



# Liquefaction and related ground failure in low-plasticity fine-grained soils: Northridge earthquake to the future

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Thanks to: Mike Bennett, Dan Ponti, Ross Boulanger, Jon Bray, and Les Youd

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# Outline

- Review liquefaction susceptibility criteria for low-plasticity fine-grained soils
- Revisit two ground failures caused by 1994 Northridge earthquake
  - Malden Street
  - Balboa Boulevard
- Future directions or recommendations



# Liquefaction susceptibility criteria for fine-grained soils

## Seed and Idriss (1982) Chinese criteria:

1. < 15 % finer than 5  $\mu\text{m}$
2. Liquid limit < 35 %\*
3. Water content/liquid limit > 0.9

\*Should be  $\sim 31$  % based on Koester (1992)

## Andrews and Martin (2000):

1. < 10 % finer than 2  $\mu\text{m}$
2. Liquid limit < 32 %

## Boulanger and Idriss (2006):

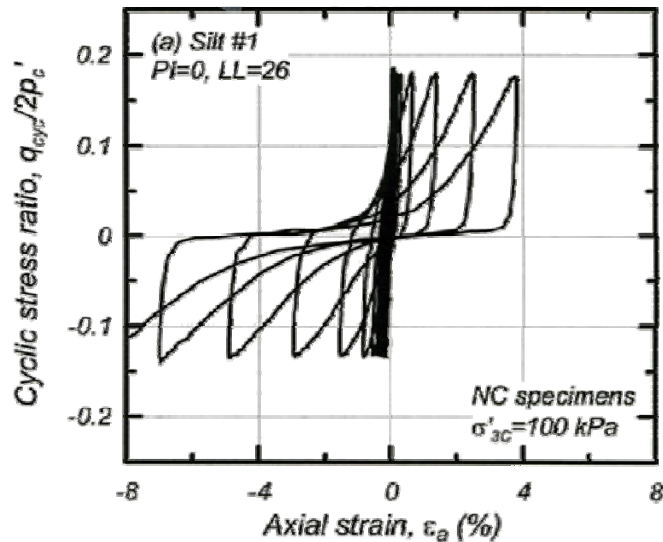
1. PI < 7 % (for CL soils)
2. PI < 5 or 6 % (for CL-ML soils)

## Bray and Sancio (2006):

1. PI < 12 %
2. Water content/liquid limit > 0.85

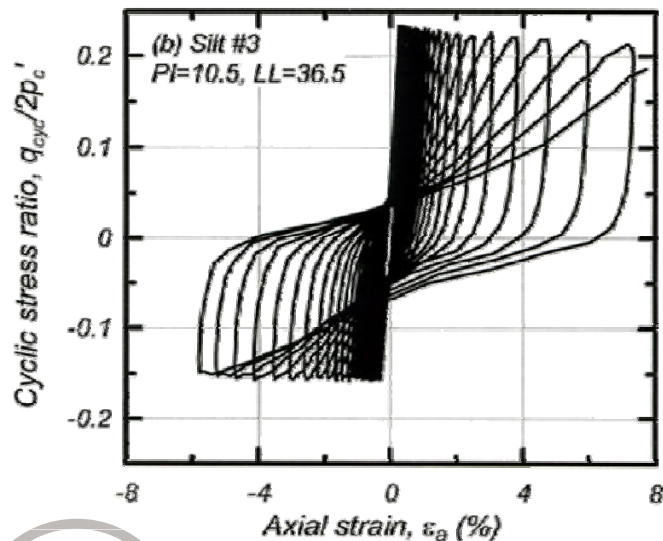


# Boulanger and Idriss (2006)



## Liquefaction

← **Sand-like behavior:** Stress-strain loops contain **flat segments**, which provide little shear resistance against shear deformation.

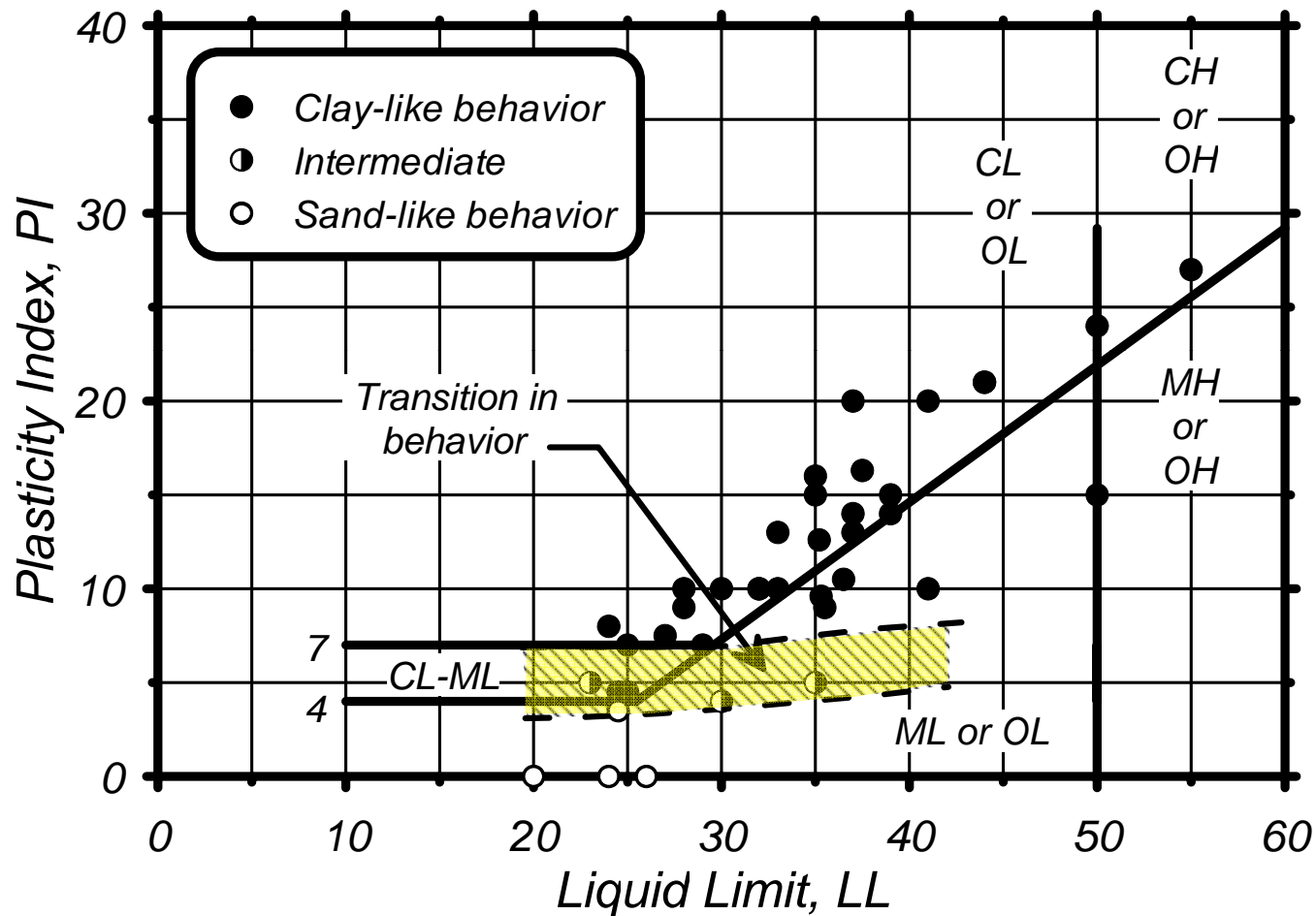


## Cyclic Softening

← **Clay-like behavior:** Stress-strain loops contain **sloping segments** which provide significant resistance against shear deformation.

