IN SITU TESTING TECHNOLOGY FOR FOUNDATION & EARTHQUAKE ENGINEERING

Wesley Spang, Ph.D., P.E.
AGRA Earth & Environmental, Inc.
Portland, Oregon

In situ testing of soil, which essentially consists of evaluating the geotechnical engineering properties of soil in their natural environment instead of the laboratory, has been proven to be a cost effective means of developing economical foundation engineering design criteria. New technologies in the past 10 to 15 years have been developed in the geotechnical engineering field which greatly facilitate in situ testing. In situ testing can include the cone penetration test, dilatometer test, pressuremeter, and geophysical methods such as seismic refraction and surface wave analysis. Today's talk will focus on the cone penetration test and dilatometer test.

Cone penetration testing consists of pushing an instrumented steel cone into the ground with a 20-ton cone truck. Data regarding cone tip resistance and sleeve friction are obtained at 4-inch-intervals. This data is used to characterize the soil with respect to soil type, stiffness, shear strength, etc. Additionally, geophysical measurements can be made to measure the soil shear wave velocity at various depths. This information is used to evaluate the response of the site to earthquake loading and to determine the potential for liquefaction of underlying soils during an earthquake.

The dilatometer test consists of inserting a hardened steel blade into the ground. A circular steel membrane is located on one side of the blade. A cone penetration truck or drill rig is used to advance the blade at a constant rate of 2 cm/sec. The shape and dimension of the dilatometer blade have been designed to minimize the induced strain (and hence disturbance) to the soil during insertion. At selected intervals (typically 8 inches) the steel membrane is expanded laterally into the soil. The pressures required to expand the membrane provide a direct measurement of the soil modulus (stiffness). In addition to the modulus other geotechnical engineering parameters that may be evaluated from dilatometer testing include undrained shear strength, friction angle, overconsolidation ratio, and permeability. Shallow and deep foundation design can then be performed using the derived geotechnical data. A main benefit of the dilatometer is that it directly measures the soil modulus (stiffness). This parameter controls foundation design since almost all foundations are designed based on their potential for settlement and not bearing capacity (i.e. failure).

The soil geotechnical engineering parameters determined from in situ testing are not affected by the level of disturbance and degradation that results from laboratory testing of soil samples obtained from conventional soil borings. Soil geotechnical engineering parameters are therefore more representative of actual in situ strength and stiffness than commonly determined from laboratory testing. In situ testing has been used to provide economical foundation design by substantiating the use of higher foundation bearing pressures than typically developed from laboratory testing. The higher foundation bearing capacities generally result in significant savings to the owner.

In situ testing is also important for the study and evaluation of sites and structures for resistance to earthquake loading. Recent earthquakes in Northridge, California and Kobe, Japan have demonstrated the consequences of earthquake motions, particularly for buildings and other structures not designed for significant levels of shaking. In situ testing techniques, particularly the cone penetration test and shear wave velocity test, have become recognized as effective ways to evaluate the potential for soil related damage at a site from earthquake motions. Correlations between shear wave velocity and ground acceleration required to cause liquefaction have become available in the past 5 to 10 years and are routinely used for site evaluation. Cone penetration test results can also be used to evaluate the potential for settlement due to earthquake motions.

In situ testing is becoming a larger part of geotechnical engineering and will increase as owners and developers look for cost effective foundation systems and evaluation of resistance to earthquake ground motions.

In Situ Testing Technology For Foundation Engineering and Earthquake Engineering

Wesley Spang
AGRA Earth & Environmental, Inc.
Portland, Oregon

In Situ Testing

Geotechnical site characterization has typically been performed by the drilling of borings and laboratory testing of retrieved soil samples

In situ testing has become more common as equipment has moved from research to commercial use and case histories have validated results

CPT Benefits

Data is obtained at 4-inch-intervals, resulting in “continuous profile”

Automated, not dependent on operator (variability due to soil, not personnel)

Real time data recording and analysis by on-board computer system

Flat Plate Dilatometer

Steel blade inserted into the ground, typically with a cone truck or drill rig. At selected intervals (usually 8 inches) the membrane located on face of blade is expanded laterally into the soil.

