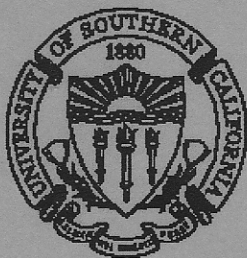# UNIVERSITY OF SOUTHERN CALIFORNIA

Database of Case Histories of Liquefaction Related Ground Deformation from the 1999 Turkey Earthquake

by

Jean-Pierre Bardet, Jianping Hu, Fang Liu,
Nazila Mokarram, and Jennifer Swift

A Report to
the National Science Foundation
and
the PEER Program of Earthquake Applied Research for Lifelines

February 9, 2004

Disclaimer

Any opinions and findings in this publication do not necessarily reflect the views of the National Science Foundation (NSF), the Pacific Earthquake Engineering Research Center (PEER), and its Program of Earthquake Applied Research for Lifelines (PEARL). Neither NSF, PEER, PEARL, nor any of their respective employees make any warranty, expressed or implied, nor assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information included in this publication.

The database of case histories of liquefaction-related ground deformation from the 1999 Turkey earthquake is intended for use by PEER researchers. This CD-ROM may not be copied without permission, nor may the data or files contained within be distributed to any third party.

TABLE OF CONTENTS

SUMMARY

Liquefaction-induced ground deformations have kept causing severe damage to lifelines and transportation systems during past earthquakes, e.g., the 1995 Hyogoken Nanbu, Japan, earthquake and the 1999 Kocaeli, Turkey, earthquake. This research report documents the field data on the ground deformations which were related to liquefaction during the 1999 Kocaeli, Turkey earthquake, and organizes this information into a geographic information systems database. This database of case histories is intended to improve models for liquefaction-induced ground deformation, and will eventually lead to enhance the retrofit and design of lifeline distribution networks.

ACKNOWLEDGEMENTS

ORGANIZATION OF REPORT

Bardet et al (2002) described in details the background and motivation for documenting the case histories of liquefaction-induced ground deformation after earthquakes. This report adds to the previous database of Bardet et al. (2002) the case histories of liquefaction-related ground deformation from the 1999 Kocaeli, Turkey, earthquake. The first section of the report describes the structures of the database, and its second section summarizes the database contents.

STRUCTURE OF DATABASE ON CD-ROM

The liquefaction ground deformation database is distributed on a CD Rom. This section describes its structure, and illustrates how it can be used through a few examples. Additional details can be found in Bardet et al. (2002).

Basic requirements

As summarized in Table 1, the CD contains various types of files, which require various programs to be viewed.

Table 1.   File formats and required software of liquefaction ground deformation database CD.

File Type	File Extension	Associated software
HTML Document	.html	Internet Explorer 5.0 or higher
Microsoft Excel Workbook	.xls	Microsoft Excel 2000
JPEG Image File	.jpg	Graphic software (e.g., PaintShop)
GIF Image File	.gif	Graphic software (e.g., PaintShop)
ASCII Text File	.txt, .dat, .cpd	ASCII file editor
Adobe Acrobat Document	.pdf	Adobe Acrobat Reader
ESRI Shapefile	.shp, .sbn, .sbx, .shx, .dbf	ArcView3.x / ArcGIS8.x / ArcExplorer2.0
ESRI Coordinate Projection file	.prj	ArcView3.x / ArcGIS8.x
USGS DEM File	.DEM	ArcView3.x / ArcGIS8.x / Surfer
ArcExplorer2.0 Project File	.AEP	ArcExplorer2.0
ArcGIS8.x Project File	.MXD	ArcGIS8.x

The CD contains HTML documents, which are viewed using Internet Explorer 5.0 (or higher). The Excel workbooks require Microsoft Excel 2000 or higher. In case Microsoft Excel 2000 is not available, the CD contains an Excel97/2000 viewer, which is freely distributed by Microsoft (www.microsoft.com). The GIS files require ArcExplorer2.0 and/or ArcGIS8.x software. ArcExplorer2.0 is a GIS viewer freely distributed by ESRI (www.esri.com). Included in the CD, it should be installed before attempting to read ArcExplorer2.0 project files. Note that ArcExplorer2.0 project files cannot be processed using ArcExplorer 3.0 and 4.0. ArcGIS8.x is a

commercial GIS program available from ESRI, which has more advanced GIS features, e.g. spatial analysis, geostatistical analysis and querying capabilities. The CD contains also boreholes data files, which can be edited and printed using LogPlot2001 (www.rockware.com), and Digital Elevation Models (DEM), which can be edited with Surfer (www.goldensoftware.com). The ESRI shape file is an ESRI file format to store spatial data information, e.g., points, polylines and polygons. The files in Table 1 are related by hyperlinks; they should be kept in the same directory.

Organization of data

As shown in Fig. 1, the information on various case histories of liquefaction ground deformation is contained in separate directories. The main access point is the HTML file *contents.htm*. The folder *HTML Files* contains accessory materials common to the case histories (e.g., logos). The folder *FileViewers* includes the installation file for ArcExplorer2.0 and Excel Viewer. The case histories of liquefaction ground deformation are organized in different folders, which are named according to geographic location.
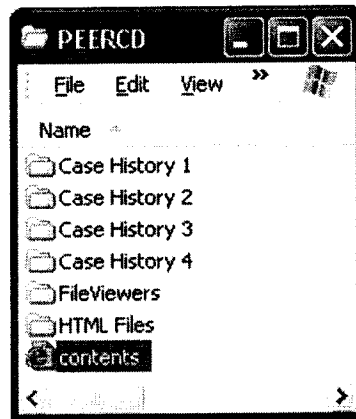

Figure 1.   Generic directory structure of liquefaction ground deformation database.

