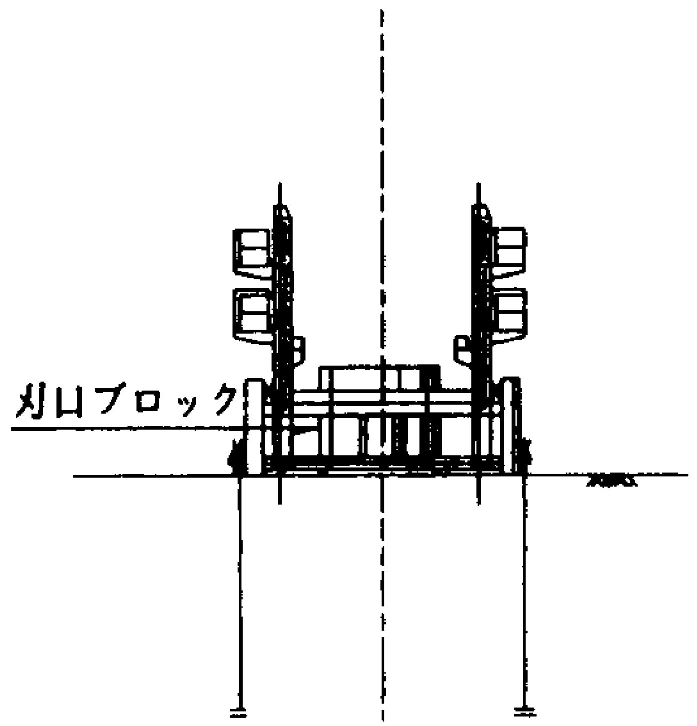
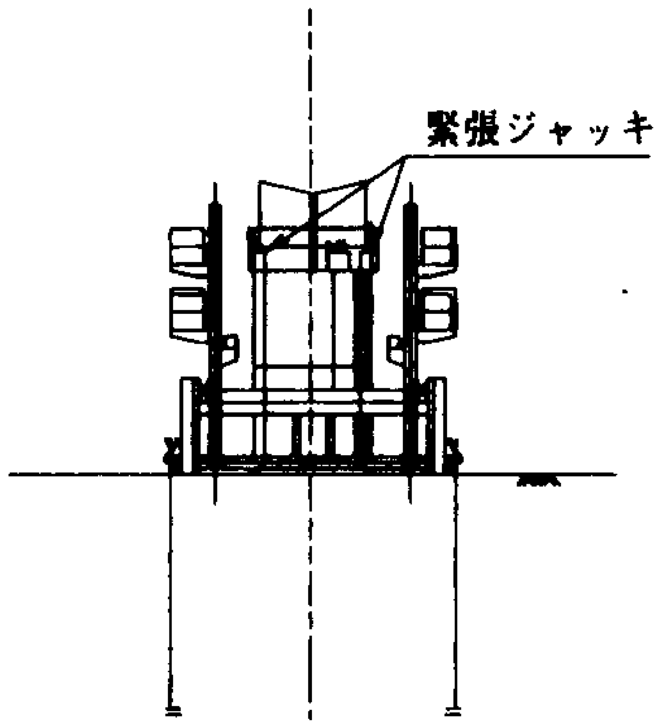
- Features:

