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A SIMPLE METHOD TO HELP DEFINE THE FISSURE HAZARD FOR SITES IN THE LAS VEGAS VALLEY, NEVADA

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ABSTRACT

Subsidence-induced earth fissuring has affected the rapid growth and development in Las Vegas Valley. Concerns over fissure-induced damage have led in part to new building codes (Clark County) requiring detailed geotechnical evaluations near pre-existing faults in the valley. These faults are located throughout the valley and have been historically reactivated by groundwater-withdrawal induced land subsidence. The faults are also associated with fissuring. The spatial relationship of fissures with respect to faults in the Las Vegas Valley have been analyzed by others. Cumulative distribution plots show that about 90% of the mapped fissures occur within 2000 feet (610 m) of mapped faults. This has been used to determine the hazard zone in the new codes. Using only this criteria in the geotechnical evaluation, the assessment of the risk for fissuring for a given site within this zone would be considered conservative since only about 10 percent of the faults (by length) in the valley have associated fissures.

A simple method has been developed to help further define the risk for fissuring within these fault-based buffer zones. This method evaluates and weighs several site aspects and conditions related to the formation of fissures. These include: 1) shallow groundwater conditions (depth to), 2) soil conditions at the site, 3) distance to the nearest fault and high capacity pumping well(s), 4) location within land subsidence bowl(s) in the valley, 5) presence of intervening faults and the center of each subsidence bowl, and 6) orientation of nearest fault(s) with center of subsidence bowl. We suggest the use of GIS applications to evaluate and adjust the relative “weight” of each of these site parameters by comparison to existing fissure maps.

INTRODUCTION

The formation of earth fissures around preexisting faults in Las Vegas Valley has been attributed to the effects of historical land subsidence due to the regional extraction of groundwater. The Windsor Park subdivision is a residential development that has seen significant damage (Fig. 1) due in part to fissures since the early 1980’s (Bell, 1981, Bell & Price, 1991 and Linnert, et al., 1994). In response to the damage to Windsor Park, the U.S. Department of Housing and Urban Development (HUD) required detailed studies be conducted for all new residential developments located within potential fissure hazard zones or 500 feet (150 m) on either side of the numerous faults mapped in Las Vegas Valley. For planning and siting purposes, Bell, et al. (1992), offered as an alternative to the HUD 500-foot (150 m) zone: a 2000-foot (610 m) zone around faults that was found to enclose 90% of all presently known and mapped fissures. In 1996, Clark County introduced revisions to their building codes requiring detailed geotechnical evaluations for sites within 2000 feet (610 m) of the preexisting faults in the valley. Concerns over the potential for damage to residential subdivisions from the effects of land subsidence including fissures led to these new codes.

Cumulatively, approximately 100 linear miles (160 km) of preexisting faults are mapped across the floor of Las Vegas Valley. Based on the fault and fissure map in Bell & Price (1991), it appears that only 10% of the faults have associated fissuring. Geotechnical investigations performed within fissure hazard zones usually include surface reconnaissance and possibly trenching to assess the fissure hazard at the site. Commonly, evidence of fissures will not be found with this approach even for sites that are thought to have a high risk for fissuring. If in fact,
fissures are found at a site or maybe, as in some cases, surface features only suggestive of fissuring are observed. Then how can one use this information alone to provide a basis for their judgment as to the ultimate risk to development of the site? Although from a regulatory and investigative standpoint it may be prudent to examine sites within 2000-feet (610 m) of faults in the valley to provide a "first look" extent, a method is needed to assist in the decision process for mitigation purposes or even for continued development of the site. With this in mind, a simple method to help define the risk for fissuring within these fault-based buffer zones has been developed. This method has been resolved by looking at the occurrence of fissures in the valley and identifying factors that may control the development of fissures at particular sites.

**GEOLOGIC SETTING**

**Geologic and Hydrologic Setting**

The Las Vegas valley, located in the Basin and Range physiographic province is approximately 50 miles (80 km) long and varies from 5 to 25 miles (8 to 16 km) wide. The valley is bounded on the west by the Spring Mountains; on the north by the Desert Sheep and Las Vegas Ranges; on the east by Frenchman and Sunrise Mountains; and on the south by the River and McCullough Mountains. The basin drains into the Colorado River at Lake Mead principally by Las Vegas Wash.

