UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PILLAR MOUNTAIN LANDSLIDE, KODIAK, ALASKA

by

Reuben Kachadoorian and Willard H. Slater

OPEN-FILE REPORT

78-217

U.S. Geological Survey
345 Middlefield Road
Menlo Park, California 94025

1978

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards

Contents

Illustrations

Tables

Plates

PILLAR MOUNTAIN LANDSLIDE, KODIAK, ALASKA

By

Reuben Kachadoorian and Willard H. Slater[1/]

Abstract

Pillar Mountain landslide on the southeast face of Pillar Mountain is about 915 m (3,000 ft) southwest of the city of Kodiak, Alaska. The landslide is about 520 m (1,700 ft) wide at its base and extends approximately from sea level to an altitude of about 343 m (1,125 ft). The slide developed on an ancient and apparently inactive landslide. Renewed movement was first detected on December 5, 1971, following removal of about 230,000 m^3 (300,000 yd^3) of material from the base of the slope. Although movement of the landslide has decreased since December, 1971, movement continues and the possibility exists that it could increase as a result of an earthquake, water saturation of the landslide mass, or other causes. In the most extreme case, as much as 3.8 to 7.6 million m^3 (5-10 million yd^3) of debris could fall into the sea at Inner Anchorage. If this took place suddenly, it could generate a wave comparable in height to the tsunami that damaged Kodiak during the Alaskan Earthquake of 1964. Therefore, we believe that the Pillar landslide is a potential hazard to the city of Kodiak and its environs that merits a thorough investigation and evaluation.

[1/] Alaska Department of Transportation, Fairbanks, Alaska

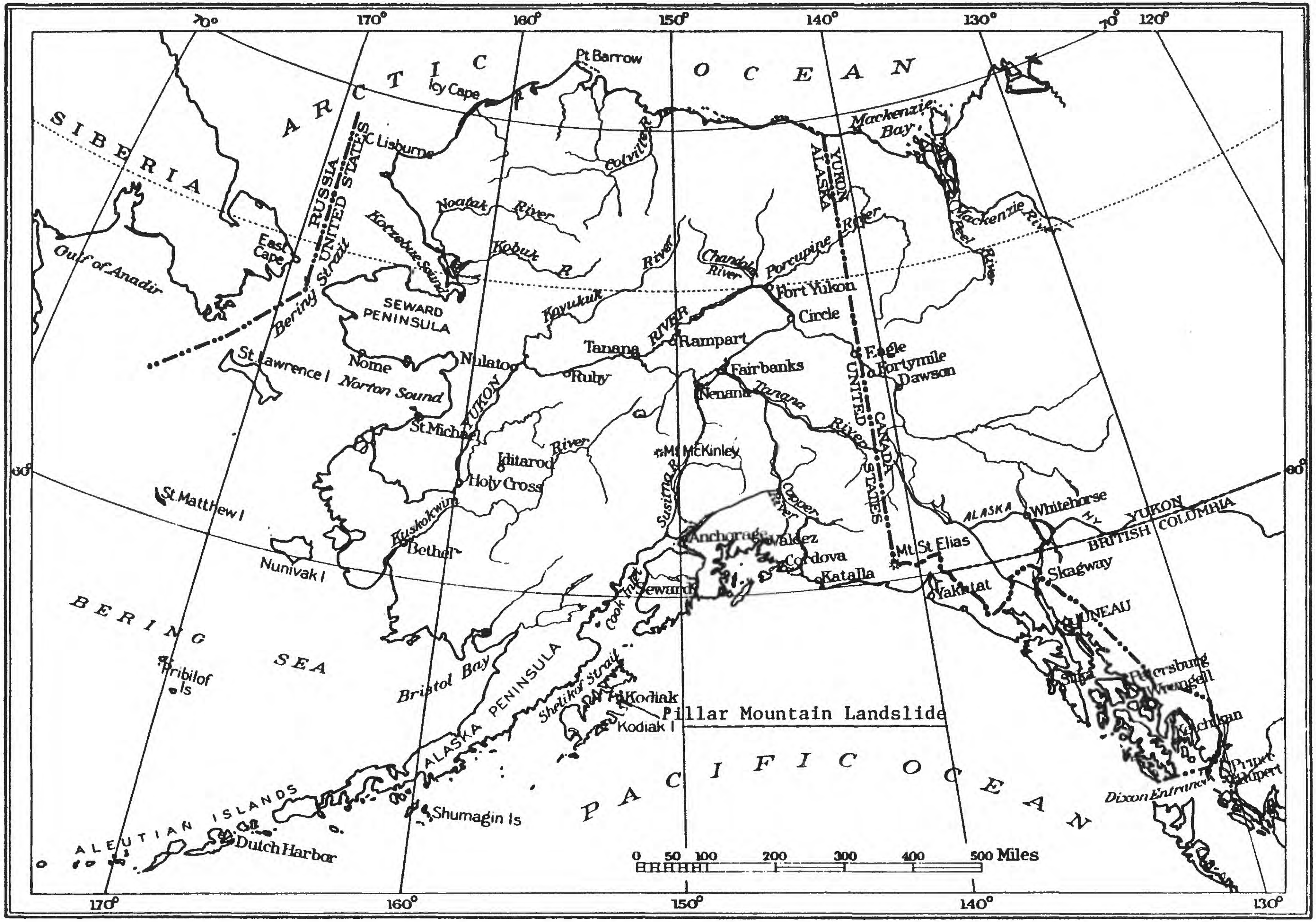
Introduction

An investigation of the Pillar Mountain landslide, Kodiak, Alaska, was undertaken to make a preliminary evaluation of the slide as a potential hazard to the city of Kodiak and its environs. This report is based on our field observations, slope-indicator casing data collected by the Alaska State Highway Department (now part of the Alaska Department of Transportation), coordinate measurements of survey control points by R & M Consultants, Inc., Anchorage, Alaska, and a report prepared for the Alaska Department of Highways by Dames and Moore (1973).

