SECOND EUROPEAN CONFERENCE ON EARTHQUAKE ENGINEERING
AND SEISMOLOGY, ISTANBUL AUG. 25-29, 2014

VIBRATION-BASED FEM UPTADING AND SEISMIC RELIABILITY ESTIMATION OF A HISTORICAL BUILDING IN ISTANBUL

Oguz SENKARDESLER[1], Gulseren EROL[2], Serdar SOYOZ[3]

ABSTRACT

Seismic demands on structures are estimated using different methods such as equivalent lateral force method, linear or nonlinear time history analysis. In all these analyses the assumption is that Finite Element Model of the building represents the actual dynamic behavior and input is characterized accurately. In this paper, the importance of uncertainties both in the input and the model for determination of seismic demand was investigated. A masonry historical building in Istanbul constructed in 1925 was considered. In-situ and laboratory test results for the building material were available and used in Finite Element Modeling. Afterwards, ambient vibration tests were carried out to obtain the actual and global dynamic characteristics of the building. Based on identified modal values, FEM was updated by changing the material properties. Seismic failure probability was obtained by fitting a log-normal distribution to the maximum base shear demands obtained under different input motions and then calculating the exceedance probability of a threshold value.

1 INTRODUCTION

In the seismic performance assessment of structures demand and capacity of the structure are compared in terms of various parameters such as inter-story drift, base shear, rotational ductility and strain values. For structures with negligible higher mode effects, equivalent lateral force method gives reasonable seismic demand values. In earthquake engineering uncertainty in the input motion has been well recognized and treated by considering design spectrum approach for static analysis. Time domain analyses require selection of design spectrum compatible input motions. On the other hand uncertainty in the structure itself; therefore, in Finite Element Model (FEM) has not been acknowledged so well. The current state-of-the-practice is that one performs in-situ or laboratory material tests and then correlates these values to material properties such as Young's Modulus in FEM. There are sources of uncertainties in this approach such as inaccuracy of material tests, equations used to obtain Young's Modulus from material tests and FEM assumptions. As an increasing trend, vibration-based identification of dynamic characteristics and FEM updating turned out to be a promising tool to assess the global behavior of the structures.

There is significant literature on structural health monitoring of buildings, bridges, offshore platforms but here only some related with historical buildings was summarized. For example, Gentile and Saisi (2007) identified modal values of a masonry bell tower with the presence of major cracks. Calibration of FEM was achieved by decreasing the material properties of the tower. Casarin and Modena (2008) carried out both non-destructive testing and ambient vibration survey to determine to physical and global dynamic values of Reggio Emilia Cathedral. They also calibrated their FEM and estimated seismic vulnerability of the structure. Ramos et al. (2010) carried out ambient vibration surveys for historical masonry structures and identified the relation between modal values and

[1] Department of Civil Engineering, Bogazici University, Istanbul, Turkey, oguzsenkardesler@gmail.com

[2] Department of Architecture, Istanbul Technical University, Istanbul, Turkey, guluse@yahoo.com

[3] Department of Civil Engineering, Bogazici University, Istanbul, Turkey, serdar.soyoz@boun.edu.tr

environmental temperature. Binda et al. (2011) identified the modal values of Spanish Fortress after L'Aquila Earthquake using ambient vibration data and indicated that the structure has the unitary vibration mode in spite of high level of damage probably due to provisional emergency steel cables. Cimellaro et al. (2012) identified modal values of a tower and a damaged palace after L'Aquila Earthquake using different output identification methods such as frequency domain decomposition, random decrement, eigensystem realization algorithm. They updated their FEM by changing material properties.

In this paper, vibration-based modal identification and FEM updating of a historical masonry structure was discussed. For non-ductile structures, the elongation in the structural period will be small and therefore the period identified using ambient vibration tests defines seismic demand on the structures. Furthermore, for non-ductile structures such as historical buildings the occurrence of the first damages may mean the limit of the structure. Therefore, in this study linear elastic analyses are used to obtain seismic demand. The importance of vibration-based identification on the determination of seismic demand was quantified by carrying out linear time history analyses.

