State of Art of Historic Structures in Bulgaria

Assoc. Prof. Dr. Eng. Doncho N. Partov, Higher School of Civil Engineering, Sofia; partov@vsu.bg

Assoc. Prof. Dr. Eng. Christo T. Christov, Higher School of Transport; chtch_sofia_bg@yahoo.com

Assist. Prof. Dr.Vesselin K. Kantchev, Higher School of Civil Engineering, Sofia; kantchev@vsu.bg

Assist. Prof. Eng. Dobromir E. Dinev, UACEG; dinev@yahoo.com

Assist. Prof. Eng. Aleksander K. Taushanov, UACEG; taushanov@hotmail.com

Arch. Edelvais E. Popova, GLAVPROEKT; edelvays@hotmail.com

Stud. Deian P. Mitev; Higher School of Civil Engineering, Sofia; mitev_d@yahoo.com

1. Abstract

In this paper the authors make attempt to see from inside the state and problems of a part of the very rich architectural and historical heritage of Bulgaria [1, 2, 3]. A short review and description of the structures of some typical representatives of historical monuments: fortresses, monasteries, basilicas, churches, cathedrals and bridges are given. The period from the early Byzantine epoch dated from the 1st century to the end of the 20th century is comprised. Special attention to the seismic monitoring system for observation of behavior of the historic monument structures during earthquakes is paid. The large role of the contemporary methods of the structural mechanics namely the finite element method for analysis of the spatial behavior of the historic structures subjected to seismic actions is emphasized. Conclusions and recommendations for study, maintenance and strengthening of the historic structures are derived.

2. INTRODUCTION

The people, who inhabited the lands of Bulgaria, have left an abundant culture heritage with respect to historic structures. For more than 1300 years the people living in this country, which had been founded in 681, were creating their own culture. Nowadays the historic structures show the way of our remarkable human and national history. Many historical structures from different historical ages have been preserves as a part of the Bulgarian national culture heritage. Some of them date back from 20 centuries ago. They are an expressions of the cultural achievements and creativity of the Bulgarian people in the course of the centuries. They show the abundant traditions in the field of our historic structures. Several examples of historical structures are presented here.

Sometimes, in spite of the economical difficulties, the Bulgarian government takes various measures, aimed at preserving the historical structures, which hold the Bulgarian national spirit and identity. A strategic line is to finance research works for investigation of the seismic vulnerability of the historic structures. Two examples of an applied seismic monitoring system and seismic analysis of a historic structure are presented.

3. HISTORIC STRUCTURES IN VIDIN TOWN

3.1 “Baba Vida" Castle

“Baba Vida” was built on the ruins on the Roman fortress Bononia, whish existed on part of today’s city limits between middle of the Ist century and the end of the VIth century (fig.1).

It was part of the Danube border of the Roman Empire. Remains of its defense system were preserved and can still be found in deferent parts of town of Vidin today. The foundations of the East corner tower were preserved best of all, and were utilized in the construction of “Baba Vida” later. Bulgarian construction on the castle dates back to the second half of the Xth century. The construction is typical for that Fig.1. “Baba Vida” Castle period: stones and bricks, welded together with mortar (fig.2).

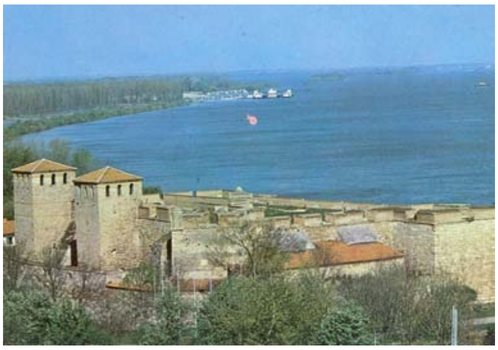

Fig.1. “Baba Vida” Castle

Fig.2. The Inner Wall

The “Stratsimir” Tower (XIII - XIV cc) is the best preserved of all other towers from the Medieval Bulgarian period. It is 16m tall with many bricks ornaments preserved in its walls (fig.3).

Today “Baba Vida” castle has a shape resembling a square. Each side is approximately 70m. The castle has two surrounding walls. The inner one is higher and has 9 towers whereas the outside one is lower and is connected by two towers.

Fig.3. “Stratsimir” Tower

Fig.4. The Moat filled with Water

A deep and wide moat was dug around the castle. The moat was filled with water from Danube River. There was a wooden draw-bridge across it (fig.4).

In reality the castle and its past are closely related to the restless centuries of feudal Bulgaria. Its strategic importance increased over time in relation to the wars of Bulgarians against Avari, Franks, and Magiars. The castle played a significant role in defending

Bulgaria's independence against Bysantium at the time of King Samuil. In 1003 the town successfully defended itself for a "full eight months" against the army of Emperor Vassilius II.

During XV – XVII centuries the castle was used only as a defense complex. It endured because it stayed outside of the scope of the Russian- Turkish wars. Today the Summer Theatre, with 350 sits, is within the walls of "Baba Vida". Traditional summer theatrical days take place there, with participants from all over Bulgaria. Now in "Baba Vida" motion pictures often shot most of them on historical topics.

4. HISTORIC STRUCTURES IN MEDIEVAL TOWN NESSEBAR

Ancient Messembria is picturesquely located at a peninsula in the Black Sea. It was surrounded both of sea and land by thick stone-walls. Merchants from all over the Mediterranean area gathered here to take part in the festivals held in the local theatre and the temple of Apollo. Once an independent state, the town minted its own coins as early as the 5th century BC. The town is included in UNESCO's World Cultural and Natural Heritage Program. Legends say once there were 41 churches. Some of them, 12 in number, have survived up to now. They are like pearls in the ancient sea town reserve. They prove the high level of workmanship of medieval Bulgarian master-builders.

4.1 The Church of "St. Joan Krastitel".

This is the most reserved medieval church in this town. It was slightly repaired.This monument belongs to the auditorium basilica of cross type. Four solid-built pillars trace out the under dome square over which a big cylindrical drum is mounted. The size of the church in plan is 12 meters per 10 meters. The material used for construction is river stones. The walls are 0.80m.thick. The bricks are used in limited quantities, only as an ornamental element.

Now, the building is used by local retailers to sell souvenirs from Nessebar (fig.5).

