EXPERIMENTAL AND NUMERICAL ANALYSIS OF THE RC MINARET OF CAROL I ROYAL MOSQUE, CONSTANŢA, ROMANIA

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Abstract

Carol I Royal Mosque is located on the shore of the Black Sea coast, in Constanţa city, south-east Romania. Ranked and historical monument (architecture category) it represents a major cultural item and a proof of the historical and present multicultural understanding in a city inhabited by Romanians, Turks, Bulgarians, Tatars and others. Built between 1910 and 1913 it is one of the first civil constructions in Romania mixing reinforced concrete elements with masonry. The mosque has a circular form reinforced concrete minaret of ~40m height, probably one of the oldest RC minarets in the world.

The mosque is exposed to several seismic sources able of producing rather strong earthquakes: intermediate-depth Vrancea source (Mmax = 8.1) in Romania and shallow sources Dulovo (Mmax = 7.1), Shabla (Mmax = 7.8) and Gorna (Mmax = 7.4) in Bulgaria. Climatic aggression, especially marine winds, World War 2 bombing, and traffic negatively contributed to the actual status of the mosque.

Ambient vibration tests were performed in 2017 and the periods corresponding to the first vibration modes of the minaret were estimated through spectral analysis and ERA method (Eigensystem Realization Algorithm), characterizing the minaret linear behavior under small amplitude vibrations. Ambient vibration tests were repeated in 2018, with different equipments. The analysis of these new records is presented and compared with the previous results.

A numerical 3D model of the minaret is calibrated with the experimental results from ambient vibration tests. The minaret's capacity curve is obtained through static non-linear analysis. Fragility curves specific to the minaret are developed and finally, the paper presents a discussion concerning the minaret's seismic assessment (based on Romanian and Japanese approaches).

Keywords: heritage, RC minaret, ambient vibrations, capacity and fragility curves

1. Introduction

Protection of heritage is a major priority worldwide. Since the 1972 World Heritage Convention, a special international consideration is given to nature conservation and the preservation of cultural properties. In earthquake prone countries a special attention is given to the seismic assessment, rehabilitation and protection of architectural, historic and cultural heritage constructions.

In European Union, in 1993, the Committee of Ministers of the Council of Europe adopted the Recommendation N° R (93) 9 on the Protection of the Architectural Heritage against Disasters, recommending to the Governments of the member States to adopt “all legislative, administrative, financial, educational and other appropriate measures,[…] as part of their general policy for conserving the architectural heritage” [1]. The document also mentions that "Each state should establish and complete the compilation of lists of the buildings, objects and monuments of interest", and in its Appendix III Organisational measures against earthquakes […] it requires to "identify and assess the vulnerability of the architectural heritage to hazard […] and assess the risks and the probable damage or loss".

Built between 1910 and 1913, “Carol I” Royal Mosque (Fig. 1) is the largest mosque in Romania and is officially listed as a historical monument, architecture category, of national or universal interest/value (historical monuments ID: CT-II-m-A-02796). Located in Constanța city in South Eastern Romania, on the Black Sea coast, the mosque is a major historic, religious, cultural, architectural and touristic asset, part of a group of religious buildings spreading onto a small area in the old city center. In its vicinity one can find the Orthodox Archiepiscopate of Tomis (1925-1932), the Orthodox Cathedral (1883-1885), Sfântul Nicolae Orthodox Church (1889), Sfântul Anton de Padova Catholic Church (1938) and the Great Synagogue (1911).

Fig.1 - “Carol I” Royal Mosque in Constanța, Romania (1930s postcard)

Several seismic sources are able of producing rather strong earthquakes that may affect the mosque: the intermediate-depth Vrancea source (Mmax = 8.1) in Romania, and the shallow sources Dulovo (Mmax = 7.1), Shabla (Mmax = 7.8) and Gorna (Mmax = 7.4) in Bulgaria. The mosque experienced several seismic events originating from Vrancea subcrustal seismic source: the major earthquakes of 1940 (M_W=7.7) and 1977 (M_W=7.4) and the medium size earthquakes of 1986 (M_W=7.1), 1990 (M_W=6.9 and 6.4) and 2004 (M_W=6.0), without suffering significant damage. During these seismic events, the estimated Modified Mercalli Intensity in Constanța was: 1940 and 1977 - VII, 1986 - V, 1990 - VI and V, and 2004 - IV [2]. The peak ground acceleration PGA was estimated as ~0.1 g in 1940 and 1977 [3], while the recorded values during the smaller events did not overpass 0.05g. According to the Romanian code for seismic evaluation of existing buildings P100-3/2019 [4], the PGA value to be considered for Constanța is PGA_{225yr}=0.20g (value with 225 years mean return period, 20% probability of exceedance in 50 years) and a probabilistic seismic hazard assessment [5] estimates PGA_{475yr} =0.22g.

Several steps toward the seismic protection of the “Carol I” Royal Mosque were made on voluntary basis: visual inspection, shape surveying, retrieval of available plans and technical data, sclerometer tests on RC elements, ambient vibration tests, and seismic evaluation of the minaret according to Romanian and Japanese procedures. Tests on masonry bricks are scheduled for the near future. The present paper presents results from the most recent ambient vibration tests performed on the minaret. The minaret capacity curve and specific fragility curves are developed.

1.1 “Carol I” Royal Mosque

“Carol I” Royal Mosque is one of the first buildings in Romania mixing masonry and reinforced concrete elements. In Fig. 2 are presented the vertical cross-section of the mosque [6] and a present day photo of its reinforced concrete minaret.