2 BUILDING

Kadikoy Health Care Center in Istanbul is a registered historical masonry building that was built in 1925, Figure 1. The building consists of basement, ground and 1st floors.

Plan of the building is U shaped, Figure 2. The maximum dimension in the longitudinal direction of the plan is 33.09 m, while the maximum dimension in perpendicular direction is 18.84 m. Plan dimensions are same in all three stories. The story heights of basement, ground floor and 1st floor are 3.45m, 4.85m and 4.45m, respectively.

Masonry walls of basement are alternated walls. Natural stones are used between the two lined solid bricks in every 60 cm. However, masonry walls of ground and 1st floor are only made of solid bricks. The wall thicknesses alter between 68-88cm in the basement, 45-76cm in the ground floor and 32-65cm in the 1st floor.

Slabs of ground floor and 1st floor are brick arch floor systems, where steel beams of INP180 are placed with 60 cm intervals. Slab of the roof is made of timber elements.

No significant damage was observed during the inspections of the building. However, there are some interventions to the building at the present state due to change in function. These interventions can be summarized as addition of some partition walls, change in the size of a few windows, filling a few door cases and transformation of a staircase to a room.

Figure 1. Front view of the building

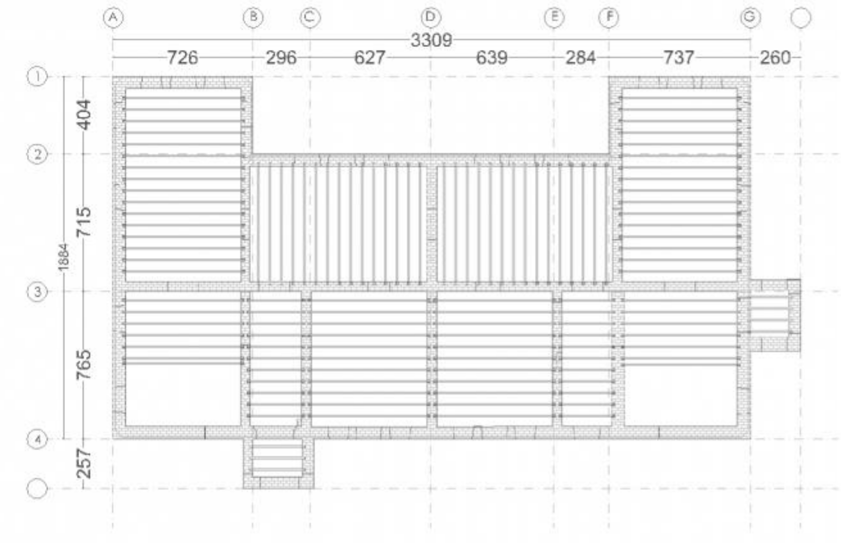

Figure 2. Plan of ground floor, (dimensions are in cm)

3 FINITE ELEMENT MODEL

Finite Element Model (FEM) of the building was constructed to be able to estimate its seismic performance. Material properties should be known to be utilized in FEM. Material properties are also needed for the capacity estimation of the building in terms of shear strength.

3.1 Material Tests

Shear tests were carried out in-situ and in laboratory conditions for masonry walls and presented as a report by previous researchers upon the request of owner of the building (Yildirim, 2011).

For in-situ shear test of masonry wall, two blocks were removed from the vicinity of a block and then this block was loaded by using a hydraulic jack. This test was performed 5 times at different locations of the building, 3 at ground floor and 2 at 1st floor. Besides these, two core samples were taken from ground floor and tested for shear in laboratory conditions. These core samples were consisted of including brick-mortar-brick layers, Figure 3. Test results are presented all together in Table 1. It should be noted that average shear strength (τ) of masonry walls for ground and 1st floors are 0.47 MPa and 0.23 MPa, respectively.

A few bricks were taken as samples from random places at the ground floor and tested for compression in laboratory. The compressive strength of these brick samples were reported as 2.2 MPa, 15.2 MPa and 14.3 MPa.

