RESIDENTIAL RETROFITTING IN İSTANBUL – REALITIES IN BAKIRKÖY

D.C. Hopkins[1], R.D. Sharpe[2], H. Sucuoğlu[3], D. Kubin[4], and P. Gülkan[2]

ABSTRACT

The feasibility study funded by the Government of Turkey through a World Bank loan is part of the Marmara Earthquake Emergency Reconstruction project and is aimed at mitigating seismic risks in the municipality of Istanbul and reducing the social, economic and financial impacts of potential future earthquakes.

The structural retrofitting (strengthening) of 369 apartment buildings in the municipality of Bakırköy in İstanbul was examined, highlighting the realities that must be addressed to make retrofitting happen. These realities include highly variable construction quality, physical, planning and legal constraints, an imperfect building controls regime, owner attitudes, the costs and benefits of retrofitting, and the challenge of finding viable funding mechanisms.

The study involved investigations into the seismological and geotechnical conditions, preparation of as-built condition surveys, structural analyses, earthquake performance assessment and development of possible retrofitting solutions. The investigation of social impacts was a key component, as was a pioneering analysis of the benefits and costs of retrofitting.

By formulating realistic solutions to real buildings, valuable information has been developed to help owners and authorities to decide on viable approaches for achieving wide-scale retrofitting in Turkey and elsewhere.

Introduction and Background

The Marmara earthquake in August 1999 heightened the need for a major reconstruction effort and recovery plan, and for a mechanism to reduce the costs of future earthquake disasters in Turkey. Several studies and projects were initiated. Of particular relevance to this project are two major projects implemented through the co-operative efforts of the World Bank and the Government of Turkey - the Marmara Earthquake Emergency Reconstruction (MEER) Project and the İstanbul Seismic Risk Mitigation and Emergency Preparedness (ISMEP) Project. This

[1]Project Manager, Beca International Consultants Ltd, Wellington, New Zealand.
[2]Director, Beca International Consultants Ltd, Wellington, New Zealand
[3]Professor of Civil Engineering, Middle East Technical University, Ankara, Turkey
[4]Managing Director, Prota Muhendislik, Consulting Engineers, Ankara, Turkey

Bakırköy project, part of the MEER project, was carried out in the context of two projects directed at the reduction of İstanbul's seismic risk, the JICA Seismic Risk Study in 2002 [JICA, 2002] and the İstanbul Earthquake Master Plan (IEMP) in 2003. [IEMP, 2003] The IEMP was conducted by four Turkish universities and examined risk reduction measures and the priorities for action over the whole city.

İstanbul is a major candidate for wide-scale retrofit applications, due to both the heightened odds of a severe earthquake along the Marmara segment of the North Anatolian Fault, and its immense building stock. This stock consists of one million buildings, half of which are expected to be affected significantly from such an event. In spite of this recognized high risk, retrofit activities to mitigate seismic risks have remained very sparse in İstanbul after 1999, especially in private residential buildings.

The Bakırköy project is a pilot to determine and test economical, socially acceptable and structurally sound approaches to the structural retrofitting of residential buildings in order to reduce their vulnerability to seismic forces and the consequent risks to occupants. The Municipality of Bakırköy was chosen because of its proximity to the North Anatolian Fault, and the previous work it had done to assess its building stock for earthquake risk [Istanbul University/Istanbul Technical University Study, 2003].

In 2002, the Bakırköy Municipality undertook preliminary surveys of its residential building stock, including of soil conditions and rapid structural performance assessments of each building. The survey (undertaken by the İstanbul and İstanbul Technical universities) enabled the authorities to identify approximately 3500 buildings, or one-third of its total stock, as at "high" or "very high" earthquake risk on the basis of structural and soil conditions. The distribution of these in Bakırköy is shown in Figure 1.