DMT Benefits

Directly measures soil modulus
(most important soil geotechnical property
for shallow foundation design).

Provides best data for design of piles
for lateral loading (bridges, waterfront
structures).

Use of Shear Velocity/Modulus in Geotechnical Engineering

- Site Characterization
- Ground Response
- Foundation Design
- Liquefaction Analysis

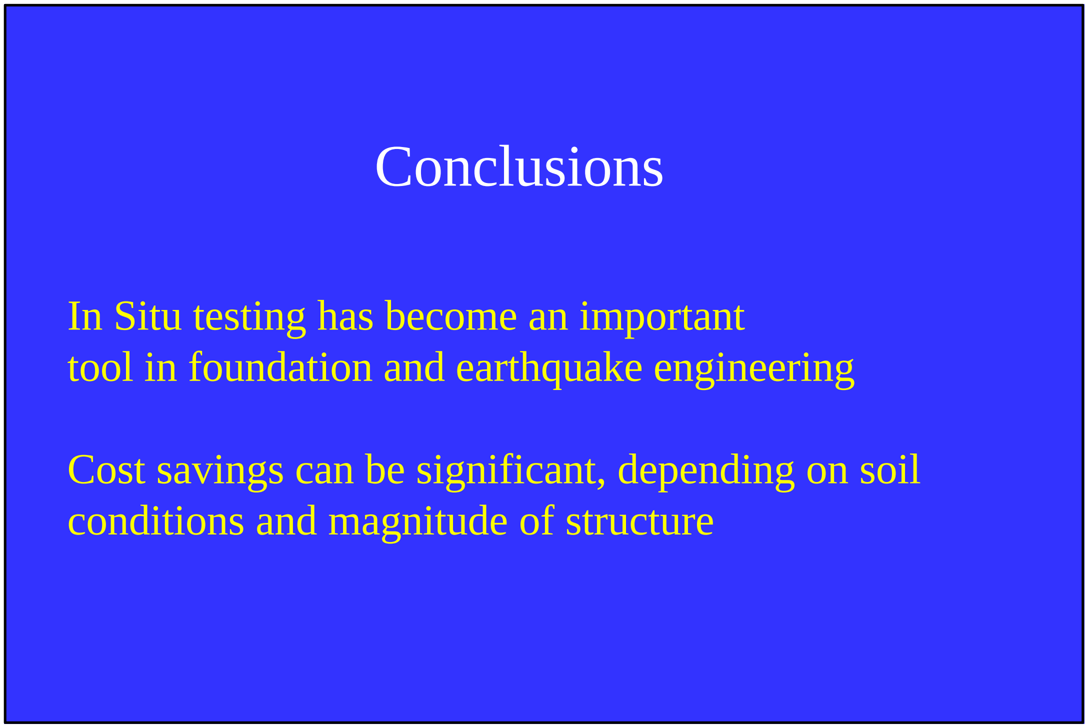
Geotechnical Earthquake Engineering

- Ground Response
  Amplification or Damping of Rock Motion

- Liquefaction
  Reduction of Soil Shear Strength

Consequences of Liquefaction

- Foundation Failure (Bearing Capacity)
- Settlement
- Lateral Spreading
- Uplift of Buried Structures



