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Design Characteristics and Constructional Techniques of a Byzantine Cistern in Istanbul

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ABSTRACT: Cisterns which are underground masonry reservoirs have played an important role in providing water for Istanbul during the Byzantine period. As well as any other initially constructed cisterns in the city, basements of some structures and churches were converted into cisterns and used for collecting water. Most cisterns which became obsolete with the Ottoman period have survived up today like an empty, dark basement left under new floors, by lacking an exact inventory. One of these found during the restoration of the Cibali Cigarette and Tobacco Factory which converted into the Kadir Has University. In present paper, all of design features, construction techniques and materials usage, also their names, their originality (which could be unknown), their measurements and observations, will be found. Also an attempt to determine its date and place in Byzantine architecture has been made.

1 INTRODUCTION

Need for water in Istanbul has always been a serious problem all the way back to Byzantium, which believed that have been founded in the 7th century B.C. In this city which housed a large population and since pre-historical times constantly defended itself regarding to its geopolitical location and resources, one of the primary means for carrying water from sources close to the city, collecting this water and providing secure and economical usage for it has been water cisterns.

Besides their main purpose of collecting water, cisterns have provided a formulation for terraces, which are suitable for movement, both up and down over the inclined lands of Istanbul. They have made the buildings which erected above them look higher and more imposing. Additionally, since they have many columns carrying the platforms formed by their homogeneous coverings, thought they receive and stabilize tremors with this system and protect their structure against an earthquake (Müller-Wiener 1977).

In Istanbul during the Late Roman period, water brought from Thrace by means of water canals or aqueducts which were collected in very large open-air reservoirs or cisterns. The reservoirs were mainly a "primary-pool" from which distributed water to the city; the cisterns were used to directly supply the structure they were beneath or in a connected position (Eyice 1994). In the early Byzantine age when Roman facilities were continued to be used, Ioannes Malalas, a 6th century chronicler wrote that "it seems that the city is over pillars" as an image to emphasize the importance of Constantinople's cisterns (Çeçen 1994). Some scholars have proposed that 10 litres of water per day for one year could be provided to every resident in the city based on the hypothesis that 800.000m^3 of water was collected in Aetius, Aspar and Mokios; the three large open pools of the 6th century and 200.000m^3 were collected in the other covered cisterns, giving a total of 1.000.000m^3 of water (Çeçen 1994).

Since the 7th century, the Roman facilities outside the city walls were the primary target for attacking from the west; the aqueducts, transfer stations and other units in the open land were destroyed in order to leave the city in lack of water and thus weaken it. As a result, the city was forced to abandon the method of carrying water into Byzantine Istanbul from outside of it as well as use of their other old facilities. In this period when the Roman system was left out of use, the importance and number of cisterns in Constantinople increasingly grew and they became the only solution to water supply except for a few small sources in the city.

After the conquest of Istanbul by the Ottomans, this system which collected water was used for abandoning and transforming clean water from sources outside of city and adopting once more. Consequently the Byzantine cisterns become redundant again, during Turkish period. Most were converted into dark and damp cellars, which were not very favourable for this usage. They were used as depots by quilt-makers and thread-makers. Sometimes, when a new building was to be erected, they were put to good use like an existing basement. Because they were thus 'left' under Ottoman buildings, they survived till now, and they have unknown existence.

Until today, the places of 71 examples used as covered cisterns in Istanbul have been founded (Müller-Wiener 1977). Some of these have been conserved and we can still admire their architecture (for example the Yerebatan and Binbirdirek Cisterns of the 6th century). Unfortunately some of them have been hidden or thought as unimportant ruins which are occupying a convenient construction site, and have tried to be demolished without sufficient analysis and documentation. However on the other hand –with research on architectural history and developing heritage awareness- the ground below Istanbul is now being studied more carefully and some previously unpublished covered cisterns are being encountered. Regarding to this, there is no definite city inventory and lots of the known cisterns keeps growing as well as town planning and conservation applications progress.

The cistern we have had the opportunity of entering during the restoration of the Cibali Cigarette and Tobacco Factory in Unkapanı is such an example. It was initially a tobacco depot, then during the years of the World War II a provisions storehouse and in 1950 was documented by photographs taken by staff of Istanbul Archaeology Museums. However it remained closed-off without a detailed study until 1995. Not any information was given except its place being marked on Müller-Wiener's map and not any reports or article prepared by the Museum staff has been published.