The Las Vegas Valley is a deep structural basin. Deposits within the basin are primarily Pliopleistocene fill characterized by coarse-grained alluvium and fine-grained fluvial and lacustrine basin fill (Bell, 1981). The coarse-grained alluvial deposits are believed to be coalescing alluvial fans derived from the mountain ranges surrounding the valley. The fine-grained basin fill is believed to have been deposited primarily in a paludal or playa environment during the late Cenozoic prior to the formation of the Colorado River System (Mifflin and Wheat, 1979).

Two separate aquifers exist in the Las Vegas Valley: a shallow relatively unconfined aquifer and a series of deep confining water-bearing zones (Plume, 1984). Each zone typically contains granular sediments that are contained by low permeability silts and clays. The fine-grained sediments occur as lenses or layers which act as semi-confining barriers or aquitards that impede vertical flow. The majority of the groundwater withdrawn in the valley is from the deeper aquifer zone at depths greater than 200 feet (61 m).

**Figure 1.** Earth fissure located in a backyard at the Windsor Park subdivision in North Las Vegas, Nevada. The house had incurred serious damage due in part to fissuring.

**Geologic Constraints**

There are several geologic constraints in the Las Vegas Valley including geologic faults, land subsidence and earth fissures.

**Geologic Faults**

Several north-trending fault scarps extend through the center of the valley (Figure 2) and are
Figure 2. Map of faults and fissure zones in the Las Vegas Valley (Bell and Price, 1991). Scale: 1:240,000.
believed to be of late Quaternary age. The scarpss are in excess of 100 feet (30 m) high and nearly all show displacement down to the east (Bell, 1981). These faults significantly affect the movement of groundwater, both laterally and vertically between aquifers. Prior to artesian head decline as a result of heavy pumping, flowing springs were often observed along these fault scarpss (Bell, 1981).

The origin of these faults scarps is still debated. One theory suggests the scarpss are the surface expressions of prehistoric differential consolidation or compaction of alluvial and playa-like sediments having dissimilar grain-size and compressibility characteristics (Maxey & Jameson, 1948 and Cibor, 1983). The second theory states the fault escarpments are tectonic in origin from faults extending up from the bedrock basement underlyng the valley. The latter would be capable of generating seismic events (Bell and Price, 1991).

Regardless of origin, the faults have been historically reactivated due to differential land subsidence as a result of groundwater withdrawal. They are also associated with earth fissures, former spring deposits and adverse geotechnical conditions (Linnert, et al., 1994).

Land Subsidence

The principal cause of historical land subsidence in the Las Vegas Valley is the regional extraction of groundwater. The valley soils contain silt and clay sediments which are very conducive to consolidation upon fluid extraction.

Evidence for land subsidence is based upon regional land level surveys conducted over years and was first documented in 1940 (Bell, 1981). Elevation surveys conducted between 1963 and 1986/87 shown the pattern for valley-wide subsidence as one large subsidence bowl punctuated by three secondary localized zones (see Figure 3). As of the last survey in 1986/87, the localized bowl in the northwest portion of the valley was the most actively subsiding of the three. Over 5 feet of surface subsidence was measured in this area between 1963-1986/87 (Bell and Price, 1991).

Earth Fissures

Earth fissures in the Las Vegas Valley are usually formed in the subsurface by tensional associated with groundwater withdrawal (Helm, 1992). They are expressed either as groups of short, discontinuous, dendritic cracks or as a single, continuous, linear crack. A fissure is believed to originate as a tensional crack approximately 0.1 to 0.2 inch (0.2 to 0.5 cm) wide in relatively loose sediment (Werle and Stilley, 1991). Infiltration of surface runoff widens the crack, and collapse of overlying sediments exposes the fissure to the ground surface. Surface water runoff further erodes and enlarges the feature.

In addition, fissures are common around high capacity groundwater pumping wells. Soils, such as hydrocollapsible sediments and expansive clays, have also been associated with fissures in localized areas of the valley (Bell, 1981, and Linnert, et al., 1994)

FACTORS AFFECTING THE FORMATION OF FISSURES IN LAS VEGAS VALLEY

Six factors have been recognized that influence the formation of fissures at sites within the valley. These conditions and/or site aspects are presented below.

Shallow Groundwater

Fissures are more likely to occur in the southwestern United States where there is characteristically a thick unsaturated and a partly saturated zone above the local water table. Sediments in this reasonably permanent passive zone would be prone to brittle deformation, as compared to the sediments beneath the water table (Helm, 1992). Sediments below the water table would be prone more to ductile deformation. Thus, fissures are unlikely beneath the water table and in the capillary fringe.

Areas of the Las Vegas Valley having depths to water less than 30 feet (9 m) are shown on Figure 4. In general, the depth to shallow ground water decreases following the flow gradient from northwest to southeast (Zikmund, 1996).