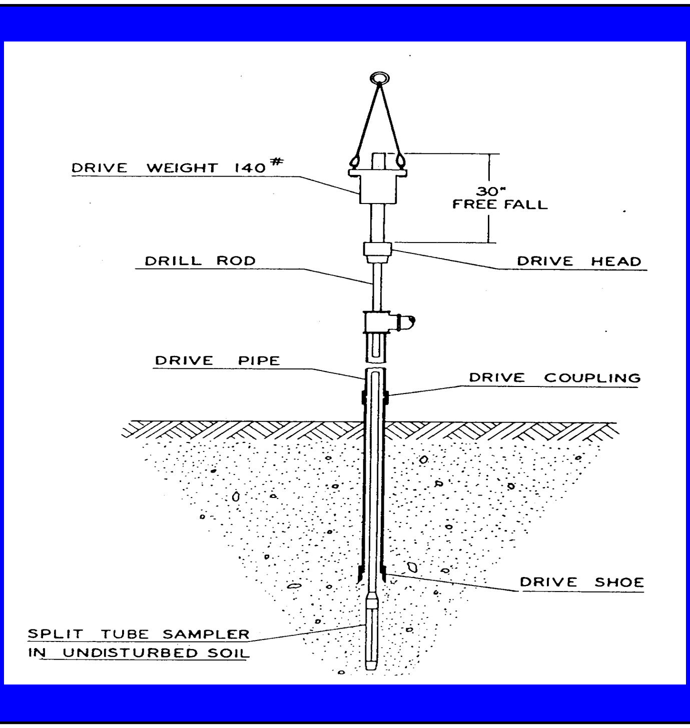
Conclusions

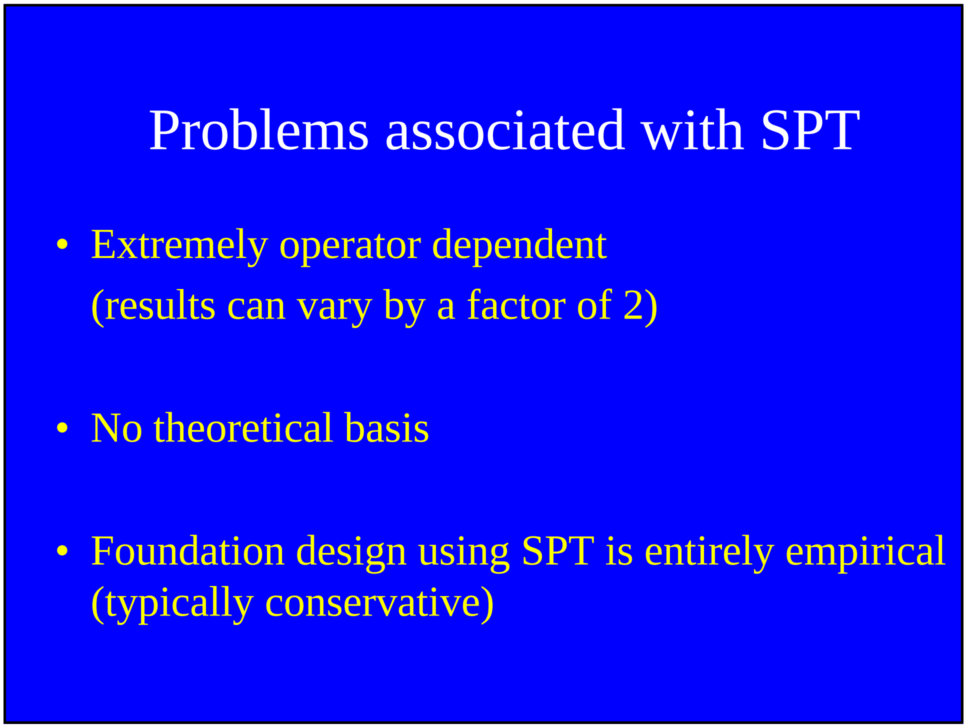
In Situ testing has become an important tool in foundation and earthquake engineering

Cost savings can be significant, depending on soil conditions and magnitude of structure