# Liquefaction Susceptibility Criteria

## Boulanger and Idriss (2006)



# Bray and Sancio (2006)

Adapazari, Turkey  
1999 Kocaeli (Izmit) EQ



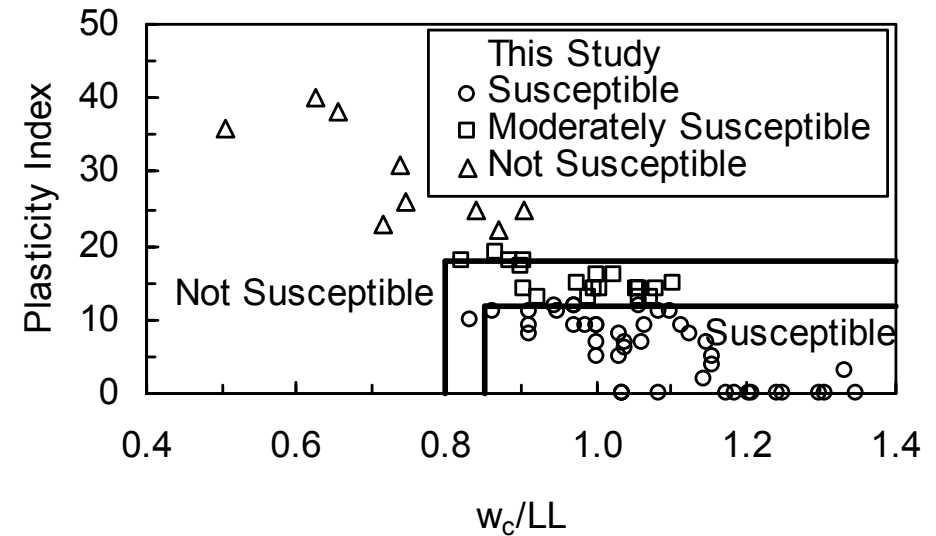
T. L. Holzer



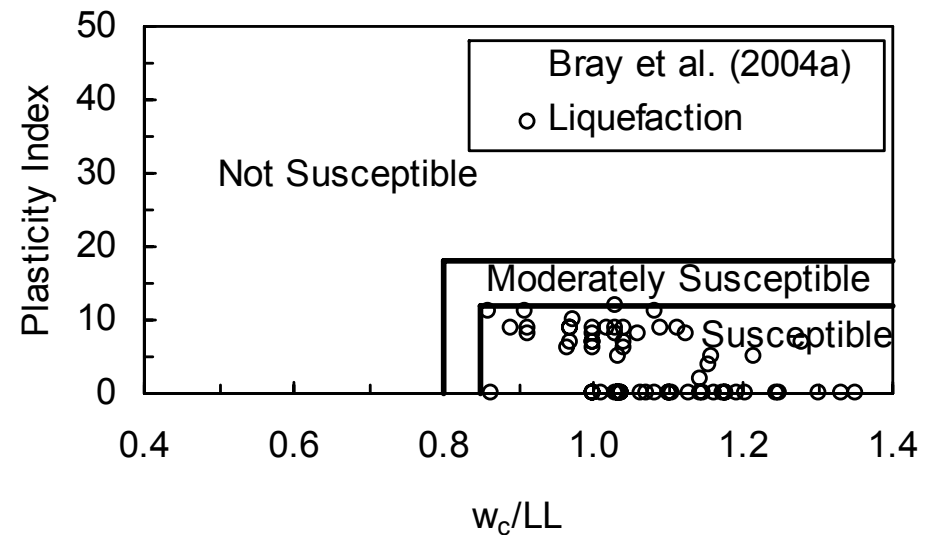
# Liquefaction Susceptibility Criteria

## Bray and Sancio (2006)

Lab tests  
Adapazari samples



Field observations  
Adapazari

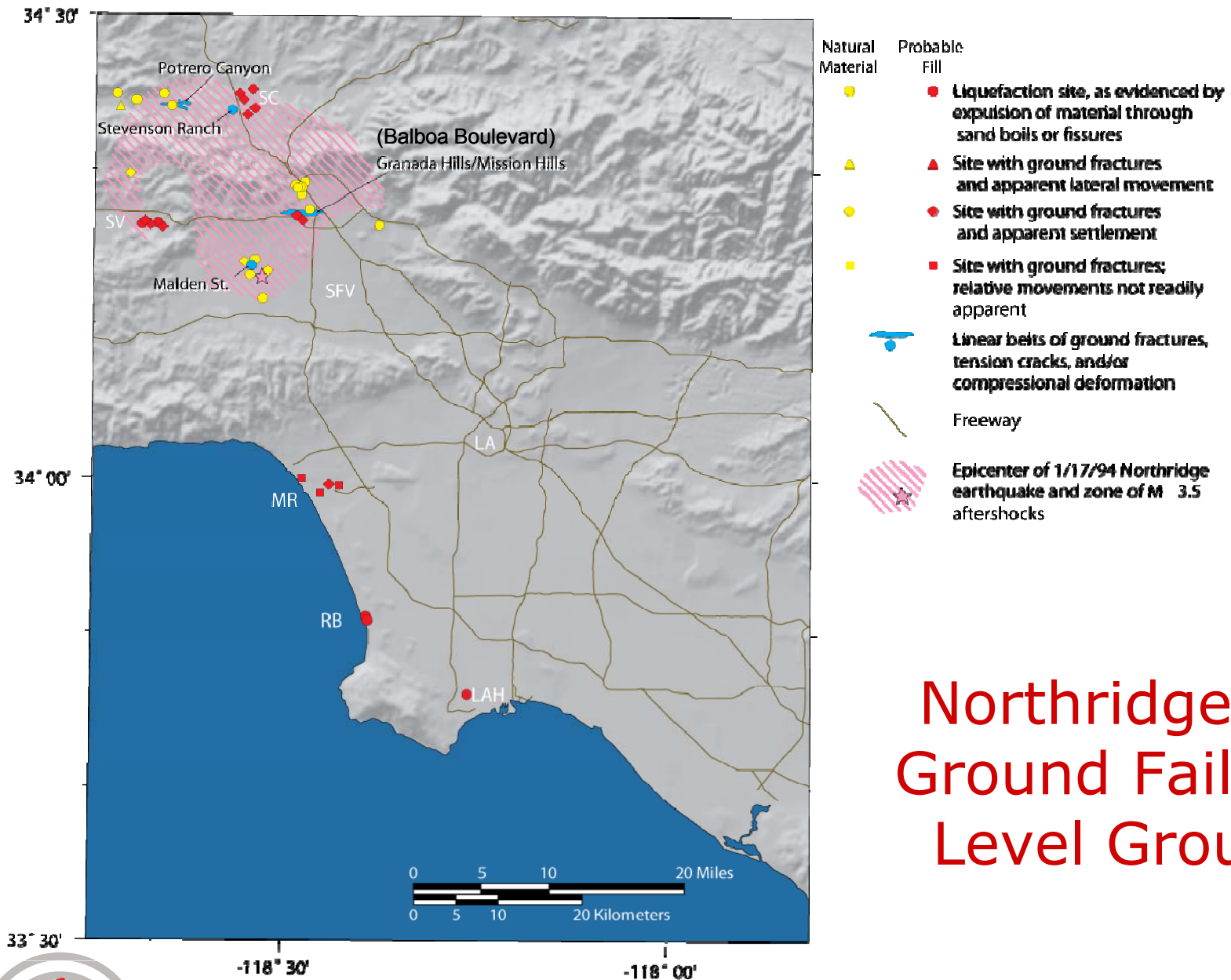


# Comparison of Bray and Sancio (2006) with Boulanger and Idriss (2006)

- Agree that:
  - lab testing of field samples is the preferred approach for silts/clays with sufficient plasticity to sample
  - current SPT/CPT liquefaction correlations will usually underestimate strengths of these silts/clays
  - any soil can permanently deform if the seismic stresses exceed its dynamic strength (liquefiable or not)
- Both criteria provide similar guidance on preferred engineering approaches, despite differences in terminology







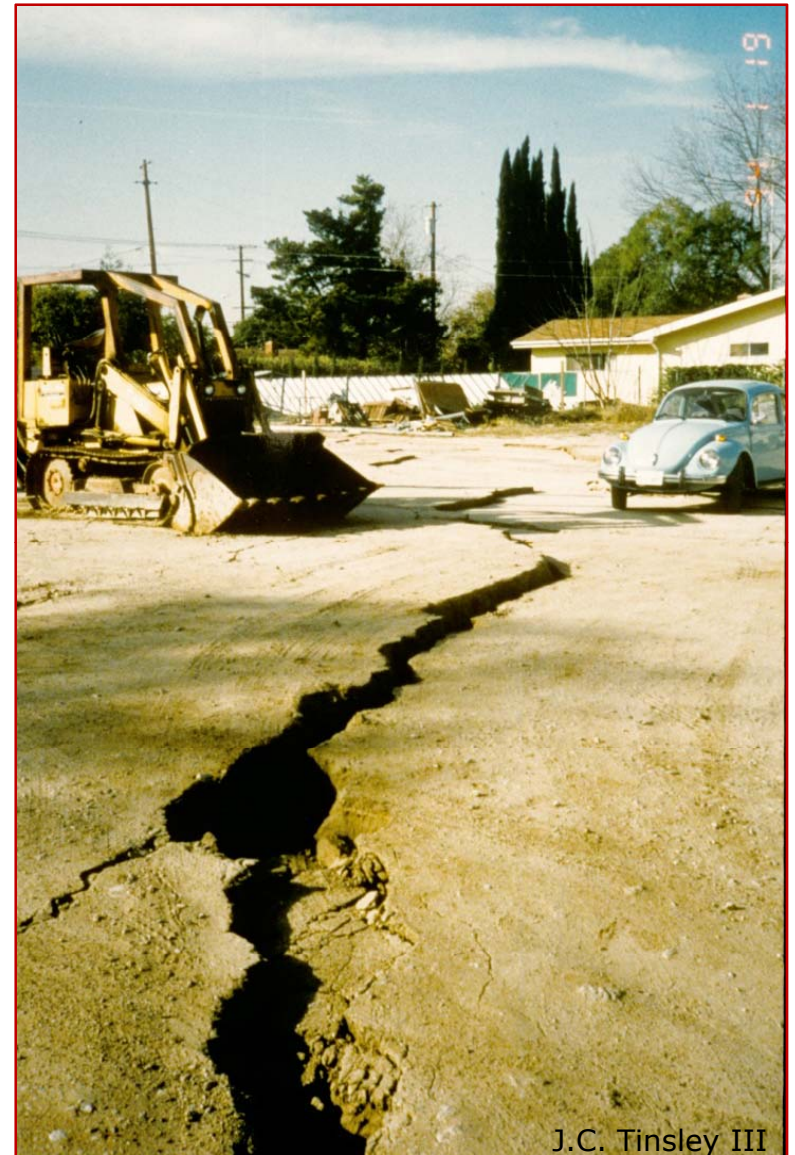
# Northridge EQ Ground Failures Level Ground



# Malden Street Ground Failure

Features of ground failure:

1. Down-dropped block
2. Extension
3. No sand boils



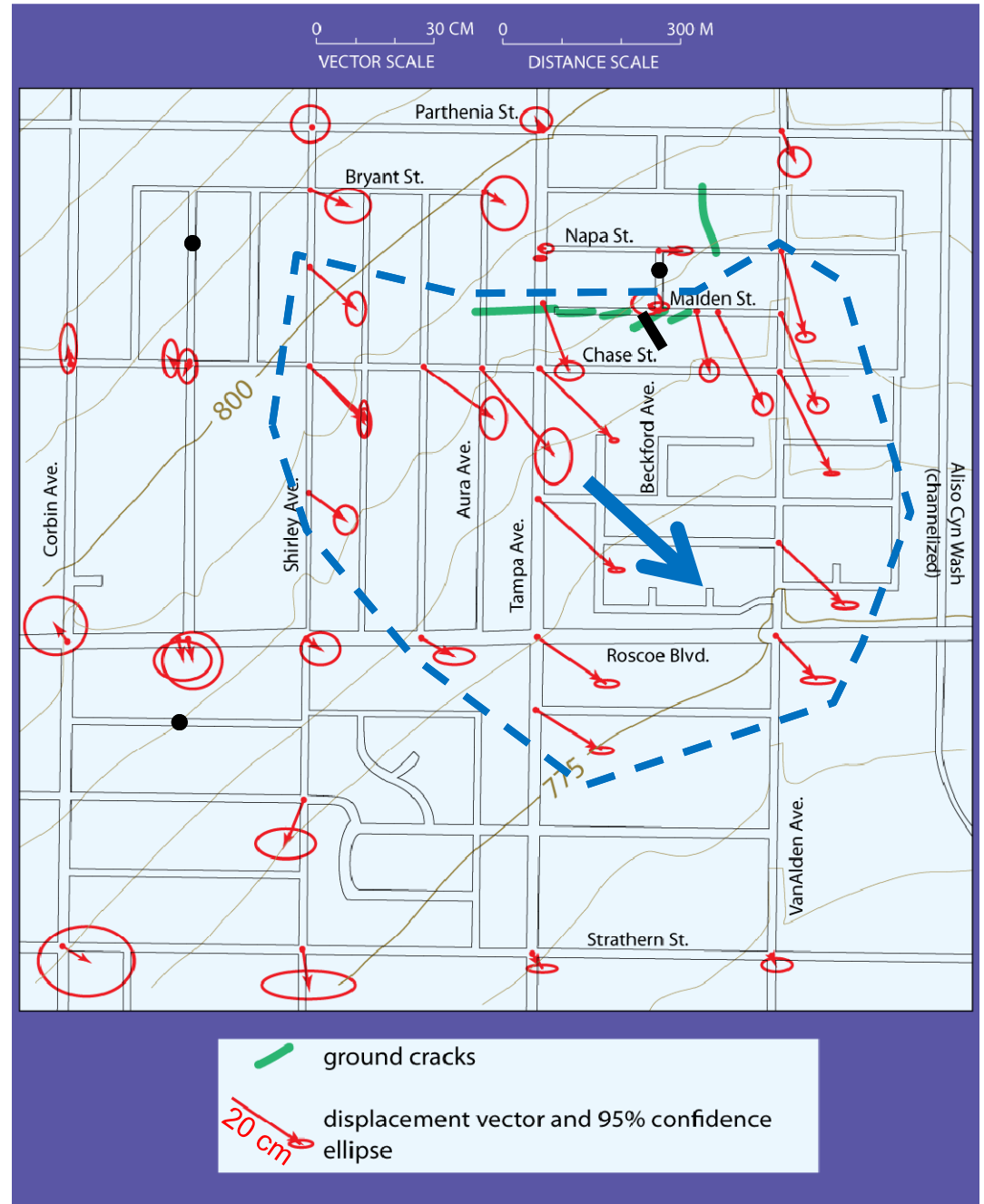
J.C. Tinsley III



# Malden Street Ground Failure

Ground Cracks  
and  
Surface Displacements

Cross Section  
and  
CPT's



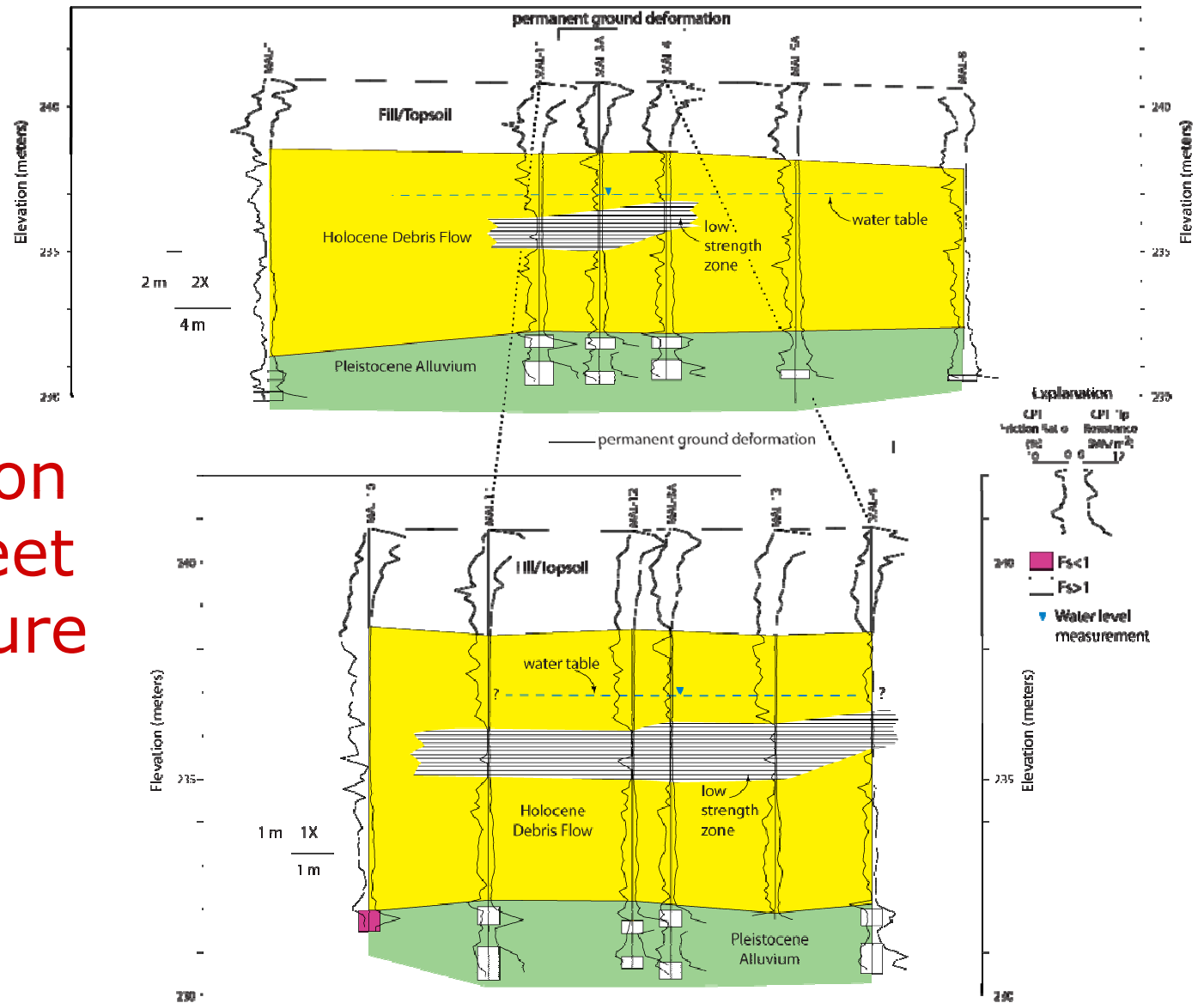
Holzer et al. (JGGE, 1999)



1994 Ground Failure

[www.northridge20.org](http://www.northridge20.org)

