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IDENTIFICATION OF GEO-HAZARDS FOR THE REHABILITATION PLAN OF YALOVA TURKEY

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ABSTRACT

On August 17th 1999 a major earthquake (7.4M_W) struck the eastern end of the Marmara Sea region causing wide spread devastation. Damage estimates ranged from $10 billion to $40 billion and an estimated 60,000 to 115,000 buildings were destroyed or damaged according to EERI [1]. The majority of the damage was located in the towns of Adapazari, Izmit, Gölcük and Yalova, where over the past twenty or so years there had been a large population increase and hence growth in the residential housing that was so badly affected by the earthquake.

As part of the British government's aid package the British Earthquake Consortium for Turkey (BECT), a group of six UK companies (Arup, Balfour Beatty, Bovis Lend Lease, Hyder Consulting, Laing and Thames Water International) was set up to develop a coherent rehabilitation plan for the Yalova region. In particular, considerable effort concentrated on establishing the principles for safe reconstruction, based on an appraisal of the existing conditions. This paper explores the geo-hazard studies that were carried out as part of the BECT work.

Keywords: Risk; Hazard; Maps; GIS; Geo-hazards; Liquefaction

INTRODUCTION

The major earthquake that struck the Marmara Sea region on August 17th 1999 caused widespread destruction to the built environment, in particular residential properties. The Turkish seismic code [2] has long recognised the potential for major earthquakes in the region though it appears that many structures were inadequate. The damaged properties were generally three to six stories high. They were generally poorly detailed reinforced concrete frame structures with masonry infill panels, they often had open ground floors and were badly constructed. Furthermore they rarely benefited from adequate foundations and in addition were sited on loose sand or poorly compacted fill. All these factors contributed to the high level of destruction observed.

Arup formed part of the British Earthquake Consortium for Turkey (BECT) which undertook a study to identify and present seismic hazards and risks for the Yalova Province, an area in north-west Turkey, which was damaged by the earthquake. The project included zoning the study area in order to provide advice to planners as to where to site future developments. The study covered an area of approximately 450km^2 and was centred on the city of Yalova. The population of the study area (1997 census) was 135,720 and the largest urban areas are Yalova and Çinarcik with a population of over 78,000 and 12,500 respectively.

The specific aim of the project that will be explored in this paper is bringing together an awareness of seismic and geological hazards with the need for planners to redevelop in areas where social benefits are highest. This was done in terms of increased redevelopment cost mapping with an aim of providing life safety performance in future seismic events.

GEO-HAZARDS

The backbone of the study was a detailed physical and spatial understanding of the local seismicity and geology, which allowed us to address each geo-hazard. These are discussed in the following sections. In addition one of the authors of this report was involved the Earthquake Engineering Field Investigation Team (EEFIT) field mission to the region immediately following the August 1999 Eastern Marmara earthquake. The EEFIT group visited Yalova Province, along with other heavily damaged areas.

Geology

The geological information was based upon a detailed review of existing geological maps and literature on the Northern Anatolia, Yalova and Sea of Marmara regions. Geomorphological information in the form of 1:25,000 scale topographic maps, stereo aerial photography and satellite imagery taken after the earthquake, were examined and evaluated. The most recent geological maps published by the General Directorate of Mineral Research and Exploration (MTA) in 1999 were obtained in digital format. These digital maps were used as a base to develop a geology map for the study area and a series of geo-hazard maps in a GIS framework. The maps were augmented with the most recent geological mapping of the Quaternary boundaries carried out following the earthquake of August 1999.

Field reconnaissance was required to confirm the geological boundaries and materials present within the study area. Two experienced engineering geologists and an engineering seismologist undertook the reconnaissance over a two week period in April 2000. The field reconnaissance confirmed that the geological boundaries mapped by MTA were substantially correct. Although no new site investigation data were collected, schematic geological sections have been developed from field mapping to illustrate stratigraphic relationships and geological hazards. Geological materials were examined to confirm their seismic engineering properties. The frequent and different types of landslide across the study area were also investigated using aerial photography interpretation, satellite imagery interpretation and field reconnaissance, hence strategies for stabilisation were developed.

In order to provide up-to-date detail of the ground, topography and land-use, IKONOS satellite imagery, recorded in April 2000, was obtained for approximately 800 km^2 of the study area. IKONOS satellite imagery is the highest resolution satellite optical data that was available commercially. A typical image is shown in Figure 1 showing earthquake induced landslides on the hilltops above Yalova and a chemical facility on the coast. Using these data, digital maps of the various geo-hazards could be developed.