This report was reviewed by David J. Varnes, Robert W. Fleming, Edwin L. Harp, George W. Moore, Henry J. Moore, John R. Williams, Lynn A. Yehle, and Leslie T. Youd, all of the U.S. Geological Survey. Their comments and suggestions have largely been incorporated into this report.

Description of the Pillar Mountain landslide

Pillar Mountain landslide is on the southeast face of Pillar Mountain, about 915 m (3,000 ft) southwest of Kodiak, on the northwest shore of Inner Anchorage, a northeast reach of St. Paul Harbor (figs. 1 and 5). The location of the slide between downtown Kodiak and Gibson Cove is shown on figure 5; the configuration on figure 2 and Plate 2. The base of the slide extends about 520 m (1,700 ft) along the roadway between the new city of Kodiak dock (fig. 2, left-foreground, A) and another docking facility (fig. 2, right-foreground, B). In 1972, the altitude from which rock debris was coming was about 236 m (775 ft). However, cracks and fractures occur in the bedrock to an altitude of



39602

Figure 1. Index map showing location of Pillar Mountain Landslide, Kodiak, Alaska

Figure 2. View northwest of Pillar Mountain landslide, Kodiak, Alaska, A, new city dock; B, dock; C, abandoned highway; arrow at skyline points to White Alice station; Qls_1, talus; $Qlsa_1$ and $Qlsa_2$, ancient slide debris; br, slate, argillite, and graywacke; line indicates approximate boundaries of Plate 2.

about 343 m (1,125 ft) or within 38 m (125 ft) from the top of Pillar Mountain (fig. 3 and Plate 2). Thus, the slope affected extends from about sea level to at least an altitude of 343 m (1,125 ft).

Before 1957 or 1958, the face of the slide area was crossed by a highway at about altitude 38 to 49 m (125 to 160 ft), labeled C on figure 2 and Abandoned Highway on Plate 2. The roadway was moved to its present lower location at the base of Pillar Mountain because of rockfall and maintenance problems.

Renewed movement of the Pillar Mountain landslide began during the removal of approximately 230,000 m^3 (300,000 yd^3) of rock from the toe of the slope of Pillar Mountain for use as fill for the new city of Kodiak dock (A on fig. 2). Material was quarried, pushed downhill from the abandoned highway (C, fig. 2) and collected at the base of the slope. It was then transported to the dock site. On Sunday, December 5, 1971, when the contractor had removed nearly 230,000 m^3 of material from the base of Pillar Mountain, showers of small rocks and occasionally large rocks began cascading down the rock slope above the abandoned highway. The source for the rockfall progressed upslope from its initial altitude of about 91 m (300 ft) to about an altitude of 215 m (700 ft) for the first four days (12/5 to 12/8, 1971) and was primarily confined to a single gully (D. S. Esch and W. H. Slater (Internal Memorandum), 1971)

Aerial observations on December 9 and December 14, 1971, by Esch and Slater (Internal Memorandum, 1971) revealed that the gully had developed along the northeast lateral scarp of a major sliding block of bedrock. Several days later heavy rockfall was observed coming from the lower left and center of the central slide mass. The crack or

