# The Alaska Earthquake
## March 27, 1964

# Effects on Transportation and Utilities


# The Highway System

GEOLOGICAL SURVEY PROFESSIONAL PAPER 545-C

THE ALASKA EARTHQUAKE, MARCH 27, 1964:
EFFECTS ON TRANSPORTATION, COMMUNICATIONS, AND UTILITIES

# Effects of the Earthquake of March 27, 1964, on the Alaska Highway System

By REUBEN KACHADOORIAN

*A description of the severe damage to the highways and bridges in south-central Alaska*

GEOLOGICAL SURVEY PROFESSIONAL PAPER 545-C

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# THE ALASKA EARTHQUAKE SERIES

The U.S. Geological Survey is publishing the results of investigations of the earthquake in a series of six professional papers. Professional Paper 545 describes the effects of the earthquake on transportation, communications, and utilities. Chapters in this volume already published include one on the Eklutna Hydroelectric project in Anchorage and one on airports, utilities, and communications. A forthcoming chapter will describe the effects on The Alaska Railroad.

Other professional papers, already published, describe the field investigations and reconstruction, and the effects of the earthquake on communities, on regions, and on the hydrologic regimen.

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# EFFECTS OF THE EARTHQUAKE OF MARCH 27, 1964, ON THE ALASKA HIGHWAY SYSTEM

By Reuben Kachadoorian


### *ABSTRACT*

The great earthquake that struck Alaska about 5:36 p.m., Alaska standard time, Friday, March 27, 1964 (03:36:13.0, Greenwich mean time, March 28, 1964), severely crippled the highway system in the south-central part of the State. All the major highways and most secondary roads were impaired. Damage totaled more than $46 million, well over $25 million to bridges and nearly $21 million to roadways. Of the 204 bridges in south-central Alaska, 141 were damaged; 92 were severely damaged or destroyed. The earthquake damaged 186 of the 830 miles of roadway in south-central Alaska, 83 miles so severely that replacement or relocation was required.

Earthquake damage to the roadways and bridges was chiefly by (1) seismic shaking, (2) compaction of fills as well as the underlying sediments, (3) lateral displacement of the roadway and bridges, (4) fractures, (5) landslides, (6) avalanches, (7) inundation by seismic sea waves, (8) scouring by seismic sea waves, (9) regional tectonic subsidence, causing inundation and erosion by high tides in subsided areas.

The intensity of damage was controlled primarily by the geologic environment (including the depth of the water table) upon which the highway structures rested, and secondarily by the engineering characteristics of the structures. Structures on bedrock were only slightly damaged if at all, whereas those on unconsolidated sediments were slightly to severely damaged, or were completely destroyed by seismic shaking. The low-lying areas underlain by saturated sediments, such as the Snow River Crossing and Turnagain Arm sections of the Seward-Anchorage Highway, were the most severely damaged stretches of the highway system in south-central Alaska. At Snow River and Turnagain Arm, the sediments underlying the roadway are fine grained and the water table is shallow. These factors were responsible for the intense damage along this stretch of the highway.

All the bridges on the Copper River Highway except for one on bedrock were damaged by seismic shaking. Lateral displacement of sediments toward a free face, which placed the bridges in compression, was the chief cause for the damage. This type of failure was extensive and widespread throughout the highway system.

The chief engineering characteristics responsible for the type and intensity of damage include (1) thickness of roadway fills, (2) type of pile bents and masonry piers, (3) the weight ratio between the substructure and superstructure, and (4) the tie between the substructure and superstructure.

The thicker the roadway fills, the more severe the damage. Wood piles did not break as extensively as piles constructed of three railroad rails welded together. Bridges that had relatively heavy superstructures, for example those with concrete decks on wood piles, were more severely damaged than those with all-wood or concrete decks on concrete piers. Failure first occurred at the tie between the superstructure and the substructure; the poorer this tie, the sooner the failure.

Seismic sea waves destroyed 12 bridges on the Chiniak Highway on Kodiak Island, one bridge on Point Whitshed road near Cordova, and about 14 miles of roadway.

The combination of regional tectonic subsidence and local subsidence and compaction of sediments caused inundation of many miles of highway by high tides, especially around Turnagain Arm. Total subsidence in some places amounted to more than 13 feet.


## INTRODUCTION

The great earthquake that struck Alaska at about 5:36 p.m., Alaska standard time, Friday, March 27, 1964 (03:36:13.0 Greenwich mean time, March 28, 1964) severely crippled the highway system in the south-central part of the State. This part of Alaska has approximately 60 percent of the total population and produces more than 55 percent of the State's gross product and revenue. Thus, the disastrous effects of the earthquake upon the highway system materially affected the economy of the whole State. After the seismic shaking and attendant seismic sea waves had stopped, much of the highway system lay in ruins. Roadways were fractured or were blocked by avalanches; locally they had sunk out of sight or had been washed away. Most of the bridges were damaged and many were completely destroyed. Some of the destroyed bridges lay in the creeks and rivers they once spanned; others had been washed away. This destruction isolated communities on the Kenai Peninsula from Anchorage and the rest of the State. On Kodiak Island, Chiniak was isolated from the town of Kodiak.

In south-central Alaska there were, at the time of the earthquake, 830 miles of primary and secondary roads with 204 bridges. Approximately 186 miles of roadway and 141 bridges were damaged; 88 of the 186 miles was severely damaged. Ninety-two bridges required replacement. Total damage amounted to about $46,798,292 (Bruce A. Campbell, written commun., 1965).

The Alaska Department of Highways responded quickly to the emergency, and by early summer of 1964 all damaged routes were passable. The only section of road not reopened by the fall of 1966 was the Copper River Highway between the Copper River (mile 27.1) and the Million Dollar Bridge (mile 49.0).

## FIELDWORK

During the summer of 1964, the author examined all bridges and roadways of the Richardson Highway between Valdez and Glennallen, Sterling Highway, Hope Road, Glenn Highway between Anchorage and the Richardson Highway, Copper River Highway, and Seward-Anchorage Highway (fig. 1), and, in addition, most of the roadways on Kodiak Island.

The author was assisted during the study by the following members of the Geological Survey: George Plafker on the Copper River and part of the Richardson Highways, M. G. Bonilla on parts of the Glenn and Seward-Anchorage Highways, and Roger Waller on parts of the Sterling and Seward-Anchorage Highways. Thor Karlstrom and Helen Foster furnished some data on the Seward-Anchorage and Sterling Highways. Richard Lemke collected and furnished the data on the Snow River Crossing on the Seward-Anchorage Highway.

## ACKNOWLEDGMENTS

This report could not have been completed without the cooperation of, and the data supplied by, Bruce Campbell and Ralph Migliaccio of the Alaska Department of Highways, the U.S. Army, the U.S. Navy, and the numerous residents of Alaska who provided the eyewitness accounts.

# EFFECTS OF THE EARTHQUAKE

## GEOLOGIC SETTING

The terrain over which the highway system in south-central Alaska passes is varied, and this variation played an important role in the type and extent of damage to roadways and bridges. The terrain, in turn, is controlled by the geologic environment.

In general, the highways are underlain by bedrock consisting primarily of argillite and graywacke or by unconsolidated material composed of glacial debris, swamp deposits, stream deposits, colluvium, and tidal deposits. With few exceptions, the low-lying areas that the highways cross are underlain by unconsolidated deposits, and most of the damage to the highway system was in these low-lying areas. The water table is close to the surface where the highway skirts a body of water or where it crosses tidal or deltaic deposits, especially on the Seward-Anchorage Highway at the head of Turnagain Arm and where the highway crosses the Snow River delta at the south end of Kenai Lake.

## SUMMARY OF DAMAGE

The earthquake that shook south-central Alaska on March 27, 1964, had a magnitude of 8.4. Its epicenter was at lat 61.06° N. and long 147.44° W., and its depth was about 21 kilometers (U.S. Coast and Geodetic Survey, 1966). Although there have been earthquakes of equal or greater magnitude, the damage created by the Alaska earthquake was particularly devastating because the shaking lasted 4 to 5 minutes. The effects of this earthquake upon the highway system in south-central Alaska were staggering. All the major highways and most of the secondary roads were damaged; these include the Sterling, Seward-Anchorage, Glenn, Edgerton, Richardson, Chiniak, Copper River Highways, and Point Whitshed Road.


1.—Index map showing earthquake epicenter and location of highways in south-central Alaska.

The total cost of repairing the highway system in south-central Alaska, including Kodiak Island, was estimated at $46,798,292 (table 1), $20,898,816 for roadways, and $25,899,476 for bridges. About 186 of the 830 miles of primary and secondary roads and 141 of the 204 bridges in the area were damaged (table 2); 88 of the 186 miles was severely damaged.

The roadways and bridges were damaged by (1) seismic shaking, (2) fracturing, (3) compaction of sediments, (4) lateral extension or displacement of sediments, (5) compression of bridges, (6) landslides, (7) avalanches, (8) seismic sea waves, (9) regional subsidence, (10) erosion, and (11) postearthquake scouring and erosion by the inundating seas in the low-lying coastal areas.

This report will not discuss in complete detail the extensive damage to the highways, but, instead, will attempt to correlate the damage with the geologic environment, and, for bridges, also with the engineering characteristics of the structures.

TABLE 1. *Estimated cost of repairs or replacement of highway structures damaged by the Alaska earthquake* [1]

| Highway | Roadway | Bridges | Total |
|---|---|---|---|
| Copper River | $4, 253, 089 | $19, 175, 596 | $23, 428, 685 |
| Glenn | 682, 812 | 41, 957 | 724, 769 |
| Hope Road | 152, 194 | ------------ | 152, 194 |
| Portage Glacier Road | 590, 888 | 318, 375 | 909, 263 |
| Point Whitshed Road | 50, 793 | 32, 165 | 82, 958 |
| Richardson | 1, 261, 034 | 277, 176 | 1, 538, 210 |
| Seward-Anchorage | 9, 606, 405 | 5, 264, 762 | 14, 871, 167 |
| Sterling | 2, 947, 657 | 602, 116 | 3, 549, 773 |
| Kodiak Island (Chiniak Highway, Anton Larsen Bay Road, Pasagshak Bay Road, Chiniak Highway to Spruce Cape via Kodiak) | 1, 116, 108 | 183, 175 | 1, 299, 283 |
| Secondary roads | 237, 836 | 4, 154 | 241, 990 |
| Total | 20, 898, 816 | 25, 899, 476 | 46, 798, 292 |

[1] This estimate differs from that given by Eckel and Schaem (1966, p. 49). The estimate given above is based on a 1965 revision and does not include Federal aid for secondary roads in towns.

TABLE 2.—*Effects of the Alaska earthquake upon roads and bridges in south-central Alaska*

| Highway or road [1] | Roadway | | | Bridges | |
|---|---|---|---|---|---|
| | Total (miles) | Damage (miles) | | Total | Number damaged |
| | | Total | Severe | | |
| Copper River Highway | 59 | 45 | 30 | 53 | 52 |
| Edgerton Highway | 40 | 0 | 0 | 4 | 1 |
| Glenn Highway | 188 | 16 | 2 | 21 | 11 |
| Hope Road | 16 | 0 | 0 | 2 | 0 |
| Kenai-Nikishka Road | 30 | 0 | 0 | 1 | 0 |
| Portage Glacier Road | 7 | 7 | 1 | 3 | 3 |
| Point Whitshed Road | 9 | 2 | 2 | 5 | 1 |
| Richardson Highway | 115 | 40 | 5 | 20 | 8 |
| Seward-Anchorage Highway | 130 | 35 | 25 | 54 | 39 |
| Sterling Highway | 145 | 11 | 5 | 13 | 5 |
| Kodiak Island: | | | | | |
| Chiniak Highway | 42 | 6 | 6 | 20 | 15 |
| Anton Larsen Bay Road | 10 | 5 | 4½ | 4 | 2 |
| Saltery Cove Road | 14 | 3 | 3 | 0 | 0 |
| Pasagshak Bay Road | 15 | 5 | 4½ | 3 | 3 |
| Chiniak Highway to Spruce Cape via Kodiak | 10 | 1 | 0 | 1 | 1 |
| Secondary roads | ------ | 10 | 0 | ------ | ------- |
| Total | 830 | 186 | 88 | 204 | 141 |

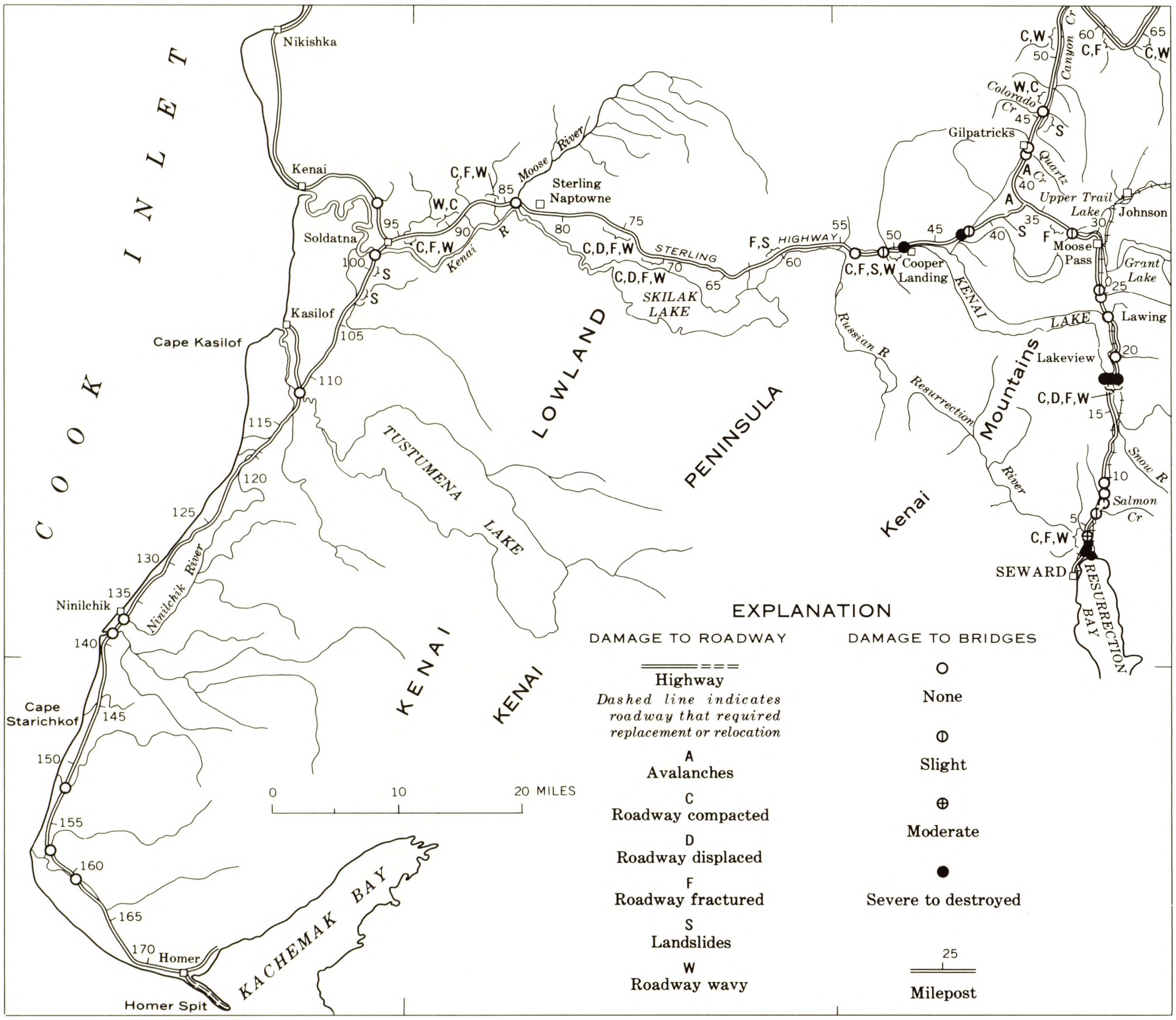
[1] Only primary and secondary highways listed. Streets and bridges in communities not included.

## DAMAGE TO ROADWAYS

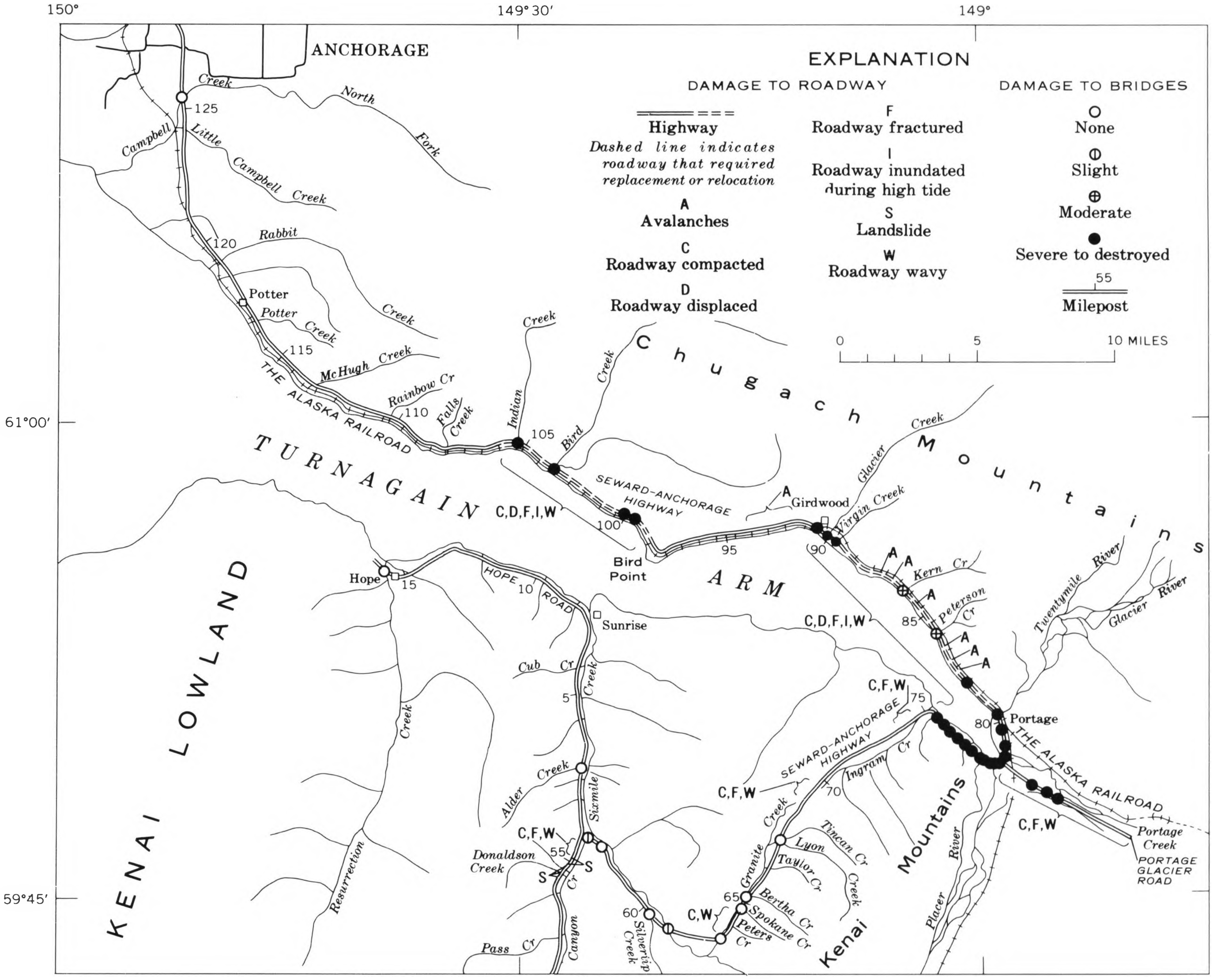
About 88 miles of roadway in south-central Alaska required replacement or relocation, but approximately 186 miles of roadway were affected in one manner or another by the earthquake. This total consists of 45 miles on the Copper River Highway, 35 miles on the Seward-Anchorage Highway, 40 miles on the Richardson Highway, approximately 16 miles on the Glenn Highway, 18 miles on the Kodiak Island road system, 11 miles on the Sterling Highway (including Homer Split), and 7 miles on the Portage Glacier Road. The remaining 10 miles of damaged roadway were on secondary roads.

The 88 miles of roadway that required replacement or relocation is considered severe damage in this report. Of the 88 miles, 30 were on the Copper River Highway, 25 on the Seward-Anchorage Highway, 5 on the Sterling Highway, 5 on the Richardson Highway, 2 on the Glenn Highway, 2 on Point Whitshed Road, 1 on Portage Glacier Road, and 18 miles on the Kodiak Island road system.

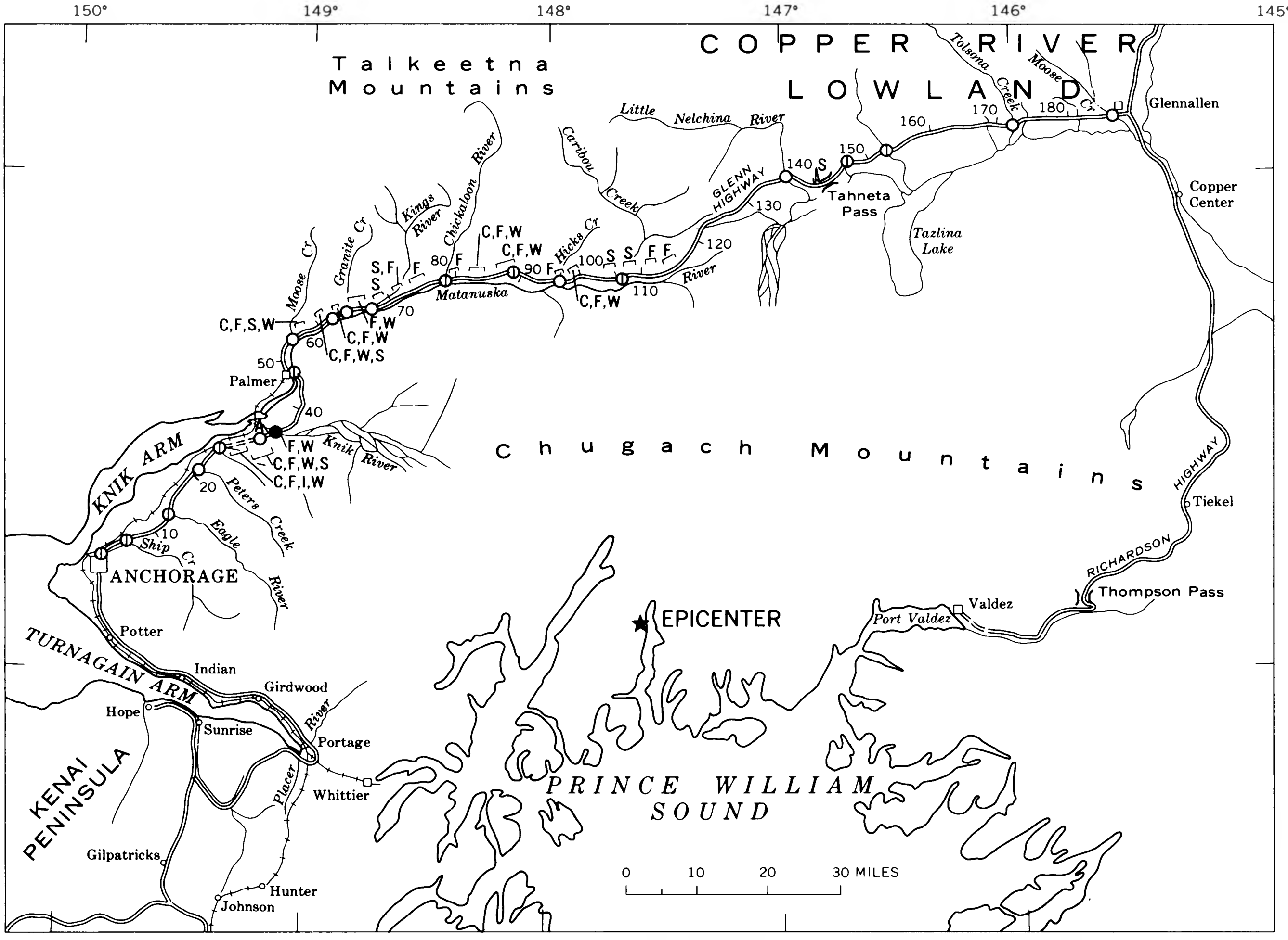
Figures 2–7 show the type and location of the damage on the major highways in south-central Alaska. A correlation between foundation material of the Seward-Anchorage, Sterling, Glenn, and Richardson Highways and damage sustained is shown on tables 3–6 (p. C53, C54).




2.—Routes of Sterling Highway and part of Seward-Anchorage Highway, and effects of the earthquake upon the highways.



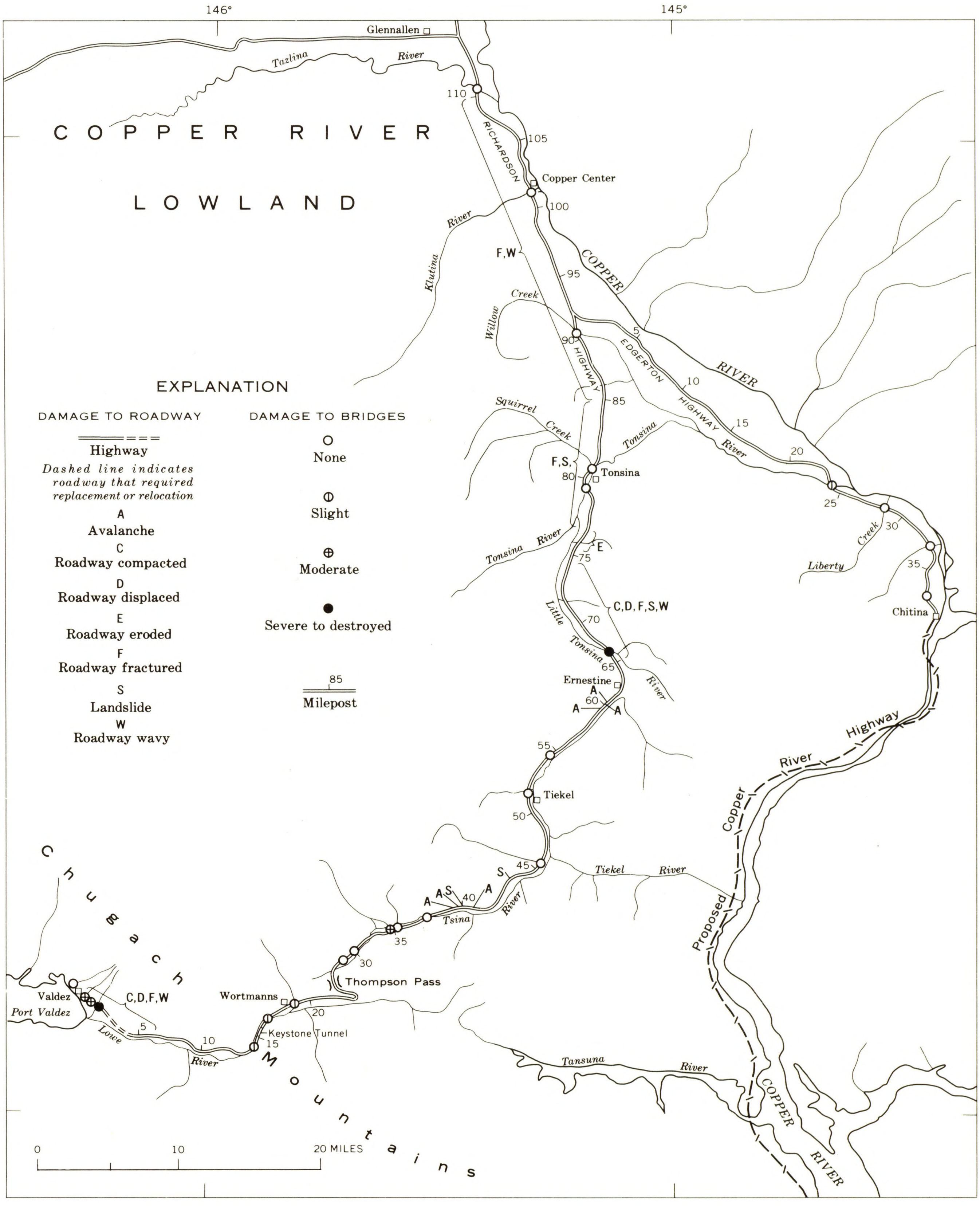

3.—Routes of part of Seward-Anchorage Highway, the Hope Road, the Portage Glacier Road, and effects of the earthquake upon the highways.



