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Material Characterization, Structural Analysis and Strengthening Proposals for İnebey Madrasa in Bursa, Turkey

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Abstract: The researcher of this paper want to analyse the current state of the madrasa by using Non Destructive Test Methods (NDT). Mechanical and physical tests are done *in-situ* and in laboratory for the characterization of the materials used in the Madrasa. Material properties are calculated for the composite materials. The composite materials properties are adopted to the curent in situ model under the death and earthquake loads and current state of the madrasa is analysed. According to the results of the analysis the proposals for restoration of the madrasa are given.

Key words: Stone · Brick · Mortar · Physical tests · Mechanical tests · NDT · Structural Analysis

INTRODUCTION

The Inebey Madrasa is dated to the end of the 14th century in the first capital of the Ottoman Empire. Bursa had many commercial, educational, public and religious buildings between 14th and 16th centuries. Madrasa was built in the period of Sultan Yİldİrİm Bayezid I (1389-1402) by SubaşĬ Eyne Beg. But the exact construction date of the Madrasa is not known.

The aims of the study were the following:

- To understand the characterisation of materials used in the Madrasa by using Non Destructive Tests (NDT)
- To analyse the Madrasa by finite element model by using SAP2000 program.
- To give proposals for the restoration of the Madrasa according to the model.

Determination of Characteristics of the Plan, Construction Technique and Materials Used in the Madrasa: Inebey Madrasa is in Osmangazi District on the İnebey Street. It is used as a library of Hand Painted and Old Printed Works. The library belongs to the General Adminstration of Waqfs. The historical building is surrounded by İnebey Street at the north and Bükük (Ebuşahme) Street at the south. İnebey Hamam which is on the west side was built with the madrasa belonging to the İnebey Kulliye, Driving Course is on the east side of the building. According to the sources it is known that the wall close to the bath was opened 75 cm.in width and 6m. depth during the 17th century because of the moisture caused by the Hamam [1].

According to a 1093 H. Dated (1683 M.) Ottoman Court Archives - Şeriyye Sicili - Madrasa was restored in the 17th century and the other restoration was done in 1965 by General Adminstration of Waqfs of Adminstration of Bursa Region [2].

It is reached to the madrasa by stairs from the İnebey Street. The entrance is from a rounded arched door under a pointed arched niche. The courtyard in the middle having dimension of 8.5x10 m. is surrounded by archades besides the rooms. The rooms are situated on the east and west side, the classroom on the north, the entrance and the library are at the South direction.

Open madrasa with an iwan planned building is one floored except the library part. It is 32 m. on north-south direction and 24 m. on the east-west direction. At the northwest corner of the building there is a toilet and a room used as adminstration on the ground floor and a library on the upper floor reached by stairs in the east wall. There are totally 9 rooms having the dimension of 4x4 m. Four of them are on the east, five of them are on the west side. The interior walls of the rooms are 90 cm. in thickness and plastered. There is a furnace, two small and

