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New Directions in Seismic Hazard Assessment through Focused Earth Observation in the Marmara Supersite

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D9.1 Improvement of the earthquake risk assessment for Istanbul

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PP	Restricted to other programme participants (including the Commission)	
RE	Restricted to a group specified by the consortium (including the Commission)	▨
CO	Confidential, only for members of the consortium (including the Commission)	

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1. INTRODUCTION

1.1 THE BUILDING INVENTORY FOR ISTANBUL

Several studies have been completed on the earthquake risk assessment for Istanbul city (Ansal et al., 2009; Erdik and Durukal, 2010; Erdik et al., 2010). These studies considered the risk with the available building inventories throughout the city.

In the risk assessment, the identification of building inventories with appropriate classification system and their potential damage levels are the essential steps.

In this study, the improvement on the risk assessment for Istanbul city has been studied through the vulnerability evaluation of typical building structures.

For a general building stock, structural (system, height, and building practices) and occupational (residential, commercial, and governmental) parameters are considered in order to evaluate the risk comprising the damage and loss characteristics.

The Istanbul building inventory has been developed in the study of the IMM, 2009 in accordance with the HAZUS building inventory (FEMA, 2003). The descriptions of 57 classes which were used in the IMM, 2009 study are shown in the Table-1 below.

In HAZUS99 the general building inventory includes residential, commercial, industrial, agricultural, religious, governmental, and educational buildings.

In the IMM 2009 study, the building inventory data includes the information on the construction year, the occupational type, the construction type and the number of floors for each building. The construction type and number of floors are the main parameters affecting the earthquake performance of buildings. Since the applicable seismic design codes in Turkey improved particularly after 1975, the buildings were classified as pre-1979 (included) and post-1980 reflecting the state of seismic design applications.

In the Marsite project WP9, a specific building typology has been studied in order to asssess the vulnerability of this building structure under a potential earthquake ground motion.

The B22 Building in Istanbul, Atakoy district is a residential apartment building which was build in 1998. This 14th store building was constructed on soft soil conditions and it is close to the main Marmara fault line passing through under the Marmara Sea in a distance of 10km. It has been proposed to develop fragility relationship for this specific type of building considering several input ground motions and ambient vibration tests. Finally, it has been proposed to establish a real-time algorithm for early warning purpose.

Table 1 Istanbul building inventory classification

CODE	BUILDING TYPE	NUMBER OF FLOORS	CONSTRUCTION YEAR	NUMBER OF BUILDINGS
B111	OTHER - UNKNOWN	1-4	-1979	588
B121	OTHER - UNKNOWN	5-8	-1979	162
B131	OTHER - UNKNOWN	9-	-1979	3
B112	OTHER - UNKNOWN	1-4	1980-2000	4,637
B122	OTHER - UNKNOWN	5-8	1980-2000	536
B132	OTHER - UNKNOWN	9-	1980-2000	30
B113	OTHER - UNKNOWN	1-4	2000-	458
B123	OTHER - UNKNOWN	5-8	2000-	10
B133	OTHER - UNKNOWN	9-	2000-	1
B211	Masonry	1-4	-1979	96,560
B221	Masonry	5-8	-1979	6,116
B231	Masonry	9-	-1979	0
B212	Masonry	1-4	1980-2000	123,341
B222	Masonry	5-8	1980-2000	333
B232	Masonry	9-	1980-2000	1
B213	Masonry	1-4	2000-	1,141
B223	Masonry	5-8	2000-	1
B233	Masonry	9-	2000-	0
B311	Precast	1-4	-1979	50
B321	Precast	5-8	-1979	0
B331	Precast	9-	-1979	0
B312	Precast	1-4	1980-2000	1,072
B322	Precast	5-8	1980-2000	0
B332	Precast	9-	1980-2000	0
B313	Precast	1-4	2000-	3
B323	Precast	5-8	2000-	0
B333	Precast	9-	2000-	0
B411	Steel	1-4	-1979	157
B421	Steel	5-8	-1979	28
B431	Steel	9-	-1979	2
B412	Steel	1-4	1980-2000	1,364
B422	Steel	5-8	1980-2000	62
B432	Steel	9-	1980-2000	9
B413	Steel	1-4	2000-	137
B423	Steel	5-8	2000-	0

B433	Steel	9-	2000-	0
B511	RC frame	1-4	-1979	84,006
B521	RC frame	5-8	-1979	53,900
B531	RC frame	9-	-1979	1,556
B512	RC frame	1-4	1980-2000	410,737
B522	RC frame	5-8	1980-2000	171,093
B532	RC frame	9-	1980-2000	8,783
B513	RC frame	1-4	2000-	15,012
B523	RC frame	5-8	2000-	120,226
B533	RC frame	9-	2000-	60,271
B611	RC wall	1-4	-1979	0
B621	RC wall	5-8	-1979	0
B631	RC wall	9-19	-1979	0
B641	RC wall	20-	-1979	11
B612	RC wall	1-4	1980-2000	69
B622	RC wall	5-8	1980-2000	128
B632	RC wall	9-19	1980-2000	327
B642	RC wall	20-	1980-2000	146
B613	RC wall	1-4	2000-	0
B623	RC wall	5-8	2000-	35
B633	RC wall	9-19	2000-	242
B643	RC wall	20-	2000-	39

2. REAL-TIME RISK ASSESSMENT BASED ON PERMANENT MONITORING DATA

A real-time risk assessment procedure has been developed to be applied to the Istanbul building inventory. The developed procedure is in the Figure 1 and summarized as below:

1. Operational modal analysis (OMA) is applied by utilizing a real-time data processing tool to the data received from the permanent structural monitoring network,
2. The analytical model (FEM) for each building typology is developed,
3. The correlation on the OMA and FEM is applied,
4. The analytical model is updated according to the OMA results,
5. The Linear Static and Dynamic analysis are applied to the updated analytical model,
6. The interstory drifts and damage states are identified according to the Turkish Seismic Design Code,
7. The real-time fragility curve is obtained,
8. The risk assessment decision is given according to the real-time fragility curve and the limits on the Turkish Seismic Design Code.