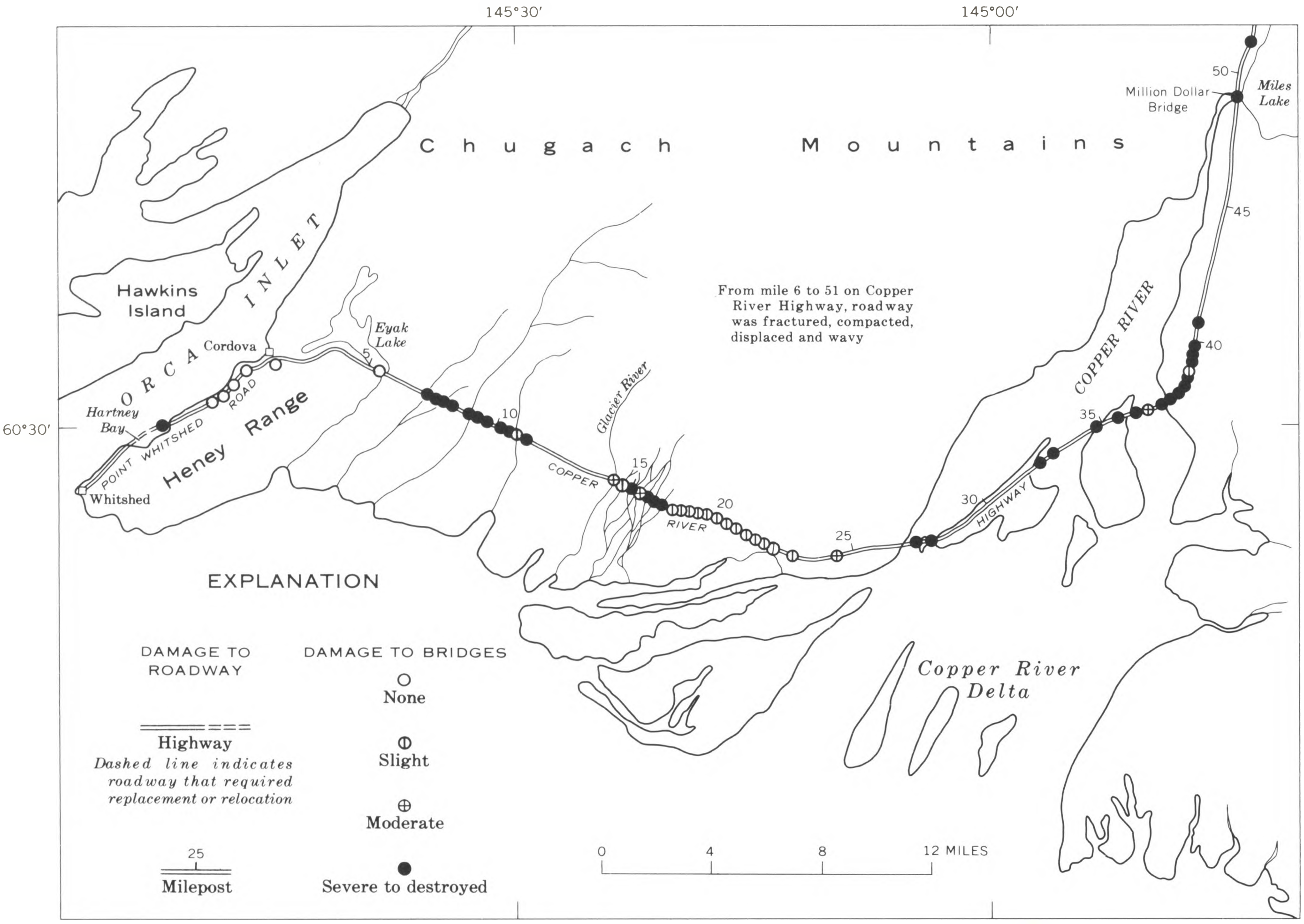

EXPLANATION

| DAMAGE TO ROADWAY | | DAMAGE TO BRIDGES |
|---|---|---|
| Highway<br>*Dashed line indicates roadway that required replacement or relocation* | F<br>Roadway fractured | None |
| | I<br>Roadway inundated during high tide | Slight |
| A<br>Avalanche | S<br>Landslide | Severe to destroyed |
| C<br>Roadway compacted | W<br>Roadway wavy | 140<br>Milepost |

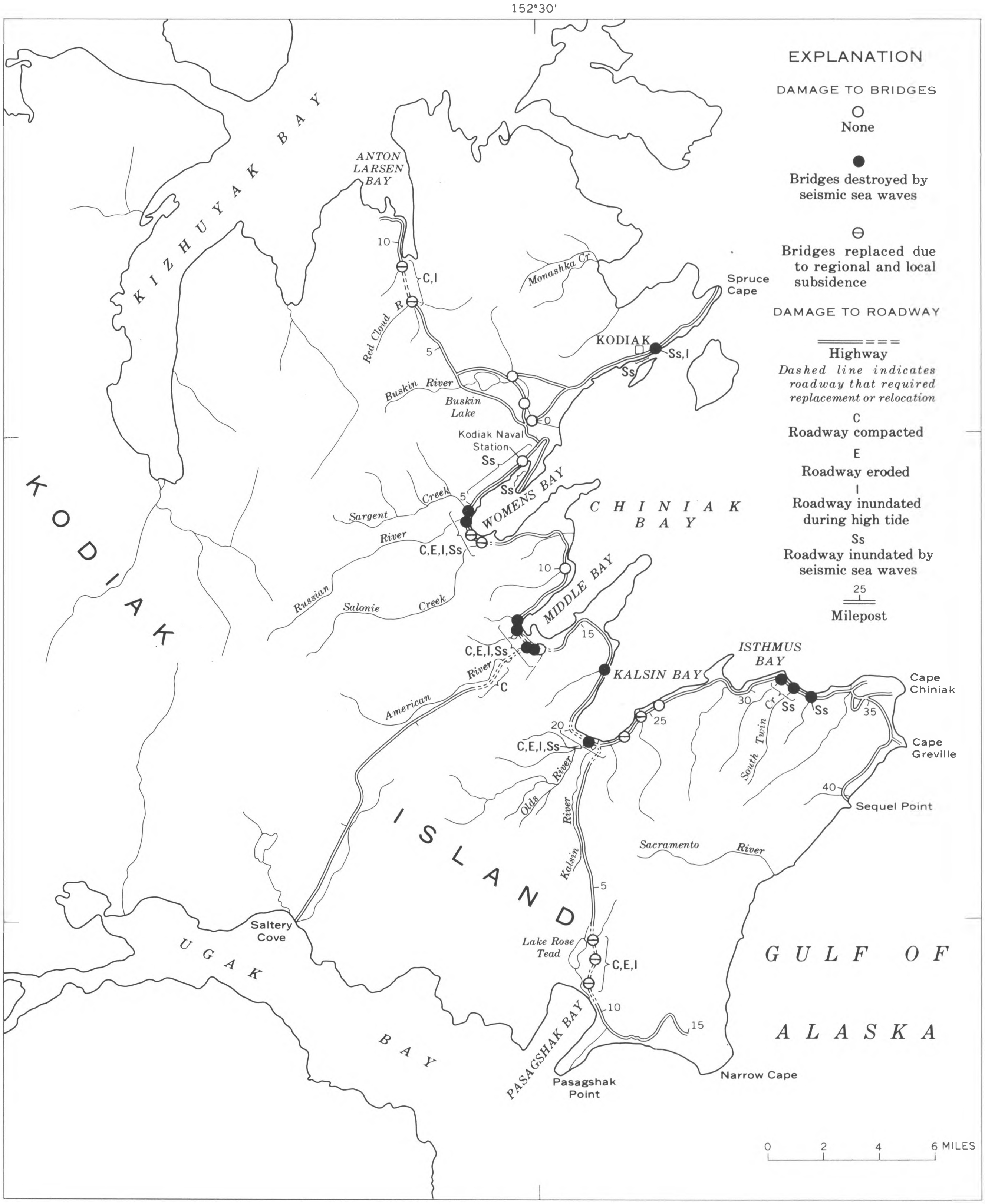
4.—Route of Glenn Highway and effects of the earthquake upon the highway.




5.—Routes of the Edgerton Highway and part of the Richardson Highway, and effects of the earthquake on the highways.



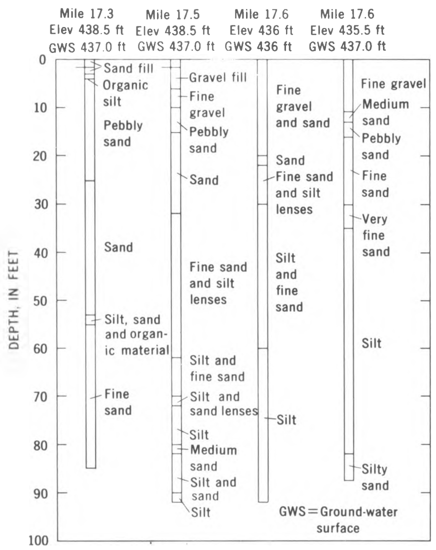

6.—Routes of Copper River Highway and Point Whitshed Road, and effects of the earthquake upon the highways.




7.—Highway routes on Kodiak Island and effects of the earthquake upon the highways.

The earthquake damaged the roadways chiefly by (1) seismic shaking, (2) compaction of the roadway fill as well as the underlying sediments, (3) lateral displacement of the roadway and underlying sediments, (4) fractures in the roadway, especially on the paved surfaces, (5) landslides onto the roadway and of the roadway itself, (6) avalanches upon the roadway, (7) inundation and erosion of the roadway by seismic sea waves, (8) inundation by the sea of the roadway along low-lying coastal areas because of regional subsidence and differential compaction of the highway, and (9) differential compaction of roadway which caused a wavy effect. Much of this damage can be directly correlated with the geologic environment of the roadway. The damage by seismic sea waves was due, of course, not to the geologic conditions but to the proximity to the open sea.

The most severe damage to roadways occurred at Snow River Crossing (fig. 2) and from mile 75.1 to about mile 90 (fig. 3) on the Seward-Anchorage Highway, on the Copper River Highway (fig. 6), and from mile 1 to mile 5 on the Richardson Highway (fig. 5). The Snow River Crossing is underlain by nonplastic silt and sand (fig. 8; table 7, p. C55). Here the groundwater table is generally within 1 foot of the surface. The Turnagain Arm section of the Seward - Anchorage Highway (mile 75.1 to mile 90) is primarily underlain by silt and sand with minor amounts of gravel (fig. 9). The sediments are nonplastic (tables 8, 9, p. C55, C56). Although not indicated on the graphic logs of the test holes, the water table lies generally within 3 feet of the surface; in the vicinity of the town of Portage the water table is within 2 feet of the surface.




8.—Graphic logs of test holes at Snow River Crossing on Seward-Anchorage Highway. Logged by Alaska Department of Highways.

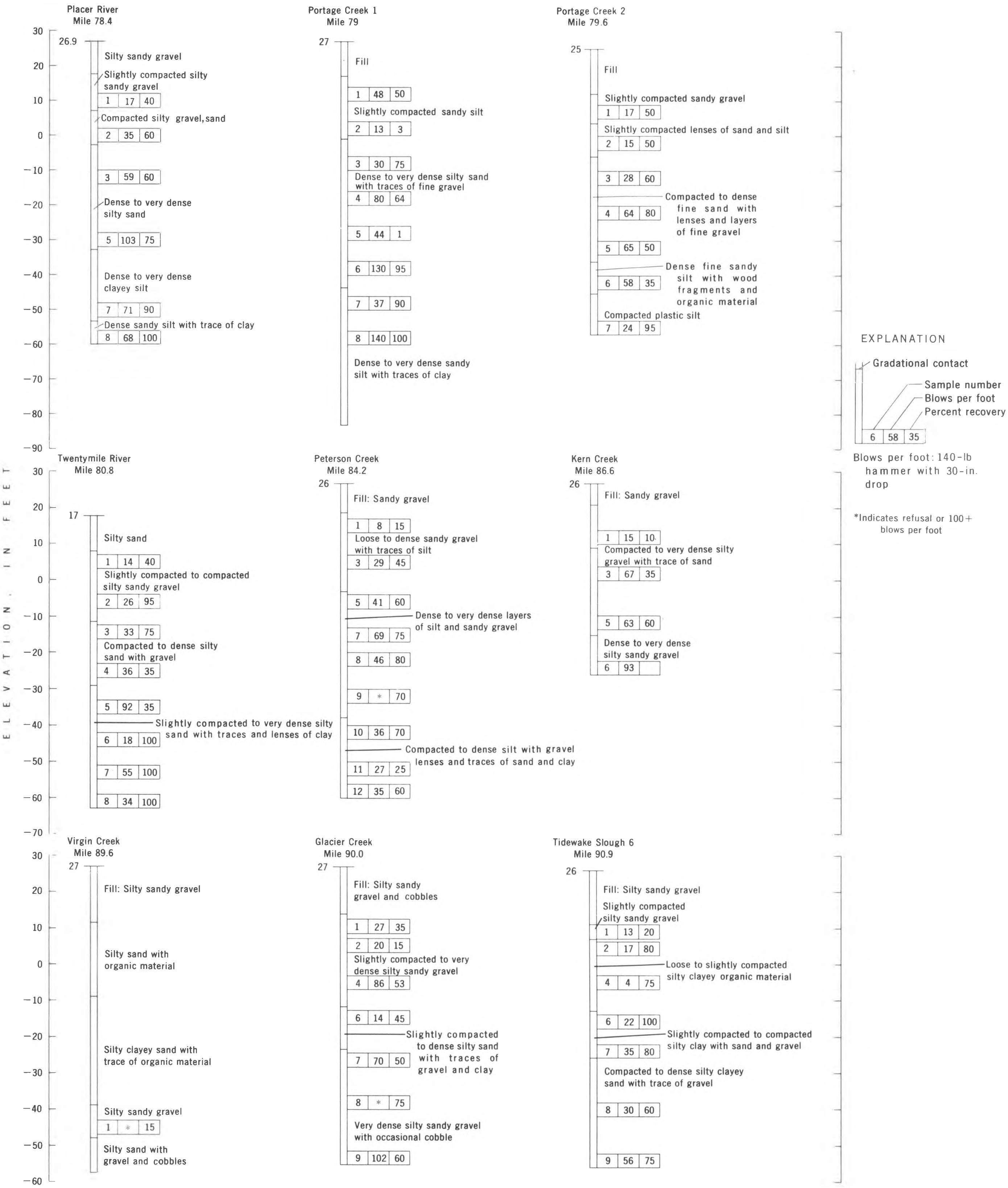
The Copper River Highway is also underlain by nonplastic sediments consisting primarily of silt, sand, and sandy gravel (fig. 10; table 10, p. C56). The water table lies within 6 feet of the surface between mile 5 and mile 18 and locally is within 1 foot of the surface. Within a few feet of the surface, much of the underlying sediments contain organic material. This material leaves much to be desired as road foundation because it will compact when fill is placed upon it or will subside or compact differentially when subjected to seismic shaking.

The Richardson Highway roadway was most severely damaged on nonplastic glacial outwash sediments consisting of sandy gravel and minor amounts of silt (fig. 11; table 11, p. C56). The water table lies within 10 feet of the ground upon which the road fill was first placed. At mile 2.1 the water table is within 1 foot of the surface, at mile 2.56 within 3 feet of the surface.

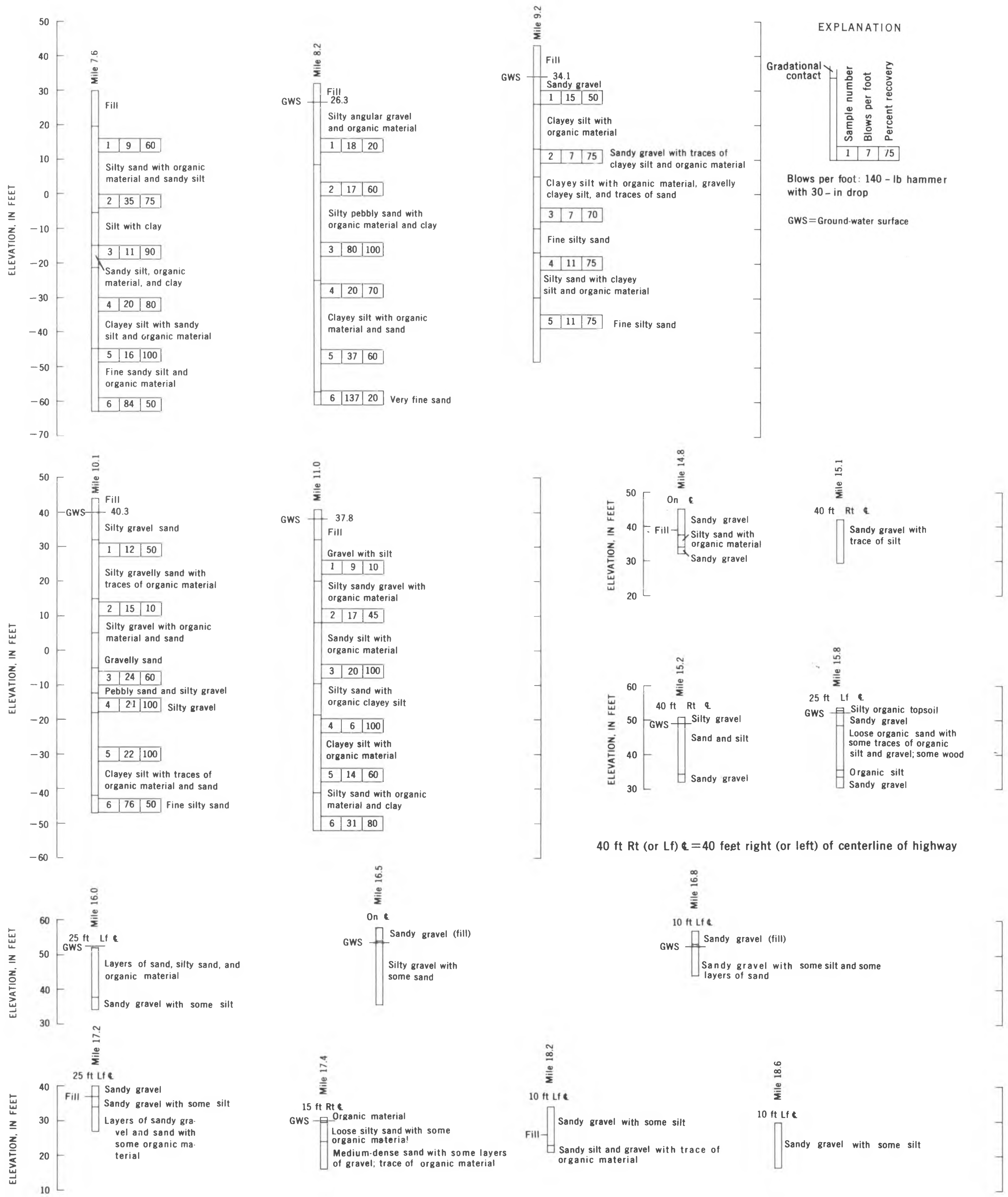
### FRACTURES

The seismic shock of the earthquake fractured the roadways of all the major highways in the south-central part of the Alaska mainland, but no fractures were observed on the Kodiak Island system except for those noted on paved streets on the Kodiak Naval Station about 6 miles south of Kodiak. This does not necessarily mean that the seismic shaking did not develop any fractures, but rather that they were not visible during our study in the summer of 1964. Nor were any fractures visible in the low-lying coastal areas where they may have developed either they did not exist or they were not visible at the time of this study; repeated postearthquake inundation and scouring by the sea may well have destroyed the fractures or eroded the roadway away completely. At the time of the Alaska earthquake, the Glenn Highway was unpaved from about mile 55 to Glennallen. Roadwork was underway in most of this stretch of the highway during the summer of 1964; this roadwork obviously destroyed any fractures in the roadway. The most reliable indications of earthquake-generated fractures were on paved roads, and some of the fractures there had to be examined carefully to determine whether they were pre- or post-earthquake.

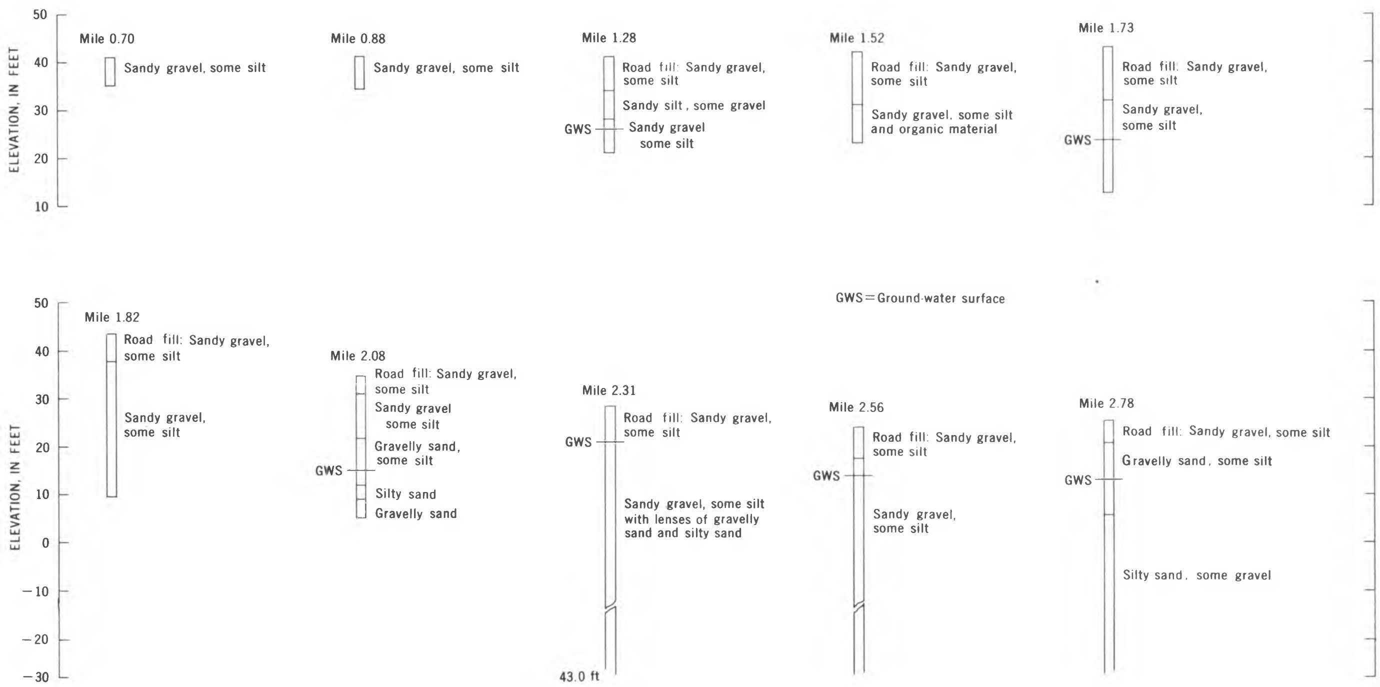
Not including fractures due to landslides, the Alaska earthquake generated at least five major fracture patterns on the Alaska roadways (fig. 12). Fractures formed (1) normal to the roadway, (2) along the center of the roadway, (3) on the shoulders parallel to the roadway, (4) as oblique fractures on original ground, then refracted normal to the roadway, and, once across the roadway, again oblique to it, and (5) oblique




9.—Graphic logs of test holes at miles 78.4, 79.0, 79.6, 80.8, 84.2, 86.6, 89.6, 90.0, and 90.9, Seward-Anchorage Highway.




10.—Graphic logs of test holes at miles 7.6, 8.2, 9.2, 10.1, 11.0, 14.8, 15.1, 15.2, 15.8, 16.0, 16.5, 16.8, 17.2, 17.4, 18.2, and 18.6, Copper River Highway.




**11.—Graphic logs of test holes at miles 0.70, 0.82, 1.28, 1.52, 1.73, 1.82, 2.08, 2.56, and 2.73, Richardson Highway. Analysis by Alaska Department of Highways.**

to the roadway. Some stretches of roadway had more than one fracture pattern.

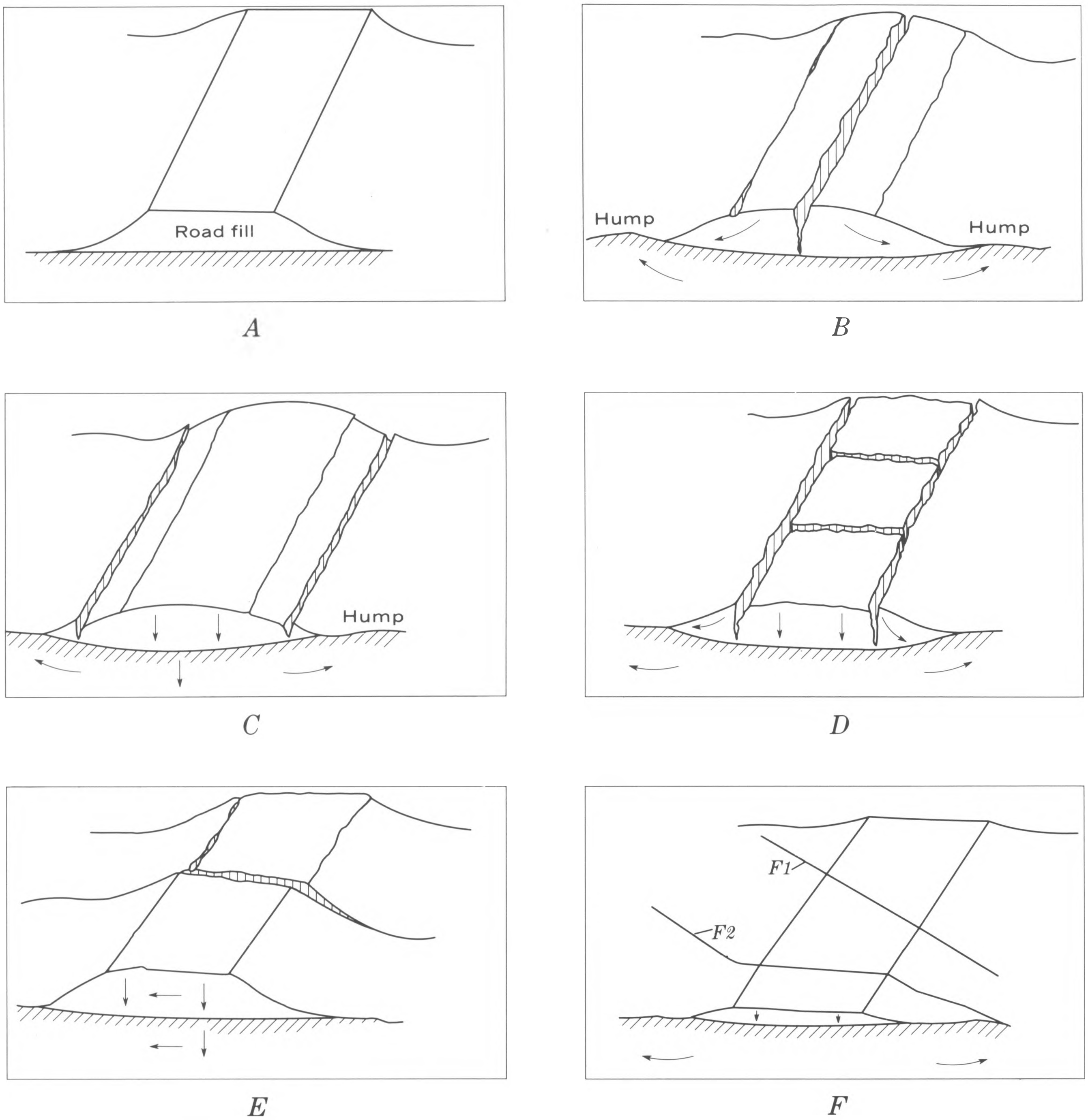
Much of the highway system was fractured by seismic shaking (figs. 2–7). The most spectacular fractures occurred on the Seward-Anchorage Highway from mile 75.1 to mile 90, but extensive fracturing also occurred on the Richardson Highway between miles 0 and 5, between miles 64 and 80, and on the Copper River Highway. The extent and nature of the fractures depended upon the type and thickness of the sediments and the depth to the water table. Fractures were conspicuous in swamp deposits and in thick accumulations of silt and sand, especially if the water table was within 6 feet of the ground surface. In general, the closer the water table was to the ground surface, the more extensive and varied the fracture patterns were. For example, at the southeast end of Turnagain Arm near Portage the Seward-Anchorage Highway passes over silt and sand, and the water table is within 2 feet of the ground surface. The fractures here were very extensive. The fractures on the highway were more pronounced than those on the roadbed of the railroad, but the railroad was displaced horizontally for about the same distance as the highway.

There are several reasons why the fracture pattern is more pronounced on the highway than on the railroad. The highway roadway is generally constructed of well-graded (poorly sorted) compacted fill and is paved. In contrast, the railroad roadbed was originally constructed by using about 1 foot of ballast that consisted chiefly of coarse gravel. Over a period of years the railroad roadbed was raised to grade by adding coarse gravel, and thus the thickness of coarse poorly graded gravel is much greater than it was originally. When the earthquake struck the Portage area and the sediments were displaced, the denser highway roadway was easily fractured, whereas the coarse gravel of the railroad roadbed, although displaced, was not extensively fractured.

As stated earlier, the most extensive fracturing occurred on the Seward-Anchorage Highway at the head of Turnagain Arm. Table 12 (p. C57) shows the correlation of foundation material and fractures from mile 75.1 (Ingram Creek) to mile 95.0.

#### FRACTURES NORMAL TO THE HIGHWAY

The most conspicuous fractures observed were those normal to the axis of the roadway (figs. 12*E*, 13); they were extensive along the Seward-Anchorage Highway and on the Richardson, Sterling, and Glenn Highways, particularly in paved sections. These fractures, plus the oblique type shown on figure 12*F*(2), represent about 90




12.—Schematic drawing of types of fracture generated by earthquake in roadways. *A*, Preearthquake. *B*, Underlying sediments compact and displace laterally. Roadway settles differentially and is moved laterally by underlying sediments; roadway fractures along centerline and is wavy; hump is formed off roadway. *C*, Underlying sediments compact and move laterally; roadway settles and longitudinal fractures develop along edges; roadway also wavy. *D*, Longitudinal fractures form as in *C;* as underlying sediments continue to compact and displace laterally, roadway settles differentially and transverse fractures develop. *E*, Fracture forms owing to horizontal displacement of roadway and underlying sediments; fracture generally originates off roadway. *F*, Fracture forms in original ground oblique to roadway; as it strikes roadway, it either continues at oblique angle (F1) or is refracted normal to roadway and, when past roadway, becomes oblique again (F2) ; these fractures occur chiefly in small roadway fills.

13.—View northwest showing conspicuous centerline fracture and more typical perpendicular fractures on Seward-Anchorage Highway between Portage and Twentymile River. Photograph by D. S. McCulloch.

14.—Centerline fracture on unpaved Copper River Highway at south approach of Clear Creek bridge 329 at mile 41.0. Photograph by George Plafker.

percent of those observed on the Richardson, Glenn, and Sterling Highways and about 75 percent of those on the Seward-Anchorage Highway.

From mile 75.1 to mile 91 and from mile 99 to mile 105 on the Seward-Anchorage Highway, the fractures normal to the axis of the highway were spaced 75 to 200 feet apart. Horizontal displacement of as much as 5 feet and vertical displacement of 1 foot were noted. Where the highway passed over fine-grained sediments and swamp debris, such as the Sterling Highway near mile 71 and again near mile 75, the roadway was skewed and displaced as much as 4 feet horizontally and 8 to 10 inches vertically, and the spacing of the fractures was as close as 10 feet.

#### FRACTURES ALONG HIGHWAY CENTERLINE

Fractures along the centerline of the highway (fig. 12*B*) formed near Portage on the Seward-Anchorage Highway (fig. 13) and on the unpaved Copper River Highway, especially from mile 40 to the Million Dollar bridge (fig. 14). This type of fracture occurred (1) where a relatively thick roadway fill was underlain by fine-grained saturated sediments in swamp deposits, and (2) where the roadway was underlain by fine-grained silty sand and gravel and the water table was within 2 feet of the surface. Most of the axes of the fractures on the centerline of the highway were normal or nearly normal to the direction of seismic motion. The centerline fractures along the Portage and Copper River Highways are perpendicular to the slope of terrain.

The largest centerline fracture occurred between Portage and Twentymile River on the Seward-Anchorage Highway (fig. 13). The fracture was about 500 feet long, as much as 10 feet wide, and 6 to 8 feet deep.

#### FRACTURES ALONG HIGHWAY EDGE

Fractures formed locally along the edges of all the highways. This type of fracture (fig. 12*C*) was responsible for considerable damage, especially on the Copper River Highway and the Seward-Anchorage Highway near mile

75.0. Because of the differential settling of the roadway associated with this fracture pattern, the roadway is wavy.

#### FRACTURES NORMAL TO AND ALONG HIGHWAY EDGE

On the Copper River Highway severe fracturing occurred along the edges of the roadway (fig. 15) as well as normal to the roadway, primarily in the roadway fill (fig. 12*D*). The fractures shown on figure 15 were in a fill 8 to 10 feet thick which subsided about 3 feet into the underlying fine sand and silt desposited by the Copper River. The waviness of the roadway shown on figure 15 indicates differential compaction and lateral displacement of the underlying sediments.

#### OBLIQUE FRACTURES

Oblique fractures, an interesting but not commonly destructive fracture system, occurred during the earthquake (fig. 12*F*). These fractures originate on the ground off the highway fill and intersect the shoulders of the fill at oblique angles. Some continue through the fill at the same angle and into the ground again (fig. 12*F*(1)). More commonly, however, where the fracture strikes the roadway it is refracted normal to the roadway axis. Once through the roadway, the fractures once again become oblique and attain their original heading (fig. 12*F*(2)). This refracted fracture is especially common where the roadway is paved. Such fractures occurred on the road at the north end of Hood Lake in Anchorage, on parts of the Richardson Highway, on the Copper River flats, and on the Seward-Anchorage Highway a few miles south of Anchorage.

Displacement, both vertical and horizontal, is very slight and thus is not very destructive.

15.—Fractures normal to and along highway edge, Copper River Highway. Looking east from Copper River bridge 2, mile 27.1. Approach subsided 3 feet and fractured.

#### COMPLEX FRACTURES

Where the highway passed over saturated fine sand and silt with a free face close by, a very distinct and destructive fracture system developed (fig. 16). The fractures of this system have horizontal displacements of as much as 2 feet and vertical displacements of 18 inches. Figure 16 shows that lateral displacements and slumping toward a free face occurred with movement to the right. Fractures normal to the roadway near the Allen River indicate that the sediments also moved toward the river, although this movement is not clear on the illustration. In addition, the underlying supporting sediments failed.