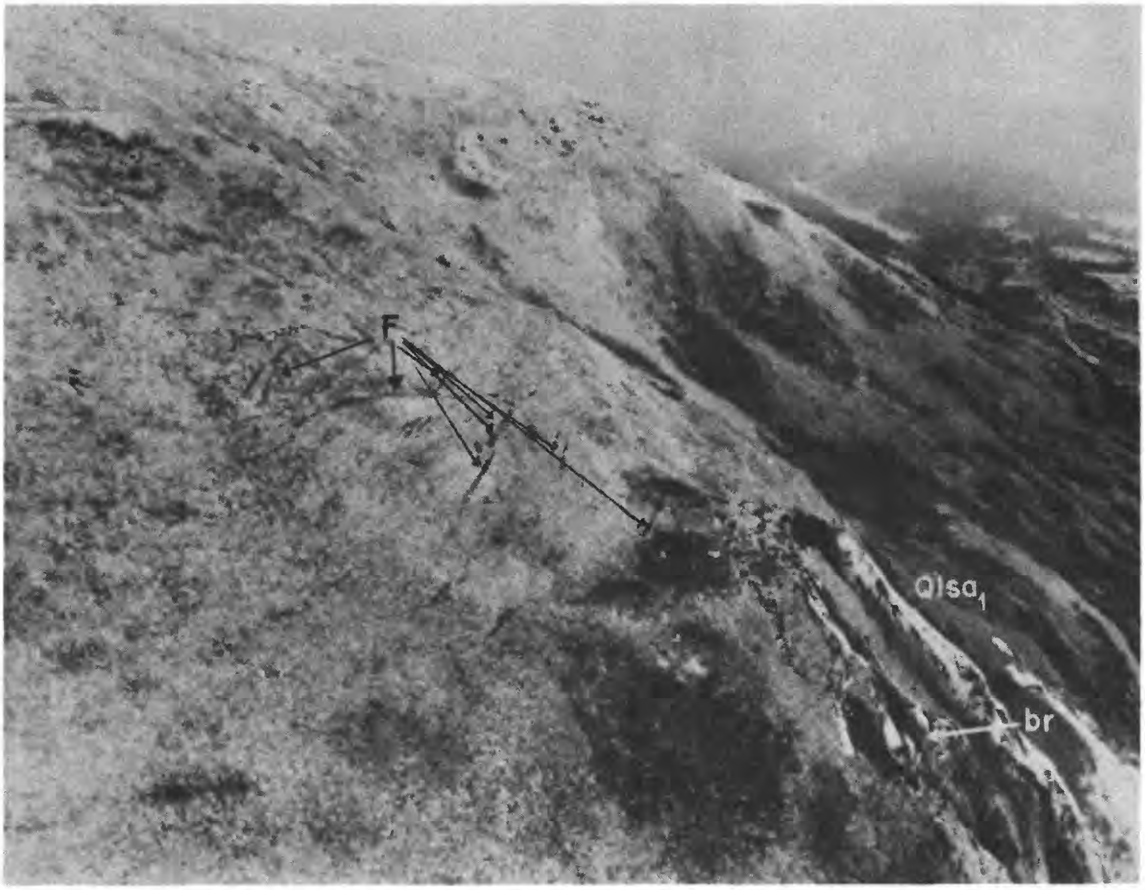


Figure 3. View northeast showing fractures on Pillar Mountain landslide, Kodiak, Alaska. F, fractures at about altitude 244 m (800 ft.); $Qlsa_1$, ancient slide debris; br, slate, argillite, and graywacke.

fracture pattern suggested that the entire center block was moving downhill. Some of these cracks can be seen in figure 3. The uppermost crack was estimated to be approximately 122 m (400 ft) horizontally and 38 m (125 ft) vertically from the White Alice communication site (arrow, fig. 2) on the crest of Pillar Mountain at about an altitude of 381 m (1,250 ft). As snow was present on the ground and none in the cracks, the observers concluded that the cracks had developed no more than a few days prior to the December 9 aerial observations.

The December 14, 1971, aerial observation was made after a snowstorm that ended about 10:00 AM, December 13. At the time of this flight, most of the cracks observed on December 9 were obscured by the snow. However, Esch noted visually that the uphill cracks were wider, about 50 percent, than when he inspected them on December 9, 1971 (Esch and Slater, Internal Memorandum, 1971). Ground inspection by Esch of the cracks on December 9 and again on December 14, 1971, indicated that they had increased in size and appeared to mirror the shape of an ancient landslide on the upper half of Pillar Mountain. The cracks or fractures were as much as 1 m (3 ft) wide. During our field observations on August 3 and 4, 1976, some cracks were as much as 1.2 m (4 ft) wide. We also noted a crack at about altitude 343 m (1,125 ft) that is not shown on Plate 1. Plate 1 is a copy of a geologic map submitted by Dames and Moore to accompany their report to the Alaska Department of Highways (1973). The crack we noted at altitude 343 m is in the vicinity of S-1 on Plate 2.

Esch and Slater (1971) estimated displacement between December 5 and December 10, 1971, to be about 1.5 m (5 ft). A comparison of survey points (C-1 and C-2, Pl. 1) between 1968 and September, 1972, revealed that the uppermost of these points (C-1) apparently moved toward the lower (C-2) a distance of about 3.7 m (12 ft) (Dames and Moore, 1973).

To maintain traffic between Kodiak and part of the Island south and west, remedial measures were taken at the landslide. At the suggestion of Dames and Moore (1973), Maccaferri Gabions (rectangular or square baskets of woven wire) filled with rock were placed between the highway and the landslide area, mainly to prevent rockfall debris from falling upon the highway at the base of the slide.

Geology

Mappable units of the Pillar Mountain landslide area, which consist of unconsolidated deposits and bedrock, are shown on Plate 1. The unconsolidated deposits are talus (Qls_1), thin veneer of slide debris (Qls_2), and ancient slide debris ($Qlsa_1$ and $Qlsa_2$). The map area on Plate 1 that is not ascribed to any particular unit is a thin veneer of colluvium and local glacial debris overlying bedrock.

The bedrock (br) consists of dark-gray to black, fine-grained slate and argillite interbedded with lesser amounts of graywacke. The fine-grained rocks range from thickly bedded slate to more massive beds of argillite. The slates, in which bedding typically parallels cleavage, commonly split readily into thin, platy fragments. Individual beds of slate and argillite range in thickness from less than 25 mm (1 inch) to 0.3 m (1 foot); the more massive argillite and graywacke beds are as much as 6 m (20 ft) thick. The bedding strikes N25°E to N40°E and dips northwest from 40° to 70°.

The southeast face of Pillar Mountain, which contains the landslide, is about 381 m (1,250 ft) high. The overall slope is slightly steeper than 1.5:1 (horizontal:vertical) with portions approaching 0.5:1.