Standard Penetration Test

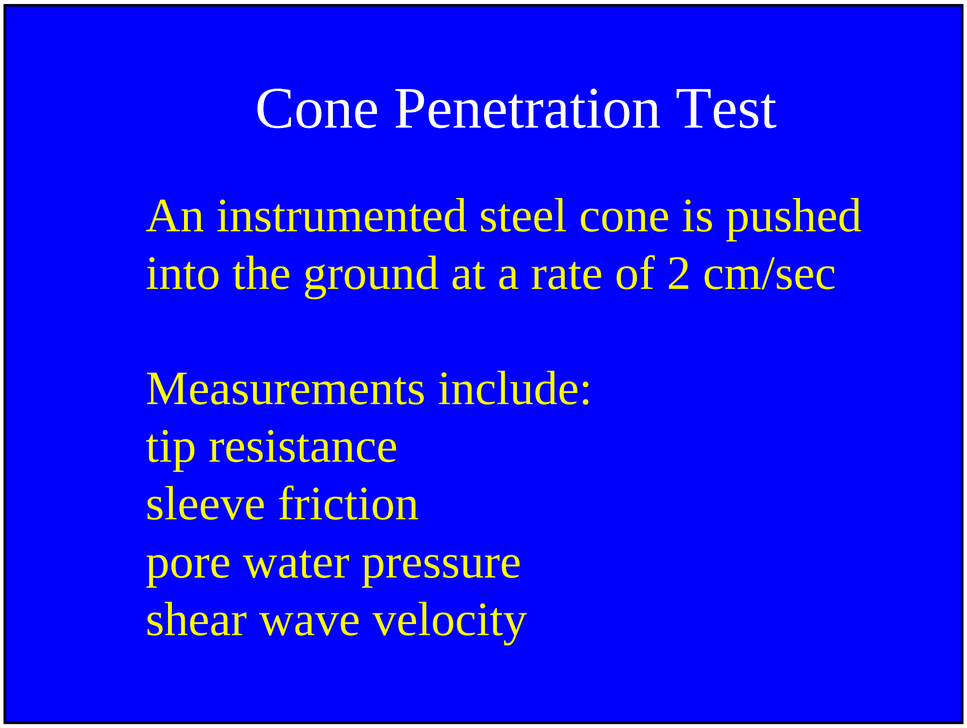
- Most common geotechnical test
- Been in use for over 50 years
- Universal availability of equipment
- Fairly well known outside of geotechnical community





Problems associated with SPT

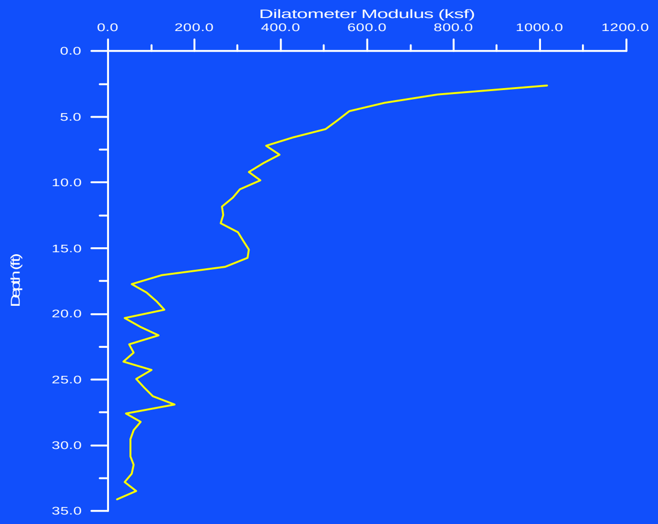
- Extremely operator dependent
  (results can vary by a factor of 2)
- No theoretical basis
- Foundation design using SPT is entirely empirical (typically conservative)



