T.C.
SELÇUK ÜNİVERSİTESİ
SELÇUKLU ARAŞTIRMALARI MERKEZİ

I.ULUSLAR ARASI SELÇUKLU KÜLTÜR

VE MEDENİYETİ KONGRESİ

BİLDİRİLER

I.CİLT

KONYA/TÜRKİYE-2001

THE STAIR SYSTEM USED IN ANATOLIAN MINARETS OF XII.-XIII. CENTURIES

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1. INTRODUCTION

Before Anatolia became an Islamic land, minarets, which are the unavoidable elements of city silhouettes and crown mosques in Islamic countries, come out as thick and dumpy towers without foundation. Anatolian Minarets of XII.-XIII. Centuries most of which belong to Anatolian Seljuks, are more slender in comparison with the minarets of Karahanlı, Gazneli and the Great Seljuks. Also they possess the cross-section at the transformation of Ottoman Minarets which represent the final stage of Classical Turkish Minarets. For this reason, Anatolian Minarets of XII.-XIII. Centuries was chosen as the research topic; and in order to restrict the study, it was decided to examine the minarets in terms of only their stair systems. In the studies carried out on minarets until today, minaret has been examined, according to only its external appearance and its position in the building; and expect a few works the stair systems of minarets was not dealt with in detail. Since the stair is the main and the most important building element and composes the most part of a minaret, it must be considered as inseparable part of minarets.

In Anatolia, these are 34 minarets survived from XII.-XIII. Centuries and also whose stair systems can be scrutinised. 31 minarets of them were studied in site by surveying (including photographs) and 3 of them were also added to the study by investigating literature.[1] In order to explain the development of stair systems of the minarets, their plans, materials, and step formation are used. Stair systems are examined in three stages: Design, construction, static.

2. DESIGN

The design of minaret stairs is examined under three headings: Stair elements, construction, form and structure.

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[1] M.E. BAŞAR; **12.-13. Yüzyıl Anadolu Minareleri**, Yayınlanmamış Doktora Tezi, Konya, 1997.

2.1. Stair Elements

2.1.1. The Steps

In most of the stairs of Anatolian Minarets of XII.–XIII. Centuries, the steps rising by spinning in helicoidal form were used. The stone steps found rarely were built with stone of one piece. The stair was formed by putting the steps one on top of the other. The ends of the steps are placed into the internal core and external case. In order to provide the steps rigidity, the middle of the internal core section in each step is pierced at both sides and these holes are filled with metals of iron and lead. On the external case, the rigidity is also provided with stones by means of metal clamps (Fig. 1).[2]

Most of the stairs of Anatolian Minarets of XII.–XIII. Centuries were built with brick steps; and these steps built with brick laid in mortar as 2-3 rows, finish with a timber plank at the top. At the same time this plank finishes inside the case of other side by passing through the case (**Fig. 2, 3**) (**Photo. 1**).

2.1.2. The Core

The core situated at the centre of the stairs of Anatolian Minarets of XII.–XIII. Centuries, and being generally in a form of cylindrical column, (changes depending on the minaret form). As the core is built with stone, it is the part of the step and its extension. While the step is constructed, at the same time the core begins to form and when the bonding of the steps finishes, then at the centre the core which is in the form of a stone column is to have completed.

Also in the minarets built with brick, the core is formed by continuing the brick bonding of the steps through the core as well. The difference of the brick bonding of the core from that of the steps, the bricks used in the core, are special products providing to form the core diameter designed beforehand (**Photo. 2**).

2.1.3. The Case

In Anatolian Minarets of XII.–XIII. Centuries, in order to protect the stair from the external condition, to develop its static and to provide a secured climb, the wall-shaped case built outside of the stair by bonding with brick or stone material, has square, polygonal and circular plan shape related to the minaret form. On this section of the minaret, whose connection with the core is supplied with steps, there are lancet windows lighting the stair and the doors giving way to the balcony and the roof (**Photo. 3**).

2.2. The Forms of Stairs Plan

The forms of stairs plan are found in three shapes: *square*, *octagon* and *circle*.

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[2] KULAÇ, Ü., 1979, **Untersuchung der Turkischen Minarette aus Naturstein und Ziegeln unter besanderer Berücksichtigung der Wendeltreppenformen und Konstructionen**, (unpublished Ph.D.), Berlin.

KULAÇ, Ü., 1981, "Türk Taş Minarelerinde Döner Merdiven ve Metal Bağlantı ElemanlarınınYatay Yükleri Karşılamadaki İşlevleri, **I. Uluslararası Türk-İslâm Bilim ve Teknoloji Tarihi Kongresi**, İ.T.Ü., s.235-240.

2.2.1. The Stairs with Square Plan

The minarets having square-planned stair which are found especially in the provinces of south-east Anatolian Region, such as Diyarbakır Great Mosque (1155 AD), are built of stone and show the influences of Syria. The cores of these minarets are also in square form. The climb lines of the minarets are in the opposite of clockwise. The cases of the minarets are also in the square form.

2.2.2. The Stairs with Octagon Plan

The stair in the minaret of Urfa Great (Ulu) Mosque built by Zengiler in 1191 or in 1146-1147, is in square plan form. However, the exterior of the minaret case in octagonal form, and the core is again in square form. The climb line is in the opposite of clockwise (**Fig. 4**).

Either the stair plan or the exterior side of the case of the minarets of Kars-Ani Menu Çehr Mosque built in 1125 during Seljukians period, are in octagonal form. The width of the steps varies on the end of the case side changing from 28 cm. to 40 cm., and in the end of the core which is in circular form changing from 10 cm. to 16 cm. The steps are directed in a way nearly tangent to the exterior side of the core (**Fig. 5**).