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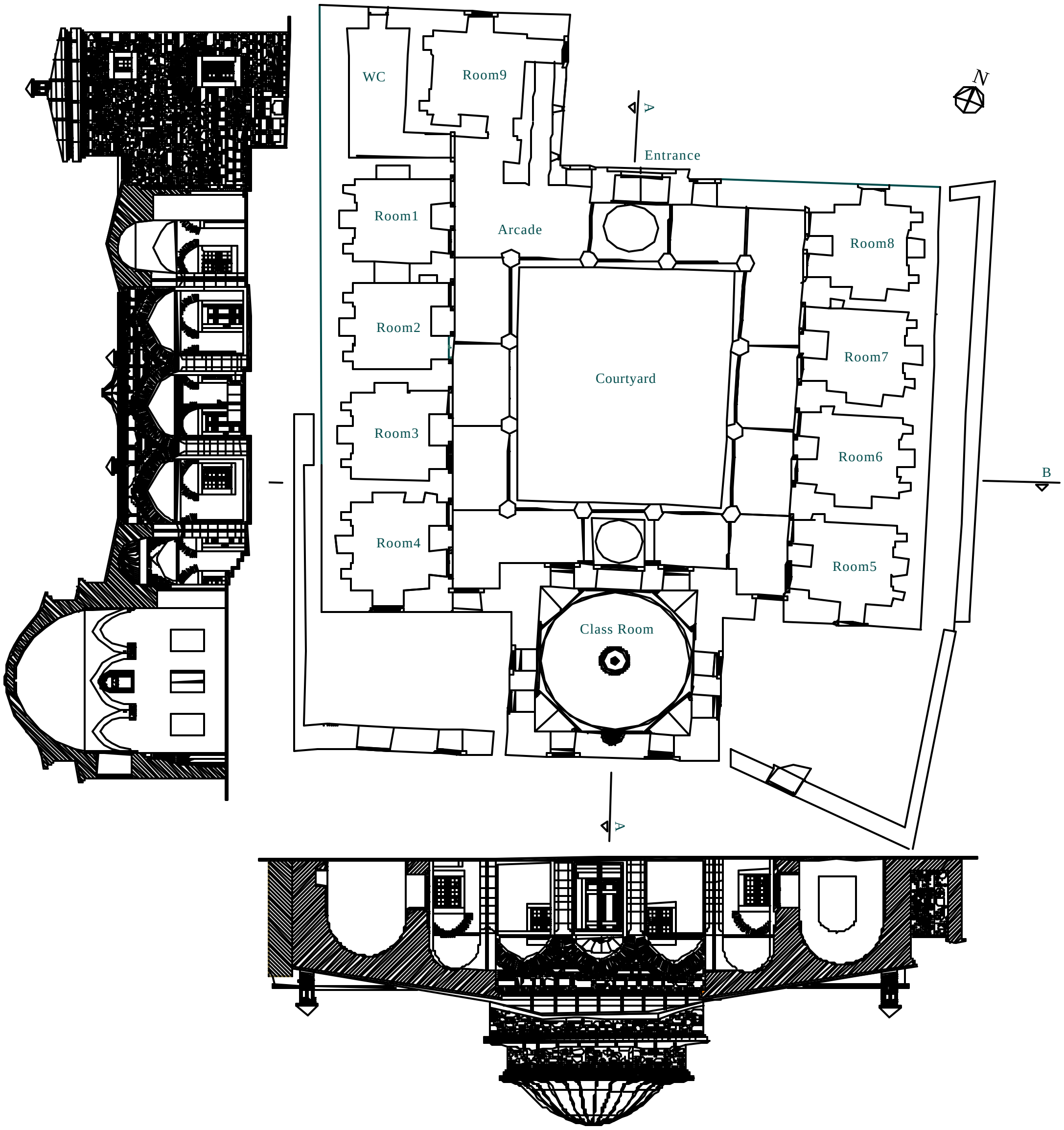


Fig. 1: Analytical survey of plan and the two sections of the Madrasa [3]

Fig. 2: The North facade of the Madrasa

Fig. 3: General view from the roof looking to the Courtyard

Fig. 4: Compression test applied on piers with Windsor Prope equipment

Fig. 7: Measure the ulltrasound pulse passing time on piers with NDT equipments

Fig. 5: To read the results of the compression tests on materials

Fig. 8: Different materials filling between and above the vaults

Fig. 6: Measure the ulltrasound pulse passing time with NDT equipments

Fig. 9: Layers of filling materials on vaults

a big niches in the rooms [1]. There are horizantal timber beams in the walls point out the use of timber beams in the construction technique to distribute loads vertically. There are pointed arched windows and door openings towards to the archades. The classroom has two windows on each wall and a second window row on the east, west and south directions.