There are at least four joint sets at Pillar Mountain (Dames and Moore, 1973). One set strikes N38°E to N48°E and dips S70°E to vertical. A second set strikes N61°E to N81°E and dips N68°W to S75°E. The third set strikes N75°W to N83°W and dips 75° to 81°NE. The fourth set strikes N25°W to N36°W and dips S68°W to vertical. At the intersection of these joints, the slate, argillite, and graywacke disintegrate into small rock fragments, and occasionally into large boulder-sized blocks.

Measurements of displacement

To determine the nature of failure occurring at the Pillar Mountain landslide and to estimate the nature of future activity, two slope-indicator casings were installed by Alaska Department of Highways in the landslide block at the locations shown on Plate 2 as D.H. 1 and D.H. 2.

D.H. 1, placed at an altitude of about 273 m (895 ft), is a 124-mm- (4 7/8-inch-) diameter hole 55.2 m (181 ft) deep drilled in early fall of 1972 within an area of surface cracking above the exposed bedrock. The second boring, D.H. 2, was drilled to a depth of 16.9 m (55.5 ft) at a location west of the talus cones (Qls_1), above the new city of Kodiak dock, at an altitude of about 44.2 m (145 ft). Sometime before February 11, 1975, D.H. 2 became distorted. On a visit to the site, after February 11, 1975, Slater attempted to take a reading in the hole but was unable to get the sensor down the casing. He looked in the hole with a mirror but was unable to see the bottom because of a marked curve in the casing about 9.2 m (30 ft) from the surface. At the time of the inspection, Slater felt that the obstruction was most likely produced by improper installation of the casing. Based on recent data and observations, he now believes that it may have been caused by movement of the bedrock.

D.H. 1 penetrated fracture zones, resulting in loss of drilling fluid circulation at depths of 10.7 m (35 ft), 16.8 m (55 ft), 17.7 m (58 ft), 20.6 m (67.5 ft), 21.6 m (71 ft), 26.8 m (88 ft), 34.2 m (112 ft), 37.2 m (122 ft), 39.3 m (129 ft), 39.9 m (131 ft), 41.0 m (134.5 ft), 49.4 m (162 ft), 50.9 m (167 ft), 52.1 m (171 ft), 54.6 m (179 ft), and 55.2 m (181 ft). The largest cracks encountered were in the intervals 39.3 m to 41.0 m (129 to 134.5 ft) and 54.6 to 55.2 m (179 to 181 ft). Since fluid loss at the 55.2-m (181-ft) depth could not be controlled, the boring was terminated at that depth. D.H. 2 encountered fractures at depths of 1.2 m (4 ft) and 10.7 m (35 ft).

Slope-indicator readings on D.H. 1 (fig. 4) indicate a displacement of about 127 mm (5.0 in) in a S10°E direction between the initial reading on September 25, 1972, and readings on August 3, 1976 (plotted as dashed vector, Plate 2). More than one-half of the total displacement occurred between the depths of 33.8 to 49.1 (111 to 161 ft). Nearly 25 mm (1 in) of movement was recorded in the lower 6.1 m (20 ft) of the hole and the data do not conclusively prove that the casing extends entirely through the landslide.

To determine the amount of displacement at the bottom of the hole the U.S. Geological Survey contracted R & M Consultants, Inc., Anchorage, Alaska in 1976 to reoccupy survey points established on Pillar Mountain in 1972. The results of the survey are shown on Table 1 and displacements

