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SEISMIC ASSESSMENT OF THE ARCHITECTURAL HERITAGE IN THE FATIH DISTRICT OF ISTANBUL

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ABSTRACT :

Istanbul, a 2500-year old city, is under threat of a devastating earthquake. Reflecting past experience a very high probability of occurrence has been postulated for an M7 or larger earthquake during the next quarter century. The Metropolitan Municipality of Istanbul has committed itself to an ambitious program that targets urban rehabilitation part of which is seismic loss mitigation. The building stock includes many irreplaceable historic buildings of different ages. The city's long history is reflected in the architectural heritage of its urban texture. While the current size and population of the conurbation have spread over a large area, the historic buildings are situated mainly in the area known as the "Historic Peninsula." Here they are confined to two administrative districts (Fatih and Eminönü) that are bound by the estuary Haliç (Golden Horn) to the north, the Strait of Istanbul to the east, Sea of Marmara to the south, and the ancient land walls to the west. The administrative district Fatih alone boasts some 5,000 registered historic buildings under protection. This paper describes the procedure for measuring, recording and assessing the seismic vulnerability of historic masonry buildings in Fatih. A sample group comprising 223 buildings was surveyed as part of field and office work that lasted one-and-one-half years. Of these, 20 will be subjected to further stress analysis and detailed assessment.

KEYWORDS: Istanbul, Fatih District, Survey, Historic Buildings, Seismic Vulnerability

1. GEOGRAPHY AND SEISMICITY

Istanbul sits astride the 30 km-long eponymous strait that connects the Black Sea with the Sea of Marmara (left frame in Figure 1). An engraving from the 16th century shows the Historic Peninsula from the east in the right frame of the same image. The walled city is separated from a smaller settlement on the north side of Haliç. A current space image is given in Figure 2.

The city has been visited by well-recorded major earthquakes in the past, and experienced major destruction. The M7.4 earthquake that occurred in Kocaeli in 1999 was only 80 km from the historic city core, but several districts on vulnerable sub-grade witnessed building collapse and life loss. There is reason to expect that the segment of the North Anatolian Fault traversing the Sea of Marmara at about 15-20 km south of the city proper may well rupture in the near future, causing damage in many buildings, modern as well as historic (Parsons, 2004; Griffiths et al., 2007). During the last 2000 years or so 55 reasonably well documented earthquakes have occurred in the Marmara Sea region. Many have been felt in the city proper and caused damage (Finkel and Ambraseys, 1997; Mazlum, 2003).

Figure 1 View of Istanbul Strait and Fatih (Circled, Left) and Historic Engraving (Right)

Figure 2 Historic Peninsula Comprising Fatih District

2. HISTORIC BUILDING STOCK CHARACTERISTICS IN FATIH

The urbanization in Fatih region goes back to the time of Constantine the Great (4th century). In the fifth century, by the construction of the Theodosian Wall, the city was enlarged in the western direction. The Theodosian Wall is a 7 km long defensive structure that suffered from several earthquakes and had to be repaired to defend the city through the Middle Ages. Along with some other parts of the historic city, it is included in the World Heritage Areas of Istanbul. Other Byzantine buildings, like the Church of Studious and Church of Monastery of Christ of Chora make up a rich legacy of religious architecture. These are monuments of high historical and artistic importance. Due to their exceptional architecture and decoration, they must be protected from further deterioration (Ahunbay, 2006).

The churches from early Christian and Medieval Period have alternating wall construction, with brick courses acting as bands uniting the wall structure. Walls were constructed of local limestone, well baked brick and good quality mortar consisting of slaked lime, crushed brick aggregate and powder and sand. Some of the walls also had timber runner beams, providing reinforcement to resist earthquakes. Yet, the fragile sections, such as the tall apse windows suffered from tremors and needed to be repaired many times. Vaults and domes also had structural failures and had to be reinforced or reconstructed.

Fatih region also has many important Ottoman buildings dating from the second half of the fifteenth century up to the early years of the twentieth. These are monuments with different functions. Small size timber and masonry houses do not present serious problems from the point of earthquake risk, but mosques with designs incorporating major domes in their composition have been facing serious problems. Due to their long life span, monuments in Istanbul have resisted several earthquakes; those of 1509, 1766 and 1894 have caused serious damages to these masonry structures. Vaults are usually made of brick, which is lighter than stone. Yet lack of tie bars or their deterioration has caused failures. Arcades were also the weak parts of the mosques and religious colleges which had small sized domes in their design.

