Earthquake Damage to Building Foundations

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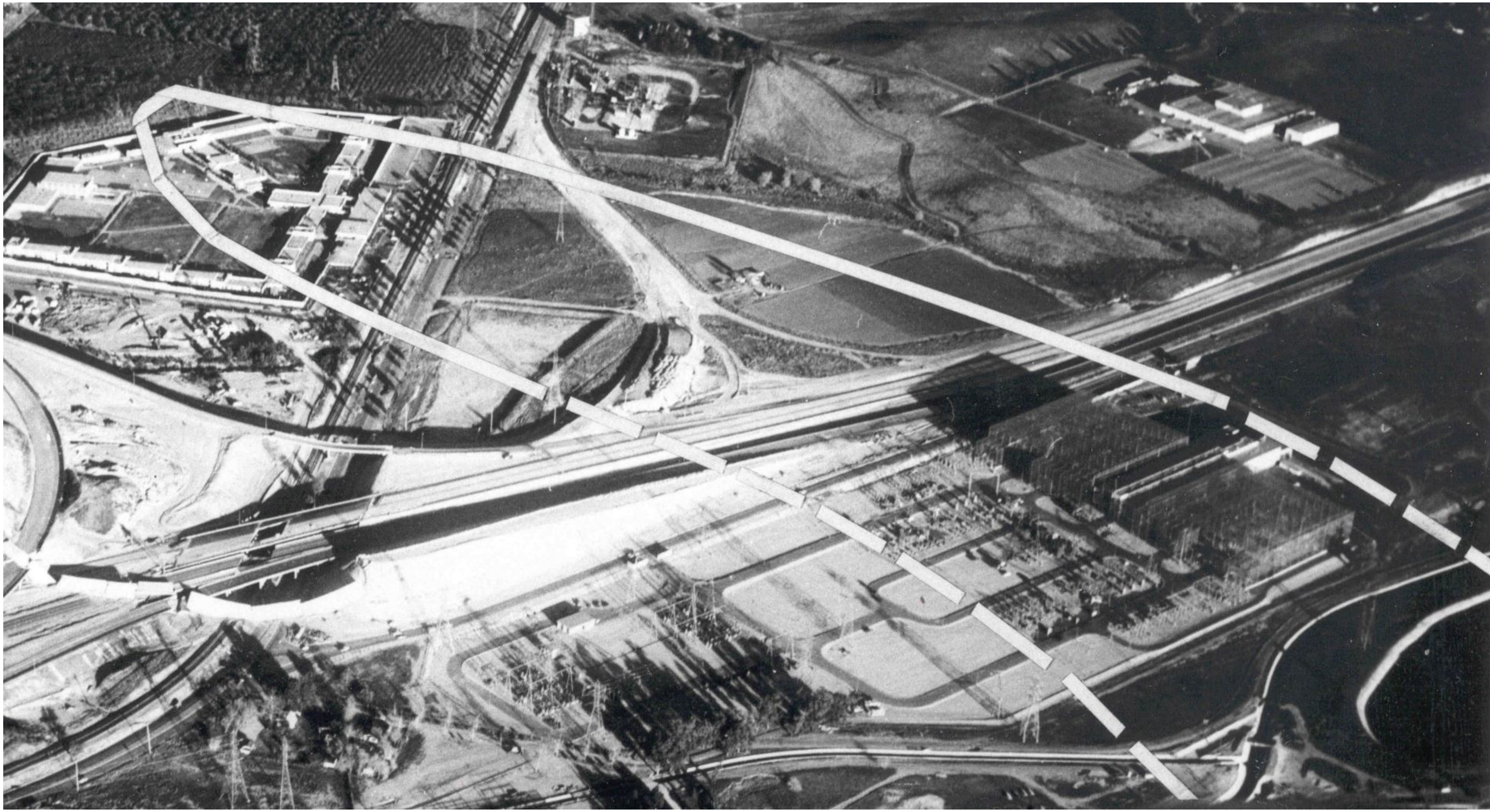
House pulled apart at the foundation level by lateral spread; 977 Varancia, Romania earthquake
(Lloyd Cluff Photo)

House in Sylmar, California that pulled apart by lateral spread during 1995 Northridge earthquake (Les Youd Photo)

