Case studies in Japan

Applications of piled raft foundations to buildings

2 cases from TAISEI Corporation
10 cases from TAKENAKA Corporation
1 case from OBAYASHI Corp. and YASUI KENCHIKU Corp.
Importance of case study

- Load transfer of piled rafts assumed in design is compatible with field performance?
- Influence of construction method on behaviour of piled rafts?
- Influence of change in ground water table (water pressure at the raft base) on behaviour of piled rafts?

- Confirmation of possibility of piled rafts through field observations.
- Development of new pile construction methods adequate for piled rafts.
Location: Tsukuba City
Number of stories: Two above grade
Building area: 530 m²
Total floor area: 1040 m²
Superstructure type: Reinforced concrete
Foundation type: Piled raft
Construction: July 1999 to March 2000

New building
Piled raft

Existing building
Pile group

TAISEI Corporation
### Piled raft for low-rise building

#### Design process

1. **Pile group in archi-design**
2. **Piled raft in final design**

#### Symbol Table

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Direction</th>
<th>Pile section</th>
</tr>
</thead>
<tbody>
<tr>
<td>○</td>
<td>H</td>
<td>H-250 × 250 × 9 × 14</td>
</tr>
<tr>
<td>●</td>
<td></td>
<td>H-250 × 250 × 9 × 14</td>
</tr>
</tbody>
</table>

#### Cross-section

- **Symbol**: ○, ●
- **Direction**: H
- **Pile section**: H-250 × 250 × 9 × 14

#### Pile arrangement

- **Building**: Cast in-situ concrete piles
- **H steel (Final Design)**: 10 - 20 - 30 - 40
- **Soil type**: Loam, Silty sand, Silt, Fine sand
- **Soil N values**: 10, 20, 30, 40

- **In archi-design**: Cast in-situ concrete piles

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**TAISEI Corporation**

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**Note**: The above image includes a diagram showing the pile arrangement and a table with symbols and directions for the pile sections.
Combined use of anti-liquefaction soil improvement and piled raft

Design process

SC piles having a length of 43 m

SC piles having a length of 25 m

Location: Tokyo
Number of stories: Three above grade
Building area: 810 m²
Total floor area: 2400 m²

Foundation type: Soil improvement + Piled raft
Construction: Nov. 2000 to May 2001

Settlement reducing piles:
SC pile: H-steel + soil cement
45 piles

Soil improvement:
178 sand piles

TAISEI Corporation
Combined use of anti-liquefaction soil improvement and piled raft

Sand piles contribute to preventing liquefaction and increasing the bearing resistance of the raft.

Length of the settlement reducing piles was reduced to 25 m from 43 m.

TAISEI Corporation
Study on behavior of vertical load transfer of pile foundations

Dr. Thesis of Tokyo Institute of Technology

Masaaki Kakurai

Tokyo Soil Research Corp.

(formerly Research Institute of Takenaka Corp.)

10 case studies
Case studies of pile raft foundations

Foundations design as pile groups
  3 cases of ordinary construction method
  2 cases of reverse construction method

Foundations designed as piled rafts
  3 cases in Alluvial ground
  2 cases in Diluvial ground

10 cases in total
Foundations constructed by ordinary construction methods

RC building
High-rise steel building
Twin building of RC structure
Reinforced concrete building

6-story above grade
1-story below grade
Building area = 1,902 m²
Total floor area = 11,132 m²
Vertical load per unit base area = 130 kPa

Piles: primarily end-bearing pile (designed as pile group)
Cast-in-situ concrete pile with bell bottom.
\( D_s = 2.1 \text{ m} \) (shaft), \( D_b = 3.1 \text{ m} \) (base)

Monitoring:
Axial forces in a pile (4 levels).
Contact pressure and water pressure at the center point of the raft.
**Vertical load, earth pressure and water pressure beneath the raft**

**Proportions of total vertical load carried by the piles and the raft**
Reinforced concrete building

Piles: primarily end-bearing pile
Cast-in-situ concrete pile with bell bottom. $D_s = 2.1$ m (shaft), $D_b = 3.1$ m (base)

Design concept of piled raft can be applied to end-bearing piles, if adequate arrangement and configuration of the piles are selected.
High-rise steel building

27-story above grade
1-story below grade
Building area = 4,127 m²
Total floor area = 34,479 m²

in Kobe Port Island

- Piles: 79 piles, primarily end-bearing pile (designed as pile group)
  - Cast in-situ concrete pile with bell bottom.
  - $D_s = 1.8$ m (shaft), $D_b = 3.1$ m (base) 24 piles
  - $D_s = 1.3$ m (shaft), $D_b = 2.5$ m (base) 55 piles
Settlements were observed during the construction of a high-rise steel building. Long-term settlements were measured at various levels in the ground. The settlements were mainly caused by the settlement of the diluvial clay layer. The differential settlement was kept constant. The diagram shows the final completion of the building and the settlements measured over time.
High-rise steel building

Loads carried by pile and raft (as for the area around the instrumented pile)
High-rise steel building

Loads carried by pile and raft
(as for the area around the instrumented pile)

Proportions of load carried by pile and raft

Load proportions are kept almost constant after final completion.
High-rise steel building

27-story above grade
1-story below grade
Building area = 4,127 m²
Total floor area = 34,479 m²
in Kobe Port Island

Piles: 79 piles, primarily end-bearing pile
Cast in-situ concrete pile with bell bottom.
$D_s = 1.8$ m (shaft), $D_b = 3.1$ m (base) 24 piles
$D_s = 1.3$ m (shaft), $D_b = 2.5$ m (base) 55 piles

Design concept of piled raft can be applied to end-bearing piles, if adequate arrangement and configuration of the piles are selected.
Intensive field measurements were carried out over a large part of the foundation area.
Twin building of reinforced concrete structure

High building
9-story above grade
2-story below grade

Low building
4-story
2-story

SPT-N
Soil pile wall
Back fill
Observation area

Cast-in-situ concrete piles
78 piles, \( D = 1 \) to \( 2 \) m
Twin building of reinforced concrete structure

Field measurements

- Low building area
- High building area
- Earth pressure (E)
- Water pressure (W)
- Pile
Twin building of reinforced concrete structure

Time histories of earth pressures and water pressures

Earth press. (including water press.)