Ground shaking

The study of earthquake hazards has been based upon a detailed review of the Turkish Seismic Code [2] and the available literature relating to the tectonics and seismology of the Sea of Marmara region [3, 4]. The earthquakes in the Marmara Sea region are associated with the North Anatolian Fault Zone. Several authors, most recently Stein *et al* [5] and

Nalbant *et al* [6] have postulated that movement on the North Anatolian Fault Zone could be characterised by periodic earthquake sequences that migrate along its length. Each sequence of earthquakes is hypothesised to allow the entire North Anatolian Fault Zone to slip.

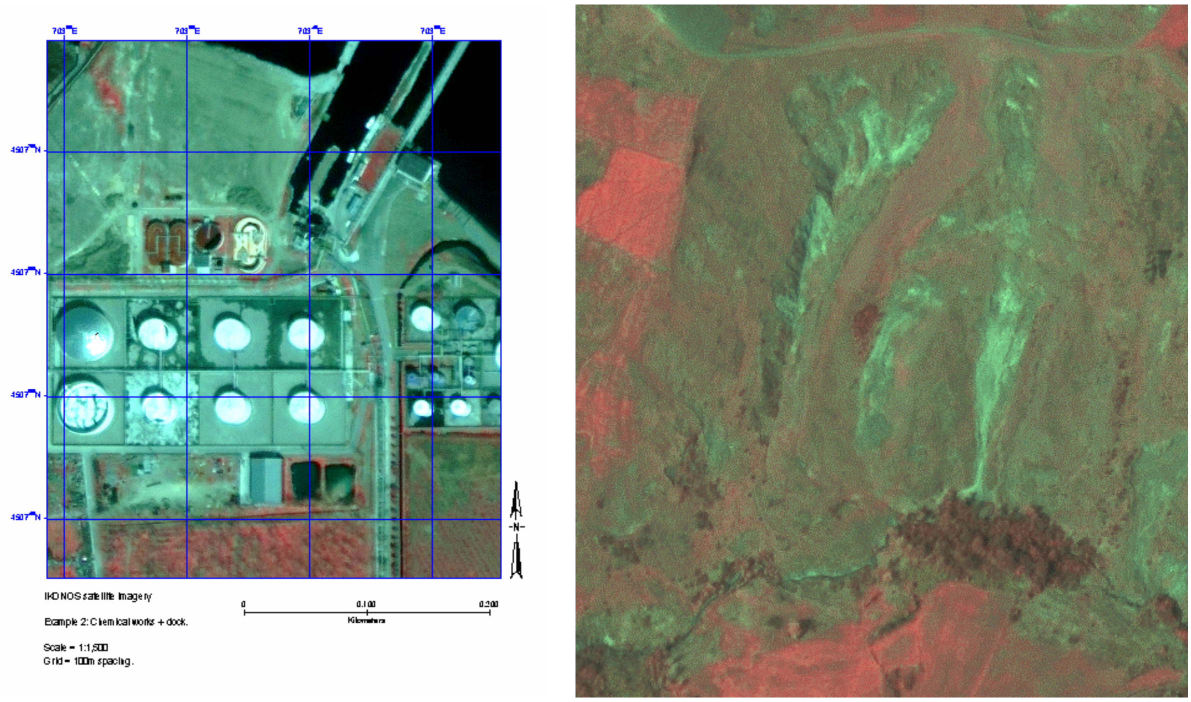

Figure 1: IKONOS examples (© Space Imaging LLC)

Parsons *et al*. [7] have also carried out an assessment of the tectonic stresses in the Marmara Sea region using the concept of earthquake interaction, in which fault rupture and the associated stress release results in the increase in stress and triggering of rupture on adjacent faults. They propose that the Eastern Marmara earthquake will have increased the stress at the eastern and western ends of the faults. It is hypothesised that this mechanism triggered the November 1999 Düzce event at the eastern end of the Izmit Fault. Clusters of aftershocks at the western end of the Izmit Fault near Yalova, Çinarcik and south of the Prince's Islands are interpreted to indicate an increase in stress in these areas.

Parsons *et al*. [7] have utilised the fault recurrence and earthquake interaction assessments to estimate the probability of an earthquake occurring on three of the major faults which could significantly affect the Yalova Province; the Yalova Fault, the Prince's Islands Fault and the Central Marmara Fault. Their results are summarised in the Table 1.

