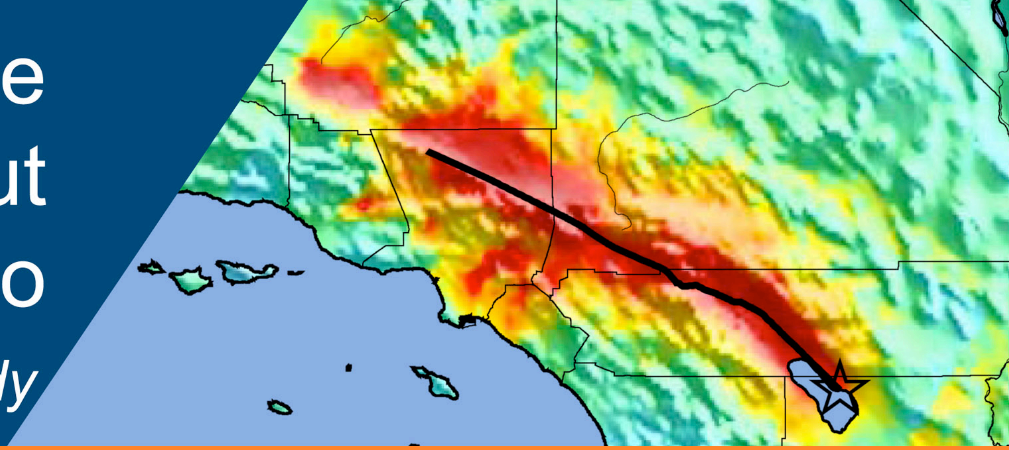
# The ShakeOut Scenario

*Supplemental Study*



# Railway Network

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and

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By
William G. Byers, P.E.
Lenexa KS
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Note: over the course of the ShakeOut Scenario, the project name evolved. Where a study mentions *the SoSAFE Scenario* or *San Andreas Fault Scenario,* it refers to what is now named the ShakeOut Scenario.

# Impacts of a M7.8 Southern San Andreas Earthquake on the Railway Network

**William G. Byers, P.E.**

## Impact of earthquakes on railroads

Railroad damage has been reported in about 100 earthquakes that occurred since 1859. Coverage of damage in the literature varies from a dedicated monograph [McCulloch & Bonilla], through detailed coverage in general reports [Dutton; Steinbrugge & Moran] and papers dedicated exclusively to railroad damage [Wallace et al; Byers 2000; Byers 2001] to single sentences in general reports. A few papers discuss the potential effects of earthquake damage on the operation of the overall railroad network [Day; Day & Barkan]. Review of the reported damage reveals several tendencies.

Except where loosening of ballast by shaking has allowed track buckling due to thermal compression in the rails, practically all track damage has been due to permanent ground movements, including landslides and rockfalls, liquefaction and embankment settlement. Such permanent ground movements occurred in at least three fourths of the earthquakes. In the 1999 Izmit (Kocaeli), Turkey earthquake, tracks were crossed by the fault rupture at three locations causing significant misalignments.

Major damage to railroad tunnels has primarily occurred where there was movement (sometimes a secondary effect) on a fault intersecting the tunnel. Fallen rocks in unlined tunnels and damage to tunnel linings from shaking have, typically, produced limited damage.

Railway bridge damage was documented in slightly over half of the earthquakes in which railroad damage was reported. Piers were separated where the rupture of the San Andreas Fault passed under a span of a Southern Pacific bridge in the 1906 San Francisco earthquake. In several earthquakes, including the 1886 Charleston, SC earthquake and the 1964 Alaska earthquake, extensive bridge damage was the result of lateral spreading in flood plains due to liquefaction. Except in cases where entire bridges were buckled by permanent ground movements, those where spans were severely displaced or dropped due to pier movement and those where spans were washed off piers by a tsunami, the greatest damage was typically to the substructures, particularly the columns of concrete viaducts. Damage to relatively massive piers due to shearing along construction joints ranged from severe to minor enough that the bridge could remain in service with a speed restriction. In the 1952 Kern County earthquake, the 1999 Izmit earthquake and the 2001Atico earthquake in southern Peru, there was no damage to railroad bridges in areas where there was severe damage to other railroad facilities. Tests on a typical steel railway span's bearings [Maragakis *et al*.] demonstrated their ability to resist very large lateral loads.

Highway or street overpasses fell on tracks in the 1964 Niigata, Japan earthquake where an overpass fell on a passing train, the 1971 San Fernando earthquake and the 1995 Kobe, Japan earthquake.

Derailments of moving trains or overturning of standing equipment, including incidents caused by tsunamis and flash floods from earthquake-caused dam failures, have occurred in about one fifth of the earthquakes that have damaged railroads. Although some have been the result of running over damaged track and one affected a train that was running across the fault rupture at the time of the 1980 El-Asnam, Algeria earthquake, many were caused by the effect of ground acceleration on equipment. Most of these were in the near field, often on tracks making angles of 30 degrees or less with the strike of the fault. Examples include the 1906 San Francisco earthquake – overturned standing freight cars and narrow gage steam locomotive with attached passenger cars and derailment of a moving freight train, all within 5km of the fault rupture, the 1994 Northridge earthquake – a freight train derailment less than 3km from the fault rupture, the

1995 Kobe earthquake – a number of incidents, including derailments of moving trains and derailment or overturning of standing equipment – much of it on collapsed structures, within about 5km of the fault rupture, the 1999 Hector Mine earthquake – a passenger train derailment about 3km from the end of the fault rupture, and the 2004 Niigata earthquake – a passenger train derailment about 10km from the fault rupture. However, trains operating in areas of severe shaking were not derailed in the 1999 Izmit earthquake or the 2001 Bhuj (Gujarat), India earthquake. Because the direction, magnitude and duration of acceleration influence the risk of derailment or overturning and no complete seismograph data are available from stations in close proximity to derailment sites or to the known locations of trains that were not derailed, the required conditions cannot be defined. Lateral/vertical wheel load ratios from 0.65 to 1.3 have been accepted as critical values for various derailment mechanisms. Because of the small frequency of earthquake-acceleration caused derailments and the uncertainty in possible train locations, the dynamic characteristics of cars carrying unknown loads and potential ground motions, an incentive to develop a practical model is lacking. However, measures to reduce the risk of derailments related to other track-wheel interactions have probably improved the performance in earthquakes. It is of interest that the locomotive engineers of the trains derailed in both the Northridge and Hector Mine earthquakes reported observing movement of the track ahead of the train before the derailment.