E1 (edge)

W1 (edge)

W2 (center)

E9 (center)

Changes are small even 7 years after the final completion
Distributions of earth pressures and water pressures beneath the raft (slab) at 1 year after the final completion.

- **45% by piles**
- **55% by the raft**
- (about 80% of the raft pressure is water pressure)

### Twin building of reinforced concrete structure

**Earth pressure, water pressure beneath the raft (kPa)**

- **Design total pressure**
- **E.P. at center of the raft**
- **E.P. at edge of the raft**
- **E.P. under foundation beam**
- **Water pressure**
Foundations in reverse construction methods

RC building #1

RC building #2
Reverse construction method

- **RFL**: 36.4m
- **7FL**: 30.7m
- **6FL**: 25.0m
- **5FL**: 19.3m
- **4FL**: 13.6m
- **3FL**: 8.0m
- **2FL**: 2.3m
- **1FL**: 0.5m

**Found. beam**

**Raft**

**1st excav.**

**2nd excav.**
Reverse construction method: RC superstructure (1)

Building:
7-story above grade
2-story below grade
Building area = 5,067 m²
Total floor area = 28,685 m²

Foundation:
**Raft foundation** in design
Ave. press. = 102 kPa
Max. press. = 139 kPa

Pile:
Cast-in-situ concrete piles with $D = 1.6$ m

Soil pile wall:
Cement mortar with steel pipe pile
### Reverse construction method: RC superstructure (1)

#### Field measurements

<table>
<thead>
<tr>
<th>Location</th>
<th>Measured item</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1 - N37</td>
<td>Settlement</td>
</tr>
<tr>
<td>S1 - S7</td>
<td>Earth pressure</td>
</tr>
<tr>
<td>W1 &amp; W2</td>
<td>Water pressure</td>
</tr>
<tr>
<td>B1 to B6</td>
<td>Axial force at the head of steel pipe pile for soil pile wall</td>
</tr>
<tr>
<td>A1 - A4</td>
<td>Axial force at the head of pile</td>
</tr>
</tbody>
</table>

**Diagram:**
- **Raft**
- **Soil pile**
- **Excavation area**
- Strain measurement at the top of steel pipe

**Dimensions:**
- 25.8 m
- 34.4 m
- 165.1 m
Reverse construction method: RC superstructure (1)

Time history of settlements

Ground heaving due to excavation work for reverse method

Long-term settlements
Small differential settlements

Settlement Heave (mm)
Reverse construction method: RC superstructure (1)

Time history of pressures for a central area

Heaving = 5 - 15 mm
Settlements = 10 - 20 mm

Even though the foundation was designed as the raft foundation, the piles carry a relative large portion of the total pressure.
Reverse construction method: RC superstructure (1)

Time history of load proportions

Due to reverse construction

Raft: 65% (60% of the raft press. is the water press.)

Piles: 35%

Changes in load proportions are very small after the final completion
Reverse construction method: RC superstructure (2)

Location: Kobe

50m

GL ± 0

-50m

Sand, $N > 50$

Sand

12-story above grade
2-story below grade
Building area = 956 m$^2$
Total floor area = 12,521 m$^2$

Designed as raft foundation

$N = 30 - 40$

Soil pile wall with H-steel
$s = 0.6m$

Piles: primarily end-bearing pile
Case-in-situ concrete piles
$L = 20.7m$, $D_s = 1.8m$, $D_b = 2.5m$
Reverse construction method: RC superstructure (2)

Field measurements
Reverse construction method: RC superstructure (2)

Time history of settlements

Acceleration at the ground surface = 0.2 m/s²
Kobe earthquake (Hyogoken-Nambu Earthquake)
January 17, 1995

Magnitude: 7.2
Maximum acceleration: 833 gal
Number of sacrifices: more than 6000
Number of damaged superstructures: more than 200,000
January 17, 1995

Hyogoken-Nambu Earthquake(1)
January 17, 1995

Hyo-goken-Nambu Earthquake (2)
Reverse construction method: RC superstructure (2)

Time history of settlements

Acceleration at the ground surface = 0.2 m/s²
Time histories of loads

Settlement = 8 mm

Load (MN)


Floor concrete

Final completion

Kobe earthquake

Raft

Piles

Time histories of load proportions

Acceleration at the ground surface = 0.2 m/s²

Proportion of load carried by raft and piles (%)

Due to excavation for reverse method

Raft: 60 % Piles: 40 % (20-30% of the raft pressure is the water pressure)
Design concepts

**Pile group:** Piles carry all the vertical load

**Raft alone:** Raft carries all the vertical load

**Reality**

- Even if buildings are supported by end-bearing piles, 20 to 50% of vertical loads (weights of buildings) are carried by rafts.
- In reverse construction methods where foundations are designed as rafts alone, 30 to 35% of vertical loads (weights of buildings) are carried by piles.

Design of a foundation as piled raft are is needed to predict behaviour of the foundation correctly.