The present CD contains only one case history, i.e., *Turkey*. As shown in Fig. 2, the Turkey case history is organized in five sub-directories (1) *Aerial Photos*, (2) *Boreholes*, (3) *Displacements*, (4) *Geology Maps* and (5) *GIS Files*. These folders include original as well as processed information.The database contains a limited amount of metadata. For instance, file *DataSummary.xls* contains data on boreholes and displacements data files. There are also Excel files in the directories *Aerial Photos*, *Geology Maps* and *GIS Files*, which summarize file size and type.
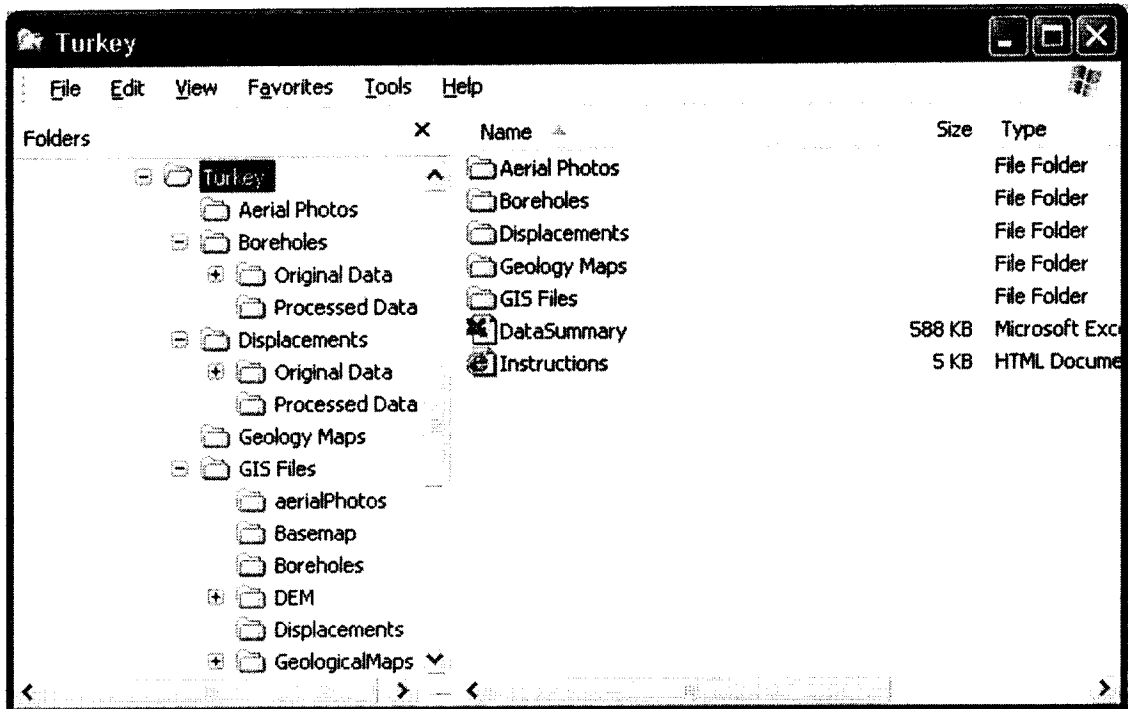
Figure 2.   Subdirectory structure of case history on liquefaction related ground deformation in Turkey.

Displaying database contents

As shown in Fig.3, the HTML page *Contents.htm* displays the case histories available in the CD. In this CD, there is only one case history, i.e. the Turkey case history. The information about this case history can be obtained by following the case history hyperlink. As shown in Fig. 4, the information is organized in five subdirectories, the content of which are explained below:

- Directory *Aerial Photos* contains the aerial photos of the areas where ground deformations were measured. This information is useful to get a better understanding of the areas under study. Most of these aerial photos have been taken after the earthquake; they are lower resolution versions of the photographs used in the processing of displacement vectors. Aerial photos are either in JPEG or GIF formats. All the information on aerial photos is summarized in the Excel workbook *AerialPhotos.xls*. Photos can be viewed by clicking on their name.

- Directory *Boreholes* contains borehole data; it includes the original borehole profiles and/or processed borehole data.
    - o Subdirectory *Original Data* contains the scanned data which were used to generate digital data for boreholes. This information is useful for verifying the transformation from hardcopy graphics (original reports) to digital data (database).

Page 6

o Subdirectory *Processed Data* contains borehole graphics, ASCII files of borehole profiles and LogPlot input data files. Using the LogPlot input data files, one can reproduce independently the boreholes graphics provided on the CD.
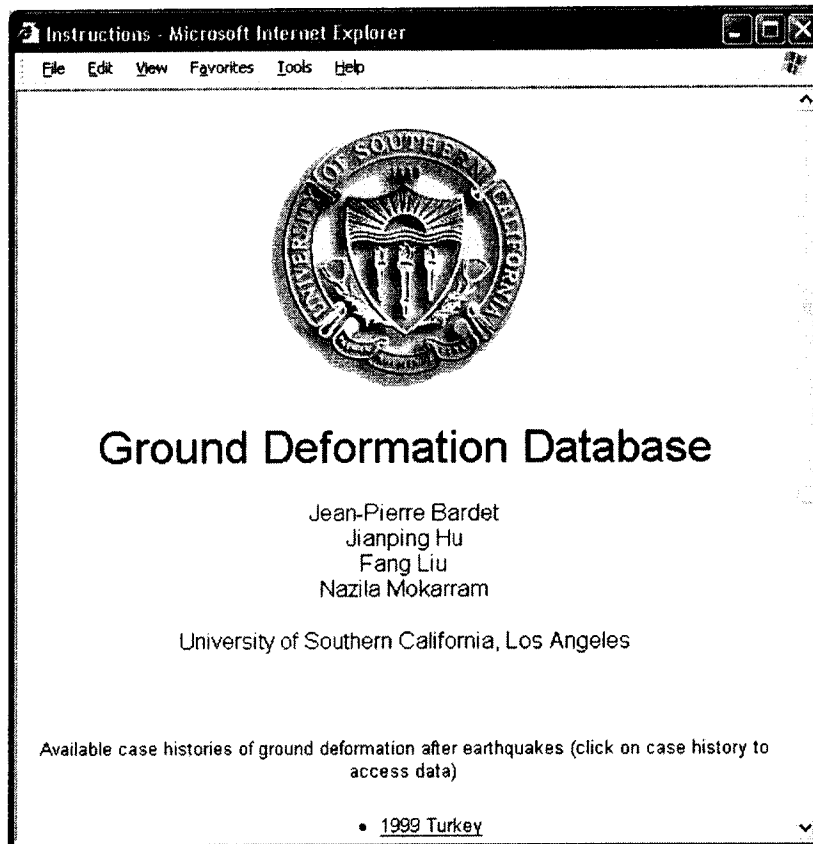

Figure 3.   Case histories of liquefaction-related ground deformation in CD.

- Directory *Displacements* contains data files on ground deformation. Workbook *DataSummary.xls* summarizes all the information available on boreholes and displacements. It also contains information on earthquakes.

- Directory *Geology Maps* contains the geology maps of the areas where ground deformations were measured. Geology maps are in either JPEG or GIF formats. All the information on geology maps is summarized in the Excel workbook *GeologyMaps.xls*.