North American railroads restrict operations and require inspections after earthquakes with magnitudes of 5 or greater. Trains will be stopped, or operated at restricted speed – depending on the magnitude, for considerable distances from the epicenter (typically, at least 100 miles stopped and 150 miles at restricted speed for large California earthquakes) until required inspections are completed. ("Restricted speed" is defined as a speed at which the train can be stopped within half the range of vision, but not exceeding 20mph, while looking out for a list of hazards.) Inspection can require from four to eight hours, even when there is no damage. Several days may be required to work out the resulting delays and recover fully normal operation, both in and well beyond the restricted area. (TranzRail, the privatized New Zealand rail system, bases inspection requirements on intensity rather than magnitude, requiring inspection for MMI=7, or greater. Although intensity is more directly related to potential railroad damage than magnitude and distance from the epicenter, it requires observations at all significant locations and, in North America, is not as readily available as magnitude and epicenter location which are usually available within a few minutes after the earthquake.)

Effects on railroads in other California earthquakes and in the 1999 Izmit earthquake on the North Anatolian Fault, frequently considered to be analogous to the San Andreas Fault, are probably particularly relevant.

**Overview of railway facilities and operations**

The Los Angeles Basin is served by two freight railroads, the Burlington Northern Santa Fe (BNSF) and the Union Pacific (UP), which acquired the former Southern Pacific (SP) in1996. Additionally, Metrolink, a commuter line, operates in the basin. Much of Metrolink's track was acquired from the freight roads (or their predecessors), is physically connected to them and is utilized by them to handle local freight, and freight to San Diego, during hours when commuter operations allow. Within the basin, the freight railroads have a large number of yards and other facilities and are interconnected at a number of locations, allowing rerouting of traffic into and out of the basin. However, rerouting will result in congestion within the basin as well as the problems usually associated with detour operations. The relationship between the lines serving the Los Angeles Basin and the rest of the rail network is shown in Fig. 1. The scenario fault rupture is indicated in purple. In addition to a line to San Diego which does not provide a connection to the rest of the US network, there are five routes out of the basin. These are shown in the insert in Fig. 1. Information on these routes is summarized in Table 1. The traffic information is estimated from historical information on annual traffic distributions since 2000 and is subject to both seasonal and daily variations. Freight trains in the area are dispatched, by the owner of the line, out of a common dispatching center in San Bernardino which allows increased efficiency in dispatching of trains moving from one road to another. Although the one-story building housing the dispatching center was built in 1989-90 and would probably survive the scenario earthquake, dispatching and/or communication equipment might be damaged to an extent that the center would become temporarily inoperable due to dispatching consoles sliding from desks and/or damage to communication equipment from overturning or sliding. Replacement of damaged equipment could take one or two weeks. If this should happen, the dispatching function would be transferred to Fort Worth for the BNSF and to Omaha for the UP within 30 minutes or less, assuming that communication with Southern California is possible. This would have no effect on the safety of operations as the operating rules provide, in case of communication or signal failure, for safe operation of trains to points where they are stopped due to having no authority to proceed. Dispatching from Fort Worth and Omaha would be less efficient than from San Bernardino due to the shortage of dispatchers familiar with the territory and easy communication between the two railroads' dispatchers.

The UP owns a line along the coast, shown in red on the main map of Fig. 1, from a connection with Metrolink at Burbank, through Santa Barbara, to San Jose where it connects with the rest of the U.S. system. Metrolink operates commuter trains as far as Oxnard (beyond Burbank) and UP has freight operations over Metrolink into downtown Los Angeles. The line crosses the San Andreas Fault near Watsonville and should not be significantly affected by the scenario earthquake as it would experience peak ground accelerations less than 0.2g and less than 0.1g except in Burbank. It normally carries traffic for coastal points and is used by Amtrak passenger trains operating north out of downtown Los Angeles over Metrolink. The line normally carries about three percent of the Los Angeles freight traffic. While other lines were impassable, it could probably carry between 20 and 30 percent of the total traffic for a period of a month or more if sufficient qualified crews, and/or pilots to work with crews not qualified on the territory, were available. It is possible that Amtrak employees qualified on the territory could be made available as pilots and, if detouring for sufficient time appears likely, additional crews could be qualified on the territory. Such a level of use would probably not allow sufficient track time for significant maintenance and could not be continued for an extended period without temporary reductions to allow maintenance.

Four lines cross the scenario fault rupture. A Metrolink line from Burbank to Palmdale was formerly owned by the SP and carries little or no freight. It crosses the fault rupture between two small lakes at Palmdale, downstream from the dam separating them. It would probably be out of service for the period that a detour route is required. Union Pacific's Inland California and Pacific Northwest traffic is handled over a line from West Colton, through Cajon Pass and Palmdale to Mojave, where it connects with other lines. This amounts to about six percent of the total traffic. Traffic to the Midwest and Northeast, and BNSF traffic to other points, is handled over the BNSF line through Cajon Pass, where the UP has operating rights from Riverside to Daggett – east of Barstow. Traffic over this line amounts to nearly 60 percent of the total freight traffic and includes a pair of Amtrak trains. The line carries approximately 100 trains per day on two main tracks. The lines in Cajon pass cross the fault rupture where the offset will be about 15 feet and will be severely damaged. Union Pacific's traffic to Arizona, Texas and the Southeast, together with two Amtrak trains, is handled over a former SP line through Yuma that crosses the fault rupture on a low embankment at a location east of the Salton Sea where the offset will be about 12 feet. This line carries nearly one third of the total traffic and is operating at near its capacity. There are active plans to construct an additional main track on the BNSF line through Cajon Pass and the UP line through Yuma. This will increase the capacity of the lines but will have no significant effect on redundancy in case of an earthquake since the additional tracks would be subject to the same damage as the existing tracks.

