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Experimental study of the church 'Sveta Sofia' in Sofia

L.Tz.Tzenov & S.L.Dimova
Central Laboratory for Seismic Mechanics and Earthquake Engineering, BAS, Sofia, Bulgaria

ABSTRACT: In connection with the project for conservation, restoration and exhibition of the church "Sveta Sofia", experimental study is carried out for establishing of the dynamic behavior of the building, needed for its seismic assurance. Analysis of the dynamic behavior of different structural elements and their interaction is made. On this basis conclusions about the seismic vulnerability are drown and recommendations for the restoration are given.

1 INTRODUCTION

The church "Sveta Sofia" is a cultural monument of national significance to Bulgaria. It is built in 5-6 centuries in the main necropolis of the antique town Serdika. Nowadays the church is situated in the north-west part of the square "Alexander Nevski" in Sofia. The church is built on a composite stratification of early-christian tombs (2,3 and 4 centuries) and ruins of two churches (4 and 5 centuries) (Kitov 1989).

The building represents a three-nave basilica with a transept (see Figure 1). The length with the apse is 46.40 m, the width of the transept is 23.00 m, the height of the central nave is 16.10 m and the height of the dome is 19.75 m. Bearing elements are the walls and the columns. The church as a whole is constructed of brick masonry and is founded on strip stone work foundations. Some of the foundations lay on the cracked antique tombs (see Figure 2). The ground is represented by a layer of alluvial sands 3.40 m thick. Some of the foundations are in contact with quaternary gravel 1.60 m thick and embarkments 1.6 m thick (Geological survey 1990).

During its 15 centuries-old history the building has suffered a lot of interventions - till the 14 century it acted as a church, in the 14 century it is reconstructed in a mosque, the earthquakes in 1818 and in 1858 caused severe damages of the structure (see Figure 3). The building is abandoned till 1910. After serious investigations from 1910 till 1912 the structure is filly restored and since then it is acting as a church. The above mentioned reconstructions and excitations have influenced the structural

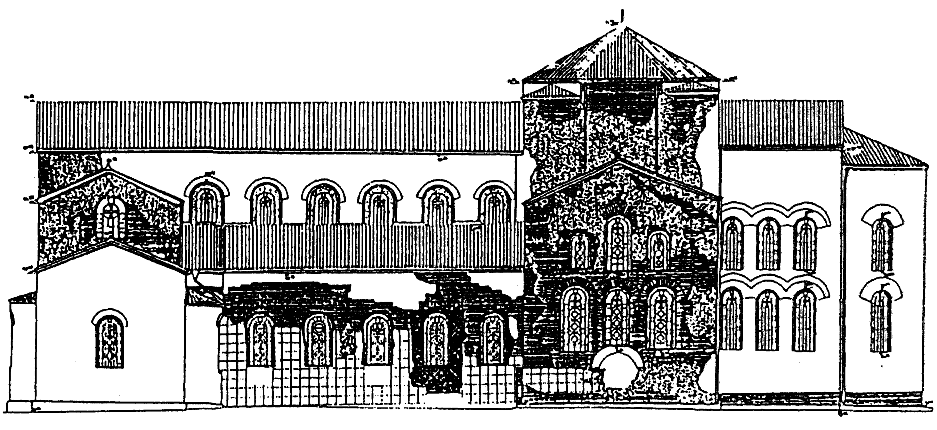

Figure 1. South facade of the church.

