Impact of Geographical Information Systems on Geotechnical Engineering

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and
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ORIGINS OF REMOTE SENSING

C. B. Adams
Method of Photogrammetry.
No. 510,758.
Patented Dec. 12, 1893.

Reconnaissance Kite-1895

Stereopair Images-1893

1908
Sherman Fairchild invented an aerial camera with a focal plane shutter in 1920.

In 1924 Fairchild compiled an exquisite map of New York City’s five boroughs using aerial images.

He went on to develop aircraft, aerial cameras and aerial photogrammetry firms.
Aerial photos allowed new features to be seen or “sensed”, which had never been mapped previously. The photo at left was taken in 1922.
During the Second World War (1939-45) aerial camera technology advanced rapidly, becoming a key component in gathering of intelligence, strategic planning, tactical planning and bomb damage assessment. Focal lengths up to 60 inches were employed from altitudes up to 34,000 feet.
The strategic import of aerial imagery was confirmed through wartime experience. From April to September 1944, 96% of Germany’s petroleum, oil and lubricants manufacturing capacity was destroyed; all of it targeted using aerial photography.
Early in the Cold War manned reconnaissance capability increased markedly; with enormous cameras carried by the RB-36 with a crew of 22 men on 50-hour missions at altitudes above 58,000 feet.
In 1956 the U-2 spy plane began flying at altitudes between 45,000 and 60,000 feet carrying 72-inch focal length cameras.

Remotely piloted craft began appearing in the 1960s, negating possibility of captured pilots.
Between 1960-1972 the Corona Project collected 800,000 images, using KH-1 thru KH-4B cameras. Film had to dropped to Earth for processing.
A sophisticated set of static and rotating cameras evolved during the Corona Project to maximize coverage of large areas using rolled film from an altitude of 80 nautical miles.
Corona image of Tell Hamoukar in Syria. Note old channels and tracks across landscape, not visible on the ground.

Photo resolution is around 1 m
Spaced based cameras continued to evolve throughout the 1960s and early 1970s, when digital and multispectral collection began.
Landsat 1 or Earth Resource Technology Satellite (ERTS) was launched in mid-1972; with new launches every 3 years.

- Carried 3 cameras, a near IR scanner and a 4 channel MSS at altitude of about 570 miles
- **Digital images** measured 111 x 102 miles, but with resolution of only about 100 ft
After 1989 reconnaissance satellites shifted to Synthetic Aperture Radar, IR and thermal IR, operating between 150 to 600 miles altitude. These systems are capable of sensing through clouds and brush cover.
Multispectral scanners (MSS) have been increasing deployed on airborne and spaced-based sensing platforms. These allow large files of information to be collected across the electromagnetic spectrum; and will eventually change the way we look at the Earth (e.g. motor tracks across water)
Mosul, Iraq as imaged by US reconnaissance satellite using Thematic Mapper Multispectral Scanners. Intelligence platforms are capable of resolutions < 6 inches for high interest areas.
In 1999 Space Imaging EOSAT launched Ikonos, offering commercial imagery with 1 m panchromatic and 4 m multispectral images, world wide.
Ikonos imagery collects MSS data at rate of 2,000 sq km per minute, making fifteen 98-minute orbits each day. They offer digital imagery with RMSE of < 0.9 m for detailed urban analysis.
Modern digital imagery is orthorectified.

This allows manipulation in GIS, integrating countless layers of information.
Orthorectified digital images can be overlain to make meaningful comparisons, as shown here.

This shows the Pentagon while under construction in 1940 (at right) and after completion in 1943 (at left).

Note details of support and frame layout.
Topographic Surface Imaging Using Light Detection and Ranging (LiDAR)

2m LiDAR DEMs
Squaxin Island
Thurston County, Washington
USGS 10m DEM
1 m LiDAR posting image of the Salmon Falls Landslide southwest of Twin Falls, ID.

