STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION

BEVERLY EAVES PERDUE
GOVERNOR

EUGENE A. CONTI, JR.
SECRETARY

April 17, 2009

MEMORANDUM TO: K. J. Kim, P.E.
Eastern Regional Geotechnical Manager

John Pilipchuk, L.G., P.E.
Western Regional Geotechnical Manager

Eric Williams, P.E.
Geotechnical Design Supervisor

Structure Design Unit Project Engineers

FROM: Njoroge Wainaina, P.E.
State Geotechnical Engineer

Greg Perfetti, P.E.
State Bridge Design Engineer

SUBJECT: LRFD Driven Pile Foundation Design Policy, Load Request Form and Structural Resistance Charts

The Geotechnical Engineering Unit (GEU) and Structure Design Unit (SDU) have completed the new LRFD Driven Pile Foundation Design Policy, Load Request Form and Structural Resistance Charts.

The following is a summary of the GEU procedure for designing driven pile foundations in accordance with the new policy.

1. Determine factored structural resistance for the selected pile type and smallest possible pile size. The nominal compressive resistance chart for steel piles and the factored compressive resistance from the interaction diagrams for concrete piles developed by SDU may be used at designer's discretion to estimate preliminary pile axial structural resistance.
2. Determine factored geotechnical resistance based on drivability analysis.

MAILING ADDRESS:
NC DEPARTMENT OF TRANSPORTATION
GEOTECHNICAL ENGINEERING UNIT
1589 MAIL SERVICE CENTER
RALEIGH NC 27699-1589

TELEPHONE: 919-250-4088
Fax: 919-250-4237

Website: www.ncdot.org./doh

LOCATION:
CENTURY CENTER COMPLEX
ENTRANCE B-2
1020 BIRCH RIDGE DRIVE
RALEIGH NC 27610

3. Determine "Maximum Factored Resistance" by reducing factored geotechnical resistance for downdrag, scour and dead load of piles above the design scour elevation. For pile bents, also determine the preliminary point of fixity (POF) elevation based on the maximum factored resistance and an assumed lateral load and ensure lateral deflection for the preliminary design is within the acceptable limits in the new policy.
4. Use the Load Request Form to provide the SDU with the maximum factored resistance and if applicable, preliminary POF elevation and request structure information.
5. SDU will provide controlling factored loads, pile configurations and bottom of cap elevations for structure information.
6. Based on structure information received, determine the "Factored Resistance" equal the maximum factored axial load and the resulting estimated pile lengths. For pile bents, also determine the new POF elevation and compare it to the preliminary POF elevation. If the difference exceeds the limits in the new policy, provide the SDU with the new POF elevation, request structure information again and repeat this step.
7. Prepare foundation recommendations with factored resistances (rounded up to nearest 5 ton increment), estimated pile lengths (rounded up to the nearest 5 ft increment), pay item quantities, foundation comments and notes including required driving resistances and if required, tip no higher than elevations and hammer energies. For pile bents, also include final POF elevations.

If there are any questions, please contact Scott Hidden, P.E. at (919) 250-4088 or Brian Hanks, P.E. at (919) 250-4046.

Attachments: LRFD Driven Pile Foundation Design Policy
Load Request Form
Structural Resistance Charts

cc: Rodger Rochelle, P.E., State Transportation Program Management Engineer
Mike Robinson, P.E., State Bridge Construction Engineer
Dan Holderman, P.E., State Bridge Management Engineer
Tom Drda, P.E., Federal Highway Administration

LRFD DRIVEN PILE FOUNDATION DESIGN POLICY
NCDOT GEOTECHNICAL ENGINEERING UNIT (GEU)
AND STRUCTURE DESIGN UNIT (SDU)

Policy Approval and Update

Approved by		Date	Approval or Update
Name and Title	**Signature**		
Njoroge W. Wainaina, P.E. State Geotechnical Engineer	Njoroge Wainaina	April 17, 2009	Approval
Greg R Perfetti, P.E. State Bridge Design Engineer			

TABLE OF CONTENTS

Section 0 Definitions 2
Section 1 Factored Structural Resistance 3
Section 2 Maximum Factored Resistance 5
Section 3 Resistance Factors 7
Section 4 Overburden Pressure and Hammer Efficiency Corrections 8
Section 5 Static Analysis 9
Section 6 Pile Bents 11
Section 7 Seismic Design 12
Section 8 Foundation Recommendations 13
Section 9 References 15

This policy is maintained by the GEU.

Section 0 Definitions

AASHTO LRFD TERMINOLOGY	DEFINITION
P_n	Nominal compressive resistance, i.e., pile axial structural resistance
P_r	Factored structural resistance based on driving conditions for steel piles and tension or compression-controlled section for concrete piles
R_n	Nominal resistance, i.e., geotechnical resistance
R_r	Factored geotechnical resistance based on drivability analysis

NCDOT TERMINOLOGY	DEFINITION
Maximum Factored Resistance	R_r reduced for downdrag load, scour resistance and dead load of piles above the design scour elevation
Factored Resistance	Resistance equal to or larger than the maximum factored axial pile load
Required Driving Resistance	Factored resistance plus any additional resistance for downdrag and scour divided by a resistance factor
Point of Fixity	Elevation below which pile is considered fixed

Section 1 Factored Structural Resistance

POLICY

1.0 Factored Structural Resistance

1.1 Pile Axial Structural Resistance
Determine nominal compressive resistance based on AASHTO LRFD Specifications.

1.2 Prestressed Concrete Piles
- Resistance factor = 0.75 for compression-controlled sections
- Resistance factor = 1.00 for tension-controlled sections

1.3 Driving Conditions
Determine factored structural resistance based on driving conditions.

COMMENTARY

C1.0
See Section 0 Definitions for "Factored Structural Resistance".