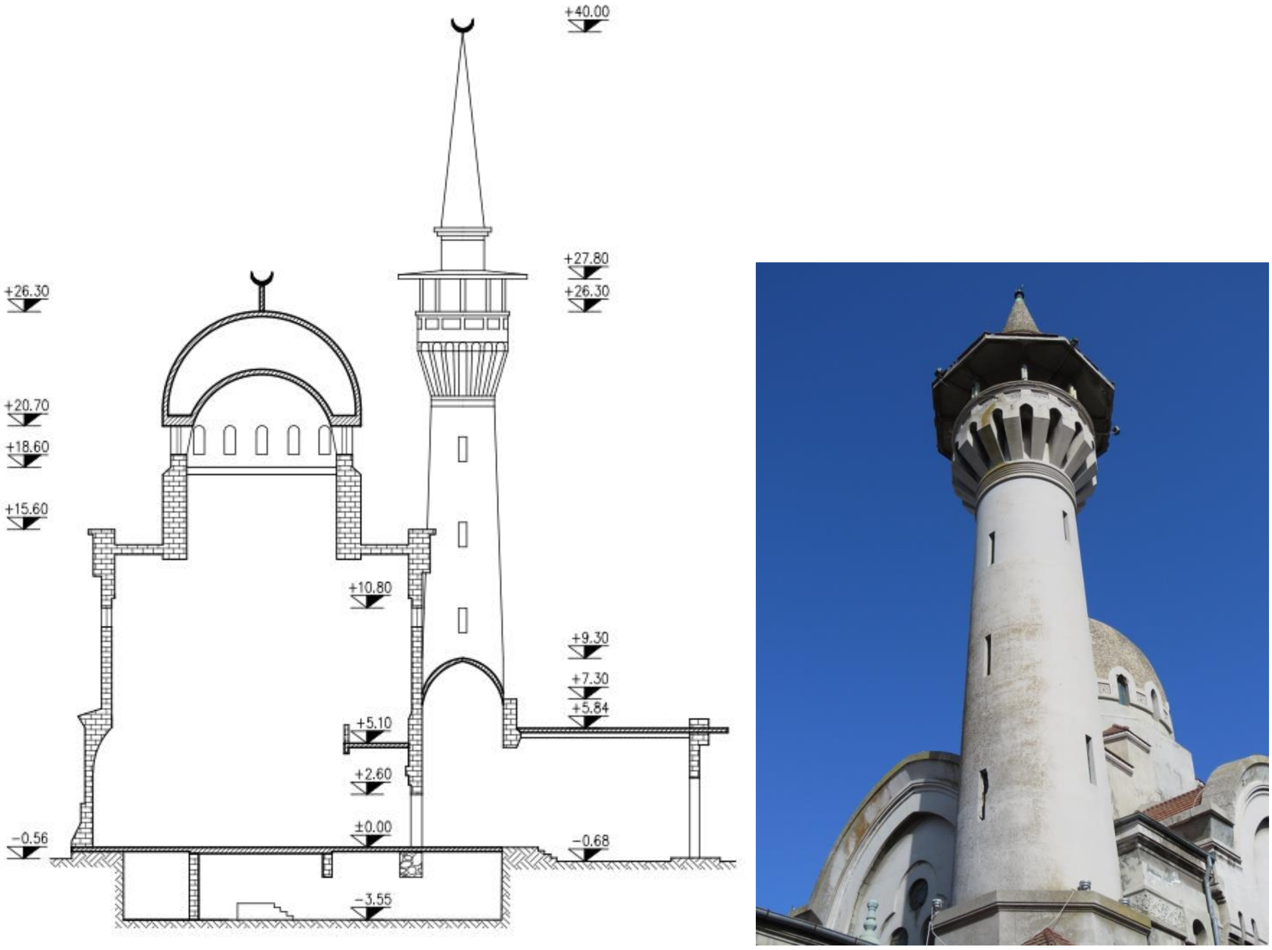

Fig. 2 – Vertical cross-section of “Carol I” Royal Mosque [6] - left; present day photo of the minaret - right

The review of archive documents indicates a rather quick degradation of the construction after its completion [7]. In 1925 a necessary partial repairing was done. In 1940 the necessity for new repairing works was expressed, and after an aviation bombing in 1942 the Great Mufti’s Office of Muslim Community of Romania strongly underlined this necessity. In 1957, A. Beleș (founder of earthquake engineering in Romania, professor at Technical University of Civil Engineering Bucharest) evaluated the mosque and proposed a retrofitting solution [8]. Due to the exposure of concrete to sea winds, the concrete material suffered degradations questioning the mosque resistance. A special attention was given to the minaret for which a significant concrete degradation and rebar corrosion were observed on the Black Sea direction (N-E). Consequently, a general reinforcement was recommended: RC jacketing all over the minaret height. The reinforcement works were executed in 1957-1958. The jacketing was intended to allow the minaret to withstand permanent and accidental loads, especially wind action, considered to be the most important load. Earthquake resistant design was not considered at that time, since the first regulation was introduced in Romania in 1963.

In 1966 the Great Mufti’s Office signaled important water infiltrations in the masonry mosque and in the reinforced concrete roof of the minaret balcony. In 1993 was executed a rehabilitation of the RC supporting structure of the minaret balcony roof.

The mosque has a reinforced concrete dome supported by masonry walls and columns. The circular shape reinforced concrete minaret has a diameter of ~3.7m at the base and ~3.0 m at the balcony level. The balcony is supported by 16 cantilever RC beams.