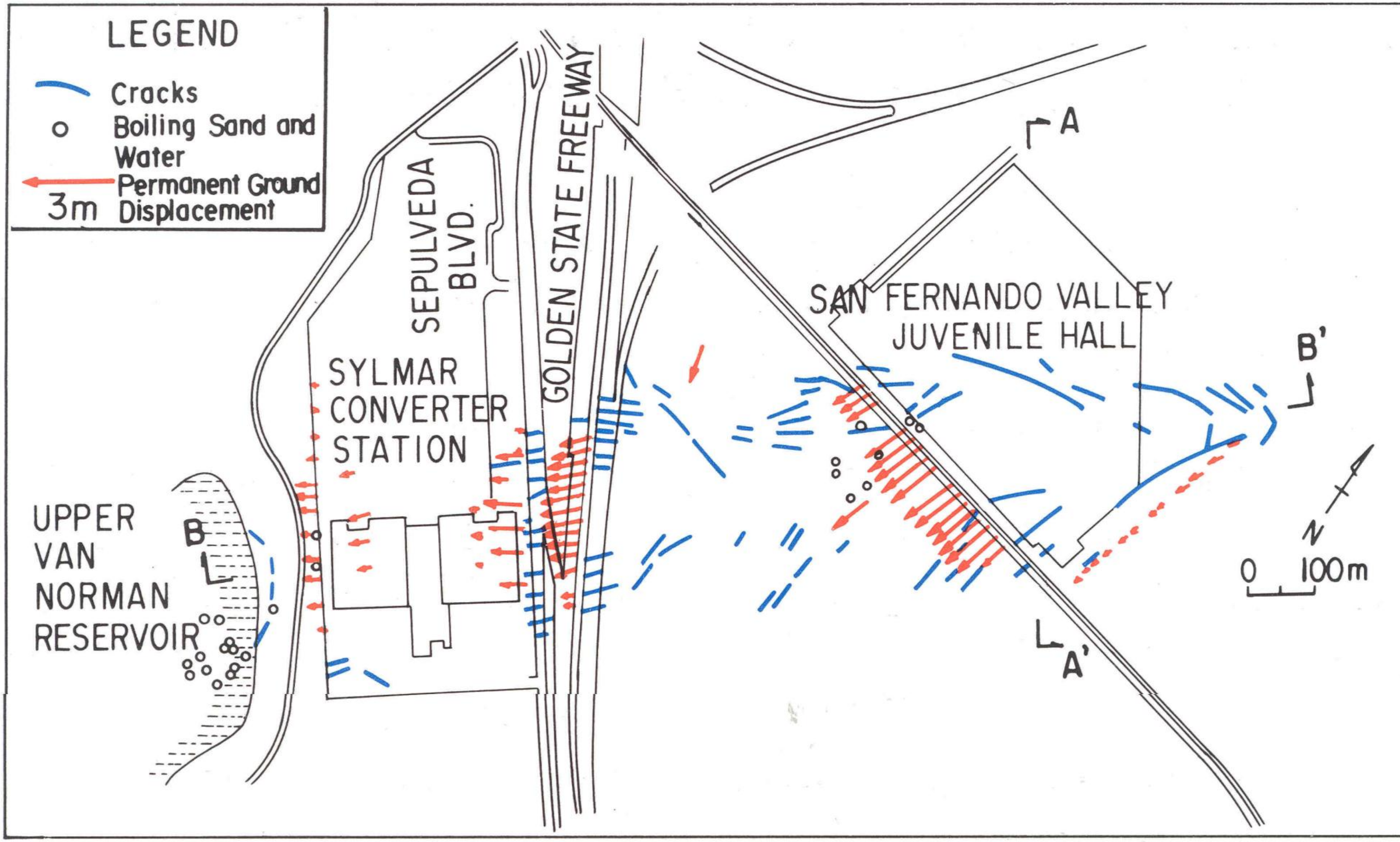
Liquefaction-generated lateral spread fissures during 1995 Kobe, Japan earthquake; the fissures pass beneath houses but caused no damage (Photo by Nick Sitar)

Foundation in Kobe, Japan under construction at the time of the 1995 Kobe earthquake; perimeter foundation is well reinforced with grade beams across the interior, creating a strong diaphragm that is capable of withstanding lateral spread displacement without fracture
(Les Youd photo)

House in liquefaction and lateral spread zone that tilted, but was undamaged structurally during 1993 Hokado, Japan earthquake; house undergoing re-leveling (Les Youd Photo)



Aerial View of San Fernando Juvenile Hall Lateral Spread Area;
1971 San Fernando, Calif. Earthquake (USGS photo)



Fissures and Ground Displacements Generated by the San Fernando Juvenile Hall Lateral Spread; 1971 San Fernando, Calif. Earthquake
(Youd, 1973, NOAA)

San Fernando Valley Juvenile Hall damaged by lateral spread during 1971 San Fernando, California earthquake (Art Keene Photo)

