LIQUEFACTION POTENTIAL MAP FOR DAVIS COUNTY, UTAH COMPLETE TECHNICAL REPORT

by
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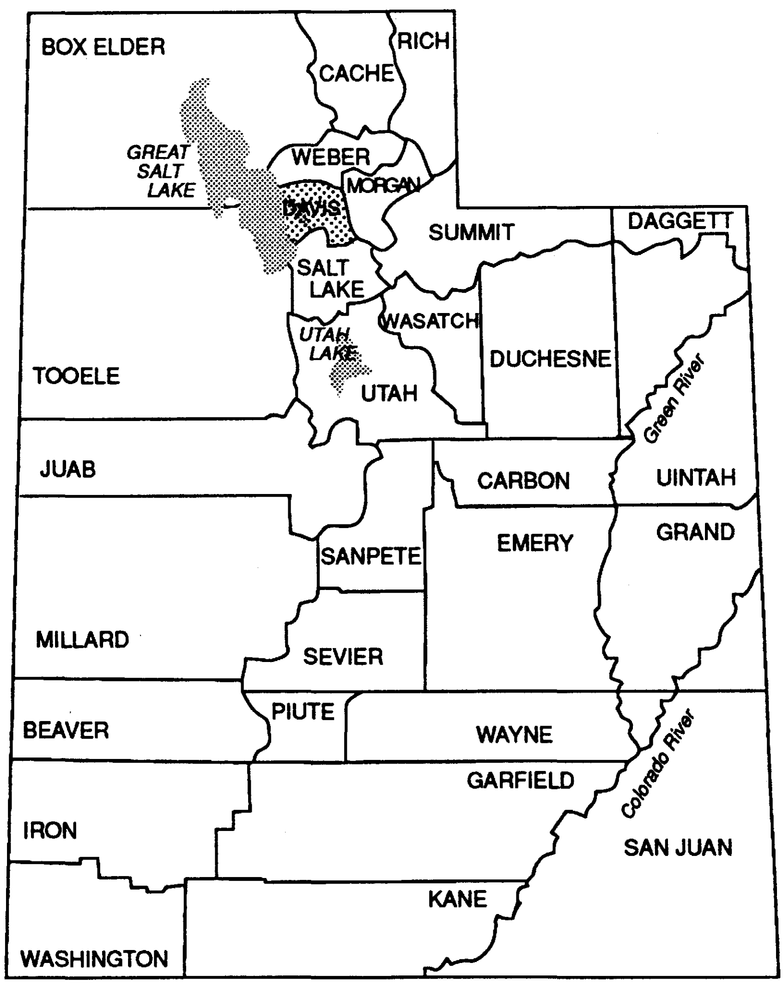

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TAKE Pride IN UTAH

LIQUEFACTION POTENTIAL MAP

for

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Loren R. Anderson, Jeffrey R. Keaton
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EXECUTIVE SUMMARY

As part of the U.S. Geological Survey's Earthquake Hazard Reduction program a "Liquefaction Potential Map" has been prepared for Davis County, Utah. Liquefaction potential was evaluated from existing subsurface data and from a supplementary subsurface investigation performed as one of the tasks in this study. All of the data used in this study are summarized on the base maps presented as Plates 1A, 1B, 2A and 2B.

For this regional assessment, *liquefaction* implies *liquefaction-induced ground failure*. The liquefaction potential is classified as high, moderate, low and very low depending on the probability that a critical acceleration will be exceeded in 100 years. The critical acceleration for a given location is defined as the lowest value of the maximum ground surface acceleration required to induce liquefaction. The catagories of high, moderate, low and very low correspond to probabilities of exceeding the critical acceleration in the ranges of greater than 50 percent, 10 to 50 percent, 5 to 10 percent and less than 5 percent, respectively.

The Liquefaction Potential Map on Plates 4A and 4B shows that for a significant portion of Davis County the probability of exceeding the critical acceleration in 100 years is greater than 50 percent. Hence, liquefaction

induced ground failure is a significant seismic hazard.

Ground slope information, as well as the subsurface conditions documented on the Soils and Ground Water Data Map, can be used in combination with the Liquefaction Potential Map as a means of assessing the type of ground failure likely to occur. Three slope zones have been identified from the characteristic failure modes induced by liquefaction during historic earthquakes (Youd, 1981, personal communication).

At slope gradients less than about 0.5 percent, loss of bearing capacity is the type of ground failure most likely to be induced by soil liquefaction. Stratified soil conditions, which exist in Davis County, provide vertical confinement for liquefiable layers and may tend to reduce the probability of bearing capacity failures. Buildings imposing light loads on the subsurface soils may not be affected by loss of bearing capacity during an earthquake. Heavy buildings, on the other hand, might be severely affected. Additionally, during earthquakes, heavy buildings subjected to movement from deformation of the subsurface soils might cause damage to adjacent lightly-loaded structures.

Buried tanks, even those full of water or gasoline, could "float" to the surface if the soils surrounding them were to liquefy. For this to happen, however, the tanks would have to be buried in very thick deposits of sand. The stratified nature of the soils in Davis County generally tends to reduce the likelihood of this type of failure.

Slope gradients ranging from about 0.5 percent to about 5.0 percent tend to fail by lateral spread processes as a result of soil liquefaction. Evidence exists in Davis County for five large lateral spread landslides (see Plates 1A and 1B). Consequently, it appears that these kinds of failures have occured in response to earthquakes within the past few thousand years.

Lateral spread landslides present the greatest concern because of the potential consequences. A small amount of movement can do a great deal of damage. Lifelines (buried utilities) are particularly vulnerable. A large amount of Davis County falls within the slope range characterized by lateral spread landslides induced by soil liquefaction.

Slopes steeper than about 5 percent tend to fail as flow slides if the mass of soil comprising the slope liquefies. In Davis County, the stratified nature of the geologic materials suggests that flow-type failures are likely to be relatively rare. Instead, translational landslides or lateral spreads are likely to result from liquefaction on slopes steeper than about 5 percent.

In some places in the county granular soils were found to be relatively loose but not saturated. Unsaturated soils are not susceptible to liquefaction; however, these soils are noted because ground water conditions could change. These soils would be susceptible to liquefaction if they were to become saturated. Areas where unsaturated, relatively loose granular soils were found are identified as "potential susceptibility" by open triangle symbols on the Ground Slope and Critical Acceleration Map (Plates 3A and 3B).

It should be emphasized that perched ground water is equal to true ground water with respect to soil liquefaction. Saturated granular material is the chief concern; the source of the saturation is immaterial.

The results of our research on the liquefaction potential of Davis County lead us to conclude that lateral spread landsliding is the type of ground failure most likely to accompany soil liquefaction. The probability of extensive damage due to this type of ground failure is very high. All types of structures could be damaged by liquefaction-induced ground failure; lifelines are especially susceptible to damage.

INTRODUCTION

General

The effects of earthquakes can cause loss of life and costly property damage; therefore, in areas of high seismic activity, earthquake hazard reduction must be an important consideration for intelligent land use planning. Damage during earthquakes can result from surface faulting, ground shaking, ground failure, generation of large waves (tsunamies and seiches) in bodies of water, and regional subsidence or downwarping (Nichols and Buchanan-Banks, 1974). Although all of these causes of damage need to be considered in reducing earthquake hazards, this report deals only with liquefaction-induced ground failure.

Ground failure associated with earthquake-induced soil liquefaction has caused major damage during past earthquakes (Seed, 1979; Youd and Hoose, 1977). The seismic history of the Wasatch front area in north-central Utah clearly indicates that ground motion of sufficient intensity and duration to induce liquefaction of susceptible soils is very likely to occure in the relatively near future.

Deposits of loose fine sand, highly susceptible to liquefaction, exist along the Wasatch front (McGregor and others, 1974). Areas of shallow ground water are also widespread (Hely and others, 1971, Fig. 80). In addition, evidence of liquefaction was observed following the 1934 Hansel Valley earthquake in Box Elder County, Utah (Coffman and von Hake, 1973, p. 71) and again following the Cache Valley earthquake of 1962 (Hill, 1979).

The seismic history, subsurface soil and ground water conditions, and evidence of liquefaction in Utah indicate that liquefaction is a significant hazard which must be assessed as an important element in seismic hazard reduction planning.

Purpose and Scope of Study

The purpose of this study was to develop a liquefaction potential map for Davis County, Utah. Davis County is located in northern Utah's urban corridor between Utah's two largest cities, Salt Lake City and Ogden. The study area extends from the base of the Wasatch Mountains to the present shores of the Great Salt Lake and Farmington Bay as shown on Fig. 1.

The liquefaction potential was evaluated on the basis of subsurface data that was obtained from private engineering consultants, state and local government agencies and from a supplementary subsurface investigation performed as one of the tasks in this study. The results of the study are summarized on four maps; each map consists of two parts (A & B) separating the county into a south and a north half.

The base maps are 50 percent reductions of U. S. Geological Survey 7½-minute topographic quadrangles (a scale of 1:48,000). The four maps are presented in later sections of this report and consist of (1) Selected Geologic Data

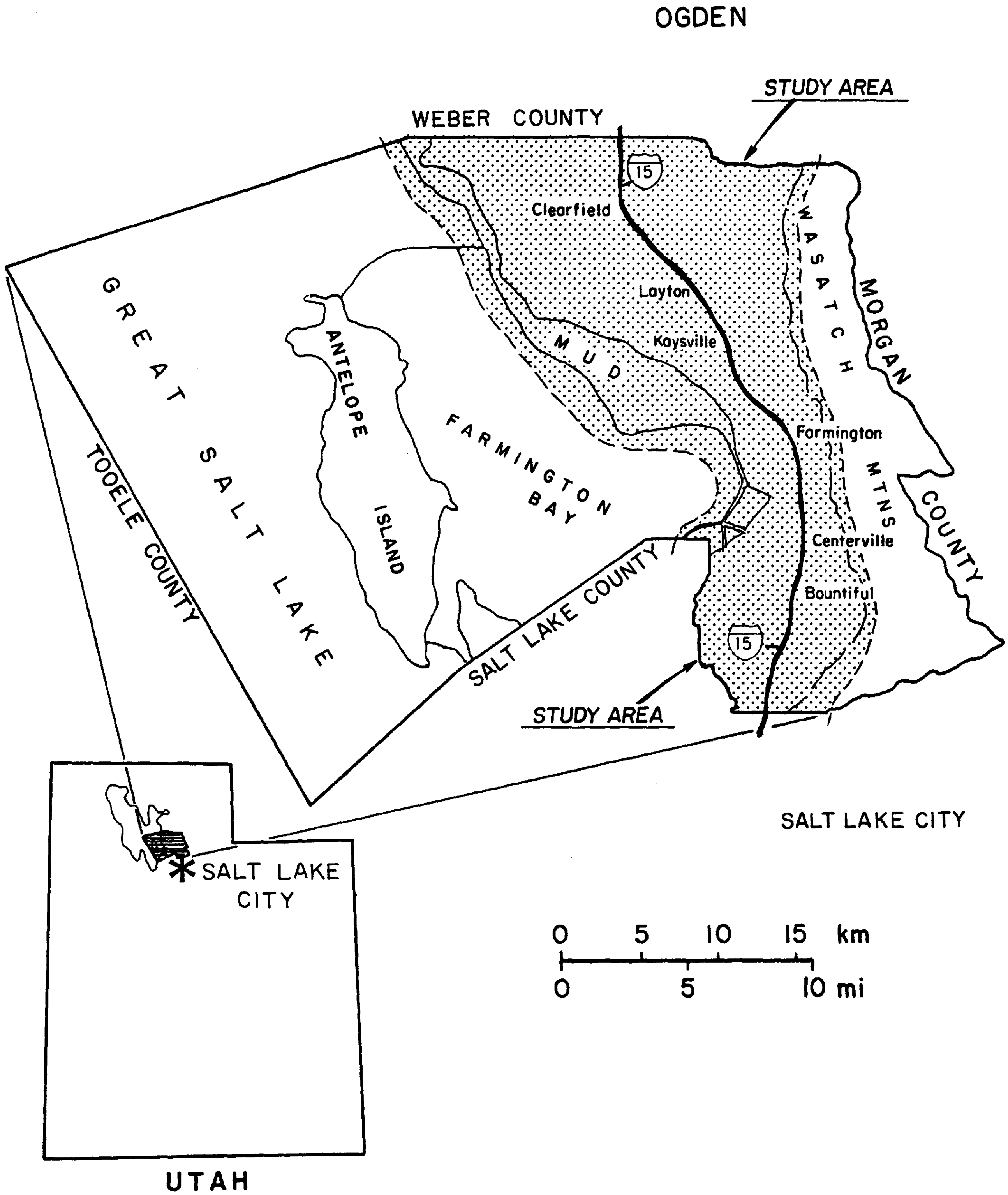


Figure 1. Davis County, Utah and boundaries of the study area.

Map, (2) Soils and Ground Water Data Map, (3) Ground Slope and Critical Acceleration Map and (4) Liquefaction Potential Map.

Boring logs and laboratory data that were collected and developed during the study are maintained in the files of the Civil Engineering Department at Utah State University.

Liquefaction-Induced Ground Failure

In this study, the term "liquefaction" implies the occurence of liquefaction-induced ground failure. This is an important distinction because it is the ground failure which causes damage, not soil liquefaction per se.

Loose, saturated fine sand deposits subjected to earthquake shaking can liquefy, losing essentially all shear strength, because pressures are rapidly transferred from the granular structure of the soil to the pore water. If the pore water pressure increases until the intergranular stress is reduced to zero, a condition of "initial liquefaction" is reached (Seed, 1976). For loose sands, this condition is usually accompanied by large deformations and ground failure typically occurs.

In general, three types of ground failure are commonly associated with liquefaction: (1) flow landslides, (2) lateral spread landslides, and (3) bearing capacity failures. Youd and others (1975) relate these types of ground failure with the slope of the ground surface. The most common type of liquefaction-induced ground failure is probably lateral spread landsliding. However, the topographic and geologic conditions of Davis County make all three types of ground failure possible.

Regional Seismicity

The state of Utah is bisected by the Intermountain Seismic Belt (Fig. 2). The occurence of earthquakes in the state is common and has been documented since 1850; a plot of the locations of epicenters from July 1962 to June 1978 (Fig. 3) graphically illustrates that earthquakes in Utah are common.

