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# Non-destructive methods for determining weathering in historical monuments: a case study from Merv city, Turkmenistan

*Tahribatsız yöntemlerle tarihsel yapılarda ayrışmanın belirlenmesi: Türkmenistan'ın Merv şehrine ait uygulama*

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## ABSTRACT

Any changes or restorations to archaeological sites or historical buildings that are protected by law are prohibited without permission. In order to preserve the architectural heritage of a structure or a residential area that has retained its original character as a historical legacy, it is important to identify the weathering of used structural material or deterioration of strength, which can occur due to environmental conditions, or damage caused by natural or artificial factors over time. It is desirable, however, to avoid applications that will cause permanent damage in the structures, such as core sampling or stripping, when such studies are made. Non-destructive methods can eliminate this problem, but must be investigated to show their applicability. In this study, ultrasonic velocity and crack depth compressive strength determinations are applied to assess the integrity of brick structures in Merv, an ancient city of Turkmenistan. Two towers and two mausoleums are investigated, where Hakem El Gifari and Bureyde el-Eslemi are lying. The structural integrity of the towers and mausoleums are classified as weak and poor, respectively, according to classifications of the International Atomic Energy Agency. Crack depth classification infers classes II and III for the structures, and the compressive strengths show a variation between 2-8 MPa in towers and 20 MPa in mausoleums. This variation in brick performance can be attributed to winds that blow from NW direction and differences in the workmanship in the restoration over the buildings' history. When restoration shall be conducted according to the results obtained, both historical heritage can be better preserved and any budget for structural reinforcement could be reduced.

**Key Words:** Crack depth, non-destructive test, compressive strength, ultrasonic pulse velocity, Turkmenistan.

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***ÖZ***

*Arkeolojik alanlar, tarihsel yapılar ve sit alanları yasa ve yönetmeliklerle korumaya alınmış ve izinsiz herhangi bir değişiklik veya restorasyon yapılması da yasal sınırlarla engellenmiştir. Tarihsel bir miras olarak günümüze kadar özelliklerini koruyan mimarı yapılar ve yerleşim alanlarında zamanla doğal veya yapay etkenlerle meydana gelen hasar, fiziksel ve iklim koşulları nedeniyle meydana gelen mukavemet kaybının tespiti önemlidir. Ancak bu tür çalışmalar yapılırken yapılarda kalıcı deformasyona neden olacak karot numunesi alma, sıyırma vb. uygulamalardan kaçınılması istenir. Bu nedenle hasarsız yöntemlerin kullanılması öncelikli ve zorunludur. Bu çalışma kapsamında Türkmenistan'ın antik şehri olan Merv'de sahabelerden Hakem El Gıfari ve Bureyde el-Eslemi'nin bulunduğu 2 kule ve 2 türbe üzerinde ultrasonik hız, çatlak derinliği ve basınç mukavemetlerinin hesaplanmasıyla yenileme yapılacak alanlar hakkında bilgiler elde edilmiştir. Hızların Uluslarası Atom Enerjisi Ajansı tarafından önerilen sınıflandırmaya göre çok kötü ve kötü kaliteye sahip olduğu, çatlak derinliği sınıflamasına göre II ve III derece çatlak sınıfına girdiği ve basınç mukavemetlerinin kulelerde 2-8 MPa arasında değiştiği, türbelerde ise 20 MPa değerlerine sahip olduğu görülmüştür. Beton kalitesinin dayanımındaki bu farklılıklar, kuzeybatıdan esen rüzgarlar ve alanın tarihin farklı dönemlerde restore edilmesinde işçilik farklılıklarından kaynaklı olabileceği düşünülmüştür. Elde edilen sonuçlar kullanılarak yapıda güçlendirme yapıldığında, hem daha iyi korunacak hem de bütçe azaltılacaktır.*

***Anahtar Kelimeler:*** *Basınç mukavemeti, çatlak derinliği, tahribatsız test, ultrasonik puls hızı, Türkmenistan.*

## INTRODUCTION

Any renovation project of a building with respect to assessing damage should be evaluated under a framework that considers the following (Aköz, 2005): a) project design, b) comparison between the project and construction, determining outbuilding, destruction, risk estimation, if necessary preparing the relief project of the structure, c) defining the areas of damage and d) determining the construction elements that need to be measured. The mechanical characteristics of the concrete can be determined by using destructive and non-destructive methods. Core tests and pull-off tests, which are destructive, generate slight damage on the concrete surface while rebound hammer tests that determine the compression strength and the use of the ultrasonic pulse velocity in the concrete are non-destructive, respectively. Studies on historical buildings and protected areas must depend on non-destructive approaches, so as not to damage them.

Determining concrete properties with non-destructive tests, has been of wide interest for many years. In the early 1930s, vibration methods were used in the laboratory on test samples. These first studies on vibration techniques using the resonance frequency method have been applied in different studies (Powers, 1938; Obert 1939; Hornibrook 1939; Thomson 1940). After the World War II, studies on non-destructive testing used another method that is based on stress wave propagation. The development of the pulse velocity method began after 1949 in Canada, using a soniscope (Leslie and Cheesman 1949), and an ultrasonic tester in England (Jones 1948). After the 1960’s pulse velocity methods were applied in the field (Malhotra 1976). Since then pulse velocity measurements have been standardized by developing procedures for concrete samples. It has been demonstrated that this method can be applied successfully to assess damage to structures due to disasters, such as earthquakes, or due to buildings falling into decay as a result of environmental impacts, for example through wetting, melting swelling, cracking and fragmentation. The pulse velocity method has also been used: i) for continuous monitoring of important structures; ii) determination of the state of the structure renovating for new usage; or iii) assessment before repairing or reinforcing a structure. There are many advantages of using this method for determining the physical properties of the concrete; these include i) estimating concrete compressive strength; ii) analysing concrete homogeneity; iii) measuring crack depth; iv) analysing the durability of concrete; and v) determining the elastic modulus of the concrete (Malhotra and Carino 2004).

Seismic techniques are often employed to determine and characterize the dynamic properties of rocks. They can be used to obtain stress-strain relation in damaged rocks, as well as define the damage pattern around tunnels or excavations (Onodera, 1963; Hudson and Jones, 1980; Gladwin 1982). There are three types of mechanical wave propagation, also known as stress waves, that occur in a solid elastic medium, which interact with a dynamic or vibrating strain (Figure 1). These waves are: (1) compression waves, known as longitudinal or P waves; (2) shear waves or S waves, which are defined by transverse motion; and (3) surface waves, which include Rayleigh and Love waves. In addition, when ultrasonic energy penetrates into relatively thin plates, the plates emit Lamb waves. Ultrasonic vibrations are reflected at the interface of two materials that have different acoustical impedance. There is also an impedance difference in water-metal and metal-metal interfaces. An important feature of the reflected wave

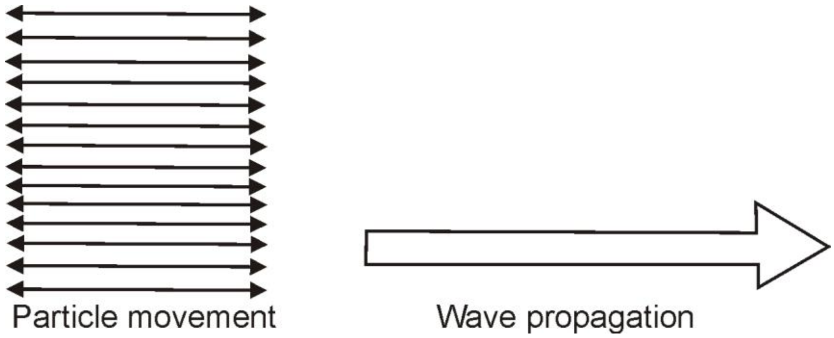



Figure 1. Particle motion and wave propagation of longitudinal waves (Mix, 2005).