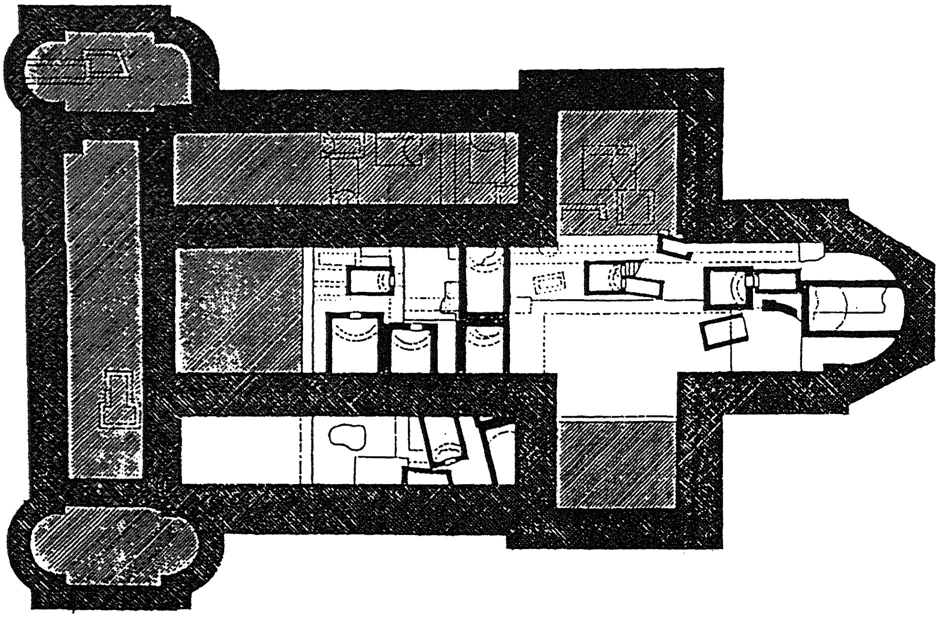

Figure 2. Plan at the archaeological level, elevation -2.50 m.

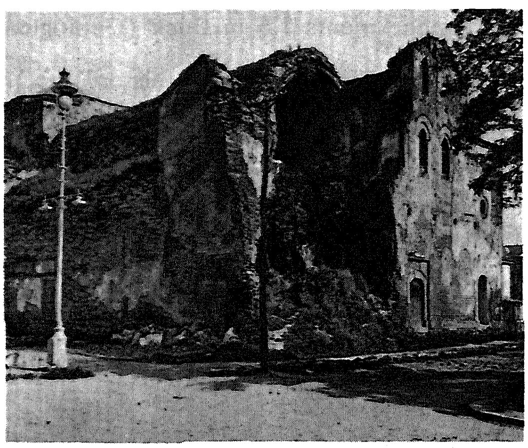

Figure 3. The church in the begining of 20 century.

integrity. Visible cracks are available in the bearing elements of the structure.

Nowadays a design project is worked out, concerning the conservation, restoration and exhibition of the building under the requirement for saving its function of acting church. The specialists are in search of solution which would permit a preservation of the traces of all stages of the long and rich biography of this cultural monument.

In connection with the above mentioned problems in 1990 a dynamic experimental study is carried out aiming at establishing of the dynamic behavior of the structure, needed for its seismic assurance.

2 EXPERIMENTATION TECHNIQUES

The free vibrations of the structure are studied. They are caused by a car passing through an obstacle. During the experiment a system of the firm "Kinametrics-SS" is used. It consist of 7 transducers of type SS-1, which registrate velocity of vibrations, amplifier SC-1 and connecting cables. The registrations are recorded simultaneously on a type recorder "Hewlett Packard" and after analogous-digital transformation on a personal computer "Pravetz 16". An oscilloscope of type "Visilight" is used as a device for visible control and observation of the records.

The records are corrected taking into account their calibration coefficients and the different amplification during the record-processing. After numerical integration the displacement time histories are obtained and by Fourier transformation the predominant periods of free vibrations are obtained from the corrected records. For these periods the amplitudes of the respective harmonic components are determined and on the basis of their analysis the corresponding eventual "modes"

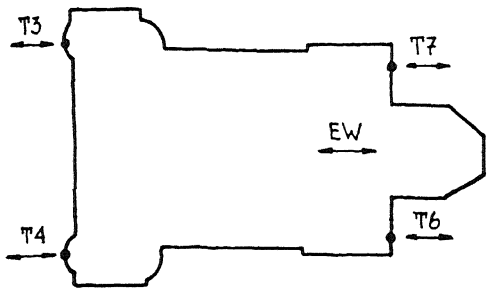

Figure 4. Transducers disposition according scheme 3.