Figure 3. Material testing

Table 1. Shear strength of masonry walls

Sample no	Location	Test Type	Shear Strength (MPa)
Z-1	Ground Floor	In-situ	0.49
Z-2	Ground Floor	In-situ	0.68
Z-3	Ground Floor	Inlaboratory	0.32
Z-4	Ground Floor	Inlaboratory	0.58
Z-5	Ground Floor	In-situ	0.27
I-6	1st Floor	In-situ	0.21
I-9	1st Floor	In-situ	0.24

Finally, brick-mortar samples were taken from random places at different stories of the building compressive strength of masonry walls were obtained, Table 2.

Table 2. Compressive strength of masonry walls.

Sample no	Location	Compressive Strength (MPa)
1	Ground Floor	6.8
2	Ground Floor	4.5
3	1st Floor	7.2

The Young’s Modulus of the walls is obtained using Equation 1 as given in Turkish Code for Buildings to be Built in Seismic Zones (2007).

$$E=200f_d \qquad (1)$$

f_d denotes the compressive strength of masonry wall.

3.2 Finite Element Model

Finite Element Model (FEM) of the building was constructed by using ETABS software as shown in Figure 4. Shell elements were used to model walls. Door and window openings were also represented in FEM.

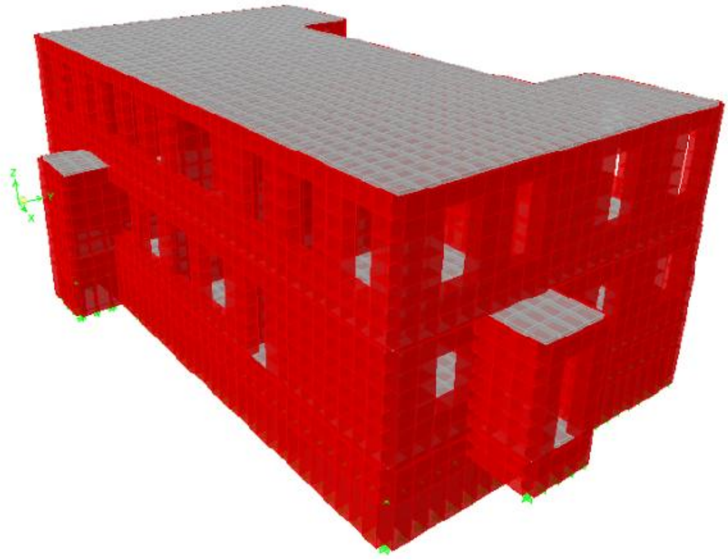

Figure 4. FEM of the building

Table 3 shows the modal frequencies of the building obtained from FEM. In this table different configurations were considered. ‘Basic‘ means the FEM with no openings and no soil restraining effects for the portion of the building under ground level, ‘openings‘ means the FEM including door and window openings, ‘restraints‘ means the FEM with the openings and the soil restraints. It was observed that because of the openings in the model the modal contribution of the first mode significantly drops and the higher mode effects increase. Therefore, first mode representation of total response turns out to be invalid.

Table 3. Modal frequencies from FEM

	Freq.(Hz)		
	Basic	Openings	Restraints
Mode1(Y)	5.50	5.16	5.37
Mode1(X)	5.74	5.09	5.27
Mode1(T)	7.49	5.89	6.16

4 FEM UPDATING

It is known that material properties show remarkable variations especially for the masonry structures. This will lead to variations of the dynamic characteristics of the structure and eventually its seismic performance. In the following chapters, construction of FEM based on average material properties and design drawing is explained. Then, updating of this initial FEM based on vibration-based identification results is discussed.

4.1 Ambient Vibration Survey

Figure 5 shows the instrumentation of the building. Five Episensors (Kinematrics Inc.) type accelerometers were used to obtain the vibration response. Two sensors were located on the ground floor and three sensors were located on the 1st floor.

