Implementation of the AASHTO LRFD Code in the NDOR Practice – Driven Piles

Andrzej S. Nowak ,
Marek Kozikowski, Tomasz Lutomirski , Piotr Paczkowski
University of Nebraska-Lincoln

and

Omar Qudus and Jordan Larsen
Nebraska Department of Roads, NDOR

Objectives

- Review and compare the available methods for pile capacity analysis
- Review the available test data (NDOR and national)
- Develop an efficient method for the pile capacity analysis for NDOR practice
- Determine the corresponding resistance factors, ϕ, for NDOR practice

Load Components for Piles Used in the Analysis

Load	Symbol	Axial load [kips]		
		D=70%, L=30%	D=50%, L=50%	D=30%, L=70%
dead load	DC	675	490	290
dead load	DW	75	50	30
live load	LL_{LRFD}	320	540	750
live load	LL_{HS25}	333	563	781

Calculation of ϕ factors

Ultimate capacity according to Standard Spec:

$$Rn = 2\,(DC + DW + LL_{HS25})$$

Ultimate capacity according to LRFD:

$$\phi Rn = 1.25DC + 1.5DW + 1.75LL_{LRFD}$$

Calculation of ϕ

$$\phi = \frac{1.25\,DC + 1.5\,DW + 1.75\,LL_{LRFD}}{2(DC + DW + LL_{HS25})}$$

Calculation of ϕ factors

Dead load	Live load	ϕ
D=70% ,	L=30%,	0.70
D=50% ,	L=50%,	0.74
D=30% ,	L=70%,	0.78

ϕ Factor for piles

- According to ASSHTO LRFD Bridge Design Specifications 4th Edition 2007, Table 10.5.5.2.3-1, ϕ -factor for nominal resistance of a single pile in axial compression, $\phi = 0.65$

- Proposed ϕ -factor = 0.70

Current Methods to Predict Pile Capacity

- Modified ENR formula (NDOR)
- FHWA Gates formula
- Wave Equation
- CAPWAP
- Static test (most accurate)

Modified ENR Formula (NDOR)

Dynamic Formulas according to Standard Specifications for Highway Constructions NDOR, 703.03

- steel

$$P = \frac{3.0E}{S + 0.1}\frac{W}{W + M}$$

- concrete

$$P = \frac{7.0E}{S + 0.1}\frac{W}{W + M}$$

where:

- P is safe load, in tons
- W is the mass of the ram
- M is the mass of pile and driving cap
- S is the average penetration of the pile per blow for the last 10 blows for steam or diesel hammers (in/blow)
- E is the energy per blow in foot-tons

Gates Formula

Gates Formula:

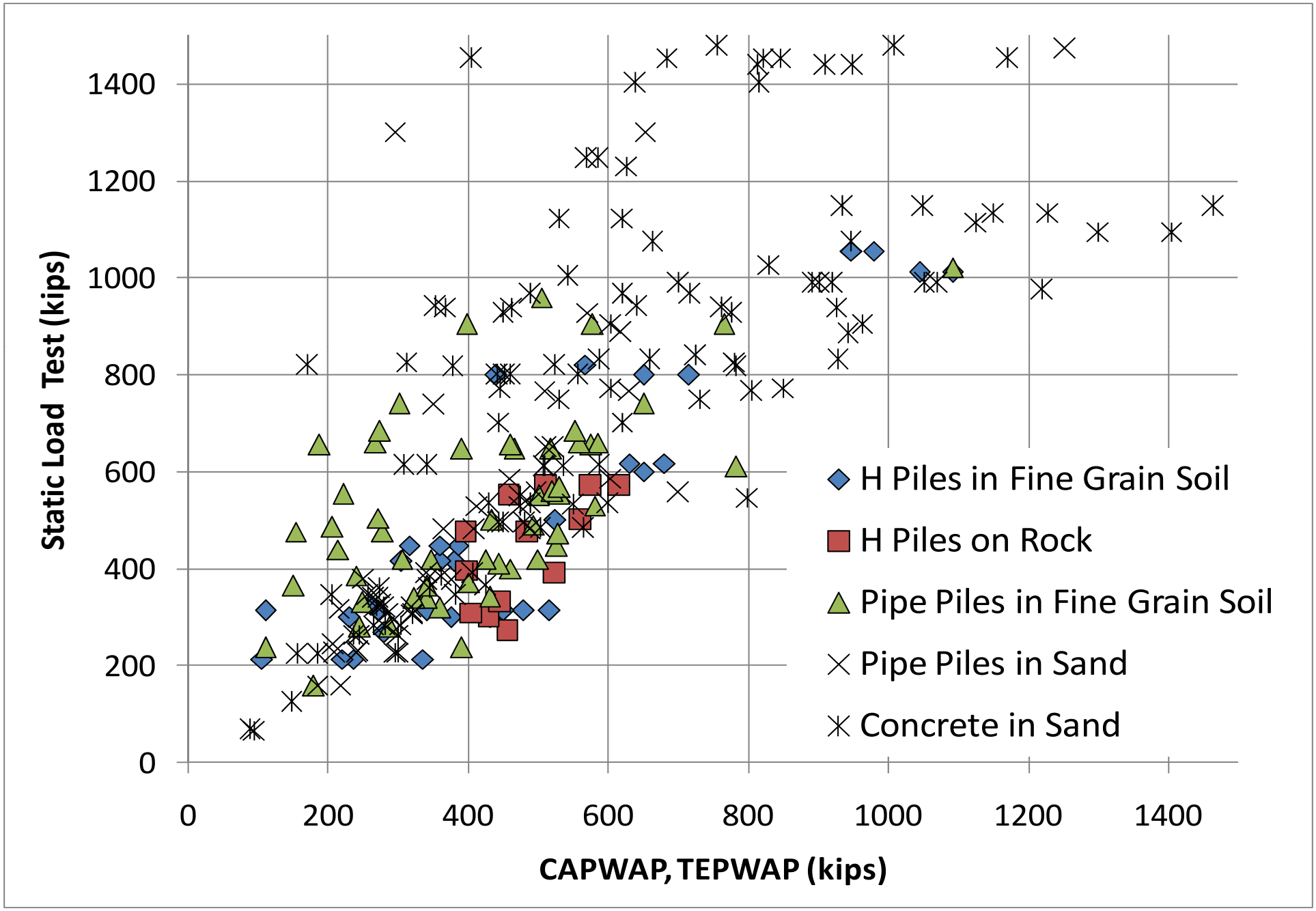
$$R_n = 1.75 \cdot \sqrt{E} \log_{10}(10N) - 100$$

where:

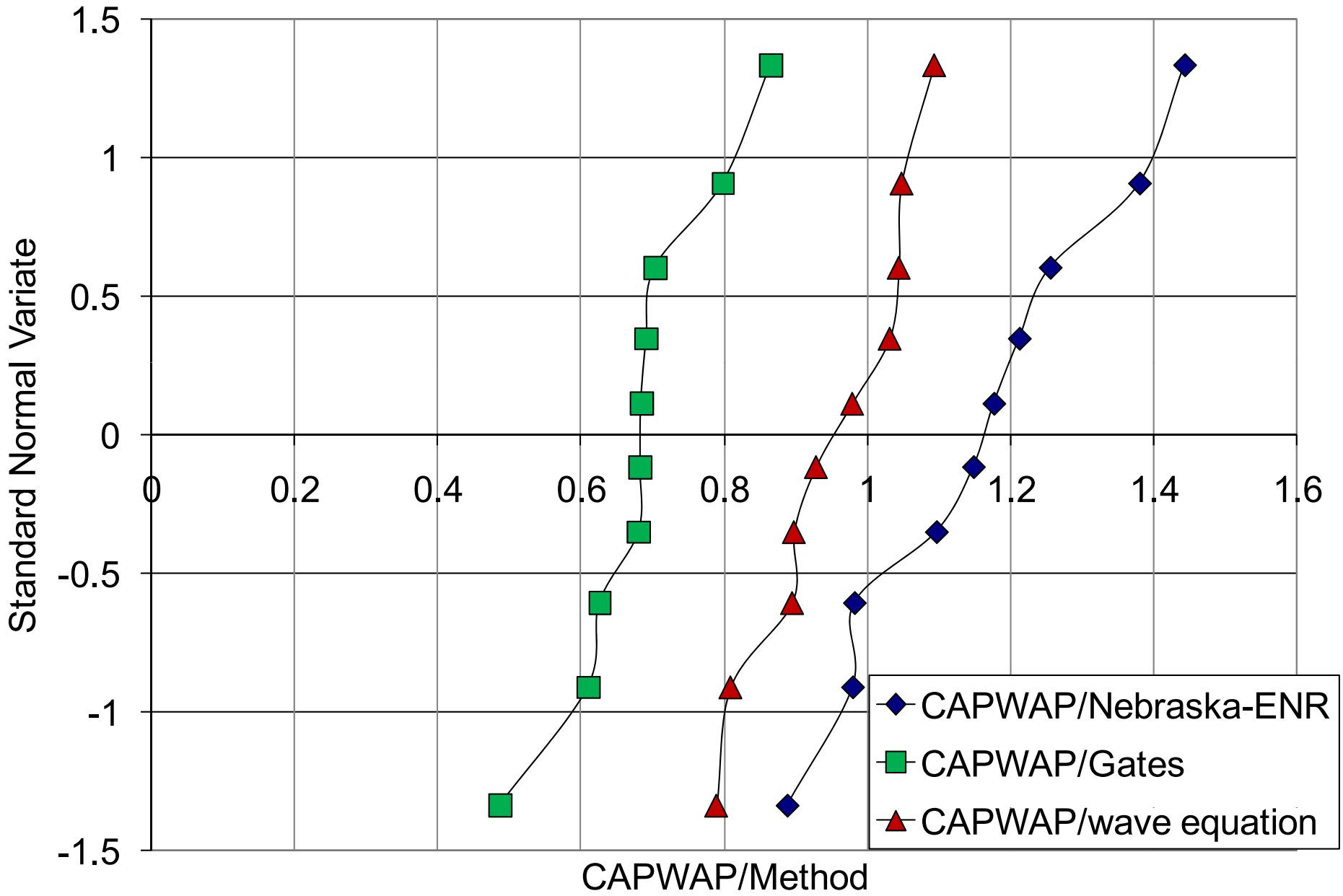
- R is nominal resistance measured during the pile driving (kips)
- E is developed hammer energy
- N is number of hammer blows for 1 in of pile permanent set (blows/in)

Safety factor for Gates formula = 3.5 (AASHTO 1992)