### ORIGIN OF FRACTURES

At the time of the earthquake, much of the roadway and ground beneath it was frozen to depths of 4 to 5 feet. A frozen roadway is more brittle than a thawed roadway, but the frozen ground probably did not play a major role in the origin of a fracture; however, once the fracture developed in a frozen roadway, it maintained its integrity.

#### NORMAL TO HIGHWAY

Fractures normal to the roadway are due to shear and tension (fig. 12*E*). The fractures due to shear first form in the ground because of mass displacement of the underlying sediments toward a free face. The lateral displacement is general, and the roadway does not show the total horizontal displacement in one fracture but in a series of them; thus, the roadway when viewed in plan is askew. At the same time, differential compaction and lateral displacement of the underlying sediments parallel to the axis of the roadway cause tension and vertical as well as horizontal displacements.

#### ALONG HIGHWAY CENTERLINE

Failures along the centerline of the highway fill are due to tension (fig. 12*B*). As the roadway and underlying sediments are subjected to seismic shaking, the denser roadway subsides into the underlying less-dense sediments. The sediments then flow outward and the overlying fill fails. The underlying sediments are not necessarily liquefied; failure can occur prior to liquefaction. There is generally a hump or fracture on the original ground where the compacted and laterally displaced underlying sediments flow toward the surface. Intense seismic shaking of relatively long duration is necessary to produce centerline fractures. Eyewitness accounts indicate that such shaking did indeed occur in the Portage and Copper River areas.

#### NORMAL TO AND ALONG HIGHWAY EDGE

Fractures along the edges and parallel to the roadway (fig. 12*C*, *D*) are caused by compaction of the underlying sediments and lateral spreading of the ground. As seen in figure 12*C* the roadway, although wavy from differential compaction, has maintained its integrity. As the roadway is subsiding differentially, it is also being displaced along the axis owing to displacement of the underlying sediment. Thus, normal and longitudinal fractures are due to tension and are confined to the road fill.

### SUBSIDENCE OF ROADWAY

Throughout south-central Alaska the highway system experienced much local subsidence because of compaction and lateral displacement of the underlying

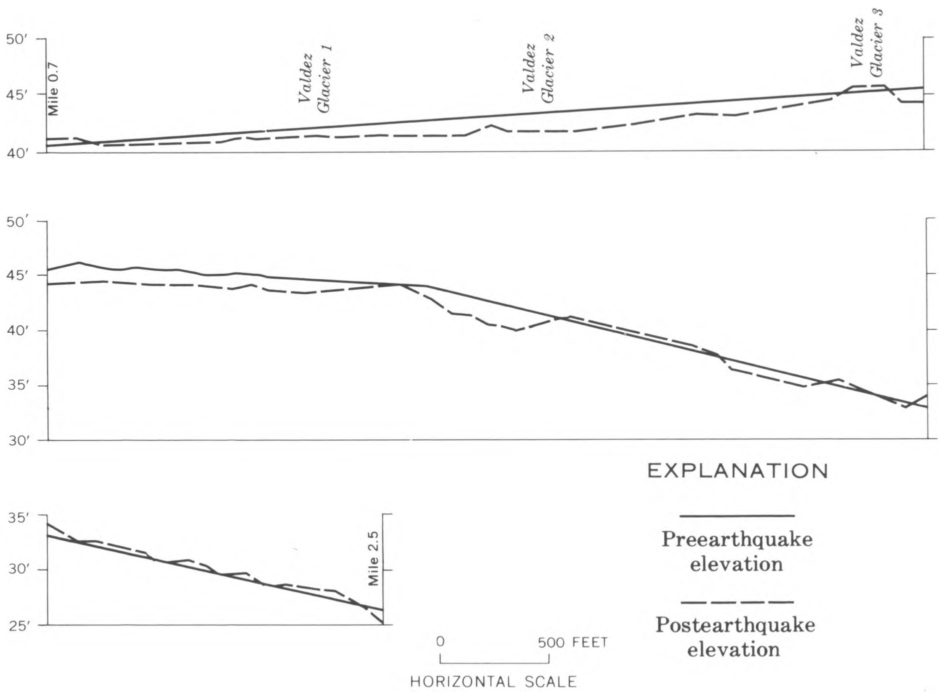
16.—Complex fractures with relatively large lateral and vertical displacements, produced by movement of saturated fine sand and silt toward free faces. View north near mile 58.5, Copper River Highway. The Allen River, which drains Allen Glacier, is in the background.

sediments. Although not as spectacular as the damage from fractures, this damage was the most widespread. The only places that escaped were those where the roadway was on bedrock. The local differential subsidence made the roadways undulating and wavy and dropped the approaches to most of the bridges.

The most spectacular local subsidence occurred (1) on the Richardson Highway between mile 0.0 and mile 5.0, (2) on the Copper River Highway near mile 28.0, and (3) on the Seward-Anchorage Highway at Snow River Crossing and from mile 75.1 to mile 91.0. Figure 17 shows pre- and postearthquake profiles from mile 0.7 to mile 2.5 of the Richardson Highway; figure 18, pre- and postearthquake profiles from mile 5.9 to mile 11.0 of the Copper River Highway; figure 19, pre- and postearthquake profiles from mile 75.1 to mile 85.0 of the Seward-Anchorage Highway; and figure 20, pre- and postearthquake profiles and pier elevations at the Snow River Crossing of the Seward-Anchorage Highway.

None of the postearthquake profiles indicate tectonic subsidence or uplift; they represent only subsidence of the roadway due to compaction and lateral displacement of the underlying sediments. A few profiles indicate uplift due to bulldozing of sediments against bridge abutments or to ground waves. Bulldozing occurs when the laterally displaced sediments of the bridge approaches strike the resisting bridge abutments and form a mound of sediments at the contact between the two.

Another type of subsidence was noted at Snow River. At the time of the earthquake, the Alaska Department of Highways was constructing a second crossing there.



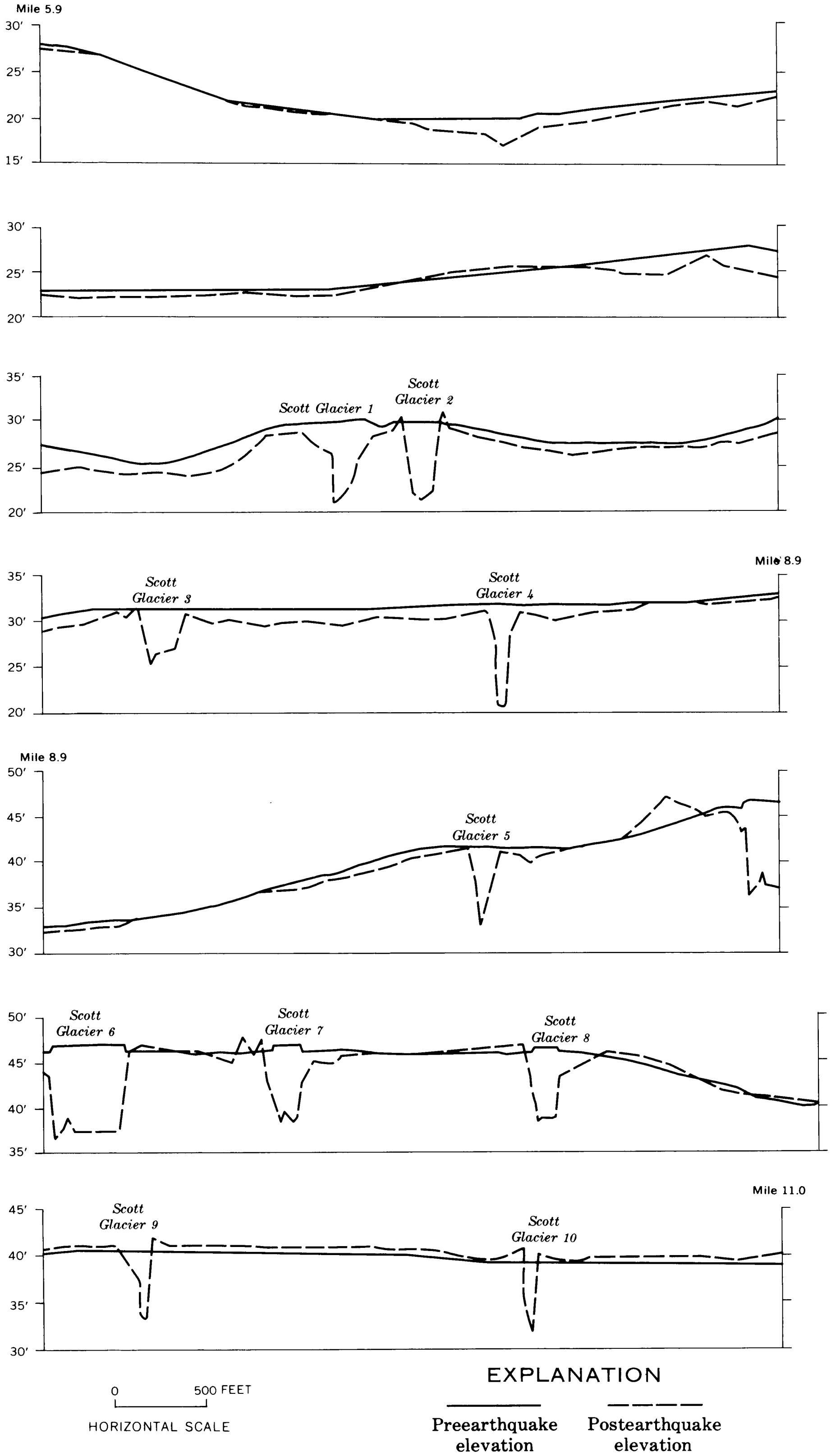

17.—Pre- and postearthquake profiles from mile 0.7 to mile 2.5, Richardson Highway. Data from Alaska Department of Highways.

The piers shown on figures 20 and 21, which are part of the new crossing and which subsided as much as 4 feet, rest on 18-inch tubular piles driven to depths of as much as 160 feet. The subsidence of these piers indicates that the underlying sediments either compacted to great depths or that seismic shaking in fine silt liquefied the sediments and allowed the piles to sink. In addition, when the piles at abutment 1 (fig. 20) were pulled, they were found to be distorted and bent by the earthquake below the ground surface.

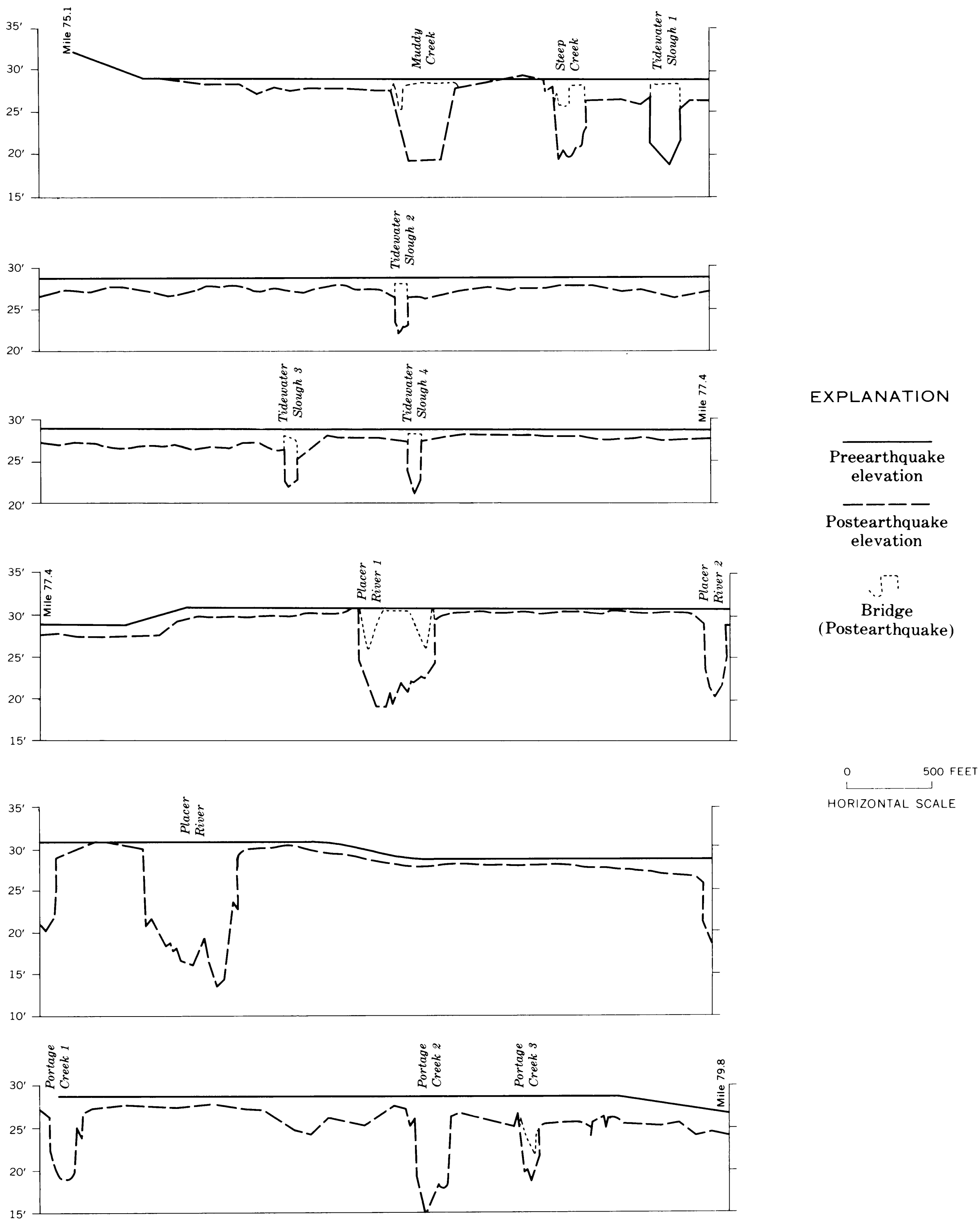
The roadway fill at the Snow River Crossing prior to the earthquake was from 4 to 7 feet thick. After the earthquake the 4-foot part of the fill had subsided as much as 2 feet beneath the ground surface. The profile in figure 20 indicates that the ground surface subsided about 5 feet. Thus, in places the roadway must have subsided as much as 11 feet, that is, the 4-foot fill subsided 6 feet and the sediments subsided 5 feet. This is the maximum recorded local subsidence due to compaction and displacement of the underlying sediment. Figure 22 shows the western bridge at the crossing; the road fill here had to be almost completely replaced.

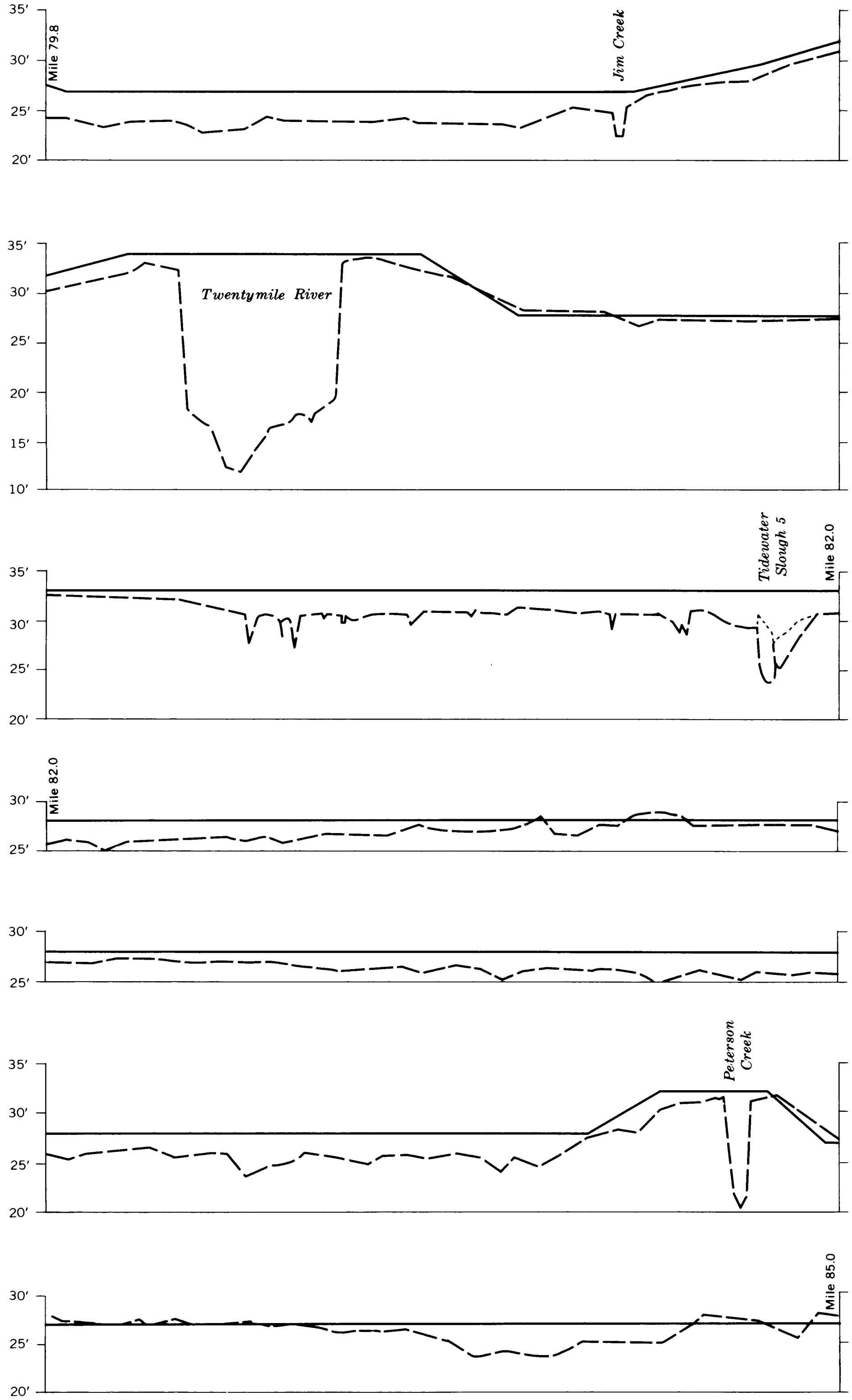
The Snow River Crossing is underlain by fine sand and silt, covered with a thin veneer of fine gravel (fig. 8). The water table is in many cases at or within a foot of the surface. The fine-grained saturated sediments had very little strength, and, when the seismic shaking struck the area, the sediments failed primarily by liquefaction and lateral spreading or displacement.

A large amount of local subsidence of the roadway occurred in the Portage area on the Seward-Anchorage Highway. Here a maximum subsidence of 54 inches was measured by the Alaska Department of Highways at mile 79.3 between Portage Creek 1 and




18.—Pre- and postearthquake profiles from mile 5.9 to mile 11.0, Copper River Highway. Data from Alaska Department of Highways.


35′
30′
25′
20′
15′
10′
Mile 75.1
Muddy Creek
Steep Creek
Tidewater Slough 1
Tidewater Slough 2
Tidewater Slough 3
Tidewater Slough 4
Mile 77.4
Placer River 1
Placer River 2
Placer River
Portage Creek 1
Portage Creek 2
Portage Creek 3
Mile 79.8
EXPLANATION
Preearthquake elevation
Postearthquake elevation
Bridge (Postearthquake)
0
500 FEET
HORIZONTAL SCALE

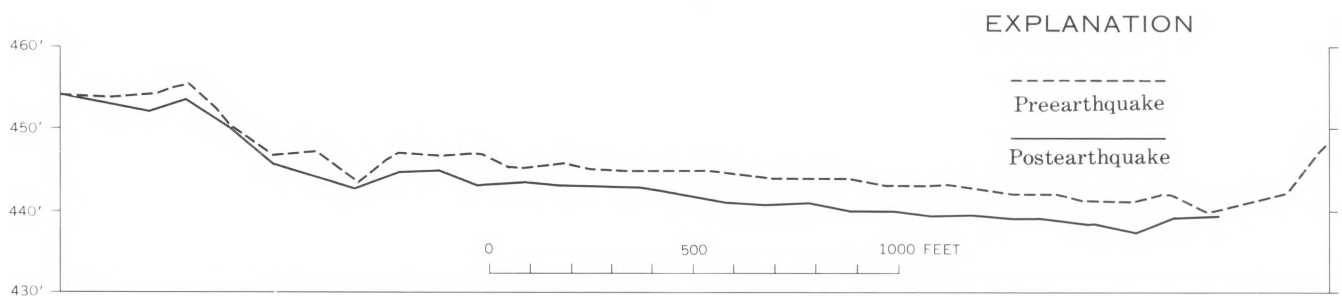



19. (Above and left)—Pre- and postearthquake profiles from mile 75.1 to mile 85.0, Seward-Anchorage Highway. Data from Alaska Department of Highways.

| ELEVATION OF TOP OF PIER, IN FEET | PIER 3 | PIER 5 | PIER 6 | PIER 7 |
|---|---|---|---|---|
| | This pier is canted 3/8 in per ft S. 15/16, in per ft E | This pier is canted 15/16 in per ft S. 3/8 in per ft W | This pier is canted [illegible] in per ft S, 1/4 in per ft W | This pier is canted 3/32 in per ft W. 15/16 in per ft S |
| | N S | N S | N S | N S |
| Before earthquake | 446.13 | 446.13 | 446.13 | 446.13 |
| After earthquake | 444.43 | 442.77 | 443.95 | 444.01 |
| North side | | | | |
| South side | 444.18 | 442.17 | 443.33 | 443.43 |

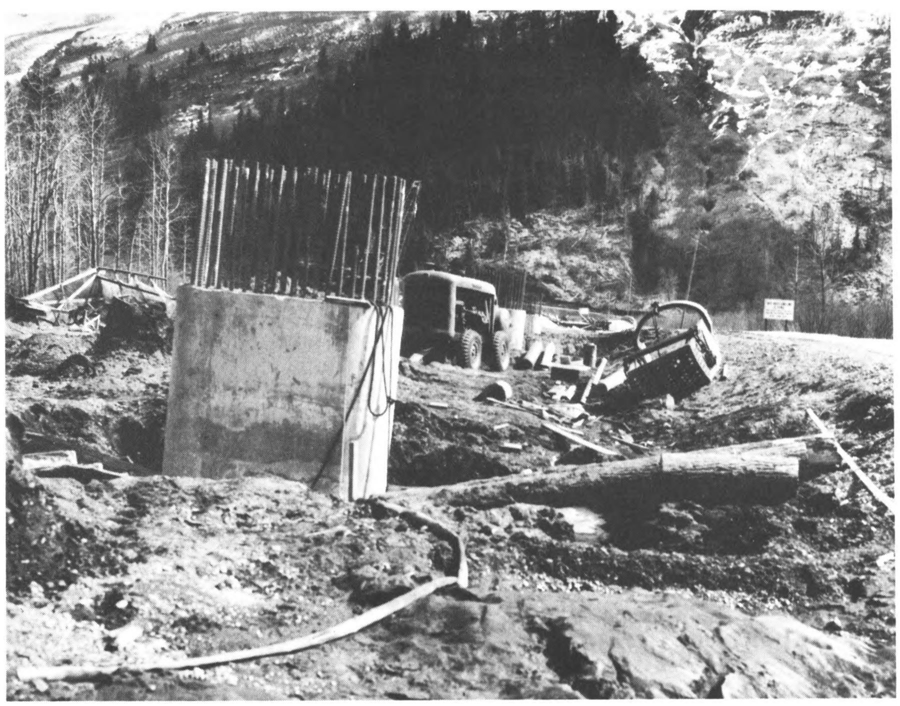
The original elevation on these columns was plus or minus 0.05 feet

*A*




*B*

20.—Pre- and postearthquake pier elevations (*A*) and profiles (*B*) near mile 17.3 at Snow River Crossing, Seward-Anchorage Highway. Profiles are at east side of Snow River Crossing. Data supplied by Alaska Department of Highways.



21.—Bridge pier for new crossing at Snow River displaced by compaction of underlying sediments or by liquefaction of fine silts. Photograph by D. S. McCulloch.

22.—View, looking west, of arched bridge at Snow River Crossing. Note that new fill in foreground was added to compensate for subsidence of approach fills and arching of bridge. Some of the original road fill had to be completely replaced. Photograph by D. S. McCulloch.

Portage Creek 2 and at mile 82.1, 0.1 mile north of Tidewater Slough 5 bridge (fig. 19). Much subsidence also occurred in the finer grained sediments around Turnagain Arm. At mile 79.3 the roadway is underlain chiefly by silty sand deposited by Portage Creek, and at mile 82.1 the roadway is underlain predominantly by silt and sand.

Local subsidence of the roadway fill caused uptilting of culverts in places on the Portage Glacier Road, the Seward-Anchorage Highway, and the Richardson Highway.

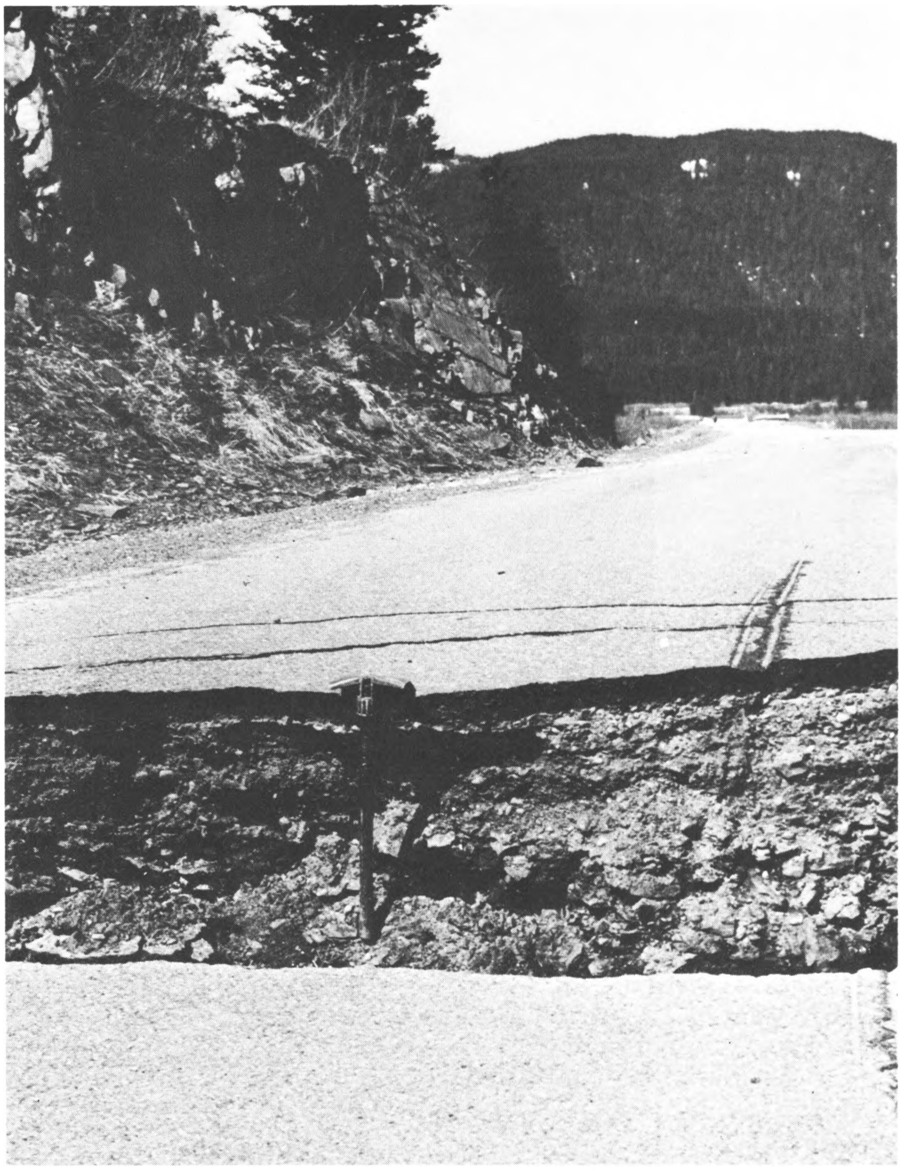
In the Portage area on the Seward-Anchorage Highway there is a definite correlation between local subsidence of roadway, type of sediments, and thickness of the roadway fill (compare fig. 9 with fig. 19). The coarser the underlying sediments, the less the roadway subsided; the thicker the roadway fill, the more the roadway subsided. Another very important factor is the location of the water table; the closer the water table was to the surface, the more the roadway subsided and the more the underlying sediments moved laterally from beneath the roadway fill.

The Richardson Highway between mile 0.7 and mile 2.5 is underlain chiefly by sandy gravel, and the maximum local subsidence of the roadway was 25 inches (compare fig. 11 with fig. 17). The water table generally is more than 6 feet below the ground surface.

Pre- and postearthquake profiles for the Copper River Highway are only available from mile 5.9 to mile 13. In this stretch of the highway a maximum local subsidence of 48 inches occurred at about mile 7.6. Here the roadway is underlain by clay, silt, sand, and organic debris (fig. 10). At mile 10.1, where the roadway is underlain by silty gravelly sand and silty gravel, it did not subside. There was about 18 inches of subsidence at mile 11.0 where the highway is underlain chiefly by silty sandy gravel, sandy silt, and silty sand (all containing organic material; fig. 10); the water table there is about 2 feet from the surface.

The Chiniak Highway on Kodiak Island also failed because of compaction and lateral displacement of the underlying unconsolidated deposits. Maximum local subsidence occurred at the heads of Womens Bay, Middle Bay, and Kalsin Bay. The amount of subsidence was not measured but is estimated to be from 3 to 4 feet at Womens Bay and Middle Bay and 3 feet at Kalsin Bay.

Wherever a highway passes from fill to bedrock, there was settlement of the fill because of seismic shaking. Commonly, the subsidence is very pronounced and may even be expressed as a fracture at or near the bedrock-sediment contact. Roadway-fill approaches to the bedrock outcrop at Bird Point on the Seward-Anchorage Highway settled 2½ to 3 feet. The pavement on both sides of the bedrock outcrop is fractured, but the vertical displacement on each individual fracture is less than 2 inches. In contrast, on the Seward-Anchorage Highway near Ingram Creek (fig. 23), a single fracture was noted between bedrock and sediments along which 22 inches of vertical displacement took place.



23.—Vertical displacement of roadway southeast of Ingram Creek on the Seward-Anchorage Highway. Pavement in foregound is underlain by sediments; in background, by bedrock. Trench shovel handle is 19 inches long. Photographs by Helen Foster.

## LATERAL DISPLACEMENT OF ROADWAY

Severe seismic shaking caused downslope lateral displacement of some sediments and the roadway resting on them. The maximum horizontal displacement measured on roadways was 13½ feet at Snow River Crossing on the Seward-Anchorage Highway. The horizontal displacement at Snow River as well as elsewhere was differential.

The maximum measured horizontal displacement on the Richardson Highway was 5.3 feet at about mile 1.6.

The amount of horizontal displacement in the Portage area of the Seward-Anchorage Highway is unknown, but the railroad in this area was displaced about 10 feet (David McCulloch, oral commun., 1966), so it is not unreasonable to assume that the highway was displaced a similar distance.

## LANDSLIDES

The earthquake triggered numerous small roadway landslides; the locations of slides are shown on figures 2–5. Most were small and only affected part of the roadway; on the Seward-Anchorage Highway near mile 44.5, for instance, about 100 feet of the roadway was displaced toward Summit Lake (fig. 24). There were also several small landslides between mile 54 and mile 56 on the Seward-Anchorage Highway.

The only relatively destructive landslides on the Sterling Highway were near Cooper Landing and at mile 60.5. On the Glenn Highway there were 10 slides; these occurred near mile 30, at Moose River, mile 61, mile 69, mile 70, at both approaches to Caribou Creek at mile 106.9, mile 139, and mile 140. The most destructive of these slides were at Caribou Creek.

