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CONDITION SURVEY OF HISTORIC BUILDINGS BY VISUAL INSPECTION - CASE STUDY: MURAT PASHA MOSQUE

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Abstract: *In heritage preservation, there is crucial need to identify the potential seismic risk in existing historic buildings for hazard mitigation, disaster preparedness and prior knowledge of potential hazards. Seismic risk evaluation is based on safety assessment which requires qualitative and quantitative data. This data is necessary before making any intervention decision. The qualitative data is visual inspection of decays, structural damages and deteriorations; and the quantitative data requires laboratory tests, structural analysis etc. Obtaining the quantitative data is detailed method, which necessitates specialists and takes more time and money. The fact that there are so many historic buildings and a few specialists on this field it is very important to make condition survey based on visual inspection as a first step of safety assessment procedure. According to these results necessity of detailed inspection and intervention and restoration works and the budged can be prioritized.*

This paper aims to present condition survey criteria generally and to focus on visual inspection as a first step of safety assessment. The data given in this paper is a part of author's PhD study in which visual inspection method for assessing the risk level of masonry monumental historic structures is developed. The paper deals with Murat Pasha Mosque as a case study.

Keywords: historic buildings, visual observation, structural geometry, damages, structural behaviour

1. INTRODUCTION

Historic structures and monuments are the most important part of the cultural heritage and human civilization and it is the human imperative to protect those structures for the future generations. Besides their artistic value those structures are open to the public and to the large assemble of people.

Most historic monumental structures that constitute the big part of historic heritage made of masonry materials such as bricks, stones, adobe and mortar are very complex (Fig. 1). Typology, construction and organization of the structure, element/block size, type of construction materials vary depending on the construction period.

During their long life, historic structures have experienced many actions occurred over long periods of time; endured long term deteriorating effects and earthquake loads. Since historic importance, cultural value and exposure of aggressive environmental loads there is no fixed criterion for evaluating safety of historic structures. Study on the structural safety of a historic building necessitates an interdisciplinary team of specialists and requires specific techniques.

Safety assessment of the buildings against natural disasters and human induced hazards is very important. In the context of cultural heritage preservation, it is very important to assess the potential seismic risk in the hazard prone areas for hazard mitigation and limiting the disaster impact. It is very difficult to make precise quantitative risk assessment for historic monumental masonry structures. There are technical codes and guidelines for new buildings however the approaches for new constructions are not applicable to the historic structures [1].

Making precise assessment of historic masonry buildings is a very difficult task. Safety assessment based on qualitative and quantitative data is necessary before making any intervention decision. Mostly surveyors get the qualitative data from a visual inspection of structural damages, decays and deteriorations; research on archive material and literature. Obtaining the quantitative data requires rather complicated methods which necessitate specialists and are time and money consuming. Consequently, such techniques are mainly used in the last step of the diagnosis and safety assessment which can be performed only on a limited number of buildings [2]. According to this fact, it is very important to use simpler methods to evaluate the potential risk of many buildings as a first step of cultural heritage preservation.

This paper deals with visual inspection criteria for surveying present condition of domed and vaulted historic monumental masonry structures in Turkey. A part of the presented data is based on PhD study of the author. Condition survey of Murat Pasha mosque is given as a case study.