The image is comprised of 13 million data points, which allowed a vertical resolution of 15 cm over a slide area of 0.2 square kilometers.
Interferometric Synthetic Aperture Radar (INSAR)

Michelson Interferometer

Figure 4: Differential Distance Gives Topography

Radar signals being transmitted and received in the SRTM mission (image not to scale).
Repeated INSAR passes allow slight variations in elevation and spatial distribution to be monitored with amazing accuracy.

Topo-removed interferograms draped over shaded DEMs of Shishaldin volcano from 1993 to 2000.

Circles indicate areas of marked elevation change.
INSAR image of the San Francisco Peak volcanic field near Flagstaff, AZ
Ian McHarg (1920-2001) is credited with being the father of map overlays, which had a big impact on Geographical Information Systems.

He was a Professor of Landscape Architecture and Regional Planning at the University of Pennsylvania from 1954-2001.
Some quotes from the “Father of GIS…”

- Ian McHarg described engineers as those individuals “who, by instinct and training, were especially suited to gouge and scar landscape and city without remorse.”

- McHarg argued that “form must not follow function, but must also respect the natural environment in which it is placed.”
McHarg took landscape architecture concepts and applied them to maps, initially as overlays; later as hybrid maps.
McHarg’s map overlay method was first used in a consulting project for a 5-mile stretch of the controversial Richmond Parkway on Staten Island in 1968.
McHarg’s hybrid map included ecological, political and aesthetic rankings to be combined with physical attributes.
McHarg’s Map Layering Concept

McHarg’s four M”s: Measurement, Mapping, Monitoring and Modeling. GIS allows a limitless combination of mapable attributes to be arbitrarily weighted and electronically combined to create hybrid “maps”; which are simply spatial representations using the Earth’s surface as their datum.
GIS has evolved with computing technology. Today, raster and vector data can be combined with increasingly sophisticated digital imagery, manipulating large data files.
GLOBAL POSITIONING SYSTEM

Navstar launched in 1982; requires a minimum of 18 operable satellites, 6 in 3 orbital planes spaced 120 degrees apart at 12,660 miles. Contact with 5 to 8 satellites required to provide fix.
By March 1994 all 24 satellites were orbiting Earth.

In May 2000 NOAA turned off selective availability, allowing public to receive GPS fixes within < 10 m under good conditions.

Worldwide, GPS industry nets $16 billion annually.

GPS allows inexpensive location fixing using hand-held receivers and palm pilots, with electronic data transfer.
REAL TIME MONITORING OF SLOPE MOVEMENTS USING GPS

- Field Station had baseline length of 70 m
- GPS readings stored, forwarded and processed for 20 minute segments of 10 second intervals, updated every 30 minutes
- Upper figure shows rainfall for interval Feb 1 to July 1 2000 shown in blue (top)
- Lower figure presents recorded median values for horizontal and vertical motion of incipient landslide block during the same interim
- Upper figure presents detail of GPS measurement noise, with median values traced in green. Red line records daily median.

- Lower figure shows daily median horizontal motion in red. Noise is typical aspect of system.
COMMON INPUT FOR GIS

- Global Positioning System data becoming dominant location tool
- **Base Maps:** USGS Digital Raster Graphics, UTM, or State Plane Coordinate Systems
- **Projection and Registration:** Spatial data must be registered using georeference points; using projection conversion subroutines
A common example of projection and georeferencing would be integrating older information prepared on maps that were not spatially configured for the Earth’s curvature, such as that shown above right.
Excerpts from older maps can be orthorectified using cadastral features, such as section lines, boundaries, or longitude and latitude. This shows electronic “stretching” of 1928 map onto an existing DRG mosaic.
Orthorectified 1928 flood map, cropped and georeferenced. By applying UTM NAD 1983 geospatial controls, the planar map is skewed slightly when orthorectified to present-day map projection standards that account for the Earth’s curvature.
When detailed map (blue) was overlain electronically on large scale inundation map (red), large discrepancies were noted.
COMMON INPUT FOR GIS

- **Data Capture**: used to be most expansive aspect of GIS because of paucity of digitized data. Subroutines designed to handle raster or data scans now

