# COLLAPSIBLE SOIL HAZARD MAP FOR THE CEDAR CITY, UTAH AREA

*by*

*Tonya Williams and Kyle M. Rollins*
*Brigham Young University*
*Civil Engineering Department*

CONTRACT REPORT 91-10 JULY 1991
UTAH GEOLOGICAL SURVEY
a division of
UTAH DEPARTMENT OF NATURAL RESOURCES

**THE PUBLICATION OF THIS PAPER IS MADE POSSIBLE WITH MINERAL LEASE FUNDS**

# TABLE OF CONTENTS

## ACKNOWLEDGEMENTS

This project was sponsored by the Utah Geological and Mineral Survey and appreciation is expressed for their financial support. Special thanks is given to Dr. Ralph Rollins and Bradford Price of R. B. & G. Engineering, Provo, Utah; Larry Murdock of Dames and Moore, Salt Lake City, Utah; Scott Davis of Kleinfelder & Associates, St. George, Edward Keane of the Materials and Research Dept. of the Utah Department of Transportation, Salt Lake City, Utah; and the U.S. Soil Conservation Service, Cedar City, Utah for contributing soil information necessary for the study. Dr. Ralph L. Rollins, Prof. Emeritus of Civil Engineering at Brigham Young University and President of R.B. & G. Engineering and William Gordon of Sergent, Hauskins and Beckwith, reviewed the report and provided valuable insights and suggestions. Their efforts are sincerely appreciated.

## INTRODUCTION

Several incidents of dramatic settlement have occurred in urbanized areas of Cedar City, Utah which can be attributed to the presence of collapsible soils. In order to reduce the potential for building damage in the future, a Collapse Potential Hazard Map of the Cedar City area has been prepared. This map provides an indication of the relative risk of collapsible soil hazard in the region and will assist an engineer in determining the extent of site investigation for collapsible soils which may be warranted. It may also be of assistance to planners in assessing the potential for collapsible soil problems in various areas. It should be recognized, however, that soils are highly variable and collapsible soils may still be encountered in zones described as having low potential for collapsible soil.

Previous work mapping collapsible soils in Cedar City was performed by Kaliser (1977) in which mapping was based primarily on historical collapse occurrences and geological considerations. Since 1977, however, a significant number of geotechnical investigations have been performed throughout the Cedar City area which improve our ability to map the potential for collapsible soils. As part of this project, an effort was made to obtain all available soil test data from geotechnical engineering firms, as well as state and federal agencies. In addition, supplemental soil samples for consolidation tests were obtained from various sites in the Cedar City area and provided a means to calculate the amount of collapse potential of soil deposits not previously investigated.

A street by street survey was made to visually determine areas where structural damage from soil settlement was apparent. This survey data was added to the historical settlement data compiled by Kaliser (1977) and information obtained in interviews with city and county officials.

Finally, the geological conditions, geotechnical test data, and damage observation data were combined in preparing the collapsible soil hazard map. The location of geotechnical test borings and the distribution of observable damage are presented on separate maps for clarity.

The information contained in this report is discussed under the following headings: (1) General Description of Collapsible Soil Characteristics (2) Methods of Collapsible Soil Identification Collapsible Soil, (3) Collapse Potential Assessment for Cedar City Area (4) Map Preparation Procedure (5) Summary and Conclusions.

## 1. GENERAL DESCRIPTION OF COLLAPSIBLE SOIL CHARACTERISTICS

Collapsible soils undergo a sudden decrease in volume due to the addition of water into the soil structure. Settlement as a result of wetting without any change in pressure is sometimes known as hydrocompaction. Collapsible soils in arid climates are generally associated with mudflow deposits and alluvial fans produced by intermittent stream flow. The soils dry prior to subsequent deposition and do not become fully consolidated under the overburden stresses. Collapsible soils typically exhibit a loose, honeycomb structure. They have a low to relatively low unit weight, a low degree of saturation, and a high dry strength. Intergranular bonds form between the larger bulky grains of the collapsible soil; these bonds develop through capillary tension or a binding agent such as silt, clay, or salts. Forces from the bonds keep the grains separated forming a loose, bulky structure and supplying the soil with its high dry strength. Wetting a collapsible soil results in the loss of capillary tension or the softening, weakening, and dissolving of cementing agents allowing the larger particles to slip past each other into a denser soil structure.

Collapse of the soil is often related to human activity such as irrigation, urbanization, and disposal of waste water. The settlement of the soil structure generally results in cracking and damage to foundations, roads, ditches, canals, pipelines, dams and other structures. Extensive damage may be mitigated by recognition of the occurrence of collapsible soils in an area and the use of measures to improve the soil or prevent wetting.

## 2. METHODS OF COLLAPSIBLE SOIL IDENTIFICATION

### 2.1 GEOLOGIC AND GEOMORPHIC SETTING

Although the majority of collapsible soils occur in wind-blown loess deposits, these soils are also associated with alluvial fan deposits in arid climates. Collapsible soils in an alluvial fan setting have been recognized throughout the southwestern United States including San Joaquin Valley, CA; Hawthorne NV; Nephi, UT; Grand Junction, CO; Espanola, NM; Tucson, AZ and many other areas (Beckwith and Hansen, 1988; Shaw and Johnpeer, 1985; Houston et al., 1988; Bull, 1964)

In arid to semi-arid regions, streams tend to flow intermittently allowing large quantities of loose weathered rock and sediment to accumulate in the drainage basin. When precipitation occurs, a stream transports large volumes of sediment which it subsequently deposits into an adjacent valley due to a change in gradient from the highlands. These accumulations of sediment form alluvial fan deposits at the base of mountainous regions. Alluvial fans are recognized to be frequently associated with the occurrence of collapsible soils. The formation of collapsible soils in an alluvial fan deposit depends upon several factors: the lithology of the rocks in the drainage basin, the mode of deposition, and the occurrence of water in the deposit.

Collapsible soils form due to the binding together of larger particles by capillary tension or other cementing agents such as clay, silt, or salts. These agents must be present in the sediments which are deposited on the alluvial fan to allow the formation of collapsible soils. The type of sediment which will eventually be deposited in the fan is a result of the lithology of the rocks in the drainage basin. In general, collapsible soils in an alluvial fan are associated with drainage basins which are dominated by soft clay-rich sedimentary rocks such as shale, mudstone, and siltstone (Bull, 1964, Owens, 1990).

Bull (1964) found that the maximum collapse of alluvial fan soils in Fresno County, California occurred with a clay content of approximately 12 percent. If a lower clay content existed in the soil, compaction of the soil occurred at the dry overburden load without the addition of water while higher clay contents caused the soil to resist compaction and occasionally expand. Soils exhibiting dramatic collapse behavior in Nephi, Utah typically contained 10 to 15% clay size material (Rollins and Rogers, 1990). Characteristically, collapsible soils are made up of silty sands, sandy silts, and clayey sands although several case histories are available regarding collapsible gravels (Hepworth and Langfelder, 1988; Beckwith and Hansen, 1988).

While the composition of the alluvial fan is the primary indicator of collapse potential, alluvial fans which are collapsible typically have larger ratios of fan area to drainage basin area. Owens (1990) found that the degree of collapse generally increased with increases in the fan area to drainage basin area along the southern Wasatch range. Similar results were observed by Bull (1964).

Two modes of deposition dominate in the formation of an alluvial fan: stream flow and debris flow. Alluvial fans are composed of interbedded deposits of these different types; the proportion of each variety of deposit depends upon the frequency and intensity of precipitation in the highlands.

Stream flow deposits in an alluvial fan are channel deposits or sheet deposits. These deposits occur due to moderate amounts of precipitation and typically do not have high sediment contents. Channel deposits are well sorted, stratified sands and gravels emplaced in the stream bed. Sheet deposits are sands and silts laid down when sediment-laden waters surge over the alluvial fan. Soils emplaced in stream flow deposits tend not to be collapsible in nature due to the small amounts of binding agents present in the deposit which do not allow the formation of intergranular bonds.

Debris flows are highly viscous sediment and water masses composed of poorly or non-sorted coarse rock fragments, boulders and cobbles supported by a fine-grained matrix of silt and clay. A variety of debris flow, mudflows are made up of sands supported by a mud matrix. Several conditions favor the formation of mudflows including unconsolidated material in the drainage basin which contains enough clay to make it slippery when wet; slopes that are steep enough to induce rapid erosion or sloughing of material; short periods of abundant water; and insufficient vegetative protection (Bull, 1964). These conditions are often met in arid to semi-arid regions allowing the deposition of mudflows on alluvial fans.

Due to the nature of deposition and composition of mudflows, these deposits tend to exhibit collapsible behavior. Mudflows form the loose structure typical in a collapsible soil through textural and structural voids such as intergranular voids, bubble cavities, interlaminar voids, polygonal and smaller desiccation cracks, and voids left by buried vegetation (Bull, 1964). Along with the void structure created by mudflow deposition, the fine-grained mud matrix contains material which characteristically forms intergranular bonds in collapsible soils.

Due to the fact that deposition on an alluvial fan is an infrequent occurrence, mudflow deposits are not usually reworked by other processes but remain in the state of deposition. Subsequent rapid burial of a mudflow deposit tends to preserve the textural and structural voids in the flow leaving the loose structure of the soil. Internal water in the mudflow evaporates creating a meta-stable soil structure with capillary tension or silts, clays, and salts forming intergranular bonds between particles.

Upon saturation, collapsible soils experience compaction and a subsequent increase in soil structure density which removes the hazard of collapse in the deposit at the existing load intensity; therefore, the exposure a soil deposit has previously had to saturation is a factor in the identification and location of collapsible soils. A soil which is below or close to the existing groundwater table or which has been subjected to extensive flooding or prolonged wetting is not subject to the same degree of settlement as a dry soil. A deep water table indicates that the probability of surface soils being saturated is unlikely; therefore, potentially collapsible soils would still retain the features which make them susceptible to hydrocompaction.

A summary of the geologic site conditions conducive to the formation of collapsible soils are as follows:

1. Arid to semi-arid climatic conditions.
2. Drainage basin composed of clay-bearing sedimentary rocks.
3. Relatively small drainage basin with small amounts of vegetation.
4. High ratios of fan area to drainage basin area.
5. Soil types: silty sands, sandy silts, and low plasticity clays.
6. Mudflow depositional environment in an alluvial fan.
7. Large depth to the groundwater table.
8. Deposits which have not been previously subjected to extensive flooding or prolonged wetting.

## 2.2 LABORATORY COLLAPSIBLE SOIL TESTING

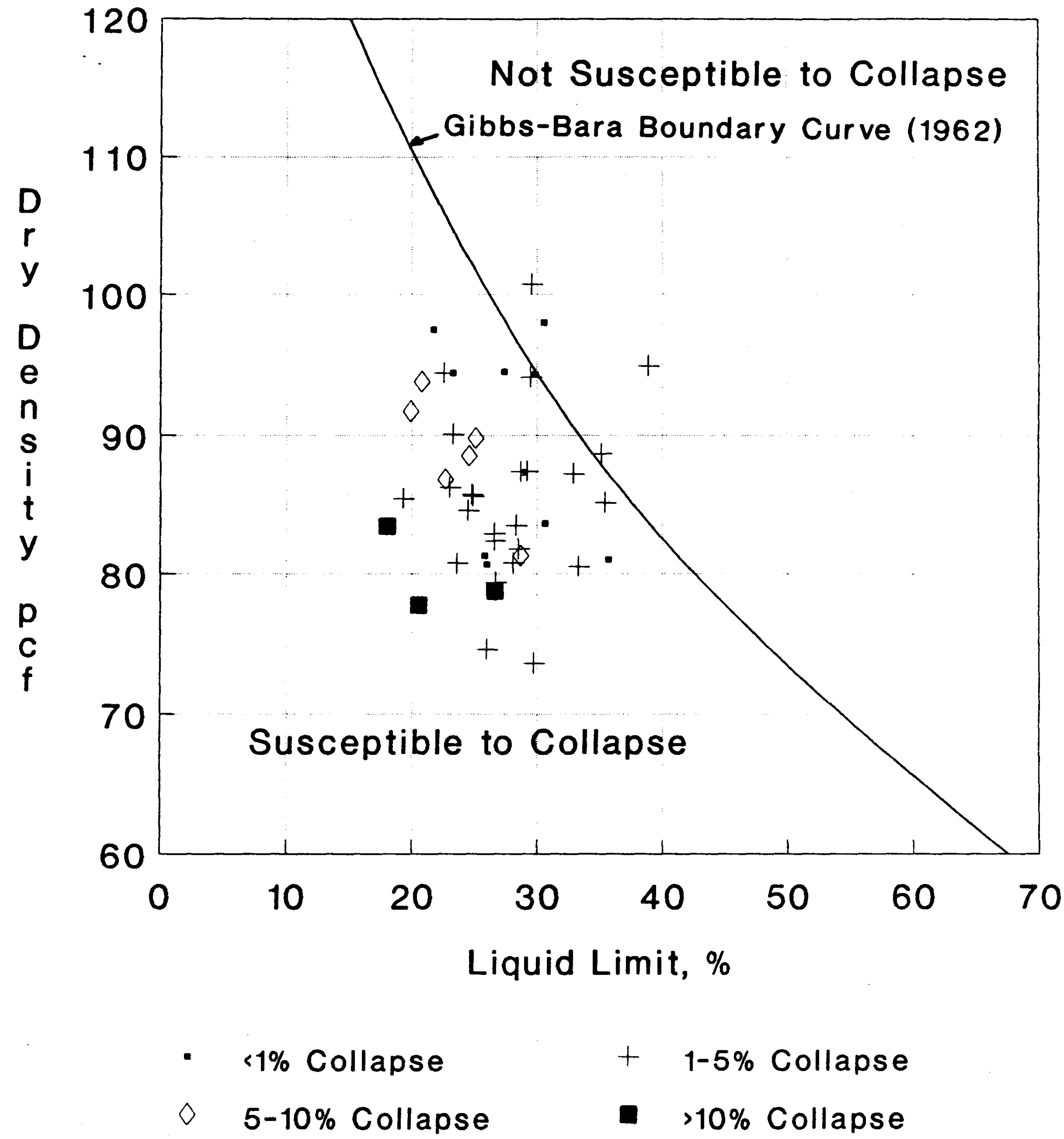
### 2.2.1 Correlations with Liquid Limit and Dry Density Test

One simple identification method for collapsible soils was proposed by Gibbs and Bara in 1962. Based on their study of soils in the central California valleys, they proposed a correlation between the liquid limit and dry density to determine whether or not a soil was susceptible to collapse (see Figure 1). This correlation is based on the concept that a soil will lose its dry strength when saturated to the point at which it performs as a liquid. The moisture content at this point would be roughly equivalent to the liquid limit determined in the Atterberg limit test.