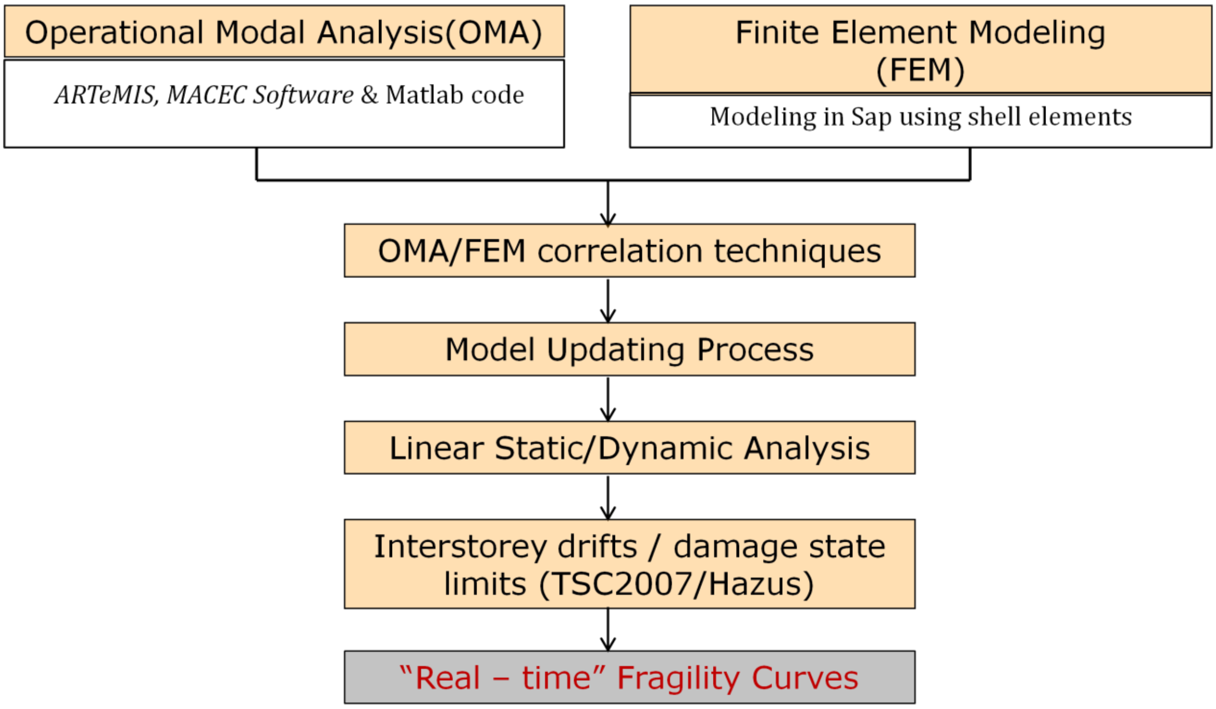

Figure 1: Developed procedure for the real-time risk assessment for the building typologies in Istanbul

2.1 THE B22 BUILDING DESCRIPTION AND STRUCTURAL CONFIGURATION

The dynamic characteristic of one of the typical building structure B22 building in Atakoy district of Istanbul has been studied in a Msc thesis study (Papadimitriou, 2013).

B22 building is a symmetrical structure as shown in Figure 2, at both x and y direction and the two similar parts of the whole building left and right from the entrance are connected through the stairwell which is located at a common area in the middle of the building.

The building has 14 storeys (Figure 3) and $500m^2$ footprint area. The first storey height is 4m and the typical storey height is 2.8m. The slab thickness is 15cm. There are two types of shear walls with 15cm and 20cm ticknesses.

The building was designed according to the regulations of **TC500** for both gravity and seismic loads. Following common practices, the materials used are reinforced concrete type C16 (27000 MPa) or C20 (28000 Mpa).