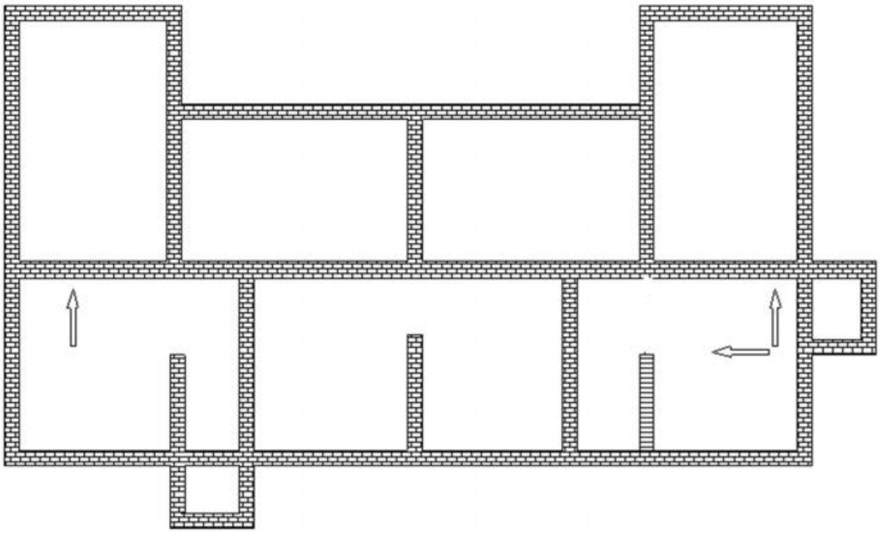

Figure 5 Positions and directions of sensors

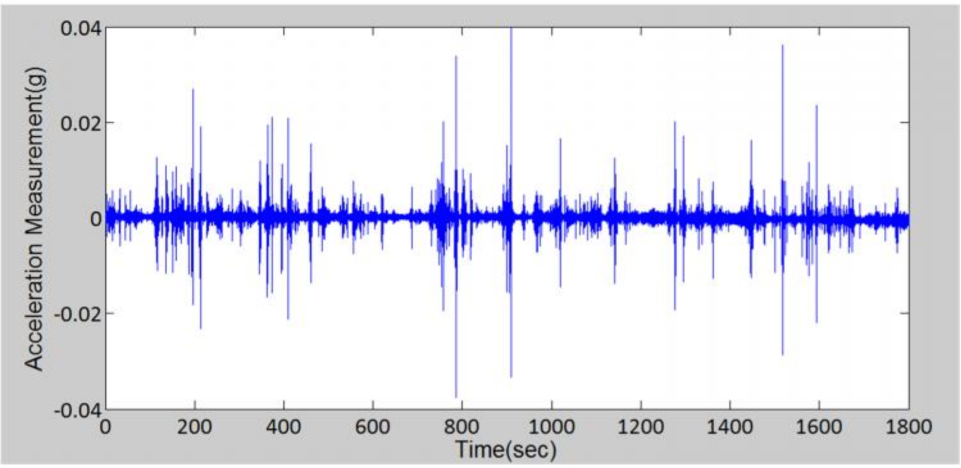

Figure 6. Acceleration time history data

An output-only method, the Frequency Domain Decomposition (FDD) method (e.g., Otte et al. 1990, Brinker et al. 2001) was used to extract modal parameters from the vibration measurements without requiring information for input. The FDD method is capable of identifying closely coupled modes, thus obtaining better estimates compared to other modal identification methods (Otte et al. 1990). In this method, spectral density matrix $S_{YY}(w)$ of the response vector *Y(t)* is decomposed by singular value decomposition, as illustrated in the Equation 2,

$$S_{YY}(w) = U(w)\Sigma(w)U^H(w) \qquad (2)$$

where
$\Sigma(w)$ = diagonal matrix of the singular values,
$U(w)$ = unitary matrix of the singular vectors,
the superscript *H* denotes the complex conjugate and transpose.

It has been shown by (Otte et al. 1990) that, when the structure is loaded with the broadband excitation, near the modal frequencies, $\Sigma(w)$ contains a set of functions which are approximations of the auto-spectral density functions of the modes' equivalent single degree-of-freedom systems in the normal coordinates, while the vectors in $U(w)$ are the modal shapes of the corresponding modes.

Figure 7 shows the power spectral density of the acceleration data. The first group of peaks represents structural peaks with meaningful mode shapes whereas peaks around 20 Hz possibly represent the effect of soil-structure interaction which deserves further investigation.

