STATE OF ALASKA

DEPARTMENT OF NATURAL RESOURCES

DIVISION OF GEOLOGICAL AND GEOPHYSICAL SURVEYS

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March 1984

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Report of Investigations 84-5
POTENTIAL FOR EARTHQUAKE-INDUCED LIQUEFACTION IN THE FAIRBANKS-NENANA AREA, ALASKA

By
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STATE OF ALASKA
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POTENTIAL FOR EARTHQUAKE-INDUCED LIQUEFACTION IN THE FAIRBANKS-NENANA AREA, ALASKA

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ABSTRACT

Ground failures resulting from earthquake-induced liquefaction of sediments have been documented for several strong earthquakes in central interior Alaska since 1937. Earthquakes potentially strong enough to cause liquefaction have been recorded nearly every 10 yr since 1929. Although it is not yet possible to identify all potential earthquake source zones in this region or to estimate with confidence how frequently they can be expected to produce strong earthquakes in the future, the area will probably continue to be subjected to strong earthquakes at rates similar to the recent past. The probability of ground shaking sufficient to cause liquefaction in the Fairbanks-Nenana area in the foreseeable future is high.

A preliminary estimate of the relative liquefaction susceptibility of a sedimentary deposit can be made if the environment of deposition and approximate geologic age are known. By using this principle, a liquefaction-susceptibility map was made for the Fairbanks-Nenana area. The map, derived from a 1:250,000-scale geologic map of the Fairbanks Quadrangle, indicates the relative probability of encountering sediments that are likely to liquefy when they are saturated and subjected to strong shaking.

Sediments in and near active river channels have a very high liquefaction susceptibility. Adjacent deposits on inactive flood plains have moderate to high susceptibility where thawed. Because of a deep water table or presence of continuous permafrost, deposits in the upland hills and creek valleys are normally less susceptible to liquefaction.

INTRODUCTION

Liquefaction is the transformation of loose, granular sediment (as opposed to clay) to a liquefied state as a result of increased pore-water pressure. Loose, uniform fine sand or silty sand below the water table is most susceptible to liquefaction (Terzaghi and Peck, 1968). Pore-water pressure increases when excess water seeps into a sediment (producing quicksand), or when a saturated deposit is compacted. If excess water is unable to drain quickly from the deposit as the volume decreases, support of the overlying material or structure is transferred from the grain skeleton to the water, and failure occurs (Seed and Idriss, 1982).

Ground failures resulting from earthquake-induced liquefaction of sediment are documented for several strong earthquakes in central interior Alaska (fig. 1) since 1937. In describing the July 1937 earthquake centered about 50 km southeast of Fairbanks ($M_s = 7.3$), Bramhall (1938) reported sand and silt flowing from cracks in the Richardson Highway, large cracks and mud boils paralleling the banks of the Chena River, large cracks in soft ground at