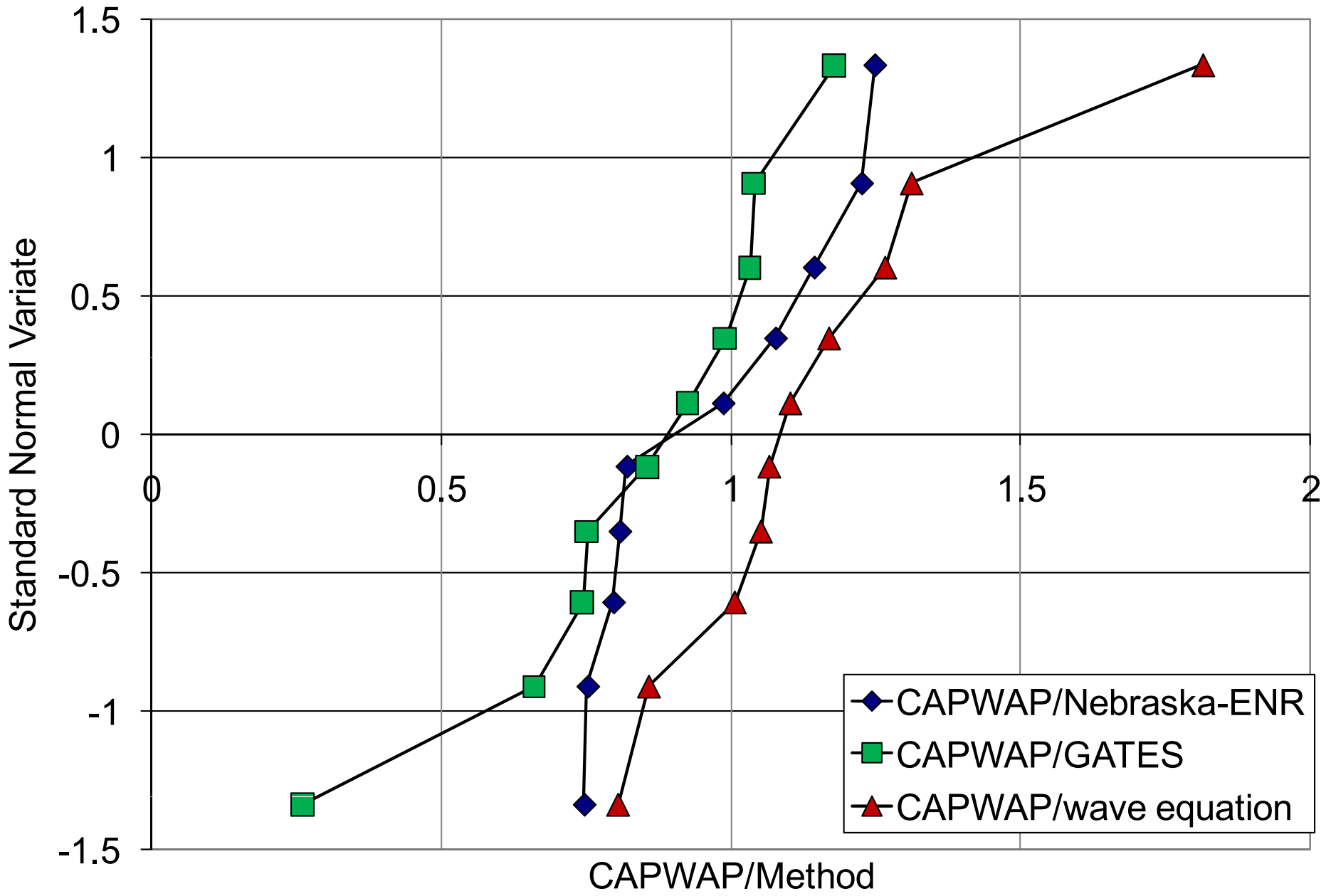
Correlation between CAPWAP and static load test results.



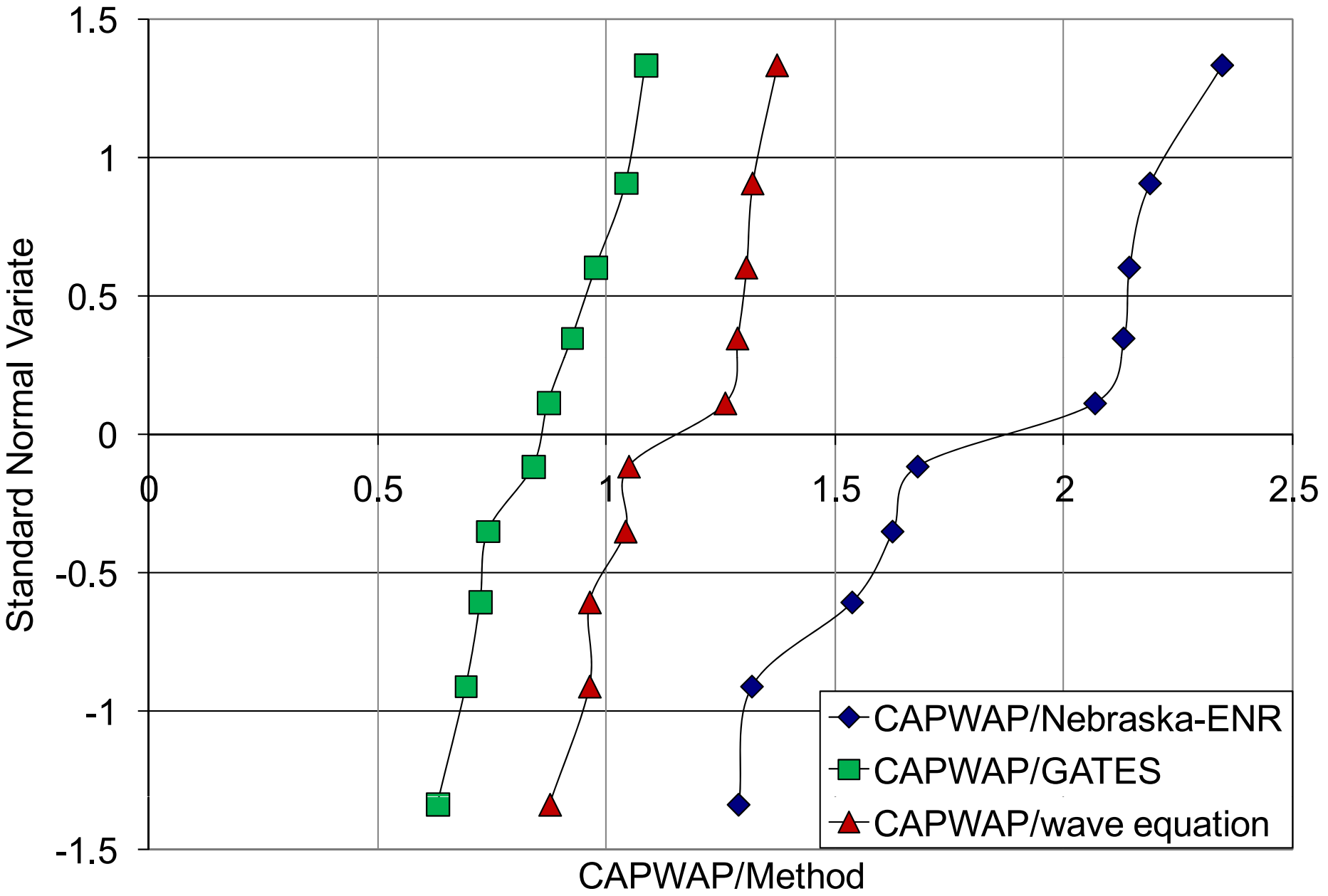
Ratios of CAPWAP Capacity and other methods for Steel H piles in fine grain soil.



