Creation of Soil Liquefaction Susceptibility Maps for San Luis Obispo & Marin Counties using Geographic Information Systems.

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Table of Contents

LIST OF TABLES .................................................................................................................. ii
LIST OF FIGURES ........................................................................................................... ii
ABSTRACT ....................................................................................................................... iii
ACKNOWLEDGEMENTS ............................................................................................... iv
INTRODUCTION .............................................................................................................. 1
LITERATURE REVIEW ............................................................................................... 2
MATERIALS AND METHODS .................................................................................... 3
RESULTS & DISCUSSION ......................................................................................... 11
CONCLUSION ............................................................................................................... 15
REFERENCES .............................................................................................................. 16
LIST OF TABLES

Table 1 Youd and Perkins Liquefaction Criteria

Table 2 Criteria used to convert USGS Lithographic and County Geologic Layers

LIST OF FIGURES

Figure 1 Study Area

Figure 2 GIS Model Builder used to Intersect Layers

Figure 3 Example of Pre-Pleistocene Selection using ArcGIS Model Builder

Figure 4 Final Layer Selection Process using ArcGIS

Figure 5 SLO County Liquefaction Risk Map using GIS

Figure 6 Marin County Liquefaction Risk Map using GIS

Figure 7 Oceano Liquefaction Locations

Figure 8 Marin County Liquefaction Locations
ABSTRACT

Liquefaction of soils in response to earthquake shaking is a pressing issue in the state of California. Using Geographic Information Systems, Geological and lithology layers, along with criteria in order to separate out the data into four risk categories, a liquefaction risk assessment map was created for San Luis Obispo and Marin Counties. The accuracy of these maps was then assessed using liquefaction occurrences for San Luis Obispo County, and it was determined that while the map is somewhat accurate, in order to obtain a greater amount of accuracy and increase the usefulness of these maps, more data would need to be obtained, analyzed, and included in each of the County Map Layers.
ACKNOWLEDGEMENTS

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INTRODUCTION

Soil liquefaction is the response to shaking of the soils where the soil grains move as though they are a liquid instead of solid. Soil liquefaction causes property damage to buildings and utilities, which can be costly to counties. This study seeks to simplify the mapping of potentially liquefiable soils by using Geographical Information Systems (GIS), and the geologic age layers created by the USGS to produce a map which could be used to evaluate potential damage in high risk areas of the county.

Using GIS in order to map the liquefaction potential of soils for different counties could allow these counties to amend building codes in susceptible areas, allowing better damage preparation. Liquefaction can create problems such as sinking houses, trapped occupants and disrupted utilities within the counties where earthquakes occur (Arulmoli et al, 1999).

Cone penetration tests are used by the USGS in order to create GIS maps (Holzer et al, 2004), but this is costly and not every county can afford to fund such studies. Geologic GIS layers are available due to the soil mapping of most counties by the USGS. Using the age of the rocks in the county, along with other available data layers to narrow down the liquefaction risk of areas within the counties, could provide a less expensive mapping alternative to the cone penetration test type mapping.

Using ArcMap, and liquefaction criteria, the geologic GIS layers for each of the three counties were modeled to select out the most liquefiable areas. These data layers were then combined to create a liquefaction risk map for each of the three counties.
LITERATURE REVIEW

Liquefaction of soils causes property damages to buildings built on top of susceptible areas. Liquefaction is the movement of soils caused by effects of the shaking of soils during a ground moving event such as an earthquake. This damage could be avoided if older buildings found to be on liquefiable soils are retrofitted. (Holzer, et al 2004). Underground pipelines and wiring are also damaged when the ground shifts, costing these counties money to pay for damage repair. Locally, the city of Oceano has been affected by the liquefaction of soils after the 2003 San Simeon earthquake. (Holtzer, et al, 2004) Marin Counties also are subject to earthquakes, and coastal, which makes them a good fit for this study.

Youd and Perkins (1978), show that geologic maps of liquefaction susceptibility can be created using data collected at the surface. Historically, most cases of earthquake-induced liquefaction have occurred in alluvial deposits of loose silty sands (Yamamuro, 1999). Criteria for the assessment of liquefaction from this study were applied to making the liquefaction maps.
MATERIALS AND METHODS

For this study, the following websites were used to obtain GIS layers for each county.


   The shapefile for the Geologic Lithographic Units of California was obtained from this site. This layer was later combined with each of the individual county boundary layers.

2. **SLO DataFinder** ([http://lib.calpoly.edu:8080/gis](http://lib.calpoly.edu:8080/gis))

   Layers obtained from this site are the county boundary, geologic information, and water bodies within the county.


   The Marin County Geology information layer was obtained, along with the county boundary layer.