Many known and suspected Quaternary faults have been mapped in Utah (Fig. 4); the Wasatch fault zone is one of the most prominent. The distribution of fault traces (Fig. 4) has a strong relationship with epicenter locations (Fig. 3). Swan and other (1980) investigated the Wasatch fault zone at two sites in the urban corridor of the Wasatch front. They estimated that moderate- to large-magnitude earthquakes (M_L = 6 ½ to 7 ½) on the Wasatch fault zone may occur as frequently as 50 to 430 years.

General Subsurface Conditions

Virtually all of the urbanized area of Davis County was inundated by Pleistocene Lake Bonneville, of which the Great Salt Lake and Utah Lake are remnants. Consequently, most of the sediments in Davis County are probably late Pleistocene or younger in age.

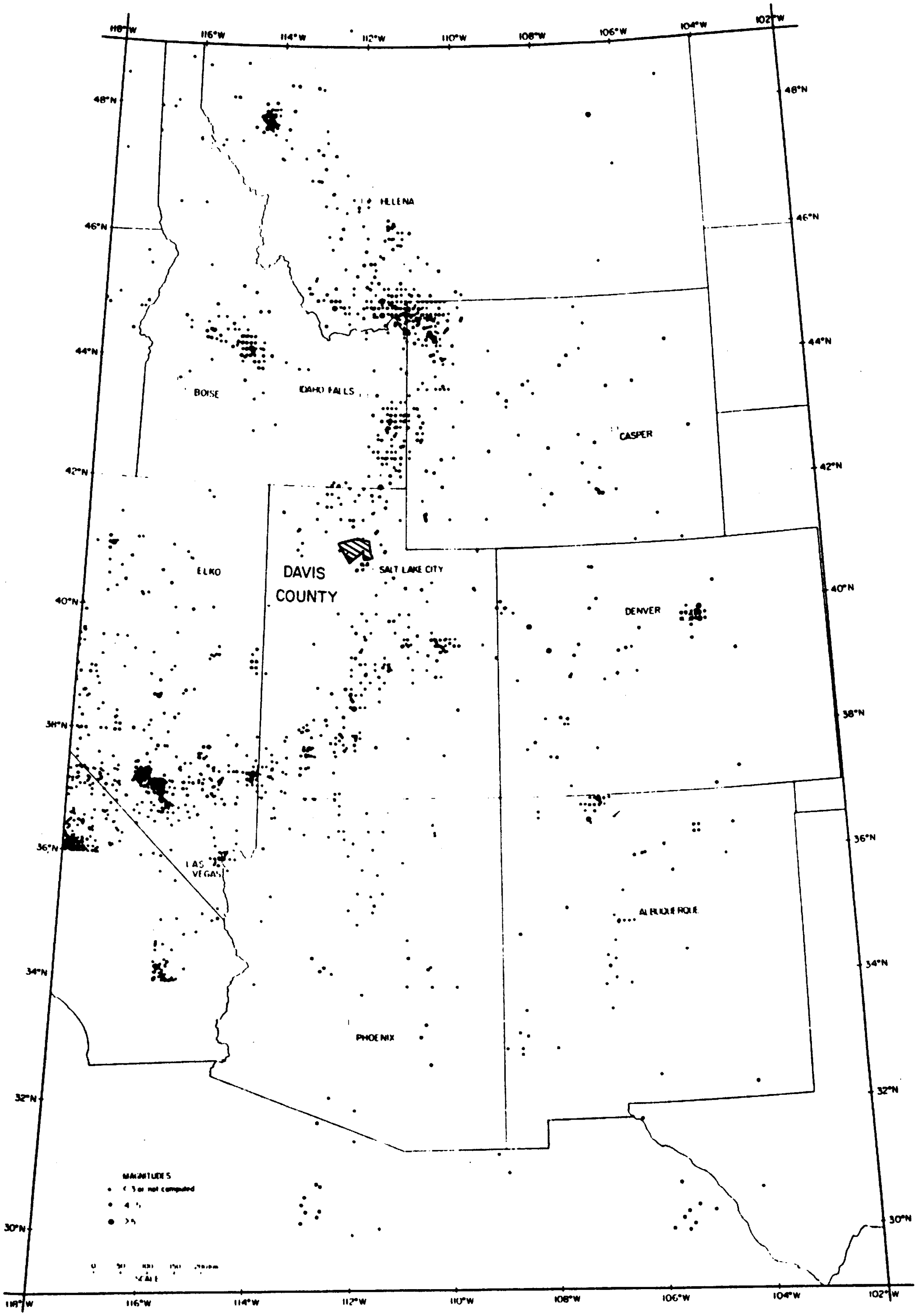


Figure 2. Intermountain Seismic Belt (1850–1974)
(After Arabasz, Smith and Richins, 1979)

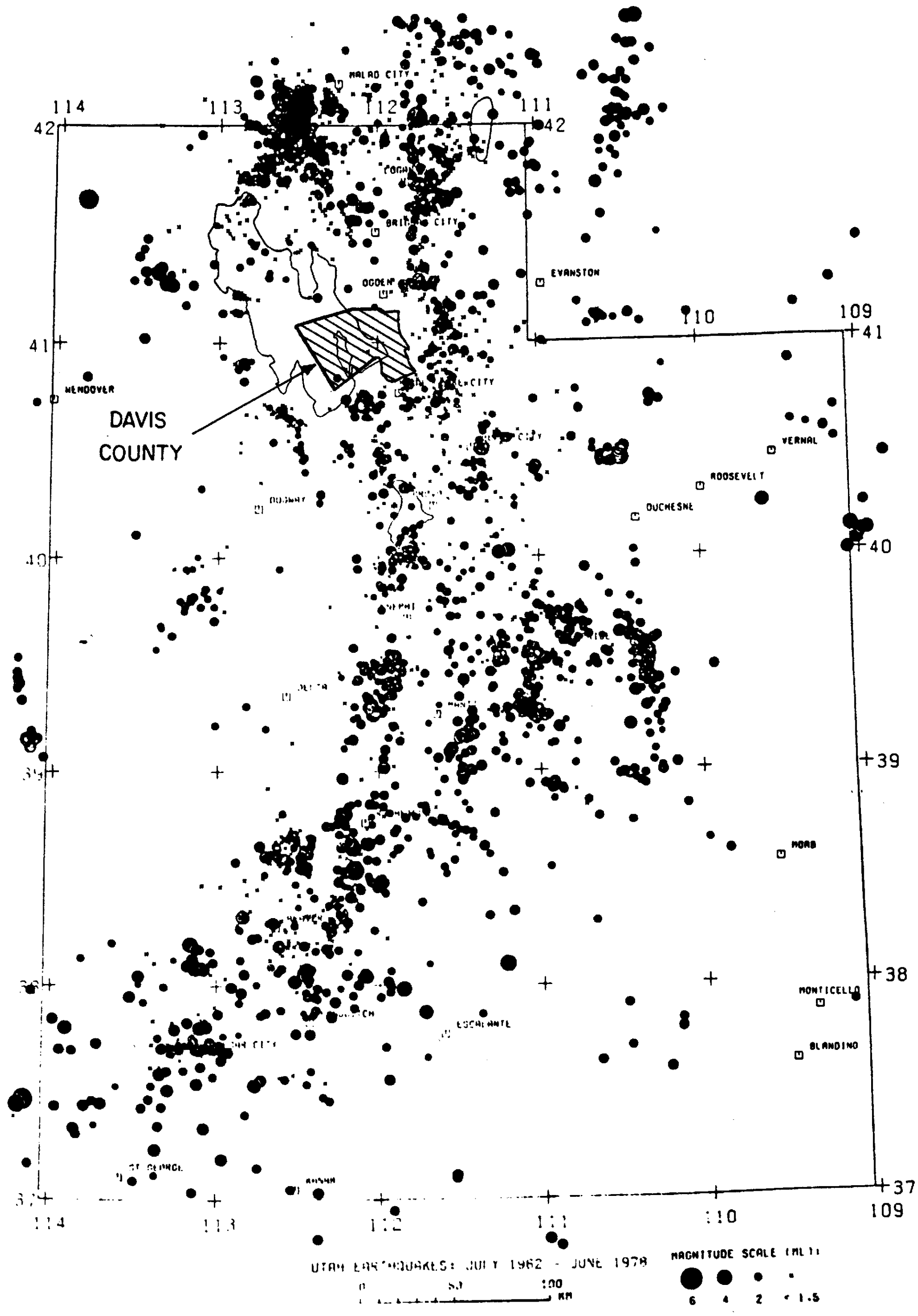


Figure 3. Epicenters in Utah, July 1962 to June 1978 (After Arabasz, Smith and Richins, 1979)

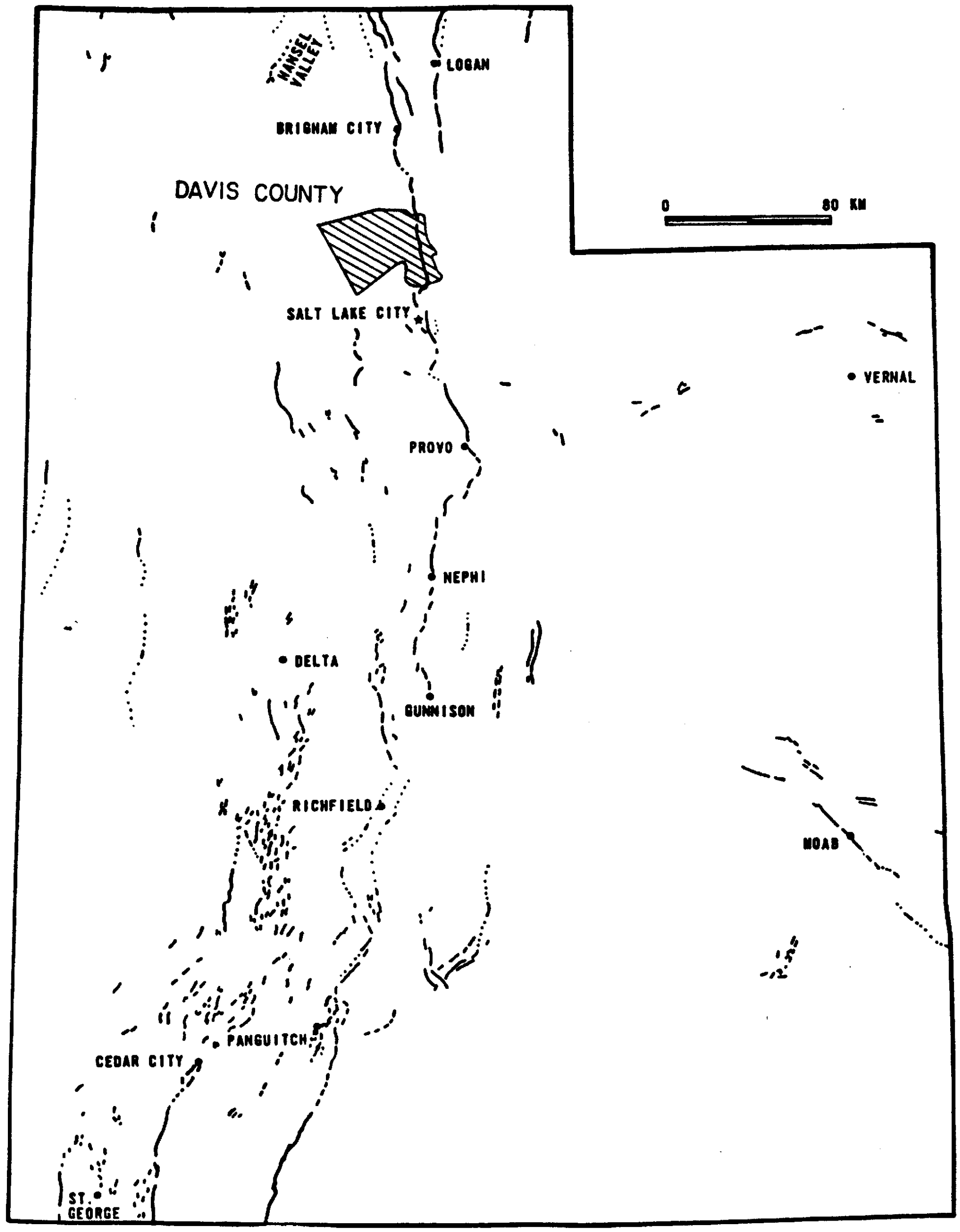


Figure 4. Known and suspected Quaternary faults in Utah (After Anderson and Miller, 1979)

The lake bed sediments of the region generally consist of deposits of sand, silt and clay. The liquefiable sand and silt deposits vary in thickness from several millimeters to several meters and occur throughout Davis County. Extensive gravel deposits are present along the east side of the study area on the upper Lake Bonneville shore lines. These gravel deposits are most notable in the Weber delta region located in the northeast part of the study area and in the area east and south of Bountiful, Utah.

The ground water table in much of the study area is within a few feet of the ground surface and local areas of artesian conditions are present. In the bench areas along the higher shore lines of Lake Bonneville, the water table is generally much deeper but cases of perched ground water are known to exist. Lawn sprinkling and other effects of additional development along the bench areas will probably contribute to the occurence of perched ground water.

METHODOLOGY

General

Subsurface data was collected for selected sites from throughout the Davis County study area. Ground surface accelerations required to induce liquefaction at each site were computed. These acceleration values are referred to as "critical accelerations." The liquefaction potential for each site was then classified as high, moderate, low or very low depending on the probability of the computed "critical" ground surface acceleration being exceeded in 100 years.

Factors Affecting Liquefaction Potential

The factors affecting liquefaction include soil properties, initial stress conditions, seismic history and the characteristics of the earthquake motion. Aside from saturated conditions, the following factors are considered fundamental: (1) soil type, (2) relative density, (3) initial confining pressure, (4) intensity and duration of ground shaking, (5) soil structure and (6) seismic history.

Deposits of loose fine to medium sand with uniform grain size distributions are generally considered to be the most susceptible to liquefaction. Soils with more than about 15 percent clay typically have sufficient cohesive strength that liquefaction will not occur. Very loose sands are most susceptible to liquefaction while very dense sands are least susceptible. High confining pressure requires more stress to initiate liquefaction than does low confining pressure. Sands that have been subjected to repeated ground shaking without inducing liquefaction are less susceptible to liquefaction than sands without such a seismic history.

