12-0661 (2)

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June 21, 2012

CF12-0661
ITEM 2, Public Safety 6/22/12
J. White

STATEMENT of J.H. McQUISTON on MOBILE APP WARNING for SEISMIC EVENTS

Honorable Chairman and Members of the Committee:

1. Although "close" seismic activity will not give persons time to "take cover" from disaster **even if they are notified at the instant of the first movement,** apps could provide warning in time to reach safety from remote seisms **which will cause disaster in Los Angeles.**

And, apps could direct people and responses **after disaster strikes.**

To illustrate **what we expect to happen in Los Angeles from a remote seism,** I will show a CD with a substantial and un-nerving demonstration of the **response of an actual 18-story building, built to Los Angees Code. It is calculated to fold in half from the** *predicted* **seism which** *will occur* **near Parkfield, California (186 miles away).**

The 1984 building demonstrated is located on Canoga Avenue in Woodland Hills. Locals know which building is depicted. Please **be shocked.**

The presentation shows that an app will be useful both for warning and for rescue, **but for rescue only if the "base station" is built to survive and be operational after the seism concludes.**

2. The United States has collected some of the data on "active" faults in the Los Angeles area, but much of the data is held by corporations and not divulged.

However, the DEIR for the Red Line shows a partial map of the most dangerous "known-active" fault in Los Angeles, called the **215-km-long** Raymond-Hollywood-Santa Monica-Malibu Coast-Santa Cruz Island- Santa Rosa Island (RHSMSS) fault system. **The Southern California Earthquake Center said,** "Rupture of the entire RHSMSS fault system conceivably could result in an earthquake **as large as Mw 7.6 to 7.7.** In addition, we speculate that the Hollywood fault may rupture together with the Santa Monica Mountains blind thrust fault and shallower blind thrust faults to the south."

This Fault System traces through Atwater, Los Feliz, Hollywood, Wilshire, Beverly Hills, Westwood Village and Santa Monica before exiting the coast at Malibu.

When (not if) this fault system "lets-go", **most of Los Angeles will be in need of the app because ordinary communication will be out-of-service.**

3. Besides the demonstration, enclosed are two technical articles **which are pertinent for public-safety consideration.**

Respectfully submitted,

[signature]

encl: 1995 SCEC; 1985, 1994, 2008 *E&S* excerpts

J. H. McQuiston, P.E. (Calif & FEMA cert)

Excerpts from Caltech's *Engineering & Science*, Volume LXXI No 4, 2008

More than 1,100 kilometers tong, the San Andreas fault separates the Pacific and North American tectonic plates. The fault marches straight down this photo of the Carrizo Plain National Monument, which is about 150 kilometers north of Los Angeles. Because the plain is an arid environment, there isn't much erosion, and the fault scarp remains visible.

On November 13, 2008, at 10 am., the San Andreas fault jolted Bombay Beach, a small town on the shores of the Salton Sea, 100 kilometers southeast of Palm Springs. In a split second, the two sides of the fault slid 13 meters. Like a zipper unzipping, the rupture shot 300 kilometers northwestward along the fault at more than three kilometers per second, sending seismic ripples across Southern California. The 7.8-magnitude earthquake rocked the Los Angeles metropolitan area, shaking the basin for nearly a minute. Buildings collapsed and dozens of city blocks went up in flames. With water lines broken, there wasn't enough water to fight the conflagration. 1,800 people died and 50,000 were injured. The quake caused **more than $200 billion in damage.**

Strong aftershocks-some bigger than the last big quake in the region, the 6.7-magnitude Northridge quake in 1994 that killed 57 people-struck often and hard. The catastrophe would **affect businesses and lives for years to come**.

Fortunately, of course, this **never really happened**. The scenario described above was the plot line of the Great Southern California ShakeOut, the biggest and most comprehensive earthquake drill ever. The ShakeOut scenario was a strong quake, but neither a worst-case scenario nor an improbable one. In fact, there's a **99 percent chance** an earth-quake of 6.7 magnitude **or greater** will hit California in the **next 30 years**, according to a recent report by the United States Geological Survey.

As some seismologists like to say, "Earthquakes don't kill people. **Buildings kill people**". Because Southern California was sparsely populated in 1857 and tall buildings were still a century away, the Fort Tejon quake claimed only two lives. But today, hundreds of buildings tens of stories high scatter the region, and the ability of these structures to hold up to earthquakes will be **the difference between life and death.**

Assistant Professor of Civil Engineering and Geophysics Swaminathan Krishnan (PhD `03) shakes buildings on a computer to see whether they will survive. For his PhD thesis, he wrote software that models how every ele-ment of a building would respond to jostling. A couple of years ago, he started collaborating with Jeroen Tromp of Princeton, who was then Caltech's McMillan Professor of Geophysics and director of the Seismological Laboratory. Tromp's area of expertise was simulating earthquakes with computers, perfectly meshing with Krishnan's work.

Together, they created the **first "end-to-end" simulations**, modeling a complete scenario from the "bottom end" of a seismic rupture and regionwide earthquake, to the "top end" of an individual shaking building. According to Tromp, their collaboration marked the **first time seismologists had joined forces with civil engineers** to analyze how struc-tures resist-or succumb to-earthquakes.

BROKEN BUILDINGS

The 1994 Northridge earthquake caused more than $40 billion in damage and **revealed the weaknesses** of so-called steel moment-frame buildings. Moment frames consist of a grid of beams and columns welded together, and are de-signed to resist the horizontal motion caused by rocking ground. **Engineers thought** the connection that joined the beams and columns were ductile, stretchy enough to resist being pulled apart. But Northridge showed that this **wasn't the case. Cracks were found along the welds, which were more brittle** than engineers thought. Also, the **welding process itself inadvertently created points susceptible to stress, making the problem worse**. Furthermore, many of the damaged buildings were built before 1976, when less was known about structural resistance to earthquakes. The lessons learned from Northridge led to updated building codes in 1997. But Los Angeles hasn't had a big quake since then-so **are the new specifications adequate**?

To find out, Krishnan's team modeled a building that was damaged in the Northridge quake-an 18-story steel struc-ture built in 1984 on Canoga Avenue in the Woodland Hills district of the San Fernando Valley. This building has been the subject of numerous studies and is relatively well understood. The researchers placed 636 identical copies of that building about 3.5 kilometers apart on a grid covering the Los Angeles metropolitan area from Huntington Beach to Simi Valley. They then shook each building with the specific seismic waves that the earthquake simulations dictat-ed for that particular location, and calculated how every beam, column, and joint of the building would move.

The researchers made two grids-one with the existing buildings designed according to 1982 codes, and one with a redesigned buildings with the updated codes.

In the simulations, the highest IDR values in buildings were **way above FEMA's collapse prevention level** of 0.05; they were more than 0.1-in the San Fernando Valley, Santa Monica, and the areas surrounding Baldwin Park, West Los Angeles, Norwalk, and Seal Beach. **Tall buildings in these areas would most likely become rubble.** In **down-**
town Los Angeles and Beverly Hills, the IDR values hit 0.05. Furthermore, the earthquake caused the most damage to the lower and middle thirds of the buildings, **increasing the risk of the structures pancaking on themselves.**

("Medium-Sized Earthquakes" excerpts germane to issue, by permission, Caltech)

The Northridge earthquake, moment magnitude 6.7, occurred on Monday, January 17, at 4:30 am. We were lucky; if the earthquake had occurred in the daytime, many more than 60 people would certainly have died. Seven large parking structures belonging to malls, hospitals, and a university collapsed, some almost completely, and many public buildings, from schools to shopping malls, suffered heavy damage, as did several freeways.

Shortly after the earthquake, the press pointed out that **all the recent earthquakes** had been in the **early morning hours**. Why was that? So we went back to our earthquake catalog and looked at the last 50 years, and the **press had indeed identified a pattern**. But big earthquakes may happen at any time, so everybody has to be earthquake-prepared day and night.

The Northridge main shock was beneath the floor of the San Fernando Valley, as shown in the map above. The main shock was about 19 kilometers deep, and the aftershocks that scattered up from there to a depth of eight kilometers or so defined the fault plane that broke during the earthquake. The aftershocks that continue straight up to the surface from there are probably related to the deformation of the near-surface material in response to the main shock; as the rock deep underground is thrust upward, the shallower layers on top of it had to move to accommodate it.

