CHAPTER 1

DAMAGE TO ROADS AND HIGHWAYS

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Introduction

Protection of transportation facilities against earthquakes should be one of the most vital concerns in planning for such a disaster. Without clear transportation corridors and intact road surfaces, emergency vehicles, including ambulances, fire fighting equipment and rescue units, will be unable to bring the immediate situation under control effectively and quickly. Even more long-range efforts, such as reuniting families and returning people to their homes, could be severely hampered by damaged or destroyed transportation routes. However, little planning has been done to insure that the overall transportation system in California, including roads and major highways, will remain intact in the event of an earthquake. I plan to discuss several types of geologic and other potential failures that can affect roads during an earthquake, and then analyze the effect of such failures on transportation routes in Berkeley.

Some experience has been gained in the field of earthquake damage to transportation facilities in two major earthquakes in the United States in the past 15 years. In the 1964 earthquake in Alaska (magnitude 8.4 on the Richter scale with the epicenter about 80 miles east of Anchorage), the highway system in the region of strong shaking was severely damaged. In particular, roads built on soft ground or on embankments suffered extensive cracking, settlement, and sloughing. In addition, subsidence in some areas subjected roads to damage from high tides, landslides destroyed several roads in downtown Anchorage, and many bridges were severely damaged due to movement of soils on stream embankments.[11]

In the 1971 earthquake in San Fernando, California (magnitude 6.4 on the Richter scale with the epicenter some 25-30 miles northwest of the Los Angeles Civic Center), ground motions of up to .75 g were recorded. Damage to roads included subsidence of fills, separation of pavement slabs, buckling of pavement, failures in cut slopes and fills, and road settlement at bridge approaches.[13] Several major bridges (highway overpasses) partially or completely collapsed while others were so damaged that they were unsafe for public use. As a result of these overpass failures, an overpass retrofitting program was begun throughout the state (this will be discussed in more detail later).

The experiences of Alaska and San Fernando point out some of the potential sources of damage to roads and highways during an earthquake. Damage in those earthquakes was due mainly to poor substrate upon which the roads were built and to structural weaknesses in highway bridges.