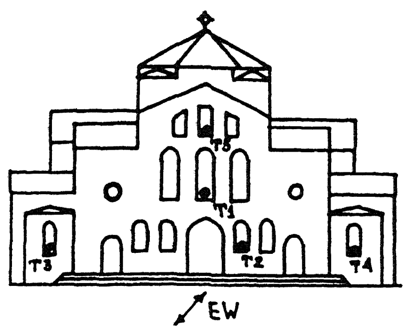

Figure 5. Transducers disposition according scheme 3.

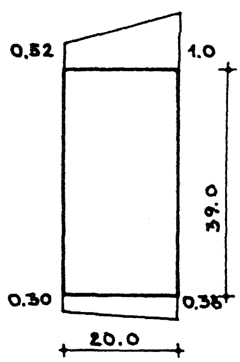

Figure 6. "Mode" of vibrations for Tew=0.107 s.

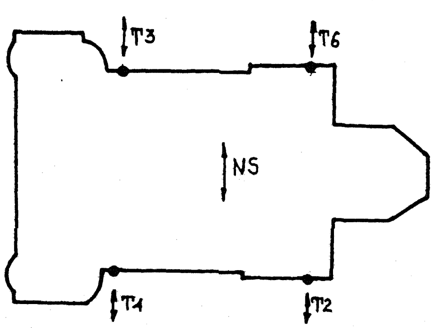

Figure 7. Transducers disposition according scheme 6.

of free vibrations are fixed.

During the experimentation and data analysis two conventional directions are accepted: East-West (EW), coinciding with the longitudinal building axis and North-South (NS) perpendicular to the first direction. Vibrations into directions EW (schemes 1,2,3), NS (schemes 4,5,6,7) and into vertical direction (one of the records according scheme 3) are registered.

7 schemes of transducers disposition on the building window openings are carried out. These schemes are established on the basis of the preliminary investigations and analyses of the building partiqularities. During the scheme 1 realization all transducers are located "in one point" on the window opening of the west facade for calibration record. According the different schemes vibrations of points of one and the same structural fragment (schemes 2,5) or vibrations of points of different structural fragments (schemes 3,4,6,7) are recorded. This gives the possibility to analyse the dynamic behavior of the different structural elements and their interaction and on this basis to establish the degree of fragmentation of the structure as a whole.

3 EXPERIMENTAL RESULTS

1. The separate structural elements of the building should not be treated as parts of a monolithic continuity. By way of illustration the results from the registrations according schemes 3 and 6 can be cited. According the scheme 3 transducers T3, T4, T6 and T7 are situates "in one horizontal plane" on the first row of windows at the corners of the building (see Figure 4). Transducers T1,T2 and T5 are located "in a vertical line" on the windows of the weste facade (see Figure 5). All transducers register vibrations into direction EW. For predominant period of free vibrations Tew=0.107 s a "mode" of vibrations in a horizontal plane is obtained (see Figure 6). Its shape gives reasons to consider the connection between the bearing walls as unsufficient good one.

According the scheme 6 transducers T2, T3, T4 and T6 are situated "in one horizontal plane" on the first row of windows in the north and the south facades of the building (see Figure 7) and register vibrations into direction NS. Data analysis shows the predominant period of free vibrations Tns=0.095 s. In Figure 8 is shown a "mode" of vibrations in a horizontal plane, corresponding to this period. Its shape is a confirmation of the above mentioned statement about the unsufficient good connection between the bearing walls of the building.

2. The available cracks influence significantly the dynamic behavior of the structure. As an illustration the results obtained from schemes 7 and 3 are shown up.