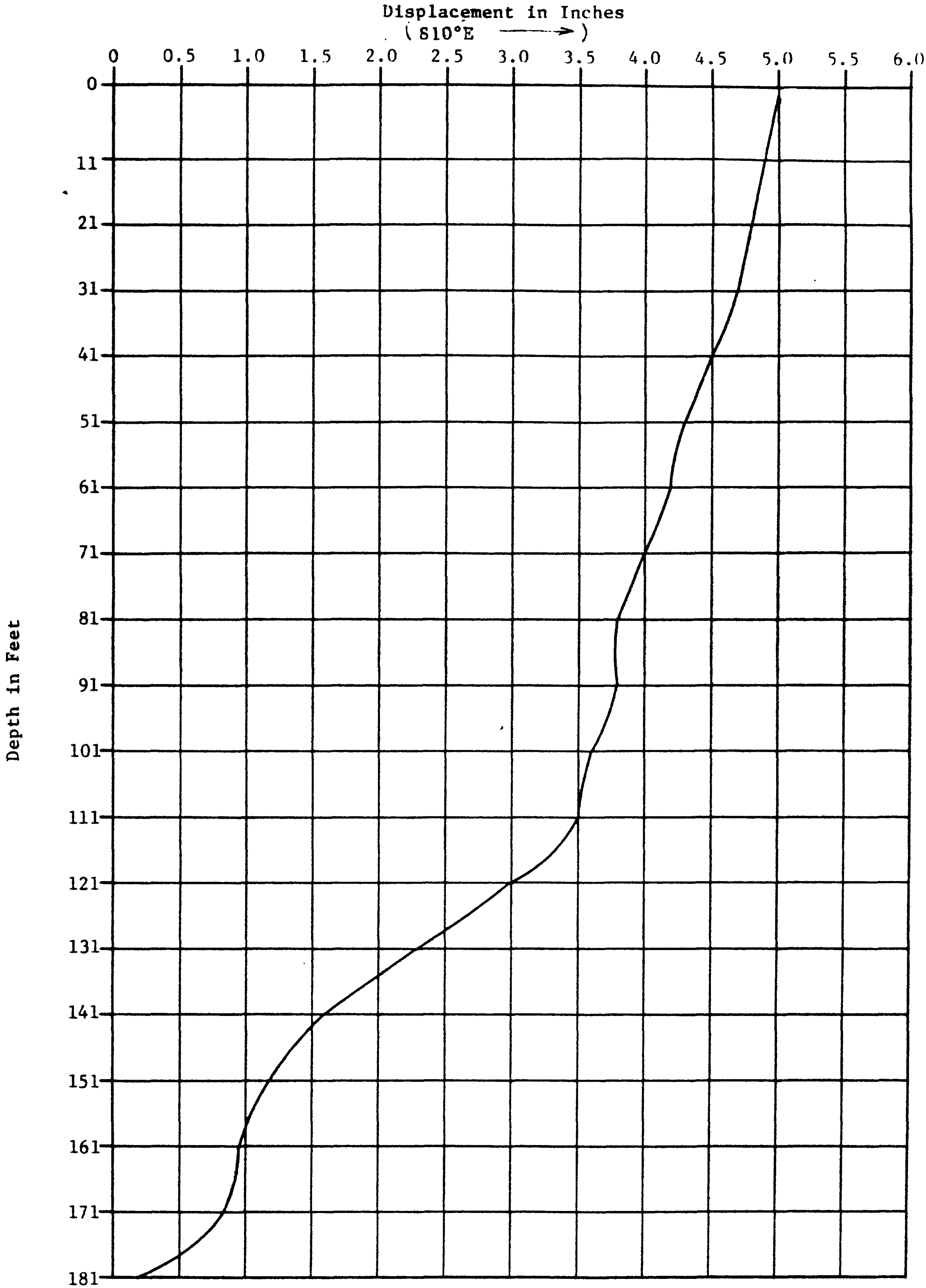


Figure 4. Slope indicator data, D. H. 1, showing amount of displacement between September 25, 1972, and August 3, 1976

Table 1.--Summary of coordinate measurements of survey control points at Pillar Mountain, Kodiak Alaska

[Survey by R & M Consultants, Inc., 1976]

Control Point	Date	Coordinates	
		North	East
C-1	7/72	1,386,473.331	805,515.681
	10/72	1,386,473.237	805,515.642
	10/76	1,386,472.993	805,515.502
C-2	7/72	1,385,533.159	805,613.590
	10/72	1,385,533.185	805,613.618
	10/76	1,385,533.152	805,613.587
S-1	10/72	1,386,982.517	805,489.601
	10/76	1,386,982.206	805,489.719
D. H. 1	10/72	1,386,550.145	805,540.405
	10/76	1,385,549.657	805,540.640
D. H. 2	10/72	1,385,574.158	805,631.108
	10/76	1,385,574.330	805,631.105

Control Point	Displacement		Direction
	in	mm	
C-1	3.27	83.1	S 29°50′45"W
C-2	0.54	13.7	S 43°12′36"W
S-1	4.00	101.6	S 25°46′40"E
D. H. 1	6.50	165.1	S 25°42′49"E
D. H. 2	2.06	52.3	N 0°59′57"W

plotted on solid-line vectors on Plate 2. The data are not conclusive. Movement of four of the five survey points was consistent with features observed on the landslide surface. However, the collar of D.H. 2, the unusable slope indicator installation, apparently moved uphill more than 51 mm (2 in) between October, 1972, and October, 1976. This may be the result from a rotational slide. We cannot conclusively prove this with the available data.

There is an apparent discrepancy of the data in D.H. 1. The slope-indicator data suggest 127 mm (5 in) of downslope movement between the top and bottom of the casing. The surface survey of the same point suggests 165 mm (6.5 in) of downslope displacement. The slope-indicator data suggest that movement may be occurring below the slope-indicator casing. We believe that this may be so and that the 38 mm (1.5 in) apparent discrepancy may in fact be a record of displacement below the casing between October, 1972 and October, 1976.

Slide stability

Geologic reconnaissance of the region around Pillar Mountain was made on August 4, 1976, to determine the stability of the slopes underlain by bedrock and terrain similar to that under the slopes of Pillar Mountain. The reconnaissance indicated that mountain faces to the northeast and southwest of Pillar Mountain contain numerous landslides that probably occurred after glacial ice retreated from the area. These ancient landslides moved essentially to the base of the slopes and presumably are now stable. This is not the case in the Pillar Mountain landslide, however. We noted an ancient landslide scarp at about altitude 343 m (1,125 ft) that had a displacement of about

7.6 to 13.7 m (25 to 45 ft). This suggested that the Pillar Mountain landslide is an ancient slide that had not slid to the base of the slope and is still potentially unstable.

To determine whether the Pillar Mountain landslide had, in the past, slid to the bottom of the slope, we made an analysis of the offshore bathymetry at the base of the mountain. The study showed a large submarine basin with an average depth of 12 fathoms (fig. 5). On either side of the basin, the depth of the water is about 9 fathoms, or about 3 fathoms shallower than the basin. Although it is possible that the basin is a feature of marine processes, we believe it may exist because ancient slides on both sides of Pillar Mountain slid to the base of the slope or into Inner Anchorage, resulting in the relatively shallow depths below them.