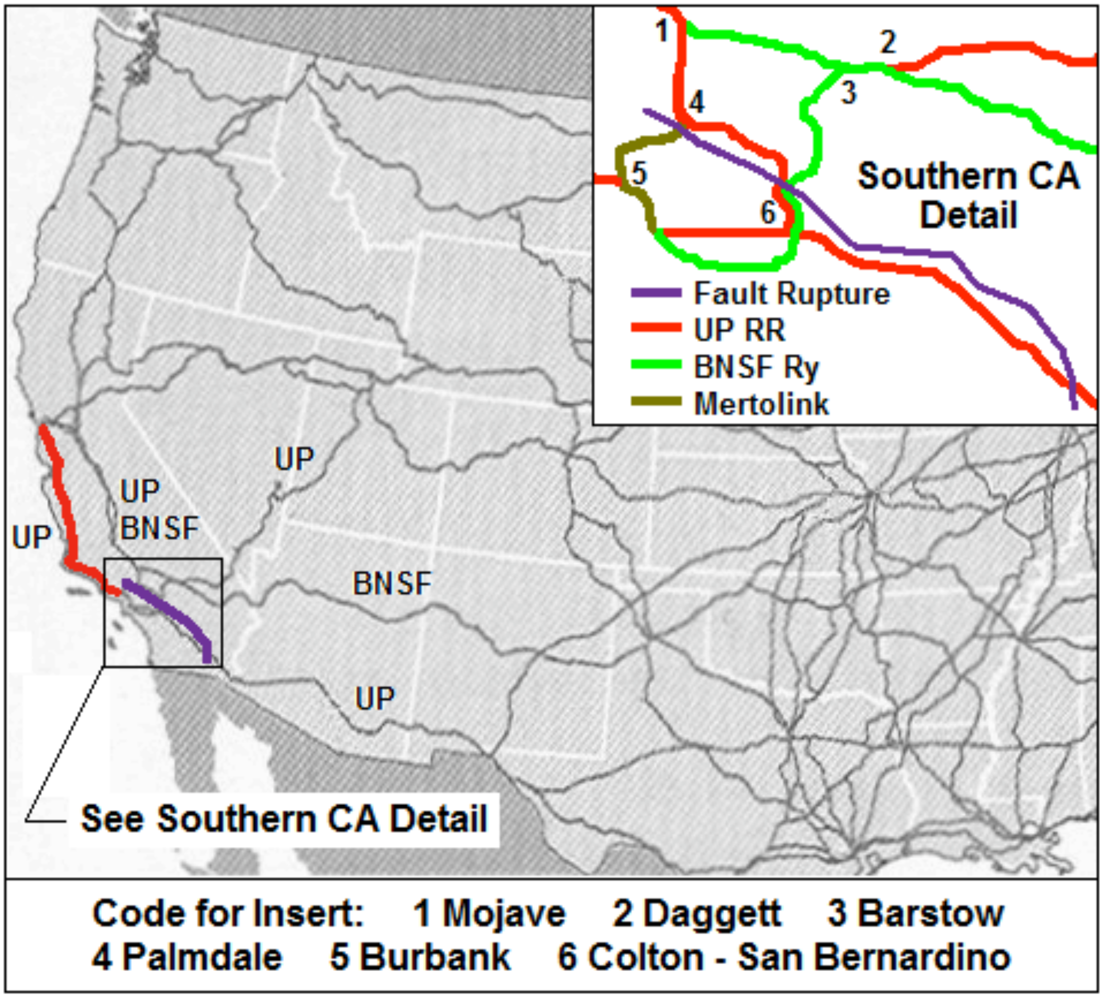


**Fig. 1 Railroad network in Western United States**

These railroads handle all types of freight that move into or out of the basin, including containers and trailers loaded with parcels or mail. The traffic includes both items used or produced locally and items moving through the ports of Los Angeles and Long Beach. Much of the traffic is carried in containers or trailers carried on flat cars. There are intermodal facilities for these at the ports of Los Angeles and Long Beach, at other locations in Los Angeles County and in San Bernardino. Bulk commodities are carried in open or covered hopper cars or tank cars. Carload lots of other commodities may be carried in gondolas, flat cars, box cars, refrigerator cars or special purpose cars such as those used for transporting automobiles. Some of the items handled are hazardous materials, including flammable liquids and gasses, toxic materials and explosives. Containers for less-than-carload quantities, the design of cars for carload quantities and, for the most hazardous materials, the location of cars in the train, are covered by federal regulations designed to minimize the hazard in case of an accident. Although performed by others, the loading or unloading of liquids or gasses can result in exposure to leakage during an earthquake. In other earthquakes, equipment in yards has been overturned by ground accelerations or derailed by liquefaction-induced settlement of tracks. Incidents of this type would have only a minor effect on operations as alternate tracks could be used until derailed cars are re-railed. There are yards in San Bernardino and Colton where this might occur. In addition to yards, there are locomotive servicing and car repair facilities at various locations in the area. They are relatively robust and, with the possible exception of the yards and facilities at San Bernardino and West Colton, are probably far enough from the fault to escape significant damage. Based on experience with other derailments, any tank cars or covered hopper cars that might be overturned while standing or moving at the slow speeds involved in yard operations are unlikely to have significant spillage of their contents. The contents of overturned open hopper cars would be spilled but would not pose any hazard although a heavy rain before cleanup might cause leaching of objectionable material.

Table 1

<table>
<tr><th rowspan="2" colspan="2">Railroad<br>Line</th><th colspan="3">Estimated<br>Freight Traffic Distribution</th><th colspan="2">Estimated<br>Earthquake Damage</th></tr>
<tr><th>% of<br>Total</th><th>Percent<br>Inbound</th><th>Excess<br>Capacity</th><th>Severity</th><th>Damage<br>Mechanism</th></tr>
<tr><td colspan="2">UP to San Jose</td><td>3</td><td>60</td><td>Significant</td><td>None</td><td>NA</td></tr>
<tr><td colspan="2">Metrolink to Palmdale</td><td>1</td><td>33</td><td>Uncertain</td><td>Severe</td><td>Shaking & ~3m (~9’) Surface Slip</td></tr>
<tr><td colspan="2">UP to Palmdale & Mojave</td><td>6</td><td>64</td><td>Moderate</td><td rowspan="3">Severe</td><td rowspan="3">Shaking & 4.5m (~15’) Surface Slip</td></tr>
<tr><td rowspan="2">BNSF – Cajon Pass (also UP to Midwest)</td><td>BNSF</td><td>47</td><td>53</td><td rowspan="2">Limited</td></tr>
<tr><td>UP</td><td>12</td><td>50</td></tr>
<tr><td colspan="2">UP to Yuma & Southern States</td><td>31</td><td>48</td><td>Negligible</td><td>Severe</td><td>Shaking & 3.6m (~12’) Surface Slip</td></tr>
</table>

**Damage scenario**

All lines in Southern California would have service interruptions of at least four to eight hours until inspections established their safety. However the UP line to San Jose, because of its location, should not have any damage beyond possible signal malfunctions due to overturned relays. These would not pose a safety issue but would slow train movement through blocks governed by affected signals and across grade crossings with inoperative crossing protection. They could be quickly repaired, probably within two or three hours after inspection is completed.