Ottoman architects were clever not to build oversized domes that would collapse during strong ground motions. The most vulnerable part of a mosque is the minaret. Their construction was reinforced by using clamps and dowels, aimed at fixing the blocks horizontally and vertically. However, the uppermost part of tall minarets usually suffered from earthquakes; the balconies and caps collapsed and had to be rebuilt.

Public baths were important in Turkish society. Many baths were built to meet the demand in the residential and commercial parts of the town. Some baths stand out with their impressive dressing halls, with domes measuring as big as those of medium sized mosques, reaching 16-18 m in diameter. Such big sized domes suffered severely from earthquakes and the baths had to be restored to continue their service. Otherwise, they were out of service and fell into neglect.

At the moment most of the historic buildings in Fatih are in poor state of preservation. The expected earthquake will affect these buildings more if they are not retrofitted carefully. The repairs demand careful analysis of the vulnerabilities and minimum intervention to maintain the authenticity of the historic buildings.

2. REMEDIAL ACTIONS

In recognition of the impending earthquake Istanbul Metropolitan Municipality has started an action program that has a component for seismic assessment of historic buildings in Fatih as part of a wider urban renewal undertaking. These buildings are mostly masonry; many serve devotional purposes, with ages often spanning centuries. The categories fall into mosques, theological schools, tombs, convents for religious orders, libraries, baths, fountains, churches, synagogues, cisterns, historic public kitchens, remains of fortified walls and cemetery appurtenances. The municipal administration developed an inventory with information for location, architectural features, historic or artistic significance, legal ownership status and whether repairs or modifications had been done on them. This detailed information that had been collected as a result of lengthy field work was useful in its own right, but provided little information on the vulnerability of a building. It was clear that, owing to time and resource limits, a smaller subset of the thousands of buildings could be considered for seismic assessment. We resolved to develop an additional information database with regard to the structural features of each building's load resisting system. This implied a complementary phase of field work following a generic procedure:

- Do survey drawings exist? If not create these with total station or other scanning technology, noting any structural defects or deviations from original state. Use 1/100 or 1/50 scale as necessary.
- Create electronic building-condition forms. Note building materials.
- Measure GPS coordinates, assess environmental conditions and site geology. Create a GIS database.
- Define seismic hazard at site.
- Create a photographic record file.

Thus the record for each building contained all of the information required in the ICOMOS Principles for the Recording of Monuments, Groups of Buildings and Sites. Additional information related to the following items is provided:

- Plan areas and total areas
- Section areas for vertical load-carrying members, and information on openings or material losses in them
- Characteristics of the structural walls and diaphragms for horizontal load resistance
- The foundation system

Fatih, shown in Figure 3, is a living city. Ancient, old and modern are intermixed, urban functions bustle. Many of the buildings are currently being actively used, or are guarded by their custodians even if they are idle. It was not easy to gain access and do lengthy measurements. Removal of material samples for testing required additional permit so it was not attempted at this stage. The program objectives did not include developing a building-specific information database for each building; such an undertaking would have been overwhelming because of the sheer number of buildings. Of the original inventory we first developed an 800-building subset, which was finally reduced to 223 entries listed in Table 1 covering a representative sampling. Even with this modest number, the Fatih Seismic Assessment Project represents a comprehensive attempt to assess the earthquake performance of the historic buildings in the historic core of Istanbul. The procedure is only a preliminary stage for ranking the buildings. Even detailed and lengthy analyses are beset by uncertainties; our objective was to create two bins, one for buildings that would likely survive and the other for those that would likely fail to achieve that objective. The dividing line can be a vague one.

The seismic assessment of selected buildings was done for an M7.2 earthquake occurring on the Marmara Sea Segment of the North Anatolian Fault closest to the city. For this purpose a building inventory system was developed to record the structural features of the buildings.

As detailed stress analysis of each building is unfeasible, a two-tiered rapid survey procedure was developed. In the first stage a simplified model of the building was created from laser scan measurements and wall stresses were computed for comparison with limits. The second stage comprises detailed stress analysis for a typical subset of about 20 buildings. The last stage will incorporate the rehabilitation measurements and typical strengthening details. This paper emphasizes the initial stage, and illustrates the assessment procedure through a sample.

2. ELEMENTS OF HISTORIC BUILDING EVALUATION

With the complete information set comprising structural (materials, wall thicknesses, and state of cracking as opposed to architectural or conservation-relevant) features, local geology, estimated ground motion we built simplified SDOF models for each building in the inventory in the style shown in Figure 4. Ground motion was assumed to act in one of two principal horizontal directions, and separate stress analyses were made in- and out-of-plane wall capacities. Openings in walls were taken into account in estimating their stiffness, and roofs or domes were assumed as inert masses. Site-specific response spectra adjusted for distance to fault rupture and local soil characteristics were tools for estimation of the spectral acceleration. No force reductions were allowed, so wall stresses or out-of-plane strengths were based on values from limited coupon tests or triple their code allowables. This elementary exercise yielded good vulnerability estimates. A sample sheet is shown in Figure 5.