We learned in the fall of 1977 that the new city of Kodiak dock at the base of Pillar Mountain (A, fig. 2) is undergoing displacement. Five slope-indicator borings drilled to bedrock have been placed in the dock to measure displacement. The cause of the inferred displacement is unknown. It may be because of displacement in the fill or more deep-seated. The dock is at the base of an old landslide identified as $Qlsa_2$ in figure 2.

Discussion and conclusions

The base of the Pillar Mountain landslide cannot be identified clearly by the data available. The data do indicate, however, that movement in the vicinity of D.H. 1 is occurring to a depth of 54.9 m (180 ft) or greater. Failure plane A, identified on the cross section

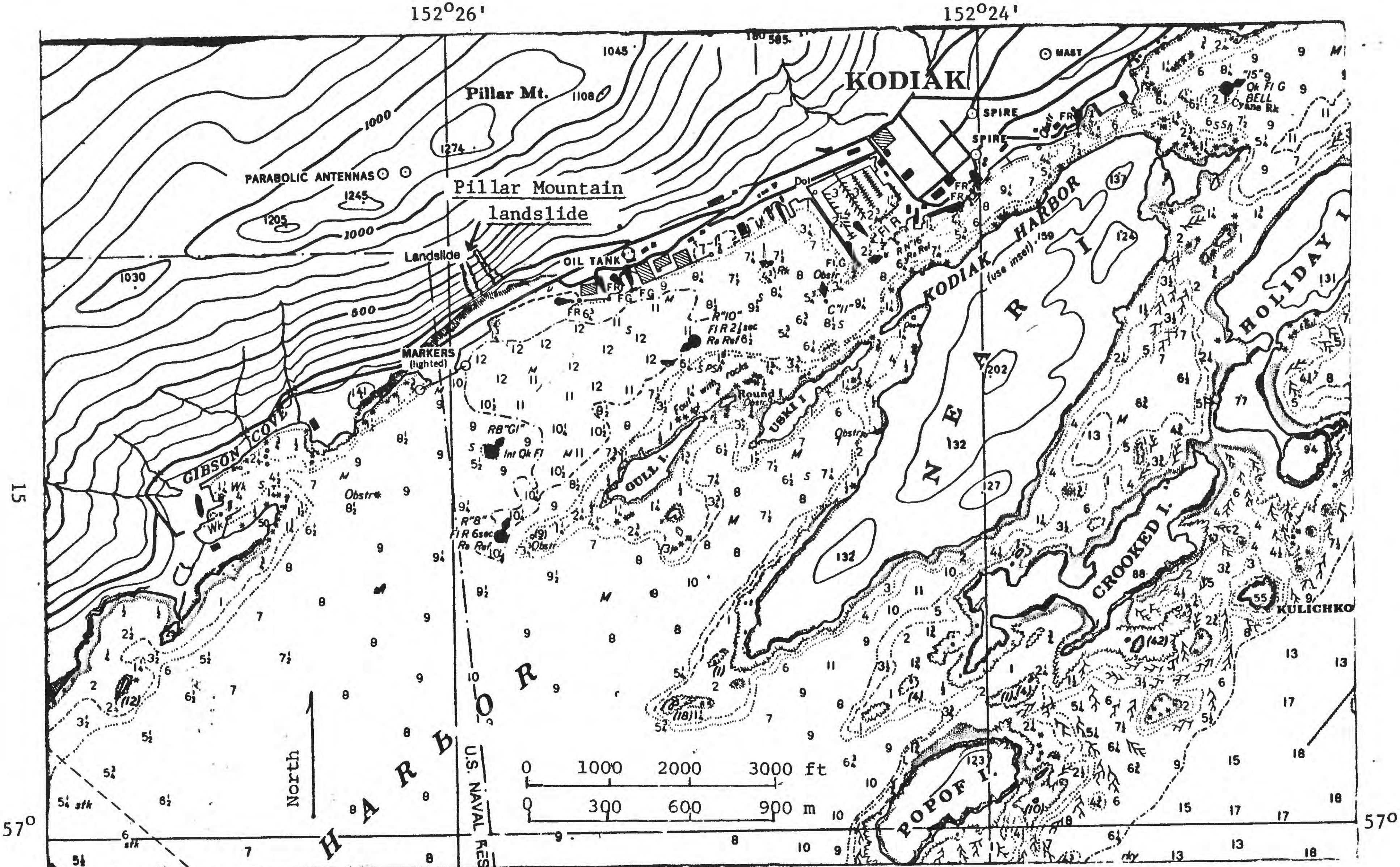


Figure 5. Bathymetry of Inner Harbor, Kodiak, Alaska. Soundings in fathoms, datum MLLW; scale 1:20,000; from NOAA Chart No. 16595--Kodiak and St. Paul Harbors, May 10, 1975.

of Plate 2, assumes failure at about 54.9 m (180 ft). This suggests that there could be about 3.8 million m^3 (5 million yd^3) of material moving downslope. However, movement could be occurring at a greater depth indicated by Failure Plane B on the cross section of Plate 2. If such is the case, there could be approximately 7.6 million m^3 (10 million yd^3) of material moving downslope. The data also suggest that movement is occurring along different planes in the landslide mass (fig. 4). It is not known if the planes at which movement is occurring are interconnected. Therefore, we do not know if single or multiple surfaces have developed.

Movement of the Pillar Mountain landslide continues, although it has decelerated relative to the movement observed in December, 1971. Figure 6 shows time versus displacement between September 25, 1972, and August 3, 1976, at a depth of 33.8 m (111 ft) in D.H. 1. Because of the limited number of observations, we are unable to define the type and nature of movement.