The slides that caused the most damage were on the Richardson Highway at mile 65 and at the bridge crossing the Little Tonsina River. The landslide compressed the bridge and left a 3- to 4-foot hump where the asphalt paving meets the bulkhead.

A much larger landslide was generated in glacial debris at mile 72.5 on the Richardson Highway where about 300 feet of the roadway was displaced about 7 inches downslope.

### AVALANCHES

The numerous avalanches generated by the earthquake caused only minor damage to the highway system in south-central Alaska. Most of the avalanches that caused highway damage occurred on the Seward-Anchorage Highway between mile 83 and mile 95; here the largest covered the roadway with at least 20 feet of snow.

Large avalanches occurred at miles 38, 39, and 42 in the rugged terrain of the Chugach Mountains through which the Richardson Highway passes. At mile 44, a rock slide developed. Although not on the roadway, a large avalanche near mile 50 dammed the Tiekel River and had to be removed by explosives because the rising waters were endangering the highway. A 200-foot landslide on the Edgerton Highway at Lower Tonsina Hill, a short distance north of Lower Tonsina, was noted by Ferrians (1966).

### SAND EJECTA BLANKETS

Formation of sand ejecta blankets, an interesting but nondestructive phenomenon, was noted along the highway system in south-central Alaska. These blankets, most common on the Richardson and Copper River Highways, were formed by the ejection of generally very fine sand, through fissures in the ground where the depth to the water table was usually less than 10 feet. The largest ejecta blanket was on the Copper River Highway about 30 miles from Cordova; it covered an area of at least an acre to a depth of as much as 3 feet.

### SEISMIC SEA WAVES

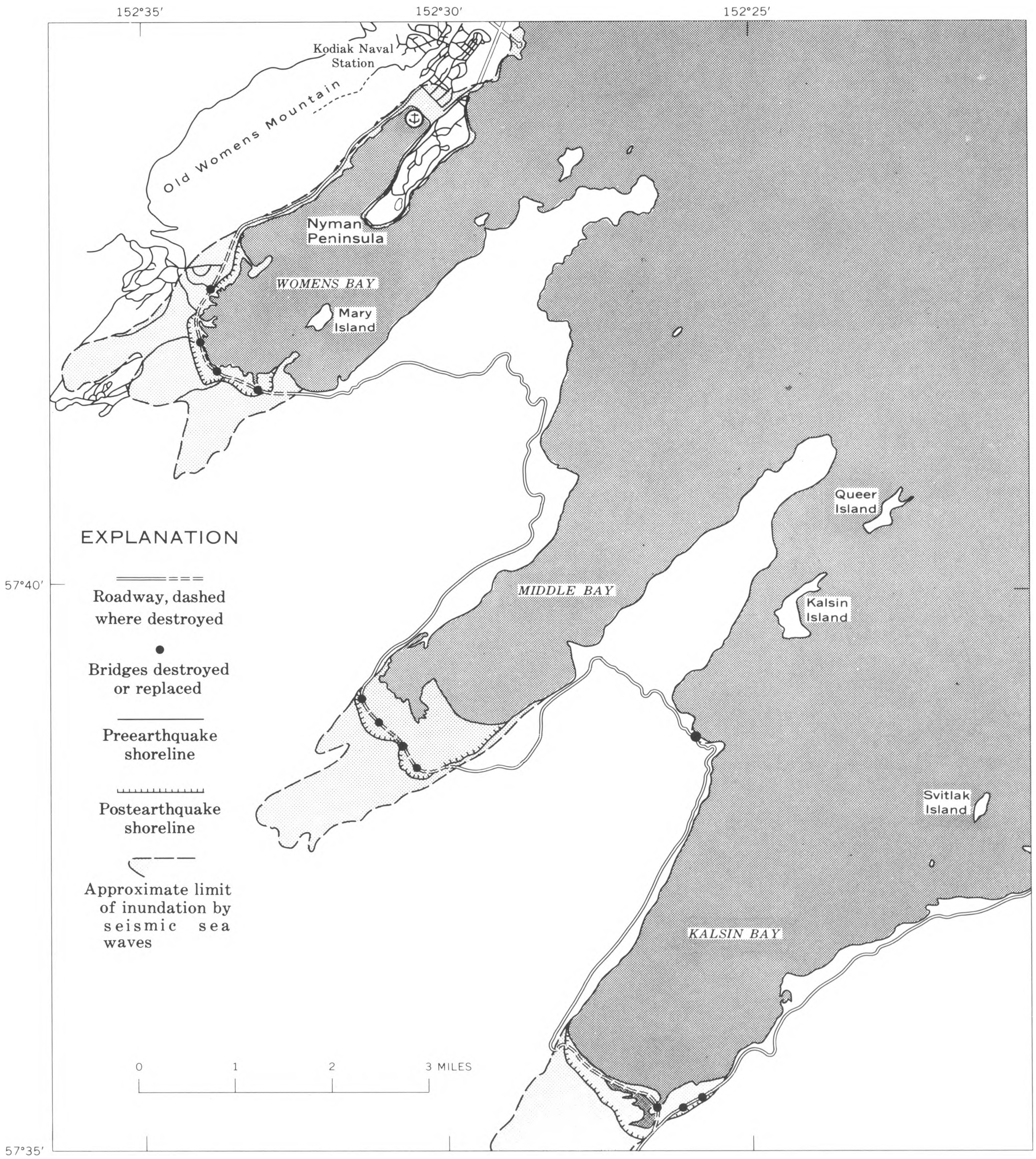
Seismic sea waves that struck Kodiak Island destroyed 13 miles of the highway net (Plafker and Kachadoorian, 1966). The waves were particularly damaging to the low-lying roadway and bridges at Womens Bay, Middle Bay, and Kalsin Bay (figs. 7, 25).


24.—Small landslide on Seward-Anchorage Highway near mile 44.5, along shore of Summit Lake.

The waves ran inland as much as 1½ miles in Women's Bay, 2½ miles in Middle Bay, and about 3 miles in Kalsin Bay. The in- and outgoing water was especially violent in Kalsin and Middle Bays (Plafker and Kachadoorian, 1966, pl. 3) and in Womens Bay (Plafker and Kachadoorian, 1966, p. D42). Three miles of road was destroyed at Womens Bay, 3 miles at Middle Bay, 1 mile at Mayflower Creek, 4 miles at Kalsin Bay, and about 3 miles at Twin Creeks east of Isthmus Bay. The roadways in these areas had to be realined because compaction of the underlying sediments and regional subsidence left them under water during high tides.

Most of the 4-mile stretch of the Chiniak Highway from the Kodiak Naval Station to Womens Bay was inundated by the seismic sea waves, but the roadway was only slightly damaged because the asphalt pavement prevented extensive erosion.

The Point Whitshed Road, between Cordova and Point Whitshed, crosses Hartney Bay on an artificial fill about 12 feet thick, 28 feet wide, and about 1 mile long. At the time of the earthquake the roadway was unpaved. Eighteen feet of the original 28 feet still remains; about 10 feet of the inland side of the roadway was cut off as if by one stroke of a huge cleaver (fig. 26). This remarkably straight-line failure could not have been along a construction joint because the fill was placed as a unit. During the earthquake, severe seismic shaking probably generated a longitudinal fracture along the axis of the fill about 18 feet from the Orca Inlet side or 10 feet from the inland side of the fill. This fracture was due to compaction and lateral displacement of the underlying saturated silt and




25.—Pre- and postearthquake shorelines and area of inundation by seismic sea waves on Kodiak Island.

gravel. When the incoming (from left to right in fig. 26) seismic sea waves topped the roadway, they must have had sufficient force to topple the inward 10-foot part of the roadway. As the seismic sea waves receded, they scoured away part of the toppled roadway.

### TECTONIC SUBSIDENCE

The Alaska earthquake caused vertical land changes throughout much of south-central Alaska (Grantz, Plafker, and Kachadoorian, 1964; Plafker, 1965). Where the highways were underlain by areas that were uplifted, no long-range damage was done. Definite problems did arise, however, where the highway passed over low-lying areas that were affected by regional tectonic subsidence. Widespread effects of subsidence were not felt until the spring tides in April 1964. These and subsequent high tides submerged much of the Seward-Anchorage Highway around Turnagain Arm from mile 75.1 to mile 91.0 (fig. 27). The town of Portage as well as the highway were inundated by the high tide.

Tectonic subsidence in the Turnagain Arm area was about 5.2 feet with additional local subsidence of as much as 4.5 feet; thus, parts of the Seward-Anchorage Highway subsided 9.7 feet. Figure 28 shows the preearthquake shoreline which is mean high water and the area inundated by the 33-foot tide of April 14, 1964.

The low-lying areas at the head of Womens Bay, Middle Bay, Kalsin Bay, and the small bay east of Isthmus Bay on Kodiak Island became subject to flooding during high tides. During a 4½-foot tide the Chiniak Highway at the head of Womens Bay was mostly under water. The area had a regional tectonic subsidence of 5.6 feet plus 3 to 4 feet of subsidence due to compaction and lateral displacement of sediments; thus, total subsidence here was 8½ to 9½ feet.

On Kodiak Island, regional tectonic subsidence plus local differential subsidence required replacing 5 miles of roadway in addition to the 13 miles destroyed by seismic sea waves. This total of 18 miles includes about 2½ miles of roadway at Pasagshak Bay and 2½ miles at Anton Larsen Bay (fig. 7).

About half a mile of the Glenn Highway near mile 27 was inundated during high tides. Tectonic subsisdence was about 2 feet, but there must have been another 6 feet of subsidence due to compaction and lateral displacement of underlying sediments—otherwise the roadway would not have been flooded during high tides.

Regional tectonic subsidence and local differential subsidence have caused a definite long-range hazard to the highway system on the Seward-Anchorage Highway around Turnagain Arm. Because space and economic factors do not permit a major change of alinement, the roadway must be brought to grade by the addition of fill. The fill will have to be riprapped because it will be subjected to tidal action and erosion during high tides.

## DAMAGE TO BRIDGE APPROACHES AND BRIDGES

The Alaska earthquake and attendant seismic sea waves raised havoc with the highway bridges in south-central Alaska. When the seismic shaking stopped, 119 bridges had been damaged. An additional 13 bridges were destroyed by seismic sea waves, and 9 more had to be replaced because regional tectonic subsidence or local subsidence of the sediments placed them under water during high tides.

On March 27, 1964, in the 586,400 square miles of Alaska, there were 480 bridges having an aggregate length of about 77,300 feet. Of these, 204 bridges with a total length of 36,311 were in south-central Alaska (tables 13, 14, p. C58). One hundred forty-one bridges or about 30 percent of the 480 bridges were damaged; 92 bridges or 19 percent were severely damaged or destroyed; and 23,267 feet or 30 percent of the total bridge footage in Alaska required replacement.

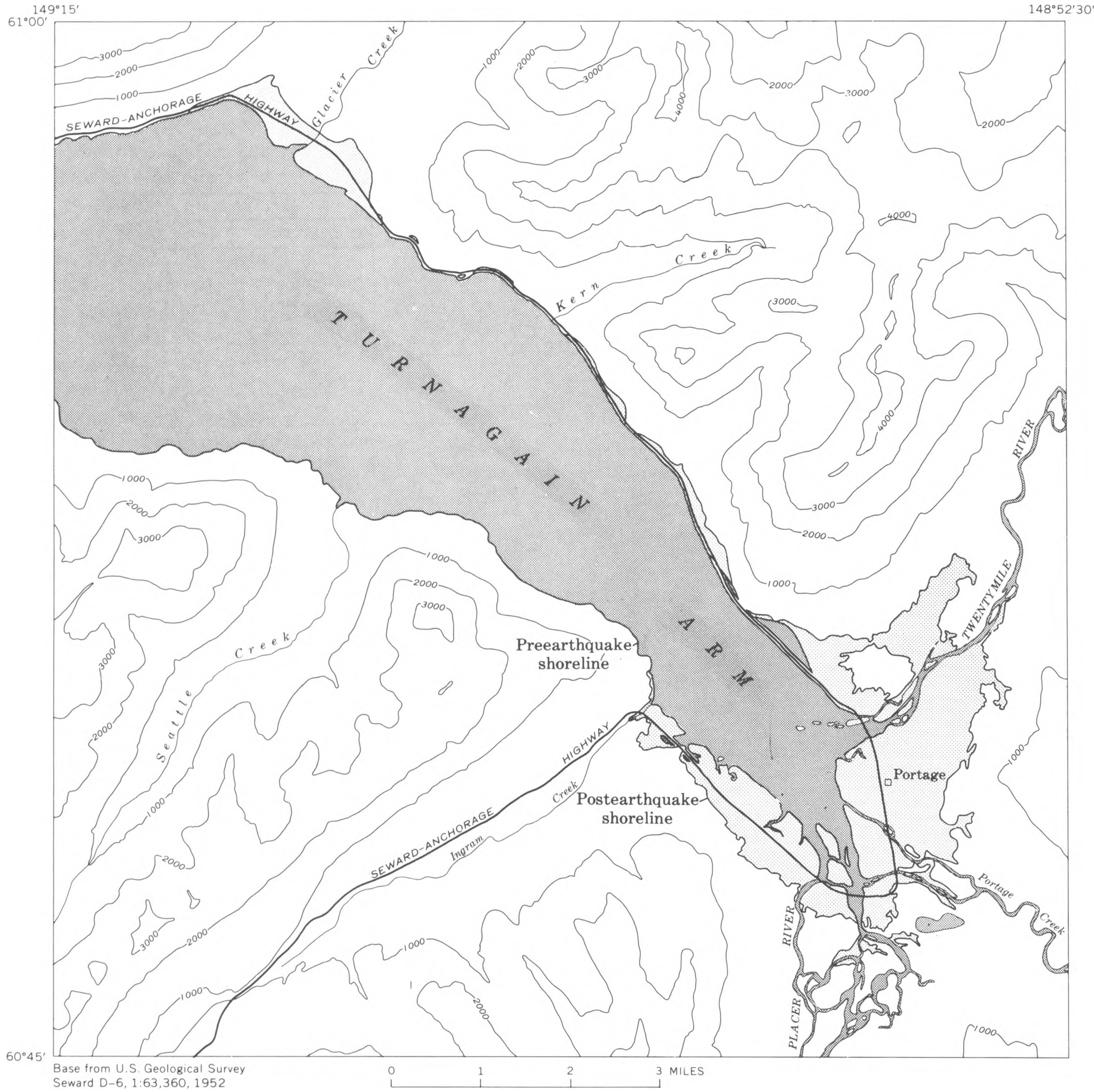
If we consider only the bridges in south-central Alaska, the statistics become even more staggering. Only 63 bridges or 31 percent were not damaged; 39 bridges or 19 percent received slight damage; 10 bridges or 5 percent sustained moderate damage; and 92 bridges or 45 percent were severely damaged or destroyed. Of the total bridge footage in south-central Alaska, 64 percent was damaged severely enough to require replacement (tables 13, 14, p. C58). The cost of repairing or replacing the structures amounted to $25,899,476. This is a tremendous loss to any State's highway system and economy.

The bridges on the Copper River Highway that were farthest from the epicenter (fig. 1) suffered the greatest damage. Of the 53 bridges on the highway, 52 were damaged and 32 were severely damaged or destroyed (tables 13, 14, p. C58). The only bridge that was not damaged rested on bedrock and spanned the Eyak River at mile 5.9. Table 14 gives the intensity of bridge damage on the other highways or roads in south-central Alaska.

Seismic shaking and its effects upon the foundations of the bridges were responsible for damage to 120 bridges. These effects include compaction of the

26.—Right side of Point Whitshed Road destroyed by seismic sea waves. Waves advanced over roadway from the left and cut sharp edge on right side of roadway. View northeast; Hartney Bay is to the right.

27.—View of Portage on Seward-Anchorage Highway during 28-foot tide, after regional subsidence caused by the earthquake. Highway is under water, just below railroad grade in far background. Photograph taken August 10, 1964.

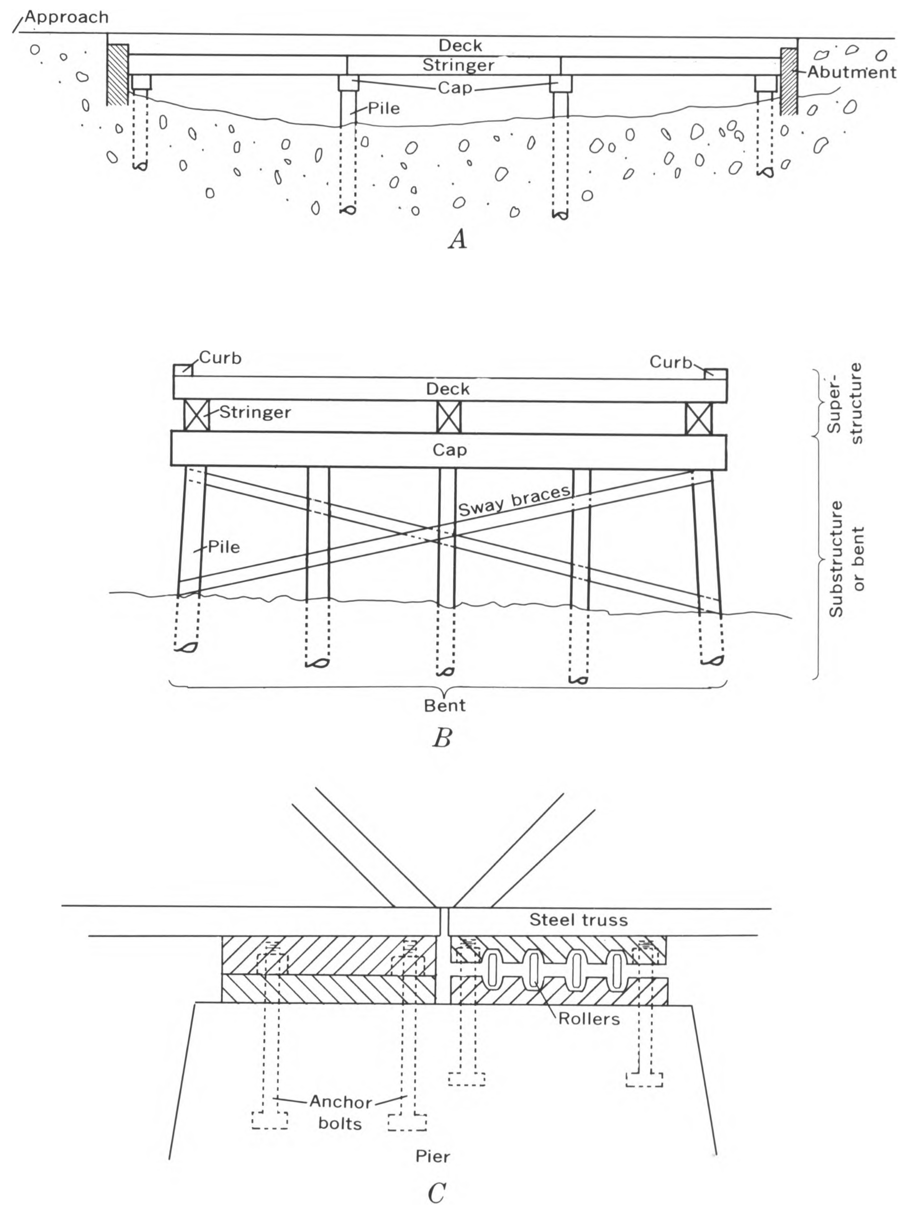



28.—Map of Turnagain Arm showing pre-earthquake shoreline based on mean high water and showing also the area inundated by the 33-foot tide of April 14, 1964. Tide height datum is mean lower low water.

sediments upon which the bridges rested and lateral displacement of the sediments toward free faces. Only five bridges on bedrock were damaged, and those only slightly. The remaining 114 bridges were underlain by unconsolidated sediments.

The damage to roadway fill approaches to a highway bridge can easily be explained, but an analysis of bridge damage is not so simple. There is a definite correlation between the damage to bridges on bedrock and to those on sediments, but analyses of damage to the bridges on sediments is more complex. Damage intensity is not only a function of the type of sediment but also the type of structure.

Tables 15–19, p. C59–C66 list the bridges on the Copper River, Seward-Anchorage, Glenn, Richardson, and Sterling Highways, respectively, and show the location, length, type, foundation material, and earthquake damage. The descriptions of damage, particularly of severe damage or total destruction, are brief and do not include all failures. The terms used in the tables are shown in figure 29, which indicates the various structural elements that make up a typical bridge.




29.—Schematic drawing showing various elements of a bridge. *A*, view parallel to stream; *B*, view perpendicular to stream; *C*, view parallel to stream.

## SEISMIC SHAKING

The approaches to nearly all the bridges in south-central Alaska subsided in relation to the bridge decks (fig. 30). Even where fill approaches were placed on bedrock, some subsidence or compaction took place.

The maximum compaction and settlement recorded for any bridge approach was 7½ to 8 feet at the north approach to Tidewater Slough 5 bridge on the Seward-Anchorage Highway at mile 82.0 (table 16, p. C63). There, the roadway is underlain chiefly by sand and silt. On the Seward-Anchorage Highway all the bridge approaches subsided because of compaction except the structures spanning Quartz Creek, Summit Creek, Colorado Creek, Spokane Creek, Bertha Creek, and Lyon and Tincan Creek. Quartz Summit and Colorado Creek bridges are short 22-foot spans anchored in bedrock with a thin veneer of coarse gravel for approaches. Lyon and Tincan, Bertha, and Spokane Creek bridges are on a thin layer of coarse gravel overlying bedrock and do not have thick approach fills.

The factors chiefly responsible for large subsidence of approaches on the Turnagain Arm section of the Seward-Anchorage Highway were (1) the highway is underlain by fine-grained silt and sand and silty gravel, (2) the water table is close to the surface, generally within 2 feet, and (3) most of the roadway and approach fills are thick. In places between Twentymile River and the town of Portage there was as much as 12 feet of fill. All these factors combined to cause failure of the underlying confining sediments by lateral displacement toward the creek and displacement normal to the roadway fill and approach.

All the bridge approaches on the Copper River Highway underwent compaction and subsidence by seismic shaking with the exception of those at the Eyak River bridge at mile 5.9. Maximum compaction of 3 feet occurred at the east approach of Copper River 2 bridge at mile 27.1. Figure 31 shows the vertical displacement of the approach. This approach fill

30.—Subsidence of bridge approach fill at Tidewater Slough 2 bridge, mile 76.4, Seward-Anchorage Highway. View is west. Photograph by Helen Foster.

31.—View looking west, Copper River bridge 2, mile 27.1, Copper River Highway. Approach subsided 3 feet as a result of seismic shaking.

32.—Mound formed by bulldozing of approach fill against bridge deck (foreground), at north end of Copper River 12 bridge, mile 36.9, Copper River Highway.

is about 10 feet thick and is underlain chiefly by silt and sand.

Displacement of the north approach of Copper River 12 bridge, mile 36.9 on the Copper River Highway (fig. 32), was unique. Here, instead of subsiding, the approach fill formed a mound 18 inches high against the north abutment of the bridge. The silty gravel fill was moved laterally against the resisting abutment and, because the bulkhead did not fail, the mound was formed. A similar mound was formed at the Little Tonsina River bridge on the Richardson Highway by a landslide.

Although the seismic shaking caused some compaction and subsidence on all the Copper River Highway bridge approaches, there were no large vertical displacements chiefly because (1) the fine-grained sediments that underlie much of the highway are coarser than those that underlie the Turnagain Arm section of the Seward-Anchorage Highway where approach subsidence was so extensive, (2) the water table on the Copper River Highway is deeper than that a Turnagain Arm, and (3) the roadway fills are generally only a thin veneer on the original ground.

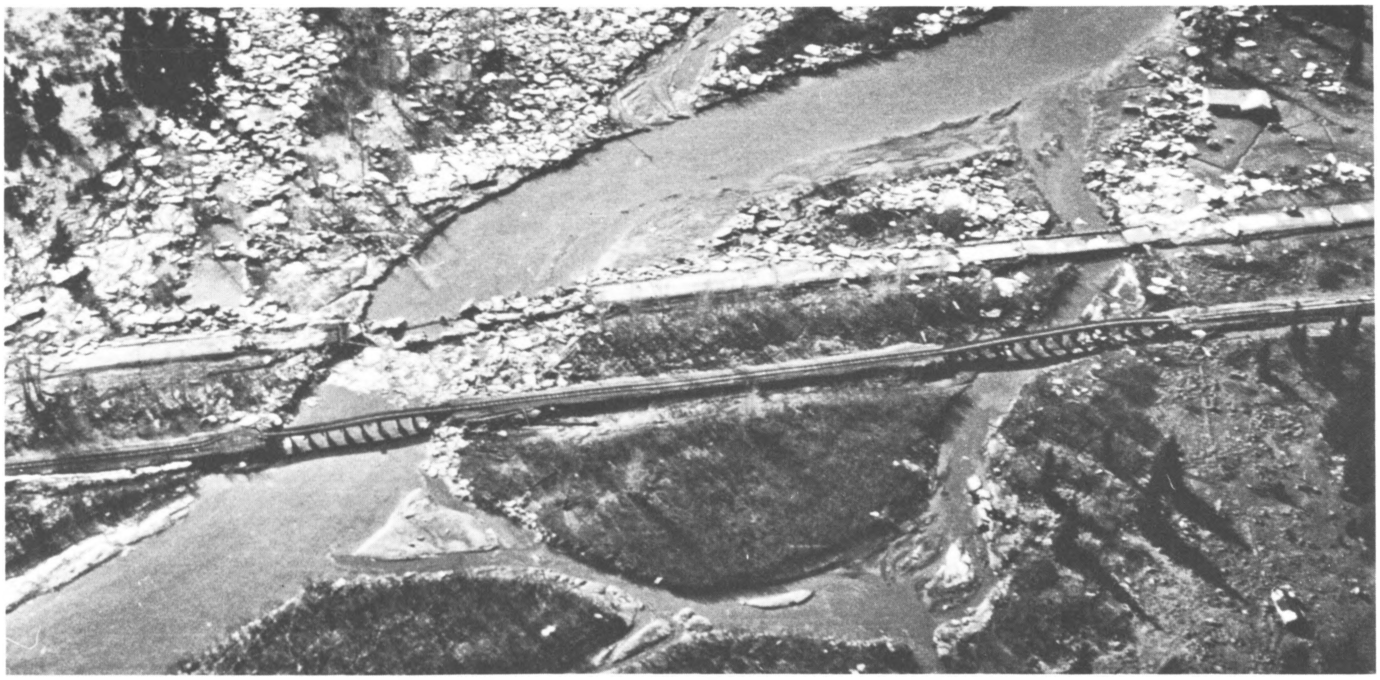
The bridge approaches on the Glenn and Sterling Highways sustained only minor damage. However, even in fill approaches placed on bedrock some subsidence or compaction took place. The Chickaloon River bridge (mile 78.2) and the Puritan Creek bridge (mile 89.3) on the Glenn Highway rest on bedrock, but the approaches are constructed of sandy gravel fill. At Puritan Creek the east approach has 10 feet of fill that subsided 3 inches; the west approach has a 6-foot fill over bedrock and subsided 1 inch. The Chickaloon River bridge approaches have 4 to 5 feet of sandy gravel fill; both approaches compacted or subsided at least 1 inch. Maximum subsidence of approaches was 3 inches recorded at Puritan Creek and at the west approach of the Little Nelchina River, mile 137.5.

On the Sterling Highway both the approaches to the Kenai River bridge, mile 48.9, subsided 8 inches (table 19, p. C66). Subsidence was not expressed as single displacements between the abutments and the approaches, but instead of spread over an area of several feet.

Maximum vertical displacement of bridge approaches on the Richardson Highway was about 6 inches (table 18, p. C65). The displacement at nearly all localities was in glacial sediments, although the Stuart Creek bridge, mile 45.6, the approaches are thick fills overlying bedrock. The main reason for the lack of large vertical displacements of approaches and roadway is the fact that the depth to the water table generally is more than 6 feet and commonly more than 10 feet.

Many types of bridges were in use in south-central Alaska at the time of the earthquake (see tables 15–19, p. C59–C66). If these bridges had rested on the same kind of sediments, the damage could have been analyzed with relative ease, but because the structures rested on different kinds of sediments, analysis was more difficult. The structural damage at first appeared to be random, but further studies indicated a pattern of failure.

The bridges failed in various ways as a result of seismic shaking. Some bridges collapsed completely; in others, anchor bolts sheared off, pilings were displaced, abutments were crowded, structures were compressed, and structural elements were displaced horizontally or vertically. Failure of the bridges on the Turnagain Arm stretch of the Seward-Anchorage Highway, was particularly spectacular. These bridges, simple T-beam spans on timber bent substructures, were underlain chiefly by silt, sand, and silty gravel, so most of the wooden piles were bottomed in this material.



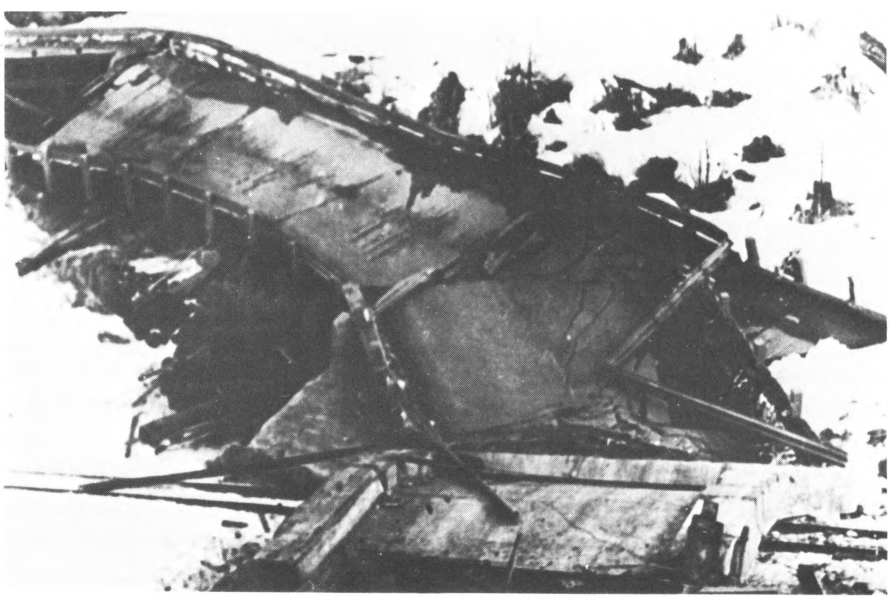
33.—Wreckage of Portage Creek bridges 2 and 3, Seward-Anchorage Highway. The Alaska Railroad grade and bridges are in foreground of highway. Photograph by U.S. Army.

Damage to these bridges occurred because of (1) failure of the wood bents, (2) lateral displacement of the sediments toward the creek which forced the abutments closer together and literally crowded the deck and compressed the bridge (fig. 33), and (3) failure at the tie between the substructure and superstructure. The seismic shaking and lateral displacement of the sediments pulled the wood ties off the caps, and the superstructure became independent of the substructure. The deck or superstructure had a vertical as well as a horizontal component of movement during the earthquake. Eventually the wood bents failed beneath the superstructure and the bridge collapsed. In many bridges the wood piles were driven through the reinforced concrete deck (fig. 34). Eyewitness reports show that the decks had an up-and-down motion period of about 1 second. That is, a wave apparently passed through the deck, and, as it passed through, the superstructure moved up and down in about a 1-second cycle. It is hard to believe that a wood pile could be driven through a reinforced concrete deck by this motion, and that at many places the saw marks could then still be seen at the end of the piles. Apparently at the same time the deck was coming down, a ground wave was displacing the piles upward. These statements should not be construed to mean that the piles actually had a higher altitude after the earthquake than they had before: Nowhere along the highways in south-central Alaska had piles been pulled out of the ground or displaced vertically upwards. On the contrary, all the piles were at lower altitudes after the earthquake, partly because of the pounding of the deck upon the piles but primarily because of the lack of strength of the sediments supporting the piles. Seismic shaking partially or completely liquefied the sediments around the piles.

