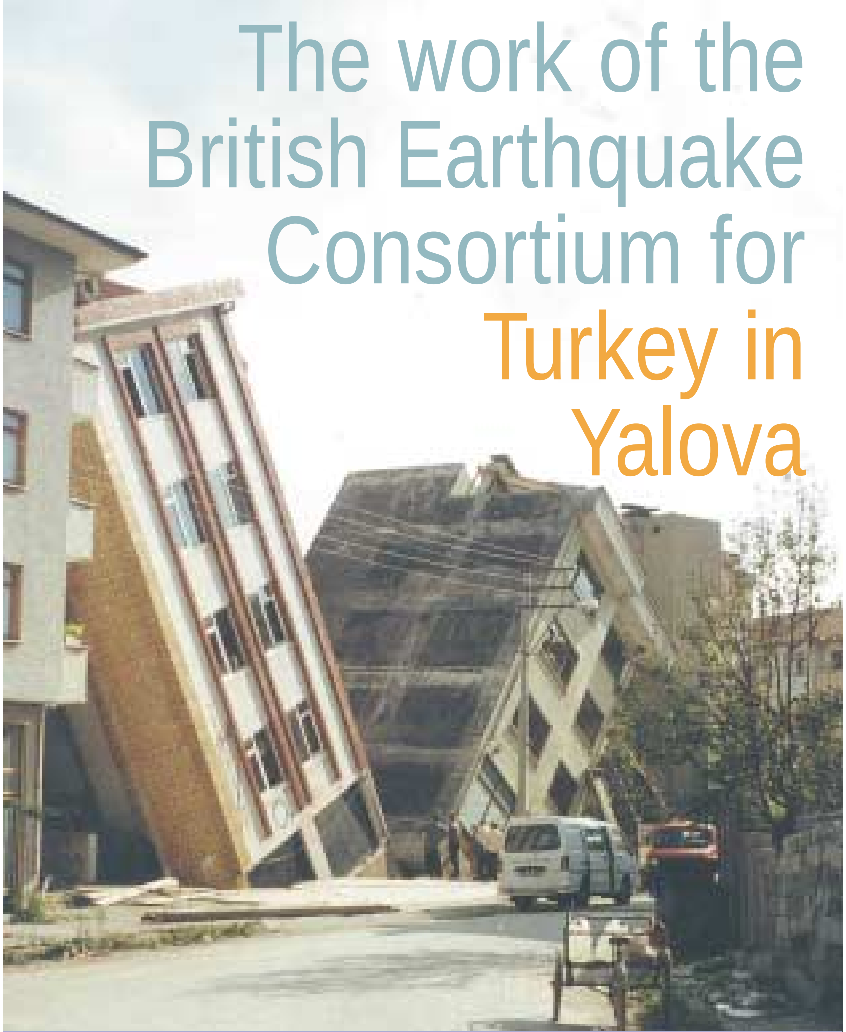
The work of the British Earthquake Consortium for Turkey in Yalova



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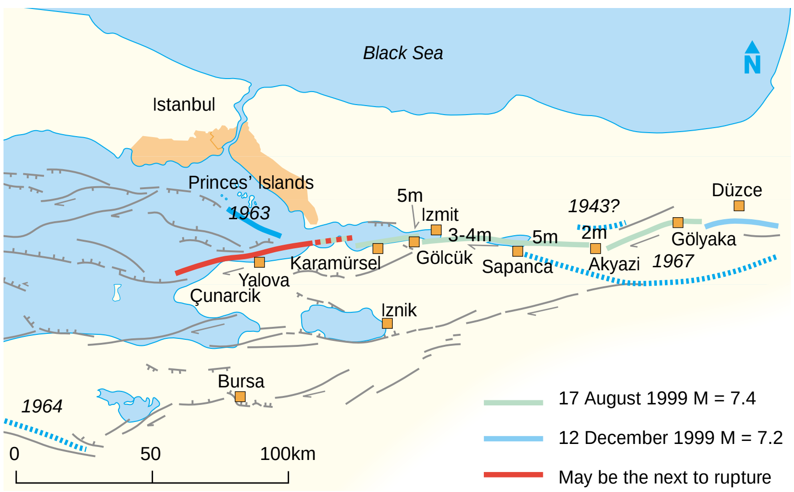
Introduction