TABLE 1

EARTHQUAKE PROBABILITIES FOR FAULTS IN THE MARMARA SEA REGION

Fault	Probability of fault rupture (%)			Maximum Magnitude (M_W)
	30 year	10 year	1 year	
Yalova Fault	33±21	14±11	1.7±1.7	7.4
Prince's Island Fault	35±15	16±9	2.1±1.6	7.2
Central Marmara Fault	13±9	5±5	0.6±0.7	7.2
Combined	62±15	32±12	4.4±2.4	7.8

Table 1 also shows the approximate maximum magnitude for each fault. This was calculated by assuming a rupture area along the entire fault segment and applying the Wells and Coppersmith [8] relationship for strike-slip faults given in Eqn 1 below.

$$M_W = 3.98 + 1.02 \log (Rupture\ Area) \tag{1}$$

As part of this study, therefore, the ground shaking due to a 7.4M_W earthquake on the Yalova segment of the North Anatolian Fault Zone has been used. The peak ground acceleration (PGA) is compared in Figure 2 with the Effective Ground Acceleration Coefficient (A_0) given in the Turkish Seismic Code [2]. The value of A_0 for Yalova is 0.4g. Figure 2 shows that the value of bedrock PGA may be significantly greater than the currently specified EPA value within about 10km of the Yalova segment of the North Anatolian Fault Zone. Therefore, the seismic design forces for 1 to 3 storey structures may be increased by the amount indicated in Figure 2. It is also interesting to note in Figure 2 that the use of near fault factors given in the Uniform Building Code [9] would more closely represent the postulated bedrock PGA from the assumed 7.4M_W earthquake. It was also estimated that the seismic design forces for taller, longer period structures could exceed the current specification up to about 15km from the Yalova segment of the North Anatolian Fault Zone.

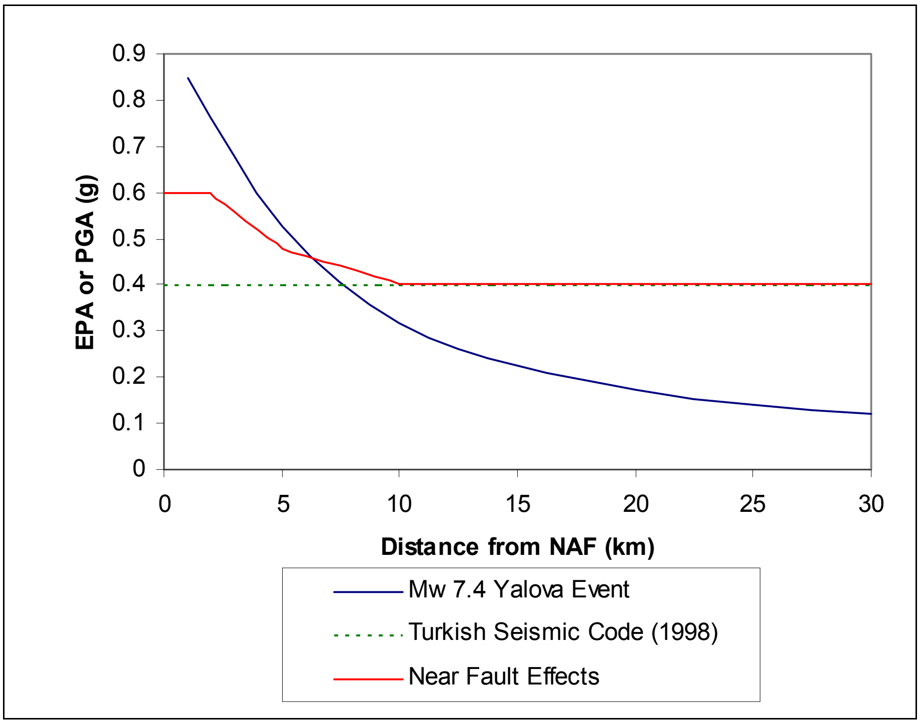

Figure 2: Comparison of acceleration with distance from Yalova segment of North Anatolian Fault for the Turkish code and the postulated magnitude 7.4M_W event

These conclusions are only indicative and may be influenced by a number of factors including: soil type and depth; spatial variability in ground motion; and onset of liquefaction. These effects would need to be addressed when defining the seismic design forces for a specific project.