- Directory *GIS files* contains GIS related information. Workbook *GISFiles.xls* summarizes the GIS files. The GIS files are compatible with ArcView and ArcInfo from ESRI. There are six types of GIS layers: (1) Base map, (2) DEM, (3) Aerial Photos, (4) Geology Maps, (5) Boreholes, and (6) Displacements. *Base map* is used for geo-referencing spatial data. *DEM* is used to create digital elevation models. *Aerial photos* and geology maps are used as base map information. *Boreholes* list the shape files used to represent spatial distribution of boring log. *Displacements* give the spatial distribution of displacement vectors.
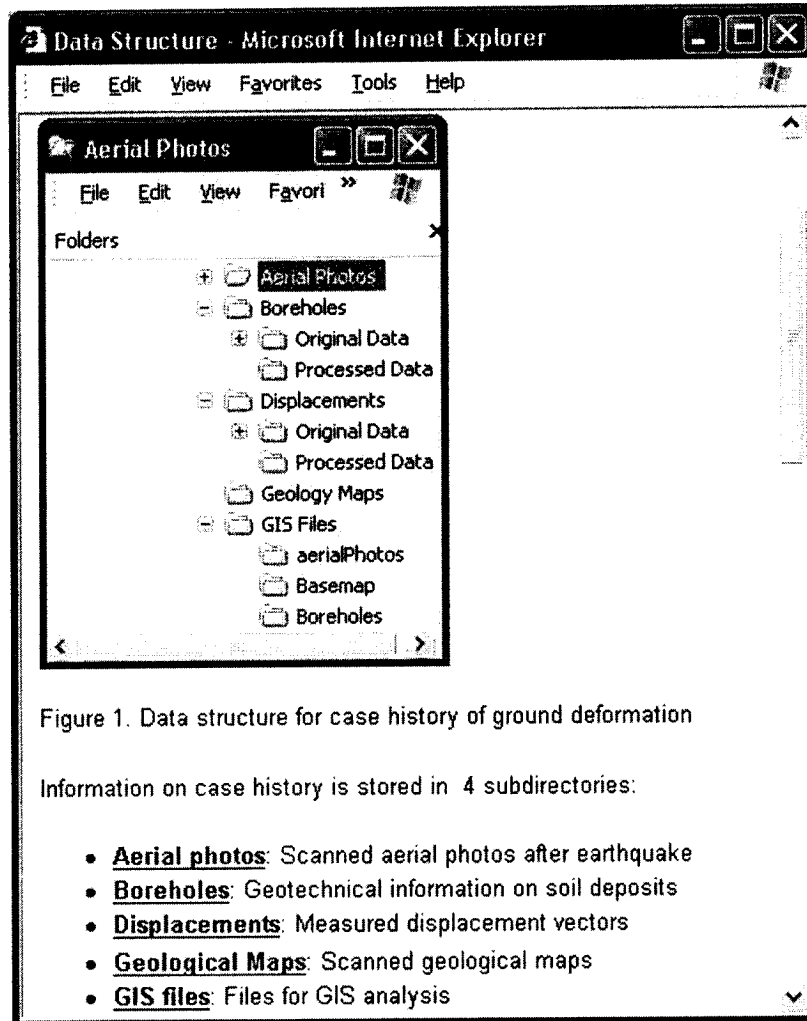
Figure 1. Data structure for case history of ground deformation

Information on case history is stored in 4 subdirectories:

- **Aerial photos**: Scanned aerial photos after earthquake
- **Boreholes**: Geotechnical information on soil deposits
- **Displacements**: Measured displacement vectors
- **Geological Maps**: Scanned geological maps
- **GIS files**: Files for GIS analysis

Figure 4.   Structure of case history as displayed in the ground deformation database CD.

Data presentation using Excel Worksheet

Displacement vectors and borehole information are tabulated and keyed using geographic coordinates. The displacement vectors and borehole data are in the Workbook *DataSummary.xls*, which has six worksheets:

1. Definitions: Terms used to characterize borehole data

2. Summary: Summary results on boreholes and displacement vectors

3. Boreholes: Coordinates, types, files, and references for boreholes

4. Displacements: Coordinates and amplitude of deformation

5. Earthquake: Earthquake information

6. References: List of references about boreholes

Table 2 defines the headers of worksheets Borehole, Displacement, Earthquakes and References.

Table 2. Headers in worksheets Boreholes, Displacements, Earthquakes and References.

Worksheet	Header	Description
Boreholes	ID	Borehole ID
	Name	Borehole name
	Type	Borehole type (SPT, CPT, etc)
	TestDate	Test date
	Northing	Northing coordinate of borehole location (m)
	Easting	Easting coordinate of borehole location (m)
	Elevation	Elevation (m)
	GWT	Ground water depth (9999 means no measurement)
	ASCII File	ASCII files contain the in-depth data of drillings
	PDF File	In-depth profile for soil or CPT data
	Location Maps	location maps showing the boring location in local area
	Graph	Graphic file of borehole profile generated using Processed Data
	Reference	Reference number on borehole
Displacements	No	Vector ID
	Xbefore	x-coordinate before earthquake (m)
	Ybefore	y-coordinate before earthquake (m)
	Zbefore	z-coordinate before earthquake (m)
	Xafter	x-coordinate after earthquake (m)
	Yafter	y-coordinate after earthquake (m)
	Zafter	z-coordinate after earthquake (m)
	Hdisp	Lateral displacement (cm)
	Vdisp	Vertical displacement (cm)
Earthquakes	EqID	Earthquake ID
	EqNm	Earthquake name
	Date	Date earthquake happened
	Latitude	Latitude of epicenter
	Longitude	Longitude of epicenter
	Magnitude	Magnitude of earthquake
	MagType	Magnitude type
References	RefID	Reference ID
	Authors	Authors
	Date	Publish date
	Title	Title of reference (including source)

Microsoft Excel offers some basic capabilities to query and extract data with particular properties, e.g., displacements vectors over a selected region. These techniques are referred to as filtering. In the *Data* menu, the function *Filter* can be used to filter data that meet a user-defined criteria. As shown in Fig. 5, data can be filtered using either *Autofilter* for basic criteria or *Advanced Filter* for more complex criteria. In most cases, *Autofilter* is versatile enough to meet most user requirements. *Advanced Filter* accepts a larger number of query parameters but is slightly more complicated to use, *Advanced Filter* performs sophisticated filtering reminiscent of