The characteristics of the earthquake motion that affect liquefaction opportunity are the intensity and duration of ground shaking. Consideration of these ground shaking characteristics is important in evaluating liquefaction potential.

Evaluation of Liquefaction Potential

An evaluation of liquefaction potential at a given site by current state of the art methods involves comparing the predicted cyclic stress ratio (τ/σ_o') that would be induced by a given design earthquake with the cyclic stress ratio required to induce liquefaction. Figure 5 illustrates this comparison. The predicted cyclic stress ratio can be computed using response analysis techniques or by a simplified procedure based on rigid body theory modified to account for the flexibililty of the soil profile (Seed, 1976). The simplified theory for computing the cyclic stress ratio induced by an earthquake is given by Eq. 1.

$$\frac{\tau_{av}}{\sigma_o'} \approx 0.65 \frac{a_{max}}{g} \left(\frac{\sigma_o}{\sigma_o'}\right) r_d \qquad (1)$$

where, a_{max} = maximum acceleration at ground surface

σ_o = total overburden pressure on sand layer under consideration

σ_o' = initial effective overburden pressure on sand layer under consideration

r_d = a stress reduction factor varying from a value of 1 at the ground surface to a value of 0.9 at a depth of about 30 ft.

The cyclic stress ratio required to cause liquefaction can be evaluated either by laboratory tests on undisturbed samples or by an emperical relationship between some insitu property of the soil and the cyclic stress ratio required to cause liquefaction. Securing undisturbed samples of sand

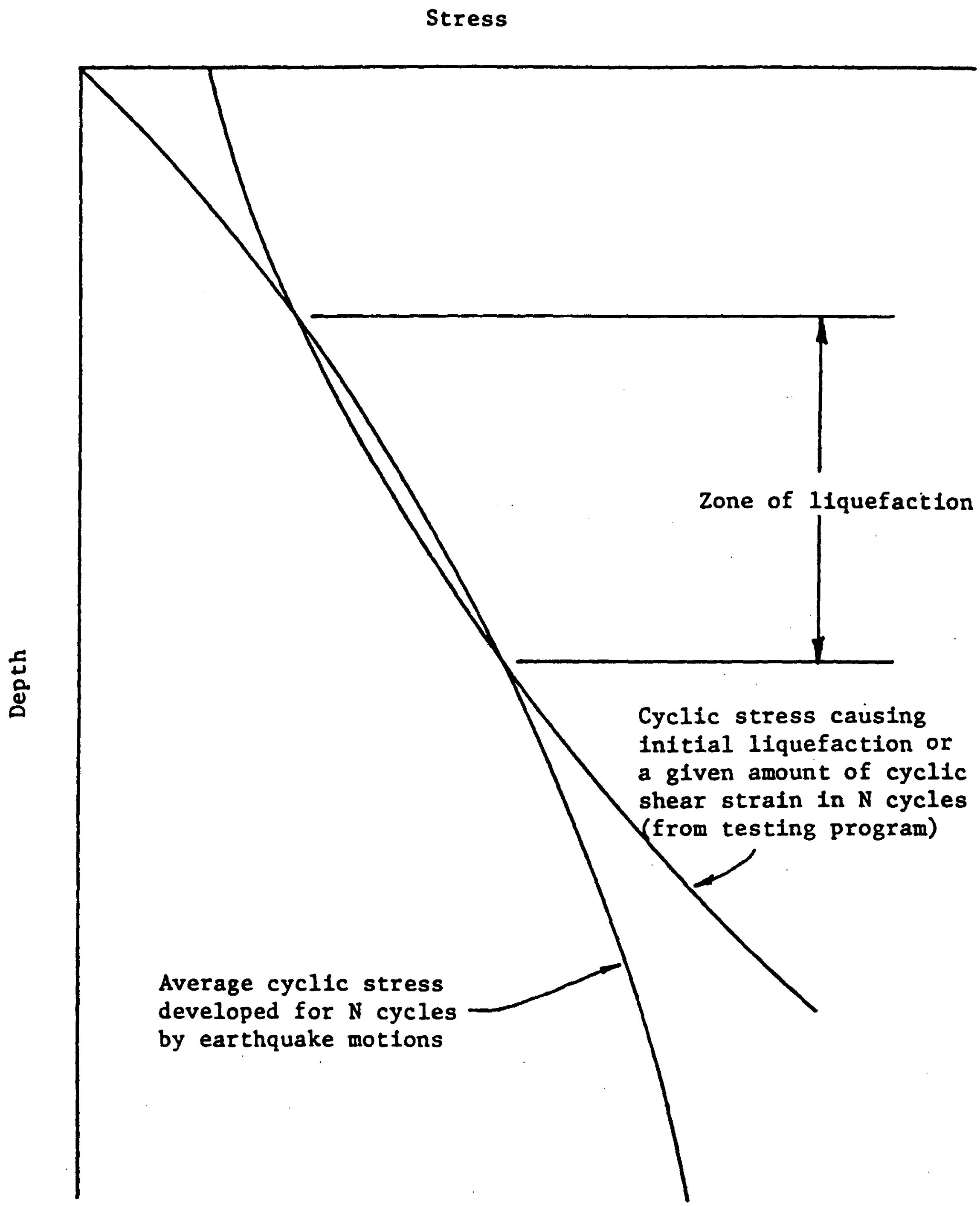


Figure 5. Method of evaluating liquefaction potential (after Seed and Idriss, 1971).

for laboratory testing is a very difficult, if not impossible, task and the use of reconstituted samples would not model the seismic history or structure of the soil deposit. Therefore, the use of laboratory tests to evaluate the cyclic stress required to induce liquefaction in natural deposits is questionable.

Seed, Mori and Chan (1977) have developed an emperical relationship (shown on Fig. 6) between the cyclic stress ratio required to cause liquefaction and the standard penetration resistance of the soil.

Seed (1976) points out that the factors that tend to influence liquefaction susceptibility such as relative density, age of the deposit, seismic history and soil structure also tend to influence the standard penetration resistance in a like manner. Although the standard penetration test has its own shortcomings, if used properly and with judgement it provides a convenient and rapid method of evaluating the insitu characteristics of sand. The standard penetration test also provides a convenient method to utilize existing data in evaluating liquefaction potential because in the past the most common method to obtain samples of sand has been the standard penetration test.

Gibbs and Holtz (1957) correlated standard penetration resistance with relative density and effective overburden pressure. Their work showed that the standard penetration resistance for a constant relative density was a function of

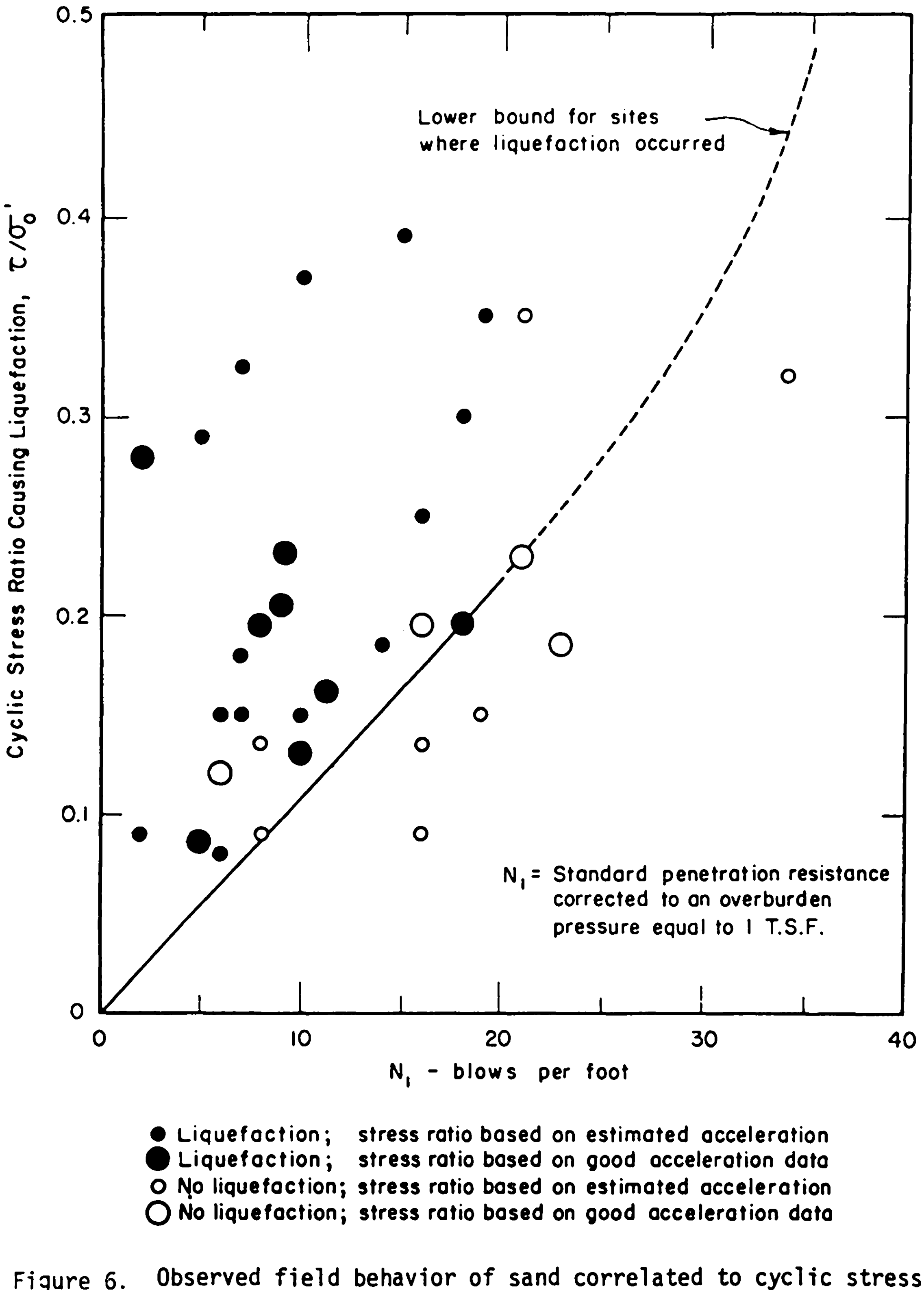


Figure 6. Observed field behavior of sand correlated to cyclic stress ratio and standard penetration resistance (after Seed, Mori and Chan, 1977).

the overburden pressure. Therefore, Seed, Mori and Chan (1977) used a standard penetration resistance corrected to an overburden pressure of one ton per square foot in developing the relationship between standard penetration resistance and the cyclic stress ratio required to cause liquefaction given by Fig. 6. The correction factor used by Seed, Mori and Chan is based on Gibbs and Holtz work and was suggested by Peck, Hansen and Thornburn (1973). The correction factor is applied as follows:

$$N_1 = C_N . N \tag{2}$$

where, $$C_N = 1 - 1.25 \log \frac{\sigma_o'}{\sigma_1'}$$

σ_o' = effective overburden pressure in tons per square foot where the penetration has a value of N

σ_1' = one ton per square foot

<u>Liquefaction Potential Based on Critical Acceleration</u>

Qualitative descriptions of the liquefaction potential in the Davis County study area were assigned on the basis of the probability that the computed values of critical acceleration would be exceeded during a 100-year time period. The critical acceleration for a given location is defined as the lowest value of maximum ground surface acceleration required to induce liquefaction.

The standard penetration test data from soil borings in conjunction with Eq. 1 and Fig. 6 were used to compute the critical acceleration at numerous locations throughout the study area. Equation 1 can be solved for the critical acceleration and stated as:

$$(a_{max})_c = \left(\frac{\tau_{av}}{\sigma_o'}\right) \left(\frac{\sigma_o'}{\sigma_o}\right) \left(\frac{1}{0.65\ r_d}\right) \qquad (3)$$

where, $(a_{max})_c$ = critical acceleration (ground surface acceleration required to induce liquefaction at a given site)

$\left(\frac{\tau_{av}}{\sigma_o'}\right)$ = cyclic stress ratio required to cause liquefaction at the given site and obtained from the standard penetration resistance and Fig. 6

σ_o = total overburden pressure at the point where the standard penetration resistance is measured

σ_o' = effective overburden at the point where the standard penetration resistance is measured

Note that the cyclic stress ratio, $\left(\frac{\tau_{av}}{\sigma_o'}\right)$ required to cause liquefaction is computed using Fig. 6 and the standard penetration results from each boring location.

Judgement was required in assigning critical acceleration values. Generally more than one boring log was available for a given site and many standard penetration values were reported for each boring. Therefore, several critical acceleration values were computed for each boring at each site. A value considered to be representative of the critical acceleration was then assigned to the site. In assigning this representative value, consideration was given to consistancy within and between borings, to the soil type and to the limitations of the standard penetration test. A single low critical acceleration value at a site was not considered representative if it was not consistant with other critical acceleration values at the site and in the general area.

Critical acceleration values were only computed for sand and silty sand, and for sandy silt with less than 15 percent clay-size material and a plastic index less than 5. Since the penetration value is the number of blows required to drive a standard sampler one foot, layers being evaluated must be at least one foot thick. For this reason, borings containing sand layers thinner than one foot could not be assigned acceleration values.

As stated above, the liquefaction potential was assigned on the basis of the probability that the critical acceleration would be exceeded in 100 years. The probabilities used in assigning liquefaction potential are presented in Table 1.

Table 1. Liquefaction potential related to exceedance probability

Probability of Exceeding Critical Acceleration in 100 years	Liquefaction Potential
> 50%	High
10 - 50%	Moderate
5 - 10%	Low
< 5%	Very Low

The probability values delineating liquefaction potential were selected partially on the basis of probability limits frequently used in selecting accelerations for structural design purposes. In structural engineering the concept of dual levels of design accelerations has become widely accepted in recent years. This concept first considers an earthquake with a moderate probability of occurrence during the projected lifetime of a structure; the structure should be designed to remain elastic (completely functional) during the earthquake event. The structure as designed for this first event should then be analyzed to estimate its probable response to a larger event which has a smaller probability of occurrence. The structure would be expected to develop ductility (be damaged) during its response to the second and larger motion but not expected to collapse.

