Performance Based Guidelines for Practitioners

- Issues Related to Mobilization of Foundation Capacity

BUILDING SEISMIC SAFETY COUNCIL

A council of the National Institute of Building Sciences

BSSC Seismic Rehabilitation Project

FEDERAL EMERGENCY MANAGEMENT AGENCY FEMA 356/November 2000

PRESTANDARD AND COMMENTARY FOR THE SEISMIC REHABILITATION OF BUILDINGS

NEHRP GUIDELINES FOR THE SEISMIC REHABILITATION OF BUILDINGS (FEMA Publication 273)

Prepared for the
BUILDING SEISMIC SAFETY COUNCIL
Washington, D.C.

By the
APPLIED TECHNOLOGY COUNCIL (ATC-33 Project)
Redwood City, California

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Geoffrey Martin

Performance Based Guidelines for Practitioners (Cont.)

- Issues Related to Mobilization of Foundation Capacity

BUILDING SEISMIC SAFETY COUNCIL
of the National Institute of Building Sciences

Program on Improved Seismic Safety Provisions

2003 Edition

NEHRP RECOMMENDED PROVISIONS FOR SEISMIC REGULATIONS FOR NEW BUILDINGS AND OTHER STRUCTURES (FEMA 450)

Part 1: Provisions

Appendix to Chapter 7

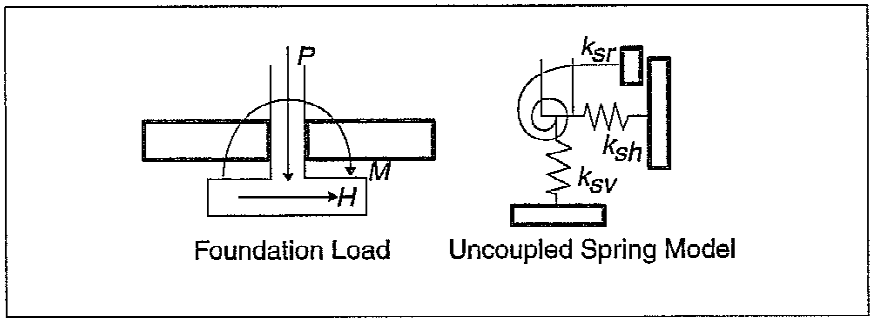
GEOTECHNICAL ULTIMATE STRENGTH DESIGN OF FOUNDATIONS AND FOUNDATION LOAD-DEFORMATION MODELING

PREFACE: This appendix introduces ultimate strength design (USD) procedures for the geotechnical design of foundations for trial use and evaluation by design professionals prior to adoption into a subsequent edition of the *Provisions*. Similarly, the appendix also introduces criteria for the modeling of load-deformation characteristics of the foundation-soil system (foundation stiffness) for those analysis procedures in Chapter 5 that permit the use of realistic assumptions for foundation stiffness rather than the assumption of a fixed base.

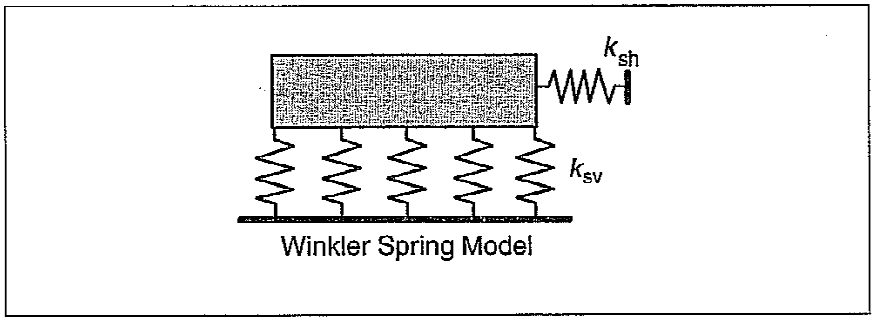
Current practice for geotechnical foundation design is based on allowable stresses with allowable foundation load capacities for dead plus live loads based on limiting long-term static settlements and providing a large factor of safety. In current practice, allowable soil stresses for dead plus live loads are typically increased by one-third for load combinations that include wind or seismic forces. The allowable stresses for dead plus live loads are often far below ultimate soil capacity. This *Provisions* appendix and the associated *Commentary* appendix provide criteria and guidance for the direct use of ultimate foundation load capacity for load combinations that include seismic forces. The acceptance criteria covers both the analyses for fixed-base assumptions and analyses for linear and nonlinear modeling of foundation stiffness for flexible-base assumptions.

Although USD for foundations has not previously been included in design provisions for new buildings, the same basic principles used in this appendix have been adapted to generate guidelines for the seismic evaluation and retrofit design of existing buildings (FEMA 273, FEMA 356, and ATC 40). The criteria and procedures presented herein for the nonlinear modeling of foundation stiffness, combining a linear or multilinear stiffness and a limiting load capacity based on ultimate soil strength, are essentially the same as those presented in the FEMA and ATC publications identified above.

