Interactions Between Buildings and Surface Fault Rupture During the 1999 Chi-Chi (Taiwan) Earthquake

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GEER- (Geoengineering Extreme Events Reconnaissance)

Technical Approach

1. Identify fault crossings on regional basis
2. Characterize fault location, width, and orientation at specific sites
3. Estimate displacement amount, direction, and distribution
4. Evaluate geotechnical soil conditions
5. Model pipeline response to seismic demand
6. Develop and install mitigation measures

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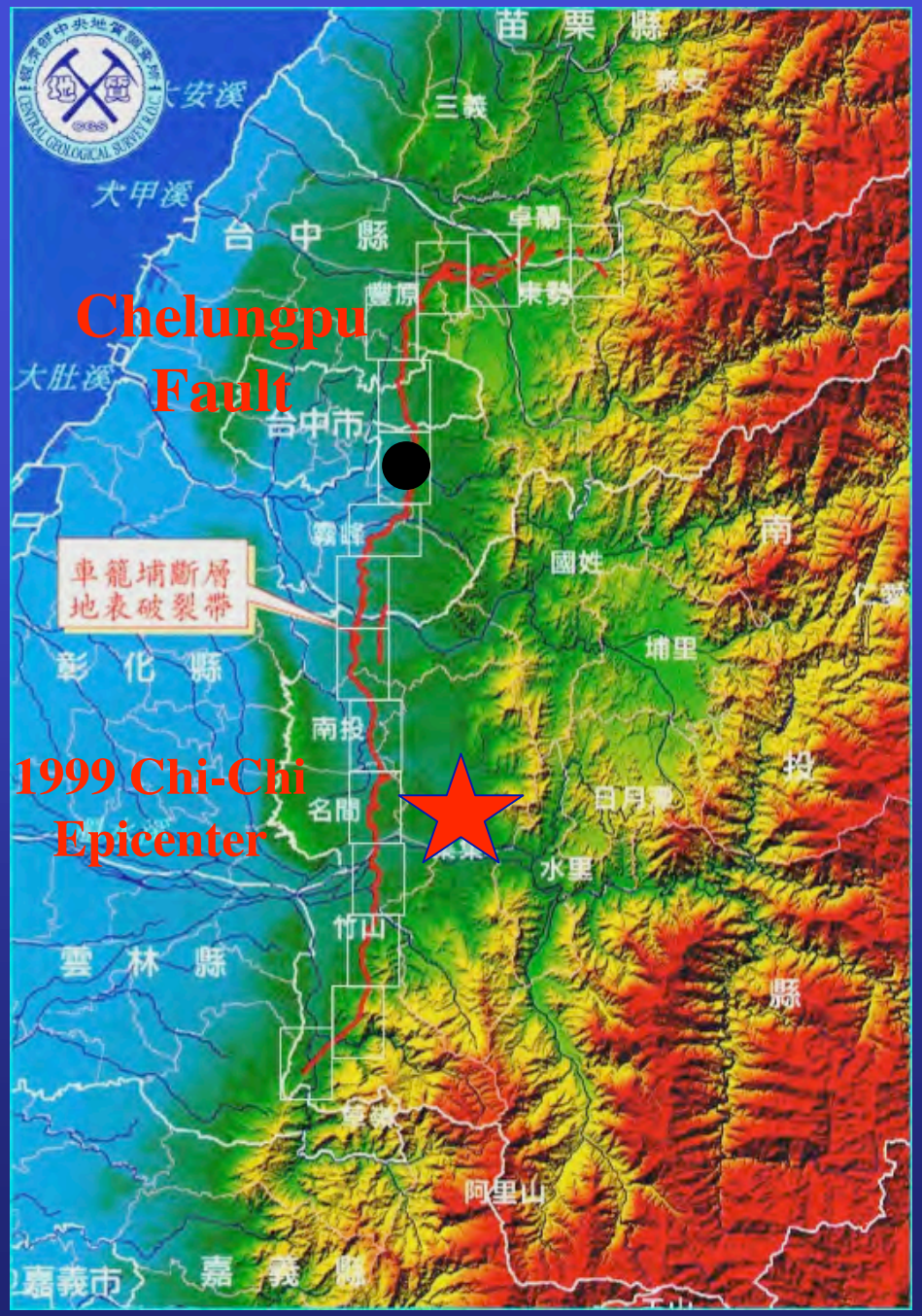
Overall Rupture Characteristics

- Surface rupture length: 85 km
- West-vergent thrust faulting, secondary left-lateral slip
- Vertical displacements:
  - Southern part: 1 - 2 m
  - Central part: 2 - 4 m
  - Northern part: 4 - 5.5 m
- Complex northern termination
- Ruptures mostly along existing fault scarps



