A COMPUTER PROGRAM AS INTERFACE BETWEEN GIS AND DYNAMIC SITE RESPONSE COMPUTING DOMAINS

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In this paper, a methodology has been introduced in order to perform geographical information system (GIS) based dynamic soil behavior analysis. DISO 7.0 computer program was developed using Visual Basic programming language to manipulate large amount of geotechnical data and to prepare a data input file for performing dynamic analyses. The scattered geotechnical data for soils of the northern coast of Izmir Bay (Turkey) area have been collected and loaded to the constructed dynamic soil database. Dynamic soil parameters were calculated, and liquefaction analysis was performed using DISO 7.0 program following the complete of site-response analyses. The post-liquefaction settlement was also calculated with DISO 7.0. Methodology and processing principles of this computer program has been introduced, and its application to the soils of the northern coast of Izmir Bay (Turkey) area is presented.

1. INTRODUCTION

Use of GIS in geotechnical earthquake engineering has enjoyed attention of engineers due to the spatial character of the subsurface data. GIS has been used for computations of spatial seismic hazard analyses, dynamic slope stability and liquefaction analysis over large regions, and more localized ground deformation assessments (Mabey, 1997; Rogers, 1997). The processes of site-specific and regional spatial hazard analysis rely on the interpretation, interpolation and extrapolation of sampled data to accommodate both the limitations in sampling resolution and the variability.

Modern GIS technology provides a powerful tool for the compilation, archival, management and relation of large amounts of spatially linked information necessary for spatial analysis of ground motion amplification (Borcherdt, 1997). Similarly, GIS tools were used in seismic hazard mapping and evaluation of liquefaction damage (O'Rourke and Pease, 1997). Mapping liquefiable layer thickness provided a useful means of locating areas of potential liquefaction. Especially 2D GIS approach was found somehow inadequate in representing 3D nature of the geotechnical information. The 3D extensions are now available in software, and it is easy to cover the area of interest in three dimensions. GIS have provided also a platform that is suitable for needs of earthquake hazard analyses. Such application of GIS in seismic hazard analyses was performed using MATLAB routines and GIS to assess liquefaction potential of western Puerto Rico (Divakarla et al., 1998). Besides, the spatial analysis for evaluating the ground motion amplification, liquefaction potential, liquefaction-induced settlements and the effect of such deformations on structures were also developed (Luna and Frost, 1998; Luna et al., 1998). GIS-based methodology has been also used to evaluate the quality of geotechnical data obtained from boreholes during the geotechnical site characterization (Deaton et al., 2001). Data quality issues related to geotechnical hazard evaluation was studied previously by Luna (1997).

A geotechnical database related with geographic information system was developed firstly by Real (1993) to support large volumes of spatial data. Similarly, geotechnical database was established for storing and analysis of geotechnical data for the purpose of liquefaction and landslide hazard zoning in California (Real and McGuire, 1998). Maps of dynamic soil response for the city of Barcelona were prepared through a GIS environment (Jimenez et al., 2000). In another study, geotechnical and geological maps of El-Fayoum depression area, which is located at 80 km south west of Cairo, Egypt, were also prepared using the GIS techniques (El-Nokrashy et al., 2001). A GIS-based analysis of the landslides induced by the Chi-Chi earthquake occurred at Taiwan in 1999 was conducted by Lin and Tung (2004).

3D modeling for site planning was studied by various researchers (Kreuseler, 2000; Döllner and Hinrichs, 2000; Lees, 2000) in the past. The use of visualization techniques for field based GIS in various spatial disciplines has been studied by different researchers (Pundt and Brinkkötter-Runde, 2000; Nelson et al., 2003). A GIS-based application tool (Geo-GIS) was developed for storing significant quantities of geotechnical subsurface data and information for bridges across the State of Alabama (Graettinger and Simmons, 2003).

Seismic risk analysis of a site is a major concern in seismically active areas. Spatial earthquake risk analysis was carried out for Bakirkoy-Istanbul district (Çinicioğlu et al., 2001), and for the city of Bursa (Topal et al., 2003). Destructive earthquakes occurred at the Kocaeli and Düzce provinces in the Marmara region of Turkey in 1999 created a strong emphasize on the effect of local site conditions on levels of damage (Kalkan and Gülkan, 2004). Following these strong events, most of the researches were concentrated on geological and geotechnical factors affecting seismic hazard.