C1.1
For steel piles, see AASHTO LRFD 6.9.4.1 for details. For prestressed concrete piles, see AASHTO LRFD 5.7.4.4 and 4.5.3.2.2b for details.

The SDU developed charts to use for a preliminary estimate of pile axial structural resistance. Use the Nominal Compressive Resistance Chart for steel piles and the Interaction Diagrams for prestressed concrete piles. The charts account for buckling and are based on pile type, size and unbraced pile length.

Use Unbraced Length (L) as defined below.
- Pile bents not subject to scour:
  L = (BOC EL – GND EL) + 5 ft
- All bents subject to scour:
  L = BOC/BOF EL – Design Scour EL

where,
BOC = Bottom of Cap
BOF = Bottom of Footing
GND = Ground
EL = Elevation

C1.2
See AASHTO LRFD 5.5.4.2.1 for details.

These resistance factors are included in SDU's Interaction Diagrams.

C1.3
See AASHTO LRFD 10.7.3.2.3 for details.

Steel piles driven to rock might be considered a severe driving condition. Consider use of pile points to reduce potential damage during pile driving.

AASHTO LRFD does not specify resistance factors for prestressed concrete piles based on driving conditions.

1.3.1 Steel H Piles

- Resistance factor = 0.6 for good (normal) driving conditions
- Resistance factor = 0.5 for severe driving conditions

C1.3.1
See AASHTO LRFD 6.5.4.2 for details.

AASHTO LRFD C6.15.2 states that "Due to the nature of pile driving, additional factors must be considered in selection of resistance factors that are not normally accounted for in steel members." See AASHTO LRFD for more details.

These resistance factors are not included in SDU's Nominal Compressive Resistance Chart and should be applied to obtain factored structural resistance.

1.3.2 Steel Pipe Piles

- Resistance factor = 0.7 for good (normal) driving conditions
- Resistance factor = 0.6 for severe driving conditions

C1.3.2
See AASHTO LRFD 6.5.4.2 for details.

These resistance factors are not included in SDU's Nominal Compressive Resistance Chart and should be applied to obtain factored structural resistance.

Section 2 Maximum Factored Resistance

POLICY

2.0 Maximum Factored Resistance

2.1 Drivability Analysis
Determine factored geotechnical resistance based on drivability analysis.

2.1.1 Minimum Blow Count (at bearing)
Minimum blow count is defined as 30 BPF.

2.1.2 Maximum Blow Count (at bearing)
Maximum blow count is defined as 180 BPF.

2.1.3 Refusal (during driving)
Refusal blow count is defined as 240 BPF.

2.1.4 Piles Driven to Rock
Piles driven to rock are defined as 5 blows per ¼ inch of movement.

2.2 Pile Driving Stress Limit

2.2.1 Steel Piles
Driving resistance, φ_{da} = 1.00 (AASHTO LRFD 6.5.4.2 and Table 10.5.5.2.3-1)

- In compression and tension: AASHTO LRFD Eq. 10.7.8-1

$\sigma_{dr} = 0.9\varphi_{da} f_y = 45$ ksi for 50 ksi steel.

2.2.2 Prestressed Concrete Piles
Driving resistance, φ_{da} = 0.75 for compression controlled sections and 1.00 for tension controlled sections (AASHTO LRFD 5.5.4.2.1 and Table 10.5.5.2.3-1)

COMMENTARY

C2.0
See Section 0 Definitions for "Maximum Factored Resistance".

C2.1
Use readily available hammers for drivability analysis and consult with GEU Operations Engineer for available hammers.

See AASHTO LRFD 10.7.8 and Section 2.2 below for details.

C2.1.1
Minimum BPF < 30 indicates that the selected hammer may be too big.

C2.1.2
Maximum BPF > 180 indicates that the selected hammer may be too small.

C2.1.3
In general, with an appropriate (approved) hammer, if blow counts exceed 240 BPF, then pile tip may have reached a very competent layer.

C2.2.1
Steel yield stress, f_y = 50 ksi

Based on judgment, stress limit may be lowered to a minimum of $\sigma_{dr} = 0.8\ \varphi_{da} f_y = 40$ ksi.

C2.2.2
In accordance with the SDU standard prestressed concrete pile details,

- f'_c = 5 ksi
- strand area = 0.153 in^2 (0.5 inch diameter)
- strand yield strength = 270 ksi
- applied prestress (before loss) =

a) Normal Environments

- In compression: AASHTO LRFD Eq. 10.7.8-4

$$\sigma_{dr} = \varphi_{da}(0.85 f_c^{'} - f_{pe})$$

$\sigma_{dr} \leq 3.5$ ksi , recommended value

- In tension: AASHTO LRFD Eq. 10.7.8-5

$$\sigma_{dr} = \varphi_{da}(0.095\sqrt{f_c^{'}} + f_{pe})$$

$\sigma_{dr} \leq 1.0$ ksi, recommended value

b) Severe Corrosive Environments

- In compression: Same as normal environments

- In tension: AASHTO LRFD Eq. 10.7.8-6

$$\sigma_{dr} = \varphi_{da}(0.85 f_c^{'} - f_{pe})$$

$$\sigma_{dr} = \varphi_{da} f_{pe}$$

$\sigma_{dr} \leq 0.8$ ksi, recommended value

270 x 0.75 = 202.5 ksi

- f_{pe_strand} = 170 ksi , effective prestressing stress per strand (after loss)
- f_{pe} = (170 ksi × strand area × number of strand ÷ concrete area), where f_{pe} is effective prestressing stress in concrete