The overhead at the east end of Snow River Crossing was destroyed by seismic shaking. It rested on wood piles and collapsed upon the tracks of The Alaska Railroad (fig. 35).

Among the severely damaged bridges along the Copper River Highway was the Million Dollar Bridge at mile 49.0. This bridge, constructed in 1910 by the Copper River and Northwestern Railway, made it possible to carry copper ore from Chitina to Cordova. The railroad was abandoned before World War II, and most of its larger bridges and roadbed from Cordova to mile 51 were reoccupied by the Copper River Highway. The rails were salvaged and used as piles on 22 of the highway bridges. Three rails (about 50-pound rails that is, rails that weigh 50 pounds a linear yard) were welded heads together and driven, but there was a history of failure even while they were being driven.

34.—Collapsed bridge across Twentymile River. Railroad bridge in upper right photograph did not collapse.



35.—Overhead at east side of Snow River Crossing. Structure collapsed upon tracks of The Alaska Railroad. Photograph by U.S. Army.

The Million Dollar Bridge, which spans the Copper River as it leaves Miles Lake at the mouth of Copper River canyon, is a historic structure in Alaska. The completion of this bridge is indeed a tribute to the engineers and construction men who built it. Rex Beach, in his book "The Iron Trail," published in 1913, did much to bring these men to the attention of the world.

The bridge consists of four steel truss spans 400, 300, 450, and 400 feet long. Migliaccio (1966) stated that caissons for piers 1, 2, and 3 were landed at 36, 36, and 50 feet below the stream bed. The foundations for all the piers except pier 3 are sand and gravel and boulders from 1 to 10 cubic feet in volume. Migliaccio reported that the foundation supporting pier 3 is sand, gravel, and boulders smaller than those underlying the

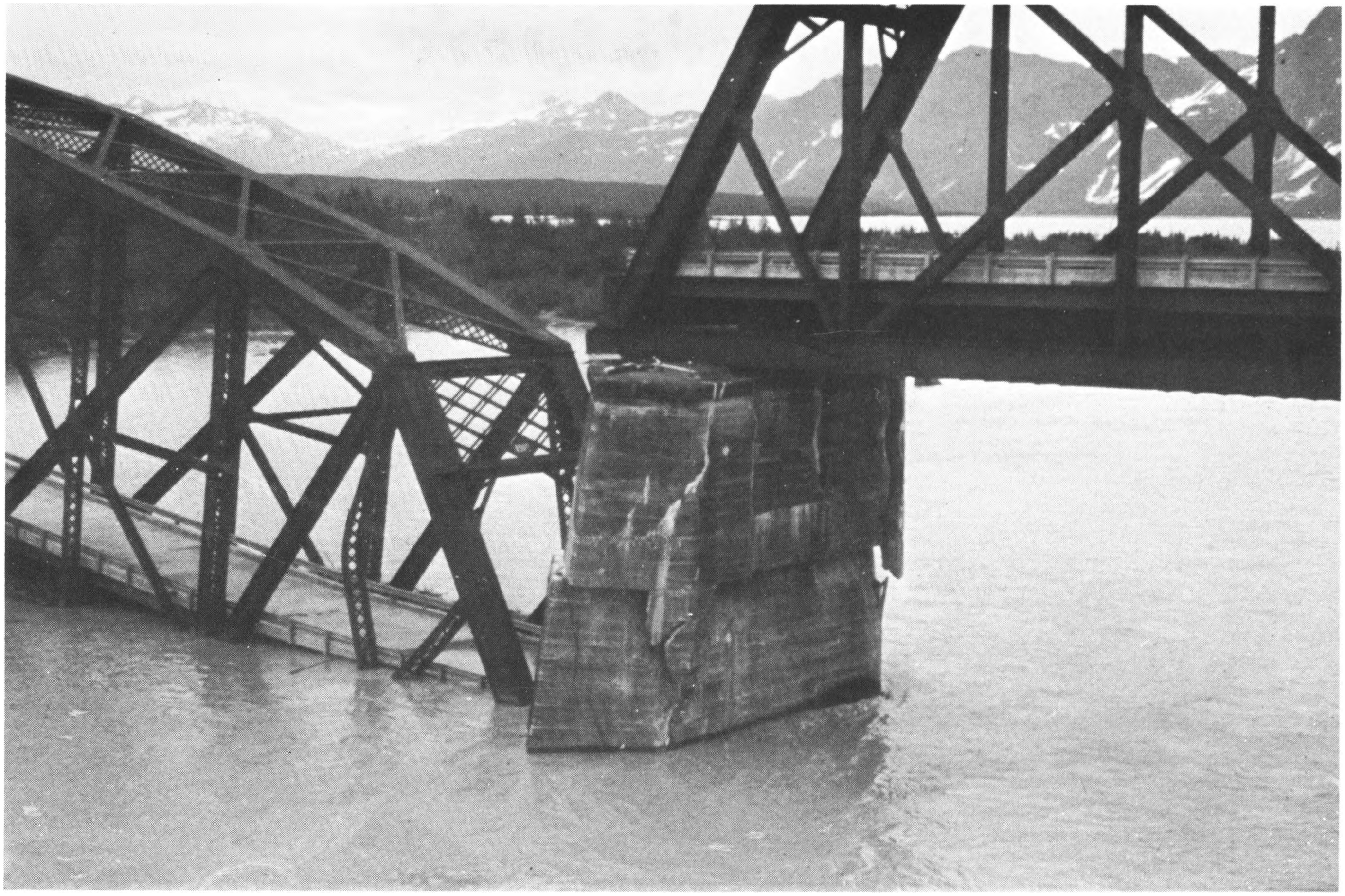
36.—Million Dollar Bridge, Copper River Highway; No. 4 span off No. 4 pier. View is southwest.

other piers. Maximum foundation pressures were less than 4 tons per square foot.

Although the bridge was very severely damaged (figs. 36, 37), the Alaska Department of Highways will no doubt make all efforts to save it because of its historic value. In view of the magnitude of this venture a more complete description of damage is presented here than is possible in table 15. The following damage report was made by Harry Golub of the Alaska Department of Highways:

Abutment 1 relatively undamaged—no sign of movement of abutment itself. Span 1 is displaced 1½ inch south and 1 foot upstream. The top of the backwall and wings are cracked and chipped from pounding of deck. Backwall is pockmarked from rivets at end of truss. New stringer seats have small sections of concrete broken away by contact with end of truss. Anchor bolts are sheared. Truss apparently undamaged. At pier 2 both spans have moved enough to turn their rollers over flat and bend their anchor bolts. In their final position bolts are about in the middle of expansion slots. Span 1 moved south and span 2 moved north. The spans are jammed tight on upstream side, separated by about 2 inches downstream, jamming together pulverized sliding beams between spans as well as the ends of the concrete deck and bent the finger joint and its connections. The bottom chords of the trusses show some crimping from passage over the rollers, but actual damage is difficult to assess without raising trusses. Only a short length of chord and some of its connecting angles are affected.

At pier 3 the following displacements were measured.



37.—Collapsed No. 4 span and horizontal fracture in No. 4 pier of Million Dollar Bridge, Copper River Highway. View is northeast.

Upstream bearings:
- Span 2
  - 19 inches upstream
  - 10 inches north
- Span 3
  - 18 inches upstream
  - 3 inches north

There is about 3½ inches between ends of trusses.

Downstream bearings:
- Span 2
  - 19 inches upstream
  - 13 inches north
- Span 3
  - 19 inches upstream
  - 4 inches north

Ends of trusses jammed together—all anchor bolts sheared. Sliding beams between spans have been pulverized—those on railroad stringer lines have damaged the end floor beam webs. Joint angles and ends of concrete slab badly damaged. Piers 2 and 3 seem to have suffered no structural damage. Pier 4 is virtually destroyed. The upper portion has split into three parts, with each of the end pieces separated from the middle by a crack up to 2 feet wide. The middle portion has a vertical crack running completely through it. The upper half of the pier has also sheared horizontally and has moved about 2 feet south in respect to the lower half. The entire pier has a list toward the south. There is no evidence of reinforcement in the upper pier and failures seem to be along construction joints. The bearings of span 3 are displaced 9 feet 9 inches from their former position on pier 4 in a northward direction and approximately 6 feet transversely. Bottom lateral bracing is mutilated from contact with the pier and the bottom chords have been dragged over the concrete, popping rivets and doing an indeterminable amount of damage to the bottom chord and its connections.

Span 4 has dropped off pier 4 and is in the river, probably resting on the bottom since the river is quite shallow north of pier 4. The truss and concrete deck appear undamaged from $L_0'$ to $L_2$, where the deck is broken and the chords apparently bent or broken by the fall. Verticals $L_1 U_1$ are bent completely out of shape in compression. End posts show no damage above water. The span is collecting some drift, but the shallowness of the river protects it from fast water or large pieces of floating ice. The span may stay where it is for some time.

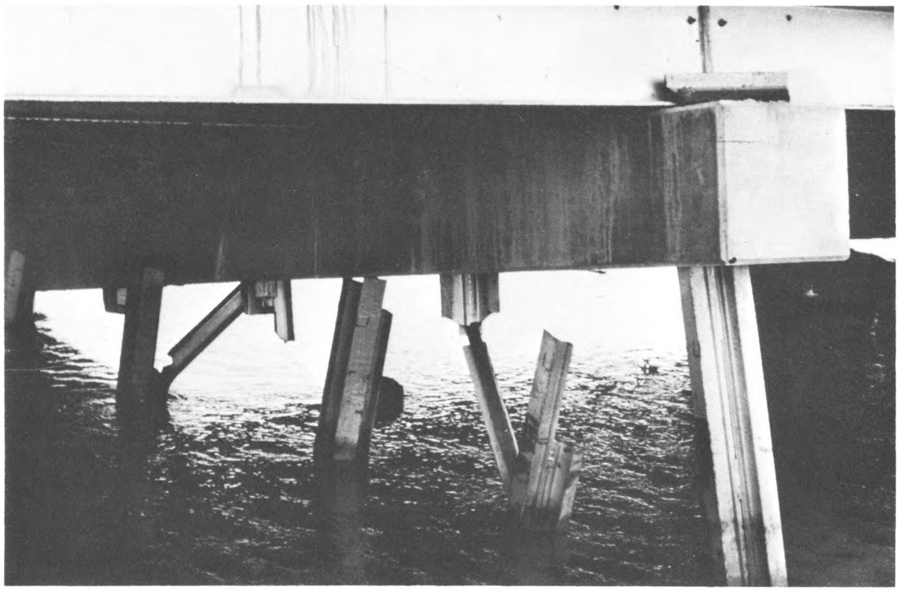
Abutment 5 does not show signs of any major damage. There is, of course, some spalling and breaking of concrete at the bridge seats caused by the fall of span 4 and all anchor bolts are either broken or bent, but the abutment itself seems structurally sound.

Mr. Golub's description of damage to the Million Dollar Bridge indicates that some crowding of the superstructure relative to the abutments and compression of the spans against one another has occurred. The abutments moved an unknown amount toward the center of the Copper River because of lateral displacement of sediments to an unknown depth. At pier 3 the relative displacement of the pier was upstream. Either the superstructure moved downstream or, more probably, the pier moved upstream because of lateral displacement of the underlying sediments. The largest free face is upstream, toward Miles Lake. There was probably some slumping or spreading of sediments upstream into the deep lake, which would account for the apparent movement of the piers upstream rather than downstream.

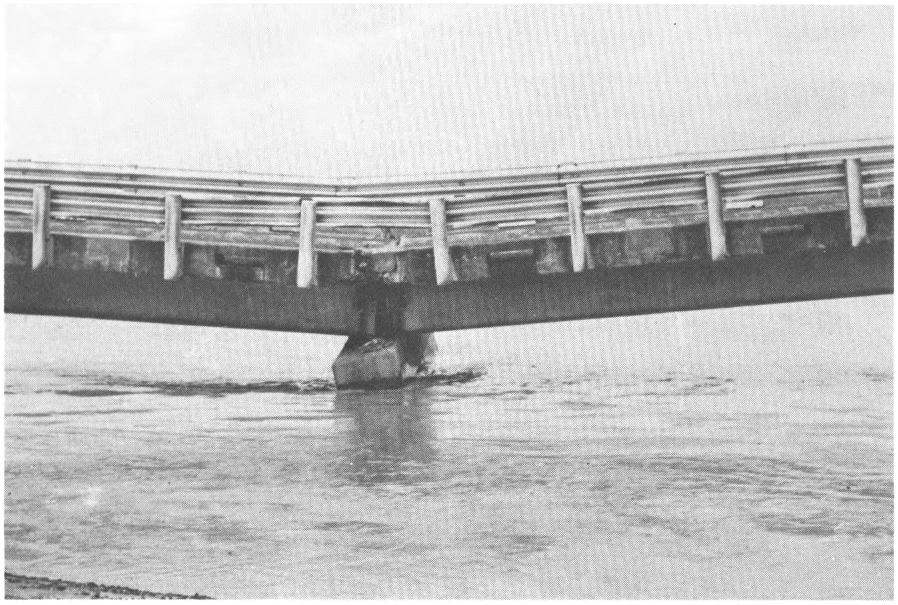
During the earthquake all the bridges supported by piles made of the old rails were severely damaged or destroyed (table 15, p. C59) because the brittle rail piles were unable to withstand the severe seismic shaking generated by the earthquake (fig. 38). Figure 39 is a photograph of a collapsed bent on Copper River 5 bridge, mile 35.0, and figure 40 is a view showing how the bent was constructed. The concrete between the rails provides protection to the bent against winter ice. This bent either broke because of partial or total liquefaction of the supporting fine-grained sand and silt sediments. The bridge deck collapsed because of differential movement of the deck and bent, lateral displacement of the bent, or a combination of the two.

The Copper River 2 bridge consisted of a reoccupied steel truss bridge of the Copper River and Northwestern Railway and a concrete deck supported by welded rail bents. The truss moved eastward relative to the concrete section of the bridge (fig. 41). The bridge elements were compressed or crowded against each other by the movement caused by the seismic shaking.

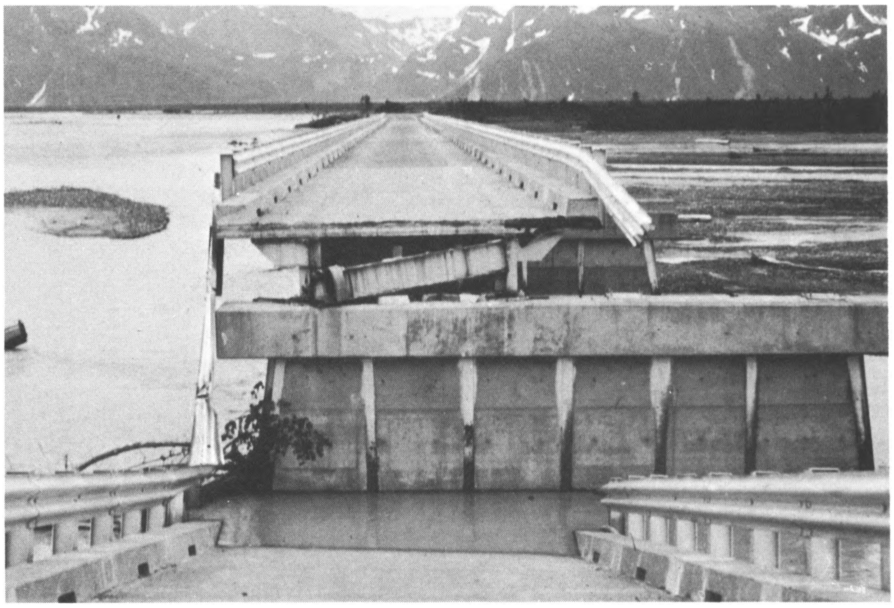
Lateral displacement of sediments toward a free face caused movement of the abutments toward the middle of the stream and made the superstructure too long for the abutments; the structure was thus compressed or crowded. Most if not all of this horizontal displacement was taken up at only one end of the structure (compare figs. 42, 43). Figure 42 shows the west abutment of Scott Glacier 5



38.—Broken rail piles on Scott Glacier 6 bridge, mile 5.9, Copper River Highway.



39.—Collapsed bent and deck of Copper River 5 bridge, mile 35.0, Copper River Highway.



40.—Collapsed deck on Copper River 5 bridge, mile 35.0, Copper River Highway. Concrete between rail piles is to protect rails against ice.

41.—Contact between steel truss and concrete deck on pier 26, Copper River 2 bridge, mile 27.1, Copper River Highway.

42.—West abutment of Scott Glacier 5 bridge, mile 9.2, Copper River Highway. Concrete cap displaced 2 inches to the left off the pile bent. Compare with figure 43.

bridge, mile 9.2, on the Copper River Highway; here the concrete cap was displaced westward off the pile bent. Figure 43 shows the east abutment of the bridge; at this end of the structure, the superstructure rammed through the wood abutment and was displaced about 2 feet to the east relative to the abutment. Maximum horizontal displacement of superstructure relative to substructure or compression of a bridge on the Copper River Highway was 6 feet. This displacement occurred at the north abutment of the Clear Creek bridge at mile 41.0 (fig. 44) and also at the south abutment of the Copper River 16 bridge at mile 38.1.

The sediments that underlie the Copper River Highway become progressively coarser eastward toward mile 22.3; they become progressively thinner from about mile 16.6 to mile 22.3, where bedrock is exposed. Thirteen slightly damaged bridges are in this stretch of the highway, but, they are all wooden structures and should not be compared with other types of structures. Rather they should be compared with similar bridges at miles 14.8, 15.3, 15.8, 15.9, 16.1, and 16.5. The bridges at miles 14.8 and 15.8 were moderately damaged; those at miles 15.3, 15.9, 16.1, and 16.5 were severely damaged or destroyed. This pattern of damage to similar bridges affords an opportunity to evaluate the effects of geologic environment on the amount of damage. Those bridges which received moderate to severe damage or were destroyed were underlain by a thicker prism of sediments than those that were only slightly damaged. The thinner the underlying sediment the less the damage, and the coarser the grain size of the underlying sediments the less the damage from seismic shaking.

Seismic damage to the bridges on the Sterling Highway was light compared to that to bridges on the Seward-Anchorage and Copper River Highways (compare figs. 2, 3, 6; tables 15, 16, 19, p. C59, C62, C66). The Quartz Creek bridge at mile 41.7 is underlain by a fine-grained thin veneer of silt and sand overlying stream gravel. The damage to this bridge was more than might have been expected because the structure was resting on concrete abutments and concrete piers. Damage was chiefly due to lateral displacement of the abut-

43.—East abutment of Scott Glacier Creek 5 bridge at mile 9.2, Copper River Highway. Superstructure is displaced about 2 feet to the right, relative to the abutment. Compare with figure 42.

44.—North abutment of Clear Creek bridge 329, mile 41.0, Copper River Highway. Superstructure is displaced to the right relative to the abutment.

ments toward the center of the creek, which placed the structure in compression. The bridge at mile 48.9 crossed the Kenai River at the outlet of Kenai Lake. The bridge, which rested on silt, sand, and gravel deposited by the river, collapsed during the earthquake. The wood piles, on some of which the saw marks were still visible when the bridge was inspected by survey personnel, were driven through the reinforced concrete deck (p. C43; fig. 45).

The three concrete bridges that span Portage Creek Overflows 1, 2, and 3, at miles 3.3, 3.8, and 4.3, respectively, on Portage Glacier Road were severely damaged. These bridges which rest on silt, sand, and gravel, were severely compressed after the earthquake and had to be replaced.

### SEISMIC SEA WAVES

The train of 10 seismic sea waves associated with the Alaska earthquake destroyed 13 bridges in south-central Alaska, 12 on Kodiak Island, and 1 on the Point Whitshed Road at Hartney Bay. Of the 12 bridges destroyed on Kodiak Island, 11 were on the Chiniak Highway and 1 at Mission Bay in the town of Kodiak.

The 11 bridges on the Chiniak Highway that were destroyed by waves spanned Sargent Creek at mile 5.0, Russian Creek at mile 5.2, the American River at mile 13.3, Mayflower Creek at mile 17.2, the Kalsin River at mile 22.8, West and East Forks of the Twin River at miles 32.7 and 32.9, respectively, and four small unnamed creeks at miles 12.0, 12.3, 13.6, and 33.7.

Eyewitness reports indicate that the first seismic sea wave was like a rapid rise of sea level and that the following waves were actually breaking. The damage to the bridges was due to the rapid retreat of the initial wave and to subsequent breaking waves. The first outgoing seismic sea wave was in part responsible for destruction of some of the bridges, but the subsequent incoming waves played the major role.

The waves destroyed the structures either by moving the superstructure off the substructure or by destroying the bents supporting the deck of the bridge. Most of the decks that were moved off their piles were carried upstream. Some ruins, however, were not found and no doubt had been carried out to sea by the outgoing waves.

45.—Collapsed bridge across Kenai River at Kenai Lake, mile 48.9, Sterling Highway. Wood piles are driven through the collapsed reinforced concrete deck. Photograph by Helen Foster.

#### REGIONAL SUBSIDENCE AND LOCAL SUBSIDENCE

Several otherwise undamaged bridges had to be replaced on the Chiniak Highway and between mile 75.1 and mile 105 on the Seward-Anchorage Highway because of flooding caused by regional tectonic subsidence and local differential subsidence. This postearthquake flooding by high tides affected the sites of 44 bridges in south-central Alaska and in itself would have required replacement of the bridges; 35 of the 44, however, had already been damaged by either seismic shaking or seismic sea wave. The nine undamaged bridges that had to be replaced because of flooding are on Kodiak Island and include (1) three bridges at Pasagshak Bay, (2) the Red Cloud River bridge (mile 7.7) and an unnamed creek bridge at mile 9.0 at Anton Larsen Bay, and (3) the bridges on the Chiniak Highway spanning Lost Creek at mile 5.8, Salonie Creek at mile 6.4, Frank Creek at mile 23.6, and an unnamed small creek at mile 24.9.

## GEOLOGIC FACTORS INFLUENCING DAMAGE INTENSITY

### GRAIN SIZE OF SEDIMENTS

The type of sediments upon which the highway rested played a major role in the amount and type of damage the structures experienced. For example, highway roadways underlain by coarse-grained sand and gravel were fractured substantially less than were roadways underlain by finer grained sand and silt. Roadways, fills, and approaches constructed of coarser grained sediments also were not fractured as much as those constructed of finer material. For example, in the Portage area, the Seward-Anchorage Highway and The Alaska Railroad are adjacent to one another. The highway roadway is constructed of well-graded (poorly sorted) compacted silt, sand, and gravel whereas the railroad roadbed is constructed primarily of poorly compacted sand and gravel. The finer grained highway fill was substantially more fractured than the railroad fill.

Structures on fine-grained sediments subsided more than those on coarse-grained sediments. For example, maximum subsidence of a highway roadway of as much as 11 feet occurred at Snow River

Crossing on the Seward-Anchorage Highway. The roadway subsided 7½ to 8 feet at mile 82.0, Seward-Anchorage Highway, on the north approach of Tidewater Slough 5 bridge. Both of these areas are underlain by sand and silt. The subsidence was due to the lateral displacement and compaction of the underlying sediments.

## THICKNESS OF SEDIMENTS

The thickness of sediments also influenced the extent of damage. The prism of sediments that underlie the Copper River Highway from mile 5.9 to mile 22.3 thins from mile 16.6 to mile 22.3 where bedrock is exposed. The sediments also became progressively coarser eastward, toward mile 22.3. In this section of the highway there were 13 slightly damaged all-wood bridges whereas all-wood bridges west of mile 16.6 received severe damage or were destroyed. The two geologic factors that controlled the extent of damage to the all-wood bridges were: the thinning of the prism of sediments underlying the roadway, and the progressive coarsening of the sediments eastward.

## DEPTH OF WATER TABLE

Other than foundation material, the most important geologic factor controlling damage is the depth of the water table. In any given geologic condition, the closer the water table to the surface, the more damage to the highway system. For example, at Snow River Crossing where the maximum compaction of 11 feet occurred, the water table is within 1 foot of the surface. At Tidewater Slough 5 bridge, the water table is within 4 feet of the surface. In the Turnagain Arm area on the Seward-Anchorage Highway, the roadway from miles 75.1 to 81.0 is underlain by silt, sand, and fine gravel. The most extensive fracture damage along the highway occurred between miles 78.4 and 81.0 where the water table is generally within 2 to 3 feet of the surface. Between miles 75.1 and 78.4, where the damage was less severe, the water table is generally 1 foot deeper.

## AMOUNT OF COMPACTION

During the earthquake both the sediments underlying the roadway and the roadway fill itself compacted. The exact amount of compaction of each is difficult to determine; however, most of the subsidence was in the underlying sediments. The sediments were not only compacted but were laterally displaced from beneath the roadway fill.

The roadway subsided as much as 11 feet, but the surrounding ground did not subside as much. Data obtained from water wells indicates that maximum measured compaction of the undisturbed sediments did not occur at Snow River Crossing or in the Portage area, but a Homer Spit near the town of Homer.

Homer Spit is underlain by the following unconsolidated deposits (Grantz, Plafker, and Kachadoorian, 1964):

| | *Feet* |
|---|---|
| Silt, sand, and gravel | 0–200 |
| Sand | 200–289 |
| Marine sand and clay | 289–321 |
| Soft clay, locally mushy | 321–462 |
| Hard clay | 462–468 |
| Kenai (?) formation | 468–477+ |

Here the sediments compacted at least 2.5 feet. Compaction no doubt occurred in the upper part of the silt, sand, and gravel layer.

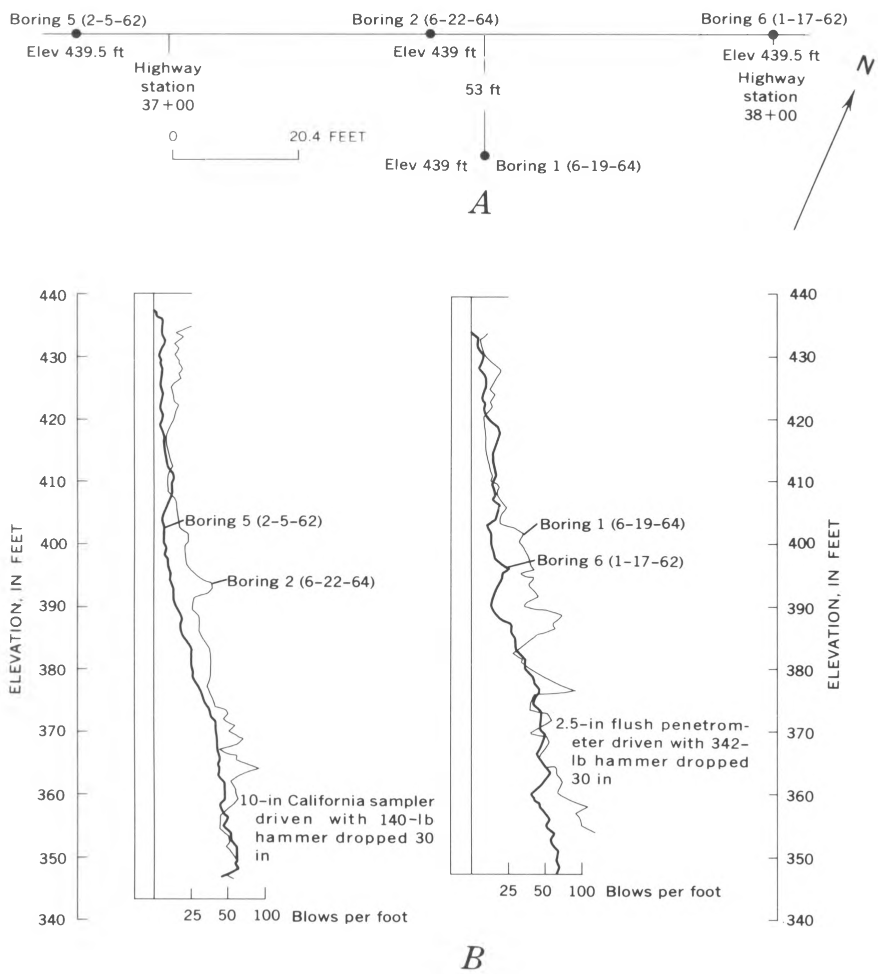
The log of the water well at the Union Oil Station at Portage shows that the station is underlain (Grantz, Plafker, Kachadoorian, 1964) by:

| | *Feet* |
|---|---|
| Sand and gravel | 0–20 |
| Clay | 20–425 |
| Sand | 425–426 |
| Clay | 426–600 |

The floor of the station subsided 16 inches around the casing of the well. Comparison of the data from Homer Spit and the Union Oil well at Portage may seem invalid, in as much as the well at Homer Spit had no structure around it, whereas the one at Portage did. However, the author feels that comparison is valid, because maximum compaction in a given area occurred where a structure was placed on original ground. Therefore, the 16 inches at the Union Oil Station is a maximum figure for compaction of original ground at Portage.

The chief factors responsible for the amount of compaction are the coarseness and the thickness of the sediments subjected to seismic shaking. The coarser the sediments the more they are compacted, and the thicker the sediments the more they are compacted. For example, there is 200 feet of silt, sand, and gravel at Homer Spit and 20 feet of sand and gravel at the Union Oil Station at Portage. According to the well logs the Homer Spit sediments are finer, but the author examined both sites and found that the Homer Spit sediments are actually coarser. The apparent discrepancy is due to the fact that the wells were logged by two different laymen.

The depth to which compaction by seismic shaking extends in the undisturbed ground is unknown.




46.—Sketch of boring locations (*A*) and pre- and postearthquake penetrometer tests (*B*) at Snow River bridge 605, mile 17.7, Seward-Anchorage Highway. Data after George E. Utermole, Jr., Alaska Department of Highways.

The only data available about depth of compaction are from the highway and railroad roadbeds, but these are engineered or semi-engineered fills placed upon the sediments. Furthermore, during seismic shaking, some of the vertical displacement of the highway roadway or railroad roadbed is due to lateral displacement of the underlying sediments. The railroad's Twentymile bridge rests upon piles about 60 feet deep. The right-of-way to the bridge approaches subsided 1 to 1½ feet more than the bridge (Grantz, Plafker, Kachadoorian, 1964). Thus, the top 50 to 60 feet of the unconsolidated material must have compacted relatively more than the material below the piers.

The Alaska Department of Highways conducted some post-earthquake penetrometer tests at Snow River Crossing Bridge 605, mile 17.7, on the Seward-Anchorage Highway and compared the results with preearthquake data. George E. Utermole, Jr., foundation geologist, Alaska Department of Highways, suggests that the postearthquake density of the sediments underlying Snow River Crossing Bridge 605 is greater than the preearthquake; however, he points out that "how much of this increase in density is due to the earthquake cannot be established" (Alaska Dept. Highways, unpub. data). Figure 46 shows the location of the borings and the results of the tests.

## LIQUEFACTION OF SEDIMENTS

Failure because of liquefaction of saturated soils was extensive in south-central Alaska, especially at the Snow River Crossing and Turnagain Arm sections of the Seward-Anchorage Highway. Failure developed locally at partial liquefaction before complete liquefaction of the saturated soils. However, at Snow River Crossing, Turnagain Arm, and on the Richardson Highway from mile 0.0 to 5.0, most of the soil was completely liquefied.