Soil Conditions

Soil conditions are a major factor influencing the likelihood of fissure formation at a site. Erodability and brittleness are governed by the consistency and type of soil. These characteristics affect the likelihood of fissure formation as well as the rate of expansion and propagation.

The nature of some soils may undergo processes which produce fissure features but which may be directly unrelated to groundwater withdrawal or land
Figure 3. Map showing land subsidence in the Las Vegas Valley between 1963-1986/87 (Bell and Price, 1991).
Figure 4. Map showing areas of shallow groundwater in the Las Vegas Valley. Depth to groundwater is less than 30 feet (9 m). Data obtained from Zikmund (1996) and various geotechnical and environmental borings performed by Converse. Scale: 1 : 240,000.
subsidence. A generalized soil map is shown in Figure 5. Fissures are predominantly located in the zone of fine-grained soils. However, under certain circumstances, fissures may also be found within the transition zone containing both coarse and fine-grained soils. These soils include hydrocollapsible deposits, expansive clays, and gypsiferous soils. Other deposits, such as former spring mounds may be conducive to fissuring and collapse since they are dry due to regional groundwater withdrawal.

Erodability

The consistency of a soil affects its erodability. Relatively loose sandy soils and firm silts are subject to erosion by surface water run-off. Fissures forming in these soils will generally spread relatively quickly in lateral extent as well as depth. Piping features are common in such soils when a resistant layer such as a stiff clay or caliche (cemented) deposit overlies the fissure.

Brittleness

The brittleness of the material will affect the likelihood of fissure formation. Soft and very loose soils will perform weakly under tensional forces and tend to cave or settle in response to fissure formation. Medium dense sands, firm to stiff silts and clays and caliche (cemented deposits) will break under tensional strain and allow a crack to form. Runoff and infiltration of surface water may widen and deepen the crack depending on the erodability of the soil deposits.

Soils are commonly brittle in the desert environment. Hence as Helm (1992) has stated, most fissures are found in the southwestern United States. Obviously, water content in soil, either from precipitation or a shallow groundwater system, will affect the brittleness of the near-surface soil deposits.

Hydrocollapsible Soils.

Hydrocollapsible soils settle rapidly upon the addition of water. They typically have a honeycomb structure which is held together with gypsum or clay as the binding agent. Water softens the clay or dissolves the gypsum which leads to collapse of the soil. Fissures have been caused by hydrocollapsible soils in a portion of eastern Las Vegas (Bell, 1981).

Expansive Soils.

Expansive soils, typically clays, have been documented at various locations throughout the Las Vegas Valley. These deposits may swell in excess of 40% upon addition of water, depending on depth below ground surface. Upon drying, they shrink and often fracture (Nelson and Miller, 1992). At several locations particularly in North Las Vegas, fissures were associated with desiccated clays in the subsurface. The fissures were found to extend vertically into a desiccated clay layer and terminate within that layer (Linnert, et. al, 1994). Desiccating clays have also contributed to fissure formation in areas of Arizona (Anderson, 1988) and Southern California (Shlemon and LaChapelle, 1992).

Gypsiferous Soils.

Gypsiferous soils are generally located in areas of the valley which have poor surface or subsurface drainage. They are soluble to variable degrees with the additional of water. This makes them subject to appreciable erosion and are conducive to piping associated with fissures.

Spring Conduits.

These deposits are typically located near geologic faults in the valley. The have been observed to be filled with a clean, fine-grained, quartz sand found in lenses and nearly vertical "pipes". Stratigraphic soil layers have been observed folding downward into the conduits or vertically displaced in collapse features. Fissures are often found parallel to these spring conduits presumably having formed from tensional stresses produced as the spring dried up due to regional groundwater withdrawal.

Distance to Faults and Wells

Bell and Price (1991) performed a statistical analysis which related the distance of known mapped fissure to geologic faults in the valley. The spatial relationships showed that 90% of all mapped fissures are located within 2,000 feet (610 m) of a mapped fault.

Fissures are commonly found concentrically around high capacity pumping wells. Burton (1991) modeled the horizontal movement of the solid, granular matrix in an aquifer in an attempt to predict the location of fissure development around the well. Although it was found that at some distance from the well, tensional strain would dominate, theoretically producing a fissure, this distance could not be precisely determined.