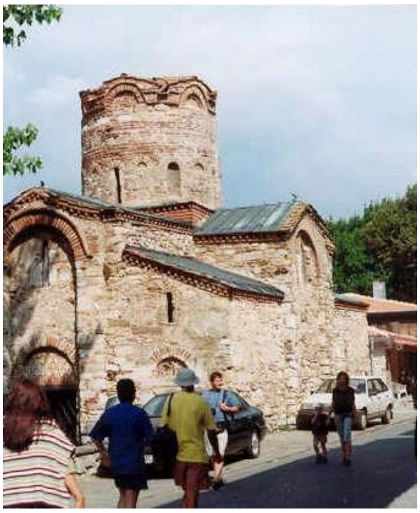

Fig. 5. The Church of "St. Joan Krastitel".

4.2 The Church of "St. Archangel Mikhail and Gabriel"

The church was built as one nave construction with a dome; the size in plan is 13.90 meters per 5.20 meters. The roof was designed as a cross of four cylindrical vault arches. The church has reached up to our days without roof. The elevations are segmented with one-step bays which upper side is shaped as an arc construction. The arcs are built of stones and bricks, and decorated with 3 rows ceramic rosettes. Some of the arcs are opened.

The construction is done with mixed masonry - 2 rows large well cuted stones and four rows of bricks. The cylindrical vault arch is built from mixed masonry - one-row stones and two rows of bricks.

The construction of the church dated back to XIII – XIV c. The church belongs to the family of one auditorium basilica of joint cross type. (Fig. 6) The walls are 0.85 and 1.30 m thick. The building is not in use at the moment.

The cylindrical vault arch were strengthened with steel stretchers.

Fig. 6. The Church of "St. Archangel Mikhail and Gabriel"

4.3 The Church of "Pantocrator" in Nessebar

The plan of the church is a rectangle with a size 16.0x6.70m. The monument belongs to the family of pantographic church and is an impressive auditorium basilica of cross type. The roof is a combination between semi cylindrical vault arch and eight walls tower and pyramidal roof. (Fig. 7) The elevations are differently designed. Three of them are with differently repeated bays, blind arches, jagged cornices and so on. The fourth elevation was designed as merged arched walls. The church was built of stones and bricks, which were used for construction and decoration at the same time. The walls were decorated with rhythmical changing 3-4 rows bricks and 3-4 rows well-carved stones. The thickness of the walls is 0.80m. The church dates back to the XIV century and represents an artistic architecture.

Today, the building is used by the local retailers to sell paintings from Nessebar.

Fig. 7. The Church of "Pantocrator" in Nessebar

4.4 The old “Metropolis” in Nessebar

It is one of the remarkable monuments of early Byzantine church architecture on Bulgarian lands. For decades passed its monumental architecture and structural image attract attention of many travellers and explorers.

The monument is an impressive basilica of 25.5m in length and 20.2 m in width. The central part is separated in three naves which are 3.7/9.3 /3.7m with two rows of five solid stone rectangular pillars - 1.2 m per 0.8m, connected with arches (Fig. 8), with height of 3.5m. Over the first row of pillars is built second row of pillars connected between themselves also with arcs.

The big arch which is built over the altar is a deep semi dome /6.50x3.25m./

The construction of the monument is made mainly of stones and bricks, which are mixed above the first 5 rows of stones. The openings over the altar are shaped only with bricks. The stones and bricks are fixed to each other with red mortar.

The middle nave of the basilica is covered with wooden structure and ridge span roof, and the two naves from aside with pent - wooden roof. The basilica was built in V century.

The building, today, is one of the attractions in the ancient town, surrounded by small shops for paintings and souvenirs. The artists from all over the country exhibit here their works.

Fig. 8. The old “Metropolis” in Nessebar

5. STRUCTURES IN HISTORICAL TARNOVO

“Tarnovo, the Royal City of the Bulgarians, is the second in words and deeds after Constantinople.” The Constantinople Patriarch Kalist (XIV c)

The hill of Tzarevets has been populated since ancient times. The earliest settlers were the Thracian people, whose culture was at its peak during VI - I c. BC. Foundations of buildings, fortress walls and considerable cultural layers testify to the busy life of the place during the Byzantine period- V – VI c. More than 200 years (1185 – 1393) uniquely picturesque town of incredible natural location was the political, administrative and cultural center of the Bulgaria. The town was situated on the hills of Tzarevets and Trapezitsa and the long the Jantra River (fig.9).

The fortification works of Tzarevets were a complex system enclosing about 100 000 sq.m. They consisted of solid stone walls, with cliffs running around at the edges, with numerous defense turrets, loop-holes and embrasures, following the configuration of the terrain. It was specially fortified at a number of places. The outer fortress wall of Tzarevets is a reliable military engineering work, which could hold up any attack any of the weapons of the time.

Fig.9. View of the Castle

The defensive system of Tzarevets is an achievement of the fortress – construction genius in XII – XIV c. Archeological excavations have led to finding out 22 churches and 4 monasteries (fig.10). They are of either basilica, or cross – domes shaped type. They were built of stone lined with bricks.

Fig.10. “St. Demetrius” Church

The Patriarchate Complex was created on the top of the hill. It was build up as a separate architectural ensemble with a citadel and a surrounding wall and turrets (fig.3).

The Patriarch church was built on the foundations of the early Byzantine basilica from V – VI c. It was reconstructed 1981 for the commemoration of 1300 anniversary of the Bulgarian statehood (fig.12).

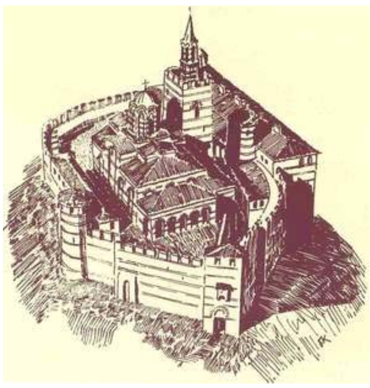

Fig.11. The “Patriarch Ensemble”

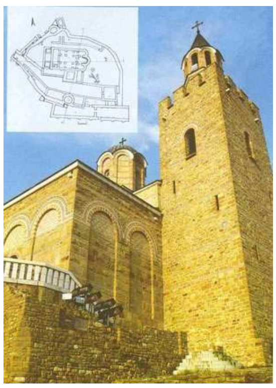

Fig.12. The “Patriarch Church”

6. HISTORIC STRUCTURES IN SOFIA

6.1 Boyana Church "St. Panteleymon"

This church is included in UNESCO's World Cultural and National Heritage Program. It was built in three stages in the 11th, 13th and 19th centuries. The size of it is 5.85m x 5.25 m. On the east side a semi-circle altar was built. 4 columns, which shaped cross on the plan, were built in the corners.