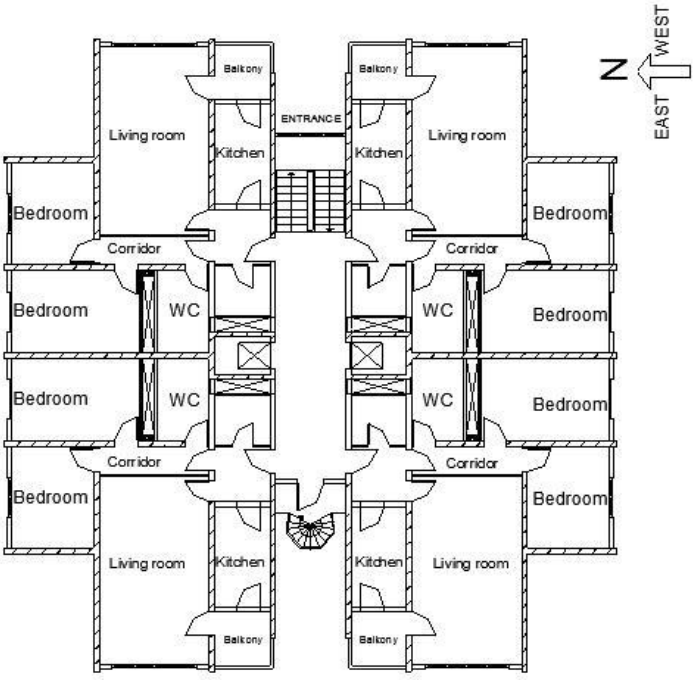

Figure 2: Typical plan view of B22 building normal storey

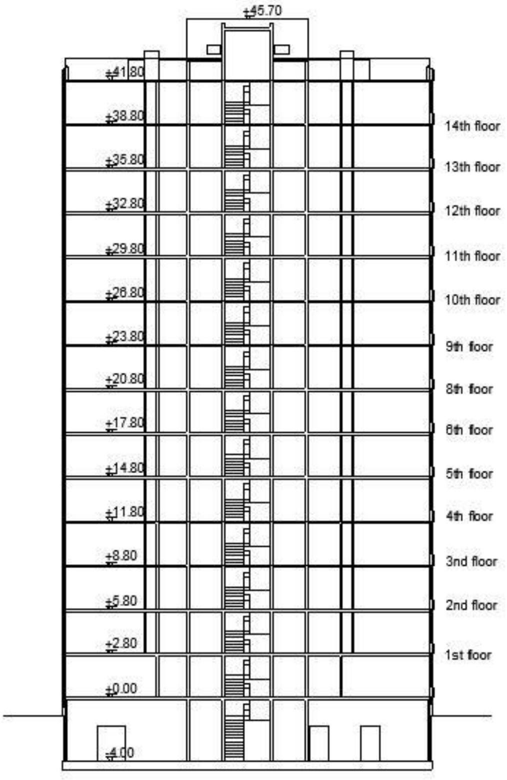

Figure 3: B22 building NS orientation section cut

2.2 THE B22 BUILDING DYNAMIC CHARACTERISTICS

The SAP2000 v.15 software has been used for the eigenvalue analysis in order to extract the natural vibration periods of the building structure. This software has been also used in order to perform elastic time history analysis and an inelastic dynamic analysis.

The structure has been modeled by assuming the lumped-masses for each storey and the slab has been considered as diaphgram. The 3D flat-slab structure model by using shell elements for the shear walls and the slabs has been considered (Figure 4). The 2 eigenvalue analyses have been conducted by changing the material properties -and in advance the modulus of Elasticity- with C16 and C20.

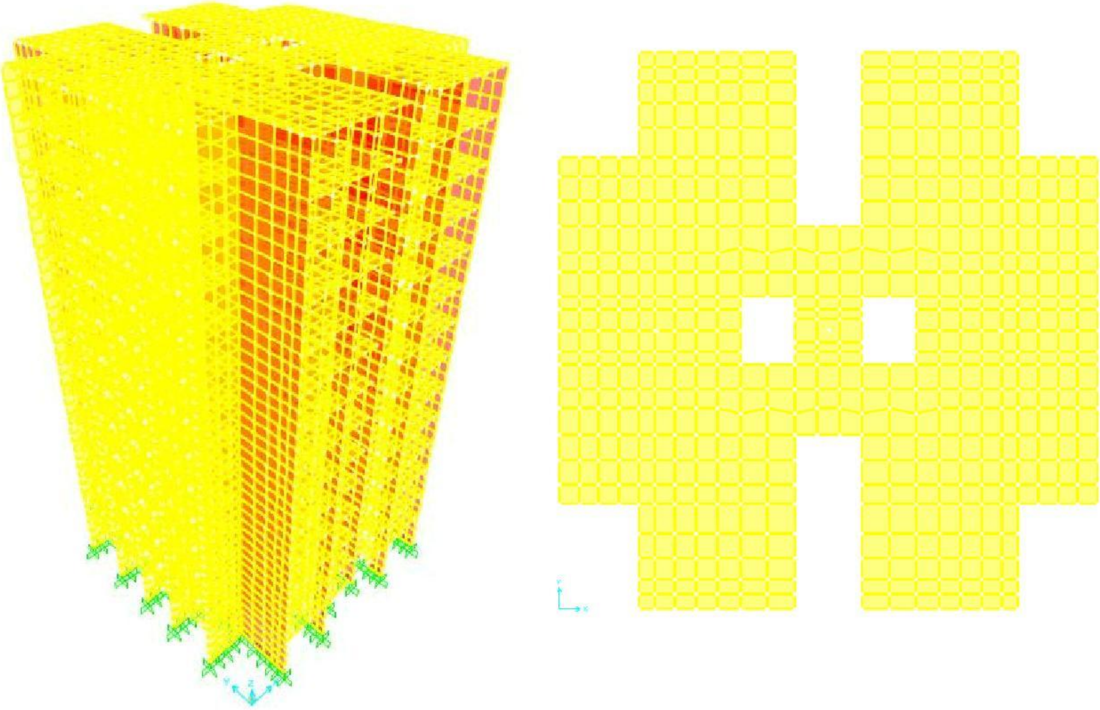

Figure 4: 3D-Model of the B22 building (Sap2000 V.15)

The eigenvalue analysis results have shown that the first three natural periods of the structure are T=0.75, 0.62 and 0.51 seconds for C16 (Figure 5) and T=0.80, 0.66 and 0.56 seconds for C20, respectively. The natural vibration periods seemed reasonable for high-rise concrete structure with shear walls and without beams.