Location within Subsidence Bowls

As discussed in the GEOLOGIC SETTING, a broad regional subsidence bowl centrally occupies
Figure 5. Generalized soils map for the Las Vegas Valley (Bell, 1981 and Cibor, 1983). Scale: 1:240,000.
Las Vegas Valley (Bell, 1981 and Bell & Price, 1991). Superimposed on this regional bowl are three regional bowls (Fig. 3). In response to fluid withdrawals (overpumping of groundwater), there are both horizontal and vertical components of sediment movement at depth (Burton, 1991 and Helm, 1992). In general, the vertical component is displayed by land subsidence with the maximum subsidence occurring in the center of the bowl and diminishing subsidence out towards the margins. In contrast, the maximum horizontal component of fluid withdrawal is greatest near the periphery of the bowl and is manifested as fissuring (if the site conditions are conducive). Between the center and the margins of the bowl, the horizontal component, and therefore the potential for fissures, increases proportionally from the center outward.

In Las Vegas Valley, this effect can be further refined to incorporate the three localized bowls within the regional subsidence bowl. We expect that sites located between two localized bowls may have a higher risk for fissures. Windsor Park is an example of this effect where the development of fissures may have been enhanced by being situated between two localized bowls.

Presence of Intervening Faults

Mapped faults in Las Vegas Valley are believed to act as a focus to the formation of fissures since the faults are zones of preexisting weakness that intercept the horizontal component of fluid withdrawal in the valley (Bell, 1981 and Bell & Price, 1991). We previously accounted for this preference for fissures to form along faults in Distance to Faults and Wells. Along with this, there is evidence in the valley for sites located near the margins of a bowl to have fewer fissures than expected when there are intervening faults to the center of the subsidence bowl. We believe that the intervening fault intercepts the cumulative horizontal strain to that point and therefore shielding the outlying site to some extent. We would also expect that the horizontal strain would begin to cumulate again from the intervening fault outward. The effect of would be the greatest for intervening faults and sites at the periphery of the bowls, since there is the greatest amount of cumulative strain at stake.

Orientation of Nearest Faults

This is another factor related to the last two described. We believe that orientation of a fault plays a major role in the formation and location of fissures. According to Helm, 1991, evidence in the valley shows that horizontal movement which results in fissure formation is in the direction towards the regional pumping center, or center of the subsidence bowls. Faults have been portrayed as having preexisting fractures or planes of weakness and thus are the focus of fissuring by intercepting the horizontal component. If most of the fault related fractures and planes of weakness are parallel or subparallel to the direction of the fault, then one might expect that faults normal to the direction away from the center of the bowl would intercept the horizontal component. Therefore, faults that trend along the direction away from the center of the bowl would not readily intercept and allow the horizontal strain to "pass through." Therefore, fissures are more likely to form near faults that are normal to the direction of horizontal movement than those that are not. Based on observations in Las Vegas Valley and using the occurrence of fissures as an indicator, this seems to be the case especially in the southern portions of the valley.

THE METHOD TO DEFINE THE FISSURE HAZARD

In the following methodology for defining the risk for fissures at a site, each of the six factors described above was further defined into subfactors that were subsequently evaluated and weighed for the effects on fissure development. The following equation was developed to define the risk for a particular site:

\[
\text{Risk Equation: } A*(B+C+D+E+F) = \text{SUM (1)}
\]

Where:

- **A** = Shallow Groundwater (Depth to)
  - Greater than 20 feet 1.0
  - Between 20 & 10 feet 0.4
  - Less than 10 feet 0.2

- **B** = Soil Conditions
  - Expansive Clays 8
  - Lean Clays, Silts, Fine Sands 6
  - Transitional Soils (fine & coarse), Caliche 3
  - Sand & Gravel 1
  - Cemented Sand & Gravel 0

- **C** = Distance to Nearest Faults and/or High Capacity Wells
  - Within 0 to 500 feet 8
  - Within 500 to 1000 feet 6
  - Within 1000 to 1500 feet 3
  - Within 1500 to 2000 feet 2
  - More than 2000 feet 0
**D = Location with Respect to Subsidence Bowls**

- At Margins of more than 1 Bowl: 8
- At Margins of 1 Bowl: 6
- ¼'s from Center: 4
- ½ from Center: 2
- Less than ¼ from Center or Outside Bowls: 0

**E = Presence of Intervening Faults with Center of Bowl**

- No Intervening Faults: 0
- Fault between ¼ & Center of Bowl: -1
- Fault between ½ & ¾: -3
- Fault between ¾ & Margins of Bowl: -5

