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Liquefaction Hazard and Shaking Amplification Maps of Alameda, Berkeley, Emeryville, Oakland, and Piedmont, California: A Digital Database

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INTRODUCTION

This Open-File Report is a digital database for hazard maps of liquefaction effects and shaking amplification in the Oakland, California, area. This accompanying pamphlet serves to introduce and describe the digital data. Paper maps are not included in the Open-File Report; instead PostScript and PDF plot files are included that can be used to plot images of the hazard maps.

This digital database is based on a previously published map of surficial geology by Helley and Graymer (1997) together with 210 newly acquired cone penetration test (CPT) soundings supplemented by unpublished commercial borings. The database identifies areas that have potential (1) to produce surface manifestations of liquefaction, for example, sand boils, ground cracks, and lateral spreading, and (2) to amplify ground shaking from earthquakes. The scale of the source map limits the spatial resolution (scale) of the database to 1:24,000 and smaller for the liquefaction map and 1:50,000 and smaller for the shaking amplification map; plotting at larger scales will not yield greater real detail. These maps depict the hazard at a regional scale and should not be used for site-specific design. Subsurface conditions can vary abruptly and borings are required to address the hazard at a given location. The liquefaction hazard map also does not account for local ground improvements that have been made to mitigate against the occurrence of liquefaction.

LIQUEFACTION HAZARD

The liquefaction hazard map predicts the approximate percentage of each designated area that will have surface manifestations of liquefaction during an M7.1 earthquake on the Hayward fault. An earthquake of this magnitude is expected if the whole Hayward fault ruptures in a single event (U. S. Geological Survey, 1999). This event dominates the deaggregated hazard near the eastern shore of San Francisco Bay (http://geohazards.cr.usgs.gov/eq/). The estimated annual probability for this earthquake is 0.00191 per year, and no such event has occurred since 1740 (U. S. Geological Survey, 1999). However, other smaller events may occur. For example, an M6.6 associated with a rupture of the northern segment of the Hayward fault has an estimated annual probability of 0.00258 per year. For these smaller events, liquefaction will be less extensive than for the M7.1 earthquake considered in this report.

The prediction of liquefaction is based on the liquefaction potential index (LPI) (Iwasaki and others, 1978). LPI is a weighted integration of the factor of safety against liquefaction within the uppermost 20 m of sediment beneath a site. A previous study by Toprak and Holzer (in press) investigated the correlation of LPI with surface manifestations of liquefaction during the 1989 Loma Prieta, California, earthquake and found that surface manifestations typically occurred where LPI values exceed 5. LPI values were computed at the 210 locations where CPT soundings were conducted in the communities of Alameda, Berkeley, Emeryville, and Oakland. Distributions of LPI values were calculated for each of the major surficial geologic units mapped by Helley and Graymer (1997). For each geologic unit in the study area, the percentage of the LPI values that exceed 5 for a M7.1 Hayward fault earthquake indicate the approximate percentage of the area in which liquefaction effects can be expected (See Holzer and others, 2002). The geologic contacts of the surficial units mapped by Helley and Graymer (1997) are included on the liquefaction map for reference.

Because of the major difference in liquefaction susceptibility between Holocene and Pleistocene alluvial fan deposits, areas where unsaturated Holocene alluvial fan deposits overlie Pleistocene alluvial fan deposits were identified by comparing the depth to the water table with the thickness of the Holocene alluvial fan deposits. In areas where the Holocene alluvial fan deposits are completely above the water table, the liquefaction hazard is derived from the underlying Pleistocene

alluvial fan deposits. Thus, the boundary between the saturated and unsaturated Holocene alluvial fan deposits distinguishes between areas with different degrees of hazard. Areas shown on the map as "not studied" are narrow valleys where Helley and Graymer (1997) mapped Holocene deposits, but in which it was not feasible to conduct sufficient soundings to document sediment thickness and liquefaction susceptibility.

SHAKING AMPLIFICATION

The shaking amplification map is based on shear-wave velocity measurements conducted during the CPT soundings and uses the 1997 National Earthquake Hazards Reduction Program (NEHRP) soil-classification scheme to categorize the potential for shallow soils to amplify ground shaking (Building Seismic Safety Council, 1998). The scheme relies on a time-averaged shear-wave velocity to a depth of 30 m (V_{S30}) to classify the soils at a site (Table 1). This classification is then used to determine appropriate amplification factors for use in engineering design, with type E soils having the largest amplification factor (Building Seismic Safety Council, 1998).