2.2.3 Timber Piles

Driving resistance, φ_{da} = 1.15 (AASHTO LRFD 8.5.2.2)

- In compression and tension: AASHTO LRFD Eq. 10.7.8-7

$$\sigma_{dr} = \varphi_{da}(F_{co})$$

$F_{co} = 0.9 \sim 1.25$ ksi

$\sigma_{dr} = 1.00 \sim 1.40$ ksi, recommended value

C2.2.3

AASHTO LRFD 2008 Interim –

F_{co} : base resistance of wood in compression parallel to grain as specified in AASHTO LRFD 8.4.1.3

Reference Design Values for Piles
(AASHTO LRFD Table 8.4.1.3-1)

Species	**F_{co} (ksi)**
Pacific Coast Douglas-Fir	1.25
Red Oak	1.10
Red Pine	0.90
Southern Pine	1.20

<u>2.3 Scour Resistance and Downdrag Load</u>

Determine maximum factored resistance by reducing the factored geotechnical resistance for downdrag load, scour resistance and dead load of piles above design scour elevation.

<u>C2.3</u>

See Section 5.1.1 and 5.1.2 for downdrag and dead load details.

For scour resistance, use static analysis to calculate skin resistance from ground line to design scour elevation. See Section 5.1 for static analysis methods.

Section 3 Resistance Factors

POLICY	COMMENTARY
3.0 Resistance Factors	
3.1 Static Analysis Use AASHTO LRFD Resistance Factors for all piles except steel H piles in the Coastal Plain.	C3.1 See AASHTO LRFD Table 10.5.5.2.3-1 for details.
3.1.1 Exception Use NCDOT Resistance Factor of 0.7 for steel H piles in the Coastal Plain.	C3.1.1 NCDOT Resistance Factors are based on NCSU localized resistance factors calibration research. This factor applies to all soils and all static analysis methods for H piles in the Coastal Plain. This is an exception to AASHTO LRFD Specifications. See Section 9.0 Reference No. 4 for details. See Subarticle 1018-2(B), (1) of the Standard Specifications for determining soils in the Coastal Plain. If in doubt, consult project geologic engineer.
3.2 Dynamic Monitoring Use the same resistance factor for both drivability analysis and pile driving criteria.	C3.2 This is an exception to the AASHTO LRFD Specifications. These resistance factors are higher than the AASHTO LRFD Resistance Factors and were established based on NCDOT's pile driving experience.
3.2.1 WEAP without PDA Use a resistance factor of 0.60 for hammer approval.	
3.2.2 PDA and WEAP – Option 1 Use a resistance factor of 0.6 for hammer approval with limited quantity of PDAs.	C3.2.2 PDA may be used without meeting AASHTO LRFD requirements in order to monitor stresses and resistance during pile driving.
3.2.3 PDA and WEAP – Option 2 Use a resistance factor of 0.75 for hammer approval with required quantity of PDAs.	C3.2.3 To use this resistance factor, follow AASHTO LRFD requirements for PDAs. See AASHTO LRFD Tables 10.5.5.2.3-1 and 10.5.5.2.3-3 for PDA requirements. Determine site variability based on judgment. However, site variability should typically be considered "low".

Section 4 Overburden Pressure and Hammer Efficiency Corrections

POLICY	COMMENTARY
4.0 Overburden Pressure and Hammer Efficiency Corrections	
4.1 Overburden Pressure Correction Correct SPT blow counts for overburden pressure.	C4.1 See AASHTO LRFD 10.4.6.2.4 for details. Software "Driven" can automatically correct for overburden pressure.
4.2 Hammer Efficiency Correction Correct SPT blow counts for hammer efficiency.	C4.2 See AASHTO LRFD 10.4.6.2.4 for details.
4.2.1 Hammer Efficiency Correction Exception Hammer efficiency correction is not required for steel H piles in the Coastal Plain where NCDOT Resistance Factors apply.	C4.2.1 NCSU did not make hammer efficiency corrections for their research.
4.2.2 Default Hammer Efficiency Correction Values Use hammer efficiency from test results if available; otherwise use 60% for manual hammers and 80% for automatic hammers.	

Section 5 Static Analysis

POLICY

COMMENTARY

5.0 Static Analysis

5.1 Static Analysis
Use AASHTO LRFD methods for static analysis.

C5.1
See AASHTO LRFD 10.7.3.8.6 for details.

Use software program "Driven" with Nordlund/Timlinson method or hand calculations with other AASHTO LRFD methods. When using Driven, select predominant soil type to determine analysis method and appropriate resistance factor.

5.1.1 Downdrag Load
To account for downdrag, add factored downdrag load to maximum factored axial load for static analysis.

C5.1.1
See AASHTO LRFD Table 3.4.1-2 for Downdrag factors. See AASHTO LRFD 3.11.8 and 10.7.3.7 for downdrag analysis.

5.1.2 Dead Load
To account for dead load of concrete piles above the design scour elevation, add factored dead load to maximum factored axial load for static analysis.

C5.1.2
See AASHTO LRFD Table 3.4.1-2 for Component and Attachments factors.

Typically, dead load for steel piles may be neglected. However, if weight of steel piles is significant, dead load of steel piles above the design scour elevation may be considered.

5.1.3 Scour Resistance
To account for scour, subtract scour resistance from nominal resistance calculated for static analysis.