If the volume of water required for the soil to reach its liquid limit exceeds the natural porosity of the soil, saturation of the soil to the liquid limit and the subsequent complete loss of the soil's dry strength will not occur. Therefore, the soil would not be considered collapsible. If sufficient void space is available in the soil at the natural porosity, saturation to the point of the liquid limit with complete dry strength loss is possible, and soils would be classified as susceptible to hydrocompaction. Using this theory, Gibbs and Bara (1962) defined a relationship between liquid limit and dry density for a specific gravity of 2.65. Soils falling below the curve in Figure 1 would be susceptible to collapse while those above the curve would not.

Using data from the San Luis Unit in California, Prokopovich (1984) determined that this relationship between liquid limit and dry density was not always reliable since collapse can occur when the moisture content of the soil is well below the liquid limit. In addition, he found that the criteria predicted collapse for materials which did not undergo any significant hydrocompaction. To determine the usefulness of this test in a specific area, soil tests would have to be performed to establish a correlation between soil collapsibility, liquid limit, and dry density.

# Figure 1 Collapse Susceptibility Chart
## Suitibility Based on Wasatch Range Data



Previous studies for soils in Utah conducted by Owens (1988) tend to verify the usefulness of the criteria as shown in Figure 1. It should be noted, however, that some of the low collapse potential soils plotted above the curve while some of the no collapse soils plotted below the line. It is likely that some of this scatter is a result of the difficulty of obtaining quality undisturbed samples in collapsible soil, nevertheless, complete reliance on the collapse susceptibility curve is not warranted by the data. While the criteria offers the advantages of simplicity and low cost, it only provides a qualitative indication of the degree of collapse which might be expected. In addition, it is not applicable for cohesionless soils such as silty sands and non-plastic sandy silts which constitute a large percentage of collapsible soils.

### 2.2.2 Consolidation Testing

Another method of collapsible soil identification is a modified consolidation test (collapse test) which can be used to calculate the percentage of collapse upon saturation of the soil. In a collapse test, the soil sample is cut to fit into a consolidometer ring (typically 2 3/8 " in diameter; 1" in height) and a standard consolidation test is performed at the soil's natural moisture content. The sample is progressively loaded up to the load intensity which will exist in the field at which point the specimen is saturated and allowed to collapse under the current load. The consolidation test is then carried out to its normal maximum loading limit. A typical consolidation curve of void ratio against pressure on a semi-logarithmic plot is presented in Figure 2. The percent strain of the soil upon saturation is given by the equation,

$$\% Strain = \frac{e_c}{(1+e_o)} \; x \; 100\%$$

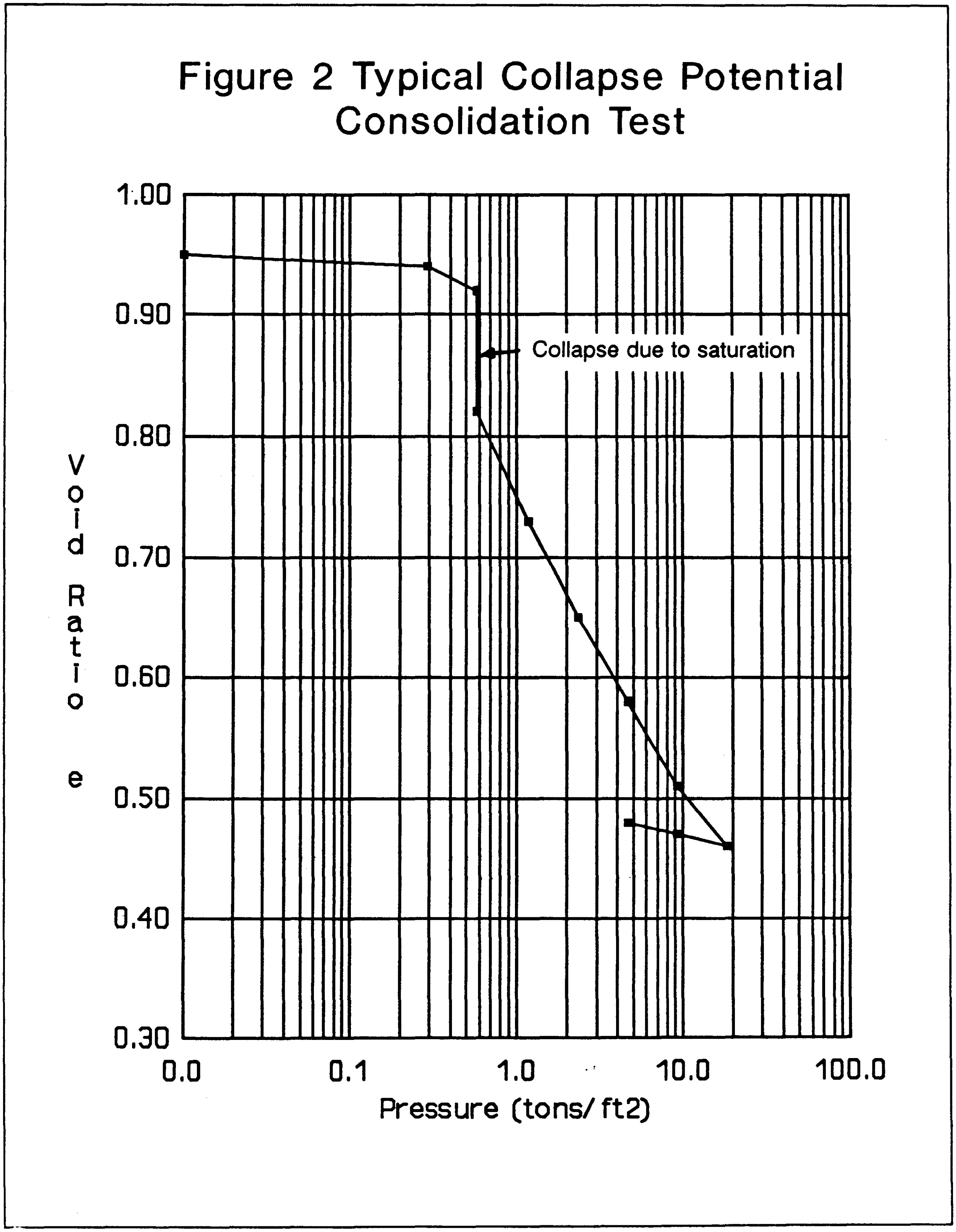


Figure 2 Typical Collapse Potential
Consolidation Test
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
Void Ratio e
Collapse due to saturation
0.0
0.1
1.0
10.0
100.0
Pressure (tons/ ft2)

where $e_c$ is the change in void ratio following saturation and $e_o$ is the initial in-place void ratio. The percent strain from the laboratory test can be multiplied by the thickness of the layer in the field to compute the expected settlement.

If the percent strain at a number of load intensities is desired, it is necessary to conduct double consolidation tests with nearly identical samples. This doubles the cost and testing effort involved. One sample is loaded at the natural moisture content and other is tested after saturation. The difference between the two curves at any load intensity is the percent strain due to hydrocompaction.

Jennings and Knight (1975) defined a term called the collapse potential as the percent strain at a load intensity of 200 kPa (2.09 Tsf). Based on their experience with collapsible aeolian soils in South Africa, Jennings and Knight (1975) established a criteria relating collapse potential with the likelihood of foundation problems as shown in Table 1. While the collapse potential is a useful indicator of the severity of collapse which could be expected at a site, it is not a design value for the prediction of settlement. With a knowledge of the collapse potential in an area, an engineer could determine if further investigation of the soils and treatment to mitigate the hazard are justified.

**Table 1**.Collapse Potential (Jennings and Knight, 1975)

| Collapse Potential | Severity of Problem |
|---|---|
| 0 - 1 % | No problem |
| 1 - 5 % | Moderate trouble |
| 5 - 10 % | Trouble |
| 10 - 20 % | Severe trouble |
| > 20 % | Very severe trouble |

## 3. COLLAPSE POTENTIAL ASSESSMENT FOR CEDAR CITY, UTAH

### 3.1 GEOLOGIC SETTING

Cedar City is located in a valley formed by normal block faulting which has subsequently filled with alluvium. East of Cedar City lies the Hurricane Cliffs which are composed of faulted and folded sedimentary rocks with sporadic extrusions of Tertiary and Quaternary tuffs and basalts. Alluvium which fills the valley is derived from these sedimentary rocks, transported by intermittent streams, and deposited along the mountain fronts in alluvial fans.

Several formations composed of clay-bearing rocks occur in the drainage basins to the east of Cedar City and are conducive to the formation of collapsible soils. The basal unit of the sedimentary sequence exposed to the east of Cedar City is the Triassic Moenkopi Formation. Due to folding and subsequent erosion of the beds in this area, the Moenkopi Fm. forms a series of ridges and valleys of resistant and non resistant rocks. The upper, middle, and lower red shale members of the Moenkopi Fm. are composed of nonresistant, red-brown shales, siltstones, and mudstones (Averitt and Threet, 1973; Gregory, 1950). Erosion and weathering of these strata from between the more resistant limestones of the other members has provided sediment accumulation for transportation by ephemeral streams and deposition in the alluvial fans in the area.

The upper member of the Chinle Formation is a nonresistant easily weathered unit composed of reddish-brown to grayish-red mudstones, siltstones, and shales (Averitt and Threet, 1973; Gregory, 1950). Argillaceous shale in this member provides a possible source for the clay needed to bind together collapsible soils.

The Moenkopi Formation and the Chinle Formation are directly adjacent to Cedar City to the east and provide a probable sediment source for the alluvial fans in the valley. Other formations in the drainage basins directly adjacent to the Cedar City area composed of mudstones, siltstones, and shales are (Averitt and Threet, 1973; Gregory, 1950): the Dinosaur Canyon Member of the Moenave Formation, lower member of the Kayenta Formation, Cedar City Tongue of the Kayenta Formation, banded member of the Carmel Formation (in previous work this unit was mapped as the Entrada Sandstone), the gypsiferous member of the Carmel Formation (formerly mapped as the Curtis Formation), and the Wahweap Formation. Sediments derived from these formations could also be a source for the large deposits of alluvial sediments in the Cedar City area. Because of intermingling and overlapping of fans, it is not generally possible to distinguish the exact source of a particular sediment.

Alluvial fan deposits are likely several hundred feet thick in the Cedar City area. Few borings by engineering firms have been performed to depths greater than about 50 feet Therefore, information on the compression characteristics of the deeper zones is lacking. The hazard presented by these deep deposits is less severe, however, since it is related to the likelihood of saturation of these soils either by groundwater or percolation of surface water. Most drill logs around the area do not indicate that the water table was encountered within the depth investigated. Therefore, the water table is probably quite deep.

The depth to the groundwater indicates that wetting of deep collapsible soil deposits by existing groundwater has probably not occurred. Significant amounts of surface water percolation would be necessary to saturate deep collapsible soil deposits; therefore, in construction of houses or small buildings, shallow collapsible soil deposits present the greatest hazard in the Cedar City area.

## 3.2 GEOTECHNICAL BOREHOLE AND TEST DATA

### 3.2.1 Collection of Geotechnical Data

During this investigation, efforts were made to obtain all available geotechnical data for the area from consulting firms as well as state and federal agencies. It is believed that all firms which have performed investigations in the area were contacted. Information was obtained from the geotechnical engineering firms: R.B. & G. Engineering, Provo, UT; Dames and Moore, Salt Lake City, UT; J. H. Kleinfelder & Associates, St. George, Utah; the Utah Department of Transportation, and the U.S. Soil Conservation Service. The information obtained generally consisted of borehole logs, soil classifications, Atterberg limits, gradations, in-place unit weights, and natural moisture contents. Since the presence of collapsible soils in the area had been previously established, some type of consolidation test data was also available for most sites.

In order to supplement the existing geotechnical test data base, 10 additional samples were obtained in areas where collapsible soils were suspected but data were limited. In general, block samples were cut by hand at a depth of 1.5 to 3 feet below the ground surface at each site. The samples were then sealed prior to transportation to the laboratory to preserve the natural moisture content. Some samples were trimmed directly into the consolidation rings in the field due to the difficulty in obtaining a block sample but most samples were trimmed into the consolidation rings in the laboratory. A summary of the geotechnical characteristics of the soils at all the sampling locations (49 sites) is presented in Plate 1. The location of each sampling site is overlain on the U.S. Geological Survey topographic quadrangle map for Cedar City, Utah in Map 1.