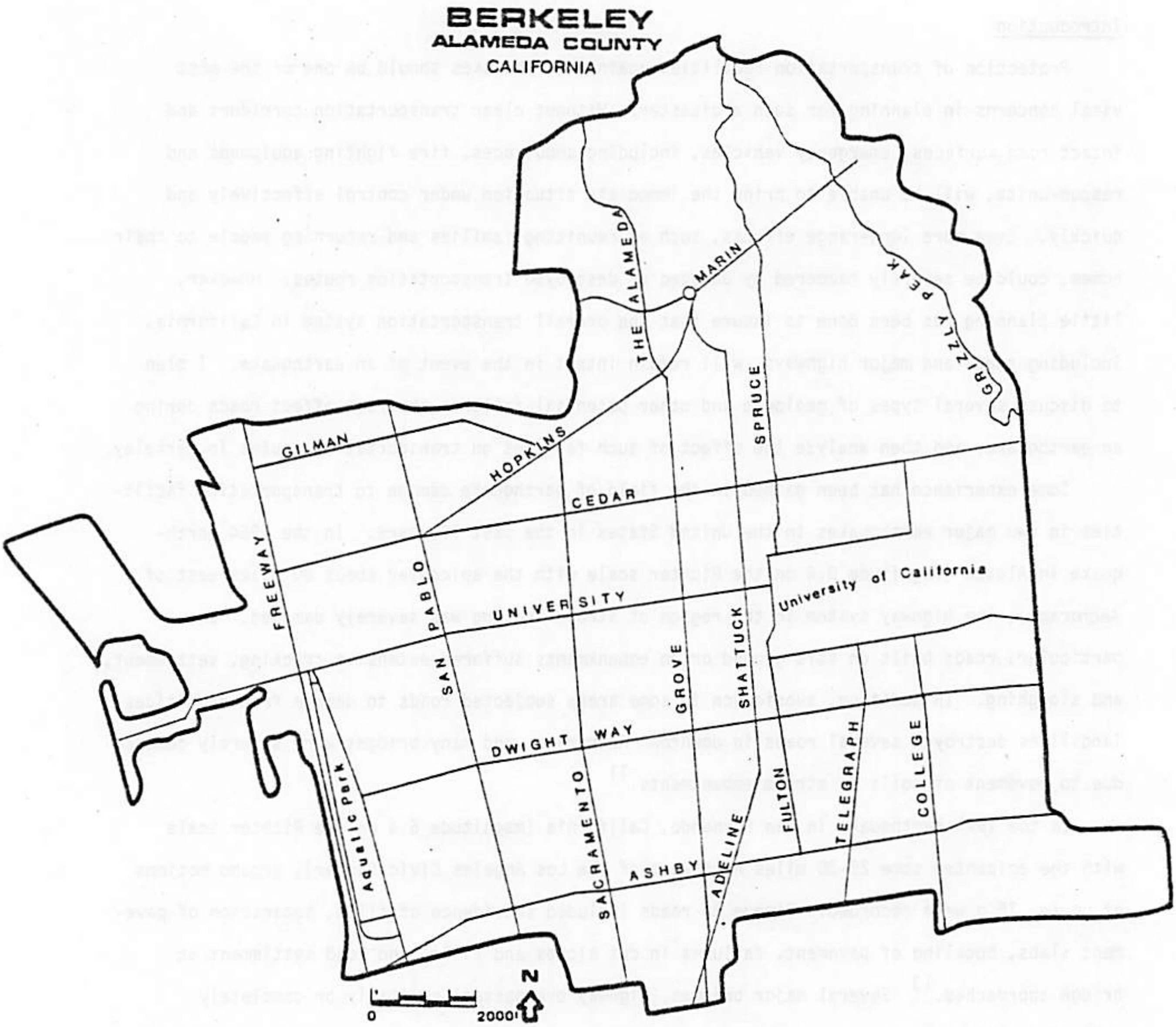

FIGURE 1. Roads and Highways in Berkeley
SOURCE: Berkeley Planning Department

Roads and Highways in Berkeley

Four state highways and one interstate highway run through Berkeley (FIGURE 1). Interstate Route 80, which coincides with State Route 17 in Berkeley, runs north-south across the west end of the city along the east side of San Francisco Bay. Consequently, this section of the highway is often referred to as the Eastshore Freeway. Highway 123, or San Pablo Avenue, runs parallel to Interstate 80 about one half mile east of the bay, while Highway 13, or Ashby Avenue, crosses Berkeley from east to west near the center of the city. Highway 24 approaches the southeastern part of Berkeley where it meets Route 13 west of the Caldecott Tunnel.

Among roads maintained by the City of Berkeley, the character of any given road depends mainly upon where it is located. For example, in the flat areas of the city (west of the hills), the streets are generally straight and intersect at right angles. The main streets, in addition to Ashby Avenue and San Pablo Avenue, include University Avenue, College Avenue, Telegraph Avenue, Shattuck Avenue, Grove Street, and Sacramento Avenue (FIGURE 1). In the hilly eastern region of the city, on the other hand, the roads are quite curvy and narrow.

Potential Failures

During an earthquake, roads can be affected by a number of problems. While surface rupture along the fault itself can cause cracks and fissures to open in roads which cross the fault, more serious and widespread problems arise from landslides, liquefaction, uneven settlement, and differential responses of rock formations to ground shaking. In addition to these geologic failures, other hazards such as falling powerlines and freeway overpasses can impede traffic and rescue operations, as well as pose severe threats to human safety.

The extent of damage to roads from geologic ground failures depends upon the substrate beneath the road, the design and topographic location of the road, and the time of year the earthquake occurs. Landslides, for example, are more likely to occur during the rainy season on slopes of relatively unconsolidated material. In hilly areas, such as the eastern part of Berkeley, slides can completely block access to whole sections of town, since detours are often difficult to establish. In addition. roads and houses built in the hills by a process of cut and fill can be brought down with the slide mass, thereby confounding the efforts to remove debris and re-open the area.

Liquefaction, which is the transformation of a granular material from a solid state to a liquid state, also depends upon the geologic substrate. It is most likely to occur in fine-grained sands and silts which are unconsolidated and saturated with water. When liquefaction occurs, segments of road built on such a substrate can settle or sink. On areas of filled land in the Bay Area, such as the extreme western portion of Berkeley, the potential for liquefaction depends on the type and thickness of fill and on the thickness of the bay muds beneath it. A roadway may settle by different amounts in different places causing severe damage and probable impassability.