*Şekil 1. Boyuna dalgaların partikül hareketi ve dalga yayınımları (Mix, 2005.)*

is that the angle of reflection must be equal to the angle of incidence. When ultrasonic waves pass from one material to another at any angle, refraction and mode conversion occurs (Smith and Stephens, 1964). Crack intervals occur by changing the direction and velocity when an ultrasonic wave passes through a boundary of different materials (Table 1).

| Concrete quality | P –Wave Velocity (m/sn) |
|---|---|
| Perfect | < 4500 |
| Good - Very good | 3650-4500 |
| Intermediate | 3050-3650 |
| Weak | 2000-3050 |
| Poor | 0-2000 |

Table 1. Crack classification on concretes (IAEA, 2002).

*Çizelge 1. Betonlardaki çatlakların sınıflandırılması (IAEA, 2002).*

The effect of weathering on the physical and mechanical properties of natural stone of monuments cause problems with the stone's stability. These properties cannot be easily studied using the common methods used for investigation in the modern construction industry, because these methods need a large quantity of testing material. For this reason the use of non-destructive techniques for determining the physical and mechanical properties of natural stone is very important, because it needs only a small quantity of testing material.

This study is designed to determine the mechanical properties on historical buildings in the city of Merv, Turkmenistan, specifically two towers and two mausoleums. A non-destructive method was used, including ultrasonic velocity and crack measurements, to assess the compressive strength of the brick, and plot these as a contour map. P–wave velocities have been calibrated to categorize the mechanical and weathering resistance of the concrete, as shown in Table 2. The results will be interpreted as showing the degree of weathering of the brick.

| Fracture Size | Fracture depth of the outside surface (mm) | Fracture depth of the inner surface (mm) |
|---|---|---|
| I. Degree | 0.05< | <0.2 |
| II. Degree | 0.05-0.5 | 0.2-1.0 |
| III. Degree | >0.5 | >1.0 |

Table 2. Classification of concrete quality/property due to P velocity (IAEA, 2002).

*Çizelge 2. P dalga hızına göre beton kalitesi ve özelliklerinin sınıflandırılması (IAEA, 2002).*

## METHODOLOGY

A PUNDIT ultrasonic non-destructive digital tester (Proceq, 2017) is used by transmitting a pulse to travel a known distance through a concrete. Measurements are applied along the axis of the studied surface and the travel time of the 54-KHz source pulse was measured. Calibration using a calibration bar is made before the measurements and if the transducer frequency is changed.

The study area consists of 2 towers and 2 mausoleums. The receiving transducers were placed every 10 or 20 cm along a measurement profile and the transmitting transducers were placed every 1 m in a horizontal direction and every 50 cm in the vertical direction. Simultaneously, ultrasonic pulse velocities and crack intervals were measured at 566 points. A view from the field study on tower walls is given in Figure 2.

Figure 2. A representative application on tower walls.

*Şekil 2. Kule duvarları üzerinde ölçü alımına ait bir örnek uygulama.*

## DESCRIPTION OF THE MERV ARCHEOLOGICAL SITE

Merv, which lies in southeast Turkmenistan, was a major oasis city in Central Asia, and operated as a trading center, and a military and administrative center for over 2500 years. It connected Europe and Africa to eastern Asia along the silk road (Herrmann, 1999; Herrmann et al. 2002). The well-preserved urban archeological site is an UESCO world heritage site. Archaeological exploration at Merv has been undertaken in recent years by the South Turkmenistan Multi-disciplinary Archaeological Expedition (YuTAKE), under the International Merv Project.3 (Herrmann et al. 2002).

Besides remains from the Bronze and Iron ages, different historical monuments, mausoleums and mosques are preserved. The archeological site includes mausoleums of ibn Al-Khuseib al-Aslami and Al- Khakim ibn Amr Al-Gifari, from the XV century Timurid dynasty (Figure 3). Two black marbles cenotaphs mark their tombs. Behind the two mausoleums are a pair of heavily reconstructed Timurid iwans, built to honour the tombs of the Askhab. The internal walls of the latter are decorated with blue and turquoise tiles in geometric designs. In front of the Askhab complex is a water cistern that is still in use, and was built probably around the same time as the iwan. Only a shallow dome and a large arched doorway on the western side are visible above ground. Uneven stone steps lead down to the water. The doorway, decorated with floral-patterned stucco, dates from the 19th century.

Figure 3. The archeological site in the Merv City (Turkmenistan).

*Şekil 3. Merv (Türkmenistan) şehrindeki arkeolojik alan.*

## Ultrasonic Pulse Velocity

The basis of ultrasonic testing depends on the transformation of mechanical waves into electrical vibrations or vice a versa. First the piezoelectric transmitters are installed. The technique is based on the principle that a pulse of longitudinal waves is induced into the concrete from the transmitting transducer (Neville and Brooks, 1997; Popovics, 1998; Meneghetti et al. 1999). Afterwards, it undergoes multiple reflections as it passes through different materials and is received and converted into electrical energy by a second transducer. The schematic diagram of a test device is shown in Figure 4. Figure 5 shows the Proceq measurement apparatus. Depending on how the transducers are arranged, the measurement type will either be defined by direct, semi-direct, or indirect methods after (Tarun et al. 2004; Figure 6).

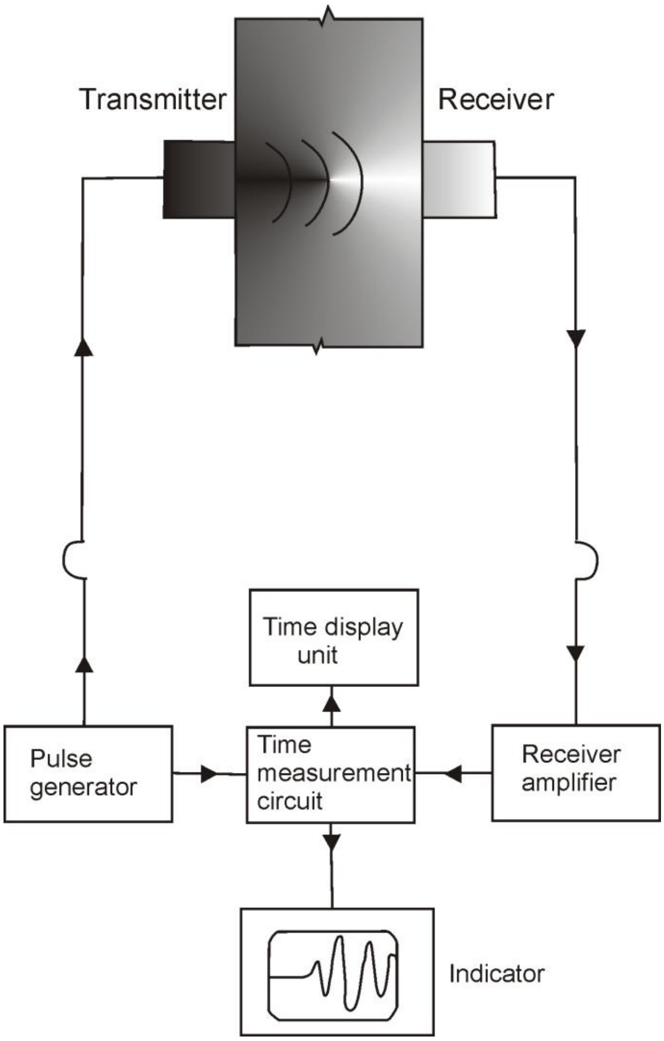



Figure 4. Schematic diagram of the vibration speed test circuit (Tarun et al. 2004).

*Şekil 4. Titreşim hızı test devresinin şematik diyagramı (Tarun ve diğ., 2004).*

The direct measurement method was applied wherever possible to ensure the maximum signal transmission between the transducers. The semi-direct arrangement is less sensitive than the direct, but more sensitive than the indirect arrangement. The path length is the distance between the centers of each transducer. The indirect method, on the other hand, is particularly useful for determining crack depth, surface quality or in the case that only a single surface is accessible. For example, the semi-direct and indirect measurements are more effective, because they are less restrictive in transducer arrangement (Tarun et al. 2004). The velocity, v, is calculated from the distance, l, between the two transducers and the electronically measured transit time, t, of the pulse as v = l/t (Figure 7). There are various


Figure 5. Measurement apparatus of Proceq Company.

*Şekil 5. Proceq şirketine ait ölçüm cihazı.*

factors that affect the speed of the wave at the ultrasonic pulse velocity test and these include: 1. the distance between transmitter and receiver; 2. the condition of brick surface; 3. brick temperature; and 4) the influence of steel reinforcement in the case of brick.