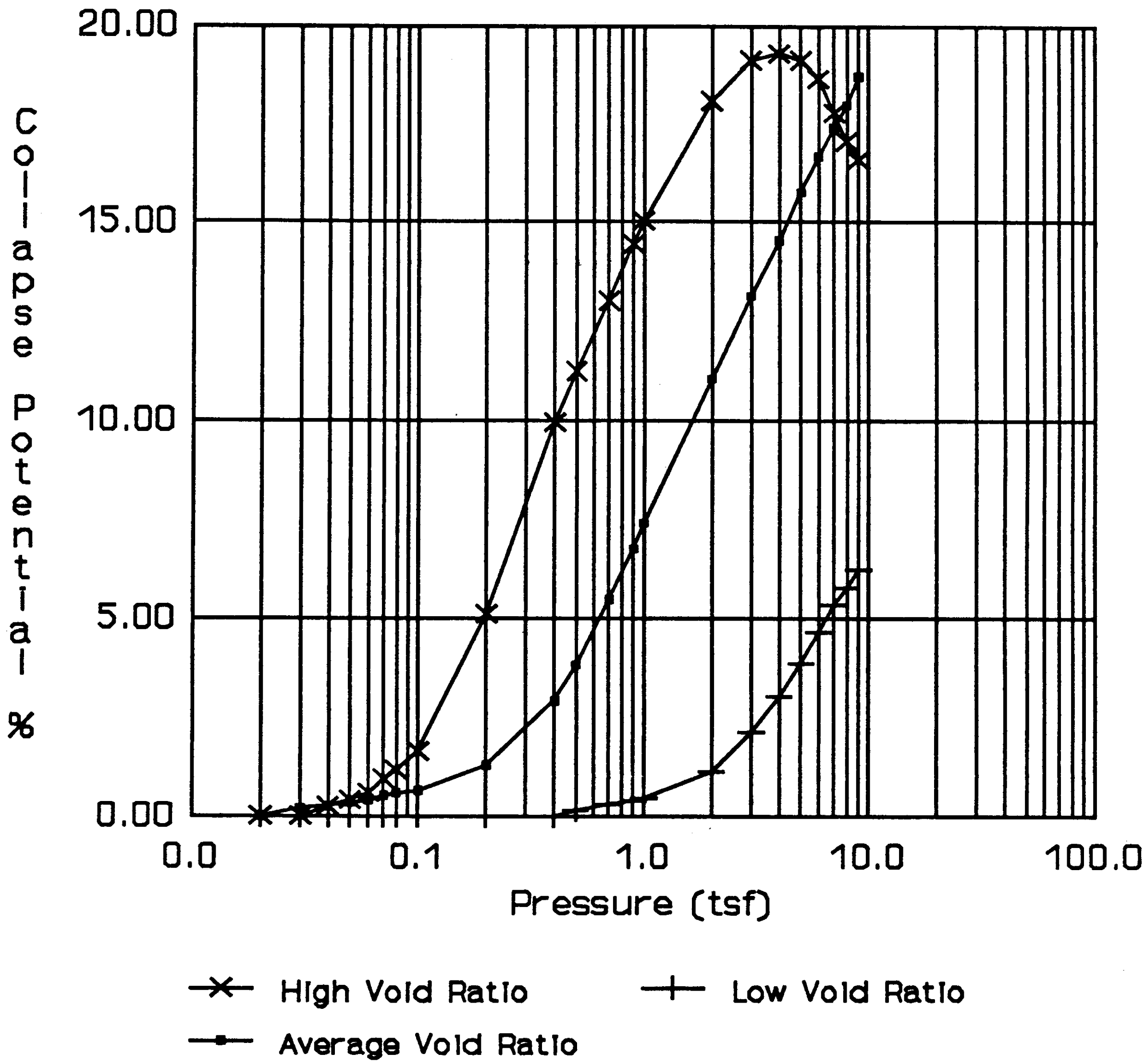
### 3.2.2 Consolidation Test Data

The consolidation test data yielded the percent collapse of the soil structure occurring upon saturation, but these values were not obtained at a consistent pressure value for all tests performed by various engineering firms and agencies. In some cases samples were saturated at the overburden pressure or at the anticipated load with a structure in place. Still others were saturated at an arbitrary load intensity or wetted at the beginning of the test. Collapse tests performed as part of this investigation were wetted at a load intensity of 56 kPa (0.58 tsf) which is representative of the overburden pressure which existed at the shallow sample locations.

In order to classify Cedar City area soils according to the collapse potential on a consistent basis, normalization of the results to a pressure of 110 kPa (1.15 tsf) was performed. This pressure was determined to be more consistent with the overburden pressure and likely structural loads in the Cedar City area than the 200 kPa (2.09 tsf) pressure used by Jennings and Knight. The higher pressure used by Jennings and Knight reflects the greater degree of cementation in the soils which were tested; while soils in Cedar City are relatively uncemented. The relative severity of the collapse potential of a soil was determined using the relationship defined by Jennings and Knight (see Table 1).

The relationship between pressure and collapse potential is not linear. As pressure increases, the collapse potential for a soil will increase until it reaches a maximum value just before the preconsolidation pressure at natural moisture content (Popescu, 1986; Ismael, 1989). Therefore, a curve was developed for the Cedar City area which indicated the relationship between the collapse potential of a soil and the applied pressure (see Figure 3). Values for collapse potential at varying pressures for typical Cedar City soils were obtained from previous work done on collapsible soils by SSuta S. Hsu (1981).

Figure 3 Collapse Potential vs. Pressure Relations for Cedar City, Utah (After Hsu, 1981)



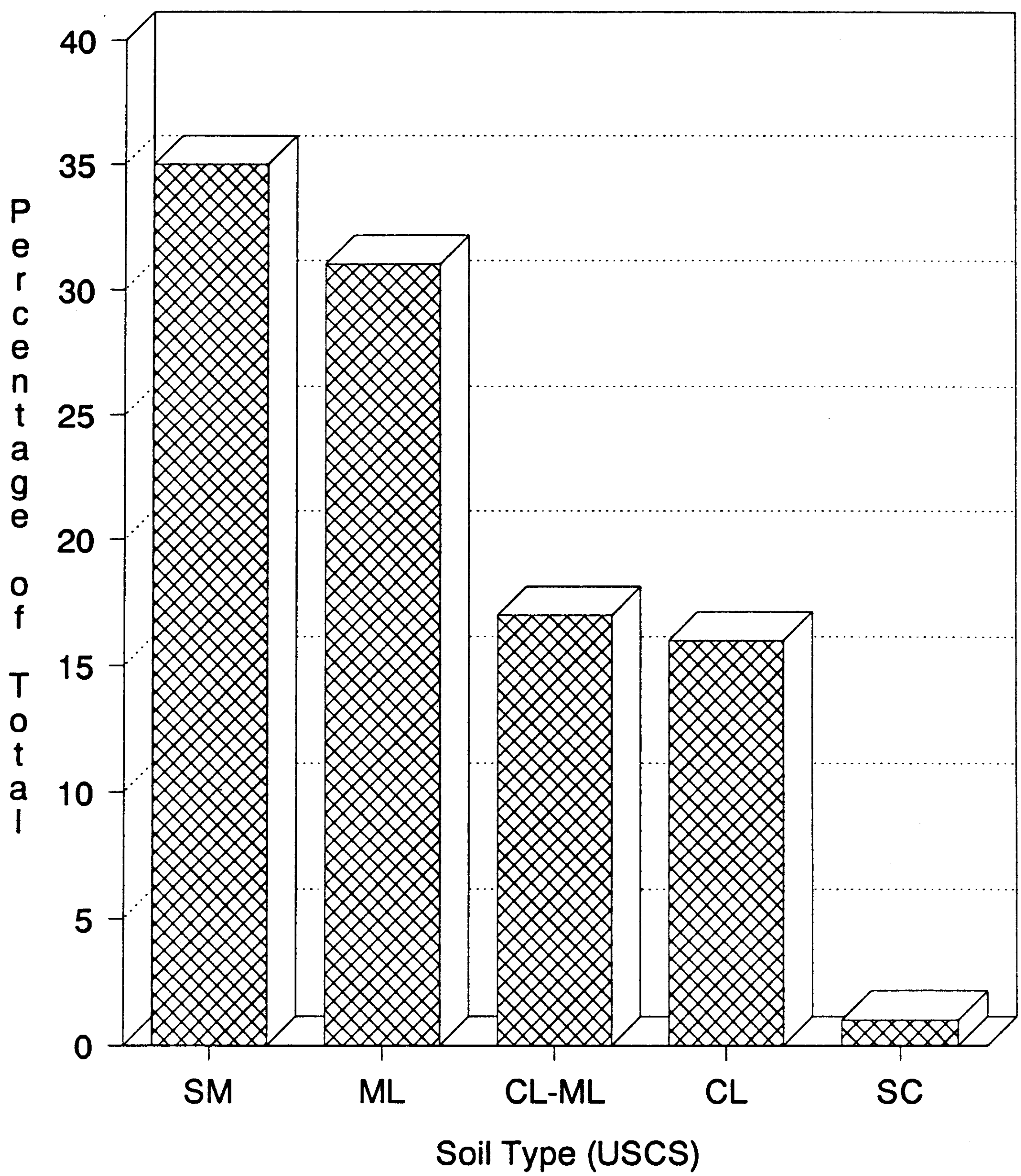
Hsu (1981) found that the amount of collapse which would occur in a soil varied with the pressure and the initial void ratio of the soil deposit. Idealized curves relating collapse potential to applied pressure for high void ratio alluvial deposits and low void ratio alluvial deposits (Hsu, 1981) for soils in the Cedar City area were used to obtain the relative collapse potential variation with pressure. Initial void ratios in the Cedar City soils ranged from 0.62 to 1.26 with the most common value occurring at approximately 0.85 to 0.95. An average line corresponding to an initial void ratio near those of the soils tested in the area (approximately 0.92) was used to normalize the percent of collapse which occurred in the consolidation test to the collapse potential which would occur at 110 kPa (1.15 tsf). A summary of the collapse potential as for each sample is listed in Plate 1 and values ranged from 0 to nearly 25%

**3.2.3 Relations Between Soil Properties and Collapse Potential**

In addition to the collapse potential tests which were performed, other soil classification data (Atterberg limits, dry density, natural moisture content, gradations) were determined for the soils in the Cedar City area. Based on gradations and Atterberg limits, soil samples were classified according to the Unified Soil Classification System. The distribution of soil types which exhibit collapsible characteristics is shown in Figure 4. It may be seen that silty sands (SM) and sandy silts (ML) account for 66 percent of the collapsible soils in the data base. The silty sands generally consist of medium to fine grained sand with 25 to 45 percent in the silt and clay size range. It appears that only 25 percent fines is sufficient to maintain the sand grains in a metastable condition subject to hydrocompaction. Gravel contents in collapsible soils ranged from 0 to 35%.

Cohesive soils such as low plasticity silty clays (CL-ML) and low to medium plasticity clays (CL) account for only 33 percent of the collapsible materials. The liquid limit of these soils is

## Figure 4 Distribution of Soil Types Exhibiting Collapse Potential




From Cedar City Data

generally between 15 and 30 percent and the plastic index is seldom higher than 12. No high plasticity collapsible soils were encountered during the investigation.

Collapsible soils typically have a low dry density (high void ratio) and a low natural moisture content. The relationship between void ratio and collapse potential in percent at a load intensity of 1.15 Tsf is presented in Figure 5 and a similar relationship with dry density is shown in Figure 6. The power regression curve for the data is also shown in both plots and has a correlation coefficient of about 50%. While there is a significant amount of scatter, the potential for collapse clearly increases as the void ratio increases and as the dry density decreases. While it is clear that the severity of collapse increases as the dry density decreases the dry density may vary as much as 25 pcf for a given degree of collapse as detailed in Table 2. As a result, predictions of collapse based on correlations with dry density alone will likely be rather crude.

**Table 2.**Variation of Dry Density (pcf) with Collapse Potential (%) in Cedar City soils

| CP (%) | DRY DENSITY (PCF) |
|---|---|
| 0 - 1 | 83.8 - 120.0 |
| 1 - 5 | 84.5 - 110.0 |
| 5 - 10 | 77.0 - 110.0 |
| > 10 | 74.6 - 98.0 |

**Table 3.**Variation of Natural Moisture Content (%) with Collapse Potential for Cedar City soils

| CP (%) | NATURAL MOISTURE CONTENT (%) |
|---|---|
| 0 - 1 | 2.3 - 33.8 |
| 1 - 5 | 2.1 - 27.7 |
| 5 - 10 | 1.5 - 22.5 |
| > 10 | 3.4 - 20.4 |