C5.1.3
For analysis purposes, lower ground line to the contraction scour elevation (CSE) to account for contraction scour reported in the bridge survey report.

- If the CSE is lower than or equal to the design scour elevation (DSE), consider all scour as contraction scour.
- If the CSE is higher than the DSE, consider the difference between the CSE and the DSE as local scour.

When calculating nominal resistance, correct blow counts for overburden pressure by lowering the ground line to the CSE.

5.2 Steel H Pile Resistance Configuration

5.2.1 AASHTO LRFD Resistance Factors
Use box shape for skin resistance and H shape for tip resistance when AASHTO LRFD Resistance Factors are used.

C5.2.1
Consider rectangular perimeter defined by the soil plugged cross-section. Also, see AASHTO LRFD 10.7.3.8.6b for details.

5.2.2 NCDOT Resistance Factors
Use H shape for both skin and tip resistance when NCDOT Resistance Factors are used. This applies to steel H piles used in the Coastal Plain.

C5.2.2
Consider the unplugged cross-section. Also, see Section 3.1.1.

Section 6 Pile Bents

POLICY

COMMENTARY

6.0 Pile Bents

6.1 Lateral Deflection & Pile Stresses
The SDU will check bent deflections and structural adequacy of piles.

6.2 Point of Fixity (POF)
This is a strength limit analysis. Use factored loads for POF analyses.

C6.2
Other methods such as cantilever beam may be used to supplement L-Pile in determining POF.

6.2.1 Preliminary POF
For preliminary POF analysis, use the maximum factored resistance and a shear load of 3 kips per pile (no moment). Also, use the following lateral deflection limits for a single pile with a free head condition for selecting pile type and size.

- Steel Piles 6”
- Prestressed Concrete Piles 3”

Point of fixity should be selected from between where the deflection curve first intercepts the “point of the first zero deflection” and the “maximum negative deflection point.”

6.2.2 Iteration Limit for POF Analysis
Terminate POF analysis if either one of the following conditions are met.

- new POF is less than **3** ft higher than the previous POF, or
- new POF is less than **2** ft below the previous POF.

Otherwise, provide the SDU the new POF and continue the iteration process or change the pile design.

Section 7 Seismic Design

POLICY

7.0 Seismic Design

7.1 General
The SDU will use a map showing general seismic zones in NC to determine whether or not a bridge will be designed for seismic loads. This will be reflected in SDU's Request for Foundation Recommendations. For seismic design, the SDU may request bridge site classification per definition in AASHTO LRFD 3.10.3.

7.2 Site Effects
The SDU will characterize the seismic hazard in accordance with AASHTO LRFD 3.10.2.

COMMENTARY

C7.1
A map showing general seismic zones in NC is available in the SDU Design Manual.

C7.2
See AASHTO LRFD 3.10.3 for details.

GEU provided the SDU with the following general site classes (see below) for development of the North Carolina seismic zone map.

- Counties with Site Class C or better are: Stanley, Union, Anson, southern part of Montgomery, Mecklenburg, Cabarrus, Divisions 9 and 11-14.

- Counties with Site Class D are: Richmond, Scotland, Robeson, Columbus, Pender, Brunswick, New Hanover, southern parts of Moore & Hoke and western part of Bladen.

If a bridge will be designed for seismic loads, determine whether the assumed site class applies to the site based on subsurface information (borings). If assumed site class is not applicable, GEU will provide the SDU with site class for the site when requesting structure information.

Section 8 Foundation Recommendations

POLICY	COMMENTARY
8.0 Foundation Recommendations	
8.1 Preliminary Foundation Recommendations Determine if PDA will be used for the project. If PDA will be used, determine appropriate resistance factor based on the purpose of the PDA. GEU will provide the SDU with the following: • Proposed pile type, size and Maximum Factored Resistance. • Preliminary POF for interior bents.	C8.1 See Section 3.2 for details. See Section 0 Definitions for "Maximum Factored Resistance". Use standard form to request structure information. The SDU will provide controlling factored loads, pile configurations (number of piles and spacing) and bottom of cap elevations for each bent.
8.2 Final Foundation Recommendations	
8.2.1 Factored Resistance Provide proposed pile type, size and Factored Resistance. Provide factored resistance equal to maximum factored axial load rounded up to the nearest 5 tons.	C8.2.1 See Section 0 Definitions for "Factored Resistance".
8.2.2 Required Driving Resistance Provide a standard foundation note on plans with Required Driving Resistance.	C8.2.2 Required Driving Resistance = (Factored Resistance + Factored Downdrag Load + Scour Resistance) / Resistance Factor
8.2.3 Estimated Pile Lengths Estimate pile lengths based on static analysis and minimum pile penetration (tip no higher than elevation).	C8.2.3 See AASHTO LRFD 10.7.3.3 and 10.7.6 for details.
8.2.4 Point of Fixity For pile bent, provide final POF elevation.	
8.2.5 Hammer Energy If it is determined that a Delmag D19-32 (or D19-42) or an equivalent hammer is not sufficient to drive piles to the Required Driving Resistance, include a standard foundation note on plans with the "Estimated Hammer Energy Range".	