Hanging Wall vs. Footwall Deformation

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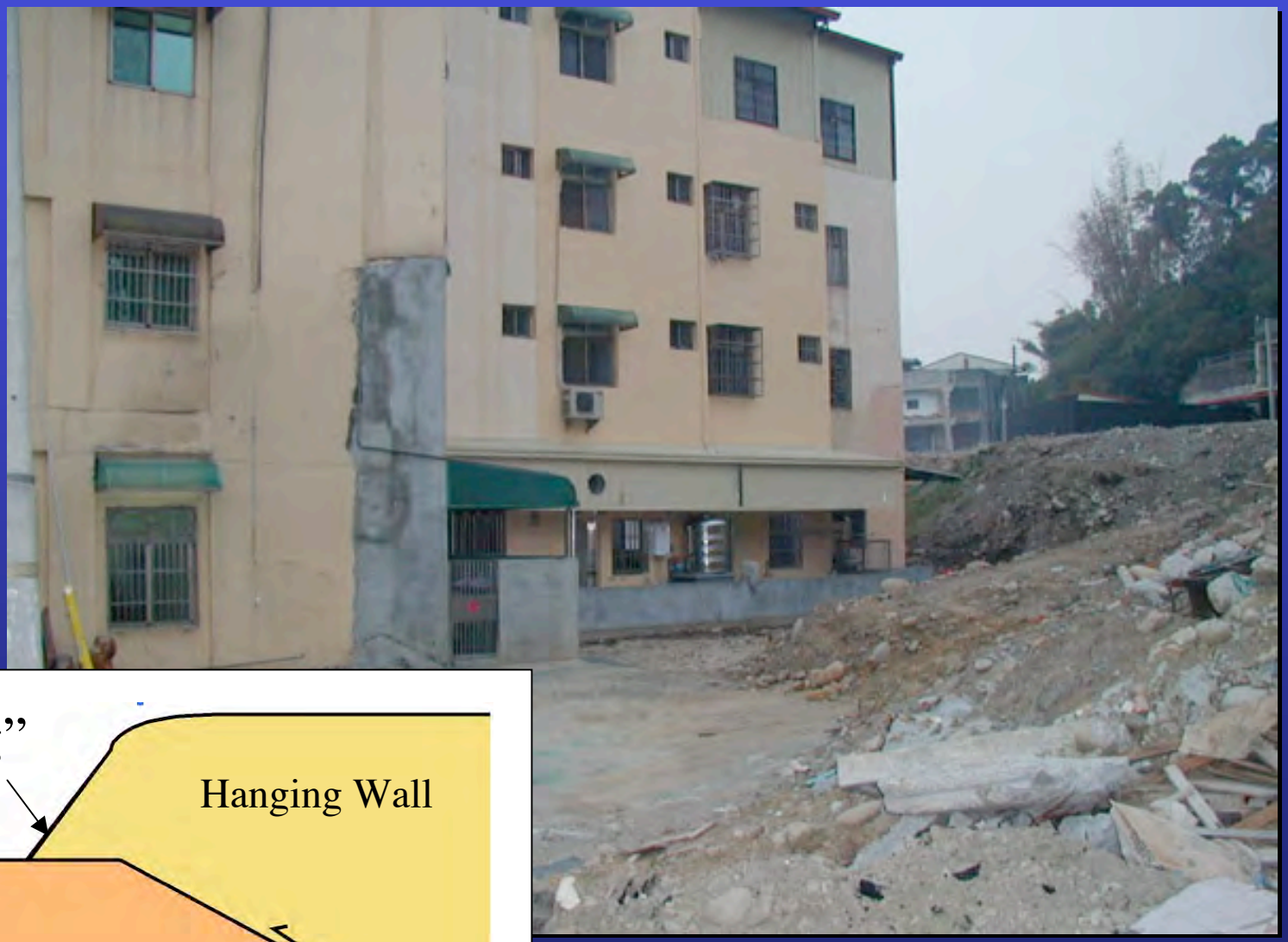
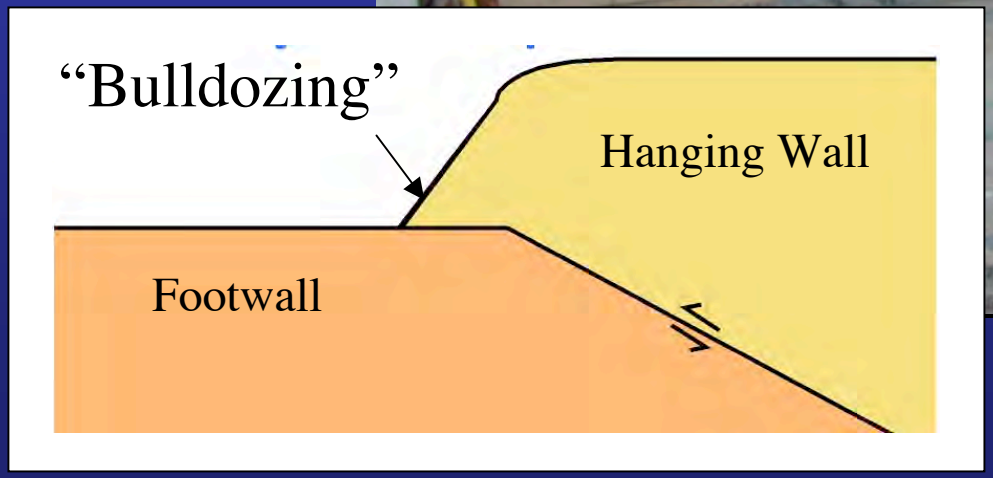
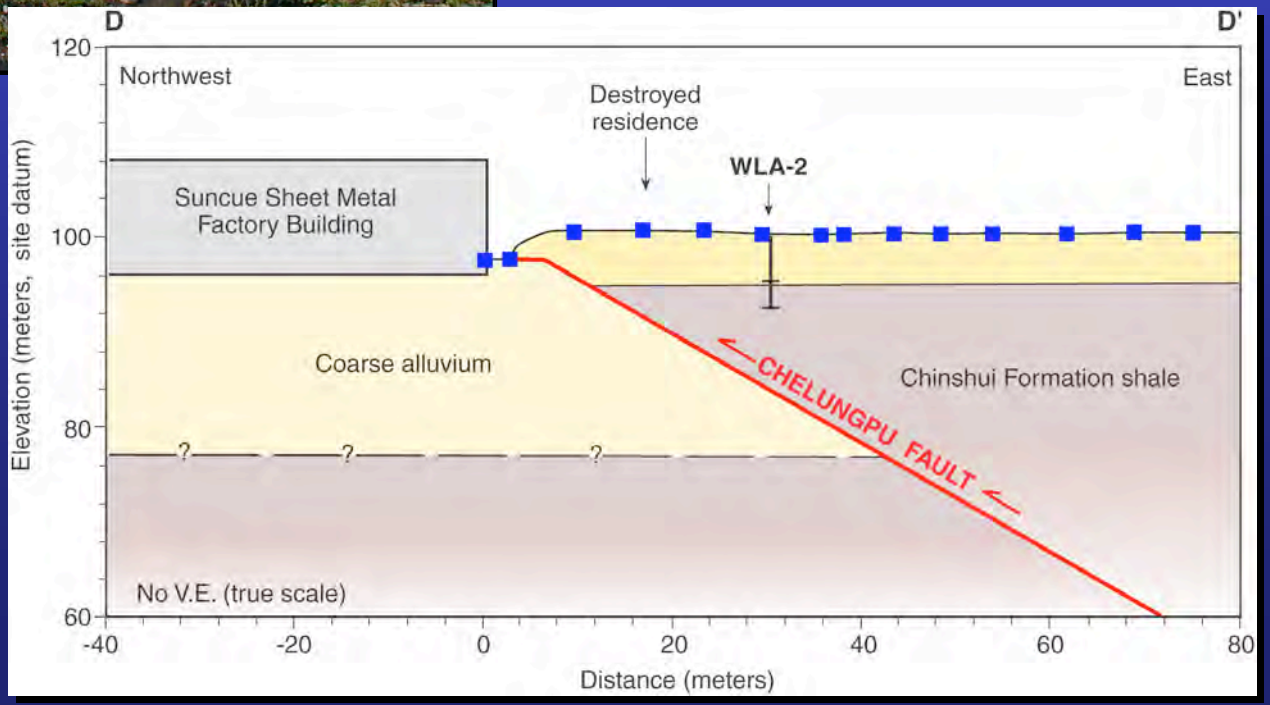
Footwall Deformation: Localized Bulldozing