those offered by SQL (Structured Query Language) in RDBMS. It is recommended to consult the Microsoft Excel Help before using *Advanced Filter*.
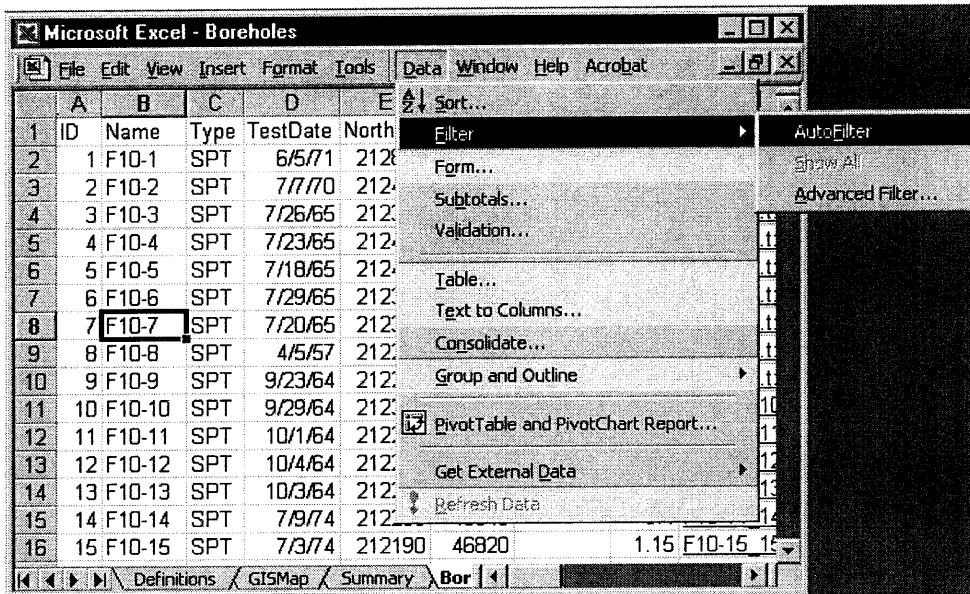

Figure 5.   Data query using *AutoFilter* in Excel spreadsheet.

Data presentation using GIS software

Spatial data (e.g., displacement vectors and borehole data) are best visualized using a GIS environment. GIS files such as Basemap and DEM files can be visualized through GIS software such as Surfer, ArcView and ArcGIS. GIS files in the ground deformation CDs are prepared using ArcGIS8.x. DEM files in CD are prepared according the standard format published by USGS (www.usgs.gov).

The case history contains two GIS project files with file extension name *AEP* or *MXD* which are in the subdirectory *GISFiles*. ArcExplorer2.0 and ArcGIS8.x are required to view *AEP* and *MXD* files, respectively. ArcExplorer2.0 is a lightweight GIS viewer, which has limited visualization capabilities. As shown in Fig. 6, ArcExplorer2.0 can visualize *AEP* project files containing displacements, boreholes, geographic and topographic data. The menu bar and tool bars are useful to add themes to existing data sources, control theme characteristics, print the maps, zoom in/out, pan and identify map features. Users can also query geographic attribute data and perform basic statistical analysis.
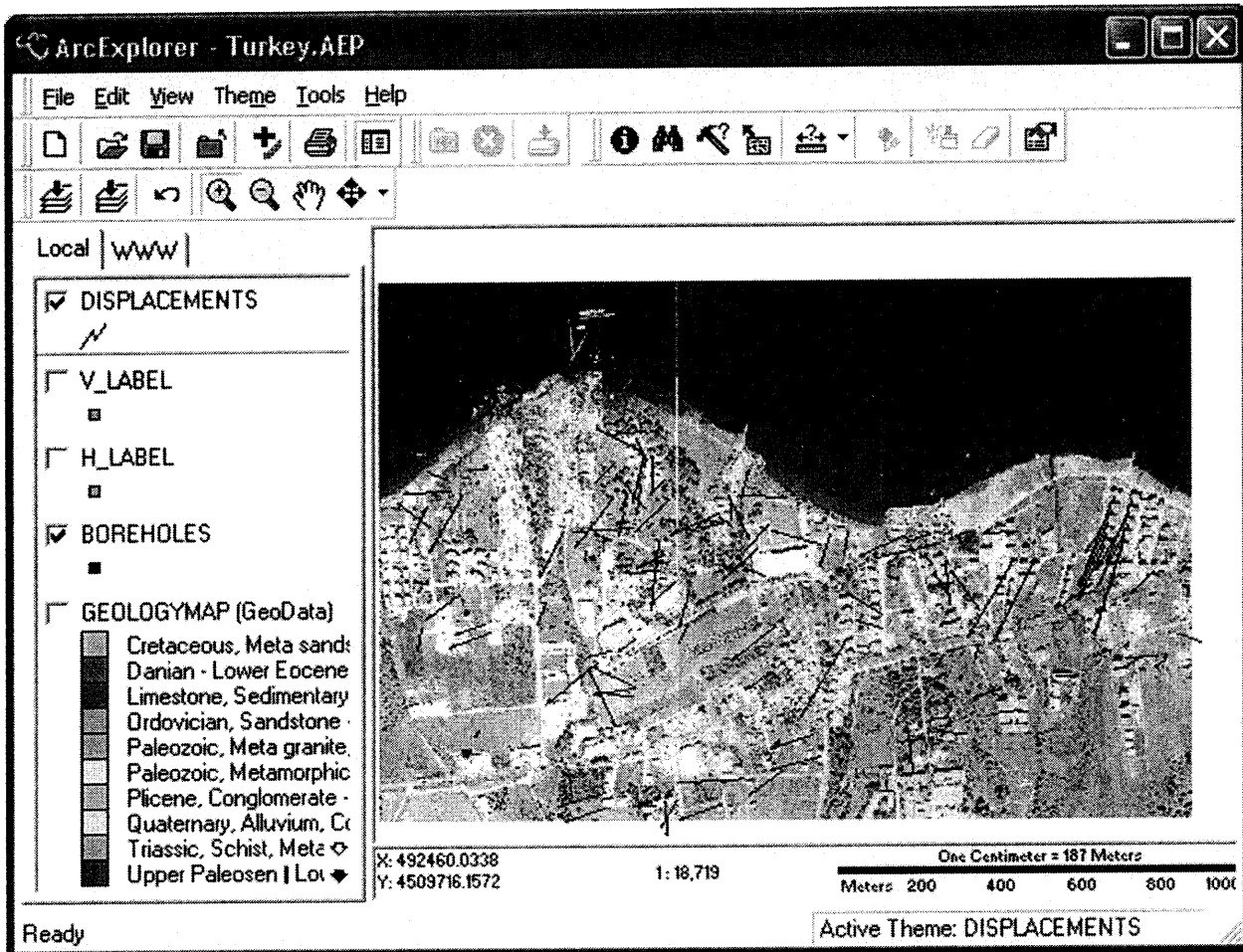
Page 10

Figure 6.   Example of ArcExplorer2.0 project file (data source from Turkey).