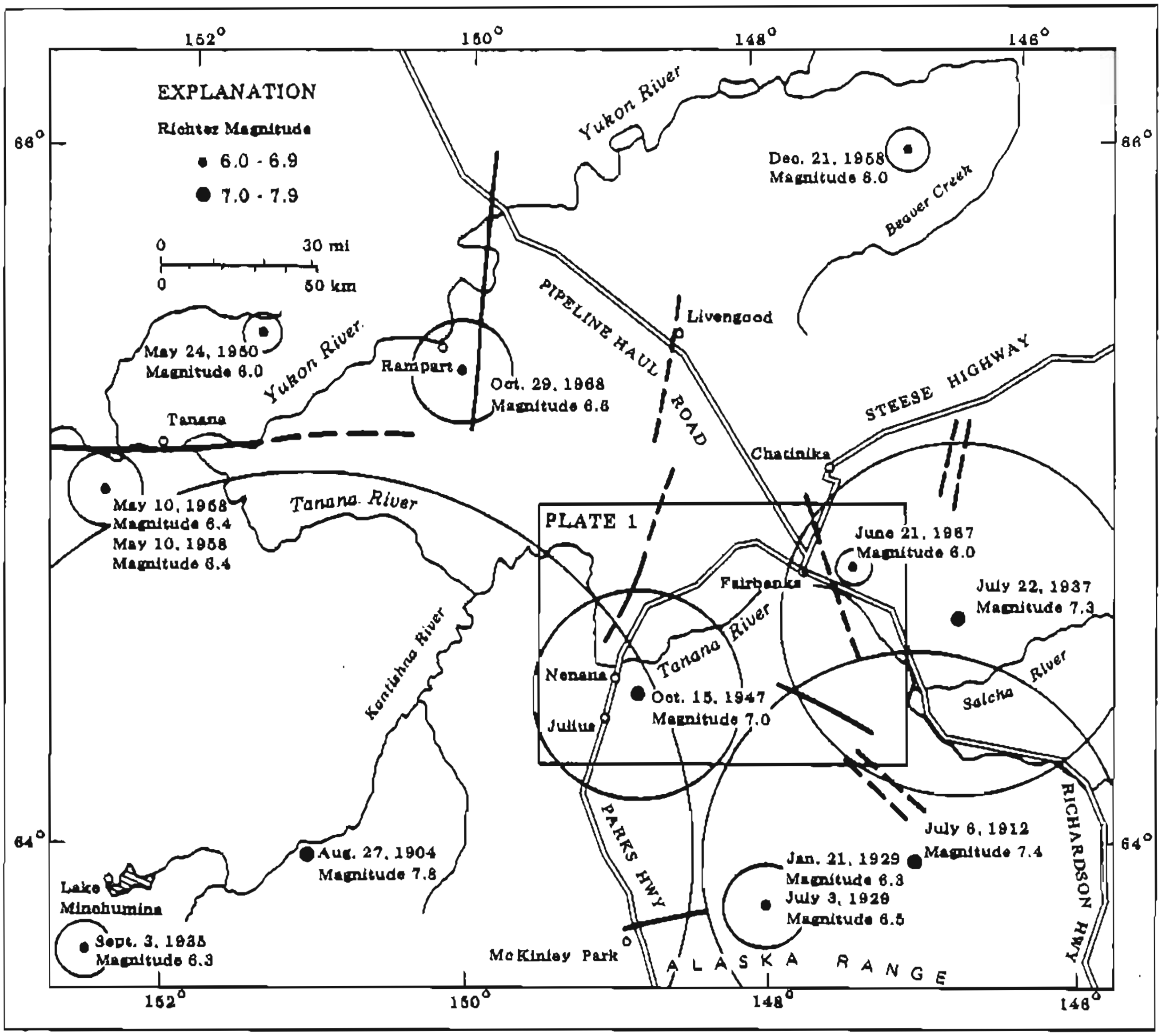

Figure 1. Distribution of earthquakes in central interior Alaska with Richter magnitudes greater than 6.0 from 1904 to 1968 and locations of faults known or inferred from geologic or seismic data (dashed where location is uncertain). The active Denali fault is beyond the south edge of the map, 150 km from Fairbanks. Circles indicate approximate areal limits of possible significant liquefaction effects during each earthquake, using the relation in figure 2. The small rectangle is the area of plate 1 (modified from Péwé, 1982, fig. 81, and Gedney and others, 1972).

the confluence of Ladue Creek and the Healy River, and mud boils and cracks up to 38 cm wide near Salcha Bluff. After the 1947 earthquake 70 km southwest of Fairbanks ($M_s = 7.0$), St. Amand (1948) described cracking of river bars on the Tanana River from Chena bluffs to Bean Ridge, on the Nenana and Tolovana