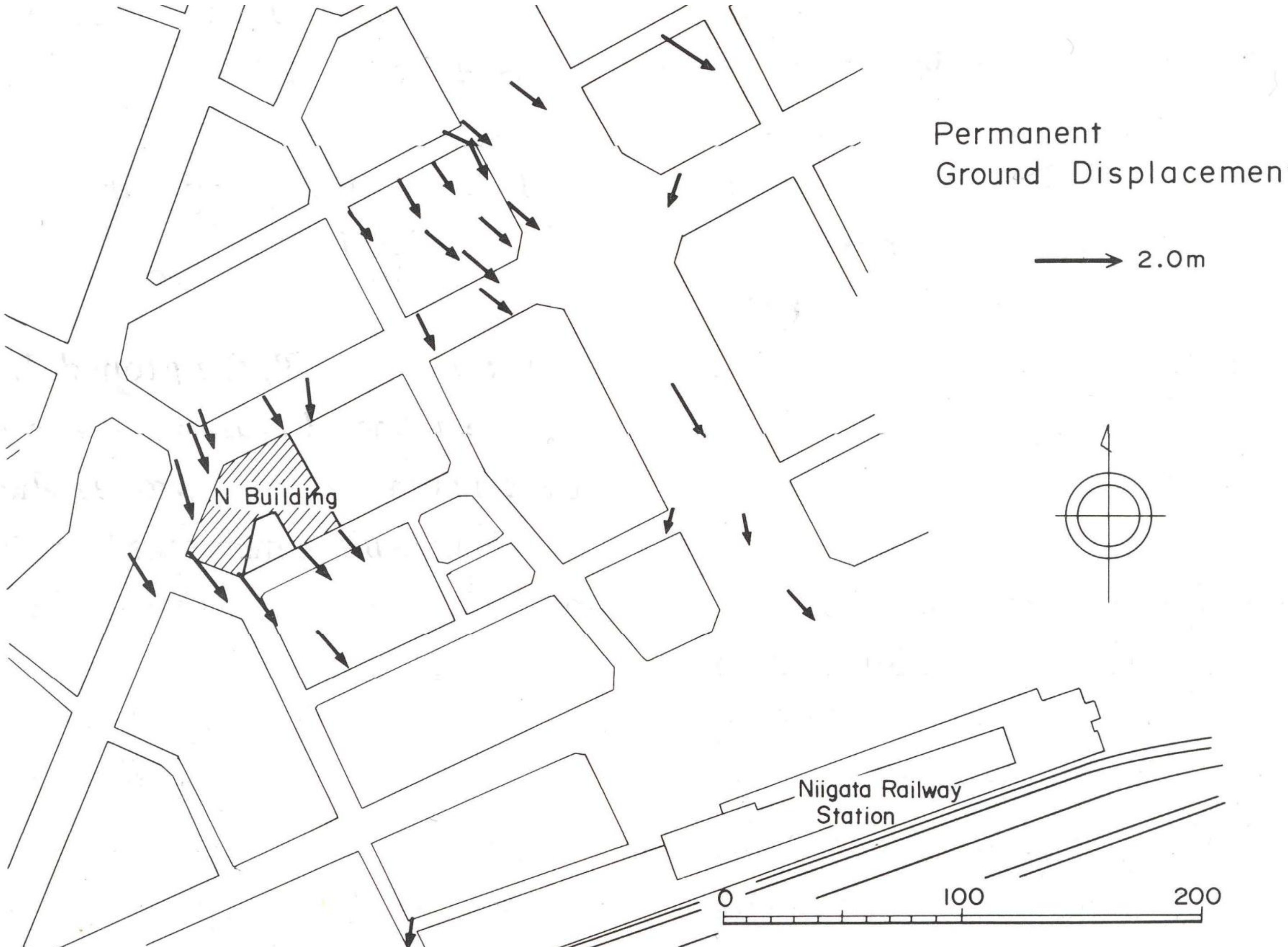
Building at San Fernando Valley Juvenile Hall pulled apart by lateral spread during 1971 San Fernando, California earthquake
(Les Youd photo)

Large-area buildings:

I recently consulted on a warehouse project to be built on site underlain by a layer of liquefiable soil that varied between one and three feet in thickness. I estimated a potential for one foot of lateral spread (by MLR procedure, Youd et al 2002) and up to one inch of ground settlement (by Tokimatsu and Seed (1987) procedure).

