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THE MASONRY TECHNIQUES OF A HISTORICAL BRIDGE IN HYPOKREMNOS (İÇMELER) (1)

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1. This study was based on Master's Thesis entitled Photogrammetric Evaluation Options for Ancient Structures in Hypokremnos, Pagos, Paradiso and Nysa by Funda Uygun in Architectural Restoration Department, Faculty of Architecture, İzmir Institute of Technology, İzmir.

2. Bozkurt (1952), İlter (1966, 1971), İşmen (1967), Çulpan (1975), Tunç (1978), Arıoğlu and Anadol (1979), İlter (1978), Çeçen (1988), Öziş (1991). Eyüce (1998), Tanyeli (2000), Sözen (2000), Türkiye Karayolları Genel Müdürlüğü (2008), Ural et al. (2008) and Canitez et al. (2009).

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INTRODUCTION

Characteristics of the site and date of construction are the primary parameters that determine the form and construction techniques of viaducts. In Roman, Byzantine, Seljuk and Ottoman periods, masonry structure in linear form carried with one or series of arches was the basic theme of the viaducts (Tanyeli, 2000).

There are a number of studies on bridges of Anatolia constructed in a specific period or region (**2**). In these studies, however, information on construction techniques and material usage is limited.

This study aims to identify elements, construction techniques and material usage of a historical bridge in İçmeler, Urla, İzmir. Urla, which is a historical settlement on the west of the metropolitan city of İzmir, is an important transition point between Karaburun-Çeşme Peninsula and the mainland of Anatolia. İçmeler is about seven kilometers at the west of Urla, and on the southern coast of Gülbahçe. On the southwest of the case study bridge in İçmeler, there is a double lane traffic way connecting Çeşme and İzmir. At its northeast, there is Gülbahçe Gulf.

There were four brooks reaching to Gülbahçe Gulf, but today brook's flow of water is low and their directions were changed due to the construction of new houses. During the site survey, remains of three bridges and remains of a roadway between them were observed on the coast. The brooks run nearby these bridge remains according to old maps and traces on the coast (**Figure 1**). The location of these remains indicates that the coastline was further to the northern side in the past.

The bridge remain at the center, which is the best preserved among the three (number 2 in **Figure 1**), was analyzed in this study. The case study bridge is a linear masonry wall (349x1637 centimeters) pierced with three round arches with different widths; western arch 200 centimeters, central arch 389 centimeters and eastern arch 193 centimeters. The wall is crowned

Figure 1. Location of the bridges on İçmeler Coast

Figure 2. Photo of the case study bridge as viewed from the south

with a road way making a crest at its center. The inclination on both sides is around 7% (**Figure 2**).

The case study was documented in detail with manual photogrammetric technique at 1/20 scale. Tgi3D SU Photoscan Calibration Tool version 2.13 and Trimble SketchUp 2013 were the tools. In order to evaluate its historical significance and date of construction, historical developments in the Urla region were considered and comparative study with similar bridges in Anatolia was made. This evaluation was supported with mortar analysis carried out in the Material Conservation Laboratory on a single original sample (**3**). Raw material composition, basic physical, chemical, mineralogical, and hydraulic properties, and pozzolanic activities of aggregates were determined by RILEM test method, XRD, SEM-EDS, and TGA analyses and electric conductivity method. The results were compared with those of other ancient remains in the region. Stone types were determined with visual analysis only. Reconstitution system detail was formed based on 3D documentation, comparative study, and historical research. The conventional drawing set was used to produce 3D reconstitution model following the principles of constructive solid geometry modeling paradigm. Autocad 2012, Archicad 12 and Artlantis Studio 2 were the tools. Hypothetical construction phases were presented on the model.

3. Sample was taken from the seaside facade on the western corner of the viaduct.

GEOLOGIC AND HISTORICAL CHARACTERISTICS OF THE CASE STUDY

Starting with the first half of 3000 BCE, ships travelling from northern Aegean to south preferred to stop at the harbor of Limantepe, a prehistoric archeological site at the north of Urla today. Their goods were carried to the southern harbors, following a historical route at the narrowest part of the Çeşme-Karaburun-Urla peninsula (Şahoğlu, 2005). In this way, time and energy was saved. Strabon (7 BCE) refers to the narrowest part of Çeşme-Karaburun-Urla peninsula as Khersonessos Isthmus (Strabon, 7 BC). The bridge ruin subject to this study is situated on Hypokremnos, at the north of Khersonessos. This zone involves a fault line running in north-south direction, series of mounts and brooks in parallel with this earthquake zone and geothermal sources, one on İçmeler coast and another on Gülbahçe Bay (**Figure 3**) (Altun, 2006-2008).

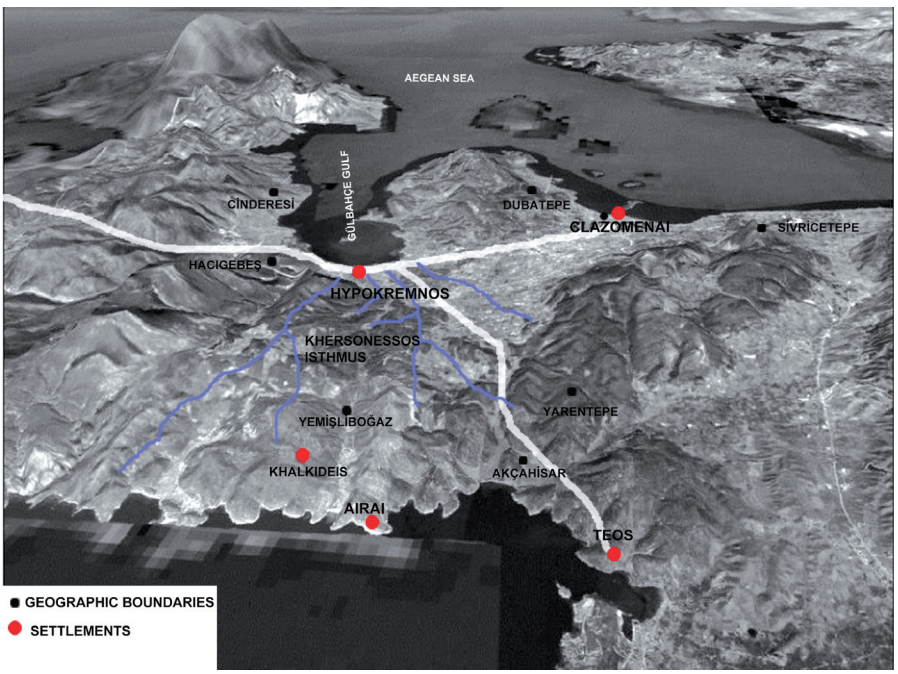

Figure 3. Aerial photo of Çeşme-Karaburun-Urla Peninsula (revised by Koparal, 2012)