Because the Northridge earthquake's fault lies directly beneath the **densely populated** San Fernando Valley, there was **tremendous damage**. By mid-February the city's Department of Building and Safety had inspected some 65,000 residential buildings in the valley and elsewhere and had declared 1,608 of them unsafe to enter, including many large apartment complexes. Another 7,374 were safe for entry only for short periods to retrieve personal possessions. (An estimated 20,000 people camped outdoors for the first few days after the earthquake, either because their homes were uninhabitable or for fear of aftershocks; some 9,000 remained in Red Cross shelters and tent cities 10 days later.) **Transportation links were severed.** Collapsed bridges shut down portions of Interstates 5 and 10 and State Routes 14 and 118, and a **freight train derailed** in Northridge, blocking the tracks. Several major high-voltage substations within a few miles of the epicenter were knocked out, and some **two million customers in the Los Angeles area lost power** for the better part of the day; 900,000 of them had their lights back by dusk, but service to some places was not restored for more than a week. Shattered ceramic insulators in Sylmar led to a **three-hour blackout for 150,000 customers in rural Idaho**, as well as isolated outages in seven western states and British Columbia.

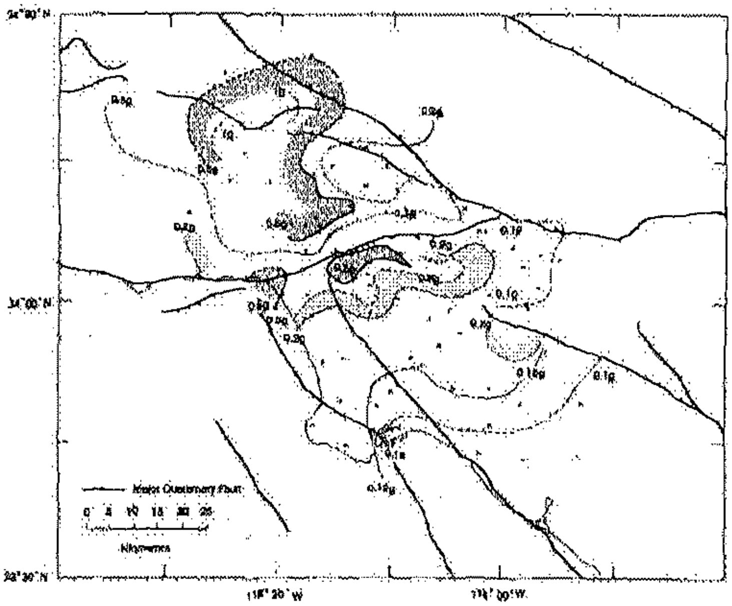
By contrast, the 1971 San Fernando earthquake, which was of equal magnitude and occurred right next door, was beneath the San Gabriel Mountains. Despite their resemblance in size and place, the San Fernando and Northridge earthquakes were **very dissimilar animals**. Most of the former's strong ground shaking was in the sparsely populated mountains, so the damage was much less severe. Their rupture planes abutted, but didn't cut across each other. A cross section through their faults reveals the key difference. The San Fernando earthquake started at a depth of 12-15 kilometers and **ruptured all the way up to the surface**. In contrast, the Northridge earthquake started at a depth of about 19 kilometers and **ruptured up to a depth of 8 kilometers**. These are two basically different types of faults: the San Fernando earthquake was caused by movement on a surficial, or surface-breaking, fault, and the Northridge earthquake was caused by movement on a blind, or buried, fault.

Both earthquakes were on reverse faults- a type of fault in which one side of the fault thrusts itself up and over the other. The San Andreas fault is a different type, called strike-slip, in which the two sides of the fault slip sideways with little or no vertical motion.

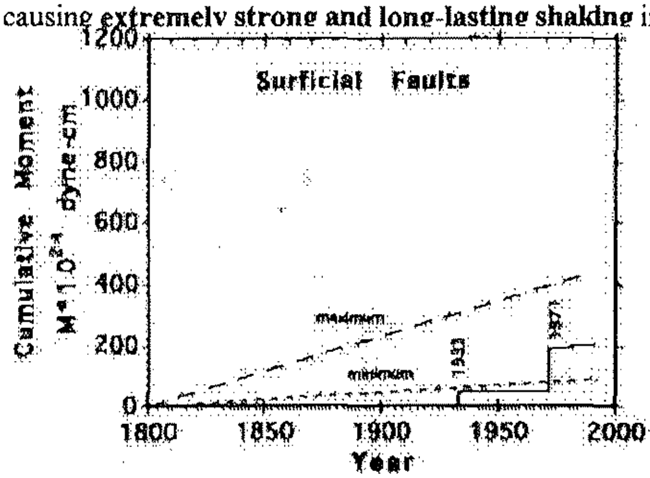
That's the first of three important lessons from the Northridge earthquake: that these **blind faults**, whose **existence was first revealed by the Whittier Narrows earthquake in 1987**, lie beneath much of the greater L.A.

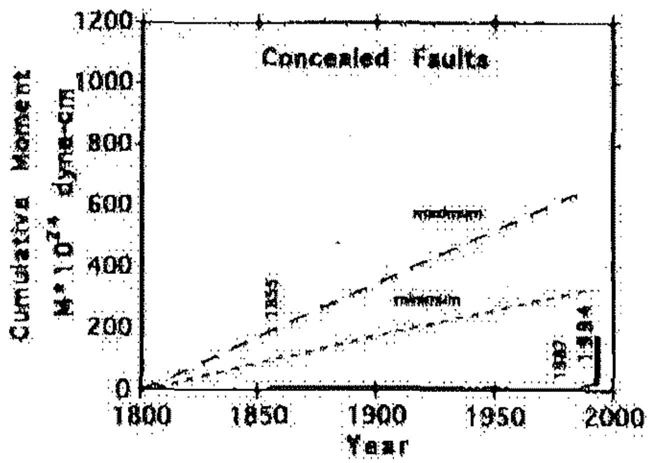
area. This earthquake **confirmed that these faults are widespread and thus extremely dangerous**. The 1971 San Fernando earthquake left a surface rupture: a fault scarp. Nothing like this followed the Northridge earthquake, because the rupture zone did nor make it up to the surface. Nonetheless, the Northridge earthquake did cause ground deformation in the epicentral region, in Mission Hills, and in Potrero Canyon. This deformation was subtle: in many cases-a slight bump in a sidewalk, an inch or two offset in a curb, but sufficient to **crack foundations and break water and natural- gas mains.**

About **95 percent of earthquake damage is caused by ground shaking**, not deformation. If the ground is shaking with an acceleration that is 10 percent of the force of gravity, you'll feel it but there won't be much damage. [Los Angeles Building Code requires only withstanding] horizontal shaking at **40 percent** of gravity. During the Northridge earthquake, the San Fernando Valley, Granada Hills, Mission Hills, and Woodland Hills all experienced **horizontal ground shaking 50 percent or more of gravity**, as did areas in Santa Monica and **Holly wood**. This is **very severe shaking**, and explains why there was so much damage. The strongest shaking generally gets focused in the direction along which the fault plane breaks. This fault plane **aimed north and to the surface** directly at the I-5/SR-14 interchange. **[Away from Hollywood. The prediction for Hollywood is for a seism of 100 percent of gravity.]]**

