

Full Length Research Paper

Reinforcement studies and renewal of installations for the contemporary use of the Bursa Inebey (Egne Beg) Madrasah

O. Koprulu Bagbanci* and M. B. Bagbanci

Engineering and Architecture Faculty, Uludağ University, Bursa, Turkey.

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The Inebey Madrasah, used by the Turkish Republic Ministry of Culture's Illuminated Manuscript Library, was restored in accordance with international scientific standards. Due to the presence of important and valuable holdings in the library, a systematic study was carried out, and all the necessary precautions were taken to prevent the building against bad weather conditions. During the restoration work, the current state of the Madrasah was investigated using mechanical, physical, chemical and non-destructive tests (NDT) *in situ* and in the laboratory to determine what materials were used in the building's construction. A structural analysis was conducted to find out the reasons of the cracks in the building, and the appropriate reinforcement techniques were determined according to the results of the structural analysis. Due to the rare books in the library, the security, mechanical and fire protection installations were adapted to the Madrasah. The electrical and plumbing systems were renewed as part of the reinforcement and restoration of the building. During this study, the original floor plan, architectural details, facade, materials and authentic value of the structure were carefully considered; the building's function was merely seen as a tool of the Madrasah's restoration.

Key words: Restoration, reinforcement, material characterisation, installation.

INTRODUCTION

Because of the natural and historical properties of the structures, modern legal codes and standards limited the actions we could take towards conservation, diagnosis, analysis and strengthening of the Madrasah. An analysis of the ancient construction techniques used to build the Madrasah was made problematic by the complex geometry of the buildings, the diversity of materials, the construction techniques and the absence of knowledge on the existing damages caused by the continual exposure of the structures. For these reasons, restoration of the Inebey Madrasah followed the recommendations of the 1964 Venice Charter and ICOMOS (URL-2, 2001)/ The International Scientific Committee for the Analysis and Restoration of Structures of Architectural Heritage

(ISCARSAH). The basic principles of the Venice Charter and the recommendations prepared by the ISCARSAH Committee present the basic concepts of conservation and provide guidelines in the form of rules and a methodology that architects and engineers should follow (Lourenco, 2005); these guidelines proved is useful in the restoration of the Madrasah.

The organisation of studies and step-by-step analyses—a multidisciplinary study—was required for the restoration work. No action was taken without a complete understanding of the benefit it would have or the harm it would cause to the building's architectural integrity. A full understanding of structural behaviour and material properties of the affected building is important for any project related to the preservation of an architectural heritage. Diagnosis is based on historical information and information gathered by both qualitative and quantitative methods. The qualitative approach is based on direct observation of structural damage and material decay as well as on historical and archaeological research. The

*Corresponding author. E-mail: ozlemkoprulu@yahoo.com, okoprulu@uludag.edu.tr. Tel: +90 224 294 21 41. Fax: +90 224 294 21 28.

quantitative approach requires material and structural tests, monitoring and structural analysis (Lourenco, 2005). Conservation and restoration problems can be successfully resolved only if the diagnosis of the extent of the damage to the building has been carefully carried out (Binda, 2000).

In this study, the restoration and reinforcement of the Inebey Madrasah was carried out according to the recommendations of both the 1964 Venice Charter and the ICOMOS. The intention is that this study will be a model for similar kinds of structures facing the same problems.

MATERIALS AND METHODS

The exact construction date of the Inebey Madrasah is not known, but Subası Eyne Beg has dated it to the end of 14th century, during the reign of Sultan Yıldırım Bayezid I (1389 - 1402); the building would have been erected in what was then the first capital city of the Ottoman Empire. There were many commercial, educational, public and religious buildings constructed in Bursa between 14th and 15th centuries because the city was situated on important trade roads, such as the Silk Road and the Spice Road. The restoration of the building began in 2007 and was finished in 2010 under the control of the Bursa Special Provincial Administration. The purpose of this article is to explain the restoration phases and to present them in detail as follows:

- (a) The investigation of the floor plan and construction techniques,
- (b) The diagnosis of the Madrasah's condition and the identification of the materials used in the Madrasah by physical, mechanical, chemical and non-destructive tests (NDT),
- (c) The performance of the structural analyses of the Madrasah,
- (d) The evaluation of the restoration and reinforcement studies of the Madrasah according to the structural analyses,
- (e) The adaptation of and installation of new protection and utility systems for the continued use of the Madrasah.

