

# Earthquake Damage to Highways in the Valdez District, Alaska

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•ON MARCH 27, 1964, at approximately 5:40 PM, the south central coast of Alaska, including the Valdez District, was battered by an earthquake lasting about 4 minutes. During these 4 minutes, damage was inflicted on nearly every man-made structure in the earthquake area.

The Valdez District is one of Alaska's five highway districts (Fig. 1). An area of approximately 50,000 sq mi, it is larger than 24 of the 50 states. The entire district was affected by the earthquake. There were approximately 900 mi of usable highway mileage within the district before March 27, 1964. After the earthquake, this usable mileage was reduced to approximately 848 mi. It is regarded as nothing short of a miracle that larger sections were not totally destroyed. Had this occurred, evacuation procedures would have been nearly impossible to carry out and food supplies and other necessities might have been completely cut off from the coastal areas.

Studies during the first few days after the earthquake indicated no special patterns. Later studies have shown, however, that definite patterns do exist. The most important fact observed was that the degree of damage is a direct reflection of the geologic environment of the structure or highway. Roads and bridges constructed on bedrock sustained little or no damage. Those built on thick sequences of alluvial materials were badly damaged. Nearly every damaged structure in the Valdez District followed this pattern. Other patterns were observed, but they were of a local nature peculiar to the highway or structure involved. No other pattern was reflected which was uniform over the entire district.

This paper describes damaged and undamaged areas. Also included are brief discussions concerning future plans for reconstruction of damaged sections.

## RICHARDSON HIGHWAY

The Richardson Highway originates in Valdez, Alaska, and terminates at Fairbanks, about 364 mi inland (Fig. 2). It is the only highway breaching the rugged Chugach Mountain Range and, as such, is the only land evacuation route available for the city of Valdez (Fig. 3).

### Mile 0 to Mile 6

The first 6 mi of the Richardson Highway crosses the Valdez Glacier outwash plain and the Lowe River floodplain. Both areas are underlaid by undetermined thicknesses of sands, gravels, silts, and possibly clay. Groundwater levels are seldom more than 4 to 5 ft below ground surface. At the time of the earthquake, the entire area was frozen to depths of 4 to 5 ft below ground surface. All embankments were frozen. The area resembled a 5- to 6-ft thick block of concrete. Thus, there was little flexibility in the roadway surface, embankment, or underlying subsoils. Within seconds of the initial tremors, ground waves were visible on the roadway and huge sections began to buckle and fracture. In most cases, fractures crossed the roadway at right angles to the centerline and assumed random patterns after breaching the roadway, as shown in Figure 4.



Figure 1. Map of Alaska, showing five highway districts.

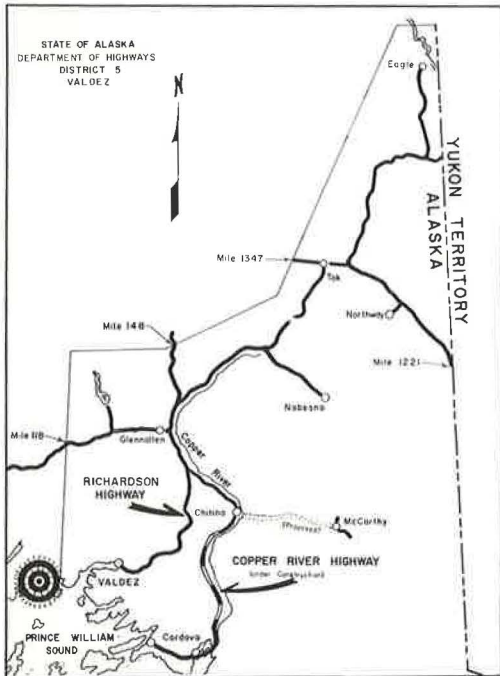


Figure 2. Study area.



Figure 3. View of Chugach Mountains between Valdez and Cordova, Alaska.



Figure 4. Crack approx. 5 in. wide and 6 ft deep in Richardson Highway near Mile 3, showing vertical displacement.



Figure 5. Ground crack adjacent to Richardson Highway near Mile 3; note fine sand ejected during quake.



Figure 6. Abutment of Valdez Glacier Stream bridge.



Figure 7. Keystone Canyon on Richardson Highway near Valdez; flat cliff face resulting from erosion on joint surfaces essentially parallel to highway.



Figure 8. Tunnel near Mile 15.8, Richardson Highway, showing spring seepage.



Figure 9. Cracks in Richardson Highway near Mile 73, showing horizontal offset of centerline.