Although there is a distinct risk that the dispatching center at San Bernardino would become temporarily inoperable, this would affect near-term resumed operations, not the immediate safety of trains. Train movements, but not train safety, depend on communication with the dispatching center. The final stage is by assigned-frequency radio but transmission to the radio tower involves railroad owned microwave systems and/or leased channels on commercial carriers. The towers involved are robust and there is considerable redundancy in the system.

A prevalent concern is the possibility of a train being derailed by running over earthquake-damaged track. Although this is a possibility, it is unlikely. Locomotives are radio equipped and any trains in the area would be notified of the earthquake within minutes of its occurrence by the train dispatcher and/or the crews of trains that had felt the earthquake. They would then either reduce their speed to restricted speed or stop. In either case, they would be able to avoid running on disturbed track. Once the epicenter location and earthquake magnitude had been determined, trains within a to-be-determined distance from the epicenter, of at least 100 miles, would be stopped until the track, bridges and signals had been inspected and found safe. Inspections would be conducted from the track, using vehicles that can operate on both track and highway, until a point was reached where the track was impassable. If possible, the vehicle would then be operated on the maintenance road on the right-of-way until it could be put back on the track. Inspections would be conducted from both ends of the affected area and, possibly, from intermediate points. If the track on the line is passable, inspection would be completed within six to eight hours after the earthquake – based on times required for earthquakes in California and the Pacific Northwest during the last 20 years. Once a portion of the track was found to be safe, it would be used to move stopped trains out of the affected area.

*Cajon Pass*

The rail lines through Cajon Pass, the area where railroad damage would be most severe and the loss of service would affect over half of the rail traffic, are shown, with scenario peak ground acceleration, in Fig. 2 and, with scenario modified Mercalli intensity, in Fig. 3. In Fig. 4, bridge and overpass locations on the BNSF line with two main tracks which carries nearly half the total Los Angeles area traffic and the location of the single track UP line are shown in greater detail.

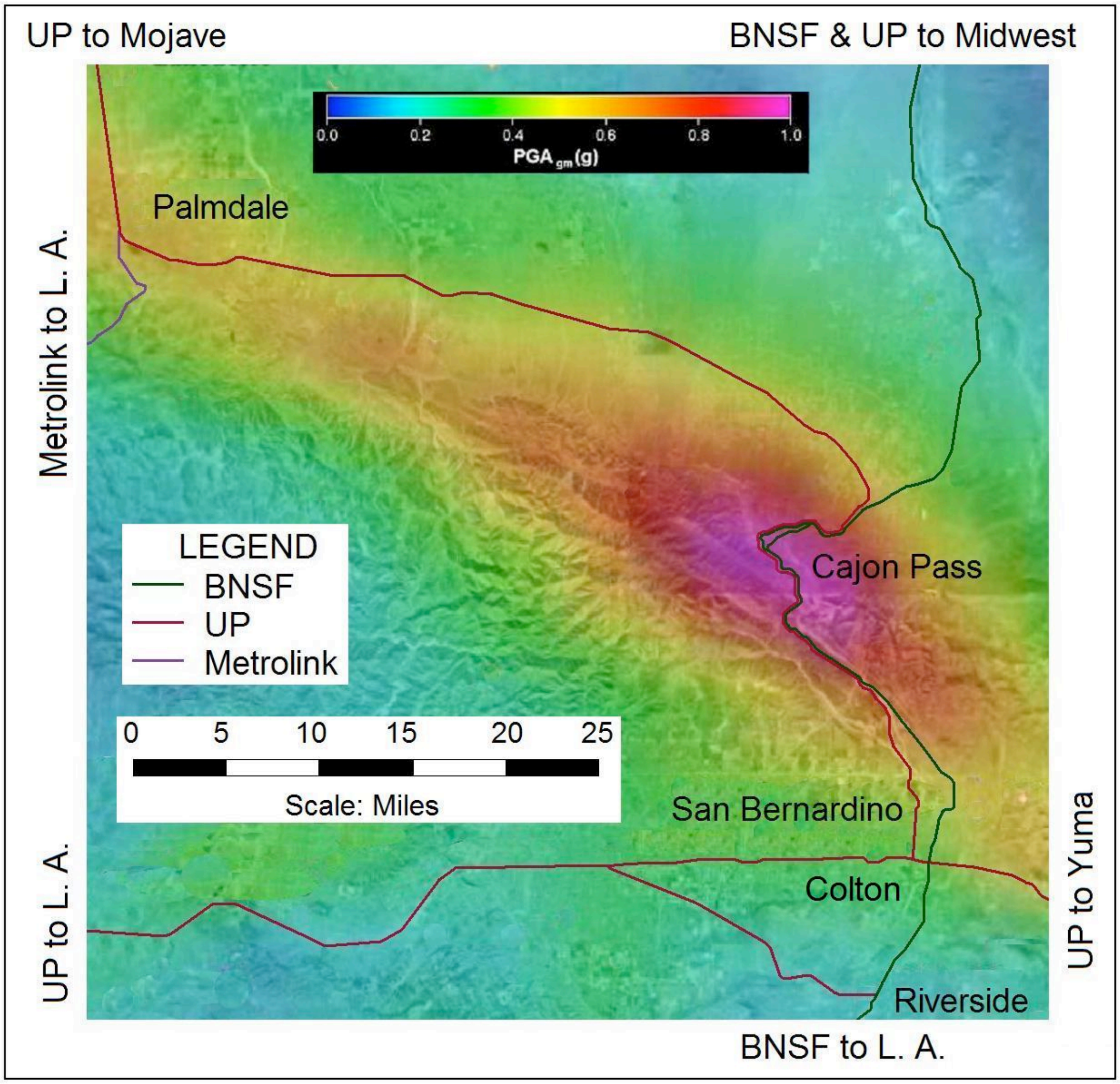


**Fig. 2 Railroads and scenario peak ground accelerations near Cajon Pass**

The most certain damage from the scenario earthquake is bending of rails and an impassable alignment due to the offset at the fault. The insert in Fig. 6 illustrates this type of damage, but on a low fill which did not require significant grading to provide a roadbed. Because of the topography, establishment of useable alignments through this area will be relatively time-consuming and the amount of equipment that can be utilized will be limited by congestion. Although possibly not realistic for permanent alignments because of interference with flow in the creek, it appears that the quickest way to reestablish rail connections would be to build new embankment on the southwest side of the fault between the BNSF and Cajon Creek to connect with the BNSF alignment to the northeast of the fault and build embankment on a similar plan for the UP. A retaining wall along the creek might be required to alleviate adverse effects on creek hydraulics. Some type of stabilization of the fault gouge to a considerable depth, possibly by injection grouting, either before constructing embankment over the fault or as soon as possible after it is completed, should be part of the construction. Considering the damage to railroads in the 2001 Atico earthquake in southern Peru, and the related recovery time, tracks should be in service on the new alignment in no more than a week.