The values usually chosen for these two levels of acceleration are (1) the value which has a 50 percent probability of being exceeded during the projected life of the structure (the elastic design motion) and (2) a value close to that which has only a 10 percent probability of being exceeded during the life of the structure (the larger acceleration for which the structure may develop ductility). These probability values of 50 percent and 10 percent were set as the limits delineating the high and moderate liquefaction potential categories. A probability value of 5 perent was then arbitrarily selected to separate low and very low liquefaction potential. For planning purposes a 100-year time period was assumed appropriate.

Other probability limits could have been selected and this would have some effect on the configuration of liquefaction potential categories on the map. However, regardless of the probability values used to define the high, moderate, low and very low classifications, those selected clearly allow a relative assessment of the liquefaction hazard within the study area.

Liquefaction Potential Map

Computed critical acceleration values for specific sites were plotted on a map of the study area. A two-step procedure was then used to develop the Liquefaction Potential Map. Contours were first drawn on the basis of the critical acceleration values and used to divide the study area into zones of high, moderate, low and very low liquefaction potential. The contours represented the critical accelerations that had exceedance probabilities of 50, 10 and 5 percent in 100 years.

After the liquefaction potential zones were initially identified from the critical acceleration contours, they were adjusted to reflect the geology of the area. This adjustment was particularly important because boring data and critical acceleration values were available only at selected locations and did not necessarily reflect specific geologic features such as the locations of stream beds and the late Pleistocene Lake Bonneville shore lines.

Ground Failure Mode

The Liquefaction Potential Map delineates the various liquefaction potential zones. It can be used in conjunction with soil data and ground slope maps to predict the probable type of ground failure. Youd (1978) suggested that the type of ground failure induced by liquefaction is related to the ground surface slope and proposed the relationships between ground slope and failure mode shown in Table 2.

Table 2. Ground slope and expected failure mode (after Youd, 1978)

Ground Surface Slope	Failure Mode
<0.5%	Bearing capacity
0.5 - 5.0%	Lateral spread
>5.0%	Flow landslide

The thickness and setting of the sand deposit should also be cosidered in determining the probable mode of ground failure. For example, a 1 meter-thick loose sand layer at a depth of 10 meters in an otherwise clay soil profile is not likely to cause a flow landslide or a significant bearing capacity failure regardless of the ground surface slope. However, this condition might induce a translational landslide in steep slopes or magnify ground surface movement due to lurching in flat areas.

A Ground Surface Slope Map and a Soil Properties Map were prepared for the study area. These maps can be used in conjunction with the Liquefaction Potential Map to evaluate the potential for various types of ground surface failure.

GEOTECHNICAL CONDITIONS IN DAVIS COUNTY, UTAH

Geology Related to Liquefaction

Introduction

The geology of Davis County is dominated by erosional and depositional features associated with the several stillstands of pluvial lakes which existed in the Great Salt Lake basin over the past 20,000 or more years. Intermittent displacement along major geologic structures in the Great Basin since early Tertiary time created fault-bounded mountain blocks separated by deep basins (Cook and Berg, 1961, p. 75). The Wasatch fault zone is the dominant structural feature of Davis County.

Geologic materials in Davis County can be characterized into three types: pre-Lake Bonneville materials, Lake Bonneville materials, and post-Lake Bonneville materials. In Davis County, pre-Lake Bonneville materials are not susceptible to liquefaction because they are dense and cemented (indurated). Lake Bonneville materials and post-Lake Bonneville materials exhibit liquefaction potentials ranging from very low to high depending on ground water conditions and proximity to the mountain front. The three types of geologic materials are identified on Plates 1A and 1B, Selected Geologic Data, and discussed below.

Pre-Lake Bonneville Materials

These materials constitute the Wasatch Mountains in Davis County and underlie lake deposits in the basin. The exposed rocks in Davis County are among the oldest in the state and consist of metamorphic rocks (gneiss) of the Farmington Canyon complex of Precambrian age (Bryant, 1979). The metamorphic rocks are exposed in the mountains from Mill Creek (east of Bountiful) to the north boundary of the county and on Antelope Island, west of the study area (see Fig. 1). South of Mill Creek, a relatively thick sequence of lower Tertiary conglomerate is exposed (Van Horn, 1975a). These rocks consist almost entirely of well-rounded quartzite cobbles derived from the Cambrian Tintic Quartzite.

Materials considered to be Tertiary in age have been encountered in wells to depths as great as 1070 m (3525 ft) in Davis County (Hanson and Scoville, 1955, p. 26 and 27). The deepest well is located in the SW 1/4 SW 1/4 SW 1/4 Sec. 26, T 3 N, R 1 W, S.L.M., about 4 km (2-1/2 mi) southwest of Farmington. Sediments considered to have been deposited in deep water lakes on the basis of the presence of ostracod fossils were reported by Eardley and Gvosdetsky (1960, Plate 1) from the Saltair core at a depth of 177 m (560 ft).

The pre-Lake Bonneville materials in the Bonneville basin are significant to liquefaction potential only to the extent that they provided the source of lake sediments. The pre-Lake Bonneville Materials exposed within Davis County are not particularly significant themselves because the currents in the lake distributed widely all but the coarsest sediments. Consequently, much of the finer sediment in the lake deposits in Davis County probably was derived from places other than Davis County.

Lake Bonneville Materials

Material Properties. These materials constitute the near-surface sediments in most of the Bonneville basin below an elevation of about 1580 m (5180 ft). This elevation is significant because it represents the shore line created by the largest lake in the basin. The elevation of the highest shore line varies considerably from place to place within the basin because of differential rebound resulting from loading and unloading of the earth's crust with the water impounded by the lake. Tectonic deformations along fault zones also contribute to the variation in elevation of shore lines.

The lake materials are principally silt. Varying amounts of sand, gravel and clay are present with the coarest fraction being found closest to the mountain front and the finest being found in the central part of the basin.

The lake sediments are commonly thinly bedded. Fine sand layers are commonly present between clayey silt layers. Locally, thick layers of sand are present in the basin. Very coarse sand and gravel are commonly located where lake shore lines were once present.

Age and Elevation of Lake Levels. Four principal lakes occupied the basin in latest Pleistocene time. The basin existed prior to late Pleistocene time and lacustrine sediments undoubtedly accumulated. Evidence for the existence of major lakes in this basin prior to latest Pleistocene time has been obscured by the younger lake deposits. Reinterpretation of evidence used by early workers to substantiate the existence of large lakes in the basin during early late Pleistocene time is currently being done (Scott, 1980). The basic conclusion is that the lake at the Bonneville level was the largest of the Pleistocene lakes in the basin. Radiocarbon dates on materials collected from the highest beach deposits suggest that Lake Bonneville existed during a period from about 19,000 to 13,000 years ago (Currey, 1980, p. 70), with a possible brief period of lake lowering about 15,000 years ago.

A probable reason that no lakes as large as Bonneville existed prior to about 19,000 years ago is that the Bear River, which formerly flowed to the Snake River, was captured about that time by one of the drainages of the Bonneville basin. With the added volume of water from the Bear River, which drains part of the northern slope of the Uinta Mountains, inflow greatly exceeded evaporation and the lake rose to its maximum level controlled by topography at Red Rock Pass at the northern end of Cache Valley in Idaho.

Approximately 14,000 years ago, Lake Bonneville eroded a channel at Red Rock Pass. The erosion cut quickly through about 110 m (365 ft) of weakly cemented materials and caused catastrophic flooding of the Snake River plain (Currey, 1980, p. 74). A new threshold elevation of approximately 1470 m (4815 ft) was established. The shore features associated with this threshold have been named the Provo shore line. This shore line apparently was occupied from about 14,000 to 12,500 years ago (Currey, 1980, p. 74).

The climate of the basin controlled lake levels after the Provo shore lines were formed. After 12,500 years ago, evaporation exceeded inflow and the lake dropped about 105 m (335 ft) to the Stansbury level at about elevation 1365 m (4480 ft). The Stansbury shore line was probably occupied between 12,000 and 11,000 years ago (Currey, 1980, p. 75).

The lake continued to drop because of hydroclimatic reasons to the lowest of the four principal latest Pleistocene shore lines. This shore line, named the Gilbert shore line, is about 75 m (240 ft) lower than the Stansbury shore line at an elevation of about 1290 m (4240 ft.). The Gilbert shore line was probably occupied between 11,000 and 10,000 years ago (Currey, 1980, p. 76). Because of its assigned age, the Gilbert shore line is considered to represent the Pleistocene/Holocene time boundary in the basin.

It appears that a period of desiccation occurred in early Holocene time in the Bonneville basin and only a playa existed in the bottom of what is now the Great Salt Lake

(Currey, 1980, p. 78). Two prominent late Holocene shore lines exist between the Gilbert shore line and the present shore line. The higher of the two is at an elevation of approximately 1285 m (4215 ft) and is known as the Fremont shore line. The Eardley shore line, at an elevation of about 1280 m (4205 ft), is actually below the historic high level of 1283.7 m (4211.5 ft) which was recorded in 1873 (Currey, 1980, p. 79). The age of the Fremont shore line is considered to be 5,000 to 4,000 years old and the Eardley shore line is considered to be 3,000 to 2,000 years old (Currey, 1980, p. 77).

Significance of Lake Environment. The ages of the lake levels are significant for the purpose of comparing the Davis County liquefaction potential analysis to published analyses of other areas. In general, Youd and Perkins (1978, p. 441) considered lacustrine deposits less than 500 years old to have high liquefaction susceptibility. They assigned moderate susceptibility to Holocene lacustrine sediments and Pleistocene lacustrine sediments were considered to have low liquefaction susceptibility.

The results of the current research on liquefaction potential of Davis County indicate that sediments deposited in late Pleistocene lakes are highly susceptible to liquefaction. This may result from the restricted ground water lowering that can take place in closed basins. Sea level is the controlling plane for erosion and deposition in coastal areas, such as San Francisco, where much research has been done with respect to liquefaction potential. Lajoie and Helley (1975, p. 50) distinguished younger and older alluvial deposits on the basis of the sea level stand to which they are graded. Young deposits comprise alluvial fans being formed under existing hydrologic conditions; active streams in young deposits are graded to present sea level. Older alluvial deposits are partly covered by Holocene sediments and were formed by streams which were graded to lower stands of sea level during the late Pleistocene.

The significance of this observation is that late Pleistocene deposits in coastal areas were either formed when sea level was low (e.g. oxygen isotope stage (chron) 2 or 6, Shackleton and Opdyke, 1973, p. 45) or deposits formed before the last low stand of sea level were drained and dissected during the last low stand. The 110 m (365 ft) drop in sea level during oxygen isotope chron 2 (approximately 17,000 years ago) would have a pronounced affect on sedimentation in coastal areas.

The age of the most recent low stand of sea level -- oxygen isotope chron 2 -- corresponds fairly well with the high stand of Lake Bonneville. This suggests that the large volume of water constituting glaciers at this time contributed not only to lowering of sea level, but raising Lake Bonneville as well. Therefore, sediments were essentially being dewatered in coastal areas at the same time they were being deposited in Lake Bonneville.

Consequently, ages of material relating to liquefaction potential on the basis of research done in coastal areas do not appear appropriate for internally-drained areas such as the Great Salt Lake basin.

Post-Lake Bonneville Materials

These materials have limited distribution in Davis County. Chiefly, they are present along the principal drainage channels in the north-central part of the county and along the Jordan River in the south part of the county. Relatively isolated alluvial and debris fans in close proximity to the Bonneville, Provo and Stansbury levels of the lake are located in the central and southern parts of the County.

Five large lateral spread landslides involving lake deposits have been mapped by Van Horn (1975b, and 1981, personal communication) and Miller (1980). Other landslides in lake deposits have been mapped in Davis County by Pashley and Wiggins (1972), Van Horn, Baer and Pashley (1972) and Goode (1975). Kaliser (1976) compiled geologic data for Davis County which included landslide locations. These ground failures are discussed in some detail later in this report on the section pertaining specifically to ground failures.

Post-Lake Bonneville materials have been mapped in Davis County by Hamblin (1954), Thomas and Nelson (1948), Feth and others (1966), and Swan, Schwartz and Cluff (1980).

One of the most dominant processes responsible for deposition of post-Lake Bonneville materials is cloudburst floods (Marsell, 1972). Material deposited by cloudburst is relatively local in nature and typically situated near the mountain front as alluvial fans and debris fans. Large boulders can be carried by the floods which consist of viscous slurries of clay, silt and sand.

The streams in Davis County drain small areas; the largest drainage area contains Farmington Canyon and is about 28.0 sq km (10.8 sq mi) (Kaliser, 1976). Consequently, post-Lake Bonneville sediments are localized and do not constitute a large volume in the County. Swan and others (1980) indicate that 4.6 m (15 ft) of post-Provo level alluvial fan material overlain by 4.6 m (15 ft) of younger sediments accumulated in a fault-produced graben at a location near the center of Sec. 1, T 3 N, R 1 W, S.L.M. Thomas and Nelson (1948, p. 110) report that post-Bonneville level "torrential" (cloudburst) deposits are typically less than 6.1 m (20 ft) thick, but they observed a maximum thickness of 12.2 m (40 ft) near Ricks Creek in Sec. 6, T 2 N, R 1 E, S.L.M.

Soil Development

In general, aside from local accumulations of alluvial fan, debris fan, and stream deposits, lacustrine materials in Davis County have been continuously exposed as lake levels dropped. The soil survey of the Davis-Weber area prepared by Erickson and Wilson (1968) shows no soil patterns consistent with geologic interpretations.

The distribution of the Kidman series provides an example of the lack of correlation between pedogenic soils and geology. In Davis County, this series has been mapped above the Provo level in the center of Sec. 2, T 4 N, R 1 W, S.L.M. and adjacent to the Gilbert level in the northeast corner of Sec. 8, T 4 N, R 2 W, S.L.M. Consequently, the same soil series has been assigned to soils developed on sediments deposited in late Pleistocene and in Holocene time.

Youd and others (1979, p. 40) used relative development of pedogenic soil profiles to distinguish Holocene deposits. Chiefly, soils in the orders Entisols, Inceptisols and Vertisols were taken as Holocene. Pleistocene deposits were generally taken as those possessing textural B (B2t) horizons which generally requires considerable time for formation.

