Analysis of Pier Structures Supported on Battered Piles Using MOTEMS

By
Robert Harn, PE, SE
BERGER/ABAM Engineers Inc.

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Purpose of Presentation

- Review MOTEMS batter pile evaluation procedure
- Review effects of deck stiffness on performance
- Present case study
- Show not all batter pile systems perform poorly
MOTEMS Evaluation Procedure

- Identify the failure mechanism of the batter pile-deck connection

- Release the lateral load between the batter pile and the deck when the lateral failure displacement is reached.

- Push on the structure until subsequent failure(s) have been identified.
**Batter Pile Rules**

- **Rule No. 1** - Tension piles almost always fail first at the connection
  - Geotechnical compression capacity is almost always greater than tension capacity.
  - Tension capacity of pile is almost always greater than connection

- **Rule No. 2** – Rule No. 1 is not always true!!
MOTEMS Example

80'

Deck

Mud line
First Failure

Batter pile connection fails in tension
First Failure Issues

- Is tension failure ductile or brittle?
- Will tension pile act in compression in later cycles or is it lost to the system?
  - Model as compression only if appropriate
  - Need to fully understand connection failure mode
- Connection detailing is important!!
Second Failure

Plumb pile connection fails in tension
Third Failure

Pile pole vaults and fails deck or pile in shear
Pushover Plot
(From MOTEEMS)
Pole Vaulting

- Batter piles will “pole vault” i.e. displace vertically in the inelastic range when tension pile fails.
- A deck structure that allows vertical displacement will minimize pile and deck forces from pole vaulting.

![Diagram showing Elastic Behavior and Inelastic Pole Vaulting](image)
Types of Deck Restraint

Unrestrained Decks

Batter piles

Stiff

Plumb piles

Flexible

Unrestrained Decks
Inelastic Displaced Shapes with Pole Vaulting

Unrestrained Decks

Restrained Decks
Battered vs. Plumb Pile Frame Pushover

Battered Frame

Plumb Pile Frame

Pushover Plot

4:12 batter
2:12 batter
Plumb
Battered vs. Plumb Pile Frame Displacement

Base Shear vs Spectral Displacement with Capacity (Pushover) Plot

4:12 batter
2:12 batter
Plumb
Performance Point

CLE_5% Damping
CLE_10% Damping
CLE_20% Damping
Capacity (pushover) Plot
Bilinear Pushover Plot

Base Shear (kips)
Spectral Displacement (in.)
Conclusion – Unrestrained Battered Frames

- Batter piles in unrestrained frames are stiffer and stronger than plumb pile frames with the same members yet they can have significant ductility.

Key Factors
- Connection strength and ductility
- Batter – B
- Width between piles – W
- Height – H
Example Pier Retrofit Concept Study

- Concrete Pier
- Not a M.O.T.
- Thin concrete deck
- Plumb piles at close spacing
- Transverse direction discussed
Example Pier Transverse Section

- 20” sq. concrete piles
- Conc. deck
- Batter piles
- Bearing layer
- Soft clay
- 120’
- 55’
Tension Pile Capacity

- Outer tension piles had minimal dead load
- Soil pullout values were low
- Connections were found to be strong enough to develop soil tension capacity
- Piles likely to slip and walk out of soil
Pushover Plot for Pier

- Batter piles alone
- Plumb piles - upper bound (UB) stiffness
- Plumb piles – lower bound (LB) stiffness

Graph showing force (V) and displacement (∆) with values at 0.4”, 3.6”, 5”, and 14”.
Site Specific Response Spectra

The graph shows spectral acceleration (g) on the y-axis and period (sec) on the x-axis. The lines represent different damping conditions:
- CLE 5% damping (solid black line)
- OLE 5% damping (pink line with squares)

The spectral acceleration decreases as the period increases, indicating a reduction in the response of the system with increasing period.
Estimate Displacement Demand Using ADRS

Base Shear vs Spectral Displacement with Capacity (Pushover) Plot

- CLE_5% Damping
- CLE_10% Damping
- CLE_20% Damping
- Capacity (pushover) Plot
- Bilinear Pushover Plot

Batters

Plumb U.B.

Plumb L.B.
Deck hinges plastically here and bends up to accommodate pole vaulting.

- Tension pile slips
- Batter pile “pole vaults” about tip
- Batter pile slips in tension
Transverse CLE Performance

- For this structure tension piles appear to slip due to minimal embedment. (i.e. Rule 1 does not apply)

- Hinge forms in deck – damage acceptable

- Tension piles (batter and plumb) likely to walk out of soil on subsequent cycles
Post CLE Earthquake Condition

- Deck tilted up about 3 to 4 inches
- Pile hinge
- Deck hinge
Summary

- MOTEMS provides on general guidance with respect to batter pile analysis and design

- Batter piles induce inelastic vertical displacements into the deck due to pole vaulting after failure of tension pile

- Therefore seismic performance is very dependant on the deck configuration.
  - Unrestrained decks do better
  - Restrained decks do worse
  - Tension connection ductility also important
Credits

- BERGER / ABAM Engineers Inc.