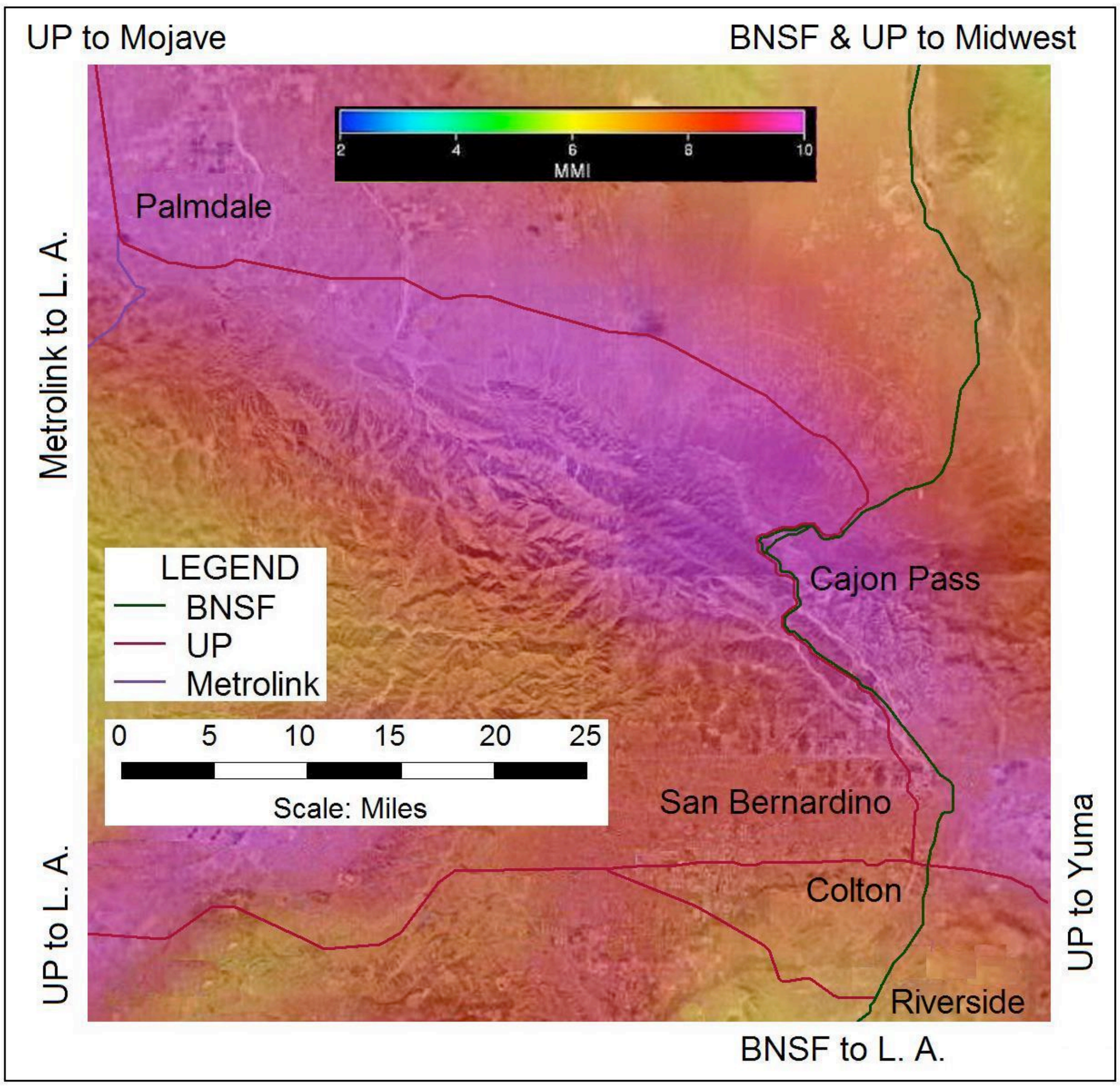


**Fig. 3 Railroads and scenario modified Mercalli intensities near Cajon Pass**

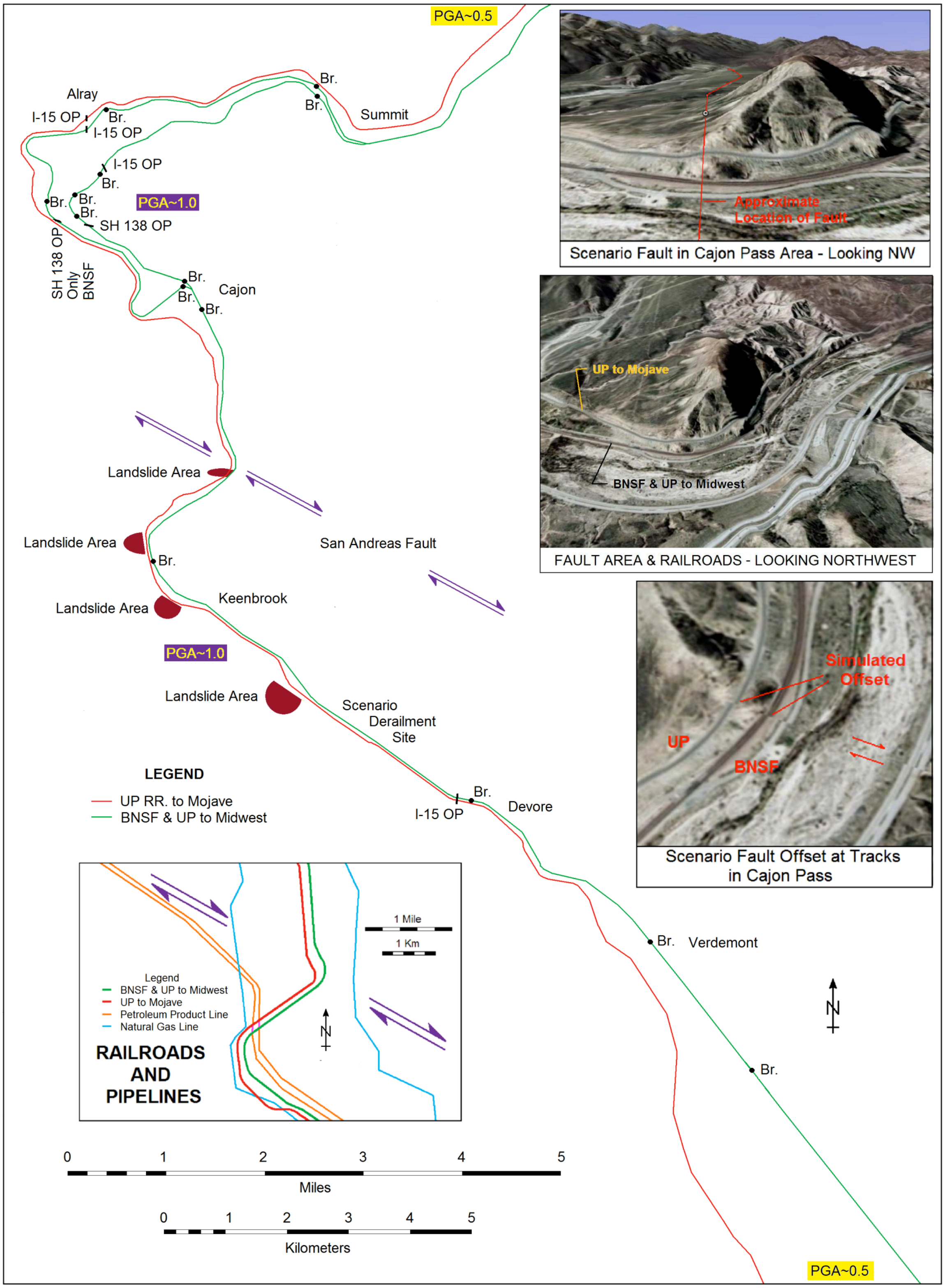


**Fig 4 Details of Cajon Pass area**

There are natural gas and petroleum product pipelines more-or-less parallel to the railroads through Cajon Pass. Their location, based on Lowe *et al*, is shown in an insert in Fig. 4. It seems almost certain that one or more of these lines would be ruptured and, although there are valves on both sides of the fault and the rupture locations would probably be at an appreciable distance from the tracks, the resulting fires could delay both inspections and repairs of railroad damage. There is even the possibility that large wildfires would be ignited, preventing access to the area for a considerable time.

Based on timetable speed restrictions for westbound trains and practical speed on the ascending grade for eastbound trains, average time that trains will be in the area with PGA>0.5 is approximately one hour. With a typical traffic density of 100 trains per day on BNSF, four trains would be within this area at the time of an earthquake. An additional train would be within the area on the parallel UP line. Although it is reasonably probable that none would be derailed, derailment of as many as three is not unrealistic for a worst-case assumption. The most probable location for a derailment would be west of Keenbrook where the railroads are nearly parallel to the fault. A reasonable scenario would involve derailment of one train between Keenbrook and Devore. According to Federal Railroad Administration statistics, there were 1009 mainline derailments in 2004, the latest year for which data have been compiled, involving 29 releases of hazardous material from locomotive consists and 47 releases from cars. There is no reason to believe that the probability of a hazmat release would be different for an earthquake-caused derailment than for derailments in general and the probability of a hazmat release becomes about 8%. Releases from locomotives would be fuel and a significant percentage of the releases from cars would be liquids. Therefore, releases requiring an evacuation, although possible, are extremely unlikely and any hazmat problems, other than fires, would probably be the necessary cleanup. The release of about 20 gallons of benzene from a broken pipe to the safety valve on an overturned tank car, as was observed in another derailment where the broken pipe was plugged by a railroad employee to stop the leak, would represent a realistic hazmat release and be an appropriate scenario. Most derailments are now cleared by contractors. One of the primary contractors specializing in this type of work has branches at Fontana and Stockton and could bring equipment in from either side of the fault. Typical times for clearing derailments without complicating fires or hazmat releases are less than 24 hours.