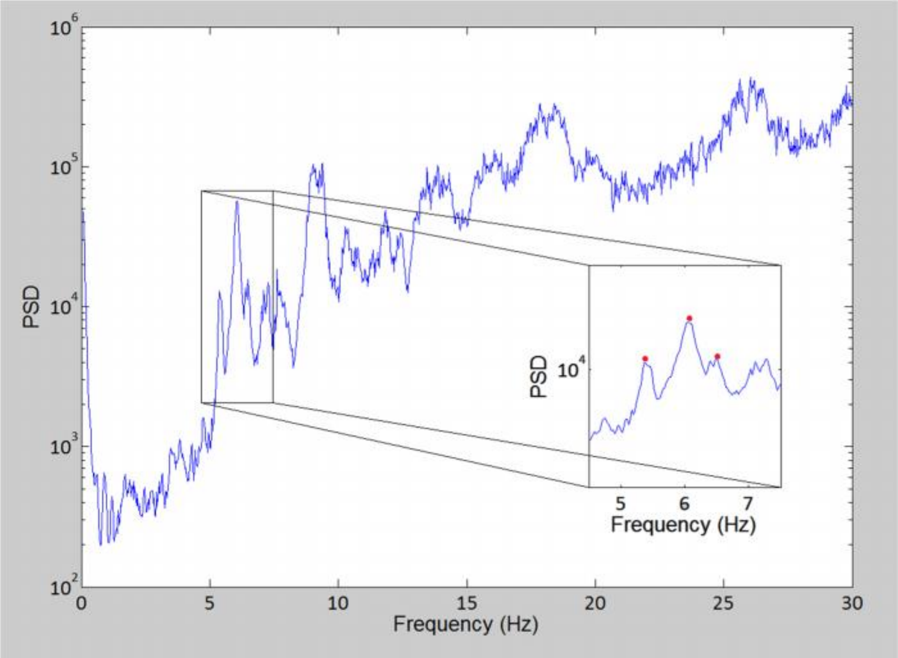

Figure 7. PSD of the acceleration data

Table 4 shows the modal frequencies identified by FDD using ambient vibration data.

Table 4. Modal Frequencies from Identification

	Freq(Hz)
Mode 1 (Y)	5.41
Mode 1 (X)	6.02
Mode 1 (T)	6.49

Although more elaborate updating procedures can be used, in this study Young's Modulus was increased 13% -from 1.08 GPa to 1.23 GPa. Modal frequencies after updating are shown in Table 5

Table 5. Modal Frequencies of updated FEM.

	Freq(Hz)
Mode 1 (Y)	5.73
Mode 1 (X)	5.61
Mode 1 (T)	6.58

4 SEISMIC PERFORMANCE ASSESSMENTS

Linear time history analyses were carried out to obtain base shear demand of the structure. North Anatolian Fault is the most important fault line in Anatolia which is a very active seismic area with several major and lots of minor fault lines. This fault line is crossing Anatolia from one end to other and produced lots of major earthquakes throughout the history. Lots of historical records show that, very destructive earthquakes were produced by this fault line. The last two of them were devastating Kocaeli (M=7.4) and Duzce (M=7.2) earthquakes which occurred in 1999. Following the East-West route, this fault line dives into Marmara Sea and continues to the West, gets close to Istanbul shores nearly 10-20 km. While trying to anticipate the seismic demand of the building, this fault line is considered as the main risk source. The building site is in the approximately 20-30 km north of the fault line. Therefore, twelve earthquake records are obtained from PEER database to simulate the seismic demand on the building. These ground motion data are selected according to their magnitude, distance and PGA values. These values are selected according to expected earthquake in Istanbul which is approximated as magnitude 7.5, and the fault segment is 20-30 km away to the building site as suggested by Erdik et al. (2004). Figure 8 shows that mean response spectra of input motions and the design spectrum at the site is quite close to each other.

