NORTH CAROLINA’S EXPERIENCE WITH LRFD IMPLEMENTATION

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION GEOTECHNICAL ENGINEERING UNIT

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TRB – WORKSHOP
1/13/08
Two Questions?

- Where have we been?
- Where are we?
OUTLINE

- Local Calibration effort
- ASD & LRFD Comparisons
- Proposed LRFD Design Process
- Planned Future Calibration effort
- Lessons learned, summary & Conclusions
Where have we been?

Concerns with AASHTO LRFD Specs:

- Proposed resistance factors were too low
- Local geology not accounted for
- Current ASD method (Vesic) not included
- Too high factors of safety used in calibration
Geology of North Carolina

- Coastal Plain- 35%
- Piedmont- 50%
- Blue Ridge Mountains- 15%
Figure 3-1. North Carolina Geologic Map (NCGS, 1985)
Coastal Plain Geology

- Quaternary Deposits: Undifferentiated, some thick organic deposits in some areas.
- Tertiary: Slightly over-consolidated clays, loose to medium dense silts & clays, N-SPT<10bpf. Weak limestone deposits.
Coastal Plain Geology

Index Map

Quaternary
- Qp

Tertiary
- Tp
- Tec
- Tt
- Tpa
- Tpyw
- Tpy
- Tob
- Tor
- Tec

Cretaceous
- Kp
- Kb
- Km
- Kc

Map with various geological layers and labels.
Current ASD Practice

Geology vs. Foundation Types:

- P/S Concrete Piles in outer Coastal Plain.
- HP Steel and P/S Concrete Piles in inner Coastal Plain.
- HP Steel piles, steel Pipe piles, Drilled Piers and Spread Footings in Piedmont & Mountains.
Axial Capacity:

- Vesic in C.P. supplemented by Nordlund.
- Both methods use Tomlinson for clays.
- By inspection in Piedmont & Mountains.
- Controlling Factor- Pile installation.
- Use F.S. of 2.
LRFD for Analysis/Design of Piles Axial capacity

- Conducted by N.C. State Univ.
  Researchers:
  M.S. Rahman, PhD, P.E., Professor
  M.A. Gabr, PhD, P.E., Professor
  K.J. Kim, PhD, P.E., NCDOT
  R.Z. Sarica, Graduate Assistant
  M.S. Hossain, Graduate Assistant
## Data Available For Calibration (C.P.)

<table>
<thead>
<tr>
<th>Pile Type</th>
<th>PDA (EOD)</th>
<th>PDA (BOR)</th>
<th>PDA (Both)</th>
<th>Static Load Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>P/S Conc.</td>
<td>85</td>
<td>26</td>
<td>20</td>
<td>22</td>
</tr>
<tr>
<td>HP Steel</td>
<td>17</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Steel Pipe</td>
<td>7</td>
<td>15</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>Conc. Cylinder</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>5</td>
</tr>
</tbody>
</table>
Limits On Available Data

- Had sufficient data for P/S concrete piles.
- Majority of HP steel pile data was PDA EOD.
- Majority of Steel Pipe pile data was from 1 project.
- Insufficient data for concrete cylinder piles.
## Recommended $\Phi$ for C.P. HP Piles

<table>
<thead>
<tr>
<th>Target Reliability</th>
<th>Vesic</th>
<th>Nordlund</th>
<th>Meyerhof</th>
</tr>
</thead>
<tbody>
<tr>
<td>Index 2.0</td>
<td>0.75</td>
<td>0.80</td>
<td>0.65</td>
</tr>
<tr>
<td>2.5</td>
<td>0.65</td>
<td>0.70</td>
<td>0.55</td>
</tr>
</tbody>
</table>
## Recommended $\Phi$ for C.P. P/S concrete piles

<table>
<thead>
<tr>
<th>$\beta$</th>
<th>Vesic $N_{Toe}$ $\leq$ 40</th>
<th>Vesic $N_{Toe}$ $&gt;$ 40</th>
<th>Nordlund $N_{Toe}$ $\leq$ 40</th>
<th>Nordlund $N_{Toe}$ $&gt;$ 40</th>
<th>M-hof $N_{Toe}$ $\leq$ 40</th>
<th>M-hof $N_{Toe}$ $&gt;$ 40</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>0.60</td>
<td>0.50</td>
<td>0.55</td>
<td>0.40</td>
<td>0.90</td>
<td>0.80</td>
</tr>
<tr>
<td>2.5</td>
<td>0.50</td>
<td>0.40</td>
<td>0.45</td>
<td>0.35</td>
<td>0.70</td>
<td>0.60</td>
</tr>
</tbody>
</table>
Comparison between AASHTO and NCDOT Φ’s

- Nordlund: Φ for NCDOT P/S Concrete piles approximately same as AASHTO.
- Meyerhof: Φ for NCDOT P/S Concrete piles significantly higher than AASHTO.
- Φ from all 3 methods significantly higher than AASHTO for HP Steel piles.
Where are we?