# Cross Section Malden Street Ground Failure

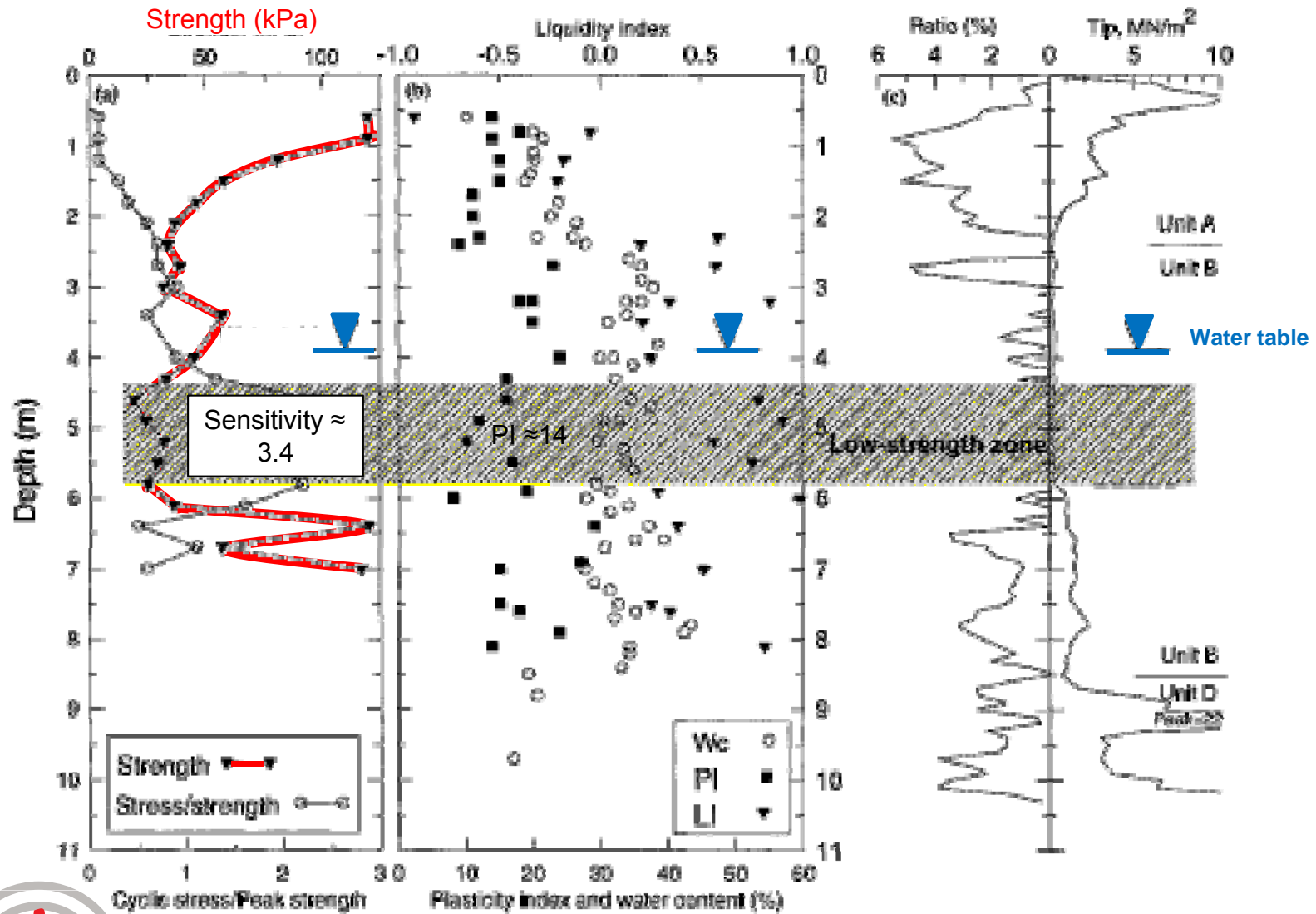


Holzer et al. (JGGE, 1999)



# Malden Street Ground Failure – CPT-3

## Geotechnical Properties



Holzer et al. (JGGE, 1999)



1994 Ground Failure

[www.northridge20.org](http://www.northridge20.org)

# Balboa Boulevard Ground Failure



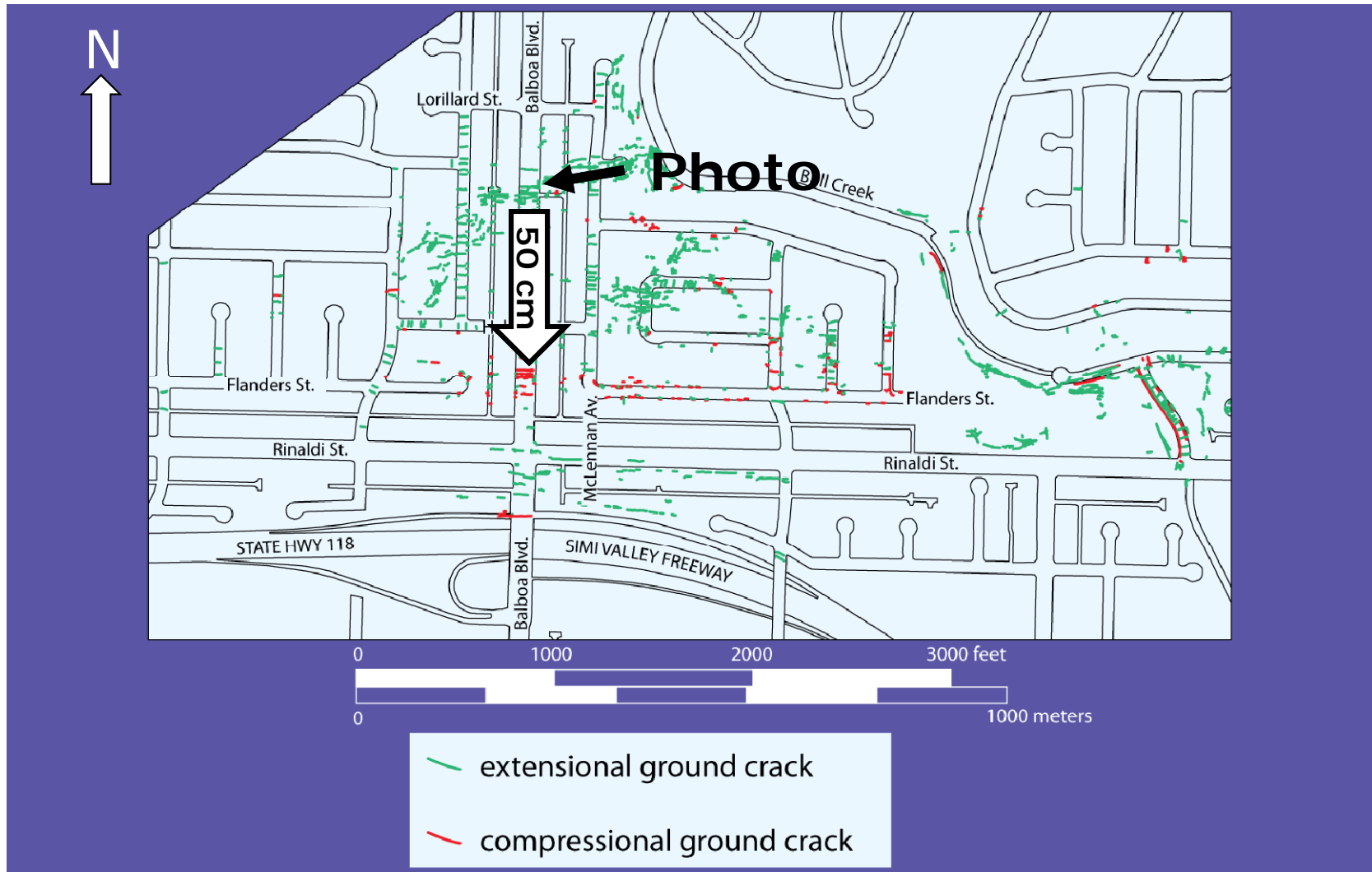
View  
Westward



1994 Ground Failure

[www.northridge20.org](http://www.northridge20.org)