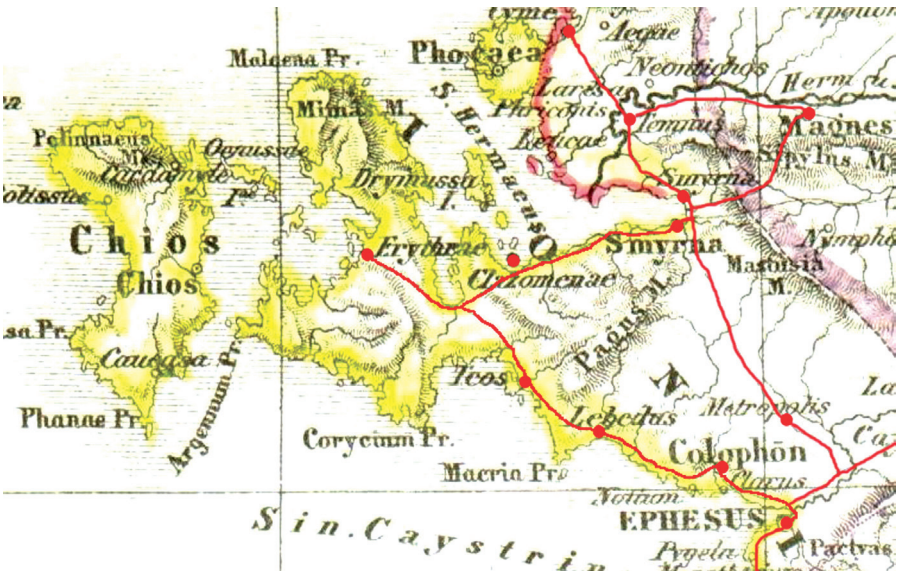

Figure 4. Cultural routes in Ionia (Map revised from Kiepert, 1869)

In the succeeding period (1050–188 BCE), Hypokremnos, known as İçmeler today, was in relation with three Ion cities; Teos, Klazomenai and Erythrai. There were roads connecting them (**Figure 4**) (Bakır and Anlağan, 1980; Meriç et al., 2012). International trade of olive oil, wine, and marble via the harbors of these cities played role in their development (Şahoğlu, 2005; Kadıoğlu, 2012; Akalın Orbay, 2003, 2005). Visual prospections have revealed the existence of Archaic, Classic and Roman ceramics and architectural remains in Hypokremnos and its surroundings (Ersoy and Koparal, 2008). After Romans (188 BCE-480 CE), Byzantine Empire controlled the region (Mater, 1982).

In Emirates Period (fourteenth century), Urla was conquered by Aydın Principality in 1330s. It became a district of Aydın City, together with Karaburun, Çeşme, Seferihisar and İzmir (Baykara, 1976). In this period, Urla was on the commercial road connecting Chios to the mainland. It was also important with its agricultural production; especially Malkoç (İçmeler) came first in oil production. Urla was named as Nefs-i Bazaar or Nefs-i Urla due to its leading character in the commercial life of the region (Atay, 2003). A population increase was recorded for Urla region in the sixteenth century. There was a caravan road connecting Çeşme to Cumaovası and Menemen passing through Urla. Remains of this caravan road can be observed in Çeşme, Barbaros, İçmeler and near Çamlıköy. Baykara (1976) claims that the bridges of Hypokremnos one of which is studied in this research was part of this Ottoman caravan route leading to Menemen at the north and Cumaovası at the south. So, the case study bridge is part of a commercial network which has existed in Urla region since prehistoric period.

ELEMENTS OF THE CASE STUDY

A masonry bridge is composed of main and secondary structural elements. Main structural elements are foundation, piers and abutments, arches, spandrel walls and wing walls (Huges and Blackler, 1997). Secondary structural elements are breakwaters, flood control arches and reliving arches (Tanyeli, 2000).

The case study bridge consists of five structural elements and two architectural elements. The structural elements are foundation, piers and abutments, arches, spandrel walls and breakwaters. Roadway and parapet are architectural elements (**Figure 5**).

Foundation: Foundation is the lowest part of a bridge that encounters ground. Masonry bridge foundations have been built with different materials and techniques as timber piled masonry foundation and without foundation on the rocky soil. Timber piled system is ideal solution for bridges located at sites that have weak soil properties (Çakır, 2011). The foundation system of the case study bridge is not observed. Timber piled foundation system was probably used, because it is located on a river bed.

Pier and abutment: Piers are wide columns which support the arched openings of a bridge. Abutments are walls which support the two ends of bridge (Khan, 2010). The case study bridge has two piers most of which are below the ground level. They are observed best on the seaside façade under minimum water level condition. Piers are made of close jointed, rectangular, finely cut sand stones (43x30, 27x33, and 63x28 centimeters); no clamps and dowels are observed. Inner fillings of the piers were not observed. Their thickness varies between 25 and 30 centimeters (**Figure 6**).

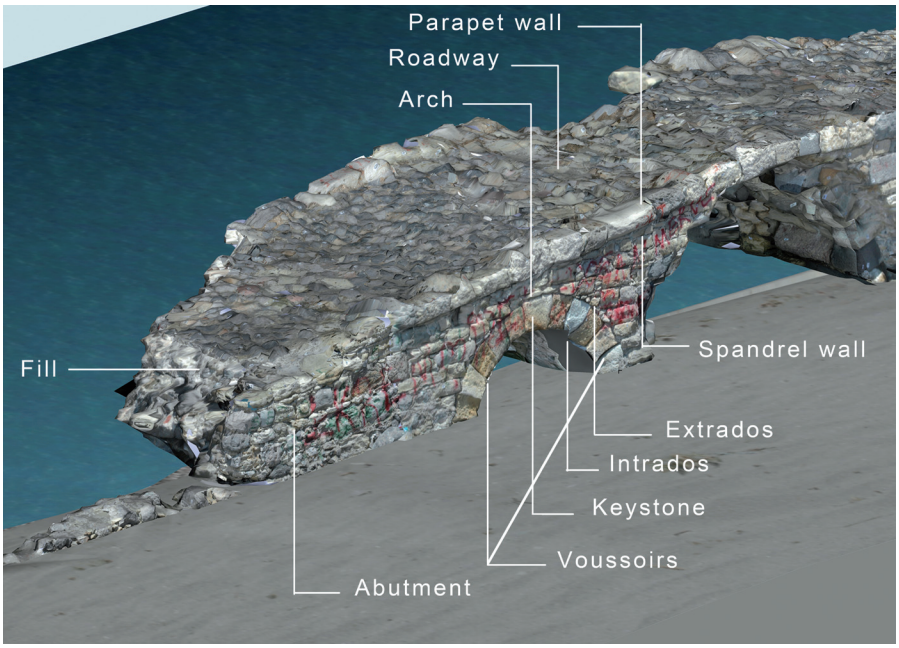

Figure 5. Elements of the Hypokremnos Bridge, axonometric view from the 3D survey model

Figure 6. Piers of the Hypokremnos Bridge, view from the north

Abutments of the bridge are constructed in triple shells; two outer facing shells and an inner filling shell between them (**Figure 5**). Thickness of the abutments is approximately 349 centimeters. Each outer shell is 25 centimeters; the inner filling shell is 299 centimeters. The outer shells are made of rough cut lime stone blocks (36x15, 46x15, 56x15 centimeters) with broad joints (between 0,2 and 0,45 centimeters) whereas rubble stones with different sizes in hydraulic lime mortar are used for the inner shells. The size of rubble stones in the filling get smaller from the outer to the center of the filling shell. Also, there are some small rubble stones connecting outer and inner shells.