Mostly applied to the construction very adjacent to the existing structure

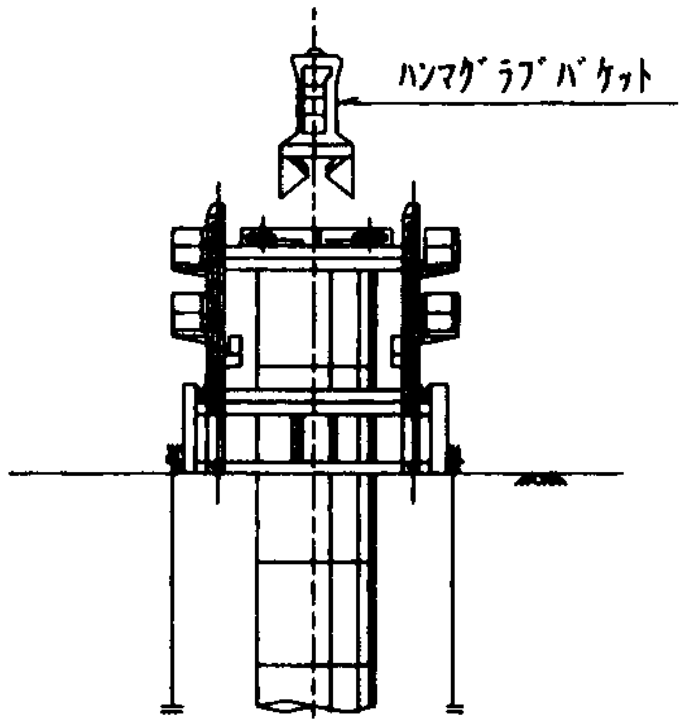
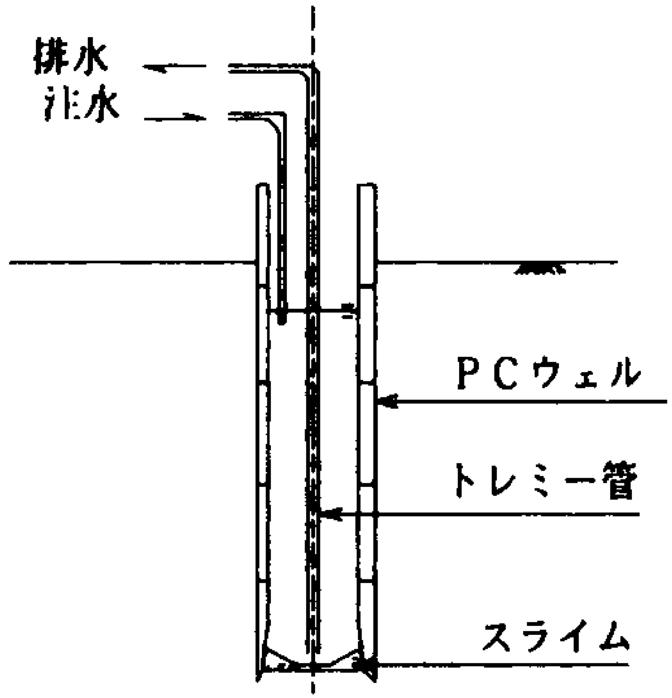
Construction Procedure

①グラウンドアンカー工	②支持圧入装置組立工
	
ＰＣウェル沈設に必要な反力としてグラウンドアンカーを施T.します。	支持圧入装置を杭心で組み立て，反力となるグラウンドアンカーと接続します。

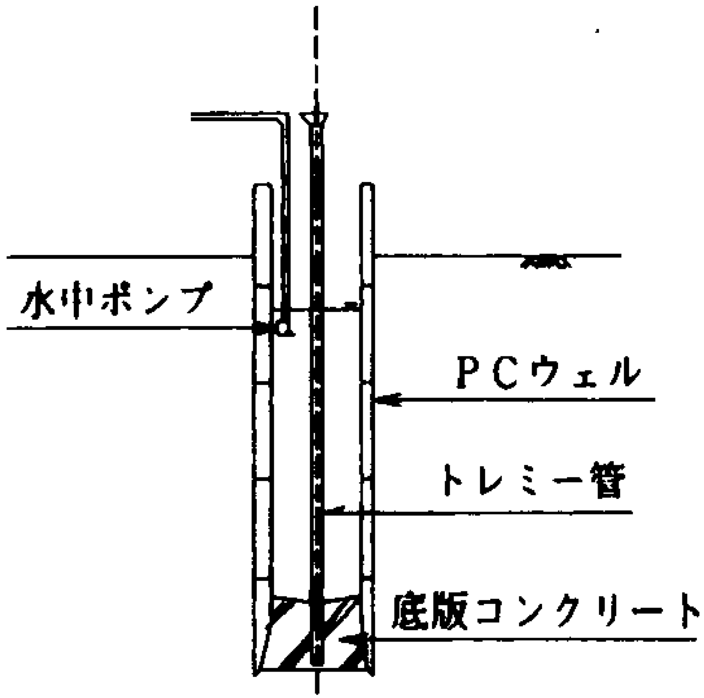
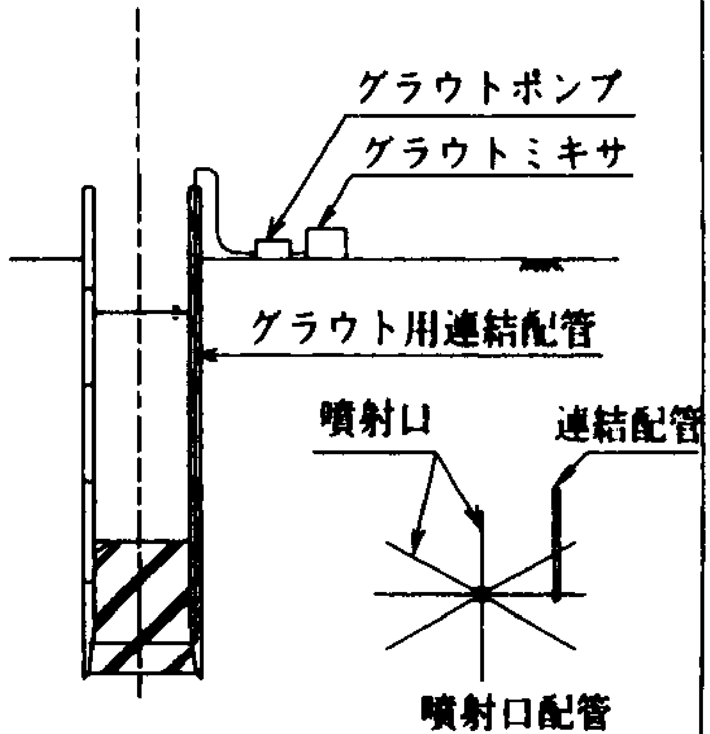
Construction Procedure(2)

