Guidelines for Evaluating Liquefaction Hazards in Nevada

I. Introduction

These guidelines were prepared by a subcommittee of the Geoscience Committee on Seismic Hazard Issues at the request of the Nevada Earthquake Safety Council, which is affiliated with the Nevada Division of Emergency Management, Department of Motor Vehicles and Public Safety, and Division of Special Services.

Significant seismic hazards are present in Nevada. With the increase in population, the evaluation of liquefaction is becoming more important for land use planning and development. The intent of these guidelines is to provide a standardized minimum level of investigation for liquefaction in Nevada. They were prepared using established guidelines for liquefaction evaluation in California, and the current standard of practice in the greater metro Las Vegas, Reno, Sparks and Carson City areas.

These guidelines were prepared by The Association of Engineering Geologists, Great Basin Section in Reno, Nevada and the Southwestern Section in Las Vegas, Nevada in conjunction with the Nevada Bureau of Mines and Geology, the University of Nevada, Reno, the University of Nevada Las Vegas, other Nevada professional geological/geotechnical engineering organizations, and the private geological/geotechnical engineering consulting community.

This document provides general guidelines for evaluating, mitigating, and reporting of liquefaction hazards in Nevada. It is intended as a guide for performing liquefaction investigations and analyses, not as a prescriptive "standard". Liquefaction hazard assessment requires considerable engineering and professional judgment. This document, therefore, should only be treated as a general guide. It is the consensus of the authors that the use of new or innovative practices should be encouraged and not be limited by this document.

For specific details on undertaking the liquefaction evaluation the readers are advised to refer to a recent publication entitled "Recommended Procedures for Implementation of DMG Special Publication 117 – Guidelines for Analyzing and Mitigating Liquefaction in California" (Martin et al., 1999- Ref. 3). This publication is available through Southern California Earthquake Center, University of Southern California.

II. When to Perform Analysis

The investigation of sites for potential liquefaction shall be included in geotechnical investigations, when any one or more of the following factors apply: (1) where there is potential for liquefaction, or (3) where required by the governing agency, or (2) when requested by the client.

III. Screening Investigations for Liquefaction Potential

A. Introduction

The purpose of screening investigations is to determine whether a given site has obvious indicators of a low potential for liquefaction failure (e.g., bedrock near the surface or deep ground water without perched water zones), or whether a more comprehensive field investigation is necessary to determine the potential for damaging ground displacements during earthquakes.

B. Screening Investigations for Liquefaction Hazards should address the Following Basic Questions:

1. Are potentially liquefiable soil types present?

The vast majority of liquefaction hazards are associated with saturated sandy and silty soils of low plasticity and density. Cohesive soils with clayey content (particle size < 0.005 mm) greater than 15% are generally not considered susceptible to soil liquefaction. Liquefaction typically occurs in cohesionless sands, silt, and fine-grained gravel deposits of Holocene to late Pleistocene age in areas where the ground water is shallow than about 50 feet. Some gravelly soils are vulnerable to liquefaction if encapsulation by impervious soils prevents rapid dissipation of seismically induced pore pressure.

2. If present, are the potentially liquefiable soils saturated or might they become saturated?

In order to be susceptible to liquefaction, potentially liquefiable soils must be saturated or nearly saturated. Preliminary analysis of hydrologic conditions such as current, historical and potential future depth(s) to subsurface water should be undertaken. Current groundwater level data, including perched water tables, may be obtained from permanent wells, driller's logs, and exploratory borings. Historical groundwater data can be found in reports by various government agencies, although such reports often provide information only on water from production zones and ignore shallower water.

3. Are the potentially liquefiable soils relatively shallow?

In general, liquefaction hazards are most severe in the upper 50 feet of the surface, but on a slope near a free face or where deep foundations go beyond that depth, liquefaction potential should be considered at greater depths. (Note that for site response characterization, the shear wave velocity of a potentially liquefiable deposit is characterized to a greater depth.)

4. Does the geometry of potentially liquefiable soils pose significant risks that require further investigation?

Thick deposits of liquefiable soils require further investigation. Additionally, relatively thin seams of liquefiable soils, if laterally continuous over sufficient area, can represent potentially hazardous planes of weakness and sliding, and may thus pose a hazard with respect to lateral spreading and related ground displacements.

IV. Evaluation of Liquefaction Resistance

Liquefaction investigations are best performed as part of a comprehensive investigation as outlined below. These Guidelines are to promote uniform evaluation of the resistance of soil to liquefaction.