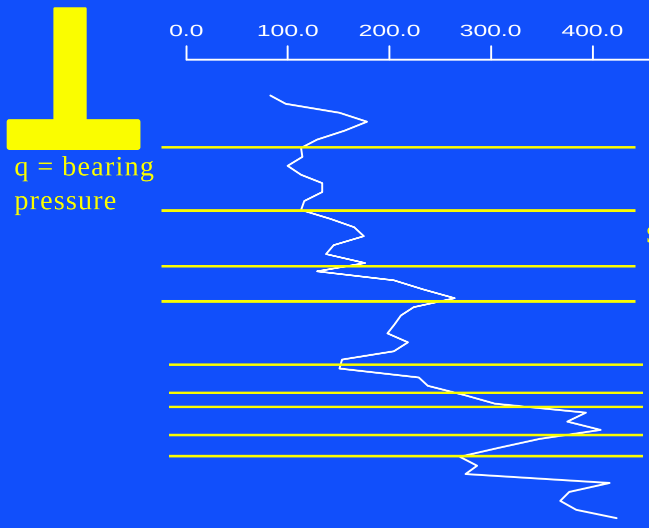
Cone Penetration Test

An instrumented steel cone is pushed into the ground at a rate of 2 cm/sec

Measurements include:
tip resistance
sleeve friction
pore water pressure
shear wave velocity



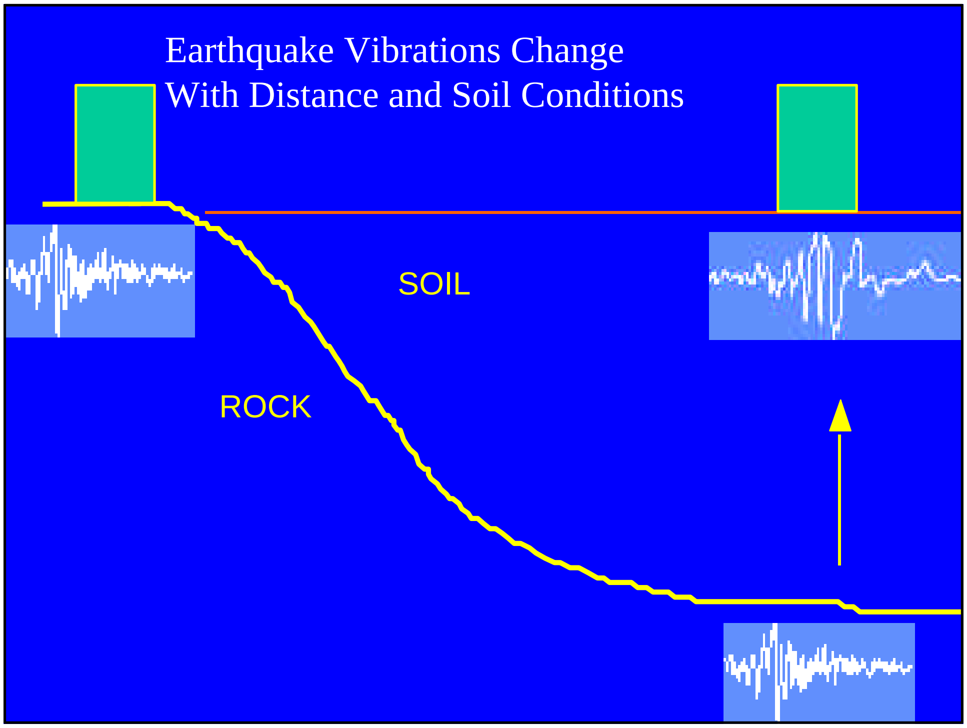
Dilatometer modulus (tsf)