Floor plan and construction techniques of the Madrasah

The library belongs to the General Directorate of Foundations. The Madrasah is in the Inebey Külliye (Complex) and is next to the Inebey Hammam (General Directorate of Foundations, 1983). According to an Ottoman *Şer'iye Sicili* (Court Archive) dated 1093 H-1683 M, it was restored in the 17th century and again in 1965 by the General Directorate of Foundations of the Bursa Region (Ayverdi, 1989). The Madrasah is reached by stairs from Inebey Street. The entrance is composed of a rounded-arch door under a pointed-arch niche. It has an open Madrasah plan type with an Iwan. There is a courtyard in the middle of the open Madrasah. Its dimensions are 8.5 × 10 m, and it is surrounded by arcades fronting the rooms. The rooms are situated on the east and west sides, the classroom are on the south, and the entrance and the library are located to the north (Figure 1). It is 32 m long from north to south and 24 m from east to west. Except for the library, the entire building is built on a single floor (Yılmaz, 2007).

There are 12 hexagonal pillars, each with a dimension of 65 cm, situated around the courtyard. The pillars are connected to each other by pointed arches and by iron tie bars that run between the arches and the rooms. These bars are 4 cm tall and 4 cm thick. The rooms and arcades have barrel vaults, and both the fronts of the classroom doors and the front of the entrance of the Madrasah have dome superstructures. There are chain, wave and hook motifs

decorating the walls of the courtyard. The walls are finished by five rows of saw-tooth eaves. The building's masonry system is composed of rubble stone, limestone, mortar, brick and timber (Figure 2 and 3). The outer walls are 116 cm thick. Brick was used in the arches, vaults and dome and in the transition elements to the domes. Khorasan mortar was used as the binder material. It was a lime mortar manufactured in Turkey using crushed or finely ground bricks as aggregate (Akman et al., 1986). The crushed bricks were mixed with the lime and left to harden in the presence of water. Khorasan mortar has high mechanical strength (Lea, 1940). The facades of the building were not plastered, but the inside of the building was plastered with Khorasan mortar.

The roof of the Madrasah had been subjected to several interventions, in which filling materials were used between and above the vaults (Figure 4 and 5). The filling materials were separate layers composed of different substances, such as clinker, limestone, brick pieces, concrete and reinforced concrete. The layer of reinforced concrete was covered by insulation material. The load on and above the vaults was calculated at 700 tons per 400 m². This showed that the roof of the Madrasah had been loaded enormously, perhaps at a rate of 1.75 ton/m² per fifteen years.

Diagnosis of the state of the Madrasah and the identification of materials

To identify the materials used in the Madrasah, physical, mechanical, chemical and NDT tests were applied *in situ* and in the laboratory. These tests were performed on the walls and piers in order to find the mechanical properties of the materials used in the Madrasah. The physical, mechanical and chemical tests were determined by using standard test methods (TS 699, 1987; ASTM C50-00, 2006). After determining the physical and mechanical properties of the unit samples, composite elements were calculated using TS EN 1996-1-1 (Eurocode 6, 2006). Two types of composite materials were found to have been used in the Madrasah. The walls were constructed with rubble stone and mortar; the superstructure and transition elements were constructed with brick and mortar. Table 1 shows the physical and mechanical properties of the composites used in the Madrasah.

The chemical properties of the mortar and plaster taken from walls and foundations were determined by the Central Laboratory of Restoration and Conservation Department of the Monuments and Museums General Directorate, which is part of the Turkish Republic Ministry of Culture in Istanbul. Experimental studies of the binder/aggregate found a ratio of about 2/3 ~ 1/2 in the walls and domes of the Inebey Madrasah. These values are compatible with the experimental values for the crushed brick-lime mortars used in some historical buildings (Moropoulou et al., 2000; 2002; 2005; Bakolas et al., 1998). The acid loss and sieve analyses as well as the ignition loss test and other basic test results for the average values are shown in Table 2.