The regional distribution of V_{S30} was estimated by dividing the study area into three approximately north-south regions. The western region is west of the predevelopment shoreline of San Francisco Bay where the upper 30 m typically consists of artificial fill placed over younger bay mud, which in turn overlies either fine-grained Pleistocene sediment or Merritt sand. The central region lies immediately east of the predevelopment shoreline where the upper 30 m typically consists of Holocene alluvial fan deposits overlying Pleistocene alluvial fan deposits. The eastern region is underlain by bedrock. To map the NEHRP soil classification in the western and central regions, maps showing the thickness of Holocene sediment and artificial fill were prepared and then the V_{S30} at points on a regular grid with 50-m spacing was computed based on average velocities of each geologic unit. With the exception of the younger bay mud, the average shear-wave velocity of each geologic unit was computed from the velocities measured during the cone penetration testing. The velocity of the younger bay mud increases linearly with depth, so a depth-dependent equation was used to compute the travel time through this layer in the estimation of V_{S30}. Because it was assumed that the Holocene sediment beneath the artificial fill at each control point in the western region was younger bay mud, which has the lowest shear-wave velocity of all of the geologic units, the map in this region may underestimate values of V_{S30} in some areas. Special studies are required in these areas to determine if V_{S30} values are indeed lower than 180 m/s, the prerequisite for a type E classification. Because points where V_{S30} was estimated were 50 m apart, stream valleys with Holocene fluvial deposits less than approximately 50-m wide were not mapped and classified.

Table 1. Ground-amplification site classes (adapted from Building Seismic Safety Council (1998)).

Site Class	Site Class Description	Shear-wave Velocity (m/s)	
		Minimum	Maximum
A	**HARD ROCK** (Eastern United States only)	1500	
B	**ROCK**	760	1500
C	**VERY DENSE SOIL AND SOFT ROCK**	360	760
D	**STIFF SOILS**	180	360
E	**SOFT SOILS**		180

Locations of and data from the CPT soundings, including the shear-wave travel times, are available on the World Wide Web at the following URL: http://quake.usgs.gov/prepare/cpt/

ACKNOWLEDGMENTS

The field investigations with the CPT soundings that provided the subsurface data used in this report were facilitated by the cooperation of Coleen Bell and David Skinner of the City of Oakland; Capt Larry Picinic and Flavio Barrantes of the City of Alameda; Maurice Kaufman, John Flores, and Hank Van Dyke of the City of Emeryville, Arrieta Chakos, Diana Aikenhead, Roger Miller, Jay Wilson, Rene Cardineaux of the City of Berkeley, and Gerald Serventi and Karl Kuhlmann of the Port of Oakland. Selcuk Toprak, Coyn Criley, Suzanna Brooks, and Eric Hand of the USGS provided help with data reduction and analysis. We also are grateful to the California Geological Survey and the Port of Oakland for providing subsurface data. Carl Wentworth of the USGS provided valuable guidance with GIS and the preparation of this report. Carl Wentworth and Manuel Bonilla (USGS Geologist Emeritus) provided thorough and thoughtful reviews of the report.

DATABASE CONTENTS

The report consists of digital files representing the 12 parts of the database, some of which are presented in more than one format. The names of the files are unique designators based on the report identifier, of02-296, followed by part numbers and an extension indicating file type. Some of the files have been have been compressed with WinZip (see Presentation, below). The files and their identities are as follows:

1. Open-File Pamphlet: The text of the open-file pamphlet (this text), which describes the database and how to obtain it.
   a. of02-296_1.txt ASCII file, 25.3 KB.
   b. of02-296_1.pdf PDF file, 103 KB.

2. Revision List: A list of the parts of the report (including bundled packages of parts), indication of the current version number for the report and in which version each part was last revised (if at all), followed by a chronologic list describing any revisions (see REVISIONS, below).
   a. of02-296_2.txt ASCII file, 3.6 KB

3. Liquefaction Hazard Spatial Database: The data files representing the polygons of the liquefaction hazard map in ArcView/ArcGIS format.
   a. of02-296_3.shp Shape file, 872 KB
   b. of02-296_3.dbf Database File, 20.4 KB
   c. of02-296_3.shx Shape Index file, 3.09 KB

4. Shaking Amplification Spatial Database: The data files representing the areas of the NEHRP soil classifications for the shaking amplification map in ArcView/ArcGIS format.

a. of02-296_4.shp Shape file, 2.84 MB
b. of02-296_4.dbf Database File, 7.41 MB
c. of02-296_4.shx Shape Index file, 832 KB