**Materials:**

The materials used for this study include ESRI ArcGIS Software, GIS data layers from the USGS, a desktop computer, and the NRCS Soil Survey studies for San Luis Obispo and Marin counties.
**Study Area:**

The study area for this project consists of Marin and San Luis Obispo Counties. (Fig.1) Both counties lie within the California Coast and the surface geology of these counties consists mostly of sedimentary layers. San Luis Obispo and Marin counties also have numerous local faults. High sand concentrations and potentially more liquefiable soils than other areas in the state create liquefaction hazards, with earthquake hazards, which put the counties at risk for damage. (Hinds et al, 2005)

![Figure 1: Red Shade indicates study area](image-url)
**Software:**

For this study, ArcGIS was used, along with ArcToolbox in order to edit the shapefiles, and model builder was used in order to single out each risk layer according to the liquefaction criteria used in this study.

**Geology:**

The USGS state geological surface geology layer consists of a shapefile containing the geologic age of the surface geology in the entire state. The surface geology layers are dated from Miocene to Holocene, and the lithology is stated in the shapefile attribute table. This information was combined with the county layers, giving a more complete geologic profile to the counties.

**GIS Layers:**

ArcView Shapefile layers were obtained from SLO data finder for San Luis Obispo County and the USGS website for the geologic lithology layer for the whole state of CA. The Geologic layers are of the UTM Zone 10, Northern Hemisphere (NAD 83) coordinate system. The USGS state lithographic layer is in the North American 1927 coordinate system and was transformed into the NAD 1983 coordinate system using ArcGIS in order to match the other layers used for each county.

For San Luis Obispo and Marin County, the county boundary layer, geologic layer, and the USGS lithology layer were imported into Using ArcGIS model builder, the county boundary layer was combined with the USGS lithology layer using ArcToolbox using the “Overlay” and then the “Intersect” commands (Fig 2).
This process outputs a layer that has the lithology information for just the county instead of the entire state while preserving the coastline of each county. Merging the different layers was necessary in order to get all of the shapefile data associated with each county onto one workable layer. The resulting merged layer was then used to narrow down the attributes found to contribute to liquefaction into the four risk categories; High, Medium, Low, and Very Low risk for liquefaction, based on the Youd and Perkins Criteria. Pre-Pleistocene rocks are generally considered very low risk for liquefaction (Youd and Idriss, 2001). Using these criteria, all of the Pre-Pleistocene rocks in the geologic information layers for each county were selected for using the ArcGIS model builder select function. Selecting for the rock layers created most of the Very Low Risk layer for each county. This process was repeated using the USGS lithographic layer in order to assure that all Pre-Pleistocene rock units were selected for (Fig.3).
Figure 3 Example of Pre-Pleistocene Selection using ArcGIS Model Builder
Table 1. Youd and Perkins (1978) Liquefaction Criteria

<table>
<thead>
<tr>
<th>Type of deposit</th>
<th>General distribution of cohesionless sediments in deposits</th>
<th>Likelihood that cohesionless sediments, when saturated, would be susceptible to liquefaction (by age of deposit)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt;500 yr</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3)</td>
</tr>
<tr>
<td>River channel</td>
<td>Locally variable</td>
<td>Very high</td>
</tr>
<tr>
<td>Flood plain</td>
<td>Locally variable</td>
<td>High</td>
</tr>
<tr>
<td>Alluvial fan and plain</td>
<td>Widespread</td>
<td>Moderate</td>
</tr>
<tr>
<td>Marine terraces and plains</td>
<td>Widespread</td>
<td>----</td>
</tr>
<tr>
<td>Delta and fan-delta</td>
<td>Widespread</td>
<td>High</td>
</tr>
<tr>
<td>Lacustrine and playa</td>
<td>Variable High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Colluvium</td>
<td>Variable High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Talus</td>
<td>Widespread</td>
<td>Low</td>
</tr>
<tr>
<td>Dunes</td>
<td>Widespread</td>
<td>High</td>
</tr>
<tr>
<td>Loess</td>
<td>Variable High</td>
<td>High</td>
</tr>
<tr>
<td>Glacial till</td>
<td>Variable Low</td>
<td>Low</td>
</tr>
<tr>
<td>Tuff</td>
<td>Rare</td>
<td>Low</td>
</tr>
<tr>
<td>Tephra</td>
<td>Widespread</td>
<td>High</td>
</tr>
<tr>
<td>Residual soils</td>
<td>Rare</td>
<td>Low</td>
</tr>
<tr>
<td>Sebka</td>
<td>Locally variable</td>
<td>High</td>
</tr>
</tbody>
</table>