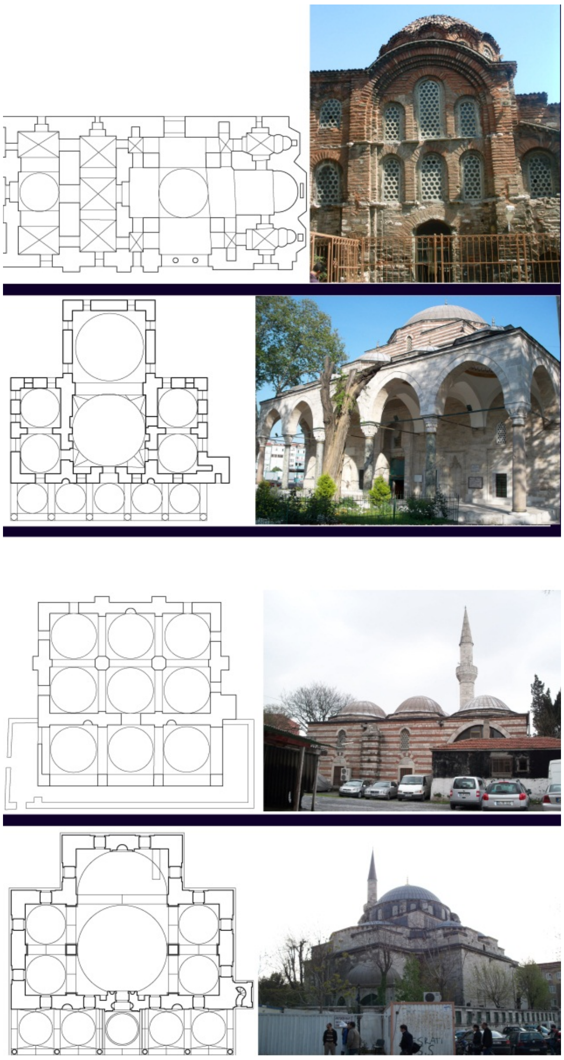

Fig. 1 Examples of historic buildings in Istanbul

2. CONDITION SURVEY

Preservation of the cultural heritage includes documentation, protection, conservation and intervention decisions on historic structures and monuments. Investigation of the present condition of the building is the main part of the preservation works and intervention decisions.

Condition survey of buildings is a necessity either before any hazard or after any disaster. Risk preparedness requires safety assessment of the buildings for being well prepared and assessing potential risk for risk management plan procedures which is based on condition survey before any hazard. On the other hand after any disaster for assessing the damage state condition survey is required. Generally evaluation of safety condition has almost the same principles in both situations. However, the main difference is the outcome. In case of pre-hazard condition survey based on damage assessment the result is "potential risk" (risk level of the property) and in case of post-disaster condition survey based on damage assessment the result is "damage level" (the usability of the property) which may lead to intervention decision.

This study is focused on pre-hazard condition survey based on visual inspection of monumental masonry structures.

2.1 General Criteria

Damage assessment which is the main part of condition survey requires both qualitative and quantitative data based on visual observations and specific techniques such as in-situ tests, laboratory tests, numerical models etc. The first step is visual observation which leads to detailed analysis if it is necessary. Detailed inspections require specific techniques, take more time and money and are applicable to the limited number of buildings (Table I). Due to this fact visual observed data is used in the evaluation as a first step and according to the results if it is necessary detailed analysis are done.

Table I. Damage assessment

Visual assessment	Detailed assessment
Based on visual observations	Detailed investigations (NDT, MDT, mechanical, physical, chemical tests...)
No necessity of experts	Necessity of experts and specific techniques
Short time/less money	Time and money consuming
Applicable to many buildings	Applicable to limited number of buildings

Condition survey of historic buildings necessitates historic research, geometric typology, previous interventions' information, and detailed knowledge of construction technique and used materials beside damage assessment.

2.2 Visual Observation Criteria

Mostly, post-hazard visual screening methods are based on street surveys which collect data getting from the exterior of the building. After any hazardous event observation of the crack pattern and damages on the building is quite enough in order to make the initial decision for the safety condition of the building. Conversely investigation of potential risk and the pre-hazard safety evaluation of the structures necessitate more data. The visual data includes damage state and physical condition of the building, structural and geometrical typology by means of load bearing scheme and each structural element, topography of the place where the building is located, earthquake zone, potential risk inducements and vulnerabilities etc.

Naturally, during the inspection the inspector compares each new case with cases he/she has experienced before and make his/her decision subjectively. Referring to this fact it is possible to say that inspection is depending not only to the existing condition of the building but also to the inspector experiences and knowledge. It is very important to take into account this fact when defining visual inspection criterion. To avoid or minimize this fact generally questionnaire with given selections are used such as check lists and these are supported by damage atlases, damage indexes, user guides etc.