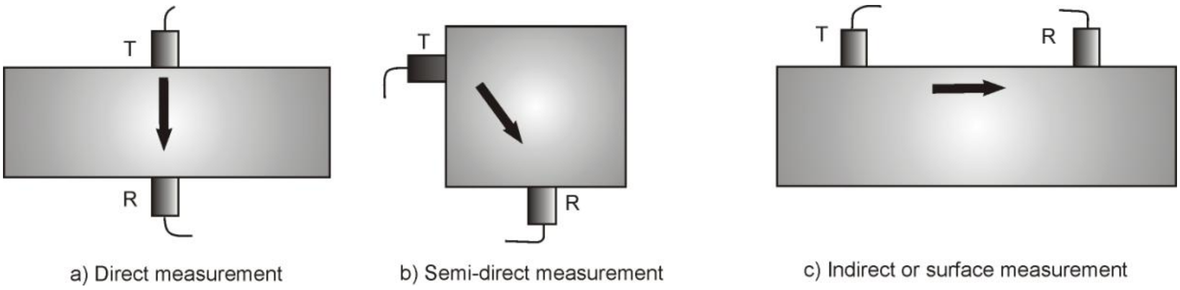



Figure 6. The vibration velocity configuration after (Tarun et al. 2004). (a) Direct method (b) semi-direct method (c) indirect method (Abbreviations: T: Transmitter, R: Receiver).

*Şekil 6. Titreşim hızını ölçme dizilimleri (Tarun ve diğ., 2004). (a) Doğrusal yöntem (b) Yarı-doğrusal yöntem (c) Doğrusal olmayan yöntem (Kısaltmalar: T: Verici, R: Alıcı).*

**Depth of Cracks**

One of ultrasonic pulse velocity test that is made on the brick is determining the crack depth. This measurement can be carried out by using indirect method, in which the transmitter and receiver are put on a surface, as shown in Figure 6b. The depth to the crack can be found from the transit time (Figure 7). In this case the transmitter is placed at a suitable point on the surface and the receiver is placed on the same surface at successive positions along a specific profile. The transit time is plotted in relation to the distance between the centers of the transducers, and a change in slope would indicate a change in the physical properties of the material. For example, a lower pulse velocity near the surface compared to deeper down in the material, suggests that the surface layer is weathered, and therefore of inferior quality. According to this plot, the thickness of the weathered surface layer is estimated as follows:

$$D = \frac{x_o}{2}\sqrt{(v_s - v_d)/(v_s + v_d)} \qquad (1.1)$$

where $V_s$ is the pulse velocity in the sound rock ($K_m$/s), while $V_d$ show the velocity in the damaged rock (Km/s). $x_o$ is the horizontal distance at which the change of slope occurs (mm), and D shows the depth of weathering (mm)) (Bruneau et al. 1995).

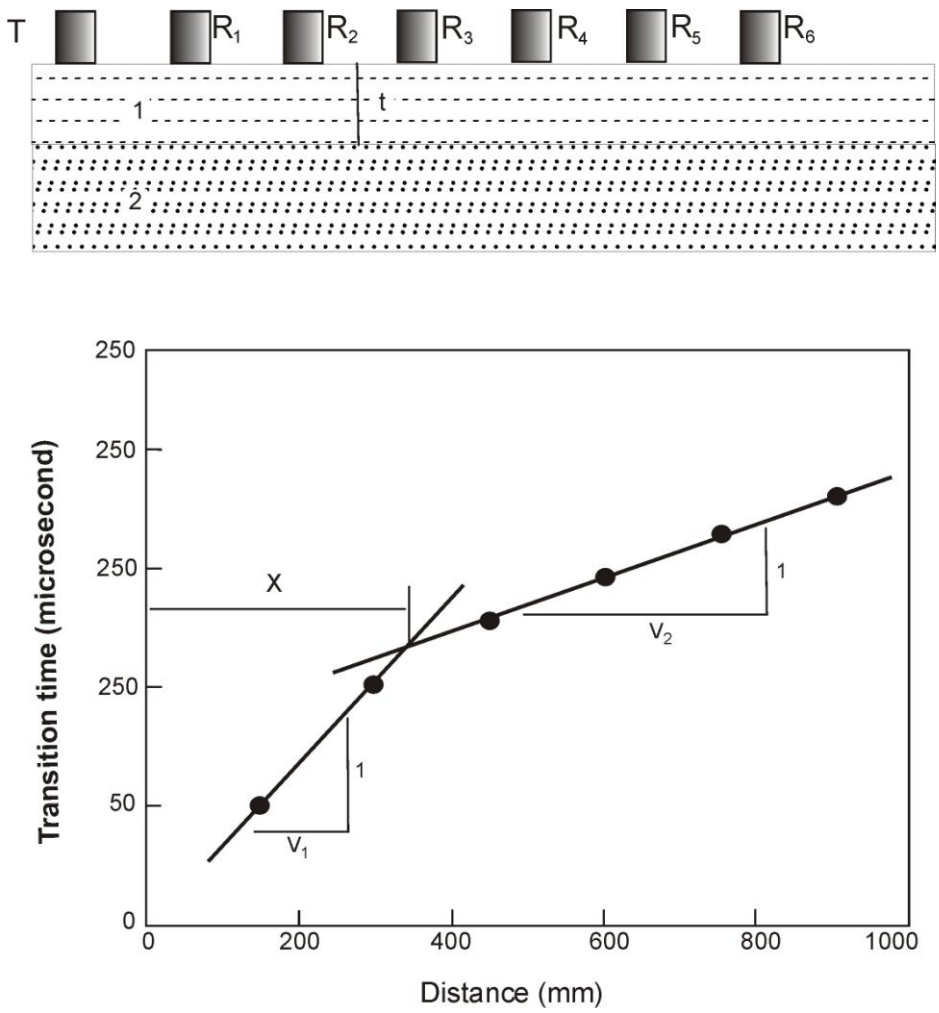



Figure 7. Indirect or surface methods for determining the depth of alteration zone (Tarun et al. 2004)

*Şekil 7 Ayrışma zonunun derinliğini belirlemede Doğrusal ve Doğrusal olmayan yöntemler (Tarun ve diğ., 2004).*

**Compressive strength based on P-wave**

The ultrasonic pulse velocity (UPV) of concrete is widely used to predict compressive strength (Lin et al. 2003; Demirboğa et al. 2004; Khan et al. 2007; Sheen et al. 2013; Yusuf and Jimoh, 2014). The compressive strength is obtained by combining the ultrasonic measurement with a rebound hammer measurement, which is known as the SonReb method (Pucinotti, 2005). The relation can be expressed as:

$$f_c = f_0\, aV^b S^c \qquad (1.2)$$

where $f_c$ is the concrete compression strength and $f_o$ indicates the unit conversion factor. a, b and c are constants, V is the ultrasonic pulse velocity in m/s, and S is the rebound value. The compressive strength (CS) is obtained from the SonReb based in an exponential equation that links compressive strength (CS) to ultrasonic pulse velocity (UPV):

$$CS=3.10^{-8}(UPV) \qquad (1.3)$$

The example in Figure 8 has a regression coefficient of $R^2$ = 0.91, which indicates a reliable relationship. The compressive strength values in this study were calculated using equation 1.3.

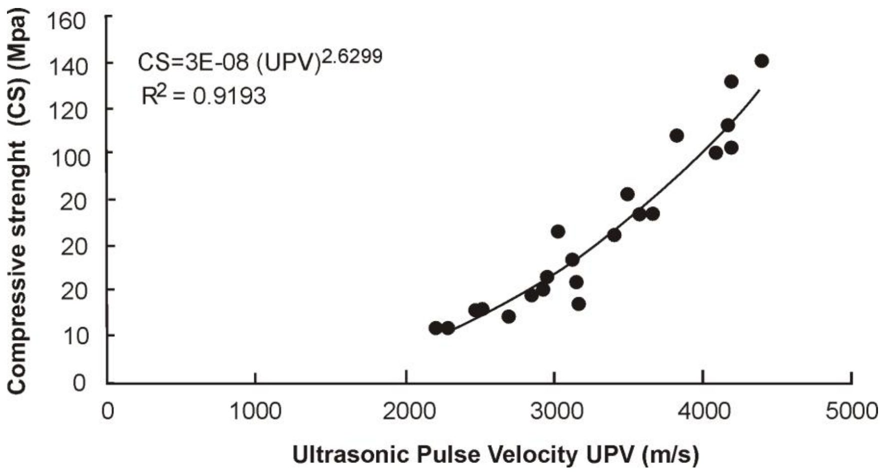



Figure 8. Estimating compressive strength of material using the rate of vibration (Tarun et al. 2004).