Figure 3 A Section of Fatih Viewed from the North

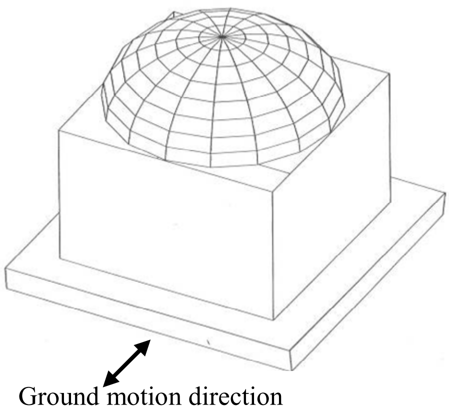

Figure 4 Simplified Model of a Historic Building

The building stock comprised disparate architectural forms and construction styles. Their variability is reflected in the numbers in Table 1.

Table 1 Breakdown of the Buildings Included in the Survey

Mosque	91	School	15	Convent	18	Church	32
Tomb	23	Seminary	14	Annexes	5	Public Bath	3
Unity Room	1	Koran School	3	Private House	8	Institutional	1
Museum	1	Hospital	2	Public Kitchen	1	Fountain	1
Library	1	Timing House	1	Oil Press	1	Cistern	1

Application of performance criteria to existing masonry buildings is not meaningful. We chose instead to estimate the shear stresses in the in-plane walls of the buildings by modeling them as simple one-degree-of-freedom systems. Openings in the walls and translations caused by rotational effects were accounted for. The strengths of out-of-plane walls were estimated by checking whether cracking was likely to occur under the postulated roof level acceleration (assumed as 2.5 times the ground acceleration) and the gravity loads. Not surprisingly the most vulnerable parts for mosques were the minarets. The churches in the stock are mostly broad and one-story buildings without any belfries. We estimated that their resistance would be sufficient in many cases.

Spreadsheet calculations for each building were enabled by the known dimensions of the walls and their masses. While this is a gross simplification for assessment of the stresses in intricate components such as vaults and transitions from curved to straight surfaces, this was left for the next phase when sample detailed stress analyses will be run for the subset of 20 of these buildings.

3. SUMMARY

According to the recommendations we have submitted to the Metropolitan Municipality nearly all of the buildings are not likely to be destroyed by the postulated earthquake. This result is compatible with the knowledge that all of these buildings have experienced at least one major earthquake, the last of which was the estimated M6.8 event in 1894 (e.g., Finkel and Ambraseys, 1997), and what we have examined in this study are the buildings that have made it to this time. The set of simplified calculations that have been made for the buildings belie the correctness of the fundamental and conservative approach that we have developed for the assessment of these more than two-hundred buildings. The procedure should be construed as a first tier method for a rapid survey of historic buildings. Its accuracy is similar to that of methods developed for buildings. In many cases the estimates for the gross shear stresses in the walls agreed well with the average stresses in those walls derived from the next tier of analyses. The exception to this was for re-entrant corners and walls with irregular plan views. In many mosques the minarets are likely to be destroyed.

ACKNOWLEDGMENTS

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Fatih İlçesinin Depreme Karşı Güvenli Kılınması Projesi
Anıt Eserler Yapı Stokunun İnceleme ve Değerlendirmesi

Bimtaş

TARİHİ YAPI DEĞERLENDİRME RAPORU

Anıtın Adı : **DAVUD PAŞA TÜRBESİ**				Blok Adı:
İmar	Pafta No. :	Ada No. : 1157	Parsel No. : 53	Kadastro No. : Harita No. :
Adres	Mahalle / Mevkii : Davutpaşa		Cadde / Sokak : Davutpaşa Medrese Sk.	Kapı No :
Yapım	Yapım Yılı : Vakfiye : --- Kitabe : 1485	Yaptıran : Derviş Davud Paşa Yapan / Mimarlar : ---		Özgün İşlev : Türbe