3. CONDITION SURVEY OF MURAT PASHA MOSQUE

Murat Pasha Mosque is constructed under the rule of Fatih Sultan Mehmet during 1465-1471. The financial owner is Murat Pasha vizier of Sultan Mehmet. The building is located in Fatih district/Istanbul, at the corner of Vatan and Millet streets.

Main part of the building is distinctively higher than adjacent parts. Construction type is masonry and used material is brick and stone masonry with mortar. Figure 2 shows photos of the mosque.

Fig. 2 Photos of Murat Pasha Mosque

Turkish Specification for Buildings to be Built in Seismic Zones – 2007 graded the country area into five seismic zones from 1 as the highest to 5 as the lowest seismicity [4]. The building is located in seismic Zone 1.

Condition survey of Murat Pasha mosque will be explained in detail in next paragraphs and below the main steps are given briefly:

- Achieving the schematic plan drawing of the building,
- Research the history of the building,
- Giving axial system to the building for representing each structural element,
- Obtaining metric data of structural elements,
- Visual inspection of the building by focusing on the existing decay and damage state of structural elements,
- Calculations according to the evaluation criteria,
- Results and recommendations.

3.1 Historic Research

Murat Pasha mosque is the last standing part of the building complex which included mosque, bath (hamam), fountain, madrasah and cemetery. The mosque has been exposed to many aggressive environmental factors during its long history; particularly it was affected severely during 17^{th} and 18^{th} centuries by fires and natural disasters. Prominent calamities are fire in 1660, earthquake in 1766 and the effect of 1999 Marmara earthquake. During the history many times the building was repaired [3].

In the beginning of 2000^{s} underground metro construction was started near to Murat Pasha mosque. During the excavations the building was affected by the motions.

Murat Pasha mosque signifies with its geometry; it is one of the three mosques in Istanbul that has two main domes which is distinctive plan type for Ottoman mosque architecture. The building has T shaped geometry and is close to Edirne and Bursa plan types [5].

The main part (Fig. 3: B-E; 3-6 axes) is worship hall with two main domes and adjacent parts (Fig. 3: B-D; 1-3 and B-D; 6-8 axes) were eating houses (tabhane) originally but nowadays connected to the main hall by a door and using as a women worship halls similarly roofed by two domes for each part. A-B; 1-8 axes in Figure 3 part is open praying part (son cemaat yeri) of the building constructed by arcades, standing on the columns and roofed by five domes. Figure 4 and Figure 5 show facades of the mosque.

3.2 Visual Obtained Data

Building area is approximately 245 m^2. The height of the walls in main part is approx. 15.11m, the height of the walls in adjacent parts is approx. 7.62m and the height of the columns of the open praying area is approx. 6.5m [6]. Defining the structural elements is provided by giving axial system to the existing building (Fig. 3).