The pillars bear cylindrical arches, which cut each other, over them was built cylindrical drum and dome shaped roof, cut with four narrow windows.

In 1259 year this construction was continued on the second floor of the extended tow story church, built by tsar Kaloian. The church was built of stones and bricks.

As a construction the church is marked with the distinguishing features of the historical constructions of churches, which are square in plan, with a dome and without freestanding pillars (Fig. 13).

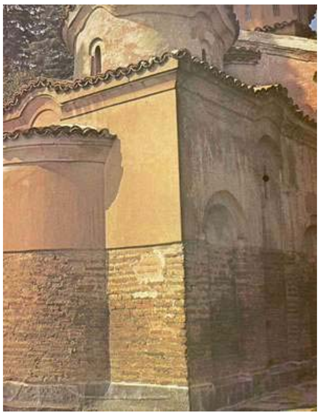

Fig. 13. Church "St. Panteleymon"

6.2 Basilica 'Saint Sofia'

This church is a unique monument from early Byzantine construction. It is a three auditorium construction with total length 46,50 m and width 23,00 m (Fig.14). The central part of the structure is divided into three auditoriums by massive masonry columns with a cross-type cross-section. They are connected one another by arches without capitals. The main auditorium after crossing with the transverse auditorium continues with a same height in altar space and forms a Latin cross. On the crossing place of the two auditorium a square is formed marked by 4 columns that sustain the main cupola by means of 4 triangular spherical surfaces. The cupola is hidden from outside by tetrahedron. The church date from the second half of the 4th century.

In 1878 the main architect of Sofia the Czech L. Bayer and engineer Prosheck pay attention to the church keeping and restoration.

6.2.1 Theoretical model for seismic analysis

The basilica 'Saint Sofia' has almost 15th century history. It had been constructed for a long time. The structure has endured some strong earthquakes. The last reconstruction of the church has been made in 1930. Two investigations are made to evaluate the seismic vulnerability of the church. The first one is accomplished in 1989 by the computer programs COSMOS/M and IES using the brick finite elements [5].

The second is performed in 1998 [6]. In this study the spatial model is composed from existing structural elements from one side and some new strengthening elements (two reinforced concrete shells above the existing masonry domes and six tension bars of the roof arches and vaults) on the other hand. The analysis is made by the finite element method (FEM) using the COSMOS/M computer program [8]. The model contains 2475 finite elements and 2283 nodes with 6 DOF (3 displacements and 3 rotations) in each one. The total number of equation is 12666.

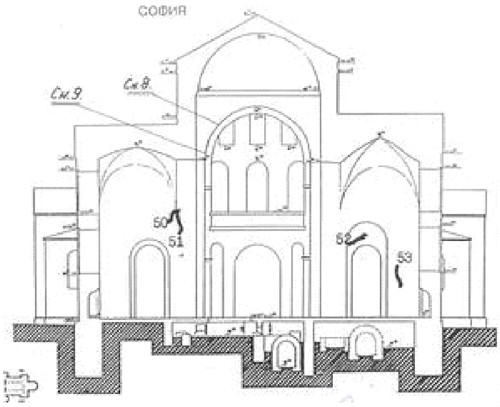

Fig.14. Basilica "St. Sofia"

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type 1: 3-node linear triangular thick shell element;

type 2: 4-node linear quadrilateral thick shell element;

type 3: 2-node linear 3-D elastic beam element.

The shell elements have bending and membrane stiffnesses. The shear deformations are taken into account. Elastic and isotropic material is assumed. The particular structural elements are defines as 'regions'. The finite element mesh of each 'region' has a maximal dimensions up to 1,5m. The adjacent 'regions' are connected each other by common nodes which guarantee displacement and rotation compatibility (fig.15). Supporting nodes are entirely fixed. The geometrical characteristics of the structure are the following: the wall thickness varies from 1,10 to 2,00 m, the masonry vault thickness is 0,30 m, the new r/c shell is 0,10 m thick. The material properties of the brick masonry are: the Young's modulus is E = 1350 MPa, the shear modulus is G = 0,4E = 540 Mpa, the mass density is γ = 1800 kg/m3, but for the concrete they are: E = 25000 Mpa, G = 0,425E = 10625 MPa, γ = 2500 kg/m3.

The basilica structure is analyzed under vertical load and seismic actions of 9th degree according to MSK-64 and Bulgarian design codes [7]. The first 6 periods of the undamped free vibration are obtained as T_1 = 0,287 sec, T_2 = 0,216 sec, T_3 = 0,197 sec, T_4 = 0,178 sec, T_5 = 0,154 sec, T_6 = 0,153 sec. The third and fourth mode shapes are shown in fig.15a and 16. The internal forces and stresses are computed considering the first 50 natural mode shapes. The seismic analysis is accomplished by two simultaneous horizontal seismic signals given by two correlated horizontal spectra. As a result the stresses in the dangerous points of the structure are obtained for the following two combinations:

Ist combination - max stress = stress caused by the vertical load + stress from the seismic action; IInd combination - min stress = stress caused by the vertical load - stress from the seismic action.

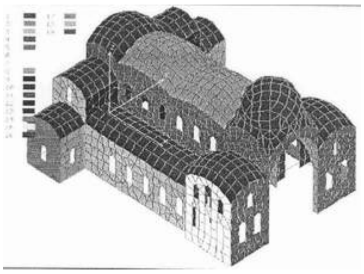

Fig. 15. F.E. mesh

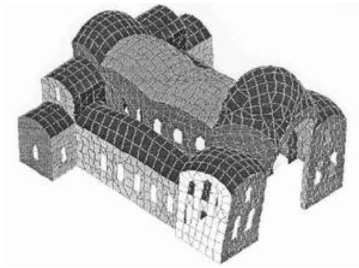

Fig.15a. 3th vibrating shape

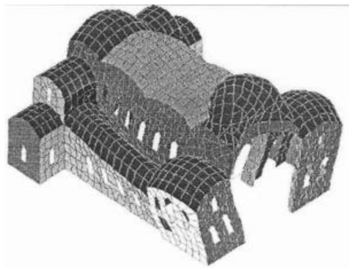

Fig.16. 4th vibrating shape

The characteristic stresses of the wall masonry are: compression stress is 0,9 MPa, tension stress is 0,03 MPa, tension stress under bending is 0,04 Mpa, shear stress is 0,05 MPa but for the roof masonry they are 0,5 MPa, 0,005 MPa, 0,01 MPa, 0,01 MPa respectively. The vertical stresses σ_z in a wall 2 caused by the vertical and seismic loads are as following. The stresses in the first column are:

max σ_z = -0,445+0,544=0,099 > 0,030 Mpa, i.e. the column can be unstuck;

min σ_z = -0,445-0,544=-0,989 > 0,9 Mpa, i.e. the compression strength is exceeded. The tangential stresses also exceed the tangential strength (Fig.17 and 18).

