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Northridge Earthquake

On a Monday designated to honor Martin Luther King Jr., fifteen million people in Southern California awakened instead to face the largest earthquake to affect metropolitan Los Angeles in this century, and the most costly natural disaster in the history of the United States. The Northridge earthquake struck at 4:31 AM PST, 17 January 1994, with a magnitude of at least 6.6. The epicenter was near the middle of the San Fernando Valley, a roughly 8 by 20 mile section of Los Angeles with a population around 1.5 million, located approximately 21 miles northwest of downtown Los Angeles.

Review of ground motion measurements indicated accelerations well over 0.5 g within ten miles of the epicenter, with vertical motion often exceeding the horizontal, and some ground motions exceeding 1.0 g. Ground motion and damage were geographically variable. Significant damage occurred up to 40 miles from the epicenter, with minor damage up to 80 miles away.

As of 28 January, 61 casualties and over 1,000 serious injuries have been reported. The early hour of the earthquake prevented the loss of life and injuries from being many times greater. Over 2,000 residences and buildings were destroyed or condemned, 15,000 people are homeless, 4,000 are unemployed due to destruction of their business, and damage estimates range from 10 to 30 billion dollars. Electricity, gas, and water were unavailable to hundreds of thousands for many hours after the earthquake, and for tens of thousands for several days. Failure of more than 14 freeway interchanges and overpasses has significantly increased travel time for millions of commuters, a situation from which the city will strive to recover for an estimated 6-12 months.

ANCO Engineers Inc. has conducted seismic research and structural analyses for more than 20 years and is a leader in dynamic shake table testing. The severe Northridge earthquake provided a dramatic live test for many of ANCO's projects. This special issue of ANCONEWS is devoted to the earthquake and the involvement of ANCO personnel and technology.

ANCO Engineers headquarters in Culver City, 17 miles south of the epicenter, sustained only cosmetic structural damage and dumping of file cabinets and bookshelves, even though we are located only 1 mile from the main collapse of the Santa Monica Freeway (US 10) and experienced on the order of 0.3g horizontal ground motion. While coping with public and personal loss, ANCO seismic personnel are also realizing the professional opportunity of a lifetime - to be in the center of what will probably be the most significant and best studied metropolitan earthquake in history, to be in "the belly of the beast".

A Tale of Two Buildings

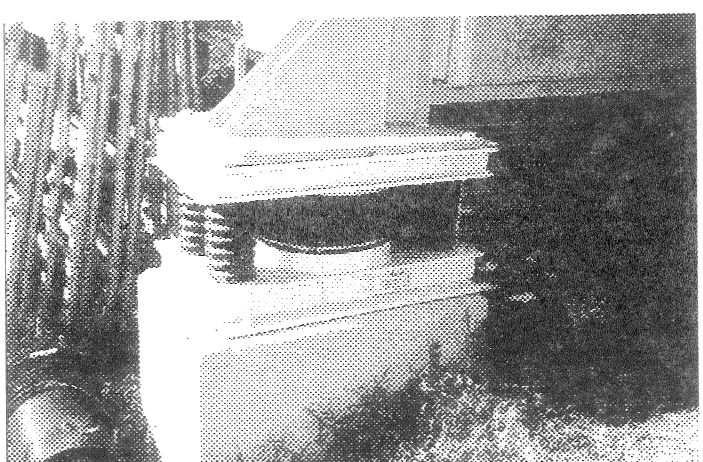

Figure 1 - GERB helical springs and visco dampers isolate a building

Figure 2 - Unusual 2nd story column failures resulted in building failure

Since 1982, ANCO has worked with GERB Gmbh of Germany, which for the past half century has employed a unique system of springs and visco-elastic dampers to base-isolate large structures and reduce piping operational and transient vibration (see ANCONEWS, 7/92 Vol 2, No. 3). Two three-story residential structures on Purdue Avenue in West Los Angeles, approximately 14 miles southwest of the Northridge earthquake epicenter, were built in 1991 and rest on an isolation system consisting of 12 GERB visco-dampers and helical spring assemblies per building (see Figure 1). This area was especially hard hit by the earthquake, and significant residential damage occurred (major plaster cracking, failed chimneys, displacement from foundations, lost block walls, failure of masonry struc-

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Two Buildings ... *Continued from page 1*