In this study, a computer based methodology was developed to perform GIS based dynamic soil behavior analysis. Development of GIS based interfacing software (DISO 7.0) provided to process large amount of geotechnical data in order to calculate parameters required for dynamic analyses and created a connection between resulting data and geographical coordinates. DISO 7.0 computer program was prepared using Visual Basic programming language. In this study, methodology and processing principles of DISO 7.0 have been introduced, and its application to the soils of the northern coast of Izmir Bay area is presented.

2. SCOPE AND METHODOLOGY

The scope of this study is to develop a GIS based methodology in order to perform dynamic site response analyses using geotechnical data. For this aim, geotechnical and strong ground motion databases were constructed, DISO 7.0 software was developed in Visual Basic, and this software was related to dynamic databases according to geographical coordinates. Use of this methodology provides to perform dynamic analysis for any parcel or selected boring locations. Thus, local soil conditions can be taken into consideration for dynamic soil behavior. Besides, geotechnical data, earthquake recordings and dynamic analysis results are loaded to related databases.

The methodology was applied to the northern coast of Izmir Bay (Turkey) area soils. The city of Izmir, which is the thirdest greatest city of Turkey, is located on the west coast of Anatolia. The Western Anatolia is one of the major seismically active zones in the Mediterranean due to its active tectonics. Coastal area on the north of the Izmir Bay having thick alluvial strata was selected for application of the methodology. Firstly, large amount of geological and geotechnical data for soils of the northern coast of Izmir Bay area was obtained. These scattered data were recorded into “Geotechnical Properties” database constructed at Access format. This database contains geotechnical data from 238 borehole locations and 106 CPT locations at selected area. Geographical coordinates of borehole locations were determined from original maps (scaled 1/1000) and recorded at the database. Digitization of these coordinates was completed, and digital map of project area was prepared using ArcView 3.2 GIS (ESRI, 1999) software.

Izmir has been subjected to moderate scale earthquakes in recent years (between 2003 and 2005, especially). Acceleration records of these earthquakes occurred in the vicinity of Izmir were obtained. “Strong Ground Motion” database have been constructed collecting these records together. The corrected acceleration records for moderate scale earthquakes were reached from the web site of European Strong-Motion database (Ambraseys et al., 2002).

3. DEVELOPMENT OF INTERFACE SOFTWARE DISO 7.0

The interface software DISO 7.0 was developed following the construction of geotechnical database. DISO 7.0 is capable of reading geotechnical data from database, performing calculations of dynamic parameters for dynamic site response analyses, and preparing a data input file for dynamic analysis software EERA (Bardet et al., 2000). The capability of software was increased then in order to perform liquefaction analysis and calculation of post-liquefaction settlement. Results of dynamic analyses were recorded to the directory as EERA files for each analyzed boring location, and summary table of results were constructed as “Results of Analysis” in the database. These results were related to the geographical coordinates of digital map. Thus, maximum ground surface acceleration, amplification ratio (surface/bedrock), factor of safety against liquefaction and post-liquefaction settlement values were evaluated with GIS methodology.

The major part of the study is development of software that can perform the abovementioned tasks of a geotechnical earthquake engineering problem since the geotechnical data can be used in dynamic site response and liquefaction analyses following additional calculations. One of the main properties of this software is to provide efficient communication with EERA (Bardet et al., 2000) software performing dynamic site-response analyses and GIS software.

DISO 7.0 provides a graphical user interface (GUIS) in order to link the constructed databases with the GIS software ArcView 3.2 (ESRI, 1999). Besides, data manipulation options such as selection of borehole locations on digital map are available. The geotechnical data for selected borehole can be displayed as a profile. From this point of view DISO 7.0 can be regarded as small-scale geographic information software. DISO 7.0 is able to perform liquefaction and post-liquefaction settlement analyses similar to its predecessors (Frost et al., 1997; Divakarla et al., 1998).

DISO 7.0 includes subroutine forms of Visual Basic. These forms were prepared for calculation of dynamic parameters and drawing digital map for software. Related form was called from each other and integrated working of forms was provided. Geotechnical data, which were collected in Geotechnical Properties database, are read using DISO 7.0, and calculations for dynamic parameters are performed. Data input file for site response analysis is prepared, and results of dynamic analysis are recorded to the “Results of Analysis” database using DISO 7.0. Liquefaction analysis is performed with DISO 7.0, and post-liquefaction settlement values are calculated. Connection between Geotechnical Properties and Strong Ground Motion databases and dynamic analysis software EERA is provided with DISO 7.0.