In areas where embankments are high, long shoulder sections slumped in a manner similar to circular arc failures. In one or two instances, these slumps reached the centerline. Vertical displacements due to slumping were minor. This was definitely not the case in the cracks which crossed the roadway at right angles. Many of these cracks exhibited vertical displacements of 1 ft and horizontal displacements of 3 to 6 in. Considerable quantities of fine sand and water were ejected from these cracks during the earthquake, as shown in Figure 5.

In this 6-mi section, there are three bridges and numerous culverts. Two of the bridges are timber trestles supported

by timber piling. The third, which crosses the Valdez Glacier Stream, is a steel stringer bridge supported by steel railroad rails welded in clusters of three and driven by conventional methods. This particular structure was not totally destroyed, but was severely damaged. It was subjected to both compressive and tensional forces. The final force was apparently compressive as the bridge was left with a large hump, as shown in Figure 6. Both abutments and several of the rail pile clusters were completely fractured. Neither of the timber structures suffered any serious damage to either the superstructure or substructure, although several timber piles were split. Culverts in this section were damaged, but a pattern was not evident. Many were unaffected, some were pulled apart, and some sagged due to differential settlement.

Perhaps the most striking features in this section of roadway are the undulations or waves which were perfectly preserved when the violent tremors subsided. Before the earthquake this section was perfectly flat. When standing at Mile 1, headlights from oncoming cars 4 mi away were plainly visible. Post-quake checks have shown that dips or waves produced by the earthquake are deep enough to cause an automobile to "disappear" several times while crossing this area. In addition, the entire section of roadway between Mile 1 and Mile 6 has moved some 5 ft seaward. A contract amounting to \$1.2 million has been awarded to replace the Glacier Stream bridge and to reconstruct the highway from Mile 1 to Mile 6.

#### Mile 6 to Mile 65

This entire section is characterized by a lack of major damage. Destruction of sufficient magnitude to warrant discussion occurred in only one instance. A steel stringer bridge at Mile 16.8 sustained damage essentially identical to that of the Valdez Glacier Stream bridge, that is, severe compression with resultant humping and cracked abutments. It is significant that subsoils at this point are nearly identical to those at Valdez. The remainder of this section, between Mile 6 and 65, is either on or very near bedrock, and only minor cracking occurred. In general, those cracks which did occur crossed the roadway at an angle of 90 degrees to centerline.

It is remarkable that severe avalanching did not occur in Keystone Canyon between Mile 12 and 17 (Fig. 7). In this zone, the highway is in a narrow gorge several hundred feet deep. The rocks are well jointed and actually overhang the highway, with the predominant joint set parallel to the roadway. Almost any rockfall or avalanche would have easily closed the highway. This same condition exists in the tunnel at Mile 15.8 (Fig. 8). The tunnel is not lined, and minor rockfalls occur periodically. There were no noticeable effects other than an apparent increase in water seeping from the ceiling.

#### Mile 65 to Mile 75

At Mile 65, the Richardson Highway leaves a narrow canyon and enters a broad U-shaped valley on the northern slope of the Chugach Mountains. In this area, the highway crosses undetermined thicknesses of ice contact and glaciolucustrine deposits. Permafrost occurs sporadically beneath the roadway throughout the section; however, all soils were frozen to a depth of at least 10 ft at the time of the earthquake.

Damage between Mile 65 and Mile 75 was spectacular, with cracks crossing the roadway at intervals seldom exceeding 100 ft. The majority crossed at right angles to centerline, as shown in Figure 9. Both horizontal and vertical displacements were common in this area, and large quantities of mud and water were ejected from nearly all cracks.

The bridge over the Little Tonsina River at Mile 65 was subjected to severe compression. This bridge, a timber structure, was considered a total loss and has been replaced by large culverts. It would appear (for descriptive purposes only) that one of the abutments remained stationary and the other received a severe push. This caused the stringers to slide over the abutment for several feet. Several stringers were splintered. The asphalt pavement at the north abutment buckled and formed a pressure ridge about 4 ft high.

### Mile 75 to Mile 82

From Mile 75 to Mile 80, the Richardson Highway crosses the flood plain of the Tonsina River which has cut a wide steep-sided valley in thick sequences of lacustrine clay and silt. The floor of this valley is covered by a veneer of sandy gravels which were frozen at the time of the earthquake. Damage to this section is conspicuously absent. Some minor cracks occurred, but they are negligible compared to those described in the preceding section.

At Mile 80, the highway ascends the valley wall. The highway follows the hillside and is perched on sidehill cut and fill. This particular section has been a maintenance problem since initial construction. The sidehill fill has failed at four points, with very slow but continual slumping. During the earthquake all four slumps were accelerated and dropped from 3 to 5 ft almost instantly. All are the circular arc type and appear to involve the fill only. The slumps are still active but have resumed their snail pace. Although the highway traverses several sidehills of the same lithology, in the same general area, with similar construction and with near identical maintenance problems, this was the only hillside on which active slumps were aggravated by the earthquake.