③刃口ブロック据付工	④ＰＣウェル構築工
	
刃口ブロックをピンブラケットで受け、支持圧入装置に据え付けます。	ウェル躯体を支持しながら刃口ブロックと次ブロックまたはブロック同士をＰＣ鋼棒で緊張一体化させ躯体を構築します。

Construction Procedure(3)

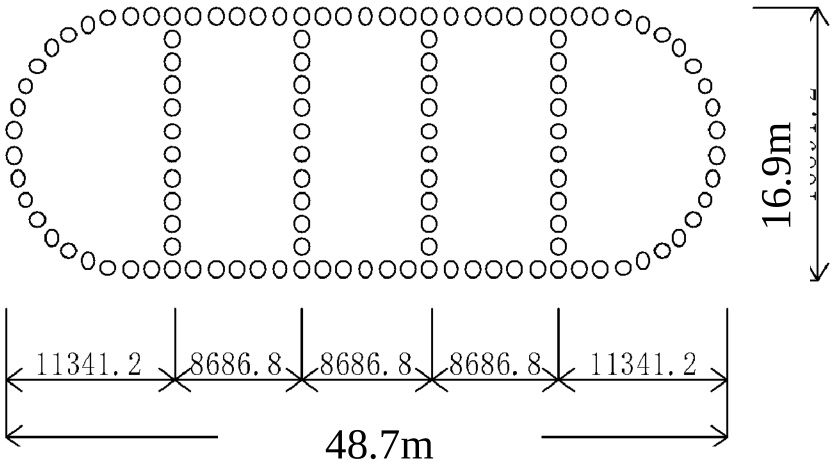
<table>
<tr><th>⑤掘削沈設工（ﾊﾝﾏｸﾞﾗﾌﾞﾊﾞｹｯﾄ使用時）</th><th>⑥スライム処理工</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>ハンマグラブバケットで掘削排土しながらブロックの継ぎ足しを繰り返し所定の深度まで沈設します。</td><td>所定の深度に沈設後，沈降剤を投入し，沈でんしたスライムをトレミー管で除去します。</td></tr>
</table>

Construction Procedure(4)

<table>
<tr><th>⑦底版コンクリート工</th><th>⑧周面コンタクトグラウト工</th></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>水中コンクリート工法で底版コンクリートを打設します。</td><td>沈設地盤が岩盤系地盤などの場合には，必要に応じてウェル周面にグラウトを施します。</td></tr>
</table>