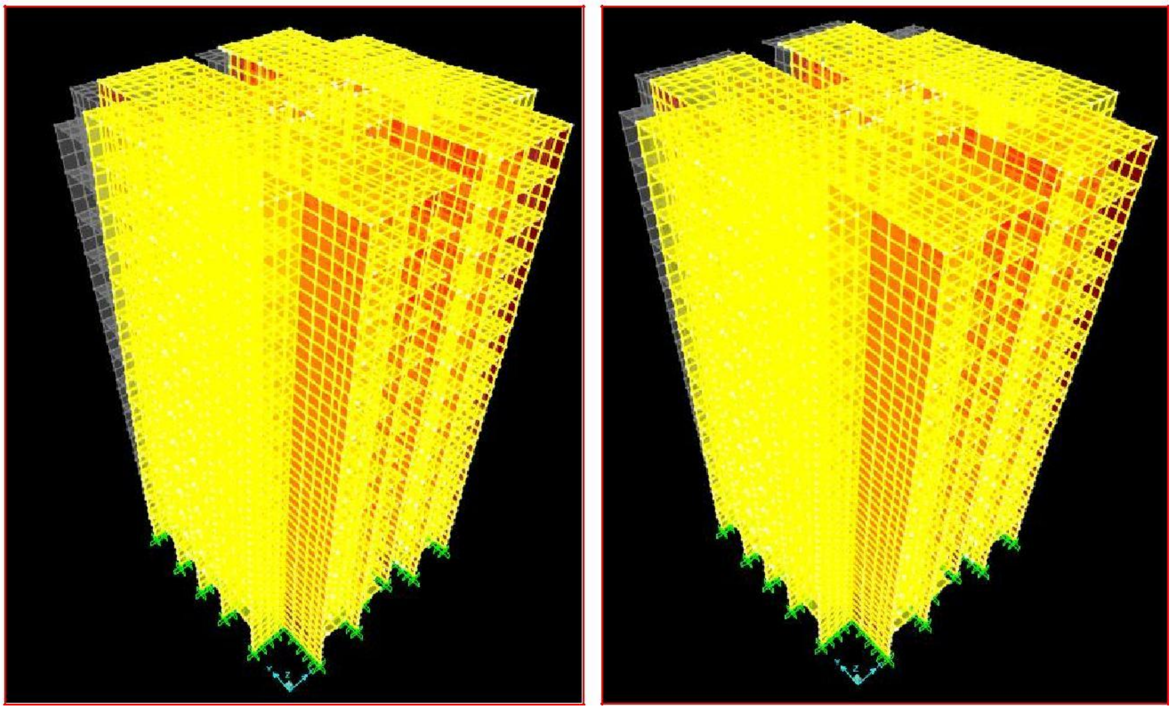

Figure 5: Mode 2- T=0.62509, f=1.59976 (left) & Mode 3-T=0.51437, f=1.94411(right)

2.3 THE B22 BUILDING AMBIENT VIBRATION MEASUREMENTS

A wireless monitoring system has been established to the B22 building in 2008 for the on-site Earthquake Early warning Algorithm testing (Fleming K., et.al, 2009).

The location of the monitoring network sensors in the B22 building is shown in the Figure 7 to Figure 9 and it is also given in the Table 2. The data provided by the network is transmitted to the BU-KOERI data center through the internet line.

The ambient vibration tests have been done on June 10th and 11th 2013. The sampling rate was fixed to 100Hz. The details on the data for each sensor are given in the Table 3.