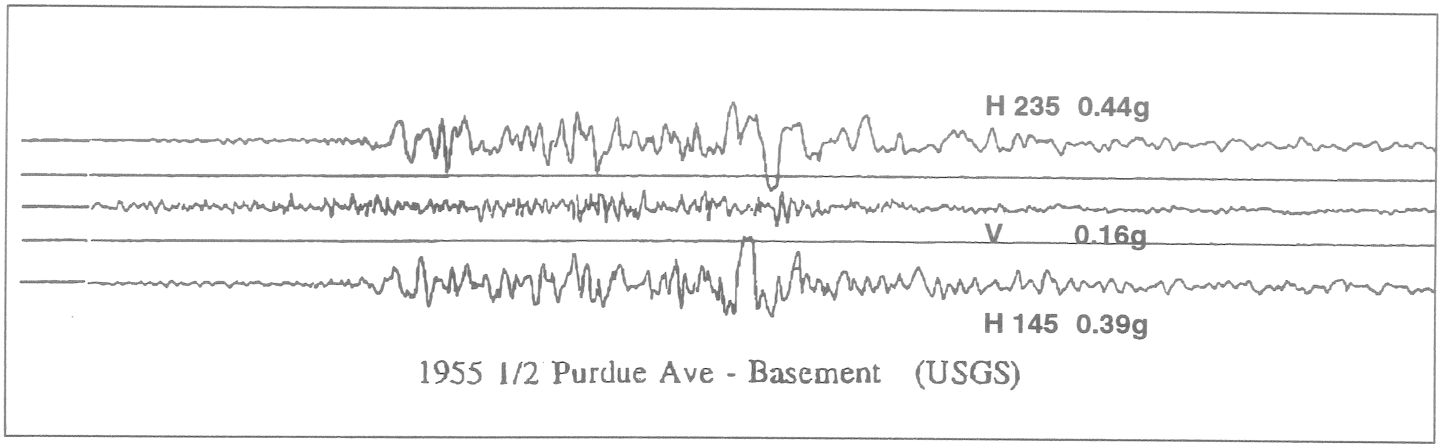


***Figure 3** - Typical Ground Motion Near the GERB Buildings (Source: USGS)*

tures, etc.). Figure 3 presents a measured ground motion near the GERB building site, which indicates ground motion on the order of 0.4 g and vertical motion of 0.15 g.

The GERB buildings sustained no damage except for the anticipated failure of a cosmetic glass block skirt that acted as a mechanical fuse for the isolation system. The isolation systems were also undamaged. Analysis of the measured response of the GERB houses is underway and will shed quantitative light on the behavior of a base-isolated structure in an actual earthquake.

In a strange juxtaposition, a modern six-story reinforced concrete office building, only a few hundred feet from the GERB houses, suffered major damage and was subsequently condemned (see Figure 2). To our knowledge, this structure, at the corner of Barrington and Olympic, is the only modern high rise structure outside of the San Fernando Valley to sustain major structural damage. Within hours after the initial earthquake, ANCO engineers spotted the nearly uniform "X" type shear failures on the building columns between the second and third and third and fourth floors. Interestingly, failure did not occur in the first floor or higher floor columns. The building is asymmetrical in plan, had additional asymmetrical shear walls, and a central concrete utility core. ANCO believes that subsequent studies of this building design will yield important insight into critical design features that lead to lower than desired seismic capacity.

This building was condemned by city engineers on the day of the earthquake. Building tenants, largely medical and psychiatric private practitioners, were not allowed to enter the structure. By the following Saturday demolition began, as the possible collapse of the structure threatened traffic on Olympic Boulevard, a major bypass route to the failed Santa Monica Freeway (US 10). The building residents were irate at not being allowed to retrieve their equipment, or at least business and medical records, bemoaning what they felt were avoidable business losses of millions of dollars. This suggests the need for better records backup and procedures and for careful evaluation of the risks and benefits of such restrictive access prior to demolition in the future.

Unexpected Realism In Nuclear Cable Tray Tests

Resolution of the US Nuclear Regulatory Commissionn A-46 issue using the SQUG GIP walkdown procedure calls for the seismic evaluation of older nuclear power plants by, in part, the comparison of plant equipment to an experience data base derived from the performance of equipment during past earthquakes and shake table testing. During such comparisons certain "caveats" and "inclusion rules" must be met. These are required to assure that the equipment being reviewed does not lie outside the data base nor contains features known to reduce seismic capacity. If such "outliers" are identified, additional special analyses or tests must be performed in order to demonstrate their seismic adequacy.