*Şekil 8. Titreşim hızı kullanarak malzemenin sıkışma mukavemetinin kestirimi (Tarun ve diğ., 2004).*

## DISCUSSIONS

The sketch map in Figure 9 illustrates the measurement site. The two towers consist of eight walls, in which the N wall is 10 m in length, and the E and W walls are 5 m in length. Measurement could not be carried out on the N wall (surface “A"), because access was blocked by building materials for the renovation. P wave velocities were used to classify the quality of the bricks, according to the International Atomic Energy Agency (IAEA, 2002). Velocities for five walls of the tower (A, C, E, F, and G) vary between 1000-2500 m/s (Figure 10a), while velocities for walls B and H are below 1500 m/s. The systematic lower velocities on the E and W walls are thought to be due to strong northerly winds and exposure to heavy rain, which leads to higher weathering. P wave velocities are around 3000 m/s on the lower part of E and D surfaces. Overall, all surfaces fall within the classification of weak and poor (IAEA, 2002). The building elements mostly with the highest weathering are concentrated on the upper surface walls of the tower. P-wave velocities were also obtained for all eight surfaces of the second tower. The lowest velocities are found on the A and B walls, and average velocity values are < 2000 m/s. This indicates the poor quality of these two walls (Figure 10b).

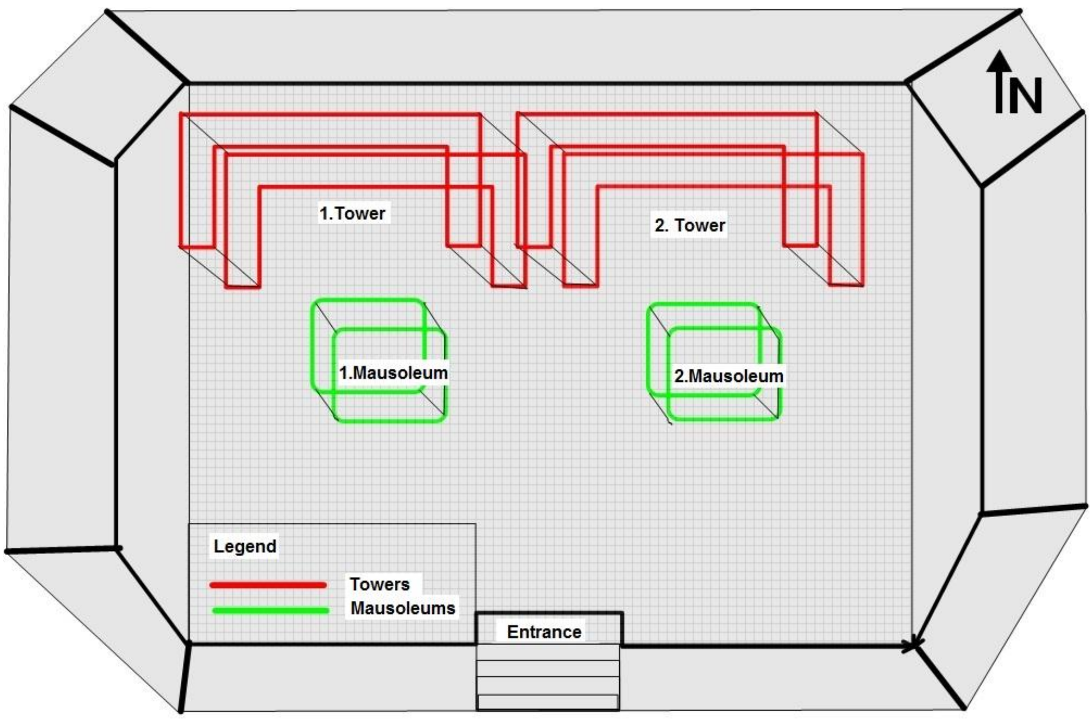
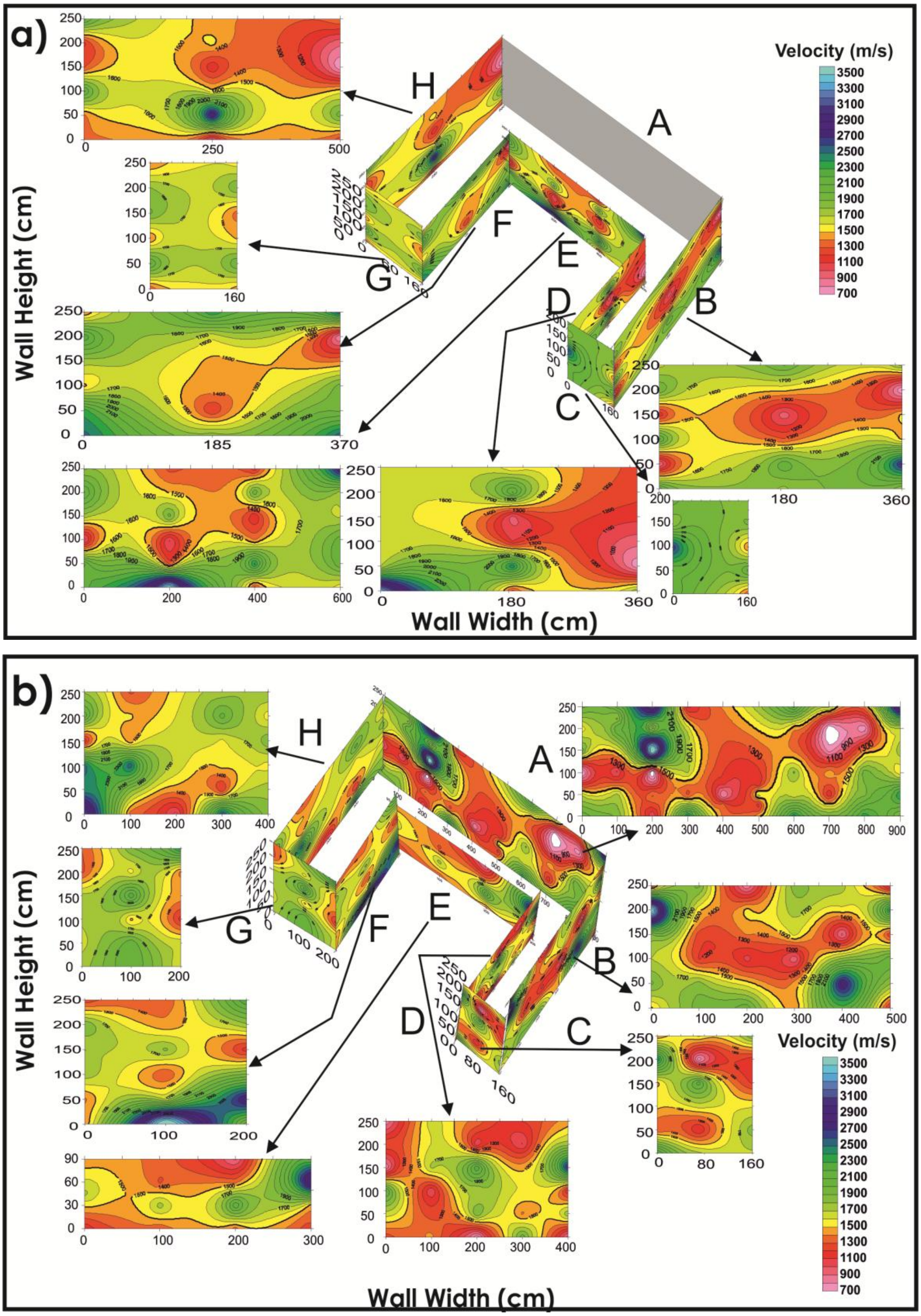



Figure 9. Sketch diagram showing the present tower and mausoleum structures of the companions Al-Khuseib al-Aslami and Al- Khakim ibn Amr Al-Gifari in Merv.

