Effects of El Niño Storms
California's Pacific Coast Highway

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During the winter of 1998, heavy rains from El Niño storms caused widespread damage along California's central coast. A number of communities were isolated as the result of numerous road closures, due mainly to landslides, flooding, and debris flows. In some cases, severe landslides damaged large sections of roadway at various locations.

Pacific Coast Highway 1 was extensively damaged at 40 different locations in Monterey County. The damaged area extended for 112 kilometers (70 miles), from Carmel to the San Luis Obispo County Line. The California Department of Transportation (Caltrans) estimates that $16 million in damage along this 112-kilometer stretch alone resulted from the storms. Particularly hard hit were the coastal communities of Monterey, Carmel, and Big Sur. Indeed, Big Sur was in semi-isolation for 3 months.

The reconstruction was an enormous task requiring a well-orchestrated organizational effort and teams of highly skilled personnel to keep work progressing as rapidly as possible. A team of Caltrans engineers and 10 private contractors worked continually on the reconstruction effort, mobilizing approximately 150 people and a huge array of heavy equipment. Frequent rain and muddy conditions regularly intensified the complexities of the reconstruction, making it especially difficult to maneuver huge pieces of construction equipment, people, and supplies within the narrow confines of the roadway.

Protecting the environment of the coast during this time was a major element of the rebuilding strategy. Caltrans environmental planners worked closely with resource agencies and elected officials to provide solutions that would avoid or minimize impacts to the marine environment, streams and creeks, sensitive animal and plant habitats, and archeological resources. When reconstruction was completed, approximately 380,000 cubic meters of material (soil, rocks, and debris) had been moved.

Landsliding

Three exceptionally large ancient or Holocene landslides (occurring within the last 11,000 years) caused some of the biggest problems with reopening the roadway. In each case the roadway crossed the landslide in the mid or upper section of the slide. Typically, what affected the roadway was a large slide within a larger landslide complex. As the slide moved, the roadway dropped.

The slides occurring in this geologically sensitive area reveal evidence of multiple landslide episodes. Their features are generally compressional in nature, although extensional features have also developed, exhibiting internal structures such as thrust ridges, grabens, and extensional cracks. Particularly because of the multiple episodes of landslide movement, these landslide configurations are very complex. The many internal structures between the head and the toe of the slide made working in the area extremely difficult.

During January–March 1998, these landslides, considered stable under current climatic conditions, were partially reactivated by a combination of extreme weather conditions. The heavy rains saturated the ground mass, reducing the shear strength of the material. Heavy runoff flooded the upper portions of the mass, increasing the driving forces. Resisting forces at the toe of the slide were reduced as record sea wave heights, in excess of 10 meters, eroded the toe. As a result of the reduction in material strength, increase in driving forces, and reduction in resisting forces, slope stability decreased to well below equilibrium, and failure of the landmass ensued (see Figure 1). Eyewitnesses reported that in some cases, movement began with slow cracking, followed by sudden movement within 30 minutes; at other locations, the creeping movement occurred over several days, followed ultimately by sudden catastrophic movement. Given the magnitude of the sliding, major repairs were required even to establish a temporary road for emergency vehicles.