Perhaps the most serious hazard to roads during an earthquake (and one which is difficult to plan for), is the differential responses of the various geologic units to ground shaking. In

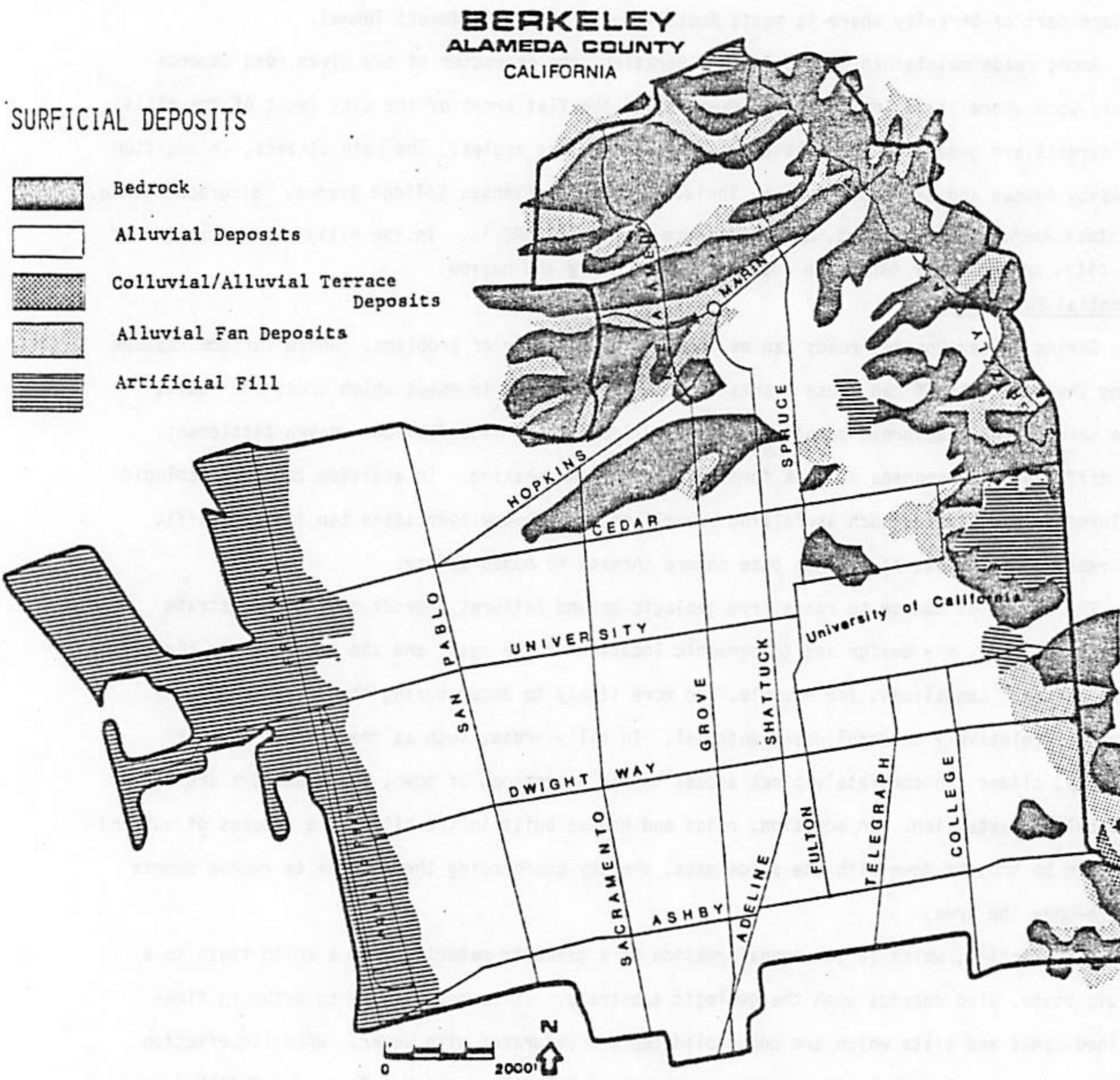

FIGURE 2. Surficial Deposits in Berkeley
SOURCE: Berkeley Planning Department

general, shaking is more severe in softer sediments, but other factors, including grain size, degree of compaction and cementation, thickness of deposit, amount of pore space, and water content, can affect the response. In addition, the ground shaking can be amplified by reflections of waves off solid bedrock and by abrupt changes in rock type through which the waves are moving. Depending on how each road was designed and constructed, ground shaking could cause anything from a cracked road surface to a jumbled mass of impassable pavement slabs.