*Şekil 9. Merv şehrinde bulunan Hakem El-Gifari ve Bureyde el-Eslemi’ye ait türbe ve kulelerin günümüzdeki halini gösterir şematik diyagram.*


a)
H
A
F
G
E
D
B
C
Velocity (m/s)
3500
3300
3100
2900
2700
2500
2300
2100
1900
1700
1500
1300
1100
900
700
Wall Height (cm)
Wall Width (cm)
b)
H
A
G
F
E
B
D
C
Velocity (m/s)
3500
3300
3100
2900
2700
2500
2300
2100
1900
1700
1500
1300
1100
900
700
Wall Height (cm)
Wall Width (cm)

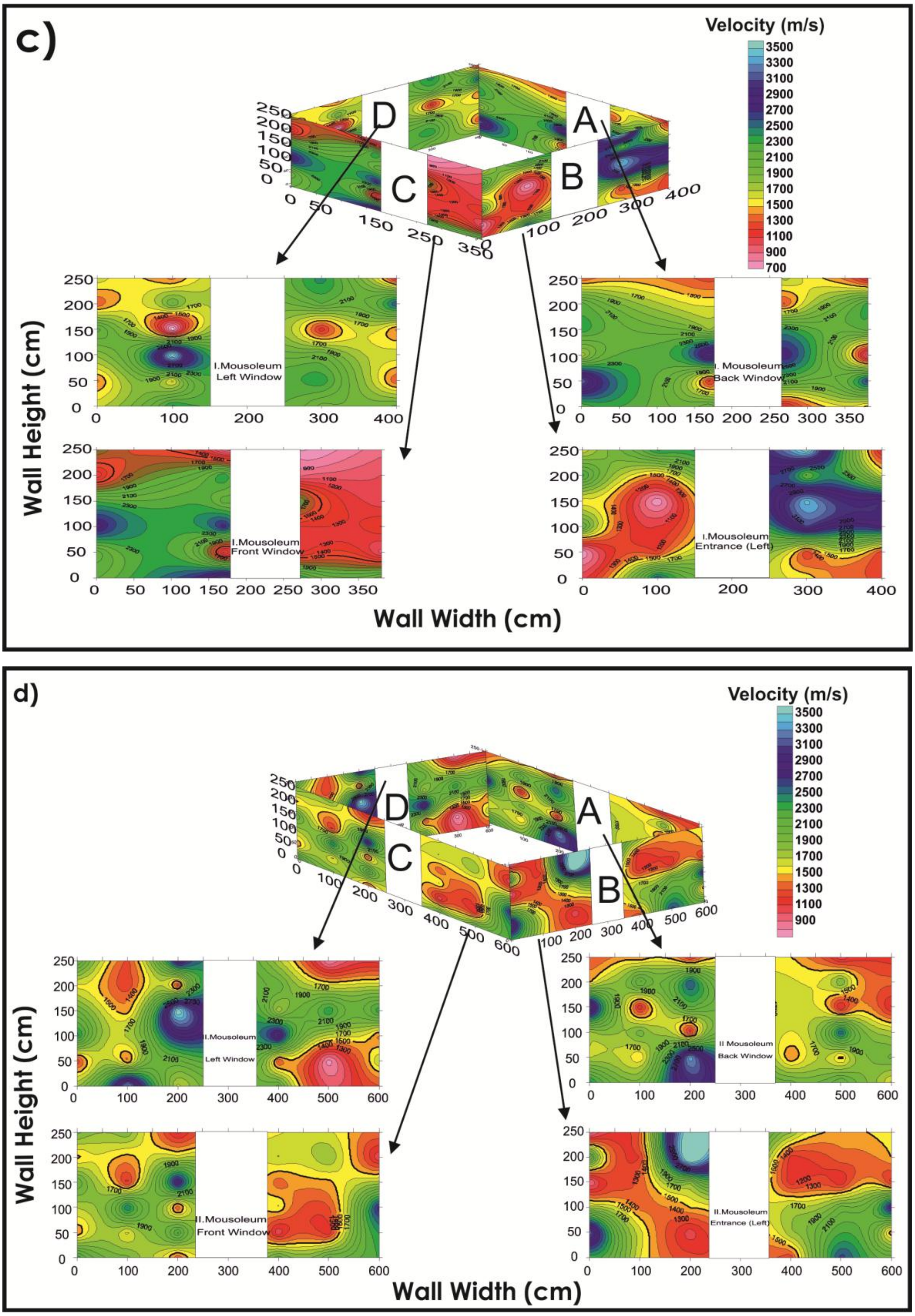
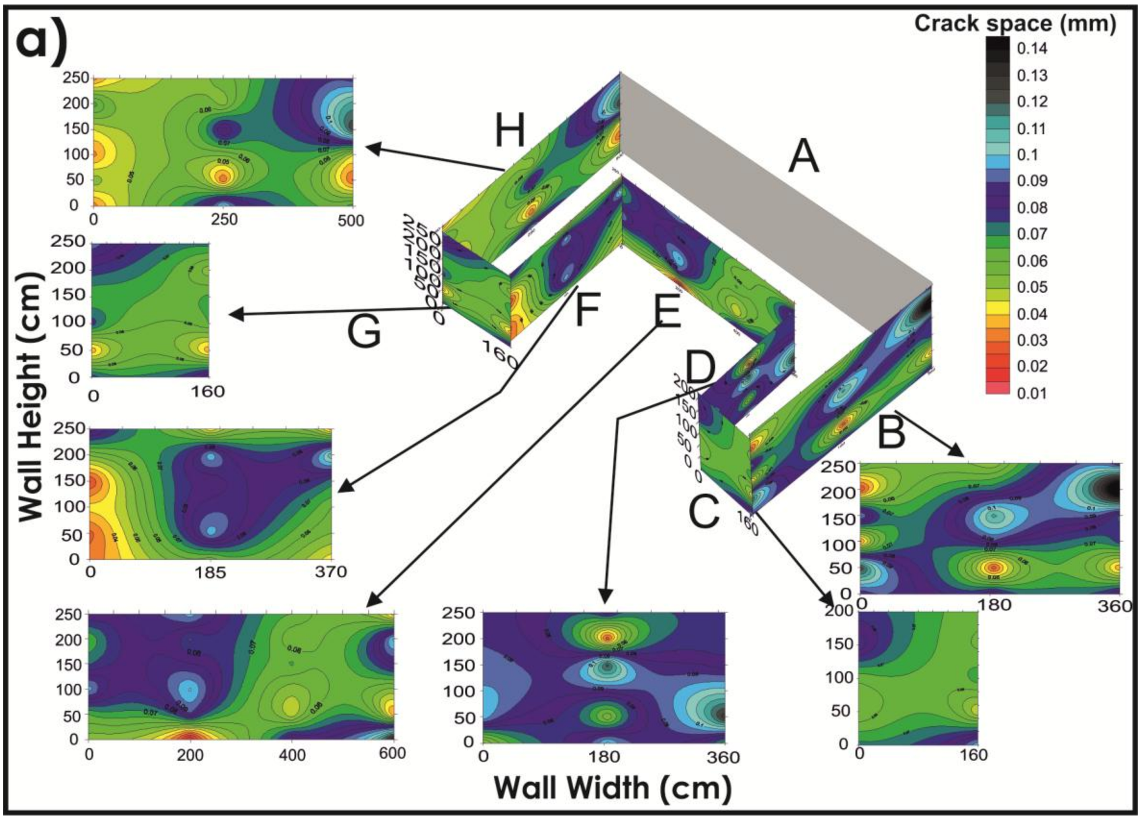