The minaret of Konya Hatuniye Masjid (which is the name of small mosques) dated to 1230 is in octagonal plan form. However, the plan form of its stair is in circular form and this is the sole brick example for this type (**Fig. 6**).

2.2.3. The Stairs with Circular Plan

The plan forms of 29 minarets of Anatolian Mosques of XII.-XIII. Centuries are circular. Of them, the stairs and the minarets of 21 examples are in circular form, and in 8 example the stairs are in circular form, and the minarets have sliced plan form. The stair steps of these minarets are generally directed to the centre of the core. (However, in some examples of them the steps were built as tangent to the core).

The minarets having circular planned stair and sliced case:

In the first example, the stair plan form of the minarets in Konya Hoca Hasan Masjid dated to the end of XII. C. And to the beginning of XIII. C., is circular. The external side of the case was built in a way that semicircular planned forms project from each for sides of the square body. In the second body of the same minaret the stair plan form is again circular. But the exterior of the case consists of 16 semicircular slices which are arranged as one small and one big alternately (**Fig. 7**).

In the minaret of Konya Sahip Ata Mosque (1258), the stair plan form is again circular. On the case elevation the body is composed of 16 slices which are arranged first three semicircular slices and then followed by one triangle planned projection in the same width alternately (**Fig. 8**).

The stair plan form of the minaret of Sivas Sahip Ata Madrasah is again circular. However, the case is composed of circular and triangle planned slices arranged one after another, and between them wide projecting string courses (**Fig. 9**) (**Photo. 4**).

The stair of the minaret of Antalya Yivli Minare (Grooved Minaret) Mosque is also in circular plan form. The case, at the exterior, consists of 8 big semicircular slices divided by slim rods (**Fig. 10**) (**Photo. 5**).

On the minaret of Erzurum Hatuniye Madrasah these slices are dimensionally kept small. The number of the rods is increased to 16 together with semicircular slices and rods between them (**Fig. 11**) (**Photo. 6**).

3. THE BUILDING TECHNIQUES

3.1. The Material

3.1.1. Stone

In Anatolia, among 34 minarets survived from XII.-XIII. Centuries, 5 minarets were built with stone. Except the minaret of Niğde Alaeddin Mosque (**Photo. 7**), other 4 minarets were influenced by the tradition of Antique Period of stone building. The stair steps of these minarets in the South and South-east Anatolia, which show similar characteristics as formal besides the material, were built with one pieces of stone.

The stone was generally embroidered plainly; when decoration was needed, then stones in different colours were used as on the minaret of Kars-Ani Menu Çehr.

3.1.2. Brick

To the contrary that stone material was found in great deal in Anatolia, and used in the architectural works extensively, most of Anatolian Minarets of XII.-XIII. Centuries were built with brick material. Of these the pedestal section of the minarets of Sivas and Siirt Great Mosques were built with brick. The pedestals of others were, however, built of either entirely stone or stone and brick in half. The stairs of those minarets were built of stone in the pedestal level and of brick in the following sections. These bricks are approximately 15 cm x 15 cm, 22 cm x 22 cm in length and 3 cm – 4 cm in thickness.

Less curved bricks were used on the broad slices seen on the body of the Madrasah Minarets of Konya Sahip Ata Darul-Hadisi (Mosque) and Sivas Sahip Ata. In some cases the curves of these bricks were enlarged, as in the slim slices of the minarets of Erzurum Hatuniye Madrasah. The bricks used in the interior sections of minarets without any process, come out, however, on the minarets elevation as special productions;

Ornamentation with glazed brick studs; as in the masjids of Konya Hatuniye and Alanya Akşebe.

Glazed bricks; as in the Great Mosques of Sivas, Kayseri and Bayburt.

Tile; as in the Great Mosques of Akşehir and in the masjid of Akşehir Güdük (Squat) Minaret

3.2. The Structure

It is possible to examine the structure of Anatolian Minarets of XII.-XIII. Centuries under two main sections. The first is the plan formation of stair, and the second in the formation of stair, and the second in the formation of underneath of stair (**Table 1**). In the stone stairs the steps were constructed as one piece. Their

parts in the centre were given a circular shape. As those steps treated like this are put one onto the other, thus the core are formed by them. During the construction of stair, the exterior side of the step is bedded into the case of the minaret and its bonding with other stones is provided with metal clamps. In the centre, the holes are made in the middle of the circular core at both ends, and then these holes are firstly stuffed with small metal pieces and secondly filled with lead providing rigidity. As a result of these stones connected each other form a pillar (or column), as it can be seen in the minaret stairs of Niğde Alaeddin Mosque (1223) and Ani Menu Çehr Mosque (1125). In some cases, while the core is formed in similar way, however, the exterior sides are bonded in a way that they form the minaret case, as it is in Kayseri Kurşunlu Mosque. In Diyarbakır Great Mosque (1155) and Diyarbakır Kale (Castle) Masjid (1160), there are two minarets which have the stair steps resting on a core of square form in the centre and again a case of square form at the outside. However, the exterior of the minaret case of Urfa Great Mosque (XII. C. The third quarter) has an octagonal form.

In the stairs built with brick, the steps are formed with 2-3 rows of brick and one piece of timber at the top. Bricks have the thickness of 4-5 cm, mortar have 2-5cm, and timbers have 5-6 cm. In the minaret of Ankara Aslanhane Mosque the timbers reached the thickness between 14-16 cm.