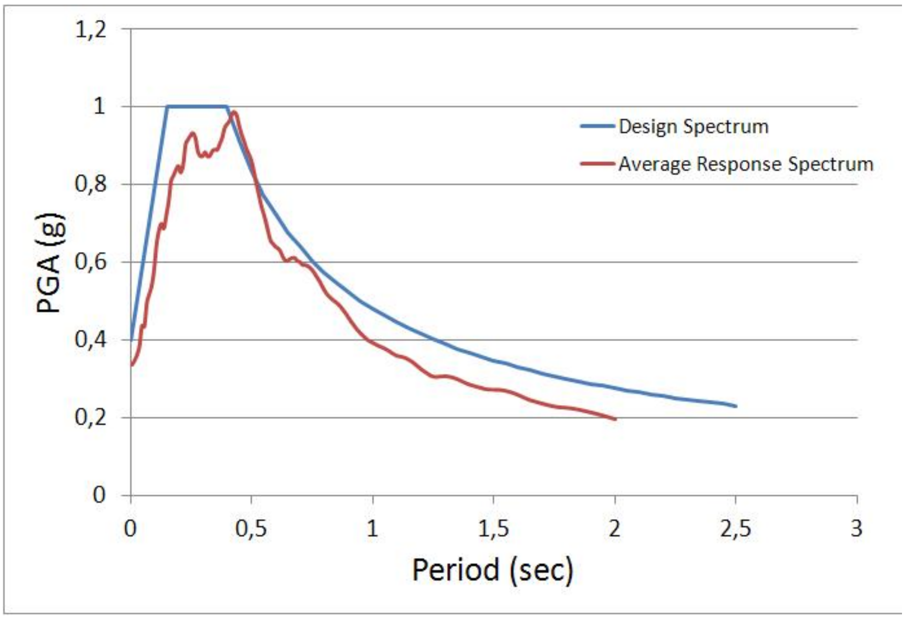

Figure 8. Response spectra of input motions

4.1 Failure Probability Calculations for Seismic Performance Assessment

Seismic performance of the structure was estimated as the exceedance of the probability density function to the threshold value. Along this line, base shear time histories were obtained for each event as shown in Figure 9 and then a lognormal distribution was fitted to the maximum base shear values of the inputs. One can then obtain the failure probability of the structure using a given threshold value.

Threshold value for the base shear can be calculated as the multiplication of average shear strength, 0.47 MPa and the wall cross section are at the ground level. Figure 10 shows that failure probability is 11% for the building.