- **Data Integration**: Allows dissimilar data bases to be merged; like NRSC soil maps; and creation of “data maps”, like average water use on individual parcels
GIS allows integration of dissimilar data sources to prepare map overlays, this one showing shoreline development in Oakland, CA.
COMMON INPUT FOR GIS

- **Data Structures**: Subroutines used to convert digitized data from one form to another without corruption; i.e. Oracle files to XML

- **Data Modeling**: Allows 3D data to be catalogued and manipulated; enables linear interpolation of Kriging; emerging ability to perform feature extraction, using spectral and physical signatures
Contouring rainfall isohytes is a typical example of data modeling; combining location information, rainfall measurements and selecting an appropriate base datum.
Subsurface information can be recalled and manipulated to create a three-dimensional image of geologic conditions.

Human judgment will remain a key component in unraveling problems with dissimilar nomenclature.
COMMON ANALYTICAL METHODS IN GIS

- This shows a hybrid development capabilities map.
- Such products are based on geologic and geotechnical data, usually collected from the public domain.
TREASURE ISLAND NGES
Created by hydraulic filling in 1936-37
Treasure Island was built on a natural bedrock rise in the central San Francisco Bay. The basins on either side are filled with several hundred feet of estuarine clay and sand.
Treasure Island Pilot Study

- **Spatial Liquefaction Assessment**
  - Spatial Distribution of Subsurface Explorations
    - Deterministic Results
    - Probabilistic Results

- **Issues Encountered During Liquefaction Analysis**
  - Distribution of Data in the Vertical (z) Direction
  - Distribution of Data in the Horizontal (x, y) Direction
Spatial Distribution of Subsurface Borings Used
LPI Severity Criteria

In the fills along SF Bay margins Chameau et al. (1991) calculated the LPI

Concept of LPI Calculation

Proposed Severity Criteria
Little to none  LPI = 0
Minor          0 < LPI < 15
Moderate       15 < LPI < 30
Major          30 < LPI
Liquefaction Severity Distribution (SPT only)
1989 M 6.9 Loma Prieta Earthquake
Liquefaction Severity Distribution
(SPT & CPT) M = 7.0 and PGA = 0.16g
Liquefaction Severity Distribution
(SPT & CPT) M = 7.5 and PGA = 0.3g

LEGEND:
- MAJOR Liquefaction
- MODERATE Liquefaction
- MINOR Liquefaction
Probability Distribution of Major Liquefaction (SPT only) M = 7.5 and PGA = 0.3g
Settlement distribution overlain with building footprint
COSMOS/NGES Virtual Geotechnical Database: Will it Become the Model Architecture for the United States?

- ESRI ArcIMS - Front Door
- XML (Excel) and COSMOSOS Database File System
- Java Script - Back end
COSMOS

- Consortium of Organizations for Strong Motion Observation Systems
  - Formed in Oakland, CA in Dec 1997
  - Core Members are the USGS, CGS, USCOE, USBR, Puerto Rico Strong Motion Program, PG&E, Caltrans, MCEER-Buffalo, PEER-Berkeley, SCEC-Los Angeles, and the World Seismic Safety Initiative
Long-Term Objective of the Virtual Geotechnical Database

- Extend the pilot system and develop a web-based system linking multiple data sets
- Capable of serving the broad needs of practicing geotechnical and earthquake hazards professionals for efficient access to geotechnical data
- Create GIS based hazard maps that can be incorporated into the geotechnical data set
National Geotechnical Experimentation Site
Database Architecture

Example Geotechnical Database Inquiry

NGES Treasure Island
<table>
<thead>
<tr>
<th>Name of Site</th>
<th>Town</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treasure Island Naval Station</td>
<td>San Francisco Bay</td>
<td>CA</td>
</tr>
<tr>
<td>Northwestern University Lake Fill Site</td>
<td>Evanston</td>
<td>IL</td>
</tr>
<tr>
<td>Massachusetts Military Reservation</td>
<td>Otis ANGB</td>
<td>MA</td>
</tr>
<tr>
<td>University of Massachusetts - Amherst</td>
<td>Amherst</td>
<td>MA</td>
</tr>
<tr>
<td>Texas A&amp;M University Riverside Campus - Clay Site</td>
<td>College Station</td>
<td>TX</td>
</tr>
<tr>
<td>Texas A&amp;M University Riverside Campus - Sand Site</td>
<td>College Station</td>
<td>TX</td>
</tr>
<tr>
<td>University of Houston Foundation Test Facility</td>
<td>Houston</td>
<td>TX</td>
</tr>
</tbody>
</table>
Example CPT Data on NGES site