There are three different applications for the underside details of steps:

The first application is to build step underside s in a way that they are staged with brick vaults which narrow to the core and widen to the case. This application is seen generally in the minarets of early periods. For example, in the entirety of the minarets of Konya Hoca Hasan Masjid (the first half of XIII. C.) and Kayseri Great Mosque (1208) (**Photo.8**), in the pedestal section of the Minaret of Erzurum Tepsi (Tray) (the second half of XIII. C.) (**Photo. 9**) and Akşehir Great Mosque (1213), in the pedestal section and to the certain part of the body of the minarets of Konya Zemburi Masjid (the first half of XIII. C.) the steps are born with vaults along the stair line.

The second application for the step undersides is a system occurred as a small steps by means of projecting bricks one over the other.

From the second half of XII. Century onward this system was seen in most of Anatolian Minarets of XII.–XIII. Centuries. In this application as closing to the core the step distances narrow (**Photo. 10, 11**).

In the third application for the step undersides, the step undersides were constructed as step. This system is seen in the details of the step undersides of stone minarets. The minaret stairs of the mosques of Ani Menuçehr (1125) and Niğde Alaeddin (1223) were built in this way.

In the brick minarets, the first and sole example of that construction way is the minaret of Ankara Aslanhane Mosque (1290). The timber elements of 14-16 cm in thickness to form the steps undersides were used in the way used for the steps and the space between two timber elements was closed by bonding with brick.

In the minarets built in pre-Anatolian period, because their core diameter enlarged, the number of step increased, and therefore, the thickness of steps grew and minarets got a view of heavy mass, as to be in the Minaret of Buhara Kalan (Its pedestal diameter is 9.40 m). In the minaret of Kars-Ani Menuçehr Mosque (1125) (which is the first application in Anatolia), there is a ratio of 1/3 between the hive height of the stair and the step thickness. That ratio is rather big, and this explain the fullness of the minaret.

If the space, which is above the stair and muezzin (who calls adhan for praying) uses to climb, is called as a hive, there is a massive part between two hives, which was filled stone and brick. This part provides us to name a minaret with and without spare as to the thickness of a stair steps. For example, the minaret of Ankara Aslanhane Mosque dated 1290 is without spare. Also the minaret of Niğde Alaeddin Mosque dated 1223 is without spare (**Photo. 12**).

However, in the minarets of Ottoman Period, the number of spare is rather less or they were built as without spare.

4. EXAMINATION OF MİNARET IN TERMS OF STATIC

In a minaret, due to its structure, its own weight is conducted from top to down. Because, due to vertical forces only in the body uniform pressure tensions would occur; and if the building material of minaret is brick or stone, it doesn't cause a problem in terms of load bearing in the elements (**Fig. 12**).

In a minaret the foundation section conducting forces to base, is formed according to the height of the minaret, its wall thickness and ground condition. Also it is necessary to provide security for the foundation against collapsing. If the total of the moments working to collapse a minaret at the side of foundation is Md, and the total moments resisting against Md is Mk, and security coefficient against collapsing is μ; therefore, it must be

$$\mu = \frac{Mk}{Md} \geq 1{,}5$$

In order to provide this coefficient, minaret base must rest on a wider foundation enlarging from the ground towards the bottom. In the minarets of XII. and XIII. C., this position was supplied with a base part (papuç) in transition from the body to the pedestal. In other words, in order to prevent collapsing of minarets, to decrease the collapsing way and to widen base area, it was transmitted from a polygonal and circular body to a square pedestal with a base element.

In the minaret body, tensile stresses can occur by the effect of horizontal forces (such as wind or earthquake), besides vertical forces. According to the characteristics of the mortar, in the building built of stone or brick, the tensile stress is required to be either too small or not at all.

As to these knowns, a minaret may be examined by this following equation in durability:

Perpendicular (normal) forces under inclination:

$$\sigma = \frac{N}{A} + \frac{M}{W} \quad (1)$$

If the pressure force is taken as positive in the minaret body, then the equation is arranged according to the conditions mentioned above in the equation '1'

$$\frac{Nx}{Ax} - \frac{Mx}{Wx} \geq 0 \quad (2)$$

$$\frac{Nx}{Ax} + \frac{Mx}{Wx} \leq \sigma_{bem} \quad (3)$$

Here;

Nx: Perpendicular force at a cross-section of 'x'
Mx: Inclination moment at a cross-section of 'x'
Ax: Cross-section moment at a cross-section of 'x'
Wx: Durability moment at a cross-section of 'x'

If the distribution of the forces affecting to a minaret is shown simply along the length of the minaret:

qw: Pressure at a unit by wind kg/m^2
Nx: Perpendicular force in a cross-section of 'x'
C: Coefficient of horizontal earthquake (Equivalance horizontal earthquake force is determined by multiplying with the weight).

As it is considered that the cross-section of a minaret is circular; and its cross-section area and durability are calculated with these following formulas:

Cross-section Area: $A = \frac{\pi}{4}(D^2 - d^2)$

Cross-section Durability: $W = \frac{\pi}{32}(D^4 - d^4)$

In order to ensure the equation '3' at each case, a material durable to pressure must be chosen. The important point is that equation '2' must be ensured.

