THE GREAT QUAKE: ON-SITE REPORTS

Random reports from the California earthquake give engineers' first impressions.

Although it will be months or perhaps years before the last judge has handed down the last opinion about why certain structures did or did not survive the San Francisco earthquake of Oct. 17, engineers across the country are drawing some preliminary conclusions. At press time, the magnitude of the quake had been increased from the original 6.9 measurement to 7.1 on the Richter scale, and serious aftershocks were still expected. Indeed, seismologists were saying there is a 50% chance of an aftershock serious enough to cause significant structural damage occurring before Christmas.

From firsthand reports received by CIVIL ENGINEERING editors, it's clear that:

- Earthquake codes do work. Seismic provisions have been added to building codes through the volunteer efforts of many members of SEAOC, the Structural Engineers Association of California, who have researched the problems for more than 15 years. On Oct. 17, buildings constructed under these provisions stood firm.
- Money for maintenance and retrofit of bridges and highways is well spent. Explanations about budget limitations fail to excuse death and destruction.

QUAKE CATCHES BOSS ON THE GOLDEN GATE

"It took many years of planning and then a marvelous quirk of timing, but there I was, driving north on the bridge when I thought something had gone wrong with the car." For 30 years, Daniel E. Mohn, Golden Gate Bridge District engineer, had said that when "the earthquake" came, he wanted to be midspan on the Golden Gate.

And he was.

Mohn and the district's deputy engineer, Marvin Giacomini, parked the car at the north end of the bridge, made an immediate inspection, determined that it was safe and thus were able to announce almost immediately that the Golden Gate was open to traffic. "When we got out of the car, I thought it had been an earthquake of 5 or so. It was only later, when we heard about the heavy destruction, that we appreciated its full force," he told CE.

Mohn compared the quake motions with the major windstorms of 1982 and '83, which he also experienced (deliberately) on the bridge. "The windstorms produced a large lateral force and minor vertical oscillation, while in the earthquake, the vertical oscillations were at a much higher frequency."

RESEARCH GROUPS MAKE FIRST REPORT

The first engineers' report to CE came on Oct. 23 through Ron Mayes, representing three earthquake oriented research groups who fielded a reconnaissance group on both sides of San Francisco Bay: the Applied Technology Council, which is the research arm of SEAOC; the Earthquake Engineering Research Institute, in El Cerrito, Calif.; and the National Center for Earthquake Engineering Research of the State University of New York at Buffalo.

Specifically, the group noted:

- The primary problem on the Cypress and Embarcadero freeways was a configuration problem (lack of continuity and redundancy, i.e., use of hinges) and a joint detailing problem. The primary problem on the I-280 and

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Highway 101 viaducts was a column shear capacity problem.

- The I-980 and 6th St. off-ramp problems are inadequate joint shear strength (both new and old designs).
- The Bay Bridge and San Mateo Bridge issues were related to inadequate bearing connections.

Noting that this is the first sizeable earthquake affecting the area's major bridge structures, the reconnaissance group called for a high priority seismic retrofit program based on funding significant research and development. They rebutted criticisms of Caltrans that had appeared in the mass media. "We believe that Caltrans engineers have been aware of the need to perform significant seismic retrofit on both the restrainer program and the column retrofit program since 1971. We also believe that joints of bents should be included in the retrofit program. We believe there are about 1,200 bridges that have been identified by Caltrans that require their columns to be retrofitted."