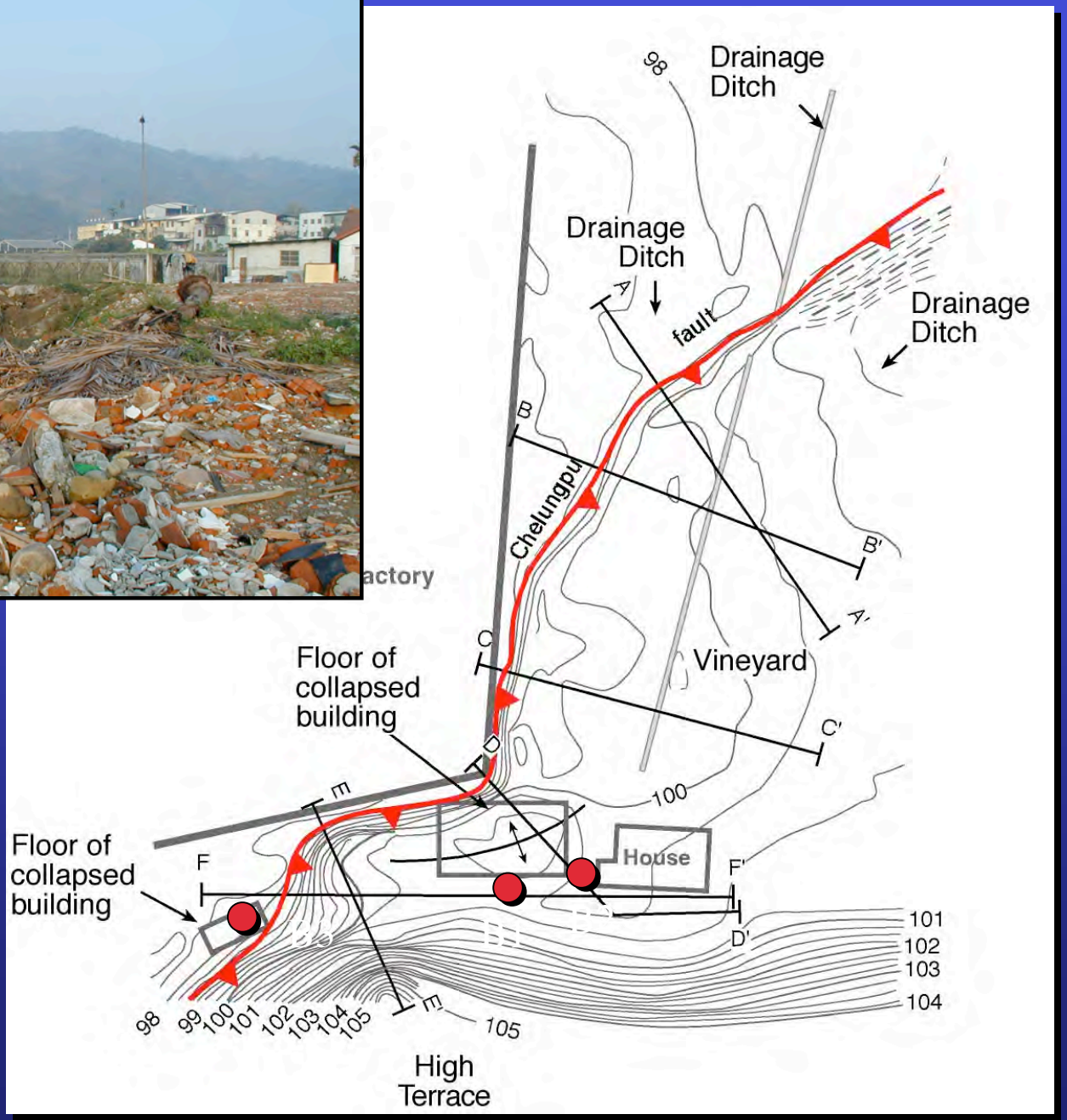




Sincue Factory Site

Fault scarp bulldozed into building, Amplified hanging wall deformation





Fault scarp wraps around corner of factory building

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Building collapse from surface fault rupture
Kuangfu Junior High School

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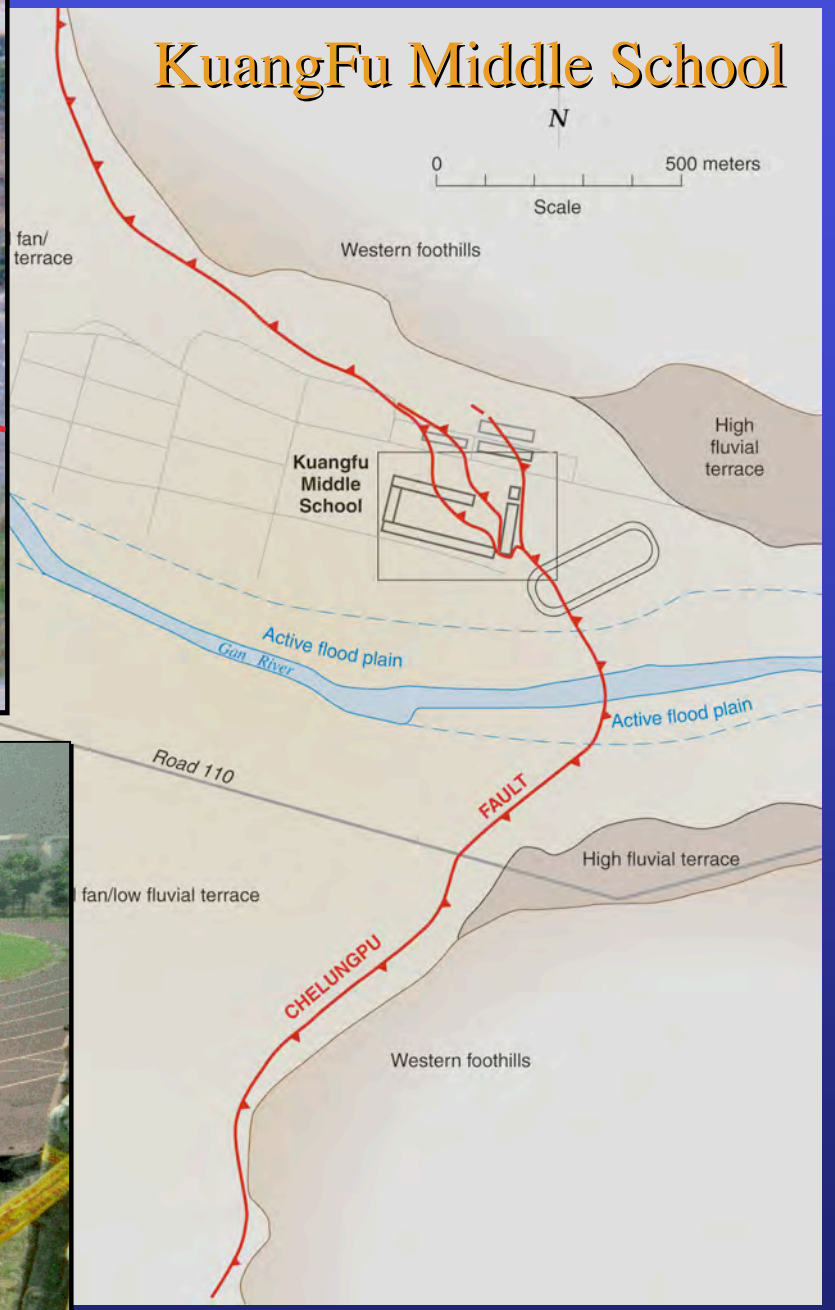
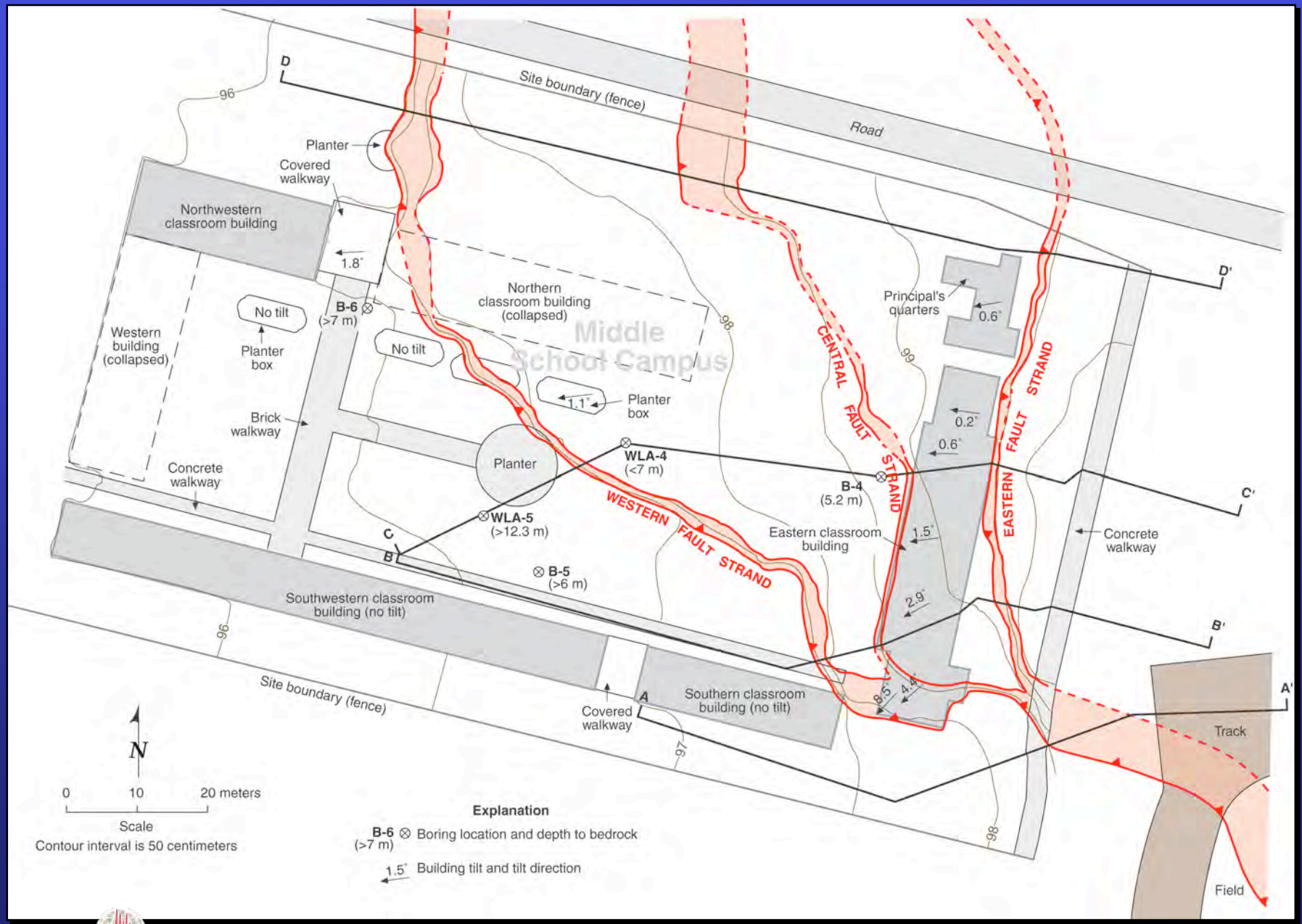