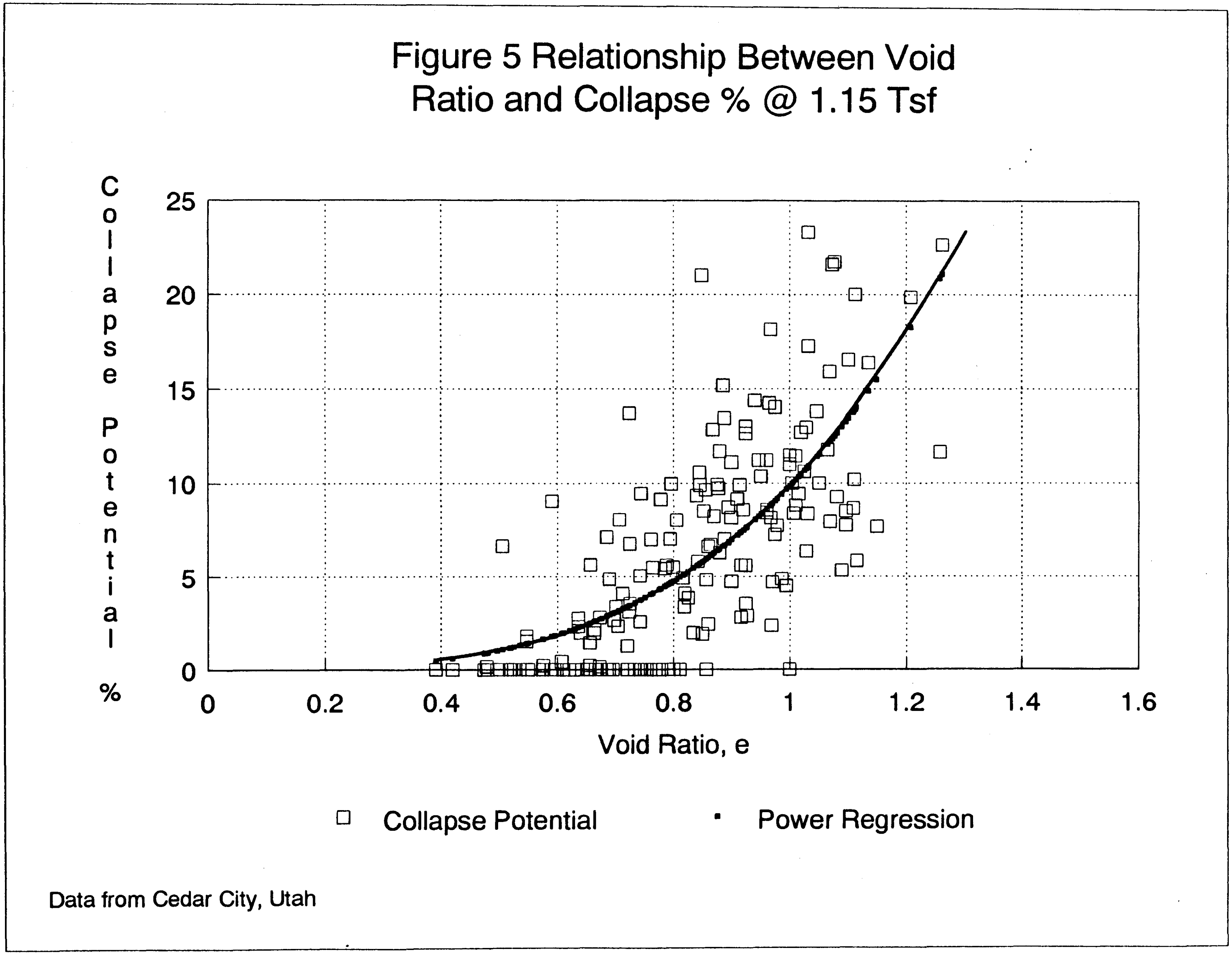
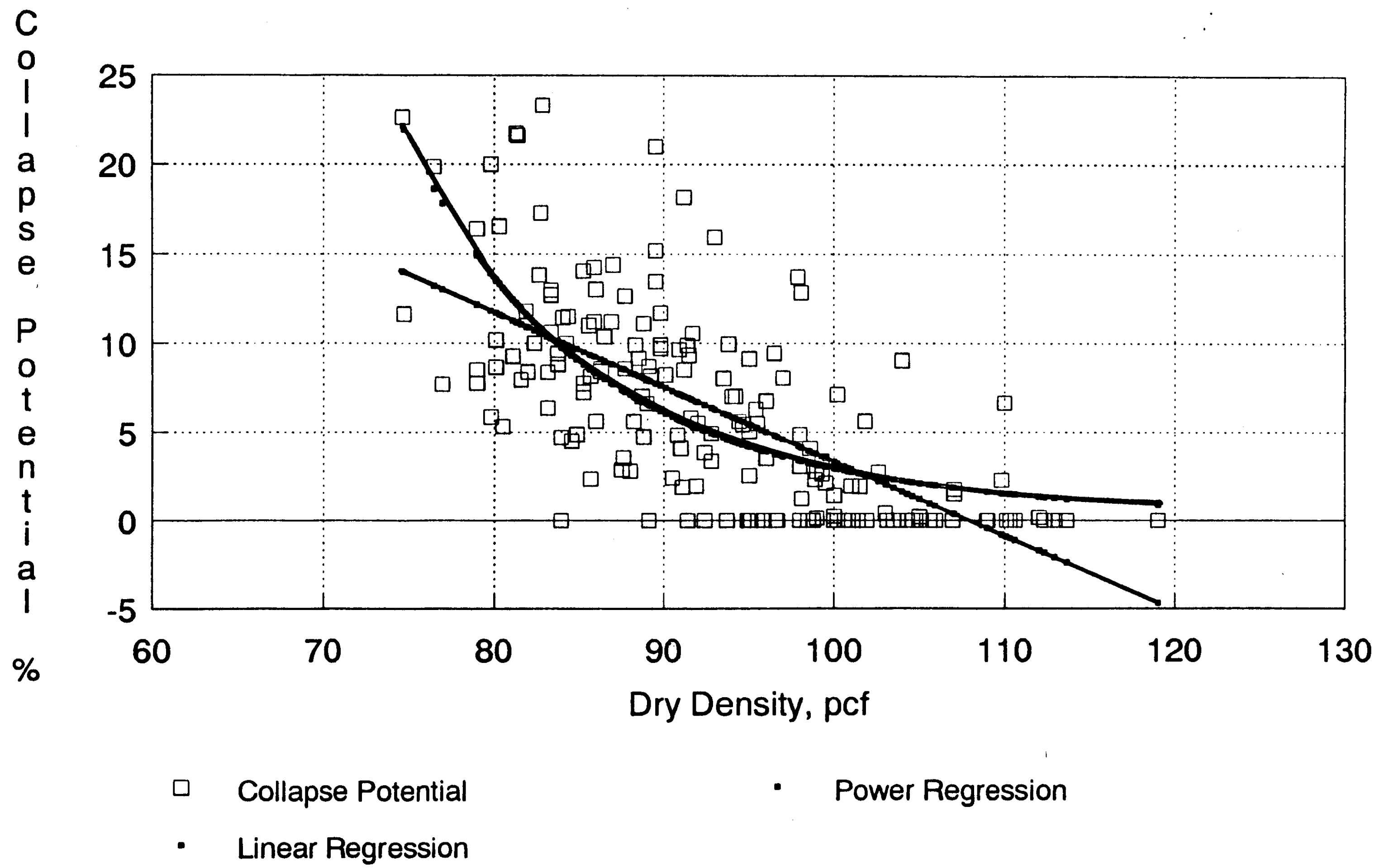


Figure 5 Relationship Between Void
Ratio and Collapse % @ 1.15 Tsf
Collapse Potential %
25
20
15
10
5
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
Void Ratio, e
Collapse Potential
Power Regression
Data from Cedar City, Utah

Figure 6 Relationship Between Dry Density and Collapse % @ 1.15 Tsf



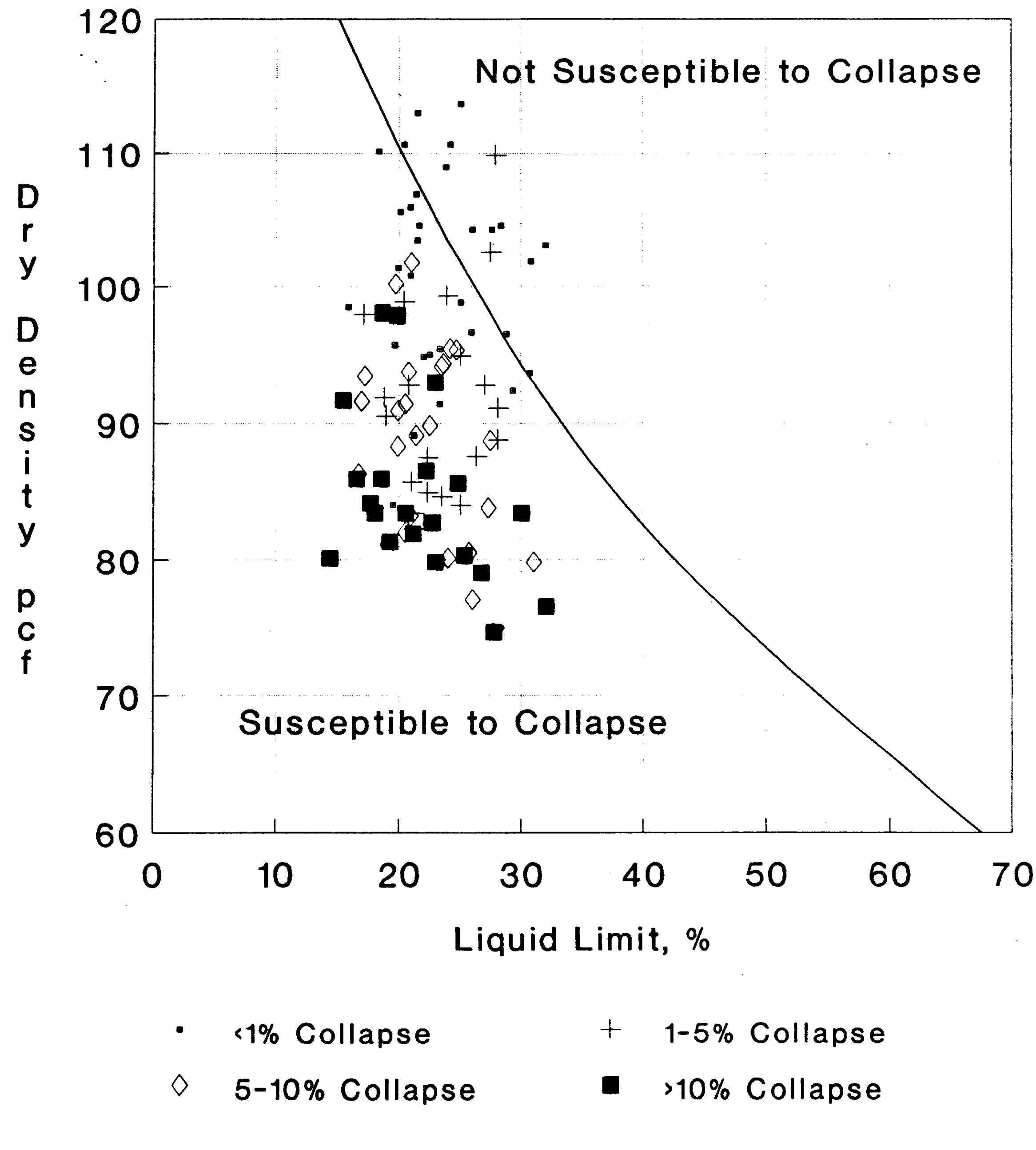

Data from Cedar City, Utah

The natural moisture content of the collapsible soils ranges between 2 and 18 percent and the variation for various levels of collapse is shown in Table 3. While there does not appear to be any relationship between collapse potential and moisture content, there is a decrease in collapse potential for increases in degree of saturation. Collapse potential as a function of degree of saturation is shown in Figure 7 along with a best fit line. It may be noted that the greatest collapse occurs for saturation less than 50%.

Since the dry unit weight, liquid limit and collapse potential are known for most of the samples, the Gibbs and Bara correlation for collapse susceptibility can be evaluated for Cedar City soils. A plot of Cedar City soil test data for samples with collapse potential less than 1%, 1 to 5%, 5 to 10%, and greater than 10 % is shown in Figure 8. Since the collapse susceptibility boundary varies with the liquid limit, the correlation gives a better estimate of the potential for collapse than a simple density correlation alone. In general, the test data indicates that the potential for collapse increases as a data point drops below the boundary line but the boundaries are somewhat fuzzy. All the data points for collapse potential greater than 5% fall below the boundary but there are a number of data points for non-collapsible soils which also fall below the boundary. The Gibbs-Bara boundary line appears to correspond to a collapse potential of roughly 1%.

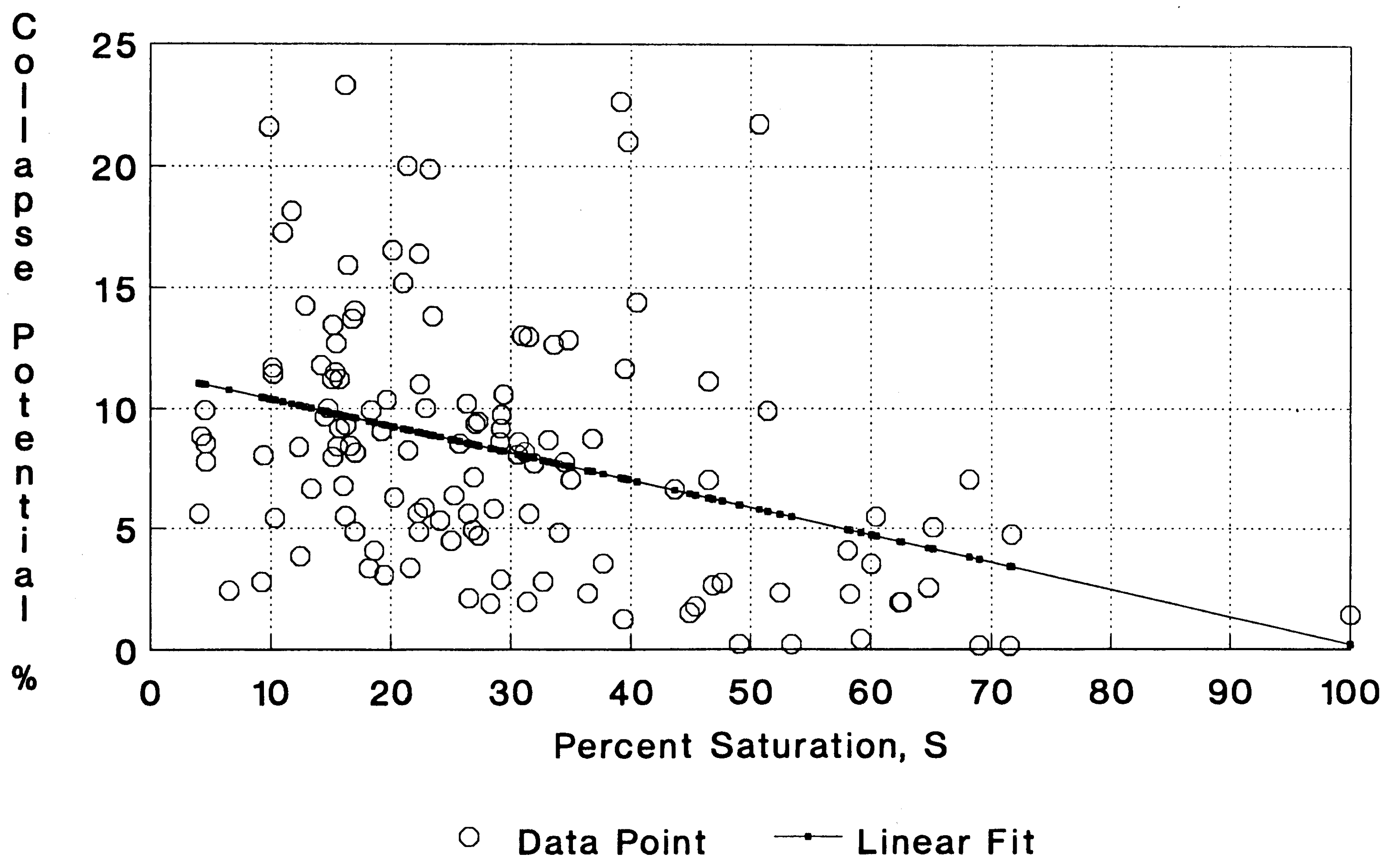
Based on the available data the correlation appears to be reasonably good for the Cedar City area and can be used as an indicator of soils which should be further tested to determine collapsibility. A similar plot for all available Utah soil data is presented in Figure 9 and the general trends appear to be about the same. Based on the field data, reasonably conservative boundaries of 5% and 10% collapse potential have been drawn and are shown in Figure 10.