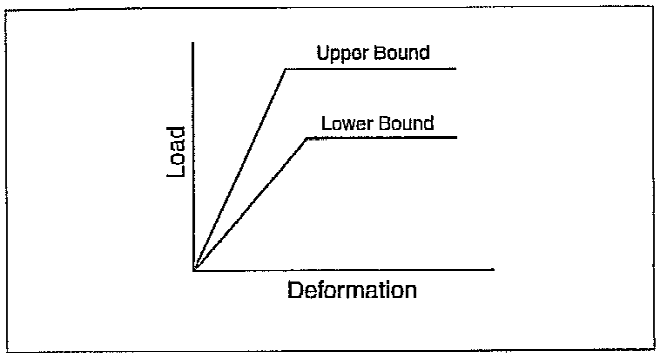
Foundation Models



Uncoupled elasto-plastic spring model for rigid footings.

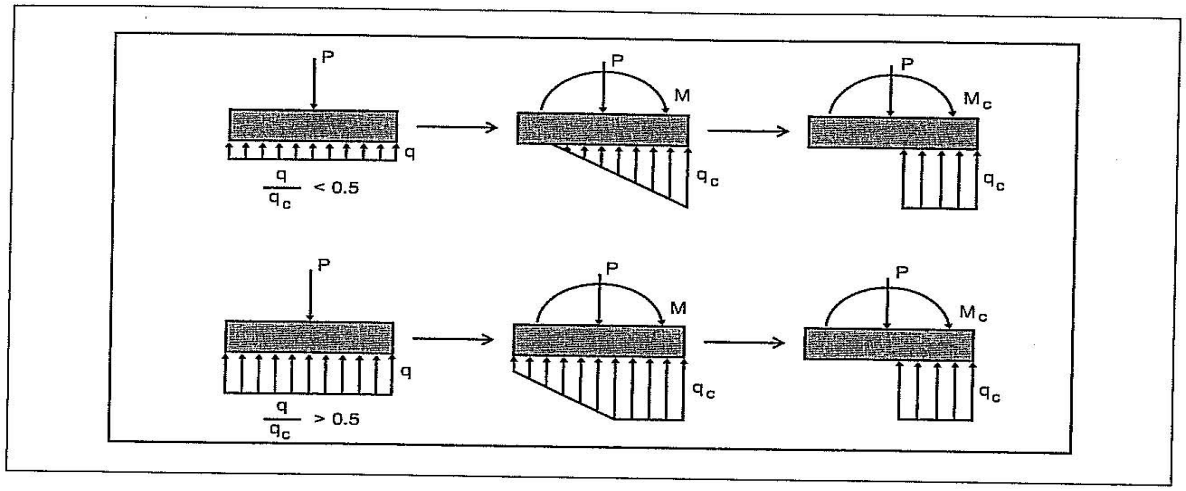


Uncoupled Winkler spring model.



Upper and lower bound approach to define stiffness and capacity.

Capacity Mobilization – Rocking



Idealized concentration of stress at edge of rigid footings subjected to overturning moment.

$$F_v = \frac{q_c}{q}$$

where q is the vertical load on footing (contact stress).