Cisterns are usually named after their original name in the Byzantine period (Floksenus Cistern) and structures above/beside them (Brias Palace Cistern, Pantepoptes Monastery Cistern) or attributions related to their architectural features (Binbirdirek Cistern). Those examples of which are not known as historic sources belong to their defined neighbourhood or their located street (the Cistern in Nişanca, the Cistern in Mercan Hill). For this reason, the structural interest shall be called the "Cibali Cistern" throughout the paper due to its relation to the Cibali neighbourhood and the tobacco factory of the same name.

2 THE CIBALI CIGARETTE AND TOBACCO FACTORY / KADIR HAS UNIVERSITY

At the end of the 19th century, when a new Istanbul silhouette emphasized by large-size structures formed, the shores of the Golden Horn was also starting to be used for industrial goals and at its south-eastern end in the Unkapanı neighbourhood, a large factory –for processing tobacco- was constructed.

The factory opened in 1884 when the tobacco monopoly was passed onto the company named "Reji İdaresi" switched to manufacturing cigarettes after 1900. The corporation which had 40.000m^2 of closed area over a land measuring 10.385m^2 was affiliated to the Turkish Monopoly Administration as the "Cibali Cigarette and Tobacco Factory" in 1925 and continued its function until the end of the 20th century. However during the period of its usage, its original spatial organization was lost regarding to various maintenance, repair and additions made out of necessity and its production was halted and the structure was emptied out in the process of privatization and liquidation of some factories affiliated to the Monopoly Head Office.

After transporting inside machines, this question aroused that, what this industrial facility would do? It is clear that the factory's place in the Golden Horn's silhouette. Its dimensional grandeur which symbolises the urban transformation at the end of the 19th century, its socio-economic effects on its surroundings, and actually being workers living places, are features for appreciating and conserving the structure as "Industrial Archaeology". Due to this, it was decided to restore the structural and functional goals as a university and the implementation began. The restoration of the Cibali Cigarette and Tobacco Factory, which now is using as the central campus of Kadir Has University, also included ruins conservation of a 16th century which is a Turkish bath below the Faculty of Fine Arts (C Block) and the "Cibali Cistern" under the car park. The conversion of these areas into the "Rezan Has Golden Horn Cultures Museum" has also begun.

3 THE CIBALI CISTERN

This cistern is in the shape of approximately square rectangle and is divided into 48 (8x6) domed units by 7 axes parallel to the north eastern-south western axis and 5 axes perpendicular to them , see Fig.1. The area of the site is 585m^2 and its dimensions are 21.85x27.10m in average. The corners of the rectangle have been cut and chamfered with oblique lines -all four having different angles-. Regarding to this, corner lengths approximately are shorter than thickness' and they are not equal to each other (south eastern-north western walls are 18.67-16.92; north eastern-south eastern walls are 24.56-23.74m. Corner chamfers from P1 to P4 are 2.68, 1.94, 2.20+1.12, 2.20cm) in west corner, because of making a difference, chamfers are looking a little bit softer and circular. Distinct from the others, at the western corner the two intersecting lines and the chamfer are softened. Most of the irregularities in dimensions must be regarding to application errors during construction; the slant in the south-eastern wall must be because of the structuring in the surroundings and the road directions.

The site is accessed from the south-east, by a ramp beginning from the basement of the C Block building at Kadir Has University. The entrance with a staircase on the northern end of the north-western wall, which is thought to be original, is not a useful staircase today. This entrance opens to the street with an arched door at the end of the landing is positioned.

The level (on which we still walk) of the space is nearly 2.20m below street level. This level formed by rubble filling on the original floor, is a mud heap which prevents a person from walking freely inside the cistern. According to the measurements of three exploratory holes opened to determine, the thickness of the filling, the original floor is 2.95m below the level of the Springer of the arches.