### Mile 82 to Mile 147 (District Boundary)

From the fill section at Mile 82 to Mile 147, the roadway suffered some cracking, but damage was light. Almost all cracks were less than 2 in. wide and crossed the roadway at right angles to the centerline. The author was driving a truck at Mile 110 when the quake struck. There was enough severe movement to make driving impossible and standing difficult, which would seem sufficient to cause considerable damage. However, the presence of permafrost appears to have helped keep damage negligible.

## COPPER RIVER HIGHWAY

When completed, the Copper River Highway will lead from Cordova on the coast of Prince William Sound, through the Chugach Mountains, to the interior transportation system (Fig. 2). The entire highway will be about 125 mi long and poses some of the most difficult engineering problems in Alaska. Probably the most intriguing of these is how to build a lasting roadway over a mass of stagnant glacial ice 3 mi long and as much as 100 ft thick.

As of March 27, 1964, approximately 50 mi of the Copper River Highway was open to traffic during summer months. Another 10 mi was under construction and preliminary engineering was nearly complete on an additional 9 mi. Thus, it had been hoped that by 1965 at least 60 mi would have been open to traffic.

The Copper River Highway is an unpaved secondary highway. It was constructed over a 20 to 25 yr period and follows closely the abandoned Copper River and Northwestern Railroad alignment. In several places steel truss bridges constructed by the Railroad were being used for the highway.

For the first 6 to 7 mi, the highway skirts the edge of Eyak Lake near Cordova. In this section, the roadway is on or near bedrock and little damage was inflicted by the earthquake. From Mile 7 to the end of road, or near Mile 50, the roadway is located on a broad floodplain, or delta of the Copper River and on outwash plains of several glaciers. Sediments vary from clay to gravel. Coarse materials deposited by the numerous glacial streams and rivers of this area occur sporadically. The streams and rivers meander and the number of bridges is high. In the section from Cordova to Mile 50, there were 52 bridges open to traffic before the earthquake. Of these, 18 were totally destroyed, 14 received severe damage, and 20 suffered lesser or negligible damage.

These figures may be misleading in that the difference between destroyed, severe damage and negligible damage does not reflect the economics of the situation. Destroyed bridges are those which dropped in the rivers, whereas those severely damaged and those sustaining minor damages are still standing. The bridges shown in Figures 10 and 11 are most certainly destroyed. In the final analysis, economic considerations may change the list of destroyed bridges considerably.



Figure 10. Aerial view of 35 Mile bridge on Copper River Highway with four spans totally destroyed; note ground breakage and evidence of sand ejection.



Figure 11. Aerial view of 37.2 Mile bridge, Copper River Highway, showing evidence of vertical movement on right-hand abutment, and ground cracks on right.



Figure 12. Crack near Mile 63, Copper River Highway, approximately 10 ft wide, 5 ft deep and 300 ft long; note fine sand ejected during quake.

cracks were large, and large quantities of mud, sand and silt were ejected at some points. Figure 12 shows an area which probably would be under construction if there had not been an earthquake. For the most part, this entire area suffered ground breakage exceeding that in any other portion of the Valdez District. However, compared to bridge damage, ground breakage is nearly insignificant from an economic standpoint.

Several patterns of bridge damage seem apparent. The first and most obvious is the failure of steel rail piling. As Figures 13 and 14 show, this particular foundation type proved to be the poorest possible when subjected to seismic action such as occurred during this earthquake. The rails were obtained from the abandoned Copper River and Northwestern Railroad and were made before 1922. Before driving, they were welded into clusters of three with additional lengths splice welded to obtain deeper penetration. Records show that considerable difficulty was experienced during driving with the rail cluster breaking at random points. This should have provided some warning about the brittleness of the rails.

It is significant that none of the destroyed or severely damaged bridges on the Copper River Highway are constructed on or near bedrock. All are constructed on gravel, sand or silt. This is also true of the roadway prism—little or no damage occurred near bedrock. In this category are 14 structures, located in two sections. The first section, between Cordova and Mile 6, contains one undamaged bridge. This was constructed near bedrock. The second section between Miles 16.6 and 22.3, contains 13 undamaged bridges, all located near bedrock. It is an understatement to say that this section illustrates vividly the effects of geologic environment under seismic conditions.

Ground cracking on the Copper River Highway was severe, but it was not as well oriented as on the primary highways. Nevertheless, many cracks crossed the roadway at right angles, and considerable shoulder slumping occurred. Some of the



Figure 13. Fractured rail piling with random breaks beneath Scott Glacier Stream bridge, Copper River Highway.