If a minaret is examined according to wind;
Approximate wind moment:

As $M_{wr} \cong \frac{qw.D.x^2}{\pi(D^4 - d^4)}$ is put in the equation '2';

$$\frac{Nx}{Ax} \geq \frac{16qw.D.x^2}{\pi(D^4 - d^4)} \quad (4)$$

If the approximate earthquake moment is examined in a case of earthquake:

If $M_E \cong \frac{Nx.c.x^2}{2}$ is put into the equation '2'

$$\frac{Nx}{Ax} \geq \frac{32Nx.c.x^2}{6\pi(D^4 - d^4)} \quad (5)$$

In a minaret the equations '4' and '5' must be ensured. Otherwise, as result of tensile stress occurred, the minaret may collapse. If in the design stage of a minaret the equation '4' and '5' can not be ensured, the procedures to be done are;

To ensure the equation '4' in case of wind, the diameter of the minaret is enlarged.

To ensure the equation '5' in case of earthquake, the best solution is also to increase the external diameter.

Increasing of perpendicular force in the equation '4' can also be a solution. In this case the cross-section may be enlarged. This situation is also valid for the equation '5'.

The other crucial point comes out in the part of minaret comb. On this part the perpendicular force is rather less. Because, generally steps do not continue in this part, there is not a system that will transfer the perpendicular force to side walls, in other words, the weight of the conical hat is not transferred to the side walls. Therefore, the stone-constructed conical hats built in XII. and XIII. C. Have a form of dome, as in Aksaray Kızıl Minaret (**Photo. 13**).

In a minaret, in the transition from the pedestal to the body and from the body to the comb where the section changes and stress accumulation occurs. Also, of these sections, in the balcony (şerefe) door and in the parts connecting the balcony and the comb, due to freezing and thawing of water, deterioration in materials and diminishing in cross-section occur. Because of these disadvantages, it was determined that most of the collapsed minaret broke down at these points. Therefore, it is understood that generally due to this reason the collapsed ones of

Anatolian Minarets of XII.–XIII. C. fell down at the level of the first balcony. Also the transition from the foundation to the body and the pedestal in the minarets built pre-Anatolian period are in the same thickness, this kind of problem does not occur. However, in Anatolian Turkish Minarets, getting body to be slim, and due to static concern, the pedestal was enlarged, therefore, a transition part was needed. That is why, a base part (papuç) occurred in Anatolia; and from then in terms of static an easiness was provided. In Ottoman Minarets this part was got suitable for static point of view.

4. CONCLUSION

In conclusion, as the building system of Anatolian minarets of XII. and XIII. C. is examined; the following results were established:

In the entire minarets, there is a stair of one-way.

In all of them there is a core, and they have square and circular plan forms as suitable for stair plan. As proportional with the height of the minarets, the diameter of minarets gets smaller towards the end of XIII. C.

The step thickness of stair gets smaller towards the end of XIII. C.

To bear vertical loads in the minarets built in the beginning or middle of XII. C., a system composed of arch or vault elements was applied to the step undersides. This system was left towards XIII. C., instead an overlapping technique formed by projecting brick over each other.

The step heights differs between 20 cm and 30 cm.

The stair is lit by lancet (small and narrow) windows.

Table 1: The Stair System of the Minarets

THE STAIR SYSTEM OF THE MINARETS																													
THE MINARETS	THE DATE OF BUILD.	THE PLAN OF STAIRS										THE PLAN OF STAIR UNDERSİDE																	
		Tor.	Tuğla	Tor.	Tuğla	Tng	Tuğla	Tor.	Tuğla	Tor.	Tuğla	Tor.	Tuğla	Tor.	Tuğla	Tuğla	Tor.	Tuğla	Tuğla	Taş	Tuğla	Tor.	Tuğla	Tor.	Tuğla	Tor.	Tuğla	Tor.	Tuğla
Ani Menu Çehr Mosq.	1125																												
Diyarbakır Great Mosq	1155																												
Diyarbakır Castle Mos	1160																												
Urfa Great Mosque	12 C., 3.Q																												
Niğde Alaeddin Mosq.	1223																												
Harput Great Mosque	1166																												
Siirt Great Mosque	1130-1260																												
Erzurum Tray Minaret	12 C., 2.Q																												
Sivas Great Mosque	End of 12c																												
Van Great Mosque	12 C., 2.Q																												
Kayseri Great Mosque	1205																												
Konya H.Hasan Masjid	End of 12c																												
Bayburt Great Mosque	13 C., 1.Q																												
Konya Zemburi Masjid	13 C., 1.Q																												
Konya Sırçalı Masjid	13 C., 2.Q																												
Akşehir Great Mosque	1213																												
Akş. Squat Min.Masjid	1226																												
KonyaHatuniye Masjid	1230																												
Kon. Akabe Sulta.Mjd.	1236																												
Antalya Grooved Min.	1236																												
Malatya Great Mosque	1247																												
Akşehir Stone Madrash	1250																												
Konya SahipAta Mosq.	1258																												
Malatya Nameless Min	Mid of13c																												
Aksaray Red Minaret	13 C., 2.Q																												
Malatya White Minaret	13 C., 3.Q																												
Kon.SahipAta Darülha.	Appr.1204																												
Sivas Cüveyni Darülha	1271																												
Sivas SahipAta Medres	1271																												
Kırşehir Cacabey Medr	1272																												
Harput Araphaba Masji	1279																												
Ankara Aslanhane Mos	1290																												
Erzurum Hatuniye Mad	1291																												
Van Red Mosque	End of 13c																												