8.2.6 Scour Critical Elevation (SCE)

1. Use 500 year hydraulics scour elevation, if available, as SCE.

2. Otherwise, use 2 ~ 3 ft below design scour elevation as SCE.

3. In all cases, at least 5 ft embedment is required below SCE.

Section 9 References

1. *AASHTO LRFD Bridge Design Specifications*, 4th (2007) Edition with 2008 Interims.
2. *Design and Construction of Driven Pile Foundations*, FHWA-NHI-05-042, April 2006.
3. *LRFD for Highway Bridge Substructures and Earth Retaining Structures*, FHWA-NHI-05-094, January 2006, January 2007 Revision.
4. *Load and Resistance Factor Design (LRFD) for Analysis/Design of Piles Axial Capacity*, Rahman, M.S., M.A. Gabr, R.Z. Sarica and M.S. Hossain, NCSU Research Report No. FHWA/NC/2005-8, July 2002
5. *Standard Specifications for Roads and Structures*, North Carolina Department of Transportation, July 2006.

NORTH CAROLINA DEPARTMENT OF TRANSPORTATION
GEOTECHNICAL ENGINEERING UNIT
Load Request Form for Piles and Drilled Piers

Revised 4/15/09

Date: (Date)

WBS No.: (WBS No.)

TIP No.: (TIP No.)

Federal Project No.: (Federal Project No.)

County: (County)

This letter will be sent to: ◉ Structure Design ○ Bridge Management ○ Other

Structure Design Project Engineer: (Engineer Receiving Letter)

Geotech should be receive loads by: (Date Due)

The letter will be sent from

○ ERO - Design ◉ Central Office - Geotechnical Design ○ WRO - Design

○ ERO - Operations ○ Central Office - Technical Support ○ WRO - Operations

Geotechnical Design Supervisor: Eric Williams, P.E. **Initials:** ENW

Geotechnical Design Engineer: (Engineer Requesting Loads) **Initials:** (Initials)

☐ The Geotechnical Design Supervisor will also be the Design Engineer for this project.

Structure Description: (Description)

Structure No.: (If there is only one Structure, leave this blank)

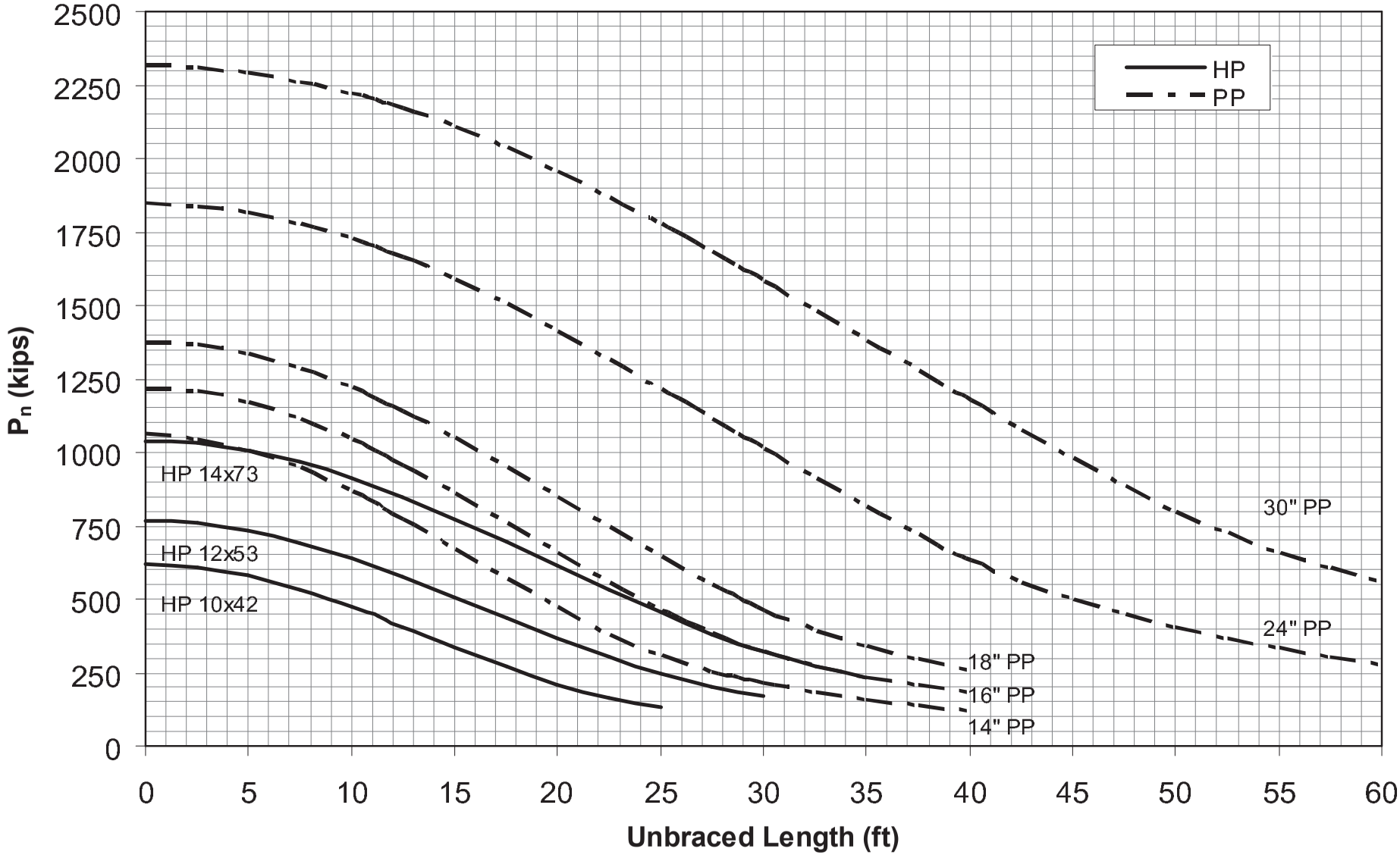
Seismic Load Information: (Select a Seismic Design Condition)