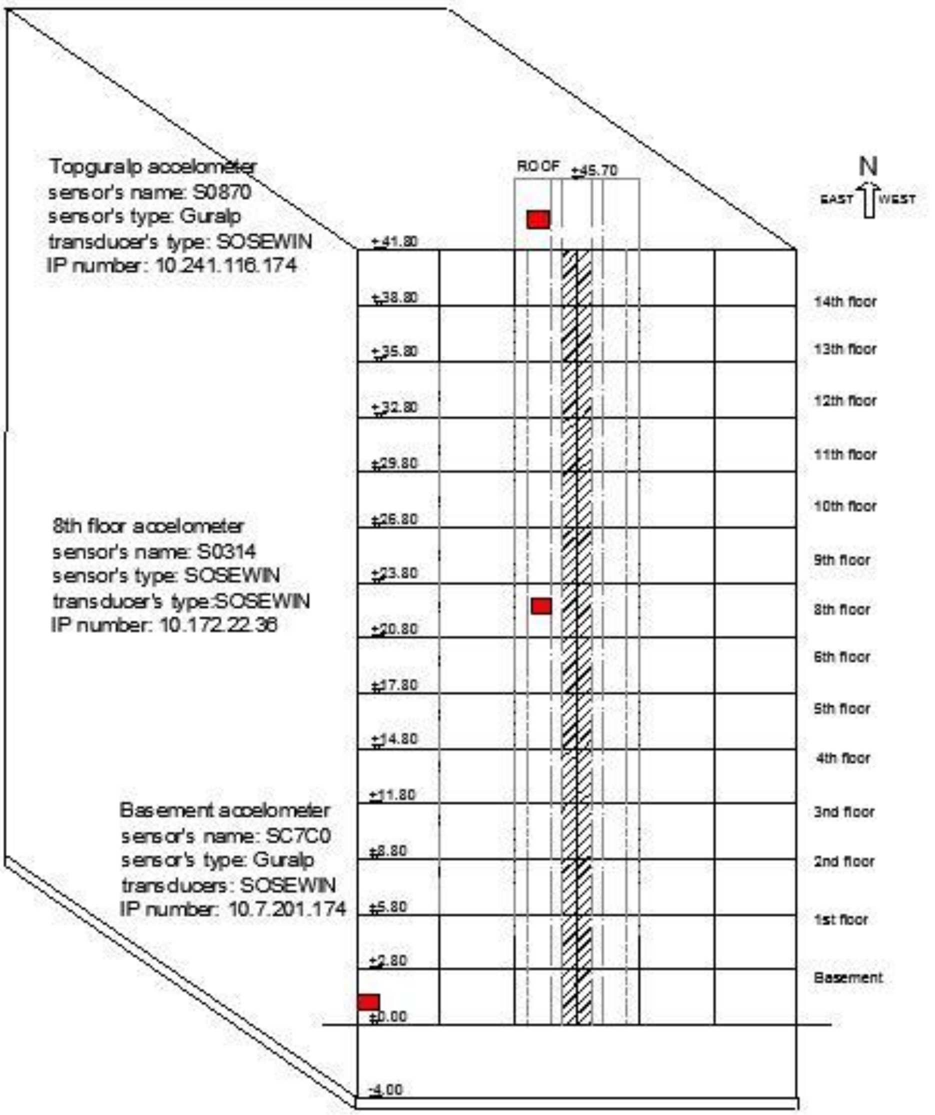

Figure 6: Location of the sensors in the B22 building

Table 2 Information on the B22 building monitoring network

Location of the Sensors	Sensors name	Sensors type	Transducers type	IP number
Basement accelometer	SC7C0	Guralp	SOSEWIN	10.7.201.174
8th floor accelometer	S0314	SOSEWIN	SOSEWIN	10.172.22.36
Top floor accelometer	S0870	Guralp	SOSEWIN	10.241.116.174

Figure 7: Location of the basement floor sensor in the B22 building

Figure 8: Location of the 8th floor SOSEWIN sensor in the B22 building

Figure 9: Location of the top floor Guralp sensor and SOSEWIN transducer in the B22 building

Table 3 Ambient vibration tests recordings at the B22 building

Ambient Vibration Data				
Sensors	**Channels**	**Date**	**Starting time**	**End time**
1	**SC7C0-EW06C**	11/6/2013	00:43:42:970	04:55:20:650
	SC7C0-NS06C	11/6/2013	00:43:42:970	04:55:19:980
	SC7C0-Vertical06C	11/6/2013	00:43:40:940	04:55:18:570
1	**SC7C0-EW064**	10/6/2013	16:49:53:840	20:42:24:650
	SC7C0-NS064	10/6/2013	16:49:55:670	20:42:22:980
	SC7C0-Vertical064	10/6/2013	16:49:53:310	20:42:24:950
1	**SC7C0-EW068**	10/6/2013	20:42:24:660	00:43:42:960
	SC7C0-NS068	10/6/2013	20:42:22:990	00:43:44:960
	SC7C0-Vertical068	10/6/2013	20:42:24:960	00:43:40:930
1	**SC7C0-EW070**	11/6/2013	04:55:20:660	08:48:21:400
	SC7C0-NS070	11/6/2013	04:55:19:990	08:48:22:550
	SC7C0-Vertical070	11/6/2013	04:55:18:580	08:48:22:210
1	**SC7C0-EW074**	11/6/2013	08:48:21:410	08:52:53:610
	SC7C0-NS074	11/6/2013	08:48:22:560	08:52:54:790
	SC7C0-Vertical074	11/6/2013	08:48:22:220	08:52:53:680
2	**S0314-EW04C**	10/6/2013	18:21:41:463	21:29:27:199
	S0314-NS04C	10/6/2013	18:21:42:023	21:29:27:419
	S0314-Vertical04C	10/6/2013	18:21:43:073	21:29:27:549
2	**S0314-EW05C**	11/6/2013	06:52:53:684	08:43:13:691
	S0314-NS05C	11/6/2013	06:52:53:554	08:43:11:771
	S0314-Vertical05C	11/6/2013	06:52:51:314	08:43:11:560