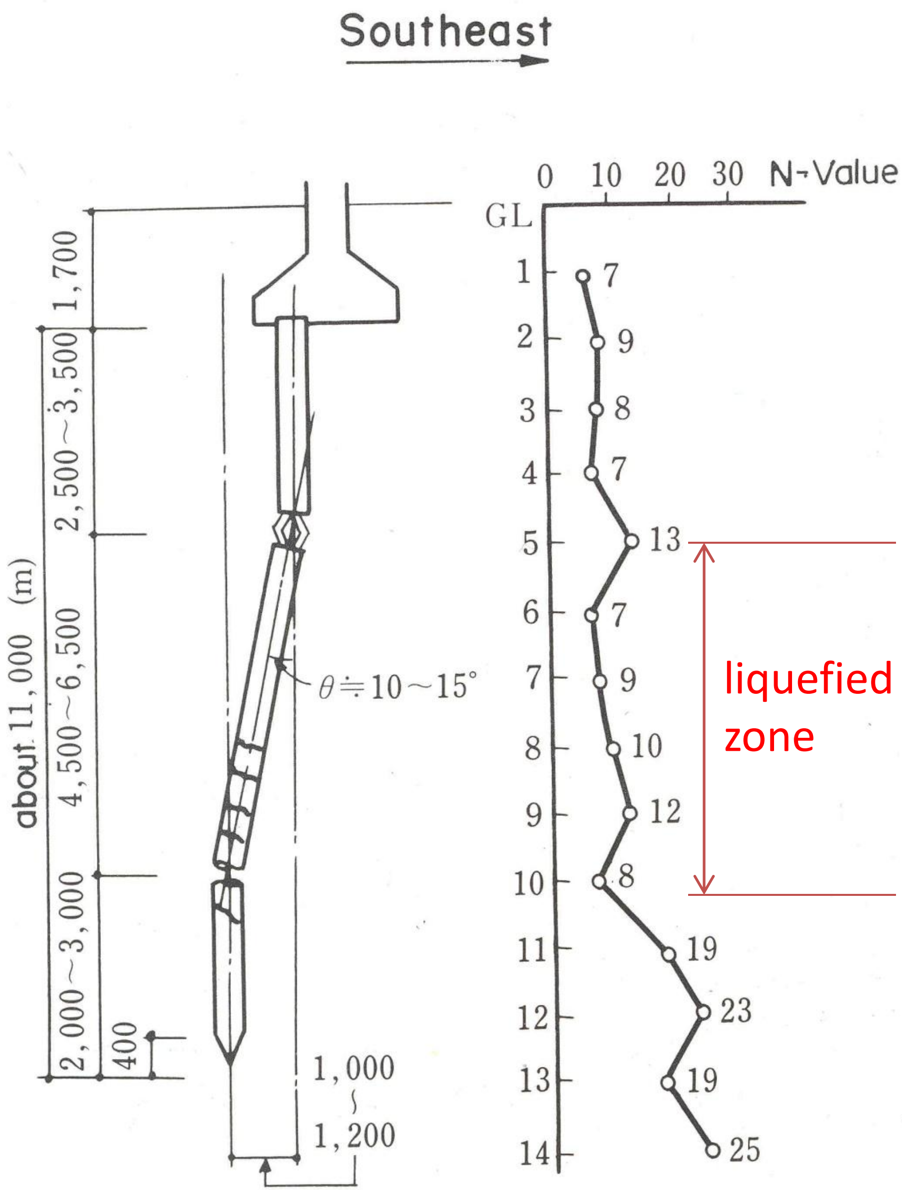
My recommendations for mitigation of liquefaction hazard were:

1. Place adequate reinforcing steel in floor slabs to resist drag forces under slabs generated by ground displacement and to bridge possible zones of differential ground settlement without cracking.
2. Adequately reinforce perimeter wall footings to prevent cracking due to lateral spread and differential ground settlement.
3. Leave connections between building segments unreinforced to force potential pull-apart and damage at those weak points.