Units: ◉ English ○ Metric

Location	No.	Foundation Type	Pile Type or Drilled Pier Diameter	Design Scour Elevation	Maximum Factored Resistance	Preliminary Point of Fixity Elevation

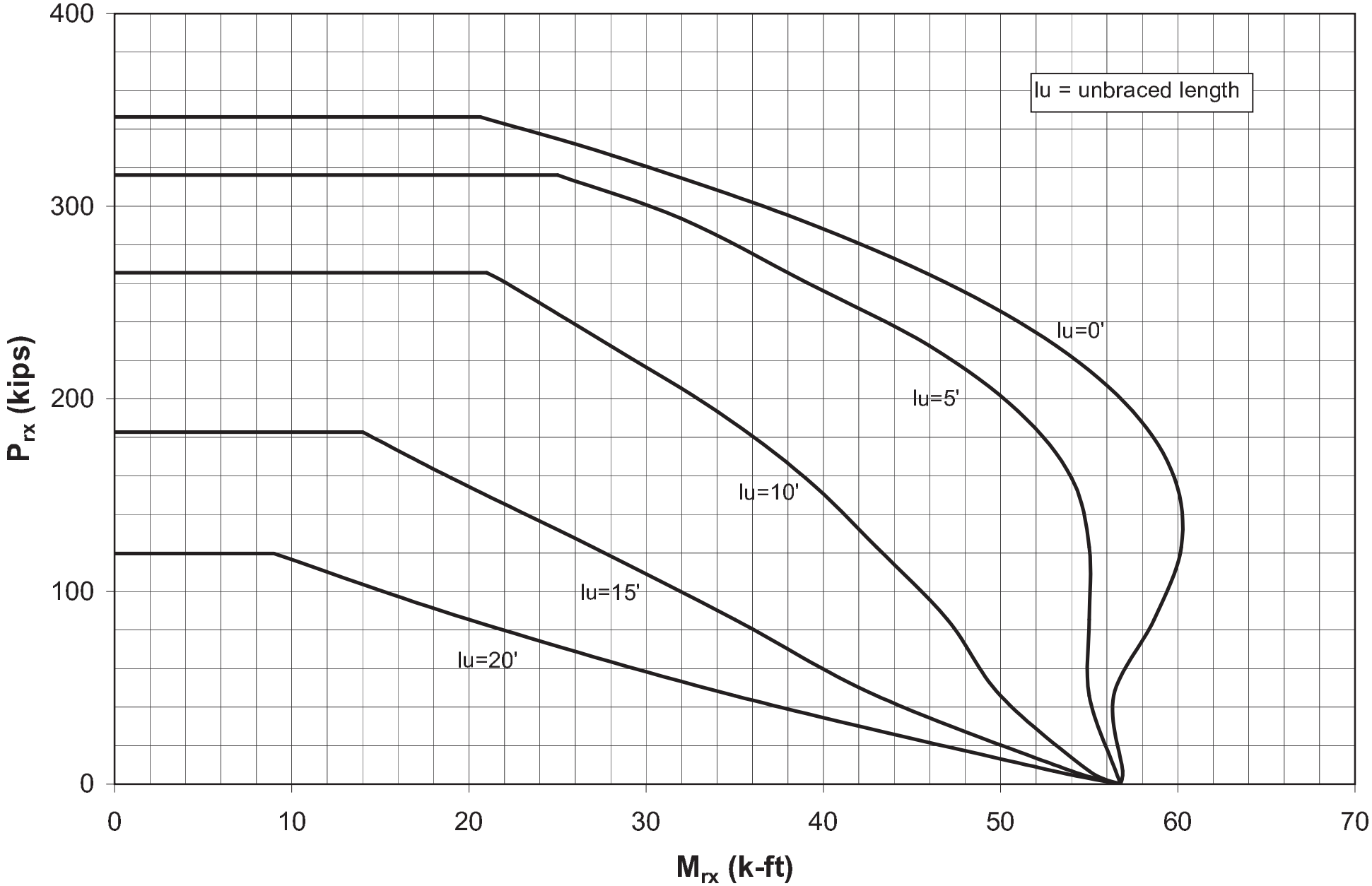
Nominal Compressive Resistance for Steel Piles

(Do not use for final design. Use for preliminary estimate of pile axial structural resistance only.)