The CD contains *MXD* project files for ArcView8.x users. Figure 7 shows an example of a *MXD* project from Sakarya, Turkey. The usability of MXD projects were extended through user-defined Visual Basic functions. As shown in Fig. 7, a hyperlink function displays borehole information on a HTML page. The names of the boreholes in an area are displayed by moving the cursor over that area. More detailed information can be obtained for a particular borehole. For instance, Fig. 8 displays the available information on a particular borehole, including the borehole ASCII file, PDF of borehole profile, and location map of the borehole.
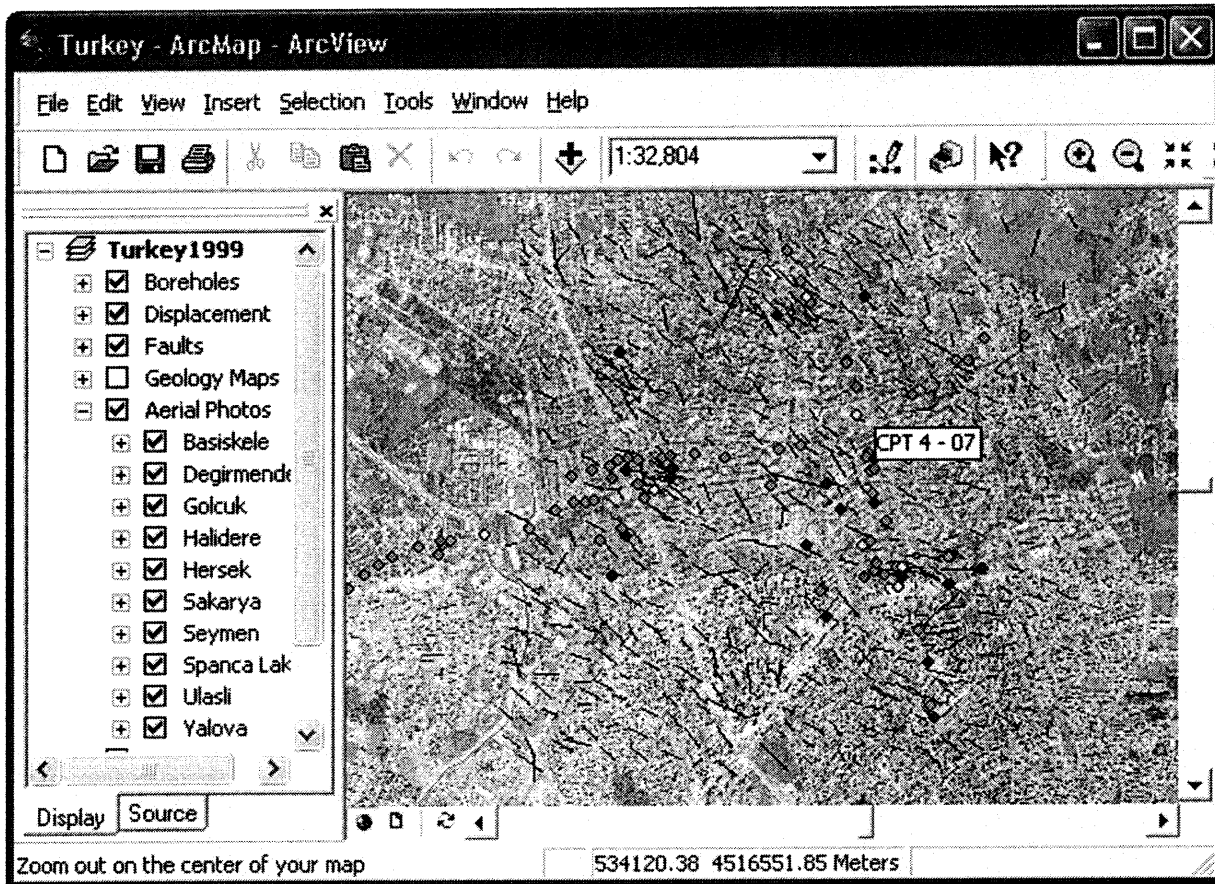
Figure 7. Example of MXD project file with Hyperlink functionality (data source from Sakarya, Turkey).
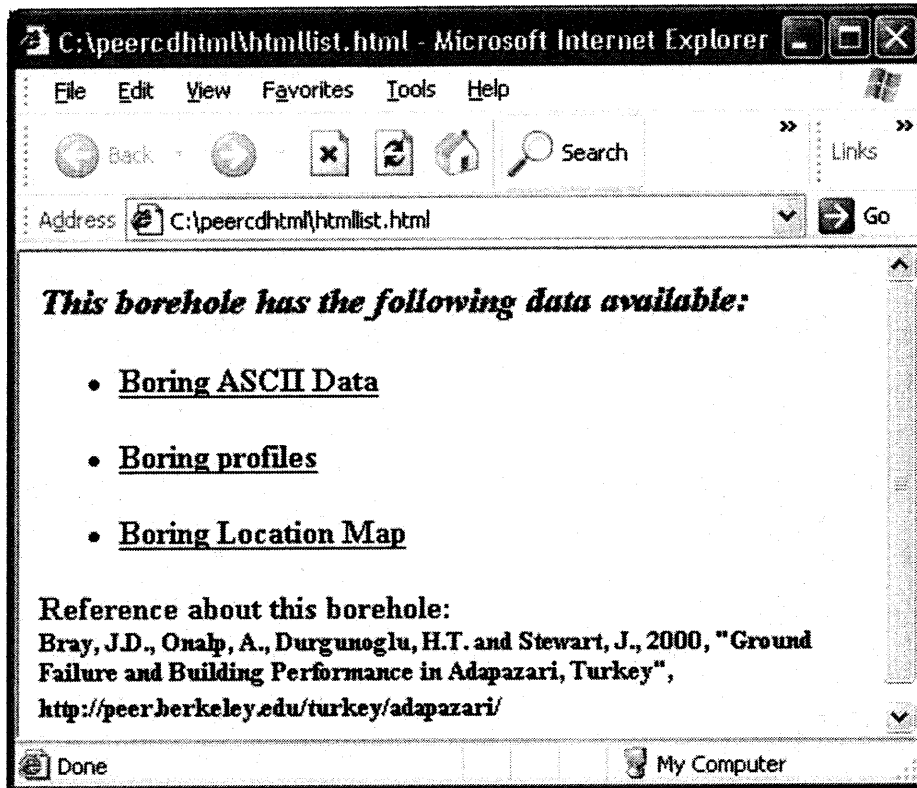
Figure 8.   List of available information at a selected borehole.

CONTENTS OF DATABASE ON CD-ROM

As listed in Table 3, the Turkey case history database assembles the displacement vectors, geotechnical data, aerial photos, geology maps and base maps from 10 different sites, namely Basiskele, Degirmendere, Golcuk, Halidere, Hersek, Lake Sapanca, Seymen, Ulasli, Yalova, Adapazari. The database contains a total of 264 boreholes, i.e., 97 SPT and 167 CPT soundings. The 1,706 vectors originate from these ten sites. Table 3 summarizes the number of displacement vectors, SPT and CPT for each site. The projected coordinate system used for spatial data is Gauss-krueger (6 degrees wide strips) with ED50 as vertical datum. The contents of the borehole, displacement vectors and other GIS files are displayed in Figs. 9-18.

Table 3. Summary of displacement, SPT and CPT data in sites under investigation.