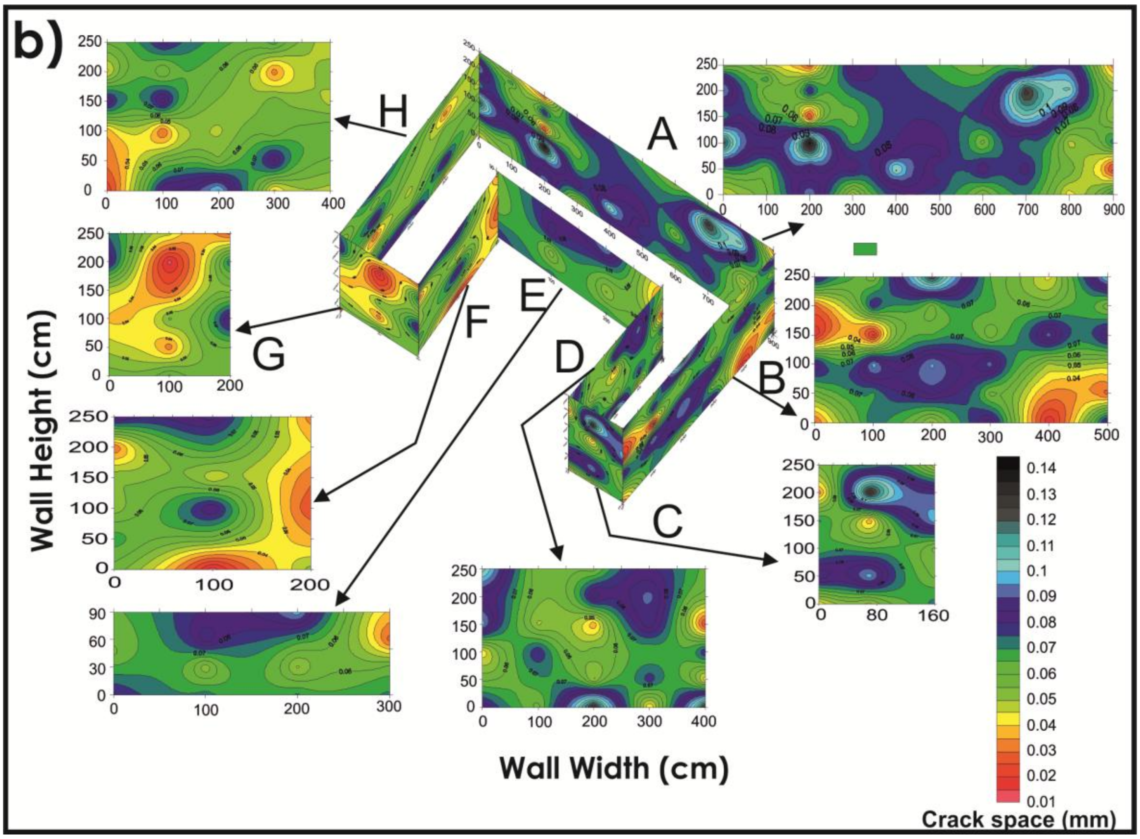

Figure 10. Velocity variation maps for the a) First tower, b) Second tower, c) First mausoleum, d) Second mausoleum.

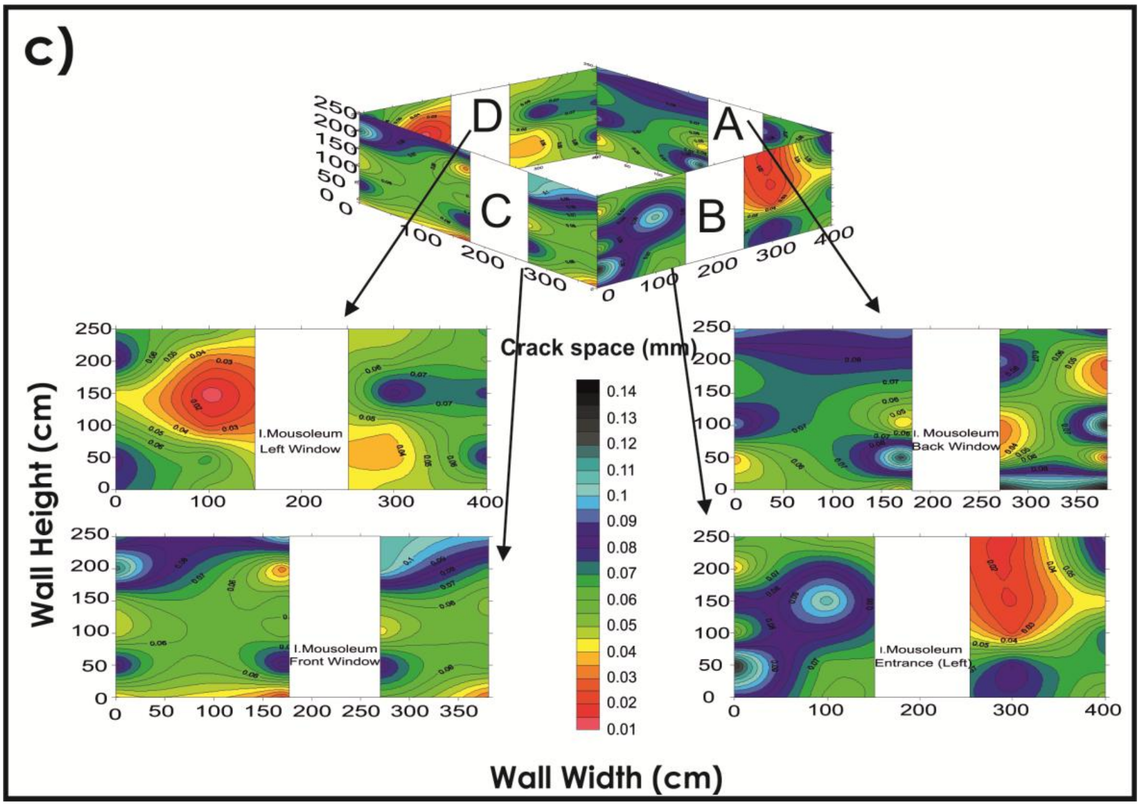
*Şekil 10. Hız değişim haritaları a) Birinci kule, b) İkinci kule, c) Birinci türbe, d) İkinci türbe.*

The two mausoleums are square-shaped, and have four walls (Figure 10c and d), whereby the first mausoleum has 4m length and the second mausoleum has 6 m length. Each mausoleum has a window on each of three sides and a door entrance on the fourth side. The P-wave velocity values are < 2000 m/s and on the C and B walls of both mausoleums, and reach lower values (< 1500 m/s) in discrete areas, of higher velocity. The quality of the building material in these areas is classified as weak to poor. Velocity is especially low on the upper surfaces of the mausoleum, and also on the eastern walls. These differences are thought not be the result of climatic conditions, but may have occurred during construction. The overall low P-wave velocities in both mausoleums, and strong gradients between poor to medium suggest poor workmanship during the construction. Climate conditions, however, may have caused weathering and deformation in different parts of the mausoleums.

Crack-depth measurements were taken approximately every 10 cm, so that both the transmitter and receiver sequence is on the brick for Tower 1 (Figure 11a). All crack depths, which are calculated from the P-wave velocities, range between 0.05 - 0.1 mm. Note that these measurements are not due to cracks but fillings in these cracks.




b)
A
B
C
D
E
F
G
H
Wall Height (cm)
Wall Width (cm)
Crack space (mm)
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01


c)
A
B
C
D
Crack space (mm)
I.Mousoleum Left Window
I. Mousoleum Back Window
I.Mousoleum Front Window
I.Mousoleum Entrance (Left)
Wall Height (cm)
Wall Width (cm)
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01