At 03.02 on 17 August 1999, a large area around Izmit in Turkey (Fig 1) was hit by a devastating 7.4Mw magnitude earthquake, resulting in the deaths of more than 16 000 people with 44 000 injured. At least 80 000 buildings were destroyed - factories, offices and homes (Fig 2). The UK Minister of State for Construction, Nick Raynsford, visited Turkey the following month and, alongside help from other governments, immediately offered British assistance to help rebuild devastated areas.



1.
Location of Yalova, showing recent and postulated fault ruptures. Dates are year in which fault segment ruptured.

2 top:
Typical damage.

The British Earthquake Consortium for Turkey (BECT) was one result, formed from six major British construction companies with significant interests in Turkey - Balfour Beatty, Bovis Lend-Lease, Laing, Thames Water, Hyder Consulting, and Arup. Funding came from the individual companies and the British government Department of the Environment, Transport and the Regions (DETR). The aims were simple: to provide improved planning procedures to choose areas less vulnerable to earthquakes for new building; to ensure that new buildings were designed to resist earthquakes; and to identify projects that could revitalise the area. The most depressing lesson learnt from the earthquake was that most of those killed would have survived if their buildings had incorporated standard features already required in the Turkish structural design codes to ensure life safety in earthquakes.

After discussions between the British and Turkish governments, the Province of Yalova, on the southern shore of the Sea of Marmara facing Istanbul, was selected as being most likely to benefit from BECT's help. Although it had suffered greatly with 2505 deaths and 6000 injured, comparatively little international assistance had been directed towards it because it wasn't industrial. Yalova is a small city of about 100 000 in winter and up to 400 000 in summer. The overall population of the province is thought to range from some 200 000 in winter to more than 1.1M in summer when the earthquake struck.

On 10 February 2000 the two governments signed the protocol establishing BECT, and five days later the first study group arrived for a fact-finding mission to Yalova and to visit the relevant Ministries in Ankara. BECT's initiative had four strands:

- to understand the geomorphological and seismic risks in potential development areas so that reconstruction could occur safely
- to produce a development framework which would lead to a reconstruction implementation plan, identifying projects to revitalise the area and provide opportunities for homeless and other displaced people
- to propose a plan to rehabilitate utilities, particularly water supply and wastewater treatment that had been badly damaged in the earthquake; later, treatment of solid waste was also identified as a priority
- to devise funding mechanisms so that priority projects identified in the studies could proceed without direct government subvention.

Leadership of the strands was allocated according to the six companies' perceived strengths. Balfour Beatty provided overall project direction, Arup led the ground engineering, Hyder dealt with planning, Thames Water looked after utilities, and Balfour Beatty supplied expertise in funding. Bovis supported Hyder's planning team and Laing supported Thames Water on utilities.

Nature of damage

The Turkish seismic code had long recognised the potential for major earthquakes in this locality, but many structures - generally 3-6 storey residential buildings - were inadequately designed to resist seismic loading. They were usually poorly detailed reinforced concrete frame structures with masonry infill panels, often with open ground floors, and badly built. They rarely had adequate foundations and in addition were sited on geologically recent soils such as soft clay, loose sand, or poorly compacted fill. Many of the damaged properties were relatively modern, built as part of the rapid development of the area over the last 20 years. All these factors contributed to the high level of destruction.