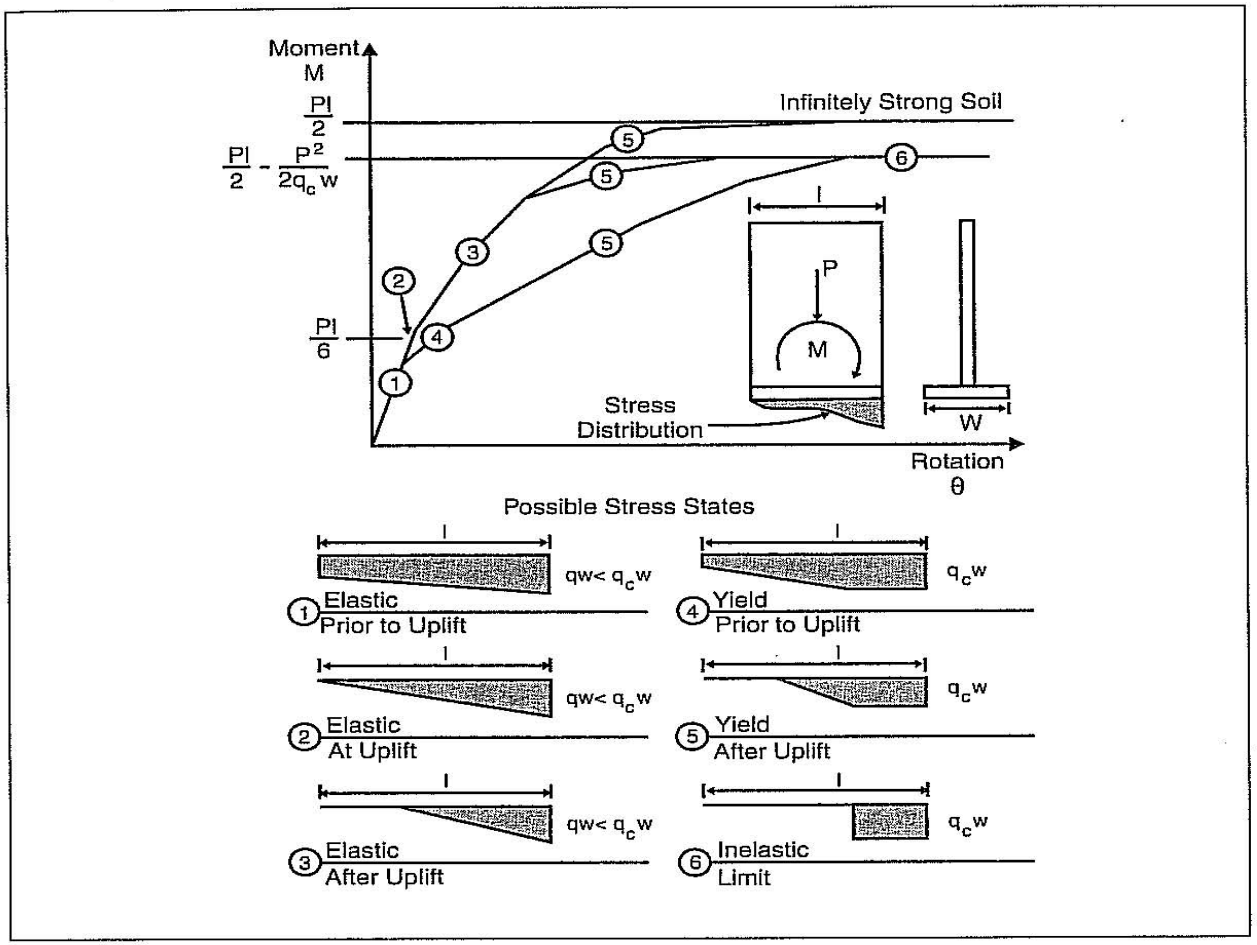
If F_v is greater than 2, uplift will occur prior to plastic yielding of the soil, but if F_v is less than or equal to 2, the soil at the toe yields before uplift begins.

With these assumptions, the moment capacity of a rectangular footing may be expressed as:

$$M_c = \frac{LP}{2}\left(1 - \frac{q}{q_c}\right) = \frac{LP}{2}\left(1 - \frac{1}{F_v}\right)$$

where P is the vertical load on footing, q equals P/BL, B is the footing width, and L is the length of footing in direction of bending.

Shear Wall Footings – Influence of Mobilization of Foundation Capacity



after NEHRP, 1997b

Rocking of shear wall on strip footing.

Research on Rocking Footings on Clays and Sands: 1970's

- Model Footings – University of Auckland

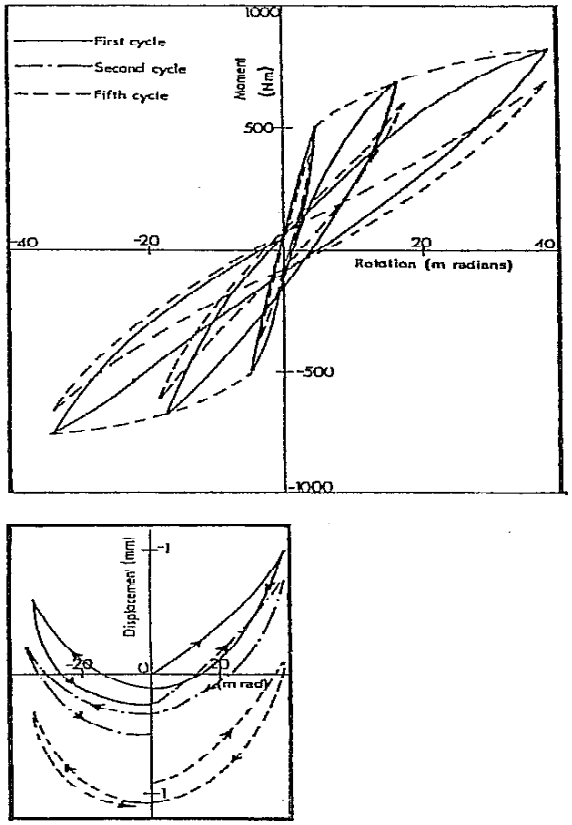


Figure 2. Measured Behavior of Type B footing on clay: experimental result for $F_v = 3.0$ (after Taylor et al. 1976).

