The Alaska Earthquake
March 27, 1964

Effects on Transportation and Utilities

Eklutna Power Project

GEOLOGICAL SURVEY PROFESSIONAL PAPER 545-A

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

Effect of the Earthquake Of March 27, 1964, on The Eklutna Hydroelectric Project, Anchorage, Alaska

By MALCOLM H. LOGAN

With a Section on

TELEVISION EXAMINATION OF EARTHQUAKE
DAMAGE TO UNDERGROUND COMMUNICATION
AND ELECTRICAL SYSTEMS IN ANCHORAGE

By LYNN R. BURTON

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THE ALASKA EARTHQUAKE SERIES

The U.S. Geological Survey is publishing the results of its investigations of the Alaska earthquake of March 27, 1964, in a series of six professional papers. Professional Paper 545 describes the effects of the earthquake on transportation, communications, and utilities. Where needed to complete the record, reports by individuals from organizations other than the Geological Survey are included in the series. Thus, this description of the Eklutna Hydroelectric Project—a key part of south-central Alaska's power system—was requested from the U.S. Bureau of Reclamation; so, too, was the section on the use of television for investigating damaged underground utility lines. Additional chapters in Professional Paper 545 will describe the effects of the earthquake on The Alaska Railroad and on highways, airports, utilities, and communications.

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

CONTENTS

ILLUSTRATIONS

FIGURES

EFFECT OF THE EARTHQUAKE OF MARCH 27, 1964, ON THE EKLUTNA HYDROELECTRIC PROJECT, ANCHORAGE, ALASKA

By Malcolm H. Logan, U.S. Bureau of Reclamation

ABSTRACT

The March 27, 1964, Alaska earthquake and its associated aftershocks caused damage requiring several million dollars worth of repair to the Eklutna Hydroelectric Project, 34 miles northeast of Anchorage. Electric service from the Eklutna powerplant was interrupted during the early phase of the March 27 earthquake, but was restored (intermittently) until May 9, 1964, when the plant was closed for inspection and repair.

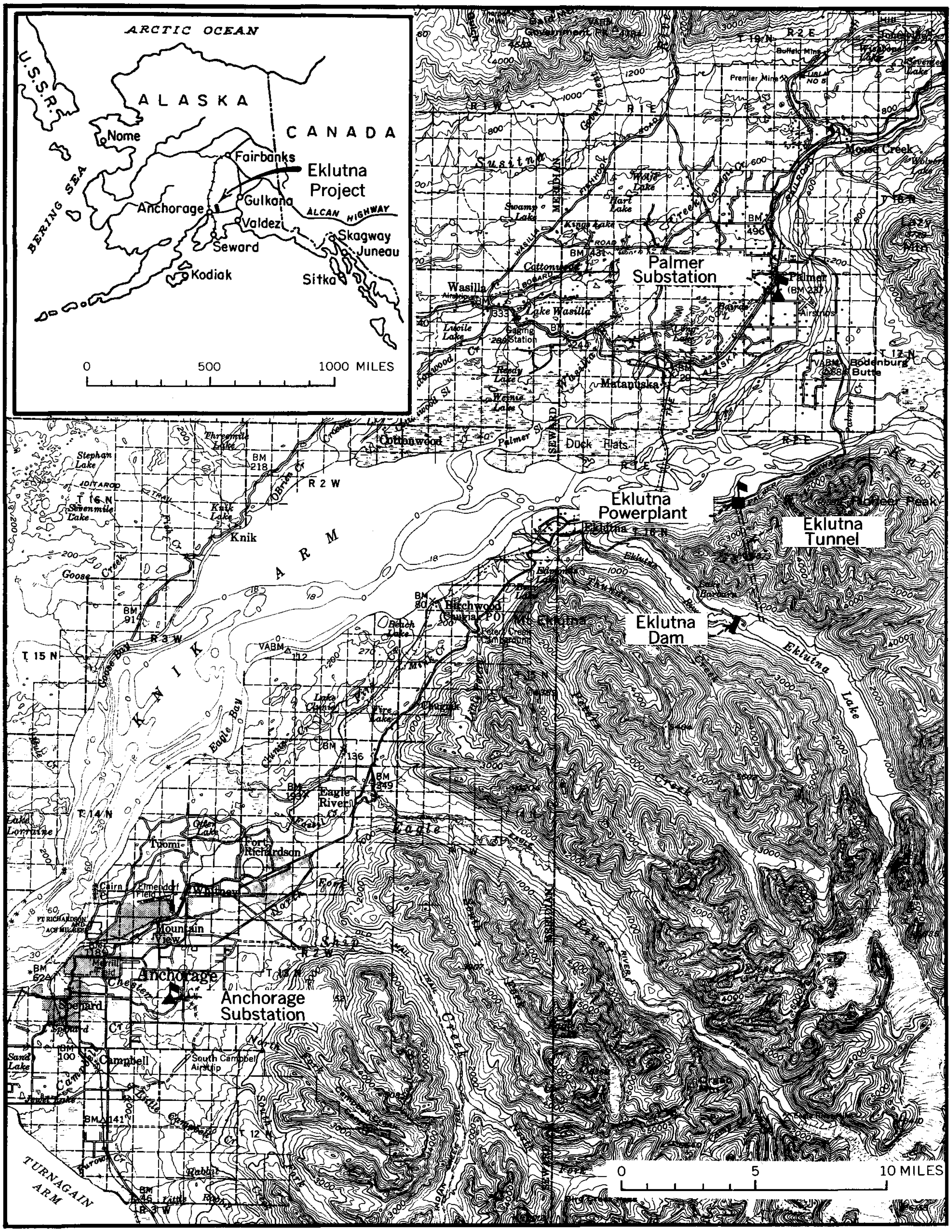
Water for Eklutna project is transported from Eklutna Lake to the powerplant at tidewater on Knik Arm of Cook Inlet by an underwater intake connected to a 4.46-mile tunnel penstock. The primary damage caused by the earthquake was at the intake structure in Eklutna Lake. No damage to the power tunnel was observed. The pile-supported powerplant and appurtenant structures, Anchorage and Palmer substations, and the transmission lines suffered minor damage. Most damage occurred to facilities constructed on unconsolidated sediments and overburden which densified and subsided during the earthquake. Structures built on bedrock experienced little or no damage.

Underground communication and electrical systems in Anchorage were examined with a small-diameter television camera to locate damaged areas requiring repair. Most of the damage was concentrated at or near valley slopes. Those parts of the systems within the major slide areas of the city were destroyed.

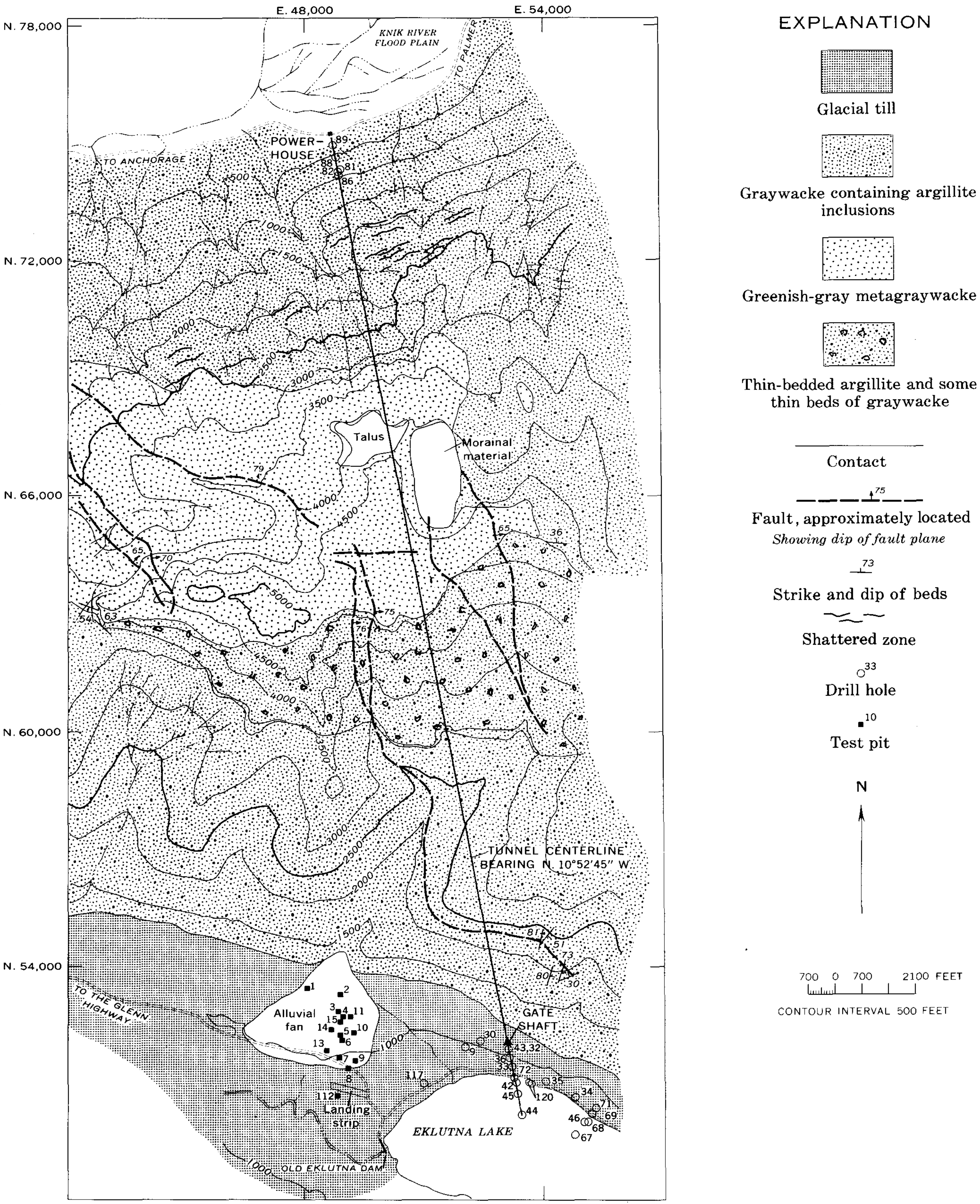
INTRODUCTION AND ACKNOWLEDGMENTS

The Eklutna Hydroelectric Project is a 30,000-kw (kilowatt) power development designed and constructed by the Bureau of Reclamation, U.S. Department of the Interior, to bring urgently needed electric power to the rapidly expanding metropolitan area at Anchorage, Alaska. The project was constructed during the 4-year period 1951–55. The powerplant (fig. 1) is located 34 miles northeast of Anchorage on the Glenn Highway and is supplied by water from Eklutna Lake, about 10 miles by road from the Glenn Highway. The lake is 7 miles long and is fed by melt water from Eklutna Glacier, 4 miles above the lake, and by precipitation runoff from a 119-square-mile watershed. Water is transported from the lake by an underwater intake connected to a 4.46-mile tunnel and tunnel penstock through Goat Mountain to the powerplant (figs. 1, 2, 3). The project is for power production only. Transmission lines, operating at 115 kv (kilovolts) and terminating at substation facilities, extend north to Palmer and south to Anchorage from the plant.

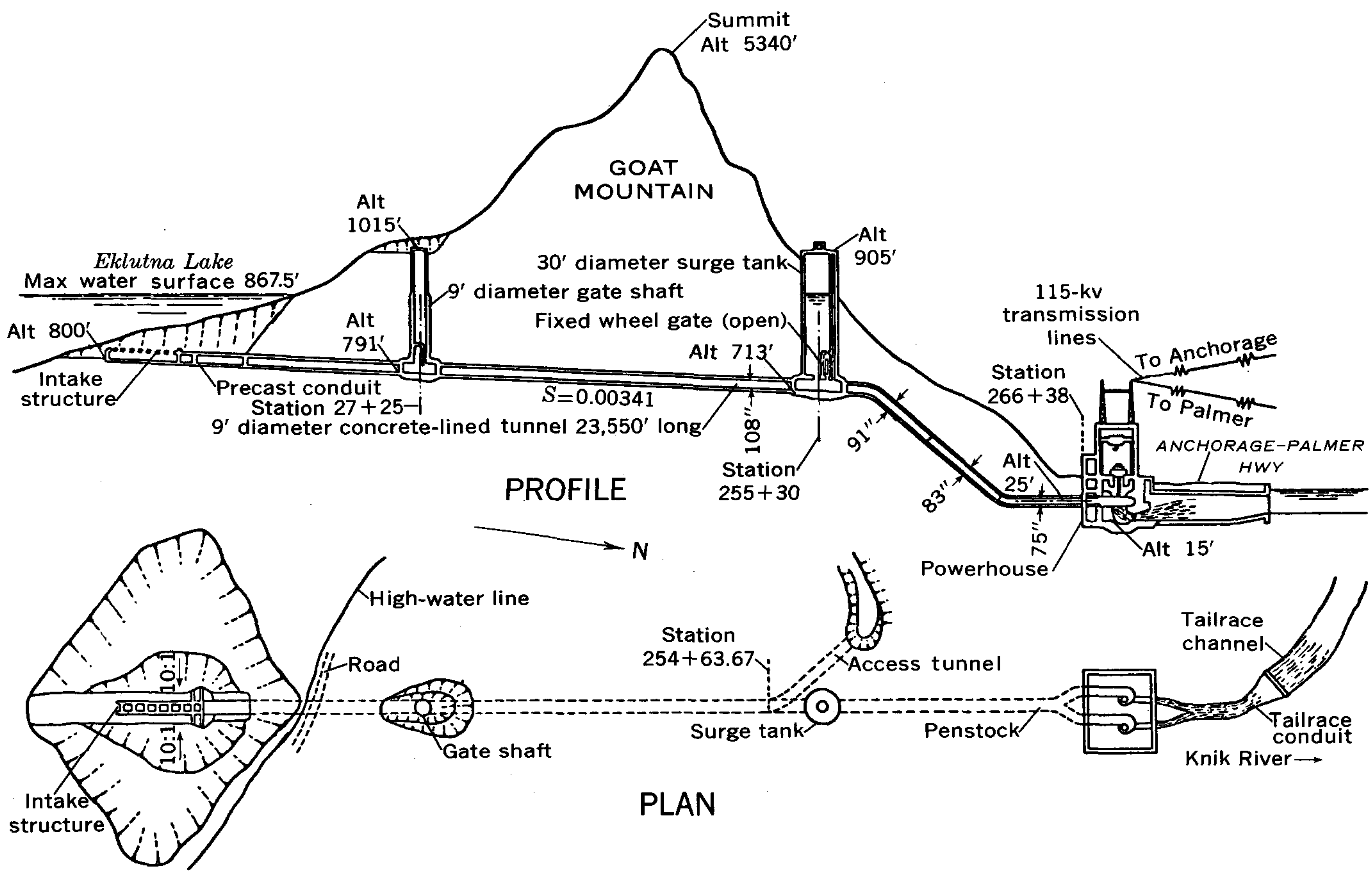
Although this report does not discuss earthquake-damage rehabilitation, the repair of facilities damaged by the great Alaska earthquake of March 1964 was difficult, hazardous, and costly. Transmission poles had to be set on steep icy mountain slopes; weakened precast-concrete conduits could be strengthened only by working under 40 feet of near-freezing water; and sand and gravel were mucked from 4.46 miles of 9-foot tunnel requiring access by means of a 220-foot vertical ladder.



1.—Index map of the Eklutna Hydroelectric Project.



2.—Topography and surface geology of the project area.



3.—Schematic plan and profile of the Eklutna project.

The decisions, actions, and improvisions of Alaskan personnel during the emergency and subsequent repair operation have since proven to have been in the best interest of communities in an area grown to depend on the continuity of flow of electric energy.