KuangFu Middle School
N
0
500 meters
Scale
fan/
terrace
Western foothills
High
fluvial
terrace
Kuangfu
Middle
School
Active flood plain
Gan River
Active flood plain
Road 110
FAULT
fan/low fluvial terrace
High fluvial terrace
CHELUNGPU
Western foothills


Site boundary (fence)
Road
D
D'
C
C'
B
B'
A
A'
Planter
Covered walkway
Northwestern classroom building
1.8°
Northern classroom building (collapsed)
Middle School Campus
Western building (collapsed)
No tilt
Planter box
B-6 (>7 m)
No tilt
1.1°
Planter box
Brick walkway
Concrete walkway
Planter
WLA-4 (<7 m)
WLA-5 (>12.3 m)
B-5 (>6 m)
B-4 (5.2 m)
WESTERN FAULT STRAND
CENTRAL FAULT STRAND
EASTERN FAULT STRAND
Principal's quarters
0.6°
0.2°
0.6°
Eastern classroom building
1.5°
Concrete walkway
2.9°
Southwestern classroom building (no tilt)
Southern classroom building (no tilt)
Covered walkway
8.5°
4.4°
Track
Field
96
98
99
97
N
0
10
20 meters
Scale
Contour interval is 50 centimeters
Explanation
B-6 (>7 m) Boring location and depth to bedrock
1.5° Building tilt and tilt direction

Surface rupture splits into two strands in eastern part of school campus

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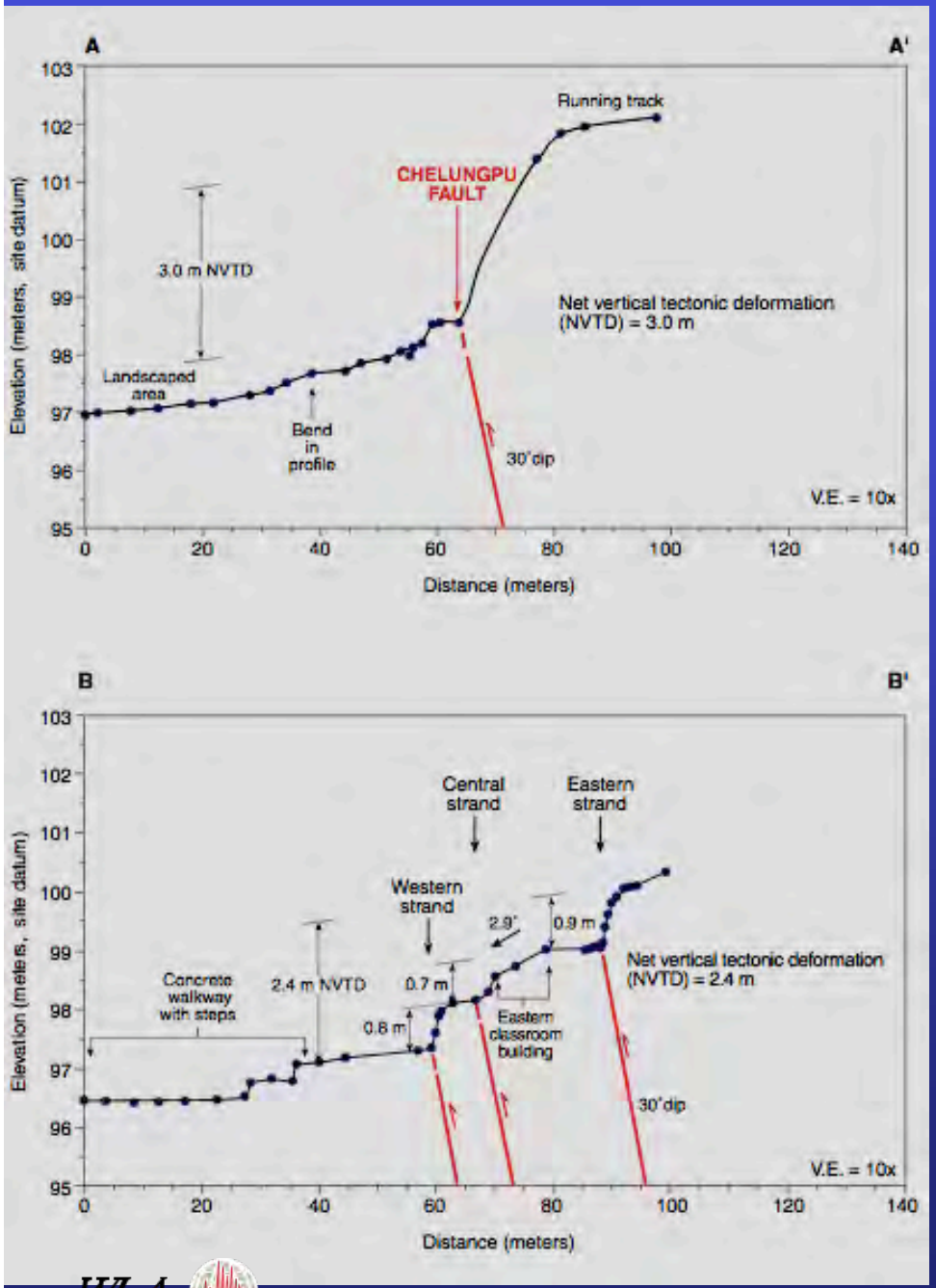
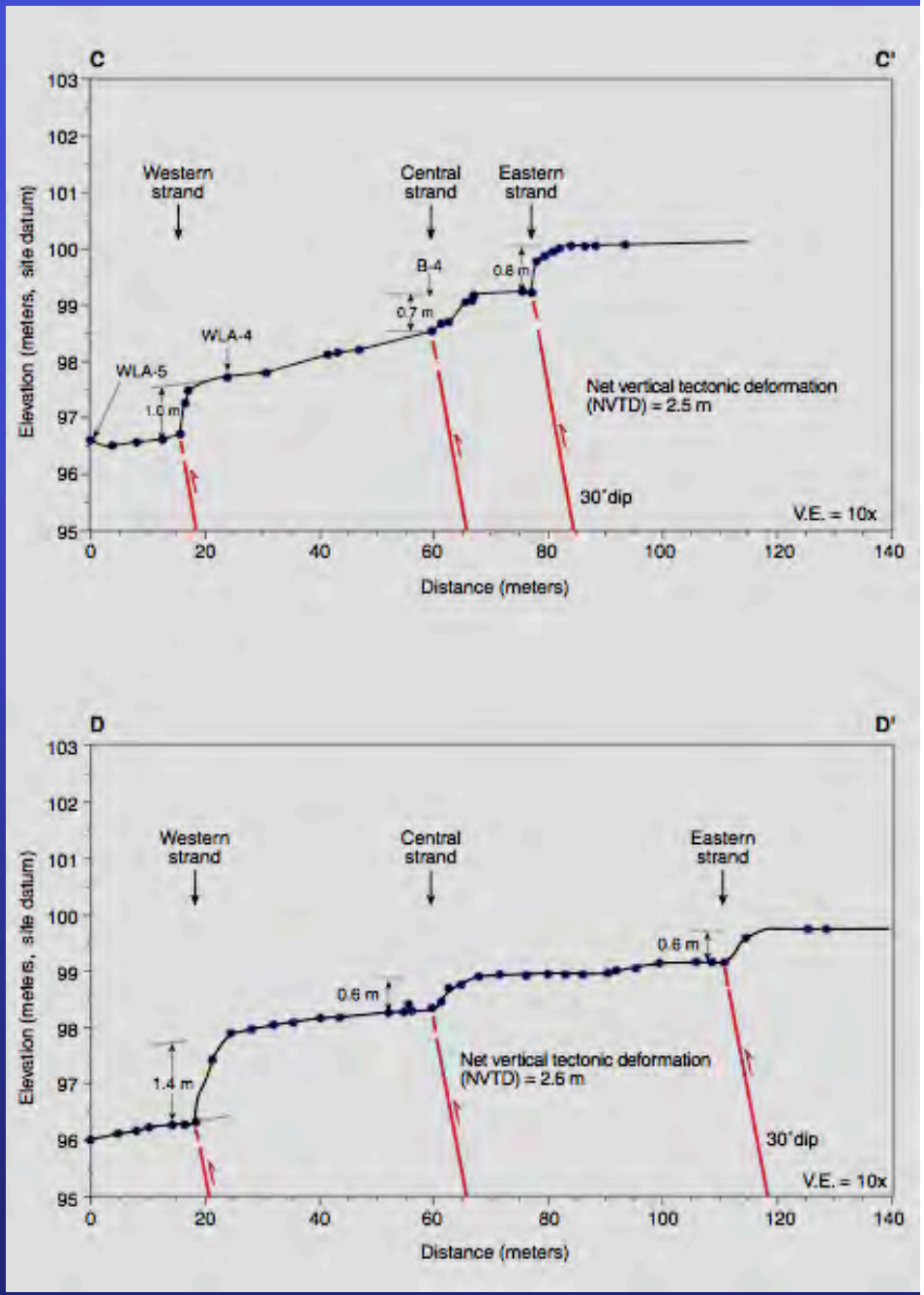
Western fault strand ruptures through Northern Classroom Building