# Figure 8 Collapse Potential Related to Liquid Limit and Dry Density



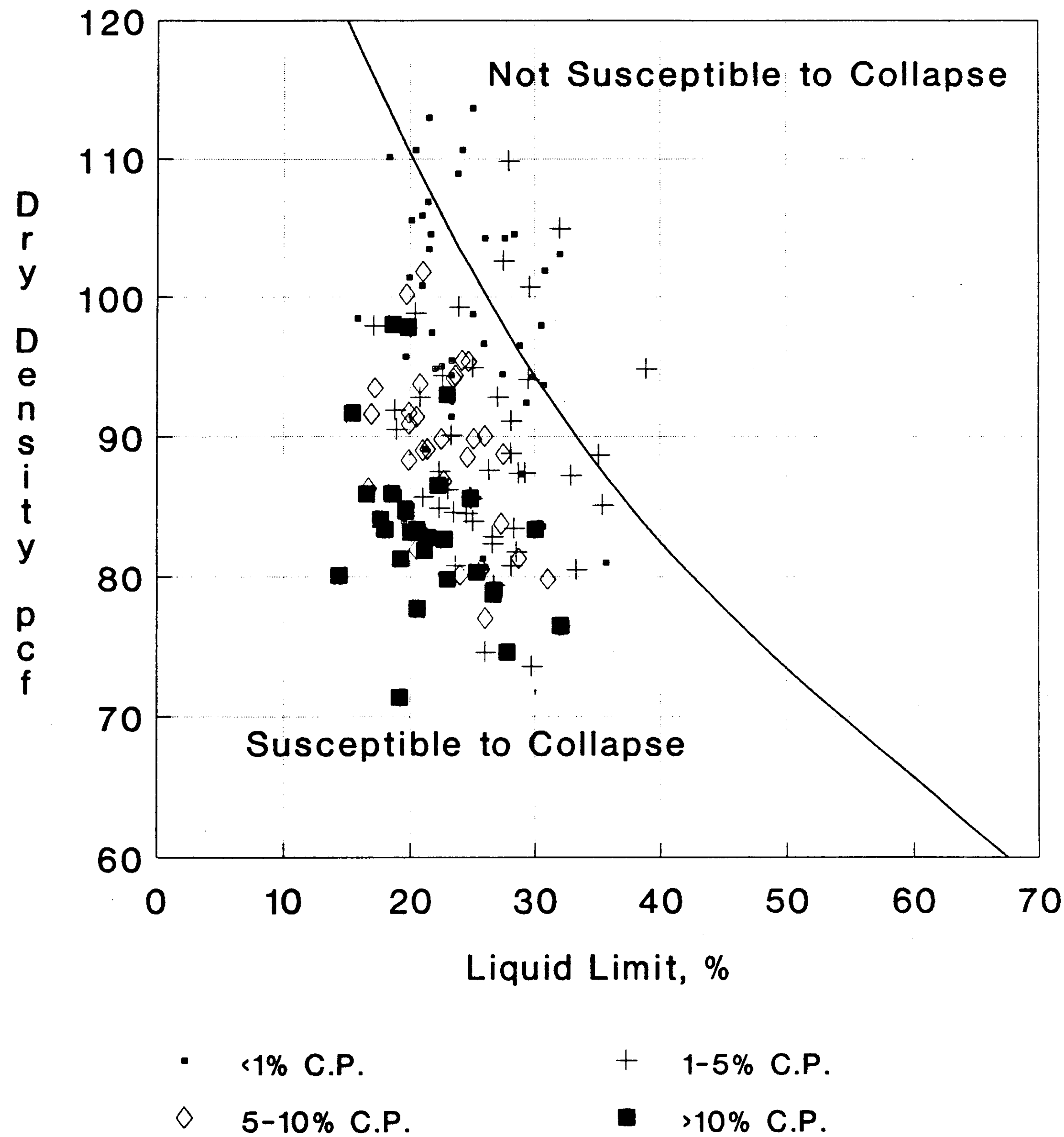

From Cedar City Data

# Figure 7 Influence of Degree of Saturation on Collapse Potential



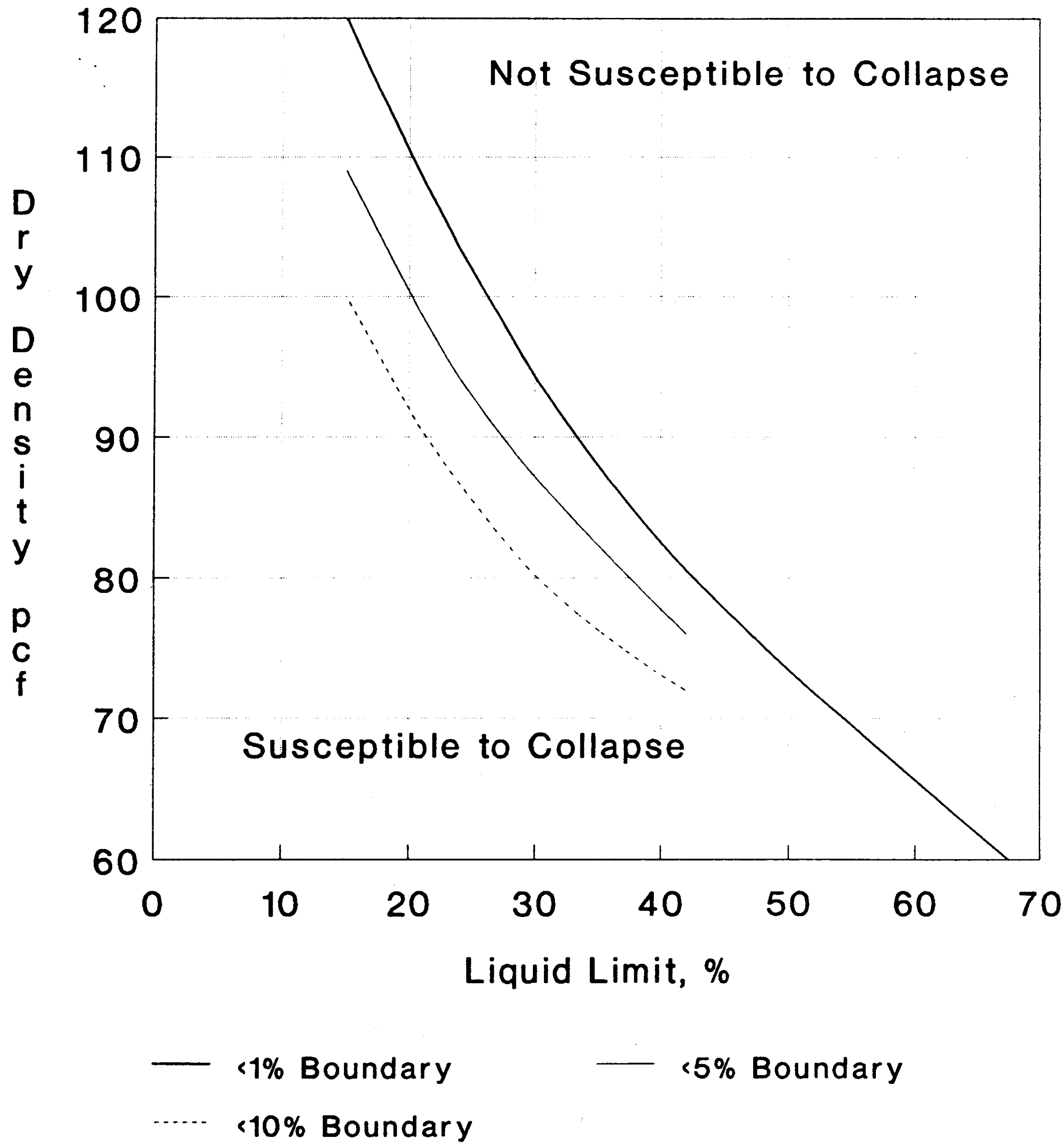

From Cedar City Data

# Figure 9 Collapse Potential Related to Liquid Limit and Dry Density




Available Utah Data

## Figure 10 Tentative Collapse Potential Boundaries From Basic Soil Properties




From Cedar City Data

While soils that plot below a boundary may have a lower collapse potential than predicted, they are relatively unlikely to have higher collapse potentials.

### 3.2.4 Correlation with Soil Survey Mapping

An existing U.S. Soil Conservation Service soil survey map of Cedar City was examined to determine if any correlation existed between the presence of a specific soil series and collapse potential. Although a general correlation does occur, the presence of a specific soil series does not necessarily mean collapsible soils are present. With reference to the Soil Survey and Interpretation of Cedar City, Iron County, Utah (USDA, 1975), the following soil series tend to correlate roughly with collapsible soils

| USDA Soil Series Classification | Unified Soil Classification |
|---|---|
| AdC | CL, ML-CL |
| AeC | CL, CL-ML, SM-MC, SC |
| CdC | CL, CL-ML |
| FbD (New Castle silt loam) | CL-ML, CL, GM-GC, GC |
| MgC (Modena sandy loam) | SM-SC, SM, SC |

## 3.3 Survey of Visible Collapse Damage

Although collapse potential consolidation tests provide the main basis for the Cedar City Collapse Hazard Map, visual observations of damage to existing structures were also found to be useful in evaluating likely performance of soils throughout the study area. A street by street survey was undertaken and any visual structural damage or soil failure features which could be attributable to the occurrence of soil collapse were mapped. While damage information does identify collapse prone areas, the absence of damage observations does not necessarily indicate the absence of collapsible soils. Damage is dependent on the age of the structure, the degree of saturation of the soil in the past, and the extent and effectiveness of any mitigation measures which might have been undertaken. Nevertheless, the occurrence of observable damage roughly correlated with the collapse potential test results. The distribution of observable damage due to collapsible soil was overlaid on the USGS quad map and is presented in Map 2.

## 4. MAP PREPARATION PROCEDURE

Based on geologic conditions, geotechnical data, and visual damage observations, the potential for collapsible soil damage was evaluated throughout the study area. Areas were classified as having low, moderate, high, or very high potential for collapsible soil damage. These classifications generally correspond to collapse potentials of 0 to 1%, 1 to 5%, 5 to 10% and greater than 10% respectively. At sites where several collapse potential values were obtained, the highest of the values was used to classify the site; therefore, the collapse potential hazard map would give an indication of the highest severity of the problem in the area. The visual damage data was considered in a qualitative way to indicate moderate to very high damage.

Correlation with the collapse mapping performed by Kaliser (1977) was used in areas of low data density to delineate the collapse potential regions. Low data density was particularly apparent in low collapse potential areas. Several areas of low collapse potential were delineated on the basis of geologic data rather than collapse potential tests. Exposures of coherent rock strata occurring to the east and the southwest of Cedar City were classified as having a low collapse potential. The alluvium to the northwest of Cedar City is composed of fair to well-sorted sand which lacks the honeycomb structure evident in collapsible soils and does not display other characteristics of a collapsible soil deposit.

Digitization of the Cedar City collapse potential map was performed to allow storage of data on computer making it easily accessible for modification and updating. The digitization procedure was performed using a computer-aided design and drafting (CADD) program in which the base topographic quadrangle of Cedar City was input into the computer and overlaid with the location of samples, the location of damaged structures, and the hazard potential zoning. The collapse potential test data was plotted, and the areas of collapse potential were delineated from the compiled data to create discrete sections with similar collapse potential severity values.

It should be recognized that the very high hazard classification does not guarantee that collapsible soils will be present and cause damage. Nor does it mean that structures can not be constructed in the area. It does, however, indicate that the potential for collapsible soils and settlement damage is relatively greater. This should alert the user of the maps to the need for more detailed investigations and engineering assessments of required mitigation measures for the particular structure contemplated at the site. Conversely, a low hazard classification does not preclude the possibility of collapsible soils although the potential for their occurrence is relatively less.

## 5. SUMMARY AND CONCLUSIONS

Collapsible soils pose a significant problem in the Cedar City area. As a result of this study, the majority of available data regarding the extent and severity of the hazard has been collected and tabulated. Basic soil properties such as density, moisture content and liquid limit were shown to provide useful criteria for evaluating the susceptibility to collapse prior to more expensive testing. Based on geologic, geotechnical, and damage evidence a collapsible soil hazard map was prepared for the study area. This map is intended to assist a geotechnical engineer or geologists in determining the extent of investigation for collapsible soils.

Conservative estimates of the collapse potential can be made using correlations with dry density and liquid limit. The use of the Jennings and Knight (1975) collapse potential test allows the soils to be classified according to the severity of collapse which could possibly occur at a site.