The preferred methodology for site response analysis is based on the equivalent linear model. The parameters G_{max} (maximum shear modulus) and ξ (damping ratio) are referred to as equivalent linear parameters of the soil material. These parameters are used to describe the dynamic behavior of soils in site response analysis. Dynamic soil parameters (G_{max} and ξ) are calculated with DISO 7.0 utilizing geotechnical data collected at Geotechnical Properties database. Maximum shear modulus (G_{max}) can be calculated from empirical relationships for clays (Hardin and Drnevich, 1972) and for sands (Seed and Idriss, 1970). G_{max} can be also determined from corrected SPT-N values (Ohta and Goto, 1976, Imai and Tonouchi, 1982). The variation of the modulus ratio (G/G_{max}) and damping ratio (ξ) with shear strain (γ) is computed from Ishibashi and Zhang (1993) formulations. Modulus ratio and damping ratio values for each layer of the soil profile are calculated for shear strains varying between 0.0001 and 10 percent using DISO 7.0. These values are recorded to the material property sheets in the data input file of EERA. The modulus reduction and damping curves are drawn for each material sheet during this process.

4. DYNAMIC SOIL BEHAVIOR ANALYSES

Dynamic site response analysis is the backbone of any deterministic seismic hazard analysis. The equivalent linear one-dimensional site response analysis methodology was applied in this study. The spreadsheet format of SHAKE (Schnabel et al, 1972) algorithm, EERA (Bardet et al., 2000) was preferred. The input data file for EERA was prepared using DISO 7.0. The modular structure of DISO 7.0 is shown in Figure 1. Detailed algorithm tree is given in Figure 2. Running procedure can be seen also in Figure 2. Liquefaction analysis can be performed with DISO 7.0 using the magnitude of earthquake and maximum ground surface acceleration calculated from dynamic site-response analysis. Post-liquefaction settlement values can be calculated also for selected boreholes. The connection between Geotechnical Properties and Strong Ground Motion databases with EERA (Bardet et al., 2000) is also provided by DISO 7.0.

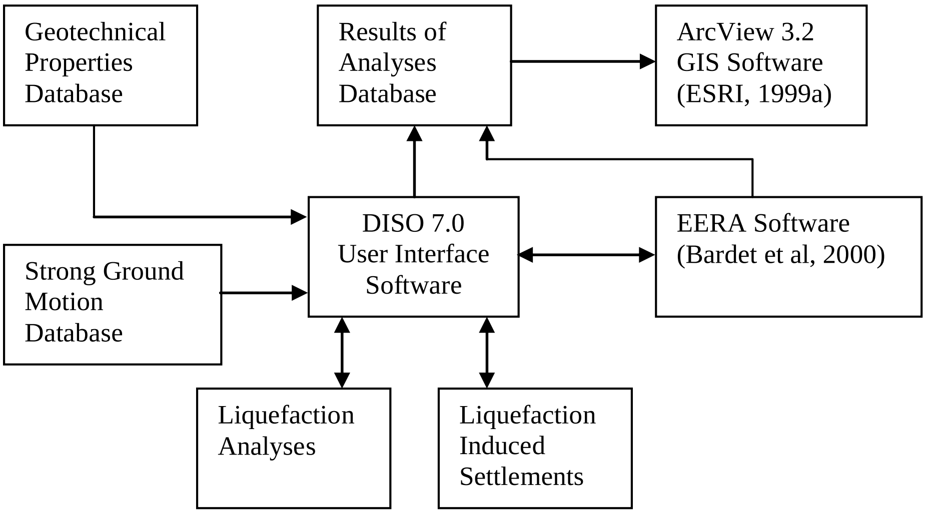


Figure 1. Modular Structure of DISO 7.0

The preferred methodology for site response analysis is based on the equivalent linear model. The parameters G_{max} (maximum shear modulus) and ξ (damping ratio) are referred to as equivalent linear parameters of the soil material. These parameters are used to describe the dynamic behavior of soils in site response analysis. The variation of the modulus ratio (G/G_{max}) and damping ratio (ξ) with shear strain (γ) is calculated using DISO 7.0, and shown graphically for each soil material sheet in EERA software.

Dynamic soil behavior analyses were performed using EERA (Bardet et al., 2000) software. EERA is run in MS Excel environment. Therefore data input and manipulations are easy. Another advantage of EERA is that the number of soil material models and integrations for Fourier analysis are not limited. Results of site-response analyses were compared with SHAKE (Schnabel et al., 1972), and both programs gave the equivalent results.