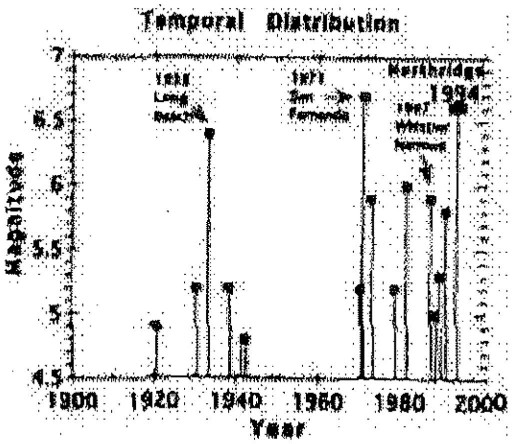


That's the second lesson from the Northridge earthquake: the **ground shaking was severe over a wide area around the epicenter. But Santa Monica and Hollywood were hard hit, too, and they're far from the epicenter and to the south-in the opposite direction.** What happened there? Part of the answer is that the ground is very soft in parts of Hollywood. In areas where the soil is water-saturated, **ground shaking is amplified and structures are more likely to he damaged**. Santa Monica may have fallen victim to an edge effect. The city sits on a sediment-filled basin whose edge is the Hollywood Hills. The earthquakes waves traveled through the hard rock of the hills into the sediment, where they reverberated off the basins rock walls and floor like a shout in an empty room. The rebounding waves canceled one another in some locations but reinforced one another in other places, causing **extremely strong and long-lasting shaking** in



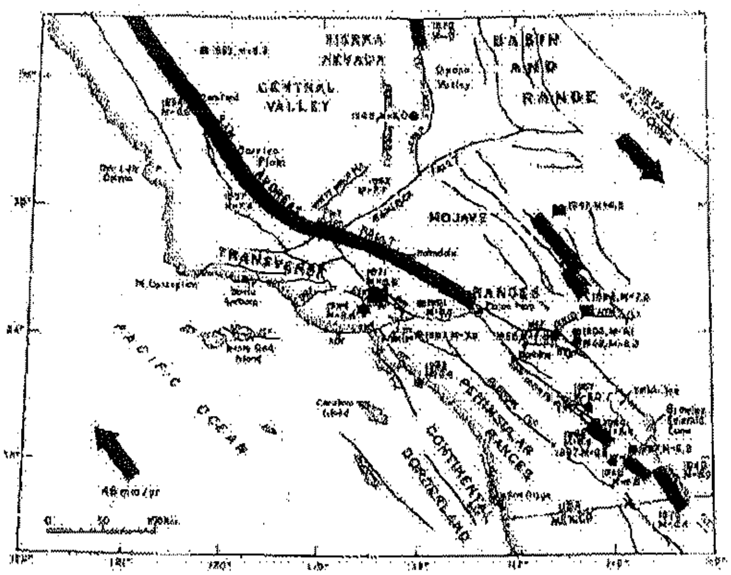


the latter spots.



Making a building earthquake-proof is **prohibitively expensive and perhaps impossible** in most cases. In addition to ground deformation and shaking, the earthquake caused **uplift. The maximum was about a foot and a half**, found at the northern end of the San Fernando Valley and In the Santa Susana Mountains where the fault plane approached the surface. That region contains **ample evidence of uplift from previous earthquakes**

The diagonal lines show the calculated minimum and maximum amounts of strain energy stored in L.A.'s faults over the years; the vertical lines show how much of that energy has been released in our various earthquakes. In the past 60 years, the L.A. area has had three sizable earthquakes and a number of moderate ones, but they haven't been evenly distributed over time or space. If we plot earthquake magnitudes since 1900 as a function of time, we find two clusters of activity. The first one, from 1920 to 1942, included the Long Beach earthquake. The second one runs from 1970 to the present. Most of the earthquakes in the first cluster were south of downtown Los Angeles. Nearly all of the second cluster have been along the northern edge of the Los Angeles Basin, along the front of the San Gabriel Mountains.



This is the third lesson from the Northridge earthquake: it drove home the point that we're in a period of increased seismicity.

There's another reason for surmising that we're in for more earthquakes; we have quite a bit of fault area that still has to move.

Quake magnitudes vs year of occurrence.

We can divide these faults into two basic types: surficial faults like the Newport-Inglewood fault, which caused the Long Beach earthquake, and buried faults like the Whittier Narrows thrust ramp (not shown on the map), and the Santa Monica thrust ramp. We can sum up the energy stored on these two groups of faults since 1800, but our knowledge of the accumulation rates isn't perfect. Still, we can get a maximum and minimum value for each fault class.

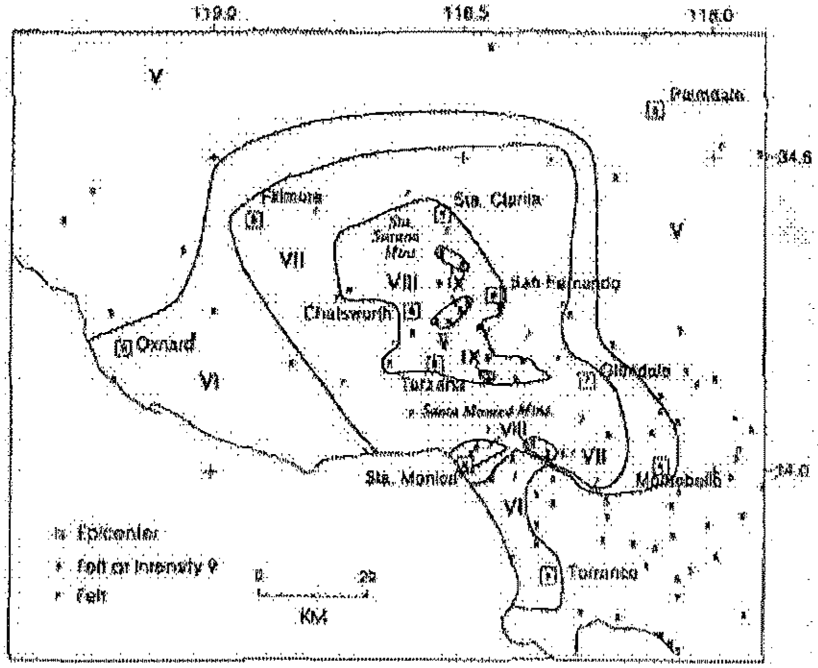
We've had two surficial-fault quakes, Long Beach and San Fernando, and we're about in balance; the energy released in those two events is about half way between our calculated minimum and maximum.

Measuring slip rates on the buried faults is much trickier, because we can't see them directly, but geologists examined data from the L.A. basin and found deeply-buried sediments known to have been deposited at sea level. Dating these sediments and noting their current elevations gives us a rough idea of how fast they're being moved. (However, **there are buried faults lurking out there that haven't made themselves known yet**.) The buried faults are accumulating energy at about **twice the rate of the surficial faults**, but we've only had one sizable `blind" earthquake-Northridge. In other words, **energy is accumulating on these buried faults faster than it's being released**.

That's why seismologists posit an earthquake deficit; we're **missing five or six Northridge-sized earthquakes, or one magnitude 7.2 or 7.3 earthquake**.

Another way to look at earthquake damage is with the modified Mercalli intensity scale, which was invented in

1902, back before we had a lot of seismological instruments. It was modified in 1931, to take into account such innovations as skyscrapers, motor cars, and underground pipelines. This scale describes the strength of the shaking observed at any given location, and goes from **I up to XII**.



In Northridge, the maximum Mercalli rating was IX; **apartment buildings lose stories**, unreinforced masonry buildings are severely damaged, and trains are knocked off their tracks. Where the Mercalli intensity was VIII, everything was thrown off shelves, chimneys toppled, and there was significant damage. At VII, there was strong shaking, but not all that much damage.

If we do a calculation for a 7.0 on the San Andreas [or in Hollywood], we see a **much larger area of intensity** VIII or **greater**. In an earthquake of this type, you would feel the shaking for a long time. **[On the fault line, there would be devastation at least intensity XI** (Damage approaches total).]

Egill Hauksson, senior research associate in geophysics, earned his MS in geophysics from the University of Trondheim in Norway in 1974, and his MA, M. Phil, and Ph.D. from Columbia University in 1978, 1980, and 1981, respectively. He joined the Caltech faculty as a research fellow in 1989. becoming a senior research associate in 1992. His wife, Lucile Jones, is a seismologist at the USGS's Pasadena office. Jones is also a visiting associate in geophysics at Caltech.

"[ ]" Added by editor.

The Modified Mercalli Scale

I - Not felt.

II - Felt by persons at rest or on upper floors.

III - Felt indoors. Flanging objects swing. Vibration feels like a passing light truck. Duration may be estimated. May not be recognized as an earthquake.