An important component of nuclear power plants are the miles of strut supported cable trays carrying power, sensing, and control signals throughout the plant. Such cable trays have been shown by both actual earthquake experience and shake table testing to be very rugged. One caveat, however, is that the nuts used to bolt the strut supports together have serrated teeth. Nuts without serrated teeth have been observed to have reduced capacity and must be evaluated separately.

Cable tray systems with unserrated nuts still have significant seismic capacity, as was recently demonstrated at ANCO in both a planned and unplanned test. As part of the A-46 walkdown, two east coast nuclear power plants were found to use unserrated nut strut systems. To establish the seismic capacity of these systems, ANCO performed quasistatic pullout and cyclic load tests on typical connections, and simulated dynamic tests on two full-sized strut and cable tray systems on the ANCO R-4 overhead seismic shake table. The simulated systems were chosen to represent the most heavily loaded and challenged configurations at the plants in question.

Just prior to the beginning of shake table testing, the Northridge earthquake unexpectedly exposed the simulated tray/strut systems to a real earthquake with ground motion estimated at 0.3 g based on preliminary USGS data. Such a motion exceeds the SSE of the east coast plants. The cable trays with the unserrated nuts were undamaged. Subsequent testing revealed that the actual fragility level of the trapeze supported system was at an earthquake with 1.0 g ZPA, and of the cantilever supported system was 2.0 g ZPA. Failure modes were pullout of the strut connection, rather than the strut lip failure common with serrated nut systems. Nevertheless, these high levels of fragility, combined with analysis based on the pullout and cyclic test capacities, are anticipated to demonstrate satisfactory capacity of the unserrated nut outlier cable trays in these two eastern plants.

Shake Table Testing Saves Museum Artworks

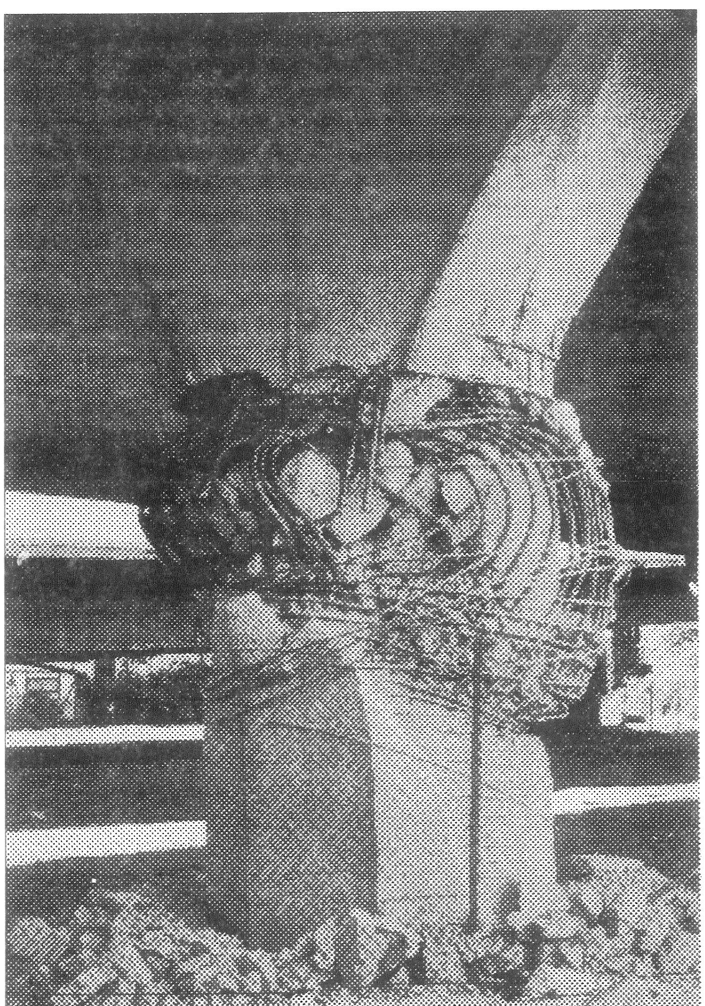
In stark contrast to the widespread destruction experienced throughout the Los Angeles basin, local museums suffered relatively little damage from the January 17 Northridge earthquake. It is no coincidence that catastrophic losses were avoided, however, because for the last decade Southern California museums have reassessed the seismic risk of virtually every object in their collections.