There is a reasonable likelihood of a landslide at one or more of the locations shown in Fig. 4 closing the UP track and a smaller probability that it would also affect the BNSF tracks. Once equipment reaches the site, clearing the debris should be a matter of several hours.

There are 20 steel bridges consisting of 47 spans with a combined length of 2227’ on the part of the BNSF line subject to potentially damaging ground motions. (This counts parallel bridges on adjacent tracks as separate bridges.) Damage that would put a steel bridge out of service for a significant length of time appears relatively unlikely. The steel bridges have massive piers which could be expected to perform at least as well as the piers at the SP’s Pajaro River bridge did in the 1906 earthquake. The most severely damaged pier in that bridge was pier no. 5 which was adjacent to the fault rupture passing between piers 4 and 5. Fig. 5 is a photograph of the damage. The corbel was doubtless shifted by relative movement of the span which crossed the fault. A failure similar to the shear failure in the pier stem could probably tolerate operation at very low speed until the spans could be supported on falsework.

Near Cajon, there are two prestressed concrete trestles on steel piles crossing Cajon Creek with lengths of 180’ and 277’, consisting of 28’, 30’ and 33’ spans. This is a bridge type that has not been exposed to large seismic loads. If reconstruction of these bridges were necessary, it could be accomplished within three days, once material and forces were on site. The worst realistic scenario is dropping of a few spans off their bents. Repairs would consist of temporary trestles in the affected spans, which would be constructed within 72 hours after the earthquake, followed by installation of replacement spans after service is restored. Between Verdemont and San Bernardino, there is a reinforced concrete underpass with spans of 36’ and

44’ under the two tracks. This bridge type would be more subject to damage than steel bridges but would be subject to less severe shaking. A damaged span could be temporarily supported on cribbing. It is entirely possible that there would be no bridge damage that would prevent continued operation of the railroad. In the worst case, repairs/reconstruction necessary to allow normal use of all bridges should be completed in less than two weeks and one BNSF track should be available within less than one week.