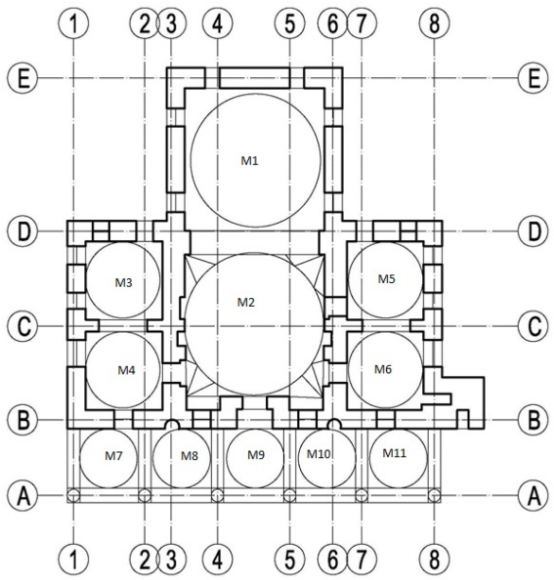

Fig. 3 Plan drawing of Murat Pasha mosque

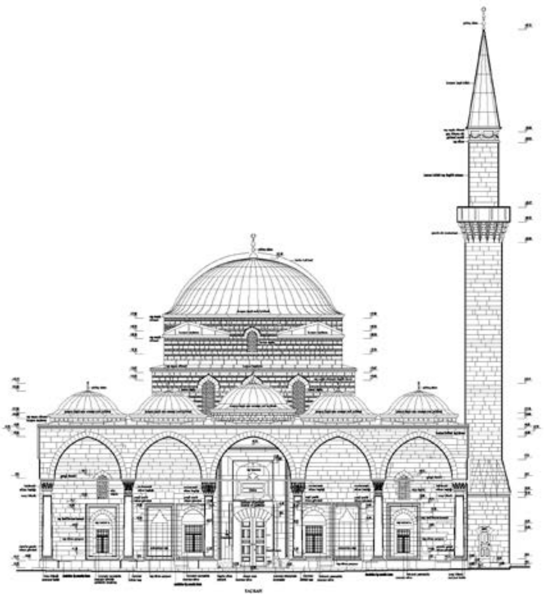

Fig. 4 The main entry (northwest) façade [3]

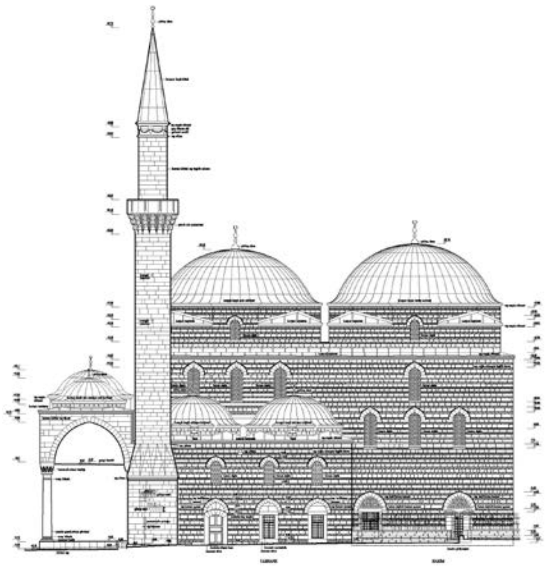

Fig. 4 Southwest façade [3]

Inspection of the structural elements and building itself is done based on the parameters listed below:

- General information
- Physical information
- Photographs of the building
- Dimensions of the structural elements (metric data)
- Roof structure and its decays/damages
- Floors and their decays/damages
- Structural elements (walls, columns, arches, transition elements and domes)

Inspection of decay and damages of the structural elements are done from interior and exterior of the building for each structural element individually.

Representation of each structural element is made by using the given axial system. Structural elements are grouped as walls, columns, roof structure and floors, arches, transition elements.

Walls' decays/damages from the exterior (facades):

Darkness of the surface mainly due to CO_2, uprasing of the surface of the walls, wetness, erosion, moss, cracks due to freeze-thaw actions (Fig. 6). All observed decays and damages are superficial and there is no serious damage on the facades' walls.

Fig. 6 Exterior walls

Walls' decays/damages from the interior:

Interior of the building generally is in good state there are some minor damages on the interior walls, but on the E3E6 and B3B6 walls there are vertical cracks from dome level through the wall that should be paid attention. Similarly there are vertical cracks on the B1B3; B6B8; D1D3 and D6D8 walls (Fig. 7).

This fact can be lead to the question if there is any movement of the building. Detailed investigation and interdisciplinary decision is a requirement for any repair or restoration work.

Fig. 7 Crack on the B3B6 wall

Columns' decay/damages:

The state of the columns that are vertical structural elements of arcades formed open praying area generally is well. There are some damages due to the corrosion of metal rings and metal girders (tension rods) and darkness of the surfaces due to CO_2.

There are not significant decay and damages on the arches, transition elements and domes. Similarly the roof structure is in good condition (Fig. 8).