- ID
- Code Space
- CPT ID
- Depth
- Tip Resistance
- Friction Resistance
- Pore Pressure
- Inclination
- Remarks
- Updates
### Cone Penetration Data

**CPT ID**: CATIFS:CPTU.01  
**CPT Type**: CPTU  
**Saturation Fluid**: Water  
**End Area Ratio Correction: Tip**: 0.9  
**End Area Ratio Correction: Sleeve**: 0.015

<table>
<thead>
<tr>
<th>Tip Area (mm²)</th>
<th>Sleeve Area (mm²)</th>
<th>Dist From Center of Sleeve to Tip (mm)</th>
<th>Number of Filter Elements</th>
<th>Position of Filter Elements</th>
<th>Capacity of Tip Load Cell (MN)</th>
<th>Rate of Penetration (mm/sec)</th>
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</thead>
<tbody>
<tr>
<td>10.0</td>
<td>150.0</td>
<td>100.0</td>
<td>TIP</td>
<td></td>
<td></td>
<td>20.0</td>
</tr>
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</table>

### Test Data

**Row: 1**

<table>
<thead>
<tr>
<th>Depth Tip Measurement (m)</th>
<th>Cone Tip Resistance (qc) (kPa)</th>
<th>Friction Sleeve Resistance (fs) (kPa)</th>
<th>Penetration pore pressure - element 1 (kPa)</th>
<th>Penetration pore pressure - element 2 (kPa)</th>
<th>Penetration pore pressure - element 3 (kPa)</th>
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<tr>
<td>1.016</td>
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<td>472.67</td>
<td>2.273</td>
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</tr>
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<td>1.022</td>
<td>627.67</td>
<td>4.523</td>
<td>-8.4</td>
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<td>1.025</td>
<td>825.67</td>
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<td>-8.4</td>
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</tbody>
</table>

7380 Total Rows Fetched
CONE PENETRATION TEST

Depth of Tip Measurement

- Cone Tip Resistance
- Friction Sleeve Resistance
- Penetration Pore Pressure - Cell 1
- Penetration Pore Pressure - Cell 2
- Penetration Pore Pressure - Cell 3
- Shear Wave Velocity