EERA software includes Excel calculation sheets. Earthquake record is selected from Strong Ground Motion database and loaded to “Earthquake” sheet of EERA, firstly. Maximum acceleration on bedrock was estimated from Campbell (1997) attenuation relationship, and written as input in the “Earthquake” sheet. The corrected records of several moderate scale earthquakes in the vicinity of Izmir were collected in the “Strong Ground Motion” database. Acceleration record is read from Strong Ground Motion database when dynamic analysis will be performed.

Properties of soil layers are transferred into “Profile” sheet, and dynamic properties of materials for each layer are collected in “Material” sheet of EERA data input file using DISO 7.0 software. When EERA is run, earthquake knowledge is read, and dynamic parameters (acceleration, velocity, and displacement) for various strain values are calculated. Maximum acceleration and spectral acceleration values on ground surface and on each layer between surface and bedrock are determined from analysis.

Dynamic analysis is performed applying three different methods according to bedrock location. Bedrock depth is assumed as the last SPT-depth of soil profile in the first method. When bedrock depth cannot be determined and absence of sufficient data for selected location occurs, user can apply this method. If bedrock depth can be estimated and the alluvial profile on bedrock is not thick, the second method is used. Bedrock depth is taken as estimated depth in this method, and soil type at last SPT-depth is extended to the bedrock depth in order to reduce the absence of geotechnical data. The third method is applied for deep alluvial soil strata on bedrock. Soil profile is extended to the bedrock depth. The confined aquifer solution is applied below 80 m depth convenient for the local geological stratification in the third method.