## REFERENCES

Averitt, P., and Threet, R.L., 1973, Geologic Map of the Cedar City Quadrangle, Iron County, Utah: United States Geological Survey, GQ-1120.

Beckwith, G.H., and Hansen, L.A.,1988, Identification and Characterization of the collapsing Alluvial Soils of the Western United States, Foundation Engineering, pp. 143-157.

Bull, W.B., 1964, Alluvial Fans and Near-Surface Subsidence in Western Fresno County, California, United States Geological Survey Professional Paper 437-A: U.S. Government Printing Office, Washington, D.C., 70 p.

Gibbs, H.J., and Bara, J.P., 1962, Predicting Surface Subsidence from Basic Soil Tests, Soils Engineering Report No. EM658, U.S. Dept. of the Interior, Bureau of Reclamation, 21 p.

Gregory, H.E., 1950, Geology of Eastern Iron County, Utah: Utah Geological and Mineral Survey Bulletin, 37, 153 p.

Houston, S.L., Houston, W.N., and Spadola, D.J., 1988, "Prediction of Field Collapse of Soils due to Wetting," ASCE Journal of Geotechnical Engineering, v. 114, no. 1, pp. 40-58.

Hsu, S.S., 1981, A Study of the Mechanics of Deformation of Hydro-Densifiable Soils, Thesis, Brigham Young University, Provo, Utah, 66 p.

Hepworth, R.C. and Langfelder, J.(1988) Settlement and Repairs to Cement Plant in Central Utah, Proceedings: Second International Conf. on Case Histories in Geotechnical Engineering, June 1-5, St. Louis, Mo. Paper No. 6.56 pp. 1349-1353

Ismael, N.F., 1989, Discussion, ASCE Journal of Geotechnical Engineering, v. 115, no. 12, pp. 1806-1808.

Jennings, J.E., and Knight, K., 1975, "A Guide to Construction on or with Materials Exhibiting Additional Settlement due to Collapse of Grain Structure", Sixth Regional Conference for Africa on Soil Mechanics and Foundation Engineering, pp. 99-105.

Kaliser, B.N., 1977, Ground subsidence in Cedar City, Utah: Utah Geological and Mineral Survey Report of Investigation RI-124, 130 p.

Owens, R.O., 1990, Collapsible Soil Hazard Map for the Southern Wasatch Front, Thesis prepared in partial fulfillment of the requirements for a Master's Degree in Civil Engineering, Brigham Young University, 80 p., 3 plates, 3 maps

Popescu, M.E., 1986, A Comparison Between the Behavior of Swelling and Collapsing Soils; Engineering Geology, no. 23, pp. 145-163.

Prokopovich, N.P., 1984, "Validity of Density-Liquid Limit Predictions of Hydrocompaction," Bulletin of the Association of Engineering Geologists, v. 21, no. 2, pp. 191-205.

Rollins, K.M., 1990, Mitigation Measures for Small Structures on Collapsible Soils, Proc. 6th Intl. Conf. on Engineering Geology, Amsterdam, The Netherlands, Aug. 4-10, v. 3, pp. 1997-2002

Shaw, D.A., and Johnpeer, G.D., 1985, Ground subsidence near Espanola, New Mexico, New Mexico Geology, v. 7, no. 2, pp. 32-34.

**PLATE 1**
**SUMMARY OF GEOTECHNICAL DATA**
**FOR COLLAPSIBLE SOILS IN CEDAR CITY, UTAH**

| SAMPLE SITE | DEPTH (FT.) | IN-SITU VOID RATIO | IN-SITU DRY UNIT WT. (PCF) | IN-SITU W (%) | CONSISTENCY LIMITS L.L. (%) | CONSISTENCY LIMITS P.L. (%) | CONSISTENCY LIMITS P.I. (%) | GRADATIONAL ANALYSIS GRAVEL (%) | GRADATIONAL ANALYSIS SAND (%) | GRADATIONAL ANALYSIS SILT/CLAY (%) | SOIL TYPE (USCS) | COLLAPSE POTENTIAL (%) | JENNINGS-KNIGHT CLASS. (@1.15 tsf) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.0 | 0.900 | 88.8 | 15.5 | | | | 0.0 | 60.5 | 39.5 | SM | 11.1 | severe trouble |
| | 6.0 | 0.924 | 87.7 | 11.5 | | | | 0.0 | 55.9 | 44.1 | SM | 12.7 | severe trouble |
| | 9.0 | 0.940 | 87.0 | 14.1 | | | | 0.0 | 67.4 | 32.6 | SM | 14.4 | severe trouble |
| | 12.0 | 0.857 | 90.8 | 10.8 | | | | 0.0 | 56.1 | 43.9 | SM | 4.8 | moderate trouble |
| 2 | 3.0 | 1.262 | 74.6 | 18.3 | 27.7 | 20.1 | 7.6 | | | | CL-1 | 22.6 | very severe trouble |
| | 3.0 | 1.108 | 80.1 | 13.6 | 24.0 | 17.3 | 6.7 | | | | CL-ML | 8.7 | trouble |
| | 5.0 | 0.986 | 84.9 | 6.2 | 22.3 | 16.0 | 6.3 | | | | CL-ML | 4.9 | moderate trouble |
| | 6.0 | 0.994 | 84.6 | 9.2 | 23.5 | 17.8 | 5.7 | | | | CL-ML | 4.5 | moderate trouble |
| | 6.0 | 1.258 | 74.7 | 18.4 | | | | | | | | 11.7 | |
| | 9.0 | 1.028 | 83.2 | 9.6 | 20.9 | 20.5 | 0.4 | | | | ML | 6.4 | trouble |
| | 9.0 | 1.088 | 80.5 | 9.7 | 25.7 | 17.8 | 7.9 | | | | CL-1 | 5.3 | trouble |
| | 11.0 | 1.004 | 84.3 | 5.5 | 28.1 | 19.5 | 8.6 | | | | CL-1 | 10.0 | severe trouble |
| | 12.0 | 1.100 | 80.3 | 8.2 | 25.3 | 19.1 | 6.2 | | | | CL-ML | 16.5 | severe trouble |
| | 12.0 | 1.046 | 82.7 | 9.1 | 22.7 | 15.7 | 7.0 | | | | CL-1 | 13.8 | severe trouble |
| 3 | 3.0 | 0.818 | 92.8 | 5.5 | 20.8 | 16.6 | 4.2 | | | | CL-ML | 3.4 | moderate trouble |
| | 6.0 | 0.724 | 97.9 | 4.5 | 19.8 | 14.2 | 5.6 | | | | CL-ML | 13.7 | severe trouble |
| | 9.0 | 0.914 | 88.3 | 6.2 | 19.9 | 15.5 | 4.4 | | | | CL-ML | 9.9 | trouble |
| | 12.0 | 1.006 | 82.0 | 5.8 | 20.5 | 14.9 | 5.6 | | | | CL-ML | 8.4 | trouble |
| 4 | 3.0 | 1.208 | 76.5 | 10.4 | 32.0 | 19.0 | 13.0 | | | | CL-1 | 19.9 | severe trouble |
| | 6.0 | 1.114 | 79.8 | 9.4 | 31.0 | 18.0 | 13.0 | | | | CL-1 | 5.9 | trouble |
| | 9.0 | 0.967 | 85.7 | 6.1 | | | | 0.3 | 56.1 | 43.6 | SM | 8.1 | trouble |
| | 12.0 | 0.816 | 92.8 | 8.1 | 27.0 | 18.0 | 9.0 | | | | CL-1 | 4.9 | moderate trouble |
| | 18.0 | 0.656 | 101.8 | 5.4 | 21.0 | 17.0 | 4.0 | | | | CL-ML | 5.6 | trouble |
| 5 | 3.0 | 0.864 | | | 27.2 | 18.5 | 8.7 | | | | CL-1 | 6.7 | trouble |
| | 3.0 | 0.926 | 87.5 | 10.0 | 22.3 | 16.0 | 6.3 | | | | CL-ML | 2.9 | moderate trouble |
| | 6.0 | 0.720 | 98.1 | 10.5 | | | | | | | CL-ML | 1.3 | moderate trouble |
| | 9.0 | 0.916 | 88.0 | 11.1 | | | | | | | CL-ML | 2.8 | moderate trouble |
| 6 | 3.0 | 1.072 | 81.4 | 3.9 | | | | 5.1 | 60.1 | 34.8 | SM | 21.6 | very severe trouble |
| | 6.0 | 1.032 | 82.8 | 4.2 | 21.4 | 15.0 | 6.4 | | | | CL-ML | 17.3 | severe trouble |
| | 9.0 | 0.920 | 87.7 | 9.9 | | | | 3.7 | 65.0 | 31.3 | SM | 8.6 | trouble |
| | 12.0 | 0.840 | 91.5 | 8.4 | | | | 5.2 | 70.7 | 24.1 | SM | 9.3 | trouble |

**PLATE 1 CONTINUED**
**SUMMARY OF GEOTECHNICAL DATA**
**FOR COLLAPSIBLE SOILS IN CEDAR CITY, UTAH**

| SAMPLE SITE | DEPTH (FT.) | IN-SITU | | | CONSISTENCY LIMITS | | | GRADATIONAL ANALYSIS | | | SOIL TYPE (USCS) | COLLAPSE POTENTIAL (%) | JENNINGS-KNIGHT CLASS. (@1.15 tsf) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | VOID RATIO | DRY UNIT WT. (PCF) | W (%) | L.L. (%) | P.L. (%) | P.I. (%) | GRAVEL (%) | SAND (%) | SILT/CLAY (%) | | | |
| 7 | 3.0 | 0.856 | 90.9 | 4.6 | 19.9 | 16.1 | 3.8 | | | | ML | 9.6 | trouble |
| | 3.0 | 1.068 | 81.6 | 6.0 | | | | 0.0 | 43.2 | 56.8 | ML | 8.0 | trouble |
| | 6.0 | 1.064 | 81.9 | 5.6 | 21.1 | 15.6 | 5.5 | | | | CL-ML | 11.8 | severe trouble |
| | 6.0 | 1.076 | 81.3 | 20.2 | 19.2 | 18.3 | 0.9 | | | | ML | 21.7 | very severe trouble |
| | 9.0 | 0.924 | 87.6 | 12.9 | 26.3 | 15.6 | 10.7 | | | | CL-1 | 3.5 | moderate trouble |
| | 9.0 | 0.968 | 85.7 | 18.8 | 21.0 | 18.9 | 12.1 | | | | | 2.3 | moderate trouble |
| 8 | 6.0 | 0.794 | 94.2 | 10.3 | 23.5 | 18.4 | 5.1 | | | | | 7.0 | trouble |
| | 9.0 | 0.700 | 99.3 | 5.6 | | | | 2.2 | 56.9 | 41.0 | SM | 3.4 | moderate trouble |
| | 9.0 | 0.788 | 94.4 | 7.7 | 23.6 | 17.2 | 6.4 | | | | CL-ML | 5.6 | trouble |
| | 9.0 | 0.895 | 89.1 | 12.2 | 21.4 | 17.3 | 4.1 | | | | | 8.7 | trouble |
| | 12.0 | 1.112 | 79.8 | 8.8 | 22.9 | 15.1 | 7.8 | | | | CL-1 | 20.0 | very severe trouble |
| | 15.0 | 0.950 | 86.5 | 6.9 | 22.2 | 18.6 | 3.6 | | | | | 10.4 | severe trouble |
| | 20.0 | 0.684 | 100.2 | 6.8 | 19.7 | 15.7 | 3.9 | | | | | 7.1 | trouble |
| | 25.0 | 0.870 | 90.1 | 6.9 | | | | 1.1 | 70.3 | 28.6 | SM | 8.2 | trouble |
| 9 | 4.0 | 0.805 | 93.5 | 2.8 | 17.2 | 16.7 | 0.5 | | | | ML | 8.0 | trouble |
| | 5.0 | 0.846 | 91.4 | 16.1 | 20.5 | 15.8 | 4.7 | | | | ML | 9.9 | trouble |
| | 5.0 | 0.876 | 89.8 | 1.5 | 22.5 | 14.2 | 8.3 | | | | ML | 9.9 | trouble |
| | 7.5 | 0.825 | 92.4 | 3.8 | | | | | | | | 3.8 | moderate trouble |
| | 8.0 | 0.974 | 85.3 | | | | | | | | SM | 7.3 | trouble |
| | 10.0 | 0.916 | 88.2 | 1.4 | | | | | | | ML | 5.6 | trouble |
| | 10.5 | 0.860 | 90.5 | 2.1 | 18.9 | 16.3 | 2.6 | | | | | 2.4 | moderate trouble |
| 10 | 3.0 | 0.662 | 101.5 | 15.3 | | | | 25.3 | 44.6 | 30.1 | SM,GM | 1.9 | moderate trouble |
| | 3.0 | 0.852 | 91.2 | 8.1 | | | | 8.2 | 59.5 | 32.3 | SM | 8.5 | severe trouble |
| | 6.0 | 0.712 | 98.6 | 4.9 | | | | 0.0 | 55.8 | 44.2 | SM | 4.1 | moderate trouble |
| | 9.0 | 0.744 | 96.5 | 7.5 | | | | 15.0 | 52.4 | 32.6 | SM,GM | 9.4 | severe trouble |
| | 25.0 | 0.764 | 95.5 | 17.1 | 24.2 | 22.3 | 1.9 | | | | ML | 5.5 | trouble |
| 11 | 3.0 | 0.868 | 98.1 | 11.2 | 18.6 | 15.3 | 3.3 | | | | ML | 12.8 | severe trouble |
| | 3.0 | 1.068 | 93.0 | 6.5 | 22.9 | 17.3 | 5.6 | | | | CL-ML | 15.9 | severe trouble |
| | 4.5 | 0.880 | 95.4 | 6.6 | 24.7 | 18.5 | 6.2 | | | | CL-ML | 6.3 | trouble |
| 12 | 3.0 | 0.697 | 99.3 | 12.1 | 23.9 | 21.4 | 2.5 | | | | ML | 2.6 | moderate trouble |
| | 6.0 | 0.635 | 102.6 | 11.2 | 27.5 | 15.5 | 12.0 | | | | CL-1 | 2.7 | moderate trouble |
| | 9.0 | 0.704 | 98.9 | 9.5 | 20.4 | 19.4 | 1.0 | | | | ML | 2.3 | moderate trouble |
| 13 | 3.0 | 0.878 | 89.8 | 9.5 | | | | 0.0 | 47.8 | 52.2 | ML | 9.7 | severe trouble |
| | 3.0 | 0.946 | 86.9 | 5.3 | | | | 0.0 | 51.7 | 48.3 | SM | 11.2 | severe trouble |
| | 5.0 | 0.886 | 89.5 | 6.9 | | | | 0.0 | 54.7 | 45.3 | SM | 15.2 | severe trouble |
| | 6.0 | 0.888 | 89.5 | 5.0 | | | | 0.0 | 59.7 | 40.3 | SM | 13.5 | severe trouble |