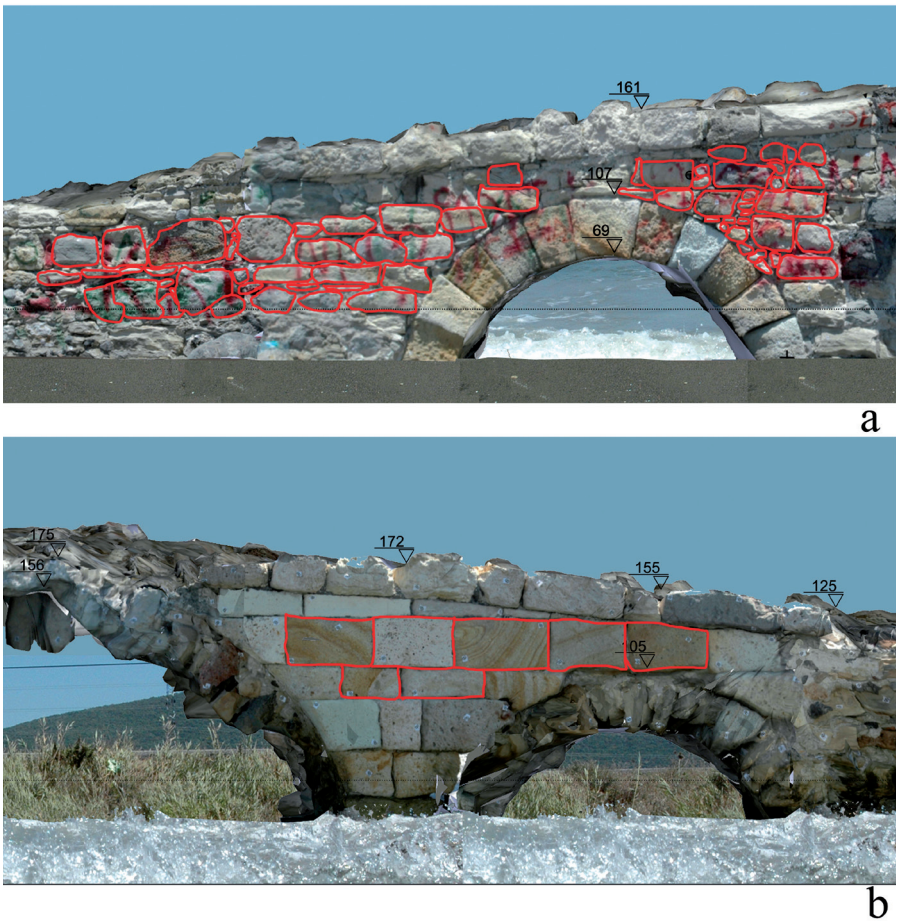

Figure 7. a) Upstream (Southwestern) Façade, b) Downstream (Northeastern) Spandrel walls, orthogonal views from the 3D survey model

Arch: Arches are the spanning elements between piers, or between a pier and an abutment. They are composed of rectangular or wedge shaped stones or bricks called voussoirs. The central voussoir at the top of the arch is called key stone; and it can be larger than others or projecting below or above (McAfee, 1998).

Most of the voussoirs and keystones of three round arches of the bridge are damaged (**Figure 2**). The narrowest among the three round arches is the best preserved one. Its trapezium voussoirs (top part: 30 centimeters, bottom part: 20 centimeters) and the keystone (top part: 46 centimeters, bottom part: 30 centimeters out of cut sand stone) are positioned radially forming close joints without exposition of mortar. The edges making the thickness were provided oblique angles so that mortar could be hidden (**Figure 9**). Clamps and dowels are not observed. White, beige, and yellow colors of the voussoirs and the keystone that do not define a system are interpreted as surface deterioration of sandstone (**Figure 2**). In the cross sections of all three arches, which are extensively damaged with splashing sea water and wind, rubble stones (40x40, 37x40 centimeters) in lime mortar positioned radially are observed.

Spandrel wall: Spandrels are triangular wall pieces between the extrados of arches and the road way (McAfee, 1998). In the case study bridge, the construction technique observed in the abutments is repeated in the spandrel walls. However, the outer shell on the southwestern (coast side) façade can be traced as rough cut lime stones (36x15, 46x15, 56x15

centimeters). Small rubble stones (12-25 centimeters) are seen at the top zone for providing the desired slope. As a second difference, the outer shell on the north eastern (seaside) façade is made of rectangular, close jointed, sand stone blocks (51x32, 54x18 centimeters) (**Figure 7**, **Figure 8**). Their thickness vary between 25-30 centimeters. Cut stones at the top zone have curvilinear edges in accordance with the slope.

Breakwaters: Breakwaters juxtaposing the upstream façade of the piers are constructed to protect the bridge from flood and fast flow rate (Türkiye Karayolları Genel Müdürlüğü, 2008). The case study had breakwaters in front of the southeastern façade, but today these breakwaters are removed. These are observed at an old photograph belongs to 1952's (Stark, 2010).

Architectural elements: Architectural elements of a bridge are parapet wall, belt, roadway, kiosk (*tarih köşkü, seyir köşkü*) and inscription panel (Çulpan, 1975). Parapet wall is a shallow threshold bordering the roadway of a bridge. Belt is a thin projection composed of a single row of stones under the parapet wall. Kiosk is located at the highest part of the bridge as a projecting element. A kiosk either provides information on the history of the bridge through inscription panels (*Tarih Köşkü*) or provides a stop

Figure 8. Differences between the outer shells a) Outer shell on the coastside: Rough cut limestone with broad joints, b) Outer shell on the seaside: Cut sandstone blocks with close joints

for enjoying the vista (*Seyir Köşkü*), (Meriç Bridge, Edirne; Tunca Bridge, Edirne; Babaeski Bridge, Kırklareli), (Tanyeli, 2000).

Architectural elements of the bridge are roadway and parapet (**Figure 5**). Roadway is out of rubble stones (14x17x12 centimeters, 11x12x10 centimeters) bonded to spandrel wall's rubble fill with lime mortar. Parapets are out of cut lime stone blocks on both facades (48x52x25, 37x52x25 centimeters).

CHARACTERISTICS OF ANATOLIAN BRIDGES AND THE CASE STUDY

The elements preferred, how they are composed, their construction technique and material usage present variation in accordance with the characteristics of the site and date of construction. In Roman, Byzantine, Seljuk and Ottoman periods, masonry bridges in linear form supported with one or series of arches was the basic theme of the bridges. Narrow streams of deep valleys were spanned with one arched bridges, while wide rivers with low flow required a series of arches, whose direction could vary in accordance with the stability of the ground (Tanyeli, 2000). If a bridge is composed of a series of same sized arches, it has a flat roadway parallel to the ground, so a bridge of this type has a rectangular façade form. If the middle arch is wide and side ones are narrow, the bridge has a triangular facade.

Roman and Byzantine Bridges were generally rectangular formed, but triangular formed ones were also possible (Tunç, 1978) (**4,5**). However, triangular form is generally basic preference in Seljuk and Ottoman periods (**6**), (Tanyeli, 2000). The case study is a triangular formed bridge (**Figure 2**). So, it can belong to any period according to façade form and organization of arches.