There are 12 pillars around the open courtyard having the dimension of 65 cm. with a hexagonal form. The pillars are connected to each other by pointed arches and iron tie bars between the arches and the rooms with the dimension of 4x4 cm. in thickness.

Rooms and archades are barrel vaulted except the front of the classroom's door and the front of the entrance of madrasa in the archades. İn these spaces small domes are used on the superstructure of the archades. İn the classroom dome is used by using squinch as a transition element. The library and the room which is under the library are constructed with cross vault. There are two gardens at the southeast and southwest direction. These gardens are surrounded by high walls and have a rubble stone construction added in later times (Fig. 1).

The building was built with rubble stone, limestone, mortar, brick and timber in the masonry system (Fig. 2). The outer walls are 116 cm. in thickness. Upper part of the pointed arches are surrounded by 12 piers. There are chain, water wave and hook motifed brick rows on the limestone are used between the brick rows. The walls are finished by two rowed saw-tooth eaves [1].

Limestone was used on the sides of the door and window openings and at the corner of the walls, all the stairs and pillars. Brick was used on the transition elements (squinches and pendantives), arches, vaults and domes. The vaults and domes consisting of superstructure were built with brick and mortar as binding material. The walls weren't plastered on the exterior but plastered in the interior except the courtyard.

Dome of the classroom and the vault of the library were covered by copper on the roof. The other part of the madrasa were covered by isolation material (Fig. 3).

MATERIAL PROPERTIES OF MADRASA

For the assesment of material properties of the madrasa, NDT Methods are used *in-situ*. Tests are applied on walls, vaults and piers in order to find the mechanical properties of materials (Fig. 4-7).

Samples are also taken, cut and dried in an oven for physical assesments. Unit weights of the masonry materials are shown in Table 1. Static moduli of Elasticity and Compressive Strengths are shown in Table 2.

Table 1: Physical properties of samples

Sample	Unit Weights (KN/m^3)
LimeStone (Küfeki)	21.57
RubbleStone	26.48
Brick	16.87
Mortar	14.22

Table 2: Mechanical properties of samples

Sample	Compressive Strength (N/mm^2)	Modulus of Elasticity (N/mm^2)
LimeStone (Küfeki)	23.4	12013
RubbleStone	75.0	42036
Brick	14.5	4586
Mortar	4.2	2128

Table 3: Mechanical and physical properties of composite materials

	Composite	
	Rubblestone-Mortar	Brick-Mortar
Compressive Strength	15.85 N/mm^2	4.96 N/mm^2
Tensile Strength	1.585 N/mm^2	0.496 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

After determining the physical and mechanical properties of unit samples, composite elements are calculated by using TS EN 1996-1-1 [4]. In madrasa two types of composite materials are used. Walls are constructed with Rubblestone and mortar, superstructure and transition elements are constructed with brick and mortar. Poisson ratio is taken 0.17 for each composite for this research. The mechanical and physical properties of composite materials are shown in Table 3.

STRUCTURAL ANALYSIS

The roof of the madrasa had several interventions by filling materials between and above the vaults (Fig. 8 & 9). The filling materials are applied by separate layers which were consist of different materials such as clinker, limestone, brick pieces, concrete and reinforced concrete. This load was calculated 700 ton for 400m^2 after taking off the filling material on and above the vaults. It is seen that the roof of the madrasa had loaded anormously which reaches to 1.75ton/m^2.

This load was applicated to the finite element model which was prepared by using the SAP2000 program [5]