Local site class map

The geological review of the area classified the geological units into local site classes (Z1, Z2, Z3 and Z4) as shown in the Local Site Class Map (Figure 3). This information provides a summary of the ground conditions in the Yalova Province in terms of the parameters that are required for determination of design seismic loads in accordance with Turkish Seismic Code [2]. All the superficial geology were considered to be either site class Z3 or Z4, whilst the solid geology was considered to be site class Z2 or Z1.

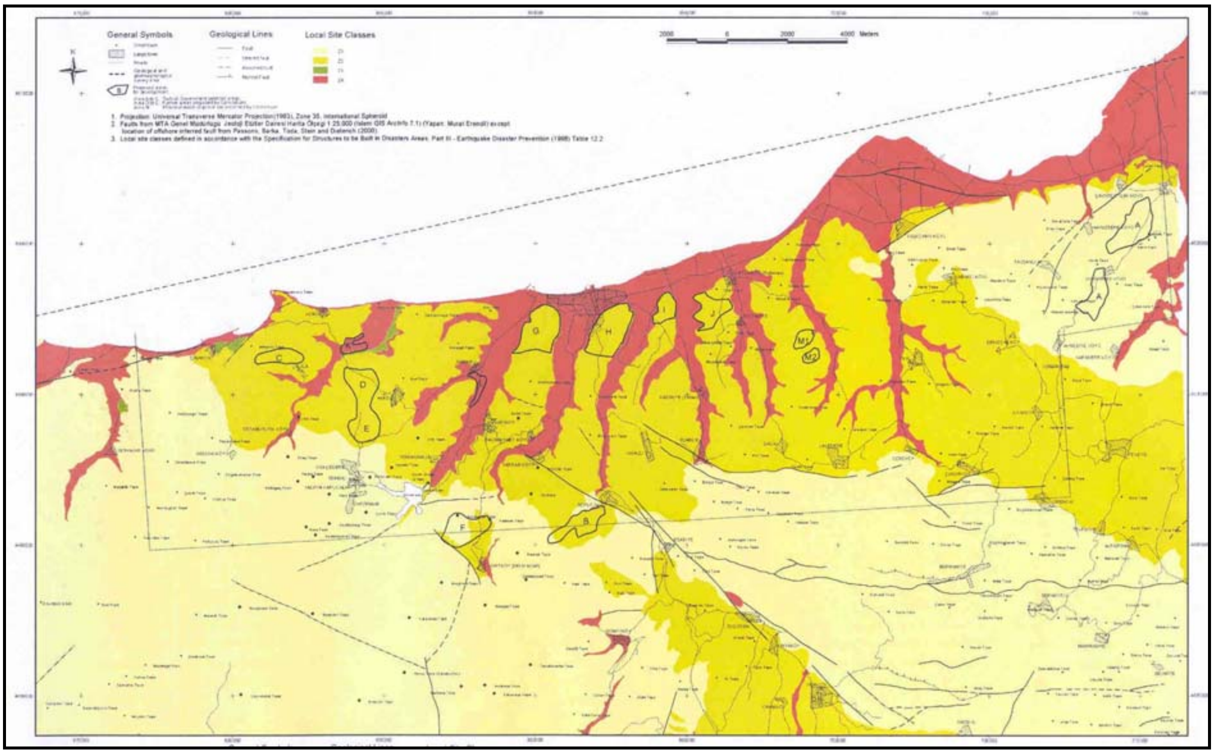

Figure 3: Local Site Class Map

It should be emphasised that the site-specific local site class determined during a site investigation for a project may differ from those shown on the Local Site Class Map. Because of the general nature of this map and the detailed nature of the site specific ground investigation, the findings of any site specific ground investigation should always take precedence. The more accurately determined local site class could then be used in the determination of the design spectrum following the methodology described above.

Liquefaction

The classification of geological units for liquefaction susceptibility was carried out using the Youd and Perkins [10] recommendations and hence used to produce the Liquefaction Susceptibility Map shown in Figure 4. This subdivided the area into six zones: very high, high, moderate, low, very low and none.

Figure 4 shows that the highest risk is in the recent superficial Quaternary deposits, such as beach, coastal, delta, levee and flood plane deposits, whilst the lowest risk is in older Quaternary deposits (e.g. upper and lower terrace deposits) and the solid geology inland.

It should be noted that site investigation information is required to clarify and confirm the liquefaction susceptibility for a number of the geological units.