	Surveying in the site		Surveying based on literature

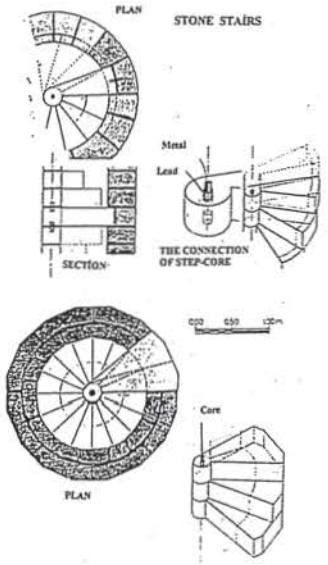

Figure 1- The building system stone steps(from Ü.Kulaç)

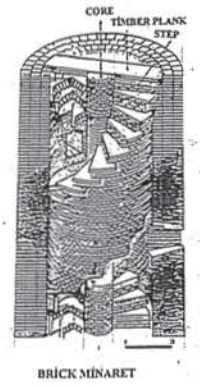

Figure 2- The detail of step underside in vault form built with bricks.(from Ü.Kulaç)

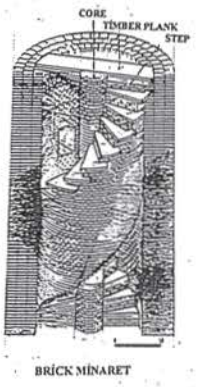

Figure 3- The detail of step underside in projected form built with bricks.(from Ü.Kulaç)

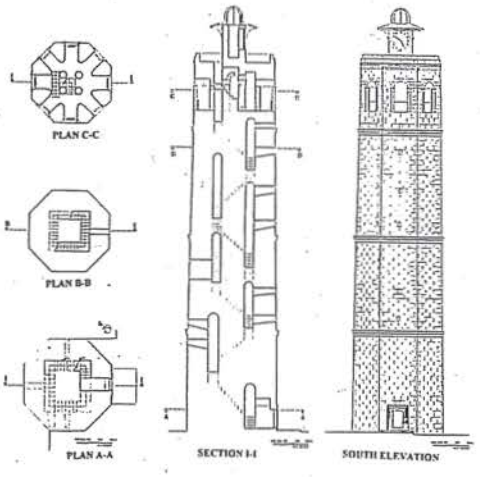

Figure 4 The Minaret of Urfa Great Mosque.

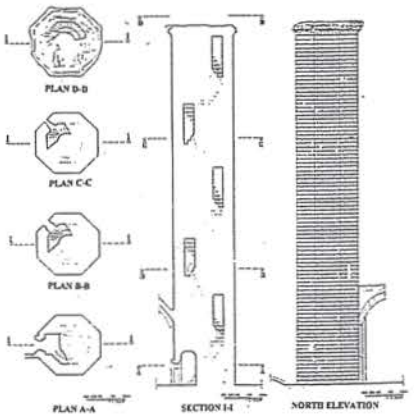

Figure 5-The Minaret of Kars Ani Menuçehr Mosque.

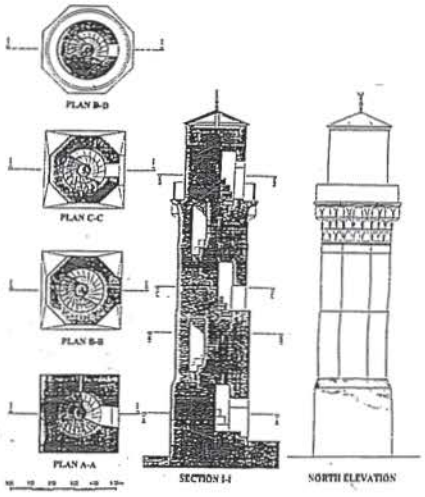

Figure 6-The Minaret of Konya Hatuniye Masjid.

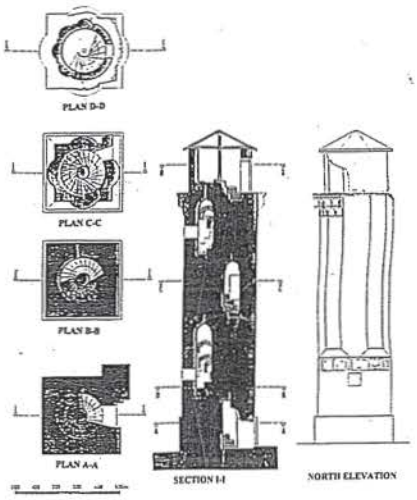

Figure 7-The Minaret of Konya Hoca Hasan Masjid.

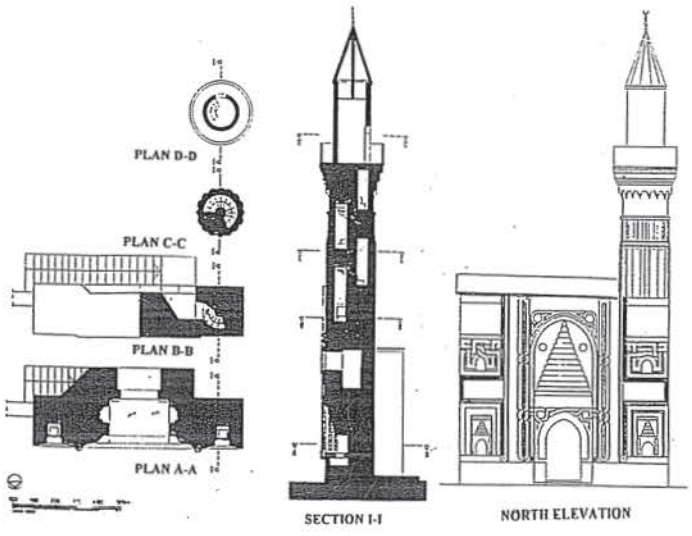

Figure 8-The Minaret of Konya Sahip Ata Mosque.