Treasure Island Naval Station
SPT Data on the same NGES site

<table>
<thead>
<tr>
<th>Specimen name</th>
<th>Type</th>
<th>Tube sample recovery (mm)</th>
<th>Depth to top of specimen (m)</th>
<th>Depth to base of specimen (m)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-B3:109</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-B3:127</td>
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<td></td>
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<tr>
<td>G-B3:05.4</td>
<td>SSD</td>
<td>5.2</td>
<td>5.6</td>
<td></td>
<td>Grey fill lay...</td>
</tr>
<tr>
<td>G-B3:08.5</td>
<td>SSD</td>
<td>8.2</td>
<td>8.7</td>
<td></td>
<td>Grey fill lay...</td>
</tr>
<tr>
<td>G-B3:10.0</td>
<td>SSD</td>
<td>9.8</td>
<td>10.2</td>
<td></td>
<td>Shool Laye...</td>
</tr>
<tr>
<td>G-B3:10.4</td>
<td>SSD</td>
<td>10.2</td>
<td>10.7</td>
<td></td>
<td>Shool layer...</td>
</tr>
<tr>
<td>G-B3:100</td>
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<td></td>
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<td>G-B3:27</td>
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<td>G-B3:54</td>
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<tr>
<td>G-B3:85</td>
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<tr>
<td>CPT ID</td>
<td>DEPTH</td>
<td>TIP RESISTANCE</td>
<td>FRICTION RESISTANCE</td>
<td>PORE PRESSURE</td>
<td>INCLINATION DEGREES</td>
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<td>--------</td>
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<td>----------------------</td>
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<tr>
<td>731 TC</td>
<td>0.05 ft</td>
<td>893.87 ton</td>
<td>2.3355 na</td>
<td>0.45</td>
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<tr>
<td>731 TC</td>
<td>0.1 ft</td>
<td>594.47 ton</td>
<td>4.4059 na</td>
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<tr>
<td>731 TC</td>
<td>0.15 ft</td>
<td>415.73 ton</td>
<td>3.4361 na</td>
<td>0.1</td>
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<td>731 TC</td>
<td>0.2 ft</td>
<td>265.97 ton</td>
<td>2.5304 na</td>
<td>0.09</td>
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<tr>
<td>731 TC</td>
<td>0.25 ft</td>
<td>223.64 ton</td>
<td>2.0594 na</td>
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<tr>
<td>731 TC</td>
<td>0.3 ft</td>
<td>207.76 ton</td>
<td>1.9412 na</td>
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<tr>
<td>731 TC</td>
<td>0.35 ft</td>
<td>158.67 ton</td>
<td>1.6396 na</td>
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<td>731 TC</td>
<td>0.4 ft</td>
<td>121.87 ton</td>
<td>0.9642 na</td>
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<td>0.45 ft</td>
<td>88.03 ton</td>
<td>0.859 na</td>
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Sieve Analysis

GENERAL DATA

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<tr>
<th>Test ID</th>
<th>Drying method</th>
<th>Total hydrometer sample weight (N)</th>
<th>Sieve number passing all hydrometer specimen</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>CATIFS:SPT.B3</td>
<td>Oven</td>
<td></td>
<td></td>
<td>Fines washed thru...</td>
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</tbody>
</table>

SIEVE ANALYSIS

<table>
<thead>
<tr>
<th>Percent passing (%)</th>
<th>Sieve opening (mm)</th>
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</thead>
<tbody>
<tr>
<td>29.6</td>
<td>0.075</td>
</tr>
<tr>
<td>45.1</td>
<td>0.106</td>
</tr>
<tr>
<td>98.2</td>
<td>0.25</td>
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<tr>
<td>99.9</td>
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<td>100.0</td>
<td>4.75</td>
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</table>

HYDROMETER ANALYSIS

<table>
<thead>
<tr>
<th>Percent passing (%)</th>
<th>Particle size (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PLOT OPTIONS

DOWNLOAD

GO BACK
COSMOS
Virtual Geotechnical Database
ArcIMS / XML System

Example Inquiry
Virtual Geotechnical Database

Identify the search area by map. Use the ARROW tool (cursor) to click and drag a rectangular search area, or enter the boundaries of the search area in the form to the right (ZOOM and PAN tools under development, to be used for navigation).

Data types:
- Find all data sets
- Specify data sets to search

Dates of investigation:
- Find all dates
- Specify a range of dates (MM/DD/YYYY)

Total borehole depth:
- Find all borehole depths
- Specify a range of borehole depths

Scale: 2,110,308
### Search Results

Your search returned 550 data sets from the following data sources:

<table>
<thead>
<tr>
<th>PROJECT NAME</th>
<th>DATA TYPE</th>
<th>DATA SOURCE</th>
<th>PROJECT DATE</th>
<th>LAST UPDATED</th>
<th>DOWNLOADS/CONTACT</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORANGE FWY 57 AND TONNER CANYON BRIDGE</td>
<td>DGC, FLL, BLG, SPT</td>
<td>50</td>
<td>1989-12-10</td>
<td>2002-03-14</td>
<td><img src="image1" alt="Download Icon" /> <img src="image2" alt="Contact Icon" /></td>
</tr>
<tr>
<td>ORANGE FWY 57</td>
<td>BLG, DGC, FLL, SPT</td>
<td>60</td>
<td>1989-12-10</td>
<td>2002-03-14</td>
<td><img src="image3" alt="Download Icon" /> <img src="image4" alt="Contact Icon" /></td>
</tr>
<tr>
<td>ORANGE FWY 57</td>
<td>DGC, FLL, BLG, SPT</td>
<td>85</td>
<td>1989-12-10</td>
<td>2002-03-14</td>
<td><img src="image5" alt="Download Icon" /> <img src="image6" alt="Contact Icon" /></td>
</tr>
<tr>
<td>C.C. Industries</td>
<td>BLG, DGC</td>
<td>51</td>
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<td>2002-03-14</td>
<td><img src="image7" alt="Download Icon" /> <img src="image8" alt="Contact Icon" /></td>
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<td>2002-03-14</td>
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<tr>
<td>Mobil Station 11-E13</td>
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<td>51.5</td>
<td>1989-12-10</td>
<td>2002-03-14</td>
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<td>City of La Habra Fire Station No. 2</td>
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<td>31</td>
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<td>2002-03-14</td>
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<tr>
<td>Lincoln Mortgage</td>
<td>BLG, DGC, FLL, SPT</td>
<td>60</td>
<td>1989-12-10</td>
<td>2002-03-14</td>
<td><img src="image19" alt="Download Icon" /> <img src="image20" alt="Contact Icon" /></td>
</tr>
<tr>
<td>Former Chevron Station No. 9-2214</td>
<td>BLG, DGC, FLL, SPT</td>
<td>35</td>
<td>1989-12-10</td>
<td>2002-03-14</td>
<td><img src="image21" alt="Download Icon" /> <img src="image22" alt="Contact Icon" /></td>
</tr>
<tr>
<td>Air Conditioning Systems, Inc.</td>
<td>FLL, SPT, DOC, BLG</td>
<td>50</td>
<td>1989-12-10</td>
<td>2002-03-14</td>
<td><img src="image23" alt="Download Icon" /> <img src="image24" alt="Contact Icon" /></td>
</tr>
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<td>Cleare Property</td>
<td>FLL, SPT, DOC, BLG</td>
<td>20</td>
<td>1989-12-10</td>
<td>2002-03-14</td>
<td><img src="image25" alt="Download Icon" /> <img src="image26" alt="Contact Icon" /></td>
</tr>
<tr>
<td>UGST Site Assessment</td>
<td>BLG, DGC, FLL, SPT</td>
<td>36</td>
<td>1989-12-10</td>
<td>2002-03-14</td>
<td><img src="image27" alt="Download Icon" /> <img src="image28" alt="Contact Icon" /></td>
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## Search Results

Your search returned 2 data sets from the following data sources:

<table>
<thead>
<tr>
<th>PROJECT NAME</th>
<th>DATA TYPE</th>
<th>DATA SOURCE</th>
<th>PROJECT DATE</th>
<th>LAST UPDATED</th>
</tr>
</thead>
<tbody>
<tr>
<td>2922</td>
<td>BUG</td>
<td>Unknown</td>
<td>1700-01-01</td>
<td>2004-02-04</td>
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<td>BUG</td>
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<td>2004-02-04</td>
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</tbody>
</table>

**Key to DOWNLOADS/CONTACT INFO:**

- ![Download available in Microsoft Excel Format](image1)
- ![Download available in COSMOS XML Format](image2)
- ![Graphical Preview of data is available](image3)

### NEW SEARCH
California Geological Survey
Seismic Hazard Mapping
ArcIMS System

Example Inquiry
Welcome to the CGS's Seismic Hazard Mapping Program (SHMP) Data Access Page

Choose a mapping option from the Left Navigation Bar

Purpose of the Map

This map will assist cities and counties in fulfilling their responsibilities for protecting the public safety from the effects of earthquake-triggered ground failure as required by the Seismic Hazards Mapping Act.

For information regarding the general approach and recommended methods for preparing this map, see DMG Special Publication 118, Recommended Criteria for Delineating Seismic Hazard Zones in California.

For information regarding the scope and recommended methods to be used in conducting the required site investigations, see DMG Special Publication 117, Guidelines for Evaluating and Mitigating Seismic Hazards in California.