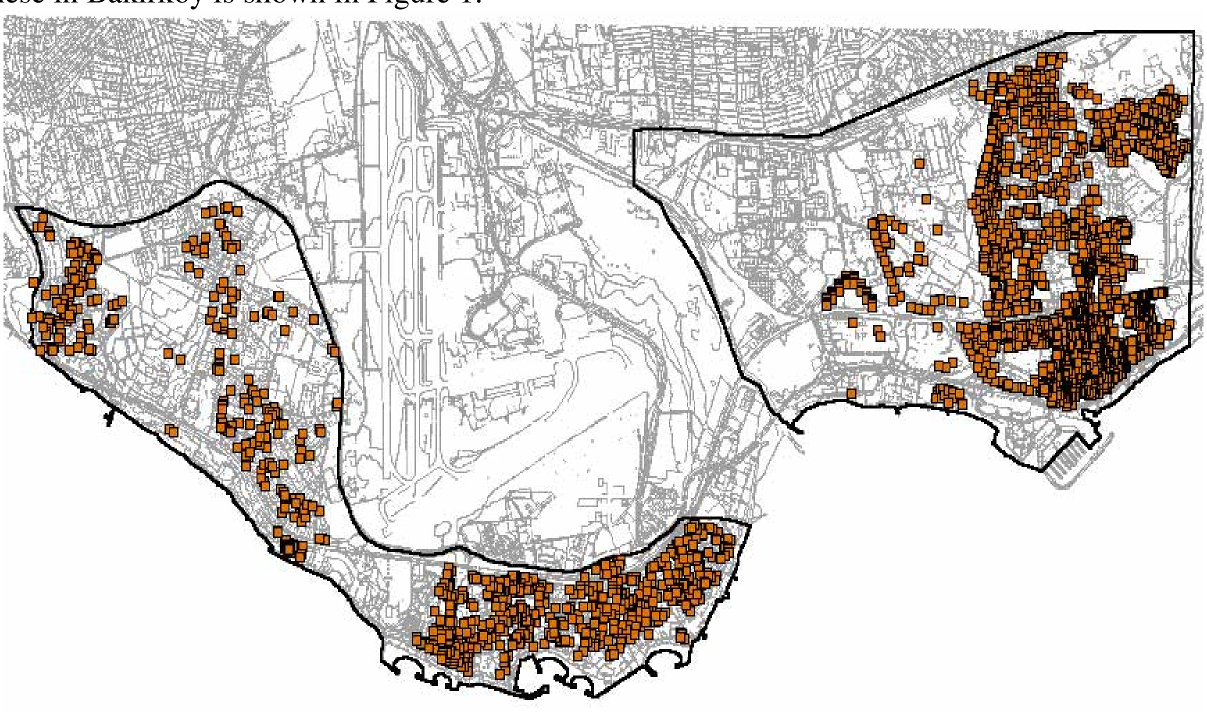

Figure 1. Distribution of High and Very High Risk Buildings in Bakırköy.
(From ITU/IU 2002 Study)

Owners of all 3500 buildings were invited to participate in the project. The invitation required that a majority of owners of each building accept, in writing, to be part of a detailed assessment. As a result of this process, 369 of these buildings were the subject of the project. A vital and unique component of the study was the inclusion of social considerations as an integral part of determining suitable retrofit solutions. One objective was to examine the feasibility of using innovative technologies to minimize the costs of effective retrofitting and so reduce disruption to occupants.

The study is intended to assist not only the owners of the subject buildings, but other owners, municipalities and the Turkish government to decide on realistic retrofitting actions, approaches and programs.

The project was funded through a portion of an IBRD loan to the Republic of Turkey. The Republic of Turkey Prime Ministry's Project Implementation Unit (PIU) was responsible for the implementation of the project.

The consultants for the study were the Beca-Prota Joint Venture. The project team involved earthquake experts from Beca International Consultants Ltd of Wellington, New Zealand, and Prota Engineering from Ankara, Turkey.

Scope and Methodology

The project required a review of seismology, geotechnical and ground motion characteristics, collection of data on each building, computer structural analysis for assessment, definition of retrofit criteria, preparation of preliminary retrofit designs, a detailed benefit cost analysis, and a review of social impacts and attitudes. Reports were required at the end of the assessment phase and following retrofit design and benefit-cost analysis.

All work was reviewed and approved by an Approval Authority consisting of four professors from the Middle East Technical University. Their role was to monitor and approve the methods and approaches used in all aspects of the work

Assessment Phase

The aim of the assessment process was to provide a reasonably realistic measure of the performance of the buildings in the scenario earthquake and sufficient knowledge of structural behavior to identify any key behaviors or critical structural weaknesses to be dealt with by retrofitting. This required detailed structural analyses of each building based on information obtained from the seismology, soils and building data investigations.