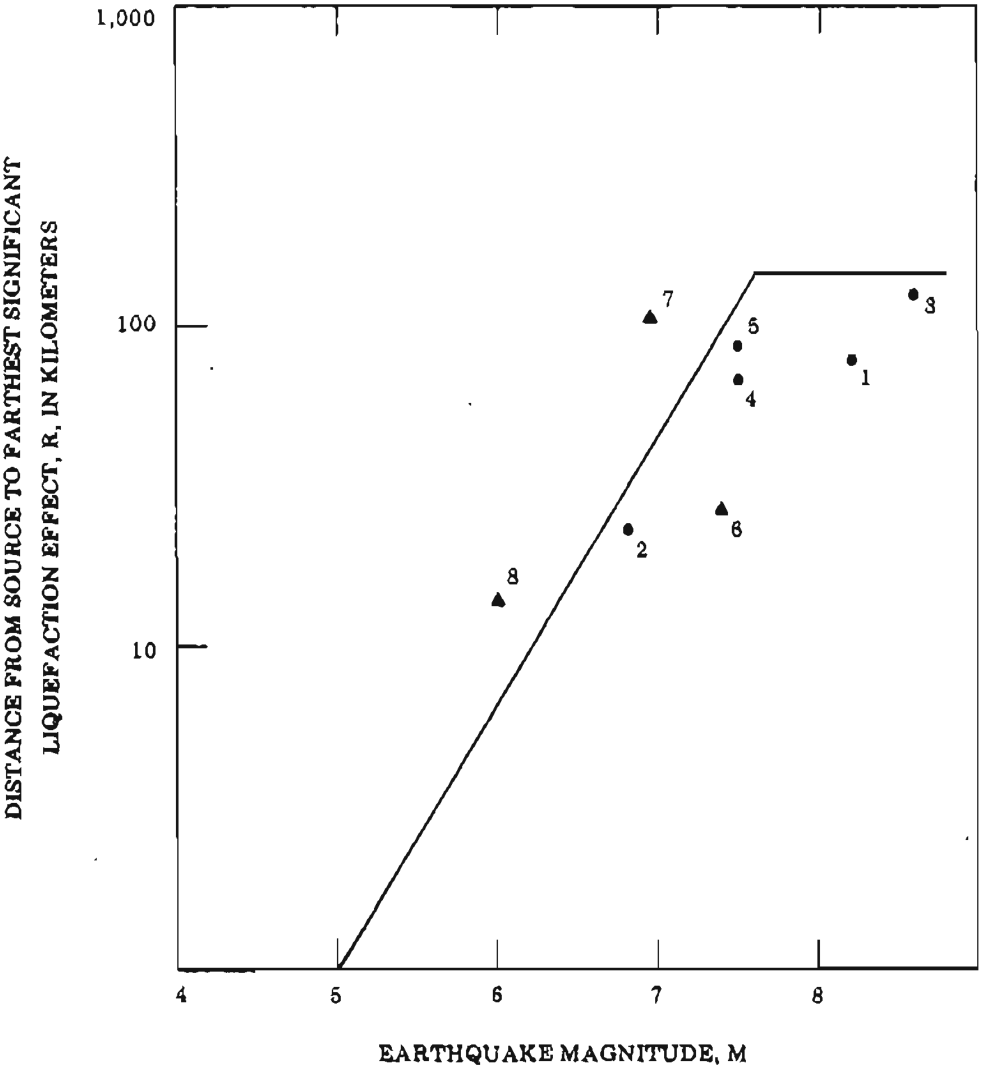

Figure 2. Earthquake magnitude versus maximum distance from seismic-source zone to significant liquefaction-induced ground failures for pertinent historic earthquakes (circles): (1) San Francisco, 1906, (2) Fallon-Stillwater, 1954, (3) southern Alaska, 1964, (4) Niigata, 1964, and (5) Gautemala, 1976 (adapted from Kuribayashi and Tatsuoka, 1975; and Youd and Perkins, 1978). Triangles represent epicentral distances to farthest reported liquefaction effects for three earthquakes in central interior Alaska: (6) 50 km southeast of Fairbanks, 1937, (7) 70 km southwest of Fairbanks, 1947, and (8) 15 km east of Fairbanks, 1967.

Rivers from Clear to Livengood, and at several places in Nenana. St. Amand believed that the cracks in the Tanana River were caused "by movement of the frozen surface layer, set up by the quake in the unfrozen alluvium beneath," and noted that all cracks observed in river bars had occurred in frozen silt or gravel underlain by unfrozen silt or sand. A magnitude 6.0 earthquake centered 15 km east of Fairbanks in 1967 produced widespread sandblows along the Tanana River (Gedney and Berg, 1969) and pumped sand into cracks in the soil (Cloud and Knudson, 1968). Most (if not all) earthquake-induced structural damage in the Fairbanks area has been to buildings located on water-saturated alluvium (Péwé, 1982). As early as 1948, builders were cautioned to avoid building on saturated silt (St. Amand, 1948) and to consider the possible effects of strong earthquakes on all saturated alluvium.

SEISMICITY OF THE FAIRBANKS-NENANA AREA

The likelihood that an earthquake will be strong enough to cause liquefaction in a given soil deposit depends on the magnitude of stresses or strains induced in the soil, which in turn is related to the intensity and duration of shaking (Seed and Idriss, 1971). In determining liquefaction potential, peak ground acceleration is most commonly used to describe intensity of shaking at a site. Liquefaction tends to occur only above a threshold level of peak ground acceleration. Peak acceleration during an earthquake is a function of earthquake magnitude, crustal attenuation properties, distance from the epicenter, and site conditions.