Façade Elements

Piers and abutments and spandrel walls are main structural elements in all periods. Spandrel walls on the same surface with the voussoirs are always used in Roman and Byzantine periods (**7**), while projected spandrel walls are common in Seljukid and Ottoman periods (**8**). The case study bridge has flat spandrel walls, as in the majority of the Roman and Byzantine examples (**Figure 7**). Round arches are generally preferred in Roman and Byzantine bridges (**9**), however depressed and pointed arches are generally preferred in Seljuk and Ottoman bridges (**10**), (İlter, 1978; Tunç, 1978; Tanyeli, 2000). The case study bridge has three round arches, as in Roman and Byzantine examples (**Figure 2**). The keystone is generally distinctive in Roman period (Aizonai Bridge, Çavdarhisar), while in Seljuk and Ottoman Periods, it is not emphasized (Fatih Bridge, Edirne), (Doğangün et al., 2007). In the case study, the preserved keystone at the northwest of the upstream facade is larger than other voussoirs of the arch as in Roman period examples (**Figure 9**).

Flood control arches are generally observed in Seljukid and Ottoman bridges (**11**) (Tunç, 1978; Türkiye Karayolları Genel Müdürlüğü, 2008). The case study bridge does not have flood control arches, as in Roman and Byzantine examples. Relieving arches are common in Seljuk and Ottoman periods, but they are rarely used in Roman period Bridges (Tunç, 1978). There is no relieving arch in the case study bridge, as in Roman examples.

4. Taş Bridge, Seyhan, Adana; Gazimihal (Hamidiye) Bridge, Edirne and Kırkgöz Bridge, Afyon are rectangular formed Roman Bridges, while Aspendos (Belkıs) Bridge, Antalya; Aizonai Bridge, Çavdarhisar and Misis Bridge, Adana have triangular façades (Türkiye Karayolları Genel Müdürlüğü, 2008).

5. Kırkgöz Byzantine Bridge, Afyon has rectangular form, while Çobançeşme Byzantine Bridge, İstanbul has triangular form.

6. Sinanlı Bridge, Alpullu; Fatih Bridge, Edirne.

7. Taş Bridge, Adana; Aspendos Bridge, Antalya; Kırkgöz Bridge, Afyon.

8. Altıgöz Bridge, Afyon; Uzun Bridge, Kırklareli; Meriç Bridge Edirne (Tanyeli, 2000; Türkiye Karayolları Genel Müdürlüğü, 2008).

9. Karaköprü, Diyarbakır; Aizonai Viadut, Çavdarhisar; Tekkeboğazı Bridge, Bergama.

10. Fatih Bridge, Edirne; Sinanlı Bridge, Alpullu; Meriç Bridge, Edirne.

11. Tunca Bridge, Edirne; Fatih Bridge, Edirne; Sinanlı Bridge, Alpullu.

Figure 9. Lime mortar connecting voissours with each other and spanderal wall

Breakwaters are preferred in all periods, if there is a necessity in relation with the stream characteristics. The bridge had breakwaters in front of its piers in the past with regard to a photograph belongs to 1952's (**Figure 11**) (Stark, 2010). So, it can belong to any period.

Architectural Elements

Architectural elements emphasizing entrances were only used in some of Roman Bridges (Cendere Bridge, Kahta) (Tanyeli, 2000). The entrances of the case study bridge are not visible today, because they are ruined and the ground level has rised up. Kiosks were typical elements enriching Ottoman caravan routes. There is no kiosk in the case study. Roadway out of rubble and cut stones is always observed in all periods. The case study bridge's roadway is paved with small rubble stones (**Figure 5**), (**12**). Belts are generally observed in Seljuk and Ottoman Bridges (**13**) (Tunç, 1978). The case study bridge does not have belt stones under its parapet as in Roman and Byzantine cases. Parapets near the two sides of the roadway of the bridges are generally observed. The case study has projected parapet stones above its spandrel wall (**Figure 5**).

Constructional Elements

Roman masonry walls were made of dressed stone with triple shells consisting of rubble laid beds in lime mortar in the inner shell and brought to a finish with a facing of finer material in the outer shells (Ward-Perkins, 1981). Facings of bridges in Roman period were made of close jointed, rectangular, large cut stone blocks (approximately 60, 96 x 121, 92 centimeters) sometimes connected by clamps and dowels (Davey, 1961; Atak, 2008). This technique was known as *opus quadratum.* Although some sources (Grant, 1980) mention the lack of pozzolanic lime mortar in Roman bridges, the opposite has been proven through laboratory studies (Uğurlu Sağın, 2012). In the case study, a similar technique with the distinction of much smaller blocks (51x32, 18x54 centimeters) and lack of clamps and dowels, and pozzolonic lime mortar is used. In Byzantine period, similar techniques with Roman period were continued to be used (Kırkgöz Bridge, Afyon), however, bricks in alternating rows were sometimes preferred and mortar was exposed in the close joints (Tunç, 1978). In Turkish period, facing material was generally smaller cut stone blocks which was either close jointed or mortar was exposed in the joints (Tanyeli, 2000). Small cut stone blocks in alternating rows were sometimes preferred in Seljuk Bridges (**14**) (Tunç, 1978).

12. Roman Bridge; Aizonai, Çavdarhisar, Byzantine Bridge; Çobançeşme, İstanbul, Seljuk Bridge; Altıgöz, Afyon and Ottoman Bridge; Fatih, Edirne.

13. In the study of Tanyeli (2000), Seljuk and Ottoman Bridges; Altıgöz Bridge, Afyon, Uzun Bridge, Kırklareli, Meriç Bridge, Edirne have belts, but Aspendos Bridge, Antalya, Taş Bridge, Seyhan, Adana constructed in Roman period do not have belts.

14. Meriç Bridge, Edirne; Tunca Bridge, Edirne; Babaeski Bridge, Kırklareli; Sinanlı Bridge, Alpullu.

The case study bridge was constructed in triple shells. The outer shells were made of rough stone blocks, whereas smaller rubble stones were used for the inner shells. However, outer shells on the northeastern façade wall (seaside) and southwestern façade wall (coast side) show different characteristics (**Figure 7**). On the north eastern (seaside) façade, the outer shell is made of close jointed sand stone rectangular blocks (39x15x29 centimeters) (**Figure 8**). Deepness of the cut stones vary between 25-30 centimeters. Cut stones at the top level of the spandrel wall are curvilinear so as to form the sloping top edge of the bridge. On the other hand, the outer shell on the southwestern (coast side) façade is made of broad jointed rough cut lime stones (36x15, 46x15 and 56x15 centimeters) (**Figure 8**). Small sized rubble stones and lime mortar are seen in the joints. Construction technique of the bridge shows similar characteristics with Turkish period.

Mortar

Studies involving characterization of material of Anatolian historical bridges are rare. In one study (Uğurlu-Sağın, 2012), mortar characteristics in the rubble core of the walls of a bridge, cistern, water basin and bath in Nysa, Aydin and Aigai, Manisa were considered. In another (Çizer, 2004), mortar characteristics in the rubble stone walls of late fifteenth, early sixteenth century baths in Seferihisar, Urla region were considered. These two studies providing information on mortar characteristics of Roman and Turkish period water structures in the region of the case study were selected for comparison.