Maps, photos, and satellite images

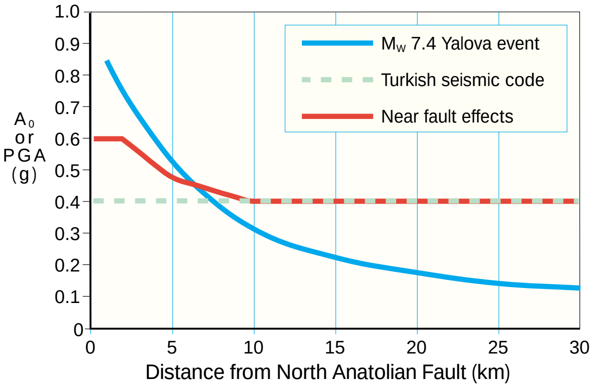
A major problem with hazard mapping in developing countries is lack of reliable maps; for security reasons maps and aerial photographs are difficult to obtain in Turkey. Some 1:25 000 maps from 1974 gave useful coverage but didn't show the most recent occupation and development. Aerial photos of the affected areas taken by the Turkish air force immediately after the disaster had been promised to the study team, but declassifying them took longer than expected and it wasn't clear if they would be available in time. The study needed current images of the area for geohazard mapping and for assessing the extent of development, so a decision was taken to buy satellite imagery.

3.
(left and right)
IKONOS examples.

Table 1

Earthquake probabilities for faults in the Marmara Sea region

Fault	*Probability of fault rupture (%)* 30 year	10 year	1 year	*Maximum magnitude (MW)*
Yalova Fault	33±21	14±11	1.7±1.7	7.4
Princes' 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



4.
Comparison of acceleration with distance from Yalova segment of NAF for the Turkish code and the postulated magnitude 7.4MW event.

Resolution has improved over the last five years and with the launch in September 1999 of the Ikonos 2 satellite with a resolution of 0.82m, a new tool was available[1]. Arup became the first UK company to order Ikonos imagery with its request for an image of 650km^2, containing 4.7GB of data across five spectral ranges. This allowed different types of terrain to be differentiated, and land scarred by the earthquake and by landslipping clearly identified. Unfortunately the satellite's stereo capability was not available at the time of the study, so when the air photos became available towards the end of the study period, they still provided useful additional data.

Design for hazards

A novel feature of BECT was that it involved ground specialists and town planners working together to choose locations with least risk for new development. Previously, the particular hazards relating to unstable ground and earthquakes were poorly understood but nonetheless influential in siting replacement buildings. Two principal hazards preoccupied local planners: design against earthquake risk, and how to avoid areas prone to landsliding, as the earthquake had triggered literally thousands of landslides across the province. However, the two hazards had very different consequences. It is thought that no deaths were attributable to landsliding; virtually all were due to building failures - a sad indictment on local building practices. An aim of the study was to provide a rational basis for ranking different areas according to the severity of the hazards faced. These are discussed in the following sections.

Geology

The most recent geological maps published by the General Directorate of Mineral Research and Exploration (MTA) in 1999 were obtained in digital format, and used as a base to develop a geology map for the study area and a series of geo-hazard maps in a Geographical Information System (GIS) framework. The maps were augmented with the most recent geological mapping of the Quaternary alluvial deposits after the August 1999 earthquake.

The geological boundaries and materials present in the study area had to be confirmed, so two experienced engineering geologists and an engineering seismologist from Arup made a two-week field reconnaissance in April 2000. This confirmed the accuracy of MTA's geological maps; geological materials were examined to confirm their engineering properties. The frequency of different types of landslide across the study area was also investigated using aerial photography interpretation, satellite imagery interpretation, and field reconnaissance, so that strategies for stabilisation could be developed.

Fig 3 shows typical Ikonos images: 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 was based on a detailed review of the Turkish seismic code and available literature on the tectonics and seismology of the Sea of Marmara region, where the earthquakes are associated with the North Anatolian Fault (NAF) Zone. Most researchers agree that movement on the NAF Zone can be characterised by periodic earthquake sequences migrating along its length, and that each sequence allows the entire NAF Zone to slip. Each earthquake represents slip along an individual fault segment within the NAF Zone.