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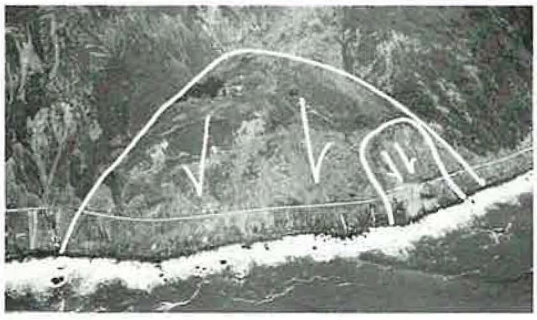
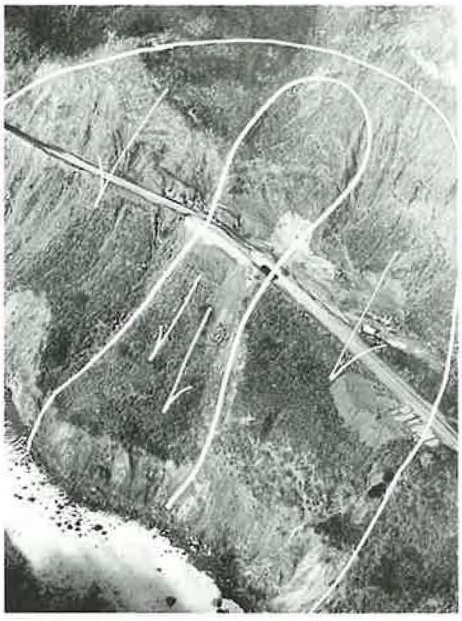
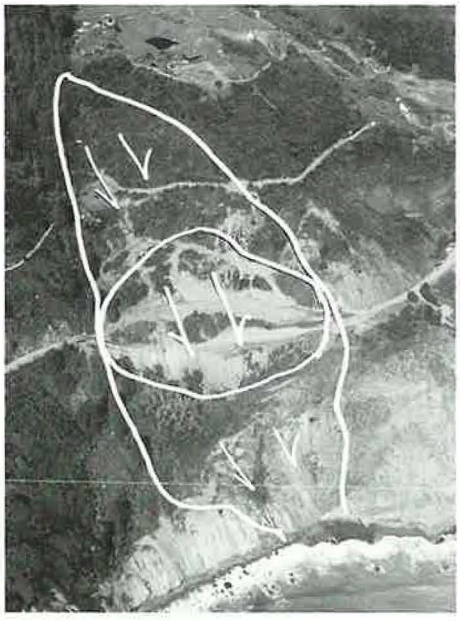
Three major landslides in Monterey, California (*from top*): Duck Ponds, Big Slide, Grandpa's Elbow.







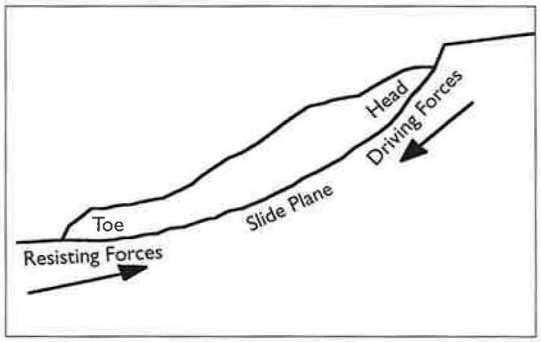


FIGURE 1 Simple schematic of a landslide.

The Duck Ponds landslide complex, which removed approximately 120 meters of roadway, is approximately 900 meters in length and 900 meters wide, encompassing about 275 acres of mountainside. The toe of the slide exits into the Pacific Ocean. The portion of the slide that affected the roadway was approximately 120 meters wide and 300 meters long, occurring within the larger landslide complex. This smaller slide moved along a portion of the ancient slide plane, connecting to the toe of the slide at sea level. The depth to the slide plane was estimated at 60 meters. Approximately 9 acres of earth moved—equivalent to 1.5 million cubic meters or 4 million tons of earth.

Big Slide landslide is approximately 600 meters long, toeing out into the Pacific Ocean. Its average width is estimated to be 200 meters and its thickness 60 meters. Approximately 32 acres of earth moved—equivalent to 7.5 million cubic meters or 17 million tons of earth. About 90 meters of roadway translated downslope approximately 5 meters. Subsequent cracking and distortion made the roadway impassable.

Grandpa's Elbow landslide transported 360 meters of roadway approximately 10 meters downslope. This slide is estimated to be 900 meters in length and 360 meters wide. The depth to the slide plane is about 60 meters. Approximately 82 acres of earth moved—equivalent to 20 million cubic meters or 45 million tons of earth.

Mitigation

The enormity of these slides made many of the standard mitigation measures impractical. Removal would have required the transportation and disposal of millions of cubic meters of material, while buttressing with a retaining structure would have necessitated a massive structure. Both approaches would have been highly expensive and taken 1–2 years or longer to complete.

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