Fig. 8 Transition element, pendentive, of the main dome

3.3 Evaluation Criteria and Calculations

Evaluation parameters and formulas used in the calculations are based on the Turkish Specification for Buildings to be Built in Seismic Zones in Turkey 2007 [4], Part 5 and the indexes of the Eurocode 6 and Eurocode 8 [7]. The designated evaluation parameters are: area of the wall to area to the building ratio, area to weight ratio, effective shear ratio, slenderness of the walls both horizontally and vertically. The parameters based on codes are given below:

- $\Sigma A_{X,Y}/\Sigma W$
- $\Sigma A_{X,Y}/\Sigma A$
- $FRd_{X,Y}/V_t$
- L/t and H/t

In these parameters; ΣW is the total weight of the structural elements of the building, $A_{X,Y}$ is the area of the walls in X and Y direction, A is the total area of the building, $FRd_{X,Y}$ is shear strength of the walls in X and Y direction, Vt equivalent seismic load of the building, L is the length of the walls, H is the height of the walls and t is the thickness of the walls. All walls taken into consideration are load bearing walls. Pillars are also added to the walls since they are load bearing elements in masonry structures.

Calculations of the structural elements according to the evaluation criteria are given in Table II – IV.

Table II. Calculation of structural walls

		H	**t**	**L**	**$\sum L_s$**	**$L_{net}=L-L_s$**	**A**	**V**	**W**	**L/t**	**H/t**
	AXES	(m)	(m)	(m)	(m)	(m)	(m^2)	(m^3)	(kN)		
X DIRECTION	E3E6	15,11	1,25	17,42	2,5	14,92	18,65	281,80	5636,03	13,94	12,09
	D1D3	7,62	1	9,87	1,7	8,17	8,17	62,26	1245,11	9,87	7,62
	D6D8	7,62	1	9,87	1,7	8,17	8,17	62,26	1245,11	9,87	7,62
	C1C3	7,62	1	10,3	4,7	5,6	5,6	42,67	853,44	10,30	7,62
	C6C8	7,62	1	10,3	4,7	5,6	5,6	42,67	853,44	10,30	7,62
	B1B3	7,62	1,1	10,3	1	9,3	10,23	77,95	1559,05	9,36	6,93
	B3B6	15,11	1,1	17,42	2	15,42	16,962	256,30	5125,92	15,84	13,74
	B6B8	7,62	1,1	10,3	1	9,3	10,23	77,95	1559,05	9,36	6,93
						Σ=	**83,61**		**18077,15**		
Y DIRECTION	B1C1	7,62	1	10,3	0,85	9,45	9,45	72,01	1440,18	10,30	7,62
	C1D1	7,62	1	10,3	1,7	8,6	8,6	65,53	1310,64	10,30	7,62
	B3C3	15,11	2,05	10,3	1,65	8,65	17,7325	267,94	5358,76	5,02	7,37
	C3D3	15,11	2,05	10,3	1,65	8,65	17,7325	267,94	5358,76	5,02	7,37
	D3E3	15,11	1,25	17,42	2,5	14,92	18,65	281,80	5636,03	13,94	12,09
	B6C6	15,11	2,05	10,3	1,65	8,65	17,7325	267,94	5358,76	5,02	7,37
	C6D6	15,11	2,05	10,3	1,65	8,65	17,7325	267,94	5358,76	5,02	7,37
	D6E6	15,11	1,25	17,42	2,5	14,92	18,65	281,80	5636,03	13,94	12,09
	B8C8	7,62	1	10,3	0,85	9,45	9,45	72,01	1440,18	10,30	7,62
	C8D8	7,62	1	10,3	1,7	8,6	8,6	65,53	1310,64	10,30	7,62
						Σ=	**144,33**		**38208,75**		

Abbreviations used in Table II -IV are:

H: the height of the wall
t: thickness of the wall
L: length of the wall
r: diameter of the column
L_s: total length of the wall openings
L_{net}: net length of the wall (without openings)
A: area of the structural elements' sections
$A_{blr.}$: total area of the building
V: volume of the wall
W: weight of the wall

Table III. Calculation of columns

AXES	**H** (m)	**r** (m)	**A** (m^2)	**V** (m^3)	**W** (kN)
A1	6,5	0,63	1,25	8,10	194,42
A2	6,5	0,63	1,25	8,10	194,42
A4	6,5	0,63	1,25	8,10	194,42
A5	6,5	0,63	1,25	8,10	194,42
A7	6,5	0,63	1,25	8,10	194,42
A8	6,5	0,63	1,25	8,10	194,42
		Σ=	**7,48**		**1166,50**