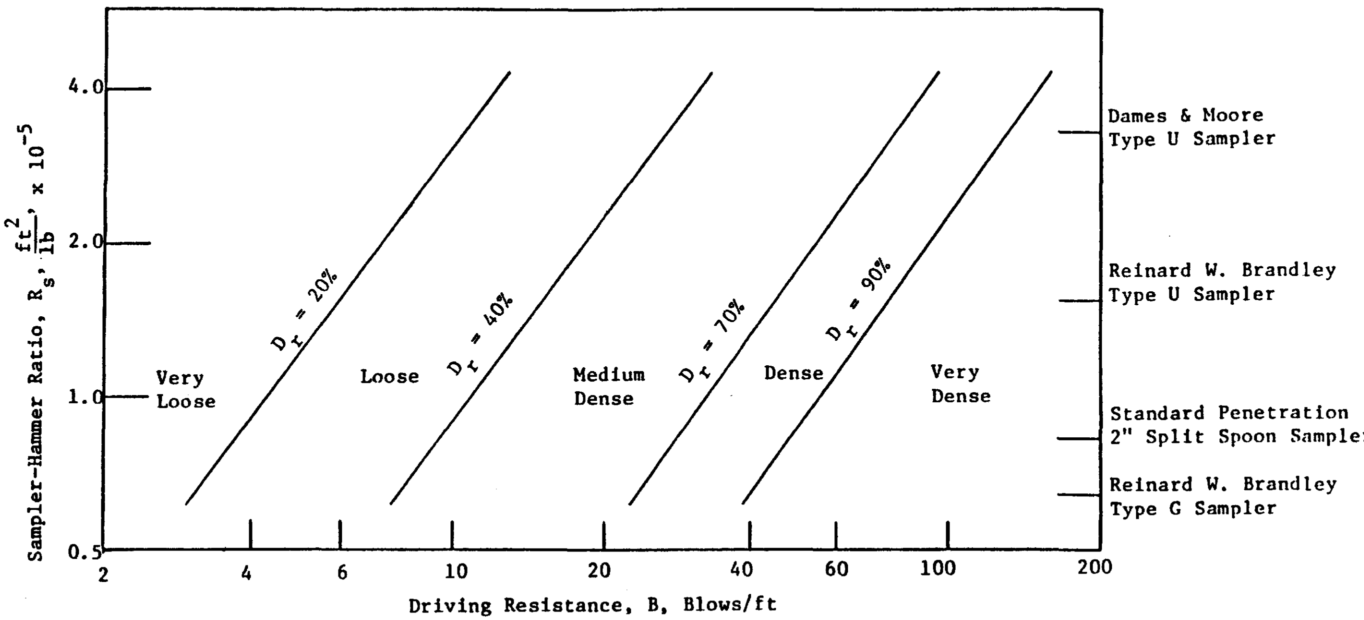
In the Davis County area, the Payson series (Typic Natrustalfs) exhibits a B2t horizon at a location with an elevation of about 1285 m (4215 ft) (Fremont Level) in the south part of Sec. 3, T 1 N, R 2 W, S.L.M. The last time that this location was inundated by lake waters was probably no more than 5,000 years ago and the first time sediments at this location were exposed to soil-forming processes was no more than 10,000 years ago. Therefore, the Payson series would be considered Plesitocene in age according to the requirement of having a textural B horizon, yet it clearly formed during Holocene time.

Geotechnical Data

Available Subsurface Data

Soils considered to be susceptible to liquefaction are found virtually everywhere within the study area. Consequently, site specific analyses were required to delineate zones of differing susceptibility. The necessary soil boring data required to perform a liquefaction analysis included accurate descriptions of the soil profiles, standard penetration resistance data, ground water depth and the grain size characteristics of granular layers. Such information was sought from existing records and supplemented by field and laboratory testing programs.

Soil boring data were obtained from various consulting firms and government agencies which had performed subsurface investigations within the study area. Numerous techniques had been used to obtain subsurface information. The standard penetration test was not used by all investigators to measure field densities and to obtain samples. Therefore, it was necessary to convert various (non-standard) penetration values to standard penetration blow count values so that the data could be used with the Seed, Mori and Chan (1977) chart (Fig. 6). The energy conversion technique presented by Lowe and Zaccheo (1975) is shown on Fig. 7 and was used to convert non-standard data.



$$R_s = \frac{D_o^3 - D_i^3}{144\ WH}$$

D_o = Outside Diameter of Sampler, inches

D_i = Inside Diameter of Sampler, inches

W = Weight of Hammer, pounds

H = Height of Drop, inches

D_r = Relative Density, %

Figure 7. Penetration resistance conversion relationship for cohesionless sands and silts (after Lowe and Zacchoe, 1975)

All existing data was then plotted on the Soils and Ground Water Data Map of the study area shown on Plates 2A and 2B. The data presented on this map consist of 1) the boring depth, 2) the location of liquefiable deposits, 3) the approximate thickness of the liquefiable deposits, 4) the depth to ground water and 5) the average and minimum equivalent standard penetration resistance blow counts in liquefiable deposits.

Field Investigation

To fill data gaps and to resolve inconsistancies in the existing data, a supplementary subsurface investigation was performed. Fifty-four hand auger borings were made to depths of up to 3 m (10 ft), and 31 borings were made with a truck-mounted rotary drill rig to depths of up to 9 m (30 ft).

The purpose of the hand auger borings was to obtain information about the soils and ground water conditions in the upper 3 m (10 ft) in the northwest section of the study area where no information existed. Soils were visually classified in the field and the depth to ground water was measured.

After a careful study of the hand auger borings and existing data, sites were selected for drilling with a truck-mounted rotary drilling rig. Soil samples were obtained, standard penetration tests were performed, and the ground water was measured in each of the 31 borings. Logs of the hand auger and rotary borings are on file at the Civil Engineering Department at Utah State University.

Laboratory Testing

A series of laboratory tests was performed on the samples obtained in the field. These tests were performed at the Utah State University Soil Mechanics Laboratory and consisted of visual classification, moisture content, grain size analysis and Atterberg limits. The laboratory test results are on file at Utah State University.

Soils with a mean grain size (D_{50}) ranging from 0.075 - 0.20 mm are considered most susceptible to liquefaction (Seed and Peacock, 1971). The D_{50} of most of the samples ranged from 0.038 - 0.25 mm, with an average of 0.11 mm. Seed (1975) showed that liquefaction usually occurs in soils with uniformity coefficient ranging from 2 to 10. The uniformity coefficient ranged from 2.1 to 23.1 with an average of 5.6. Atterberg limits were determined for the silty soils. Silty soils were classified as susceptible if they had a plasticity index (PI) less than 5. Not all samples containing less than 15 percent clay-size particles had a PI less than 5. Most of Davis County has soils with physical properties which fall within ranges considered susceptible to liquefaction.

Soils and Ground Water Data Map

The Soils and Ground Water Data Map shown on Plates 2A and 2B was prepared to summarize the aerial extent and vertical depth of the liquefiable soil deposits and the ground water conditions in Davis County. The soils and ground water data include:

1. Depths at which liquefiable layers exist
2. Thickness of liquefiable layers
3. Depth to ground water
4. Minimum and average standard penetration values obtained in liquefiable deposits.

Ground water contour lines showing zones of various depths to first ground water have been drawn on the map. As shown on Plates 2A and 2B a letter designation was used to show the range of water table depths.

Existing Ground Failure

Introduction

Ground failures involving lake deposits exist in several areas of Davis County as shown on the Selected Geologic Data Map, Plates 1A and 1B. Five failures have been interpreted as "lateral spread" failures induced by earthquake shaking. Other ground failures have been interpreted simply as "landslides" which are not necessarily caused by earthquake shaking. However, earthquake activity could have played a role in the timing of such landslides.

Lateral Spread Failures

Lateral spread failures have been identified by Van Horn (1975b and 1981, personal communication) and by Miller

(1980). These failures are shown on Plates 1A and 1B and are located below an elevation of 1340 m (4390 ft). These areas are characterized by ground slopes ranging from 0.5 to 5.0 percent. Slopes of this range are considered to be susceptible to the lateral spread process during liquefaction events.

The paleo-seismicity record in the region has been studied by Swan, Schwartz and Cluff (1980). One of their trenching sites was located in Davis County just south of Fruit Heights (Sec. 1, T 3 N, R 1 W, S.L.M.). The results of their research led them to conclude that moderate to large magnitude earthquakes accompanied by surface faulting on this segment of the Wasatch fault occur once every 500 to 1000 years. It follows logically, then, that Davis County has been severely shaken by a number of earthquakes during the relatively recent geologic past. It is reasonable to expect that evidence of liquefaction-induced ground failure should be relatively wide-spread. As mentioned earlier, five lateral spread failures have been identified in the study area. The surface expression of these failures is very subtle.

Nine test pits were excavated in the west part of the county where a high susceptibility to liquefaction was expected. The test pits were excavated at locations shown on Plates 1A and 1B to permit examination of subsurface materials for evidence of ground failure.

The test pits were relatively small and severely limited by shallow ground water conditions. The test pits were 3.0 - 4.3 m (10-14 ft) in length and ground water was encountered in all pits at depths ranging from 0.15 - 2.0 m (0.5-6.5 ft). As the walls of the test pits were examined, particular attention was given to the continuity of stratification in the thinly-bedded lake deposits. Disturbance of the uniformly-bedded lake deposits certainly would have accompanied liquefaction-induced ground failure.

Such disturbance of bedding was observed in two of the nine test pits. The disturbance was minor, on the order of one to two centimeters of offset of marker beds. Both of the test pits (No. 7 and 8) were located within a younger lateral spread landslide identified by Van Horn (1981 and personal communication). Disturbed bedding was not observed in the other seven test pits.

The absence of disturbed bedding in the test pits may be due to one of several factors. It is possible that liquefaction-induced ground failure did not occur at the test pit locations. If ground failure did occur, it is possible that the test pits were not long enough to intersect the edge of a block of material that may have moved as a unit. In two of the test pits (No. 4 and 6), no traceable markers were exposed.

Other Ground Failures

Landslides involving lake deposits have been mapped in Davis County by Pashley and Wiggins (1972), Van Horn, Baer and Pashley (1972), and Goode (1975). Kaliser (1976) compiled geologic data for Davis County which included landslide locations.

All but one of the landslides that have been mapped in Davis County are located on the relatively steep banks of drainage channels in the northeast part of the county. One landslide has been mapped on the south bank of Mill Creek in Bountiful.

A large landslide mass is located on the south bank of the Weber River near the northern boundary of the county. Other relatively large landslides are situated along the flanks of streams northeast of Layton. These landslides have occurred in lake deposits composed of interbedded silty clay, clayey silt, and fine sand; ground water seepage from the fine sand layers is seasonal.

Earthquake shaking could have played a significant role in initiating the landslides. However, they could be static failures related simply to down-cutting of the Weber River and other streams caused by lowering of lake levels. The down-cutting would tend to create oversteepened slope conditions which promote instability.

Ground Slope Data

As discussed earlier, the major types of ground failure which result from earthquake-induced liquefaction include flow landslides, lateral spreading landslides, and loss of bearing capacity. Youd (1978) suggests that the type of ground failure induced by liquefaction is related to the ground surface slope. A letter designation was used on Plates 3A and 3B, Ground Slope and Critical Acceleration Map, to show the range of slopes which may be used to predict the type of failure that might occur. The ground slope ranges shown on Plates 3A and 3B were estimated from U.S. Geological Survey topographic quadrangles.

LIQUEFACTION POTENTIAL

Critical Acceleration as a Liquefaction Potential Indicator

Critical accelerations computed for specific sites within the study area were assigned liquefaction potential classifications according to the probability that the critical acceleration would be exceeded during the next 100 years. The liquefaction potential and the corresponding exceedance probabilities were discussed earler and presented in Table 1.

Seismic risk studies by Algermissen and Perkins (1972) and Dames & Moore (1978) indicate that the probability that a given ground surface acceleration will be exceeded is nearly the same throughout Davis County, Utah. The exceedance probability curve shown on Fig. 8 (Dames & Moore, 1978) and summarized in Table 3 was used to assign liquefaction potential classifications in the study area.

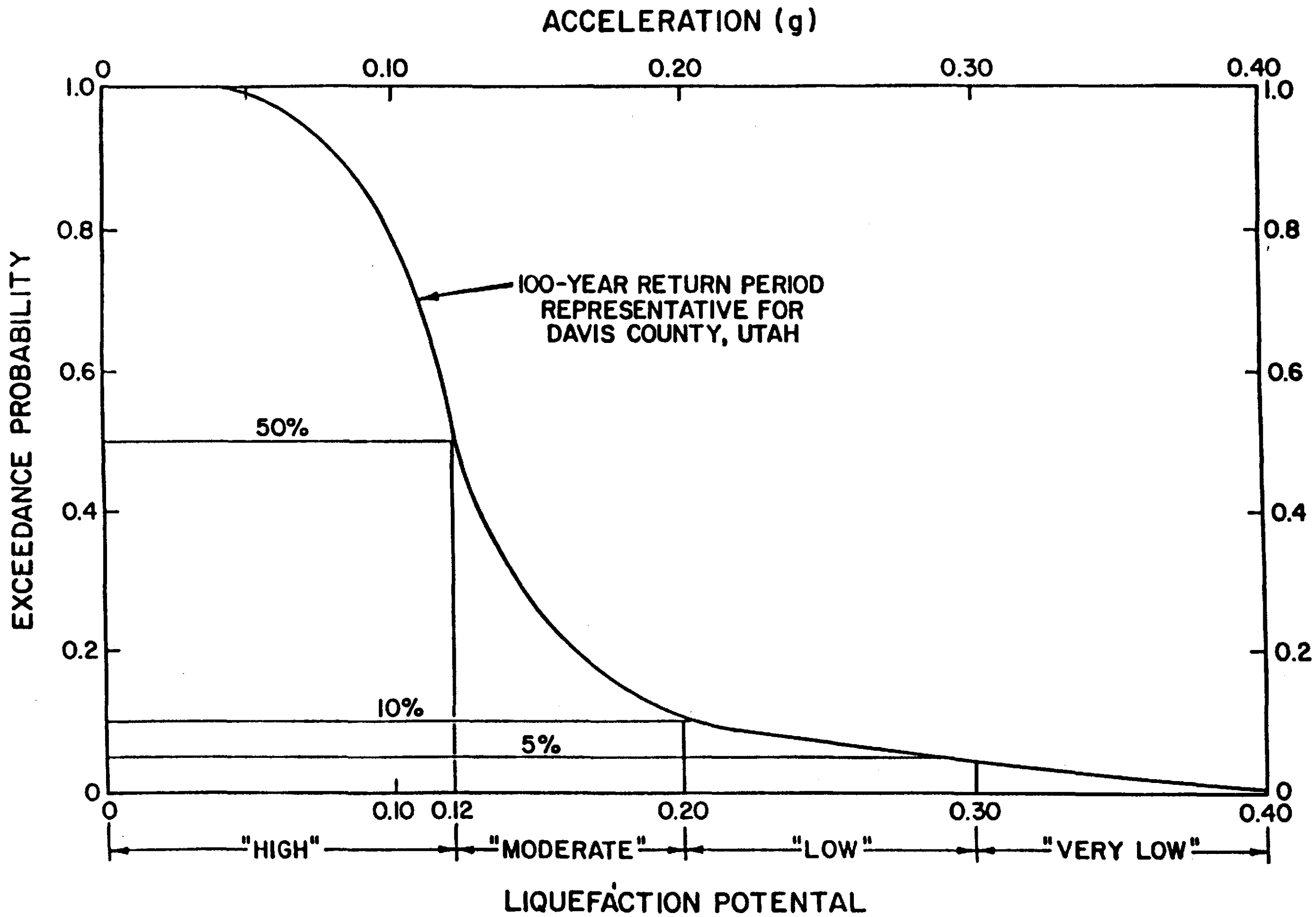


Figure 8. Acceleration probability curve for Davis County, Utah (After Dames and Moore, 1978)