In Berkeley, bedrock is found in the hills, and alluvium underlies the flat western part of the city. The softer bay mud sediments and bay fill are found, of course, along the Bay shore (FIGURE 2).

Potential Damage to Roads and Highways

State and Interstate Highways

Interstate Highway 80/State Highway 17, which is the major transportation artery to and from Berkeley, is located in the area of Berkeley that is perhaps the most vulnerable to damage from a large earthquake. From the northern limit of Berkeley to the vicinity of the University Avenue offramp, the land beneath the highway was once bay marshland and tidal flats. Then, from University Avenue to south of the San Francisco-Oakland Bay Bridge approach, the road is built on filled land which was formerly part of San Francisco Bay (FIGURE 2).

The highway was constructed in the mid-1950's, and its design took into consideration the difficulty of building on filled lands. Since the engineers recognized the inherent instability of the younger bay muds, the area to be filled was excavated down to the more compact older bay muds. These muds generally provide a good foundation for piles and other such structures and for all loads except the most heavily concentrated.[8] The site was then filled with coarse sand dredged from farther out in the bay and overloaded to induce compaction. This procedure was followed simply to create a more stable roadway and not specifically for seismic safety. The high relative density of the resulting fill greatly reduces the potential for liquefaction (recall that liquefaction occurs in loose, saturated, cohesionless materials). Tom Walsh, Senior Transportation Engineer at the California Department of Transportation, points out that although the roadway has been in place for 25 years, it has shown no signs of failure and its condition with respect to the foundation is excellent.[19]

More serious than potential damage to Interstate 80, however, is failure of the eastern approach to the Bay Bridge which could leave hundreds of cars stranded on the bridge for an indefinite period of time. The bridge itself is likely to remain standing because it is built on piles, but the approach may settle as much as three of four feet during an earthquake.[7] This is because the roadway is built on fill that was placed directly on top of the younger bay muds. When the approach was built in the early 1930's, seismic safety considerations were not taken into account, and, indeed, much less was known about engineering for seismic hazards at that time. During the construction of the fill north of the toll plaza in 1947, the younger bay mud was overloaded with sand fill and failed. The sand sank 20 feet while the underlying mud was forced sideways more than 500 feet.[8] The present uneven condition of the roadway and the tilting of a small structure near the toll plaza indicate that uneven settlement is occurring. During an earthquake, the soft, unconsolidated younger bay muds have a high probability of liquefying and thereby destroying the eastern approach to the bridge.

As a contingency measure for rapid recovery after an earthquake, the California Department of Transportation has a list of active contractors who can quickly bring in soil to repair temporarily the bridge approach and get traffic moving again. In addition, all new bridge approaches contain a concrete slab beneath the road surface, one end of which is attached to the bridge. After an earthquake, the concrete ramp would remain even if the surrounding approach sustained damage.[7]

Other state highways in Berkeley will probably fare just as well as Interstate 80 during an earthquake. Highway 123 (San Pablo Avenue) could sustain damage due to amplification of seismic waves, since it is located on a flat alluvial fan. However, the extent of the damage and resulting length of time the road would be unusable depends upon the size of the earthquake. In a moderate earthquake, damage could be repaired and debris removed relatively quickly due to the width of the street.

In contrast to San Pablo Avenue, however, Ashby Avenue (Highway 13) is relatively narrow as it bisects Berkeley, especially in the southeastern portion of the city where it becomes Tunnel Road. Debris falling in the road would be difficult to remove quickly, causing the road to be closed after the earthquake. Between its intersection with Highway 24 and the intersection with Highway 580, Highway 13 (here called the Warren Freeway) runs directly through the flat, linear valley of the Hayward fault. Therefore, depending upon the exact location of the epicenter and the amount of displacement along the fault, surface rupture could seriously damage this portion of Highway 13.