Kodiak is in a zone of high seismic activity, and although the 1964 earthquake did not accelerate or rejuvenate the ancient Pillar Mountain landslide, seismic stresses from future earthquakes may do so. Since the removal of material to construct the new city of Kodiak dock took place after the 1964 earthquake, the performance of the Pillar Mountain landslide during a future earthquake should not be evaluated in the light of lack of activity in 1964. In an abnormally high rainfall season the numerous cracks that developed after December 5, 1971, could collect sufficient water to saturate the landslide mass. If positive pore pressures develop as a result of this saturation, accelerated sliding could occur.

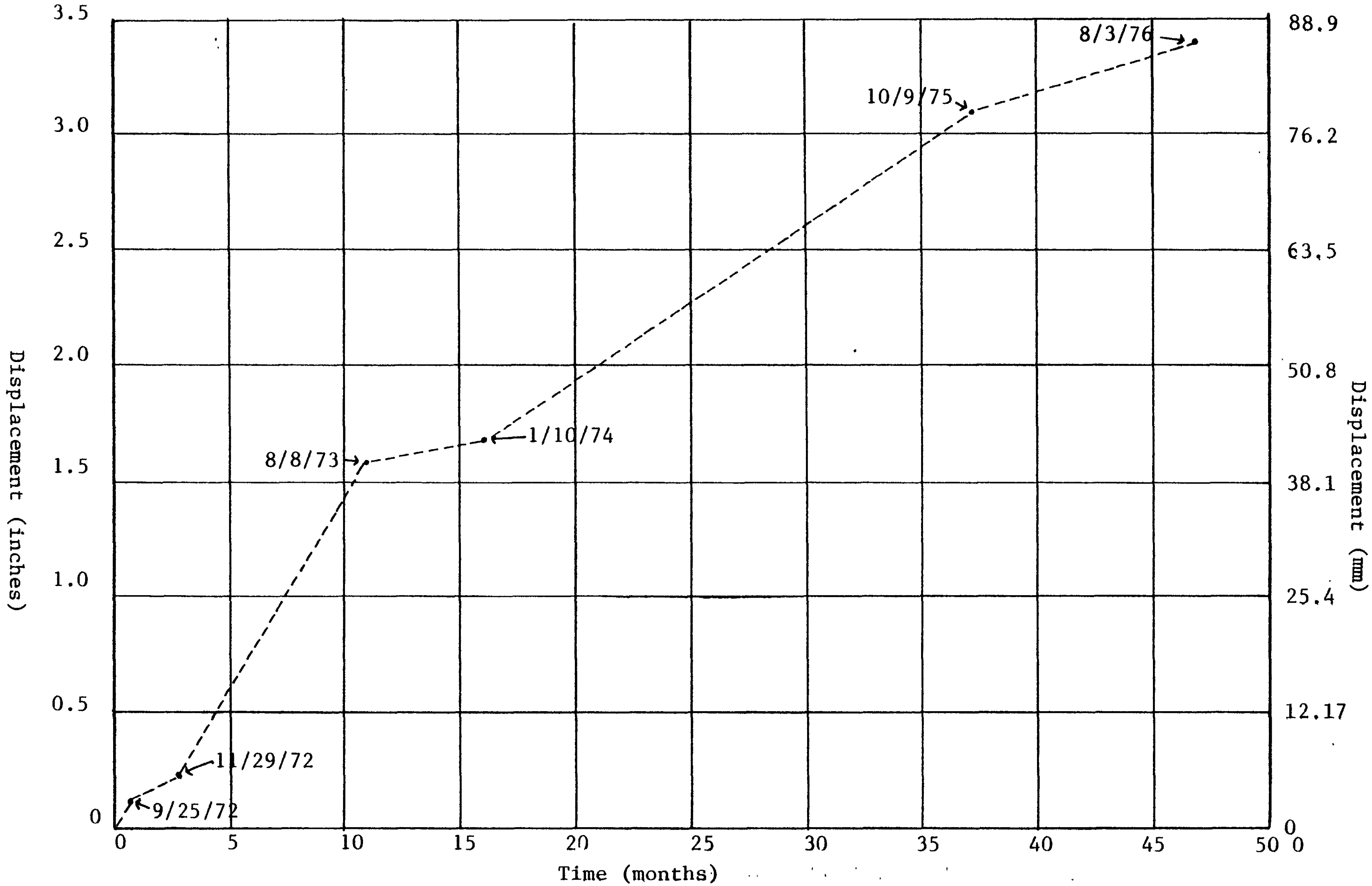


Figure 6. Graph showing time vs. displacement at a depth of 111 feet (33.83 m) in D.H.1, Pillar Mountain Landslide, Kodiak, Alaska.

Although the rate of movement of the Pillar Mountain landslide has decelerated since its initial movement in 1971, it is possible that a rapidly moving landslide could develop. If such a landslide did occur, it is possible that it could move into Inner Anchorage. The critical question is: would the slide generate a wave, block the harbor, or otherwise adversely affect the city of Kodiak and its environs?