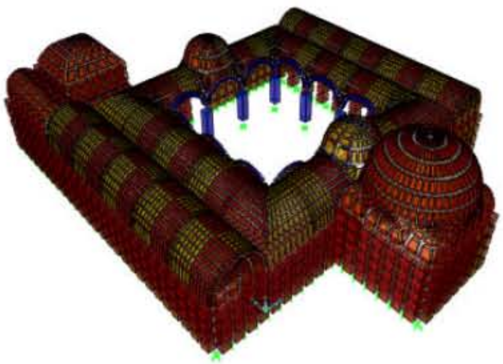


Fig. 10: Finite Element Model of the Madrasa

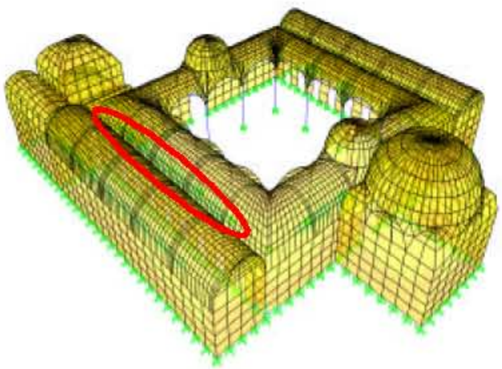


Fig. 11: Tensile stresses on the edge of the vaults

Fig. 12: *In-situ* cracks under vaults in North-South direction

and the cracks of the madrasa are investigated. Also modal analysis were conducted to understand the behaviour of madrasa under dynamic loads.

The model of the madrasa was consist of 6777 shell and 28 frame elements (Fig. 10).

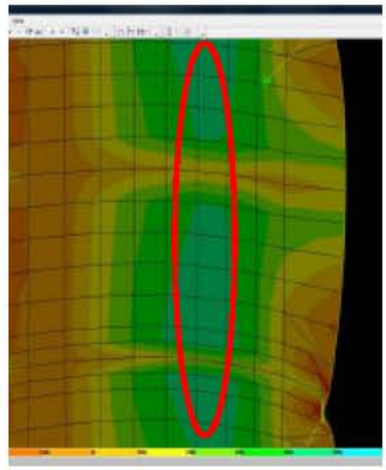


Fig. 13: Maksimum tensile stresses under vaults in North-South direction

Fig. 14: *In-situ* cracks under vaults in North-South direction

The filling load on the vaults cause tensile stresses on the edge of the vaults maximum 0.3-0.4 N/mm² but not exceeded the limit tensile stresses of 0.499 N/mm² as shown in Fig. 11 under dead loads. *In-situ* cracks seen irregularly on this area.

Under the vaults it was seen in the analyse program that the maximum tensile stresses has reached 0.43 N/mm² which was close to the 0.495 N/mm² limit tensile stress value. *In-situ* there were main and regular cracks observed on this area which were same results in the analysis program. Figure 12 & 13 shows the North-south direction, Figure 14 & 15 shows the east-west directions.