IV - Vibration as of passing heavy trucks, ot a heavy object striking the wall. Standing motor cars rock. Windows, dishes, doors rattle. Glasses clink. Crockery clashes. Wooden walls and frames creak, especially in the upper range of IV.

V - Felt outdoors. Direction may be estimated. Sleepers wakened, Small, unstable objects displaced or upset. Doors, shutters swing closed or open. Pictures knock against wall and tilt. Pendulum clocks stop, start, or change rate.

VI - Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Many dishes and glasses and a few windows break; knicknacks, books fall off shelves. Pictures fall off walls. Light furniture often overturns; heavy furniture and appliances move. Weak plaster and masonry cracks. Small church bells ring. Trees, bushes sway visibly and rustle audibly.

VII - Difficult to stand. Noticed by drivers of motor cars. Furniture broken. Unreinforced masonry cracks. Weak chimneys snap off at roof line. Waves in ponds, swimming pools. Plaster, loose bricks, tiles, cornices fall. Large bells ring.

VIII - Steering of motor cars affected. Partial collapse of well-built but unre inforced masonry; masonry properly reinforced against lateral forces endures. Stucco walls fall. Chimneys, monuments, towers, elevated tanks twist and fall. Frame houses move off foundations if not bolted down, panel walls thrown out. Branches broken from trees. Cracks appear in wet ground and on steep slopes.

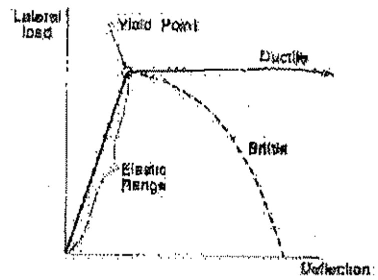
IX - **General panic**. All masonry, except that especially designed and reinforced to withstand lateral forces, destroyed or seriously damaged. General damage to foundations. **Bolted-down frame houses thrown out of plumb**. Serious **damage** to reservoirs. Underground pipes may break. Conspicuous cracks in ground. Sand blows and craters in alluvial areas.

X - Most masonry and **frame structures and their foundations destroyed.** Large landslides. Serious **damage to dams,** dikes, embankments. Sand arid mud shifted horizontally on beaches and flat land. Railroad rails bent slightly.

XI - Rails bent greatly. All buried pipes broken. Widespread ground disturbances of all sorts, including fissures, slumps, and slides.

XII - Damage nearly total. Large rock masses displaced. Rivers change course. Lines of sight and level distorted.

Germane Excerpts from "Risky Buildings", by Permission from Caltech



In a steel-frame building, the frame supports nor only the weight of the building-a vertical load-but also withstands lateral loads from winds and earthquakes. These lateral loads cause the frame members to bend, and the engineering term for the action that causes bending is "moment". Hence these frames are called moment frames, or moment-resisting frames. The frame consists of vertical columns and horizontal beams, and in order to transfer the bending moments between these members, we need to have very strong connections-usually made with welds.

If you apply a lateral force to a building, it will displace sideways in response. Engineers plot this behavior in a load-deflection curve, such as the one here. In the curve's elastic range, from zero load up to the elastic limit, or yield point, you can apply a load on and off and the building always springs back to its original position; it behaves elastically. At loads above the yield point, the building no longer behaves elastically. The post-elastic behavior can be ductile, which means that the members deform, they stretch like chewing gum, but maintain the strength of the building. Or, the behavior can be brittle; as the deflection increases, there's a loss of strength as something snaps. Whenever possible, it's best to design structures to have enough strength to carry their loads in the elastic range to avoid the damage associated with yielding. (For example, airplanes are designed to behave elastically while airborne.)

Wind is one lateral load to be considered when designing a building. The wind exerts a sideways pressure on the building, and engineers understand this force pretty well. They treat wind as a constant pressure, and even though the pressure is significant, it's possible and economical to design the building to withstand it in the elastic range. This is fortunate, because if a windstorm came up strong enough to make the building yield, the steady pressure would actually push it over.

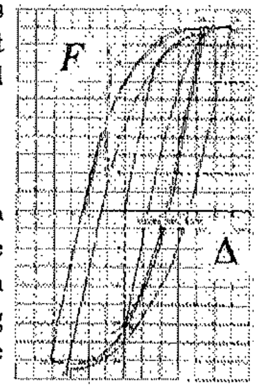
An earthquake, like the wind, causes a building to deflect sideways. But unlike the wind, an earthquake is a back-and-forth action. It reminded the ancient Japanese of how a landed fish wiggles, so in their legends, a giant catfish causes earthquakes. This giant catfish can make the ground move pretty violently, and so earthquake loads are larger than wind loads; in fact, **it's not economically possible to design a building to respond elastically to a strong earthquake. That means the building is going to yield.** How can we be sure that the building won't **collapse when it yields in a strong earthquake**?

Back in the 1960s and 1 970s, engineers invented computerized methods to calculate the responses of buildings to earthquakes. These mathematical models were pretty simple, and assumed that the buildings would behave in a ductile manner. The engineers used the ground-motion records that were available at the time, and were thought to be representative of strong ground shaking, for the inputs. This led to two conclusions.

For one, if the building has to yield, it's much better to have the yielding occur in the beams than in the columns. So the engineers started making the columns stronger than the beams. The yielding then showed up as kinks, like in a wire that's been bent too hard, at the ends of the beams where the bending moments are highest. This was good, because the columns held and the building stayed up. The computer programs could also predict the amount of yielding in the structure. I'll quantify that for our purposes by something called "story drift," which is the sideways movement in a story divided by its height from ceiling to ceiling.

This led to the second finding: the engineers calculated that a reasonable story drift for the earthquakes they were using was about 1.5 per- cent, or a lateral deflection of two inches per 10- foot story. (A building begins to yield at about 0.4 percent, so most of this story drift actually occurs in the yield range.) So they then had to determine whether the actual materials used in a building, the steel beams and columns, could take this kind of drift without losing strength after yielding. In other words, did the members have sufficient ductility?

The only way to determine something like that is in the laboratory, and the easiest method is to build a small piece of the building and apply forces to it to reproduce what it would feel if it were a part of the building during a strong earthquake. Then we measure the story deflection, and the story drift is determined by dividing that number by the story height.



Left is an actual force-deflection curve from such a setup, taken from a report written back in the early I 970s. The curve's bending toward the horizontal is due to the yielding. You can see that the assemblage yields in first one direction, then the other, but you don't see much degradation in strength as the cycles continue. That's very good, ductility, the strength is being maintained as the material yields. If we convert the deflect ions from this test into story drifts, we get about 4 percent, which is greater than the needed 1 .5 percent. Things looked pretty good; the engineers considered their designs to be validated, and the building code was written accordingly. It's important to note that the code is essentially a life-safety document, whose **goal is to preserve lives by avoiding building collapses. The code is not intended to prevent damage to buildings.**

Now, in the Northridge earthquake, the **engineers got a terrible shock of their own**: the welded connections in **many steel buildings fractured**. The fact that the welds failed means that these buildings are not as ductile as we thought-they're more on the brittle side. (Remember that ductility is the foundation of our design philosophy.) Furthermore, **many welds failed well within their elastic range**. Because they never reached yield, the **designed strength of those members was never achieved.**

One optimistic point of view says that since the code is a life-safety document, and since Northridge was a pretty good shake and none of the steel buildings fell down, the code was a success. This view is actually still held by some engineers, **but you can make a couple of points against it.**

First, the **buildings really didn't get shaken all that hard**. The most damaging ground motions occurred in the Santa Susana Mountains to the north, where there are very few steel buildings, or other buildings for that matter. So **most of the steel buildings got only moderate shaking**. Leading to the second point: the way in which the **code represents an earthquake is deficient.**

Ground motions and velocities to the north of the epicenter **were larger than anticipated by the building code**. The records that the engineers used to validate their design procedures back in the 1960s and 1970s didn't show any such velocities.

In summary, then, the **building code is supposed to be written for larger earthquakes** than Northridge, yet the code **didn't anticipate the ground motions felt even in this moderate quake**. Furthermore, the welds failed in buildings that didn't get the strongest shaking that Northridge had to offer. What does this tell us about **what's going to happen in larger earthquakes**?