Seismology

The Marmara Sea region, in which one-third of Turkey's population of 70 million is located, is also one of the most seismically active regions in the country. In the last century, this region has shown unusual seismic activity, and produced nine distinct events having $M_w \geq 7.0$. In 1999, two destructive earthquakes (Kocaeli and Düzce) occurred in the eastern part of the Marmara region on the North Anatolian Fault (NAF) system which has produced seven large earthquakes in a westward migrating sequence since 1939 [Parsons et al, 2000a]. The Kocaeli earthquake is the most recent event on the NAF on the border of İstanbul, the most populated city in Europe. The probability of occurrence of a Magnitude seven or greater earthquake in the Marmara Sea region targeting İstanbul was computed in 2000 as 62 ±15 % in the next 30 years, and 32 ± 12 % in the first decade [Parsons, 2000b]. This probability has later been recalculated to be somewhat less [Parsons, 2004]. The epicenters of $M_w \geq 6$ earthquakes during the last five centuries are shown in Fig. 2 where all of the major fault structures are also shown.

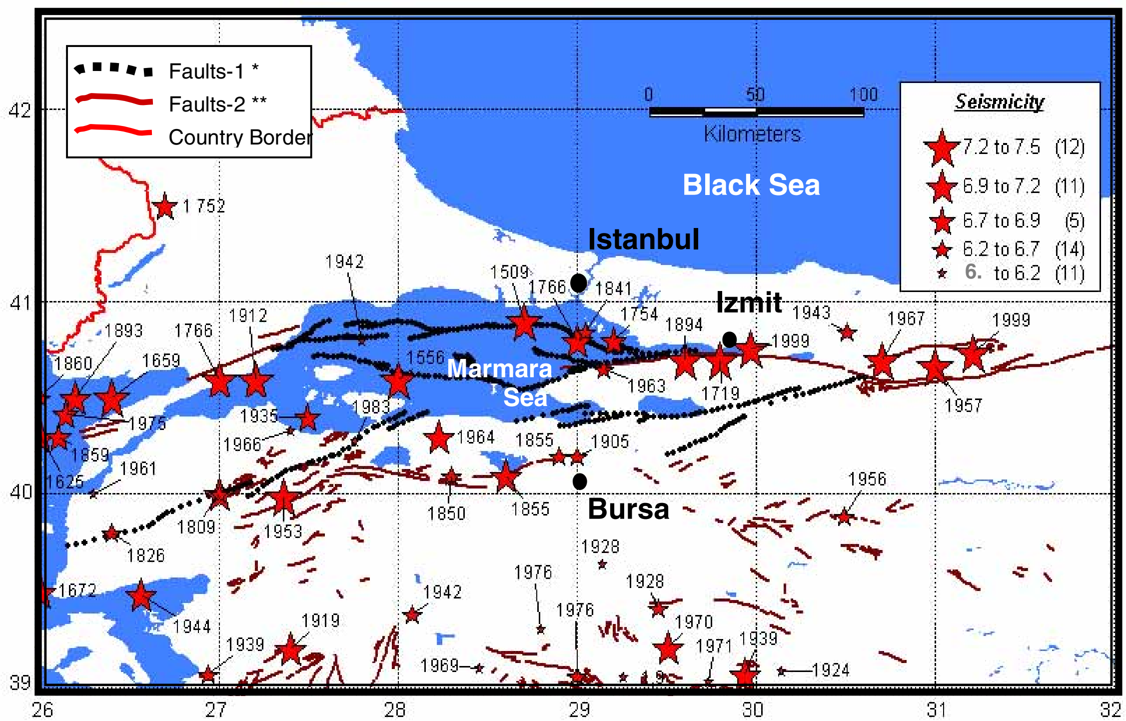

Figure 2. Locations of $M_w \geq 6.0$ earthquakes (A.D. 1509-1999).

(Note: Parentheses denote the number of earthquakes falling in that specific magnitude range; Category-1 faults have been recently explored by using bathymetric and seismic reflection data [1-4]; Category-2 faults indicate the previously known faults [MTA]).