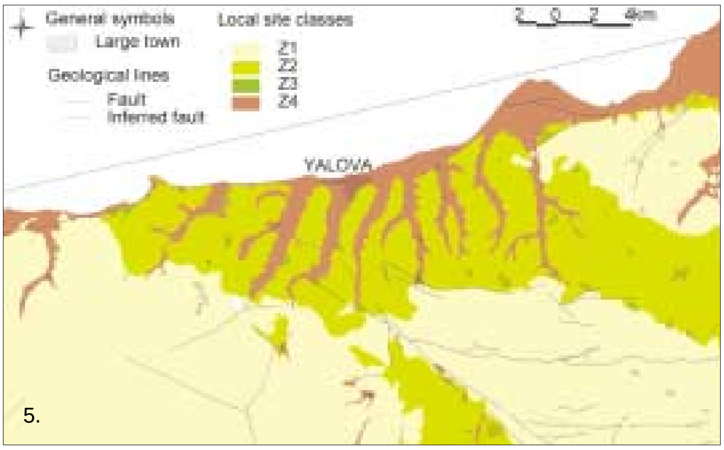
Assessing the tectonic stresses in the Marmara Sea region using the 'earthquake interaction' concept indicates that the August 1999 earthquake increased stresses at the eastern and western ends of the Izmit Fault segment of the NAF. Recent seismological studies have hypothesised that this mechanism triggered the later event of November 1999 centred around Düzce at the eastern end of the Izmit Fault, while clusters of aftershocks at its western end near Yalova, Çinarcik, and south of Princes' Islands in the Sea of Marmara were interpreted to indicate an increase in stress in these areas. This assessment estimated the probability of an earthquake on three of the major fault segments that could significantly affect Yalova Province: the Yalova Fault, the Princes' Islands Fault, and the Central Marmara Fault (Table 1). All would be much closer to Yalova than the August 1999 event, and so could affect it much more severely.

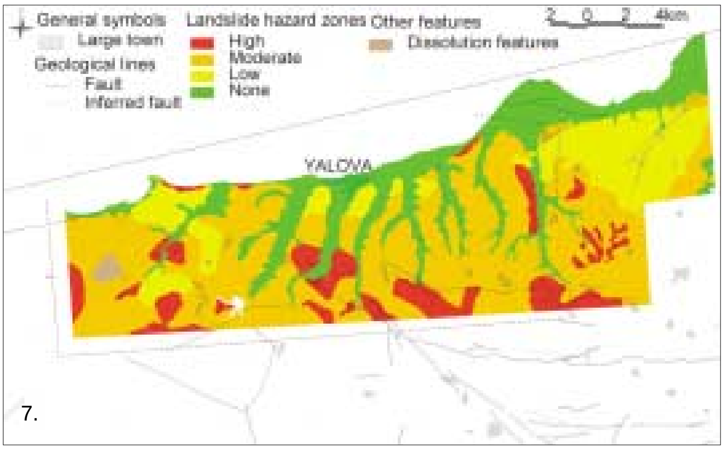
As part of this study, ground shaking due to a 7.4MW earthquake on the Yalova Fault segment of the NAF Zone was assessed. The peak ground acceleration (PGA) is compared in Fig 4 with the Effective Ground Acceleration Coefficient (A0 = 0.4g for Yalova) given in the Turkish seismic code. The value of bedrock PGA is shown in Fig 4 to be significantly greater than the currently specified A0 value within about 10km of the Yalova Fault segment, so the seismic design forces for 1-3 storey structures may be increased by the amount indicated in Fig 4. It was estimated that the seismic design forces for taller, longer period structures could exceed the current specification for a distance up to c15km from the Yalova segment of the NAF Zone.

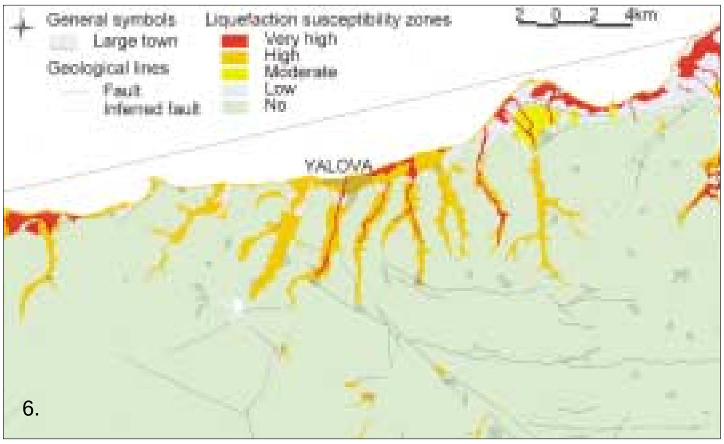
These conclusions are only indicative and could be influenced by various factors including soil type and depth (characterised as the local 'site class'), spatial variability in ground motion, and onset of liquefaction. These effects would need to be addressed when defining the seismic design forces for a specific project.