2	**S0314-EW048**	10/6/2013	15:14:05:113	18:21:41:453
	S0314-NS048	10/6/2013	15:14:03:843	18:21:42:042
	S0314-Vertical048	10/6/2013	15:14:02:923	18:21:43:063
2	**S0314-EW050**	10/6/2013	21:29:27:209	00:37:17:597
	S0314-NS050	10/6/2013	21:29:27:429	00:37:20:327
	S0314-Vertical050	10/6/2013	21:29:27:559	00:37:18:897
2	**S0314-EW054**	11/6/2013	00:37:17:607	03:45:10:369
	S0314-NS054	11/6/2013	00:37:20:337	03:45:03:139
	S0314-Vertical054	11/6/2013	00:37:18:907	03:45:10:669
2	**S0314-EW058**	11/6/2013	03:45:10:379	06:52:53:674
	S0314-NS058	11/6/2013	03:45:09:149	06:52:53:544
	S0314-Vertical058	11/6/2013	03:45:10:679	06:52:51:304
3	**S0870-EW07C**	10/6/2013	07:49:33:960	11:25:42:240
	S0870-NS07C	10/6/2013	07:49:35:740	11:25:40:430
	S0870-Vertical07C	10/6/2013	07:49:35:720	11:25:41:340
3	**S0870-EW08C**	10/6/2013	22:28:15:660	02:41:13:830
	S0870-NS08C	10/6/2013	22:28:16:210	02:41:16:620
	S0870-Vertical08C	10/6/2013	22:28:17:110	02:41:15:360
3	**S0870-EW070**	10/6/2013	20:04:14:670	20:44:02:290
	S0870-NS070	10/6/2013	20:04:11:990	20:44:00:950
	S0870-Vertical070	10/6/2013	20:04:12:680	20:44:01:320
3	**S0870-EW074**	10/6/2013	00:02:56:950	04:08:32:260
	S0870-NS074	10/6/2013	00:02:57:970	04:08:31:000
	S0870-Vertical074	10/6/2013	00:02:56:320	04:08:32:710
3	**S0870-EW078**	10/6/2013	04:08:32:270	07:49:33:950
	S0870-NS078	10/6/2013	04:08:31:010	07:49:35:730
	S0870-Vertical078	10/6/2013	04:08:32:720	07:49:35:710
3	**S0870-EW080**	10/6/2013	11:25:42:250	15:02:36:590
	S0870-NS080	10/6/2013	11:25:40:440	15:02:35:360
	S0870-Vertical080	10/6/2013	11:25:41:350	15:02:35:340
3	**S0870-EW084**	10/6/2013	15:02:36:600	18:36:56:370
	S0870-NS084	10/6/2013	15:02:35:370	18:36:55:530
	S0870-Vertical084	10/6/2013	15:02:35:350	18:36:56:790
3	**S0870-EW088**	10/6/2013	18:36:56:380	22:28:15:650
	S0870-NS088	10/6/2013	18:36:55:540	22:28:16:200
	S0870-Vertical088	10/6/2013	18:36:56:800	22:28:17:100
3	**S0870-EW094**	11/6/2013	06:27:13:560	07:38:47:780
	S0870-NS094	11/6/2013	06:27:14:310	07:38:50:320
	S0870-Vertical094	11/6/2013	06:27:12:090	07:38:48:460

A Matlab code has been developed in order to process the ambient vibration recording and extract the fundamental period of the structure.

The acceleration-time history and Fast Fourier transform of the top floor recording are shown in the Figure 10 and Figure 11, respectively.

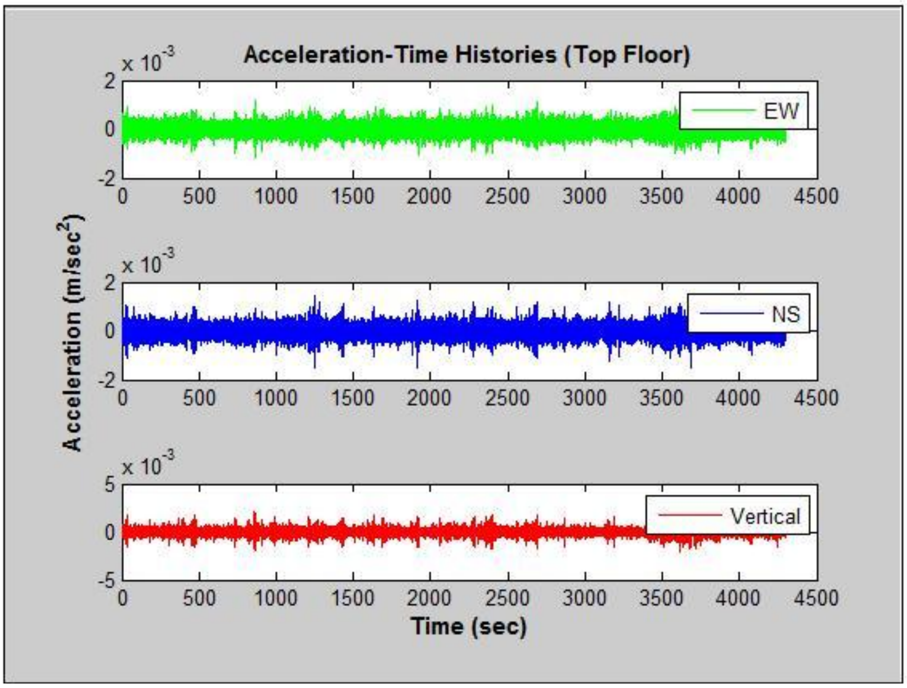

Figure 10: Acceleration time histories of sensor 3 at the top floor for the record 7C