**F = Orientation of Nearest Faults with Center of Bowl**

- 90 Degrees to Direction of Center of Bowl: 8
- 60 Degrees to Direction of Center of Bowl: 6
- 30 Degrees to Direction of Center of Bowl: 3
- 0 Degrees to Direction of Center of Bowl: 1

If resulting sum is:
- between 28 & 32: **High** Risk of Fissures
- between 20 & 28: **Moderate** Risk of Fissures
- between 6 & 20: **Low** Risk of Fissures
- less than 6: **Negligible** Risk of Fissures

**DISCUSSION**

Examples using this simplified method to predict fissuring at a particular site are shown below. In general, we looked at five sites in the valley: Windsor Park (North Valley), South Valley, Downtown Las Vegas (Central Valley), East and West Valley. The locations (Figure 2) used as examples for our method are generally representative of the chosen locale with the exception of North and South Valley locations, which represent the apparent worst conditions in their respective areas. We did this to “gauge” the methodology on its upper end.

**North Valley (Windsor Park)**

**Risk Equation:**

\[ A \times (B + C + D + E + F) = \text{SUM} \]

- A. Shallow Groundwater: 1.0X
- B. Soil Conditions: (8+)
- C. Distance to Faults or Wells: 8+
- D. Respect to Subsidence Bowls: 8+
- E. Intervening Faults: 0+
- F. Orientation of Faults: 8)

**SUM = 32**

Therefore a **High** risk for fissuring is expected for Windsor Park. Since this site appears to have the greatest frequency of fissures in Las Vegas Valley, we have designed our empirical method to give us the highest sum obtainable. As such, the risk for fissures for the remainder of the north part of the valley would be lesser, although overall, this portion of the valley has more potential for fissures than the rest of the valley.

**South Valley**

**Risk Equation:**

\[ A \times (B + C + D + E + F) = \text{SUM} \]

- A. Shallow Groundwater: 1.0X
- B. Soil Conditions: (8+)
- C. Distance to Faults or Wells: 8+
- D. Respect to Subsidence Bowls: 6+
- E. Intervening Faults: 0+
- F. Orientation of Faults: 8)

**SUM = 30**

Therefore a **High** risk for fissuring is expected for this south valley site. Since this site appears to have the greatest frequency of fissures in the south portion of Las Vegas Valley, we have designed our empirical method to give us the highest sum obtainable. As such, the risk for fissures for the remainder of the south part of the valley would be lesser.

**Central Valley (Downtown)**

**Risk Equation:**

\[ A \times (B + C + D + E + F) = \text{SUM} \]

- A. Shallow Groundwater: 0.4X
- B. Soil Conditions: (6+)
- C. Distance to Faults or Wells: 8+
- D. Respect to Subsidence Bowls: 0+
- E. Intervening Faults: 0+
- F. Orientation of Faults: 1)

**SUM = 6**

Therefore a **Negligible** to **Low** risk for fissuring is expected for downtown. This may be surprising since downtown Las Vegas is at the center of the regional subsidence bowl for the valley. As such, as much as 10 feet of land subsidence has occurred here. Nevertheless, the horizontal component of fluid withdrawal should be zero.

**East and West Valley**

**East**

**Risk Equation:**

\[ A \times (B + C + D + E + F) = \text{SUM} \]

- A. Shallow Groundwater: 0.4X
B. Soil Conditions (6+)
C. Distance to Faults or Wells 0+
D. Respect to Subsidence Bowls 6+
E. Intervening Faults -1+
F. Orientation of Faults 6)

SUM = 8

West
Risk Equation: \( A \cdot (B + C + D + E + F) = \) SUM
A. Shallow Groundwater 0.4X
B. Soil Conditions (3+)
C. Distance to Faults or Wells 8+
D. Respect to Subsidence Bowls 2+
E. Intervening Faults -3+
F. Orientation of Faults 8)

SUM = 7

Therefore a Low risk for fissuring is expected for the east and west valley sites chosen. These sites are thought to be representative of these regions of the valley.

SUMMARY AND CONCLUSIONS

Within the past few years, significant damage to residential developments and infrastructure in Las Vegas Valley have been attributed to earth fissures. Federal, State and local agencies have responded to these concerns with new requirements for geotechnical investigations for proposed development within the affected areas. Statewide guidelines have been suggested to evaluate the land subsidence hazards in Nevada but these guidelines fall short assessing the risk for fissuring. The method presented here can be utilized to aid in the judgment required after the results of the field investigation are complete.

This methodology would also be conducive as a planning tool. A fissure map could be generated by combining mapped fissures in the valley with the results of this method. GIS would be a practical way to conduct this.

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