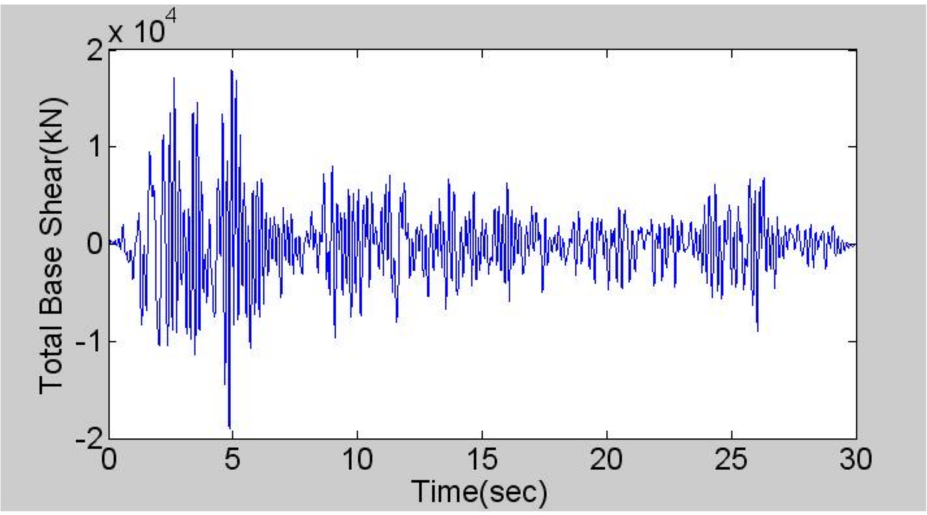

Figure 9. Base shear time history for El Centro ground motion

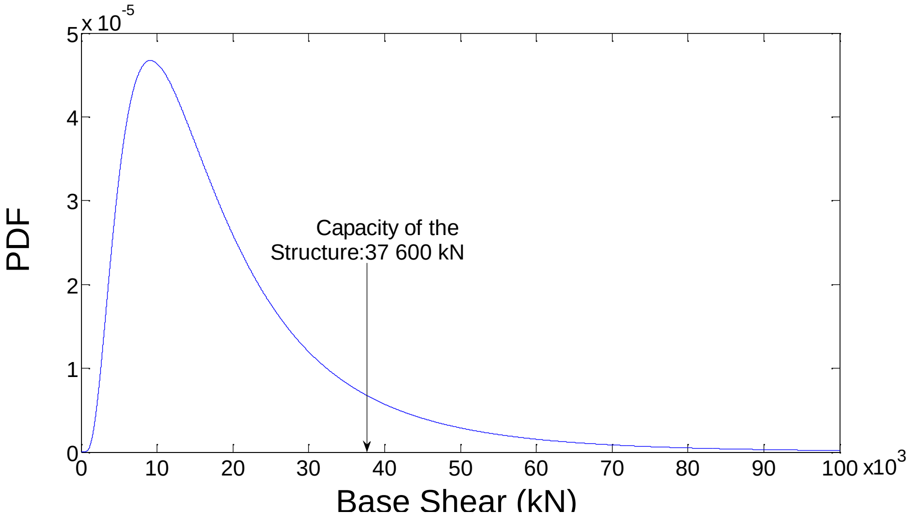

Figure 10. Probability of Failure of the structure

5 CONCLUSIONS

This study covers instrumentation, system identification using FDD method and FEM updating of a masonry building. FEM updating was carried out by changing the Young's Modulus of structural elements in FEM.

Moreover, the effects of the structural openings and soil restraints on the response of the structure were highlighted. It was observed that due to structural openings first mode representation of total response of the building turns out to be invalid as the first mode contribution decreases significantly.

Most importantly a probabilistic framework for the eveluation of the structural failure probabilities under seismic actions is proposed.

.

REFERENCES

Binda, L., Modena, C., Casarin, F., Lorenzoni, F., Cantini, L., Munda, S., 2011. *Emergency actions and investigations on cultural heritage after the L'Aquila earthquake: the case of the Spanish Fortress,* Bulletin of Earthquake Engineering, 9: 105-138.

Brinker, R., Zhang, L. and Andersen, P., 2001. Modal identification of output-only system using frequency domain decomposition, *Smart Materials and Structures*, 10(3), 441–55.

Casarin, F., Modena, C., 2008. *Seismic assessment of complex historical buildings: application to Reggio Emilia Cathedral, Italy,* International Journal of Architectural Heritage, 2: 304-327.

Cimellaro, G.P., Pianta, S., De Stefano, A., 2012. *Output modal identification of ancient L'Aquila City Hall and Civic Tower,* Journal of Structural Engineering ASCE, 138: 481-491.

Erdik, M., M., Demircioglu, K., Sesetyan, E., Durukal and B., Siyahi, 2004, "Earthquake Hazard in Marmara Region, Turkey", *Soil Dynamics and Earthquake Engineering,* No. 24, pp. 605–631.

Gentile, C., Saisi, A., 2007. *Ambient vibration testing of historic masonry towers for structural identification and damage assessment,* Construction and Building Materials, 21: 1311-1321.

Otte, D., Ponseele, P. V. D. and Leuridan, J., 1990. Operational shapes estimation as a function of dynamic loads, in *Proceedings of 8th International Modal Analysis Conference*, Society for Experimental Mechanics, Orlando, FL, 413–21.

Ramos, L.F., Marques, L., Lourenco, P.B., De Roeck, G., Campos-Costa, A., Roque, J., 2010. *Monitoring historical masonry structures with operational modal analysis: two case studies,* Mechanical Systems and Signal Processing, 24: 1291-1305.

Turkish Code for Buildings to be Built in Seismic Zones, 2007.

Yildirim, H., 2011. *Technical report on the shear strength of Kadikoy Public Health Building,* Istanbul Technical University.