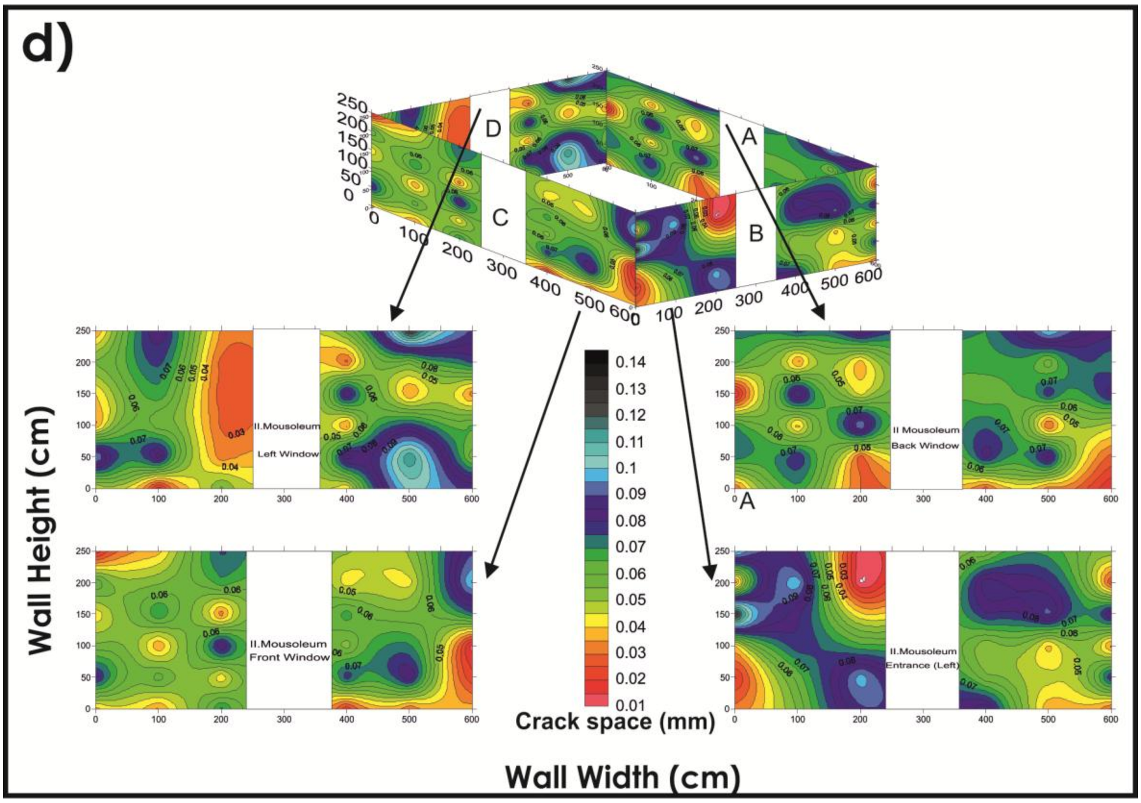



Figure 11. Crack space maps on a) First tower walls, b) Second tower walls, c) First mausoleum walls, d) Second mausoleum walls.

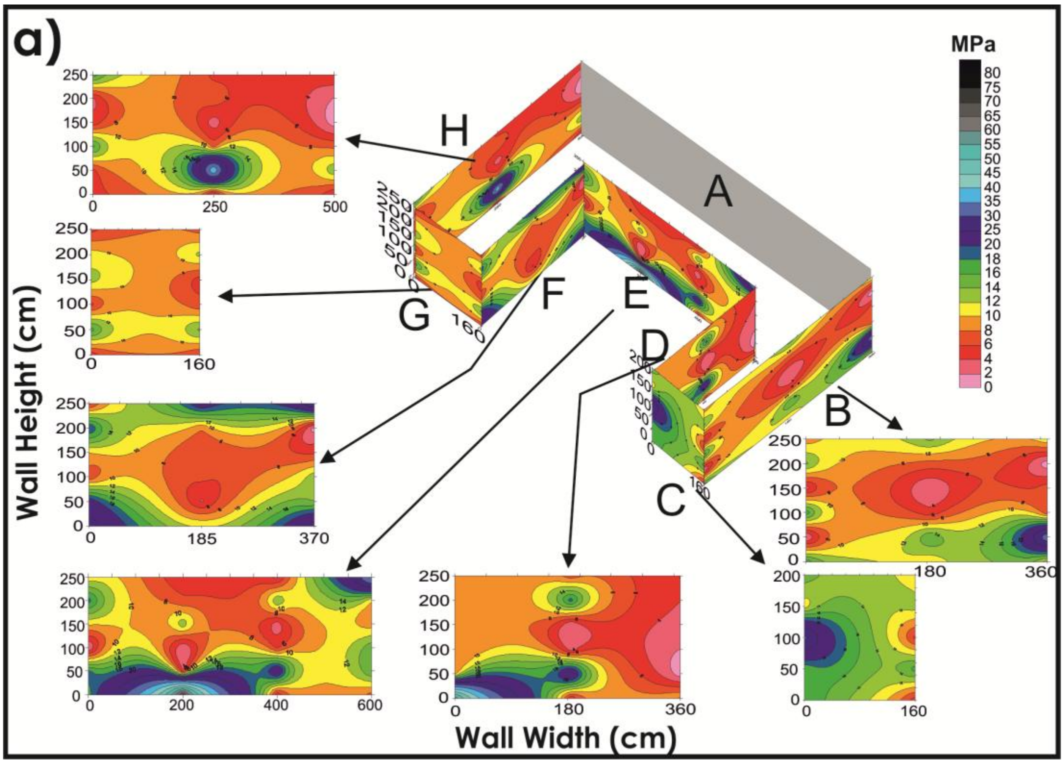
*Şekil 11. Çatlak aralığı değişim haritaları a) Birinci kule duvarları, b) İkinci kule duvarları, c) Birinci türbe duvarları, d) İkinci türbe duvarları.*

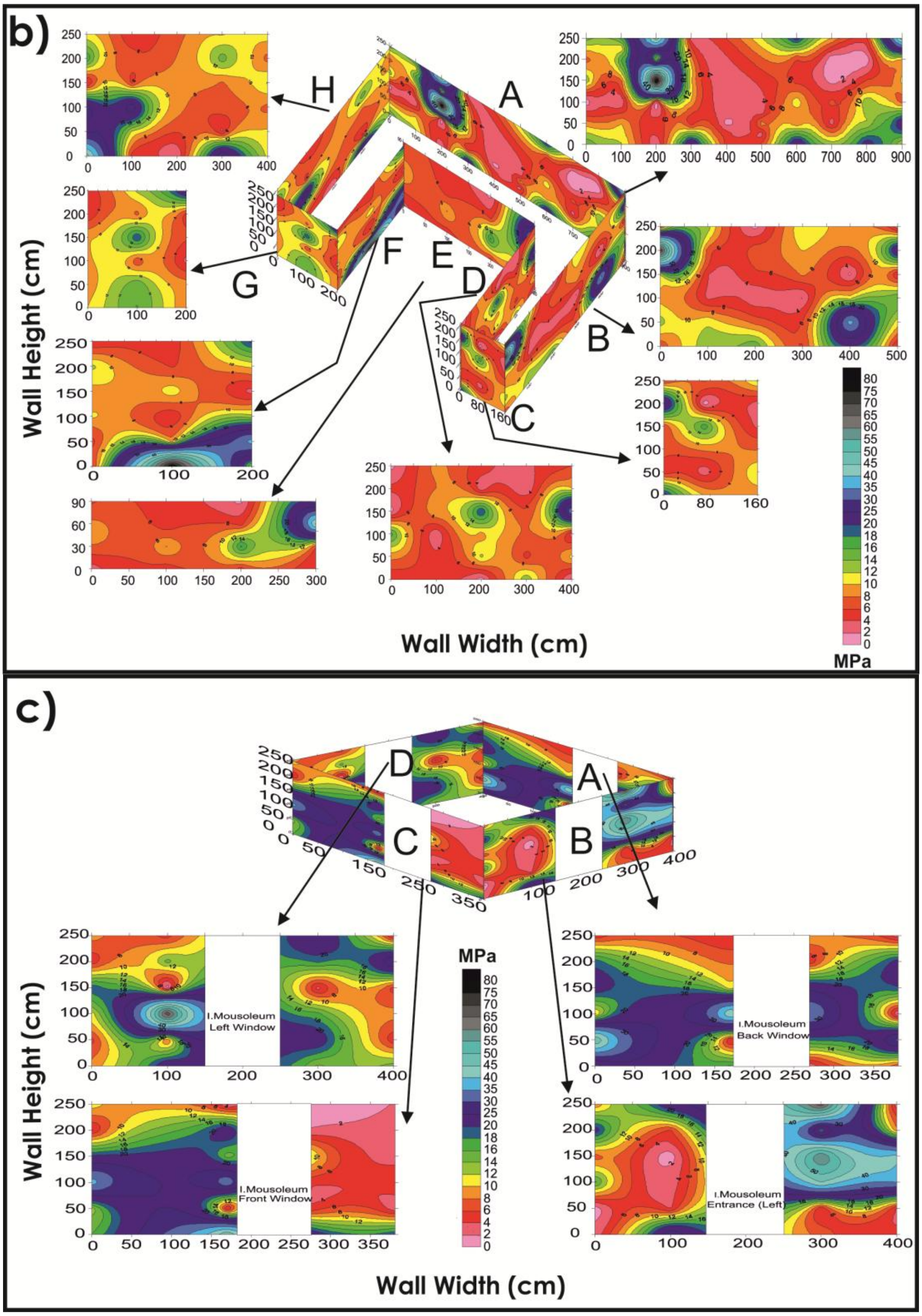
The crack depth obtained on the outer surface of the tower 1 show a crack classification of II. degree (Table 2). Although there are similar crack depths in Tower 2, diagonal variation on walls B, F, G and H are small when compared to the other walls, and crack depth that varies between 0.01-0.05 mm (Figure 11b). This tower is defined as II and III crack classification degree. When compared with the P-wave velocity values it is shown that the P-wave velocities increase relative in the same areas and the brick quality shows a medium degree.