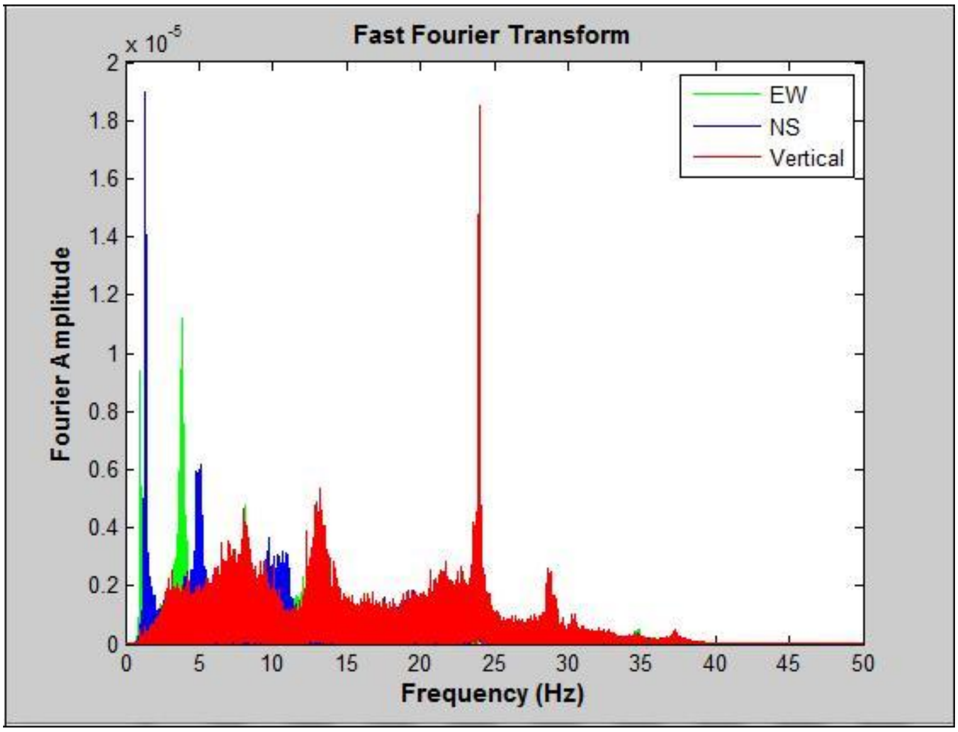

Figure 11: Fast Fourier Transform for the tree components in comparison for the sensor 3 and record 7C at the top floor

When the records from basement, 8th and top floors are compared, it is seen that the top floor records FAS gives clear peaks at certain frequencies referring the modal periods of the building as shown in the Table 4.

Table 4 B22 building modal frequencies according to the ambient vibration tests

Ambient Vibration Results_Top Floor records				
Orientation	**1st mode**	**2nd mode**	**3nd mode**	**4nd mode**
NS	1.36Hz	5.71Hz	9.75Hz	10.65 Hz
EW	1.53Hz	5.85Hz	8.086Hz	11.85Hz

In the application of the real-time data processing algorithm several procedures have been tested. In order to filter the high amplitude noise due to the environmental conditions and mechanical vibrations the running window method has been used. The smoothing has been applied to FAS of each running window in order to reduce the noise effect called as SFAS. A series of frequency bands have been defined in order to identify the modal frequencies.

The first four fundamental modal frequencies for the two horizontal directions and the vertical one are identified through the data processing algorithm are shown in the following Table 5.

Table 5 SFAS applied B22 natural modes at each direction

No Mode	North-South(x)	East-West(y)	Vertical(z)
1st	0.74 sec	0.65 sec	0.26sec
2nd	0.18 sec	0.17 sec	0.18sec
3rd	0.10 sec	0.12 sec	0.12sec
4th	0.095sec	0.085sec	0.09sec

The comparison of B22 building natural modes between the data processing algorithm analytical model is shown in Table 6.

Table 6 Comparison between the data processing algorithm and analytical model

No Mode	North-South -X Direction		East-West-Y Direction	
	Matlab code	Analytical Model-Sap	Matlab code	Analytical Model-Sap
1st	0.74 sec	0.63 sec	0.65 sec	0.51 sec
2nd	0.18 sec	0.15 sec	0.17 sec	0.13 sec
3rd	0.10 sec	0.07 sec	0.12 sec	0.06 sec
4th	0.095 sec	0.04 sec	0.085 sec	0.03 sec

2.4 THE MODEL UPDATING BASED ON THE AMBIENT VIBRATION MEASUREMENTS

A methodology for the numerical model updating based on the ambient vibration data has been followed. The aim of the procedure is to find the best suitable model within a class of simulated numerical models, based on incomplete modal data, as well as the most probable value of the system natural frequencies and the full system mode shapes.

Mean and standard deviation of the Young's Modulus, percentage of variability of the modal masses and type of distribution of the aforementioned sensitivity parameters among the structural members are needed in order to define the simulation of the numerical models. By changing the modulus of Elasticity we make difference to the stiffness of the structure taking into consideration the cracked concrete caused by a ground hazard motion. Changes in geometry, boundary conditions and other structural characteristics are not considered in this specific study. The level of accuracy between measured and numerical mode shapes is estimated through the definition of a *Generalized Modal Error (GME)* (e.g. Alvin, 1997), which involves both frequencies and modal displacements.

2.5 FRAGILITY CURVES DERIVATION BASED ON FIELD MEASUREMENT RESULTS

The Fragility curves represent the probability of the occurrence of a specific damage state to a structure, under a certain level of ground motion shaking. As a result, any phenomena, such as degrading of the structural material properties due to aging or probable damages by various events during the lifetime of the structure could inherently influence the extent of response of the building to any arbitrary excitations in comparison to the original intact state. This is to imply that the "fragility curves" of a specific structure might not potentially hold their initial configuration and could need an upgrade to the "real time" condition.o

Accordingly, in order to derive the "fragility curve" for the specific B22 building based on the latest dynamic characteristics, measured on-site data which are assumed to reflect the most updated condition of the building have been used.

The following step-by-step procedure has been followed in the derivation of the fragility curve:

1) Structural response evaluation,
2) Ground motion hazard level selection,
    2.1) Records selection,
    2.2) Interstory drift profile based on the records selection,
3) Numerical evaluation and aritmetic statistics,
4) Building damage states,
5) Curve fitting and fragility functions,
6) Derivation of fragility curves,

Seismic vulnerability analysis of existing buildings requires basic information on their structural behaviour. The ambient vibrations of buildings and the modal parameters (frequencies, damping ration and modal shapes) that can be extracted from them naturally include the geometry and quality of material in the linear elastic part of their behaviour. The aim of this work is to use this modal information to help the vulnerability assessment.