Highway 24, where it approaches Berkeley's southern border, would probably have no major problems. Landsliding in the relatively unconsolidated material in the vicinity of the Caldecott Tunnel could block the tunnel entrances and tiles lining the inside walls of the tunnel might fall. The tunnel itself, however, probably would not collapse, since tunnels generally tend to strengthen the hillsides they bisect.[10]

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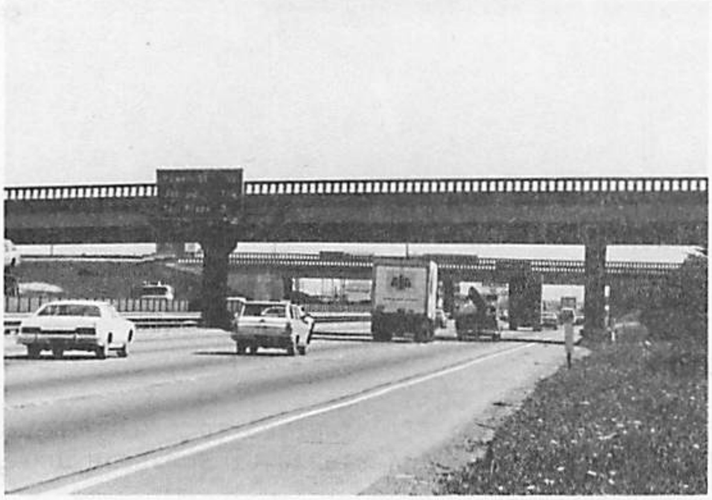
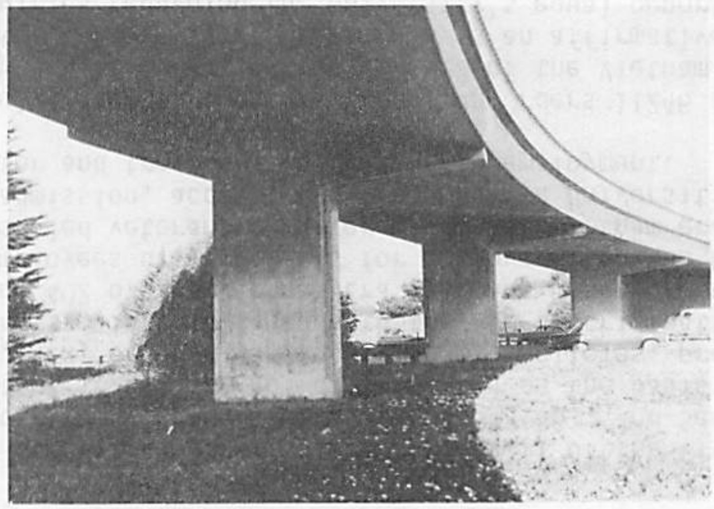
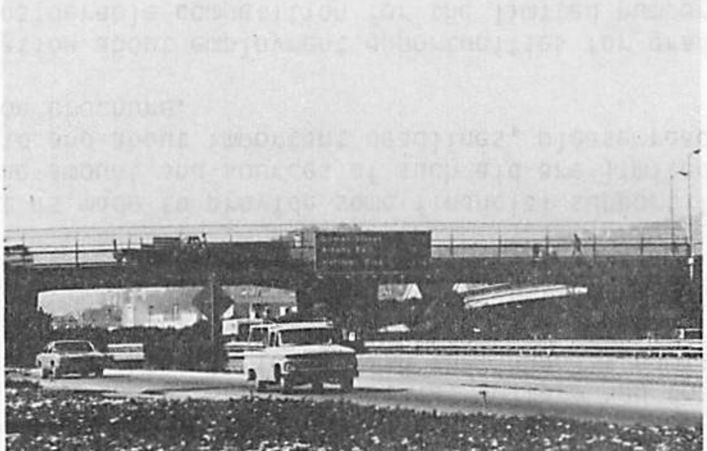


Ashby Avenue overpasses, north and south. Looking south.



Concrete columns of Ashby Avenue north overpass.



University Avenue overpass.

FIGURE 3. Highway Structures on Interstate 80 in Berkeley

Photos by Joel A. V. Sabenorio

District 4 of CalTrans (Bay Area district), Roy Oakes, Berkeley's Director of Public Works requested information on the "seismic status" of the bridges on Interstate 80.[6] The four bridges within the Berkeley city limits include Gilman Street overcrossing, University Avenue underpass, and Ashby Avenue overcrossing (north and south) (FIGURE 1). In his reply on July 14, 1977, T.R. Lammers, CalTrans District Director, analyzed the bridges using a "conservative or pessimistic view in assessing the vulnerability of the bridges" since the structures are located on a vital transportation artery.[2] The Ashby Avenue north and the University Avenue bridges were found to be marginally resistant to seismically induced shaking since they are supported on reinforced concrete single column bents designed to pre-1971 standards[2] (FIGURE 3). These bridges also contain expansion joints similar to those that failed in 1971 but since the joints are fairly wide, the bridges may be able to withstand a moderate earthquake.[7] The Ashby Avenue south and Gilman Street overpasses were found to have good seismic resistance because they either have no joints or have very wide joints.[2, 7] It is possible to build a bridge of continuous concrete with no expansion joints provided the bridge is short enough (200-300 feet). Extra strength is built into the columns and abutments.[7]

