"We Have Built Our Houses on Sand"

Daily news reports in the wake of last week's Prieta earthquake in northern California have featured declarations of the causes of various structural failures. But, in fact, engineers and seismologists disagree widely on many of the whys and wherefores, and the truth is unlikely to emerge for some time.

Among the points of contention are the effectiveness of California's program to retrofit aging and potentially dangerous elevated freeways and the degree to which soils are to blame for the seemingly capricious pattern of destruction.

Not everything is in doubt, of course. As in Mexico City 4 years ago, soil conditions appear to have played a major role in the collapses of the Oakland freeway and of homes in the Marina district of San Francisco, relatively far from the epicenter. "The damage the earthquake did around the Bay cries out that we have built our houses on sand," says geologist Howard Wilshire of the U.S. Geological Survey, "and now we're paying the price."

Those spectacular collapses tended to divert attention from the less shocking but nevertheless serious problems of areas closer to the epicenter, says USGS seismologist Robert Page. There, in the towns of Watsonville and Santa Cruz, the damage was what one would have imagined, he says: the collapse of masonry buildings and single family homes that are susceptible to the high-frequency waves that do not reach more distant sites.

But beyond these obvious points, other answers will come more slowly to the scores of seismologists and civil engineers surveying the shaken area. Many are wondering, for example, why there was not more damage in San Jose, the closest major city to the quake. Page speculates that the recent drought, and resulting depletion of the aquifer on which the city rests, may have made its soils more stable than those in the damaged areas of Oakland and San Francisco. Others focus on the fact that San Jose has fewer old structures than San Francisco and Oakland.

While stable soil conditions may have helped save San Jose, the sandy landfill under San Francisco's Marina district clearly contributed to the demise of many homes there. But how that destruction occurred was debated in the days following the quake. While the structural engineers contacted by *Science* blamed the failures on amplification of the earth's shaking by the soft soils, Page and other geologists pointed to liquefaction, a condition in which sandy, water-saturated soil is converted to a liquid slurry by the shaking of the earthquake.

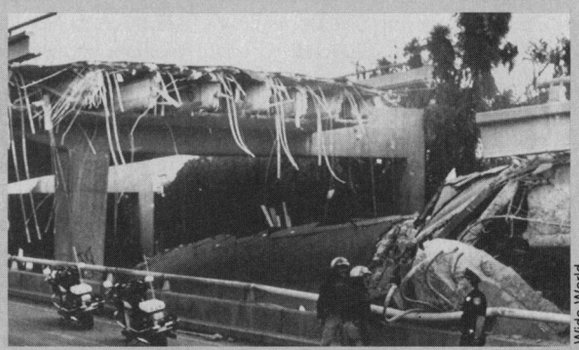
Geysers of sand and water were indisputable evidence that liquefaction occurred in the Marina, but Craig Cole, a structural engineer with URS/John A. Blume & Associates, a major San Francisco earthquake engineering company, said he was not certain that liquefaction brought down the homes he examined since he saw no sign of sinking foundations.

Cole and others blame the failure of the Marina homes on a combination of amplified shaking and a fundamental design flaw. Although wood-frame buildings are generally expected to fare well in earthquakes, those that collapsed were generally row houses in which the entire first floor was garage space. "There were no walls to resist the horizontal forces," Cole said.

Even the most highly publicized and examined casualty of the Prieta quake, the elevated section of Interstate 880 in Oakland, has been the subject of considerable argument among the experts over what specifically caused the collapse. The freeway, along with hundreds of others built in California before design standards were tightened following the 1971 San Fernando earthquake, was the target of a retrofitting program begun to accommodate design weaknesses revealed in 1971.

In the first phase of the program, which had been completed on the 880 freeway, steel cable was used to tie roadways to the support columns at expansion joints—junctions where the roadway is free to pull apart slightly to allow for thermal expansion and contraction. Many of the freeway failures in 1971 occurred when road decks slipped off the narrow support shelves at the joints. Brittle concrete support piers also contributed to the 1971 collapses, but California has not yet begun a retrofitting program directed to strengthen older piers erected before the San Fernando quake.

Joseph Nicoletti, a San Francisco structural engineer who headed an investigation of the 1971 San Fernando freeway collapses, doubts that the completed retrofits of expansion joints would hold under the forces of an earthquake. "It's almost impossible to tie these big, heavy, massive sections together," he told *Science*. "I suspect what they did wasn't adequate."



Wide World

Cypress freeway *failed, despite 1970s reinforcements.*

Ian Buckle, deputy director of the National Center for Earthquake Engineering Research at the State University of New York at Buffalo and the head of a team brought in by the governor of California to investigate the highway failure (until fired by the governor as *Science* went to press), placed complete confidence in California's retrofit project. "It's the columns that went down," he said in a press conference following a preliminary inspection of the collapsed roadway. "Because the retrofit was in place, there was no possibility of the expansion joints pulling out and the span dropping down."

"Engineers who venture to say 'this is it' now are really using mainly their imaginations," countered Piotr Moncarz, principal engineer at Failure Analysis Associates, a Palo Alto engineering firm. After spending several hours examining the collapsed structure, Moncarz told *Science* he had seen some expansion joints that were still tied together and others that had pulled apart. "It's quite possible that the failure initiated at an expansion joint," he said. But he said the failure could have begun with a pier collapsing as well, and he said it would require a major engineering effort to distinguish between the two.

Only when the engineers finish picking through the rubble and analyzing the quake's forces on the failed structures through computer simulation will the answers emerge. And along with those answers will come a new wave of ideas for how to shore up California's freeways and buildings to face the potentially larger and more destructive quakes to come. ■ **MARCIA BARINAGA**