The scenario earthquake chosen for the project is an $M_w = 7.2$ strike-slip event occurring on the NAF in the same position as the estimated epicenter of the 1509 earthquake. No other earthquake at, or greater than, this size has occurred close to the city during the last 500 years. The closest distance from the likely under-water fault rupture to the shoreline of the urban area that defines Bakırköy is about 10 km.

Geotechnical Investigation

Site soil classification to estimate earthquake ground motions was required, as well as knowledge of the likely strength and stiffness of the soils under each building.

Boreholes were drilled at 182 locations totaling over 4800 m. In-situ tests (SPT) were conducted in each borehole at 1.5 m intervals; a total of 128 samples were collected and subjected to laboratory tests. Because the high urbanization in the project area made access difficult in some locations, it was decided to complement the soil-drilling program with seismic refraction studies at 15 locations, and micro-tremor tests at 14 locations. Information from this investigation supplemented data from previous investigations, and will be added to the municipality's database.

In order to provide owners with specific information about the soil conditions at their building site, individual building geotechnical reports were prepared for each of the 369 buildings included in the project.

Ground Motions

Response spectra were derived using a combination of attenuation relationships [Joyner and Boore 1988, and Kalkan and Gülkan, 2004]. This provided a balance between well-established methods based on Californian earthquakes and relationships more recently developed from Turkish earthquake data.

Figure 3 shows the uniform-risk response spectra derived for distance of 8.5 km from the fault – corresponding to the closest part of Bakırköy. The figure shows spectra of expected acceleration with 50 % probability of exceedance (median) and 16 % probability of exceedance (median-plus-one standard deviation).

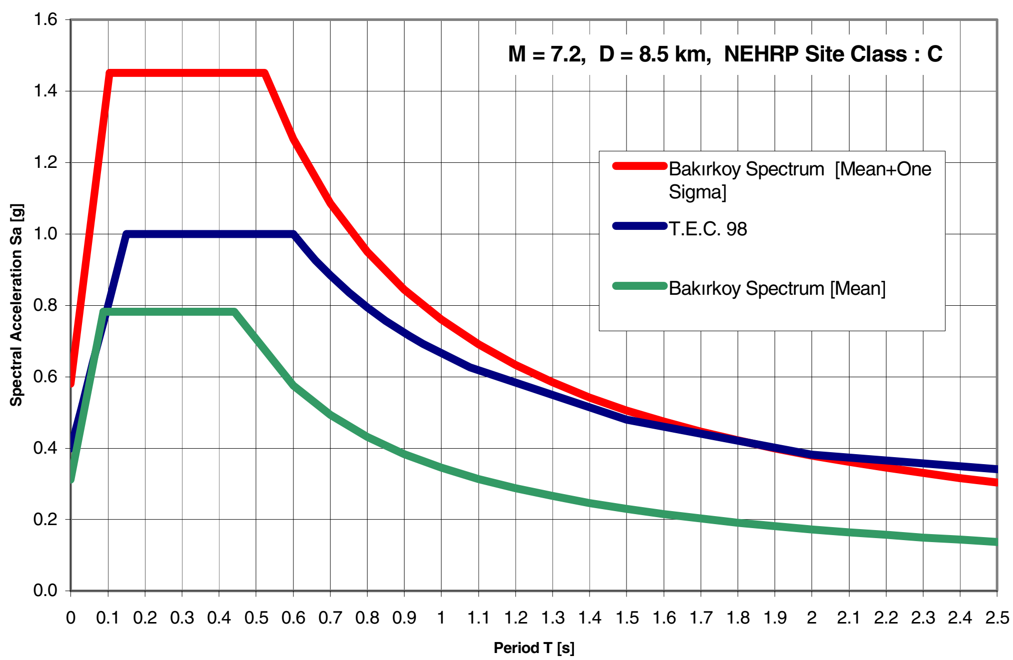

Figure 2. Response spectra for M 7.2 scenario earthquake.

Considerable variation with distance is evident, reflecting the proximity of the fault line. Spectral ordinates for the furthest part of Bakırköy from the fault (13.25 km) were 70 % of the values shown.