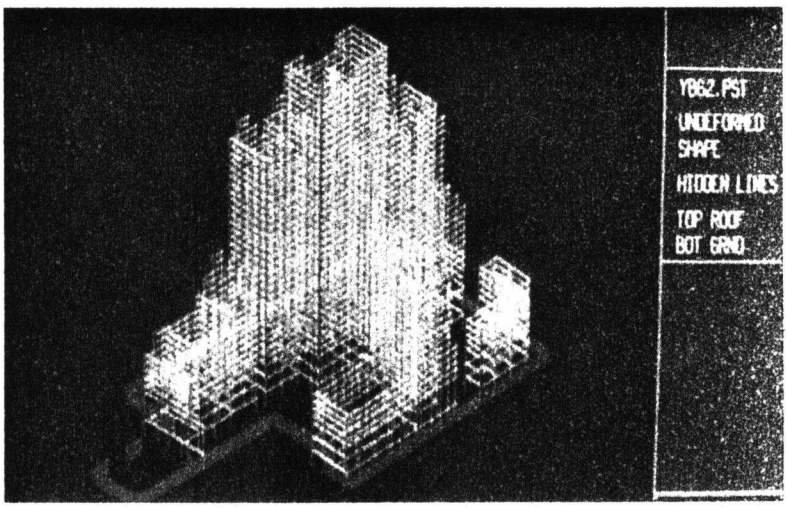
The engineers expressed concern that "the seismic retrofit program has not been given very high priority by those responsible for allocating funding," and pointed out that the $50 million Phase 1 retrofit program took 16 years to complete. "There are some difficult technical issues to solve in the column and joint retrofit program, and their solutions [and implementation] must become a high priority, even though it may be expensive. If this does not happen, the disaster we saw on I-880 may be repeated in the next significant earthquake."

BUILDINGS, BRIDGES: FIRST IMPRESSIONS

The I-880 collapse was a tragic case of deficient structural design, according to S.K. Ghosh, director of engineered structures for the Portland Cement Association, who is also an observer on the SEAOC seismology committee. He was quick to add, "The devastation must not overshadow clear evidence of engineering and construction advances in seismic resistant design."

The deficiencies of I-880, he noted, include the hinge action of short reinforcing dowels at the top and bottom of columns that supported the upper deck. Many of the columns along the 1.5 mi collapsed stretch pulled out of their bottom supports and top restraints, landing upright on the ground below. Columns in another section remained standing because hinges were eliminated.

A masonry paint store building in Santa Cruz, Calif., designed to seismic codes, stood firm while the rest of the Pacific Garden Mall collapsed. The Marriott Hotel, below, designed with seismic oriented software, opened only hours before the earthquake but suffered no damage.



Ghosh also observed that cables added to connect the roadway deck slabs for seismic upgrading did little to improve the failed segments' resistance to the lateral movements of the quake.

Another engineer cited ground conditions. "The three viaducts that were damaged were all on very poor ground, and that may have something to do with the failures," reported Charles Seim, a principal at T.Y. Lin International, San Francisco structural engineers. He was less sure about the Bay Bridge. "I'm surprised that it went down at a braced tower. It was designed at the joints for differential movement, and well tied together."

(Caltrans, however, quickly put forth its plan to repair the structure and install new decking on the Bay Bridge rather than repair the existing failed deck. The announcement said that traffic would resume in only four weeks.—*Ed.*)

"In hindsight about the viaducts—and we've got to qualify any judgment we make—there are things we know today that we would do differently," Seim continued. "We're now aware of shear capacity in columns, which was not a requirement when I-880 was built. And articulation—today we provide continuity, resistance in the transverse direction and, of course, redundancy."

About upgrading existing structures, Seim said, "I'm not so certain we can do it technically or financially. Caltrans has submitted second-phase retrofit proposals every year, but never got the funding. We need the dollars for research, and that's a political matter. As for the technology, I'll fall back on the old engineering statement: We may not know exactly how to do it today, but we *can* do it."

According to Allan Porush, a Dames & Moore associate dispatched to San Francisco from the

Los Angeles office, "Well designed buildings on competent soil did not suffer significant damage. I'll qualify that. Well designed means designed to current building standards. And competent soil is important because we saw a lot of damage to buildings in lousy soil."

Porush, who "feels encouraged about how the newer buildings performed," was on a mission to document damage to industrial buildings in the quake area. "Except for one powerplant south of Monterey, I'm not finding much damage to look at," he told CE.

CONGRESS SENDS NIST RESEARCHERS TO SITE

Following a five day investigation of earthquake ravaged Northern California, experts led by the National Institute of Standards and Technology (NIST) are working on a report on reasons behind some of the structural damage. They will also make recommendations for future "hazard mitigation."

According to Richard Wright, F.ASCE and director of NIST's Center for Building Technology, the report will address what the "national approach" should be in preparing for future earthquakes. As CE went to press, the report was being compiled and should be released in late December or early next year.