According the scheme 7 transducers T1, T3, T4 and T6 are situates "in one horizontal plane" on the first row of windows on the north and the south facades of the building and transducer T5 - on the window opening of the lantern basilica light, over a column of the south colonnade (see Figure 9). The transducers register vibrations into direction NS. Transducers T1 and T3 are placed on adjacent windows in the north facade, between which there are visible cracks, as it is marked in Figure 9. Transducers T4 and T6 are located on the adjacent windows in the south facade. The displacements time histories obtained by the transducers registrations are shown in Figure 10. The comparison of the "adjacent" transducers registrations shows the interaction between the respective elements is "partial" because of the available cracks. Data analysis shows the predominant period of the facade walls free vibrations Tns=0.100 s. and for the south colonnade Tk=0.139 s (or more precisely of the column under the transducer T5, as far as there was not possibility for more than one transducer disposition on the windows of the lantern light and for this reason - for more detailed analysis of the dynamic behavior of the colonnade as a whole). The difference between the obtained Tns and Tk is hardly likely to be caused by cracks in the south vault arch, which could be extended profoundly in the masonry. For this reason a new, more precise survey of the structure was made and cracks located longitudinally in the vault arches over the south and north naves were found out.

From the other hand, the non-synchronous vibrations registered by the two adjacent transducers T1 and T3 (see Figure 10) as well as their dissimilar amplitudes of vibration give reasons to consider the visible cracks as penetrating deeply in the masonry. The vibrations registered by the situated on the opposite wall transducers T4 and T6 give another reason to consider the monolithicness of the wall between them to be decreased. On the other hand, the non-synchronism of these vibrations in comparison with those, registered on the opposite wall, confirms the unsufficient good connection between the bearing walls of

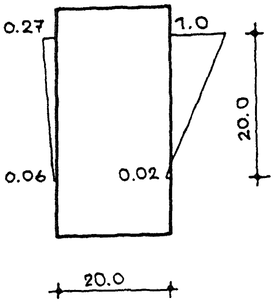

Figure 8. "Mode" of vibrations for Tns=0.095 s.

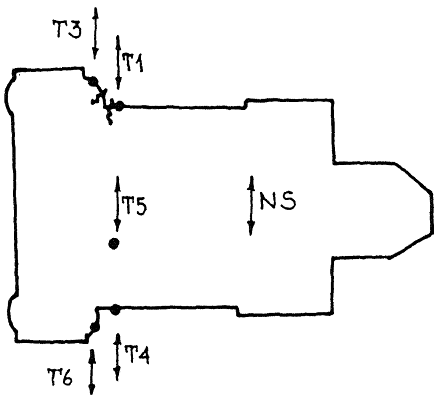

Figure 9. Transducers disposition according scheme 7.

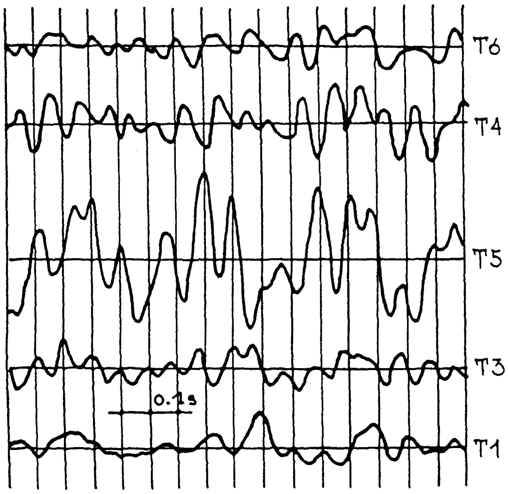

Figure 10. Displacements time histories according scheme 7.

the building, established in p.1.