Table IV. Seismic calculations

ΣW (kN)	$\mathbf{A_{bld.}}$ (m^2)	**ΣFR$_d$** (kN)		$\mathbf{V_t}$ (kN)	**ΣA/W** (m^2/MN)		**ΣA/ΣA$_{bld.}$**		**ΣFR$_d$/V$_t$**	
		X Direction	**Y Direction**		**X Direction**	**Y Direction**	**X Direction**	**Y Direction**	**X Direction**	**Y Direction**
57452,40	1293,66	91089,60	151807,60	40216,68	1,59	2,64	0,07	0,12	2,26	3,77

In determining the $FR_{dX.Y}$ shear strength of the walls in X and Y direction using equation (1), shear stress (τ) is taken as 1 MPa according to the report on laboratory material tests of some historic buildings [8].

(1) $FR_{dX,Y} = \Sigma A_{wX,Y} * \tau$

In determining the equivalent seismic load of the building (Vt) as shown in equation (2), structural behavior factor is assumed as R=2 [7].

(2) $V_t = \Sigma W * A(T)/R$

ΣW, total weight of the structural elements of the building is calculated according to their unit weight (γ). Unit weight is taken 20 kN/m^3 for brick/stone masonry [8].

To calculate A(T), spectral acceleration coefficient as shown in equation (3), there is no specific building importance factor (I) for historic monumental buildings. For historic monumental buildings closest value 1,4 for museums in Turkish Specification, is taken in this study. Spectrum coefficient is indicated as S(T)=2,5 and A_0 (g) spectral acceleration coefficients are indicated according to the seismic zones in the Turkish Specification for Buildings to be Built in Seismic Zones in Turkey 2007 [4].

(3) $A(T)=A0*I*S(T)$

3.4. Results of Calculations

The evaluation parameters are given in Table V [7; 9; 10].

Table V. Parameters for each evaluation criteria

Criteria	**Evaluation**
$\Sigma A_{X,Y}/W$	≥ 1,2 m²/MN
$\Sigma A_{X,Y} / \Sigma A_{bld}$	≥ 0,1
$FR_{dX,Y} / V_t$	> 1
L / t	≤ 18
H / t	≤ 9

According to these parameters the results of calculations are discussed below.

- The ratio of the walls and columns area to the building weight is minor than 1,2 m²/MN for both X and Y direction. $\Sigma A_{X,Y}/W$ (√)
- The ratio of the walls and columns area to the building area is minor than 0,1 in X direction, but is more than this in Y direction. $\Sigma A_{X,Y} / \Sigma A_{bld}$ (!)
- The ratio of shear strength of the walls to the equivalent seismic load of the building is more than 1. $FRd_{X,Y} / V_t$ (√)
- The ratio of the length of the wall to its thickness is minor than 18 for all structural walls. L / t (√)
- The ratio of the height of the wall to its thickness is not minor than 9 for all structural walls. L / t (!)

The result of the calculations above shows that due to their geometry some structural elements of Murat Pasha mosque are weak against seismic loads. It should be taken into consideration that the weak points of the building during any possible earthquake would be those structural elements.

3.5. Explanatory Results: Consideration of the Building as a Whole

During decision making or evaluating the condition survey of the building it is very important to consider building as a whole. It is needed to associate the whole data and to decide final remarks. In this case study the data on hand are: decay and damage state of the structural elements (individually), geometric and metric data, results of the evaluation criteria's calculations.

T shape building geometry itself is dangerous against earthquake loads. Due to this fact during surveying of the building it is given special attention to find out if main part and adjacent parts of the mosque are constructed separately with joint gaps. If it is, in this case the building will behave as three different buildings during an earthquake and the safety wouldn't be in danger due to the geometric shape of the building. Construction of the walls of adjacent parts is particularly investigated and it is decided that highly possibly there are joint gaps between main part of the building and its adjacent parts (Fig. 9). The construction of the wall and order of stones and bricks seems that there are two different structural walls without connection.