Building Data Collection

Data collection for the project buildings was a major task. Four teams took concrete cores from buildings, reinstated the sampling places, determined and checked reinforcing steel amounts, checked for corrosion, and verified location and depth of foundations. Up to six teams determined the location and size of structural elements and an indication of the condition and general standard of construction of each building. The team based in the Bakırköy office totaled 50 professionals and staff at its peak, and completed the task in just over four months.

The number and range of buildings required formal procedures to be developed to achieve a high level of consistency and confidence in the information obtained. Building permit drawings were obtained for 320 of the 369 project buildings. Where available, these were used as base information against which site measurements were recorded. A comprehensive file that included photos, material test results, a soils report, and up to 10 as-built drawings, was produced for each building.

A total of 1955 concrete samples were taken from the 369 buildings in the project, ranging in age from 20 to 40 years, and containing over 4200 apartments. The majority of the buildings were five stories, with a basement. There were considerable constraints imposed by lack of access allowed by occupants and the small size of concrete columns, beams and walls. Schmidt Hammer readings were taken at locations of concrete cores, and especially at locations where core sampling was not possible. Figure 3 shows the range of concrete core strengths. The high variability and very low values evident reflect hand-mixing and placing, and the use of poor aggregates in some instances.

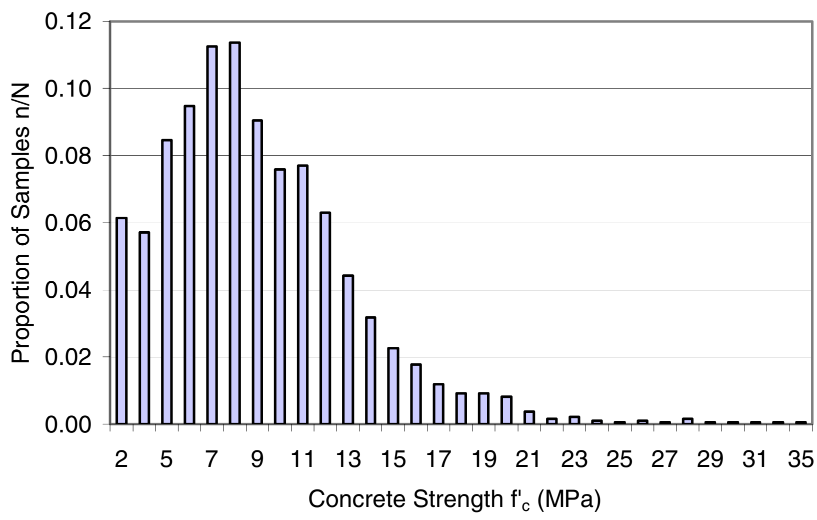

Figure 3. Distribution of Concrete Core Strength Results.

Assessment of Likely Performance

Studies of earthquake damage in Turkey in the last decade have revealed that the causes of heavy losses are rather simple and generic to all buildings. The selected 369 buildings in Bakırköy reflect similar characteristics. There are many instances where the concrete quality is low, detailing is poor, reinforcing bars are corroded, and basic seismic design features are absent. Many buildings have heavy overhangs that place high demands on the ground-floor columns, while the incorporation of brick partition-wall in some areas can create soft stories in others.

The assessment involved careful modeling of the structure to include all elements having a significant influence on overall strength and performance, and an examination of the ability of these elements to maintain their integrity and load-carrying capacity when subject to increasing deformation. The likely performance of the buildings in their present state was assessed by estimating the level of earthquake load at which the building would sustain sufficient structural damage for the probability of collapse or partial collapse to be unacceptably high. The detailed assessment process indicated strengths varying from 7 % to 133 % of the demand earthquake. This range reflects the high variability of concrete found in Bakirkoy buildings (from 3 to 33 MPa), the lack of ductile detailing, and the influence of partition walls on the structural behavior. Details of the assessment process are given in a companion paper [Sucuoğlu et al 2006].

Retrofit Design

The primary objective of retrofitting was to reduce the probability of collapse (and, therefore, of fatalities) in the scenario event to an acceptable level. A secondary objective was to conceive retrofit designs that minimize cost and disruption to the owners, while still meeting the primary objective.