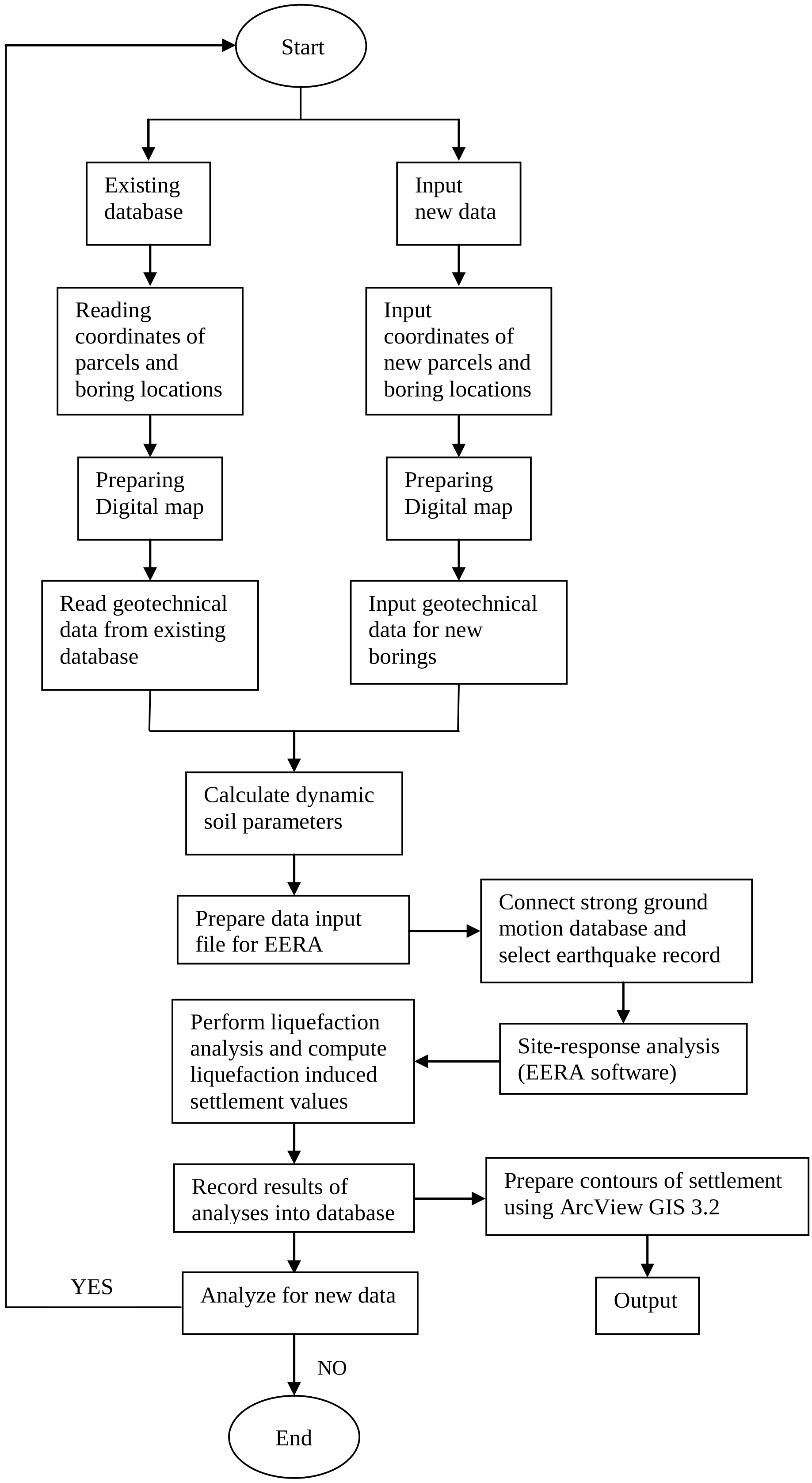


Figure 2. DISO 7.0 algorithm tree

Liquefaction analysis is performed following the estimation of maximum ground surface acceleration from dynamic analysis. The state-of-the-art methodology developed by Youd and Idriss (1997) is employed during liquefaction analysis. Estimation of two variables is required for evaluation of liquefaction resistance of soils: The cyclic stress ratio (CSR) and the cyclic resistance ratio (CRR). The cyclic stress ratio required to generate liquefaction was calculated using the simplified methodology developed by Seed and Idriss (1971). The cyclic resistance ratio can be determined from $(N_1)_{60}$ value for M=7.5 earthquake. The cyclic resistance ratio for other magnitudes can be obtained by multiplying CRR for M=7.5 earthquake by magnitude correction factors (Youd and Idriss, 1997). The ratio of cyclic resistance ratio to cyclic stress ratio gives the factor of safety against liquefaction, FS_L. Factor of safety less than 1.0 means saturated layer liquefiers, otherwise liquefaction does not occur.

Liquefaction induced settlements can be calculated using Ishihara and Yoshimine (1992) approach based on Tokimatsu and Seed (1987) methodology. A chart is used for estimating post-liquefaction volumetric strain of clean sand as a function of FS_L. The relative density, SPT resistance, or CPT tip resistance can be used to obtain post-liquefaction volumetric strain. The volumetric strain for each layer is multiplied by thickness of the layer and post-liquefaction settlement values are obtained.

When DISO 7.0 is run, a digital map displaying parcels and boring locations at selected project area can be seen on the screen. Any parcel or group of boring locations can be selected from digital map drawn in DISO 7.0 (Figure 3). Soil profile for selected boring location and variation of SPT-N values with depth are shown on a new screen as illustrated in Figure 4. Geotechnical properties of this location are given as the Geotechnical Data table in Figure 5.