Liquefaction was responsible for both vertical and horizontal displacement of sediments. The sediments underlying the roadway where liquefaction occurred actually flowed out and downslope from underneath the roadway fill. Where this flow occurred, the roadway (1) subsided into the sediments and at some places, as at the Snow River Crossing, was completely submerged into the sediments, (2) was displaced laterally, and (3) was fractured. Statement by eyewitnesses that water spouts continued for several minutes after the seismic vibration stopped at Portage indicate that failure of the sediments underlying the roadway in the area must also have continued after the earthquake had stopped.

Field tests by the author and M. G. Bonilla at Portage also indicated that liquefaction continued after the vibrating force was removed. A small plot underlain by silt was selected for the test. Prior to any vibration the silt looked dry and one could walk upon it without difficulty. The silt was vibrated by foot for about one-half minute at which time moisture began to collect at the surface. When moisture appeared, the vibration was stopped. The depth of liquefied silt was 1½ inches. The water continued to seep out, and in 2 minutes it started to flow out as fountains in the center of the vibrated mass. Four minutes after the force was applied, water began to flow out of the liquefied jelly-like mass of silt. After 7 minutes the water began to clear up, although it was still flowing. The depth to firm ground had migrated down to 4 inches within 8 minutes after vibration was stopped. The test was abandoned after 8 minutes. The area that was liquefied was about 18 inches square and the softest spot was in the center where the initial force was applied.

The sediments that underlie the Snow River Crossing were especially prone to liquefaction. During testing in 1962, many of the samples collapsed in sampling tubes when vibrated or when a shock was applied. In addition, some of the silt contained gases (derived from the decomposition of organic debris in the silt) under pressure and was thixotropic.

Mrs. Hadley Roberts of Lawing, Alaska, described what occurred at Snow River to a friend. Part of the letter is quoted here:

> * * * Don and Ed Estes had been caught in the mile stretch crossing Snow River and the flats. They said the whole highway across there was waving up and down like someone was shaking a blanket. As it would heave up the pavement would crack and it would come together again as it settled down. Finally the mud started oozing through the cracks and they no longer would come together, and the pavement then started settling into the mud. They finally had to abandon the car about 50 yards from the other side as the cracks were too big. They ran for bedrock with the mud licking at their heels. This was quite a run for them as it was all uphill now and lots of cracks to jump over. Their car was pulled out of the mud a few days later. * * *

This description brings out three important facts: (1) fractures developed before liquefaction of the sediments and were caused by seismic ground waves, (2) liquefaction did not occur immediately, and (3) the roadway, although cracked, settled into the underlying sediments after liquefaction developed. The first point appears to conflict with the statement made earlier on this page that when liquefaction occurred the underlying sediments flowed out and downslope from beneath the roadway, and that this outflow caused fracturing of the roadway. The fractures at Snow River Crossing were first caused by shear and tension failure, because the roadway was differentially displaced laterally; additional later fractures may have been caused by liquefaction.

## LATERAL DISPLACEMENT

Seismic shock was the chief cause for lateral displacement of sediments. As seismic ground waves passed through the ground, they imparted a motion to the sediments similar to that which a vibrating table does to debris upon it. The sediments were displaced laterally downslope or toward a free face. This type of failure was extensive in the Copper River Highway and was responsible for moving bridge abutments toward the centers of creeks. When this movement occurred, a bridge was either compressed or, more commonly, the superstructure became substantially too long for the span between the abutments and one end of the deck was displaced as much as 6 feet over an abutment. Lateral displacement due to seismic shock not only moved the abutments, piers, and bents toward the center of the creek, but it also moved them upstream or downstream.

As the sediments were displaced laterally, the roadway failed in tension and fractures formed. Some of these fractures formed during the passing of the seismic ground wave before the actual displacement of the sediments.

Lateral displacement and subsidence occurred in bridge approach fills overlying bedrock owing to seismic shaking; it was noted even in completely dry fills less than 10 feet thick.

# ENGINEERING FACTORS INFLUENCING DAMAGE INTENSITY

Although geologic factors played the major role in controlling intensity of damage to the roadways and bridges, they were by no means solely responsible. The engineering characteristics of the roadways and bridges also influenced the damage intensity.

In low-lying saturated areas, especially those at Portage and at Snow River, the roadway fill had a higher density than the supporting underlying sediments. In short, the fill was floating upon the sediments. The thicker the fill, the heavier the load on the underlying sediments. When the earthquake struck, the sediments were unable to support the roadway and failed. At Snow River, the roadway locally sank out of sight into the sediments. Failure, no doubt, first occurred at sites where fills were thickest. The maximum thickness of fill in the Turnagain Arm section of the Seward-Anchorage Highway was at about mile 80.5 near the Twentymile River and was about 12 feet. The geologic conditions from mile 78.4 to mile 81.0 are similar, yet the roadway at mile 80.5 was the most severely damaged by the earthquake. Therefore, it is proposed that under given geologic conditions, especially in saturated soils, the thicker and heavier the fill, the greater the damage to the roadway.

An analysis of the damage to bridges on the Seward-Anchorage and Copper River Highways indicates that there is a correlation between damage and the type of bridge. Figure 47 is a chart show-

| Superstructure | Substructure | Foundation | DAMAGE | | | |
|---|---|---|---|---|---|---|
| | | | None | Slight | Moderate | Severe or destroyed |
| Concrete | Concrete abutments | Bedrock | 381-1137-1138-1139 | | | |
| Concrete | Concrete abutments | Sediments | 741 | | | 603-604 605-606 |
| Steel | Concrete abutments | Sediments | 617 | 600 | 330-599 | 333 |
| Concrete | Concrete piers | Sediments | | 615 | | |
| Concrete | Wood | Sediments | 608-609-611 | 601-610 | | 603-605-606-621-622-623-624-625-626-627-628-629-630-631-632-633-634-635-638-640-641-642 |
| Wood | Wood | Bedrock | | 395 | | |
| Wood | Wood | Sediments | 602 | 368-369-370-371-372-373-374-375-376-377-378-379-395 | 361-364 | 363-365-366-367 |
| Steel | Concrete piers | Sediments | | | | 331-332-206-596-597-598-620-644 |
| Steel | Wood piles | Sediments | 619 | | 636 | 348-349-350-351-352-639-643 |
| Steel | Railroad rails | Sediments | | 410-343 | 337 | 406-407-408-409-411-354-334-335-336-338-339-340-341-342-344-345-346-329-331 |
| Steel | Wood | Bedrock | 607 | | | |
| Steel | Steel | Bedrock | 613 | 612 | | |
| Steel | Concrete piers | Bedrock | 614 | 616 | 637 | |

47.—Chart showing type of bridge, foundation material, and intensity of damage to bridges on Seward-Anchorage and Copper River Highways. Numbers are bridge designations (see tables 15, 16). The 200, 300, and 400 series structures are on the Copper River Highway; the others are on the Seward-Anchorage Highway. Length of bar is proportional to number of bridges damaged.

ing type of bridge, foundation material, and intensity of damage to bridges on the Seward-Anchorage and Copper River Highways.

The most significant engineering fact that the chart shows is the relation between the superstructure and substructure. During the construction of 22 of the bridges on the Copper River Highway, Copper River and Northwest Railway rails were used as piles. Three of these rails, believed to be 50-pound rails were welded with their heads together. They were then driven, and when a bent was completed the rails were cut off and a concrete cap placed upon them. At some places, steel sway braces were welded on the rails. Where icing of the creek would present a problem, concrete curtains were placed between the rails (fig. 40). These rails are brittle, and one of the techniques track-layers used to cut off a rail was to first mark it with a chisel and then strike the rail sharply with a hammer. The rail would break at the chisel mark. During the driving, the welded rail piles were occasionally broken. When the earthquake struck, all except two (Scott Glacier 10, mile 10.8, and Copper River 14, mile 37.5) of the bridges whose bents consisted of rail piles were moderately or severely damaged or were destroyed. The rail piles were broken above the waterline in most of the structures that did not have a concrete curtain. In those that had concrete curtains, failure of the piles generally occurred below the waterline. Figure 39 shows results of such a failure.

A significant comparison between all-wood bridges and bridges with concrete superstructure and wood substructure can also be made. For example, a remarkable difference in damage intensity can be seen if we compare the all-wood structures on the

48.—North abutment of Copper River 9 bridge, 338, mile 36.1, Copper River Highway, showing displacement of deck laterally to the left relative to substructure. Photograph by George Plafker.

Copper River Highway with the concrete and wood bridges on the Seward-Anchorage Highway, neglecting for a moment the geologic conditions. Most of the all-wood bridges were only slightly damaged whereas most of the concrete and wood bridges were severely damaged or destroyed (fig. 47). If we now take into account the geologic factors, the comparison becomes more complex. The Turnagain Arm bridges were definitely in a more geologically unfavorable environment. The extent to which this unfavorable environment would have affected all-wood highway structures is unknown. However, on the basis of the types of damage to concrete and wood bridges, all-concrete bridges (on Portage Glacier Road), and all-wood bridges caused by the earthquake, it is proposed that if the superstructure was relatively heavier than the substructure, the bridge was more severely damaged. If the deck is heavier than the substructure, the tie between them is more easily broken because of differential movement of the two units by seismic shaking. When this movement occurs, the substructure and superstructure, in effect, become independent of one another and, instead of reinforcing one another they actually compound the effects of seismic shaking. Figure 48 is a photograph looking south at Copper River 9 bridge, 338, mile 36.1, on the Copper River Highway. The deck of the structure apparently had a seismically induced motion independent of the substructure and actually destroyed the top of much of the north abutment. Note that the final position of the superstructure indicates that the deck was displaced to the east relative to the abutment and the remainder of the substructure.

# SUMMARY

The earthquake of March 27, 1964, caused $46,798,292 worth of damage to the highway system in south-central Alaska. Damage was caused by seismic shaking, seismic sea waves, and regional tectonic subsidence. The table summarizes the effects associated with these three major causes of damage. Seismic shaking and the effects associated with it apparently caused the most damage. The effects of the Alaska earthquake upon the highway system once again demonstrated the significant fact that structures on bedrock were not damaged as much as those on sediments.

*Effects on highway system caused by seismic shaking, seismic sea waves, and regional tectonic subsidence by the Alaska earthquake*

**Seismic shaking**

Lateral displacement of sediments:
- Subsidence of roadway and bridge approaches
- Displacement of roadway parallel to highway axis
- Displacement of roadway normal to highway axis
- Displacement of bridge abutments, bents, and piers toward center of creek
- Displacement of bridge piers and bents upstream and downstream
- Placement of bridges in compression
- Formation of fractures:
  - Along roadway centerline
  - Along roadway edges or shoulders
  - Normal to axis of roadway
  - Oblique fractures:
    - Refracted normal to roadway
    - Continued through roadway at oblique angles

Compactions of sediments:
- Fractures in roadway normal to axis
- Fractures along edge of roadway
- Subsidence of roadway and bridge approaches
- Inundation during high tides
- Wavy roadway due to differential compaction

Landslides:
- Slides onto roadway
- Slides in roadway:
  - Fracture of roadway normal to axis
  - Fracture of roadway parallel to axis
  - Displacement of roadway normal to axis
  - Displacement of roadway parallel to axis
  - Destruction of bridge

Seismic shock:
- Damage to bridges:
  - Differential movement of structural elements
  - Broken tie between superstructure and substructure
  - Bridge in compression
- Seismic wave in bridges:
  - Vertical movement of bridge during shaking
  - Horizontal movement of bridge during shaking:
    - Displacement of deck upstream or downstream
    - Displacement of deck along axis of bridge
    - Bridge in compression
- Ground waves in roadway

Avalanches: Upon roadway

Sand and mud ejecta: In roadway

**Seismic sea waves**

Destruction of bridges:
- Sweeping away of superstructure
- Destruction of substructure

Damage to roadway: Scouring of fill

**Regional tectonic subsidence (coupled with compaction of sediments)**

Inundation of roadway during high tides

Inundation of bridge sites

Erosion of roadway by high tides

# REFERENCES CITED

Eckel, E. B., and Schaem, W. E., 1966, *in* Hansen, W. R., and others, The Alaska earthquake, March 27, 1964: Field investigations and reconstruction effort: U.S. Geological Survey Professional Paper 541, p. 46–69.

Ferrians, O. J., Jr., 1966, Effects of the earthquake of March 27, 1964, in the Copper River Basin area, Alaska: U.S. Geol. Survey Prof. Paper 543–E, p. E1–E28.

Golub, Harvey, 1964, Bridge damage report—mile 13 to mile 59, Copper River Highway—FAS 851: Alaska Dept. Highways Document.

Grantz, Arthur, Plafker, George, and Kachadoorian, Reuben, 1964, Alaska's Good Friday earthquake, March 27, 1964, a preliminary geologic evaluation: U.S. Geol. Survey Circ. 491, 35 p.

Kachadoorian, Reuben, 1965, Effects of the earthquake of March 27, 1964, at Whittier, Alaska: U.S. Geol. Survey Prof. Paper 542–B, p. B1–B21.

Migliaccio, R. R., 1966, Earthquake damage to highways in the Valdez district, Alaska: Natl. Research Council, Highway Research Board, Highway Research Rec. 91, p. 64–72.

Plafker, George, 1965, Tectonic deformation associated with the 1964 Alaskan earthquake: Science, v. 148, no. 3678, p. 1675–1687.

Plafker, George, and Kachadoorian, Reuben, 1966, Geologic effects of the March 1964 earthquake and associated seismic sea waves on Kodiak and nearby islands, Alaska: U.S. Geol. Survey Prof. Paper 543–D, p. D1–D46.

U.S. Coast and Geodetic Survey, 1966, The Prince William Sound, Alaska, earthquake of 1964 and aftershocks: Washington, U.S. Govt. Printing Office, v. 1, 263 p.

# TABLES 3-19

TABLE 3.—*Foundation material and major effects of Alaska earthquake on the roadway of Seward-Anchorage Highway*

| Mile | Foundation material | Effects of earthquake |
|---|---|---|
| 1 to 3 | Stream sediment | Roadway fractured, wavy; differential compaction. |
| 17 | Silt and sand | Two-foot slump where road goes onto Snow River delta. |
| 17 to 20 | do | Roadway down as much as 11 feet, horizontally displaced 13½ ft. |
| 33.0 to 33.0 | Stream sand and gravel. | Roadway fractured. |
| 35 | Bedrock | Avalanche from east side of road. |
| 40.0 to 40.5 | Swamp sediments on stream sediments. | Roadway wavy; differential compaction of sediments. |
| 40.4 | do | Culvert up 1½ ft; compacted sediments. |
| 41.7 | do | Avalanche from east side of road. |
| 44.8 to 45.6 | Till | Roadway slumped into Summit Lake. |
| 46.3 to 46.7 | Swamp deposits over stream deposits. | Roadway wavy; mile 46.6 culvert bent. |
| 51.1 to 51.8 | Fine till | Roadway wavy; maximum subsidence is 6 in. |
| 54.5, 54.9, 55.0, 56.0. | Till | Small slides onto road. |
| 56.0 to 56.4 | do | Roadway fractured, compacted, and wavy. |
| 61.8 to 62.0 | Stream sediments | Roadway fractured; local subsidence. |
| 63.2 to 64.9 | Fine till | Roadway wavy; subsidence as much as 6 in. |
| 66.8 to 67.2 | do | Roadway fractured; local subsidence. |
| 73.2 to 73.6 | Fill over swamp deposits. | Roadway fractured, wavy; subsided 6 in. |
| 75.0 to 90.5 | Tidal sediments | Roadway fractured, displaced vertically and horizontally; maximum compaction of 4.4 ft plus regional subsidence of 5.6 ft, total subsidence of 11 feet; six large avalanches between mile 82.5 and mile 87.5. |
| 92.0 to 93.5 | Bedrock | Eight large avalanches. |
| 98.5 to 105.5 | Tidal silt, sand, and gravel. | Roadway compacted, fractured, wavy; inundated during high tides. |

TABLE 4.—*Foundation material and major effects of Alaska earthquake on roadway of Sterling Highway*

| Mile | Foundation material | Effects of earthquake |
|---|---|---|
| 39.5 | Coarse sediments | Slide across roadway. |
| 44.9 | do | Landslide across roadway. |
| 44.9 to 51 | Stream gravel | Roadway fractured, compacted, and wavy. |
| 60.0 to 60.2 | Till over bedrock | Roadway fractured; slide across road. |
| 70.5 to 71.5 | Swamp deposits over till. | Roadway compacted 2–3 ft; displaced south 4 ft; severely fractured, wavy. |
| 74.9 to 76.5 | do | Roadway compacted, fractured, wavy, and displaced. |
| 85.8 | Swamp deposits over glacial outwash. | Roadway fractured, compacted, and wavy. |
| 90.0 | do | Roadway compacted and wavy. |
| 94.8 | do | Roadway fractured, compacted, and wavy. |
| 100 | Lake sediments | Slumps on road. |
| 102 | Lake silts and sands | Do. |
| Homer Spit | Gravel | Compacted, subsided; eroded by the sea. |

TABLE 5.—*Foundation material and major effects of Alaska earthquake on roadway of Glenn Highway*

| Mile | Foundation material | Effects of earthquake |
|---|---|---|
| 27 to 35 | Swamp deposits | Roadway compacted, fractured, wavy; locally displaced and inundated during high tides. |
| 37 | Bedrock | Slide across roadway. |
| 38 | do | Large avalanche across roadway. |
| 39 to 40 | Outwash gravel | Roadway slightly fractured and wavy. |
| 58 to 59 | Ground moraine | Roadway fractured, compacted, wavy; small slide at mile 59. |
| 60.5 to 60.7 | do | Roadway compacted, fractured, and wavy; small slide at mile 60.6. |
| 61.0 to 61.2 | Ground moraine and stream sediments. | Roadway compacted, fractured, wavy. |
| 63.5 to 65.5 | Terrace gravels | Roadway fractured and wavy. |
| 69 | do | Small slide on roadway edge. |
| 71 | do | Do. |
| 74 | Ground moraine | Roadway slightly fractured. |
| 78.5 | do | Do. |
| 82.0 to 82.5 | Outwash gravel | Roadway compacted, slightly fractured, and wavy. |
| 88.5 to 89.5 | do | Roadway slightly compacted, fractured, and wavy. |
| 97.7 to 98.3 | Ground moraine | Roadway fractured. |
| 99.0 to 100 | do | Roadway compacted, fractured, and wavy. |
| 106, 107.2 | do | Roadway slid downslope. |
| 111 | do | Roadway fractured. |
| 114 | do | Do. |
| 138 | do | Roadway slid two places. |
| 140 | do | Do. |

TABLE 6.—*Foundation material and major effects of the Alaska earthquake on the roadway of the Richardson Highway*

| Mile | Foundation material | Effects of earthquake |
|---|---|---|
| 0 to 6 | Glacial outwash | Roadway compacted, displaced, fractured, and wavy. |
| 38 | Bedrock | Avalanche. |
| 39 | do | Do. |
| 40 | Stream sediments | Landslide. |
| 42 | Bedrock | Avalanche. |
| 44 | do | Rockslide. |
| 59 to 61 | Gravel | Three avalanches. |
| 64 to 75 | Glacio-lacustrine sediments. | Roadway compacted, displaced, fractured; landslide at Tonsina Bridge (mile 66.0) and Tonsina Hill (mile 73). |
| 75 to 85 | Stream deposits, silt and clay. | Roadway fractured; at mile 80, four landslides; at mile 76, water eroding roadway. |
| 85 to 110 | Sand and gravel | Local fractures in roadway and small stretches of wavy road. |

TABLE 7.—*Analyses of sediments at Snow River Crossing, Seward-Anchorage Highway*

[Analyses by Alaska Dept. Highways. NV, no value; NP, nonplastic]

| Material | Mile | Depth (feet) | Grading analysis: percent passing— | | | | | | | | | Atterberg limits | | Natural moisture content (percent) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ¾ in. | ½ in. | ⅜ in. | No. 4 | No. 10 | No. 40 | No. 200 | 0.02 mm | 0.005 mm | Liquid limit | Plastic index | |
| Pebbly sand | 17.3 | 13–15 | ------ | ------ | 100 | 95 | 71 | 18 | 4 | ------ | ------ | NV | NP | 15 |
| Do | 17.3 | 23–25 | 100 | 91 | 78 | 45 | 9 | 0 | 0 | ------ | ------ | NV | NP | 4 |
| Sand | 17.3 | 43–45 | ------ | 100 | 98 | 94 | 85 | 73 | 15 | 3 | 1 | NV | NP | 16 |
| Sand-silt | 17.3 | 53–55 | ------ | 100 | 98 | 93 | 88 | 59 | 16 | 6 | 2 | NV | NP | 23 |
| Fine sand | 17.3 | 63–65 | ------ | ------ | ------ | 100 | ------ | ------ | 35 | 8 | 4 | NV | NP | 28 |
| Do | 17.3 | 73–75 | ------ | ------ | ------ | 100 | ------ | 90 | 20 | 5 | 3 | NV | NP | 24 |
| Do | 17.3 | 83–85 | ------ | ------ | ------ | ------ | 100 | 98 | 29 | 7 | 4 | NV | NP | 27 |
| Sand | 17.5 | 20–22 | 100 | 99 | 98 | 96 | 92 | 61 | 11 | 5 | 4 | NV | NP | 20 |
| Silty sand | 17.5 | 50–52 | ------ | ------ | ------ | ------ | ------ | 100 | 72 | 27 | 9 | 24 | NP | 30 |
| Silt and sand | 17.5 | 60–62 | ------ | ------ | ------ | ------ | 100 | 94 | 54 | 17 | 9 | 25 | NP | 30 |
| Silt | 17.5 | 70–72 | ------ | ------ | ------ | ------ | ------ | 100 | 88 | 35 | 12 | 27 | NP | 32 |
| Sand and silt lenses | 17.5 | 90–92 | ------ | ------ | ------ | ------ | 100 | 76 | 64 | 37 | 12 | 27 | NP | 27 |
| Pebbly sand | 17.6 | 20–22 | 100 | 93 | 84 | 81 | 80 | 78 | 21 | 6 | 3 | NV | NP | 18 |
| Silt and fine sand | 17.6 | 30–32 | ------ | ------ | ------ | ------ | ------ | 100 | 60 | 14 | 6 | 26 | NP | 32 |
| Do | 17.6 | 40–42 | ------ | ------ | ------ | ------ | ------ | 100 | 68 | 21 | 4 | 25 | NP | 34 |
| Silt | 17.6 | 60–62 | ------ | ------ | ------ | ------ | ------ | 100 | 98 | 49 | 16 | 29 | NP | 33 |
| Do | 17.6 | 70–72 | ------ | ------ | ------ | ------ | ------ | 100 | 99 | 64 | 20 | 31 | NP | 33 |
| Do | 17.6 | 90–92 | ------ | ------ | ------ | ------ | ------ | ------ | 100 | 66 | 14 | 31 | NP | 40 |
| Medium sand | 17.6 | 10–12 | ------ | 100 | 99 | 88 | 97 | 66 | 4 | 3 | 1 | NV | NP | 20.7 |
| Fine sand | 17.6 | 20–22 | ------ | ------ | ------ | ------ | 100 | 98 | 18 | 5 | 2 | NV | NP | 26.5 |
| Do | 17.6 | 25–27 | ------ | ------ | ------ | ------ | 100 | 96 | 52 | 19 | 5 | NV | NP | 26 |
| Very fine sand | 17.6 | 30–32 | ------ | ------ | ------ | ------ | ------ | 100 | 50 | 13 | 5 | NV | NP | 24.7 |
| Silt | 17.6 | 40–42 | ------ | ------ | ------ | ------ | ------ | 100 | 92 | 50 | 17 | NV | NP | 26.1 |
| Do | 17.6 | 45–47 | ------ | ------ | ------ | ------ | ------ | 100 | 88 | 43 | 13 | NV | NP | 28.4 |
| Do | 17.6 | 50–52 | ------ | ------ | ------ | ------ | ------ | ------ | 100 | 64 | 23 | NV | NP | 24.5 |
| Do | 17.6 | 55–57 | ------ | ------ | ------ | ------ | ------ | 100 | 98 | 63 | 22 | NV | NP | 29.5 |
| Do | 17.6 | 60–62 | ------ | ------ | ------ | ------ | ------ | 100 | 98 | 61 | 19 | NV | NP | 32.1 |
| Do | 17.6 | 65–67 | ------ | ------ | ------ | ------ | ------ | ------ | 100 | 68 | 24 | NV | NP | 25.1 |
| Do | 17.6 | 70–72 | ------ | ------ | ------ | ------ | ------ | ------ | 100 | 70 | 25 | NV | NP | 27.6 |
| Do | 17.6 | 75–77 | ------ | ------ | ------ | ------ | ------ | ------ | 100 | 76 | 31 | NV | NP | 25.3 |
| Do | 17.6 | 80–82 | ------ | ------ | ------ | 100 | 98 | 98 | 98 | 78 | 33 | NV | NP | 25.9 |
| Silty sand | 17.6 | 85–87 | ------ | ------ | 100 | 99 | 99 | 95 | 93 | 81 | 41 | NV | NP | 35.8 |

TABLE 8.—*Analyses of sediments at miles 78.4, 79, and 80.8 on Seward-Anchorage Highway*

[Analyses by Alaska Dept. Highways. NV, no value; NP, nonplastic]

| Material | Mile | Depth (feet) | Grading analysis: percent passing— | | | | | | | | | | Atterberg limits | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 in. | ¾ in. | ½ in. | ⅜ in. | No. 4 | No. 10 | No. 40 | No. 200 | 0.02 mm | 0.005 mm | Liquid limit | Plastic index |
| Silty sandy gravel | 78.4 | 15–17 | ------ | ------ | ------ | ------ | ------ | 47 | 24 | 4 | ------ | ------ | ------ | ------ |
| Silty gravel sand | 78.4 | 25–27 | ------ | ------ | ------ | ------ | ------ | 66 | 25 | 5 | ------ | ------ | ------ | ------ |
| Dense silty sand | 78.4 | 35–37 | ------ | ------ | ------ | ------ | ------ | 83 | 49 | 13 | ------ | ------ | ------ | ------ |
| Do | 78.4 | 55–57 | ------ | ------ | ------ | ------ | ------ | 98 | 83 | 22 | ------ | ------ | ------ | ------ |
| Dense clayey silt | 78.4 | 75–76.5 | ------ | ------ | ------ | ------ | ------ | 100 | 97 | 94 | ------ | ------ | ------ | ------ |
| Dense sandy silt | 78.4 | 85–86.5 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | 100 | ------ | ------ | ------ | ------ |
| Compact sandy silt | 79 | 15–17 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | 100 | ------ | ------ | ------ | ------ |
| Dense silty sand | 79 | 25–27 | ------ | ------ | ------ | ------ | ------ | 94 | 72 | 66 | ------ | ------ | ------ | ------ |
| Do | 79 | 35–37 | ------ | ------ | ------ | ------ | ------ | 65 | 27 | 4 | ------ | ------ | ------ | ------ |
| Do | 79 | 45–47 | ------ | ------ | ------ | ------ | ------ | 69 | 21 | 4 | ------ | ------ | ------ | ------ |
| Do | 79 | 55–57 | ------ | ------ | ------ | ------ | ------ | 3 | 1 | 0 | ------ | ------ | ------ | ------ |
| Do | 79 | 65–66.5 | ------ | ------ | ------ | ------ | ------ | 35 | 24 | 10 | ------ | ------ | ------ | ------ |
| Dense sandy silt | 79 | 75–77 | ------ | ------ | ------ | ------ | ------ | 99 | 92 | 87 | ------ | ------ | ------ | ------ |
| Do | 79 | 85–86.5 | ------ | ------ | ------ | ------ | ------ | 89 | 83 | 74 | ------ | ------ | ------ | ------ |
| Compact sandy gravel | 79.6 | 15–17 | 100 | 93 | 83 | 78 | 55 | 29 | 8 | 3 | ------ | ------ | NV | NP |
| Sand and silt lenses | 79.6 | 25–27 | ------ | ------ | ------ | 100 | 98 | 93 | 66 | 53 | ------ | ------ | 21 | NP |
| Compact fine sand | 79.6 | 35–37 | ------ | 100 | 98 | 94 | 85 | 75 | 42 | 5 | ------ | ------ | NV | NP |
| Do | 79.6 | 45–47 | ------ | ------ | ------ | 100 | 94 | 76 | 26 | 5 | ------ | ------ | NV | NP |
| Do | 79.6 | 55–57 | ------ | ------ | ------ | 100 | 98 | 96 | 84 | 31 | ------ | ------ | NV | NP |
| Dense sandy silt | 79.6 | 65–67 | ------ | ------ | ------ | ------ | 100 | 99 | 97 | 53 | 12 | ------ | 22 | NP |
| Compact plastic silt | 79.6 | 80–82 | ------ | ------ | ------ | ------ | ------ | ------ | 100 | 99 | 84 | ------ | 43 | NP |
| Silty sandy gravel | 80.8 | 10–12 | ------ | 100 | 88 | 79 | 61 | 44 | 16 | 4 | ------ | ------ | NV | NP |
| Do | 80.8 | 20–22 | ------ | 100 | 99 | 96 | 83 | 56 | 18 | 4 | ------ | ------ | NV | NP |
| Silty sand | 80.8 | 30–32 | ------ | ------ | ------ | 100 | 96 | 82 | 32 | 6 | ------ | ------ | NV | NP |
| Do | 80.8 | 40–42 | ------ | ------ | ------ | 100 | 99 | 98 | 81 | 20 | ------ | ------ | NV | NP |
| Compact silty sand | 80.8 | 50–52 | ------ | ------ | ------ | ------ | ------ | 100 | 97 | 47 | 16 | ------ | NV | NP |
| Do | 80.8 | 60–62 | ------ | ------ | ------ | ------ | ------ | ------ | 100 | 81 | 31 | ------ | 22 | NP |
| Do | 80.8 | 70–72 | ------ | ------ | ------ | ------ | ------ | ------ | 100 | 68 | 34 | ------ | NV | NP |
| Do | 80.8 | 78–80 | ------ | ------ | ------ | ------ | ------ | ------ | 100 | 80 | 42 | ------ | 22 | NP |

TABLE 9.—*Analyses of sediments at miles 84.2, 86.6, 89.6, 90.0, and 90.4 on Seward-Anchorage Highway*