A
A'
Running track
CHELUNGPU FAULT
3.0 m NVTD
Net vertical tectonic deformation (NVTD) = 3.0 m
Landscaped area
Bend in profile
30˚dip
V.E. = 10x
Elevation (meters, site datum)
Distance (meters)


C
C'
Western strand
Central strand
Eastern strand
B-4
0.8 m
0.7 m
WLA-4
WLA-5
1.0 m
Net vertical tectonic deformation (NVTD) = 2.5 m
30˚dip
V.E. = 10x
Elevation (meters, site datum)
Distance (meters)

B
B'
Central strand
Eastern strand
Western strand
2.9˚
0.9 m
Concrete walkway with steps
2.4 m NVTD
0.7 m
0.8 m
Eastern classroom building
Net vertical tectonic deformation (NVTD) = 2.4 m
30˚dip
V.E. = 10x
Elevation (meters, site datum)
Distance (meters)

D
D'
Western strand
Central strand
Eastern strand
0.6 m
0.6 m
1.4 m
Net vertical tectonic deformation (NVTD) = 2.6 m
30˚dip
V.E. = 10x
Elevation (meters, site datum)
Distance (meters)

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Surface rupture at Wu Hsi Bridge

Two bridges, on 16-m-deep caisson foundations

Eastern spans collapsed
Western spans damaged

Rupture pushed spans off piers

Northern piers: shear failure

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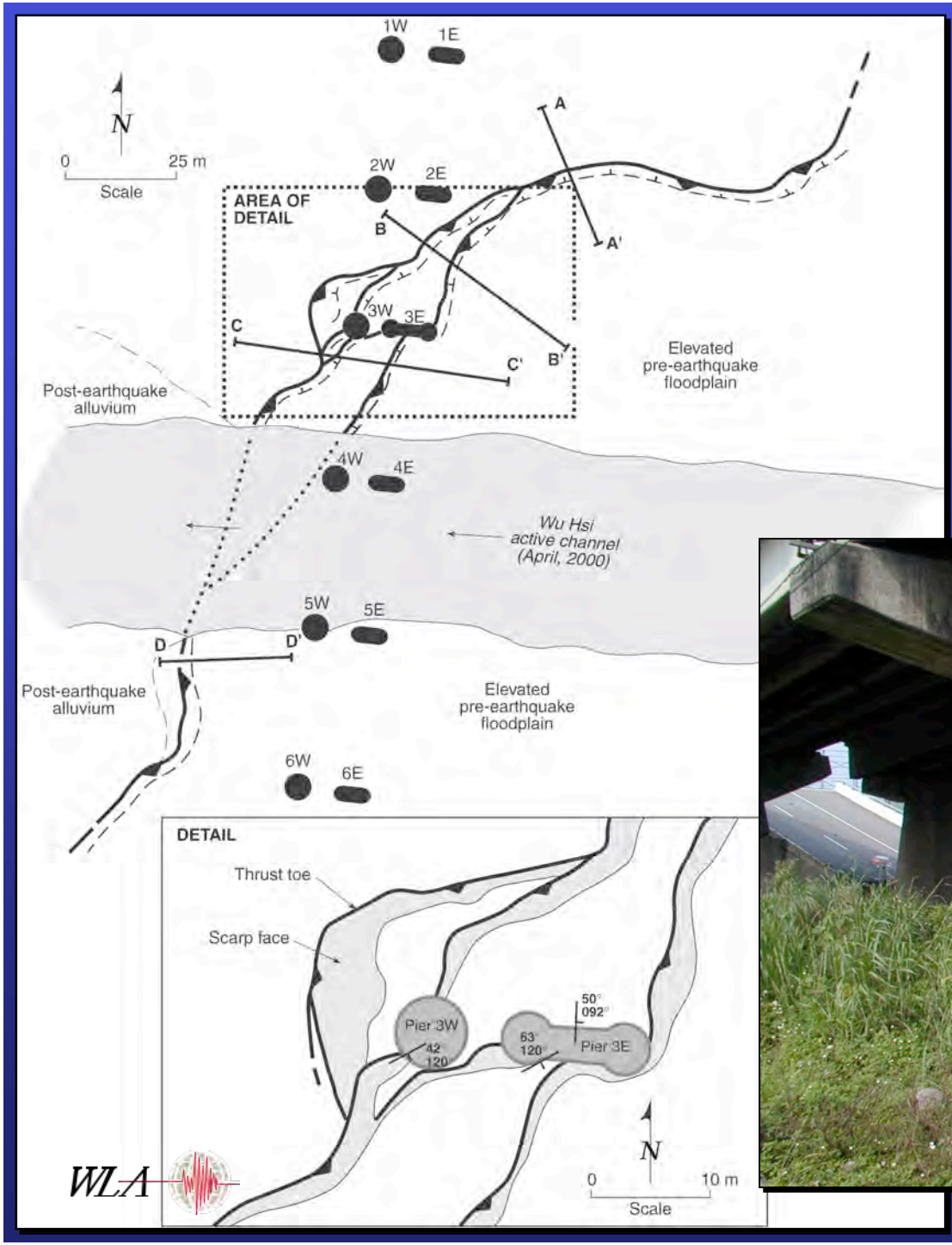
1W
1E
N
0
25 m
Scale
A
2W
2E
AREA OF DETAIL
B
A'
3W
3E
C
C'
B'
Elevated pre-earthquake floodplain
Post-earthquake alluvium
4W
4E
Wu Hsi active channel (April, 2000)
5W
5E
D
D'
Post-earthquake alluvium
Elevated pre-earthquake floodplain
6W
6E
DETAIL
Thrust toe
Scarp face
Pier 3W
42
120
63
120
50
092
Pier 3E
N
0
10 m
Scale
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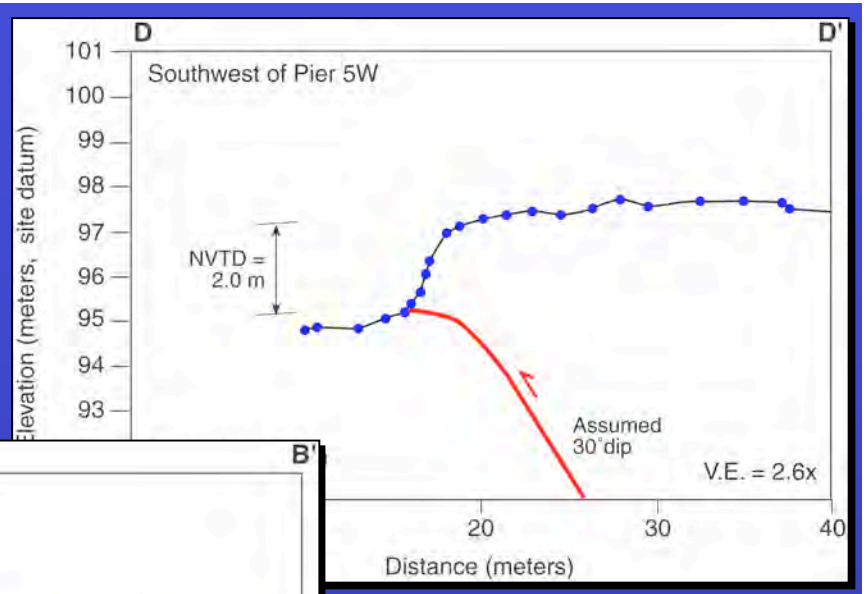
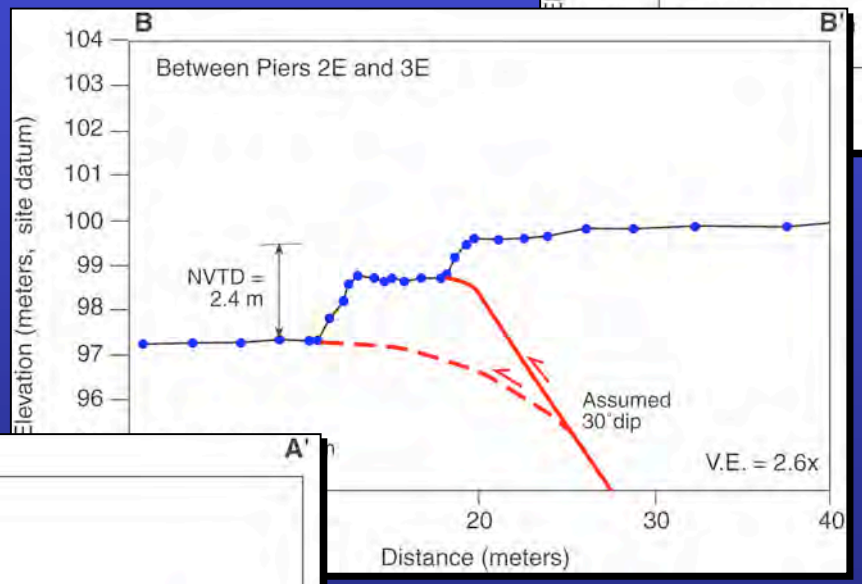
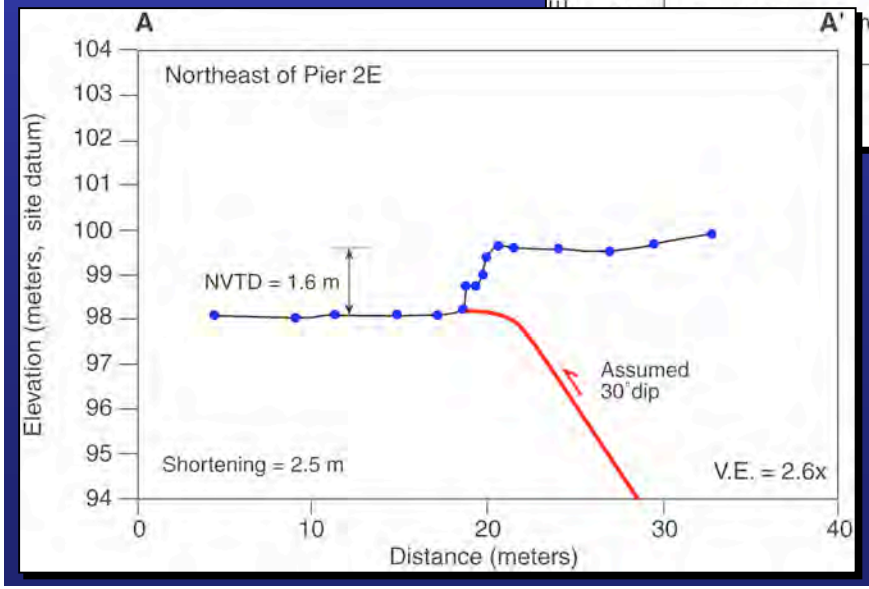
Pier 3E

Pier 3W
Pier 3E

Single, 2-m-high scarp north and south of bridge







Multiple scarps where rupture encountered deep piers

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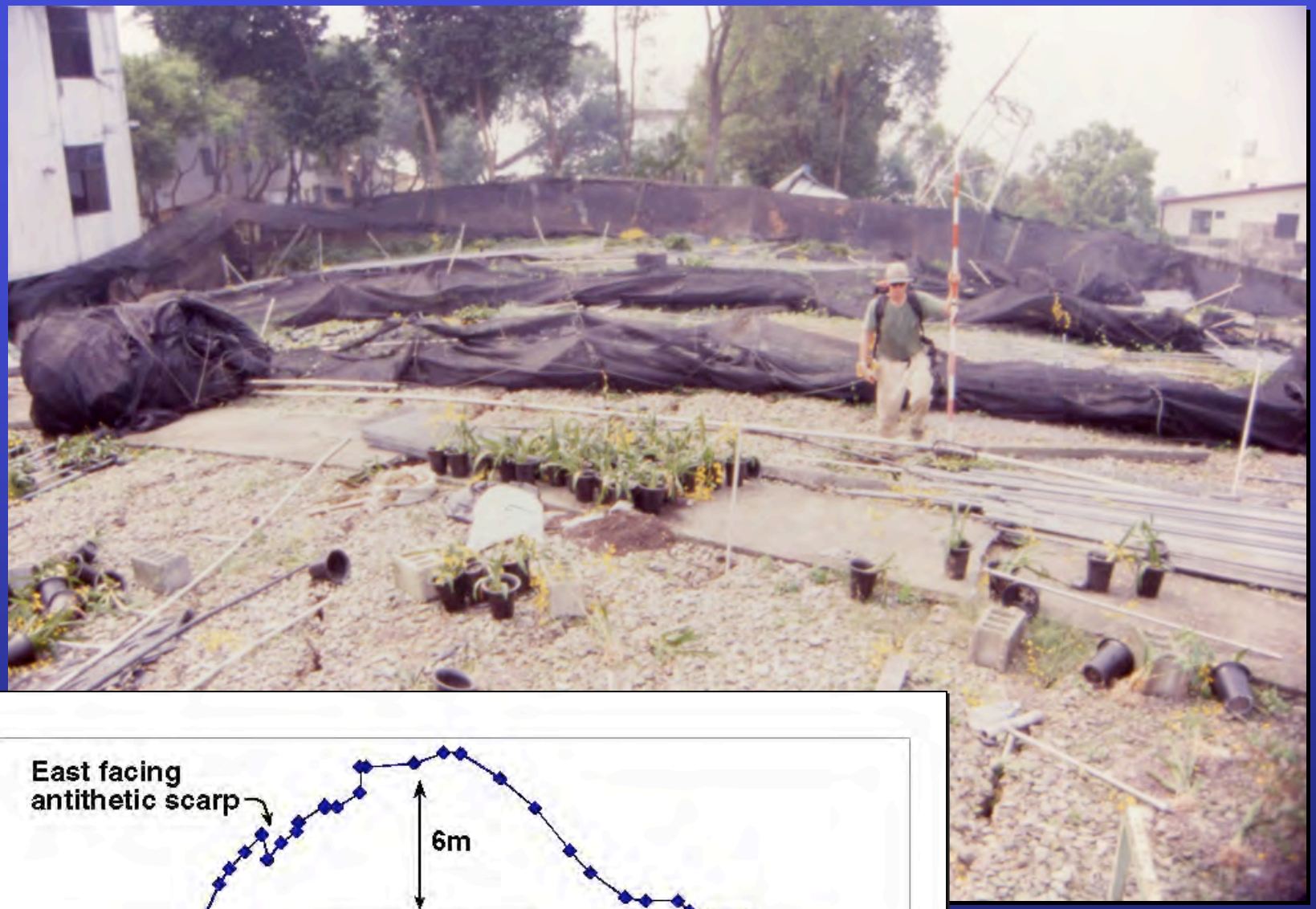