This report was prepared in the Engineering Geology Division of the Chief Engineer's Office, U.S. Bureau of Reclamation, Denver, Colo. Acknowledgment is made to G. N. Pierce, district manager, Juneau, Alaska, to W. Williams, project superintendent, Anchorage, Alaska, and to their staffs whose written contributions, photographs, and assistance during the investigation formed the basis of this work.

GEOLOGIC SETTING

Cook Inlet is an elongated intermontane structural basin that trends northeast-southwest between the Chigmit and Talkeetna Mountains on the north and the Kenai and Chugach Mountains on the south. Knik Arm, a northeasterly extension of Cook Inlet, occupies a lowland that is characterized by glacial and alluvial sediments, braided streams, marshy areas, and broad tidal flats.

Goat Mountain, a prominent local feature of the Chugach Range, rises abruptly from the southeastern flank of the Knik Arm lowlands and forms a divide between the Knik River and Eklutna River drainages.

The Knik and Eklutna Rivers are in old glacial valleys, and hence the overburden consists of glacial till containing material ranging in size from large boulders to clay. In places, glacial and more recent streams have reworked the till, so it is sorted and somewhat bedded. In some areas, nearly pure silt and clay are interstratified with coarser material. In the stream channels and flood plain of the Knik River, well-rounded gravel and clean sand predominate.

Very little well-rounded gravel occurs along Eklutna River—the stream which drains Eklutna Lake.

The present stream channel is narrow and the steep banks have been cut through a succession of sand, clay, silt, and "dirty" gravel beds. All this material is partly reworked glacial till. Where the velocity of the present stream is slow, rounded gravel is found but its extent is not great. Shingle gravel mantles the ground surface in the vicinity of the dam.

Several terrace remnants, representing old glacial lakeshores, are present at higher altitudes along the Eklutna River valley. Drill holes through the glacial till on this shore revealed varying depths to bedrock. In the floor of the valley, bedrock is estimated to be several hundred feet below the surface; elsewhere it is closer to the surface.

The mountain through which the tunnel is driven is composed of a series of graywacke, argillite, and slate, all metamorphosed to varying degrees (fig. 2). The rocks in the graywacke-slate-argillite series on the north slope have been extremely metamorphosed and crushed; bedding planes are indistinct, and the rocks are highly weathered along the intricate fractures and are jointed, in several places the rocks are serpentinized and slickensided. On the south slope the rocks are poorly exposed. The bedding planes are recognizable but vary in attitude within short distances. The higher peaks are composed of dark-greenish-gray graywacke.

The most obvious factor contributing to the destruction of the Eklutna project facilities was the densification of unconsolidated sediments and overburden. Myriad cracks, ranging from a fraction of an inch to several feet in width, were formed in areas underlain by the unconsolidated sediments. Near bedrock outcrops, a linear pattern of cracks formed which, in general, paralleled the bedrock configuration. As distance from bedrock and depth of overburden increased, the linear pattern graded into a blocky pattern having the general appearance of magnified mud cracks. All cracking observed on the Eklutna project was caused by tensional failure resulting from densification of saturated alluvial sediments. No failures were observed where structures were built on bedrock.

THE FIRST 24 HOURS

When the earthquake occurred, at 5:36 p.m. (Alaska standard time) on March 27, 1964, the powerplant was operating at near maximum capacity (31,000 kw), and the power system was interconnected through the Anchorage, Reed, and Palmer substations. Major damage was sustained by two 115-kv air circuit breakers and bushing-type circuit transformers serving the Anchorage and Palmer lines, but there was no visible indication of damage to either generating unit. The two 20,000-kva (kilovolt-ampere) power transformers had shifted on their rails and had subsided several inches, as had the Camp line transformer. All bushings and connecting busses were intact, although under abnormal mechanical strain. The generator, which had been stopped for examination, was started and station service was restored at 5:55 p.m.

A wood-pole transmission line structure on the 115-kv Palmer line had been carried away by snow slides. Two adjacent spans of transmission line, totalling 7,500 feet, were destroyed.

Radio communication was temporarily interrupted between the Anchorage substation and the powerplant. Damage at the Anchorage substation consisted of fractured porcelain on all three 115-kv lightning arresters. All transformers shifted on their bases, but, although the 115-kv bus work was distorted and severe strain placed on several bushings, there were no failures. Indicating and alarm circuits had conduit damage, but all circuits remained operable. A temporary bypass was installed, and the Anchorage line was energized through a bus tie switch at 10:10 p.m. The 115-kv Palmer line, which had been damaged by the slide, was isolated at the powerplant. Service was first restored to the Matanuska Electric Association at Reed substation at 10:43 p.m., March 27, after completion of system repairs. Service was restored to the Palmer substation about 10:00 a.m. on March 28 after completion of system repairs.

At 12:12 a.m., March 28, both generating units at Eklutna went off the line when the normal penstock pressure dropped appreciably. At 12:40 a.m., penstock pressure restored itself and Unit 2 was put back on the line. An examination of the intake area showed that the headgate was still in full open position but was accepting only a very small flow of water. There was no apparent damage although shattered and upturned ice on the lake indicated that there had been considerable disturbance in the lakebed and shoreline. At approximately 1:30 a.m., low penstock pressure again caused a complete plant outage. At 3:55 a.m., pressure began to return to normal, so one unit was again started and station service and the camp load was picked up. At about 8:00 a.m., the penstock pressure started dropping again, then suddenly surged to above normal before leveling off. A considerable amount of debris was noted in the tailrace. The Anchorage line was again energized and an aerial patrol of all lines and the lake was made.

At 2:40 p.m., March 28, a shear pin was lost on the Unit 1 wicket-gate drive, and thus began the first of a long series of shutdowns to remove rock and other debris from the gates and scrollcases.

During this period, other utilities in the area were also having problems. In the city of Anchorage, two 15,000-kv gas turbines were inoperable because of broken gas mains and ruptured oil tanks. The Chugach Electric Association Knik Arm steamplant lost coal- and ash-handling facilities, and areal subsidence disrupted cooling-water facilities. Structural damage also occurred to the powerplant building and boilers. The Chugach Electric Association Cooper Lake plant was isolated by extensive damage to its 115-kv transmission line, and widespread damage in the Anchorage area produced many distribution-system faults which had to be located, then either repaired or isolated. The power-generating facilities at Elmendorf Air Force Base and Fort Richardson were partly crippled by the loss of cooling-water facilities.

EFFECTS ON INDIVIDUAL FEATURES OF THE EKLUTNA PROJECT

EKLUTNA DAM

The dam is an enlargement of a natural dam formed by a receding alpine glacier. As indicated in figure 4, the site was thoroughly explored by means of drill holes, test pits, and geologic mapping. The reservoir, which is an enlargement of Eklutna Lake, is about 10 miles southeast of the powerplant. The lake has a surface area of 3,247 acres, a length of 7 miles, and a capacity of 182,000 acre-feet at maximum water surface altitude of 867.5 feet.

Construction of Eklutna Dam was completed by private interests in 1929. In 1943 it was purchased by the city of Anchorage from which the Federal Government purchased it at the time the Bureau's Eklutna project was built. The dam was raised to a crest altitude of 875 feet above sea level. The upstream and downstream slopes of the dam and other areas have been covered with riprap. On the upstream slope of the dam, the riprap is underlain by a sand and gravel blanket 12 inches thick. The dam has a height of 26 feet above the foundation, a length of 555 feet, and a volume of 5,000 cubic yards.

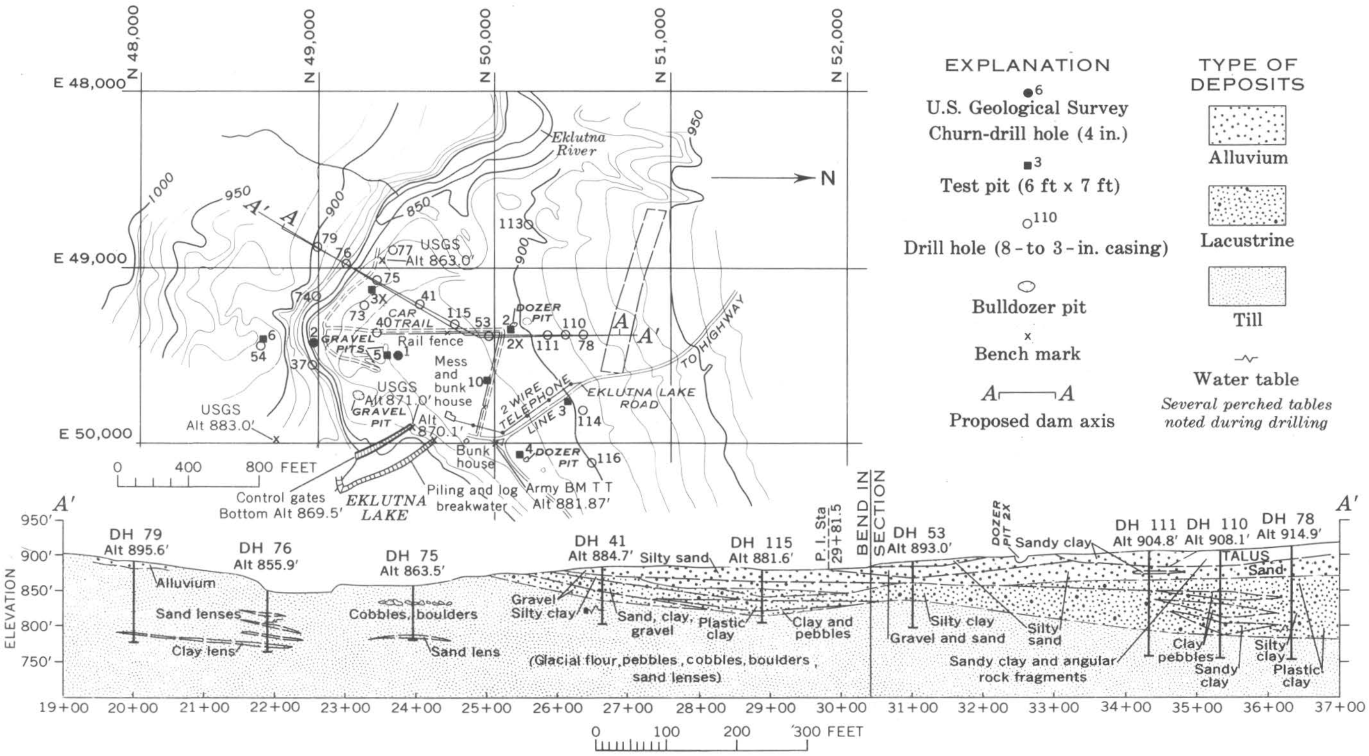
An uncontrolled overflow spillway having a crest altitude of 867.5 feet and a length of 150 feet is located on the right abutment. Lake level at the time of the earthquake was approximately 20 feet below the spillway gate sill.

Early inspections of the dam after the earthquake revealed no apparent damage. Immediately after the quake, no cracks or other evidence of quake-induced movement were found in the vicinity of the dam and spillway. The frozen ground near the surface probably moved as a mass during the quake. Later observations, however, showed that the alluvium beneath the frozen layer had densified and created a void. As thawing progressed, therefore, the upper layers of alluvium under the spillway gate structure (fig. 5) began to subside into the underlying void. This movement did not take place to any noticeable extent until early in July 1964. At this time, two cracks approximately 1 inch wide formed—one in the base of the spillway slab and one in the sill of the gate structure. In addition, a large part of the spillway base slab had been deprived of foundation support by the densification that caused the void. The gate structure was then declared unsafe for impounding water. All gates were locked open, pending reconstruction of the dam.

INTAKE STRUCTURE

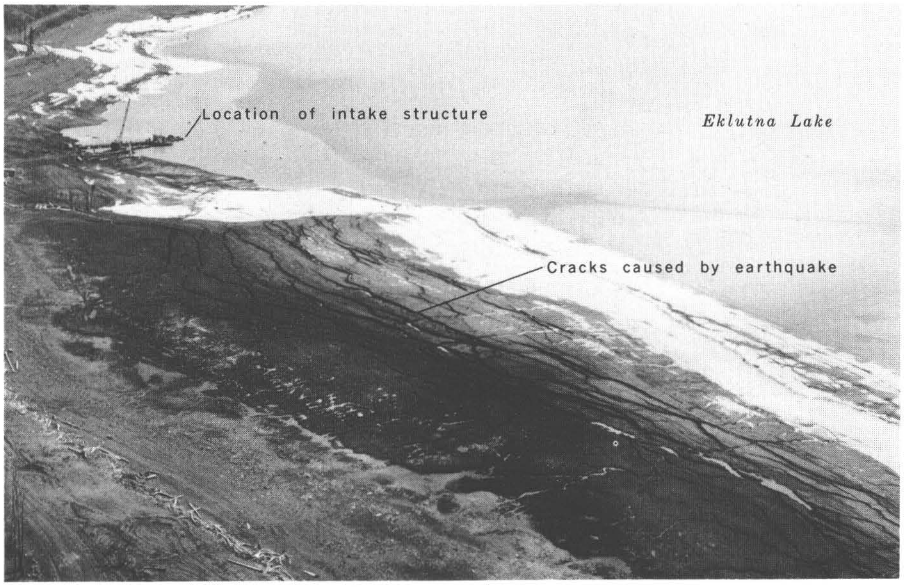
Diversion from Eklutna Lake is made through an inlet channel, 100 feet wide and about 500 feet long, excavated in the lake bottom about 60 feet below lake-surface altitude (fig. 3). The intake structure extends from this inlet channel for 133 feet 8 inches.

The intake structure has an initial trashrack, 112 feet long, built



4.—Map and Section of damsite area showing exploratory work.

5.—Spillway gate structure.



6.—View of Eklutna intake area, showing intricate network of cracks caused by the earthquake along the shore of the lake.

of rectangular precast-concrete sections. Each section is 26 feet 8 inches wide and 37 feet long. Immediately downstream from the trashrack structure is a precast-concrete transition section, 14 feet 2 inches long. The inside of this transition section tapers from a rectangular reinforced-concrete section 9 feet by 22 feet 8 inches to a circular section 9 feet in diameter. At the end of the square-to-round transition section is a bulkhead section 7 feet 6 inches long. Slots are provided in the bulkhead section for either stop planks or a fabricated bulkhead to be used in the event of an emergency or for inspection purposes.

From the end of the bulkhead section the water is conveyed to the entrance of Eklutna tunnel through a 9-foot (inside-diameter) precast-concrete pipe 225 feet long. The wall of the pipe is 12 inches thick. The pipe was cast in 16-foot sections, each section weighing about 40 tons.

Numerous holes were drilled in the general area of the tunnel intake to select the best location for the structure and to obtain samples of the glacial flour and till on the lake bottom for stability studies.

Two types of glacial materials, designated A and B, were found in the intake structure area. These materials were classified primarily by their compaction and related construction characteristics rather than by composition:

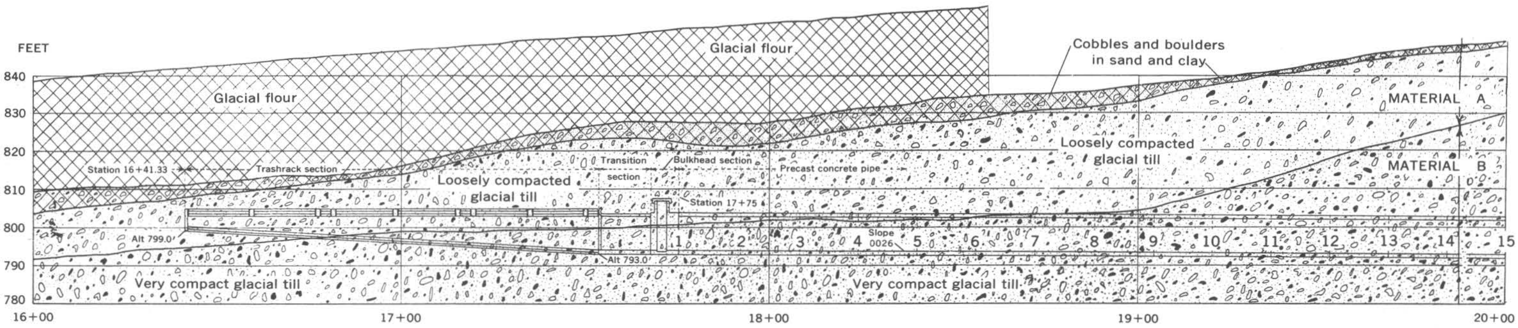
Material A.—Owing to the instability of the material, the glacial flour was excavated on a 20 to 1 slope, and the lower part of material A was excavated on a 10 to 1 slope. A thin layer of sandy clay containing many boulders as much as 3 feet in diameter underlies the glacial flour and overlies a loosely compacted glacial till.