A. Detailed Field Investigation

1. Engineering Geologic Investigations

The engineering geologic investigations should include relative age, soil classification (percentage of fines passing the #200 sieve and Plastic Index), three-dimensional distribution, and general nature of exposures of earth materials within the area. Surficial deposits should be described in terms of their general characteristics (including environment of deposition) and their relationship to present topography and drainage. Due care should be exercised in interpolating or extrapolating subsurface conditions. Engineering geologic investigations should determine:

a. The presence, soil type, gradation, and distribution (including depth) of unconsolidated deposits;

b. The age of unconsolidated deposits, especially for Quaternary Period units (both Pleistocene and Holocene Epochs);

c. Zones of flooding or historic liquefaction; and,

d. The groundwater level to be used in the liquefaction analysis based on data from well logs, boreholes, monitoring wells, geophysical investigations, or available maps.

2. Geotechnical Field Investigation

The vast majority of liquefaction hazards are associated with sandy and/or silty soils. For such soil types, there are currently two widely accepted approaches available for quantitative evaluation of the soil's resistance to liquefaction. These are: (a) correlation and analyses based on in-situ Standard Penetration Test (SPT) (ASTM D1586-92) data (see Ref. 3 for details), and (b) correlation and analyses based on in-situ Cone Penetration Test (CPT) (ASTM D3441-94) data. Both methods have relative advantages and disadvantages (see Table 1 below). Although either method will suffice for certain site conditions, there is considerable advantage to using them jointly. Another valid approach is the shear wave velocity based liquefaction hazard evaluation (Youd and Idriss, 1997; Andrus, et al. 1999).

3. Geotechnical Laboratory Testing

Laboratory testing is recommended for determining grain size distribution (particularly the fines content [percent passing the #200 sieve]), plasticity, unit weight, and moisture content of potentially liquefiable layers. Note that the moisture content of a sample taken below the water table can be used to assess the in-situ void ratio and thereby density.

Table 1: Relative Merits of SPT and CPT

SPT ADVANTAGES	CPT ADVANTAGES
A sample is retrieved. This permits identification of soil type with certainty, and permits evaluation of fines content (which influences liquefaction resistance).	Continuous penetration resistance data is obtained and so it is less likely to "miss" thin lenses and seams of liquefiable material.
Liquefaction resistance correlation is based primarily on field case histories, and the vast majority of the field case history database is for in-situ SPT data.	The CPT takes less time than the SPT since no borehole is required.
MAJOR DISADVANTAGE	MAJOR DISADVANTAGE
The SPT provides only averaged data over discrete increments. It does not distinguish data particular to thin inclusions (seams and lenses).	The CPT provides poor resolution with respect to soil classification, and so usually requires some complementary borings with samples to more reliably define soil types and stratigraphy.

B. Evaluation of Potential Liquefaction Hazard

For most common structures built using the Uniform Building Code (UBC), as a minimum a probabilistically derived peak ground acceleration with a 10% probability of exceedance in 50 years (i.e. 475-year return period) should be used when site-specific analyses are performed. The factor of safety for level ground liquefaction resistance has been defined as FS = CSRliq / CSReq where CSReq is the cyclic stress ratio generated by the anticipated earthquake ground motions at the site, and CSRliq is the cyclic stress ratio required to generate liquefaction (Seed and Idriss, 1982). A factor of safety in the range of about 1.1 is generally acceptable for single family dwellings, while a higher value in the range of 1.3 is appropriate for more critical structures. Furthermore, consequences of different liquefaction hazards vary. For example, hazards stemming from flow failure are often more disastrous than hazards from differential settlement. Table 2 provides general guidelines for selecting a factor of safety. This factor of safety assumes that high quality, site-specific penetration resistance and geotechnical laboratory data were collected, and that appropriate ground-motion data were used in the analyses. If lower factors of safety are calculated for some soil zones, then an evaluation of the level (or severity) of the hazard associated with potential liquefaction of these soils should be made.

Table 2: Factors of Safety for Liquefaction Hazard Assessment*

		Factor of Safety	Factor of Safety
Consequence of Liquefaction	$(N_1)_{60}$Clean Sand	Non Critical Structure	Critical Structure
Settlement	≤15	1.1	1.3
	≤30	1.0	1.2
Surface Manifestation	≤15	1.2	1.4
	≤30	1.0	1.2
Lateral Spread	≤15	1.3	1.5
	≤30	1.0	1.2

* Developed based on guidelines given in Ref. 3

Such hazard assessment requires considerable engineering and professional judgment. The following is, therefore, only a guide. The assessment of potential liquefaction of soil deposits at a site must consider two basic types of hazard:

1. Translational site instability (sliding, edge failure, lateral spreading, flow failure, etc.) that may potentially affect all or large portions of the site; and

2. A more localized hazard at and immediately adjacent to the structures and/or facilities of concern (e.g., bearing failure, settlement, localized lateral movements).

As Bartlett and Youd (1995) have stated: "Two general questions must be answered when evaluating the liquefaction hazards for a given site:

1. 'Are the sediments susceptible to liquefaction?'; and

2. 'If liquefaction does occur, what will be the ensuing amount of ground deformation'?"