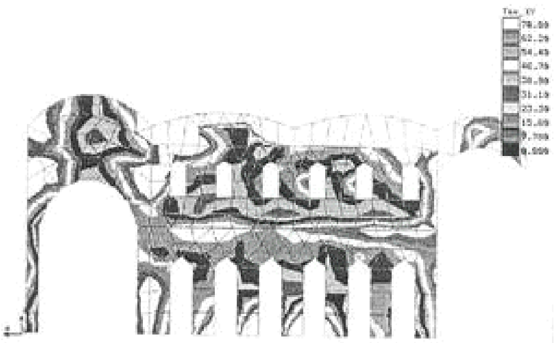

Fig.17. Tangential stress in plain of wall 2 from seismic action

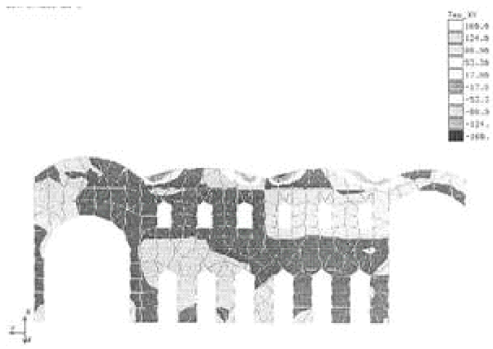

Fig.18. Tangential stress in plain of wall 2 from vertical loading

As a result the brick columns are in danger. The von Mises stresses in the new roof r/c shell are drawn in Figs. 19 and 20. The stress concentration around the tension bar can be observed. Full scale dynamic experiment is realized too. The numerical and experimental results have good agreement [4].

An SIKA injection technology for restoration the masonry continuity is applied (Figs. 21 and 22).

Fig.19. New r/c roof shells – Stress Von Mises from vertical loading

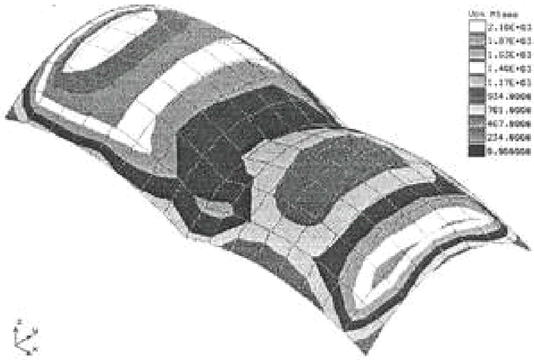

Fig. 20. New r/c roof shells – Stress Von Mises from seismic action

Fig. 21. “St. Sofia” - after resturation inside if view

Fig.22. “St. Sofia” – inside view

6.3 “ALEXANDER NEVSKI” – PATRIARCHAL CATHEDRAL

“Alexander Nevski” church – monument is an impressive five auditorium basilica of joint type combining the main Byzantine style elements that in some parts show the influence of eastern models. It was built on the area of 3170 sq.m with general cubic measurements of 86 000 cub. m. Its outer length amounts to 7350m and its width 50.52m. From the sidewalk level to the church tower cross its height is 50.52m. The central dome amounting to 46.27m and the roof bridge – to 28m. The main cupola lies in the form of a big cup turned bottom upward. Its diameter is 18m.On the west side of the main three folded vaulted entry door, towards the narthex, stand the bell tower ending in a cupola.

The cupola rest on three – fold little columns, among which there are wide openings. One could see through them 12 bells, the biggest of which weighs 11 758 kg (fig. 23).

The inside of Alexander Nevski Patriarchal Cathedral Church strikes with its size, harmony of architectural design, lighted space and rich art decoration. Its foundation stone was laid in 1882 and construction work came to close in 1912. As an aesthetic achievement, in terms of architecture and decorations, it rivals the most famous world monuments of this kind (fig.24).

Fig.23. "Alexander Nevski" Cathedral

Fig.24. Inside view

7. HISTORICAL STRUCTURES IN THE "RILA MONASTERY"

7.1 "Rila Monastery"

The "Rila Monastery" is the largest monastery complex on Bulgarian lands dating back to the Renaissance Age in Bulgaria. It is considered the most remarkable achievement of Bulgarian builders in this period both with respect to its architecture and its structure. According to historical sources the Monastery was found in 927-941 by St. Ivan Rilski. The Monastery is situated on the southern slope of the Rila Mountain at 120 km from Sofia. In the course of centuries the Monastery passed through several stages of reconstruction. It was burned down several times and rebuilt again. The present Central Building was re-constructed in 1816-1847. In 1960-1964 the east wing was re-built with a new structure.

Fig.25. Plan of "Rila Monastery"

Fig.26. View of monastery yard

The Monastery was erected as a closed complex of buildings, surrounding an inner yard in the form of an irregular quadrangle (Fig. 25). Its total area is 8800 m2. The outer architecture has the characteristics of a fortress. The walls were built by using stone masonry and have window openings. The width of the walls varies in proportion to their height from

1.6m at the foundations to 0.8m at the top. The front elevation consists of two main elements- arches and columns (Fig. 26). The inside walls have timber structures filled with brick masonry.

The floor and roof structures are made of timber. The roof was repaired in the twenties. The Central Building has six storeys, two of which are underground. The monastery housing wings have four storeys and contain more than 300 monastic accommodations, 4 chapels and numerous guest-rooms and storerooms.

The most interesting of all premises is the large monastery kitchen, called “magernitsa”. It is a massive tower in the form of a pyramid, which passes through all floors and ends up over the roof in a dome. It was erected on 4 massive arches on a square base and reaches the height of 22m. The pyramid structure was built due to 10 consecutive rows of arches arranged over one another on a base in the form of an octagon.

With its structure, tectonics, spatial solution and architecture this part of the Rila Monastery is a unique achievement (Fig. 26).

7.2 Church “HOLLY VIRGIN”

The Church “Holly Virgin” in the Rila Monastery was built in 1834-1838 in the middle of the monastery yard. With its layout, design and front elevation solutions, the church represents an astonishing achievement of Bulgarian architecture during the age of the Renaissance. It is a five-domed building with two lateral chapels and a gallery opened to the West, to the North and to the South (Fig. 27).