Structural analyses

The structural analyses were conducted by using the SAP2000 finite element programme (Computers and Structures, Inc., 1998). A roof load of 1.75 ton/m² was applied to the model to find out what effect the filling material was having on the structure. The model of the Madrasah consisted of 6777 shell elements and 28 frame elements (Figure 6). In the self-weight analyses, the highest level of tensile stress, measured at around 0.4 - 0.5 MPa, was found under the vaults. *In situ* observation revealed that there were continuous cracks in these areas (Figure 7 - 9). It was clear that the load on the vaults was making the structure hazardous. The structural analyses were continued, this time by analysing the effect of removing the load from the roof. The results showed that the tensile stress under the vaults dropped to around 0.1 ~ 0.2 MPa, 3 times less than

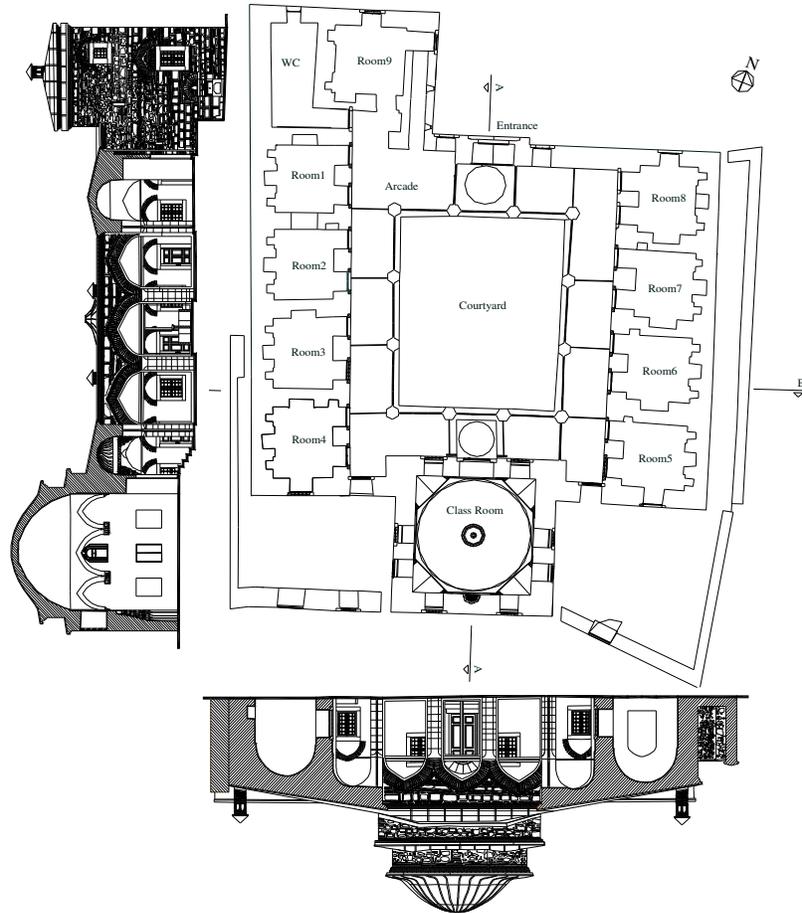


Figure 1. The plan of the Inebey Madrasah.



Figure 2. The general view of the Inebey Madrasah.



Figure 3. The north facade of the Inebey Madrasah (Entrance).



Figure 4. Different materials filling between and above the vaults.



Figure 5. Layers of filling materials on vaults.

Table 1. Mechanical and physical properties of composites.

	Stone-mortar composite	Brick-mortar composite
Compressive strength	15.9 N/mm ²	4.9 N/mm ²
Tensile strength	1.59 N/mm ²	0.5 N/mm ²
Modulus of elasticity	15853 N/mm ²	4963 N/mm ²
Shear modulus	6341 N/mm ²	1985 N/mm ²
Poisson's ratio	0.17	0.17
Unit weight	23 N/mm ³	16 N/mm ³

Table 2. Chemical test results on mortar and plaster.