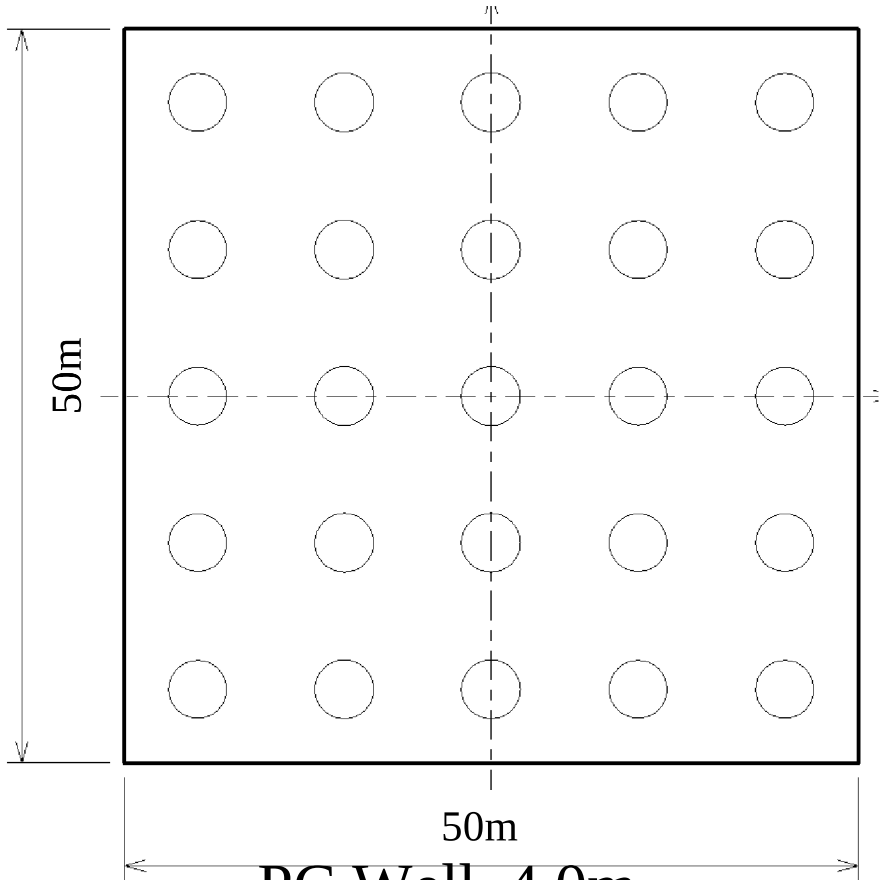
Comparison between Steel Sheet Pipe Pile Foundation and PC Well

Steel Sheet Pipe Pile Foundation



Steel Sheet Pipe Pile ..1.2m

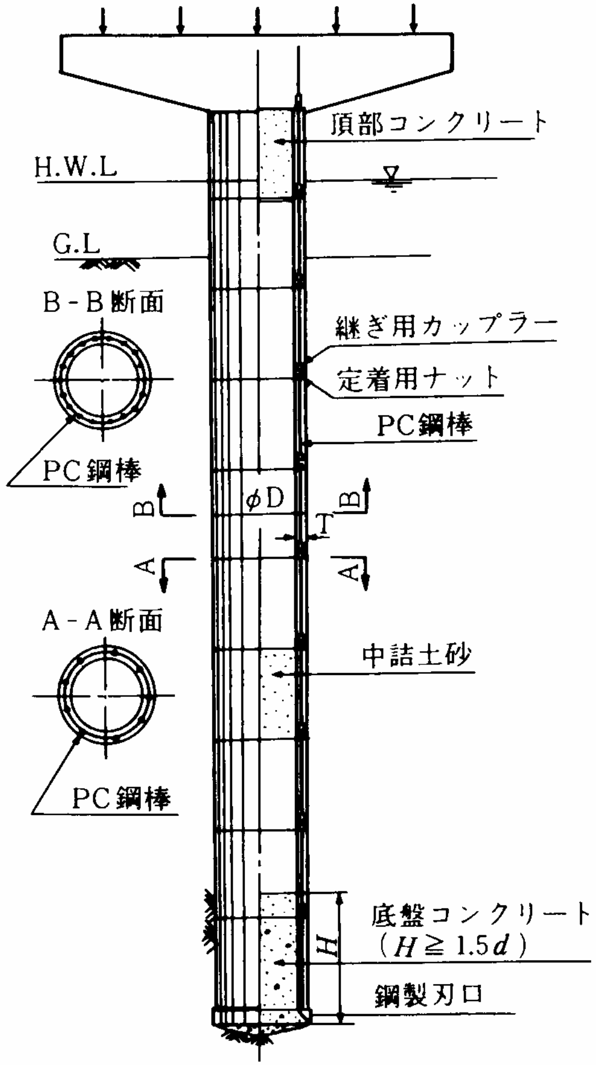
PC Well



PC Well..4.0m

Comments about PC Well Foundation

- PC Well is mainly used for T type of Bridge single pier.
- Based on the comparison study, in case of PC Well, top concrete footing is a little bit larger than Steel Sheet Pipe Pile foundation
- There is some difficulties for large diameter and deep foundations