Conservators have worked with engineers, scientists, and technicians to seismically upgrade mounts, pedestals, hanging devices for objects on display and improved storage systems. These upgrades include dense elastomeric bumpers and heavy-duty hanging hardware (for framed wall-hung artwork), cabinets with art objects attached by tethers of mono-filament line, or micro-crystalline wax and form-fitting brackets (to secure small sculptures and ceramics). Large sculptures are securely mounted to lead-filled bases to lower their center of gravity and then placed on teflon pads to induce sliding rather than tipping over. Extremely fragile and/or valuable sculptures are mounted on base isolation pedestals.

The J. Paul Getty Museum, in Malibu, is the undisputed leader in seismic safety for museum collections. ANCO has been instrumental in assisting the Getty with shake table testing of a variety of weighted bases, cabinets, simple base isolation pedestals and the elaborate base isolator used on the sculpture "Aphrodite" (see ANCONEWS, 4/92, Vol 2, No 2). Aphrodite's isolation pedestal, which was designed by Wayne Haack, a conservation technician and mount maker, attaches the 7-1/2 ft, 1000 lb sculpture (by means of a tensioned metal cable running through the center of the statue) to a 1,000 lb isolator which is concealed in the pedestal. This isolator, which consists of a series of layered plates which roll on tracks to avoid transfer of horizontal movement to the sculpture, is estimated to absorb up to 80% of the ground movement during an earthquake. Working with Getty conservators and technicians as well as engineers from Lindvall, Richter and Associates, ANCO tested this system in our seismic laboratory on the ANCO R-5 shake table. The conclusion drawn from the testing was that the isolator could protect Aphrodite during during a nearby quake measuring 6 to 8 on the Richter scale. This conclusion was at least partially validated when Aphrodite serenely rode out the 6.6 magnitude quake without injury.

A Seismic Engineer's Personal Experience

Dr. George Howard, ANCO Chairman, Lives in Granada Hills where Ground Motion Reached 1.0g



Failed freeway column located at the Gothic Avenue overpass of the Simi Valley freeway (Hwy 118). 1/2 mile from the Howard home.

When the severe ground motion struck my Granada Hills neighborhood, about 4 miles northeast of the epicentral region, we awoke to almost explosive noise while being violently bounced on the bed and thrown against the headboard. My initial reaction was more astonishment than fright (that came later) at the severity of the short-duration, high-frequency shaking. I thought from major fault proximity (San Andreas, Newport-Inglewood) that surely the 1971 San Fernando earthquake was an upper bound for this area.

After struggling in darkness to find flashlights, we quickly surveyed our house - a shambles on the interior but only minor apparent structural damage - and then helped our immediate neighbors. Outside in the morning darkness, we heard muffled detonations which were followed almost immediately by brilliant orange flames jetting up near a major north-south street (Balboa Blvd.) about a mile away. A second large jet appeared a few minutes later adjacent to the first. News reports later confirmed that the flames, which engulfed five to six houses on both sides of Balboa, arose from ruptured subsurface natural gas lines.

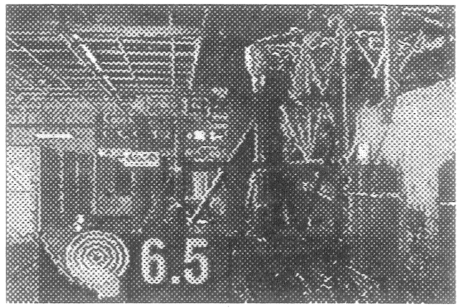
Over the next few days I inspected my neighbors' homes. The damage became progressively worse moving south on the street: differential settlements of perhaps 8 inches, roof cracking and opening at house intersections, base slab fissures with some punching through interior and exterior walls as they progressed. Five of the severely damaged homes on my street have been evacuated and are likely demolition candidates.

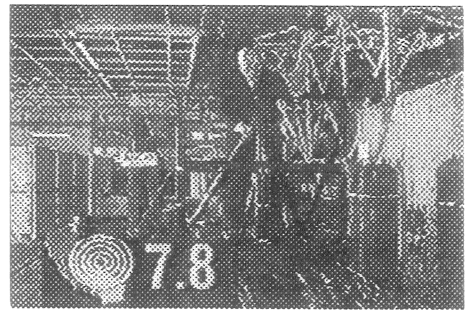
The earthquake proved to be a severe test of lifelines - electricity, telephone service, and water. Freeway sections were knocked out in our area and surface streets were difficult to use because of failed traffic signals (no electricity) and water running from ruptured mains. Many grocery stores and pharmacies were closed for days. Local hospitals were swamped with injury cases with services being provided, in at least one case, out of the hospital parking lot.