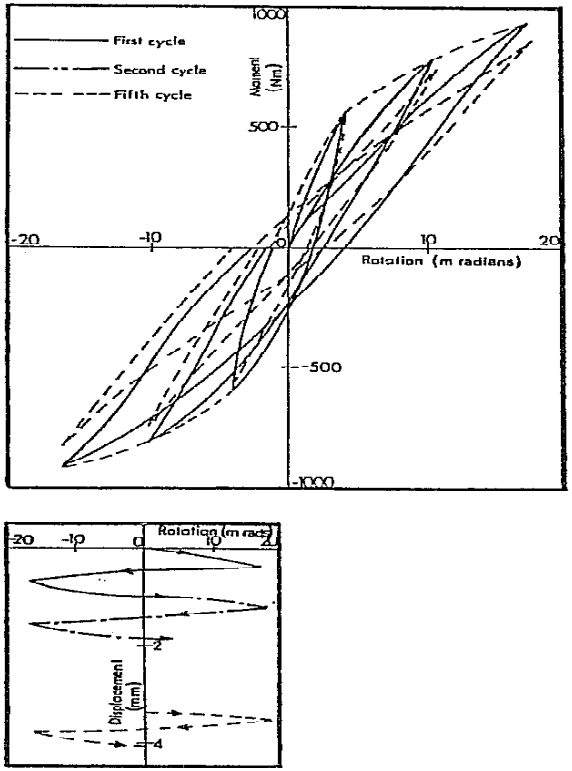


Figure 1. Measured Behavior of Type B footing on clay: experimental result for $F_v = 1.5$ (after Taylor et al. 1981).

Research on Rocking Footings on Clays and Sands: 1970's (Cont.)

EARLY RESEARCH AT THE UNIVERSITY OF AUCKLAND, NEW ZEALAND IN THE 1970'S, ON FOUNDATION ROCKING:

"The research shows that rotational yield may occur under spread footing when earthquake loadings are applied, without serious detriment to vertical load-bearing capacity, and that, under suitable conditions, vertical displacement, even after several cycles of rocking, can be small. Thus, spread footings may be intentionally design to yield in high-intensity earthquake and this may be preferable to the yielding of columns at base level in reinforced concrete frame structures."

Extracted from a paper by Taylor, P.W., Bartlett, P.E., and Wiessing, P.R. (1981) "Foundation Rocking under Earthquake Loading," Proceedings of the Tenth International Conference on Soil Mechanics and Foundation Engineering, Vol. 3, pp. 33-322.

Simulation of Test Results using FLAC

- After Yan and Martin (1999)

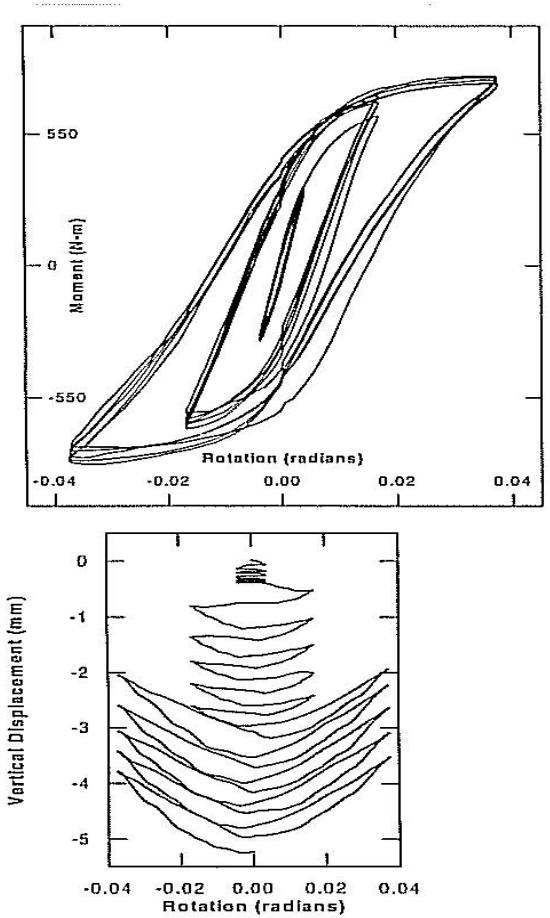


Figure 6. Simulated behavior of Type B footing on clay: F_v = 3.0.

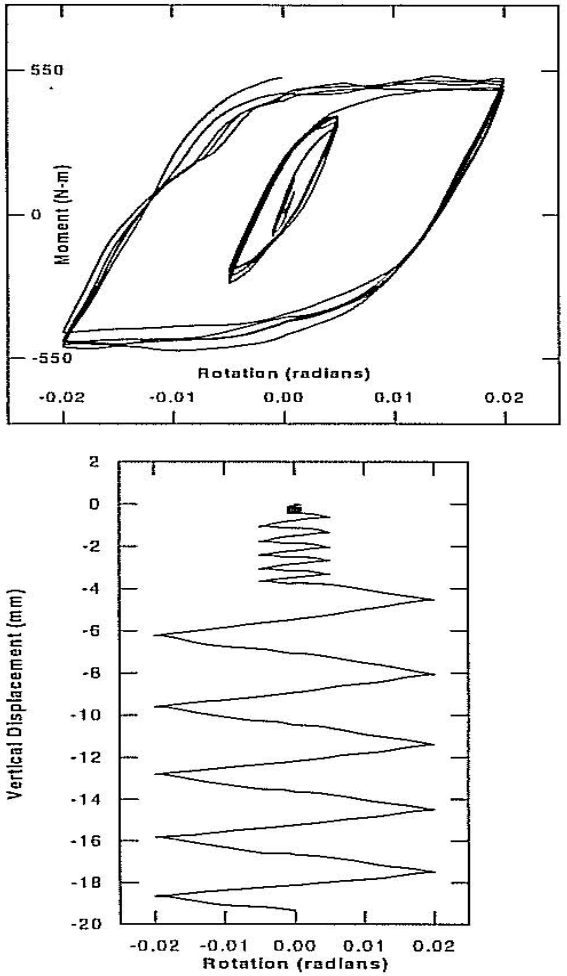


Figure 7. Simulated behavior of Type B footing on Sand: F_v = 5.0 and D_r = 93%.