Because bricks and joints show similar structural properties, it is suggested that the differences in the opening can develop due to time and atmospheric conditions. The difference in the classification between Towers 1 and 2 depends not only on wind direction and rainfall, but also on physical factors from the west. The crack openings observed in the Mausoleum 1 are about 0.1 mm, while on the left window and the right surface of the door are 0.01 mm. In the Mausoleum 2, however, a randomly increase or decrease is observed in many areas. The cracks are classified as II and III degree (Table 2), similar to the crack classification for the towers, which suggests that wind and precipitation from the north and west are effective in weathering. Since the domes on the mausoleums are under structural pressure, the tensional force that may occur in the dome can lead to cracks in the vertical direction. Thus resulting damage or deep cracks on the bricks which are beneath the dome, indicates that the bricks need to be renewed because of the decrease on their rigidity.

The compressive strength of the structural elements was calculated and mapped using the velocity values given in Figure 10 to show the resistance of existing structures and structural systems before the renovation process (Figure 12). Bricks in the Towers 1 and 2 show compressive strength of 2-8 MPa (Figure 12 a and b). In the mausoleums, the compressive strength were relatively higher while building materials show a compressive strength of 20-30 MPa on four sides of the Mausoleum 1 with a similar result for Mausoleum 2 (Figure 12 c and d).

While structures were destroyed partially by various invasions, renovations that led to reinforcement of the structures were not homogenous. In addition, strong winds blowing from the northwest in the spring and autumn were effective eroding different edges of the structures.




b)
A
B
C
D
E
F
G
H
Wall Height (cm)
Wall Width (cm)
MPa
c)
A
B
C
D
I.Mousoleum Left Window
I.Mousoleum Back Window
I.Mousoleum Front Window
I.Mousoleum Entrance (Left)
Wall Height (cm)
Wall Width (cm)
MPa

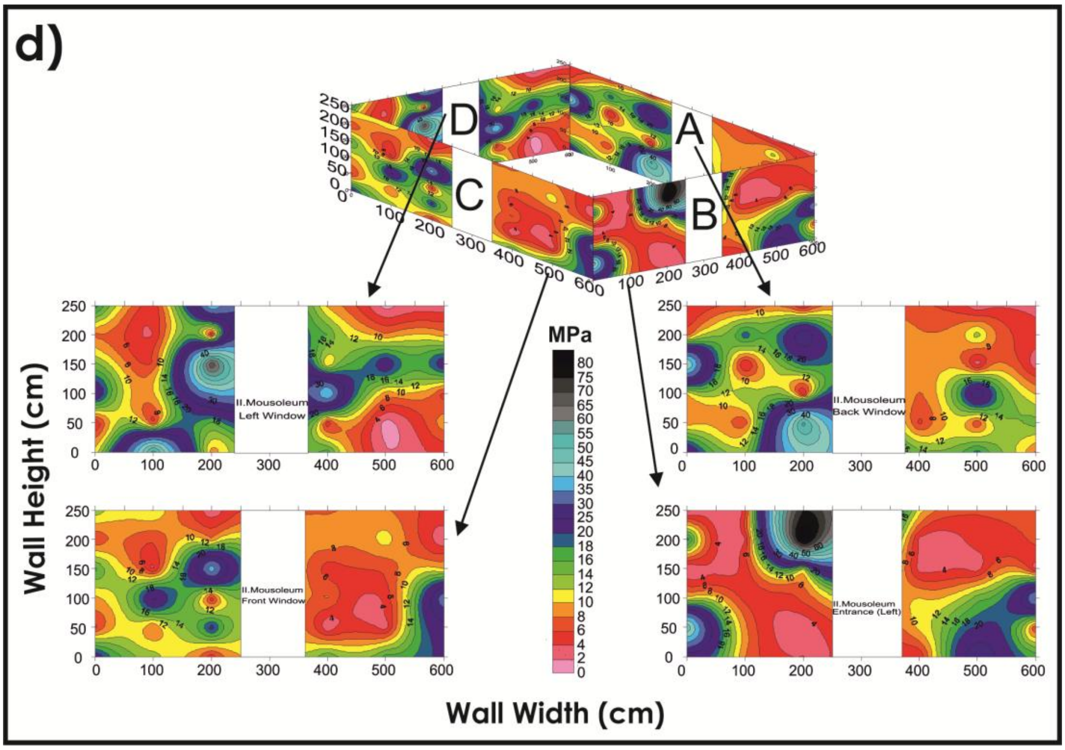



Figure 12. Variation of compressive strength maps a) First tower walls, b) Second tower walls, c) First mausoleum walls, d) Second mausoleum walls.

*Şekil 12. Basınç mukavemetleri değişim haritaları a) Birinci kule duvarları, b) İkinci kule duvarları, c) Birinci türbe duvarları, d) İkinci türbe duvarları.*

## RESULTS

Non-destructive geophysical methods including ultrasonic pulse velocity, crack depth and the related compressive strength were measured and calculated on in-situ structures at a total of 1132 points in order to show the current status of the mausoleums and towers in the city of Merv in Turkmenistan.

Classification of any material can be explained with its physical values. Pulse velocity values obtained from this study change between 900 and 2300 m/s. The building material (brick) in both towers and mausoleums were classified as weak and poor according to the classification by IEAC (2002). The average crack interval value was found to be 0.07 mm. Velocity values are compatible with crack depth values. High crack depth values are measured where low phase velocity values are found which are thought to be the reason of weathering. For this reason, it was suggested that P wave velocity and crack depth values were affected by climatic conditions or poor workmanship during the construction. Crack depth changes between II and III class, according to IEAC (2002). This situation emphasizes that each walls were exposed under similar conditions. The compressive strength of towers and mausoleums have different values below and above 10 MPa, respectively. Overall, the velocity and pressure strength values in the western and northern parts of the walls were lower and crack intervals were higher due to climate conditions including wind, rain, and temperature. The weathering degree on walls B, D and H is higher than other walls on the N-W fronts. The crack spacing was larger in the walls lying on the western front and the joint walls. This may be due to the quality of workmanship because the wall on the western front was recently restored.

During the restoration, water drainage of the mausoleums and the towers' foundations was completed and the dome and vaults were reinforced in their upper parts. The sutures of the mausoleums were opened, and the classic brick and rubble stones were removed from the ground by the digestion method and replaced by the same kind of durable and original material. The sutures in the surface were renewed and strengthening was made with the original material by the injection system.

In a final stage, drainage was completed in order to protect the basic substructures of the iwans and to protect them from the ground water. On the top of the mausoleums, slope levelling was made to drain rain water. Landscape projects were created in order to correspond the number of visitors. 80% of the original suture were completed on the main walls after the production of the vault and the injection of the tiles.

Some walls should be protected with higher strength materials when compared to others. It should be noted that any restoration of this archeological site should benefit the results of this study. It is of great importance whether to use the appropriate material for a long time resistance with minor financial loss.

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