The mortar sample from the case study has low density and high porosity. It is made of lime and stone aggregates in the range of 1/2 by weight. Composition analysis of the mortar indicated that the mortar is composed of mainly high amount of CaO (Calcium Oxide) and SiO_2 (Silisium Dioxide). They are composed of calcite, quartz, muscovite, anorthite and albite crystals. Mortar used in Hypokremnos Bridge is hydraulic due to the pozzolonic reaction between fine natural aggregates and lime. Hydraulic lime mortars may be manufactured by mixing lime with natural and artificial fine pozzolanic aggregates. When aggregates are finely crushed, the surface area of the material increases. By mixing lime and these fine aggregates, high surface area of the aggregates enhances the reactivity of pozzolan (Allen, 2003).

- The density and porosity of lime mortars in the case study is approximately 1.5 and 35.5. Lime/aggregate ratio is around 0.62. These values are almost in the same range with those of the lime mortars from the Roman and Ottoman period buildings.
- Chemical analysis of mortar indicated that mortar from Hypokremnos is composed of mainly high amount of CaO (Calcium Oxide) (approximately 47%) and SiO_2 (Silisium Dioxide) (approximately 30%) and low amount of Al2O3, MgO, Na2O, SO3, K2 and FeO. The chemical compositions of binders from Hypokremnos Bridge are similar to the compositions of mortars from Roman period samples mentioned in the above.
- The mortar samples of the case study have good pozzolanicity (7.496) with the help of the pozzolanic stone aggregates. Pozzolanic activity measurement of lime mortars from the case study is similar to above mentioned Roman samples.

- CO_2/H_2O ratio of lime mortar sample from Hypokremnos Bridge is 1.18.

  The mortar sample taken from Hypokremnos has hydraulic character as Roman and Ottoman samples.

- Binders of Roman and Ottoman period lime mortars were found to be composed of mainly calcite, quartz, muscovite and anorthite similar to binders of lime mortars from the case study bridge.

Briefly, the case study has a triangular façade form with series of semicircular arches in different sizes; the middle one is wide and sides are narrow. The keystones are visible in the arches. It has flat spandrel walls and breakwaters in front of the piers. It does not have relieving arches above the main arches and flood control arches. It has projected parapet stones, while it does not have belt under the parapet. It is a masonry structure out of rubble stone infill and cut stone blocks. The mortar sample taken from Hypokremnos Viaduct showed similar features with mortar samples from a few Roman and Ottoman monuments in terms of raw material composition, basic physical, chemical, mineralogical, and hydraulic properties, and pozzolanic activities of aggregates.

According to this comparison, the case study is thought to be a Roman Period Anatolian viaduct according to its physical properties, but its construction techniques are similar to Turkish period (**Table 1**).

Characteristic Features of Bridge	Roman Period	Byzantine Period	Seljuk Period	Ottoman Period
Triangular form	✔	✔	✔	✔
Series of arches in different size	✔	✔	✔	✔
Visible keystone	✔			
Round arches	✔	✔		
Flat spandrel walls	✔	✔		
Without relieving arch	✔			
Without flood control arch	✔			
With breakwaters	✔	✔	✔	✔
Without belt	✔			
Parapet	✔	✔	✔	✔
Outer facing shell: Large cut stone blocks Infill: Rubble stone	✔	✔		
Inner facing shell: Small rough cut stone blocks with rubble stones in the joints			✔	✔
Close jointed (sea facade) Mortar not seen in the joints	✔			
Broad jointed (coast facade) Mortar seen in the joints			✔	✔
Characteristics of the mortar	✔			✔

Table 1. Dating of Hypokremnos Bridge

RECONSTITUTION OF THE CASE STUDY

Three sources were utilized for reconstitution; comparison within the building itself and with other similar bridges and old photographs. 3D measured survey provide data on surfaces of the object. Information on cross section of the bridge was collected from a few damaged parts (**Figure 10**). Removal elements were tried to be find with the help of old photographs. An old photograph belongs to 1952's shows that the case study had breakwaters in front of the southeastern façade (**Figure 11**).

Unobserved parts, especially foundations, were completed with data coming from literature review. Most of this literature is on Roman foundations and some on Ottoman ones. Closed timber piled foundation was generally preferred in Roman and Ottoman bridges in Anatolia to stretch the foundation level below the deep water table (Cowan, 1977; Tanyeli, 2000). Cofferdam was used as a temporary support for construction work supported under water in Roman and Ottoman period (Brown, 2001; Tanyeli, 2000). Construction of a Roman cofferdam consists of three simple phases: A double ring of wooden stakes was driven into the river bed around the planned location of a bridge pier by a manually operated pile driver. Clay was packed into the division between the two circles, and then water was emptied from the enclosed space. After that, timber pile foundations were installed (Brown, 2001).

Vaults and arches were probably constructed with the help of a wooden centering. The centering, which determines the profile the intrados of an arch or vault, remains in place until the arch can stand on its own (Mark, 1993). When the sea level in Hypokremnos decreases, projecting parts (buttresses) at the springing level of the arches can be observed (**Figure 6**). Buttresses were probably supporting wooden centering to protect wood from water. The centering consisted of at least two parallel arches braced by triangulated framing. These arches were made up of short joined timbers and supported planks between timbers. There are pairs of opposing wedges under the wooden centering. The stones were set one by one on the plank from the springing line to the center; latest, keystone was set in place, and construction was completed. First, wedges were removed, the centering drop down a few centimeter, this allowed the voussoirs to wedge themselves into place , then whole centering was driven out (Mark, 1993).

On the basis of this information, first, 2D reconstitution drawing (**Figure 12**) was prepared with gathered data from damaged parts of the bridge, literature review, and an old photograph; then by using 2D drawings as layout, 3D model was constituted. Twelve phases of construction were defined and modeled from bottom to top (**Figure 13**).

1. Construction of wooden cofferdams
2. Emptying of water from the enclosed space (**Figure 14**)
3. Construction of timber piled foundation system (**Figure 14**)
4. Covering timber piles with rubble infill
5. Construction of outer facing shells of piers, abutments and breakwaters (**Figure 15**)
6. Construction of inner filling shell of the piers, abutments and breakwaters (**Figure 15**)
7. Removal of wooden cofferdams
8. Construction of wooden centering (**Figure 16**)
9. Construction of arches and vaults and completion of breakwaters