Fig.27. Church “Holly Virgin”

Three large domes with high drums form the axis of the main space of the church, which has the impressive dimensions of 14/31m. Wide-span arches at the transverse axes of the domes create a complex cross-like composition. The one-storeyed arched gallery is interesting with its unequal spans between the columns and blind domes at the roof. The western wall of the church bends into a triple yoke-like gable, which forms the main cornice of the building. The walls of the church were erected by using layers of stones and bricks. The complicated architectural and structural composition of the Church “Holy Virgin” represents the emphasis in the whole monastery complex. This remarkable religious monument is an integral part of the thorough harmony of the monastery complex.

7.3 “HRELIO’S” Defensive Tower

The oldest building preserved in the historical Rila Monastery is the “Hrelio’s” Defensive Tower, which belonged to the feudal landlord Hrelio. The Rila Monastery was situated in his estate. The defensive tower was erected in 1335. Its purpose was to protect both feudal lords and monks from the attacks of enemies. The outer architecture of the Tower is austere and imposing (Fig.28).

The walls are 1.8m wide and are filled with crumbled stone and lime. They are supported by massive stone counterforces uninterrupted along their length. The counterforces are connected at the top by arch structures (Fig.28). In the walls under the arches the builders made wide openings for defense purposes. The Tower resembles a fortress. There are crenelles and a platform at the top of the Tower. Its total height is 23m. The Tower has 6 levels. A staircase of stone built in the wall served for ascension. As far as layout is concerned the Tower has square dimensions. There is a ground floor with an arch-formed ceiling. A chapel with a domed ceiling with 6 ribs was built in the top floor. The floor structures between storeyes were made of timber. The emphasized vertical articulation adds dynamics and plasticity to the thorough appearance of the monument. Finishing the counterforces by arches presents an interesting architectural approach unique for the period of construction. Bricks were used only for decoration of arches over the counterforces and the corners between them.

Fig.28. "Hrelio's" Defensive Tower

7.4 Seismic Monitoring System

Bulgarian government takes various measures aimed at preserving Bulgarian cultural heritage, which holds Bulgarian national spirit and national identity. One strategic line is to finance research work on the reactions of respective structures to seismic forces. The following paragraph is aimed to present the approach and the results of a research performed at CLSMSE-BAN. The objective of the research was to determine the dynamic characteristics/parameters of the Rila Monastery building, as well as the church "Holy Virgin" and the Hrelio's Defensive Tower. The dynamic characteristics were determined in result of analysis of registered real earthquakes, regenerated by a system for seismic monitoring. The latter had been created by using equipment donated by UNESCO. The equipment involved consists of 4 digital accelerographs, produced by the Swiss company GEOSYS. The digital accelerographs include an accelerometer block SSA-20 and an operational computer block GSR-20. Three independent seismic channels in SSA-20 register three perpendicular movement components. The operational computer block is a 12-byte system for recording seismic data. The seismic monitoring system ensures:

- Registration of seismic signals, featured as input signals for the respective structure [11]
- Registration of the movements of specific structural points in result of the impact of seismic forces. Two earthquakes have been registered with the system described in the preceding paragraph. The earthquake on 03/07/1998 had a magnitude of M = 3.7. The epicenter was at a distance of 27km to the Northwest from the Monastery with seismic

focus at a depth of 13 km. The earthquake on 10/09/1998 had a magnitude of M = 3.1 and the epicenter was at 48km to the Northeast from the Monastery (Fig.5). Due to the analysis of the data recorded during the earthquakes the fundamental vibration period, the frequency (f_I = 3.613Hz; T_I = 0.277sec) and the frequency spectra of amplification of the three structural components at level 1157m compared to the ground level (1139m) were determined. The dynamic characteristics obtained could be used for analysis of seismic loading (fig. 29).

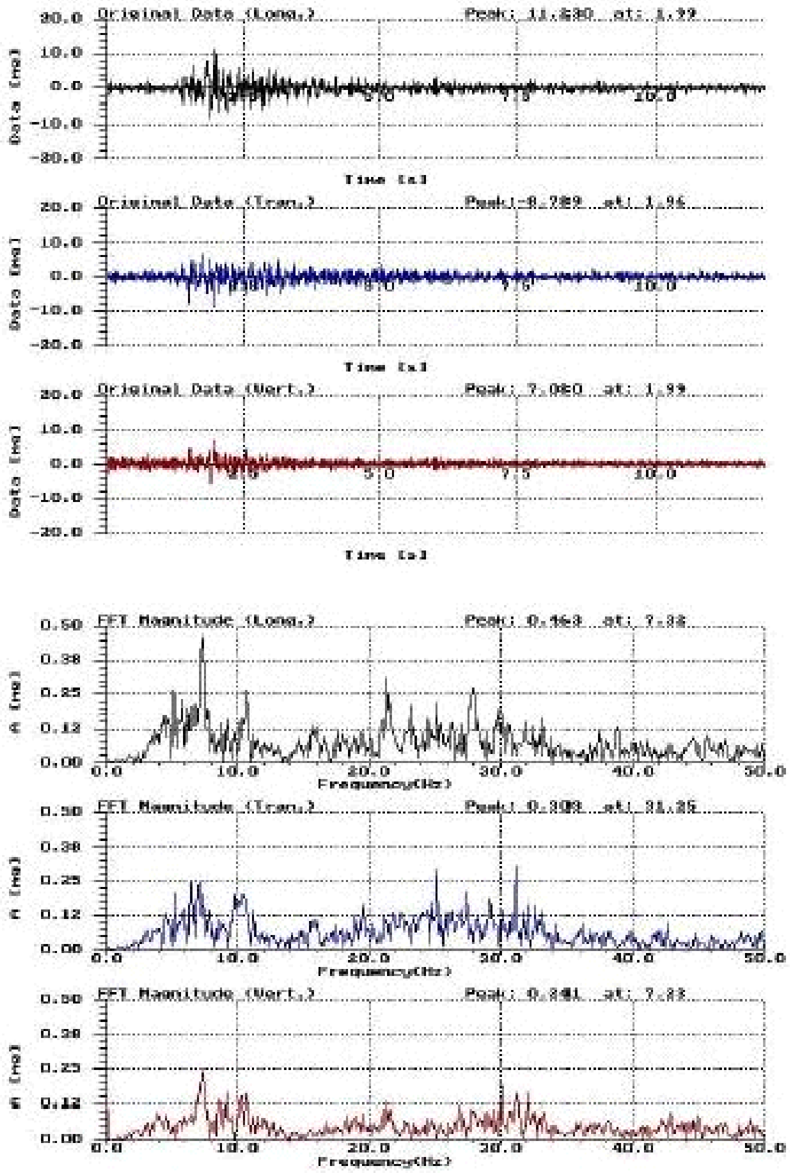

Fig.29. Accelerograms

8. HISTORICAL STRUCTURES IN SVISHTOV TOWN

8.1 The Cathedral “Sveta Troitza” in Svishtov

The cathedral “Sveta Troitza” in Svishtov was built in 1865-1867 by the Bulgarian master-builder Nicola Fitchev. It is a striking example of the monumental buildings from the Renaissance. The cathedral is like typical auditorium building with size inside 20x30 m.