Kachadoorian and Plafker (1967), in investigating the seismic waves that inundated and devastated much of Kodiak during the 1964 earthquake, reported the maximum wave generated by the 1964 earthquake to be 3.90 m (12.8 ft) superimposed on a zero tide. The most damaging wave at Kodiak was a 3.48-m (11.4-ft) wave superimposed on a 2.26-m (7.4-ft) tide. On this basis, the height of the wave that would adversely affect Kodiak is about 3.05 m (10 ft). Mean higher high water referred to a datum of Mean Lower Low Water (MLLW, 0.0 m) is 2.6 m (8.6 ft) at Kodiak. The mean tide level is 1.3 m (4.3 ft). A 3.05-m (10-ft) wave superimposed upon the mean tide would give a 4.36-m (14.3-ft) wave above MLLW.

Of the many parameters that determine the height of a landslide-generated wave, one of the most critical is the velocity of the sliding mass. Our data do not permit a refined determination of the potential velocity of the Pillar Mountain landslide if it were to fail completely and slide to the base of the mountain into Inner Anchorage. They do, however, permit us to make a reasonable estimation of the velocity.

Shreve (1966) computed the minimum velocity of the Sherman landslide which was triggered by the Alaska earthquake of 1964, on the assumption of simple conservation of energy. Banks and Strohm (1974) report that the equation used by Shreve was:

$$v^2 = 2gS(\sin i - \tan \phi \cos i)$$

where: v = velocity down the slide plane

g = gravitational constant

S = distance of sliding of centroid parallel to the plane

i = slope angle of plane

$\tan \phi$ = equivalent coefficient of friction equal to ratio between height of fall and horizontal distance traveled with respect to centroid of sliding block.

Using Shreve's equation, we considered two cases to compute the potential velocities of the Pillar Mountain landslide upon complete failure. Case 1 assumes that the sliding mass is from the surface to the failure plane labeled A on the cross section of Plate 2. Case 2 assumed failure on the plane labeled B. The centroids for both cases are shown on the cross section.

The assumptions in Case 1 are:

S = 186.9 m (610 ft)

i = 34°

height of fall, relative to centroid = 76.2 m (250 ft)

horizontal distance travelled, relative to centroid = 167.6 m (550 ft)

$\tan \phi$ = 76.2 m/167.6 m (250 ft/550 ft) = 0.455

Case 2 assumptions are:

S = 277.4 m (910 ft)

i = 36°

height of fall, relative to centroid = 152.4 m (500 ft) horizontal distance travelled, relative to centroid = 228.6 m (750 ft)

tan Ø = 152.4 m/228.6 m (500 ft/750 ft) = 0.667

Based on the above assumptions, the velocity in Case 1 is about 25.6 m/sec (84 ft/sec). The slide will have a ballistic trajectory once it leaves the face of Pillar Mountain. The velocity of the slide in case 2 is about 16.2 m/sec (53 ft/sec). These velocities are comparable with the 18 m/sec (60 ft/sec) velocity calculated by Hsü (1960) for the Vaiont Reservoir Landslide, Italy, and are about one-half the peak velocities of 37-46 m/sec (120-150 ft/sec) that are possible in rockslides (Banks and Strohm, 1974).

A critical question then is: what is the consequence of a large mass estimated to be as much as 3.8-7.6 million m^3 (5-10 million yd^3) sliding into Inner Anchorage at the velocities given? The Waterways Experiment Station at Vicksburg, Miss. constructed physical and mathematical models to predict wave characteristics resulting from landslide into Koocanusa Reservoir at Libby Dam, Mont. Comparing the results of their studies (Davidson and Whalin, 1974; Raney and Butler, 1975) with conditions of the Pillar Mountain landslide area, we believe it possible that a 3.05-m (10-ft) wave could be generated. A 3.05-m wave could damage the city of Kodiak, the extent depending in part on the tidal stage at the time the wave occurred.

Admittedly, the data do not provide a conclusive prediction of danger to Kodiak. The evidence of movement to great depths, enlargement of cracks, and harbor bathymetry do suggest that the slope is failing. Predictions of slide velocity and resulting wave heights are necessarily speculative. A high-velocity landslide of large volume reaching

Inner Anchorage could be serious.

In conclusion, we infer that Pillar Mountain landslide poses a potential hazard to the city of Kodiak and its environs. Additional data are needed for a more exact evaluation of the potential hazard posed by the landslide.

References cited

Banks, D. C., and Strohm, W. W., 1974, Calculations of rockslide velocities: Internat. Soc. Rock Mechanics Cong., 3d, Proc.

Dames and Moore, 1973, Consultation and geotechnical investigation, Pillar Mountain Slide, Kodiak, Alaska: Alaska Dept. Highways Rept.

Davidson, D. D., and Whalin, R. W., 1974, Potential landslide-generated water waves, Libby Dam and Lake Koocanusa, Montana: U.S. Army Corps Engineers Tech. Rept. H-74-15.

Hsü, K. J., 1969, Role of cohesive strength in the mechanics of overthrust faulting and landsliding: Geol. Soc. America Bull., v. 80, no. 6, p. 927-952.

Kachadoorian, Reuben, and Plafker, George, 1967, Effects of the earthquake of March 27, 1964, on the community of Kodiak and nearby islands: U.S. Geol. Survey Prof. Paper 542-F, p. F1-F41.

Raney, D. C., and Butler, H. L., 1975, A numerical model for predicting the effects of landslide-generated water waves: U.S. Army Corps Engineers Research Rept. H-75-1.

Shreve, R. L., 1966, Sherman landslide, Alaska: Science, v. 154, no. 3757, p. 1639-1643.