# Balboa Boulevard Ground Failure

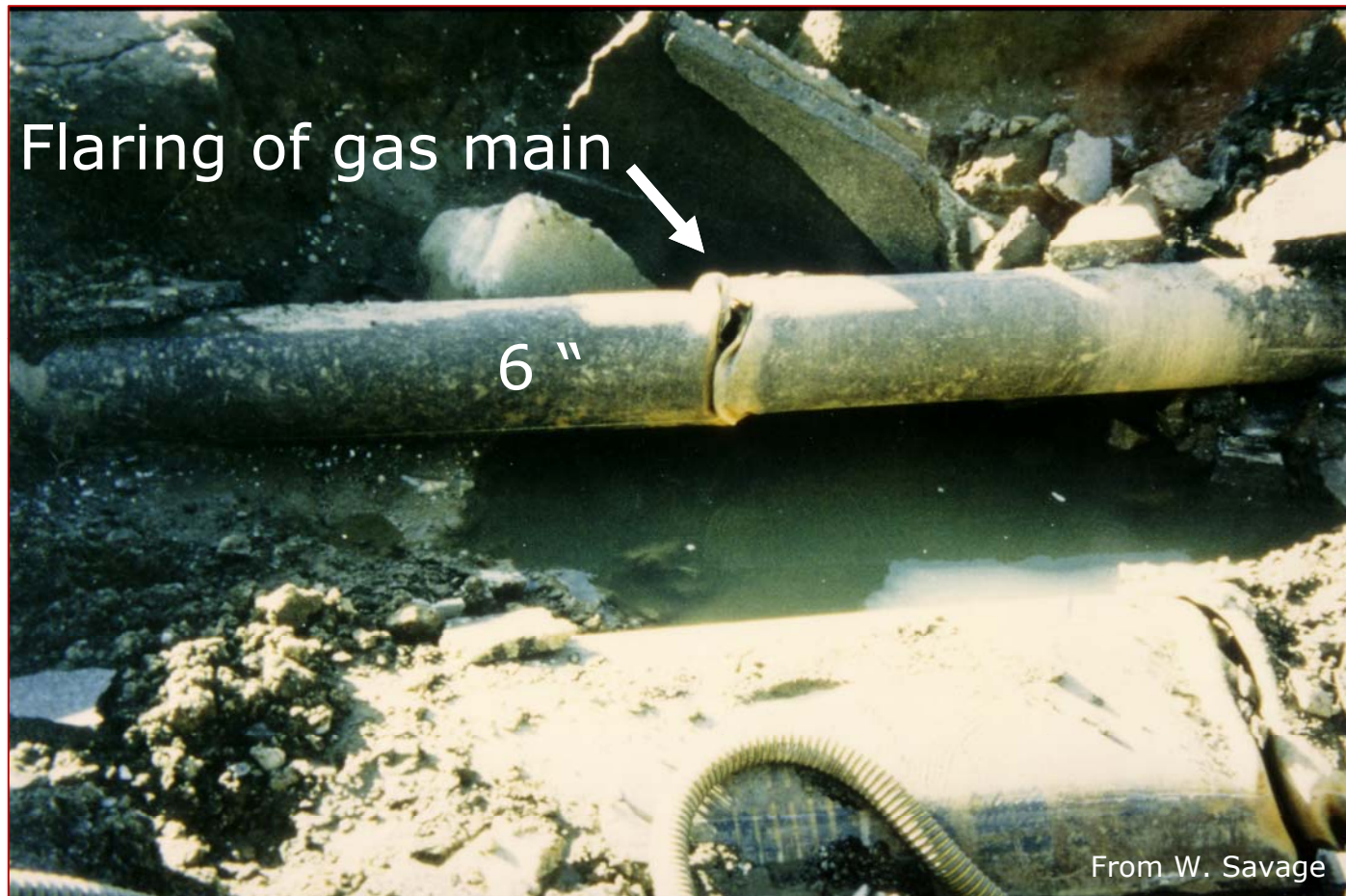


1994 Ground Failure

Hecker et al. (1995)

[www.northridge20.org](http://www.northridge20.org)