V. Mitigation of Liquefaction Hazards

Mitigation should provide suitable levels of protection with regard to the two general types of liquefaction hazards previously discussed. The scope and type(s) of mitigation required depend on the site conditions present and the nature of the proposed project. Individual mitigation techniques may be used, but the most appropriate solution may involve using them in combination. For more details on the effectiveness of various mitigation techniques see Ref. 3.

VI. Reporting

Reports that address liquefaction hazards may also need to include the following:

A. If methods other than Standard Penetration Test (SPT; ASTM D1586-92) and Cone Penetration Test (CPT; ASTM 3441-94) are used, description of pertinent equipment and procedural details of field measurements of penetration resistance (borehole type, hammer type and drop mechanism, sampler type and dimensions, etc.).

B. Boring logs showing raw (unmodified) N-values if SPT's are performed; CPT probe logs showing raw qc-values and plots of raw sleeve friction if CPT's are performed.

C. Explanation of the basis of the methods used to convert raw SPT, CPT or non-standard data to "corrected" and "standardized" values.

D. Tabulation and/or plots of corrected values used for analyses.

E. Explanation of methods used to develop estimates of field loading equivalent uniform cyclic stress ratios (CSReq) used to represent the anticipated field earthquake excitation (cyclic loading).

F. Explanation of the basis for evaluation of the equivalent uniform cyclic stress ratio necessary to cause liquefaction (CSRliq) at the number of equivalent uniform loading cycles considered representative of the design earthquake.

G. Factors of safety against liquefaction at various depths and/or within various potentially liquefiable soil units.

H. Conclusions regarding the potential for liquefaction and likely deformation and its likely impact on the proposed project.

I. Discussion of proposed mitigation measures, if any, necessary to reduce potential damage caused by liquefaction to an acceptable level of risk.

J. Criteria for SPT-based, CPT-based, or other types of acceptance testing, if any, that will be used to demonstrate satisfactory remediation.

VII. Definitions

ASTM	American Society for Testing and Materials
CPT	Cone Penetration Test (ASTM D3441-94).
CSR	Cyclic stress ratio — a normalized measure of cyclic stress severity, expressed as equivalent uniform cyclic shear stress divided by some measure of initial effective overburden or confining stress.

CSReq	The equivalent uniform cyclic stress ratio representative of the dynamic loading imposed by an earthquake.
CSRliq	The equivalent uniform cyclic stress ratio required to induce liquefaction within a given number of loading cycles [that number of cycles considered representative of the earthquake under consideration].
FS	Factor of safety — the ratio of the forces available to resist failure divided by the driving forces.
Ground Loss	Localized ground subsidence.
Liquefaction	Significant loss of soil strength due to pore pressure increase.
N	Penetration resistance measured in SPT tests (blows/ft).
N_1	Normalized SPT N-value (blows/ft); corrected for overburden stress effects to the N-value which would occur if the effective overburden stress was 1.0 tons/ft2.
$(N_1)_{60}$	Standardized, normalized SPT-value; corrected for both overburden stress effects and equipment and procedural effects (blows/ft).
PI	Plasticity Index; the difference between the Atterberg Liquid Limit (LL) and the Atterberg Plastic Limit (PL) for a cohesive soil. [PI(%) = LL(%) - PL(%)].
q_c	Tip resistance measured by CPT probe (force/length2).
$q_{c,1}$	Normalized CPT tip resistance (force/length2); corrected for overburden stress effects to the qc value which would occur if the effective overburden stress was 1.0 tons/ft2.
SPT	Standard Penetration Test (ASTM D1586-92).
UBC	The Uniform Building Code, published by the International Conference of Building Officials (ICBO, 1997), periodically updated.

VIII. References

(1) Andrus, R., Stokoe, K.L., and Chung, R.M. (1999). "Draft Guidelines for Evaluating of Liquefaction Resistance using Shear Wave Velocity Measurements and Simplified Procedures," Report No. NIST IR-6277, National Institute of Standards and Testing, Gaithersburg, MD.

(2) Bartlett, S.F., and Youd., T.L. (1995). "Empirical Prediction of Liquefaction-Induced Lateral Spread," Journal of Geotechnical Engineering, Vol. 121(4), pp. 316-329.

(3) Martin G.R., and Lew M. (Editors) (1999). "Recommended Procedures for Implementation of DMG Special Publication 117 – Guidelines for Analyzing and Mitigating Liquefaction in California," Southern California Earthquake Center, University of Southern California, March.

(4) National Research Council (NRC) (1985). “Liquefaction of Soils During Earthquakes,” Committee on Earthquake Engineering, National Research Council, Report No. CETS-EE-001.

(5) Seed, H.B., and Idriss, I.M. (1982). “Ground Motions and Soil Liquefaction During Earthquakes,” Earthquake Engineering Research Institute (EERI) Monograph.

(6) Youd, T.L., and Idriss, I.M. (Editors) (1997). “Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils,” Salt Lake City, NCEER Technical Report NCEER-97-0022, Buffalo, NY.

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