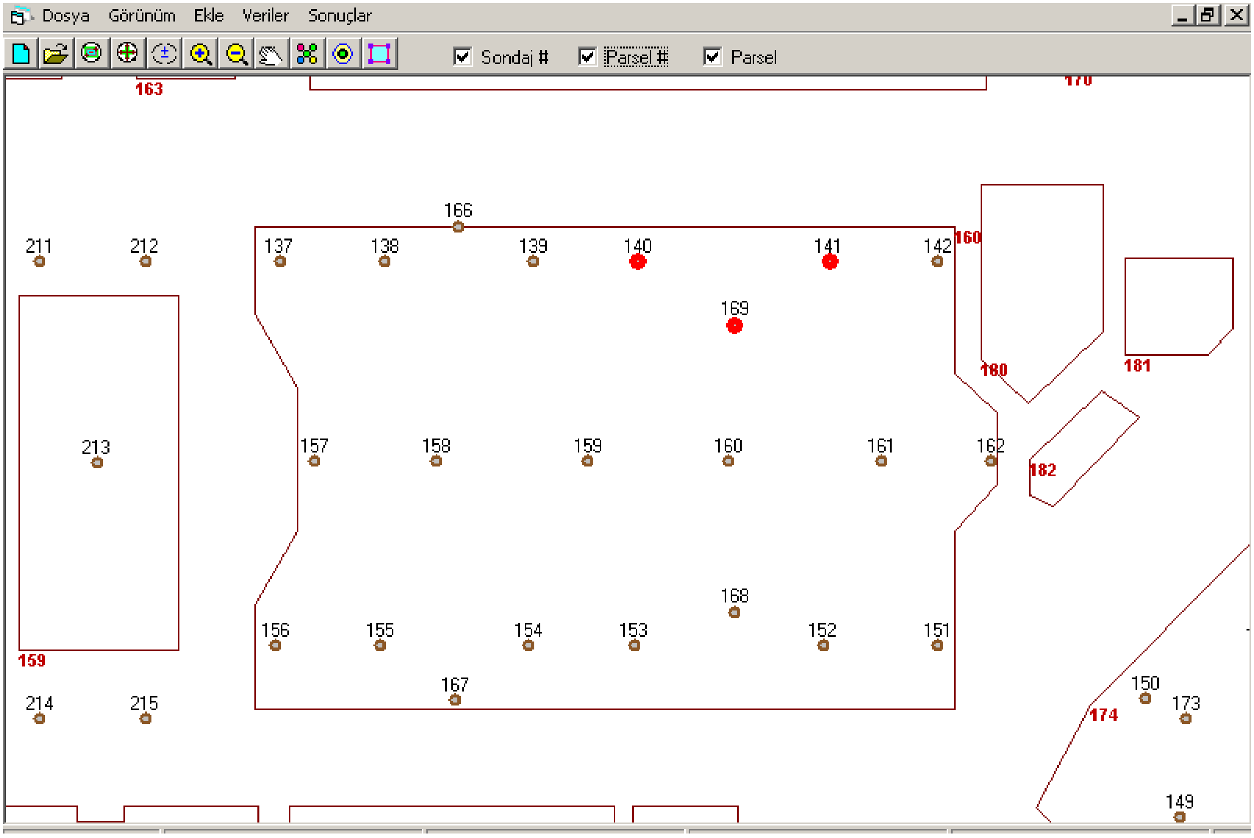
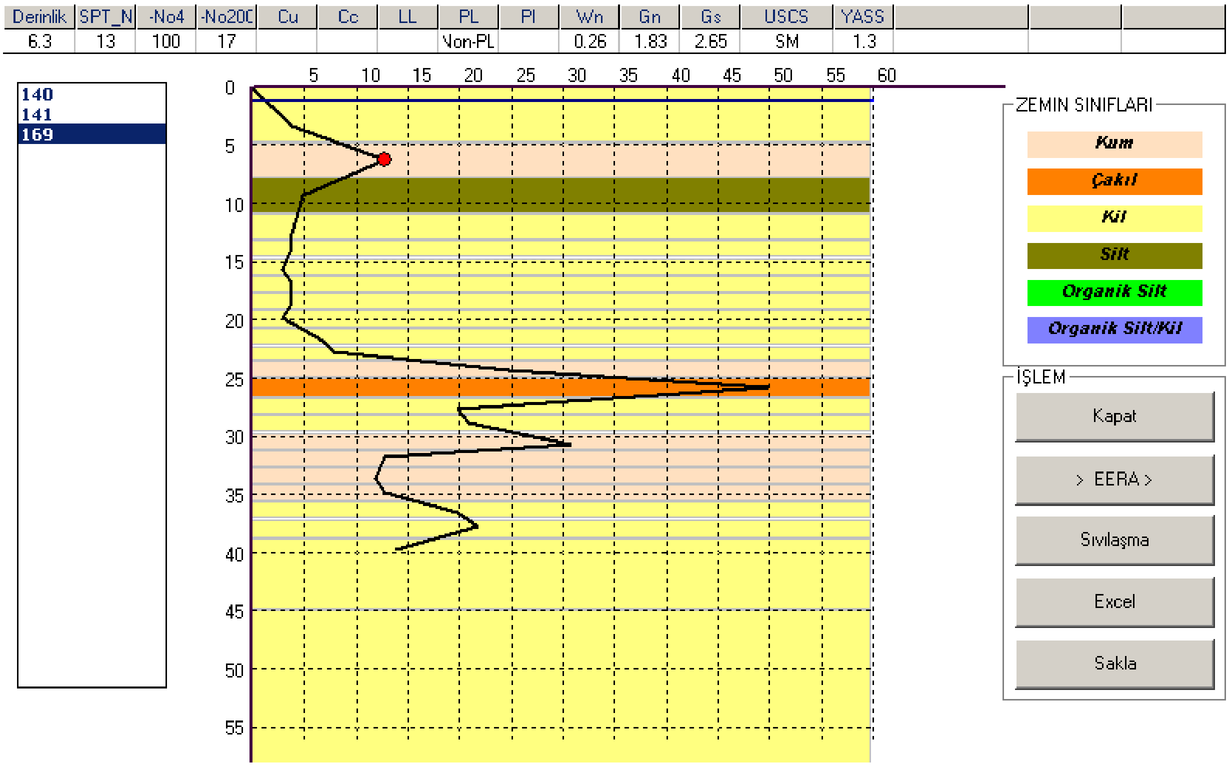