Landslide

New landslides and evidence of earlier slope instability were identified both in the field, on aerial photographs and IKONOS satellite images and then classified and plotted onto overlays to the topographical maps at 1:25,000 scale. From these analyses, the Landslide

Hazard Map (Figure 5) has been produced, based on a combination of the following criteria:

- presence or absence of landslide features, old or recent;
- type of slope failure, shallow or deep-seated
- density of distribution of landslides
- geological formation
- general slope angle

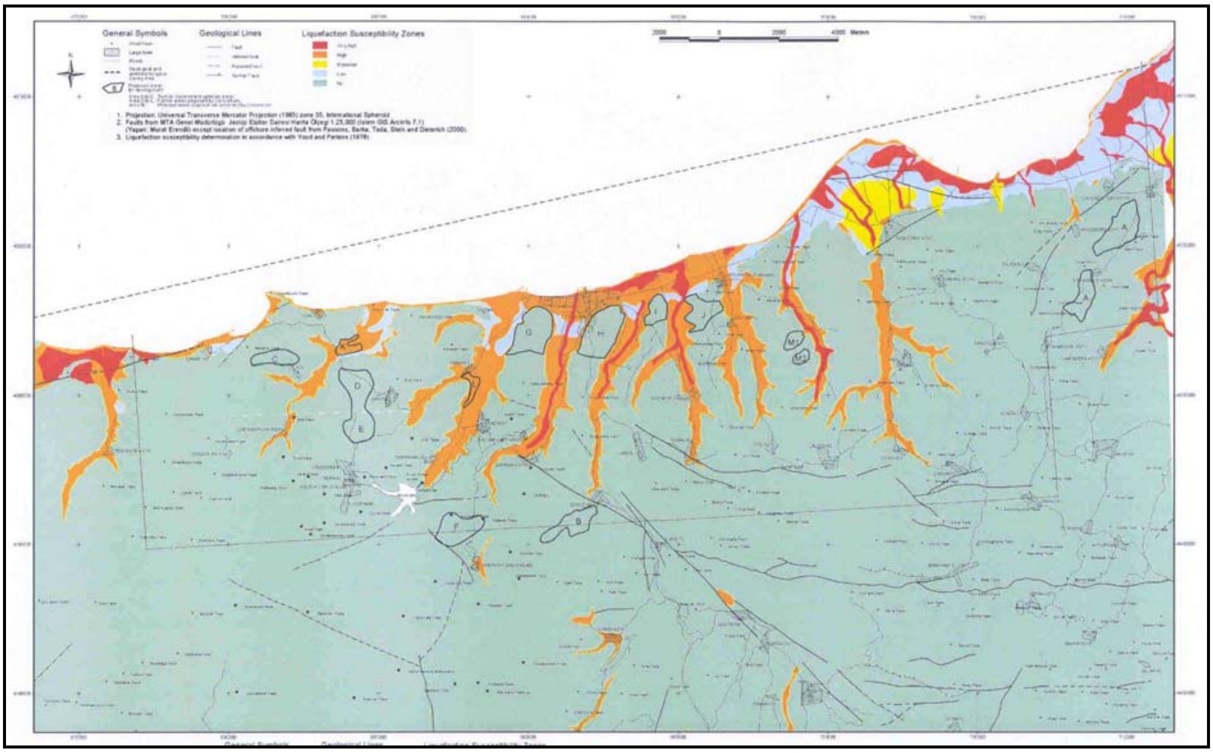

Figure 4: Liquefaction Susceptibility Map

The Landslide Hazard Map has been zoned according to the following four hazard classes (nil, low, moderate and high).

The Quaternary marine and alluvial deposits are flat, apart from low steps or banks at the edge of terraces, hence no slope instability was observed.

The low hazard landslide zone is designated wherever no landslides or only isolated shallow landslide features have been identified.

The moderate hazard landslide zone has only shallow landslide features widely dispersed on moderate to steep slopes of all rock formations.

The high hazard landslide zones have deep-seated rotational and/or a high frequency of shallow landslides on moderate to steep slopes of the inland mountain range. It also includes steep coastal locations subject to wave erosion and moderate to steep slopes of the Kiliç formation where there are fossil rotational landslide forms resulting from past river and coastal erosion when sea levels were higher.