# Balboa Boulevard Ground Failure

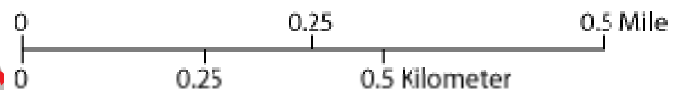




# PROPERTY LOSS AND GROUND FAILURE



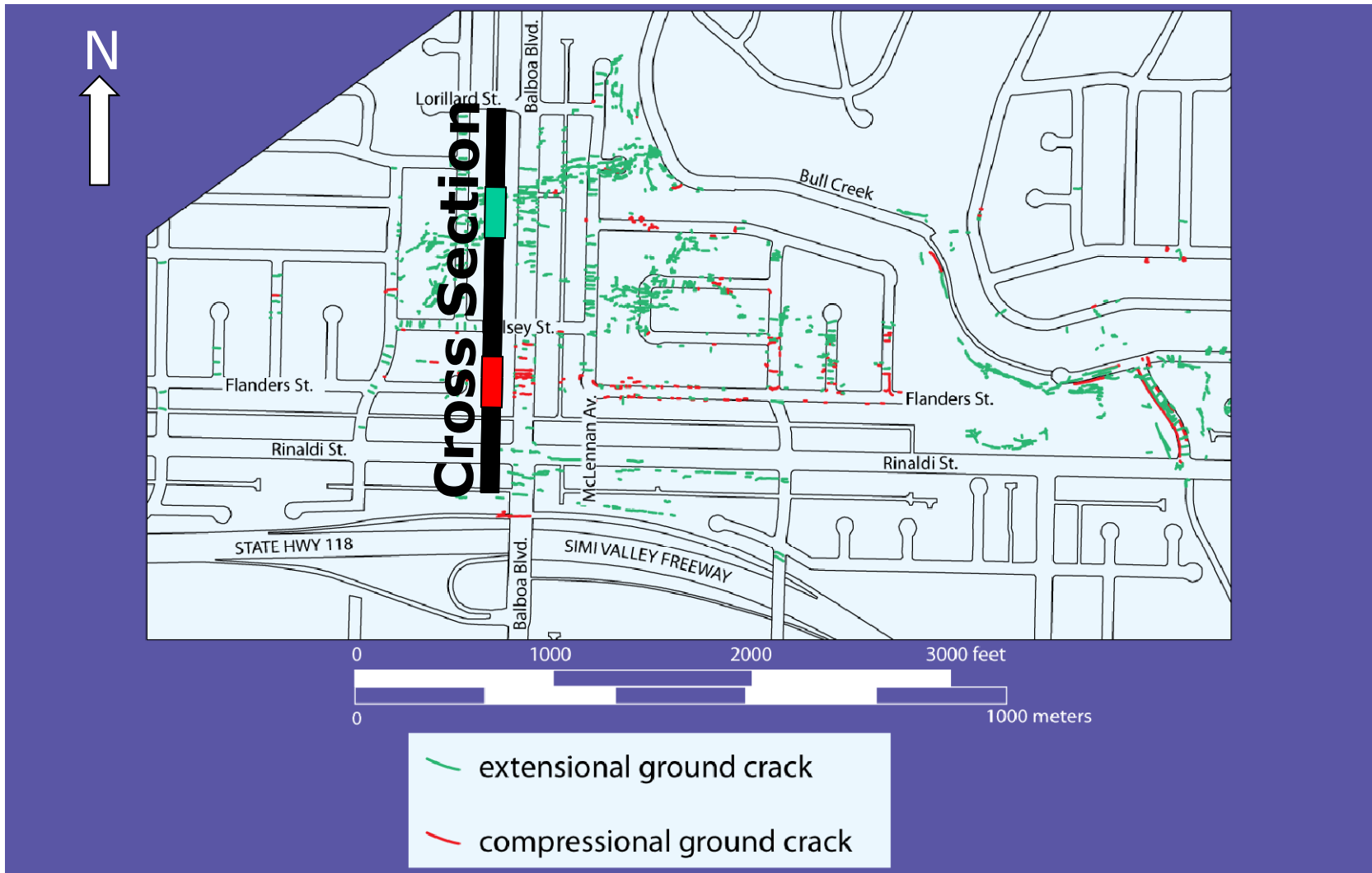
## ESTIMATED REPAIR COSTS



--- GROUND CRACKS  
■ Ts SAUGUIS FORMATION (LOCAL BEDROCK)



# Balboa Boulevard Ground Failure

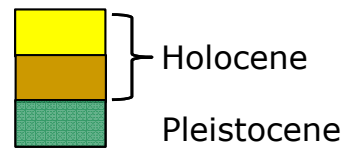
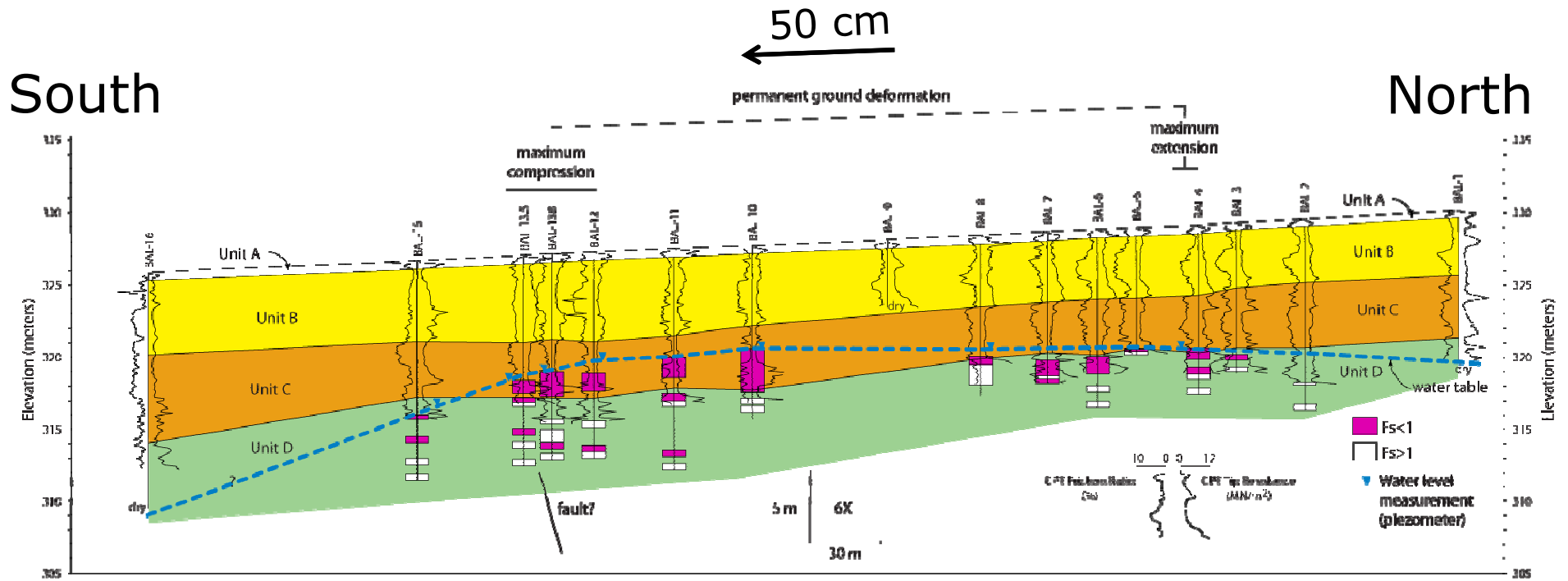


1994 Ground Failure

Hecker et al. (1995)

[www.northridge20.org](http://www.northridge20.org)