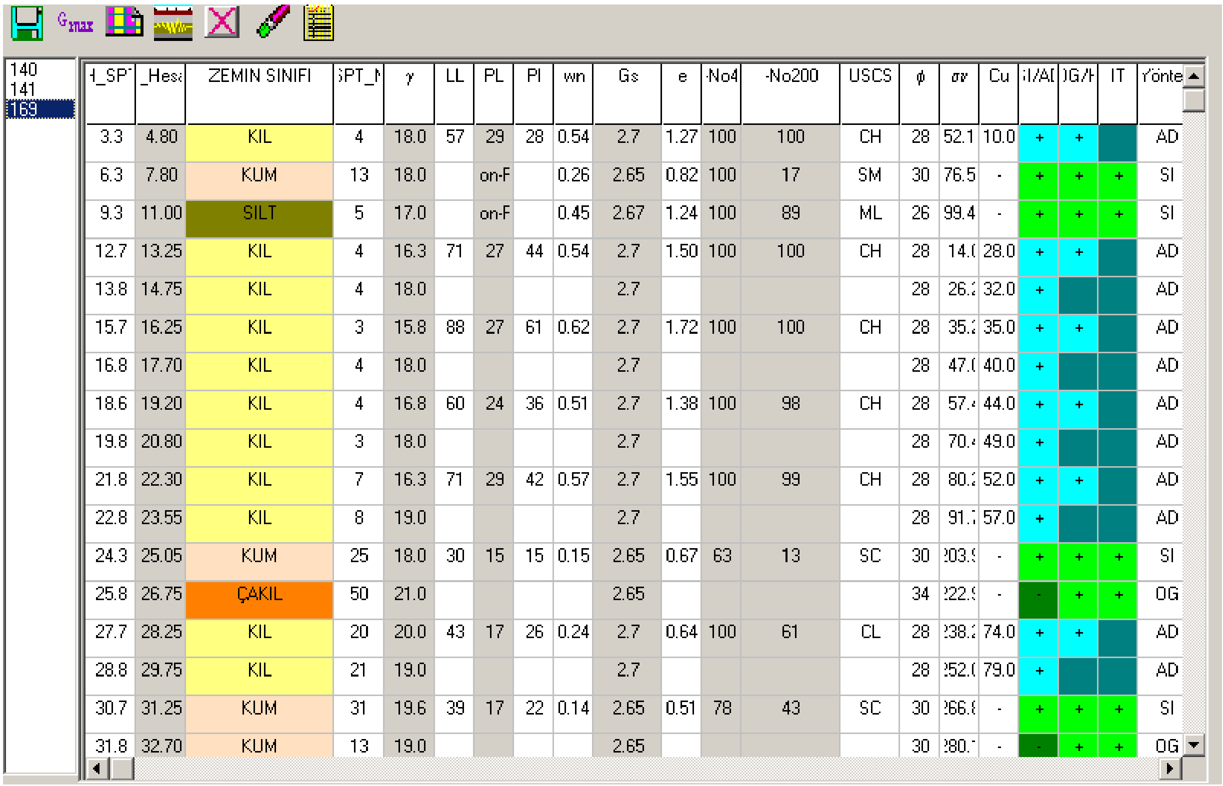