Location	Displacement vector	CPT	SPT
Basiskele	42		
Degirmendere	121	3	2
Golcuk	90	10	5
Halidere	62		
Hersek	132		
Lake Spanca	249	13	40
Seymen	117		
Ulasli	66		
Yalova	237	4	3
Adapazari	590	137	47
Total	1706	167	97

Table 4 lists the characteristics of the aerial photos used to measure the ground displacements. The small-scale original air photos (pre- and post- earthquake) were enlarged up to about 1:5000 for stereo-photogrammetric measurement. In view of the scarcity of clear targets in the sites under investigation, three types of objects were used:

1. Spot at the corner of roads and some points on the ground

2. Foot of (small) trees (on the ground)

3. houses and piers

More than 70% of points are of type 2. When the trees are small and isolated, the measurement accuracy is estimated satifactory. Table 5 summarizes the accuracy of measurement from aerial photos. The overall accuracy of the aerial photo measurements is about 70 cm for both horizontal and vertical displacements.

Table 4.   Characteristic of the aerial photos used for ground displacement measurement.

	Scale	Date of Photo
Pre-earthquake	1/35,000	1994
Post-earthquake	1/16,000	1999

Table 5.   Accuracy of ground displacement measurement

	Horizontal (m)	Vertical (m)
Pre-earthquake	0.63	0.62
Post-earthquake	0.11	0.25
overall	0.64	0.67

The digital elevation model (DEM), included in the CD, originates from an interferometric analysis of synthetic aperture radar (SAR) data from the ESA ERS-1 and ERS-2 satellites (Fielding, 2004). Pairs of SAR images from Tandem acquisitions, with temporal separation of one day, were processed separately to produce a height map in ground range coordinates. The DEM generated from SAR interferometry has gaps because of lack of coherence in pair images. The SAR DEM gaps were filled in with data from the GTOPO30 DEM (USGS, 2004). Figure 19 shows the resulting DEM. As shown in Fig. 16, only one street map was generated from aerial photograph and geo-referenced, this street map covers the Hotel Sapanca area.
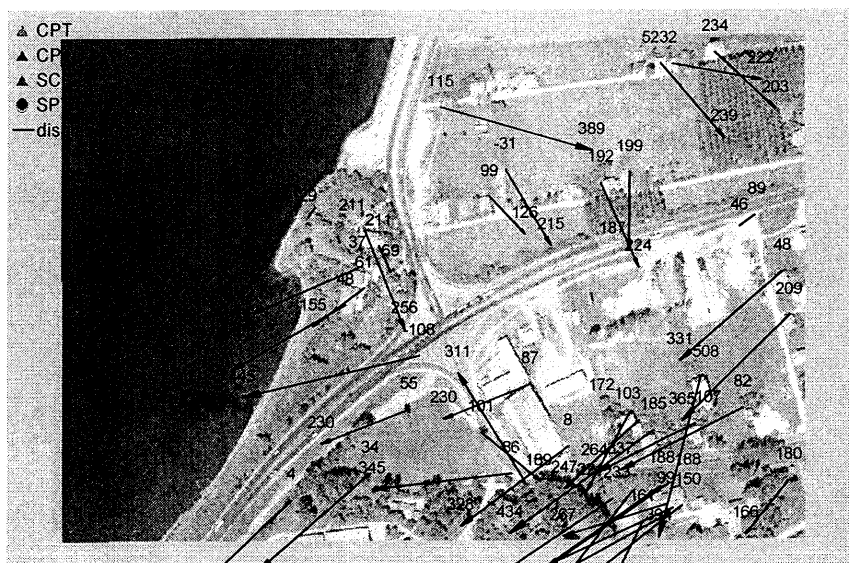
Figure 9.   Ground displacement vectors after the 1999 Turkey earthquake, superimposed on aerial photograph at Basiskele, Turkey.

Figure 10. Ground displacement vectors after the 1999 Turkey earthquake, superimposed on aerial photograph at Degirmendere, Turkey.
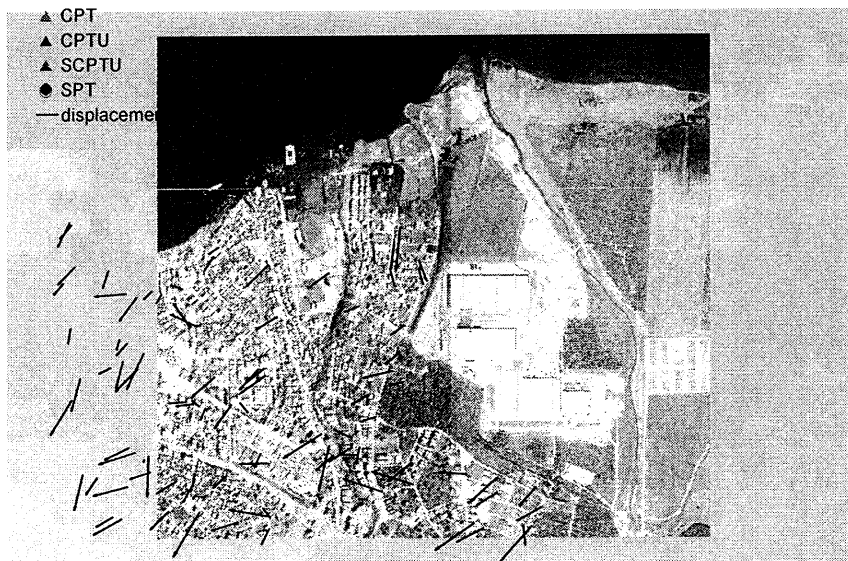

Figure 11. Ground displacement vectors after the 1999 Turkey earthquake, superimposed on aerial photograph at Golcuk, Turkey.
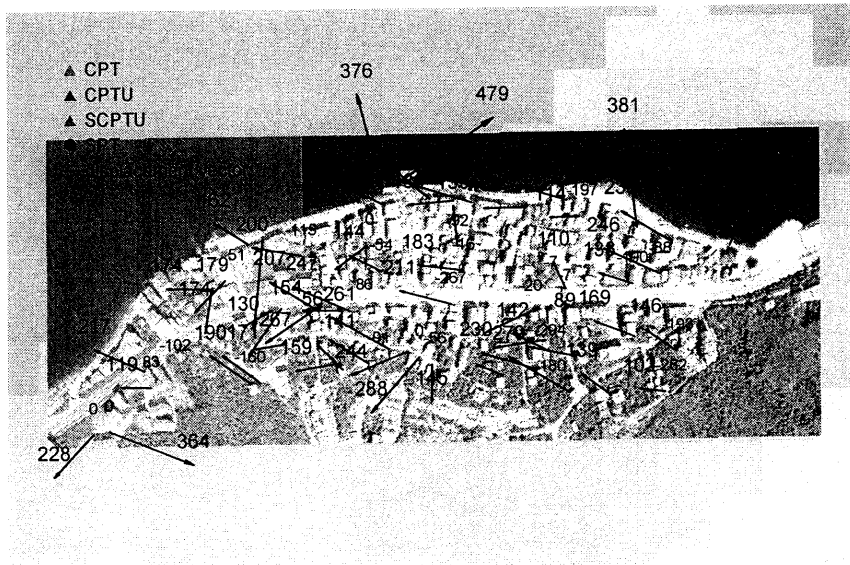
Page 16