Earthquake duration is an important factor in determining whether liquefaction will occur because the greater the number of stress cycles, the lower the intensity required for failure (Seed and Idriss, 1971). Both intensity and duration are determined by earthquake magnitude and epicentral distance in a given region; therefore, estimates of the expected frequency, magnitudes, and locations of future earthquakes is useful in assessing the potential for liquefaction-induced ground failures---and ultimately, the effect on people and property in a region.

Estimates of future seismicity require knowledge of the locations, geometry, and recorded earthquake activity of potential source zones for large earthquakes. Seismic source zones can be identified and studied by monitoring regional seismic activity over a number of years and by conducting geologic studies to locate faults that show recent displacement. In central interior Alaska, large earthquakes have been recorded since the early 1900's. Since 1904, 11 earthquakes of Richter magnitude 6.0 and above have occurred in this region, four of which were magnitude 7.0 or greater (fig. 1). Liquefaction effects have been described for at least three of these events.

Many active faults have been mapped in central interior Alaska by using geological and seismological techniques (fig. 1). An active fault is one that shows seismic or geologic evidence of displacement during Holocene time (about the last 10,000 yr). A major difficulty in assessing the earthquake potential of the region is that many faults are buried beneath thick deposits of sediment and cannot be accurately mapped. Plots of all recorded earthquakes above about magnitude 2 show some correlation with mapped faults (Gedney and others, 1972), but most larger events cannot be definitely assigned to any known source zones. The Denali fault, 150 km south of Fairbanks, is considered active and capable of producing major earthquakes. According to Forbes and others (1976), the active segments have experienced little or no displacement for about the time necessary for enough strain to develop to produce a magnitude 8 earthquake. If such an earthquake occurs on the part of the fault nearest Fairbanks, ground shaking will probably be strong enough to cause liquefaction and other destructive effects in the Fairbanks area.

Another study (Davis and others, 1978) calculated probable recurrence intervals for earthquakes greater than specified magnitudes within 80 km of the Chena Flood Control Dam (about 24 km southeast of Fairbanks). Predictions from this study are shown in table 1. An average of 14 earthquakes strong enough to cause liquefaction (magnitude 5 or greater) is predicted every 50 yr, or one every 3.6 yr.

Table 1. Predicted recurrence intervals for earthquakes greater than specified magnitude occurring within 80 km of the Chena Flood Control Dam (from Davis and others, 1978, table 7).

Magnitude	Average number expected in 50 yr	Average recurrence interval
3.0	906	20 d
4.0	110	170 d
5.0	14	3.6 yr
6.0	2.67	19 yr
6.5	1.85	27 yr
7.0	1.25	40 yr
7.5	0.85	59 yr
8.0	0.58(?)	86(?) yr
8.5	?	no prediction

Historical records of liquefaction during earthquakes in other parts of the world can be used to make a preliminary estimate of the future potential for liquefaction in the Fairbanks region. Empirical correlations show an apparent log-linear relationship between earthquake magnitude and the distance from the seismic source zone to the farthest significant liquefaction effect (Kuribayashi and Tatsuoka, 1975; Youd and Perkins, 1978; fig. 2). Limiting factors observed to be consistent among the earthquakes studied are: a) that liquefaction-induced ground failures are not known to have resulted from earthquakes with magnitudes less than 5.0, and b) that the distance to the farthest significant liquefaction effects does not exceed about 150 km, even for the largest events. Plotting the logarithm of the distance R to farthest liquefaction effects as a function of magnitude M gives a linear relation, with log R increasing with M, the intercept at $M = 5$, and a cutoff at $R = 150$ km (fig. 2).

Using the relationship in figure 2, maximum distances (R) for possible liquefaction from epicenters of historic earthquakes in central interior Alaska were estimated, and circles of radius R were plotted with each epicenter as the center (fig. 1). Some epicenter locations may be in error by as much as several tens of kilometers. The circles approximate areas that, since 1904, have been subjected to ground shaking potentially strong enough to liquefy susceptible sediments, assuming the relation in figure 2 is valid for central interior Alaska.

Reported liquefaction effects in the Fairbanks-Nenana area can be used to assess the validity of the relation in figure 2 for estimating the maximum distance from an epicenter to farthest significant liquefaction effect in the region. The reports suggest that the relation underestimates the maximum distance to liquefaction in the study area. Some liquefaction effects were reported far outside the circles for the respective earthquakes plotted in figure 1. For example, cracking of river bars resulting from the 1947 earthquake extended from Clear on the Nenana River (25 km south of Nenana) to near Livengood on the Tolovana River, and sandblows were widespread on the Tanana River as a result of the 1967 earthquake (Gedney and Berg, 1969). One possible explanation for the discrepency is that the points plotted on figure 2 for events in central interior Alaska represent epicentral distances. Because an epicenter does not define the entire zone of energy release, the actual distance from the source zone to observed liquefaction effects may be smaller than the epicentral distance.