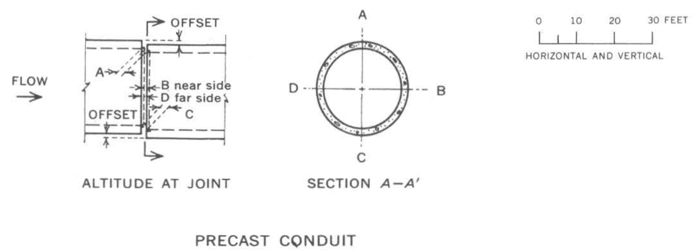
Material B.—From the top of the B glacial-till contact to the bottom of the inlet channel, the material had to be blasted prior to dredging. Its clay content and impermeability caused the material to be very compact in place and even to settle back as a compact mass on the lake bottom after blasting.

The trashrack, transition, bulkhead, and conduit sections back of station 19+06 in the bottom of Eklutna Lake sustained the major damage from the earthquake. (Station numbers start at the intake and increase in the direction of water flow.)

Earthquake-induced densification of materials in Eklutna Lake (fig. 6) caused the intake structure to move approximately 44 inches toward the lake. Principal movement was in a horizontal direction, but was accompanied by a lesser amount of vertical displacement.

Tensional forces produced by the horizontal shift caused separation along joints in the precast conduit, as shown in figure 7. Unconsolidated sediments, ranging in size from fine sand to cobbles the size of a football, funneled through these ruptures. An elliptical cone-shaped depression, approximately 40 feet in maximum dimension, formed at the edge of Eklutna Lake over the conduit alinement near station 18+55, and numerous cracks were present along the lakeshore on either side of the conduit.





JOINT SEPARATIONS, IN INCHES					OFFSET, IN INCHES
Joint	A	B	C	D	
1	1⅞	1¼	⅜	1⅛	0
2	1	½	⅝	⅞	0
3	1¼	1	1⅜	1½	0
4	1¼	1½	1¾	1½	0
5	2½	1⅞	⅜	1⅝	0
6	10	10		10	4
7	6½	6¾		8	4½
8	3¾	3		3¾	0

JOINT SEPARATIONS, IN INCHES					OFFSET, IN INCHES
Joint	A	B	C	D	
9	1¾	2		1¾	0
10	3½	3¼	2	2½	0
11	3	3½		3¾	0
12	1½	1¾	2	1½	0
13	2¾	2½	1½	1½	0
14	¾	1¼		1¼	1
15	2¾	2⅛		1½	0

7.—Geologic section showing location of earthquake damage to intake structure. Rupturing of joints in the precast conduit occurred at the numbered locations. Amount and direction of movement is shown in the table. Failure on or within the bedding material, induced by the earthquake, is believed to have caused the damage to the intake structure. No earthquake damage in the glacial till foundation was detected.

TUNNEL AND GATE SHAFT

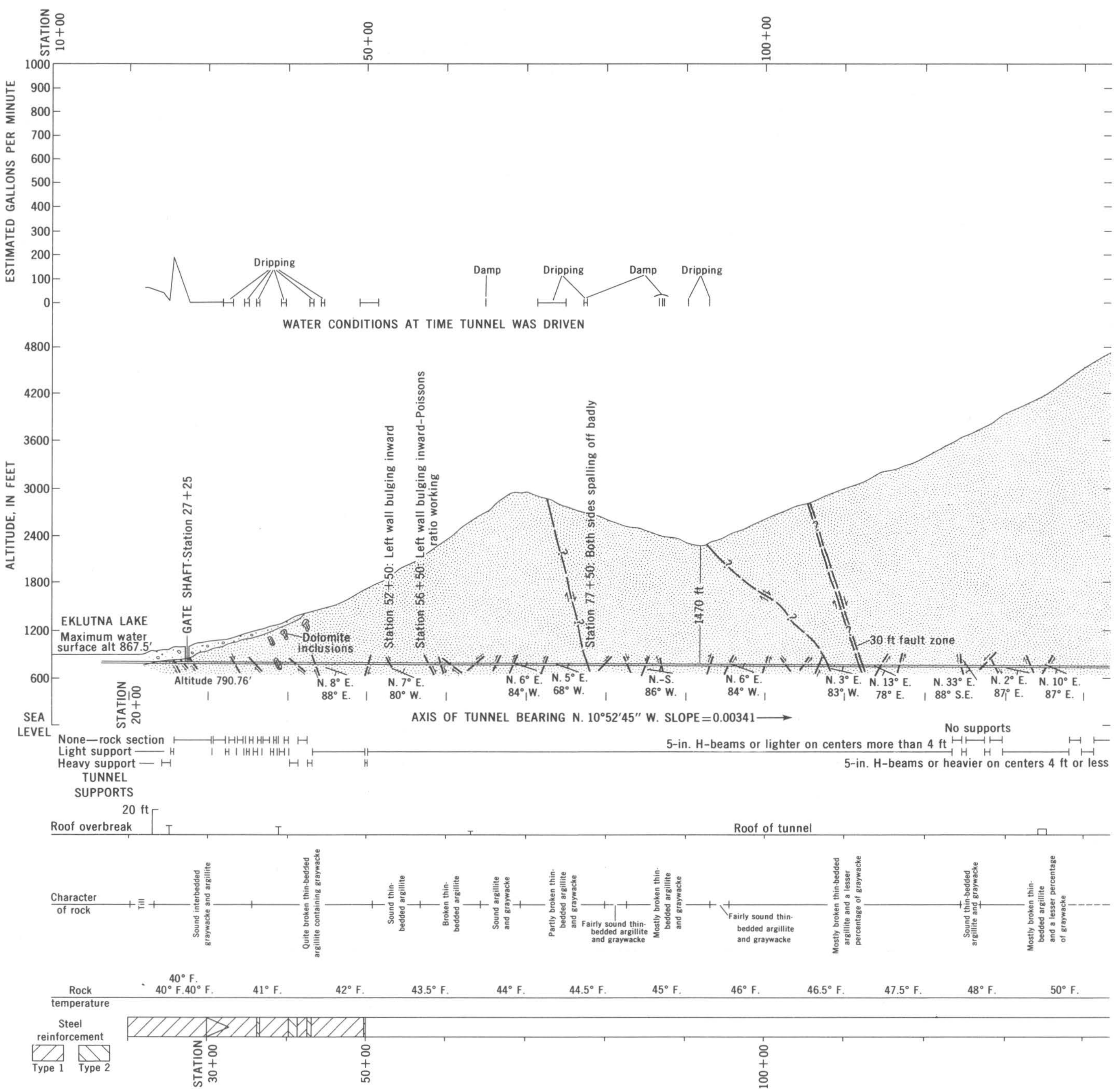
A circular concrete-lined pressure tunnel, 9 feet in inside diameter and 23,550 feet long (4.46 miles), conveys water from the intake structure to the penstocks leading to the powerplant. The capacity of the tunnel is 640 second-feet at a velocity of 10.06 feet per second. The slope of the invert is 0.00341. A 9-foot-diameter gate shaft, between invert altitude 790.76 and 1,012 feet, is located at station 27+25 so that the tunnel may be dewatered.

The tunnel terminates at a surge tank installed directly over the tunnel 22,805 feet downstream from the bulkhead gate shaft. The surge tank, of the restricted-orifice type, has an inside diameter of 30 feet and a concrete-wall thickness of 18 inches, it extends 176 feet vertically above the tunnel. A 4½-foot rectangular separation serves as a slot for the fixed wheel gate that is used both for emergency closure of the tunnel in case the penstocks below or the turbine in the powerplant are damaged and for dewatering the penstock for inspection and maintenance.

A tunnel adit is located at the outlet end of the tunnel near the surge tank. The adit, which is virtually the same diameter as the main tunnel and is approximately 300 feet long, provides one means of access to the tunnel for inspection and maintenance. It also acts as a free-flow conduit for draining the tunnel when entrance into the tunnel is necessary. The access door from the adit to the tunnel is watertight.

From station 20+00 to station 25+32 (fig. 8) the material consists of B-type glacial till. The sand layers contain some ground water, which has a maximum total flow of approximately 300 gallons per minute. From station 25+32 to station 198+00 the rock is mostly interbedded argillite and graywacke. The bedding planes are closely spaced and are recognizable but erratic. Much of the rock is intensely fractured, and innumerable minor fault planes and slippage planes cut through the rock at various angles to the tunnel axis. From station 198+00 to station 234+75 the rock is a metamorphosed greenish-gray graywacke. From station 234+75 downstream, the rock is uniformly fractured graywacke containing irregular inclusions of argillite. During construction, ground water flowed from most of the open joints. Water also flowed through many fault-gouge seams, which range in thickness from a fraction of an inch to several feet and dissect the rock at varying angles.

Approximately 2,000 cubic yards of material was deposited along the



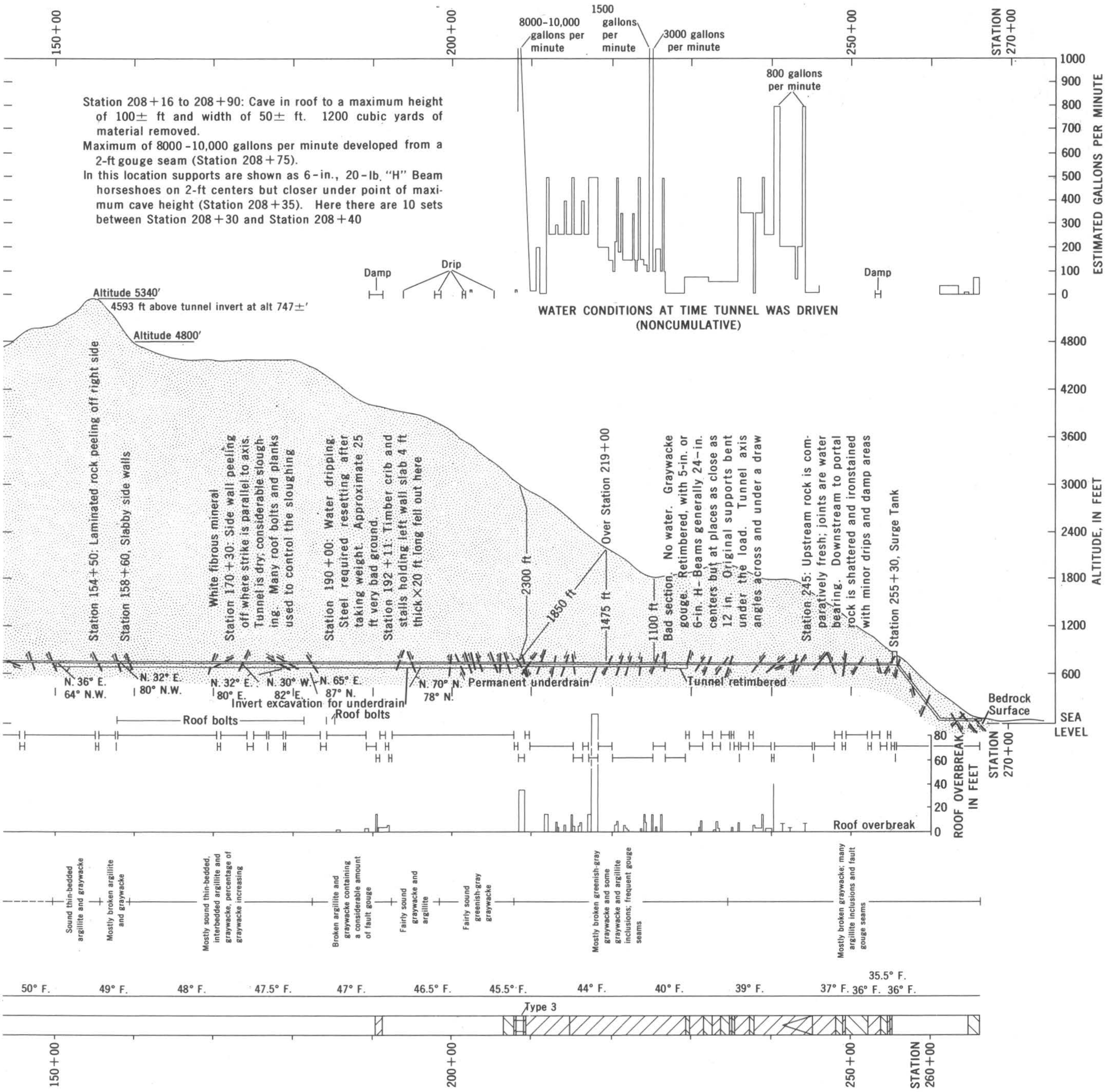
EXPLANATION

Glacial till

Steeply dipping interbedded graywacke and argillite

Fault trace
Showing direction of movement

N. 8° E.
88° E.
Strike and dip of bedding planes (In plan view)

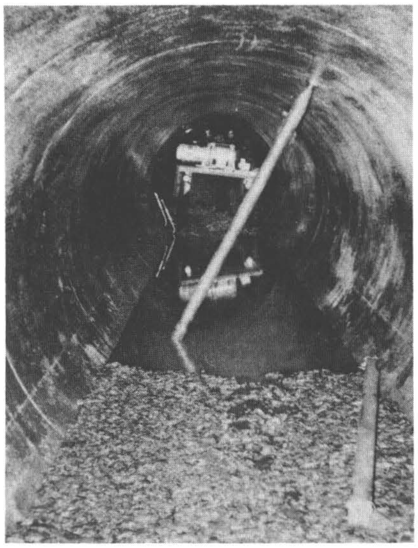


NOTE: Bedding symbols are averages of bedding planes in areas indicated. Bedding dip and strike symbols are averages in areas indicated and are plotted in plan view with tunnel line bearing N. 10°52′45″ W.