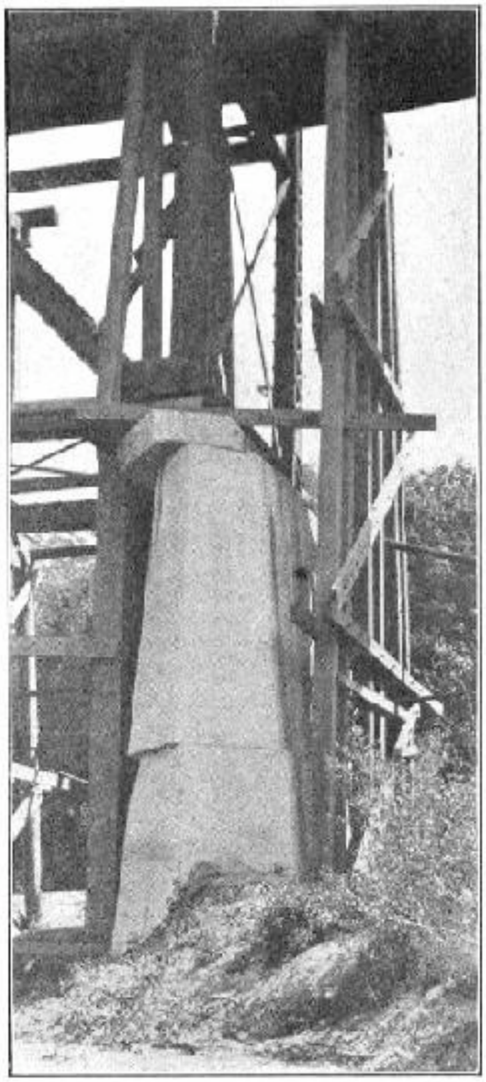

**Fig. 5 Pier 5 – Pajaro River Bridge**
[Fig. 2 of Wallace *et al*]

There are 13 overpasses over the BNSF in regions with a PGA>0.4g. Five of these and two over the UP, shown in Fig. 4, are likely to be exposed to a PGA>0.8g. An additional seven are in the San Bernardino Basin, primarily on city streets, and could have an unexpected response to basin-induced amplification and oscillation at a critical period. It seems likely that, in spite of seismic retrofits, one or more overpasses would fall on the track. Clearing debris from a span collapsed on a track would probably require about 24 hours.

Considering inspection time, mobilization time in the order of 24 hours and time for repairs which would occur simultaneously at several locations, the lines through Cajon Pass would be back in service within one week.

*UP Line to Yuma*

About sixty miles of the Union Pacific line from San Bernardino to Yuma runs roughly parallel to and, for about half of its length, between five and ten miles from, the San Andreas Fault. The line runs along the east side of the Salton Sea, within one or two miles of the fault for about 20 miles, as shown in Fig. 6, until it turns east and crosses the fault. If there is a train in this area at the time of the earthquake – a realistic assumption considering the traffic density, there is a considerable risk of its derailment. For most of the rest of its length, it is far enough from the fault that, although possible, derailments caused by ground acceleration are unlikely. The location of the line does not make landslides a hazard and major bridge damage is unlikely.

The line crosses the fault rupture on a low embankment, as is evident from the insert in Fig. 6, at a location where the offset will be about 12 feet. Unless a high water table from the Salton Sea results in liquefaction, this situation will be very similar to one of the fault crossings in the 1999 Izmit earthquake where one of two tracks was returned to service within 45 hours after the earthquake. A photo furnished by the State Railways of Turkey, showing this damage, is an insert in Fig. 6. After the Izmit earthquake, a new alignment was constructed to connect the offset tracks within a few days but over a month after they were placed in operation it was still impossible to maintain track surface over the fault as an arch of compacted material had not yet formed over the loose gouge. (Operating speed was severely limited and the track was inspected after every train.) Some type of stabilization of the fault gouge to a considerable depth, possibly by injection grouting, should be part of the reconstruction at the fault crossing.

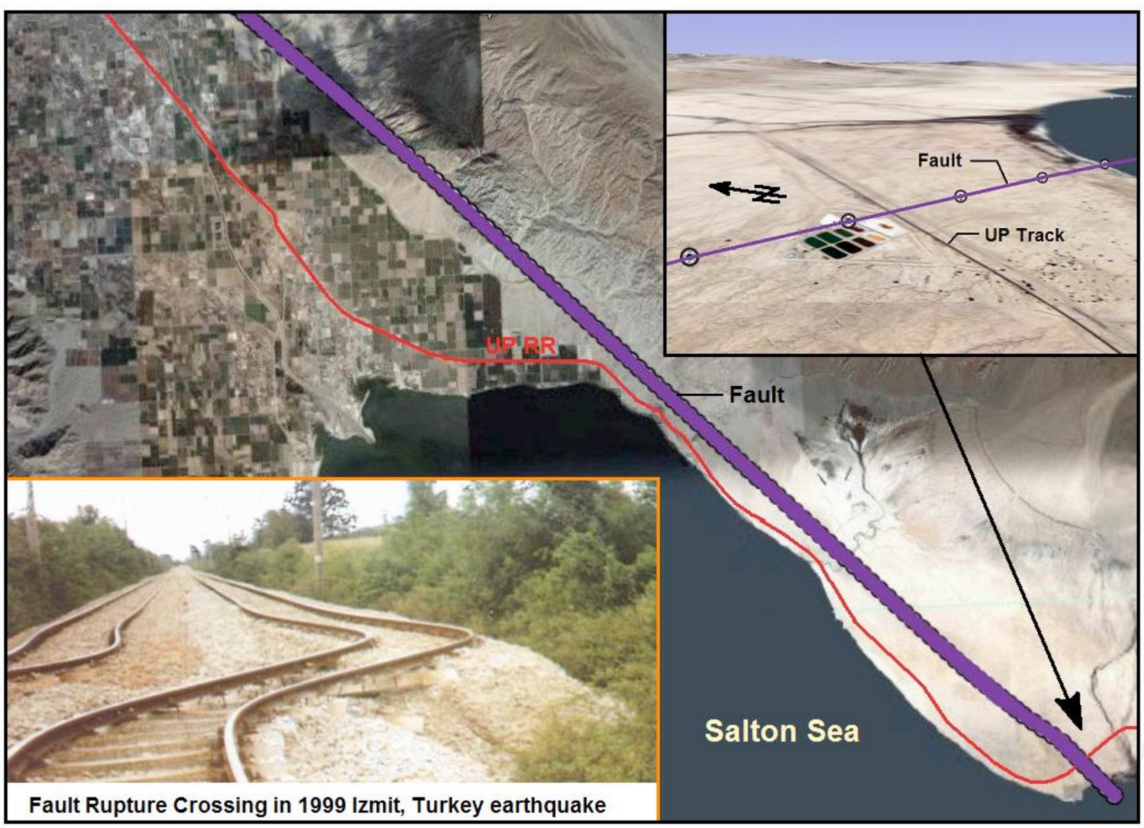


**Fig. 6 Fault crossing and alignment along Salton Sea of UP line to Yuma**

*Metrolink line to Palmdale*

The Metrolink line carries little freight traffic and will be out of service due to crossing the fault rupture where the offset is about nine feet. The line is about 100 yards downstream from the dam for Lake Palmdale which also crosses the rupture as shown in Fig. 7. If the dam is breached – which is probable, the track and embankment will be washed out for the length of the breach. If this happens, the flood water may be rapidly dissipated allowing repairs to begin. A longer period out of service could result from precautions related to a damaged dam with a full reservoir. Any train, including commuter trains, operating in the vicinity of the breached dam could be exposed to the flash flood. Other, less significant damage to the line, including slides in cuts or embankments and minor damage to tunnels, is possible. If the dam is not breached, repairs at the fault rupture may be complicated by a high water table which may result in liquefaction and generalized instability of soils at the location. Stabilization of fault gouge under the embankment will be required. If the dam is breached, the line would probably be back in service in about a week. If it is not, the line would be out of service until the Lake Palmdale reservoir is drained and repairs taking an additional three or four days are completed.