Perhaps the most reasonable conclusions regarding future earthquake potential in central interior Alaska are that strong earthquakes will probably continue to occur at a rate similar to that of the recent past (that is, an event of magnitude 6.0 or greater about every 10 yr), and that they occasionally will be close enough to the Fairbanks-Nenana area to produce ground shaking of sufficient intensity and duration to cause liquefaction of susceptible deposits.

DISTRIBUTION OF SEDIMENTS SUSCEPTIBLE TO LIQUEFACTION

For a given intensity and duration of earthquake-induced ground shaking, the susceptibility of a deposit to liquefaction is influenced by three primary factors: grain-size distribution, void ratio, and initial confining pressure. The sediment generally must be saturated (or nearly so) for liquefaction to occur. When saturated, recently deposited, well-sorted (uniform) fine sand within 10 m of the ground surface is most susceptible to liquefaction. Deposits that contain appreciable quantities of gravel, clay, or organic material are less susceptible. Because grain-size distribution, void ratio, and initial confining pressure are determined by the sedimentation process and postdepositional history of a deposit, a qualitative estimate of liquefaction susceptibility can be made if the environment of deposition and approximate geologic age of the deposit are known (Youd and Perkins, 1978).

Published earthquake reports have provided sufficient data on liquefaction effects to allow estimates of the relative liquefaction susceptibilities of various types of sedimentary deposits (table 2). Where a reliable geologic map is available at an appropriate scale, these criteria can be used to produce a derivative map that shows the distribution of cohesionless deposits and the relative likelihood that these deposits contain sediments susceptible to liquefaction. This derivative map can be used in the preliminary planning process or as a guide for soil-testing programs in areas that may have liquefaction-related soil instability.

Péwé and others (1966) indicate that a considerable portion of the Fairbanks Quadrangle is covered by geologically young deposits of cohesionless sediment. Because active, inactive, and abandoned flood plains compose much of the area, a shallow water table is widespread.

Table 2. Estimated susceptibility of sedimentary deposits to liquefaction during strong seismic shaking (from Youd and Perkins, 1978, table 2).

Type of deposit	General distribution of cohesionless sediments in deposits	500 yr	Holocene	Pleistocene	Pre-Pleistocene
		Continental deposits			
River channel	Locally variable	Very high	High	Low	Very low
Flood plain	Locally variable	High	Moderate	Low	Very low
Alluvial fan and plain	Widespread	Moderate	Low	Low	Very low
Marine terraces and plains	Widespread	- -	Low	Very low	Very low
Delta and fan-delta	Widespread	High	Moderate	Low	Very low
Lacustrine and playa	Variable	High	Moderate	Low	Very low
Colluvium	Variable	High	Moderate	Low	Very low
Talus	Widespread	Low	Low	Very low	Very low
Dunes	Widespread	High	Moderate	Low	Very low
Loess	Variable	High	High	High	Unknown
Glacial till	Variable	Low	Low	Very low	Very low
Tephra	Widespread	High	High	?	?
		Coastal zone			
Delta	Widespread	Very high	High	Low	Very low
Estuarine	Locally variable	High	Moderate	Low	Very low
Beach					
High wave energy	Widespread	Moderate	Low	Very low	Very low
Low wave energy	Widespread	High	Moderate	Low	Very low
Lagoonal	Locally variable	High	Moderate	Low	Very low
Foreshore	Locally variable	High	Moderate	Low	Very low
		Artificial			
Uncompacted fill	Variable	Very high	- -	- -	- -
Compacted fill	Variable	Low	- -	- -	- -

A derivative liquefaction-susceptibility map (pl. 1) was constructed for the northeastern part of the Fairbanks Quadrangle using the criteria in table 2. The map indicates the relative likelihood that, when saturated, a deposit would be susceptible to liquefaction. Additional assumptions were made to account for the presence of permafrost, organic matter, or gravel. Perennially frozen silt in upland creek valleys, for example, is less susceptible to liquefaction than unfrozen silt, because there is little or no opportunity for pore pressure to increase in response to ground shaking.