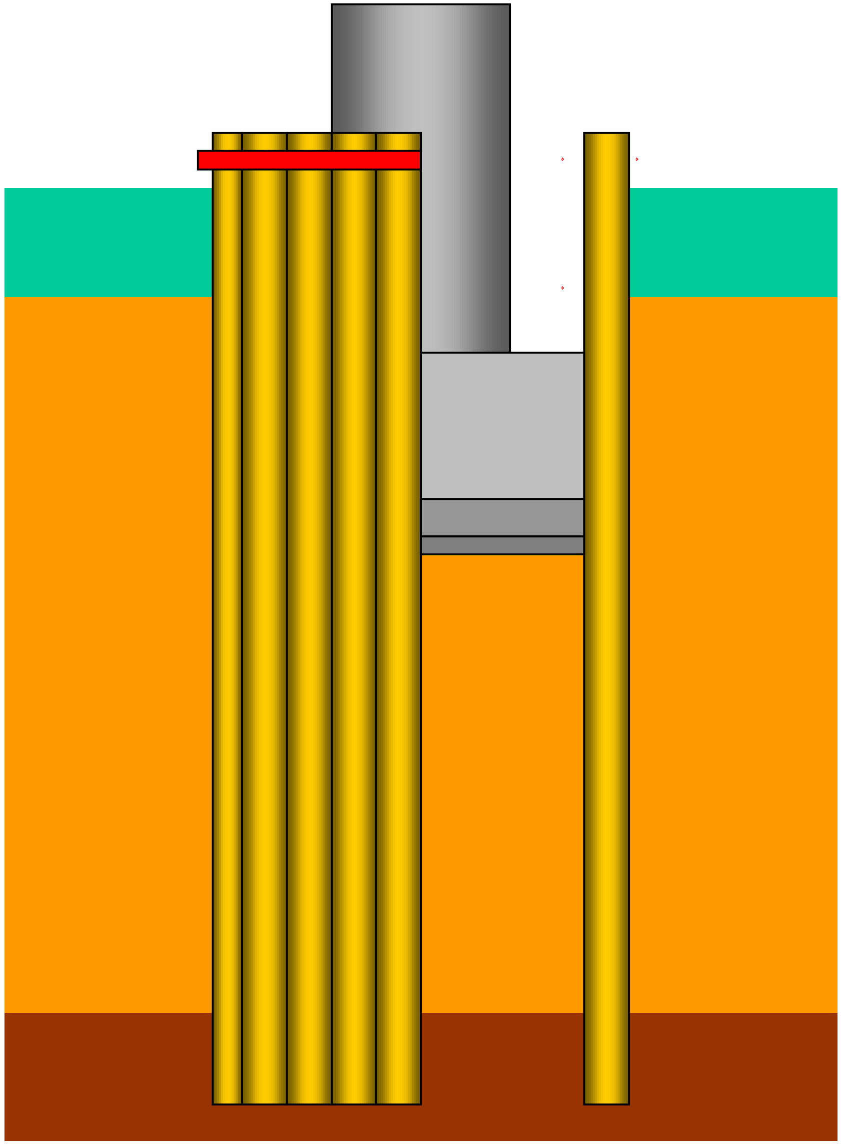
7.Subjects of applying the Steel Pipe Sheet Pile Well in Vietnam

1. To transfer and develop the design methods
2. This foundation is required of the construction experience

   - Construction Procedure

   - Materials of Steel Sheet Pipe Pile

Advantage of Steel Pipe Wells Foundation



.Large depth of water and soft ground

.Construction time and cost reducible
without temporary cofferdam

.Small area required during work because
the foundation body is compact

.Rational and economical design using
best fit of diameter and wall thickness of
steel pipe well

.Applicable to deep bearing stratum with
High safety

.High reliability of large seismic