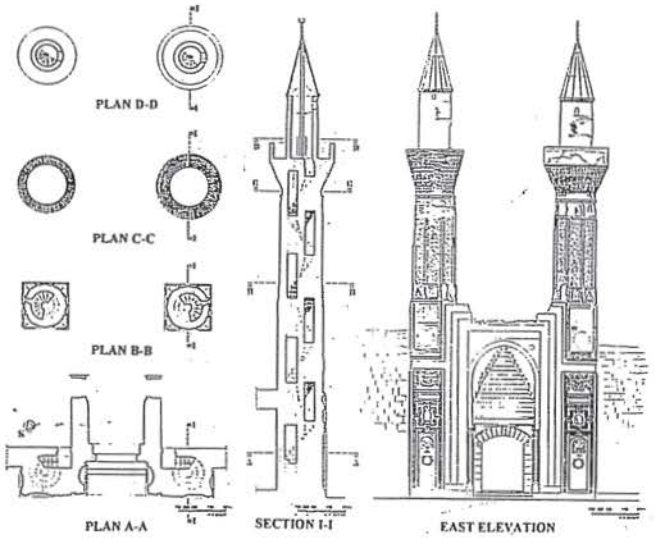

Figure 9-The Minaret of Sivas Sahip Ata Medrasah.

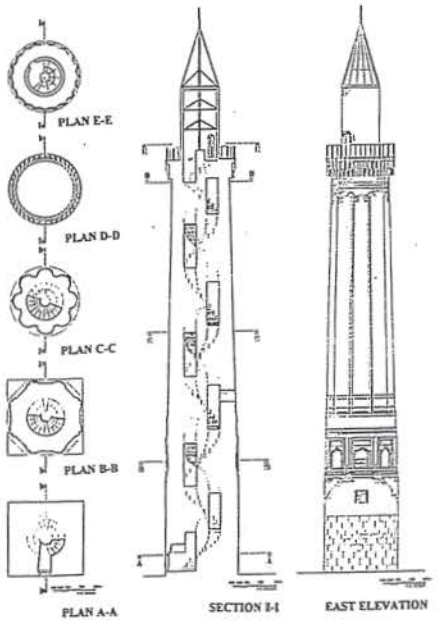

Figure 10-The Minaret of Antalya Yivli (Grooved)

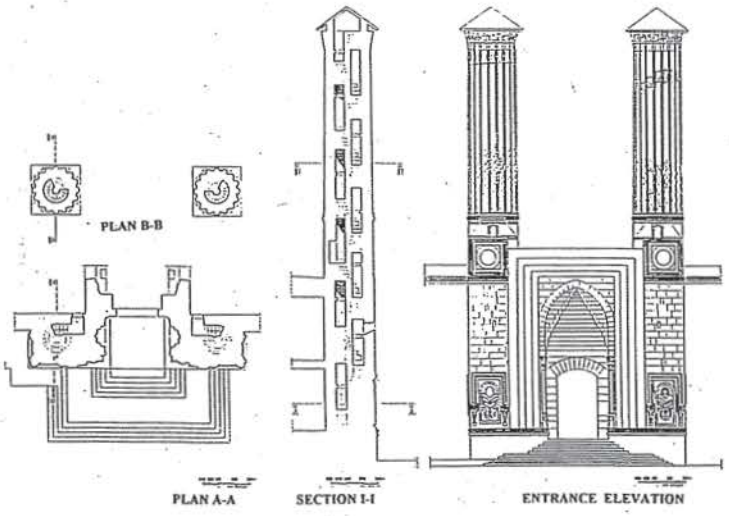

Figure 11-The Minaret of Erzurum Hatuniye Medrasah.

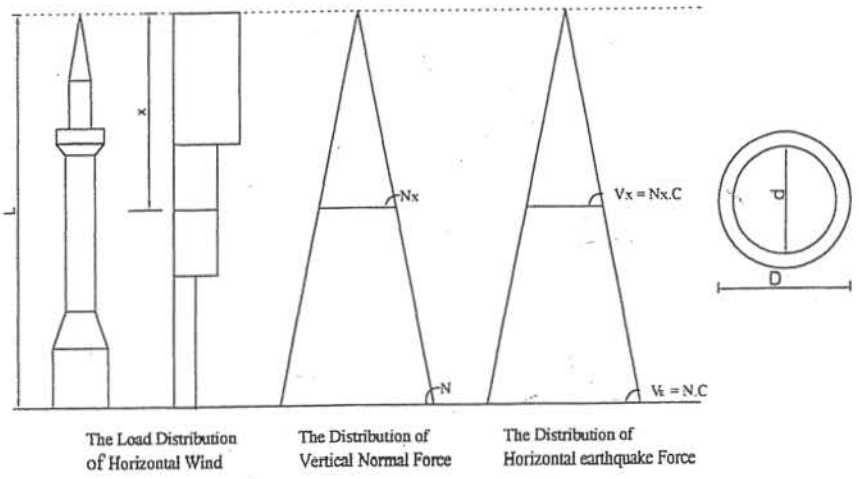

Figure 12-The force and load distribution in minarets.