**PLATE 1 CONTINUED**
**SUMMARY OF GEOTECHNICAL DATA**
**FOR COLLAPSIBLE SOILS IN CEDAR CITY, UTAH**

| SAMPLE SITE | DEPTH (FT.) | IN-SITU | | | CONSISTENCY LIMITS | | | GRADATIONAL ANALYSIS | | | SOIL TYPE (USCS) | COLLAPSE POTENTIAL (%) | JENNINGS-KNIGHT CLASS. (@1.15 tsf) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | VOID RATIO | DRY UNIT WT. (PCF) | W (%) | L.L. (%) | P.L. (%) | P.I. (%) | GRAVEL (%) | SAND (%) | SILT/CLAY (%) | | | |
| 14 | 3.0 | 1.135 | 79.0 | 9.4 | 26.7 | 16.3 | 10.4 | | | | | 16.4 | severe trouble |
| | 6.0 | 1.050 | 82.4 | 8.9 | 26.6 | 16.8 | 9.8 | | | | | 10.0 | severe trouble |
| | 9.0 | 0.850 | 91.1 | 8.9 | 28.1 | 17.6 | 10.5 | | | | | 1.9 | moderate trouble |
| | 12.0 | 0.720 | 98.5 | 4.4 | 15.8 | 14.7 | 1.1 | | | | | 0.0 | no problem |
| | 15.0 | 0.775 | 95.1 | 6.1 | 22.5 | 15.5 | 7.0 | | | | | 0.0 | no problem |
| 15 | 3.0 | 0.744 | 94.9 | 18.4 | 22.0 | 15.5 | 6.5 | | | | CL-ML | 0.0 | no problem |
| | 3.0 | 0.857 | 89.1 | 18.3 | 21.2 | 15.9 | 5.3 | | | | CL-ML | 0.0 | no problem |
| | 6.0 | 0.733 | 95.5 | 22.8 | 23.3 | 15.5 | 7.8 | | | | CL-1 | 0.0 | no problem |
| | 6.0 | 1.000 | 84.0 | 23.0 | 19.5 | 19.4 | 0.1 | | | | ML | 0.0 | no problem |
| | 9.0 | 0.791 | 92.4 | 33.8 | 29.3 | 16.2 | 13.1 | | | | CL-1 | 0.0 | no problem |
| | 12.0 | 0.811 | 91.4 | 26.0 | 23.3 | 17.5 | 5.8 | | | | CL-ML | 0.0 | no problem |
| 16 | 3.0 | 0.525 | 110.6 | 12.7 | 20.4 | 15.2 | 5.2 | | | | CL-ML | 0.0 | no problem |
| | 3.0 | 0.620 | 104.3 | 19.5 | 26.0 | 19.4 | 6.6 | | | | CL-ML | 0.0 | no problem |
| | 6.0 | 0.590 | 105.9 | 14.9 | 20.9 | 19.6 | 1.3 | | | | ML | 0.0 | no problem |
| | 9.0 | 0.575 | 106.9 | 14.1 | 21.4 | 18.7 | 2.7 | | | | ML | 0.0 | no problem |
| 17 | 3.0 | 0.480 | 113.6 | 14.4 | 25.0 | 14.0 | 11.0 | | | | CL-1 | 0.0 | no problem |
| | 6.0 | 0.665 | 101.4 | 16.2 | 19.9 | 11.9 | 8.0 | | | | CL-1 | 0.0 | no problem |
| 18 | 3.0 | 1.025 | 83.4 | 21.4 | 30.0 | 18.7 | 11.3 | | | | CL-1 | 10.6 | severe trouble |
| | 6.0 | 1.015 | 83.8 | 19.7 | 27.3 | 17.1 | 10.2 | | | | CL-1 | 9.4 | trouble |
| | 9.0 | 0.888 | 88.7 | 22.4 | 27.5 | 18.1 | 9.4 | | | | CL-1 | 7.0 | trouble |
| | 12.0 | 0.900 | 88.8 | 23.9 | 28.1 | 18.2 | 9.9 | | | | CL-1 | 4.7 | moderate trouble |
| | 15.0 | 0.720 | 98.8 | 23.2 | 25.0 | 22.6 | 2.4 | | | | ML | 0.0 | no problem |
| | 20.0 | 0.675 | 100.8 | 20.7 | 20.9 | 16.8 | 4.1 | | | | CL-ML | 0.0 | no problem |
| | 25.0 | 0.620 | 104.6 | 19.3 | 21.6 | 17.3 | 4.3 | | | | CL-ML | 0.0 | no problem |
| | 35.0 | 0.535 | 110.1 | 13.7 | 18.3 | 16.4 | 1.9 | | | | ML | 0.0 | no problem |
| | 40.0 | 0.525 | 110.6 | 17.2 | 24.2 | 16.3 | 7.9 | | | | CL-1 | 0.0 | no problem |
| 19 | 3.0 | 0.778 | 95.0 | 8.4 | | | | 0.0 | 64.2 | 35.8 | SM | 9.1 | trouble |
| | 3.0 | 0.965 | 85.9 | 4.6 | 16.5 | 15.7 | 0.8 | | | | ML | 14.3 | severe trouble |
| | 6.0 | 0.785 | 94.6 | 3.0 | | | | 0.1 | 68.5 | 31.4 | SM | 5.4 | trouble |
| | 9.0 | 0.880 | 89.8 | 3.3 | | | | 0.1 | 58.5 | 41.4 | SM | 11.7 | severe trouble |
| 20 | 3.0 | 0.800 | 93.7 | 15.5 | 30.7 | 17.6 | 13.1 | | | | CL-1 | 0.0 | no problem |
| | 6.0 | 0.750 | 96.6 | 12.6 | 28.8 | 18.1 | 10.7 | | | | CL-1 | 0.0 | no problem |
| | 9.0 | 0.842 | 91.6 | 8.9 | 16.9 | 14.4 | 2.5 | | | | ML | 5.8 | trouble |
| | 12.0 | 0.834 | 91.9 | 9.7 | 18.8 | 16.8 | 2.0 | | | | ML | 2.0 | moderate trouble |

**PLATE 1 CONTINUED**
**SUMMARY OF GEOTECHNICAL DATA**
**FOR COLLAPSIBLE SOILS IN CEDAR CITY, UTAH**

| SAMPLE SITE | DEPTH (FT.) | IN-SITU VOID RATIO | IN-SITU DRY UNIT WT. (PCF) | W (%) | CONSISTENCY LIMITS L.L. (%) | CONSISTENCY LIMITS P.L. (%) | CONSISTENCY LIMITS P.I. (%) | GRADATIONAL ANALYSIS GRAVEL (%) | GRADATIONAL ANALYSIS SAND (%) | GRADATIONAL ANALYSIS SILT/CLAY (%) | SOIL TYPE (USCS) | COLLAPSE POTENTIAL (%) | JENNINGS-KNIGHT CLASS. (@1.15 tsf) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 21 | 4.0 | 0.760 | 104.3 | 11.6 | 27.6 | 10.7 | 16.9 | | | | CL-2 | 0.0 | no problem |
| | 4.0 | 0.650 | 103.1 | 16.3 | 32.0 | 17.9 | 14.1 | | | | CL-1 | 0.0 | no problem |
| | 7.0 | 0.695 | 100.2 | 10.8 | | | | | | | | 0.0 | no problem |
| | 7.0 | 0.650 | 96.7 | 13.1 | 25.9 | 14.0 | 11.9 | | | | CL-1 | 0.0 | no problem |
| | 9.0 | 0.685 | 100.6 | 19.6 | | | | | | | | 0.0 | no problem |
| 22 | 4.0 | 0.550 | 110.3 | 7.7 | | | | 8.6 | 50.1 | 40.5 | SM | 0.0 | no problem |
| | 7.0 | 0.520 | 112.9 | 7.3 | 21.5 | 12.4 | 9.1 | 0.0 | 39.2 | 60.8 | ML | 0.0 | no problem |
| | 11.0 | 0.750 | 100.0 | 7.1 | | | | 0.0 | 53.7 | 46.3 | SM | 0.0 | no problem |
| 23 | 3.0 | 0.760 | 95.8 | 12.7 | 19.6 | 14.4 | 5.2 | | | | CL-ML | 0.0 | no problem |
| | 3.0 | 1.010 | 84.1 | 3.8 | 17.6 | 16.9 | 0.7 | | | | ML | 11.4 | severe trouble |
| | 6.0 | 0.595 | 105.6 | 6.9 | 20.1 | 16.2 | 3.9 | | | | ML | 0.0 | no problem |
| | 9.0 | 0.978 | 85.3 | 12.5 | | | | 0.0 | 54.8 | 45.2 | SM | 7.7 | trouble |
| 24 | 3.0 | 0.655 | 101.9 | 19.9 | 30.8 | 15.1 | 15.7 | | | | CL-2 | 0.0 | no problem |
| | 3.0 | 0.610 | 104.6 | 19.7 | 28.3 | 16.3 | 12.0 | | | | CL-1 | 0.0 | no problem |
| | 6.0 | 0.630 | 103.5 | 6.7 | 21.5 | 14.0 | 7.5 | | | | ML,SM | 0.0 | no problem |
| | 6.0 | 0.550 | 108.9 | 12.7 | 23.8 | 13.1 | 10.7 | | | | CL-1 | 0.0 | no problem |
| | 9.0 | 0.420 | | | | | | | | | ML | 0.0 | no problem |
| 25 | 3.0 | 0.496 | 110.6 | 16.4 | | | | | | | ML | 0.0 | no problem |
| | 6.0 | 0.474 | 112.3 | 14.4 | | | | | | | ML | 0.0 | no problem |
| | 9.0 | 0.518 | 109.0 | 19.1 | | | | | | | CL-1 | 0.0 | no problem |
| 26 | 4.0 | 0.635 | 109.8 | 13.7 | 27.9 | 24.7 | 3.2 | 0.0 | 26.5 | 73.5 | ML | 2.3 | moderate trouble |
| | 6.0 | 0.967 | 91.2 | 4.2 | | | | | | | ML | 18.2 | severe trouble |
| 27 | 3.0 | 1.080 | 81.1 | 6.5 | | | | 2.3 | 59.8 | 37.6 | SM | 9.3 | trouble |
| | 5.0 | 0.960 | 85.9 | 5.6 | 18.5 | 15.6 | 2.9 | | | | ML | 11.2 | severe trouble |
| 28 | 3.0 | 1.030 | 83.2 | 4.7 | | | | 0.0 | 52.7 | 47.3 | SM | 8.4 | trouble |
| | 3.0 | 0.960 | 86.3 | 10.9 | 16.7 | 16.6 | 0.1 | | | | ML | 8.6 | trouble] |
| | 6.0 | 0.723 | 98.0 | 5.2 | 17.1 | 16.4 | 0.7 | | | | ML | 3.1 | moderate trouble |
| | 6.0 | 0.845 | 91.7 | 9.2 | 15.4 | 15.3 | 0.1 | | | | ML | 10.6 | severe trouble |