In order to predict damage, the interstory drift ratio has been chosen as damage index as in HAZUS (FEMA, 2003). A linear dynamic model based on experimental modal parameters is proposed and the fragility curve corresponding to the damage state "Slight" is built using this model and a simple formula is proposed. This curve is particularly interesting in moderate seismic areas. Istanbul is a city with moderate seismic behavior and the procedure could be followed for the residential building B22 in Ataköy district.

As the model remains simple, many runs can be computed and particularly many ground motions can be used as input. Therefore, the probability of (slight) damage with respect to a ground motion parameter can be studied, i.e. the first fragility curve of the building can be drawn. It is modeled as a cumulative lognormal distribution with its median and its lognormal standard deviation.

For moderate seismicity countries, this method is able to discriminate buildings that should not be reinforced and buildings that should be more precisely studied. Moreover, even if the Slight damage grade is not interesting for life safety issues and catastrophic earthquakes, it is valuable information for moderate earthquakes that compose the major part of the risk in North-Western Europe. In order to better estimate the financial amount of this risk, a good knowledge of the low damage grades is necessary.

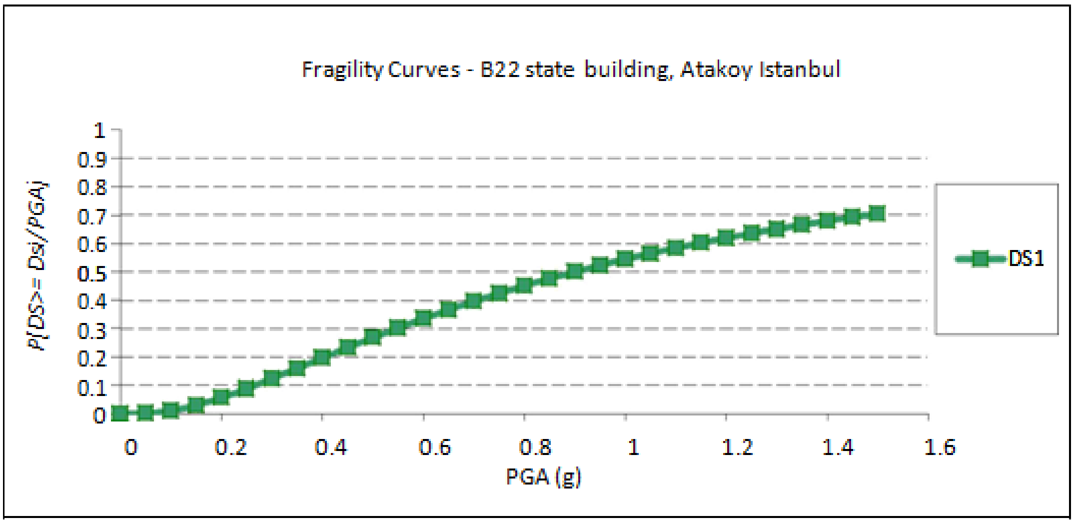

Figure 12: Fragility curve derivation for the Slight damage state limit and scaling levels of PGA:0.1g, 0.3g and 0.5g.

The method by Porter et.al, 2007 has been followed for derivating fragility curves for flat-slab buildings which are constructed only by shear walls and slabs without beams as in the B22 building as shown in the Figure 12.

3. SUMMARY AND CONCLUSION

A building typology within the Istanbul building inventory has been studied in detail for the development of the real-time risk assessment procedure. It is considered to adopt this developed methodology for the other building typologies in the inventory.

The utilization of a set of simple techniques using Ambient Vibration recordings to complement seismic vulnerability assessment to existing buildings has been studied. Decomposing the motion of a building into simple modes (bending and torsion) is the first step in the assessment of its behaviour under an earthquake. The building modal parameters has been extracted by using the Frequency Domain Decomposition (FDD) method, which is easy to perform and reliable even in case of close modes. The analysis of recordings showed that the FDD is able to extract reliable information (frequency, modal shapes and eventually damping) even if the basic assumption of white noise is not fulfilled. The values of the measured frequencies are directly linked to the stiffness of the building so that the average stiffness ratio between the longitudinal and the transverse directions can be assessed.

For vulnerability assessment, only analysis of recordings is not sufficient so the analytical approach with a simple lumped-mass model with an assumption on the stiffness matrix (shear wall) in order to calculate the stiffness at each storey has been applied. The choice of the stiffness model is based on the sequence of the resonance frequencies of the studied building.

The concept of fragility curves in the safety assessment has been first applied for the nuclear power plants and there has been still an ongoing effort towards the generalization of the methodology for the vulnerability and risk assessment of various structures. Furthermore and based on the definition of the seismic fragility of any arbitrary object, the analytical procedures should target the evaluation of the probability of reaching or exceeding a certain damage level under a specific demand state, here taken to be the ground motion hazard level. It needs to be reminded that all the numerical evaluations have been specifically performed, using the actual recorded data of the reinforced flat slab building at Ataköy so that the derived diagrams and functions could be interpreted as the ‘real-time’ properties of the structure under consideration.
It is believed that the developed procedure in this study can be applied to other building typologies.

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