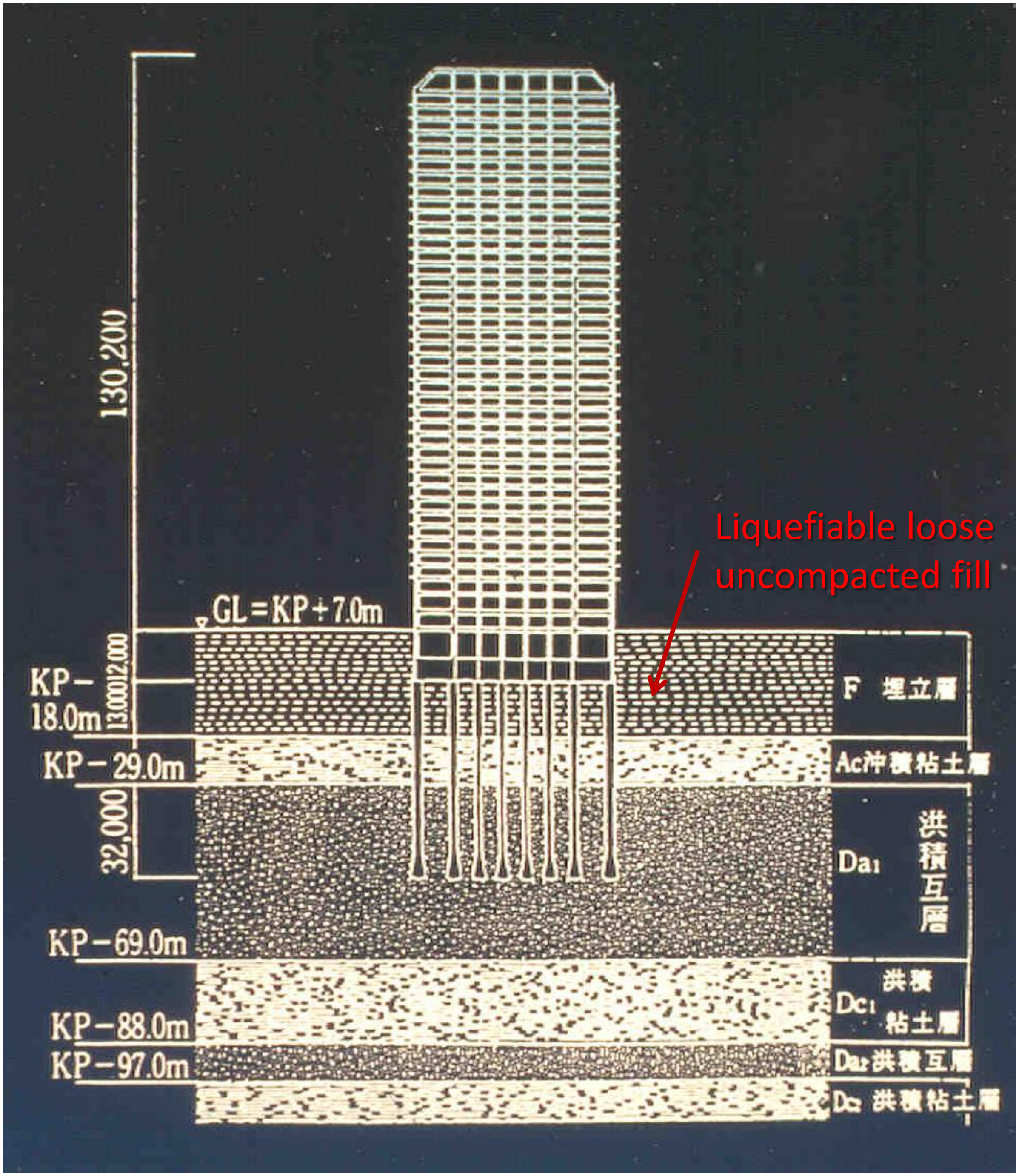


Measured lateral spread displacements around N Building following the 1964 Niigata, Japan earthquake (Hamada, et al, 1986)

Fractured Piles Beneath N Building exposed during excavation for a new building in 1985; damage to piles caused by Lateral Spread during 1964 Niigata, Japan Earthquake (Japanese contractor photo)



Post earthquake pile configuration and standard penetration resistance beneath N Building



Cross section showing pile configuration for a building on Rokko Island, Kobe , Japan. Area was shaken by 1995 Kobe, Japan Earthquake. Liquefaction and ground settlement (average 0.75 m) occurred without significant structural damage to buildings on pile foundations.

Piles have proven effective structural mitigation measure against liquefaction at sites with tolerable lateral ground displacement.

0.5 m of differential settlement between building, founded on piles, and ground caused no significant structural damage; Port Island, Kobe, Japan (Les Youd photo)

Tipped building in Adapazari, Turkey caused by liquefaction-induced loss of bearing strength during 1999 Koaceli, Turkey earthquake
(Les Youd photo)

Tall building supported on piles pulled apart at foundation level by lateral spread toward nearby island edge; building located on, Rokko Island, Kobe, Japan and was damaged during 1995 Kobe earthquake
(Les Harder photo)

Ferry Building on Port Island undamaged by lateral spread (note fissures in graded area) and ground settlement during 1995 Kobe, Japan earthquake; building is founded on reinforced concrete mat supported on reinforced concrete shafts (Les Youd photo)

Ground settled approximately 0.5 m around Ferry Building
(Les Youd photo)

Waterfront side of Ferry Building showing pavement that settled and pulled away from building due to liquefaction and lateral spread, exposing foundation elements
(Les Youd photo)

