LOMA PRIETA EARTHQUAKE

Bay area laboratories do well

San Francisco

RESEARCH facilities at universities and national laboratories in the San Francisco Bay area fared well in the earthquake of Tuesday 17 October and subsequent aftershocks, in many cases because buildings were new or had been reinforced after previous upheavals.

The University of California at Santa Cruz, just a few miles from the earthquake's epicentre, was one of the institutions hardest hit. But because it rests on a hill above the town, the university suffered less than Santa Cruz itself, which is largely built on loose soil in the flood plain below. Residence halls were evacuated for only a few hours, and most facilities were soon functioning normally.

But the four major science facilities, including the new Sinsheimer Laboratories building scheduled for dedication later this month, suffered considerable interior damage, including chemical spills and broken laboratory equipment. By Friday, three had been declared safe, both structurally and with regard to hazardous materials, but Natural Sciences II, which houses astronomy, physics and some chemistry and biology, was still being evaluated.

Although it escaped structural damage, the Stanford Linear Collider (SLC) suffered some minor power failures, leaks in some fluid lines, and a break in a vacuum chamber. Fortunately, SLC was in the middle of a shutdown and no beam time was lost. Had the collider been running, said spokesman Michael Riordan, "the beam would have hit the wall somewhere and everything would have shut down because of the control system".

The biggest concern is that some of the 1,000 beam-guiding magnets have probably been thrown out of alignment. Next week, surveying crews will check the magnets; if too many are misaligned, the whole machine will have to be reconfigured. A preliminary laser-beam measurement has indicated that some segments of the accelerator may have shifted, although only by 100 micrometres, which is at the limit of detectability. Whether or not this is due to the earthquake is not yet known.

Stanford University itself was probably the hardest hit university in the area, and estimates damage at $160 million. Twenty-five out of 240 major buildings have been shut, 12 of which are residence halls. Memorial Church, in the centre of campus, will be closed indefinitely. The keystone, the critical block in the archway near the altar, has moved by more than half an inch, and the church will probably need large-scale structural repairs.

Several other buildings were damaged to varying degrees, but Stanford had reason to be grateful for a 1988 report, *Earthquake Risk Management Report*, which paved the way for a series of structural modifications. Two older buildings, Roble Hall and the Old Pavilion, were furnished with seismic bracing just a few weeks before the earthquake.

Science facilities fared better. There was broken glass, overturned bookcases and damage to light fixtures, and some experiments were set back for a few days. But for the most part, no major equipment was destroyed. The one exception was the Keck building, the first completed facility in the new Near West campus science complex. The building itself held up well, but as much as $30,000 worth of equipment may have been lost.

At the University of California at Berkeley, there was minimal structural damage. A few cracks appeared in various buildings, but no scientific facilities, including the seismographic station, were disrupted. At classes were officially closed.

Above the campus, the Lawrence Berkeley Laboratory (LBL) suffered no structural damage, LBL's automatic system shut down gas valves, and a few buildings had trouble starting services up again. But otherwise, no problems were reported. All three accelerators are operating.

Lawrence Livermore National Laboratory also withstood the earthquake well. After two buildings were destroyed in 1980 by an earthquake of magnitude 5.9 with the epicentre just a few miles from the laboratory, $25 million has been spent in seismic upgrades. This included reinforcing buildings and putting doors on cabinets containing chemicals. The most serious damage was a flood in Building 41, a laser facility, as a result of broken water pipes.

Finally, the University of California at San Francisco reported no big upsets — a few chemical spills, some cracked walls, but no significant structural damage.

Robert Buderi

The physics of destruction

San Francisco

THE fact that some areas suffered considerable damage while others escaped almost unscathed is no cause for surprise. According to Robert Page, a geophysicist with the US Geological Survey in Menlo Park, one of the major factors was "liquefaction", which occurs in sandy material that is saturated with water. The earthquake's vibration transforms such material into a slurry: because the sand particles are all about the same size, they lose contact with each other, water flows between them, and mobile near-liquid is formed. This is what happened in San Francisco's most devastated area, the Marina district, which is built largely on land-fill. The hilly areas rest on bedrock, which is much less susceptible to disruption.

In Santa Cruz, the buildings hit hardest were those of unreinforced masonry situated on the flatland in the centre of town, which lies on a flood plain. Page said a similar story probably unfolded there, exacerbated by the fact that in an earthquake ground tends to move horizontally towards rivers.

A second factor contributing to the wide variation of damage is building resonance. If a building's own natural frequency of vibration closely matches that of the driving force applied by the seismic waves, the resonance amplifies the motion, making the structure more likely to tumble. Close to the epicentre, where shock waves are of higher frequency, resonance is more likely to strike low-lying structures, explaining why, in areas such as Santa Cruz, many houses in the flatlands were knocked off their foundations. Further away, as in San Francisco, the seismic waves are of lower frequency, and resonate with taller buildings, but in the city such structures are built to cope with earthquakes of this magnitude. They also have deep foundations that extend past the loose topsoil and into hard ground below.

Edward Wilson, a professor of civil engineering at the University of California in Berkeley who specializes in the response of buildings to earthquakes, observed that although resonance and liquefaction are important, "clearly, if you look around, the site is the most critical element". Hard sites, such as the hills of San Francisco, afford little amplification of a seismic wave; softer soil, even if liquefaction does not take place, will amplify the waves.

This probably holds true even for the Cypress section of Interstate 880 in Oakland, where a still undetermined number of people died. An upper section of the double-decker freeway collapsed onto the lower deck, because supporting columns gave way. The freeway was built in the 1950s, and the structure had been only partially strengthened since then: the cross-links that keep each deck together had been stiffened, but the vertical columns between decks had not.

Nevertheless, Wilson said, it was likely that loose underlying soil might be the crucial factor in the freeway collapse: "We had many freeway overpasses of similar design, and not all of them failed".

Robert Buderi