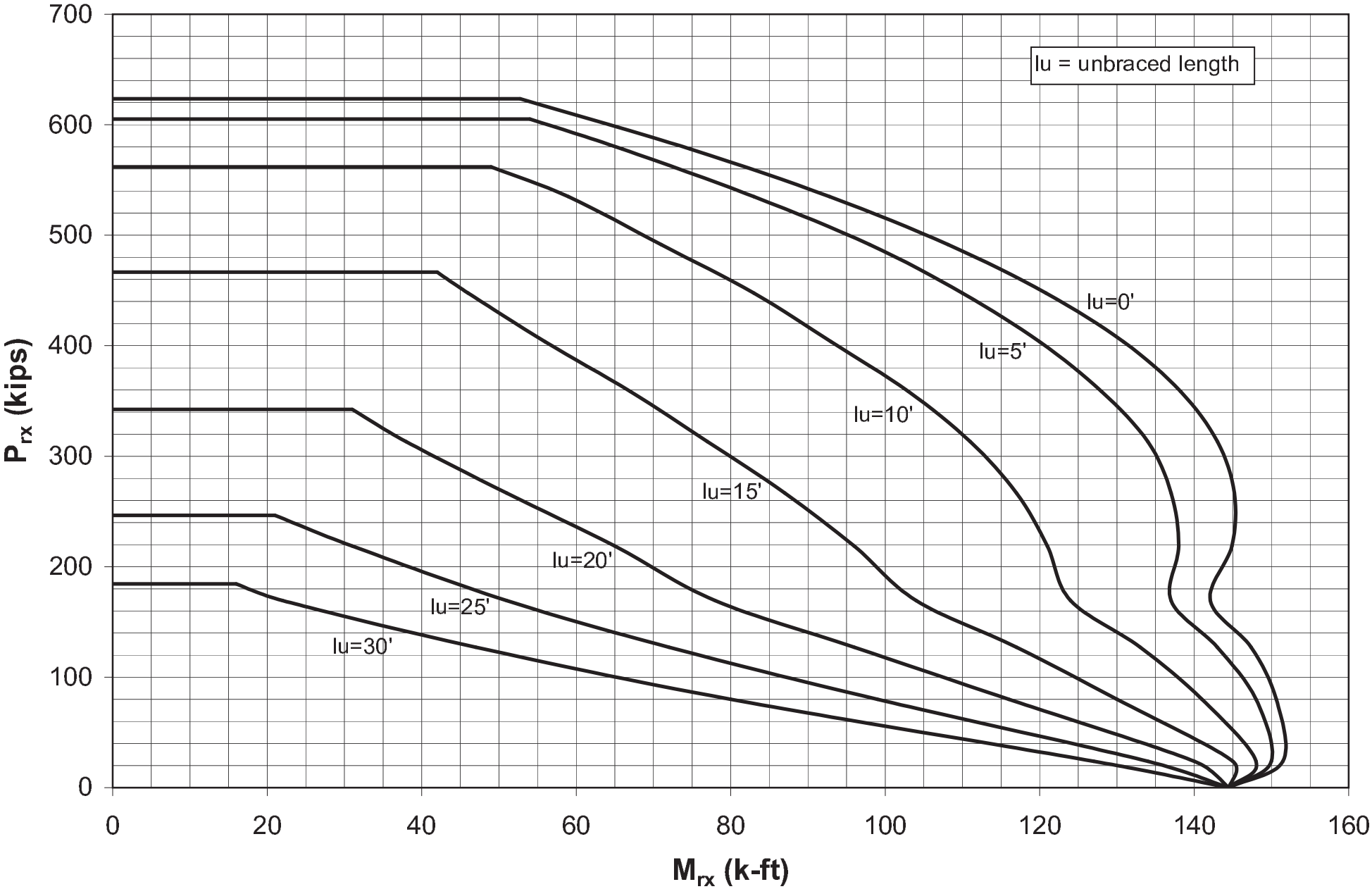
12 x 12 PCP Interaction Diagram (Longitudinal)

(Do not use for final design. Use for preliminary estimate of pile axial structural resistance only.)



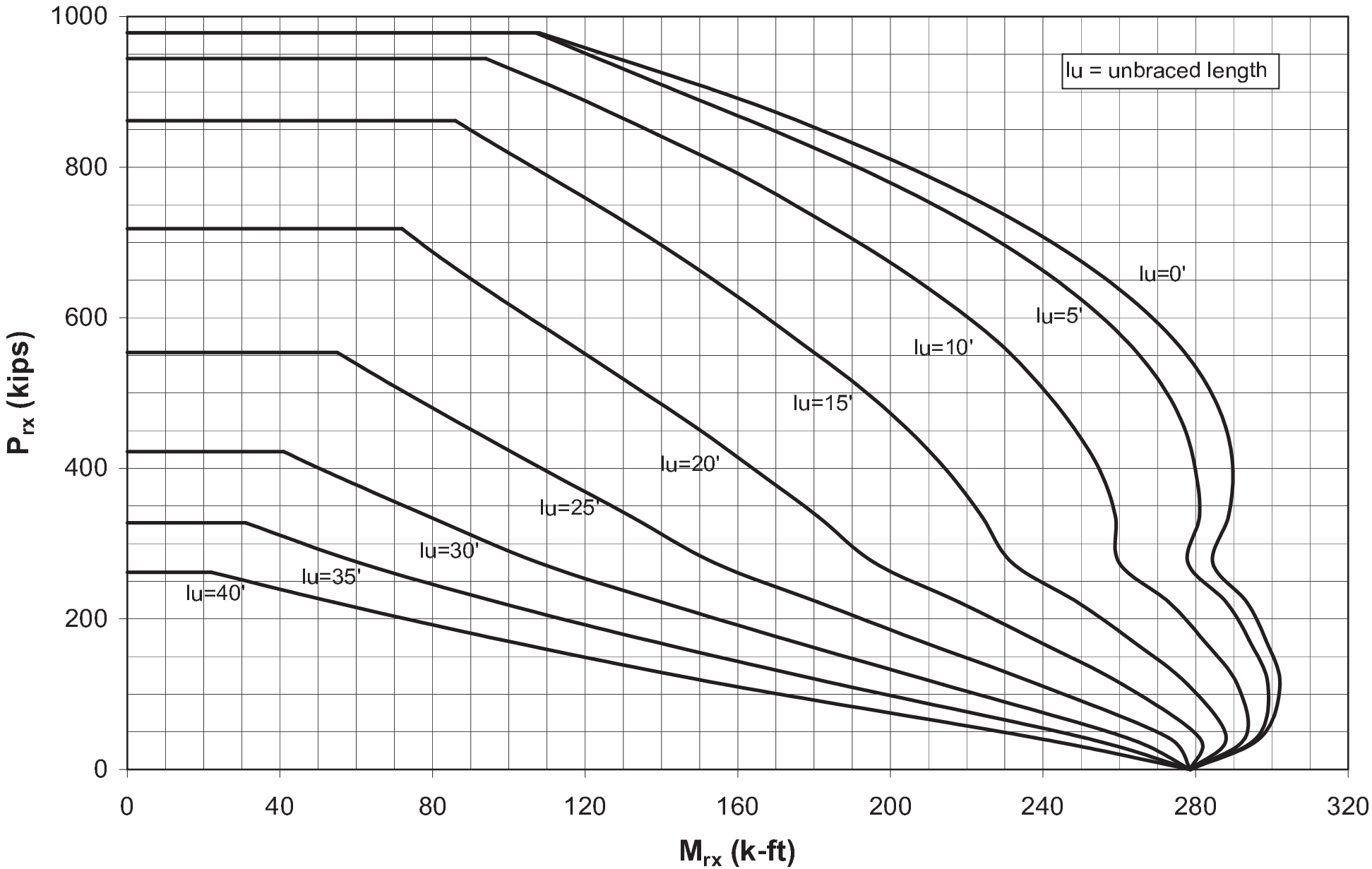
16 x 16 PCP Interaction Diagram (Longitudinal)