The minaret has an interior spiral staircase and an internal circular reinforced concrete column (diameter 1.75 m at the base and 0.64m at the balcony level). The base of the minaret is contained within the mosque itself. The outer wall has 20 cm thickness at the base and 15 cm at the top, with a reinforcement consisting of a system of 18mm thick longitudinal bars located at the middle of the wall thickness, spaced at 20cm at the base up to 15cm at the top, with 8mm thick circular stirrup at about 15-20 cm distance [8].

The 40m height reinforced concrete minaret of “Carol I” Royal Mosque is most probably one of the oldest RC minarets in the world.

2. Ambient vibration tests

The analysis of ambient vibration measurements for identification of structural modal parameters is a frequently used method in the last decades. This fast and low cost method was applied on a wide typology of constructions: buildings, towers, bridges, dams, nuclear power plants, etc. Frequencies, mode shapes and damping estimated from ambient vibrations tests are useful results helping to improve the quality of structural behavior modeling under seismic or wind loads.

Many studies ([9], [10], [11], [12], [13] etc.) involving the calibration of computer models based on the results from ambient vibration tests were also done in case of minarets. Minarets in Turkey were the subject of many papers, not only due to their religious, historic and cultural importance, but, unfortunately, also due to a large number of minarets collapse and/or damage due to earthquakes and/or wind storms.

The results presented in this paper focus on the RC minaret of “Carol I” Royal Mosque, Romania.

2.1 Previous results

Ambient vibration measurements were performed in May 2017 using three disposal layouts of 6 to 8 velocity sensors. Two orthogonal measurement directions were considered: NS and EW. The equipment used consisted of a 24 bits acquisition system and 1-second velocity sensors produced by Buttan Service-Tokyo & Tokyo Soil Research Co., Ltd, Japan. Preliminary results [14] estimated the first two modal frequencies of the minaret: f_1=2.38 Hz and f_2=3.80 Hz. The corresponding modal periods are T_1=0.42s and T_2=0.26s.

In a more detailed analysis [6] of the 2017 measurements, the modal frequencies of the minaret were estimated through the Peak Picking (PP) method and the Eigensystem Realization Algorithm (ERA) method. In the frequency domain PP approach it is considered that peak spectral values appear at natural frequencies of building vibration. The peaks are usually identified on the Fourier Amplitude spectra, but cross spectra may also be considered. The PP method allows a reasonable estimation of modal frequencies. The ERA method involves data assembly, decomposition, matrix realization, eigenvalue problem solving and the extraction of system properties. It is widely used in many fields, including civil engineering, and it allows the estimation of modal frequencies, mode shapes and damping ratios. The identified modal frequencies through the PP and ERA methods showed very small differences, the corresponding modal periods being practically identical: T_1=0.42s on both directions (PP) and T_1=0.41s on NS and 0.42s on EW (ERA); T_2=0.26s on both directions (PP) and T_2=0.25s on both directions (ERA); T_3=0.10s on NS and 0.09s on EW (PP) and T_3=0.09s on both directions (ERA), and T_4=0.08s on both directions and with both approaches. Average modal damping ratio was estimated using ERA method for first mode: 1% on NS direction and 1.3% on EW direction.

The results characterize the minarets’ linear dynamic behavior in case of low-amplitude vibrations. As expected, the frequencies/periods corresponding to peak spectral amplitudes on both measurement directions (NS and EW) showed negligible differences.

2.2 New results

In 2018 new ambient vibration measurements were done at the mosque using different equipment: Cityshark II and Minisark acquisition system [15] and Lennartz Le3D-5s velocimeters [16].

Samples of 20-30 minutes length recorded at 200Hz sampling rate were obtained in free field near the mosque, in the basement and at the balcony of the minaret. Data processing was performed with Geopsy software [17].

2.2.1 Measurements in free field and in the basement

Site response in free field near the mosque and in the basement of the mosque (at -3.55m) is characterized through the Nakamura H/V method [18]. The method provides good estimation of the fundamental resonance frequency for 1D horizontally layered structures [19]. Calculations are done using Geopsy open source software [17], [20]. First, we select the time windows in which the signal is stationary in order to fulfill one of the requirements of H/V computation. The minimal time windows length considered for the data processing is equal to 30 seconds. The number of selected windows varies according to each measurement. An automatic anti-trigger selection based on the short-term average (STA) and the long-term average (LTA) is used to get rid of strong transient signals.

The LTA is fixed to 30 seconds and the STA equals 1 second. The minimal threshold for the ratio between the LTA and the STA is set at 0.2 and the maximal threshold is taken equal to 2.5. A 5 % cosine taper is applied on both ends of the windows. The ratio between the mean of the horizontal components and the vertical component of each selected signal windows is computed in the frequency range 0.5 Hz – 15 Hz using the Fast Fourier transform (FFT). A Konno & Ohmachi [21] smoothing with the parameter b of 40 has been applied on each spectrum. The H/V curve is computed by averaging all individual smoothed ratio.

The first peak of a H/V curve is assumed to indicate the resonance fundamental frequency of the soil column at the measurement point. But this assumption can be made only for curves with well-defined and sharp peak with amplitude level above than 3 according to the SESAME (Site EffectS assessment using Ambient Excitations) European project [22].

At both measurement sites (free field and basement) the estimated predominant frequency of ground vibration is around 1.5Hz (Fig.3), confirming the hypothesis that the mosque has a simple traditional foundation supporting just the masonry walls and the minaret, without any raft.