All geology on this summary sheet is from tunnel logs rather than projections from the surface

0 600 1200 1800 2400 FEET

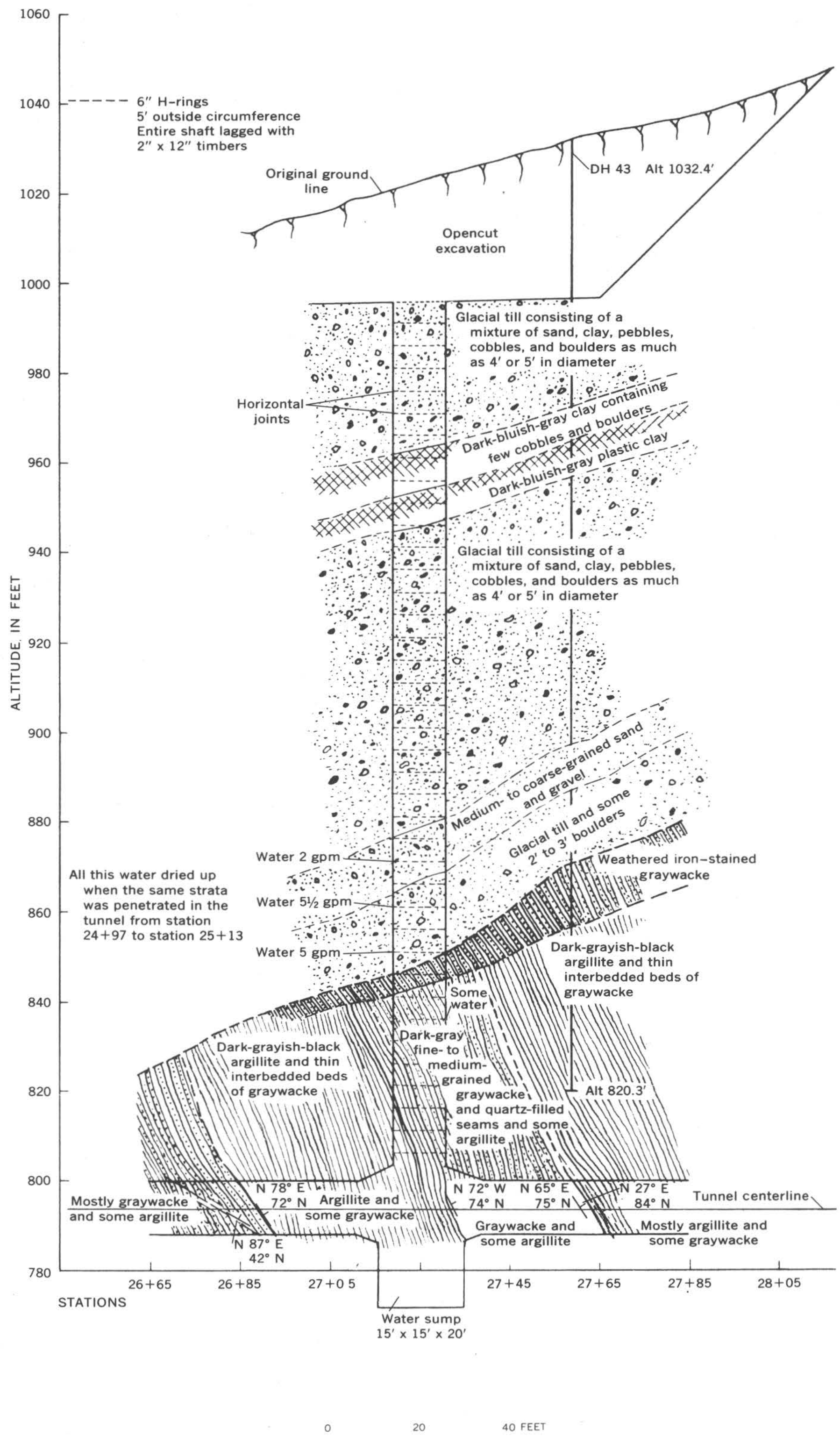
8 (above and left).—Geologic section along the line of the pressure tunnel.



9.—Debris in Eklutna tunnel, typical of that deposited throughout the initial 3½ miles of tunnel as a result of the earthquake.

tunnel invert. The debris consisted predominantly of rock fragments 1 inch in diameter, but ranged in size from sand to an occasional fragment 14 inches across. The debris (fig. 9) was 12–18 inches deep and was uniformly distributed from the gate shaft at station 27+25 to near Station 103+00. From station 103+00 to station 235+00, debris was deposited in gravel bars of varying depths. The last mile of tunnel was relatively free of material. No structural damage to the tunnel was found.

As part of the plan to design an earthquake-resistant structure, the gate shaft at station 27+25 was founded in competent rock (figs. 8, 10); it was reinforced to withstand internal bursting pressures. Horizontal joints in the shaft, indicated by dashed lines on figure 10, helped compensate for any possible vertical deflections during an earthquake. No damage to this structure was discernible.



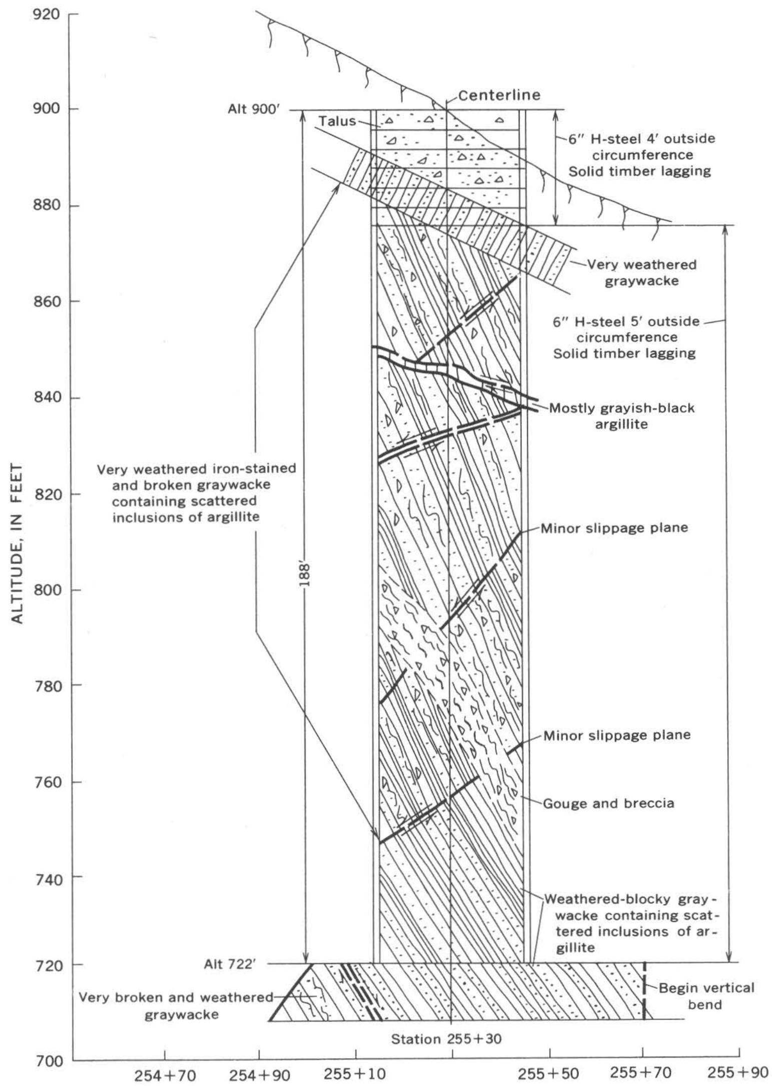
10.—Geologic section through gate shaft.

PENSTOCK, SURGE TANK, AND ANCHOR BLOCK

The power penstock conveys water from the surge tank at the end of the Eklutna tunnel to the powerplant turbines. The penstock is about 1,088 feet long, is installed in 30-foot sections, and is a variable-diameter (91-, 83-, and 75-inch outside diameter) welded and coupled steel pipe encased in concrete. Plate thickness of the penstock varies from 5/16 inch at the initial section to 1½ inches at the terminal section. In profile, the penstock roughly parallels the mountainside, descending for approximately 864 feet at an angle of 53°; it then levels off and continues through a horizontal section about 501 feet in length. At the powerplant the penstock bifurcates into two 51-inch-diameter 23-foot-long branches which are connected to the spiral cases of the turbines.

The penstock tunnel was excavated in weathered rock, except at the lower end where the tunnel section emerges into overburden material (figs. 11, 12). In order to traverse this overburden material, which lay between the rock-tunnel section and the pile-supported penstock anchor, a special tunnel section had to be designed and built. In effect, this reach of tunnel was designed as a length of conduit supported at one end by the tunnel rock and at the other end by a pile-supported bent.

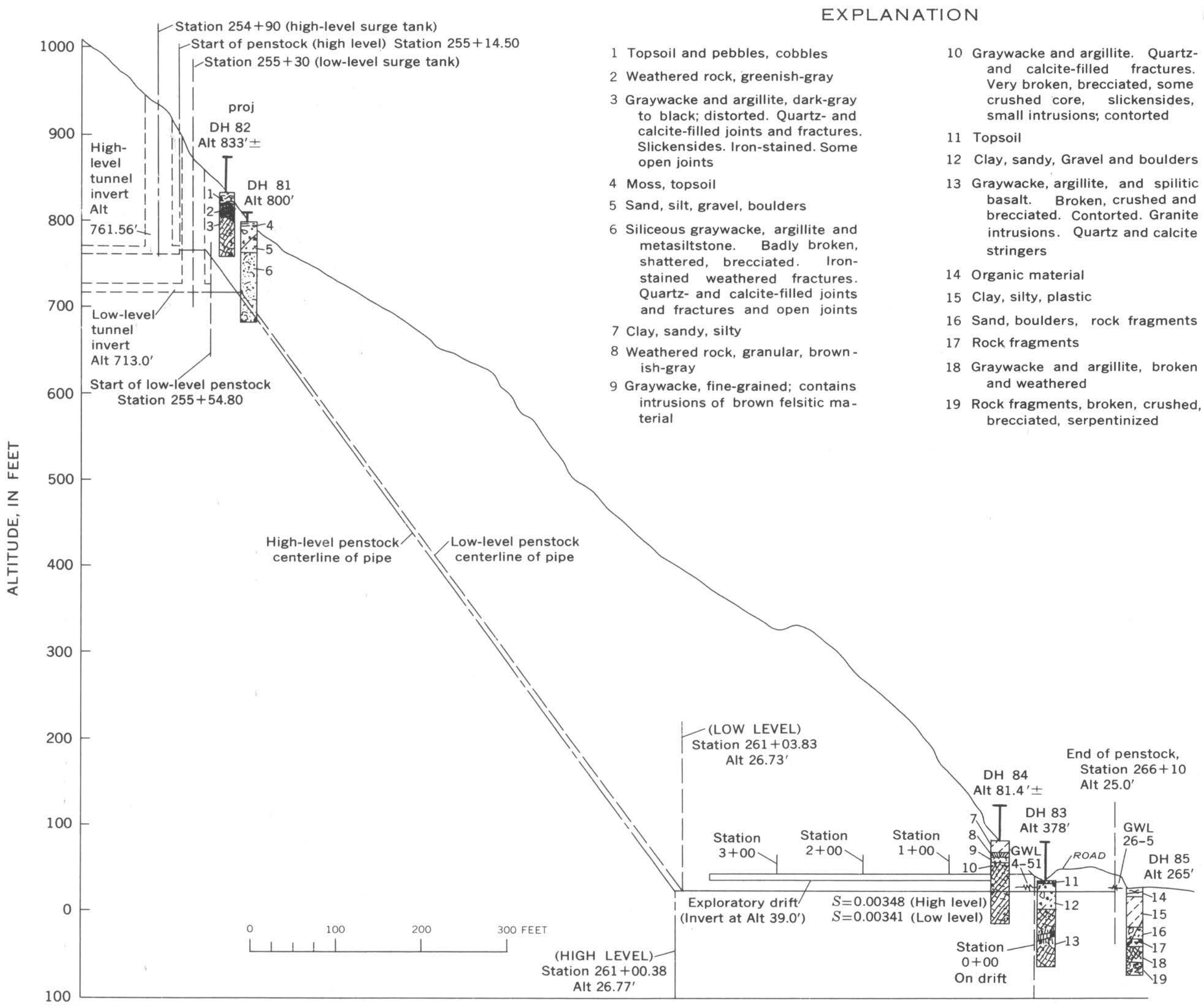
The penstock, surge tank, pile-supported anchor block, and powerhouse evidently oscillated as an integral unit during the earthquake. Very little relative movement occurred between these features although backfill in the anchor-block area subsided (fig. 13).



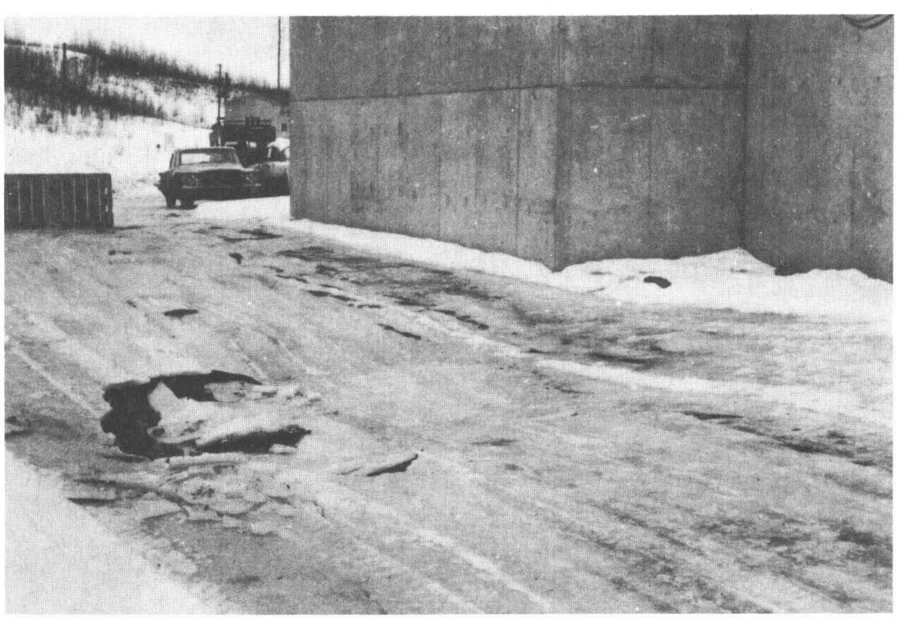
11.—Geologic section through surge tank.

A maximum residual separation of one-sixteenth to one-eighth inch was measured in the penstock ports of the powerhouse wall. The entire penstock from the tunnel to the units appeared to have sustained no permanent deformation. Fine line cracks in the overlapped painted surfaces at the coupled sleeve joints did, however, indicate unusual pipe vibration.

In order to examine the interior of the penstock, an unusual method of descending through this 6-foot-diameter pipe was devised. The penstock was filled with tunnel leakage water. After the penstock was filled, the leakage was diverted out through the adit-tunnel door and a two-man liferaft was floated down the penstock. The desired rate of descent of the raft was controlled by releasing the water from the penstock through the butterfly valves, wicket gates, and drain lines. Instructions to obtain the desired water discharge were relayed from the raft to the plant by radio and telephone.



12 (above).—Section through surge tank, penstock, and anchor-block area, showing drill-hole data.



13 (left).—Earth settlement over the penstock anchor block directly behind the powerhouse. This settlement did not appear until 2 weeks after the earthquake. Presumably, the bridging effect of the blacktop and ground frost concealed the settlement during this period.

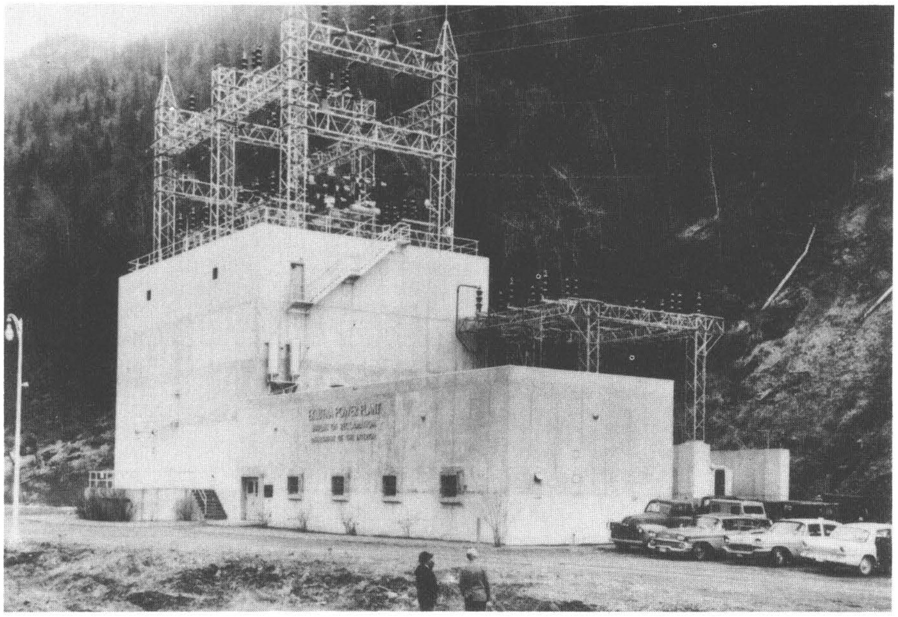
POWERPLANT AND ASSOCIATED STRUCTURES

The powerplant (fig. 14) is divided into four main structures: the powerhouse containing the generating units and accessories, the machine shop, the transformer structure, and the switchyard. Surrounding the powerplant is a yard area containing an automotive repair shop, warehouse, and office building.