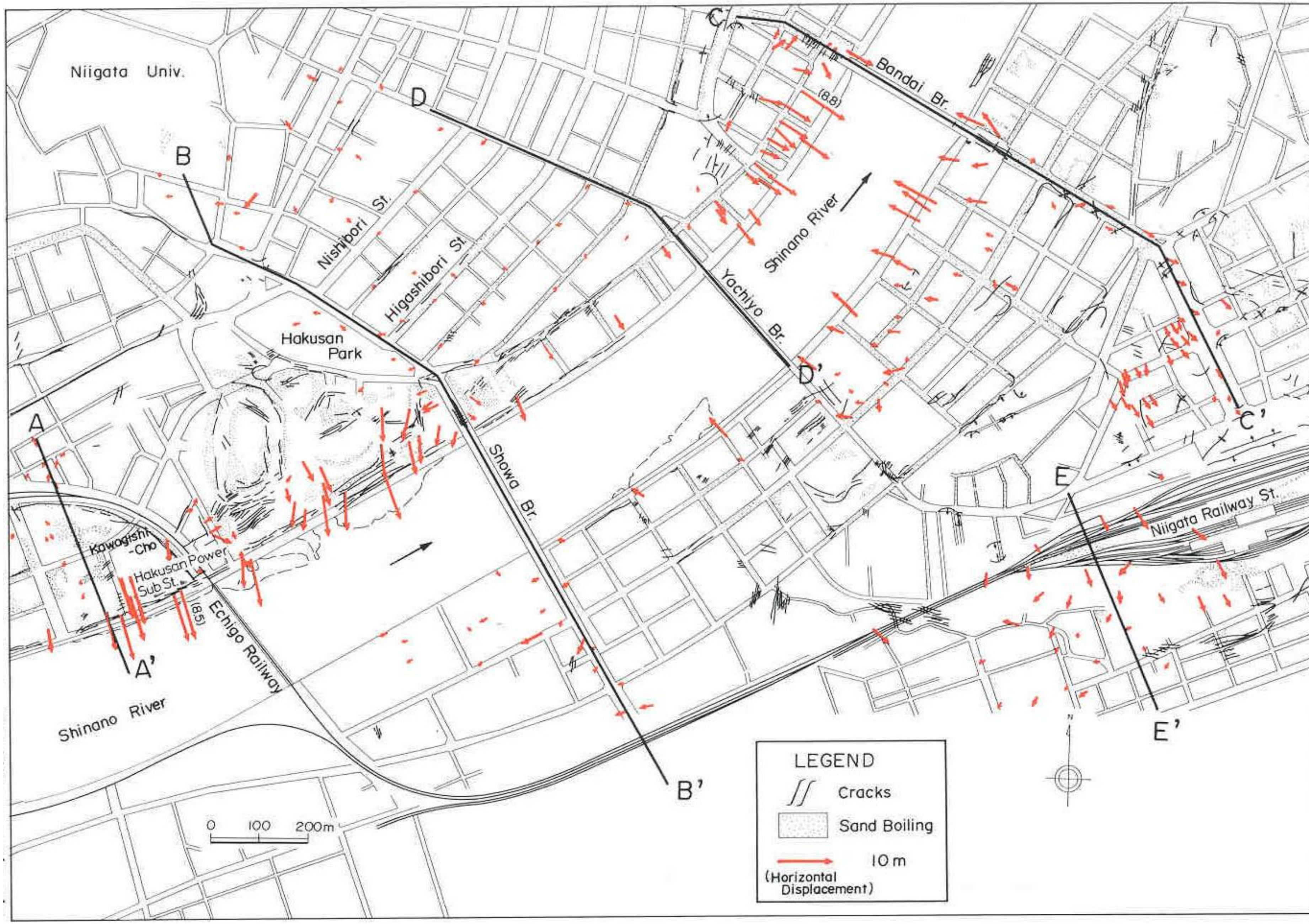
Waterfront side of Ferry Building showing pavement that settled and pulled away due to liquefaction, ground settlement and lateral spread; Jetways were pulled away from building and utilities broken but building was undamaged

(Les Youd photo)

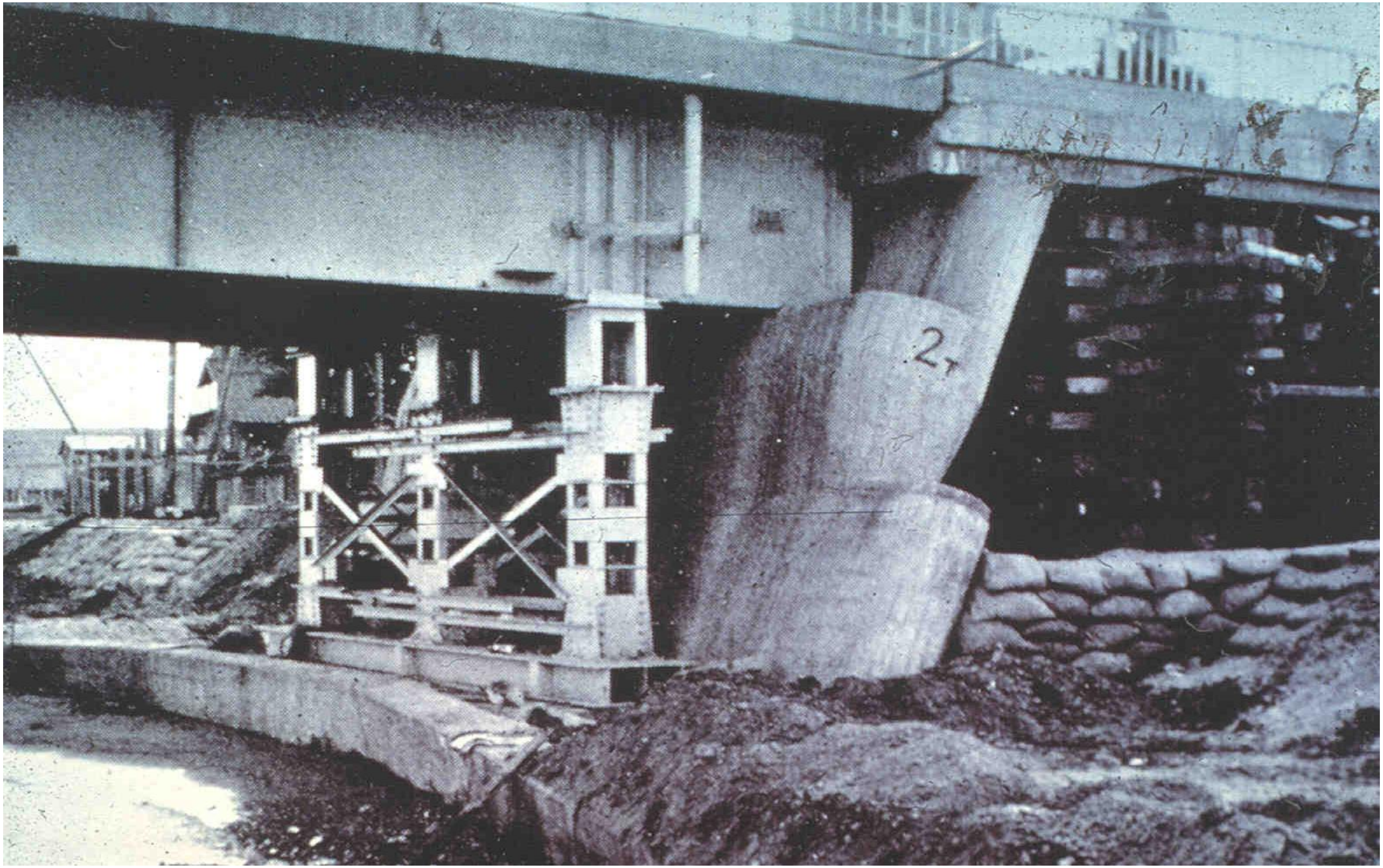
Shaft exposed by pull away of soil on waterfront side of Ferry Building; shaft is strongly tied into the concrete mat, pinning the shaft at the top while the bottom is pinned in alluvial gravels beneath the liquefied zone