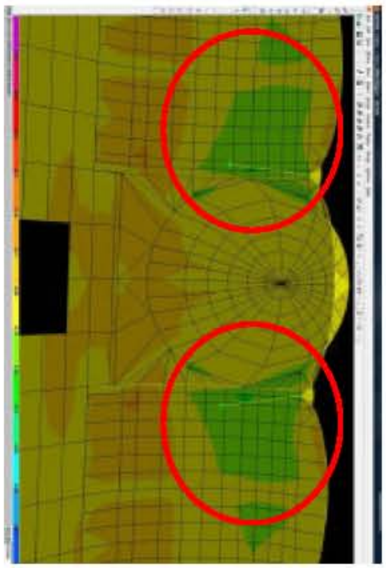


Fig. 15: Maksimum tensile stresses under vaults in North-South direction

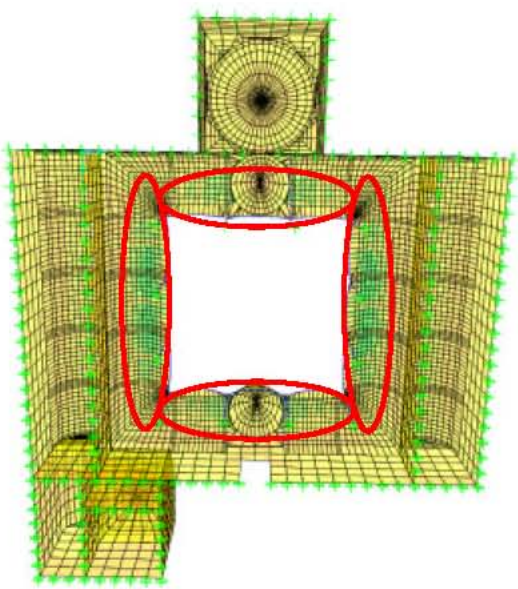
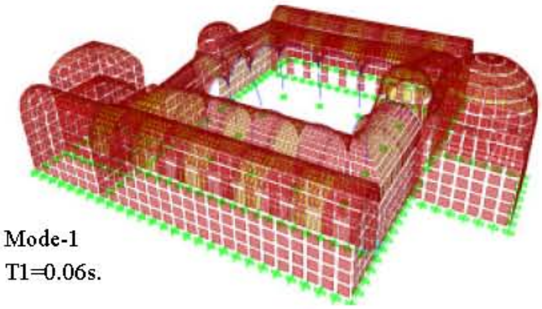


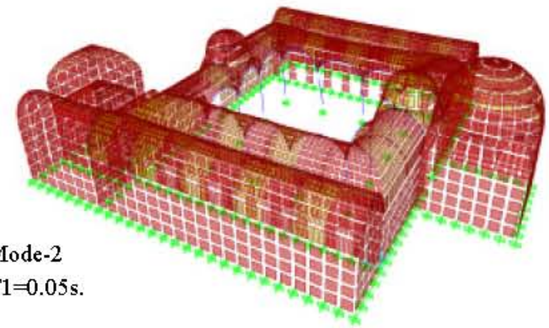
Fig. 16: Maximum tensile stress areas under dead loads

Figure 16 shows the maximum tensile stress areas under dead loads. *In-situ* cracks are contuniously occured under the vaults close to the statical analyses.

The earthquake analysis was conducted using response spectrum approach. Madrasa is located on eartquake Zone 1, the most seismically risky regions in Turkey. In determining the earthquake loads, "Turkish Eartquake Code, 2007, Section 5" is used [6] . Ground spectral accelaration coefficient was taken 0.4. The soil



Mode-1
T1=0.06s.



Mode-2
T1=0.05s.

Fig. 17: Mode shapes of the Madrasa

conditions were determined siltly clay material which equal to ground type Z2 and the characteristic spectrum periods were Ta=0.15 sec. and Tb=0.40 sec.

The structural analysis of madrasa shows that the natural vibration period starts from a low period which was 0.06 sec. The first two modes are shown in Fig. 17.

Tensile stresses were developed under the dead + earthquake loads between 4 N/mm^2– 8 N/mm^2 where large deformations on the edge of the vaults and the domes are seen which was over then the tensile stress of the brick-mortar composite metarials used in superstructures and transition elements. *In-situ*, continuous big cracks were observed under and centre of the vaults.

CONCLUSION

The historical İnebey Madrasa is analysed by using SAP2000 program to determine the structural behaviour for the self-weight and earthquake loading. The material characteristics were found by physical tests in laboratory and mechanical tests by using NDT methods. The filling material loads which are above and between vaults and composite material characteristics are adopted to the finite element model for structural analysis. Analysis results shows that the tensile stresses are exceeded limit values under earthquake loads on vaults and domes at the edges, under the vaults and connection points of the vaults. It is seen that the loads on the roof especially using concrete material for filling caused a very big problem in the structure. All the cracks were occured after the loading on the roof. For decreasing the tensile stresses all cracks can be filled with the adequate injection material and the maximum tensile stress areas that caused big cracks can be covered with the FRP (fibre reinforced polymer) materials for strengtening the structure. Also existing tie bars which were exposed to the corrosion can be cleaned and strengthened, timber beam gaps can be fulfilled by the new timber beams during the restoration works, with the respect to the safety of the structure.

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