Figure 14. Fractured rail piling beneath Scott Glacier Stream bridge, Copper River Highway.



Figure 15. Loss of entire bent supported by timber piling; one of Scott Glacier Stream bridges.



Figure 16. Aerial view of Million Dollar Bridge.

During the earthquake, this type of piling failed in nearly every instance. It is apparent that the economy gained by salvaging rails for use as piling is quickly lost under such severe seismic conditions. The rails simply had insufficient strength to withstand the forces of the earthquake. It is only fair to state that there is serious doubt that any piling could have survived such a beating. In a number of cases the piles are tipped with no apparent breakage. This condition, in view of the damage visible above surface, would seem to indicate breaks rather than bends below the ground surface. In any event, it is doubtful if bridges supported by this type of foundation can ever be trusted when located in areas subject to severe earthquakes.

Bridges supported by timber piling were damaged, but not nearly as severely as that mentioned previously. Some piles were split, and some broke off. In one case, an entire bent disappeared (Fig. 15). It may have failed and dropped vertically due to subsoil liquefaction and friction loss, or it may have broken off at the groundline. Either condition seems difficult to visualize.

One structure on this severely damaged highway was not pile supported. The largest bridge, at Mile 49, known as the Million Dollar Bridge, was founded on concrete



Figure 17. Steel truss bridge at Mile 28, Copper River Highway, with center pier missing; span tipped over as a result of movement of river ice.

caissons resting on boulders and gravels. This bridge (1), shown in Figure 16, was built in 1910 and consists of four steel truss spans 400, 300, 450, and 400 ft long. Caissons for Piers 1, 2 and 3 were landed at 36, 36, and 50 ft below stream bed, respectively. The foundation for all piers and abutments, except Pier 3 is sand, gravel, and boulders from 1 cu ft to 10 cu yd in volume. Under Pier 3, the boulders were much smaller and surrounded by sand and gravel. Maximum foundation pressures were less than 4 tons/sq ft.

Pier 3 failed completely, splitting into four separate pieces along horizontal and vertical construction joints. These pieces were prevented from toppling into the river by the 450-ft truss still resting on the pier, its bearing plates displaced longitudinally more than 9 ft from the masonry plates on which they were seated. Span 4 slipped from Pier 3 and its south

end is resting on the river bottom. Several truss members were badly damaged by the fall. Pier 2 appears to have a residual displacement of more than 1 ft. The other superstructure units show the effects of repeated horizontal movements. Sheared or bent anchor bolts, shattered roller nests, pulverized sliding joints and both lateral and longitudinal displacements of the huge truss spans testify to the magnitude of the forces involved (2). In two instances, the caissons do not appear to have been damaged or displaced.

Other foundation types, such as spread footings, have not been extensively utilized on this highway.

The other pattern of damage which appeared common on many damaged structures, regardless of foundation type, is the failure of those members utilized for connecting the superstructure to the substructure. Either these connections failed and the entire superstructure shifted, or the connections did not fail and the superstructure shifted doing considerable damage to substructure members. Had the substructure been anything other than railroad rails, it is possible damage would have been quite different.

Lateral movement with either failure or nonfailure of superstructure to substructure connections manifested itself in several different ways, depending on structure types. Steel truss bridges with several individual spans were usually left with one or more spans dropped completely off their piers. Or, if as apparently occurred at Mile 28, the connections did not fail, but the substructural members were pulled to failure. In fact, at this location the center pier has completely disappeared and both trusses have dropped into the river (Fig. 17).

It seems reasonable to assume that the degree of damage to structures on the Copper River Highway depended directly on the following factors (assuming, of course, that the tremors were of nearly equal magnitude at all points).

1. Type of foundation soil and its position in relation to bedrock—the conspicuous lack of damage to structures located on or near bedrock is considered ample evidence for this conclusion.

2. Type of foundation, i. e., steel rails, timber piling, or caissons—timber piles and caissons appear more dependable under seismic conditions, at least on the Copper River Highway.

3. Strength of connections between superstructure and substructure—this conclusion is open to speculation and will undoubtedly be covered in a more detailed structural analysis.



Obviously, these factors are inseparable, but the elimination of one of them may have resulted in a considerable difference in the damage incurred.

Damage to other highways in the Valdez District was insignificant. All are located in the interior, in areas of almost continual permafrost. In this one instance permafrost could be considered an advantage rather than a detriment.

In addition to destroying areas over which new highways would have been built, the earthquake caused numerous changes in drainage. Thus, not only will damaged highways have to be rebuilt, but in some instances new routes must be found.

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