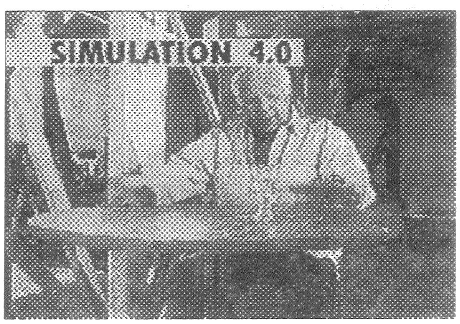
Although natural gas remained in service, electricity was off for four days and water for five. Water service was finally restored by using fire truck pumping to bridge water over broken main segments. Drinking water, flashlight batteries and food were unavailable locally or in very short supply for days. The "safe drinking water" problem was eased after several days by water trucks parked at schools and parks.

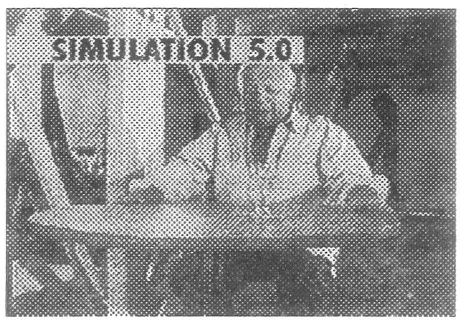
Effectively, we returned for a week to 1930 rural America, drawing water from the local "pond" (our swimming pool) for sanitation and relying on candles and kerosene for lighting.

Television Relies on ANCO Shake Table Simulations









To both educate and calm local citizens who are unnerved by the continuing aftershocks from the January 17 Northridge earthquake, Fox KTTV Channel 11 television once again relied on ANCO's shake tables to show the effects of various magnitude earthquakes. David Garcia, a Fox TV reporter, sat through simulations of the main event aftershocks in a mockup of a dining area installed on ANCO's large R-4 overhead triaxial shake table (see above). Broadcast January 24, the simulations clearly illustrated for the public that aftershocks of magnitudes 3 to 5 would not cause the major property damage or injuries that occurred during the initial 6.6 earthquake.

Back in July 1993, limited video footage was available of the 7.8 earthquake in Northern Japan, Hokkaido. Three local TV stations (KNBC, KCAL, Fox KTTV) asked ANCO to provide immediate visual evidence for local citizens of the ground motion felt during a 7.8 earthquake. David Garcia, then with KNBC, was the first local reporter to show the public the impact of various magnitude earthquakes by riding through several simulations on ANCO's R-5 triaxial shake table, including a simulated 7.8 quake, during live TV news broadcasts from ANCO's Culver City laboratory. Barbara Schroeder from Fox KTTV also included live interviews with Paul Ibanez, ANCO's President, and Steve Keowen, Associate and Laboratory Manager, following several shake table simulations. ANCO provided the simulations as a public service and local reminder of the need for earthquake preparedness.

Following the Klamath Falls, Oregon, earthquake in September 1993, ANCO also provided shake table simulations of earthquakes of similar magnitude during early television news broadcasts. Phil Shuman, a reporter from KNBC television, and David F. Jackson and Frank Buckley from KCAL participated in simulations run on ANCO's R-5 triaxial shake table during live TV broadcasts from ANCO.

ANCO Tests Damaged Switchyard Equipment

As in the magnitude 6.4 1971 San Fernando earthquake with epicenter about 6 miles to the northeast, the 1994 Northridge earthquake caused damage to electric substation switchyard equipment in the epicentral region, including the Sylmar Converter Station. Fortunately, even though the ground motion was greater and the inventory of equipment larger in 1994 than in 1971, the damage was less, showing that lessons were learned from earlier earthquakes. As in 1971 (when ANCO was only six months old) we are working with engineers from Southern California Edison and the Los Angeles Department of Water and Power to inspect the damage and shed light on the dynamics of switchyard equipment that leads to failure or survival in an earthquake. Using in-situ testing, beginning 9 days after the earthquake, ANCO measured the dynamic properties of undamaged equipment so as to better understand the failures that occurred in identical damaged equipment in the same or nearby switchyard. The unusual problems of structural design with porcelain post insulators, and the low damping found in switchyard equipment, often leads to less than seismically rugged designs. Such damage surveys may emphasize the need for new post insulator designs and materials, such as the Polysil epoxy systems developed by the Electric Power Research Institute (and tested, in part, by ANCO). After 23 years, quick and cost-effective field testing of structures still offers design and analysis insights unobtainable by other means.

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