Permafrost is generally continuous and several tens of feet thick except near the margins of these areas and beneath lakes and streams; liquefaction is unlikely in the sediment beneath permafrost that is more than 10 m thick because of high overburden pressure. Other lowland areas are underlain by discontinuous permafrost, and scattered massive ground ice may be present. The assigned susceptibilities in all deposits except the perennially frozen silt assume permafrost-free conditions (pl. 1).

The presence of continuous permafrost may enhance the susceptibility of overlying material in some areas. The underlying permafrost restricts drainage and may maintain a shallow water table. In deposits of silt or fine sand where the permafrost table is relatively deep (such as beneath cleared fields or in thaw bulbs near lakes and streams), a locally high liquefaction susceptibility may exist. However, this condition is likely to be limited to late summer and early fall, when the seasonal frost layer has thawed to maximum depth. Earthquake-induced liquefaction in these areas is unlikely the rest of the year.

The sand and gravel content of recent flood-plain alluvium varies. Although the gravelly flood-plain deposits also contain some sand lenses, their overall liquefaction susceptibility is probably lower than indicated in table 2 because a) the susceptibility of gravelly deposits is lower, and b) the likelihood of encountering sizeable sand bodies is less than in other parts of the same deposit. The gravelly areas were therefore assigned moderate liquefaction susceptibility, whereas flood-plain areas blanketed with thick silt and silty-sand deposits were assigned a high susceptibility. Swamp deposits were assigned a low liquefaction susceptibility because of the presence of abundant organic matter, which inhibits compaction by providing grain support.

Water-table depth was not considered in determining liquefaction susceptibilities. Water-table depth can be taken into account by using the following criteria: a) if the water table is more than about 10 m deep, the likelihood of occurrence of liquefaction in most deposits is low; b) if the water table is below the base of a deposit, even if less than 10 m deep, liquefaction is unlikely; and c) if the water table is less than 10 m deep and is above the base of the deposit, the susceptibility indicated on the map is applicable (Youd and Perkins, 1978).

Generalized water-table depths in the Fairbanks area (Nelson, 1978; Péwé and Bell, 1975a,b, 1976) were extrapolated over the map area. Under normal conditions, the water table in the active and abandoned flood-plain areas is within 10 m of the surface, whereas it is much deeper in the upland hills and in the creek-valley bottoms where confined under continuous permafrost. The liquefaction susceptibility of any deposit is low where the water table is normally deeper than 10 m.

Hydrologic conditions may cause the water table to rise locally, which will increase the liquefaction susceptibility of the sediments. Sustained high discharge from spring snowmelt or heavy rain often causes a temporary increase in ground-water levels near rivers (Nelson, 1978). If a strong earthquake coincides with this condition, liquefaction is very likely, especially along rivers where the liquefaction susceptibility is moderate to very high. If the earthquake of June 21, 1967 (magnitude 6.0) had occurred 2 months later, when waters of the August 15 flood were still high, the damage from the earthquake may have equaled or exceeded the flood damage.

CONCLUSIONS

Assuming that strong earthquakes will continue to occur in central interior Alaska at rates comparable to those of the past 60 yr, the probability is high that, in the near future, ground shaking will be strong enough to cause liquefaction of sediments in the Fairbanks-Nenana area. A preliminary determination of liquefaction susceptibilities of deposits in the area, based on the environment of deposition and geologic age, indicates that saturated sediments in and near the active river channels of the Tanana, Chena, and Nenana River flood plains are highly likely to liquefy during strong shaking. The liquefaction susceptibility of Holocene abandoned flood-plain deposits ranges from moderate to high, depending on the relative quantity of gravel.

Although the liquefaction susceptibility of primary and retransported eolian silt on upper slopes and hilltops is high, the likelihood that this sediment would liquefy is low because of the deep water table in these areas. Retransported silt in the upland creek valleys has a low liquefaction susceptibility because it is rich in organic material and is generally underlain by thick, continuous permafrost. Although the active frost layer above the permafrost becomes saturated when thawed, the layer is too thin in most places for major liquefaction to occur. The liquefaction susceptibility may be high where the permafrost table is deeper than about 2 m, but this condition is probably limited to late summer and early fall, when the active frost layer has thawed to maximum depth.

ACKNOWLEDGMENTS

Early drafts of this paper were reviewed by R.D. Reger and N.I. Johansen, whose comments are appreciated. J.N. Davies and R.G. Updike contributed constructive review comments on the manuscript, and J.H. Ewing drafted the figures.

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