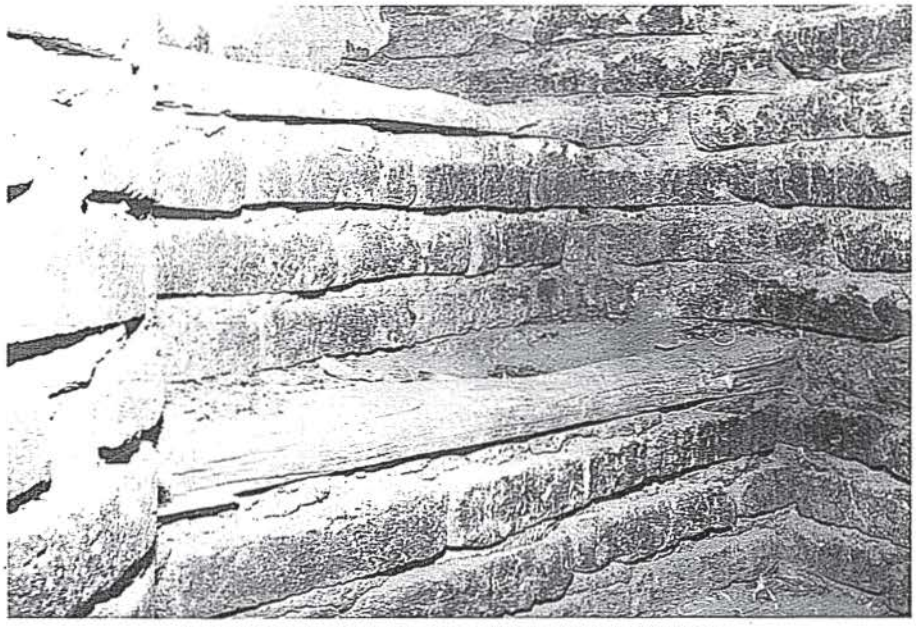

Photo 1: The detail of brick step in Aksaray Red (Kızıl) Minaret.

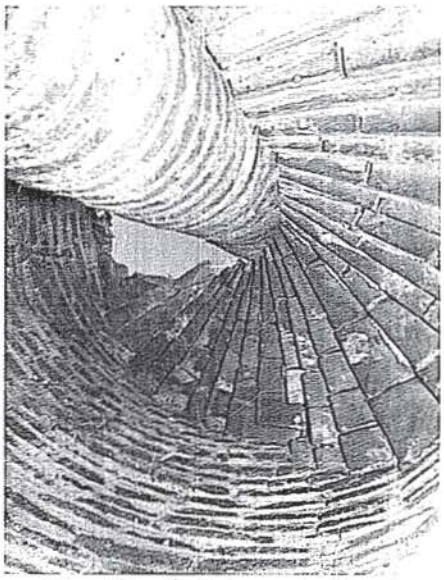

Photo 2-The detail of step underside and core in Malatya White (Ak) Minaret.

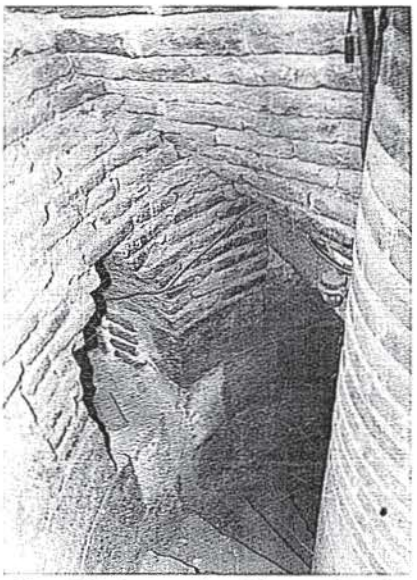

Photo 3-The connection of the core, the stair and the case in Antalya Grooved (Yivli) Minaret.

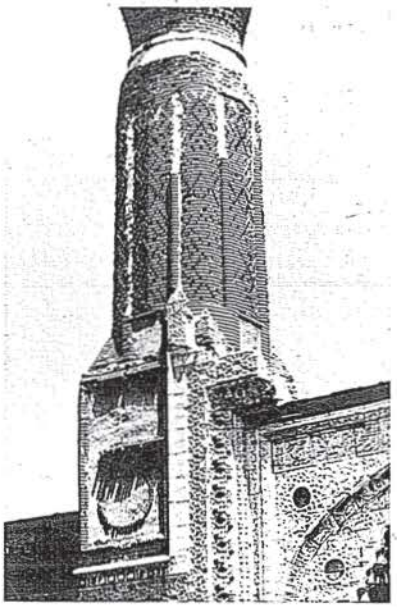

Photo 4-The detail of the minaret body in Sivas Heaven (Gök) Medrasah.

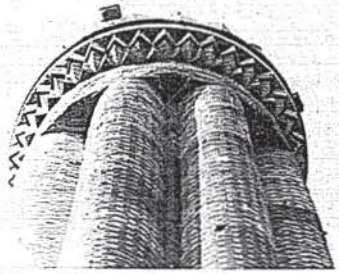

Photo 5- The body detail from Antalya Grooved (Yivli) Minaret.

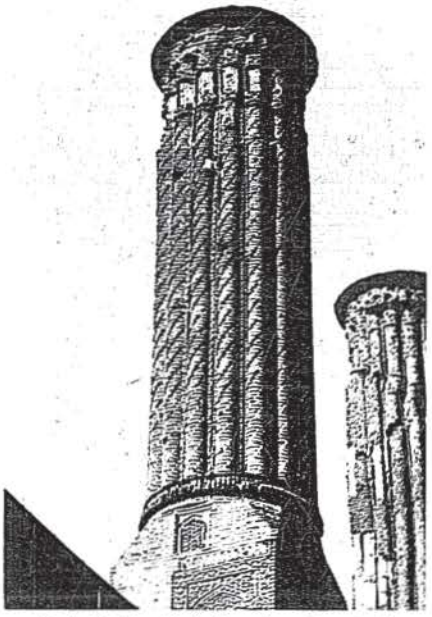

Photo 6- The details from the minarets of Erzurum Hatuniye Medrasah.