Figure 12. Ground displacement vectors after the 1999 Turkey earthquake, superimposed on aerial photograph at Halidere, Turkey.
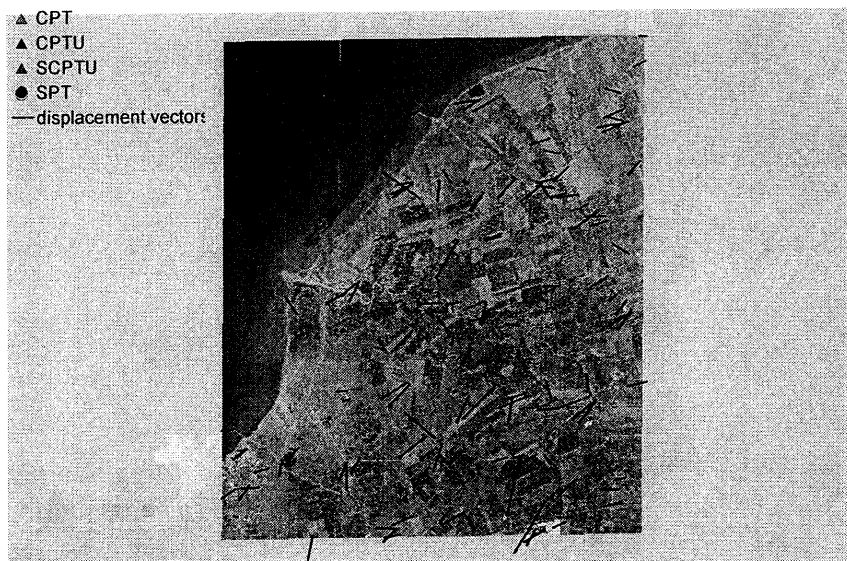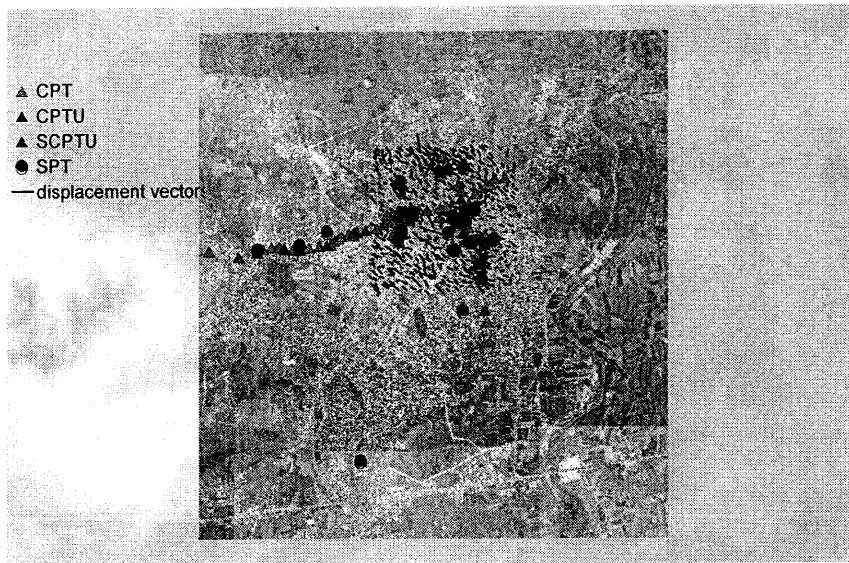

Figure 13. Ground displacement vectors after the 1999 Turkey earthquake, superimposed on aerial photograph at Hersek, Turkey.

Figure 14.　Ground displacement vectors after the 1999 Turkey earthquake, superimposed on aerial photograph at Sakarya, Turkey.
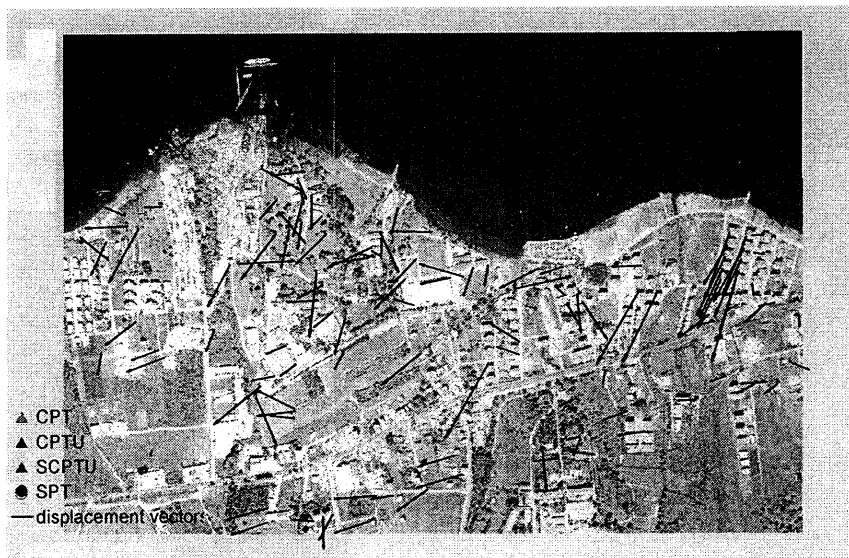