This result shows that in case of repair, restoration or any intervention it is very important paying attention to the attached walls with different heights and wouldn't tend to connect those walls structurally. Detailed investigation of the walls' construction is required before any intervention decision.

Fig. 9 The corner joint of the walls of adjacent part and main part of the building

Due to the fact that minarets are slender elements obviously the weakest part of the building is minaret that could be collapse from the level of adjacent wall (Fig. 10).

Fig. 10 The minaret of Murat Pasha mosque

The topography where the building is located is flat. There is no basement of the building or different parts in different levels. That makes building's (as a whole) behavior good against seismic movements.

Consequently;

- The building is located in the Zone 1(the highest risk) seismic risk region,
- The building geometry is dangerous against earthquake loads,
- The movement in X direction is possible; it should be monitor and measure the vibration of the building by detailed techniques and equipment,
- The effect of underground metro construction should be monitor and keep under control,
- Slender walls should be investigate in detail,
- Detail investigation is needed for understanding if there are joint gaps between main worship hall and adjacent lowest parts of the building. X ray or some other specific techniques can be used for this purpose.
- Traffic vibration effect needed to be monitor,
- CO2 effect of the heavy traffic should be monitor,
- Vandalism is not an important problem for this building, it is very important to protect the security state,
- The building itself is in good condition and it is not under high risk against earthquake.

4. CONCLUSIONS

The results of condition survey of Murat Pasha mosque supported the fact that there are key principles for visual observation of historic monumental buildings in order to determine the present state of the building and build up the data for detailed investigation. This first step work gives possibility for assessing seismic risk of historic structures, prioritizing repair and restoration works, managing the budget for those works. Particularly in countries that have a few specialist and many historic structures, less budgets etc. this is very important to make first step survey.

The key principles of visual inspection are:

- Geometry of the building,
- Seismic zone,
- Topography of the area where the building is located,
- Historic research,
- Information of construction,
- Metric data of structural elements,
- Divide structural elements as vertical and horizontal.

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- Decay/damage state of each structural element,
- Interrelate all data of each element and take into consideration building as a whole for final decision.

In preservation of the cultural heritage, pre-hazard safety assessment of historic structures will help to identify the potential seismic hazard in existing historic buildings for hazard mitigation, disaster preparedness and prior knowledge of potential hazards. Depending on the aim, budget and requirements there are simple and detailed methods for assessing the present condition of historic structures. Detailed analyses are technically complex, expensive, take more time and can be applied to limited number of buildings. Since the experts on the historic structures who can carry out detailed researches are a few and the historic building stock is huge, it is very important to use visual observation methods as a first step of the safety assessment works. The results of visual inspections will lead to detailed methods in order to prioritize the intervention works that require team of specialists.

It is very important to determine the decay/damage state of the structural elements, to research the possible causes of decay/damage processes, monitor the building and see is there any continuation of the decay/damage process and to take into account building as a whole during final decisions. The intervention decision should be considered by interdisciplinary team of specialists. The main basis of intervention decision is the results of investigation of possible damages' causes and to propose an approach for preventing them otherwise the whole works could be just make up and damage process could be accelerated.

Some needs for research in the future, based on this study can be listed as follows:

- A great deal of work has been carried out on damage assessment of reinforced concrete buildings and masonry buildings with regular geometry after any hazard. It is very important to make safety assessment of historic monumental structures before any hazard.
- The fact that the historic monumental building stock is huge and specialists in this field are a few obviously it is necessary to develop step by step methods for safety assessment of these structures. As a first step of detailed works and vulnerability assessment it is necessary to widespread first step simplified methods for prioritization of needs.
- Documentation and monitoring of historic monumental structures is the important requirement in the field of conservation and protection of cultural heritage. Development of the national data base system for historic monumental structures is an important need in order to list and monitor all buildings. And to integrate these data in the risk management plan of the cultural heritage in national level.
- Due to the fact that the big part of cultural heritage consists of monumental masonry structures development of "The code for Monumental Masonry Structures" will make a significant contribution to the field of conservation and protection of cultural heritage.

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SHORT BIOGRAPHY

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