Research on Rocking Footings: PEER

- Centrifuge Tests – University of California, Davis

Workshop on Modeling of Nonlinear Cyclic Load-Deformation Behavior of Shallow Foundations

Wednesday, March 5, 2003
University of California, Davis

Bruce L. Kutter
Department of Civil and Environmental Engineering
University of California, Davis

Geoffrey Martin
University of Southern California, Los Angeles

Tara Hutchinson
University of California, Irvine

Chad Harden
University of California, Irvine

Sivapalan Gajan
University of California, Davis

Justin Phalen
University of California, Davis

PEER Report 2005/14
Pacific Earthquake Engineering Research Center
College of Engineering
University of California, Berkeley
March 2006

Research on Rocking Footings: PEER (Cont.)

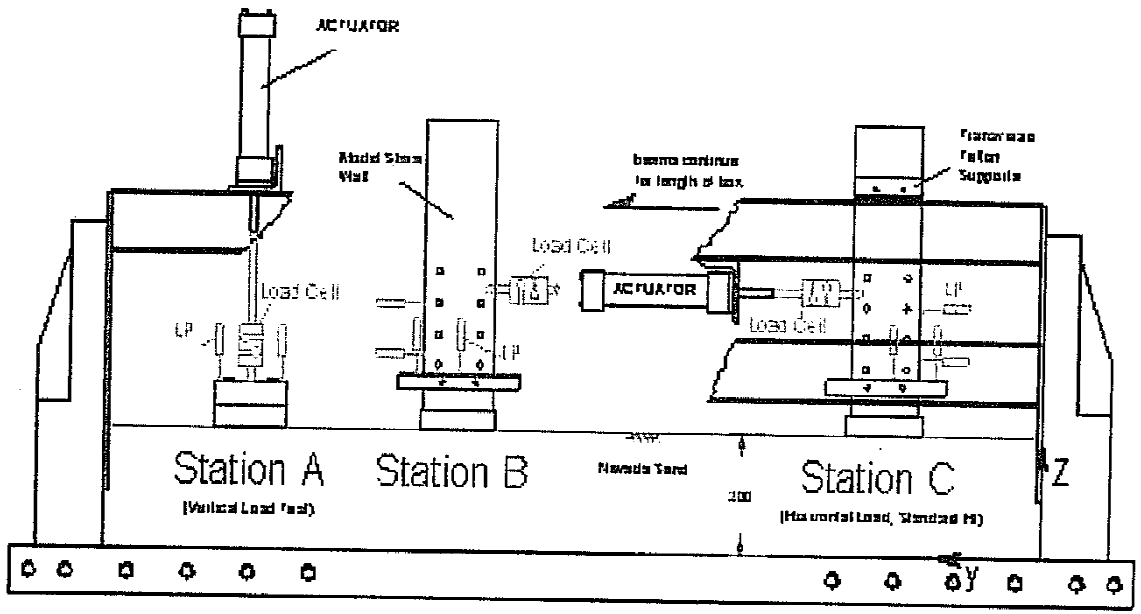


Figure 11. Side View of Model Container with Selected Wall and Footing Locations with Typical Instrument Configuration for Slow Cyclic Tests

Research on Rocking Footings: PEER (Cont.)