Wright led the team of six construction experts from NIST, the U.S. Geological Survey and the Federal Highway Administration. As required by law, they responded to a call from the U.S. Senate Committee on Commerce, Science, and Transportation, headed by senators Ernest Hollings (D-S.C., chairman of the committee) and John Danforth (R-Mo., its ranking member). The team arrived in San Francisco on Wednesday, Oct. 18, the day after the earthquake, and stayed through Sunday.

The report will address at least two problems in San Francisco that could translate into future catastrophes for the nation:

- The nation's vulnerable "lifelines." With San Francisco's water supply in shambles immediately after the quake, Wright said, the city was just plain lucky that no wind was blowing that night as it struggled to extinguish the fire in the Marina district. "This earthquake should serve as a national reminder to get our lifelines in proper order."
- Major damage outside the epicenter. If destruction well beyond the epicenter proves to be the tendency of other earthquakes, "modern society" especially from "an Eastern perspective" will be particularly vulnerable. Many of the damaged buildings in Northern California are built on soft fill, Wright said. "You will find major, important buildings in almost all parts of the country that are built on soft soil deposits."

BASE ISOLATION PERFORMS AS PROMISED

While no buildings protected by base isolation systems (CE November, page 64) were jolted by the earthquake, two other projects in the area were put to their first real test.

A 10 span, eight lane bridge on Highway 101 between San Francisco's airport and Candlestick Park had been retrofitted with 36 lead-rubber isolators in 1985. "This reduced the seismic forces by a factor of 6, permitting elastic response of the columns," said Ron Mayes, president of Dynamic Isolations Systems, Inc. (DIS), Berkeley, Calif., which designed and supplied the isolators.

At Stanford University's underground linear accelerator in Palo Alto, Calif., DIS base isolators protect two key components, the Mark II detector and the liquid argon calorimeter, while supporting the 3.2 million lb collider unit. No damage occurred during the earthquake, Mayes told CE.

STATE OFFICIALS REPORT NO DAMAGE AT MOST DAMS

Of the 120 dams within a radius defined by 5% of gravity ground shaking, only the Austrian Dam near Los Gatos, Calif. was seriously damaged by the earthquake, reported Don Babbitt, chief of the field engineering branch, dam safety division, California Department of Water Resources. Seven others—all embankment dams like Austrian—showed surface cracking, which the dam owners promptly began to investigate for depth.

The area's reservoirs were nearly empty after three years of drought, so there was no immediate flood threat, Babbitt told CE. Nevertheless, "We were calling owners within hours. Our computer program determines the 5% radius from the epicenter and gives us the dam, the owner and a phone number for all dams affected. This time there were 120 and we've sent engineers to see all of them by now (eight days later), some for a second time. We're being cautious."

REINFORCED CONCRETE BUILDINGS STAND FIRM

"The principles we've put into the codes work very well for all materials, not just reinforced concrete masonry. Where structures were engineered for lateral load resistance, they performed well," Mark Hogan told CE after returning from an inspection trip to San Francisco and Santa Cruz, Calif.

Part of Hogan's job as director of engineering for the National Concrete Masonry Association, Herndon, Va., is to check out earthquake sites to verify seismic provisions that have been or should be added to the building codes. "In the Marina area of San Francisco, there was little lateral load resistance in the first level of those buildings that collapsed or damaged. Unreinforced masonry continues to be a very clear problem."

In Santa Cruz, Hogan found reinforced masonry buildings, and their contents, intact, "standing in contrast to the rubble around them. They're designed with shear walls and are so stiff they resist seismic energy by brute force. When I arrived, I found about 60 building officials and engineers in one that's 10 stories. There had been no damage except to a couple of pictures and mirrors, and an overturned TV. That's where the experts sought refuge."