In the cistern which is divided into four main sections parallel to the shorter side of the rectangle by three rows of pillars, every section is divided again into two by a row of columns. First are columns and the second some pillars which have been placed successively on the intersection points of the horizontal and vertical axes, beginning from the southeastern and northwestern walls. The pillars which have larger sections than the column shafts define clearly the above mentioned main spaces. On the other hand, because of the column series on the long axis of the spaces and the domed units continuing homogeneously in the space, this layout with four naves becomes unclear.

There are 15 pillars and 20 columns in total in the cistern. The pillars are connected to each other and the columns joined by arches-together with the wall added to the main section from four directions- and form a cruciform shape. The intersection of the wall and pillar shaft has been softened with quarter circle sectioned infill, so niches with semi-circular plans similar to exedras are formed in the directions facing the rows of columns. This formation of the pillars reflects loyalty to the tradition of making inner corners of cisterns curvilinear (Eyice 1994).

As it is known, in cisterns or fountain reservoirs, because of the precaution of stored water pressure water escaping from these spaces, so joining the walls in right angles was strongly avoided. The corners were made curvilinear during the stage of covering the inner surfaces are covered with waterproof plaster. In this way, the thickness of the plaster layer is increased in the critical regions and -even if the walls did open- a filling would be exist and that would prevent water from reaching the cracks. However this method is only sufficient for small examples.

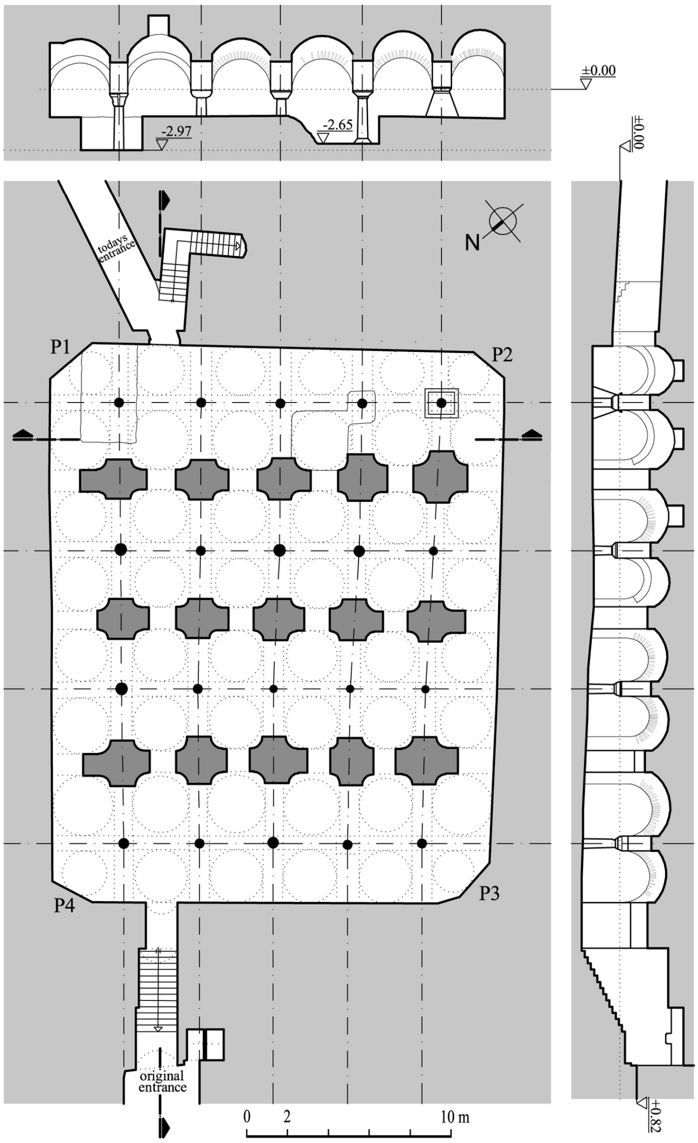

Figure 1: Plan and sections of the Cibali Cistern

In cisterns of large capacity, the priority belongs to obtain a right-angle which joins and making corners with obtuse angles which taken as a "design principle" and so the outer walls had corner chamfers. In other words, to have chamfered edges in the inner corners of underground reservoirs, rather than rounding them with plaster, the structure was initially designed to store water and was not one of the instances where a basement was later converted into a cistern.