This assessment of landslide hazard is a qualitative assessment based on observation of past and recent slope instability landforms. Analysis by slope angle from the topographic maps contours was not carried out, because digital topographic information was not available at the time of the study and the digitisation of existing hard copy topographic maps was not feasible due to financial and time constraints. For all new developments, the stability of slopes in the vicinity should be assessed.

It should be noted that the Landslide Hazard Map does not include liquefaction-induced lateral spreading. The likelihood for liquefaction-induced lateral spreading may be deduced from the Liquefaction Susceptibility Map (Figure 4).

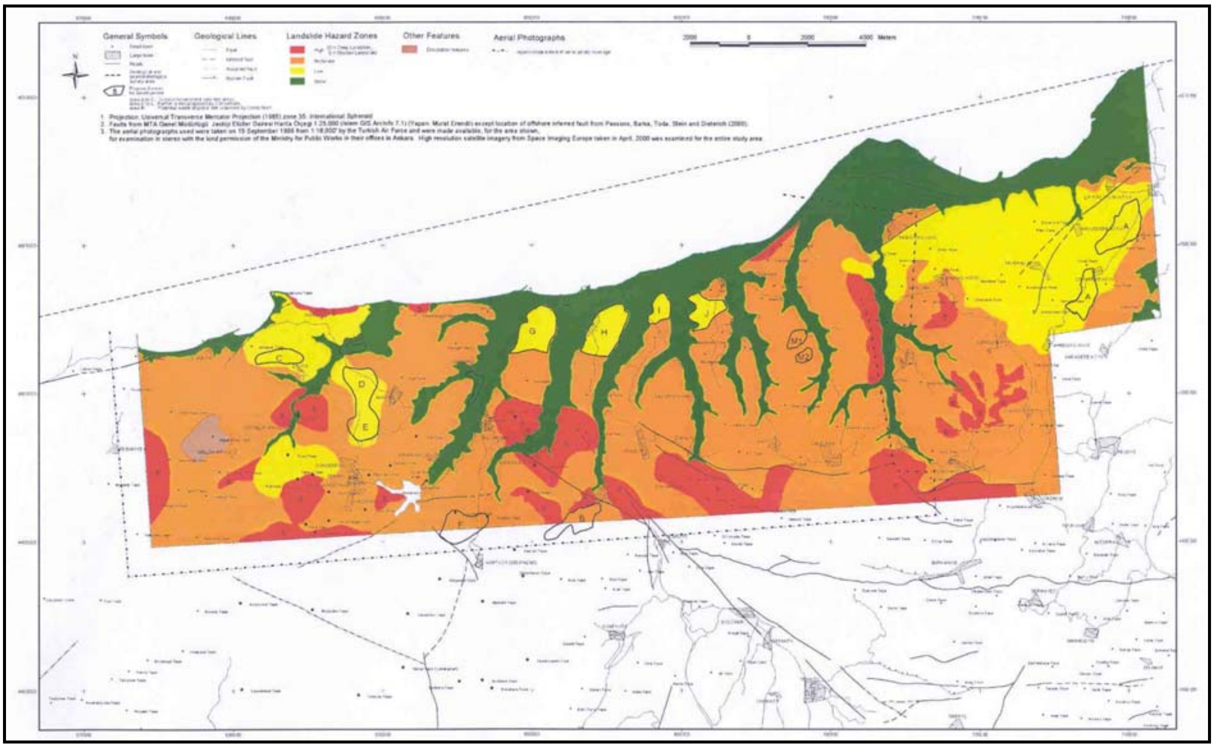

Figure 5: Landslide Hazard Map

RISK MAPPING

The geological, geomorphological and seismic hazards that exist in Yalova Province have been described in previous sections and the level of hazard presented in three maps,

- Local Site Class Map
- Liquefaction Susceptibility Map
- Landslide Hazard Map

When considering the location and design of new structures, these maps can be used to gain an understanding of the severity of each hazard in an area and to design measures to reduce vulnerability and to mitigate the risk. However, due to the nature of the maps, they should not be used for site-specific design. A site investigation and an assessment of all the hazards and should be carried out for each site prior to development.

Whilst it is important to consider each hazard individually for each site or project, it is useful for development planning, to consider them in combination and to assess the overall risk. In order to assist this planning process, an Additional Costs Map (Figure 6) for 3-6 storey structures has been produced, based on the following analysis:

Using the design response spectra, the vulnerabilities of structures built in accordance with the Turkish Seismic Code [2] of 1-2, 3-6 and >6 storeys have been assessed.