For retrofit design, the limit of acceptable risk has been taken to be the attainment of the maximum allowable displacement of the structure compatible with Life Safety performance as defined in FEMA 356 [FEMA 2000]. Designs were based on these limits not being exceeded when the structure was subjected to displacement demands corresponding to ground motions at the building site due to the M7.2 scenario earthquake (mean-plus-one standard deviation level). Designs meeting this requirement will have similar performance to new buildings designed to the current Turkey Earthquake Loadings [Turkish Code 1998] and its corresponding materials codes.

Development of the retrofit designs involved consideration of structural configuration, reinforcement detailing, effect of masonry partition walls, variable concrete strength, physical constraints such as adjacent buildings, the need to maintain functional layouts. The strong feedback from the social impact questionnaire that cost was a key factor for owners and that they were most reluctant to move out during retrofitting was taken into account.

Retrofit design solutions developed generally involved addition of stiff, strong and ductile structural elements in strategic locations to improve structural configuration and protect existing elements (particularly columns) from the effects of excessive lateral displacement. Jacketing of key columns was called for on occasion to improve their load-carrying capacity and to make up for inadequate ductile detailing. Two basic options were sought - one with interior elements and another with external elements only. Some buildings incorporated base isolation. Where necessary, corrosion treatment and protection were called for. Retrofit solutions for buildings immediately adjacent to one or more neighbors were developed on the basis that adjacent buildings would neither increase nor reduce the performance. In the context of this project, there was no other way to deal with such buildings. Owners of such buildings were encouraged to consult with neighbors if they were serious about retrofitting - in the hope that some mutual solution could be found.

For each building, information on the retrofit solutions was compiled in the form of an Individual Building Retrofit Report, containing information on the building, retrofit design, benefit-cost and the location of retrofit elements at each level. The information was intended to give owners a good indication of the extent and nature of work required and any resulting changes to the functional layout or amenity. Further details of the retrofit design approach are given in a companion paper [Sucuoğlu et al 2006].

Benefit-Cost Analysis

The methodology for the benefit-cost analysis was developed specifically to meet the needs of the project, and provided estimates of benefits and costs of retrofit/replacement options. These benefits and costs were then compared with the costs of doing nothing, and with the option of replacement for the building with a new one of the same size

The analysis compared its effect on the existing and retrofitted/replaced buildings for a range of times between retrofitting/replacement and occurrence of earthquake. The scenario earthquake dominates the overall seismic hazard in İstanbul, and this approach relates to clearly to people's perception of earthquake hazard, and is more readily understood by owners and administrators.

The analysis model was split into three main sections: Initial Benefits and Costs, including costs of relocation of occupants during retrofitting; Time-dependent Benefits and Costs, comprising maintenance, depreciation, insurance and rental differentials; Earthquake-dependent Benefits and Costs, including building damage, loss of contents, injuries and fatalities, and an allowance for overall business interruption and social disruption.

For each selected time-to-occurrence of the scenario earthquake, the benefits and costs were computed for Do Nothing, Demolish and Reconstruct, Retrofit 1 and Retrofit 2 options. When applicable, values were discounted to net present values (NPV). For each of the 369 buildings, values of benefits, costs and benefit-cost ratios were computed for times of 0, 5, 10, 20 and 50 years.

The heart of the benefit-cost analysis was the difference in damage ratio before and after retrofitting, values for which were derived to be compatible with data from past earthquakes in Turkey. Relationships were derived between damage ratio and casualty rates, again made compatible with Turkish earthquake data from the 1999 earthquakes.

The benefit-cost data was used to assess the merits of retrofitting for each building, since the costs of retrofitting used were based on the retrofit designs. This meant that buildings requiring significant column jacketing or corrosion treatment had higher than usual costs, making them less economic. The analysis clearly indicated that replacement was the best option for such buildings and provided clear comparisons across the range of buildings.

Social Issues

A unique aspect of this project was the inclusion of the social impacts of retrofitting. This proved to be a most important addition, offering insights into the non-technical factors that influence decisions on retrofitting. Interactions with the owners included three sets of meetings, the issuing of information on retrofitting, and a survey of owner/occupant attitudes.

The main aim of assessing the potential social impact of seismic retrofitting was to determine the factors that may affect owners, tenants and the wider community in their attitudes, behaviors and decisions about retrofitting. Information on the socio-demographic characteristics of the owners/tenants of the 369 selected buildings, and their attitudes to improved safety, disruption to daily life, and their perceptions of costs and benefits of retrofitting, was evaluated.