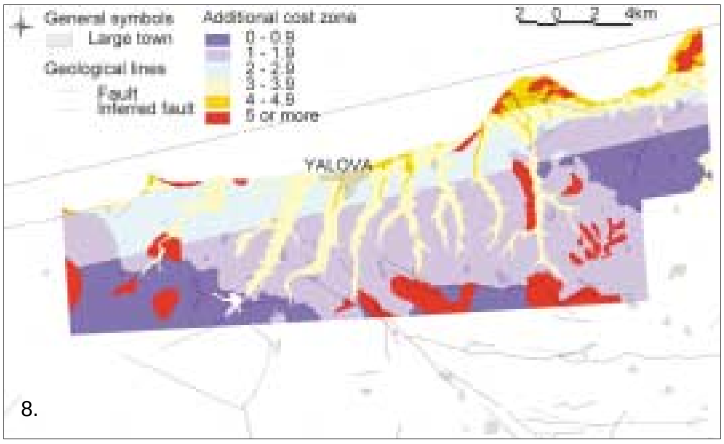
Local site class map

The geological review of the area classified the geological units into local site classes (Z1, Z2, Z3 and Z4) as shown in Fig 5. All the softer superficial deposits, which can increase the effect of earthquake ground shaking, were considered to be either Z3 or Z4, whilst the stiffer soils and rocks were considered to be Z2 or Z1. This information summarises the ground conditions in Yalova Province in terms of the parameters required to determine design seismic loads in accordance with the Turkish seismic code.









5 top left:
Local site class map.

6 above left:
Liquefaction susceptibility map.

7 top right:
Landslide hazard map.

8 above right.
Additional cost summary map.

Liquefaction

Liquefaction is the loss of strength in loose saturated granular deposits as a result of pore pressure increased during cyclic loading. The consequences were seen throughout the earthquake-affected region with many buildings suffering bearing capacity failures. The classification of geological units for liquefaction susceptibility was carried out using standard geological criteria that led to the liquefaction susceptibility map (Fig 6). This subdivided the area into six zones: very high, high, moderate, low, very low and none. The highest risk was in the softer superficial deposits - beach, coastal, delta, levee and flood plain - whilst the lowest risk was in older and denser gravels and the stiffer soils and rocks inland.

Landslide

New landslides and evidence of earlier slope instability were identified in the field, on aerial photographs, and on the 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 (Fig 7) was 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.

This map was zoned according to four hazard classes: nil, low, moderate, and high. It does not address lateral spreading, which is a liquefaction phenomenon. 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 none or only isolated shallow landslides have been identified. The moderate zone has only shallow landslide features widely dispersed on moderate-to-steep slopes of all rock formations. The high hazard 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 (a stiff overconsolidated clay) where there are fossil rotational landslide forms resulting from past river and coastal erosion when sea levels were higher.

Risk mapping

When considering the location and design of new structures, these three maps can be used to gain understanding of the severity of each hazard in an area and to design measures to reduce vulnerability and mitigate risk. However, due to their nature, they are intended for general zoning and not for site-specific design. Whilst it is important to consider each hazard individually for each site or project, it is much more useful for development planning to consider them in combination and to assess the overall risk. On this project, this requirement was essential to allow the planning team to identify areas where new development could take place. To assist this, an additional costs map (Fig 8) for 3-6 storey structures was produced.