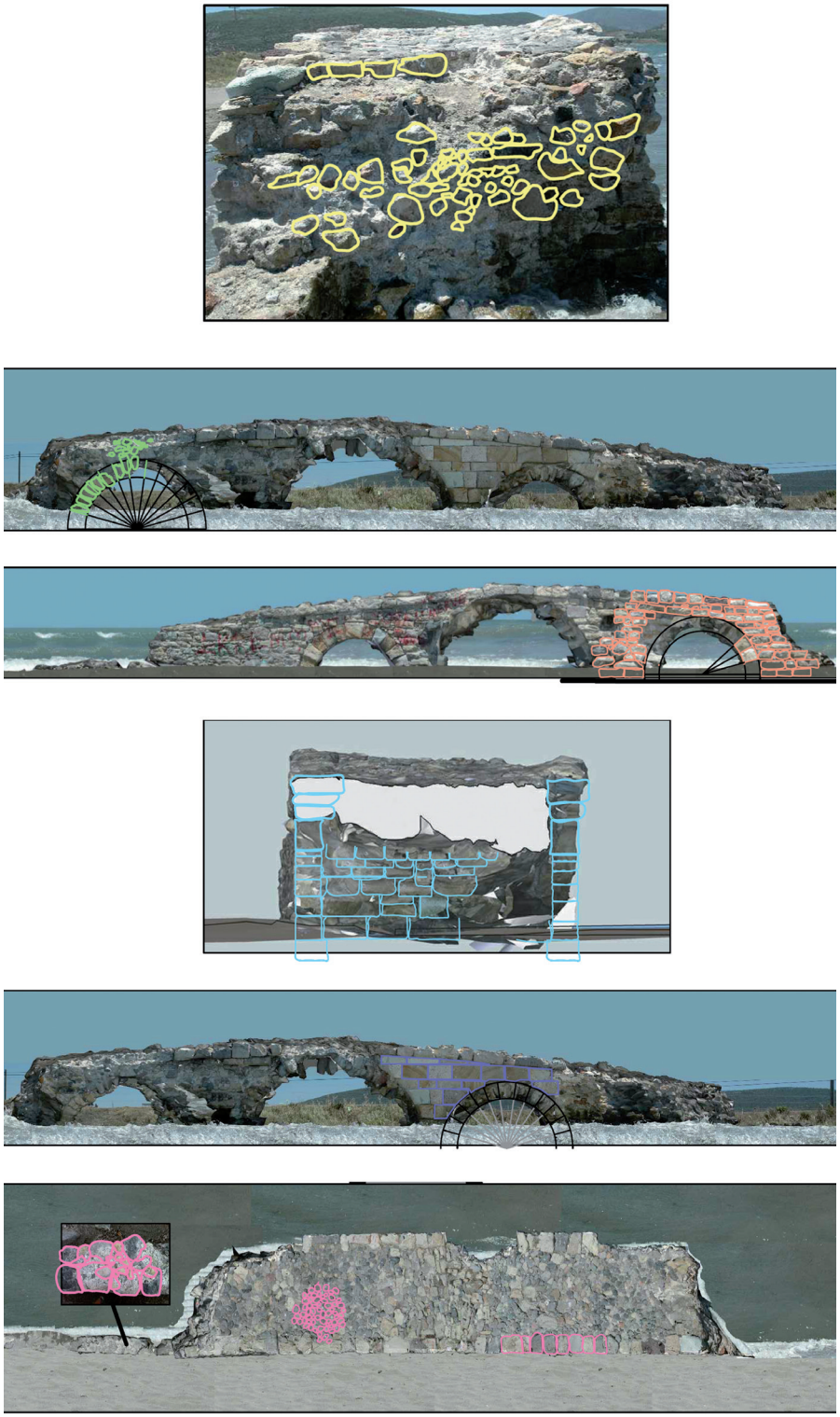

Figure 10. Sources of reconstitution, orthogonal views from the 3D survey model

10. Placing of keystones of arch
11. Construction of inner and outer shells of the spandrel walls
12. Construction of parapet walls and paving of rubble stones (**Figure 17**)

Figure 11. An old photograph of case study bridge having breakwaters juxtaposing its facade (Stark, 2010)