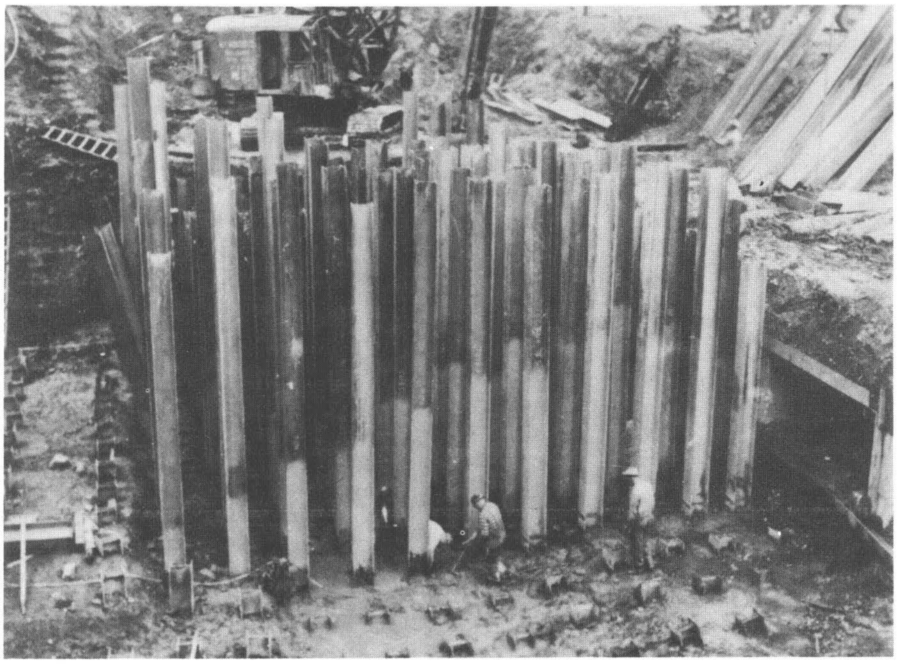
The powerhouse is a reinforced-concrete structure 71 feet long and 80 feet 8 inches wide. Because of the relatively unstable foundation conditions and the high earthquake potential, the design included pile foundations for the powerhouse, machine shop, transformer structure, and penstock anchor block. The foundation included 289 vertical and 110 battered 14-inch, 73-pound, H-section piles (fig. 15) and was designed to withstand an earthquake factor of 0.15 gravity and an acceleration of the foundation of 4.8 feet per second per second. An average pile penetration of 5.0 feet into bedrock was achieved. Foundation material between the piles consisted of in-place water-bearing river sand and gravel.

Adjacent to the west wall of the powerhouse is a pile-supported machine shop 78 feet long, 27 feet wide, and 20 feet high. The superstructure of the machine shop has structural-steel framing and reinforced-concrete walls 10 inches thick. The structure is pinned to piles through concrete pile caps.

The main power transformers that step up the generator low voltage are located in the pile-supported transformer structure adjacent to and southwest of the powerhouse at altitude 41.25 feet. Protective walls were placed on the south side of the structure to



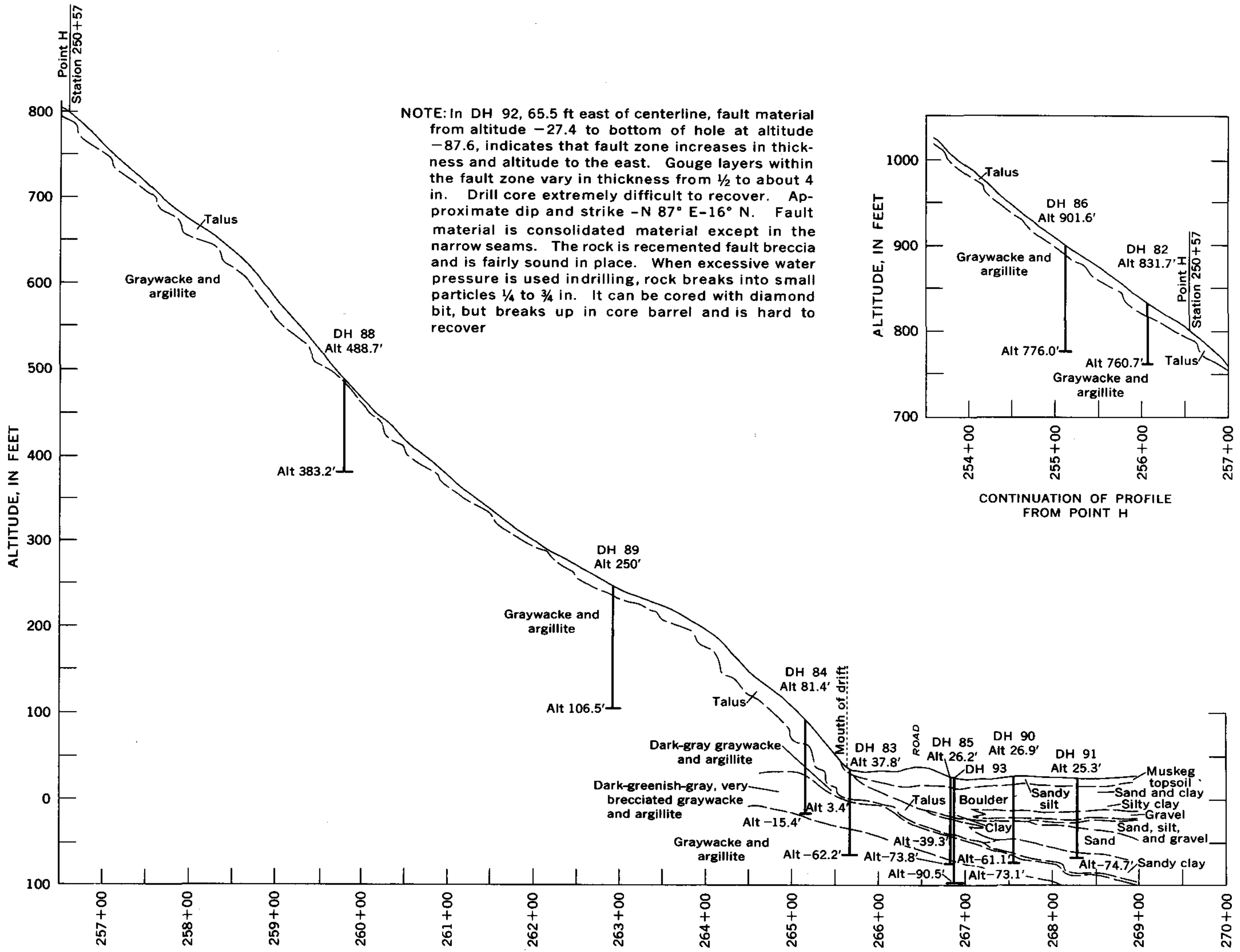
14.—Eklutna powerplant before the earthquake.



15.—Some of the piling in the powerplant foundation during construction. Piles in lower foreground and along left side have been cut off to grade prior to capping.

protect the transformers from snow and rock slides. Firewalls separate the transformers and serve as foundations for the takeoff structures that carry the powerlines to the switchyard on the powerhouse roof.

The switching equipment for the powerplant is located on three levels. The switchyard equipment itself—consisting of the power circuit breakers, disconnecting switches, and main busses—is on the roof of the powerplant at



16.—Generalized geologic section through surge tank, penstock, and powerhouse.

altitude 92.50. The main power transformers that step up the generator low voltage are located in the transformer bay at altitude 41.25. The high-voltage bushings of these main power transformers are connected to the main switching equipment located on the roof at altitude 92.50. The 115-kv bus structure on the powerplant roof consists of two bays to supply the 115-kv lines to the cities of Palmer and Anchorage.

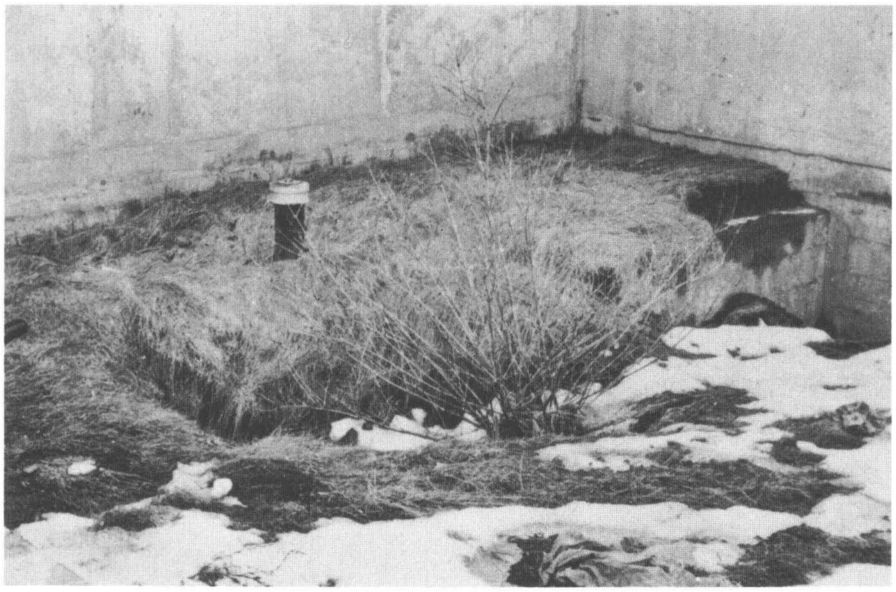
About 30 holes were drilled in the powerplant area during the exploratory and early construction stages. Nineteen of these were penetration resistance holes made to evaluate the bearing capacity of the overburden material under the powerhouse foundation. A generalized geologic section is shown in figure 16.

The upper 10–12 feet of the section consists of organic, slightly plastic silt containing occasional angular graywacke fragments. Below the silt a layer of talus 5–8 feet thick, containing angular graywacke boulders in dark-brownish-gray organic sandy clay, lensed out downstream from the powerhouse foundation. The base of the powerhouse and the tailrace conduit were excavated in water-bearing river sand and gravel, and the area had to be pumped during excavation. Some sloughing of the backslope in the northeast corner of the excavation occurred during the extreme high-water period of the Lake George breakup.

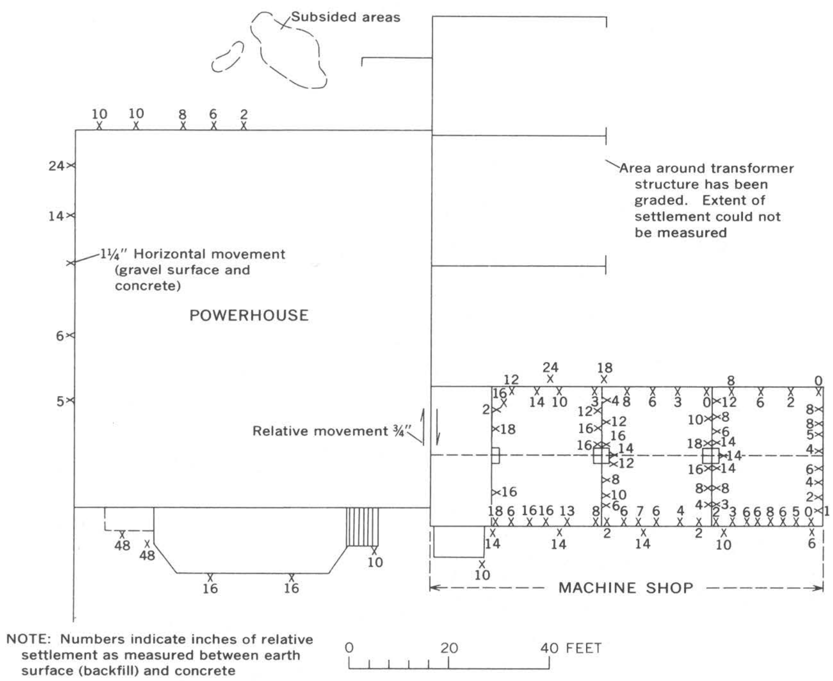
Interstratified discontinuous layers of stream gravel, sand, silt, and clay underlie the talus and overlie the weathered bedrock surface. A flood plain extends north and west from the powerplant site for several miles. The drainages from both the Knik and Matanuska Rivers spasmodically aggrade, degrade, and change their channels throughout the spring, summer, and fall seasons. These erratic sedimentation phases account for the interstratified sediments in the powerplant area. Talus from the adjacent hillside extends a short distance from the toe of the slope. The talus is generally overlain by slightly plastic organic silt recently deposited during the annual flood stage of the Lake George breakup. The water table beneath the powerplant fluctuates with the Knik River and has a mean depth of 28 feet.

The principal area of damage occurred between the powerhouse and machine shop along the 1-inch cork-filled expansion joint. The two structures oscillated at different intensities, and the interconnecting drainage and electrical systems were sheared. The differential horizontal displacement between buildings was three-fourths of an inch, but the vertical displacement was negligible. Backfill around the entire periphery of the plant and under the machine shop settled erratically from a few inches to a few feet (figs. 17–19).

The fill in which these failures occurred is composed of well-graded sand and gravel obtained from the Knik River. Most of the gravel particles were subrounded and were composed of a wide variety of unweathered igneous, metamorphic, and sedimentary rocks. The sand ranged in shape from rounded to angular, a noticeable percentage being elongated and flattened. The sand was composed predominantly of slate grains. Silt-size particles were present in small amounts, but tended to wash away during handling. The pit run material consisted of 35.1 percent sand and 64.9 percent gravel. A weighted average of size distribution in the gravel fraction of the backfill material is as follows:



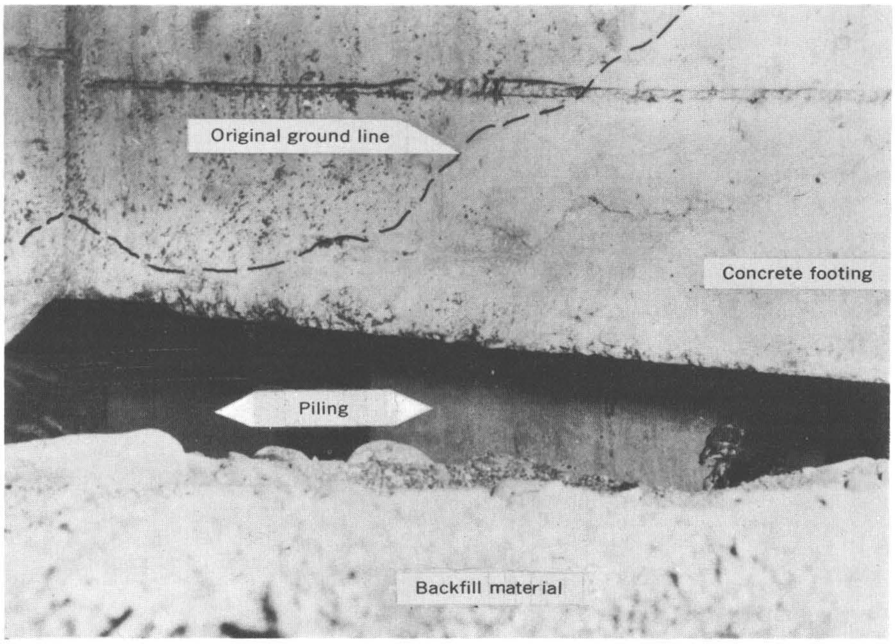
17.—Typical ground settlement resulting from the earthquake. Settlement is near the northeast corner of the powerhouse at the location of the septic tank.