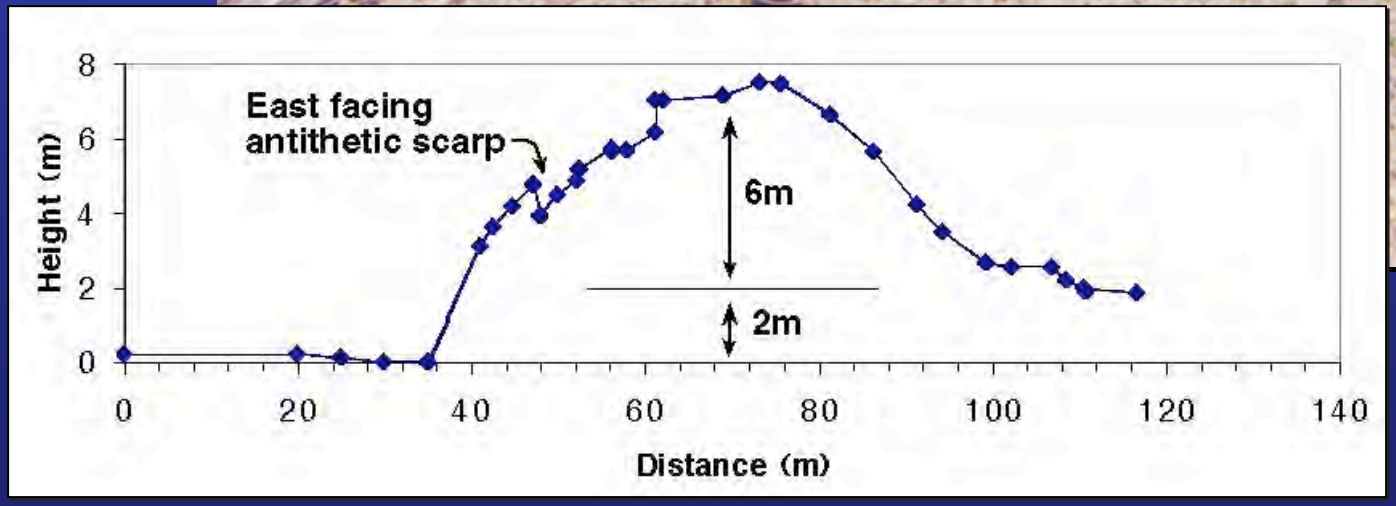
East facing
antithetic scarp
6m
2m
Height (m)
0
2
4
6
8
0
20
40
60
80
100
120
140
Distance (m)

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Secondary Hanging-Wall Deformation

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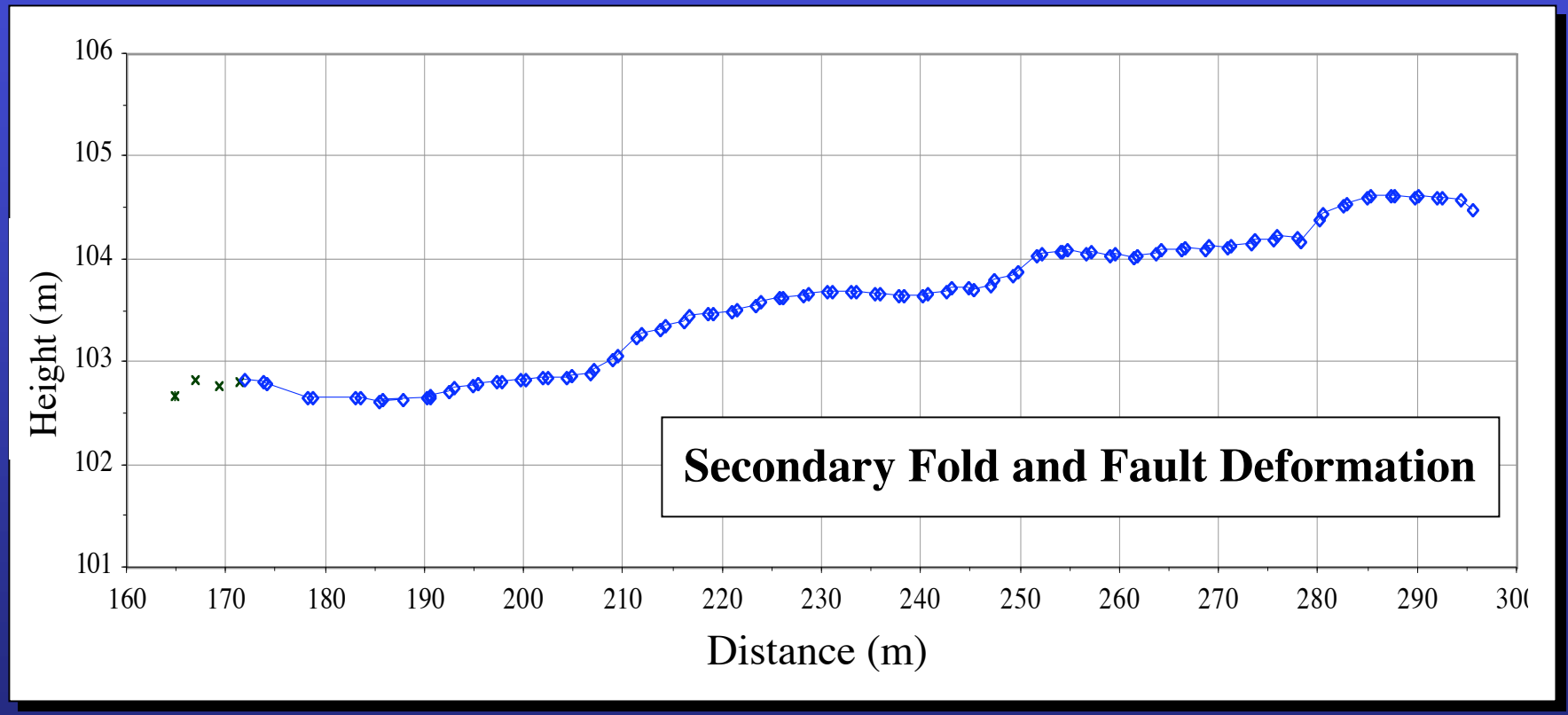
Chung Cheng Park Stream Channel:

Multiple small folds/faults within the hanging wall block

Chung Cheng Park: Stream Channel Profile



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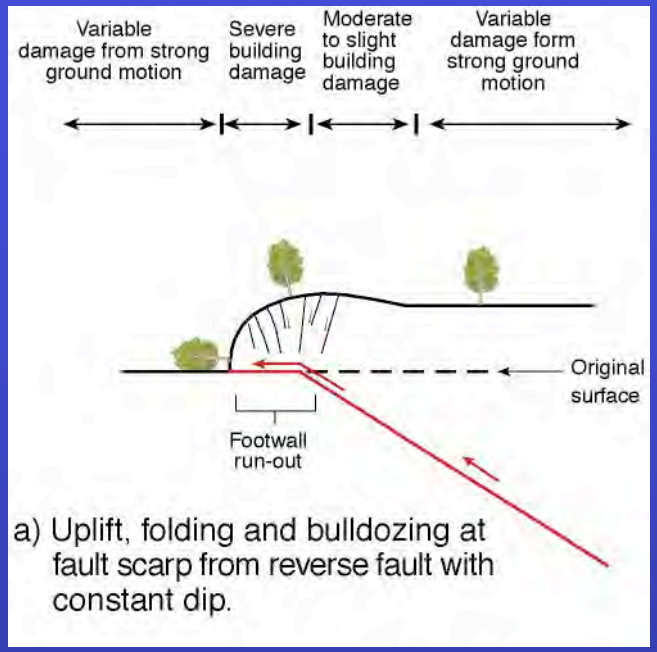
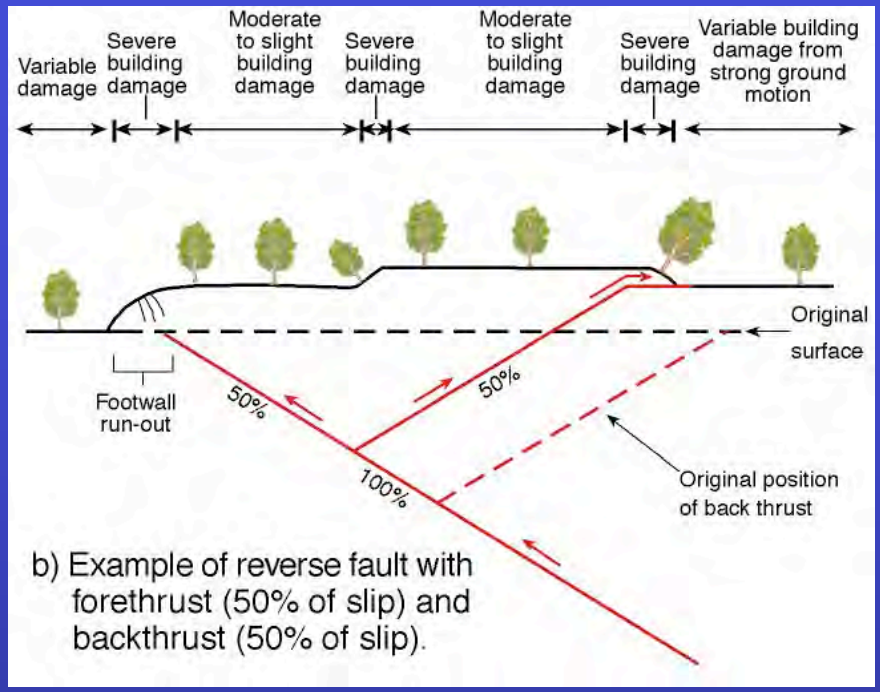
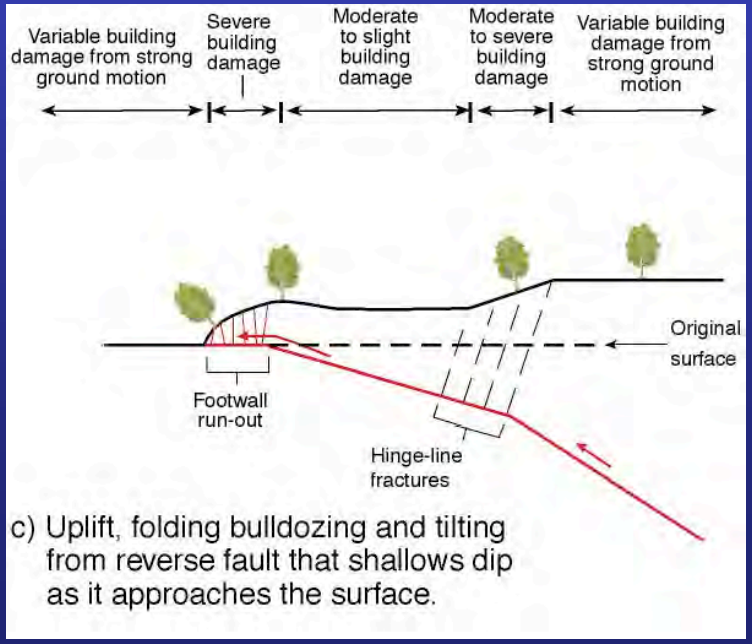


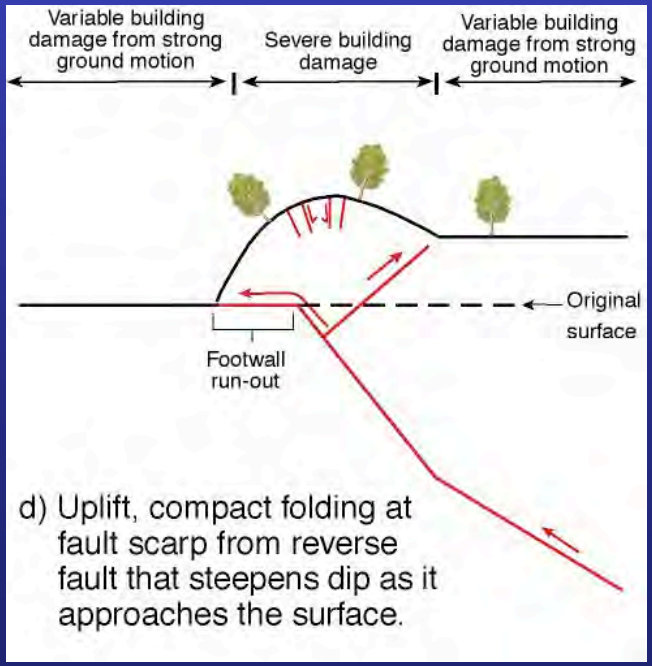
a) Uplift, folding and bulldozing at fault scarp from reverse fault with constant dip.



b) Example of reverse fault with forethrust (50% of slip) and backthrust (50% of slip).



c) Uplift, folding bulldozing and tilting from reverse fault that shallows dip as it approaches the surface.



d) Uplift, compact folding at fault scarp from reverse fault that steepens dip as it approaches the surface.

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Summary

- Complex variability along fault strike
  (Rubin et al., 1996; Ghose et al., 1997)

- Footwall deformation:
  Bulldozing at fault tip (1 - 10 m)

- Hanging wall deformation:
  Primary Fault Rupture and Folding (10 - 50 m)
  Secondary Fault Rupture and Folding (10 - 500 m)
  Rotation of Fold Limbs (10 - 1500 m)

- Structures may be able to withstand some rupture
  if located, designed and built appropriately

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Application to Structures

- Structural response to rupture influenced by
  - Location relative to fault trace (e.g., footwall, scarp)
  - Amount of surface run-out (bulldozing)
  - Type of run-out material (alluvium, bedrock)
  - Orientation relative to rupture direction
  - Structural integrity / construction
- Structures may influence location and pattern of surface rupture
- Interaction between structures and deformation may produce damage to adjacent structures

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