- Typical Test Results

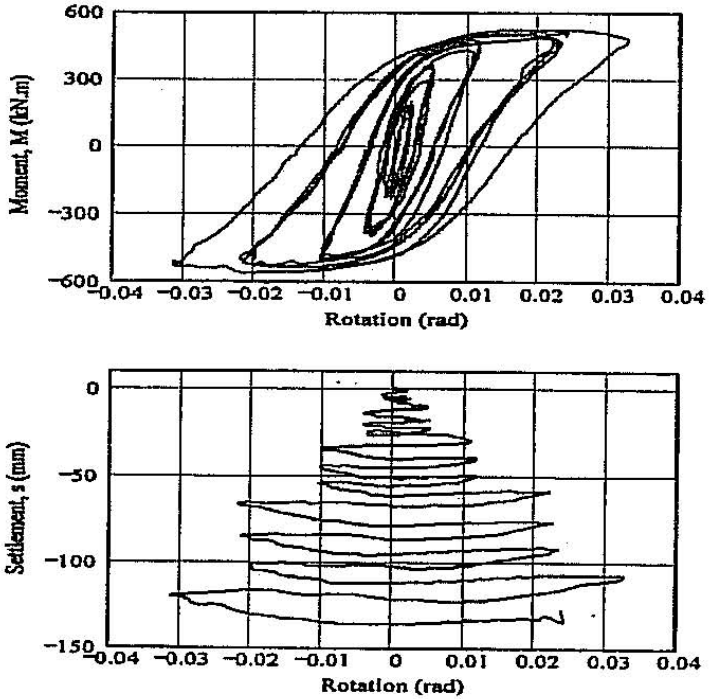


Figure 12. Centrifuge Spread Footing Test, FS=3.3

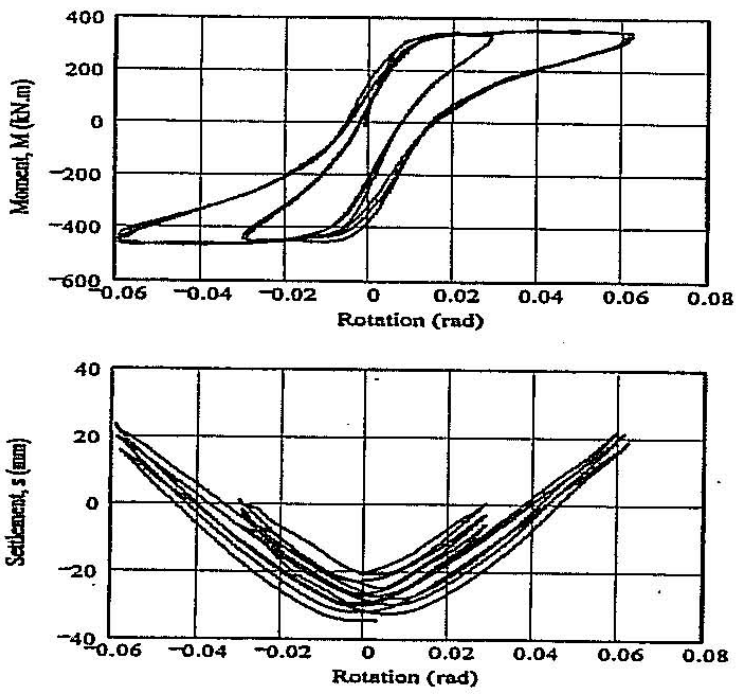


Figure 13. Centrifuge Spread Footing Test, FS=8.4

Research on Rocking Footings: PEER (Cont.)

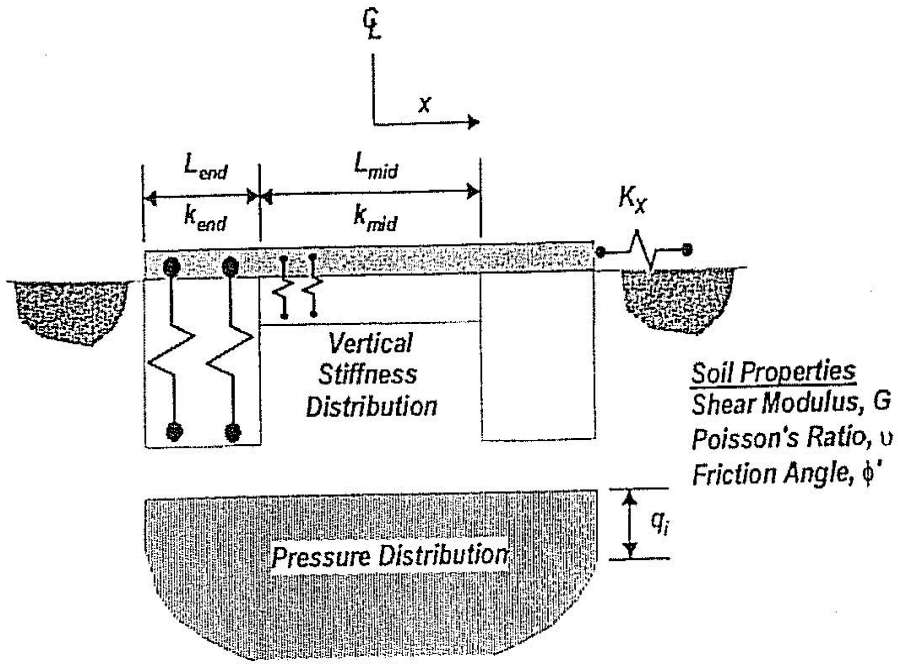


Figure 13. Beam on a Nonlinear Winkler Foundation (BNLW) Model (after Harden, 2003)