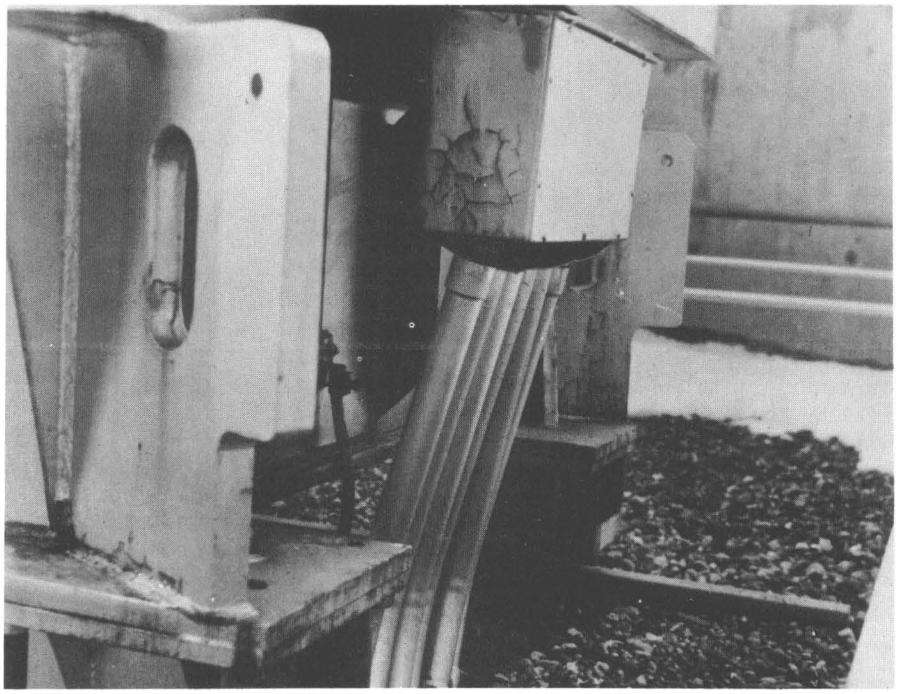
18.—Measurements of settlement and deflection at the powerplant.

Standard sieve size	*Percent retained*	*Percent cumulative*
6 in	0	0
3 in	2	2
1½ in	22	24
¾ in	36	60
⅜ in	27	87
No. 4	13	100

A dragline and two bulldozers were used for placing and spreading the backfill. The material was wetted for proper compaction and consolidated by equipment travel. Gasoline-powered immersion-type vibrators and mechanical tampers were used in areas inaccessible to the bulldozers.



19.—Machine-shop foundation showing the separation of backfill material from the concrete footing. Approximately 1.5 feet of H-section pile is now exposed as a result of settlement caused by the earthquake.



20.—The 20,000-kva transformer conduit and terminal box damaged by movement of the transformer during the earthquake. Rail stops consisted of a ¼- by 1-inch-wide bar tack-welded to the rail. The tack-welds broke and allowed the transformer to move on the rails.

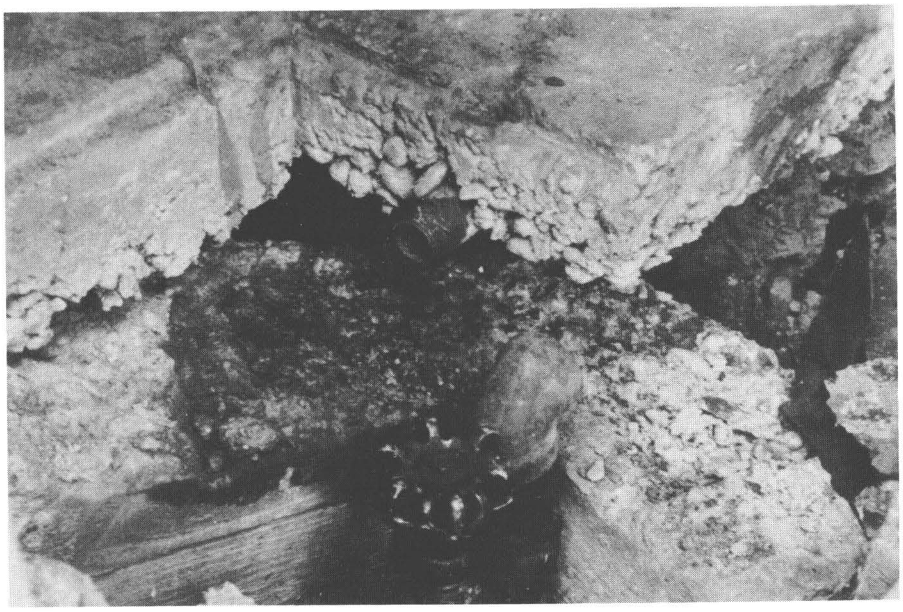
Postearthquake examination showed that the drainage system leading into the floor sump was plugged with a mixture of finely ground concrete and cork and the drainage line from the fanroom area was sheared. In addition, an aroma of fuel oil from several of the drains was quite prevalent. Ground water from the surrounding sediments and fuel oil from a ruptured, buried tank entered the drainage system through the sheared line.

Within the transformer structure, the two 20,000-kva transformers moved from 3 to 5 inches when tack-welded rail stops broke loose. Both transformers settled a few inches but not enough to overstress any of the bushings or bus connections. Although the bottom of the 120-volt terminal cabinet (fig. 20) on one of the transformers broke open and the attached conduits were pulled loose, the circuits remained operative. The 750-kva camp transformer settled nearly a foot, and the primary leads had to be lengthened to relieve the strain.

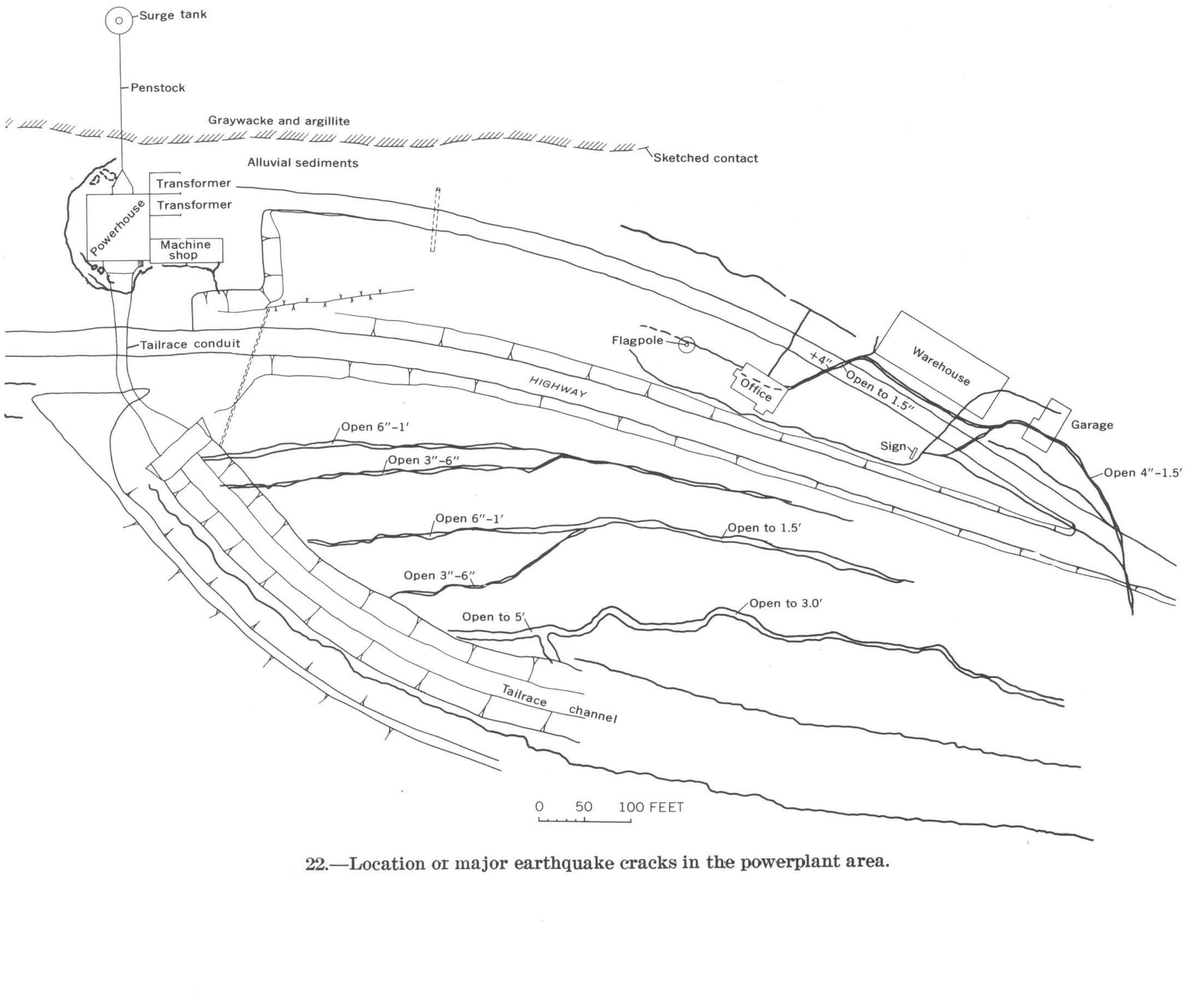
The 115-kv switchyard on the roof of the powerplant was extensively damaged. Two single-phase air circuit breakers were damaged. Each phase consists of an air receiver, two hollow porcelain insulator columns, porcelain extinction chambers, arcing contacts, and a bushing-type current transformer. The hollow insulator columns are mounted at the ends of the air receiver and carry compressed air to, and provide support for, the extinction chambers and arcing contacts. The free-standing hollow insulator columns broke at the base and thus caused complete collapse of the contact mechanism. Porcelain of the current transformer cracked and oil was lost.

The ground beneath the north end of the wood-frame structure housing the automotive repair shop settled about 1 foot and moved approximately 10 inches horizontally along a tensional crack that destroyed the floor and the radiant heating system in the floor slab (fig. 21). Lighting fixtures were torn loose from the wall.

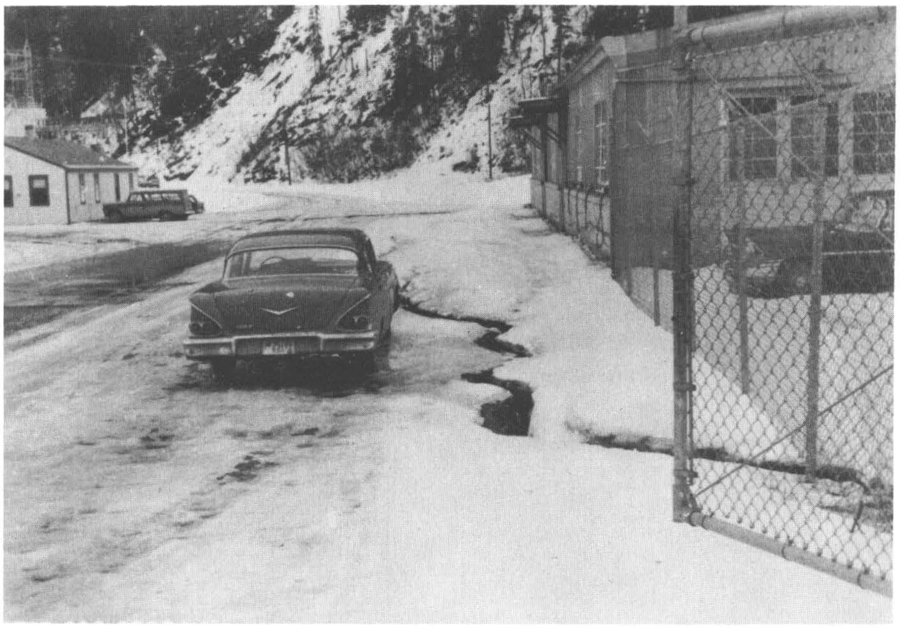
From a point west of the garage, cracks as much as a foot wide and several feet deep (figs. 22, 23) extended eastward adjacent to the north wall of the warehouse and crossed the roadway to the project office building. Cracks also extended from the garage to the southwest corner of the warehouse.



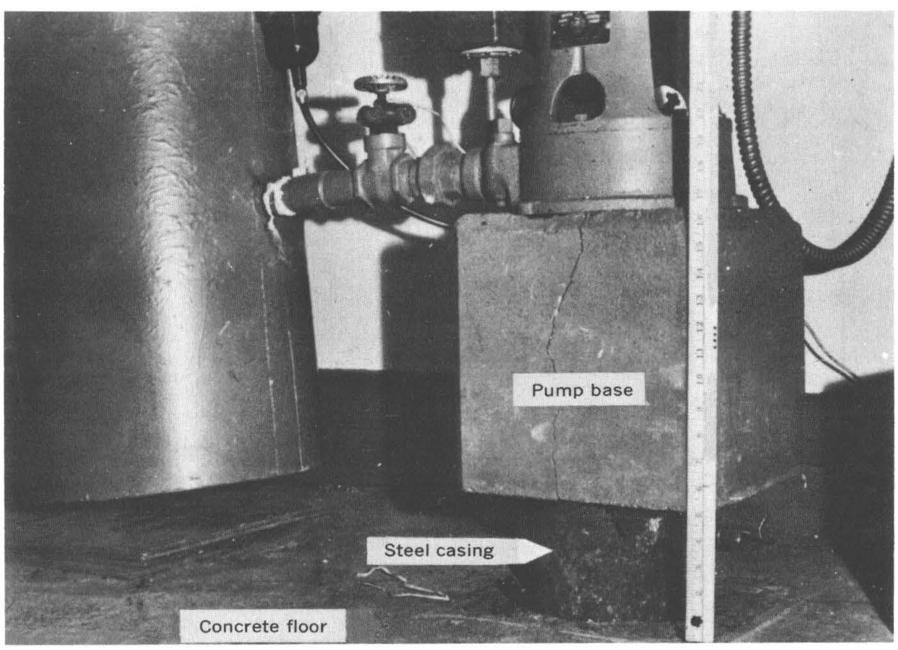
21.—Damage to the heating-system piping in the floor of the automotive repair shop caused by the earthquake.



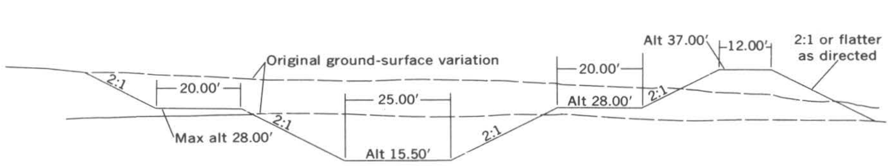
22.—Location of major earthquake cracks in the powerplant area.



23.—Pavement damage caused by the earthquake. Cracks extend from the garage east along the north wall of the warehouse (right of photograph) and thence across the road to the project office (left of photograph).



24.—Pump in Eklutna project office showing the effect of the earthquake. Base of pump is now approximately 5 inches above the floor.



25.—Typical section of tailrace channel.

A much larger crack occurred in State Highway 1 opposite the entrance to the project area. Backfilling the pavement cracks was a continuing operation for several weeks as adjustment—believed to have been caused by ground thaw along the cracks—continued to take place.

Damage to the camp housing was not extensive. Chimneys were damaged, and two heating-oil tanks tipped over.

The project office is a wood-frame structure with concrete floors. The concrete foundation and curb separated from the floor slab as much as 2 inches. The floor settled around the well casing, leaving the pump base approximately 5 inches above the floor (fig. 24). Miscellaneous damage consisted of overturned files and storage cabinets, cracked floors, damaged light fixtures, and broken joints in the chimney.