(Les Youd photo)

1964 Alaska earthquake: lateral spread floodplain deposits displaced abutments 1 m toward channel buckling deck upward
(USGS photo)



Lateral spread vectors, 1964 Niigata, Japan Earthquake (Hamada et al, 1986)



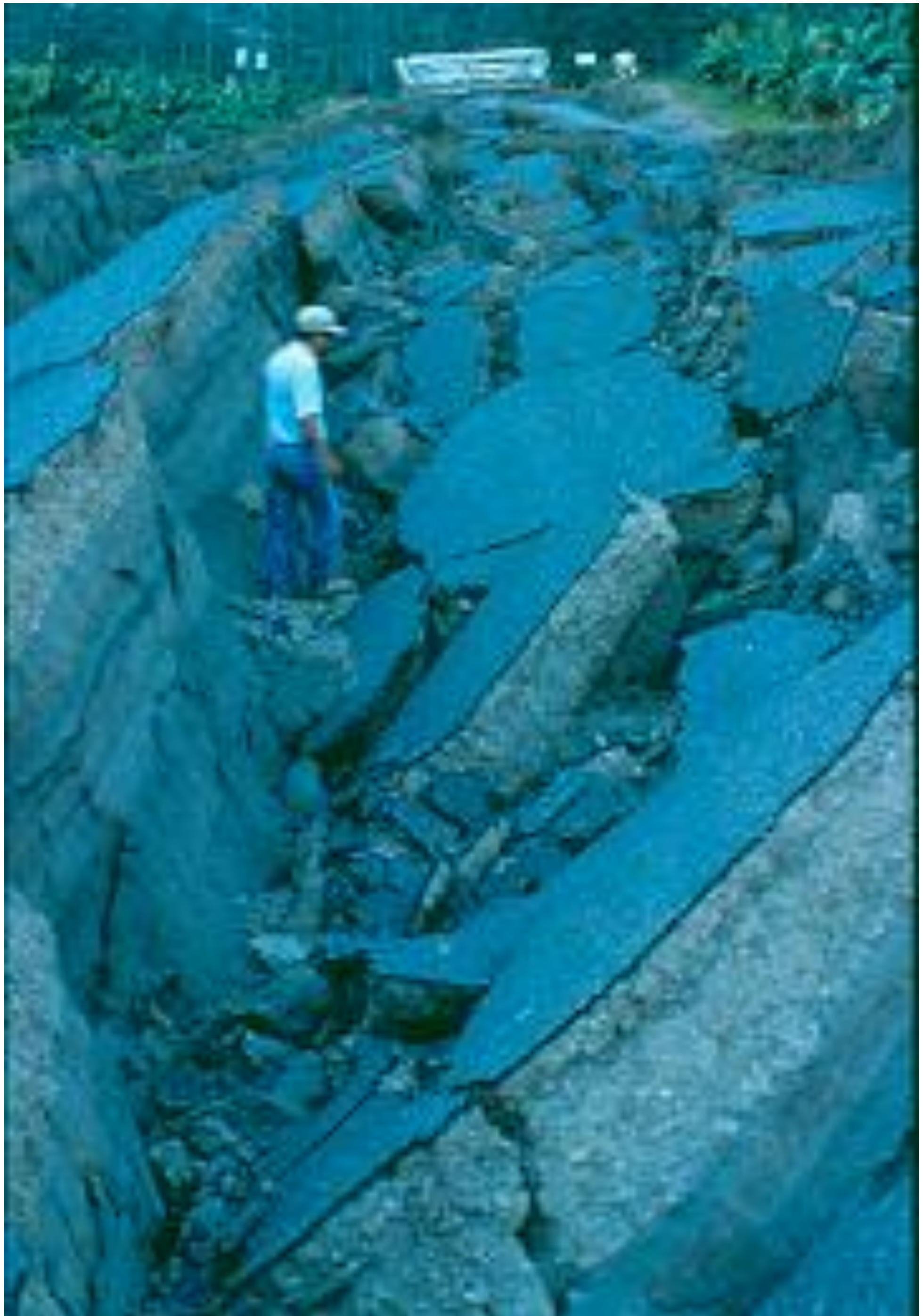
Bridge pier displaced toward Shinano River during 1964 Niigata, Japan earthquake (1964 Niigata, Japan Earthquake Report)