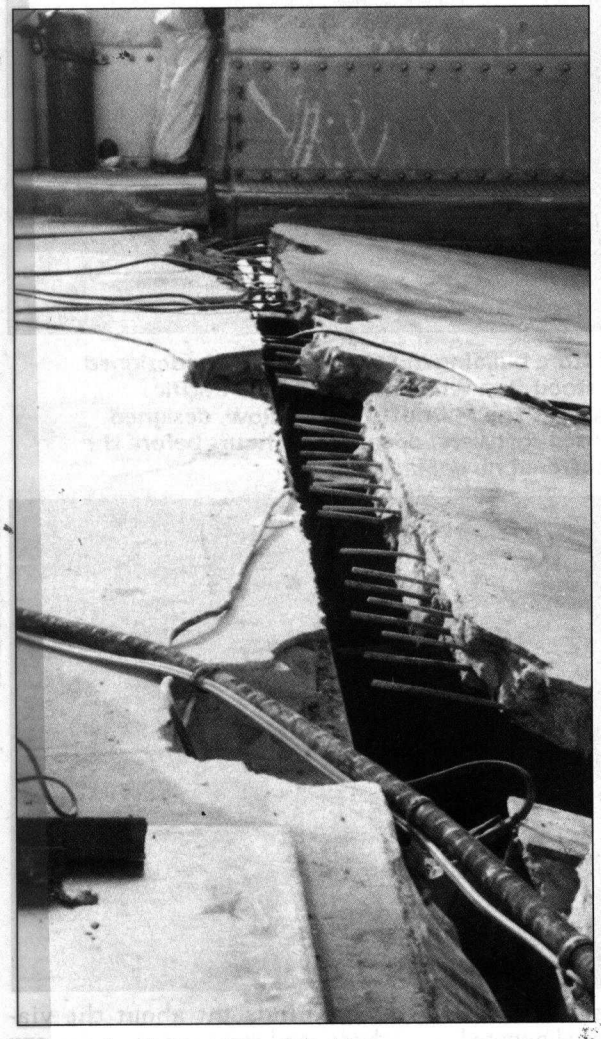
Under the codes, maximum height for a reinforced masonry shear wall building is 160 ft, which for an apartment house might be as many as 17 stories.

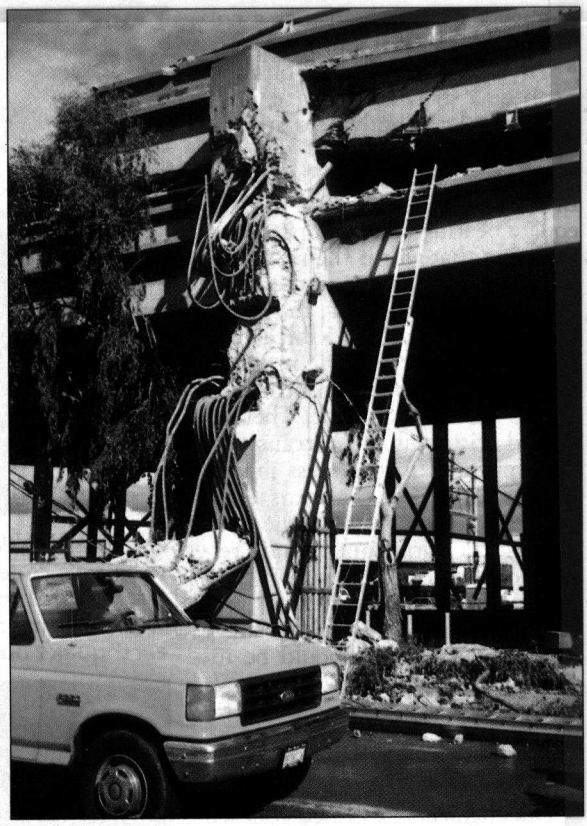
NEWEST HOTEL OPENS TO QUAKE REVIEW

The San Francisco Marriott celebrated its grand opening only hours before the earthquake struck. "The building came through in great shape. There was no structural damage. It was incredible," marveled Michael Connelly, Marriott's coordinator of engineering.

The hotel, as most other San Francisco high rises built in the last 15 years, had been designed with special seismic provisions and analyzed by computer. "The structure was designed to flex, and it did. It's based on the latest technology, and only one piece of glass in the whole place got cracked," said Ashraf Habibullah of Computers & Structures, Inc. (CSI), Berkeley. His firm developed ETABS, the stress analysis software used by Martin & Middlebrook, the San Francisco A/E firm that designed the Marriott.