Specimen no.	Acid loss (%)	Sieve analysis (%)					Ignition loss (%CaCO ₃)	Other tests	
		1180 μ	600 μ	250 μ	125 μ	<125 μ		(SO ₄) ⁻²	Cl ⁻
Mortar	51.34	37.39	10.68	24.63	14.24	13.06	22.65	-	+
Plaster	76.37	21.21	11.69	33.77	19.91	13.42	49.50	-	+

the stress from the first analysis (Bagbanci, 2008). After the analyses, it was clear that the load on the roof must be removed from the structure.

Restoration and reinforcement works

After the structural analyses, the process of removing the filling

material from the structure commenced, using small drilling machines to transmit fewer vibrations to the structure. During the removing work, the roof was protected against the rain. The emptied vaults are shown in Figure 10. The reinforcement work began after the load had been removed from the structure. The local cracks emerging on the walls were repaired by removing the cracked parts from the structure. The old bricks and stones that were not considered hazardous were reused for the walls. The new

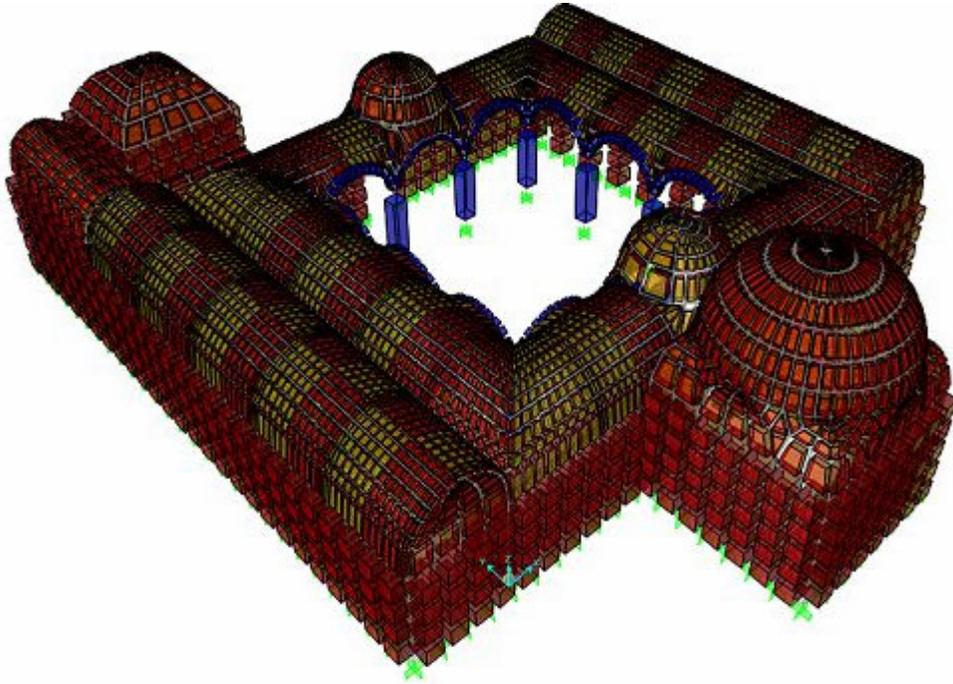


Figure 6. Finite element model of Madrasah.



Figure 7. *In-situ* cracks under vaults in North-South direction.