According to this information, it can be said that the Cibali cistern is a structure which was designed at the beginning to collect water. The curvilinear plasters on the pillar corners show that it is an important example on which the final details were applied with care. However no historic record or structural data pointing to a structure (which has not survived) built over it in the Byzantine period has been found.

The Gül Mosque at the north of the cistern and Zeyrek Mosque at its south-west were two ends of the Armatiu (known as Platea in Late Byzantine and Unkapanı in the Ottoman and current times) region known as an important trade area since the Early Byzantine age (Alioğlu and Alper 1998). The land between these religious centres was most probably used as a residential area by people who worked in the port and trade business. Zeyrek Mosque is the church of the Pantocrator Monastery with comprehensive structures and has a large surviving reservoir called the "Pantocrator Cistern" which feeds the structures of the complex. In contrast the date and commissioner of Gül Mosque is not accurately known; the basement below it was used as a depot serving the port and was not a cistern. Thus it can be said that the Cibali Cistern (considering its proximity) was constructed to serve the Gül Mosque and commercial buildings in that area from the axis connecting the church and the cistern to the shores of the Golden Horn.

4 DESIGN AND CONSTRUCTION TECHNIQUE OF THE CIBALI CISTERN

4.1 Layout of the load bearing system and dimensioning features of the load bearing axes

In the Cibali Cistern, a traditional system consisted of vertical load bearers placed in an order of a row of columns-a row of pillars, and arches connecting them to each other and the walls. The space formed by the outer walls is divided into square-like units and every unit is covered by a dome. When the unit dimensions are analysed, it is seen that they are all different and that their areas are not (except one unit at the north western wall) exact suitable squares for dome construction. Since this condition stems from varied arch thickness, we will give the lengths before the units (Look at Table 1 & Table 2).

Table 1 : Arches thickness of north eastern walls, according to their parallel series (cm)

1st columns' axe* arches	1st pillars axe* arches	2nd columns' axe* arches	2nd pillars axe* arches	3rd columns' axe* arches	3rd pillars axe* arches	4th column axe* arches
77	107	76	88	80	107	74
74	97	72	107	73	108	65
76	103	77	110	70	114	65
76	99	77	108	72	121	65
76	128	71	97	70	126	71
76	127	72	108	68	129	71

* The numbers of axes are beginning from south eastern wall.

Perpendicular to these elements, the arches which are connected to a column on one end and a pillar or the outer wall on the other end, form the second large group and their thicknesses (mostly between 85-100cm) is chosen to be equal to the long side of the column capital. The arches which are the least thick are those which connect the columns to one another and at the last axes, to the outer walls. These generally measure 65-75cm and are dimensioned according to the short side of the column capitals.

Table 2 : Arches thickness of south eastern walls, according to their parallel series (cm)

1st axe* arches	2nd axe* arches	3rd axe* arches	4th axe* arches	5th axe* arches
80	102	105	99	81
88	100	93	98	91
90	105	104	105	84
90	105	105	87	96
104	102	97	100	81
103	95	101	102	97
90	90	90	96	96
94	97	97	90	99

* The numbers of axes are beginning from north eastern wall.

The wall protrusions due to the pillars and the inconsistency in the arch thicknesses have caused variations in the dimensions of the domed units. In Table 3, it is shown that the shortest length (211cm) is in the 6th unit of the 1st row and the longest (307cm) is in the 2nd unit of the 2nd row, and most of the lengths are in the range of 260-290cm. Despite their position which are unlike squares with differences of 72, 65, 65cm in their lengths, in most of units the difference in side lengths is around 15-30cm. In 13 units the difference is less than 15cm and very close to squares. However, in the end it is seen that during the construction it was not possible to make them equal to each other or at least exact squares within themselves. The axis system was formed after the surrounding walls were erected, and the application of the axis of symmetry passing through the rectangular sides must have been faulty. When the variation in column diameters and capital sizes are added on top of this, the geometry of the units is disrupted and the domes diverge from their ideal shapes and take on random / elliptical forms.