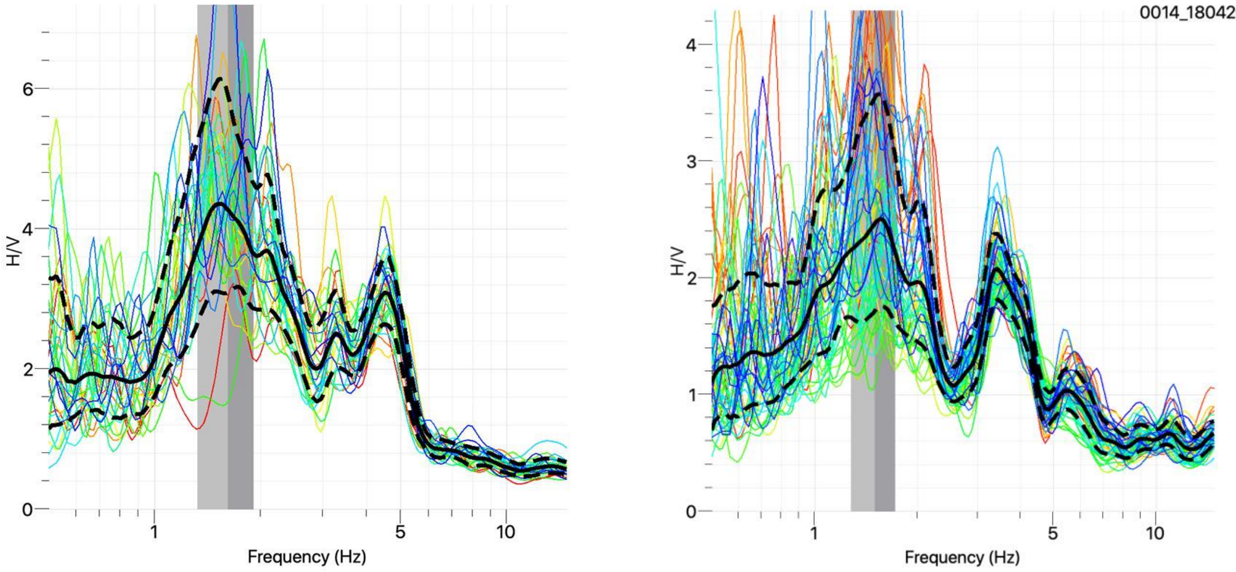

Fig. 3 – H/V spectral ratios: free field - left, mosque basement - right

In the historic centre of Constanta where the mosque is located, the geotechnical data indicate at surface a thin non homogenous backfill (thickness ~1m), followed by a loess layer (~1÷2m), and high plasticity clay layers, lying over a limestone basement.

2.2.2 Measurements at the top of the minaret

Ambient vibration measurements were performed on the top of the minaret interior RC column, at the balcony level. The analysis done with Geopsy considered the non-smoothed power spectral densities of 1416 windows of 20 seconds length. The results obtained on the two orthogonal horizontal directions of measurements display a negligible difference, Fig.4. For example, the first mode frequencies are 2.36Hz and 2.41Hz (corresponding periods 0.41-0.42 seconds). A second peak is observed at 7Hz (0.14 seconds). These results are in good agreement with the ones obtained in 2017.

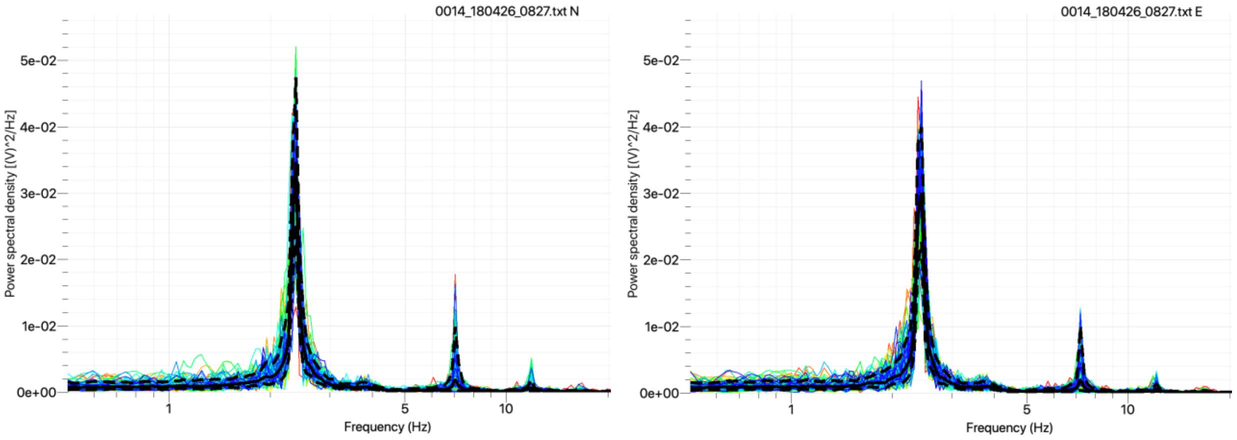

Fig.4 - Power spectral densities for records at the top of the minaret: NS direction - left, EW - right

Geopsy damping toolbox (random decrement technique) was used for estimating the damping associated to the minaret natural frequency, Fig.5. A 40 second window and 4th order causal Butterworth filter were considered.