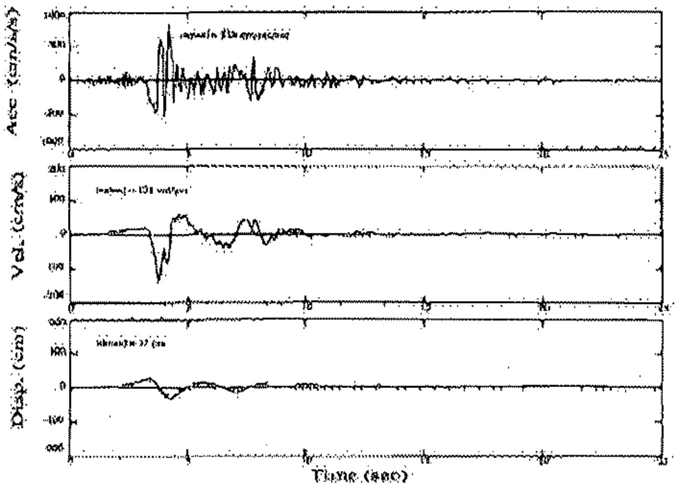
Let's take a closer look at what did happen. Most of the steel buildings that were shaken in the Northridge earthquake look fine from the outside. But if you go inside, and uncover some of the beam-to-column connections, work, by the way), you'll see the flanges, which carry most of the bending moment, are cracked clear through at the welds. The cracks sometimes extend into the web of the beam or column, and, very occa- sionally, the member is torn in two. We know **this problem exists in about 100 or so buildings**. In some cases, **more than 50 percent of the welded connections are broken**; in a few buildings, nearly every connection has given way. And there are perhaps **another 200 suspect buildings that we haven't really looked at yet.**

Why did this happen? There are at least four reasons. First of all, quality conttol, to put it bluntly, is often not very good as these buildings are built. There **aren't enough building inspectors for the volume** of construction, and some **contractors aren't well-educated in the importance** of following the code. A badly built building can stand for quite a while before its weaknesses are revealed in an earthquake. Second, the material used for the welds was not very fracture-resistant. No one was expecting brittle fracture to be a problem, so why pay more for fracture-resistant material when the need is not apparent? Third, there was little or **no heat treating done during the welding**, which means that the welds cooled very fast, and that tends to embrittle them. The more slowly a weld cools, the more ductile it will be. And finally, the **backup bar, which helps retain the molten material as the weld cools, often didn't fuse completely with the column**. That gap between the bar and the column often became the notch where the crack started.

One might reasonably ask why the laboratory tests didn't pick this kind of thing up. There are multiple reasons here, too. The tests were generally done at small scales, say, one- third scale, and at slow loading rates, because there wasn't enough money to buy the large equipment and fast actuators necessary to give full-sized connection specimens the shaking they would really feel in an actual earthquake. Also, the quality control on the laboratory welds that the researchers made was probably a lot better than it is at the construction site. These factors worked together to **make the test results better than, and not a fair indication of, what might happen in the field.**

However, if you go back through the old laboratory reports, **you do find a fair number of premature fractures caused by the weld-fracture problem, even in those small-scale specimens.** The Federal Emergency Management Agency is [in 1995] funding a research program to try to find a solution. Phase I, which I was involved in, was wrapping up, and Phase II was about to start. The first thing the task force did was investigate the scale effect by testing more nearly full-sized connections in the higher-capacity rigs that are now available. And although the task force improved quality control, used better weld material, ground off the backup bar, and did heat treatments, **the cracks appeared, so it seems that our fundamental design was bad.** We're trying to reduce the stress the welds must carry by welding cover plates over the joints. The cover plates strengthen the connection of the beam to the column, forcing the yielding out into the beam where there's no weld to break. This **method still had problems** that we hoped Phase II will solve. The **solution is liable to be pretty expensive.**

Left is a record of the ground motion felt in Sylmar during the Northridge earthquake, in a region of strong shaking to the northeast of the epicenter. It shows pretty high accelerations, which are a concern, but **focus on the rapid displacement**; a roughly 60-centimeter (about two feet) peak-to- trough pulse happened in less than a second. **That kind of motion has a very high damage potential, and it simply wasn't present in the old ground-motion records that the engineers used when they were validating the design procedures.**



These large, rapid displacements are what seismologists call "near-source directivity effects", a very important idea. Over the last decade, Professor of Engineering Seismology Tom Heaton (PhD '78) and his colleagues at the U.S. Geological Survey (USGS) and Caltech have discovered some very interesting things about how a rapture proceeds on a fault; namely that, at any given instant, only a small part of the fault is involved in the slip. The slip actually takes place in a pulse that propagates along the fault, as shown above, and the amount of slip within this pulse is quite large. The fault's slip produces shear waves that travel out in all directions. Since the slip pulse travels at a slightly lower speed than the shear wave (a fact also discovered by Heaton, et al.), **each successive bit of fault slip contributes more energy to the part of the shear wave being sent out ahead of the rupture**, building the wave up to a **very large amplitude**. So, in general, the largest ground motions are going to be observed in areas toward which the fault is rupturing.

The Northridge earthquake was **only a magnitude 6.7, yet it created stronger ground motions than are represented in the code. But we have even larger earthquakes in California.** What about Los Angeles? You may be surprised to learn that in the 1920s, the seismic threat to L.A. was quite a lively topic.

Measurements by many people have documented a north-south compression of the Los Angeles region by about one centimeter per year, which is thought to arise from the bend in the San Andreas fault to the city's north. Last January, eight geologists associated with the Southern California Earthquake Center, including Jim Dolan (a Caltech postdoc now at USC), and Caltech Professor of Geology Kerry Sieh as lead authors, published a paper that assumed thar this compression is accommodated by the system of thrust faults and calculated how these faults could plausibly release the accumulated pressure, **based on their known slip rates and other data.** [Excerpted in this Statement] We don't know whether this stress is relieved in a few large earthquakes, or a lot of smaller ones, or some mix in between, but **this compression by itself is enough to give us one magnitude 7.3 shaking about every 150 years. In the last 200 years, we've only had two magnitude 6.7s, Northridge and the San Fernando earthquake of 1971, so this indicates that there are going to be some large earthquakes sooner or later, and that one such quake might be overdue.**

Seismologists have developed a pretty good idea of how ground rupture takes place, so they can impose a reasonable fault- rupture scenario on a mathematical model of a chunk of the earth. From this they can compute the ground motion anywhere, including on the surface. For a hypothetical magnitude 7.0, the most dam- aging ground motions occur to the south, in the area toward which the rupture is propagating. In this region, say at location C5, the peak acceleration isn't so big, because **we're some distance from the fault.** But the peak **displacement is about six feet**, and **this fault doesn't even break the surface!** And the accompanying velocity is about **four and a half feet per second**, which is a pretty good leap for a piece of solid ground. Needless to say, **this is very worrisome.**

Let's consider how a building could be affected. The outward movement gets the building going forward at a high velocity; then the ground doubles back (and the lower stories with it), putting the building under enor- mous stress. **Even if the building can arrest its forward motion, it's liable to experience severe deformations** in the lower part of its structure. If the welds are popping on top of this, it's going to have a very **hard time stopping, greatly increasing the likelihood of collapse.**

I fed the ground motions-the Sylmar one from the Northridge earthquake and the C5 one from the simulated magnitude 7.0-into a computer model of how a steel-frame building behaves when shaken. This model is a more sophisticated descendant of the ones that the engineers were using back in the 1970s. And the base places, which secure columns to their foundations, can fail; concrete slabs can crack; beams can buckle in torsion; the list goes on and on... Sometimes the program computes **very large story drifts**, and I'd have to think that if it had **included more deterioration mechanisms, the building would have collapsed**. We should **interpret these large story drifts as actual collapses**, even **though the output doesn't explicitly say so.**

The peak story drifts for a six- and a twenty-story structure subjected to the ground motions showed **collapse for the 20-story and 12.4 percent story drift [complete failure] for the C5 simulated 7.0 earthquake.**

Are our steel buildings, which we thought were our most earthquake-resistant type of structure, **liable to collapse?** We've seen that they're going to behave brittlely during earthquakes, not ductilely as we expected. Also, we can get near-source ground motions from large earthquakes that are **considerably stronger than the building code provides for.** Furthermore, large earthquakes have **duration effects that are not anticipated properly. A magnitude 7.5 can give you 30 seconds of strong shaking, instead of the seven or eight seconds felt in the cases I've shown here, and deterioration is a function of duration.** So I think that when we consider these things, we **have to admit the possibility that some of our steel buildings will collapse. In Japan, where they build stronger buildings with much better quality control than we do here, they had some problems in the Kobe quake.**

What about the real high-rises? I only looked at a 20-story building. It turns out that they are actually probably safer, for various reasons. They're relatively stronger than the mid-rise and shorter buildings, because they're designed to carry larger loads: higher wind loading on their bigger surface areas, and, of course, their own heavier weights. Also, skyscrapers like to vibrate back and forth very, very slowly; their natural resonant frequencies are quite low, and only a very large earthquake would have enough low-frequency motion to really make them move. **However, the geologists aren't ruling out such an earthquake**, and our experience with Northridge tells us that **we have to assume that the welds in these buildings are deficient.** So that's something that deserves more study.