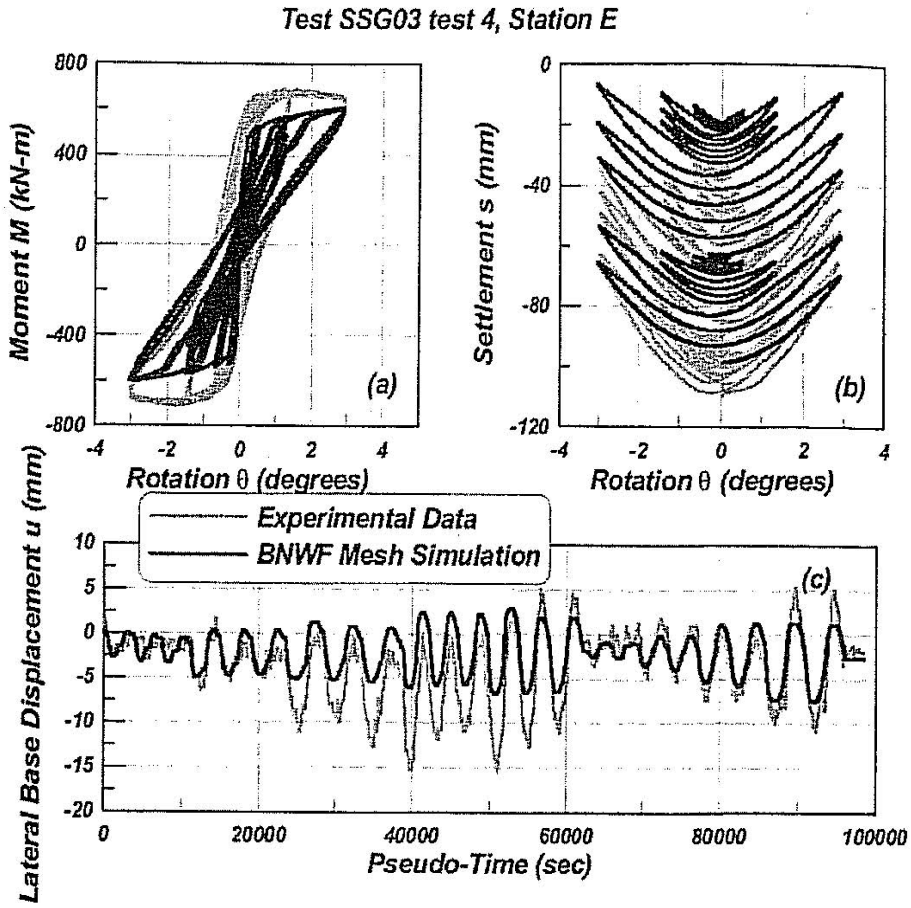
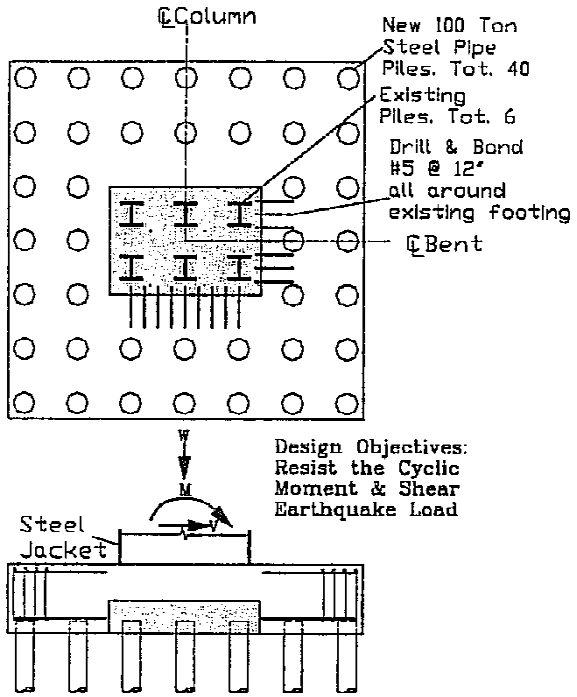
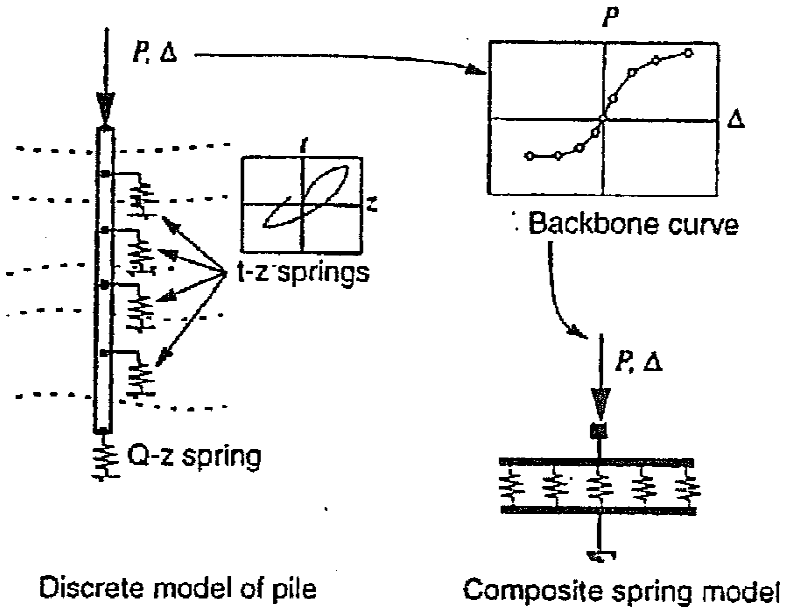