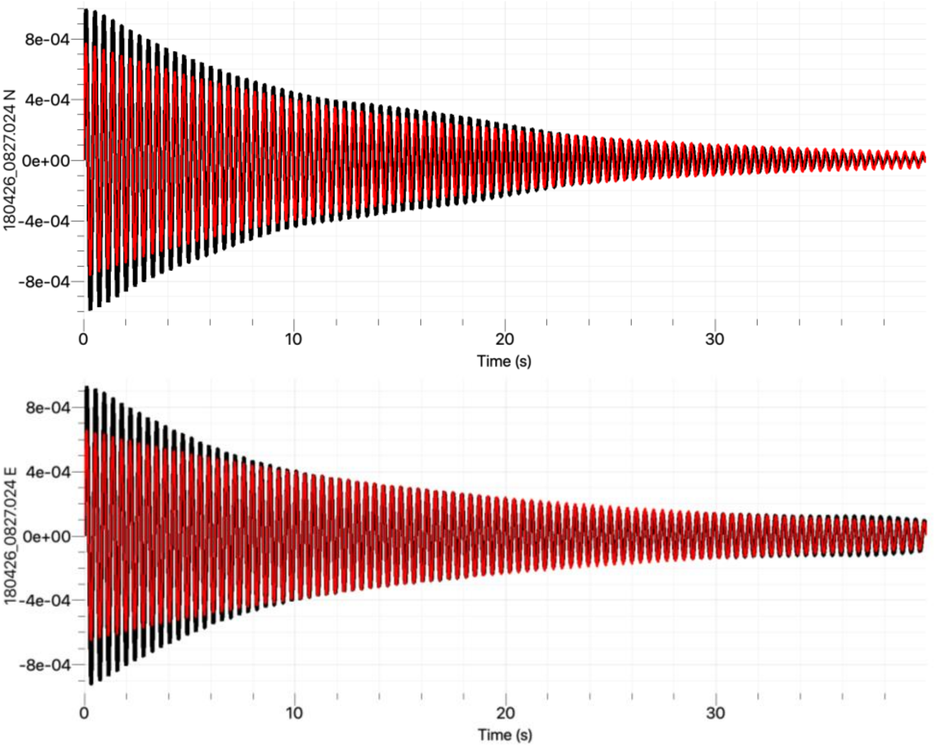

Fig.5 - Application of Random decrement technique for damping estimation: NS direction - top, EW - bottom

The estimated damping values are 0.45% for NS direction and 0.34% for EW. These values are a little bit lower than the one estimated in 2017. This small difference may be due to the uncertainties linked to the two different considered approaches.

3. Seismic capacity

The seismic capacity of the minaret is assessed using the pushover analysis performed with SeismoStruct code [23]. The Mander et al. [24] model was applied for the concrete fibres, while the reinforcement layers are modelled by using the stress-strain relationship proposed by Menegotto and Pinto [25] and implemented by Monti et al. [26]. The concrete and rebar properties are as in Lozinca et al. [27]. Inelastic force-based plastic hinges (concentrating the inelasticity at the ends of the structural elements) are assigned for all the structural elements of the model. Since the structure was built over 100 years ago, the pushover analysis was performed considering the effects of corrosion of reinforcement in the external (exposed) structural elements. The reduced diameter Drb of a reinforcing steel bar with initial diameter of Db subjected to corrosion for a time period Δt is computed as [28]:

$$\mathrm{Drb} = \mathrm{Db} - 0.023 \cdot \mathrm{icorr} \cdot \Delta \mathrm{t} \tag{1}$$

where icorr represent the mean annual corrosion current per unit anodic surface area of steel. In this analysis we have selected a corrosion current icorr = $1.2\mu\mathrm{A/cm}^2$ corresponding to a high level of reinforcement corrosion [28].

The fundamental period of the SeismoStruct minaret model is 0.39 s, a value close to the 0.41-0.42 s obtained from ambient vibration measurements.

The pushover curve for the minaret structure considering the corrosion effects according to Eq. (1) is presented in Fig. 6, along its bilinear fit.

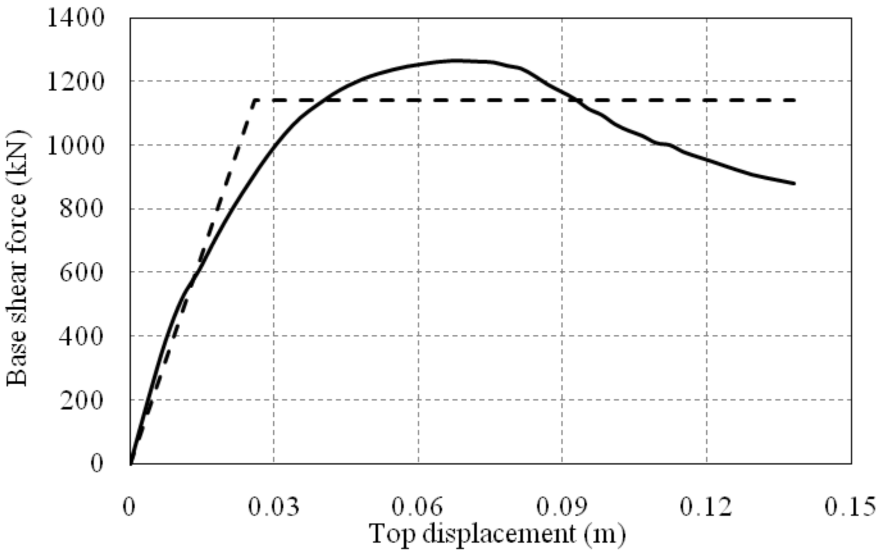

Fig.6 - Pushover curve and its bilinear fit for the RC minaret structure

4. Seismic fragility assessment

The seismic fragility assessment for the minaret structure is performed using an approach based on incremental dynamic analysis method (IDA) [29]. The ground motion dataset used for the analysis consists of 18 horizontal components recorded at various seismic stations in Romania during three Vrancea intermediate-depth earthquakes. The earthquakes and ground motions characteristics are given in Table 1.