Collapsed highway bridge over Rio Estrella, 1991 Limon Costa Rica earthquake (Les Youd photo)

Central pier of Rio Estrella highway bridge

1991 Limon Costa Rica: Central pier of Rio Estrella highway bridge

Central pier of Rio Estrella, Costa Rica highway bridge (Les Youd photo)



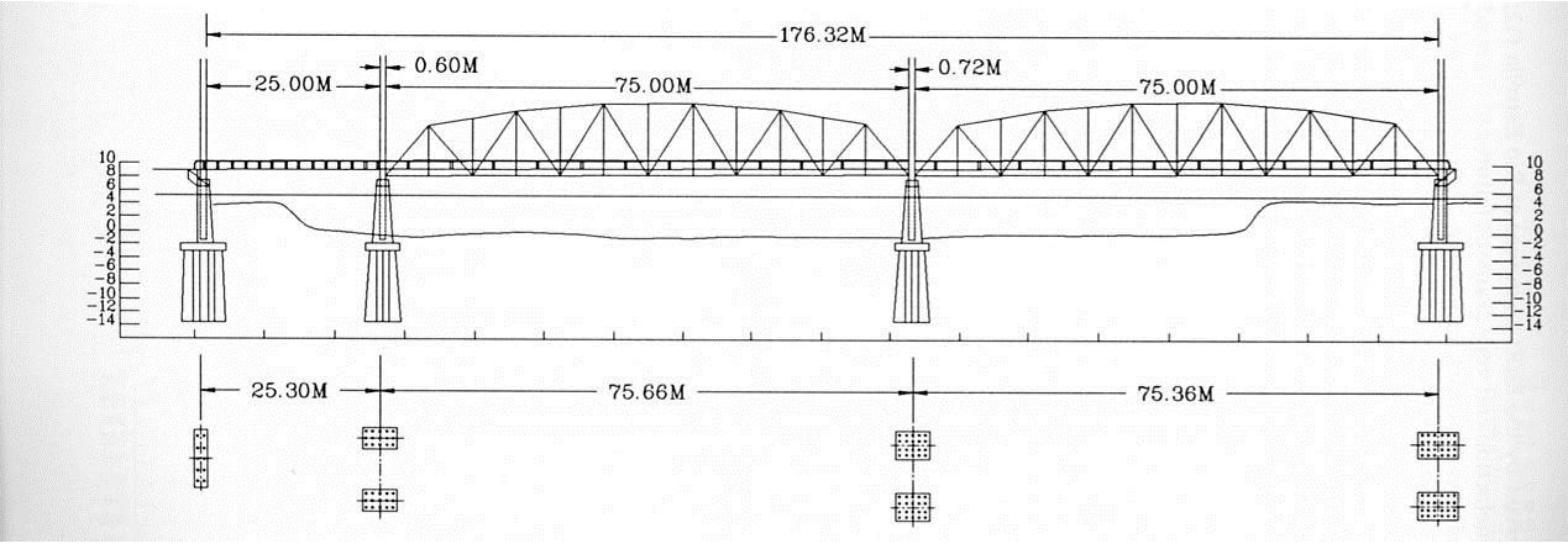
Shattered and spread embankment approach to collapsed Rio Estrella highway bridge (Univ. of Costa Rica photo)

Cracked and settled highway embankment at abutment of collapsed Rio Estrella highway bridge (University of Costa Rica photo)

Abutment and collapsed truss of Rio Estrella highway bridge
(University of Costa Rica photo)

Northern abutment

Southern abutment



Plans for Rio Estrella highway bridge

TABLE 6-1 Comparison of plan and measured post-earthquake distances between bridge elements for the highway bridge of Rio Estrella.

Distance between center of bridge seats on	*Plan Distance m*	*Measured post-earthquake distance m*
North Abutment and Pier 1	25.00	24.96
Pier 1 and Pier 2	75.00	75.02
Pier 2 and South Abutment	75.0	75.24
North and South Abutments	176.32	176.14

(Youd, T.L., Rollins, K.M., Salazar, A.F., and Wallace, R.M., 1992, “Bridge damage caused by liquefaction during the 22 April 1991 Costa Rica earthquake,” Proceedings, 10th World Conference on Earthquake Engineering, Madrid, Spain, 19-25 July, 1992, vol. 1, p. 153-158.)

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