5. Boundary of Study Area Spatial Database: The data files representing the polygon of the boundary outline of the study area in ArcView/ArcGIS format.
   a. of02-296_5.shp Shape file, 8.74 KB
   b. of02-296_5.dbf Database File, 0.3 KB
   c. of02-296_5.shx Shape Index file, 0.1 KB

6. Hayward Fault Spatial Database: The data files representing the lines of the Hayward Fault in ArcView/ArcGIS format.
   a. of02-296_6.shp Shape file, 16.1 KB
   b. of02-296_6.dbf Database File, 6.26 KB
   c. of02-296_6.shx Shape Index file, 1.13 KB

7. Water Boundary Spatial Database: The data files representing the polygons of the water boundary in ArcView/ArcGIS format.
   a. of02-296_7.shp Shape file, 189 KB
   b. of02-296_7.dbf Database File, 5.29 KB
   c. of02-296_7.shx Shape Index file, 0.7 KB

8. Liquefaction Map Database Package: The zipped file containing the open file pamphlet, revision list, boundary of study area polygon, Hayward fault polyline and liquefaction hazard map polygons.
   a. of02-296_8liq.zip WinZip file, 372 KB

9. Shaking Amplification Map Database Package: The zipped files containing the open file pamphlet, revision list, shaking amplification map polygons, boundary of study area polygon, Hayward fault polyline, and water boundary polygons.
   a. of02-296_9sa.zip WinZip file, 3.50MB

10. Liquefaction Map Images: The image files representing the liquefaction hazard map as a complete PostScript file (.ps) or Portable Document Format file (.pdf). Files with an (-sg) extension contain the major streets and highways displayed on the map.

    a. of02-296_10liq.ps PostScript file, 1.96 MB
    b. of02-296_10liq.pdf Portable Document Format, 382 KB
    c. of02-296_10liq-sg.ps PostScript file, 2.66 MB
    d. of02-296_10liq-sg.pdf Portable document Format, 542 KB

11. Shaking Amplification Map Images: The image files representing the shaking amplification map as a complete PostScript file (.ps) or Portable Document Format file (.pdf). Files with an (-sg) extension contain the major streets and highways displayed on the map

    a. of02-296_11sa.ps PostScript file, 4.19 MB
    b. of02-296_11sa.pdf Portable Document Format, 9.06 MB
    c. of02-296_11sa-sg.ps PostScript file, 4.88 MB
    d. of02-296_11sa-sg.pdf Portable Document Format, 9.21 MB

12. CPT Location Map Images: The image files representing the location of 210 CPT soundings on the liquefaction map (cptliq) and the shaking amplification map (cptsa) as complete PostScript files (.ps) or Portable Document Format files (.pdf).

    a. of02-296_12cptliq.ps Postscript file, 1.29 MB
    b. of02-296_12cptliq.pdf Portable Document Format, 351 KB
    c. of02-296_12cptsa.ps Postscript file, 4.19 MB
    d. of02-296_12cptsa.pdf Portable Document Format, 9.08 MB

PRESENTATION

The text files are provided individually as text (.txt) or Portable Document Format (.pdf) files and are also packaged with the database files in WinZip compressed form. The database files are provided individually as ArcView shape files (.shp), database files (.dbf) and shape index files (.shx). Some of the files are also packaged together in compressed form with WinZip (.zip).

Separate Text Files: The revision list (of02-296_2.txt) and the two formats of the open-file text (of02-296_1) are provided separately. These text files in both formats are also bundled in the database packages.

Separate Database Files: The liquefaction hazard map database (of02-296_3), the shaking amplification map database (of02-296_4), the boundary of study area database (of02-296_5), the Hayward fault database (of02-296_6), and the water boundary database (of02-296_7) are provided separately as ArcView/ArcGIS files, as well as being bundled in the database packages.

Liquefaction Database Package: The liquefaction hazard database package contains the liquefaction hazard map database (of02-296_3), the boundary of study area database (of02-296_5), the Hayward fault database (of02-296_6) packaged together in a single WinZip-compressed file along with the revision list (of02-296_2.txt) and this pamphlet (of02-296_1) in both .txt and .pdf formats.

of02-296_8liq.zip 372 KB, uncompresses to 1.07 MB

Shaking Amplification Map Database Package: The shaking amplification database package contains the shaking amplification map (of02-296_4), the boundary of study area database (of02-296_5), the Hayward fault database (of02-296_6), the water boundary database (of02-296_7) packaged together in a single WinZip-

compressed file along with the revision list (of02-296_2.txt) and this pamphlet (of02-296_1 in both .txt and .pdf formats.

of02-296_9sa.zip 3.5 MB, uncompresses to 11.32 MB

Liquefaction Map Images: The liquefaction hazard map images are provided in both .pdf and .ps formats. They are also provided with (of02-296_10liq-sg) and without (of02-296_10liq) streets and highways.