Table 1 - Characteristics of the ground motion recordings used for IDA

No.	**Date**	**Focal depth** ***h*** **(km)**	**Moment magnitude** M_w	**Seismic station**	**Comp.**	**Epicentral distance (km)**	**PGA (g)**
1	4.03.1977	94	7.4	Chișinau	N42E	269	0.10
2	30.08.1986	131	7.1	Baia	N95E	195	0.03
3	30.08.1986	131	7.1	Bacau	NS	120	0.09
4	30.08.1986	131	7,1	Carcaliu	NS	137	0,07
5	30.08.1986	131	7.1	Cernavoda	EW	181	0.06
6	30.08.1986	131	7.1	Giurgiu	EW	186	0.04
7	30.08.1986	131	7.1	Chișinau	NS	251	0.20
8	30.08.1986	131	7,1	Tulcea	EW	186	0,06
9	30.08.1986	131	7.1	Valenii de Munte	N84W	51	0.19
10	30.08.1986	131	7.1	Vaslui	EW	157	0.17
11	30.05.1990	91	6.9	Baia	N05E	185	0.09
12	30.05.1990	91	6.9	Bacau	NS	83	0.13
13	30.05.1990	91	6,9	Carcaliu	NS	120	0,17
14	30.05.1990	91	6.9	Cernavoda	EW	187	0.10
15	30.05.1990	91	6.9	Giurgiu	NS	226	0.11
16	30.05.1990	91	6.9	Pitesti	EW	190	0.05
17	30.05.1990	91	6,9	Tulcea	EW	165	0,07
18	30.05.1990	91	6.9	Valenii de Munte	N174W	98	0.15

In Fig. 7 the normalized acceleration response spectra are compared with the design response spectrum for Constanta computed according to Romanian seismic design code P100-1/2013 [30].

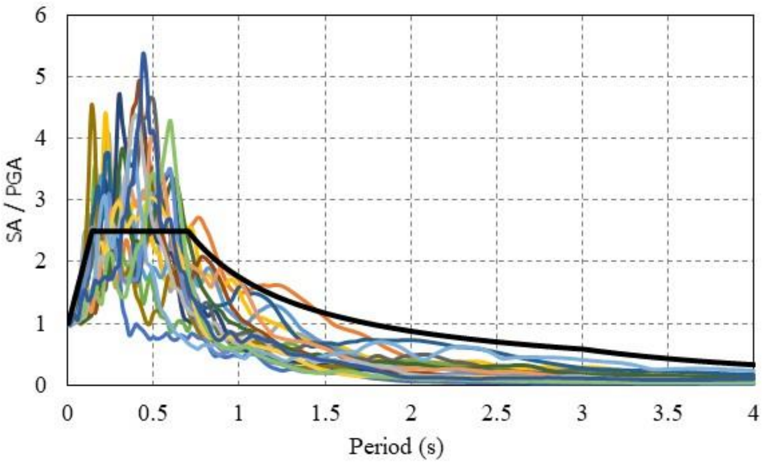

Fig. 7 - Normalized acceleration response spectra for the ground motions used in IDA. With black line is shown the design response spectrum for Constanta according to P100-1/2013

One can notice that the selected ground motion recordings match reasonably well the design response spectrum for Constanta (for site conditions characterized by a control period of response spectra Tc=0.7s).

In order to derive the parameters of the lognormal fragility functions based on the results obtained from IDA, the fitting procedure proposed by Baker [31] is used. The obtained parameters of the lognormal fragility functions (median value and logarithmic standard deviation) corresponding to various damage states are given in Table 2. The displacement limits corresponding to each damage state (DS) were obtained based on the threshold values proposed by Kappos et al. [32]. Damage states are those from [32]: DS1 - slight damage, DS2 - moderate, DS3 - substantial to heavy and DS4 - very heavy.

Table 2 - Parameters of the fragility functions

Damage state	**Fragility parameters**	
	Median value (g)	**β**
DS1	0.25	0.43
DS2	0.56	0.47
DS3	1.04	0.51
DS4	1.64	0.44

The fragility functions for the four considered damage states are illustrated in Fig. 8.

