Piled raft foundations in Alluvial and Diluvial grounds

- 3 cases in Alluvial ground
  (Coal silo, Building #1, Building #2)
- 2 cases in Diluvial ground
  (Building #3, Building #4)

Foundations were designed as piled raft foundations.
Analytical model used in the design of piled raft foundations in the case studies by Takenaka Corporation
Coal silo in Alluvial ground

Average contact pressure as the raft foundation = 73.6 kPa

Design as pile foundation:
10 piles, $L = 40$ m

Design as piled raft foundation:
5 piles, $L = 22.7$ m

Steel pipe piles

$N = 1 - 2$

$D = 0.4$ m  $L_d = 22.7$ m

$N = 5 - 8$

Strain gauge

Foundation slab ($t = 0.6$ m)

Foundation beam  ($B \times H = 1.0\text{m} \times 1.3\text{m}$)

\begin{itemize}
  \item Piles
  \item Settlement measurement
\end{itemize}
Coal silo in Alluvial ground

Time histories of settlements

Final completion

8 mm

D1
D2
D3
D4
D5
Coal silo in Alluvial ground

Time histories of pile head loads

- Final completion
- Settlement = 30mm

Pile head load (kN)

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<tr>
<th>11</th>
<th>12</th>
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1983    1984
Time histories of loads carried by piles and raft

Final completion

Settlement = 30mm

Raft 60%
Piles 40%

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<tbody>
<tr>
<td>Load (MN)</td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>6</td>
<td>8</td>
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<tr>
<td>Proportions of vertical loads (%)</td>
<td>0</td>
<td>20</td>
<td>40</td>
<td>60</td>
<td>80</td>
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</table>
RC building #1 in Alluvial ground

2-story RC structure
Building area = 967 m²
Average contact pressure = 50 kPa

Soil-cement piles with H-steel
ϕ650 H-400  ϕ550 H-300

Normally consolidated condition below this level

L = 22.8 m

Alluvial clay
RC building #1 in Alluvial ground

Field measurements

- ● P1 - P12: pile head force
- □ E1 - E4: earth pressure
- ▲ W1 & W2: water pressure
- △ L1 - L4: settlement
RC building #1 in Alluvial ground

Settlements

Settlement (mm)

5 mm
3 mm

2nd floor completed

Final completion

42 m

Settlements

1988
RC building #1 in Alluvial ground

Time histories of loads carried by piles and raft

- Load (MN)
- Proportion of loads by raft and piles (%)

Settlement = 5 mm

Raft: 50 %
Piles: 50 %
Design objective:

Prevention of differential settlements when liquefaction of the foundation ground occurs.
RC building #2 in Alluvial ground

2-story RC structure
Building area = 610 m²
Average contact pressure = 47 kPa

Safety factor for liquefaction, $F_L$ ($M = 7.5$)

Settlement of raft foundation = 20 mm

Soil-cement pile with H-steel

Clay ($N = 5$)

Fine sand ($N = 5$–10)

Fine sand ($N = 15$–30)

Sand ($N = 15$–20)

Post-earthquake settlements

prone to liquefaction
RC building #2 in Alluvial ground

Field measurements

Soil-cement pile with H-steel
- φ 600 H - 400 × 400 × 13 × 21
- φ 500 H - 300 × 300 × 10 × 15
RC building #2 in Alluvial ground

Time histories of settlements

<table>
<thead>
<tr>
<th>Settlement (mm)</th>
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<tbody>
<tr>
<td>10</td>
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<td>5</td>
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<th>1987</th>
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<td>2</td>
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</tbody>
</table>

2nd floor completed

Allowable settlement
RC building #2 in Alluvial ground

Time histories of loads carried by raft and piles

Settlement = 3 mm
RC building #2 in Alluvial ground

Time histories of load proportions carried by piles and raft

Corner area

Raft 52%
Piles 48%

Center area

Raft 40%
Piles 60%
RC building #3 in Diluvial ground

4-story RC structure
Building area = 470 m²

Average contact press. = 60.8 kPa
Max. contact press. = 82.4 kPa (as raft foundation)

Loam (∇ =2)
Sandy clay (∇ =1-2)
Sand (∇ =10-15)
Clay (∇ =2)
Sand (∇ =10-15)
Sandy silt (∇ =10-15)
Sand (∇ =20-40)
Hard silt (∇ =5-7)
Silty sand (∇ =15-20)
Hard silt (∇ =5-10)
Clay (∇ = 10
Sandy gravel (∇ > 50)
Sand (∇ =40-50)
RC building #3 in Diluvial ground

**DESIGN PROCESS**

Bearing capacity of the raft on the loam layer was estimated as 124 kPa.