Table 3. Liquefaction potential related to critical acceleration. (From Dames & Moore, 1978)

Liquefaction Potential	Critical Acceleration	Approximate 100 year Exceedance Probability
High	< 0.12 g	> 50%
Moderate	0.12 - 0.20 g	50 - 10%
Low	0.20 - 0.30 g	10 - 5%
Very Low	> 0.30 g	< 5%

Six different symbols were used to illustrate accelerations on the Critical Acceleration Map on Plates 3A and 3B. The four circular symbols indicate the various liquefaction potential classifications based on the critical acceleration value.

Open triangle symbols were used on Plates 3A and 3B to indicate unsaturated granular soils with densities susceptible to liquefaction. This condition is termed "potential liquefaction susceptibility." It infers that a rise in the ground water table or the development of perched ground water may saturate the deposit giving it the potential suggested by the critical acceleration value plotted next to the symbol.

The open square symbol indicates that the soil profile contains sand layers that are less than one foot thick. The method of evaluating liquefaction potential in this study is based on the results of the standard penetration test which measures the resistance a soil exhibits to driving a standard sampler one foot. Therefore, a critical acceleration value could not be assigned to sand layers less than one foot thick.

Liquefaction Potential Map

The Liquefaction Potential Map developed for the Davis County study area is shown on Plates 4A and 4B. Liquefaction potential has been classified as high, moderate, low and very low depending on the probability that the critical acceleration will be exceeded in 100 years. As previously discussed, the probable types of ground failure may be predicted by using the Liquefaction Potential Map in conjunction with the Ground Slope Map and the Soils and Ground Water Data Map.

A general summary of the liquefaction potential of Davis County can be made with reference to the ground surface elevations. Generally, the areas most susceptible to liquefaction are below an elevation of about 1310 to 1330 m (4300 to 4350 ft.) The areas with a liquefaction potential classifications of very low are located at the higher elevations of the study area as shown on the Liquefaction Potential Map, Plates 4A and 4B.

The geology and subsurface conditions are relatively complex along and west of Highway 89 from North Farmington Junction to the Davis-Weber County line. Many streams dissect the area; there is steep topography along stream banks; many local landslides have been noted; and the existance and further development of perched ground water is likely. As shown on the Liquefaction Potential Map of Plate 4B, much of the area along the streams has been classified as high liquefaction potential. It is not known whether the local landslides along the steep stream banks were initiated by liquefaction.

A change in the perched ground water conditions along the foothills area along Highway 89 could change the liquefaction potential classification. A rise in the ground water table would increase the liquefaction potential.

CONCLUSIONS AND RECOMMENDATIONS

Ground failure caused by liquefaction is a primary hazard associated with earthquakes. The first step in avoiding this hazard is to recognize where liquefaction might occur. A Liquefaction Potential Map has been compiled for Davis County, Utah showing areas where conditions are favorable for liquefaction to occur.

Fine sand and silty sand are the soil types most conducive to liquefaction and they are found throughout Davis County. Soil type alone, however, does not determine the liquefaction potential of a given site. Several important factors influencing liquefaction potential were considered in this study. The standard penetration test provided a useful means for evaluating the influence of the soil structure, previous seismic history, and age of the deposit as well as the relative density of the soil. An increase in the resistance to liquefaction from any of these factors is reflected by a corresponding increase in the standard penetration resistance.

The standard penetration resistance was used to compute the ground surface acceleration that would be required to induce liquefaction (critical acceleration). The liquefaction potential was then assigned on the basis of the probability that the critical acceleration would be exceeded in 100 years. Local geologic conditions were also considered in refining liquefaction potential boundaries.

The information generated by this study should prove to be valuable for those concerned with future land development. Planners and other concerned parties should realize that areas showing a high liquefaction potential need not be ruled out as possible sites for construction. However, we believe further analyses should be required for these sites including an economic analysis of preventive or protective measures that can be used to reduce the liquefaction potential. Haldar (1980) has developed a decision analysis framework which considers both the technical and economic aspects of limiting or eliminating damage associated with liquefaction.

One problem often encountered during this study was how to assess the susceptibility of thin sand layers and lenses. Since the standard penetration test was used as a basis for this study, reliable data could only be obtained for sand strata greater than one foot thick. Damages associated with the liquefaction of thin sand layers and lenses are not uncommon (Seed, 1968) but an accurate means for identifying the relative density of such strata has not been developed. A method that can be used and one that is gaining popularity in the United States is the cone penetrometer test. The cone penetrometer not only offers an economical means for continuous subsurface soil profiling (Baligh, Vivatrat, Ladd, 1980), but could also provide a direct means for continuously identifying the liquefaction potential in the soil profile (Schmertmann, 1978).

It is recommended that the liquefaction potential map be updated continually as more soil boring information becomes available and as new and improved techniques are developed for analyzing liquefaction.

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EXPLANATION

Pre-Lake Bonneville Materials
chiefly above an altitude of 1580 m (5180 ft.).

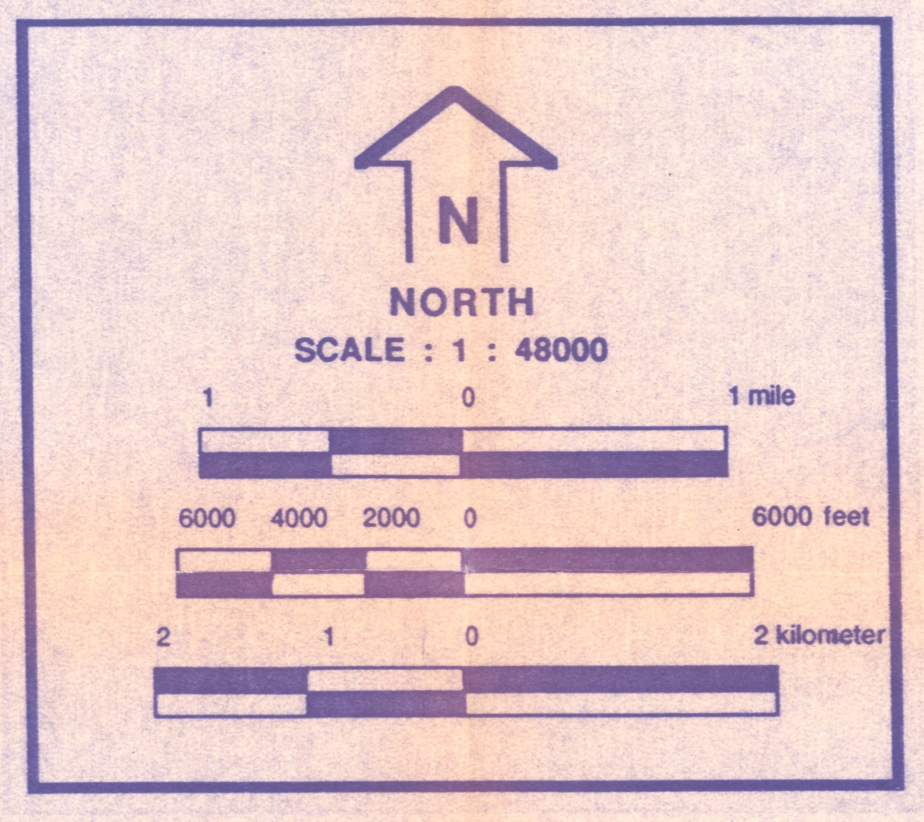
- pЄm Precambrian Metamorphic Rocks (chiefly Farmington Canyon Complex)
- Tc Tertiary Conglomerate

Lake Bonneville Materials
below an altitude of 1580 m (5180 ft.).

- —B— Bonneville Shoreline; Altitude ± 1580 m (5180 ft.), age 19,000 to 13,000 years B.P.
- —P— Provo Shoreline; Altitude ± 1470 m (4815 ft.), age 14,000 to 12,500 years B.P.
- —S— Stansbury Shoreline; Altitude ± 1365 m (4480 ft.), age 12,000 to 11,000 years B.P.
- —G— Gilbert Shoreline; Altitude ± 1290 m (4240 ft.), age 11,000 to 10,000 years B.P.
- —F— Fremont Shoreline; Altitude ± 1282 m (4215 ft.), age 5000 to 4000 years B.P.
- —E— Eardley Shoreline; Altitude ± 1279 m (4205 ft.), age 3000 to 2000 years B.P.

Post-Lake Bonneville Materials

- a Stream Deposits
- f Alluvial Fan Deposits and Debris Fan Deposits
- Landslide Deposits
- Isy Younger Lateral Spread Landslide Deposits
- Iso Older Lateral Spread Landslide Deposits



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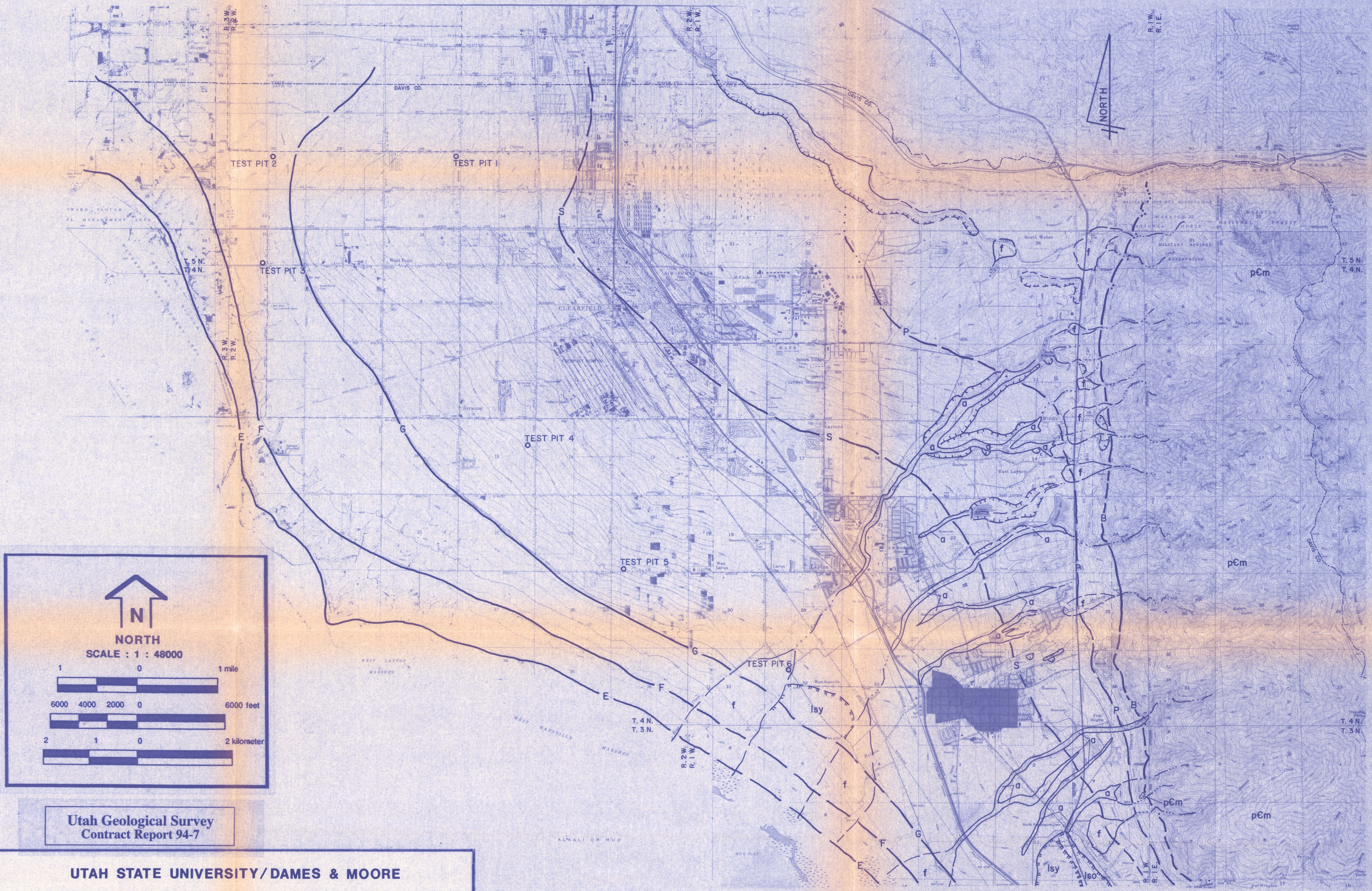
UTAH STATE UNIVERSITY/DAMES & MOORE
LIQUEFACTION EVALUATION OF DAVIS COUNTY, UTAH

SELECTED GEOLOGIC DATA

PLATE 1A (SOUTH HALF)