- Plan to use Nordlund method and AASHTO $\Phi$ for P/S concrete piles.
- Plan to use Nordlund method and $\Phi$ of 0.70 for HP steel piles & 0.60 for Steel Pipe piles in the interim.
- Plan to collect more PDA BOR data for HP Steel piles & re-calibrate HP steel piles.
- Completed 3 comparative examples.
- Established LRFD process for end bents.
Where are we?

- Working on interior bents design process.
- 4 Geotechnical Engineers attended the 3-days LRFD NHI class.
- Planning to have an internal training for rest of Geotech.’s in Feb. or March 2008.
Planned Calibration Efforts

- HP Steel piles.
- PDA with a minimum of 96 hours re-strike.
- Minimum of 20 tests.
- Develop Resistance Factors.
- Steel Pipe piles will follow.
Comparisons for end bents only.

- B-3467 Halifax Co. Cretaceous formation.
- B-3692 Robeson Co. Tertiary over Cretaceous formations.
- B-3871 Martin Co. tertiary soil formation.
- HP Steel piles in all cases.
## Case Studies-HP piles

### AASHTO Φ

(Estimated Pile lengths ft.)

<table>
<thead>
<tr>
<th>Project</th>
<th>ASD</th>
<th>LRFD with PDA</th>
<th>LRFD no PDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-3467 Halifax</td>
<td>840 (8)</td>
<td>840 (4)</td>
<td>725 (5)</td>
</tr>
<tr>
<td>B-3692 Robeson</td>
<td>960 (8)</td>
<td>825 (5)</td>
<td>840 (6)</td>
</tr>
<tr>
<td>B-3871 Martin</td>
<td>1395 (9)</td>
<td>1100 (5)</td>
<td>1225 (7)</td>
</tr>
</tbody>
</table>
Case Studies - Observations

- ASD pile lengths based on current policy of using an allowable load of 50 tons for HP 12x53 Steel piles.
- LRFD pile lengths based on AASHTO specs that allows loads up to structural capacity of a pile.
- Adopting LRFD and AASHTO specs may result in shorter pile lengths.
Case Studies - Observations

- Influence of geology on pile lengths is evident.
Proposed LRFD Design Process
End Bents

- Structures Design Unit (SDU) provides Nominal Compressive Structural Resistance.
- Geotechnical Engineering Unit (GEU) Computes Factored Compressive Resistance, Nominal and Factored Static & Dynamic Resistance.
- GEU Provides Preliminary Foundation recommendations to SDU.
Proposed LRFD Design
End Bents

- GEU requests factored structure loads, with & without PDA, # of piles needed per bent for each case.
- GEU completes analysis & provides final recommendations using maximum factored structural load as maximum factored geotechnical resistance.
Summary & Conclusions
P/S Concrete piles

- Had sufficient data for calibration.
- Good match- Nordlund & PDA BOR.
- Vesic slightly over-predicted PDA BOR.
- Meyerhof under-predicted PDA BOR.
- Good match- Nordlund & static load test but COV was high.
- Vesic over-predicted Static L. T. but COV was reasonable.
Summary & Conclusions
P/S Concrete

-Computed R.F. almost equal to AASHTO for Nordlund.
Summary & Conclusions
HP Piles

- Computed $\Phi$ higher than p/s concrete for Nordlund & Vesic.
- Computed $\Phi$ almost equal to p/s concrete for Meyerhof.
- Computed $\Phi$ based on PDA EOD $< \text{ recommended}$, but those computed based on PDA $> \text{ recommended}$. Recommended is close to ASD $FS = 2$
Summary & Conclusions

General:

- Reliability not constant for the same F.S. depended on static analysis method, field test and pile type.
- Computed Resistance Factors (R.F.) were almost equal for Vesic and Nordlund for HP steel & p/s conc. piles.
- Significant difference between computed $\Phi$ and AASHTO’s for M-hof. 29
Summary & Conclusions

General

- Need separate R.F.’s for low & high displacement piles.
- Based on 3 case studies, Adopting LRFD & AASHTO Specs may result in pile length estimates lower than NCDOT’s current ASD procedure.