The three hazard maps, together with the ground shaking hazard, have been combined with the vulnerabilities, in order to assess the risk to different height structures to damage from a major earthquake for the Yalova Province.

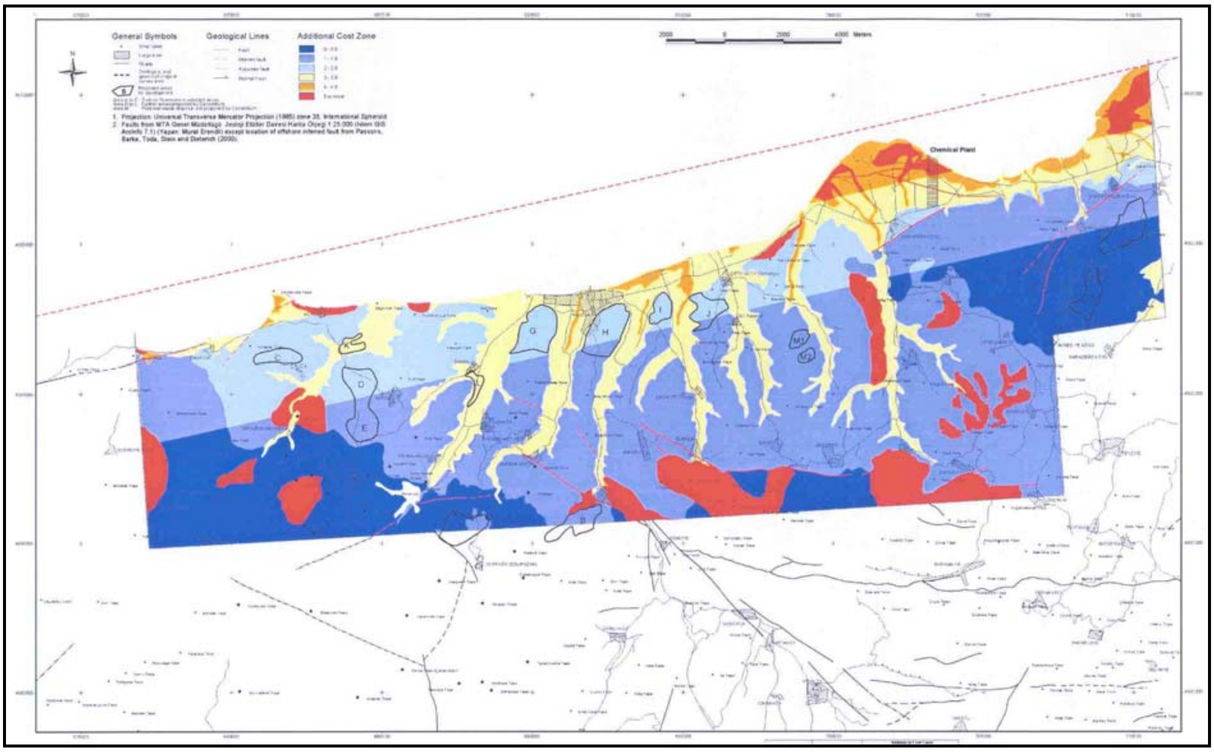

Figure 6: Additional Cost Summary Map

The risk has been presented as additional costs for both foundations and superstructure above a reference level, as shown in Table 2. The table uses a scale of "increase in costs", where the reference level is for a site on flat ground underlain by hard soil or rock and the structure designed and built in accordance with the Turkish Seismic Code [2]:

0 = reference level
1 = low
2 = moderate
3 = high
4 = very high
5 = extremely high

Level 5 has been applied to hazards that are considered unacceptable and should therefore be avoided, such as deep landslides or the zone within 20m of an active fault. Cost increases are based on the need for increased design, site investigation, construction and construction control and are only intended to be indicative.

The additional costs for foundations and superstructure have been combined, assuming that the foundations costs (including site investigation) is approximately 25% of the total design and construction costs.

In addition to the hazards presented in Table 2, there are some specific hazardous facilities such as the dam and industrial facilities, which should be taken into consideration in the development planning process. These have not been included in the zonation of the Additional Costs Map, but have been indicated on the map.