The height of the naves is 11m. The columns are graceful with a height 9.5m.. The size between the axes of the columns is10m. The graceful columns together with the arches and domes have different shapes and look like thin pedicle with flowers. The elevation is perfectly, vertically segmented with graceful columns. Some of the columns are revolving. The master-builder did tell about them, that if they stop to revolve one day, the foundations should be checked.

The cathedral had stood several earthquakes. The last one was in 1977 which was 6.3 degree according the scale of Richter

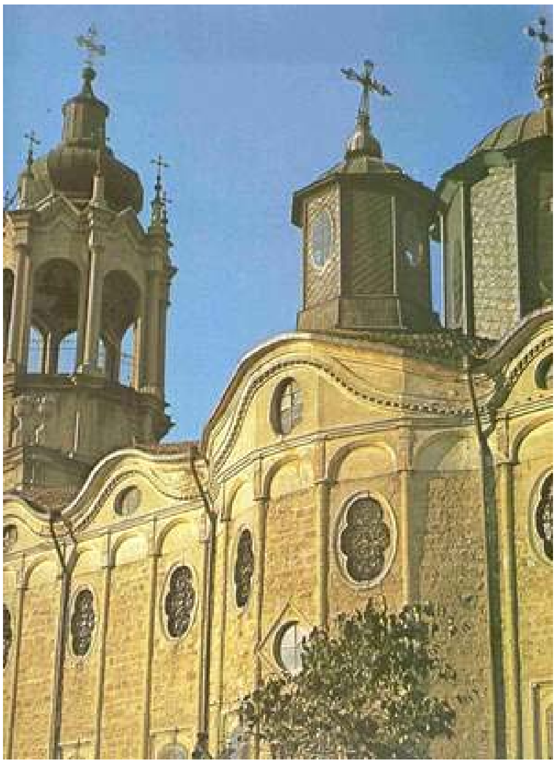

Fig. 30. The Cathedral "St.Troitza"

9. HISTORICAL DEVELOPMENT OF BULGARIAN BRIDGE CONSTRUCTION

The territory of Bulgaria is a crossroad from the antiquity of an important roads connecting in the direction north- south Dacia, across the Denube – to Greece and in the direction west-east connecting central and west Europe with the countries of the Orient. These roads have crossed the dense network of rivers using a lot of bridges which remains we can found in our days in our country.

In our days in Bulgaria we have preserved 250 bridges, which have been constructed in the period between XIII and XIX centuries. They are objects of special of treatment and conservation and some of them are in use nowadays.

9.1 Stone bridges

9.1.1 "Kadin" Bridge

As an example of these stone bridges can serve "Kadin bridge" which passed the "Struma" river on the way between Kyustendil - Dupnitsa (fig.31)

The construction of this arch stone bridge has been made in the time 1470 year. The total length of the bridge is 100 m and the width 6.5 m. It has 5 arch spans made from granite stones.

Fig.31. "Kadin" bridge

9.1.2 The bridge near to the town Biala

The bridge near to the town Biala was built in 1865-1867. It has 135 years history. The bridge represents one of the most significant engineering works in Bulgaria from the period of Renaissance (Fig.31).

The Bridge is remarkable as an engineering achievement among the stone bridges from this period in Bulgaria. It is with considerable length of 226 m. and 9.0 m. width. The arched-shaped openings are fourteen in number, each with 17 m. width. The solid-built stone piers are with thickness –5.40 m. In their upper part they have holes for flood control. The bridge is with a horizontal road line. Nicola Fitchev, the master-builder of this bridge designed it as a work of art. The rhythm of alternating arches and detailed high piers, create an impression of an architectonical elevation of a building.

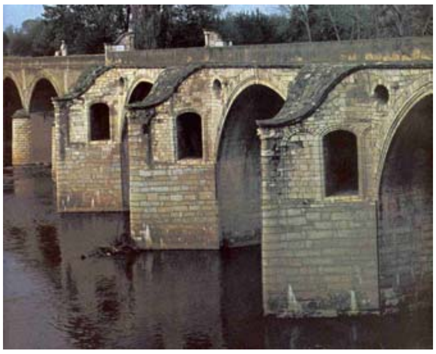

Fig. 31. The bridge of "N. Fichev"

9.2 Reinforced and prestressed concrete bridges

In the middle of the 50's began modernization of transport communications in Bulgaria. The construction of bridges has been made in the time of big shortage of materials and supporting systems. In this time, years between 1955-1966 the system "mail art" of "continuous deck girder stiffened polygonal thin arch" is used. There have been constructed bridges of this type of the arch between 25 and 90 meters.

For monolithic bridge construction in and of 50's is of XX centuries, began trend of development, after the implementation of modern steel framework for multiply use. A lot of them have been imported from Germany produced from companies as "Peiner" and "Hunebeck"

In the end of 50's to meet the growing request of bridge construction began the use of plant for pre-fabricating of sectional reinforced and prestressed concrete structures. Today these plants can meet all enquires for sectional bridge structures with span up to 35m, and assembly weight of 600kN.