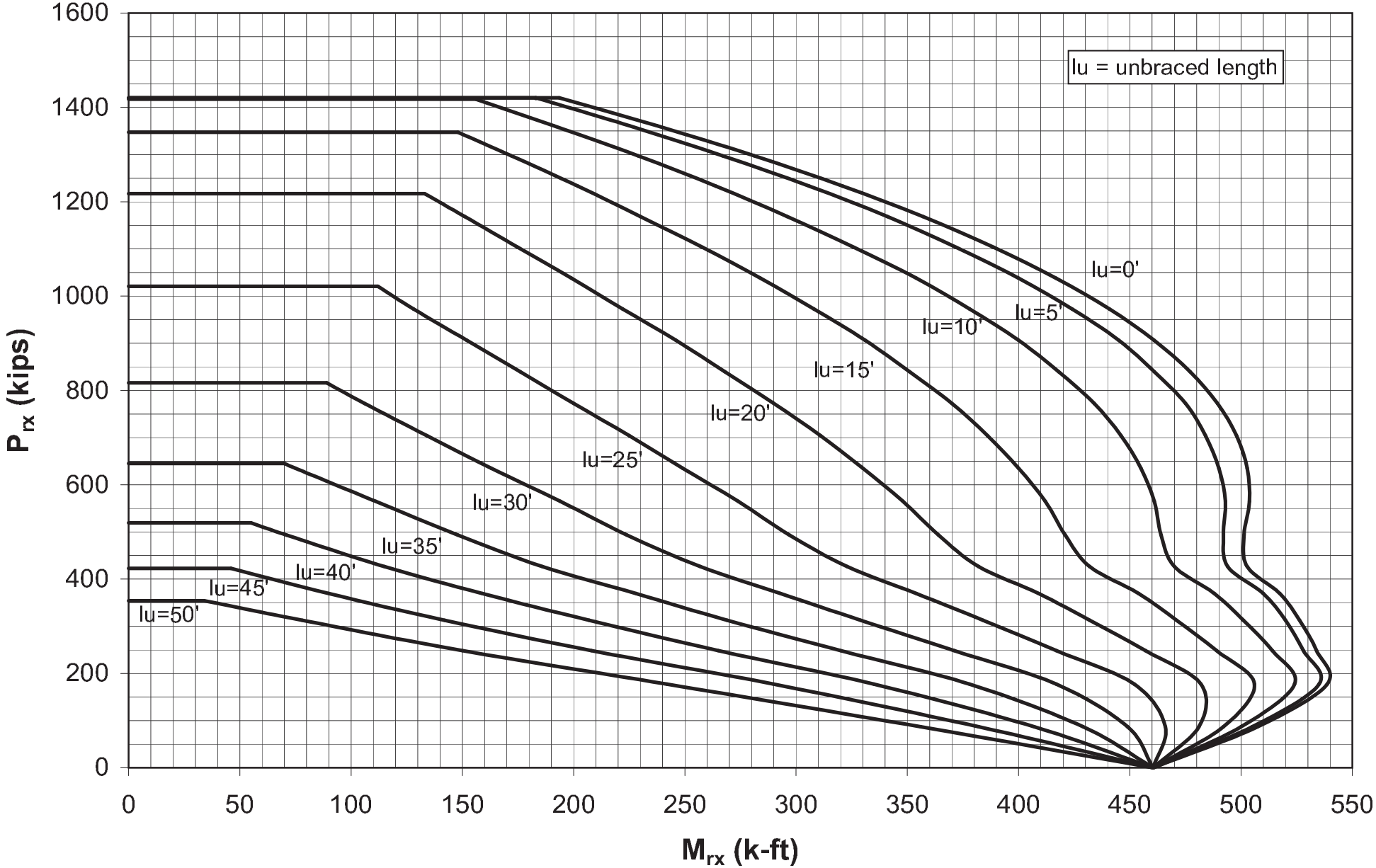
(Do not use for final design. Use for preliminary estimate of pile axial structural resistance only.)



20 x 20 PCP Interaction Diagram (Longitudinal)

(Do not use for final design. Use for preliminary estimate of pile axial structural resistance only.)



24 x 24 PCP Interaction Diagram (Longitudinal)

(Do not use for final design. Use for preliminary estimate of pile axial structural resistance only.)