TABLE 2
INCREASE IN FOUNDATION AND SUPERSTRUCTURE COSTS

Hazard	Hazard level	1 to 2 storey		3 to 6 storey		> 6 storey	
		Fo.	Su.	Fo.	Su.	Fo.	Su.
Ground motion	Z1	0	0	0	0	0	0
	Z2	0	0	1	1	1	1
	Z3	1	0	2	1	3	2
	Z4	2	0	3	1	4	2
Liquefaction	Normal	0	0	0	0	0	0
	Low	1	1	1	1	1	1
	Moderate	2	1	2	1	2	1
	High	3	1	3	1	3	1
	Very High	4	1	4	1	4	1
Landslide	None	0	0	0	0	0	0
	Low	1	0	1	0	1	0
	Moderate	2	0	2	0	2	0
	High (shallow)	3	0	3	0	3	0
	High (deep and shallow)	5	1	5	1	5	1
Proximity to fault	<0.02km	5	5	5	5	5	5
	<2km	1	1	1	2	1	2
	<5km	0	0	0	1	0	1
	<10km	0	0	0	0	0	0

CONCLUSIONS

The main conclusions from the study of ground-related hazards can be summarised as follows.

- The entire Yalova Province is prone to large earthquakes and it has been postulated that there is about a 60% probability of a major earthquake affecting the region in the next 30 years.
- Within about 10km of the Yalova segment of the North Anatolian Fault the ground motions are predicted to exceed those given in the Turkish Seismic Code [2] (see Figure 2). Use of Uniform Building Code [9] near fault factors could overcome this difference.
- Site response effects will be more important for any structure greater than about 3 storeys in height, sited on Quaternary deposits (Z4).
- Liquefaction and associated effects are likely to occur on recent Quaternary sand and silt deposits and areas of fill with a high water table. Hence river valleys and coastal plains are particularly susceptible. Coastal areas are particularly vulnerable to lateral spreading of near shore deposits.
- New structures should avoid active fault zones. Fault protection boundaries should be established for guidance and the width of these boundaries should be defined based on fault zone width data measured in the region.
- Ground levels below +2.5mMSL along the coastline may be prone to inundation due to tsunamis.
- In areas prone to shallow landslides, structures will be vulnerable to damage; slope

stabilisation measures and / or foundations constructed beneath the slip plane will be required.

- In areas prone to deep landslides, there is a very high risk of structural damage. Where possible, these areas should be avoided for new developments.
- With a proper appreciation of these earthquake hazards, all new structures can be designed to mitigate or avoid their effects. However, there may be an associated increase in costs.

The study demonstrated that based on reasonably accessible data that an awareness of the principal hazards coupled with modern GIS techniques could lead to a zonation plan to assist reconstruction of the Yalova Province.

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REFERENCES
1. EERI. Kocaeli, Turkey, Earthquake of August 17, 1999 Reconnaissance Report, Earthquake Spectra 2000; Supplement A to Volume 16.
2. Specification for Structures to be Built in Disaster Areas, Part III – Earthquake Disaster Prevention. Ministry of Public Works and Settlement, Government of Republic of Turkey, 1998.
3. Wong, H.K., Ludmann, T., Ulug, A. and Gorur, N. The Sea of Marmara: a plate boundary sea in an escape tectonic regime. Tectonophysics 1995; 244: 231-250.
4. Barka, A. and Kadinsky-Cade, K. Strike-slip fault geometry in Turkey and its influence on earthquake activity. Tectonics 1988; 7(3): 663-684.
5. Stein, R.S.A., Barka, A. and Dietrich, J.H. Progressive failure of the North Anatolian fault since 1939 by earthquake stress triggering. Geophysical Journal International 1997; 128: 594-604.
6. Nalbant, S.S., Hubert, A., and King, G.C.P. Stress coupling between earthquakes in Northwest Turkey and the north Aegean Sea, Journal of Geophysical Research 1998; 103: 24469-24486.
7. Parsons, T., Toda, S., Stein, R., Barka, A. and Dieterich, J.H. Heightened Odds of Large Earthquakes near Istanbul: An Interaction-based Probability Calculation, Science 2000; 288.
8. Wells, D.L. and Coppersmith, K.J. New Empirical Relationships Among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement. Bulletin of the Seismological Society of America 1994; 84(4): 974-1002.
9. Uniform Building Code, Volume 2, Chapter 16, Division IV: Earthquake Design, International Conference of Building Officials, Whittier, California, 1997.
10. Youd, T.L. and Perkins, D.M. (1978). Mapping of liquefaction-induced ground failure potential. Journal of the Geotechnical Engineering Division, American Society of Civil Engineers 1978; 104(4): 433-446.