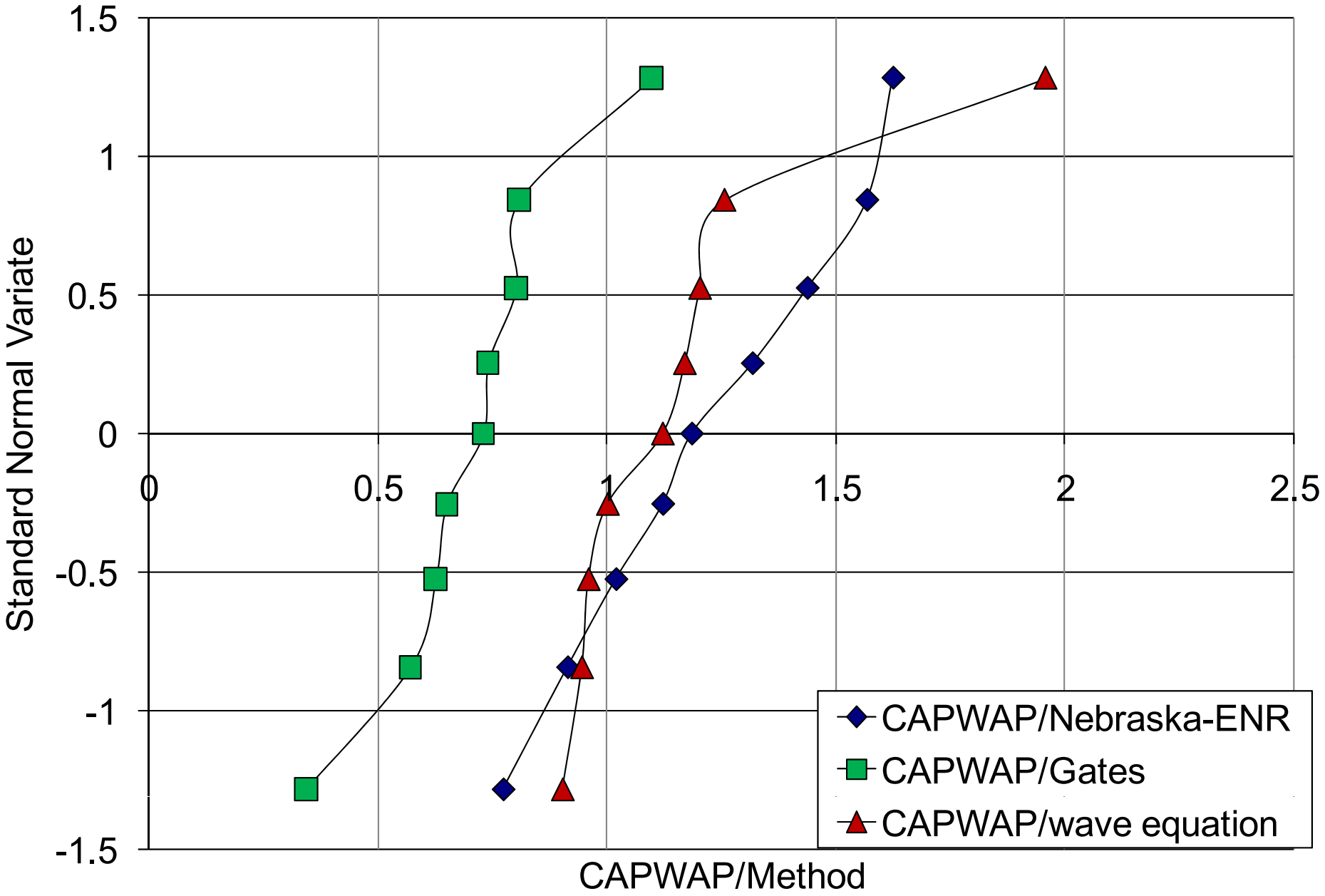
Ratios of CAPWAP Capacity and other methods for Steel H piles on rock .