**PLATE 1 CONTINUED**
**SUMMARY OF GEOTECHNICAL DATA**
**FOR COLLAPSIBLE SOILS IN CEDAR CITY, UTAH**

| SAMPLE SITE | DEPTH (FT.) | IN-SITU VOID RATIO | IN-SITU DRY UNIT WT. (PCF) | IN-SITU W (%) | CONSISTENCY LIMITS L.L. (%) | P.L. (%) | P.I. (%) | GRADATIONAL ANALYSIS GRAVEL (%) | SAND (%) | SILT/CLAY (%) | SOIL TYPE (USCS) | COLLAPSE POTENTIAL (%) | JENNINGS-KNIGHT CLASS. (@1.15 tsf) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 29 | 3.0 | 0.960 | 86.3 | 5.9 | | | | 3.6 | 59.9 | 36.5 | SM | 8.4 | trouble |
| | 3.0 | 0.910 | 88.5 | 5.3 | | | | 2.9 | 59.2 | 37.9 | SM | 9.2 | trouble |
| | 3.0 | 1.028 | 83.4 | 12.0 | 20.5 | 17.3 | 3.2 | | | | ML | 13.0 | severe trouble |
| | 6.0 | 1.000 | 85.6 | 8.3 | 24.8 | 15.9 | 8.9 | | | | CL-1 | 11.0 | severe trouble |
| | 9.0 | 1.000 | 84.4 | 5.7 | | | | 0.0 | 72.0 | 28.0 | SM | 11.5 | severe trouble |
| | 9.0 | 1.110 | 80.1 | 10.8 | 14.3 | 13.9 | 0.4 | | | | ML | 10.2 | severe trouble |
| | 9.0 | 0.900 | 89.2 | 10.4 | | | | 1.7 | 47.0 | 51.3 | ML | 8.2 | trouble |
| 30 | 3.0 | 0.724 | 96.0 | 4.3 | | | | | | | ML | 6.8 | trouble |
| | 3.0 | 0.799 | 92.0 | 4.8 | | | | | | | SM | 5.5 | trouble |
| | 4.5 | 0.672 | 99.0 | 2.3 | | | | | | | SM | 2.8 | moderate trouble |
| | 5.0 | 0.391 | 119.0 | 2.4 | | | | | | | SC | 0.0 | no problem |
| 31 | 3.0 | 0.819 | 91.0 | 17.6 | | | | | | | SC | 4.1 | moderate trouble |
| 32 | 1.5 | 0.576 | 105.0 | 14.6 | | | | | | | CL | 0.0 | no problem |
| | 3.5 | 0.576 | 105.0 | 14.7 | | | | | | | CL | 0.0 | no problem |
| | 4.5 | 0.689 | 98.0 | 12.4 | | | | | | | CL | 0.0 | no problem |
| | 5.5 | 0.742 | 95.0 | 5.3 | | | | | | | CL | 0.0 | no problem |
| | 6.5 | 0.924 | 86.0 | 10.8 | | | | | | | CL | 5.6 | trouble |
| | 9.5 | 0.591 | 104.0 | 4.2 | | | | | | | CL | 9.0 | trouble |
| 33 | 7.0 | 0.924 | 86.0 | 10.6 | | | | | | | | 13.0 | severe trouble |
| 34 | 4.0 | 0.639 | 101.0 | 14.8 | | | | | | | ML | 2.0 | moderate trouble |
| | 4.5 | 0.689 | 98.0 | 5.7 | | | | | | | SM | 4.9 | moderate trouble |
| | 14.5 | 0.478 | 112.0 | 12.2 | | | | | | | ML | 0.2 | no problem |
| | 19.5 | 0.547 | 107.0 | 9.1 | | | | | | | ML | 1.5 | moderate trouble |
| 35 | 4.5 | 0.672 | 99.0 | 17.8 | | | | | | | | 0.1 | no problem |
| | 5.5 | 0.607 | 103.0 | 13.3 | | | | | | | | 0.4 | no problem |
| | 10.5 | 0.655 | 100.0 | 11.9 | | | | | | | | 0.2 | no problem |
| | 30.5 | 0.576 | 105.0 | 11.4 | | | | | | | | 0.2 | no problem |
| 36 | 4.0 | 0.706 | 97.0 | 8.0 | | | | | | | | 8.1 | trouble |
| 37 | 6.0 | 0.761 | 94.0 | 13.1 | | | | | | | SM | 7.0 | trouble |
| | 7.5 | 0.547 | 107.0 | 9.2 | | | | | | | ML | 1.8 | moderate trouble |
| | 10.0 | 0.505 | 110.0 | 2.5 | | | | | | | SM | 6.6 | trouble |
| 38 | 20.5 | | | | | | | | | | SM | 0.5 | no problem |

**PLATE 1 CONTINUED**
**SUMMARY OF GEOTECHNICAL DATA**
**FOR COLLAPSIBLE SOILS IN CEDAR CITY, UTAH**

| SAMPLE SITE | DEPTH (FT.) | IN-SITU VOID RATIO | IN-SITU DRY UNIT WT. (PCF) | W (%) | CONSISTENCY LIMITS L.L. (%) | CONSISTENCY LIMITS P.L. (%) | CONSISTENCY LIMITS P.I. (%) | GRADATIONAL ANALYSIS GRAVEL (%) | GRADATIONAL ANALYSIS SAND (%) | GRADATIONAL ANALYSIS SILT/CLAY (%) | SOIL TYPE (USCS) | COLLAPSE POTENTIAL (%) | JENNINGS-KNIGHT CLASS. (@1.15 tsf) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 39 | 1.5 | 1.095 | 79.0 | 1.9 | | | | | | | SM | 8.5 | trouble |
| | 1.5 | 1.095 | 79.0 | 1.9 | | | | | | | SM | 7.8 | trouble |
| 40 | 16.5 | 0.970 | 84.0 | 9.8 | 25.0 | 21.0 | 4.0 | 34.0 | 16.0 | 50.0 | | 4.7 | moderate trouble |
| 41 | 11.5 | 0.860 | 89.0 | 13.9 | | | | 7.0 | 20.0 | 73.0 | | 6.6 | trouble |
| | 21.5 | 0.742 | 95.0 | 17.8 | 25.0 | 20.0 | 5.0 | 1.0 | 9.0 | 90.0 | | 2.6 | moderate trouble |
| | 31.5 | 1.149 | 77.0 | 13.6 | 26.0 | 22.0 | 4.0 | 0.0 | 8.0 | 92.0 | | 7.7 | trouble |
| 42 | 11.5 | 0.663 | 99.5 | 6.5 | | | | 6.0 | 63.0 | 31.0 | | 2.1 | moderate trouble |
| 43 | 16.5 | 0.724 | 96.0 | 16.1 | | | | 0.0 | 74.0 | 26.0 | | 3.5 | trouble |
| 44 | 11.5 | 0.655 | 100.0 | 27.5 | | | | 14.0 | 49.0 | 37.0 | | 1.4 | moderate trouble |
| | 21.0 | 0.742 | 95.0 | 17.9 | | | | | | | | 5.0 | trouble |
| | 31.5 | 0.849 | 89.5 | 12.5 | | | | 15.0 | 37.0 | 48.0 | | 21.0 | very severe trouble |
| 45 | 1.0 | 1.010 | 83.8 | 1.6 | | | | | | | | 8.8 | trouble |
| 46 | 1.0 | 0.975 | 85.3 | 6.1 | | | | | | | | 14.0 | severe trouble |
| 47 | 1.0 | 1.032 | 82.9 | 6.2 | | | | | | | | 23.3 | very severe trouble |
| 48 | 1.0 | 1.019 | 83.4 | 5.8 | 18.0 | | | | | | | 12.7 | severe trouble |
| 49 | 1.0 | 0.796 | 93.8 | 3.8 | 20.8 | | | | | | | 10.0 | severe trouble |

9/49 no problem

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

CEDAR CITY QUADRANGLE
UTAH-IRON CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)


# COLLAPSIBLE SOIL HAZARD MAP FOR CEDAR CITY, UTAH

Plate 1
Collapse Potential Tests
and Data Location
(+ indicates data point)

by
*Tonya Williams*
*Kyle M. Rollins*

UTAH GEOLOGICAL SURVEY
Contract Report 91-10
July 1991

Mapped, edited, and published by the Geological Survey

Control by USGS, NOS/NOAA and State of Utah

Topography from aerial photographs by multiplex methods
and by plane table surveys 1950
Aerial photographs taken 1948

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system,
south zone
1000-meter Universal Transverse Mercator grid ticks,
zone 12, shown in blue

Red tint indicates area in which only
landmark buildings are shown

Dashed land lines indicate approximate location

Purple tint indicates extension of urban areas

UTM GRID AND 1978 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10 FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

QUADRANGLE LOCATION

Revisions shown in purple compiled from aerial photographs
taken 1976 and other source data. This information not
field checked. Map edited 1978

ROAD CLASSIFICATION

Heavy duty — Light duty
Medium duty — Unimproved dirt
U. S. Route — State Route
Interstate Route

CEDAR CITY, UTAH
N3737.5—W11300/7.5

1950

PHOTOREVISED 1978
DMA 3359 II NE—SERIES V897

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

CEDAR CITY QUADRANGLE
UTAH-IRON CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)


Mapped, edited, and published by the Geological Survey

Control by USGS, NOS/NOAA and State of Utah

Topography from aerial photographs by multiplex methods and by plane table surveys 1950
Aerial photographs taken 1948

Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system, south zone
1000-meter Universal Transverse Mercator grid ticks, zone 12, shown in blue

Red tint indicates area in which only landmark buildings are shown

Dashed land lines indicate approximate location

Purple tint indicates extension of urban areas

UTM GRID AND 1978 MAGNETIC NORTH DECLINATION AT CENTER OF SHEET

SCALE 1:24 000

CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10 FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929

THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U S GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST

QUADRANGLE LOCATION

Revisions shown in purple compiled from aerial photographs taken 1976 and other source data. This information not field checked. Map edited 1978

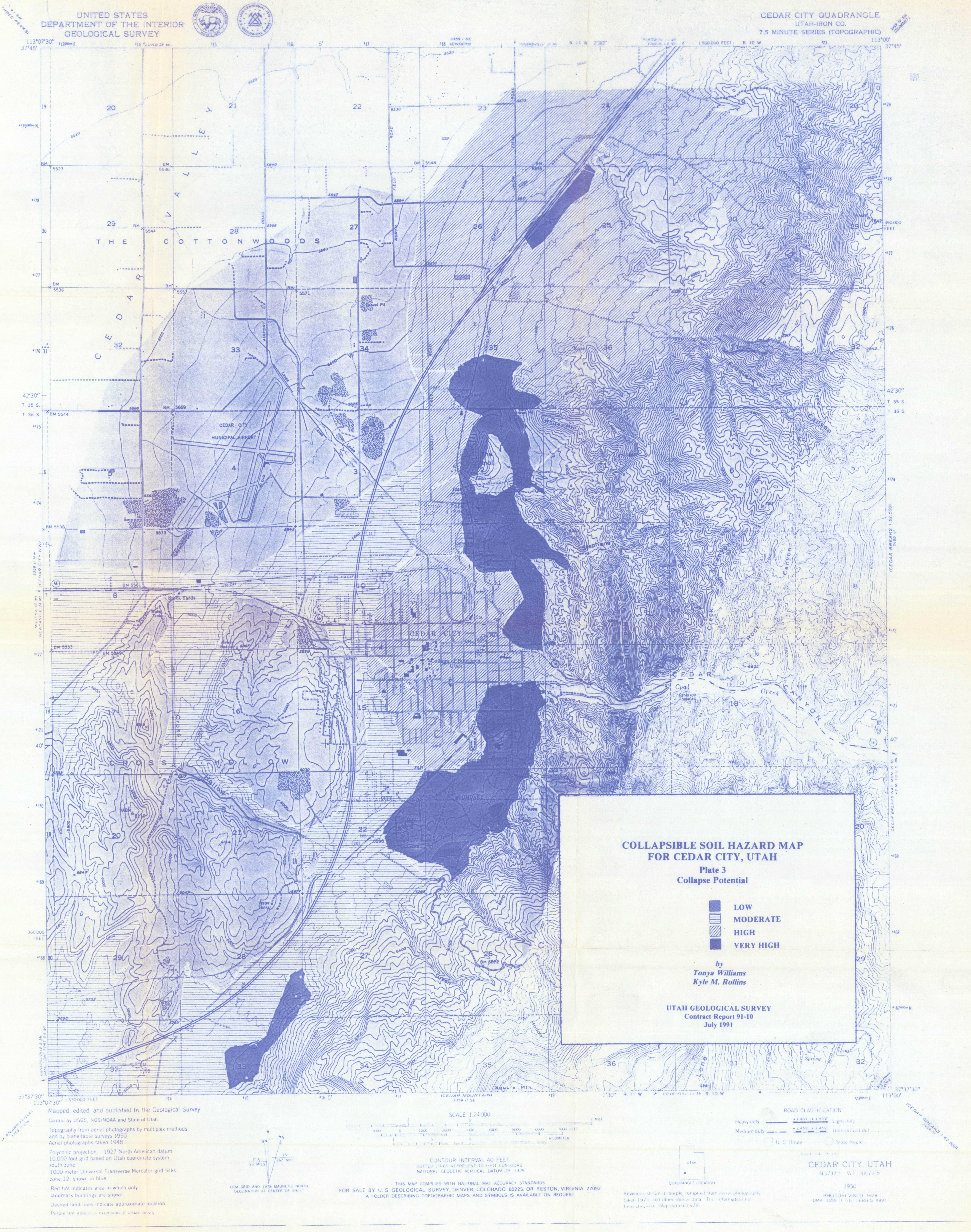
ROAD CLASSIFICATION

Heavy duty — Light duty
Medium duty — Unimproved dirt
U. S. Route — State Route
Interstate Route

CEDAR CITY, UTAH
N3737.5- W11300/7.5

1950

PHOTOREVISED 1978
DMA 3359 II NE SERIES V897


UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY
CEDAR CITY QUADRANGLE
UTAH-IRON CO.
7.5 MINUTE SERIES (TOPOGRAPHIC)
THE COTTONWOODS
CEDAR VALLEY
CEDAR CITY MUNICIPAL AIRPORT
CEDAR CITY
CROSS HOLLOW
CEDAR CANYON
COLLAPSIBLE SOIL HAZARD MAP
FOR CEDAR CITY, UTAH
Plate 3
Collapse Potential
LOW
MODERATE
HIGH
VERY HIGH
by
Tonya Williams
Kyle M. Rollins
UTAH GEOLOGICAL SURVEY
Contract Report 91-10
July 1991
Mapped, edited, and published by the Geological Survey
Control by USGS, NOS/NOAA and State of Utah
Topography from aerial photographs by multiplex methods
and by plane-table surveys 1950
Aerial photographs taken 1948
Polyconic projection. 1927 North American datum
10,000-foot grid based on Utah coordinate system,
south zone
1000-meter Universal Transverse Mercator grid ticks,
zone 12, shown in blue
Red tint indicates area in which only
landmark buildings are shown
Dashed land lines indicate approximate location
Purple tint indicates extension of urban areas
UTM GRID AND 1978 MAGNETIC NORTH
DECLINATION AT CENTER OF SHEET
SCALE 1:24 000
CONTOUR INTERVAL 40 FEET
DOTTED LINES REPRESENT 10 FOOT CONTOURS
NATIONAL GEODETIC VERTICAL DATUM OF 1929
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U. S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
CEDAR CITY, UTAH
1950
PHOTOREVISED 1978