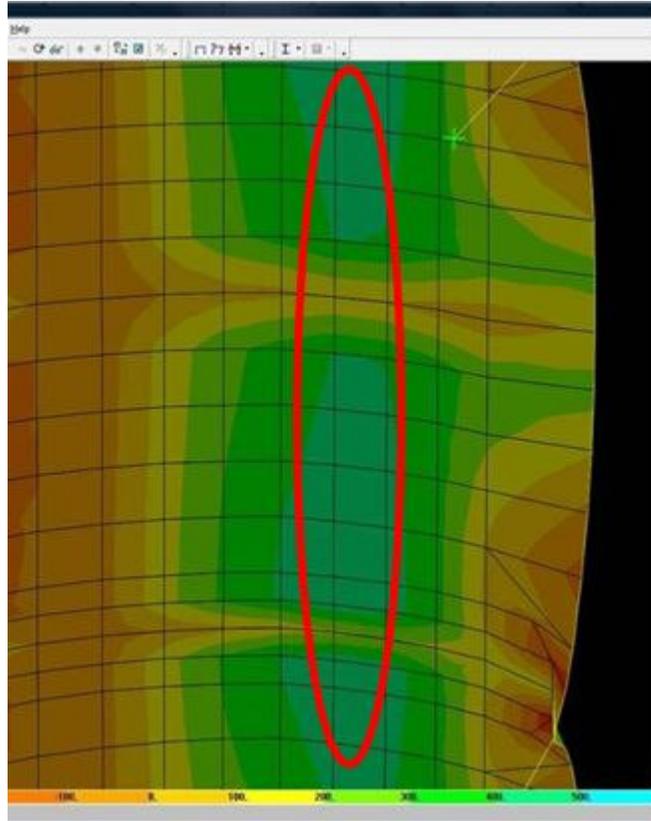


Figure 8. Tensile stress areas under vaults in North-South direction.

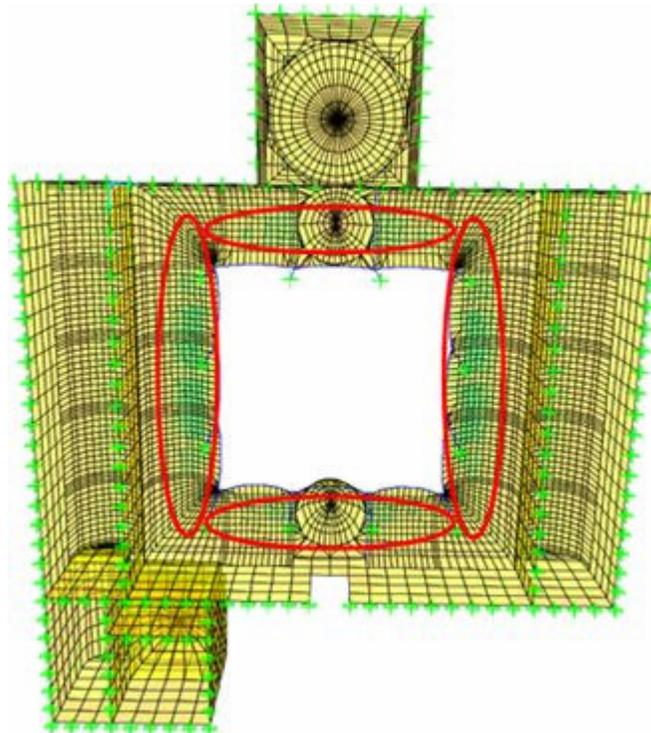


Figure 9. Maximum tensile stress areas under roof loads.



Figure 10. The general view of the emptied vaults.

mortar and the other new materials needed were formed or chosen to resemble the old ones as closely as possible by consulting the test results. The continuous cracks under the vaults were filled with the appropriate mortar, and the surface was made ready for the application of fibre reinforced polymer (FRP) composite material. The FRP composite material was applied to the surface along the length of the vaults without any interruption. The FRP material was also applied to the edges between the vaults and the walls (Figure 11 and 12).

After the application of the FRP material was completed, the inside of the building was plastered in preparation for the distribution of the injection material. All visible cracks were repaired, either by the injection of hydraulic lime mortar, or by the reconstruction of the crack parts with new materials that closely resembled the old ones. Finally, the invisible pores and cracks that were not visible were filled by an injection of hydraulic lime mortar from the cracks above the superstructure (Figures 13 and 14). After the reinforcement of the building was finished, the roof was constructed using wooden materials. Wood was chosen because of its lightness and because it was easy to make interventions with after the restoration work was finished. The wooden materials were impregnated to protect them from damage caused by fire and water. The load of the roof was carried by trusses running parallel to the vaults, the main load-bearing structures. The trusses were supported on the walls by steel plates and anchor bolts placed between the vaults and on the piers. The supporting points of the wooden trusses and the perspective view of the east side of the building can be seen in Figure 15 and 16. Lead was used as a cladding material after the construction of the wooden roof. The timber elements that had decayed were exchanged for new ones or were renewed, specifically by sandblasting the iron tie bars that had

corroded, cleaning the façade and applying plaster, which continued in accordance with the roof construction.