[Analyses by Alaska Dept. Highways. NV, no value; NP, nonplastic]

| Material | Mile | Depth (feet) | Grading analysis: percent passing— | | | | | | | | | | Atterberg limits | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 in. | ¾ in. | ½ in. | ⅜ in. | No. 4 | No. 10 | No. 40 | No. 200 | 0.02 mm | 0.005 mm | Liquid limit | Plastic index |
| Dense sandy gravel | 84.2 | 10–12 | 100 | 87 | 69 | 50 | 32 | 15 | 3 | 1 | ------ | ------ | NV | NP |
| Do | 84.2 | 20–22 | 87 | 82 | 70 | 64 | 50 | 32 | 13 | 6 | ------ | ------ | NV | NP |
| Layers silt and sandy gravel | 84.2 | 30–32 | 100 | 90 | 86 | 77 | 60 | 39 | 17 | 11 | ------ | ------ | NV | NP |
| Do | 84.2 | 40–42 | 100 | 99 | 89 | 83 | 69 | 57 | 45 | 37 | 4 | ------ | 24 | NP |
| Do | 84.2 | 45–47 | ------ | ------ | 100 | 95 | 87 | 81 | 78 | 63 | 5 | ------ | 24 | NP |
| Do | 84.2 | 55–57 | 100 | 94 | 85 | 76 | 56 | 38 | 23 | 9 | ------ | ------ | NV | NP |
| Silt, gravel clay | 84.2 | 65–67 | ------ | ------ | ------ | ------ | ------ | 100 | 99 | 80 | 10 | ------ | 22 | NP |
| Do | 84.2 | 75–77 | 100 | 95 | 85 | 78 | 61 | 35 | 17 | 8 | ------ | ------ | NV | NP |
| Do | 84.2 | 85–87 | 100 | 97 | 94 | 92 | 82 | 72 | 10 | 46 | 8 | ------ | 24 | NP |
| Sandy (fill) gravel | 86.6 | 15–17 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| Silty gravel | 86.6 | 25–27 | 89 | 80 | 62 | 57 | 45 | 29 | 12 | 7 | ------ | ------ | NV | NP |
| Do | 86.6 | 40–42 | 82 | 69 | 65 | 58 | 41 | 23 | 9 | 5 | ------ | ------ | NV | NP |
| Silty sandy gravel | 86.6 | 50–52 | 93 | 83 | 73 | 67 | 52 | 30 | 14 | 7 | ------ | ------ | NV | NP |
| Do | 89.6 | 70–71 | 100 | 74 | 65 | 55 | 35 | 16 | 3 | 1 | ------ | ------ | NV | NP |
| Do | 90.0 | 15–17 | 92 | 89 | 74 | 65 | 44 | 25 | 6 | 2 | ------ | ------ | NV | NP |
| Do | 90.0 | 20–22 | 84 | 84 | 82 | 73 | 41 | 15 | 1 | 0 | ------ | ------ | NV | NP |
| Do | 90.0 | 30–32 | 100 | 93 | 76 | 67 | 48 | 31 | 17 | 5 | ------ | ------ | NV | NP |
| Silty sand with gravel and clay | 90.0 | 40–42 | ------ | 100 | 97 | 94 | 83 | 61 | 20 | 8 | ------ | ------ | NV | NP |
| Do | 90.0 | 50–52 | 93 | 88 | 72 | 65 | 47 | 31 | 12 | 5 | ------ | ------ | NV | NP |
| Silty sandy gravel | 90.0 | 65–67 | 86 | 71 | 61 | 58 | 40 | 22 | 6 | 2 | ------ | ------ | NV | NP |
| Do | 90.0 | 80–82 | 100 | 84 | 72 | 61 | 44 | 27 | 11 | 5 | ------ | ------ | NV | NP |
| Do | 90.4 | 15–17 | 100 | 100 | 84 | 75 | 55 | 34 | 17 | 8 | ------ | ------ | NV | NP |
| Silty clay | 90.4 | 20–22 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | 100 | 26 | ------ | 24 | NP |
| Do | 90.4 | 30–32 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | 100 | 83 | ------ | 50 | 11 |
| Silty clay with sand | 90.4 | 40–42 | ------ | ------ | ------ | ------ | ------ | 100 | 99 | 94 | 46 | ------ | 27 | NP |
| Do | 90.4 | 50–52 | ------ | ------ | ------ | ------ | ------ | ------ | 100 | 87 | 13 | ------ | 28 | NP |
| Silty clayey sand | 90.4 | 65–67 | ------ | ------ | ------ | ------ | ------ | ------ | 100 | 67 | 12 | ------ | 23 | NP |
| Do | 90.4 | 80–82 | 100 | 96 | 89 | 86 | 72 | 53 | 20 | 4 | ------ | ------ | NV | NP |

TABLE 10.—*Analyses of sediments underlying Copper River Highway*

[Analyses by Alaska Dept. Highways. NV, no value; NP, nonplastic]

| Mile | Boring and sample No. | Depth (feet) | Grading analysis: percent passing— | | | | | | Atterberg limits | | Moisture content (percent) | Specific gravity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 3 in. | No. 10 | No. 40 | No. 200 | 0.02 mm | 0.005 mm | Liquid limit | Plastic index | | |
| 14.8 | TH 3 | 5–7 | 100 | 35 | 20 | 8.0 | 4.4 | 2.1 | NV | NP | 4.2 | 2.75 |
| 14.8 | TH 3 | 9–10 | 100 | 72 | 54 | 19.9 | 8.1 | 3.6 | NV | NP | 14.3 | 2.73 |
| 15.1 | TH 5 | 10–13 | 100 | 44 | 23 | 4.1 | 2.2 | 1.1 | NV | NP | 6.8 | 2.74 |
| 15.8 | TH 15 | 3½–4½ | 100 | 8 | 3 | .4 | .3 | .2 | NV | NP | 1.3 | 2.71 |
| 15.8 | TH 15 | 8–9½ | 100 | 78 | 68 | 35.6 | 11.2 | 2.9 | NV | NP | 23.5 | 2.70 |
| 15.8 | TH 15 | 13–14½ | 100 | 97 | 90 | 47.3 | 14.9 | 3.8 | NV | NP | 34.1 | 2.69 |
| 15.8 | TH 15 | 18–19 | 100 | 97 | 95 | 85.3 | 48.9 | 20.7 | 27 | NP | 48.4 | 2.65 |
| 16.0 | TH 19 | 3–4½ | 100 | 100 | 89 | 33.6 | 10.3 | 2.4 | NV | NP | 29.7 | 2.73 |
| 16.5 | TH 24 | 5–7 | 100 | 42 | 26 | 15.2 | 9.3 | 5.1 | 23 | NP | 13.2 | 2.73 |
| 16.7 | TH 34 | 4–5 | 100 | 37 | 21 | 14.1 | 10.3 | 6.0 | 22 | 6 | 5.1 | 2.74 |
| 17.4 | TH 38 | 3–4½ | 100 | 89 | 77 | 29.0 | 11.1 | 3.5 | NV | NP | 26.2 | 2.73 |
| 17.4 | TH 38 | 8–9½ | 100 | 70 | 49 | 24.2 | 13.4 | 5.4 | NV | NP | 36.1 | 2.74 |
| 17.4 | TH 38 | 13–14½ | 100 | 70 | 56 | 9.8 | 3.3 | 1.2 | NV | NP | 17.1 | 2.73 |
| 18.2 | TH 46 | 1–3 | 100 | 39 | 20 | 8.1 | 5.2 | 2.8 | NV | NP | 3.3 | 2.71 |
| 18.2 | TH 46 | 11–12 | 100 | 67 | 56 | 35.5 | 19.0 | 7.6 | 17 | NP | 15.1 | 2.70 |
| 18.6 | TH 50 | 2–4 | 100 | 43 | 23 | 11.4 | 7.9 | 4.2 | NV | NP | 3.2 | 2.74 |
| 18.6 | TH 50 | 11–13 | 100 | 48 | 23 | 5.7 | 3.4 | 1.8 | NV | NP | 8.5 | 2.73 |

TABLE 11.—*Analyses of sediments on Richardson Highway from mile 1.00 to mile 2.78*

[Analyses by Alaska Dept. Highways. NV, no value; NP, nonplastic]

| Mile | Boring and sample No. | Depth (feet) | Grading analysis: percent passing— | | | | | | Atterberg limits | | Moisture content (percent) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 3 in. | No. 10 | No. 40 | No. 200 | 0.02 mm | 0.005 mm | Liquid limit | Plastic index | |
| 1.03 | TH 1 | 8 | 100 | 84 | 72 | 42.4 | 24.6 | 10.2 | NV | NP | 18.0 |
| 1.03 | TH 1 | 18 | 100 | 63 | 40 | 16.0 | 9.0 | 5.0 | NV | NP | 12.5 |
| 1.28 | TH 2 | 7 | 100 | 36 | 20 | 8.7 | 6.6 | 3.4 | NV | NP | 2.8 |
| 1.28 | TH 2 | 13 | 100 | 56 | 31 | 15.7 | 11.0 | 5.6 | NV | NP | 13.2 |
| 1.28 | TH 2 | 19 | 100 | 54 | 40 | 22.1 | 13.5 | 6.1 | NV | NP | 13.4 |
| 1.52 | TH 3 | 15 | 100 | 47 | 28 | 15.9 | 10.4 | 5.7 | 16 | NP | 3.8 |
| 1.52 | TH 3 | 29 | 100 | 48 | 27 | 14.1 | 10.0 | 5.8 | NV | NP | 5.6 |
| 1.73 | TH 5 | 16 | 100 | 46 | 24 | 8.6 | 6.0 | 3.9 | NV | NP | 3.6 |
| 1.73 | TH 5 | 25 | 100 | 52 | 18 | 5.3 | 3.8 | 2.7 | NV | NP | 9.8 |
| 1.82 | TH 6 | 12 | 100 | 83 | 66 | 34.5 | 18.5 | 7.4 | NV | NP | 25.3 |
| 1.82 | TH 6 | 25 | 100 | 95.4 | 86 | 52.7 | 23.6 | 8.8 | NV | NP | 26.2 |
| 1.82 | TH 6 | 33 | 100 | 90.3 | 77 | 38.6 | 19.0 | 8.0 | NV | NP | 24.0 |
| 2.08 | TH 8 | 5 | 100 | 21.4 | 10 | 5.3 | 3.5 | 2.0 | NV | NP | 1.6 |
| 2.08 | TH 8 | 18 | 100 | 64.3 | 37 | 6.6 | 4.7 | 3.0 | NV | NP | 12.1 |
| 2.08 | TH 8 | 25 | 100 | 92 | 80 | 39.2 | 23.6 | 11.1 | NV | NP | 29.7 |
| 2.08 | TH 8 | 28 | 100 | 67 | 30 | 10.2 | 7.4 | 3.7 | NV | NP | 15.0 |
| 2.31 | TH 10 | 28 | 100 | 63 | 31 | 9.3 | 6.2 | 3.4 | NV | NP | 12.8 |
| 2.56 | TH 12 | 15 | 100 | 50 | 30 | 15.6 | 8.5 | 4.4 | NV | NP | 9.5 |
| 2.56 | TH 12 | 32 | 100 | 58 | 28 | 9.4 | 5.7 | 2.7 | NV | NP | 13.7 |
| 2.78 | TH 14 | 15 | 100 | 81 | 52 | 16.8 | 10.1 | 5.8 | NV | NP | 8.2 |
| 2.78 | TH 14 | 22 | 100 | 73 | 64 | 31.7 | 14.4 | 6.6 | NV | NP | 14.0 |

TABLE 12.—*Correlation of foundation material of roadway and fractures of Seward-Anchorage Highway from mile 75.1 (Ingram Creek) to mile 95.0*

| Mile | Foundation material | Extent and nature of fractures |
|---|---|---|
| 75.1 to 77.1 | Silt, sand, and fine gravel; water table generally within 3 ft of surface. | Fractures normal to and along edge of roadway; normal fractures, spaced about 75 ft apart, have vertical displacement of as much as 6 in.; fractures along edge are as much as ¼ mile long, 6 in. wide, with north or downslope side down as much as 6 inches. From mile 76.4 to mile 76.9, fractures about 100–125 ft apart. |
| 77.1 to 78.4 | do | Fractures normal and along edge of roadway, but larger than those from mile 75.1 to mile 77.1; fractures refracted normal to roadway, cross roadway, and then continue on original heading. Have vertical displacements as much as 6 inches, horizontal to 1 ft. |
| 78.4 to 81.0 | Silt, sand, and fine gravel; water table generally within 2–3 ft of surface. | Heavily fractured; fractures normal to roadway, along edges, and in center of roadway; largest fracture occurred in this section of roadway (figs. 12, 13). Fractures normal or perpendicular to roadway may have 4 feet horizontal displacement and 1 foot vertical; spaced 100 to 150 feet apart. Maximum width of fracture in center of roadway 10 ft, length 500 ft depth 6–8 ft. |
| 81.0 to 82.6 | Silt, sand, and sandy gravel; water table within 4 ft of surface. | Series of fractures normal or perpendicular to highway spaced 200–250 ft apart with horizontal displacement to 6 in. and vertical displacement to 4 in.; fractures along edge of roadway, although not as extensive as those from mile 77.1 to mile 78.4. |
| 82.6 | Bedrock for 150 ft | No fractures; fill at each end fractured at contact. |
| 82.7 to 84.9 | Coarse sand and sandy gravel; water table more than 6 ft from surface. | Fractures, normal to roadway, occur as series locally spaced 75–100 ft apart; series are at miles 82.8–82.9, 83.2, 84.1–84.2; at mile 84.2–84.9, single fractures normal to highway spaced 400–500 ft apart; very little displacement on fractures in this section of roadway. |
| 84.9 to 84.95 | Bedrock | No fractures; fill at each end fractured and compacted; displaced vertically 3–3½ ft. |
| 84.95 to 86.6 | Coarse sand and sandy gravel. | Series of small fractures normal to roadway; no displacement; bedrock from mile 85.6 to mile 85.7. |
| 86.6 to 87.8 | Talus over bedrock | No fractures. |
| 87.8 to 87.9 | Swamp deposits over bedrock. | Closely spaced fractures normal to roadway; displacement slight because swamp deposits shallow. |
| 87.9 to 88.9 | Bedrock | No fractures. |
| 88.9 to 91.0 | Tidal silt and sand; water table close to surface locally, especially at Girdwood. | Small fractures normal to roadway and locally along edge of roadway. Only slight horizontal displacement in normal fractures. |
| 91.0 to 95.0 | Veneer of glacial outwash less than 10 ft thick overlying bedrock. | No fractures. |

TABLE 13.—*Bridges in south-central Alaska severely damaged or destroyed by the Alaska earthquake*

[Only primary and secondary highways listed; streets and bridges in communities not included]

| Highway or road | Number of bridges | Length (feet) | Severely damaged or destroyed | | | |
|---|---|---|---|---|---|---|
| | | | Number of bridges | Length (feet) | Bridges (percent) | Length (percent) |
| Copper River Highway | 53 | 14, 208 | 32 | 12, 015 | 60 | 85 |
| Edgerton Highway | 4 | 642 | 0 | 0 | 0 | 0 |
| Glenn Highway | 21 | 5, 000 | 1 | 2, 006 | 5 | 40 |
| Hope Road | 2 | 200 | 0 | 0 | 0 | 0 |
| Kenai-Nikiska Road | 1 | 75 | 0 | 0 | 0 | 0 |
| Portage Glacier Road | 3 | 279 | 3 | 279 | 100 | 100 |
| Point Whitshed Road | 5 | 374 | 1 | 100 | 20 | 27 |
| Richardson Highway | 20 | 2, 739 | 2 | 231 | 10 | 8 |
| Seward-Anchorage Highway | 54 | 9, 318 | 30 | 6, 370 | 55 | 68 |
| Sterling Highway | 13 | 1, 220 | 2 | 553 | 15 | 45 |
| Chiniak Highway | 20 | 1, 700 | 15 | 1, 330 | 75 | 78 |
| Anton Larsen Bay Road | 4 | 256 | 2 | 83 | 50 | 32 |
| Saltery Cove Road | 0 | 0 | 0 | 0 | 0 | 0 |
| Pasagshak Bay Road | 3 | 250 | 3 | 250 | 100 | 100 |
| Chiniak Highway-Spruce Cape Road | 1 | 50 | 1 | 50 | 100 | 100 |
| Total | 204 | 36, 311 | 92 | 23, 267 | 45 | 64 |

TABLE 14.—*Intensity of damage to bridges on primary and secondary roads in south-central Alaska*

[Only primary and secondary highways and roads listed; streets and bridges in communities not included]

| Highway or road | Number of bridges | Damage intensity | | | | | | | | Damage total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | None | | Slight | | Moderate | | Severe or destroyed | | | |
| | | Number | Percent | Number | Percent | Number | Percent | Number | Percent | Number | Percent |
| Copper River Highway | 53 | 1 | 2 | 16 | 30 | 4 | 8 | 32 | 61 | 52 | 98 |
| Edgerton Highway | 4 | 3 | 75 | 1 | 25 | 0 | 0 | 0 | 0 | 1 | 25 |
| Glenn Highway | 21 | 10 | 47. 5 | 10 | 47. 5 | 0 | 0 | 1 | 5 | 11 | 52. 5 |
| Hope Road | 2 | 2 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Kenai-Nikiska Road | 1 | 1 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Portage Glacier Road | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 100 | 3 | 100 |
| Point Whitshed Road | 5 | 4 | 80 | 0 | 0 | 0 | 0 | 1 | 20 | 1 | 20 |
| Richardson Highway | 20 | 12 | 60 | 3 | 15 | 3 | 15 | 2 | 10 | 8 | 40 |
| Seward-Anchorage Highway | 54 | 15 | 28 | 6 | 11 | 3 | 6 | 30 | 55 | 39 | 72 |
| Sterling Highway | 13 | 8 | 62 | 3 | 23 | 0 | 0 | 2 | 15 | 5 | 38 |
| Chiniak Highway | 20 | 5 | 25 | 0 | 0 | 0 | 0 | 15 | 75 | 15 | 75 |
| Anton Larsen Bay Road | 4 | 2 | 50 | 0 | 0 | 0 | 0 | 2 | 50 | 2 | 50 |
| Saltery Cove Road | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Pasagshak Bay Road | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 100 | 3 | 100 |
| Chiniak Highway-Spruce Cape | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 100 | 1 | 100 |
| Total | 204 | 63 | 31 | 39 | 19 | 10 | 5 | 92 | 45 | 141 | 69 |

TABLE 15.—*Damage to bridge approaches and bridges (except Allen River bridge) along the Copper River Highway*

[Designations west and east are used to indicate direction from Cordova (mile 0) to Bridge 332, Copper River 3 (mile 27.9) respectively. South and north designation is used from mile 33.0 to Million Dollar Bridge (mile 49.0); south and east is toward Cordova, north and west toward Chitina. Numbering of spans and bents runs west to east from mile 0 to mile 27.9 and south to north from mile 33.0 to Million Dollar Bridge. All displacement of spans is measured in relation to movement from original position of bearings on substructure units. Abbreviations used for structure and deck types are (structure type first, deck type second): PCG, prestressed concrete girder; PCS, prestressed concrete slab; SA, steel arch; SS, steel stringer; STT, steel through truss; TTS, treated timber stringer; TS, timber stringer; LT, laminated timber; TP, timber plank; RC, reinforced concrete; prefix T, preservative-treated material; suffix R, running plank. Bridge number and name and route mileage from Alaska Dept. Highways, Bridge Inventory Rating Report, 1964. Length and superstructure data primarily from Alaska Dept. Highways, Bridge Inventory Rating Report, 1964, supplemented by U.S. Geol. Survey data. Bridge damage data from U.S. Geol. Survey and Alaska Dept. Highways]

| Bridge No. | Bridge Name | Route mileage | Length Ft | Length In. | Type Superstructure | Type Substructure | Foundation material | Damage Approaches | Damage Bridges |
|---|---|---|---|---|---|---|---|---|---|
| 381 | Eyak River | 5.9 | 225 | 0 | PCS | Concrete abutments. | Bedrock | None | None. |
| 348 | Scott Glacier 1 | 7.6 | 150 | 0 | SS, RC | Wood piles | Fine-grained silty sandy gravel. | East approach subsided 3 in.; west approach subsided slightly. | Destroyed. East abutment subsided about 3 in. Bent 1: north pile down 3 in., west 8 in. Bent 2: north pile down 2½ in., west 8 in. Bent 3: north pile down 1 in., west 2 in. Bent 4: north pile down 4 in., west 5 in. Bent 5: north pile went east 8 in. Concrete deck raised about 5 in. off stringer. Deck moved about 3 in. west and broke concrete bulkhead between stringers. Some piles were split due to pounding. |
| 349 | Scott Glacier 2 | 7.7 | 200 | 0 | SS, RC | do | do | Approaches subsided unknown amount. | Severe. East abutment piles driven down as much as 2 in.; center pile moved 4 in. west. Bent 1: north pile down 3 in., two piles split. Bent 2: north pile down 4 in., west 4 in.; No. 5 pile split. Bent 4: north pile down 3 in., east 3 in. Bent 6: north pile down 3 in., east 3 in. Bent 7: north pile down 3 in., east 3 in. |
| 350 | Scott Glacier 3 | 8.2 | 150 | 0 | SS, RC | do | do | Unknown | Destroyed. Bridge collapsed over bent 5; stringers not resting on piles in several places. |
| 351 | Scott Glacier 4 | 8.6 | 75 | 0 | SS, RC | do | do | West approach subsided about 10 in.; east approach subsided about 3 in. | Destroyed. East end: concrete cap moved 2 in. east, deck jammed into bulkhead. Piles apparently moved beneath the bridge toward center of creek; west end of deck collapsed. |
| 352 | Scott Glacier 5 | 9.2 | 75 | 0 | SS, RC | do | do | Unknown | Severe. Concrete bulkhead between steel stringers and tied to concrete cap moved east about 2 ft. Bent 1: stringers moved off piles eastward. West end: stringers off piles; fell behind piles and down about 2 ft. |
| 406 | Scott Glacier 6 | 9.5 | 375 | 0 | SS, RC | Railroad rails welded together. | do | East approach subsided and fractured; west approach subsided unknown amount. | Destroyed. Bridge collapsed over broken piles in bents 3, 6-9, 12, and 13. |
| 407 | Scott Glacier 7 | 9.8 | 175 | 0 | SS, RC | do | do | West approach subsided 3 in.; east approach unknown. | Destroyed. Bridge collapsed at bents 3 and 4. Many broken piles. |
| 408 | Scott Glacier 8 | 10.1 | 151 | 2 | SS, RC | do | do | West approach fractured; east approach subsided unknown amount. | Severe. East end: compression cracks in bulkheads. Bent 2 cap cracked above north pile. Rails cracked in bents 1, 2, 4, and 5. |
| 409 | Scott Glacier 9 | 10.4 | 75 | 8 | SS, RC | do | do | East approach subsided about 3 in.; west approach subsided unknown amount. | Severe. Slight break in east abutment. Deck 6 in. over abutment bulkhead at west end. Bulkhead cracked. |
| 410 | Scott Glacier 10 | 10.8 | 75 | 8 | SS, RC | do | do | Both approaches subsided about 1 ft. | Slight. East abutment cracked; west abutment slightly cracked. |
| 411 | Scott Glacier 11 | 11.0 | 352 | 6 | SS, RC | do | do | do | Severe. Rail bents broken. East and west abutments broken due to movement of bridge deck. Caps on four rail pilings and several piles broken, especially in center of bridge. Every bent has some rail pilings cracked. Bridge wavy. East end steel stringer broken loose and abutment bulkhead cracked. |
| 361 | Sheridan Glacier 2. | 14.8 | 151 | 8 | TTS, TLT | Wood piles | do | East approach subsided 1 ft. West approach subsided about 10 in. | Moderate. Pile bracing split on bent 3. Upstream pile of bent 4 shifted from under cap. Timber cap split on bent 5. Backing plank on abutment 6 pushed away from piles. Span 5 stringers split. |
| 230 | Sheridan Glacier 3. | 14.9 | 201 | 4 | PCG, RC | Steel casing piles | do | Both approaches subsided about 8 in. | Slight. Backwall of abutment 1 is broken above the bridge seat; slight spalling of upstream stringer at abutment 1. |
| 363 | Sheridan Glacier | 15.3 | 201 | 8 | TTS, TLT | Wood piles | do | West approach subsided 5 in. East approach subsided about 6 in. | Severe. Pile cap at pier 2 split; spans dropped on top of piles. Abutment 1 crowded, causing buckling of laminated deck. |
| 364 | do | 15.8 | 26 | 8 | TTS, TLT | do | do | Both approaches subsided about 6 in. | Moderate. West abutment moved east 2 in.; east abutment west 4 in.; bridge in compression. |
| 365 | do | 15.9 | 39 | 8 | TTS, TLT | do | do | Both approaches subsided more than 6 in. | Severe. Abutment 1 cap is tipped and not bearing on piles; backing plank is tipped back. |
| 366 | do | 16.1 | 27 | 8 | TTS, TLT | do | do | Both approaches subsided slightly. | Severe. Abutment 2 cap has moved off center of piles; two piles are split. |
| 367 | do | 16.5 | 50 | 0 | TTS, TLT | do | do | Both approaches subsided about 1 ft. | Destroyed. Span 4 severely damaged; in bent 2 the cap is split and downstream pile is split. |

TABLE 15.—*Damage to bridge approaches and bridges (except Allen River bridge) along the Copper River Highway*—Continued

| Bridge | | Route mileage | Length | | Type | | Foundation material | Damage | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Name | | Ft | In. | Superstructure | Substructure | | Approaches | Bridges |
| 368 | Sheridan Glacier | 16.6 | 51 | 8 | TTS, TLT | Wood piles | Fine-grained silty sandy gravel. | Approaches subsided unknown amount. | Slight. Change in drainage putting more water under bridge than it can safely carry. Bridge in compression; deck moved west 4 in.; down 1 in. |
| 369 | do | 16.9 | 101 | 8 | TTS, TLT | do | do | West approach subsided 4 in.; east approach subsided very little. | Slight. Change in drainage pattern of area directs more water under bridge and aggravates scour at abutment 5. |
| 370 | do | 17.4 | 26 | 8 | TTS, TLT | do | do | Both approaches subsided slightly. | Slight. Deck moved west about 2 in.; bridge in compression. |
| 371 | do | 17.9 | 39 | 8 | TTS, TLT | do | do | West approach subsided 6 in.; east approach subsided very little. | Slight. Bridge in compression; west end deck moved west 4 in. |
| 372 | do | 18.2 | 51 | 8 | TTS, TLT | do | do | Approaches subsided about 4 in. | Slight. Cap and backing plank on abutment 1 have both moved in relation to piles; bridge in compression about 8 in. |
| 373 | do | 18.3 | 101 | 8 | TTS, TLT | do | do | Both approaches subsided about 5 in. | Slight. Bridge in compression about 8 in.; west abutment moved east 5 in.; east abutment moved west 3 in. |
| 374 | do | 18.9 | 101 | 8 | TTS, TLT | do | do | Unknown. | Slight. Deck moved east about 10 in.; bridge in compression. |
| 375 | Alaganik Slough | 19.3 | 51 | 8 | TTS, TLT | do | Silt and sand | Both approaches subsided slightly. | Slight. Bridge in slight compression. |
| 376 | do | 19.8 | 101 | 8 | TTS, TLT | do | do | West approach subsided and has large fracture 15 ft from deck; east approach subsided slightly. | Slight. Bridge in compression; one pile broken. |
| 377 | do | 20.2 | 151 | 8 | TTS, TLT | do | do | Both approaches subsided slightly. | Slight. Bridge in compression; deck moved 2 in. to the east. |
| 378 | do | 20.8 | 58 | 8 | TTS, TLT | do | do | Unknown. | Slight. Bridge in slight compression. |
| 379 | do | 21.9 | 151 | 8 | TTS, TLT | do | West end, bedrock; east end, sediments. | No damage to west approach; east approach subsided 4 in. | Slight. Bridge compressed and curved upstream; damage at east end; deck moved 2 in. east off of caps. |
| 395 | do | 22.3 | 176 | 8 | TTS, TLT | do | Silt and sand | East approach subsided 4 in. | Slight. Damage on east end of bridge; railing clamps broken; bridge in slight compression. |
| 330 | do | 24.0 | 42 | 0 | SS, RC | Concrete abutments. | do | Both approaches subsided slightly. | Moderate. Curbs at east end are broken where tied to abutments. All abutment backwalls have been spalled and cracked by movement of curbs. Curb reinforced steel extends into backwalls. Diaphragm concrete has moved away from backwalls. |
| 331 | Copper River 2 | 27.1 | 2,437 | 0 | STT, TLT, SS, RC. | Concrete piers and welded rails. | Fine-grained silt | East approach subsided 3 ft; west approach subsided about 3 in. | Severe. Span 1, a 300-ft through truss, has been displaced approximately 22 in. east and 8 in. downstream. Abutment 1 anchor bolts sheared off or bent out of shape. Rollers in roller nests lying flat on their sides. Span 2 displaced 19 in. eastward and 5 in. downstream. Span 3 displaced 25 in. eastward and 1½ in. downstream. Piers show sheared or bent anchor bolts and some spalling. Spans 3 and 4 jammed together at pier 4. Several broken piles; webwalls cracked on almost all bents. Truss spans 22–25 moved westward. Abutment 36 tipped back and badly cracked. |
| 332 | Copper River 3 | 27.9 | About 800 | 0 | STT, TLT | Concrete piers | do | Approaches subsided as much as 2½ ft. | Destroyed. Middle pier has disappeared; span 1 still hanging from west abutment with other end in river; span 2 in river. |
| 354 | Long Island Overflow. | 33.0 | 124 | 4 | SS, RC | Railroad rails welded together. | do | Approaches subsided 1 ft; side of roadway subsided 2 ft; downstream shoulders subsided the most. | Severe. Abutment 1 backwall cracked and spalled from tied-in curb ends, and anchor bolts bent. Pier 2 concrete curb spalled over pier, pier tipped northward; downstream end is low, pier cap cracked. Span 2 slab has separated from beams near pier 2. Abutment 3 backwall has been destroyed by movement of superstructure. |
| 333 | Copper River 4 | 33.9 | 766 | 7 | STT, TLT | Concrete piers | do | Approaches subsided 10 to 12 in. | Severe. Pier 2 concrete bolster columns cracked; end of deck and curbs of span 2 broken up by movement. Span 1 downstream bearing rollers lying flat, displaced 5 in. northward, bolts sheared. Spans 2–4 and piers 3–5 appear to be tipped upstream. At pier 6 concrete bolster columns cracked. Curb ends and top of backwall of span 5 broken by movement. Span 6 rollers at full travel with bolts bent, 5 in. southward movement. Span 7 anchor bolts sheared, displaced 8 in. southward. |
| 334 | Copper River 5 | 35.0 | 1,576 | 0 | SS, RC | Railroad rails in concrete. | do | Approaches subsided 4 in. | Destroyed. Spans 2–5 and piers 3–5 completely destroyed; span 15 fallen off pier 16. |
| 335 | Copper River 6 | 35.6 | 122 | 0 | SS, RC | do | do | Approaches subsided slightly. | Severe. Abutment 1 shows backwall and curb end cracking. Spans 2, 3, and 4 show 1 in. northward displacement, shearing bolts on span 2 at pier 3, span 3 at pier 4, and breaking sole plate welds on span 4 at pier 4. The backwall of abutment 5 has been destroyed by the northern movement of the steel. |