# Balboa Boulevard Cross Section

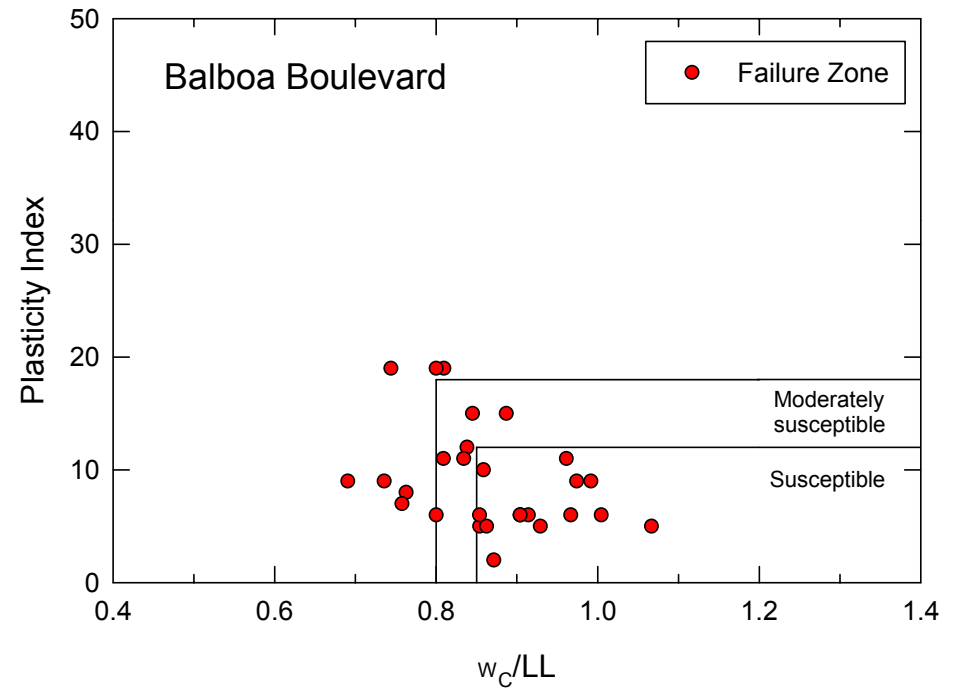
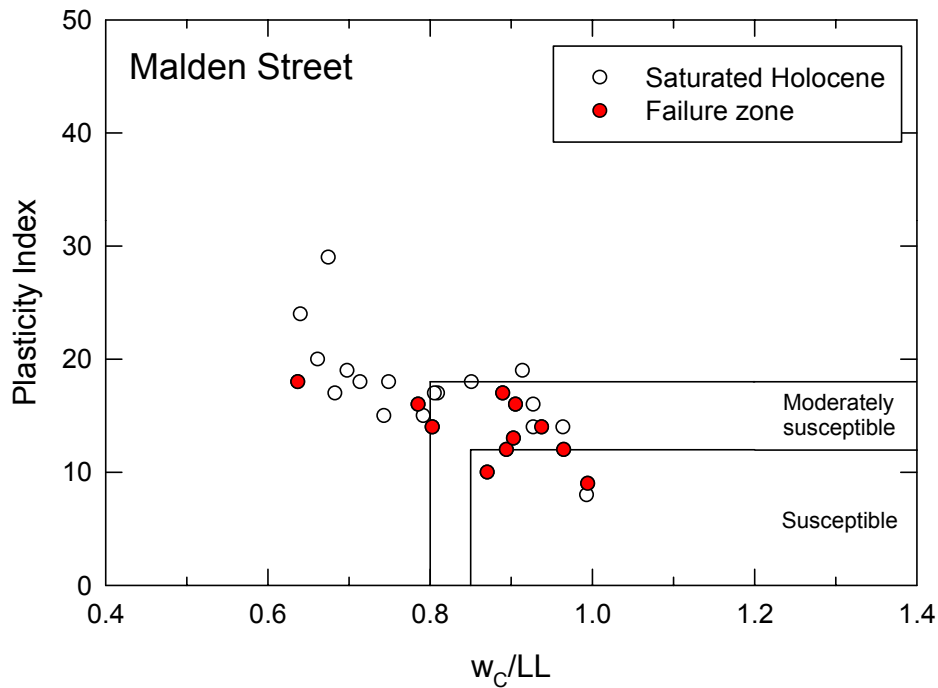


1994 Ground Failure

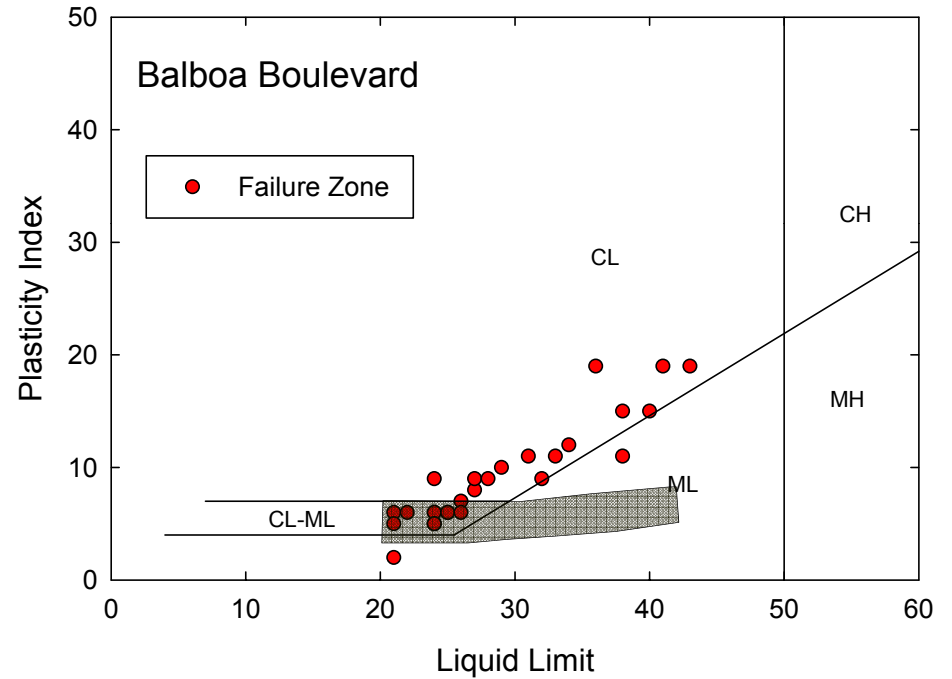
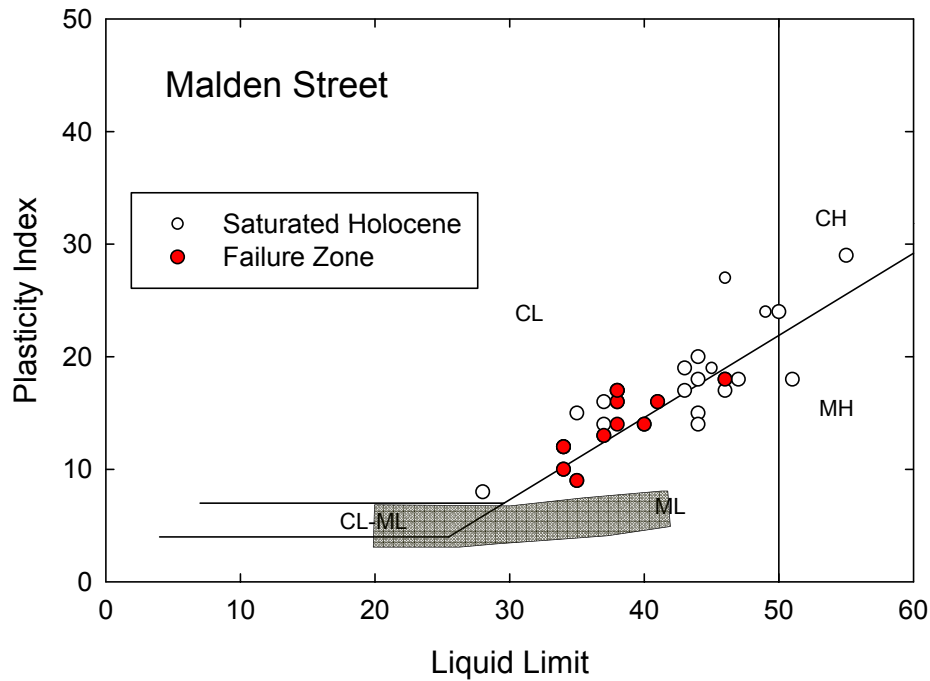
Holzer et al. (JGGE, 1999)

[www.northridge20.org](http://www.northridge20.org)

# Bray and Sancio (2006) Criteria



# Boulanger and Idriss (2006) Criteria



## Future Directions –

### Ground failure in low-plasticity fine-grained soils

- California Seismic Hazard Zonation Program - Update criteria and complete mapping
- Assemble “community” database of case histories
- Ground failures in low-plasticity fine-grained soils be investigated by experienced field investigators
- Instrument representative fine-grained site(s)?