U.S. GEOLOGICAL SURVEY
CONTRACT NO. 14-08-0001-19127
EARTHQUAKE HAZARD REDUCTION PROGRAM

L. ANDERSON, J. KEATON
K. AUBRY & S. ELLIS
(1981)



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UTAH STATE UNIVERSITY/DAMES & MOORE

LIQUEFACTION EVALUATION OF DAVIS COUNTY, UTAH

SELECTED GEOLOGIC DATA

PLATE 1B (NORTH HALF)

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EXPLANATION

Soils Data

I a b, c-d

I = Location of Boring within Section

a = Thickness of Liquefiable Layer

1 = interbedded deposits

2 = layer < 0.3m

3 = layer > 0.3m

b = Depth to Ground Water, meters

c = Minimum N-Value in Liquefiable Deposits

d = Average N-Value in Liquefiable Deposits

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Symbol indicates depth of Boring and Liquefiable Deposits

Symbol	Depth of Boring
○	>10.0m
□	<10.0m

Symbol	Depth of Liquefiable Deposits
	0-3.0m
	3.0-6.0m
	6.0-10.0m
	>10.0m

Ground Water Data

Letter indicates depth to water table

Letter	Depth to Ground Water
A	0-3.0m
B	3.0-9.1m
C	9.1-15.2m
D	>15.2m

N

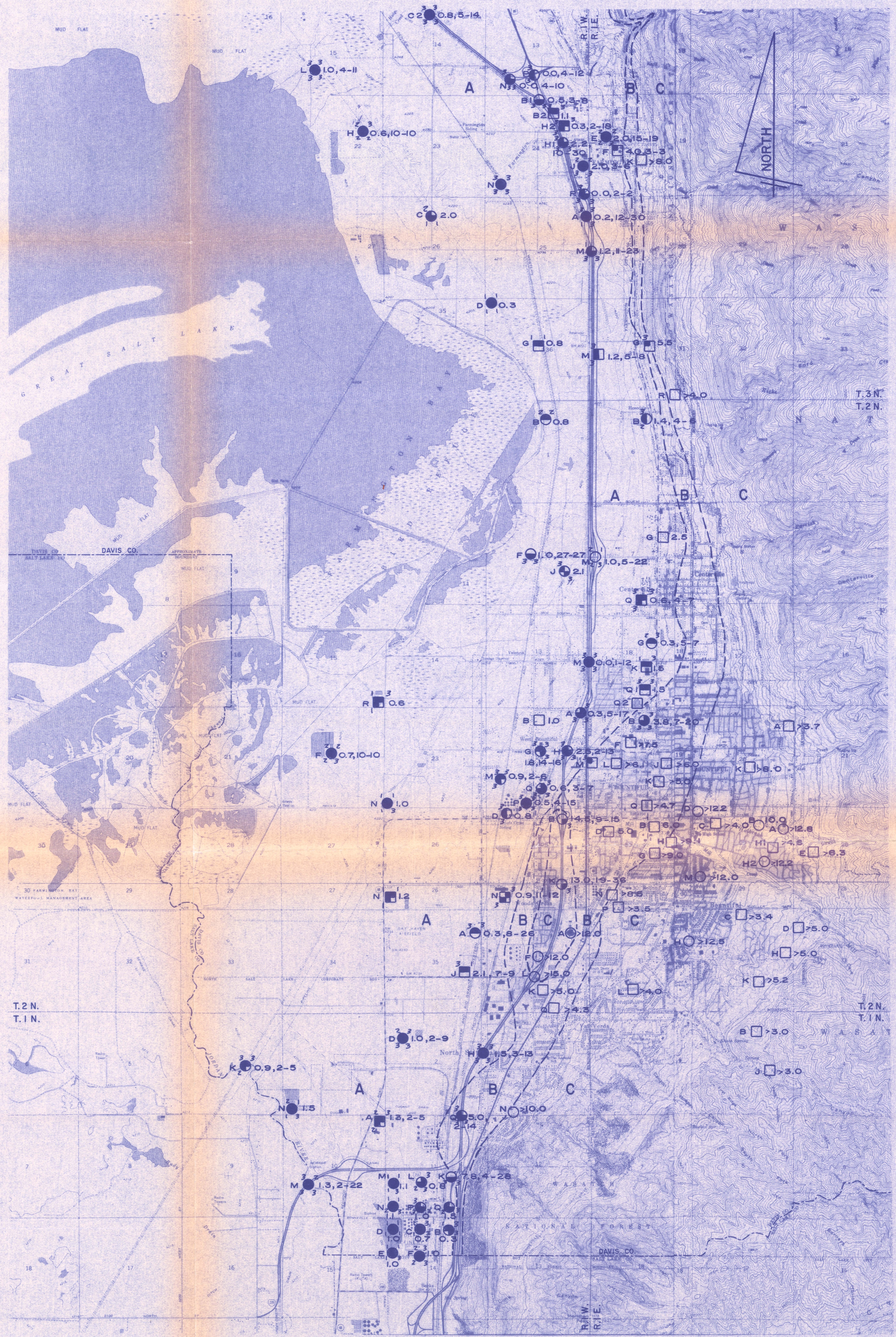
NORTH

SCALE : 1 : 48000

1 0 1 mile

6000 4000 2000 0 6000 feet

2 1 0 2 kilometer



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LIQUEFACTION EVALUATION OF DAVIS COUNTY, UTAH

SOILS AND GROUND WATER DATA

PLATE 2A (SOUTH HALF)

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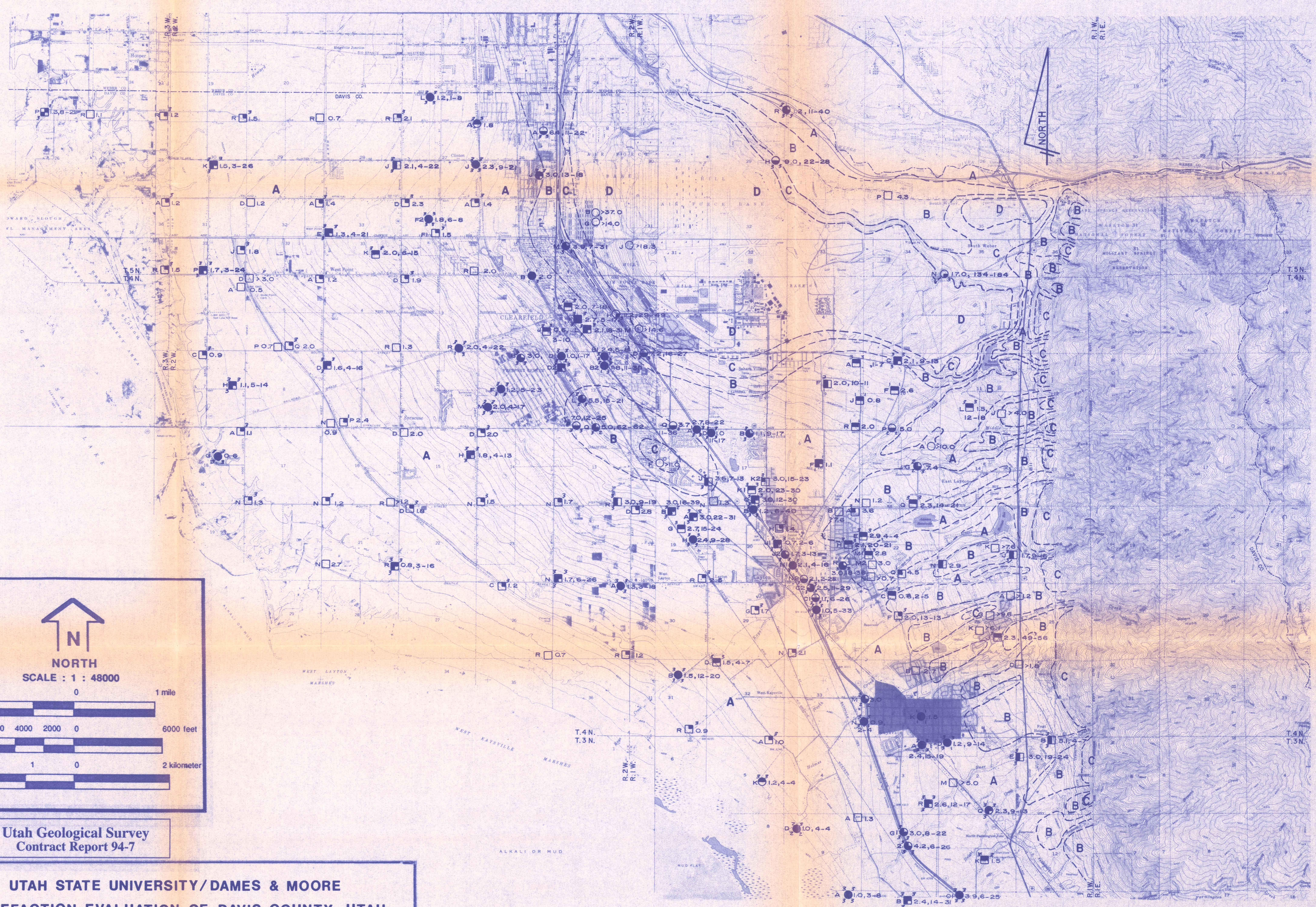

N
NORTH
SCALE : 1 : 48000

1 0 1 mile

6000 4000 2000 0 6000 feet

2 1 0 2 kilometer

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LIQUEFACTION EVALUATION OF DAVIS COUNTY, UTAH

SOILS AND GROUND WATER DATA

PLATE 2B (NORTH HALF)

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947
2B

EXPLANATION

Critical Acceleration Data

I ◒ a

I = Location of Boring within Section

a = Critical Acceleration

D	C	B	A
E	F	G	H
M	L	K	J
N	P	Q	R

Symbol indicates liquefaction susceptibility

Symbol	Susceptibility	Ground Acceleration Required to Induce Liquefaction
●	High	0.0-0.12g
◒	Moderate	0.12-0.20g
⊙	Low	0.20-0.30g
○	Very Low	>0.30g
△	Potential	Unsaturated sand layers
□	Thin Sand Lenses	Unable to Assign Accelerations

Ground Slope Data

Letter indicates ground slope

Letter	Slope	Failure Mode
A	< 0.5%	Bearing Capacity
B	0.5-5.0%	Lateral Spreading
C	> 5.0%	Flow Landslides

N

NORTH

SCALE : 1 : 48000

1 0 1 mile

6000 4000 2000 0 6000 feet

2 1 0 2 kilometer

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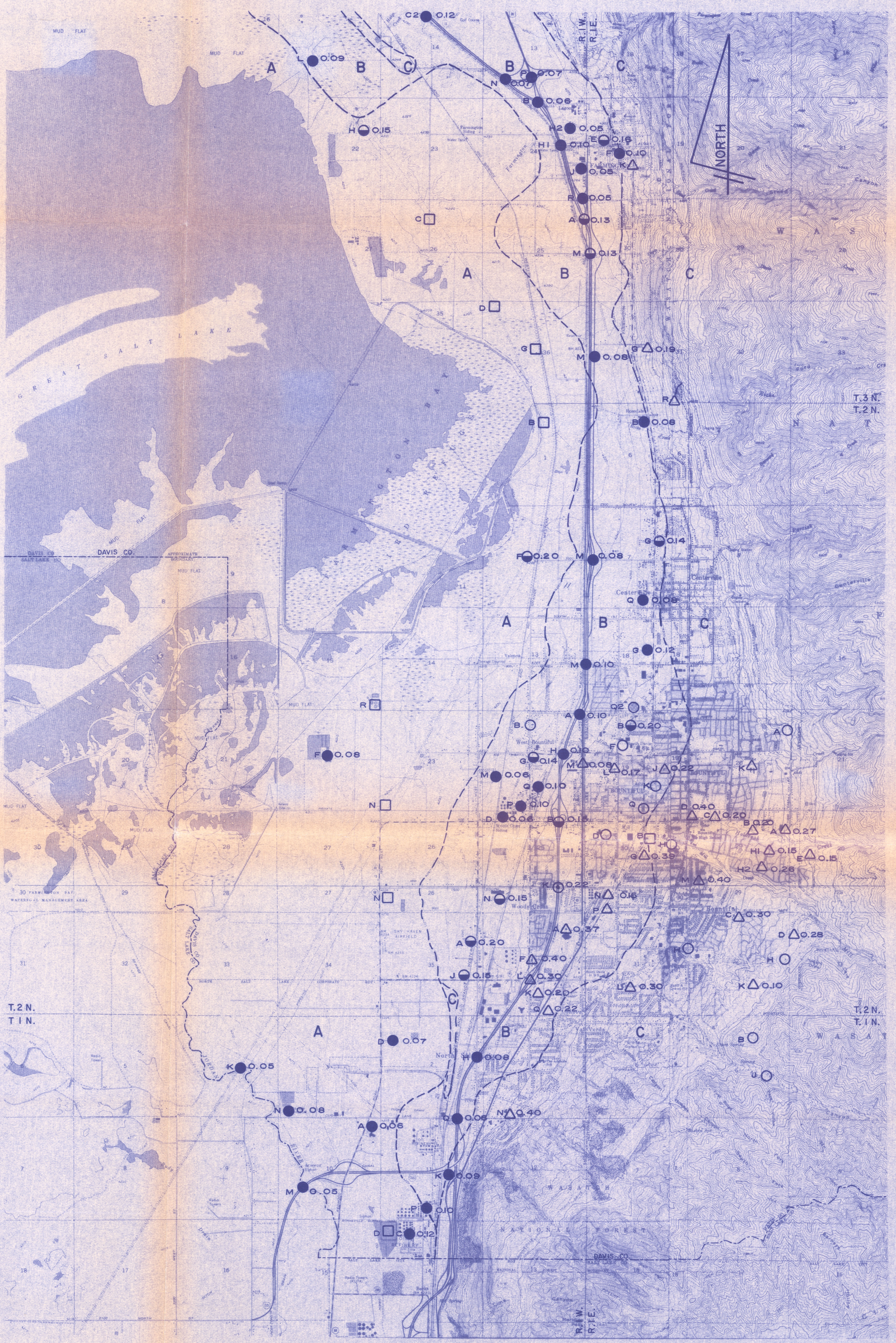

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LIQUEFACTION EVALUATION OF DAVIS COUNTY, UTAH

GROUND SLOPE AND CRITICAL ACCELERATION

PLATE 3A (SOUTH HALF)