TABLE 15.—*Damage to bridge approaches and bridges (except Allen River bridge) along the Copper River Highway*—Continued

| Bridge | | Route mile-age | Length | | Type | | Foundation material | Damage | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Name | | Ft | In. | Super-structure | Substructure | | Approaches | Bridges |
| 336 | Copper River 7 | 35.8 | 282 | 0 | SS, RC | Railroad rails in concrete. | Fine-grained silt | Approaches subsided about 3 in. | Severe. Abutment 1 settled ±1 ft. Back wall cracked and spalled at curb ends. Slab and curb cracked over pier 2 owing to abutment settlement. Pier 3 tipped northward, shows severe cracking of webwall at downstream pile. Concrete cap cracked. Sole plate welds on span 2 are broken; no residual displacement. Pier 4 tipped northward. Webwall failed at downstream pile, concrete cap cracked over pile. Span 4 twisted; expansion joint closed at downstream curb and open about 3 in. at upstream curb. Pier 5 tipped northward. Spans 4 and 5 are 18 in. off their bearings to the north. Piers 6 and 7 settled and tipped downstream. Abutment 8 demolished; superstructure was driven through it. |
| 337 | Copper River 8 | 36.0 | 182 | 0 | SS, RC | do | do | North approach subsided 3 in.; south approach subsided 2 in. | Moderate. Abutments cracked by curb ends; settled 6± in. Expansion joints opened to fullest travel; joint filler material fallen out. |
| 338 | Copper River 9 | 36.1 | 182 | 0 | SS, RC | do | do | Both approaches generally subsided about 6 in.; at north approach 1-ft mound at abutment. | Severe. Abutment 1 curb cracked and spalled. Pier 3 webwall broken at upstream pile and tipped northward, a pile broken, a cap broken. At pier 4, span 3 displaced 4 in. north. At pier 5, spans 4 and 5 displaced 6 in. north. At pier 6, span 5 displaced 6 in. north and expansion joint jammed shut, crushing the deck concrete. Span 6 driven through abutment 7, demolishing it. Abutment 7 settled about 6 in. |
| 339 | Copper River 10 | 36.4 | 422 | 0 | SS, RC | do | do | North approach subsided about 2 ft; south approach subsided about 6 in. | Severe. Abutment 1 demolished by southward movement of superstructure; appears to have settled about 1 ft. Entire superstructure displaced southward 18 in. with respect to piers; shows a definite undulation. Abutment 8 moved forward with the superstructure and settled about 1 ft. |
| 340 | Copper River 11 | 36.7 | 242 | 0 | SS, RC | do | do | North approach subsided, but 18 in. mound bulldozed at abutment; south approach subsided 4 in. | Severe. Fill settled away under abutment 1. Abutment backwall badly cracked at curbs. At pier 2, spans 1 and 2 displaced 7 in. north. At pier 3, spans 2 and 3 displaced 4 in. south. Piers 3 and 4 tipped north. Abutment 5 demolished by northbound superstructure. |
| 341 | Copper River 12 | 36.9 | 142 | 0 | SS, RC | do | do | North approach subsided 2 in.; south approach subsided 4 in. | Severe. Both abutments have settled about 1 ft and show backwall cracking and spalling at curbs. At pier 3 the step in the concrete cap is cracked at the downstream bearing. Expansion joints are jammed shut by a northward movement. |
| 342 | Copper River 13 | 37.2 | 282 | 0 | SS, RC | do | do | Both approaches subsided about 6–8 in. | Severe. Cap of pier 3 is cracked. Pier 4 failed completely, dropping spans 3 and 4 into the river. Pier 5 tipped southward. Spans 5 and 6 show crimping of their bottom flanges due to compression. Abutment 7 has a cracked backwall. |
| 343 | Copper River 14 | 37.5 | 122 | 0 | SS, RC | do | do | Both approaches subsided about 3 in. | Slight. Abutment 1 shows usual cracking at curbs; appears to have settled about 6 in. Piers 2 and 3 show slab and curb cracking over supports. At pier 4 the expansion joint is open about 3 in.; joint filler has fallen out and bolts are at limit of travel in their slotted holes. |
| 344 | Copper River 15 | 37.8 | 272 | 0 | SS, RC | do | do | North approach subsided 4–5 in.; south approach subsided about 1 ft. | Severe. Abutment 1 shows backwall damage at curbs. Pier 2 has severe webwall cracking. At pier 4 both spans are displaced about 2 in. north, and anchor bolts are sheared. There has been a definite vertical displacement in this bridge; pier 4 has probably been uplifted. |
| 345 | Copper River 16 | 38.1 | 362 | 0 | SS, RC | do | do | South approach subsided 1½ ft; north approach subsided 3 in. | Severe. Abutment 1 tipped northward and superstructure driven through backwall with resultant displacement of ±6 ft. Pier 2 tipped south 4 to 6 in. At pier 3, span 2 is 1 in. north of masonry plate. Sole plate welds failed. At pier 4, spans 3 and 4 are 4 in. north of bearings and 8 in. downstream. Anchor bolts sheared. Pier 4 tipped southward. Pier 5 cap cracked at upstream bearing. At pier 6 both spans displaced 4 in. north and 2 in. upstream. Diaphragm bolts are gone. |
| 346 | Clear Creek | 38.9 | 182 | 0 | SS, RC | do | Outwash gravel | South approach subsided about 3 in.; north approach subsided about 1 ft. | Severe. Abutment 1 demolished by bridge going south; also appears to have settled. Pier 2 tipped about 2 ft south. At pier 3, span 2 is displaced 4 in. south. Pier has settled. Span 3 is 6 in. south of bearing. Abutment 4 shows usual curb cracking and appears to have settled. |

TABLE 15.—*Damage to bridge approaches and bridges (except Allen River bridge) along the Copper River Highway*—Continued

| Bridge No. | Bridge Name | Route mileage | Length Ft | Length In. | Type Superstructure | Type Substructure | Foundation material | Damage Approaches | Damage Bridges |
|---|---|---|---|---|---|---|---|---|---|
| 329 | Clear Creek | 41.0 | 182 | 0 | SS, RC | Railroad rails in concrete. | Outwash gravel | South approach cracked in middle of road for 500 ft. Fractures 2 ft wide; road subsided 2½–3 ft. North approach fractured about 500 ft and subsided 1½ ft. | Severe. South abutment demolished by southward movement of superstructure about 3 feet. Pier 2 tipped northward. Spans 1 and 2 are displaced 4 in. southward at pier 2. At pier 3 both spans displaced 1 ft northward. At pier 4 both spans are displaced 18 in. northward; at pier 5 both spans displaced 32 in. northward and 6 in. upstream. At pier 6, which tipped south, the spans are displaced 55 in. north and 1 ft upstream. Abutment 7 demolished by superstructure. Piers 5 and 6 moved laterally. |
| 206 | Million Dollar Bridge. | 49.0 | 1,400 | 0 | STT, RC | Concrete piers | do | Both approaches subsided 6–8 in. | Destroyed. Span 4 dropped off pier 4 and is in the river. Pier 4 is virtually destroyed. Rest of bridge has been damaged and shows displacements. |

TABLE 16.—*Damage to bridge approaches and bridges along the Seward-Anchorage Highway*

[Abbreviations used for structure and deck types are (structure type first, deck type second): CG, concrete girder; PCG, prestressed concrete girder; SS, steel stringer; TTS, treated timber stringer; RFC, rigid frame concrete; SPG, steel plate girder; TS, timber stringer; suffix C, cantilever or continuous bridge; A, asphalt; LTA, laminated timber and asphalt; RC, reinforced concrete; TP, timber plank. Bridge number and name and route mileage from Alaska Department of Highways, Bridge Inventory Rating Report, 1964. Length and superstructure data primarily from Alaska Dept. Highways, Bridge Inventory Rating Report, 1964, supplemented by U.S. Geol. Survey data. Damage data collected by U.S. Army and U.S. Geol. Survey]

| Bridge No. | Bridge Name | Route mileage | Length Ft | Length In. | Type Superstructure | Type Substructure | Foundation material | Damage Approaches | Damage Bridges |
|---|---|---|---|---|---|---|---|---|---|
| 596 | Resurrection River 1. | 2.9 | 198 | 0 | SS, RC | Concrete piers | Stream sediment | Subsided unknown amount. | Severe. Abutments cracked; anchor bolts sheared; pier cracked; spans down; piers subsided; span moved south and north. Maximum movement on south span as much as 7 in. north and 2 in. west. |
| 597 | Resurrection River 2. | 2.9 | 135 | 6 | SS, RC | do | do | North approach subsided 16 in. South approach estimated subsidence 12 in. | Severe. Abutments cracked; bridge in compression; span moved as much as 8 in. |
| 598 | Resurrection River 3. | 3.0 | 185 | 6 | SS, RC | do | do | Both subsided several inches. | Severe. Abutments cracked; north pier cracked at base, moved north and out of plumb; bridge in compression; span moved north 4 in., east 2 in.; center span down ½ in.; anchor bolts sheared. |
| 599 | Clear Creek | 3.5 | 75 | 0 | SS, LTA | Concrete abutments. | Sediments | Unknown | Moderate. Bridge in compression. |
| 600 | Salmon Creek | 6.5 | 125 | 6 | SS, RC | Concrete piers | Sandy gravel | Slight subsidence, up to 3 in. in both approaches. | Slight. Decks moved south about 1 in.; slight crack in south abutment; north abutment moved north about 1 in.; bridge in compression. |
| 601 | Bear Creek | 7.0 | 51 | 8 | CG, RC | Wood piles | do | North approach subsided about ½ in. | Slight. North abutment subsided about ½ in. |
| 602 | Grouse Creek 1 | 8.0 | 39 | 8 | TTS, RC | do | Stream sediments. | Fill compacted 3–4 in | None. |
| 741 | Grouse Creek 2 | 9.4 | 23 | 8 | RFC, A | Concrete abutments. | do | Subsided 3–4 in | Do. |
| 603[1] | Snow River 1 | 17.3 | | | TS, TPA | Wood piles | Fine-grained silt and sand. | Subsided about 4–6 ft | Severe. Bridge in compression; deck wavy; deck, in places, is off cap. |
| 604[1] | Snow River 2 | 17.6 | 95 | 0 | TS, TPA | do | do | Approaches subsided about 6 ft. Surrounding sediments settled about 12 ft. | Severe. Roadway bowed up in middle; bridge in compression; deck wavy; deck in places, is off cap. |
| 605[1] | Snow River 3 | 17.7 | 209 | 0 | TS, TPA | do | do | Approaches subsided about 6 ft. Surrounding sediments settled about 12 ft. | Destroyed. Third bent from north end did not settle. All others settled as much as 12 ft; 3 spans nearest south end slightly twisted and rolled. |
| 606[1] | Snow River Overhead (4) | 18.2 | 1,471 | 0 | TS, TPA | do | do | West approach subsided unknown amount; east approach subsided about 18 in. | Destroyed. South end of bridge pulled 6 in. away from abutment; bridge slightly canted and wavy. Piles on west side settled 6 in. to 2 ft lower than east side in first 1,120 ft (from south end). For next 100 ft, timber bents all canted south and offset. Last 225–250 ft (north end) completely destroyed; it fell or twisted to ground about 75 ft below, destroying roadway and bents. |
| 603A | Snow River, west channel. | 17.1 | 188 | 6 | PCG, RC | do | do | Under construction | Bridge under construction. No decks; piers moved downstream as much as 5 ft and canted. |
| 605 | Snow River, center channel. | 17.7 | 648 | 6 | PCG, RC | do | do | do | Do. |
| 606 | Snow River Overhead. | 18.2 | 289 | 2 | PCG, RC | do | do | do | Do. |
| 607 | Victory Creek | 20.0 | 197 | 3 | SSC, RC | do | Fill on bedrock | Fill subsided 2–3 in | None. |
| 608 | Ptarmigan Creek | 23.5 | 151 | 8 | CG, RC | do | Outwash gravel and stream gravel. | Fill subsided 4–5 in | Do. |
| 609 | Falls Creek | 25.0 | 126 | 9 | CG, RC | do | Sediments | do | Do. |
| 610 | Trail River | 25.5 | 351 | 8 | CG, RC | do | do | Fill subsided 3–4 in | Slight. Bridge in compression. |

TABLE 16.—*Damage to bridge approaches and bridges along the Seward-Anchorage Highway*—Continued

| Bridge No. | Bridge Name | Route mile-age | Length Ft | Length In. | Type Super-structure | Type Substructure | Foundation material | Damage Approaches | Damage Bridges |
|---|---|---|---|---|---|---|---|---|---|
| 611 | Moose Creek | 32.0 | 76 | 8 | CG, RC | Wood piles | Sediments | Both approaches subsided 2–3 in. | Slight, Bridge in compression. |
| 1137 | Quartz Creek | 42.0 | 22 | 1 | RFC | Concrete abutments. | Bedrock | None | None. |
| 1138 | Summit Creek | 42.6 | 22 | 1 | RFC | do | do | do | Do. |
| 1139 | Colorado Creek | 45.8 | 22 | 1 | RFC | do | do | do | Do. |
| 612 | Canyon Creek | 56.8 | 302 | 0 | SS, RC | Steel towers | do | Fill subsided | Slight. |
| 613 | Dry Gulch Creek | 57.1 | 120 | 0 | SSC, RC | do | Thin veneer of sediments over bedrock. | do | None. |
| 614 | Silvertip Creek | 60.7 | 86 | 6 | SS, RC | Concrete piers | Bedrock | do | Do. |
| 615 | East Fork Six Mile Creek. | 61.6 | 265 | 9 | SPGC, RC | do | Stream deposits | North approach subsided 6 in. in about 10 ft fill over stream deposits. South approach subsided about 2 in. | Slight. |
| 616 | Granite Creek | 63.2 | 206 | 3 | SS, RC | do | Bedrock | Fill subsided 2 in | None. |
| 617 | Spokane Creek | 64.9 | 86 | 0 | SS, RC | Concrete abutments. | Coarse gravel | None | Do. |
| 618 | Bertha Creek | 65.6 | 145 | 0 | SS, RC | Unknown | do | do | Do. |
| 619 | Lyon and Tin Can Creek. | 67.8 | 146 | 0 | SS, RC | Wood piles | do | do | Do. |
| 620 | Ingram Creek | 75.1 | 206 | 0 | SS, RC | Concrete piers | Sand and gravel | Unknown amount | Severe. Bridge in compression; abutments moved toward center of creek. |
| 621 | Muddy Creek | 75.8 | 375 | 0 | CG, RC | Wood piles | Silty sand and gravel. | East approach subsided 14 in., west approach subsided 17 in. | Destroyed. From east end: 2 piles under first 12 spans are split. All bracings split. All piles on east side are canted west. Pi ings under last 3 spans are crushed and spans are collapsed. Bridge bowed north; not straight across. |
| 622 | Steep Creek | 75.8 | 200 | 0 | CG, RC | do | do | East approach subsided 30 in.; west approach fractured and subsided 12 in. | Destroyed. Western half of bridge, 4 span buckled and canted over split, crushed, or canted piles. |
| 623 | Tidewater Slough 1. | 75.9 | 176 | 0 | CG, RC | do | do | Fill. East approach subsided 38 in.; west approach subsided 21–36 in. | Severe. Two piles settled with road and are not supporting bridge. Separations of 4 in. and 2 in. between spans in 2 places; replaced. |
| 624 | Tidewater Slough 2. | 76.4 | 76 | 0 | CG, RC | Wood piles | Silt, sand and silty gravel. | Fill. East approach subsided 30 in.; west approach subsided 24 in. | Structure received only slight damage from seismic shock, but bridge was flooded during high tide and had to be replaced. Effects of earthquake therefore are considered severe. |
| 625 | Tidewater Slough 3. | 77.0 | 76 | 0 | CG, RC | do | do | Fill. East approach subsided 40 in.; west approach subsided 28 in. | Do. |
| 626 | Tidewater Slough 4. | 77.1 | 76 | 0 | CG, RC | do | do | Fill. East approach subsided 15 in.; west approach subsided 17 in. | Do. |
| 627 | Placer River 1 | 77.9 | 450 | 0 | CG, RC | do | do | West abutment up about 2 in. West approach subsided about 8 in.; east approach subsided 16 in. | Destroyed. Westernmost spans collapsed over first bent (pilings crushed); easternmost 6 spans collapsed over crushed piles. |
| 628 | Placer River 2 | 78.2 | 125 | 0 | CG, RC | do | do | West approach subsided 22 in.; east approach subsided 24 in. | Destroyed. East abutment damaged; pilings in center bent crushed and spans collapsed over them. |
| 629 | Placer River Main Crossing. | 78.4 | 600 | 0 | CG, RC | do | do | West approach subsided 7 in.; east approach subsided 22 in. | Destroyed. Both abutments destroyed; all pilings destroyed; many punched through concrete roadway; all spans collapsed. |
| 630 | Portage Creek 1 | 79.0 | 175 | 0 | CG, RC | do | Silty sand | South approach subsided 27 in.; north approach subsided 42 in. | Destroyed. Pilings destroyed; some driven up through concrete deck; all spans collapsed. |
| 631 | Portage Creek 2 | 79.6 | 225 | 0 | CG, RC | do | Sand, silt, and sandy gravel. | South approach subsided 18 in.; north approach subsided 24 in. | Destroyed. Both abutments destroyed; all pilings destroyed, spans twisted and collapsed, some under water. |
| 632 | Portage Creek 3 | 79.6 | 125 | 0 | CG, RC | do | do | South approach subsided 23–42 in.; north approach subsided 46 in. | Destroyed. Abutments slightly damaged. Center piles crushed and deck collapsed over them. |
| 633 | Jim's Creek | 80.3 | 50 | 0 | CG, RC | do | Silt, sand, and silty gravel. | South approach subsided 24 in.; north approach subsided 22 in. | Severe. Abutments slightly damaged; deck settled over center bent; replaced. |
| 634 | Twentymile River. | 80.8 | 820 | 0 | CG, RC | do | Silty sand and sandy gravel. | South approach subsided 21 in.; north approach subsided 5 in. | Destroyed. North abutment destroyed by fissures. All pilings destroyed, and in many places are driven through the concrete deck. All spans collapsed and under water. |
| 635 | Tidewater Slough 5. | 82.0 | 140 | 0 | CG, RC | do | Silt and sand | South approach subsided 45 in.; north approach subsided 90–96 in. | Severe. Deck raised on either end and bowed down in center. |

[1] Numbers 603, 605, and 606 have been reassigned to bridges under construction at the time of the earthquake. 604 no longer exists.

TABLE 16.—*Damage to bridge approaches and bridges along the Seward-Anchorage Highway*—Continued

| Bridge | | Route mileage | Length | | Type | | Foundation material | Damage | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Name | | Ft | In. | Superstructure | Substructure | | Approaches | Bridges |
| 636 | Peterson Creek | 84.2 | 126 | 6 | CG, RC | Wood piles | Sandy gravel | South approach subsided 9 in.; north approach subsided 9 in. | Moderate. Replaced. |
| 637 | Kern Creek | 86.6 | 155 | 6 | SS, RC | Concrete piers | North, bedrock; south, stream gravel. | South approach down 4 in.; north approach down 1 in. | Do. |
| 638 | Virgin Creek | 89.6 | 100 | 0 | CG, RC | Wood piles | Silty sand | South approach subsided about 3 in.; north approach subsided 6 in. | Destroyed. Both abutments damaged; bridge collapsed over northernmost bent; pilings shifted and slightly crushed under all spans. |
| 639 | Glacier Creek | 90.0 | 155 | 6 | SS, RC | do | Silty sandy gravel. | South approach subsided 6 in.; north approach subsided 4 in. | Severe. Both abutments damaged. |
| 640 | Tidewater Slough 6. | 90.9 | 120 | 0 | CG, RC | do | do | South approach subsided 12 in.; north approach subsided 20 in. | Destroyed. North abutment slightly crushed; south abutment entirely crushed; bridge collapsed over center bent; piles driven through reinforced concrete. |
| 641 | Tidewater Slough 7. | 98.3 | 76 | 0 | CG, RC | do | do | do | Awash at high tide. Replaced; damage considered severe. |
| 642 | Tidewater Slough 8. | 98.9 | 76 | 6 | CG, RC | do | do | South approach subsided 18 in.; north approach subsided 12 in. | Severe. Awash at high tide. |
| 643 | Bird Creek | 103.8 | 205 | 4 | SS, RC | do | Sand and gravel | South approach subsided 12 in.; north approach subsided 12 in. | Severe. |
| 644 | Indian Creek | 105.3 | 165 | 6 | SS, RC | Concrete piers(?) | do | Unknown | Severe. Bridge in compression. |
| 645 | Campbell Creek | 125.3 | 22 | 0 | SS, RC | | do | Approach subsided about 2 in. | None. |

TABLE 17.—*Damage to bridge approaches and bridges along Glenn Highway from Anchorage to Richardson Highway*

[Abbreviations used for structure and deck types are (structure type first, deck type second): SA, steel arch; SPG, steel plate girder; SPT, steel pony truss; SS, steel stringer TTS, treated timber stringer; TS, timber stringer; STT, steel through truss; suffix C, cantilever or continuous bridge; TPA, timber plank with asphalt-wearing surface; LTA, laminated timber with asphalt-wearing surface; RC, reinforced concrete. Bridge number and name, route mileage, and superstructure data from Alaska Dept. Highways, Bridge Inventory Rating Report, 1964. Substructure and damage data by U.S. Geol. Survey]

| Bridge | | Route mileage | Length | | Type | | Foundation material | Damage | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Name | | Ft | In. | Superstructure | Substructure | | Approaches | Bridges |
| 417 | Ship Creek | 0.4 | 163 | 0 | TTS, TPA | Wood piles | Stream sediments | | Slight. Bridge in compression. |
| 534 | do | 3.2 | 73 | 6 | TS, LTA | do | do | | Do. |
| 535 | Eagle River | 13.5 | 243 | 5 | SS, RC | Concrete piers | Glacial gravel | Both approaches subsided 1½ in. | Slight. Bridge has 5 stringers; all bolts on stringers 1, 2, 4 and 5 are sheared; downstream shoe bolt on stringer 3 sheared. Opened up about 1 in. above first pier from south. |
| 536 | Peters Creek | 21.6 | 103 | 8 | SPT, RC | do | Bedrock | Ten ft of fill; no subsidence. | None. |
| 537 | Eklutna River | 26.0 | 257 | 0 | SA, RC | do | do | None | Slight. North abutment moved about 2 in. North end shows 1-in. tension crack between abutment and bridge. |
| 538 | Goat Creek | 36.0 | 77 | 0 | TS, LTA | Unknown | Sediments(?) | do | None. |
| 539 | Knik River | 38.7 | 2,006 | 6 | STT, LTA | Concrete piers | Stream sediments | Both approaches subsided unknown amount. | Severe. Concrete pier cracked and canted; piers slightly displaced toward center of creek. |
| 540 | Matanuska River | 46.8 | 353 | 8 | STT, RC | do | East abutment, bedrock; west abutment, gravel. | None | Slight. Bridge in compression; crack on pier at waterline; west abutment moved east about 1 in. |
| 541 | Moose Creek | 54.9 | 183 | 2 | SSC, RC | do | Coarse gravel | do | None. |
| 542 | Eska Creek | 61.0 | 31 | 7 | SS, RC | Steel piles | Glacial gravel | Subsided about ½ in. | Do. |
| 543 | Granite Creek | 62.6 | 183 | 2 | SSC, RC | Concrete piers | Coarse gravel | do | Do. |
| 544 | Kings River | 66.8 | 243 | 7 | SS, RC | do | do | Subsided ½ in. | Do. |
| 545 | Chickaloon River | 78.2 | 253 | 10 | SSC, RC | do | Fill over bedrock | Fill subsided about 1 in. | Slight. On east abutment, downstream sliding shoe broke at weld with stringer. |
| 546 | Puritan Creek | 89.3 | 21 | 7 | SS, RC | Steel piles | do | East approach: 10 ft fill subsided 3 in.; west approach: 6 ft fill over bedrock subsided 1 in. | Slight. Anchor bolts on shoe plates sheared; shoe moved 2 in. west; deck moved 2–2½ in. (west abutment). |
| 547 | Hicks Creek | 96.7 | 133 | 3 | SSC, RC | Concrete piers | Bedrock | None | None. |
| 548 | Caribou Creek | 106.9 | 233 | 2 | SS, RC | do | do | East approach subsided slightly. | Slight. West abutment separated from span about 1½ in.; all cracks on abutment between middle stringers. |
| 549 | Little Nelchina River. | 137.5 | 183 | 2 | SS, RC | Steel H-piles | Silt, sand, gravel | West approach subsided 3 in.; east approach subsided 2 in. | None. |
| 550 | Cache Creek | 147.2 | 22 | 3 | SS, RC | do | do | Both subsided 2 in.; approaches on about 15 ft of fill. | Slight. Bridge in compression; bottom of both bulkheads moved toward middle of stream. |
| 551 | Mendeltna Creek | 152.7 | 61 | 5 | SS, RC | do | do | Subsided unknown amount, probably not more than 3 in. | Slight. East concrete abutment has small cracks; concrete deck cracked at east abutment. |
| 552 | Tolsona Creek | 172.6 | 81 | 5 | SS, RC | | do | Subsided unknown amount, probably not more than 2–3 in. | None. |
| 553 | Moose Creek | 186.2 | 41 | 6 | SS, RC | Concrete abutment(?). | do | Subsided unknown amount. | Do. |

TABLE 18.—*Damage to bridge approaches and bridges along the Richardson Highway from Valdez to Glenn Highway*

[Abbreviations used for structure and deck types are (structure type first, deck type second): SPG, steel plate girder; SS, steel stringer; SDT, steel deck truss; STT, steel through truss; TS, timber stringer; TTS, treated timber stringer; suffix C denotes cantilever or continuous bridge; LT, laminated timber; TP, timber plank; RC, reinforced concrete; prefix T, preservative-treated material; suffix A, asphalt-wearing surface; suffix R, running plank. Bridge number and name and route mileage from Alaska Dept. Highways, Bridge Inventory Rating Report, 1964. Superstructure data primarily from Alaska Department of Highways, Bridge Inventory Rating Report, 1964, supplemented by U.S. Geological Survey data. Substructure, foundation materials, and damage data collected by U.S. Geological Survey]

| Bridge | | Route mileage | Length | | Type | | Foundation materials | Damage | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Name | | Ft | In. | Superstructure | Substructure | | Approaches | Bridges |
| 554 | Valdez Glacier Stream 1. | 0.9 | 134 | 0 | TTS, TTPR. | Wood piles | Glacial sediments. | Approaches subsided 2–5 in.; roadway wavy. | Moderate. West abutment jammed about 1 ft to west; bridge in severe compression; deck wavy. |
| 555 | Valdez Glacier Stream 2. | 1.1 | 216 | 0 | TTS, TTPR. | do | do | Approaches subsided 2–6 in.; roadway wavy. | Moderate. Seventy-five ft from east end, bridge has moved downstream about 1 ft to 18 in. Fourth bent from east end, downstream pile moved about 4 in. Second bent from west end, downstream 3 in. Fifth bent, 2 center piles moved to east about 3 in. Downstream pile cracked through about 3 in. from surface. Sixth bent, downstream pile split; middle 2 piles moved east about 3 in. |
| 556 | Valdez Glacier Stream 3. | 1.4 | 196 | 5 | SS, RC | Concrete piers | do | Approaches subsided 3–6 in. | Severe. West abutment cracked; displaced west about 18 in., bulkhead down about 1 ft. First 3 bents from west end in tension. East abutment sidewall cracked. |
| 557 | Lowe River Lower Crossing. | 14.7 | 254 | 7 | STT, TLTA. | Concrete piers(?) | Bedrock | None. | Slight. South abutment has pushed against span, and bridge is in compression. |
| 701 | Keystone Tunnel | 15.8 | 636 | 0 | Tunnel | | do | do | None. |
| 558 | Lowe River Upper Crossing. | 16.6 | 193 | 0 | SS, RC | Steel piles | do | do | Slight. Bridge compressed and low at each end. |
| 559 | Sheep Creek | 19.0 | 193 | 0 | SPG, RC | Concrete piers | Glacial outwash | do | Slight. Anchor bolts, north pier, bent north. Anchor bolts bent, north abutment. Bridge may have moved 2 in. |
| 560 | Worthington Glacier 1. | 29.2 | 41 | 0 | TTS, LTA. | Wood piles | do | Approaches subsided 4–5 in. | None. |
| 561 | Worthington River. | 30.1 | 61 | 6 | TTS, TLTA. | do | do | Approaches subsided 4–6 in. | Do. |
| 562 | Cascade Creek | 35.1 | 58 | 0 | TS, TPR. | do | Silt, sand, gravel | North approach subsided slightly. | Moderate. Piles canted. Some moved downstream about 2–3 in., especially on south abutment. |
| 563 | Small Creek | 35.9 | 23 | 0 | TS, LTA. | Wood abutments | do | Approaches subsided slightly. | None. |
| 564 | Tsina River | 37.8 | 163 | 8 | SDT, RC. | Concrete abutments. | Bedrock | do | Do. |
| 565 | Stuart Creek | 45.6 | 81 | 8 | SS, RC | Steel H-piles | do | South approach subsided about 2 in.; north approach subsided about 6 in. | Do. |
| 566 | Boulder Creek | 51.5 | 26 | 8 | TTS, TLTA. | Wood abutments | Silt, sand, gravel | None. | Do. |
| 567 | Squaw Creek | 54.8 | 41 | 5 | SS, RC | do | do | Approaches subsided slightly. | Do. |
| 568 | Little Tonsina River. | 66.0 | 35 | 0 | TS, TP | do | do | Mound about 2½ ft high; roadway fractured at both approaches. | Severe. North end moved south about 17–20 in. Stringer 6 in. by 14 in. split. Other stringers are broken or split at north end. Bridge replaced. |
| 569 | Tonsina River | 79.1 | 255 | 10 | SSC, RC. | Concrete piers(?) | do | Approaches subsided 2–3 in. | None. |
| 570 | Squirrel Creek | 80.4 | 22 | 6 | TTS, LTA. | Wood abutments | do | None. | Do. |
| 571 | Willow Creek | 90.7 | 27 | 0 | TTS, TLTA. | do | do | do | Do. |
| 572 | Klutina River | 101.0 | 242 | 9 | SPGC, RC. | Concrete piers(?) | do | do | Do. |
| 573 | Tazlina River | 110.4 | 463 | 2 | STT, LTA. | Concrete piers and steel H-piles. | do | do | Do. |

TABLE 19.—*Damage to bridge approaches and bridges along Sterling Highway*

[Abbreviations used for structure and deck types are (structure type first, deck type second): CG, concrete girder; SS, steel stringer; STT, steel through truss; CMP, corrugated metal pipe-multiplate and arch; TS, timber stringer; RFC, rigid frame concrete; suffix C indicates cantilever or continuous bridge; RC, reinforced concrete; LTR, laminated timber with running plank; TLTA, preservative-treated laminated timber with asphalt-wearing surface. Bridge number and name, route mileage, length and superstructure data from Alaska Dept. Highways, Bridge Inventory Rating Report, 1964. Substructure, foundation materials, and damage data collected by U.S. Geological Survey]

| Bridge | | Route mileage | Length | | Type | | Foundation materials | Damage | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Name | | Ft | In. | Superstructure | Substructure | | Approaches | Bridges |
| 680 | Daves Creek | 41.3 | 21 | 0 | RFC | Concrete abutments. | Bedrock | None | Slight. Bridge in compression. |
| 676 | Quartz Creek | 41.7 | 152 | 1 | CG, RC | Concrete piers | Thin veneer of fine-grained sediments. | Fill differentially subsided about 1½–2 in. on each side of bridge. | Severe. East end moved south relative to middle section and west end moved north about 3–4 in. Expansion cracks in deck widened about 2 in. |
| 675 | Kenai River | 48.9 | 400 | 1 | CG, RC | Wood piles | Sediments | Approaches subsided as much as 8 in. | Destroyed. Wood piles driven through 6-in. reinforced concrete. Bridge collapsed. |
| 674 | Cooper Creek | 52.6 | 67 | 6 | SS, RC | Concrete abutments. | Deltaic sediments | Both approaches had 2 in. slumps. | Slight. Anchor bolts slipped ½ inch. Abutment cracked. Flashing between bridge and abutment squeezed out. |
| 673 | Kenai River | 54.1 | 282 | 0 | SS, RC | Steel piles | Sediments-terrace gravels. | None | Under construction. |
| 672 | Moose River | 84.0 | 159 | 0 | SSC, RC | Concrete piers | Sediments | Both approaches wavy | Slight. West abutment and bridge deck opened 1½ in. |
| 671 | Kenai River | 97.8 | 379 | 9 | STT, TLTA | Steel piles | do | None | None. |
| 670 | Kasilof River | 111.6 | 273 | 6 | STT, TLTA | do | do | do | Do. |
| 669 | Ninilchik River | 137.0 | 159 | 2 | SSC, RC | Unknown | do | do | Do. |
| 668 | Deep Creek | 139.0 | 135 | 3 | SS, RC | do | do | do | Do. |
| 667 | Stariski Creek | 152.0 | 76 | 6 | TS, LTR | do | do | do | Do. |
| 796 | North Fork Anchor River. | 161.7 | 32 | 0 | CMP | do | do | do | Do. |
| 666 | South Fork Anchor River. | 196.7 | 80 | 9 | SS, RC | do | do | do | Do. |

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