Fortunately, the two vulnerable bridges in Berkeley are scheduled to be retrofitted in the early 1980's. The contract will be put out to bid in December, 1981 at a cost of $106,000 for University Avenue and $8,000 for Ashby Avenue north.[7] All vulnerable overpasses in the vicinity of the Bay Bridge eastern approach have already been retrofitted.[7]

At the interchange of Highways 13 and 24, two overpasses are located in the Alquist-Priolo Special Study Zone (within 1/8 mile of the Hayward fault). The Broadway bridge, while it was built in 1973, was designed before 1971. However, after the San Fernando earthquake, the design was changed to make the bridge seismically resistant.[7] The Temescal bridge was built in 1970 but was determined not to be vulnerable because it contains no expansion joints.[7] Although these two bridges are as seismically resistant as they can be, their close proximity to the fault means that problems still may arise due to strong ground shaking and/or surface rupture.

Berkeley City Roads

Damage to and blockage of roads maintained by the City of Berkeley will depend upon the nature of the road and its proximity to the fault. Roads which cross the fault will be subject to surface rupture, offset and extensive cracking. In addition, the more narrow roads such as Telegraph Avenue and College Avenue could be blocked and closed immediately following an earthquake due to debris from falling buildings and powerlines, and from auto accidents. On some of the wider streets such as Shattuck Avenue and University Avenue, on the other hand, debris clearance will be quicker and detour establishment easier. Finally, the narrow and curvy roads in the hills will be subject to landsliding (especially if the earthquake occurs during the rainy season). Damage can occur by sliding of the roads themselves as well as by debris sliding onto the roads from above. The hills region will be especially hard hit since the Hayward fault runs directly through the area.

Although many problems can occur on Berkeley city roads which would block emergency access to many sections of town, the Berkeley Emergency Operations Plan does little to deal with the situation. The Plan sets up a Transportation Service at the time of an emergency, whose basic function is "to coordinate needs and requests for vehicles with available drivers and vehicles (4, p. 179). In other words, the objective of the Service is to make transportation available by gathering and allocating vehicles and drivers, with little thought given to the conditions of the roads upon which the vehicles are supposed to be travelling. Some attention, however, is given to the problem of street clearing during an emergency. While street clearing is the responsibility of the Public Works Department, some input is needed from the Transportation Service Chief as to priorities if more than one street needs clearing.[4] The Plan gives a list of priority streets to be cleared and priority diverters to be removed in an emergency.

During and immediately after an earthquake, the Transportation Service of the Berkeley Emergency Operations Plan may be almost totally useless. There will undoubtedly be many streets needing clearing at one time and several will need actual structural repair before they can be used. In addition, drivers and vehicles assigned to report to various stations will probably find it difficult to reach their destinations. Those that do arrive will then have a hard time carrying out emergency assignments due to road damage.

The Berkeley Seismic Safety Element, designed to deal specifically with the earthquake hazard, does little better than the Emergency Operations Plan. The Seismic Safety Element does not discuss road damage at all but instead outlines evacuation routes from Berkeley. Evacuation of Berkeley after an earthquake, however, not only may be unfeasible but undesirable as well (except in case of a large fire or reservoir failure. During and after an earthquake, in the absence of fire or dam rupture, people should remain where they are since attempts at mass exodus will merely cause increased chaos and severely hamper emergency and rescue operations. Even if people desired to leave the city, six of the eight evacuation routes cross the fault and therefore may sustain damage resulting in closure of the roads for some time.

<u>Conclusions and Recommendations</u>

Little planning has been done concerning road damage during an earthquake. The City of Berkeley as well as the State of California should draw up plans which include lists of roads and highways likely to be damaged during an earthquake and how the major roads can be repaired quickly. Emergency procedure drills should assume that main roads are impassable and contingency plans should not depend on clear transportaion corridors. Finally, the earthquake hazard should be considered in the design and placement of all future roads built in California.

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