(b) Coastal Zone

<table>
<thead>
<tr>
<th>Delta</th>
<th>Esturine</th>
<th>Beach</th>
<th>High wave energy</th>
<th>Low wave energy</th>
<th>Lagoonal</th>
<th>Fore shore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Widespread</td>
<td>Locally variable</td>
<td>Very high</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Very low</td>
</tr>
<tr>
<td>Moderate</td>
<td>Low</td>
<td>Very low</td>
<td>Very low</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(c) Artificial

<table>
<thead>
<tr>
<th>Uncompacted fill</th>
<th>Compacted fill</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td>Very high</td>
<td>----</td>
</tr>
<tr>
<td>Low</td>
<td>----</td>
<td>----</td>
</tr>
<tr>
<td>----</td>
<td>----</td>
<td>----</td>
</tr>
</tbody>
</table>
Using the Youd and Perkins criteria (Table 1), the individual rock units in each county were classified by risk type using ArcGIS model builder to separate each group out into a layer of either VL, L, M or H liquefaction risk (Table 2).

Table 2 Criteria used to convert USGS Lithographic and County Geologic Layers

<table>
<thead>
<tr>
<th>Risk</th>
<th>Very Low</th>
<th>Low</th>
<th>Moderate</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock Types and Age Associated with each Risk Type</td>
<td>Older than Pleistocene Rock Layers. Pleistocene dunes, Quaternary Old alluvium, Jurassic, Cretaceous or Quaternary and Tertiary combined as the prefix.</td>
<td>Pleistocene rock layers. Holocene estuary, alluvial fan, marine terrace, volcanic rocks. Td (Talus).</td>
<td>Quaternary sands, Quaternary Land Slides, dune sand. Pleistocene to Holocene dune sands.</td>
<td>Recent Dunes, Recent Riverbeds, Recent Alluvial Fan, Coastal River Delta, Quaternary young alluvium, Quaternary Young Alluvium and Quaternary Sands mixed. Quaternary Artificial Fill.</td>
</tr>
</tbody>
</table>

In Marin County, the artificial fill is known to be high risk of liquefaction (Hinds, 2005). Rock descriptions (Churchill, 2008) were also utilized for each county in order to further separate out the categories for each rock unit type. For each of the three counties, 4 individual risk shapefile layers were then added onto the same document, along with other relevant layers such as water bodies, in order to create the liquefaction risk map (Fig.4).

In order to assess the accuracy of this study, actual liquefaction locations were imported for each county. For San Luis Obispo County, the areas in Oceano that liquefied during the 2003 San Simeon Earthquake were digitized using ArcGIS Georeferencing, and placed onto the finished Liquefaction Risk Assessment Map for San Luis Obispo County (Fig.8).
Figure 4 Final Layer Selection Process using ArcGIS
RESULTS & DISCUSSION

**SLO County**

The resulting map (Fig.5) shows potential liquefaction areas in each of the counties. In San Luis Obispo County, the most liquefiable areas are composed of Holocene riverbeds or dune sands. Most of the county is on Pre-Pleistocene bedrock which is seen as a very low risk for liquefaction. Looking at the NRCS soil survey layers, high liquefaction risk areas are areas where sandy beaches, dunes or the Baywood Soil Type occurs. Moderate areas tended to consist mostly of Tierra Soils, Conception Loam, Chamis Shaly Loam, and Elder flooded sandy loam. (NRCS SLO) A map comparing the actual occurrence of liquefaction in Oceano, CA to the map created in this study was made in order to help assess the accuracy of this study (Fig.6).

**Marin County**

In Marin County, the most liquefiable areas were determined to be coastal areas of artificial fill on top of muds, and Holocene beach sands. Most of the area is on Pre-Pleistocene rock units which are not highly liquefiable (Fig.7).
Figure 5 SLO County Liquefaction Risk Map using GIS
Figure 6 Actual Liquefaction Areas in Oceano
CONCLUSION

Using GIS in order to create liquefaction maps requires complete, accurate data, and criteria. Comparing the risk assessment map to the actual liquefied areas in Oceano on the San Luis Obispo County Map, the area is shown as moderately liquefiable when in reality it seems to be highly liquefiable (Fig.6). The maps created for this study were created only using lithographic GIS layers, along with the NRCS soils information (NRCS SLO). In order to be more accurate, this study would have to take into account water table depth, soil bore hole data for each county, and for even more accuracy, a USGS “shaker truck” that would record the movement of the soils as they are shaken by the equipment on the trucks. The maps created in this study could be a good general guideline, but until more data such as bore-hole soil information, and water table depths are added to the map layers, they should not be viewed as perfectly accurate for the counties represented.
REFERENCES


Holzer et al, 2004 Liquefaction-Induced Lateral Spreading in Oceano, California, During the 2003 San Simeon Earthquake

Jahns, Richard H. 2006 Preliminary geologic map of the Chise quadrangle, Sierra County, New Mexico.