Figure 3. Selection of boring locations in a parcel (DISO 7.0 software)



Derinlik	SPT_N	-No4	-No200	Cu	Cc	LL	PL	PI	Wn	Gn	Gs	USCS	YASS
6.3	13	100	17				Non-PL		0.26	1.83	2.65	SM	1.3

Figure 4. Soil profile of Borehole #169 in Bostanlı-Izmir region (DISO 7.0 software)



I_SPT	_Hesa	ZEMIN SINIFI	SPT_N	γ	LL	PL	PI	wn	Gs	e	-No4	-No200	USCS	φ	σv	Cu	il/AD	OG/H	IT	Yönte
3.3	4.80	KIL	4	18.0	57	29	28	0.54	2.7	1.27	100	100	CH	28	52.1	10.0	+	+		AD
6.3	7.80	KUM	13	18.0		on-F		0.26	2.65	0.82	100	17	SM	30	76.5	-	+	+	+	SI
9.3	11.00	SILT	5	17.0		on-F		0.45	2.67	1.24	100	89	ML	26	99.4	-	+	+	+	SI
12.7	13.25	KIL	4	16.3	71	27	44	0.54	2.7	1.50	100	100	CH	28	14.(	28.0	+	+		AD
13.8	14.75	KIL	4	18.0					2.7					28	26.:	32.0	+			AD
15.7	16.25	KIL	3	15.8	88	27	61	0.62	2.7	1.72	100	100	CH	28	35.:	35.0	+	+		AD
16.8	17.70	KIL	4	18.0					2.7					28	47.(	40.0	+			AD
18.6	19.20	KIL	4	16.8	60	24	36	0.51	2.7	1.38	100	98	CH	28	57.4	44.0	+	+		AD
19.8	20.80	KIL	3	18.0					2.7					28	70.4	49.0	+			AD
21.8	22.30	KIL	7	16.3	71	29	42	0.57	2.7	1.55	100	99	CH	28	80.:	52.0	+	+		AD
22.8	23.55	KIL	8	19.0					2.7					28	91.:	57.0	+			AD
24.3	25.05	KUM	25	18.0	30	15	15	0.15	2.65	0.67	63	13	SC	30	:03.:	-	+	+	+	SI
25.8	26.75	ÇAKIL	50	21.0					2.65					34	:22.:	-	-	+	+	OG
27.7	28.25	KIL	20	20.0	43	17	26	0.24	2.7	0.64	100	61	CL	28	:38.:	74.0	+	+		AD
28.8	29.75	KIL	21	19.0					2.7					28	:52.(	79.0	+			AD
30.7	31.25	KUM	31	19.6	39	17	22	0.14	2.65	0.51	78	43	SC	30	:66.:	-	+	+	+	SI
31.8	32.70	KUM	13	19.0					2.65					30	:80.:	-	-	+	+	OG

Figure 5. Geotechnical data for Borehole #169 in Bostanlı-Izmir region (DISO 7.0 software)

A sample liquefaction analysis for Borehole #169 in Bostanlı-Izmir (Turkey) region was performed using DISO 7.0. Liquefaction potential was determined in sand layers (red color displays that liquefaction may occur in the analyzed depth) of soil profile shown in Figure 6 for M=6.5 earthquake and a_{max}=0.27g. The post-liquefaction settlement within the 20 m depth from ground surface was obtained as 28 cm. Since liquefaction was not estimated to occur below 20m depth, sand layer, having liquefaction potential, between 32.0-35.0 m depths would not be taken into account. Dynamic soil behavior analyses were performed for 238 borehole locations available at constructed database. Then, results of site response and liquefaction analyses were related to the geographic coordinates of borehole locations using GIS software, and contour maps of dynamic parameters were prepared using GIS mapping techniques.

CONCLUSIONS

In this study, a methodology and processing principles of DISO 7.0 computer program has been introduced, and its application to the soils of the northern coast of Izmir Bay (Turkey) area is presented. DISO 7.0 computer program was developed using Visual Basic programming language in order to manipulate large amount of geotechnical data and to prepare a data input file for performing dynamic analyses. DISO 7.0 provides an interface between geographical information system (GIS) and dynamic site response computing domains. The large amount of geological and geotechnical data for soils of the northern coast of Izmir Bay area have been loaded to the constructed dynamic soil database. The city of Izmir, which is one of the greatest cities of the country, has been subjected to moderate scale earthquakes in recent years (1977 Izmir Earthquake, M=5.3; 1992 Doganbey Earthquake, M=6.0; 2003 Urla Earthquake, M=5.6; 2005 Sigacik Bay Earthquakes, M=5.6-5.9; 2005 Uzunkuyu-Urla Earthquake, M=5.9). Acceleration records of these earthquakes occurred in the vicinity of Izmir are loaded to the “Strong Ground Motion” database. DISO 7.0 provides a link between these databases. Dynamic parameters required for equivalent-linear 1-D dynamic site response analyses are calculated using DISO 7.0. Dynamic site response analyses are performed using EERA (Bardet et al., 2000) software, and liquefaction analyses are performed with DISO 7.0 using results of dynamic analyses. The post-liquefaction settlement values are also calculated with DISO 7.0. A sample application of liquefaction analysis is given for the northern coast of Izmir Bay area soils. DISO 7.0 provides also a link between constructed databases and GIS software. Results of site response and liquefaction analyses were related to the geographic coordinates of borehole locations, and contour maps were prepared using GIS software.

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