Using design response spectra, the vulnerabilities of structures built to the Turkish seismic code of 1-2, 3-6, and 6+ storeys were assessed. The risk of damage to these different height structures from a major earthquake affecting the Yalova Province was presented as a risk matrix of additional costs for both foundations and superstructure above a reference level (see Table 2 overleaf). This 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:

0 = reference level 1 = low 2 = moderate

3 = high 4 = very high 5 = extremely high.

Level 5 was applied to hazards considered unacceptable and thus to 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 were combined, assuming that the foundation and any substructure costs (including site investigation) was approximately 25% of the total design and construction costs.

Table 2

Risk matrix for increase in foundation (F) and superstructure (S) costs

Hazard	*Hazard level*	*1- 2 storey*		*3- 6 storey*		*6+ storey*	
		F	S	F	S	F	S
Ground motion – local site class	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

As well as the hazards detailed in Table 2, other specific hazardous facilities such as a dam and several chemical-processing facilities need to be taken into consideration in development planning. A more detailed account of the risk assessment process will be published[2].

Table 3

Proposed projects and participants

Project	*Lead*	*Partners*
Solid waste management system	Arup	Balfour Beatty
Freshwater supply system	Thames Water	Balfour Beatty, Hyder
Wastewater collection treatment	Thames Water	Balfour Beatty, Hyder
Regional hospital	Laing	Balfour Beatty, Arup
University	Bovis Lend Lease	Balfour Beatty, Arup
Tourism project	Hyder	
Yalova province masterplan	Hyder	

'The most valuable and lasting benefit will be if local planners can ensure that when the next earthquake hits, people in new dwellings escape unharmed.'

The future

The inter-governmental agreement required BECT to produce a Reconstruction Implementation Plan to guide the Turkish authorities and potential investors in an orderly and phased approach to reconstruction. The consortium produced a developed framework and a shortlist of projects, and identified some of these to be advanced by BECT members. The final report[3] was submitted on programme on 16 August 2000, and officially presented to the Turkish Minister for Public Works and Settlement, Mr Koray Aydin, by Nick Raynsford on a return visit to Turkey. Seven TV crews covered the presentation, transmitted live on CNN Turk. BECT proposed seven projects as priorities with the various Turkish authorities (Table 3) and these were confirmed in an inter-governmental Memorandum of Understanding, signed on 9 September 2000.

Yalova's main commercial activity was tourism, as it has beaches and is only one hour by ferry from Istanbul. Before the earthquake, its popularity had started to wane and after the enormous loss of life many questioned whether they could continue to live in Yalova. Each project is therefore intended to fulfil particular development objectives, to revitalise Yalova city and province, and encourage people to stay. The first three aim to rehabilitate the damaged infrastructure to levels meeting EU standards, the next two provide a more diverse economy, and the last two respond to particular needs of local planners.

The geohazard zoning of the project is an excellent example of Arup's strengths in multi-office working, efficiently harnessing worldwide resources. The project was led from London office, its skills embracing geotechnics, seismicity, geomorphology, image manipulation and interpretation, with very important contributions from Istanbul (civil engineers), Leeds (geological and solid waste), Hong Kong (seismic and geographical information systems), and Sydney (geographical information systems).

Unfortunately, the Turkish economy faltered in late February 2001 and since then little real progress has been made on any of the projects because of the poor investment climate. It is hoped that they will restart when the Turkish economy recovers. Arup's input, however, was always intended to be broader than specific projects. Many valuable contacts were made in both governments and in partner companies, demonstrating what could be achieved in identifying hazards in a form readily usable by planners in a high-risk area. The most valuable and lasting benefit will be if local planners can ensure that when the next earthquake hits, people in new dwellings escape unharmed.

References

(1) 'Private eyes in the sky', *The Economist*, 4 May 2000.

(2) LUBKOWSKI ZA, CHAPMAN, TJP, and FREE, M. Identification of geo-hazards for the rehabilitation plan of Yalova Turkey. 12th European Conference on Earthquake Engineering, paper reference 618. [To be published in 2002]

Credits

BECT partners:
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Balfour Beatty

Bovis Lend-Lease

Laing

Thames Water

Hyder Consulting

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