Table 3 : Dimensions of the domed units in the order parallel to the north eastern wall (cm)

After the south-eastern wall	1st Unit	2nd Unit	3rd Unit	4th Unit	5th Unit	6th Unit
1st row	302x252	305x246	286x238	289x228	291x219**	272x211
2nd row	296x289	307x288	298x285	298x290	291x268	260x267
3rd row	303x244	292x260	282x255	283x253	281x253	280x254
4th row	296x265	292x244	282x241	282x246	282x261	277x257
5th row	291x253	270x256	269x252	278x248	285x246	306x241
6th row	289x276	276x266	271x255	274x255	269x254	296x250
7th row	304x293	276x310	282x315	274x307	260x302	295x303
8th row	303x250	275x258	262x260*	283x261	257x257*	282x257

* Units which can be taken as exact squares
** Unit with the most difference (72cm) in dimension

4.2 Walls

From the area at the intersection of the chamfer at the southern corner and the southern wall where the plaster has fallen off, it could be said that the surrounding walls were built in an alternating system of 2 rows brick-1 row stone. However, it is noticeable that the stone and brick rows in the main wall and chamfer do not match. The counterpart of the 2 rows of brick in the chamfer can be 3 or 4in the wall; in a row of stone which should continue steadily, bricks can be found in some places (which are of random shape and understood to be used to fill the space of a stone).

The stones are 18-25cm, the bricks 4-5cm (most of them being 4cm) and the joints 3, 5-5cm tall. When repeating dimensions are being analysed, it could be said that the joint height is determined to be equal to the brick and is 4cm. The brick widths vary between 22-34cm; since the most common measure is 34cm, it gets clear that some pieces were reduced in size and the dimensions of an original brick used in the walls is 34x34x4cm.

By looking at the horizontal joints of the southern chamfer which are not continuing ones as in the walls and being more systematic and also the different measures of length and angles in the others, it could be understood that during the process of construction, first the main walls were built (with their ends open) and after that the corners were joined. Since the application was not done (by determining the start and finish points of the walls accurately) well enough at this stage, the angles of the chamfers built hater must also have changed. However it has been determined that a more careful application was conducted on the chamfer walls, as if to show the importance given to the static safety of the corners.

4.3 Columns and column capitals

Heights of 20 marble columns (19 circular, and one octagonal shaft) in Cibali Cistern has, because of the infill on the floor, not been measured; however from the instances in which exploratory holes were opened, it is understood that they are nearly 2.60m. Once more because of the infill, we do not know if all have bases and the dimensions of their lower diameter or not. The upper diameters under the capital are different in each column and vary between 26-55cm; this shows that the columns were not made especially for the Cibali Cistern but probably brought from other structures. Similarly, the capitals must also be collected.

All the capitals are of rectangular plan, the dimensions at the place where the arch sits is 65-86 (the most common value being around 70cm) x 90-113 (the most common value being around 100cm) and their heights are between 25-62cm (the most common value being 35-40cm). The capitals have been placed with their long sides in a line with parallel axes to the short side of the cistern; this has caused arch chords connecting the columns to decrease.

The capitals are decorated very roughly and are in Byzantine style. There are types with two identical faces and those with the same ornamental characteristic on four sides.

4.4 Arches

In the construction of the arches which are semi-circular shape and generally have a thickness of two rows of brick, two different types of brick have been used. One those which are thicker and randomly cut brick piece placed between the front and rear faces and desired dimension is achieved.

Among the most frequently recurring maximum values (the smaller dimensions must have arisen from one full brick being cut into pieces), the first type brick dimension is 38x38x5 cm, the second type is 34x34x4cm. These two types (1 large-1 small in alternating order and with a joint spacing of 3.5 -5.5cm) are found together in the arch bond; however the smaller ones are 4cm behind the outer faces of the larger ones.

In the areas where the jointing mortar has not fallen off, the bricks are 4,5cm the joints are 10-16 cm thick. The joints are made to be 1-3cm (2cm in average) behind the surface of the brick, in other words the "weighed down joints" method is used. In this way, the surfaces of the bricks which are 4cm behind the large ones are covered with a mortar 2cm thick; the thickness of the weighed down joints seems nearly three times the brick. This bonding technique called "hidden brick" is significant for the dating of the structure.

The hidden brick technique is a feature with a certainty which, unlike other wall bonds used in Byzantium, allows us to dating structures within period of 100 years (Kahya 1997). This bond of which the most typical examples are seen in Istanbul was used from the mid-11th century to the late 12th century and was especially widely applied in the 12th century.