Figure 15.　Ground displacement vectors after the 1999 Turkey earthquake, superimposed on aerial photograph at Seymen, Turkey.
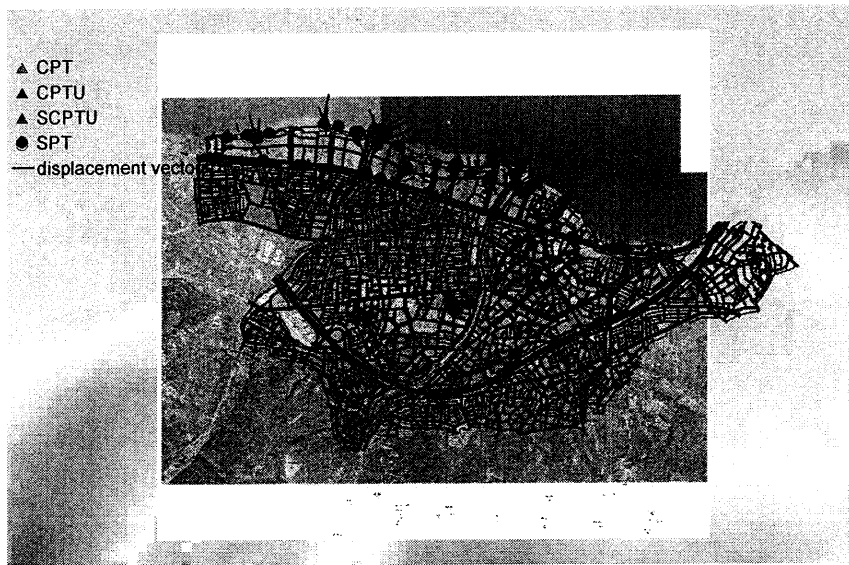
Figure 16. Ground displacement vectors after the 1999 Turkey earthquake, superimposed on aerial photograph at Spanca Lake, Turkey.
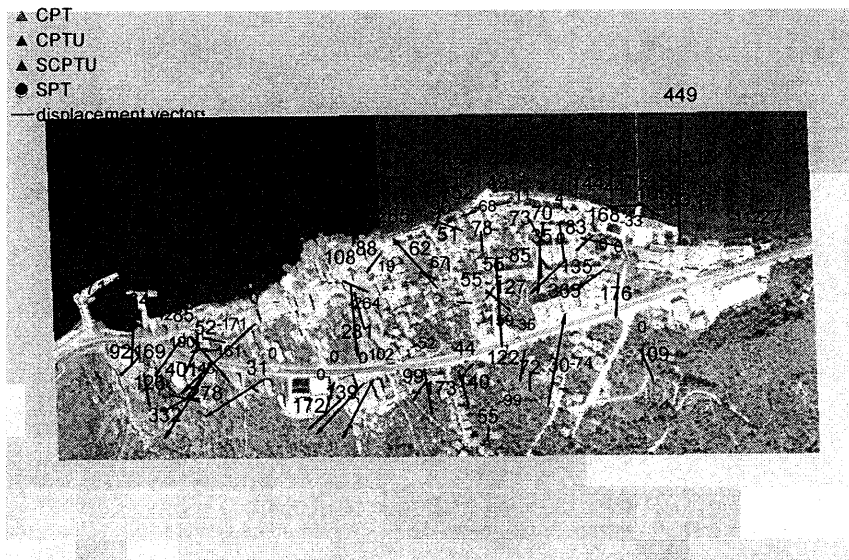

Figure 17. Ground displacement vectors after the 1999 Turkey earthquake, superimposed on aerial photograph at Ulasli, Turkey.
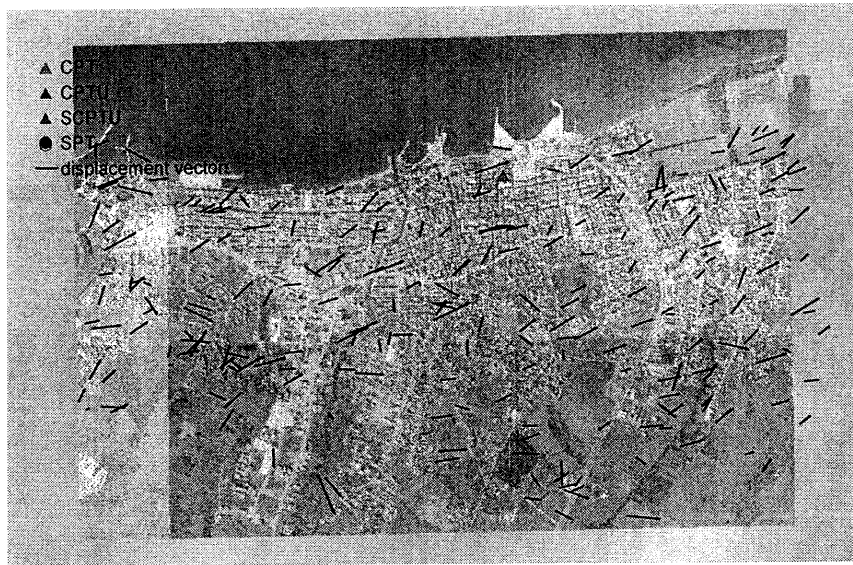
Figure 18.   Ground displacement vectors after the 1999 Turkey earthquake, superimposed on aerial photograph at Yalova, Turkey.
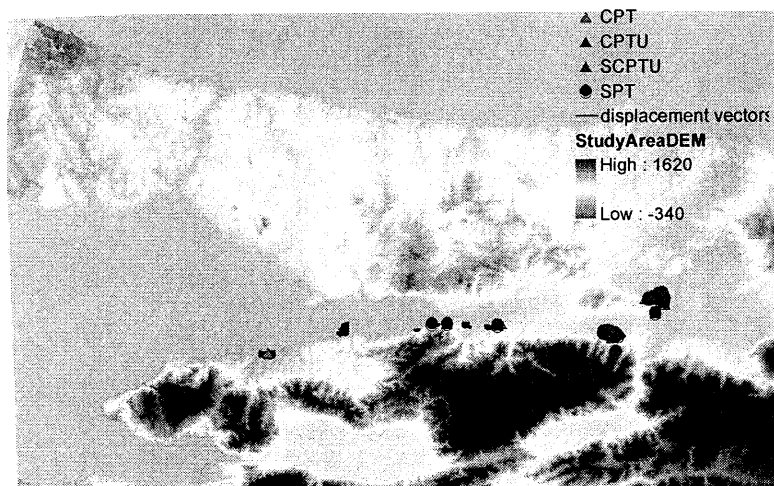

Figure 19.   Display of DEM files on study area.

REMARKS

The ground displacements, which were measured from the aerial photos, include both liquefaction-induced ground deformation and tectonic movements. The separation of deformations resulting from surface faulting and liquefaction is rather complicated for the case histories from Turkey in view of the close proximity of surface faulting and shallow soil failure in the ten sites under study. In some sites, the surface faulting, which may have caused the shallow ground deformation, could not even be documented as it occurred under water. The separation of deep tectonic deformations and shallow ground deformation definitely requires further research, and is beyond the scope of the present report. In view of the complexities above, the title of the report refers to "liquefaction-related ground deformations" instead of "liquefaction-induced ground deformations."

REFERENCES

1. **Bardet, J. P., J. Hu, J. Swift and T. Tobita,** 2002 , "Liquefaction Ground Deformation Database", A Report to PG&E-Caltrans-PEER Program of Applied Earthquake Engineering Research on Lifelines, Civil Engineering Department, University of Southern California, Los Angeles.

2. **Fielding, E.,** 2004, "Izmit Turkey ERS SAR interferometry," http://www.earth.ox.ac.uk/~eric/Turkey/index.html