If you work [**or live**] in a steel building, you're probably starting to **wonder about your chances.** Life is full of risks, and there are ways to quantify them. **[If you work 40 hrs per week, and are home the rest of the week (128 hrs), your danger at home is 3.2 times your danger at work. Inasmuch as the great earthquakes occur when people usually are at home, multiply the factor by 3 (9.6) for the relative risk at home compared to work. If you work at home, you are in danger always.**

[If you work in a zone which is near or over a fault, your danger is about 6.25 times over the building code's safety margin. If you are in a building at an elevation higher than what is possible to leap to safety, and you are over a fault, you may want to consider relocating.]

You can reduce your calculated risk still further because most buildings don't pancake when they fail. Usually, only a few floors collapse; we saw that a lot in Kobe. So also consider the odds that you're going to be on one of those floors. If you work all of that out, you may find a number you can live with.

But there's more to an earthquake's toll than lives lost; there's property damage. The Northridge quake cost us about $20 billion at last count; direct property damage from the Kobe quake is currently about $100 billion. An Elysian Park earthquake under downtown Los Angeles would easily cost as much as Kobe. Can our economy **take a $ 100-billion hit?**

When people were coming up with the building codes philosophy 43 years ago, we weren't having many earthquakes. Therefore it seemed reasonable to design minimal buildings that were just strong enough to avoid collapse (or so they thought), and it wasn't economical to worry about damage control. Today we have a much better idea of the earthquake threat, and things look more ominous. I'd be willing to bet that if it were possible to do a proper economic analysis, it would now make much more sense to design stronger buildings to limit damage. And, of course, stronger buildings would also save more lives. I think that such designs will become more common as more people, including the code writers and the government, realize the benefits of damage control.

It has become traditional, in the months following a damaging earthquake in California, for the governor to call on a blue-ribbon panel to investigate the structural failures caused by that quake. The panel eventually issues a report summarizing the engineering lessons learned, and recommending modifications in the building codes and other precautions that, if implemented, should significantly reduce damage in subsequent earthquakes. A glance at the titles of these reports gives us an **unintended insight into California's earthquake problem**. After the 1989 Loma Prieta quake, the Board of Inquiry viewed the situation as Competing Against Time." The Seismic Safety Commission, in its recent report on the Northridge earthquake, sees the need for "Turning Loss To Gain," although someone has said that, following the lead of Loma Prieta's Board of Inquiry, a better title **would have been "We Lost."** Certainly, **if we don't pay serious attention to our earthquake threat, we'll be "Picking Up the Pieces" in a future report.**

Associate Professor of Civil Engineering John Hall was the team leader for the Earthquake Engineering Institute's reconnaissance of the North ridge earthquake. and participated in the Seismic Safety Commission study of that quake. (He was the secretary to the Board of Inquiry into the Loma Prieta earthquake.) He is also a member of Caltrans' Seismic Advisory Board and the White House Office of Science and Technology Policy's National Earthquake Strategy Working Group. His research combines computer simulations, laboratory models, and field testing, and focuses on the nonlinear response ofstructures. especially high-rise buildings and concrete dams, to earth quakes. Hall's degrees in civil engineering are a BS from West Virginia University in 1972, an MS from the University of Illinois in 1973. and a PhD (with a minor in seismology) from UC Berkeley in 1980: he also has several years' worth of "real-world" experience in a structural design office.

"[ ]" signifies editorial additions.

Southern California Earthquake Center Final Task Report on

THE CHARACTERISTICS OF EARTHQUAKE GROUND MOTIONS FOR SEISMIC DESIGN

Submitted to State of California Department of Transportation, Los Angeles County Department of Public Works, & City of Los Angeles Department of Public Works from the Southern California Earthquake Center University of Southern California. December, 1995

TASK H-2

PALEOSEISMOLOGY, TECTONIC GEOMORPHOLOGY AND SEISMIC HAZARDS OF THE HOLLYWOOD AND SANTA MONICA FAULTS

by James F. Dolan, Department of Earth Sciences, University of Southern California, and Kerry Sieh, Seismological Laboratory, California Institute of Technology

(By permission, Caltech) Portion of Report Germane to Subject Issue. For Complete Report, *see* Dept of Public Works.

INTRODUCTION

During the **past several years** earlier ideas about the **seismic hazards facing urban Los Angeles have undergone dramatic revision and refinement**. Previously, earthquake scenarios for the Los Angeles metropolitan region focused primarily on the effects of a great (Mw 7.7 to 7.9) earthquake generated by the San Andreas fault, which is located more than 50 km northeast of downtown Los Angeles (Figure 1; e. g., Wesnousky, 1986; WGCEP, 1988)). Except for a postulated magnitude -7.0 earthquake scenario for the northern segment of the Newport-Inglewood fault (Toppozada et aL, 1988), seismic hazard assessments generally did not include the numerous active faults located within the Los Angeles metropolitan region. The 1987 Mw 6.0 Whittier Narrows earthquake, and more recently the **1994 Mw 6.7 Northridge** earthquake, focused attention on the seismic hazards associated with these urban faults. Because of their proximity to metropolitan Los Angeles, moderately large-to-large earthquakes (Mw 7.0 to 7.5) generated by them could cause at least as much, and possibly more damage, than a much larger earthquake occurring on the San Andreas fault (Dolan and others, 1995; Heaton and others, 1995).

Despite a heightened awareness of the potential for destructive earthquakes from faults beneath metropolitan Los Angeles, too little information exists about the earthquake histories and recent kinematics of these faults to construct realistic probabalistic hazard maps for the metropolitan region. Specifically, we have only sparse data concerning recurrence intervals, dates and sizes of past events, slip rates, or kinematics of fault movement for many structures in the Los Angeles metropolitan region. Furthermore, we do not even know the exact nature and location of the surficial expression of many of these faults. Knowledge of these fault parameters is an essential part of the foundation for construction of the Southern California Earthquake Center's 'Master Model', a prototype probablistic seismic hazard model for southern California.

Over the past several years we have been studying the active tectonics and paleoseismology of the northern Los Angeles metropolitan region, an area extending from Pacific Palisades and Santa Monica on the coast, eastward through Beverly Hills, Hollywood, downtown Los Angeles, and East Los Angeles to Whittier Narrows.

This report is divided into two chapters. In the first chapter we discuss our results from the Hollywood fault, which extends for 14 km through this densely urbanized region (Figure 2). The second chapter details our results from the Santa Monica fault, which runs through west Los Angeles, Westwood, Santa Monica, Pacific Palisades, and offshore parallel to the Malibu coast.