It has been mentioned above that the Gül Mosque, that its date is unknown but is assumed to be from this period (Freely and Çakmak 2005) may have a functional link to the Cibali Cistern. In addition, when we consider the existence of the hidden brick technique, we can propose that the cistern was constructed in a period from the mid-11th century to the late 12th century.

4.5 Domes

Although covered space is not an exact square but a rectangle, the domes have not been constructed as ideal semi-spheres. For this reason, to use the term dome is not very accurate, it can be said that they are actually vaults.

The irregular elliptical forms of the vaults in the shape of a dome are figured by lining up the bricks in a spiral, beginning with the springier of the arches. Mortal infill has been made around the bricks placed in a cross shape forming a keystone which we have not encountered in any other Byzantine structure.

We have found the third type of brick dimension in the structure in the bond. These are more delicate than those used in the wall and arches, and their most common dimensions are 28x28x3.5cm.

4.5.1 Plasters

The walls and pillars are plastered 30-40cm up to the top from the springer level of the arch. The thickness of the plaster is not definitely known but from the peeled off areas in the south, we understand that it is as thick as to reach 10cm in places. It is seen that the main material except from the binder is brick shards and dust; it is a brick dust mortar strong enough to be waterproof. However since the restoration of the structure has not yet begun, it has not been possible to take samples and determine their exact content by laboratory analyses.

5 CONCLUSIONS

The covered cisterns in Istanbul have some common features in terms of planning principles, usage of materials and constructional techniques. According to characteristics of their plans, they are separated into types such as "single unit", "supported single unit", "supported double unit", "supported triple unit", "multiple support" in literature (Tezcan 1989). An example which analysed is among their multiple support types and can be considered one of the large cisterns of the city.

Nearly in all the cisterns, the floor is covered with bricks and the walls are plastered with thick, pink, waterproof brick dust mortar containing thin brick shards. Even if it has not been possible to define the original floor covering of the Cibali cistern at this stage, it can be assumed to be of similar character.

Covered cisterns are constructed with chamfers -to prevent leaks from the corners- or plastered curvilinear and for easy access, a ladder is placed adjacent to one of the walls. It is seen that the columns and capitals are generally spolia taken from older structures. The columns and pillars are connected to one another with arches and their covering is in the shape of vaults with brick bond. Actually all the coverings are domed vaults, cross-ribbed vaults and in rare instances, barrel vaults. Beside the marble columns carrying the vaulting there are mostly roughly executed composite or ionic marble capitals. On top of these and under the abutment of the arch, an impost capital has been placed (Tezcan 1989).

The Cibali Cistern with its architecture consistent with these defined features and its suggested construction date (mid-11th century-late 12th century) based on the existence of the “hidden brick technique”, can be accepted as an important example of Byzantine cisterns in Istanbul.

REFERENCES

Alioglu, F. and Alper,B. 1998.Cibali tütün ve sigara fabrikası - sanayi yapısından üniversiteye. *İstanbul* 27, p. 40-48.

Çeçen, K. 1994. Roma suyolları, *Dünden bugüne Istanbul ansiklopedisi,* volume6,p. 340-343. Istanbul: Türkiye Ekonomik ve Toplumsal Tarih Vakfı.

Eyice, S. 1994. Sarnıçlar, *Dünden bugüne Istanbul ansiklopedisi,*volume 6 , p. 469-472. Istanbul: Türkiye Ekonomik ve Toplumsal Tarih Vakfı.

Freely,J.and Çakmak, A.S. 2005. *Istanbul'un Bizans anıtları.* Istanbul: Yapı Kredi Yayınları.

Kahya, Y. 1997. Gizli tuğla tekniği, *Eczacıbaşı sanat ansiklopedisi,*volume 2 , p. 684-685. Istanbul: Yapı-Endüstri Merkezi.

Müller-Wiener,W. 1977. *Bildlexikon zur Topographie İstanbuls.* Tübingen: Verlag Ernst Wasmuth.

Tezcan, H. 1989. *Topkapı Sarayı ve çevresinin Bizans devri arkeolojisi*. Istanbul: Türkiye Turing ve Otomobil Kurumu.