Figure 14. Comparison Between a BNWF Model and Centrifuge Test Results (after Harden, 2003)

Non-Linear Models – Pile Footing Analyses

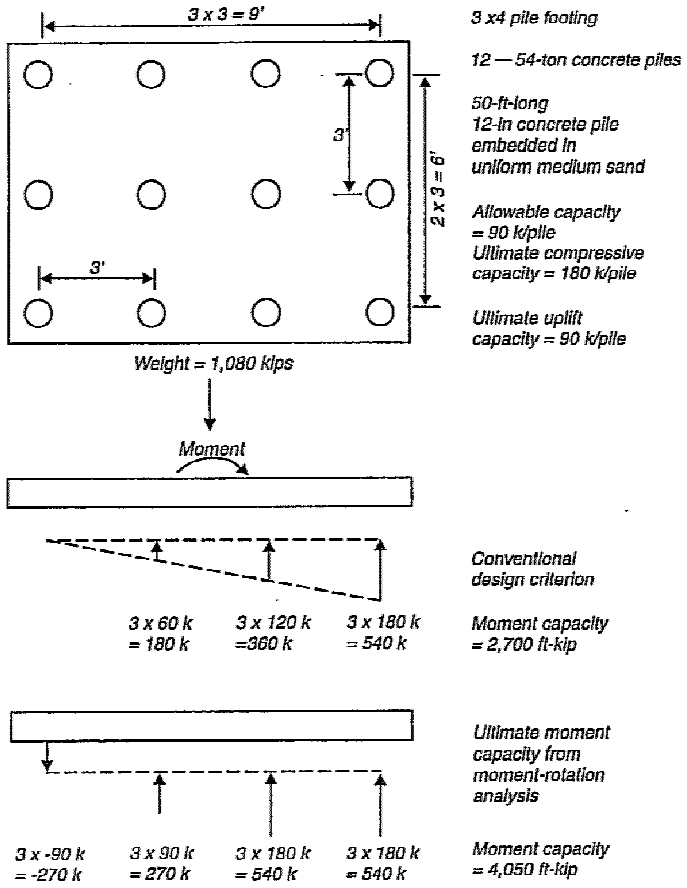


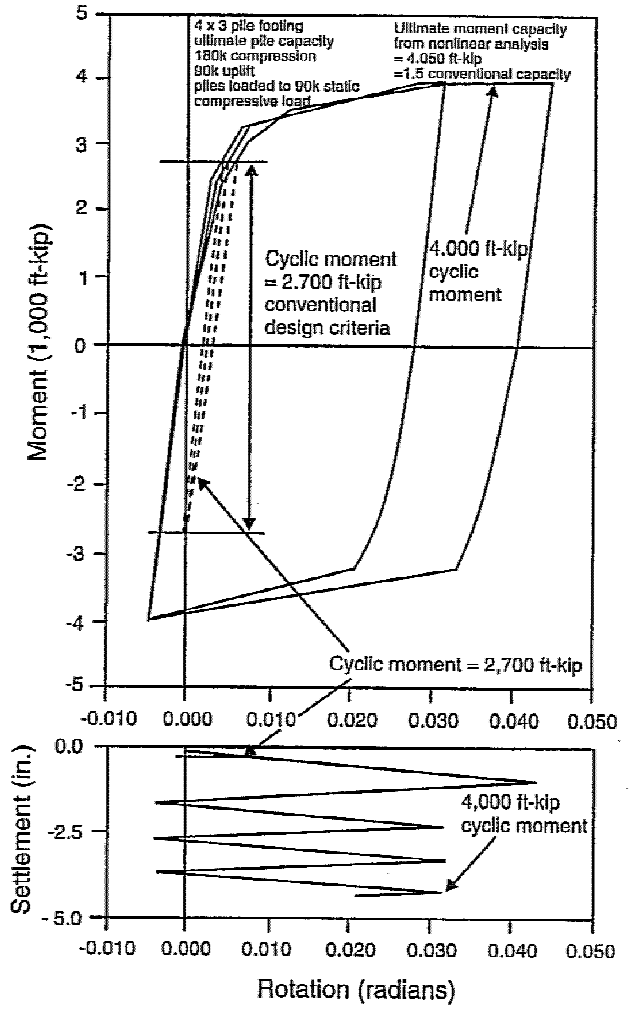
Example of Traditional Pile Footing Retrofit



Discrete Spring Model

Non-Linear Models – Pile Footing Analyses (Cont.)





Capacity Evaluation: Uncertainty

Predicted and Measured Behavior of Five Spread Footings On Sand

Proceedings of a Prediction Symposium Sponsored by the Federal Highway Administration at the occasion of the Settlement '94 ASCE Conference at Texas A&M University, June 16-18, 1994.

Edited by Jean-Louis Briaud and Robert M. Gibbens

Geotechnical Special Publication No. 41

Capacity Evaluation: Uncertainty (Cont.)