CHAPTER 2:

ACTIVE TECTONICS, PALEOSEISMOLOGY AND SEISMIC HAZARDS OF THE HOLLYWOOD FAULT, SOUTHERN CALIFORNIA

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Submitted to Journal of Geophysical Research, August 12, 1995

ABSTRACT

Data from geotechnical boreholes and trenches, in combination with geomorphologic mapping, indicate that the Hollywood fault is an oblique reverse, left-lateral strike-slip fault that has experienced at least one surface-rupturing earthquake during latest Pleistocene to mid-Holocene time. Geomorphologic observations indicate that the Hollywood fault extends for 14 kilometers along the southern edge of the eastern Santa Monica Mountains, from the Los Angeles River westward to northwestern Beverly Hills, where the locus of active deformation steps 2 km southward along the West Beverly Hills lineament to the Santa Monica fault. We interpret the Hollywood fault as part of the predominantly left-lateral, **215-km-long** Raymond-Hollywood-Santa Monica-Malibu Coast-Santa Cruz Island- Santa Rosa Island (RHSMSS) fault system, which accommodates relative westward motion of the southern Transverse Ranges. The absence of geomorphologic or structural evidence for through-going connections between these faults suggests that they are not the same fault, but this **does not preclude the possibility that they may rupture together** during large earthquakes. Rupture of the entire 14 km length of Hollywood fault, by itself, would **produce a Mw ~6.6 earthquake,** similar in size **but even closer to more densely urbanized areas than the highly destructive, 1994 Northridge earthquake.** Assuming a 0.6 to 1.4 mm/yr fault slip rate consistent with available geologic data, we calculate an average recurrence interval for such moderate events of about 1000 to 2300 years. Such a short recurrence interval seems unlikely in light of the probable early to mid-Holocene age of the most recent Hollywood fault earthquake, which implies that the fault **ruptures in less frequent, and therefore larger, events.** Simultaneous rupture of the Hollywood, Santa Monica, and Malibu Coast faults **could produce a Mw 7.3 earthquake,** for which we calculate an average recurrence interval of about 2350 to 5500 years. Rupture of the entire RHSMSS fault system conceivably could result in an earthquake **as large as Mw 7.6 to 7.7.** In addition, we speculate that the Hollywood fault may rupture together with the Santa Monica Mountains blind thrust fault and shallower blind thrust faults to the south.

Downtown Hollywood

Over most of the westernmost part of downtown Hollywood, the fault exhibits a single south-facing scarp along the topographic break in slope at the southern edge of the Hollywood Hills. In contrast, in downtown Hollywood the fault exhibits several parallel, locally overlapping south-facing scarps that indicate a wide, complex zone of surficial faulting. Data from previous geotechnical and groundwater studies, in combination with our geomorphologic results, confirm that the **fault comprises at least three major splays through much of downtown Hollywood** (Converse Consultants, 1981; Crook and Proctor, 1992; F. Denison, pers. comm., 1991). The **most prominent scarp in the downtown area extends nearly continuously for 2 km along and just south of Franklin Avenue, from about 250 m east of La Brea Avenue to just east of Gower Street.** There the scarp disappears as the fault crosses the 650 m- wide Brushy Canyon alluvial fan. The **Yucca Street strand** appears to correlate with a prominent, 5m to 6 m-high topographic scarp traceable both eastward and westward of the active fan. Beyond a point about 300 m west of Cahuenga Boulevard this strand does not exhibit a surficial scarp. However, groundwater data indicate that the fault acts as a groundwater barrier approximately 375 m west of Cahuenga Boulevard, with much shallower ground water levels north of the fault (5 m depth) than to the south

(> 12 m depth) (G" in Figure 4; F. Denison, pers. comm., 1991). The location of the Yucca Street strand has not been established west of this point.

At least two additional fault strands occur north of the Yucca Street strand. The central splay, which we refer to as the Franklin Avenue strand, is defined by a pronounced scarp just west of Cahuenga Boulevard and by a fault mapped in Miocene bedrock near Vine Street (Dibblee, 1991a). The northern strand is defined by discontinuous scarps at the topographic mountain front that disappear beneath the Brushy Canyon fan. The northern strand probably connects with the prominent scarp along the northeast shoulder of the Brushy Canyon fan, suggesting that the trace of the strand is rather arcuate, convex-to-the-north.

Age of Most Recent Activity of the Hollywood Fault

In the **absence of demonstrable** evidence for Holocene displacements (Crook et al., 1983; Crook and Proctor, 1992), the Hollywood fault has not been zoned as active by the State of California. Our data indicate that, **although the Hollywood fault has not ruptured the surface** in the past several thousand years, **it did rupture in latest Pleistocene to mid Holocene.** * * * At 2.8 to 4.5 mm/yr, this long quiescent period yields approximately 22 to 36 m of accumulated elastic strain on the Hollywood fault. Since this is clearly unreasonable, we use the approximate 7900 yr age of the Unit 2/Unit 3 contact, in conjunction with the observation that even the largest strike-slip earthquakes do not produce slip significantly greater than about 10 m, to argue that the current overall slip rate on the Hollywood fault must be no more than about 1.3 mm/yr. This rate yields a maximum of approximately **10.3 m of accumulated elastic strain** since 7900 yrs BP. Thus, we **propose** that current the strike-slip rate on the Hollywood fault lies between about 0.5 to 1.3 mm/yr. Addition of the -0.25 mm/yr dip-slip rate indicates an overall late Pleistocene- Holocene oblique, reverse/left-lateral slip rate of between 0.6 and 1.4 mm/yr. This range yields a minimum of approximately **1.8 to 6 m of stored slip** since development of the Vista Street soils, with **more likely values in the range of 4.5 to 10.5 m since early to mid Holocene** time. As a corollary to this argument, we note that the ratio of left-lateral strike- slip to reverse displacement is between about 2.4:1 to 5.6:1. The present 0.5 to 1.3 mm/yr left-lateral strike-slip rate on the Hollywood fault is much slower than the long-term, 2.8 to 4.5 mm/yr left-lateral strike-slip rate along the southern margin of the Transverse Ranges. These conflicting slip rates indicate either that: (1) the strike-slip rate has slowed significantly with time; or (2) that much of the active strike-slip motion along the southern Transverse Ranges is accommodated off the RHSMSS fault system, possibly as oblique motion along blind thrust faults or as distributed deformation.

Size and Frequency of Future Hollywood Fault Earthquakes

Although we have **no direct data concerning the recurrence interval** for Hollywood-fault earthquakes, the probable long duration of the present quiescent period implies that the fault exhibits a recurrence interval measurable in terms of thousands, rather than hundreds of years. In the absence of direct recurrence data we can use the size of the Hollywood fault plane and reasonable slip rate estimates to speculate about the size and frequency of future Hollywood fault earthquakes.

Dolan and others (1995) presented new regressions for moment-magnitude (Mw) versus rupture area [Mw=4.56 + 0.S6log(Rupture Area)] and average coseismic slip [Mw=6.30 + 1.9llog(Slip)] for off-San Andreas southern California earthquakes. The Hollywood fault is 14 kilometers long. Assuming an average fault dip of 70° and a depth to the bottom of the seismogenic zone of about 15 km yields a total fault plane area of 230 km^2. If the Hollywood fault is well-characterized by these parameters, then **rupture of the entire fault could produce a Mw -6.6 earthquake with about 1.4 meters of average slip across the rupture plane.**

Assuming a slip rate for the Hollywood fault of 0.6 to 1.4 mm/year yields a recurrence interval for such an earthquake of about 1000 to 2300 years. This postulated interval appears unlikely in light of the probable early to mid-Holcoene age for the most recent surface rupture on the Hollywood fault; One possible way of reconciling these apparently contradictory intervals is to assume that the fault **ruptures in less frequent, but larger,** earthquakes. Perhaps the most plausible scenario involves **rupture of the Hollywood fault together with the Santa Monica and Malibu Coast faults.**

If the entire Hollywood-Santa Monica-Malibu Coast fault system were to rupture it would produce a Mw 7.3 earthquake with about 3.3 meters of average coseismic slip (Dolan and others, 1995). The 0.6 to 1.4 mm/year slip rate yields a recurrence interval for such an event of about 2350 to 5500 years, more consistent with the minimum elapsed interval for the most recent Hollywood fault surface rupture, but still incompatible with the probable early to mid-Holocene age of the most recent earthquake. Multiple-thousand-year recurrence intervals have also been suggested for the Malibu Coast and Santa Monica faults (Drumm, 1992; Dolan et at, 1992). These data suggest that this part of the strike-slip fault system may break in conjunction with the underlying Santa Monica Mountains blind thrust fault.