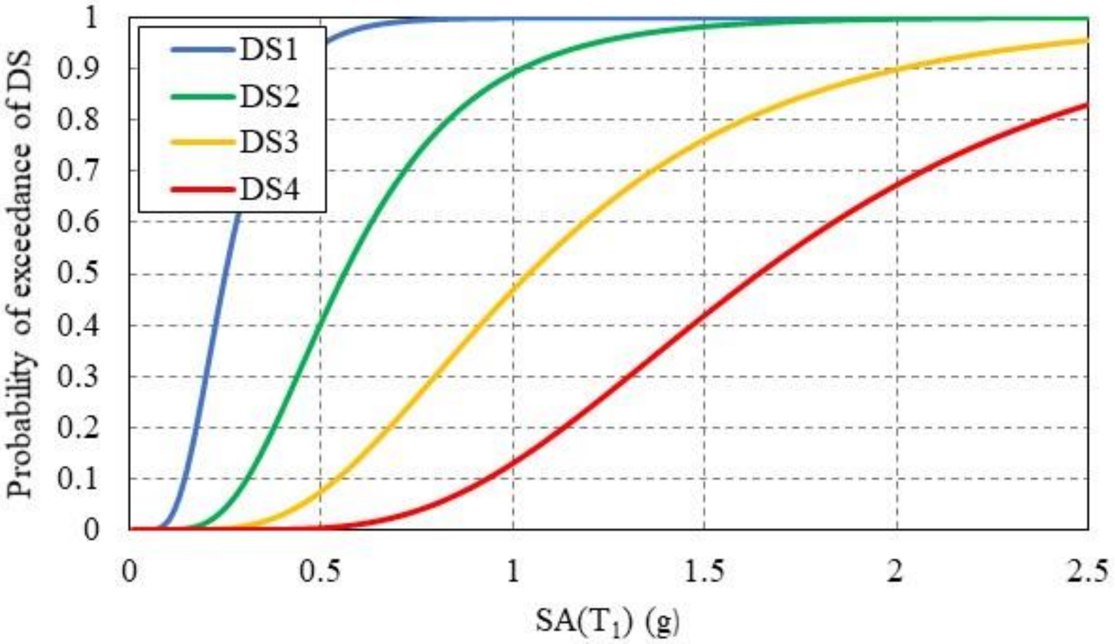

Fig. 8 - Lognormal fragility functions for the RC minaret

Fig.9 indicates the probability of being in a particular damage state for a spectral acceleration SA(T_1) = 0.5 g, which represents the design spectral acceleration for Constanta according to the current seismic design code in Romania P100-1/2013 [30].

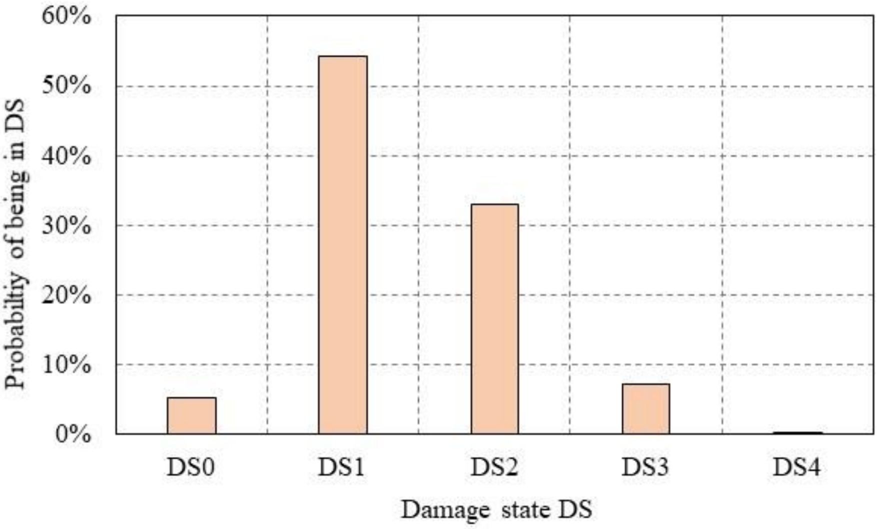

Fig. 9 Damage state probability distribution for a spectral acceleration SA(T_1) = 0.5 g

4. Final considerations

Two ambient vibration measurements campaigns (in 2017 and 2018) allowed the estimation of the fundamental frequency/period of vibration of the reinforced concrete minaret of "Carol I" Royal Mosque in Constanta, probably one of the oldest RC minarets in the world. The minaret computer model was defined and calibrated, considering the rebar corrosion. The minaret pushover curve and fragility functions were obtained. The pushover analysis revealed characteristics of the minaret seismic behavior that are similar to those identified through the application [27] of the Japanese Standard for Evaluation of Existing Reinforced Concrete Chimney [33]: not sufficient shear capacity.

In the Romanian seismic evaluation code P100-3/2008 [34] the values of three different indexes (R1, R2 and R3, resulting from three evaluation criteria) are used for establishing the seismic risk class of an existing building (RsI being the worst). The assessment of existing damage state induced by previous earthquakes and/or other actions (index R2) is presented in Aldea et al. [14]. The in-situ inspections of the mosque revealed significant structural damage reducing its strength to both gravity and lateral loads and also reducing its overall lateral stiffness. Considering the minaret as an independent structure and taking into account only the damage index R2, the minaret was ranked in the seismic class RsIII (associated to the buildings that after the design level earthquake might suffer some structural damage not affecting the overall structural safety).

Considering the importance of the mosque and all the results from [14], [27] and from the present paper, the minaret of "Carol I" Royal Mosque requires an adequate rehabilitation method should aiming to increase its shear capacity.

A detailed investigation of the construction materials (masonry, concrete and rebar) characteristics is necessary for an improved seismic evaluation. The recent 2019 edition of the (Romanian) Code for the Seismic Evaluation of Existing Buildings [4] should also be applied. Since minarets are also sensitive to wind action, a wind response assessment of the minaret is also necessary.

5. Acknowledgements

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6. References

[1] https://www.coe.int/en/web/herein-system/council-of-europe

[2] Kronrod T, Radulian M, Panza G, Popa M, Paskaleva I, Radovanovich S, Gribovszki K, Sandu I, Pekevski L (2013): Integrated transnational macroseismic data set for the strongest earthquakes of Vrancea (Romania). *Tectonophysics,* **590**, 1-23.

[3] Văcăreanu R, Radulian M, Iancovici M, Pavel F, Neagu C (2015): Fore-arc and back-arc ground motion prediction model for Vrancea intermediate depth seismic source. *Journal of Earthquake Engineering,* **19**:535-562.

[4] P100-3/2019 (2019): (Romanian) *Code for the Seismic Evaluation of Existing Buildings*, Ministry of Regional Development and Public Administration

[5] Pavel F, Vacareanu R, Douglas J, Radulian M, Cioflan CO, Barbat A (2016): An updated probabilistic seismic hazard assessment for Romania and comparison with the approach and outcomes of the SHARE project. *Pure and Applied Geophysics*, **173**:1881-1905.