It was concluded that building owners had to have **belief** in earthquake risk and retrofitting solutions; **trust** in designers, approval authorities and builders to make the solutions effective; and **funding** mechanisms and assistance that make it possible for owners to invest in the protection of their life and property. Efforts to encourage retrofitting should therefore focus on these three fundamental aspects.

Conclusions

Overall the project has resulted in a potentially valuable information resource for use by owners, municipalities and the Turkish government. This covers seismology and ground motion data, a significant addition to geotechnical information for Bakirkoy, important information on concrete quality, comprehensive data on the as-built condition of buildings and on their likely performance in earthquake.

The process of assessment and development of retrofit designs confirmed that there is a need for improved structural designs for residential buildings in Bakirkoy. Retrofitting of these buildings was shown to be technically feasible and a worthwhile investment.

The social impact survey proved crucial in identifying that for retrofitting to happen, owners must believe retrofitting will effectively reduce earthquake risk, owners must trust the designers, authorities and builders, and that viable funding mechanisms and assistance must be found.

To make retrofitting happen, all possible means will need to be explored to address these belief, trust and funding issues. Thus the most critical challenges are not technical, but political, economic and social.

Acknowledgements

The authors acknowledge the efforts of all involved in carrying out this project, particularly the members of the Approval Authority, those who allowed their buildings to be assessed, and the project's site investigation and design teams. The foresight and dedication to disaster mitigation of the officers of the Turkish Prime Ministry's Project Implementation Unit who scoped and monitored the study is especially acknowledged.

References

Ambraseys, N.N., K.A. Simpson and J.J. Bommer, 1996. Prediction of Horizontal Response Spectra in Europe, *Earthquake Engineering and Structural Dynamics* 25(4): 371-400.

Ambraseys, N.N. and J.A. Jackson, 2000. Seismicity of the Sea of Marmara (Turkey) since 1500, *Geophys. J. Int*. 141: F1-F6

Ambraseys, N.N., 2002. The Seismic Activity of the Marmara Sea Region over the Last 2000 Years, *Bulletin of the Seismological Society of America* 92(1): 1-18.

İstanbul University/İstanbul Technical University, 2003. Building Risk Assessment Study, *Bakırköy Municipality, İstanbul.*

Johnston, D., N. Karanci, M. Arikan and D.C. Hopkins, 2006. Residential Retrofitting in Istanbul – Social and Economic Consideratons, *8NCEE* San Francisco, April.

Joyner, W.B. and D.M. Boore, 1988. Measurement, Characterization, and Prediction of Strong Ground Motion, Earthquake *Engineering and Soil Dynamics II-Recent Advances in Ground Motion Evaluation, Geotechnical Special Publication 20, ASCE, NY*, pp. 43-102.

Kalkan, E. and P. Gülkan, 2004. Attenuation Characteristics of Turkey Based on Recent Strong Ground Data, *ARI, The Bulletin of the Istanbul Technical University* 54(2).

Parsons, T., A. Barka, S. Toda, R.S. Stein and J.H. Dieterich, 2000a. Influence of the 17 August 1999 İzmit Earthquake on Seismic Hazards in İstanbul, *The 1999 İzmit and Düzce Earthquakes: Preliminary Results; A. Barka, O. Kozacı, S. Akyuz and E. Altunel (Eds.)*, İstanbul Technical University, 295-310.

Parsons, T., S. Toda, R. S. Stein, A. Barka and J. H. Dieterich, 2000b. Heightened Odds of Large Earthquakes near İstanbul: An interaction-based Probability Calculation, *Science* 288: 661-665.

Parsons, T., 2004. Recalculated Probability of $M \geq 7$ Earthquakes beneath the Sea of Marmara, Turkey, *Journal of Geophysical Research* 109: B05304.

Sucuoğlu, H., D.C. Hopkins, J. Kubin, S.A. Özmen, G. Özcebe, P. Gülkan, S.B. Bakır and R.D. Jury, 2006. Residential Retrofitting in Istanbul – Structural Assessment and Retrofitting, *8NCEE* San Francisco, April.