The north wall of the structural-steel warehouse separated from the floor slab from 1 to 3 inches. Storage bins were tipped, and spare insulators were damaged. Foundations supporting the main structural members settled approximately an inch along the north side and a slight cracking of the building resulted. The electrical service-drop attached to the roof pulled loose during the earthquake, and breaks in the asphalt roofing were caused by the flexing of the cold roofing paper.

TAILRACE

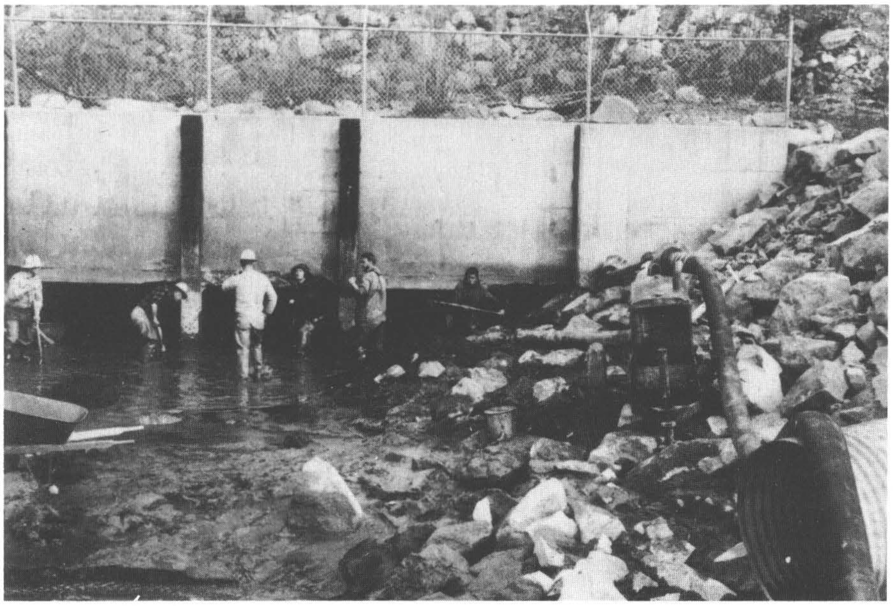
Water from the draft tubes of the turbines in the powerplant is discharged through a 209-foot-long pressure tailrace conduit under the Glenn Highway to an open tailrace channel leading to the Knik River.

The tailrace conduit is made up of rectangular reinforced-concrete transition sections of varying widths and depths. The terminal section of the conduit is 50 feet long and flares outward in the downstream direction from a width of 14 feet 6 inches to 46 feet 6 inches. This terminal section is also of varying depth and has five openings separated by 10-inch walls through which the water passes into the tailrace channel. Stoplog slots at the outlet of the conduit are used to dewater the conduit or to dewater both draft tubes at the same time.

The banks of the open tailrace channel (fig. 25) are built on a 2 to 1 slope and are lined with riprap at the junction with the tailrace conduit. The channel has a top width of about 75 feet, a bottom width of 25 feet, and a depth of about 12 feet 6 inches.

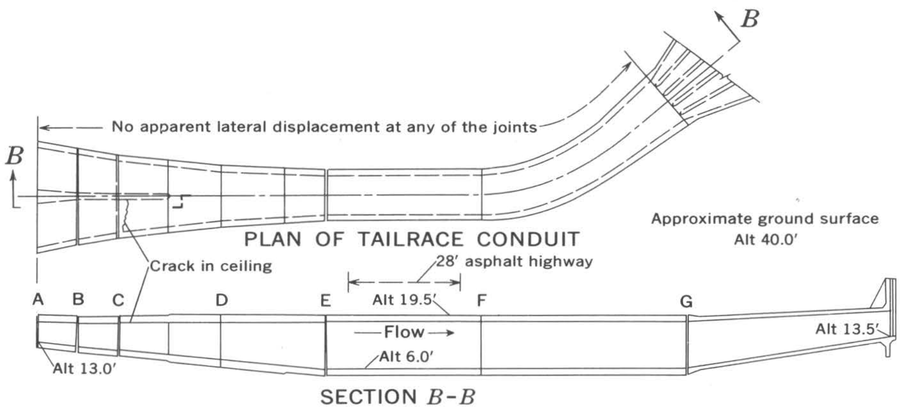
The upper 4–6 feet of material underlying the tailrace is silt and sandy silt, which in turn is underlain by a 2-foot layer of sand and fine gravel. Beneath the sand and fine gravel is sand and coarse gravel. During construction of the tailrace, some sloughing occurred in the sand and gravel layers during extreme high tides and when water was added to the channel by operation of the powerplant. Also, during the period of extremely high water at the time of the Lake George breakup, there was some sloughing of the banks.

When the powerplant was shut down for repair of the intake (fig. 26), the 209-foot-long pressure tailrace conduit was inspected and cleaned. About 110 cubic yards of rock and mud had been deposited in the conduit, presumably after the break in the precast pipe section of the tunnel intake. The inspection also revealed considerable shifting of the sections nearest the powerplant (fig. 27). Regional subsidence raised the high-tide water level approximately 3 feet.



26.—Cleaning-up operation at the outlet of the tailrace conduit. Debris was deposited following the rupture of the tunnel intake at Eklutna Lake during the earthquake.

	TAILRACE CONDUIT
Joint	Remarks
A	Joint open 2¼ in. on top, open ¾ in. on bottom Waterstop torn for about 1 ft, gravel visible above tear
B	Joint open ¾ in. on top, open 1½ in. on bottom with 3 in. vertical offset, downstream side lower. Larger leak on left side of left unit near floor
C	Joint closed on top, open 1½ in. on bottom with 1¼ in. vertical offset, upstream side lower
Between C and D	Crack in ceiling, right unit
D	Joint closed
E	Joint open evenly 1¼ in. all around with 2½ in. vertical offset, upstream side lower
F	Joint closed
G	Joint open 1 in. all around with ¾ in. vertical offset, upstream side lower. Leaking at top



27.—Summary of damage to tailrace conduit.

28.—Location of ground cracks in the vicinity of the powerplant.

The ground surface was severely cracked (fig. 28) in the area adjacent to, and parallel with, the 2,000-foot-long open canal section of the tailrace. The cracks ranged in width from a few inches to 5 feet and had the effect of squeezing in the sides of the channel. The invert was irregularly mantled by gravelly debris ranging in depth from a few inches to several feet.

TRANSMISSION LINES

The 115-kv Anchorage line was not damaged, but the earthquake triggered a snow and ice slide near the Knik River bridge that swept away a three-pole guyed structure, 7,500 feet of conductor cable, and an access road on the Palmer line.

The transmission lines were repaired on April 8, 1964, and service was restored on April 16, 1964, after the air circuit breaker was repaired at the Eklutna switchyard. While the Palmer line was out of service, power was delivered to the Palmer substation from the Reed substation over the Matanuska Electric Association's 34.5-kv line and the 12.47-kv Palmer area distribution system. In order to carry the Palmer load through the limited capacity of the Reed substation, auxiliary cooling had to be provided by truck-mounted fans.

SUBSTATIONS

The Anchorage substation is situated on a terrace of glacial till overlain by less than 1 foot of soil. Beneath this overburden and beyond a depth of 8 feet, or below foundation grade, the material consists of a fairly uniform clayey sand and gravel. The water table is 25 feet below ground surface.

Lightning arresters on each of the single-phase power transformers at the substation were damaged. The arresters broke at their bases and dangled from the line. All three "stacks" of each arrester were broken. One lightning arrester on the Chugach Electric Association 16-mva (millivolt-ampere) transformer was also damaged. All three transformers at the Anchorage substation shifted on their bases. Primary bushings were not damaged, but one secondary bushing had sufficient stress on it to bend the transformer cover. Conduits for the indicating circuits on the phase C transformer were broken at the ground line, but the circuits remained operative. Sections of the rigid bus at the high-voltage bus were bent. The single-phase station service transformer shifted on its base but was not damaged. The battery rack and radio equipment inside the substation building shifted but were not damaged.

The Palmer substation is in a heavily wooded area immediately south of the town of Palmer. Foundation materials consisted of 0.8 feet of dark humus and topsoil, 3.0 feet of dark-grayish-brown slightly sandy silt, and about a 1-foot mixture of dark-gray silty sand and poorly graded gravels and cobbles. The depth to the water table was not determined. The only evidence of damage at the Palmer substation was an oil leak at the base of a transformer bushing.

OTHER EARTHQUAKE EFFECTS IN THE AREA

There is evidence, though meager, indicating a general subsidence of the Eklutna powerplant area, including Goat Mountain. An exceptionally high tide was reported during the week of May 12–15, 1964, but settlement of the general area probably contributed to the flooding.

A helicopter reconnaissance of the Eklutna Lake drainage area (fig. 29) disclosed that earthquake slides had blocked three valleys. The slides were composed of talus fragments held in an ice matrix, but water was freely flowing beneath them and no ponding was taking place. Earthquake effects were confined to alluvial deposits, and conspicuous cracks were observed in nearly all alluvial fans bordering Eklutna Lake.

Aerial surveys were conducted to determine if major damage had occurred at potential project areas. The results of these surveys can be summarized as follows:

1. No major slides were observed along the Copper River main stem, although a slide was present across Klutina River, a tributary of the Copper River. No water was being impounded.
2. Numerous snowslides were seen along the Matanuska River valley.
3. Some shifting of the Lake George, Surprise, and Columbia glacier icefield was noted.

29. Aerial photograph showing general area surrounding Eklutna Lake.

4. The U.S. Geological Survey assessed the earthquake effects on potential damsites in the Anchorage-Seward area. These sites are on Nellie Juan Lake, Surprise Creek, Lost Creek, Kashwitna River, Talkeetna River, Sheep Creek, Swan Lake near Juneau Creek, Moose Horn Rapids, Kenai River, Juneau Creek, Kasilof River, and Hongkong Bend. The only new large-scale landsliding was on the Kashwitna River, but this slide did not affect consideration of a damsite upstream.

TELEVISION EXAMINATION OF EARTHQUAKE DAMAGE TO UNDERGROUND COMMUNICATION AND ELECTRICAL SYSTEMS IN ANCHORAGE

By Lynn R. Burton, U.S. Bureau of Reclamation

INTRODUCTION

As a result of the earthquake of March 27, 1964, the city of Anchorage experienced severe damage to its underground utilities systems in addition to the great damage sustained by surface structures. Temporary repairs to these systems were made as quickly as possible after the earthquake to permit resumption of necessary services within the city. Permanent repairs were included in that phase of the Alaska Restoration Program administered by the Corps of Engineers.

In order to avoid costly excavation of the buried communication and electrical systems to determine the specific locations requiring repair, the Corps of Engineers requested the use of a small-diameter closed-circuit television camera owned by the U.S. Bureau of Reclamation. This instrument, 2½ inches in diameter, was the only television camera available which was small enough to pass through the cable ducts. The television equipment was flown from Denver, Colo., to Anchorage and back by the Military Air Transport Service (fig. 30). During September and early October 1964, 23,594 linear feet of communication system and 10,510 feet of electrical system were examined in the Anchorage business district and various residential areas by means of this equipment.

UNDERGROUND SYSTEMS

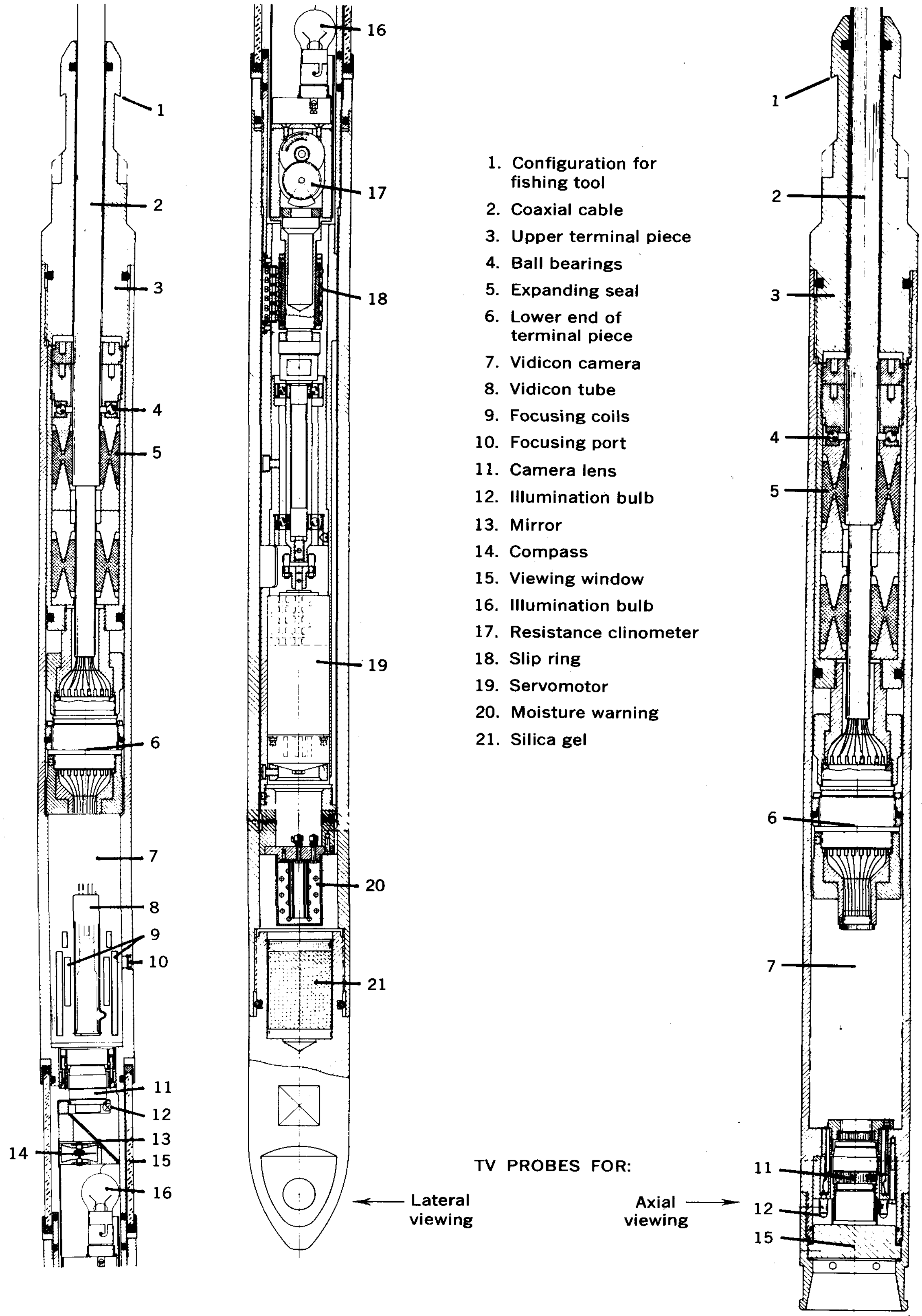
The underground communication and electrical systems consist generally of banks of four to twelve 3½-inch-inside-diameter asbestos-cement ducts, buried 4–6 feet beneath the streets and alleys of the city. These ducts, containing telephone and power cables, are encased in concrete envelopes. Manholes, spaced 180–540 feet apart, provide access to the envelopes. Each bank of ducts includes at least one empty duct that was used for the television examination. Any damage observed in this duct was assumed to indicate damage to the entire envelope at that location. In areas where the two systems are closely parallel, only one system was examined. The ducts were cleaned by mandrel and brush before the examination.

That part of the communication system extending from A Street to E Street along the alley between Third and Fourth Avenues was destroyed by the Fourth Avenue slide, and a section of the system along Eighth Avenue west of L Street was destroyed by the L Street slide.