Raft foundation was acceptable from the aspect of the bearing capacity.

Instant average settlement of 60 mm and differential settlements were predicted for the raft foundation.

Piled raft foundation with pile tip depth of 17.2 m was adopted.

If pile group foundation was adopted, pile tip depth became 43 m.

**Piles:**
Soil-cement pile with H-steel.
RC building #3 in Diluvial ground

Piles:
Soil-cement pile with H-steel
\[ D = 500 \text{ mm} \& 600 \text{ mm} \]
H-250: \( P_{ult} = 730 \text{ kN} \)
H-300: \( P_{ult} = 1170 \text{ kN} \)
H-400: \( P_{ult} = 1430 \text{ kN} \)

Average contact press. = 60.8 kPa
Max. contact press. = 82.4 kPa (as raft foundation)
RC building #3 in Diluvial ground

Field measurements

<table>
<thead>
<tr>
<th>Diameter (m)</th>
<th>Size of H-steel (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>◎ 0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>○ 0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>● 0.5</td>
<td>0.25</td>
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</tbody>
</table>

S1-S4: Settlement
E1-E6: Earth pressure
A, B & C: Instrumented piles
RC building #3 in Diluvial ground

Time histories of settlements

Settlement (mm)

4th floor completed

Final completion

13 m

25 m

4 mm

7 mm
RC building #3 in Diluvial ground

Time histories of loads (for whole monitored area)

Final completion
Settlement = 4 - 11 mm

4 years after the final completion
Raft: 45 %    Piles: 55 %
RC building #3 in Diluvial ground

Time histories of loads for areas of pile A and Pile C

Graphs showing the proportion of load (in %) over time for areas of Pile A and Pile C. The graphs indicate changes in load distribution from 1986 to 1991, with a final completion mark in 1987. The graphs also illustrate the relationship between the raft and piles.
RC building #4 in Diluvial ground

5-story RC structure
Building area = 545 m²
Av. contact press. = 84.4 kPa
Max. contact press. = 101 kPa

Depth (m)
RC building #4 in Diluvial ground

**DESIGN PROCESS**

Bearing capacity of the raft on the loam layer was estimated as 163 kPa.

Raft foundation was acceptable from the aspect of the bearing capacity.

Settlements of 60 mm at the center and 20 mm at the corners were predicted for the raft foundation.

Piled raft foundation with pile tip depth of 17.2 m was employed.

(If pile group foundation was adopted, pile tip depth was 43 m.)

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Bearing capacity of the raft on the loam layer was estimated as 163 kPa.

Raft foundation was acceptable from the aspect of the bearing capacity.

Settlements of 60 mm at the center and 20 mm at the corners were predicted for the raft foundation.

Piled raft foundation with pile tip depth of 17.2 m was employed.

(If pile group foundation was adopted, pile tip depth was 43 m.)
RC building #4 in Diluvial ground

20 piles:
Soil-cement pile with H-steel

\[ D = 700 \text{ mm} \& 800 \text{ mm} \]
RC building #4 in Diluvial ground

Field measurements

- Pile head force
- Distribution of axial forces of pile
- Earth pressure
- Water pressure
RC building #4 in Diluvial ground

Field measurements

Time (day)

Settlement (mm)

Settlements = 5 - 15 mm
RC building #4 in Diluvial ground

Time histories of loads (for whole monitored area)

- Total
- Raft
- Piles

Final completion

Load (MN)

- Raft: 55%
- Piles: 45%
RC building #4 in Diluvial ground

Time histories of loads for separated monitored areas

- Corner area
- Side area

Proportion of load (%)

Final completion

1991
Summary of case studies of piled raft foundations

- In all the 5 cases of piled raft foundations, proportion of total load carried by the raft was larger than that by the piles at early stages of construction, and then the proportion of total load carried the piles increased as the construction of the superstructure progressed. (Typically, 40 to 60% of the total load was carried by the raft at the final completion.)

- In some cases where long-term observations were performed, load proportion at the final completion remained for a long time.

Piled raft foundations are stable for long-term.