New installation systems for the re-use of the Madrasah

The Library of Illuminated Manuscripts belonging to the Turkish Republic Ministry of Culture planned to use the Inebey Madrasah after the building's restoration. For that reason, new installations were adapted to the building and systems that had been recently installed were renewed (Figure 17). The heating, plumbing, electrical, fire protection and security control systems were chosen in accordance with modern technology and were chosen and installed with care to prevent the Madrasah from being damaged in any way. The FM200 automatic gas extinguishing system was found to be the preferable fire system for protecting the historically invaluable manuscripts in the library against fire (Figure 18). It gets activated very quickly, and the endangered area does not require cleaning after the system has been triggered (URL-1, 2010). It was installed under the new wooden roof because it could be easily accessed there.

RESULTS

The Inebey Madrasah, used by the Turkish Republic Ministry of Culture's Illuminated Manuscript Library, was restored in accordance with international scientific standards. A systematic study was carried out due to the presence of important and valuable holdings in the library.



Figure 11. FRP applications under the vaults.



Figure 12. FRP applications at edge of the vaults.



Figure 13. Application of injection materials above the domes.



Figure 14. Application of injection materials above the vaults.



Figure 15. Supporting points and the wooden construction.



Figure 16. Perspective view of new wooden roof system.



Figure 17. New installation systems.



Figure 18. Automatic gas extinguishing system (FM200) under the wooden roof.

The content of the study was based on several sets of historical, geometrical, physical-chemical, structural information and installation of new protection and utility systems. The roof of the Madrasah had been subject to several interventions, in which filling materials were used between and above the vaults. The filling materials were separate layers composed of different substances, such as clinker, limestone, brick pieces, concrete and reinforced concrete. A 3d model of the building was formed by using SAP2000 structural analyses program for understanding the structural behaviour of the building. In the self-weight analyses, the highest level of tensile stress, measured at around 0.4 - 0.5 MPa, was found under the vaults. *In situ* observation revealed that there were continuous cracks in these areas. It was clear that the load on the vaults was making the structure hazardous. The structural analyses were continued, this time by analysing the effect of removing the load from the roof. The results showed that the tensile stress under the vaults dropped to around 0.1 - 0.2 MPa, 3 times less than the stress from the first analysis. After the structural analyses, it was clear that the load on the roof must be removed from the structure and the process of removing the filling material from the structure commenced, using small drilling machines to transmit fewer vibrations to the structure.

The cracks under the vaults were reinforced against tensile loads by using Fibre Reinforced Polymers. After the application of the FRP material was completed, the inside of the building was plastered in preparation for the distribution of the injection material. All visible cracks were repaired, either by the injection of hydraulic lime mortar, or by the reconstruction of the crack parts with new materials that closely resembled the old ones. The roof was constructed using wooden materials. The wooden materials were impregnated to protect them from damage caused by fire and water. The load of the roof was carried by trusses running parallel to the vaults, the main load-bearing structures. The timber elements that had decayed were exchanged for new ones or were renewed, specifically by sandblasting the iron tie bars that had corroded, cleaning the façade and applying plaster, which continued in accordance with the roof construction. The heating, plumbing, electrical, fire protection and security control systems were chosen in accordance with modern technology and were chosen and installed with care to prevent the Madrasah from being damaged in any way. The FM200 automatic gas extinguishing system was found to be the preferable fire system for protecting the historically invaluable manuscripts in the library against fire.

DISCUSSION AND CONCLUSIONS

This study is of vital importance because the Inebey Library possesses valuable, rare, illuminated manuscripts from the Ottoman Empire. The scientific restoration work

of the Ottoman Madrasah was carried out within the framework of conservation, restoration and reinforcement principles. Interventions were planned for the structure according to the results of the diagnosis studies. The original design specifications, plans and material characteristics were preserved according to the 1964 Venice Charter and ICOMOS/ISCARSAH recommendations. New installations were adapted and the existing installations were renewed for the contemporary use of the library. Inebey Madrasah had been badly affected by the careless interventions of past eras. Interventions should be carefully planned only after the behaviour of the structure has been thoroughly analysed. Historical structures can be confidently preserved for the future by applying multi-disciplinary policies to their maintenance and conservation.

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