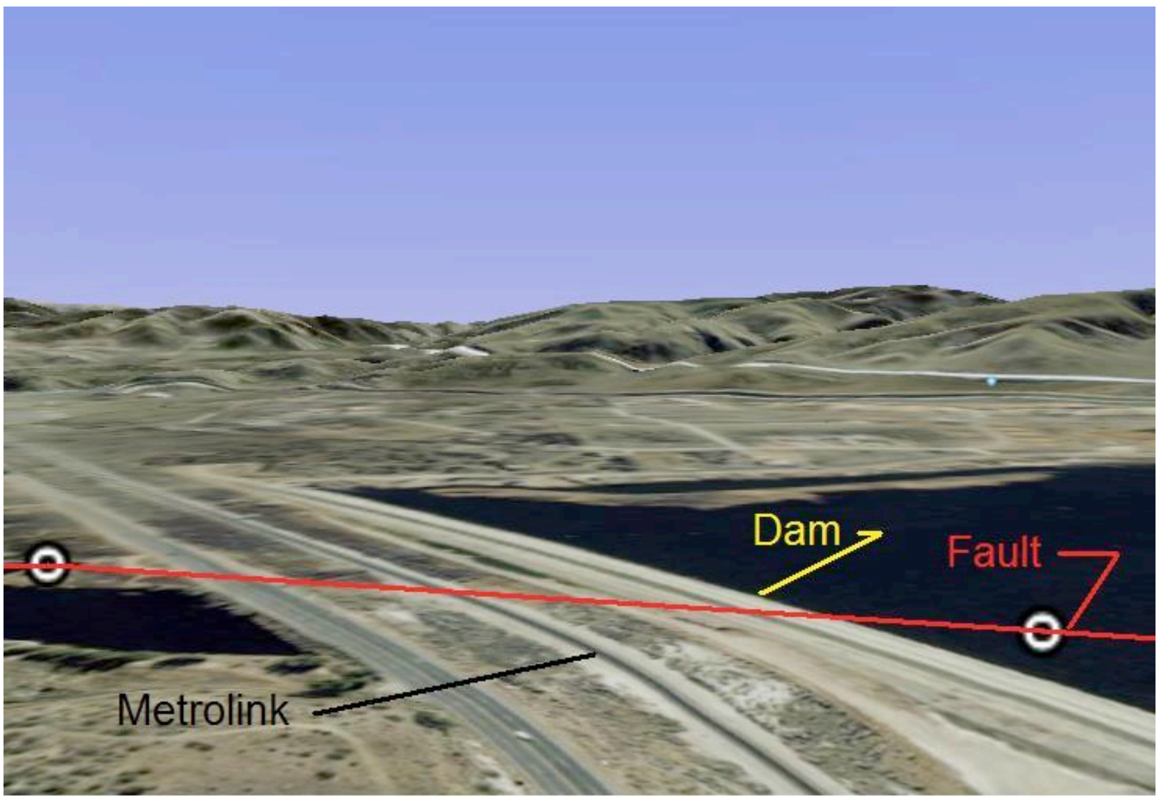


**Fig. 7 Fault rupture, Lake Palmdale. Dam and Metrolink track**

*Post-Earthquake Operation*

Initially, all traffic will be handled over the UP line to San Jose which, unless traffic is unusually light at the time of the earthquake, will be stressed to carry 30 percent of the traffic. There will be a conflict between the needs of commuters and the efficient movement of freight on the portion of the line between downtown Los Angeles and Oxnard. The UP line through Yuma will probably be out of service for two days and has limited capacity for additional traffic but could carry some BNSF traffic to Texas. The lines through Cajon Pass will be out of service for approximately a week, possibly more. Traffic to Northern California and the Pacific Northwest carried by the UP line through Cajon Pass and traffic to the Midwest carried by the BNSF line could be carried by the San Jose line. Some BNSF traffic to Arizona, New Mexico, Texas and the South could be added to the UP traffic on the line through Yuma. Many shipments will have to be delayed until the Cajon Pass lines are repaired. There will probably be extreme competition for repair resources but the railroads will do a portion of the work with their own forces, bringing in forces from other areas as necessary, and may be able to make commitments to contractors ahead of government agencies.

**Recommendations**

Although impassability of the tracks in Cajon Pass would be obvious almost immediately, obtaining, by usual means, the information necessary to plan repairs could be seriously delayed. Advance arrangements should be made to have helicopters committed for use in post-earthquake inspections. During the 1993 floods in the Midwest, helicopters were used successfully to assess railroad damage over a large area. Although they would not provide the access necessary to assure safe operation and provide a substitute for detailed on-track inspection, they would make possible the determination of the locations and extent of damage such as fault offsets, landslides and collapsed structures in otherwise inaccessible areas, as well as facilitating the removal of stranded train crews.

There is a strong possibility that the dispatching center at San Bernardino will survive without structural damage but become inoperable due to damage to essential equipment. Although trains could be dispatched from other locations, the advantages of having all involved dispatchers in the same room during the recovery period would be even greater than during normal times. Communication, dispatching and emergency power generation equipment should be physically secured to reduce the risk of damage. This could also be beneficial in the case of other Southern California earthquakes.

Since there may well be a conflict between the needs of commuters and the efficient movement of freight, coordination of commuter operations and the potential operation of a sizeable number of fright trains on the Metrolink route between downtown Los Angeles and Oxnard should be planned in advance of a major earthquake on the San Andreas Fault. This should be worked out between the Union Pacific and Metrolink, with or without input from local government.

The relocation of the rail lines at the fault crossing in Cajon Pass will be necessary for the restoration of normal rail service into the Los Angeles area and should be accomplished as rapidly as possible. Work to this end should be started as soon as physically possible, without waiting for permits or other governmental requirements. The arrangements necessary to allow the necessary work for connection of lines across the fault rupture, at least on a temporary alignment, without environmental impact studies or other preliminaries should be investigated.

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