F. Hasar ve Mevcut Durum Tespit Bilgileri

Tespit Edilebilen Deprem Kayıtları :	Tarihi: 1509 Bilinen Hasar :	Tarihi: 1766 Bilinen Hasar :	Tarihi: 1894 Bilinen Hasar :	Tarihi: 1999 Bilinen Hasar :
Yapının Halihazır Durumu :	İyi Korunmuş ☐ Orta ■ Kötü Korunmuş ☐	Taşıyıcı Dış / İç Duvar : Hasarsız ■ Az Hasarlı ☐ Çok Hasarlı ☐	Döşeme Taşıyıcı Sistemi : Hasarsız ■ Orta ☐ Yüksek ☐	Döşeme Sehimi : Yok ■ Orta ☐ Çok ☐
Binada Oturma :	Oturma Yok ■ Kısmen Var ☐ Çok Fazla var ☐	Oturmadan Kaynaklı Gözlenen Hasar : Var ☐ Çok Az ☐ Yok ■	Çatıda Sistem Hasarı : Hasarsız ■ Orta ☐ Yüksek ☐	Nemden Kaynaklı Hasar : Yok ■ Orta ☐ Çok ☐
Malzeme Deneyleri :	Yapıldı ☐ Yapılamadı ■	Sonuçlar Özeti : Açıklama :		
Mevcut Durum İle İlgili Diğer Gözlemler :				

G. Vaziyet Planı

KAGİR YAPILARDA BASİTLEŞTİRİLMİŞ HESAP METODU İLE PERFORMANS DEĞERLENDİRMESİ			
Referans No:	FA263	Anıtın Adı:	DAVUD PAŞA TÜRBESİ

Tavan İzdüşüm Alanı(m²) =	78.62	Döşeme x_{ank}(cm)=	490.9	$G_{kaplama}$ (kN/m²) =	2
Tavan Döşeme Kalınlığı (cm) =	70	Döşeme y_{ank}(cm)=	483.1	Q_{kar} (kN/m²) =	1.5
w_{kubbe} / h_{kubbe} (m) =	7.43/4.27	Kubbe x_{ank}(cm)=	490.9	Varsa İlave Yük +(G+n*Q) (kN) =	
Döşeme Özgül Ağırlığı (kN/m³) =	20	Kubbe y_{ank}(cm)=	485.0	Hareketli Yük Katılım Katsayısı=	0.6
TOPLAM BİNA AĞIRLIĞI ΣW(kN)=			7673.35		

DEPREM HESABI PARAMETRELERİ			
$M_{kütle}$ (ton) =	388.72	a_g (m/s²) =	1.339
Sax (m/s²) =	2.32	Tx (sn) =	0.7145
Say (m/s²) =	2.37	Ty (sn) =	0.7016
Deprem Yükü Fx (kN)=	903.3	Deprem Yükü Fy (kN)=	919.9

Duvar Malzemesi ve Emniyet Gerilmeleri	
Taş duvar	
σ_{em} (MPa) =	0.9
τ_{em} (MPa) =	0.18

TAŞIYICI DUVAR HESAPLARI

Duvar No	Malzeme Özellikleri		Yükseklik	Duvar Plan Yerleşim Bilgileri					Düşey Yük Hesabı			Rijitlik Hesabı		Kritik Duvar Parçacı Özellikleri		Düzlem İçi Etkiler		Düzlem Dışı Etki ve Dayanım		Eleman Kontrol
	E_{duvar} MPa	γ_{duvar} kN/m3	h cm	X sol-alt cm	Y sol-alt cm	Lx/Ly cm	Lnet cm	Açı derece	A_{etkin}	Ek Yük (kN)	ΣP	kx kN/m	ky kN/m	k kritik / k kesit	A kritik cm2	τ MPa	σo MPa	Md kN-m	Mr kN-m	
1	450	20	876	290	0	405/97	310	0	97839		547.5	8118	0	0.53	14259	0.09	0.20	-	-	Yeterli
2	450	20	876	695	0	404/105	300	44	96544		569.0	3573	3235	0.54	15750	0.05	0.19	-	-	Yeterli
3	450	20	876	874.4	279.5	105/412	310	0	97404		577.8	0	9361	0.54	15750	0.09	0.19	-	-	Yeterli
4	450	20	876	619.4	902.4	402/100	296	-45	97211		553.2	3203	3203	0.54	15000	0.05	0.19	-	-	Yeterli
5	450	20	876	280	867.7	406/101	311	0	97953		561.3	8716	0	0.54	15150	0.09	0.19	-	-	Yeterli
6	450	20	876	0	679.3	104/402	297	-45	95668		562.1	3331	3331	0.54	15600	0.05	0.19	-	-	Yeterli
7	450	20	876	2.3	280	103/400	313	0	96254		558.7	0	8598	0.54	15450	0.09	0.19	-	-	Yeterli
8	450	20	876	289.6	0.9	103/401	302	44	96158		559.3	3117	3444	0.54	15450	0.05	0.19	-	-	Yeterli

Figure 5 Selected Sheets for Assessment of a Tomb

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