Shaking Amplification Map Images: The shaking amplification map images are provided in both .pdf and .ps formats. They are also provided with (of02-296_11sa-sg) and without (of02-296_11sa) streets and highways.

CPT Location Map Images: The locations of 210 CPT soundings are overlaid on both the liquefaction map (of02-296_12cptliq) and the shaking amplification map (of02-296_12cptsa) in both .pdf and.ps formats.

OBTAINING THE DIGITAL FILES

The database and image files can be downloaded from the Western Region Geologic Information Web Server or by anonymous ftp over the Internet.

1. Anonymous ftp over the Internet

The files for this report are stored on the Western Region publication server of the U.S. Geological Survey. The Internet address of this server is:

ftp://geopubs.wr.usgs.gov/

Connect to this address directly using ftp or through a browser, log in with the user name 'anonymous', and enter your e-mail address as the password. This will give you access to all the publications available from the server. The files for this report are stored in the subdirectory:

pub/open-file/

2. From the Western Region Geologic Publications Web Server

The U.S. Geological Survey supports a set of graphical pages on the World Wide Web from which digital publications such as this one can be obtained. The Web server for digital publications from the Western Region is:

http://geopubs.wr.usgs.gov

This report can be reached by number (of02-296) through either the California or Open-File Reports 2002 options.

3. The files for this report are stored on the Western Region publication server of the U.S. Geological Survey. The Internet address of this open file report is:

http://geopubs.wr.usgs.gov/open-file/of02-296

PROCESSING THE FILES

The database files require initial processing before they are usable if they are bundled compressed files. These files were intended for PC platforms. For other formats contact the senior author at tholzer@usgs.gov.

OPENING WINZIP FILES

Some of the files are packaged as WinZip (.zip files). Thus, WinZip or another similar utility is required to uncompress the files. Once extracted from the compressed files, the ArcView shape files can be imported into ArcView, ArcGIS or ArcInfo. The necessary utility for uncompressing and extracting from zipped format (WinZip) is available on-line. This commercial package runs on PCs. An evaluation copy of WinZip can be downloaded from:
http://www.winzip.com/ddchomea.htm

VIEWING FILES

Interested users of the data files without access to ArcView, ArcGIS or ArcInfo may obtain ArcExplorer 4, a free stand-alone product that allows anyone to view, explore and print these shape files. A copy of ArcExplorer 4 can be obtained by visiting http://www.esri.com/software/arcexplorer/download4.html - windows. ArcExplorer 4 is available in formats to run on Windows PC, Unix and Linux platforms.

REVISIONS

Changes to any part of this report (parts are the numbered items described above in 'Report Contents' and listed in the revision list (of02-296_2.txt) may be made in the future if needed. This could involve, for example, fixing files that don't work properly, revising details, adding new file formats, or adding other components to the report.

The report begins at version 1.0. Any revisions will be specified in the revision list and will result in the recording of a new version number for the report. Small changes will be indicated by decimal increments and larger changes by integer increments in the version number. Revisions will be announced and maintained on the Web page for this report on the Western Region Geologic Publications Web Server. Consult the revision list there to determine if a revision is significant for your purposes.

SPATIAL RESOLUTION

The digital database should not be used in ways that violate the spatial resolution of the data. Although the digital form of the data removes the physical constraint imposed by the scale of a paper map, the detail and accuracy inherent in map scale are also present in the digital data. Use of the

liquefaction and shaking amplification databases, respectively, at scales larger than 1:24,000 and 1:50,000, will not yield greater real detail although it may reveal fine-scale irregularities below the intended resolution of the database. Similarly, where this database is used in combination with other data of higher resolution, the resolution of the combined output will be limited by the lower resolution of these data. The quadrangle boundaries in the images are accurate at 1:24,000.

DESCRIPTION OF THE SPATIAL DATABASE

The spatial database consists of five shape files (liquefaction hazard, shaking amplification, boundary of study area, Hayward fault, and water boundary). The contents of the several database layers are described in terms of the database field names for each of the five shape files. Descriptions of these database fields are listed below in tables 2-10. The shape files are in decimal degrees of longitude and latitude, prepared by projecting and converting the primary UTM coverages.