[6] Aldea A. , Demetriu S., Neagu C., Lozincă E., Iliescu M. (2018): Ambient vibration tests at "Carol I" Royal Mosque in Constanţa, Romania, *16th European Conference on Earthquake Engineering*, Thessaloniki, Greece

[7] Pauleanu D., Coman V. (2010): *Royal Mosque "Carol I" Constanta 1910-2010*, Ed. Ex Ponto Constanta

[8] Beleş A. (1957): *Technical report for the reinforcement of the minaret* (in Romanian)

[9] Dogangun A., Acar R., Sezen H., Livaoglu R. (2008): Investigation of dynamic response of masonry minaret structures, *Bulletin of Earthquake Engineering*, **6**:505–51.

[10] Cakti, E., Oliveira, C.S., Lemos, J.V., Saygili, O., Gork, S. and Zengin, E. (2013): Earthquake behavior of historical minarets in Istanbul, *COMPDYN 2013, 4th ECCOMAS Thematic Conference On Computational Methods*, In Structural Dynamics And Earthquake Engineering, Eds. M. Papadrakakis, V. Papadopoulos, V. Plevris, Kos Island, Greece.

[11] Sezen H., Acar R., Dogangun A., Livaoglu R (2008): Dynamic Analysis and Seismic Performance of Reinforced Concrete Minarets, *Engineering Structures*, **30**, 2253-2264.

[12] Yetkin M., Calayır Y., Erkek H. (2018): Determining Dynamic Characteristics Of Reinforced Concrete Minarets And Updating Of Their Finite Element Models Using Environmental Vibration Data, *Turkish Journal of Science & Technology*, **13(1),** 93-98.

[13] Oliveira, C. S., Çaktı, E., Stengel, D., & Branco, M. (2012): Minaret behavior under earthquake loading: The case of historical Istanbul. *Earthquake Engineering & Structural Dynamics*, **41(1),** 19-39

[14] Aldea A., Neagu C., Lozinca E., Demetriu S., El-Amine Bourdim S.M., Turano F. (2018): Toward the Seismic Evaluation of "Carol I" Royal Mosque in Constanța. In: Vacareanu R., Ionescu C. (eds) *Seismic Hazard and Risk Assessment*. Springer Natural Hazards. Springer, Cham, 345-359

[15] http://keas-group.com/

[16] http://www.lennartz-electronic.de/

[17] http://www.geopsy.org/

[18] Nakamura, Y. (1989): A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. *Quaterly Report of the Railway Technical Research Institute* **30** (**1**), 25-30.

[19] Bonnefoy-Claudet, S., Kohler, A., Cornou, C., Wathelet, M., Bard, P.-Y. (2008). Effects of Love Waves on Microtremor H/V Ratio. Bulletin of the Seismological Society of America 98, 288–300. https://doi.org/10.1785/0120070063

[20] Wathelet, M. (2005). Array recordings of ambient vibrations: surface-wave inversion (Thesis). Université de Liège.

[21] Konno K. and T. Ohmachi (1998). Ground-motion characteristics estimated from spectral ratio between horizontal and vertical components of microtremor. *Bull. Seismol. Soc. Am.*, vol. 88, p. 228-241.

[22] Bard, P.Y., SESAME-Team (2005). Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations-measurements, processing and interpretations. SESAME European research project.

[23] Seismosoft (2018) SeismoStruct - A computer program for static and dynamic nonlinear analysis of framed structures, available from http://www.seismosoft.com

[24] Mander JB, Priestley MJN, Park R (1988): Theoretical stress-strain model for confined concrete. *Journal of Structural Engineering* **114**: 1804-1826.

[25] Menegotto M, Pinto PE (1973) Method of analysis for cyclically loaded R.C. plane frames including changes in geometry and non-elastic behaviour of elements under combined normal force and bending, *Symposium on the resistance and ultimate deformability of structures acted on by well-defined repeated loads*, International Association for Bridge and Structural Engineering Zurich, Switzerland.

[26] Monti G, Nuti C, Santini S (1996): *CYRUS - Cyclic response of upgraded sections*. Report No. 96-2, University of Chieti, Chieti, Italy.

[27] Lozincă E., Seki M., Aldea A. (2018): Seismic evaluation of the minaret of "Carol I" Royal Mosque in Constanța, Romania, *16th European Conference on Earthquake Engineering*, Thessaloniki, Greece

[28] Pantazopoulou SJ, Papoulia KD (2001): Modeling cover-cracking due to reinforcement corrosion in RC structures. *Journal of Engineering Mechanics* **127**: 342–351.

[29] Vamvatsikos D, Cornell CA (2002): Incremental dynamic analysis. *Earthquake Engineering and Structural Dynamics* **31**: 491-514.

[30] P100-1/2013 (2013): (Romanian) *Code for seismic design – Part I – Design prescriptions for buildings*. Ministry of Regional Development and Public Administration, Bucharest, Romania.

[31] Baker JW (2015): Efficient analytical fragility function fitting using dynamic structural analysis. *Earthquake Spectra* **31**: 579–599.

[32] Kappos AJ, Panagopoulos G, Panagiotopoulos C, Penelis G (2006): A hybrid method for the vulnerability assessment of R/C and URM buildings. *Bulletin of Earthquake Engineering* **4**: 391-413.

[33] JBDPA (2015). *The Standard for Evaluation of Existing Reinforced Concrete Chimney*, Japan Building Disaster Prevention Association.

[34] P100-3/2008 (2008), (Romanian) *Code for the Seismic Evaluation of Existing Buildings*, Ministry of Development, Public Works and Housing, Romania.