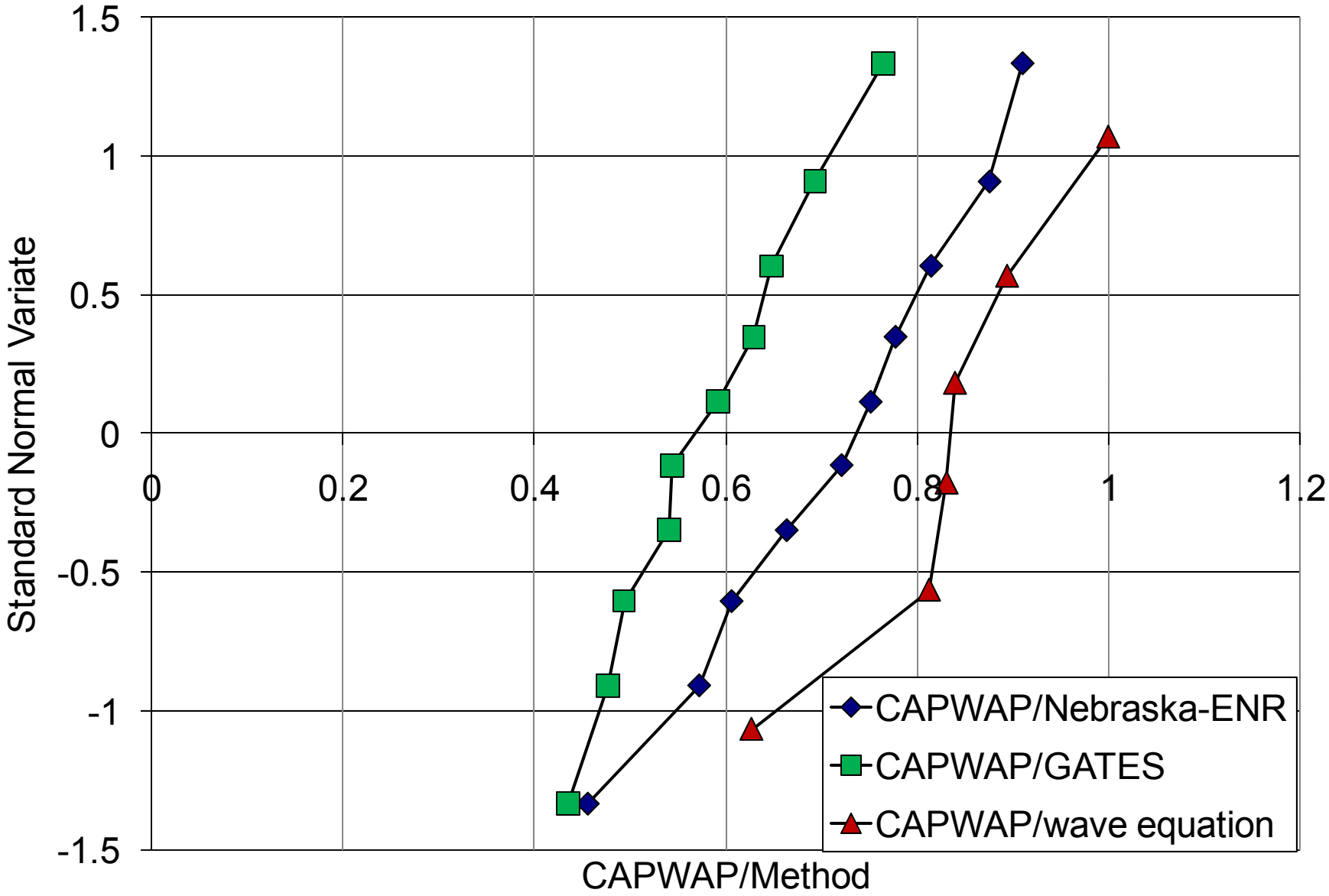
Ratios of CAPWAP Capacity and other methods for Pipe piles in granual.



Ratios of CAPWAP Capacity and other methods for Pipe piles in fine grain soil.