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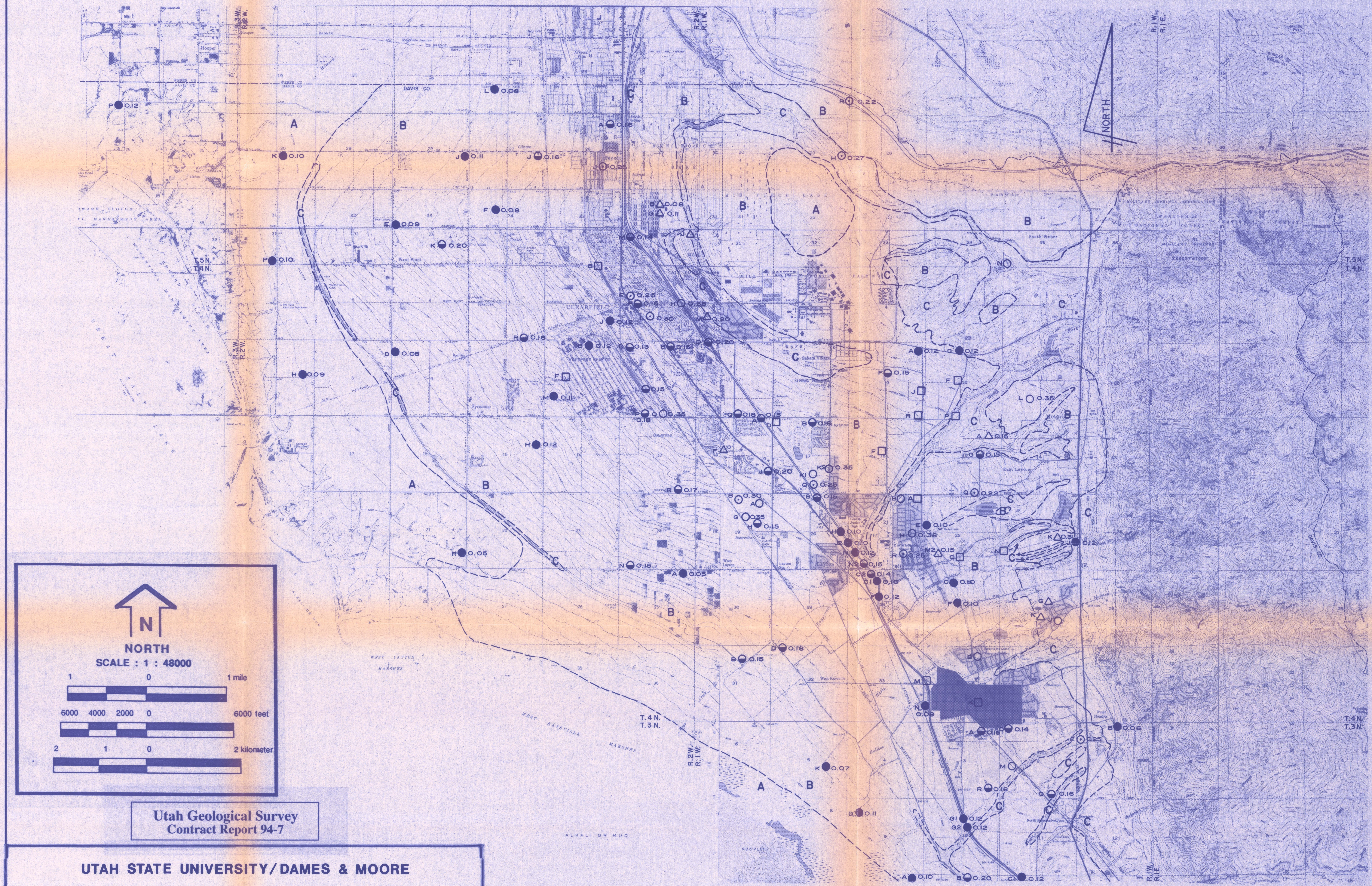

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GROUND SLOPE AND CRITICAL ACCELERATION

PLATE 3B (NORTH HALF)

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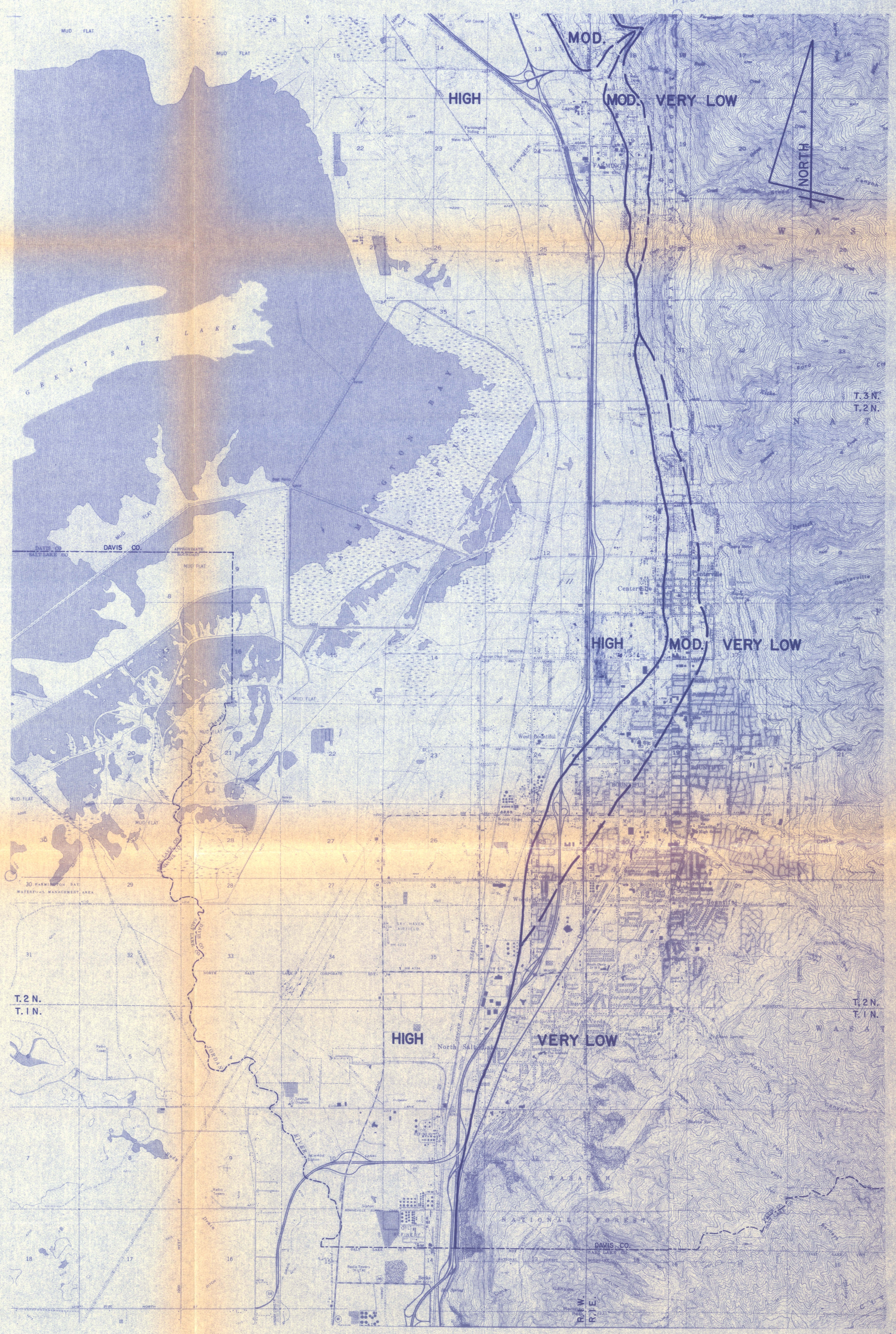

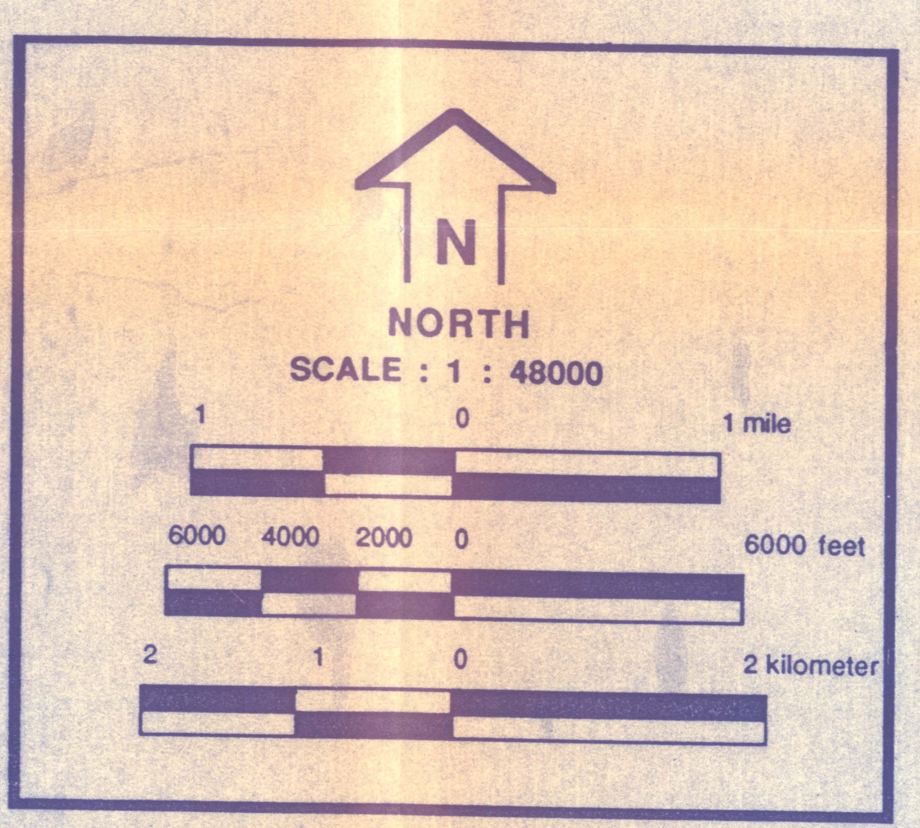

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LIQUEFACTION EVALUATION OF DAVIS COUNTY, UTAH

LIQUEFACTION POTENTIAL

PLATE 4A (SOUTH HALF)

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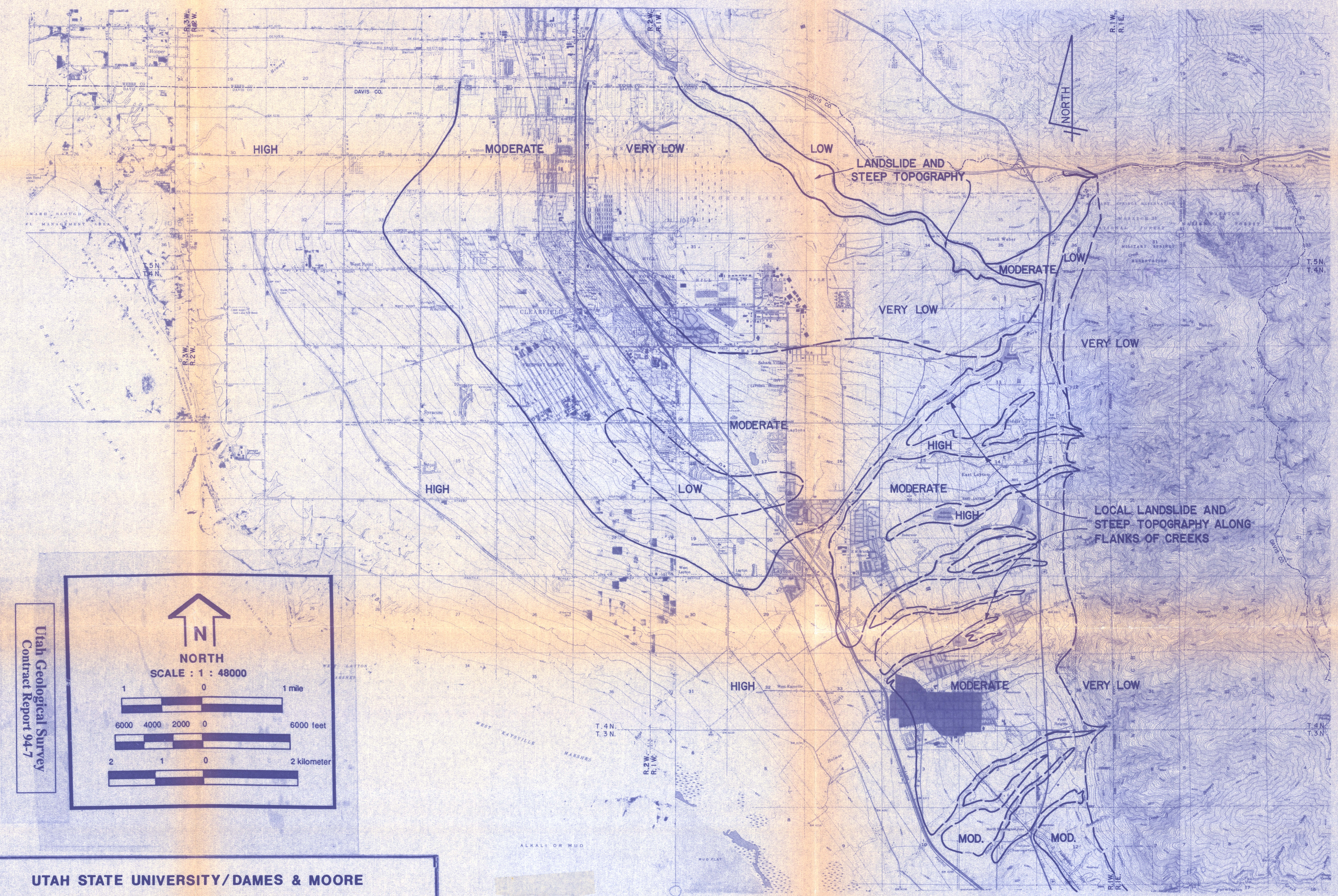

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LIQUEFACTION EVALUATION OF DAVIS COUNTY, UTAH

LIQUEFACTION POTENTIAL

PLATE 4B (NORTH HALF)

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