A "mode" of free vibrations, corresponding to the predominant period of free vibrations Tew=0.107 s (see Figure 11) is obtained from

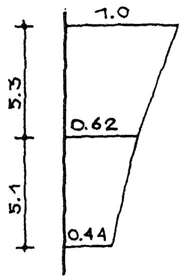

Figure 11. "Mode" of vibrations for Tew=o.107 s.

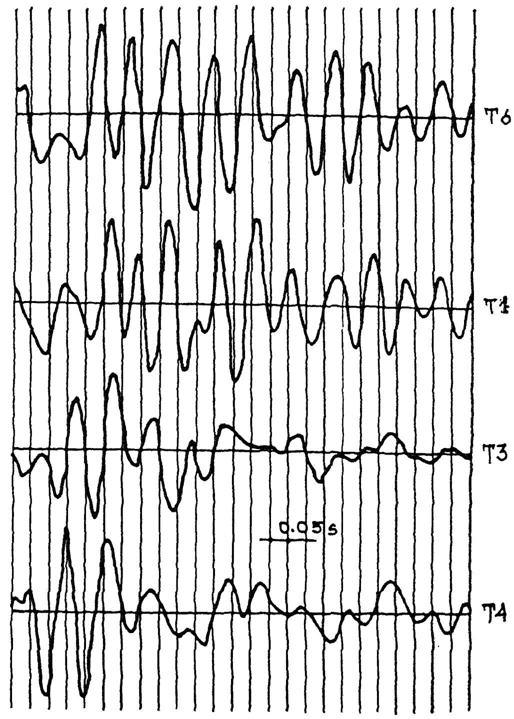

Figure 12. Displacements time histories according scheme 3.

the registrations of transducers T1, T2 and T5 according the scheme 3. The subconcave shape of this "mode", taking into account that the building is constructed of brick masonry, gives the reasons to consider the stiffness at the level of the second row of windows to be decreased not only by the respective window openings, but by the available horizontal cracks, too.

3. The characteristics of the foundation base are not identical under the different parts of the structure. The horizontal vibrations registrations according the scheme 3 show some "delay" of the vibrations along the structure. In Figure 12 the displacements time histories obtained by the registrations of transducers T3, T4, T6 and T7 are shown. As far as the excitation is applied nearby the west facade wall, a delay of the order of 0.08 s is registered by the transducers T6 and T7 located in the eastern facade wall (see Figure 4). This fact could be explained as by the available cracks in the walls, as by the non-identical characteristics of the foundation base under the different parts of the structure. In other words, the registered vibrations could be treated as vibrations of a complicate system of interacting fragments, which is located on a base, consisting of interacting fragments, too.

4. The following predominant periods of free vibrations of the studied structure are obtained by the analysis of the different schemes data:

direction EW	Tew=0.104 s
direction NS	Tns=0.098 s
vertical direction	Tv =0.108 s

These close values of the free vibrations predominant periods, taking into account the configuration in plan of the building and the way of its erection, are an evidence for the predominant shear deformations in the structure.

The available cracks, which are extended profoundly in the masonry of the structure bearing elements do not give the reason to treat the building as a monolithic whole. For this reason it is not correct to consider the obtained free vibrations predominant periods as fundamental ones.

4 CONCLUSIONS

1. The seismic vulnerability of the building is heightened. The structure is not able to withstand the seismic loading, corresponding to the expected seismic excitation. The building needs of repairing by means of global construction intervention including its base.

2. The structure as a whole is divided in fragments by cracks, extended profoundly in the masonry. There are reasons to assume that the fragmentation of the structure is aided by the lack of good connections between the bearing elements.

3. On the grounds of the carried out study the natural periods in NS, EW and vertical directions are expected to be of the order of 0.1 s when the repairing will be made.

4. When the mathematical model of the structure will be chosen for determination of the design seismic loading, the following recommendations should be taken into account:

- the predomination of the shear deformations in the structure;
- the foundation base conditions with all their complexity;
- the value of the base natural period could be of the order of 0.1 s.

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