Ratios of CAPWAP Capacity and other methods for Concrete piles in granual soil



Proposed Modified Nebraska ENR Formula

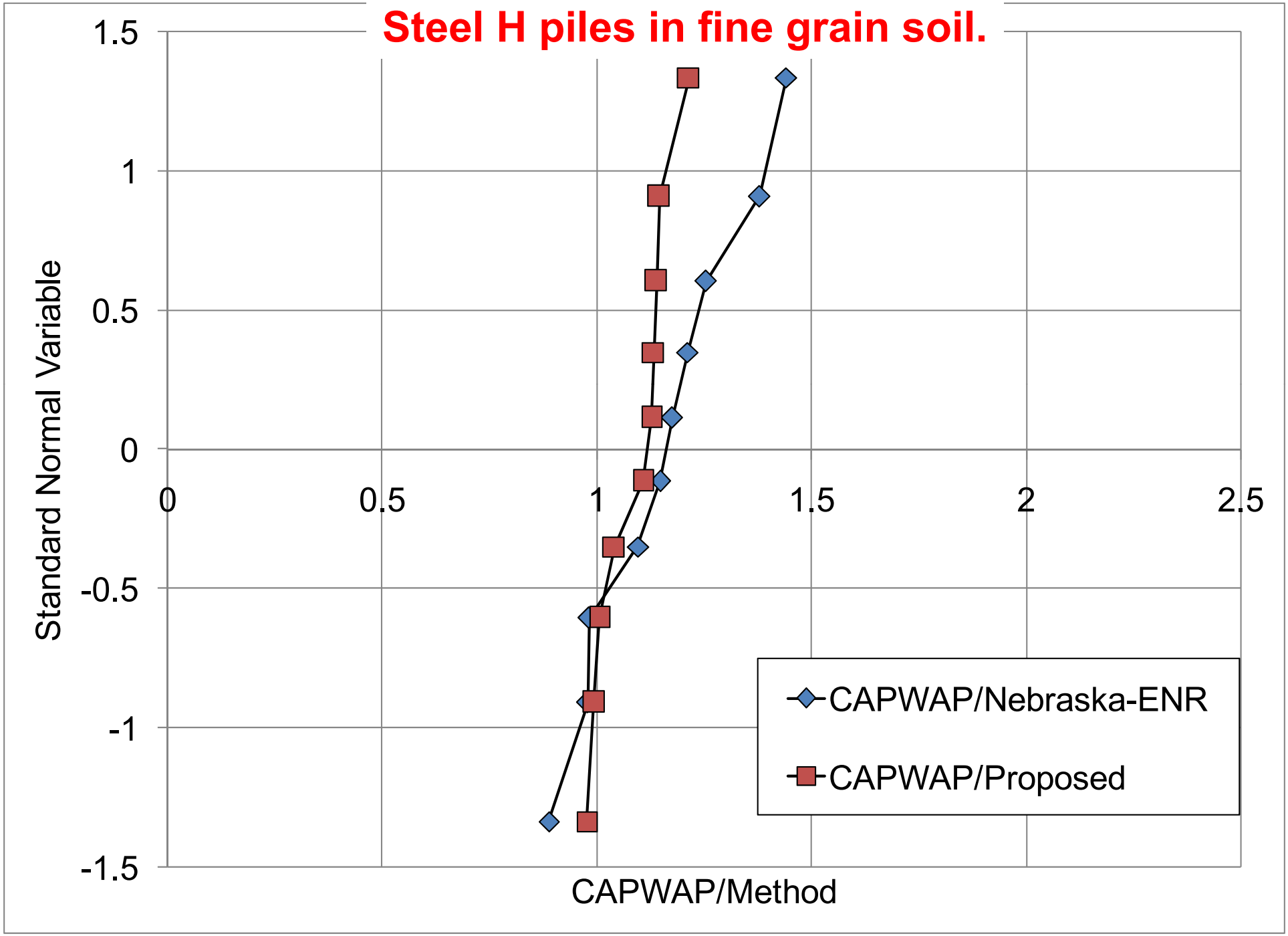
Proposed formula

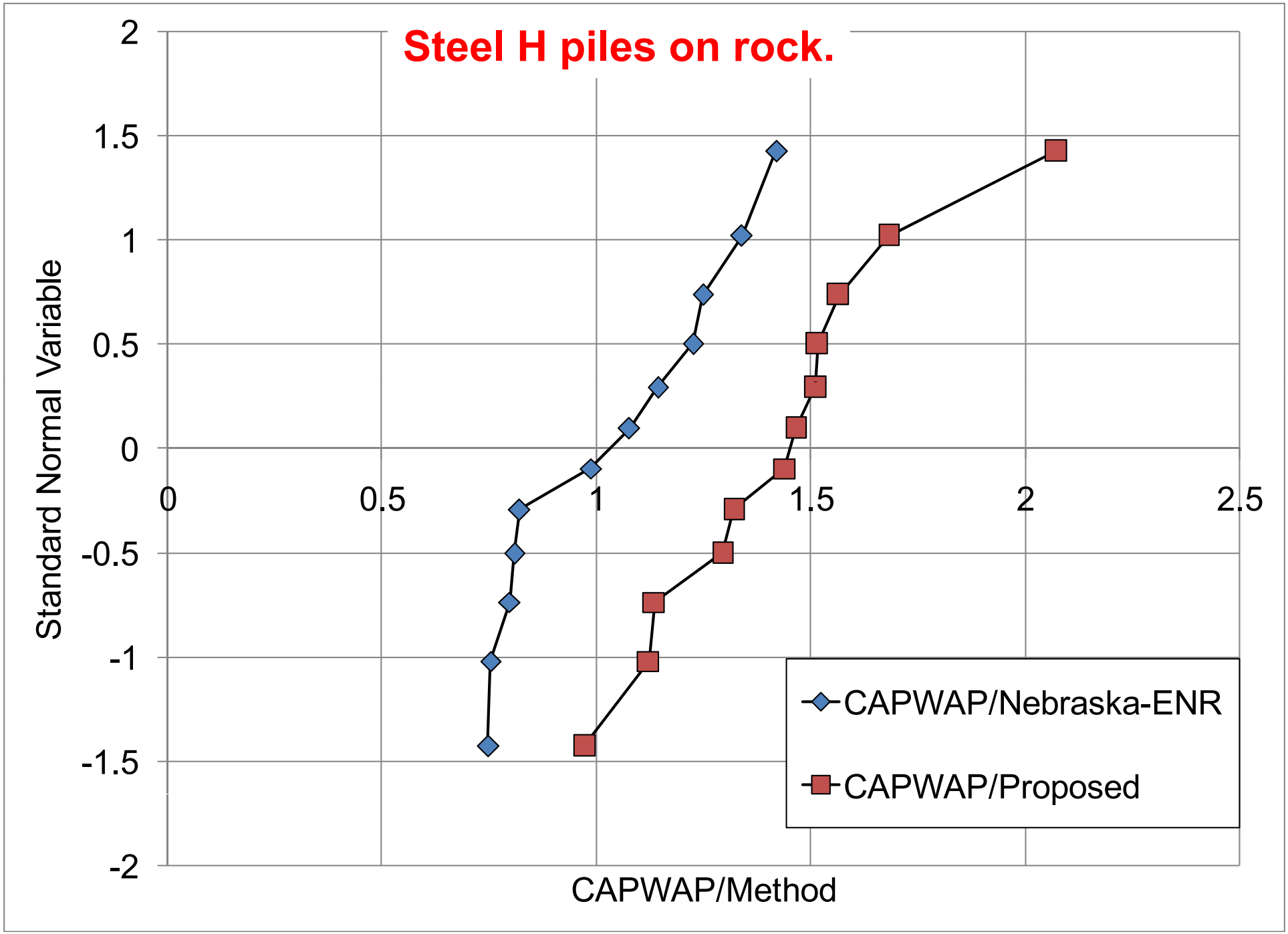
For all piles:

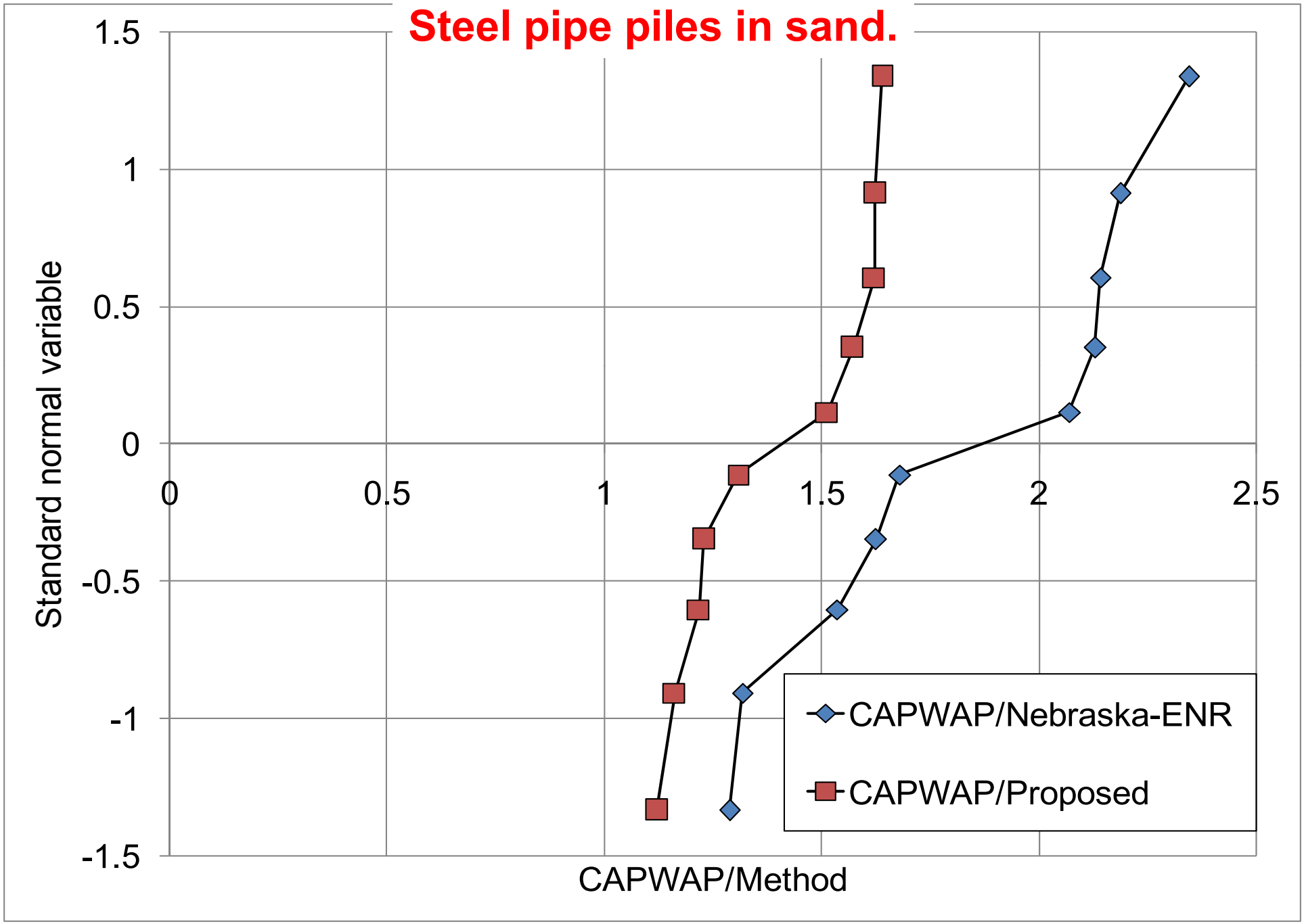
$$P = \frac{6E}{S + 0.5}$$

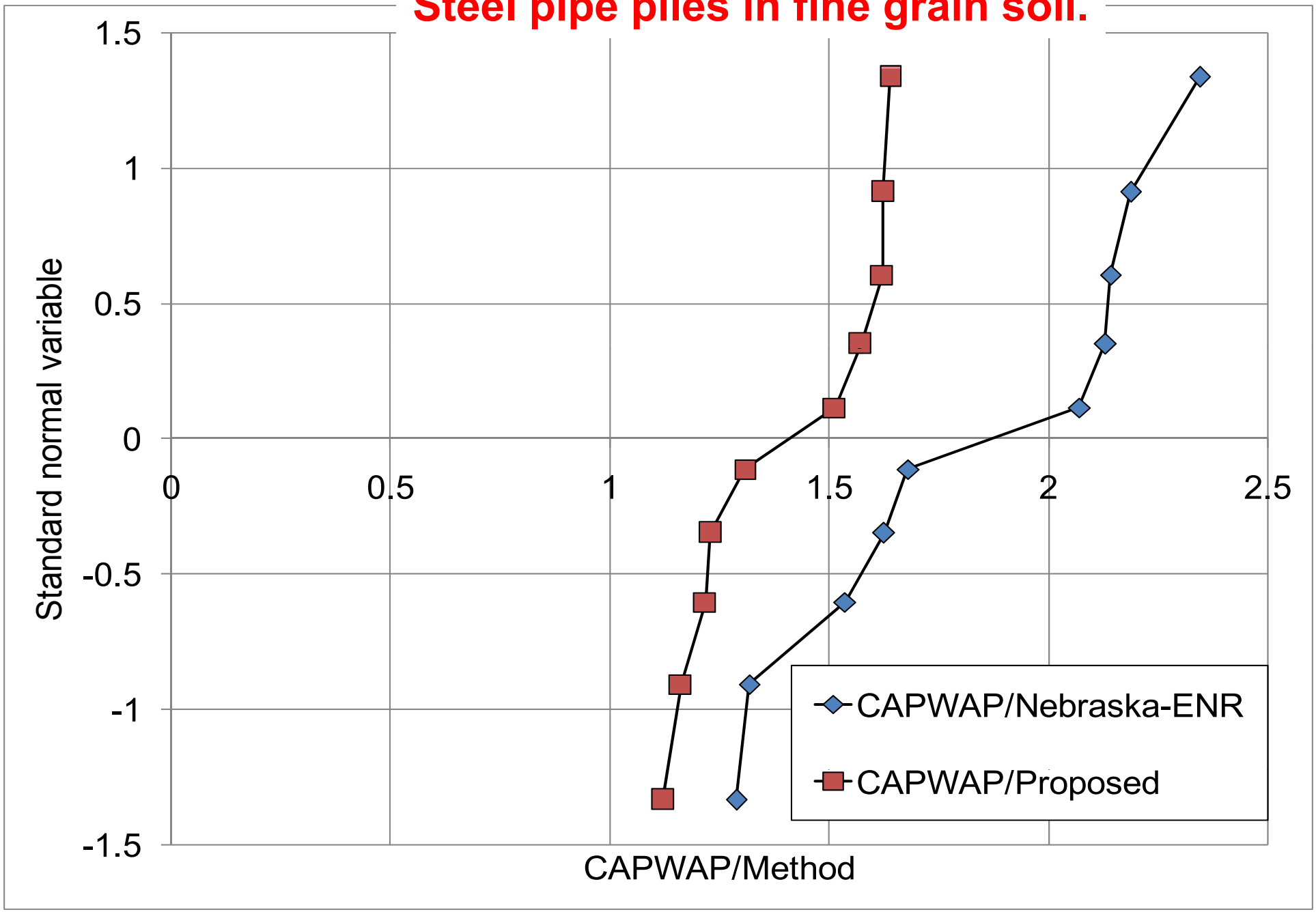
where:

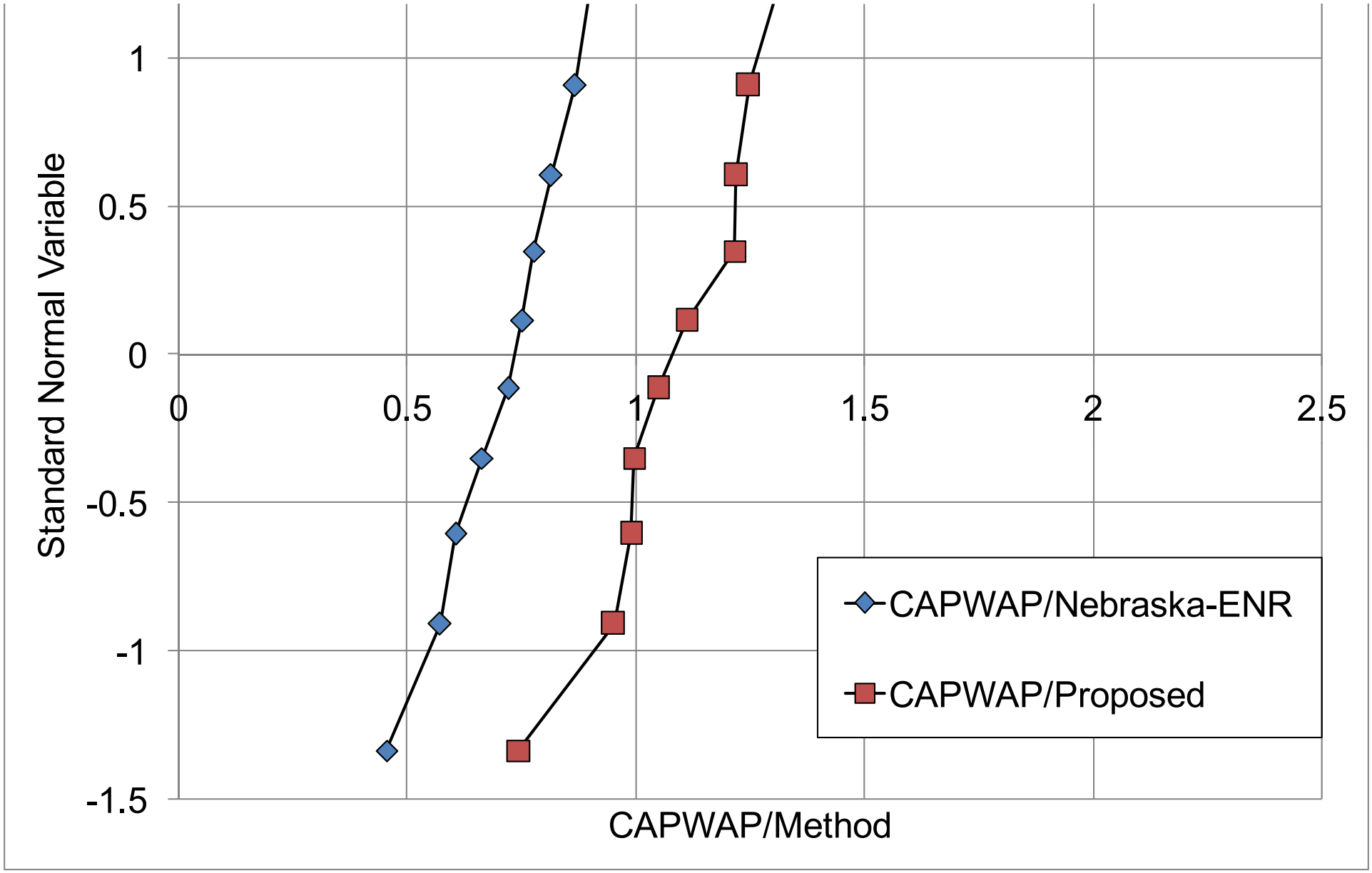
- P is safe load, in kips
- S is the average penetration of the pile per blow for the last 10 blows for steam or diesel hammers
- E is the energy per blow in foot-kips


Steel H piles in fine grain soil.
1.5
1
0.5
0
-0.5
-1
-1.5
Standard Normal Variable
0
0.5
1
1.5
2
2.5
CAPWAP/Method
CAPWAP/Nebraska-ENR
CAPWAP/Proposed


Steel H piles on rock.
Standard Normal Variable
CAPWAP/Method
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
0
0.5
1
1.5
2
2.5
CAPWAP/Nebraska-ENR
CAPWAP/Proposed


Steel pipe piles in sand.
1.5
1
0.5
0
-0.5
-1
-1.5
Standard normal variable
0
0.5
1
1.5
2
2.5
CAPWAP/Method
CAPWAP/Nebraska-ENR
CAPWAP/Proposed


Steel pipe piles in fine grain soil.
1.5
1
0.5
0
-0.5
-1
-1.5
Standard normal variable
0
0.5
1
1.5
2
2.5
CAPWAP/Method
CAPWAP/Nebraska-ENR
CAPWAP/Proposed


Standard Normal Variable
1
0.5
0
-0.5
-1
-1.5
0
0.5
1
1.5
2
2.5
CAPWAP/Method
CAPWAP/Nebraska-ENR
CAPWAP/Proposed

Conclusions

- ϕ factor for driven piles can be 0.70
- Pile capacity can be calculated using

$$P = \frac{6E}{S + 0.5}$$