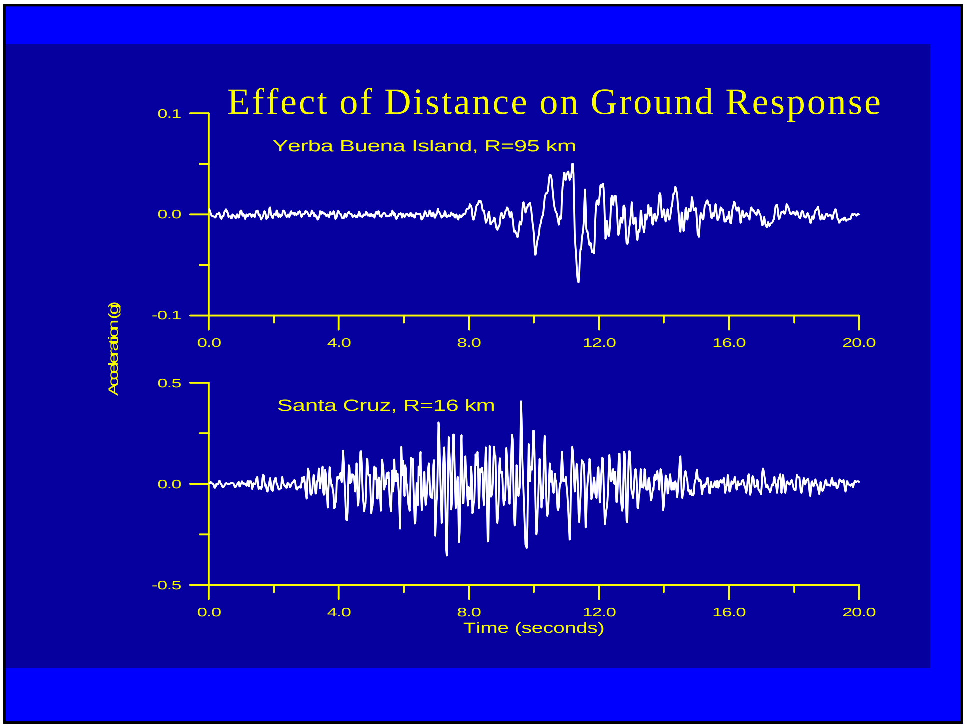
q = bearing pressure

$$s_i = \frac{\Delta q_i}{E_i} \cdot z_i$$

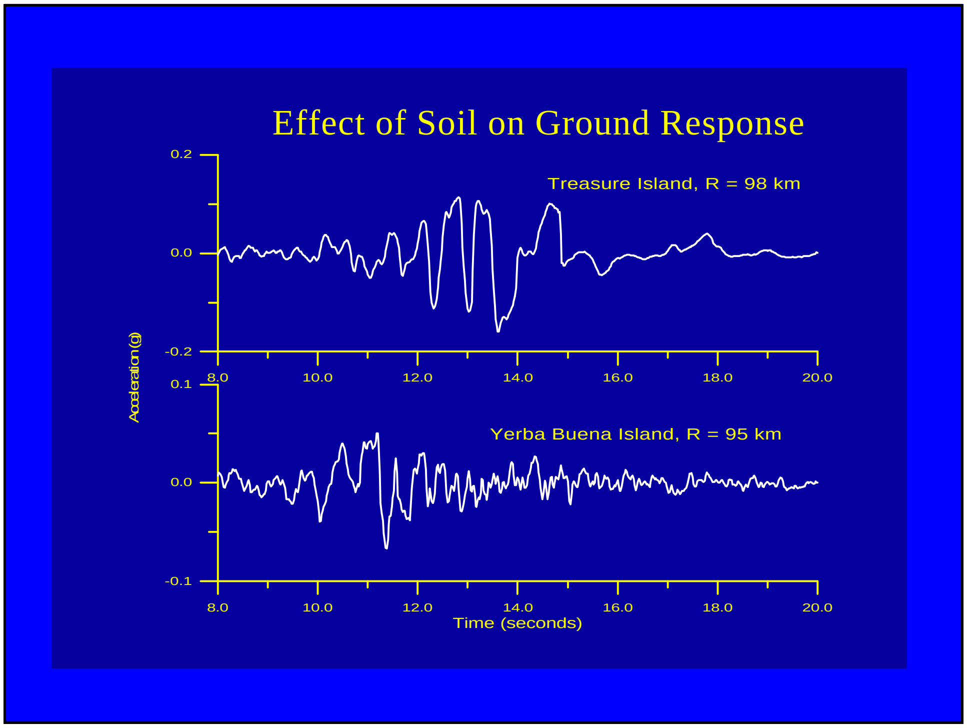
$$s = \sum s_i$$



Earthquake Vibrations Change With Distance and Soil Conditions



Effect of Distance on Ground Response



Effect of Soil on Ground Response