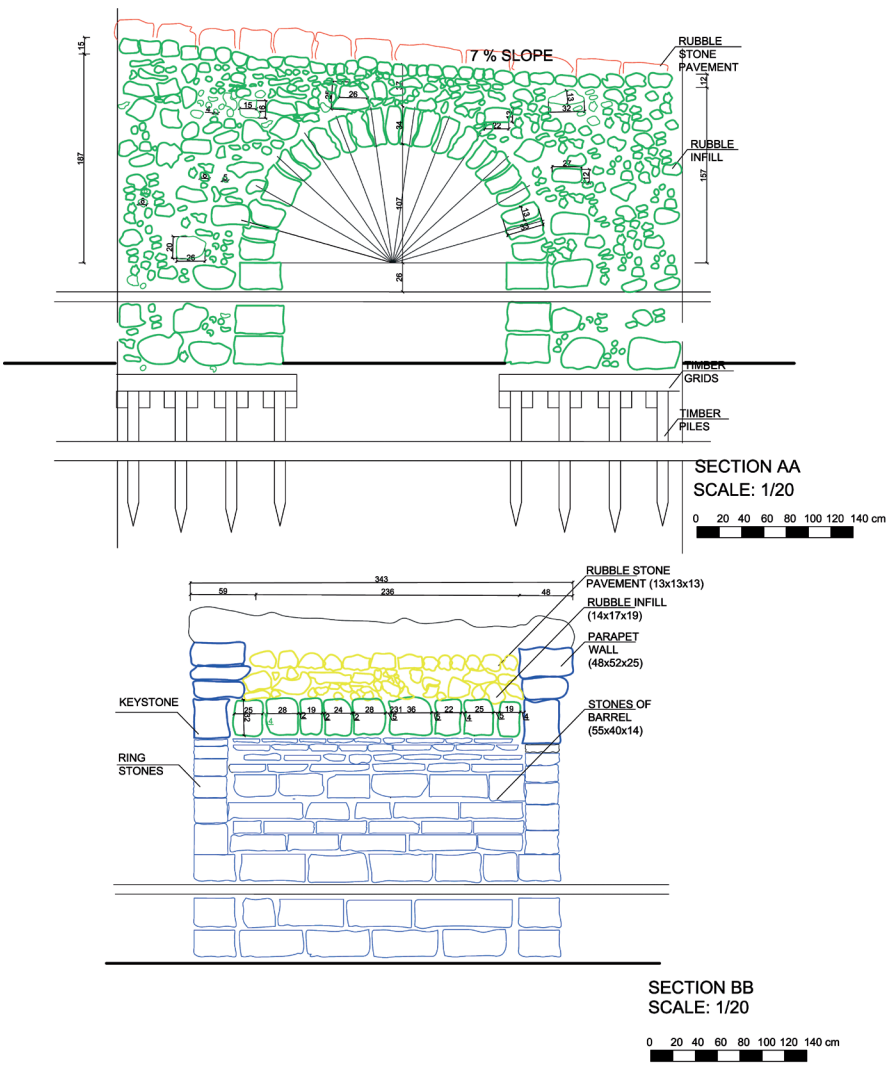

Figure 12. Reconstitution drawings of the structural system, 2D detail drawings

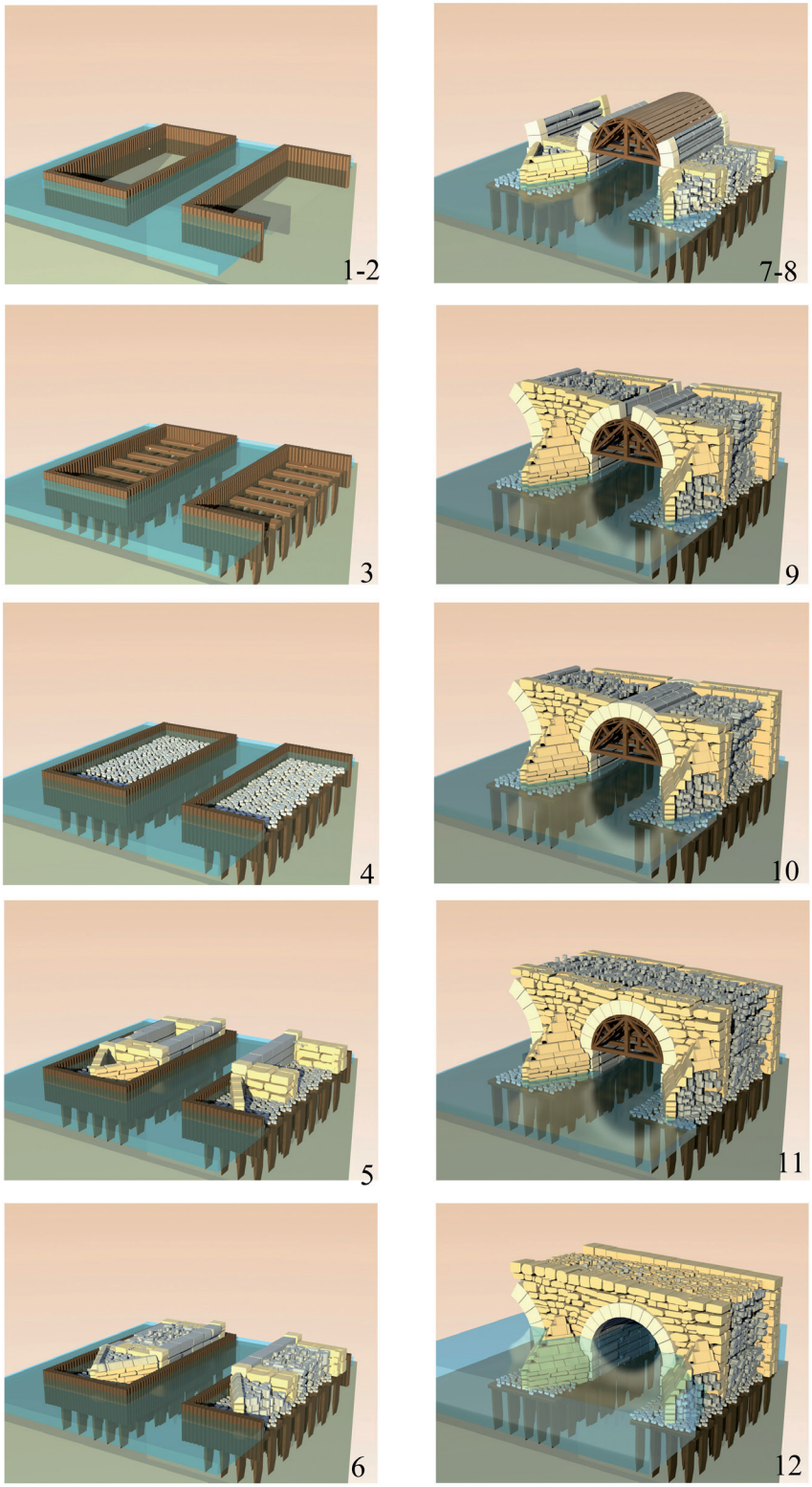

Figure 13. Possible sequence of the original construction; perspective views from the 3D reconstitution model

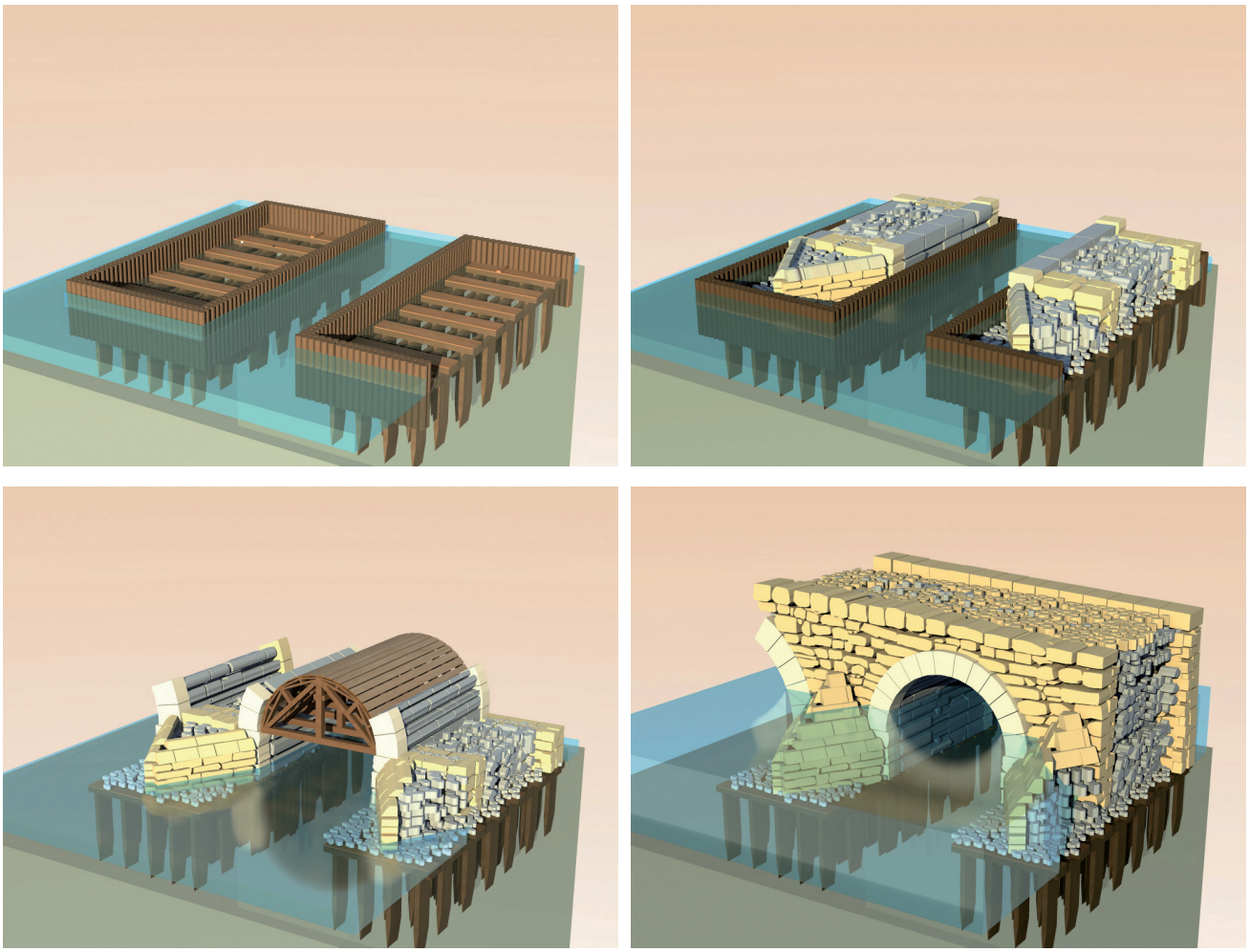

Figure 14. Construction of foundation system; perspective view from the 3D reconstitution model

Figure 15. Construction of masonry wall of the bridge; perspective view from the 3D reconstitution model

Figure 16. Construction of centering of arches; perspective view from the 3D reconstitution model

Figure 17. Perspective view from the 3D reconstitution model

CONCLUSION

The masonry bridge in Hypokremnos (İçmeler) has a triangular façade form with series of round arches in different sizes; the middle one is wide and sides are narrow. The keystones are visible in the arches. It has flat spandrel walls. It does not have relieving arches above main arches and flood control arches, while it has breakwaters in front of the piers. It has projected parapet stones, while it does not have belt under the parapet.