Table 2. Map Projection

Projection	GEOGRAPHIC
Units	DECIMAL DEGREES
Datum	NAD27
Spheroid	CLARKE1866
Parameters	NONE

Table 3. Definition table included as the .dbf file for the liquefaction hazard map (of02-296_3.dbf)

FIELD NAME	DESCRIPTION
Shape	feature type (polygons)
Liq_map_id	unique identification number
Poly_	unique identification number
Liq_Hazard	user defined field for liquefaction hazard level. See Table 4 for code assignments.
Area_m2	area of polygon in square meters.
Perimet_m	length of perimeter in meters

Table 4. Table of codes for Liq_Hazard in Table 3 and their meanings.

LIQ_HAZARD	DESCRIPTION
0	water bodies
1	areas predicted to have 0% liquefaction for a M=7.1 earthquake
2	areas predicted to have <1% liquefaction for a M=7.1 earthquake
3	areas predicted to have 3% liquefaction for a M=7.1 earthquake
4	areas predicted to have 38% liquefaction for a M=7.1 earthquake
5	areas predicted to have 73% liquefaction for a M=7.1 earthquake
6	areas not studied

Table 5. Definition table included as the .dbf file for the shaking amplification map (of02-296_4.dbf)

FIELD NAME	DESCRIPTION
Shape	feature type (points)
NEHRP_id	unique identification number
Longitude	longitude in Decimal Degrees
Latitude	latitude in Decimal Degrees
Vs30	shear wave velocity at a depth of 30m in meters per second
Soil_Type	user defined field for NEHRP soil type. See Table 6 for NEHRP soil type code assignments.

Table 6. Table of code assignments for Soil_Type in Table 5.

Soil_Type	DESCRIPTION
1	NEHRP soil type E: $V_s < 180$ m/s
2	NEHRP soil type D: $180 < V_s < 360$ m/s
3	NEHRP soil types Band C: $V_s > 360$ m/s

Table7. Definition table included as the .dbf file for the boundary of study area (of02-296_5.dbf)

FIELD NAME	DESCRIPTION
Shape	feature type (polygon)
Boundry_id	unique identification number
Area_m2	area of polygon in square meters.
Perimet_m	length of perimeter in meters

Table 8. Definition table included as the .dbf file for the Hayward fault (of02-296_6.dbf)

FIELD NAME	DESCRIPTION
Shape	feature type (polyline)
Hayward_id	unique identification number
Fnode_	starting node of polyline (from node)
Tnode_	ending node of polyline (to node)
Length_m	length of arc in meters

Table 9. Definition table included as the .dbf file for the water boundary (of02-296_7.dbf)

FIELD NAME	DESCRIPTION
Shape	feature type (polygons)
Watrbnd_id	unique identification number
Ptype	unit label. See Table 10 for unit label
Area_m2	area of polygon in square meters.
Perimet_m	length of perimeter in meters

Table 10. Table of Ptype unit labels

Ptype	DESCRIPTION
H2O	water

REFERENCES CITED

Building Seismic Safety Council, 1998. 1997 edition NEHRP recommended provision for seismic regulation for new buildings and other structures, FEMA 302/303, Part 1 (provisions) and Part 2 (Commentary). Washington, D.C., Federal Emergency Management Agency.

Helley, E.J., and Graymer, R.W., 1997a, Quaternary geology of Alameda County, and parts of Contra Costa, Santa Clara, San Mateo, San Francisco, Stanislaus, and San Joaquin Counties, California: A digital database: U.S. Geological Survey Open-File Report 97-97, map scale 1:24,000.

Holzer, T.L., Toprak, S., and Bennett, M.J., 2002, Liquefaction potential index and seismic hazard mapping in the San Francisco Bay Area, California: Seventh national conference on earthquake engineering, Boston, Ma., July, 2002 proceedings, available on CD-ROM from EERI, Oakland, Calif.

Iwasaki, T., F. Tatsuoka, K. Tokida, and S. Yasuda (1978). A practical method for assessing soil liquefaction potential based on case studies at various sites in Japan, in 2nd International conference on microzonation, San Francisco, p. 885-896.

Toprak, S., and T.L. Holzer, 2002. Liquefaction potential index – a field assessment: Journal of Geotechnical and Geoenvironmental Engineering, in press.

Working Group on California Earthquake Probabilities, 1999, Earthquake probabilities in the San Francisco Bay Region: 2000 to 2030 - A summary of findings: U.S. Geological Survey Open File Report 99-517, Online Version 1.0 is obtainable at: http://geopubs.wr.usgs.gov/open-file/of99-517/