Another possible scenario would involve **rupture of even larger sections** of the RHSMSS fault system. If the same fault parameters that we used for the Hollywood fault apply to all faults in the system (dip 70°; max seismogenic depth 15 km) then rupture of the entire 215 km-long system could possibly produce **an earthquake as large as** Mw 7.6 or 7.7.

Implications for Seismic Hazard Assessment in northern Los Angeles Basin

The **Hollywood fault, by itself**, appears to be capable of generating a -Mw 6.6 earthquake, slightly smaller than the Mw 6.7 1994 Northridge event, which **directly caused 31 deaths and resulted in more than $20 billion in damage** (Scientists of the USOS/SCEC). The Northridge earthquake occurred beneath the San Fernando Valley, a predominantly residential region northwest of downtown Los Angeles. In contrast, the **Hollywood fault traverses a much more densely urbanized region**. Of particular concern are the numerous older structures in this section of Los Angeles, including many unreinforced masonry buildings and older highrises. Many of these buildings sustained damage during the Northridge earthquake, **despite the fact that they were located more than 25 kilometers from the nearest part of the rupture plane**. One **additional** concern is that the **Hollywood fault**, in contrast to the blind thrust fault that produced the Northridge earthquake, **ruptures through to the surface in large earthquakes**. In addition to the obvious implications for infrastructure damage associated with potential surface displacements as large as several meters, **surface-rupturing earthquakes are likely to excite much stronger long-period surface waves than the Northridge event** (e. g., Liu and Heaton, 1984; Vidale and Helmberger, 1988). **Such long-period surface waves could represent a significant hazard to the many high-rises in the region** (Heaton et al., 1995).

The Landers earthquake served as a reminder of the **importance of source directivity** as one of the primary controls on the location and magnitude of strong ground motions and consequent damage (Wald and Heaton, 1994). If the Hollywood fault were to rupture as part of a much larger earthquake involving major portions of the RHSMSS system, source directivity could play an important role in controlling damage patterns. If, for example, a future earthquake were to nucleate near the eastern end of the system and propagate westward, much of the energy would be dissipated beneath the Pacific Ocean and the sparsely populated western Santa Monica Mountains. Except for the Westwood and Century City areas, the northwestern part of the Los Angeles Basin has relatively fewer high-rises and multi-story older buildings than the Hollywood-downtown-East LA region to the east. **If, on the other hand, a future rupture were to start at the western end of the system and propagate eastwards, very strong accelerations would be focused on older, vulnerable structures in Hollywood, Elysian Park, downtown Los Angeles, and East Los Angeles.** These parts of the city were among the first to be urbanized, and they contain some of the region's most vulnerable, and most densely occupied, buildings. In addition to older structures, the **latter scenario would focus energy towards the downtown Los Angeles high-rise district. The stability of some of these structures during relatively close, large earthquakes has recently been the subject of intense scientific discussion** (e. g., Heaton et aL, 1995).

CONCLUSIONS

From a seismic hazard perspective, perhaps our most important result is that the **Hollywood fault is probably active and capable of producing damaging earthquakes beneath the densely urbanized northern Los Angeles basin. Prior to this study no useful paleoseismologic information was available for the fault, which is consequently not zoned as active** by the State of California. The fault has ruptured to the surface at least once during the past 20:000 years. Two unfaulted soils that cross the fault required 1,500 to 4,000 years to develop, indicating that the most recent earthquake occurred at least that long ago. However, stratigraphic relations in several excavations lead us to suspect that the most recent surface rupture probably occurred -5,000 to 15,000 years ago, during latest Pleistocene to early or mid-Holocene time. The long elapsed time since the most recent earthquake is inconsistent with recurrence intervals calculated for rupture of the Hollywood fault by itself in moderate (-Mw 6.6) earthquakes. This inconsistency implies that the **fault may break during less frequent**, but therefore **much larger (Mw>7.O) earthquakes** involving either rupture of major portions of the Raymond- Hollywood-Santa Monica- Malibu Coast-Santa Cruz Island-Santa Rosa Island fault system, or the blind thrust ramp beneath the Santa Monica Mountains and shallow blind thrust faults to the south, or both.

Another surprising results involves the kinematics of Hollywood fault. Although it has generally been considered a reverse fault, recent mountain-side-down displacements, coupled with the extremely steep dip of the fault (65° to 90°N), indicate a **significant, possibly predominant, component of left-lateral strike-slip** motion along the fault. In addition to the strike-slip component, the **Hollywood fault exhibits a long-term component of reverse displacement** 0.25 to 0.44 mm/year, indicating that overall motion is oblique reverse, left-lateral strike-slip.

Chapter 3: SANTA MONICA FAULT

ABSTRACT

The Santa Monica fault is a 50 km-long oblique reverse-left-lateral strike-slip fault that extends through the densely

urbanized northwestern Los Angeles Basin and offshore parallel to the Malibu coast. The fault, which exhibits near-surface strain partitioning, has experienced **at least six, and possibly as many as nine surface ruptures** during the last 30,000 to 40,000 years. At least three, and possibly as many as six of these earthquakes have occurred since burial of a prominent paleosol about 16,000 to 17,000 years ago. This yields an average latest Pleistocene-Holocene recurrence interval of -2700 to 4200 years, considerably longer than the -1900 year average recurrence interval that we calculate for a hypothetical Mw 7.0 earthquake generated by rupture of the entire Santa Monica fault. The disparity between the measured and calculated recurrence intervals implies that the **Santa Monica fault ruptures in less frequent, and therefore larger earthquakes** (Mw»=7.0). Since the Santa Monica fault is probably not capable of generating earthquakes much larger than -Mw 7.0 by itself, we conclude that the fault may have ruptured together either with other faults in the R-H-SM-MC-SCI-SRI fault system, or with the Santa Monica Mountains blind thrust fault, or both. Assuming a slip rate for the Santa Monica fault of 1.1 mm/yr yields a calculated recurrence interval for hypothetical Mw 6.6 earthquakes of about 1250 years. These same slip rates yield a calculated recurrence interval for a hypothetical Mw 7.0 event of about 1800 years. There is evidence for at least four, and possibly as many as 6 surface ruptures since burial of Paleosol 3 about 16,000 to 16,750 years BP. If 4 events have occurred since Paleosol 3 burial, then the average recurrence interval over that span is -4000 to 4200 years. If 6 events have occurred, the average recurrence interval is about 2700 to 2800 years. Thus, during latest Pleistocene-Holocene time the Santa Monica fault exhibits an average recurrence interval for surface ruptures of about 2700 to 4200 years. The calculated recurrence intervals for hypothetical Mw 6.6 and 7.0 events are significantly shorter than our measured Holocene recurrence intervals. The simplest explanation of this apparent contradiction is that the **Santa Monica fault ruptures in infrequent, and therefore larger earthquakes. Because the measured recurrence intervals generally exceed those expected for Mw 7.0 events, we hypothesize that the paleo-earthquakes recorded in the Santa Monica fault trenches may have been larger than Mw 7.0.** Since the Santa Monica fault, by itself, is probably not capable of producing earthquakes much larger than Mw 7.0, the veiy large paleo-events implied by the trench data probably involved rupture of either multiple faults within the R-H-SM-MC-SCI-SRI fault system, or simultaneous rupture with the Santa Monica Mountains blind thrust fault, or both. However, as we noted above, we could be missing events, and incomplete data will always bias such estimates in favor of less frequent, and therefore larger earthquakes.

Implications for Seismic Hazard Assessment in Northern Los Angeles Basin

The Santa Monica fault, by itself, appears to be **capable of generating earthquakes as large as Mw 7.0, considerably larger than the Mw 6.7 1994 Northridge event, which directly caused 31 deaths and resulted in more than $20 billion in damage** (Scientists of the USOS/SCEC). As discussed above, the apparently long recurrence intervals for the Santa Monica fault are more consistent with rupture of the fault in large (Mw»=7.0), infrequent earthquakes possibly involving rupture of multiple faults in the R-H-SM-MC-SCI-SRI fault system. The **effects of such large earthquakes would be dramatically different from the Northridge event, producing strong ground shaking over a much wider area with a longer duration. The location and style of faulting on the Santa Monica fault further compound the problems presented by such large earthquakes.**