Failed columns of I-880 are mute reminders that older bridges and highways need seismic upgrading. Below, the lower deck of the Bay Bridge pulled apart.





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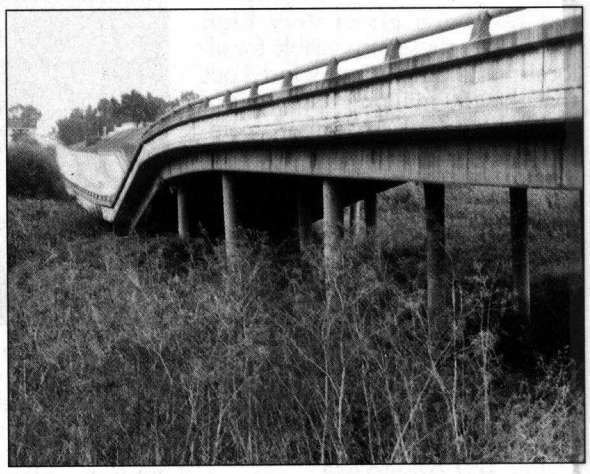
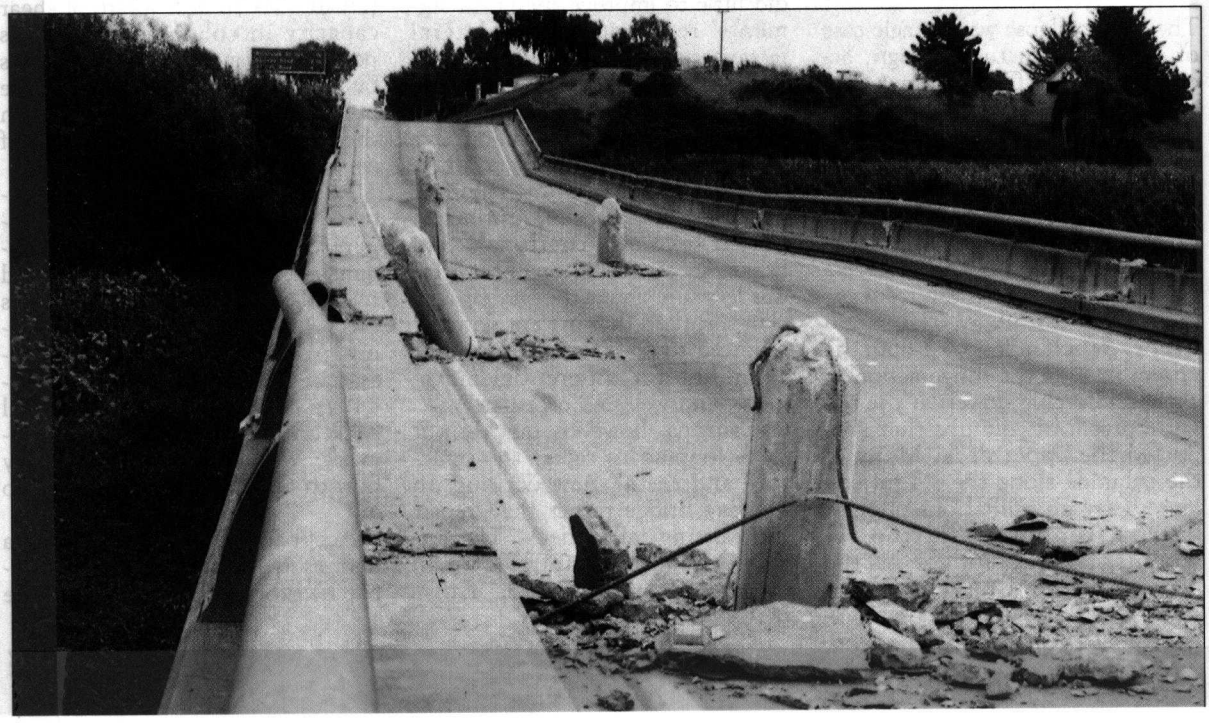
When the Struve Slough bridge near Watsonville, Calif. collapsed, columns poked right through deck slabs.