It is a masonry structure made of triple shell, inner rubble lime stone in thick lime mortar and outers rough cut lime stone blocks with broad joints. The finely cut sand stones observed at the sea façade on the faces of the arches are interpreted as repair material. Sizes of large cut stone blocks (39x15 centimeters) on the seaside façade are smaller than cut stones used in Roman period. Mortar used in the bridge is hydraulic due to pozzolanic reaction between fine natural aggregates and lime. Its characteristics present similarities with Roman and Ottoman period water structures in Aegean. Clamps and dowels, or their traces were not observed. The construction process of the bridge was throught to involve construction of woodehn cofferdams, timber piled foundation system and wooden centering.

Elements and composition of the bridge show present features with Roman Bridges, however, masonry techniques and dimensions of the

materials used present similar features with Ottoman Bridges. The history of the Hypokremnos region also shows that there was a trade road since Roman period to Ottoman period. Therefore, the case study may be a Roman period Anatolian Bridge. Nevertheless, there is possibility of comprehensive repair or reconstruction in the Turkish period.

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ABBREVIATIONS

RILEM: Reunion Internationale des Laboratoires D'Essais et de Recherches sur les Materiaux et les Constructions
XRD: X-Ray Diffraction
SEM-EDS: Scanning Electron Microscopy with X-ray microanalysis
TGA: Thermal gravimetric analysis

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Anahtar sözcükler: Tarihi köprüler; yığma yapım teknikleri; Hypokremnos

HYPOKREMNOS'TAKİ (İÇMELER) TARİHİ BİR KÖPRÜNÜN YIĞMA YAPIM TEKNİKLERİ

Bu çalışmada, İzmir, Urla'daki İçmeler sahilinde yer alan tarihi bir köprü ele alınmıştır. İzmir'in batısında konumlanan, tarihi bir yerleşim olan Urla, Karaburun ve Çeşme Yarımadalar'ı ve Anadolu anakarası arasında önemli bir geçiş noktası oluşturmaktadır. Köprünün yapım özelliklerinin ve malzeme kullanımının anlaşılması ve yapım sürecinde izlenen olası sıranın ortaya konulması amaçlanmıştır. Çizgisel planlı köprü yığma sistemle inşa edilmiştir. Köprü, ortada büyük, güneybatıda orta ve kuzeydoğuda küçük olmak üzere, üç farklı boyutta dairesel kemerden oluşmakta olup, kenarlara doğru alçalan üçgen bir cepheye sahiptir.

Çalışma; belgeleme, yapım tekniği ve malzeme kullanımı analizi, tarihi değerlendirme ve restitüsyon olmak üzere dört aşamada gerçekleştirilmiştir. İlk aşamada Tgi3D Su Photoscan 2.13 ve Trimble SketchUp 2013 yazılımları kullanılarak manuel fotogrametrik belgeleme yöntemi ile, yapının üç boyutlu rölöve modeli elde edilmiştir. İkinci aşamada, köprünün yapım tekniği ve malzeme kullanımının görsel analizi yapılmış; alınan harç örneği malzeme koruma laboratuvarında incelenmiştir.

Üç boyutlu manuel fotogrametrik belgeleme yöntemi yapının yapısal detaylarının elde edilmesinde avantaj sağlamıştır. Gözlemler sonucu elde edilen yapısal özellikler dikkate alınarak, köprü, cephe kompozisyonu, mimari elemanları, strüktürel elemanları ve yapım tekniği ve malzeme kullanımı açısından Roma, Bizans, Selçuk ve Osmanlı Dönemleri'nde inşa edilmiş Anadolu köprüleri ile karşılaştırılmıştır. Köprünün farklı noktalarından toplanan detay bilgileri, konvansiyonel teknikte sistem detayı rekonstitüsyonunun üretilmesi için kullanılmıştır. Rekonstitüsyon modelinin üretiminde sistem detayından yararlanılmıştır. Ayrıca, köprünün yapım aşamalarının belirlenebilmesi için literatür araştırması yapılmıştır.

Köprünün elemanları ve kompozisyonu dikkate alındığında, Roma döneminde inşa edildiği düşünülmektedir, öte yandan gerek köprü duvarının dış kabuğunu oluşturan kabayonu kireç taşlarının biraraya gelişindeki gelişi güzellik, gerekse kemer yüzlerindeki ve deniz cephesindeki kesme kum taşlarının biçim ve rengindeki sistemsizlik, köprünün Türk döneminde kapsamlı tamir gördüğünü ya da tümüyle yeniden yapıldığını düşündürmektedir.

THE MASONRY TECHNIQUES OF A HISTORICAL BRIDGE IN HYPOKREMNOS (İÇMELER)

This study focuses on characteristics of a historical bridge in İçmeler, Urla, İzmir. Urla, a historical settlement on the west of İzmir, has been part of a commercial network between Karaburun, Çeşme and Anatolia throughout history. The aim is to understand the construction technique and material usage in Hypokremnos Bridge and identify a possible sequence of the original construction. The linear bridge was constructed by using masonry technique. It has three openings with various sizes and supported with rounded arches. The bridge wall is crowned with a road way making a crest at its center a inclined façade.

This study is composed of four phases; documentation, analysis of construction technique and material usage, historical evaluation and

restitution. In the first phase, by using Tgi3D Su Photoscan 2.13 and Trimble SketchUp 2013 software, three dimensional model was prepared. Visual analysis of construction technique and material usage was carried out and the mortar sample from the bridge was investigated in the conservation laboratory in the second phase.

Three dimensional manual photogrammetric documentation of the historical bridge has provided the advantage of conceiving many constructional details. This condensed observation of constructional features supported with comparative study on historical bridges in Anatolia has revealed that the elements and composition of the studied bridge presents Roman characteristics, but the masonry techniques used recall those of Turkish period. The detailed data about structural system gathered from different locations of the bridge was used for the production of reconstitution of system detail. Reconstitution model of the bridge was produced by using reconstitution of system detail. To identify construction phases of the bridge, literature survey was carried out.

According to structural elements and composition of the bridge, it is thought to be constructred in Roman Period, however, both the randomness in the composition of the rough cut lime stones used in the outer shells of the bridge wall, and lack of system in the form and color composition of the cut sand stones in the arches and the sea façade may be interpreted as an end result of a comprehensive repair on total reconstruction in the Turkish period.

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