Step by step the assembling crane-truss took a place in Bulgarian construction practice and a big part of viaducts on the high way are erected using this system. There are in use two types of it:

1. spans up to 40 m and assembling weight 1200 kN using Italian truss girder "Sichet"
2. spans up to 60 m and assembling weight 220 kN using truss girder "Bankov system"(fig.32 and 33)

Fig.32. Crane - truss

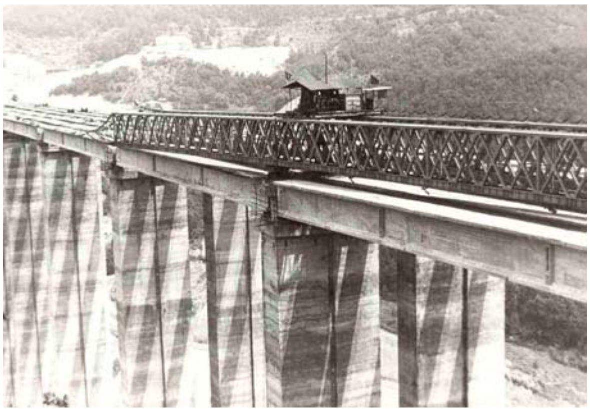

Fig.33. Assembling of bridge girders.

9.3 Seel bridges

9.3.1 "Stambolov" Bridge

In this period from the liberation of our country in 1878 the steel bridges applied as road and railway bridges. The main quality of the bridges was steel trusses with spans from 25 to 40 m. All these steel structures were imported mainly from Belgium, Germany and Austria - Hungary.

The bridge of Stambolov, built in 1892 year, in the town of Tirnovo hold a place apart among these bridges.

In the bridge construction is used steel truss girders with falling diagonals and parabolic lower chord (fig.34).

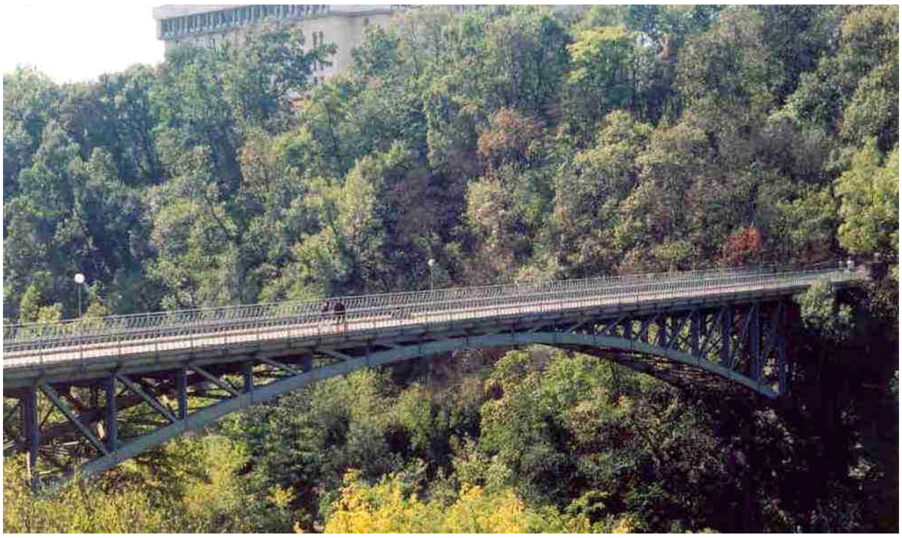

Fig. 34. "Stambolov" Bridge in V.Tarnovo

The length of the bridge is 60 m and the width of the line 7 m. Throughout the 110 years life the bridge has resisted the strong earthquakes in 1913, 1928 and 1977 years and is serving up to now as a footbridge.

9.3.2 “Friendship Bridge” between Russe – Giurgiu

With 50 years history is the so-called “Friendship Bridge” between Russe – Giurgiu over the Danube River, between Bulgaria and Romania. The main bridge has the following spans L=4x80+2x160+86+2x160+2x80m (fig.35).

This bridge was designed in the USSR and the steel superstructures were fabricated in Czechoslovakia and Hungary. The well chosen technological procedures and the combined efforts of constructors, allowed the bridge to be finished in a very short time - 2 years between 1952 – 1954. In the last two years the bridge capacity was verified (structural capacity for EC1 loads and remaining fatigue life according to the “Real Time – Stress History). The conclusion is that the bridge behaves well for the present traffic conditions.

Fig.35. “Friendship” Bridge

The most remarkable steel bridges designed and fabricated in Bulgaria are:

9.3.3 “Asparuhov” road Bridge

“Asparuhov” road bridge in Varna The whole bridge is 2100m long, but only the part over the channel is steel structures with spans 80 + 160 + 80m (fig.36) The bridge is a box girder with orthotropic plate. The bridge was opened for traffic at 1976.

Fig. 36. “Asparuhov” Bridge

9.3.4 “Hemus” motor way Bridge

Two road bridges on motorway “Hemus”, with orthotropic steel plate girder with spans 56 + 4x72 + 56 m- the first one (fig.37), and 100+160+100m- the second one (fig.38). The bridges were inauqurated in 1984.

Fig.37. Six spans continuous beam

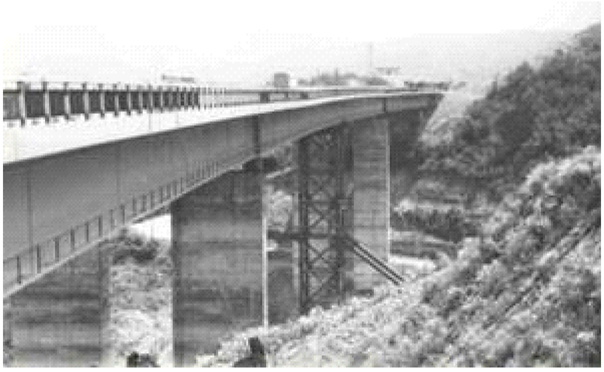

Fig.38. Three spans continuous beam

9.3.5 The Road Bridge between the International Airport of Sofia the City

The Road Bridge, serving as a connection between the International Airport of Sofia and the City. It is the longest bridge in Bulgaria with total length 2114m. total width 21.5m, and the middle height above the ground about 10 m. The multi – span structures is composed from a middle steel part of 90 m long, situated over railway (fig.39 and 40) and many reinforced concrete parts on the two sides with spans of 49m long each one. In transverse direction the steel bridge consists of two particular box- girders. Each box- girder has orthotropic plate with 7.5m widths. The bridge was put into operation from 4.10.1983 (fig.41).