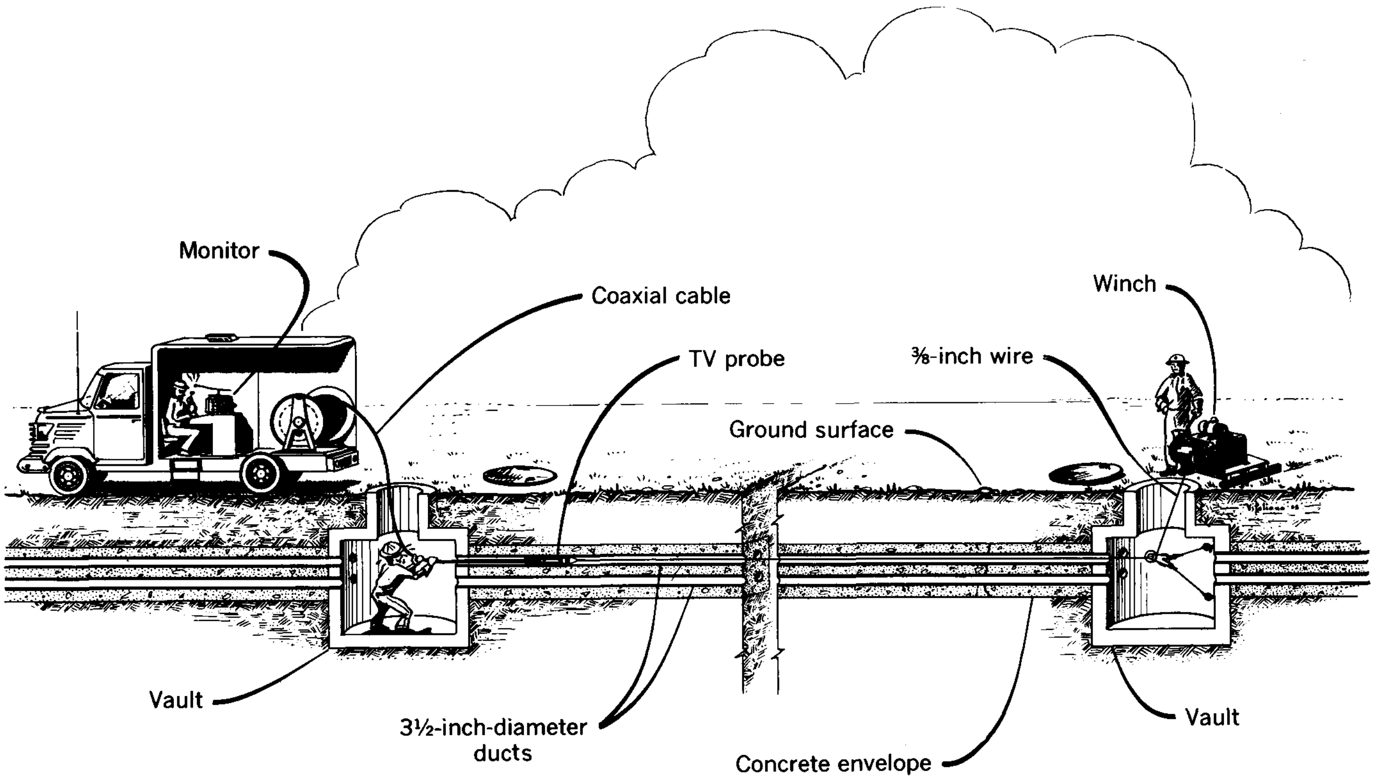
EQUIPMENT

The closed-circuit television equipment used was designed primarily for examination of exploratory drill holes 3 inches or more

30.—Truck-mounted television equipment being loaded at Denver for its flight to Anchorage, Alaska.



31.—Details of television probes.



32.—Arrangement of television equipment during examination.

in diameter to obtain various geologic data. It also has numerous nongeologic applications. The equipment is mounted on a truck and includes a control console and monitoring unit, approximately 1,000 feet of coaxial cable, and two types of probes in which the miniaturized television camera is inserted (fig. 31). All operating switches and an 8-inch monitor or viewing screen are located at the control console. The instrument operates on 110-volt 60-cycle alternating current. An attempt was made to use a lateral-viewing probe in this examination, but its length (55 inches) prevented passage through many of the bends in the duct lines. The axial-viewing probe, which is only 30 inches long, could be passed through all but the sharpest of the bends and was used throughout the examination.

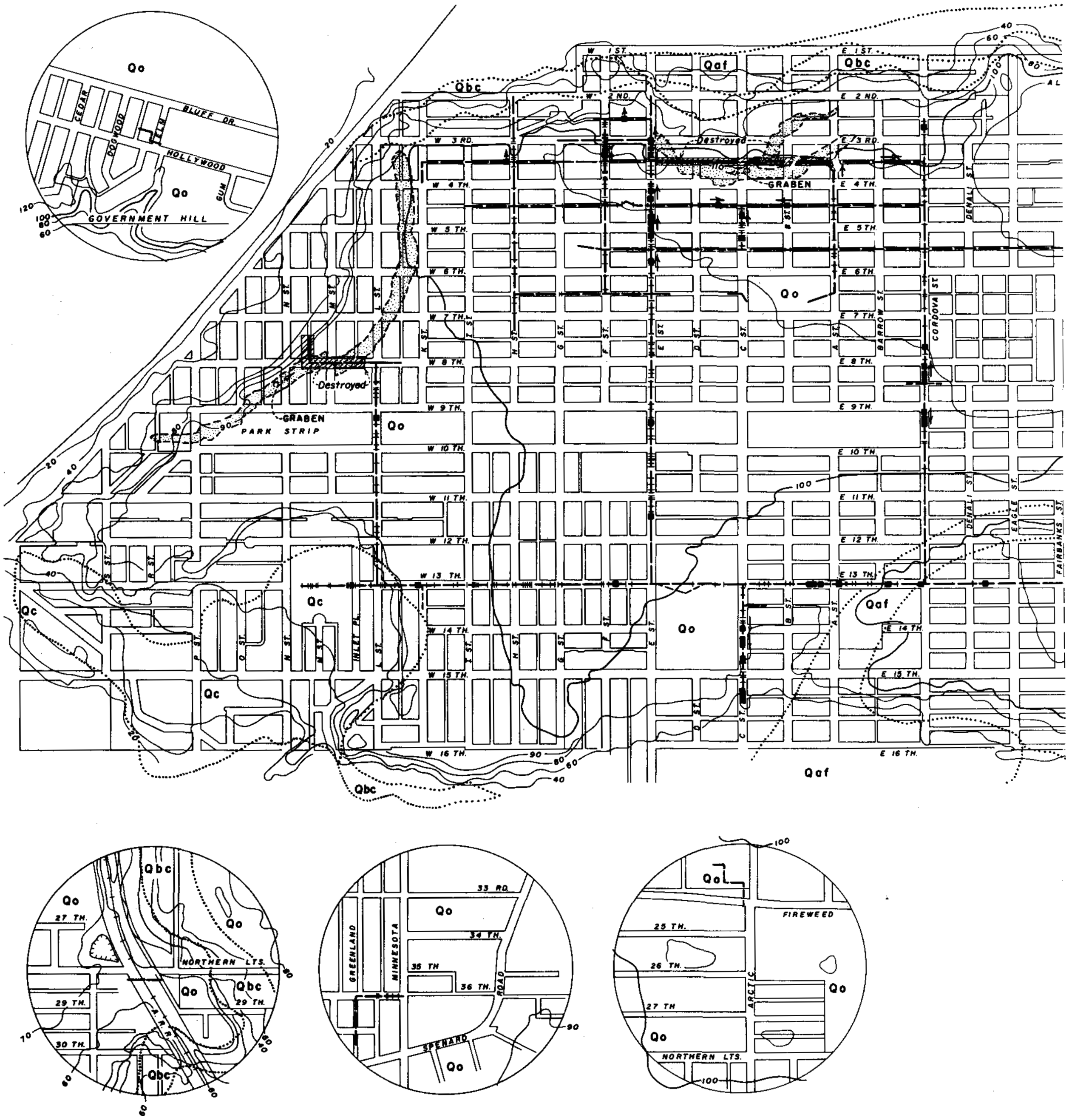
PROCEDURE

The television probe was drawn through the ducts by a small-gage wire rope attached to a pulling bridle on the probe and wound on a winching drum. The winching drum was coupled to an electric motor through a variable-speed transmission to permit variation in logging speed. Direct communication between the television and winch operators by sound-powered telephone provided coordination of viewing and logging speed, which was normally 10–12 feet per minute in undamaged ducts. The general arrangement of the various components of equipment during operation is shown in figure 32.

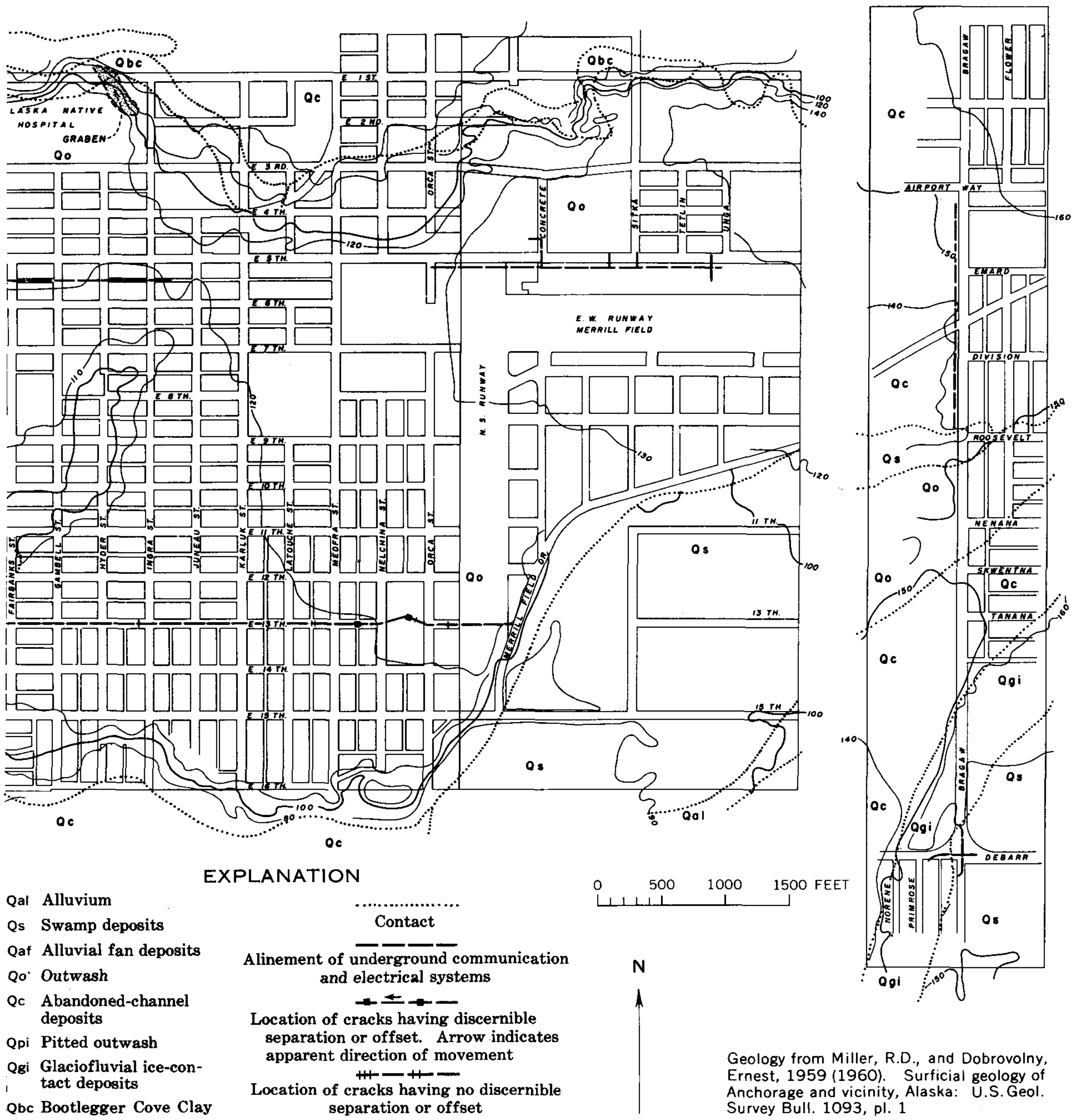
DAMAGE TO SYSTEMS

Topography and surface geology of the northern half of the city, alinement of the underground systems, locations of cracks observed during the examination, and approximate positions of the grabens formed at the heads of the L Street, Fourth Avenue, and First Avenue slides are shown in figure 33 (p. A28, A29). For simplicity, the alinements of the two systems are combined and shown as a single system. The direction of movement, where it could be determined, is indicated by small arrows.

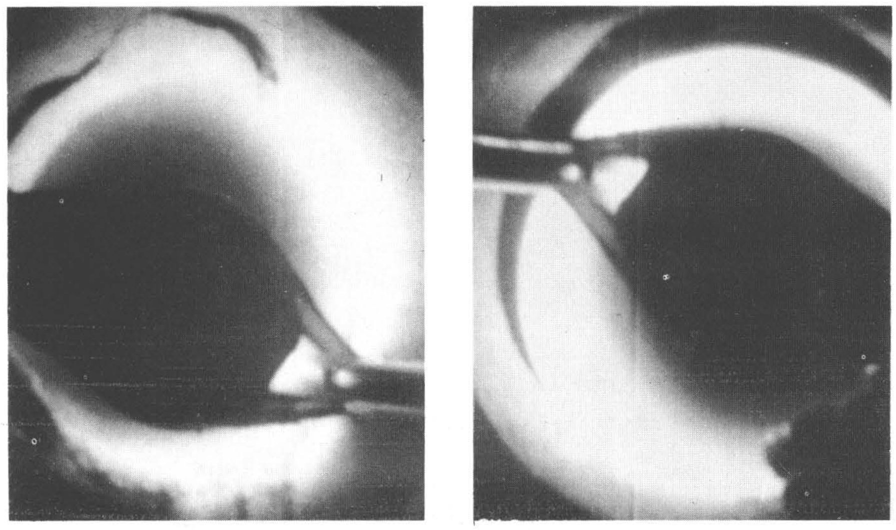
Cracks in the ducts were clearly visible on the monitor screen, and the amount of separation and offset was accurately determined. Approximately 90 percent of the cracks exhibited no measurable displacement and were not considered indicative of serious damage to the concrete envelopes. Lateral, vertical, and longitudinal displacements along fractures were



33.—Topography, surface geology, and location of fractures



in underground communication and electrical systems.



34.—Axial views of breaks in the ducts, as seen on the television monitor screen.

observed at 52 locations. Photographs of two such fractures, as viewed on the monitor screen, are shown in figure 34. The maximum displacement noted was 1 inch, although most were in the $\frac{1}{16}$- to $\frac{1}{4}$-inch range. Soil and water had entered the ducts through many such openings, and water was found in some areas where only hairline cracks were present.

INTERPRETATION OF DATA

Although their plotted locations exhibit no well-defined pattern, the cracks are concentrated in the vicinity of the Fourth Avenue slide and in areas near the slopes of stream valleys and local drainage channels. The concentrations of fractures north of Sixth Avenue between Barrow and F Streets are clearly the result of ground adjustments related to the Fourth Avenue slide. Others, such as those located on Thirteenth Avenue and along C Street south of Thirteenth Avenue, probably reflect local subsidence resulting from incipient failure of outwash and alluvial materials on valley slopes.

The direction of movement was determined at 18 of the 52 locations where displacement occurred. Movement was to the north or south at 13 of these locations. In general, these data suggest that the north-south component of ground motion was more severe than the east-west component and that the direction in which the induced tensile forces acted was strongly influenced by the free faces represented by Ship Creek valley to the north, Chester Creek valley to the south, and the Cook Inlet bluffs to the west. Lack of a comparable free face to the east may explain the absence of serious damage to the underground systems in the eastern part of the area.

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