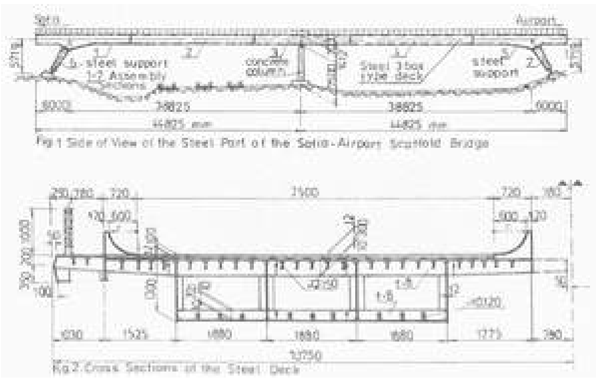

Fig.39. View and Cross-section

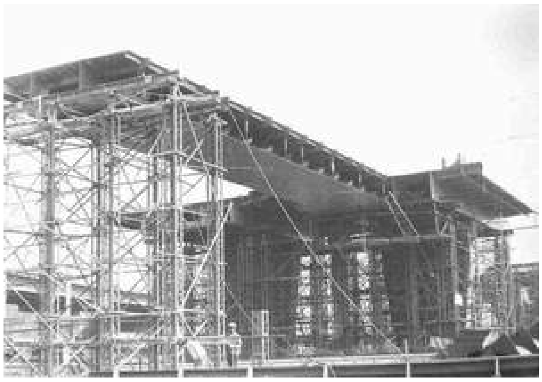

Fig.40. Bridge under construction

Fig.41. Side of view of the Bridge

9.3.6 Road Bridge “Novi-Han- Elin Pelin”

Road bridge on motorway “Novi-Han- Elin Pelin” nearly Sofia. The bridge is constructed as plate girder with orthotropic steel deck, type “Gerber” beam (fig.). The bridge has total length 293m and was delivered to traffic in 1981 year (fig.42 and 43).

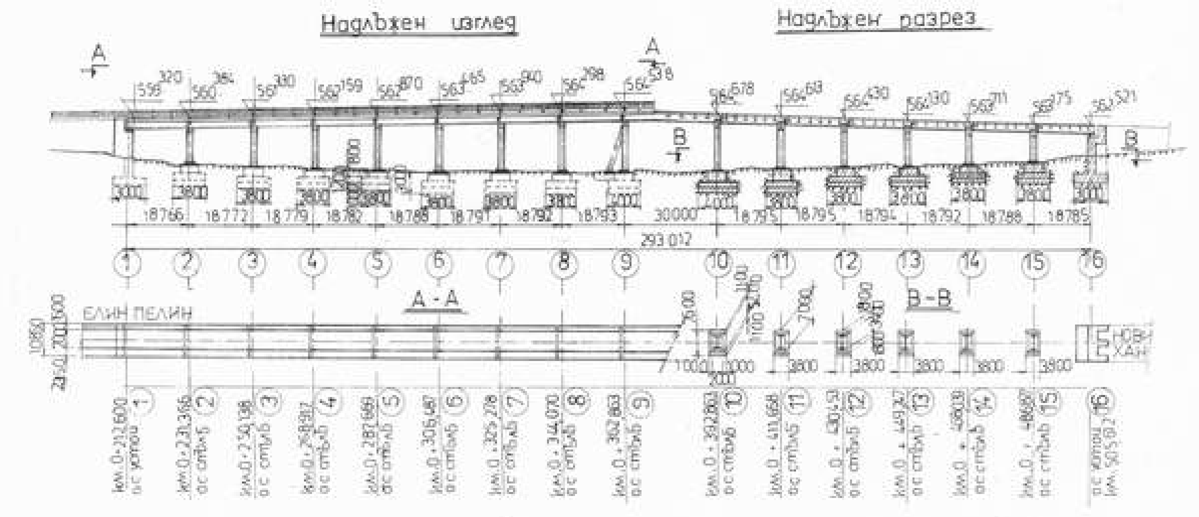

Fig.42. View and section of the bridge

Fig.43. Side of view

9.4 Seismic analyses of the Steel Road Bridge

The 15-spans road bridge has a steel structure. It comprises fourteen spans 18,80 meters long and a 30 meters long span. A various types of experiments were performed, including with vehicle machines loading for obtaining dynamic characteristics. It was settled the natural vibration periods in to be as follows: in longitudinal direction 0,40 sec.; in transverse direction 0,11 to 0,20 seconds in the different locations.

The bridge structure is modeled by SAP2000 (Structural Analysis Program – prof. Wilson and Habibullah, CSI, Berkley University, California, 1998), using ”frame” finite elements only. Working drawings are turn to use to fix the general dimensions and cross sections. All available degrees of freedom (U1, U2, U3, R1, R2 and R3) are considered in the 3-D model. Eigenvalue analysis is preferred, which determines the undamped free-vibration mode shapes and frequencies of the system. The number of modes is limited to the mass degrees of freedom. Both distributed and lumped masses are used the model.

So obtained natural periods give us an excellent feeling into the behavior of the structure. In longitudinal direction they are 0,44-0,48 sec., depending on the stiffness of the fixed supports at the bases and some other joint connection properties into the structure; in transverse direction 0,09 to 0,22 seconds in the different locations.

According to the present Bulgarian Design Codes [7], base shear force is to be:

E = C R kc □ Q = 1602 [kN], where:

Importance factor C=1.00

Response factor R=0.25 for this type of structure.

Numerical coefficient □ defined as $0.8 \leq 1.2/T \leq 2.5$ for a soil category. (□=2.4 or more)

Seismic zone factor kc=0.27

Total dead load Q=9890 kN.

The structure has been designed according to old Bulgarian Design Codes with different (smaller) coefficients which led to force E=742 kN, which is 2,15 times smaller. The bridge needs to be strengthened after severe engineering analyze.

10. CONCLUSIONS AND RECOMMENDATIONS

The old historical structures are living witnesses of the previous national achievements, traditions and culture [9,10]. Their value is great and it is very important to preserve them for the next generation. These structures are survived many catastrophic events but it does not guarantee their survival in the future. The structure damages from by natural phenomena or by human actions can cause their failure in some extreme situation. Each historic structure is unique. There are no standard or generally accepted method for analysis, maintenance and strengthening of these structures. An estimation of the present state is very important and necessary as a first step. Every historical object should have a ‘passport’ including all necessary data: monument history, geometrical characteristics, material and soil properties, crack propagation, atmospheric effects, dynamic characteristics, endured damages and repairs, results from monitoring, numerical and experimental results from previous analysis. The material properties can be obtained by using nondestructive methods such as rebound test, ultrasonic test, radiographic test, surface hardness test, permeability test. Crack depth and direction can be studied applying ultrasonic test around the crack zone before and after strengthening. Data obtained in laboratories or at the site can be treated by statistical methods. Finally all these data should be used to create adequate models for spatial analysis by the FEM and strengthening of the structure.

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