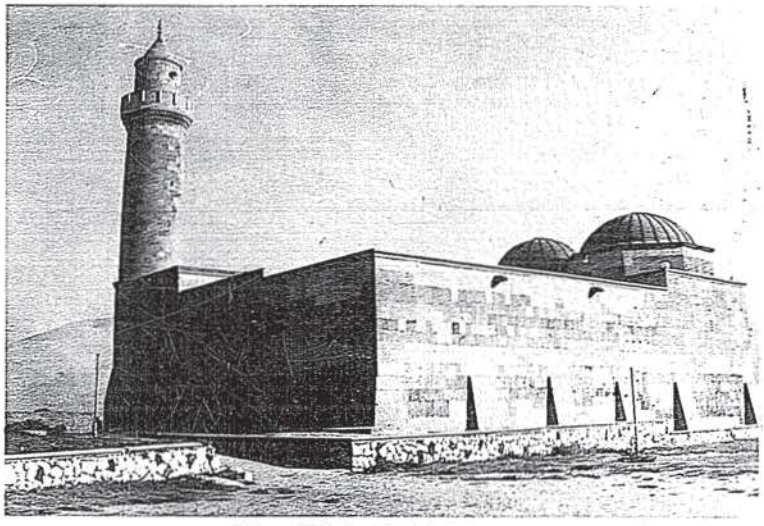

Photo 7-Niğde Alaeddin Mosque.

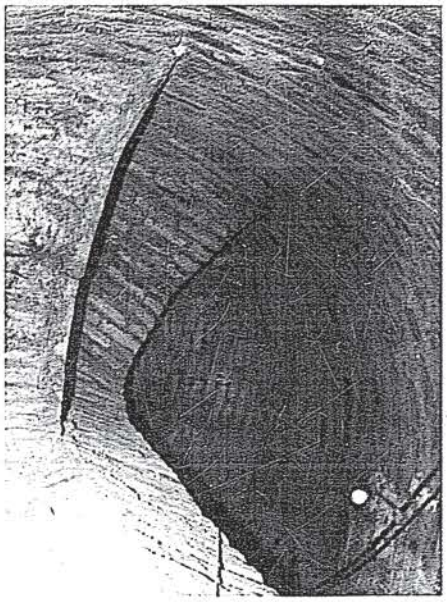

Photo 8-The detail of step underside of Kayseri Great (Ulu) Mosque.

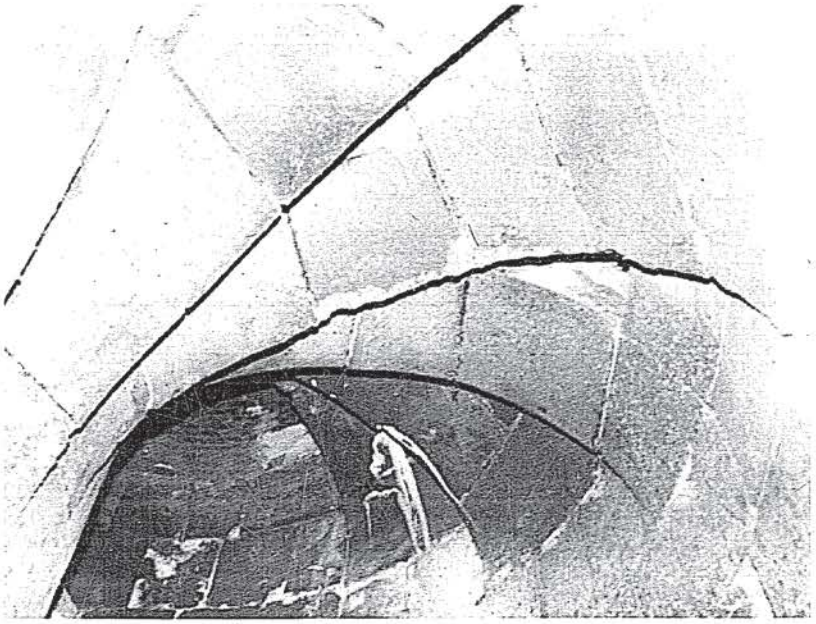

Photo 9-The detail of step underside of Erzurum Tray (Tepsi) Minaret.

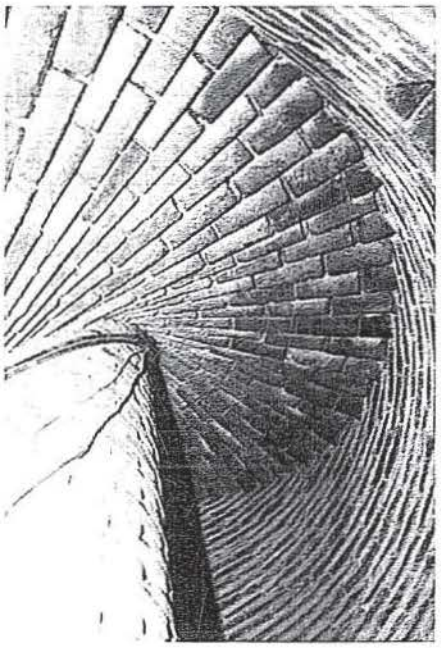

Photo.10- The detail of step underside of Sivas Heaven (Gök) Medrasah.

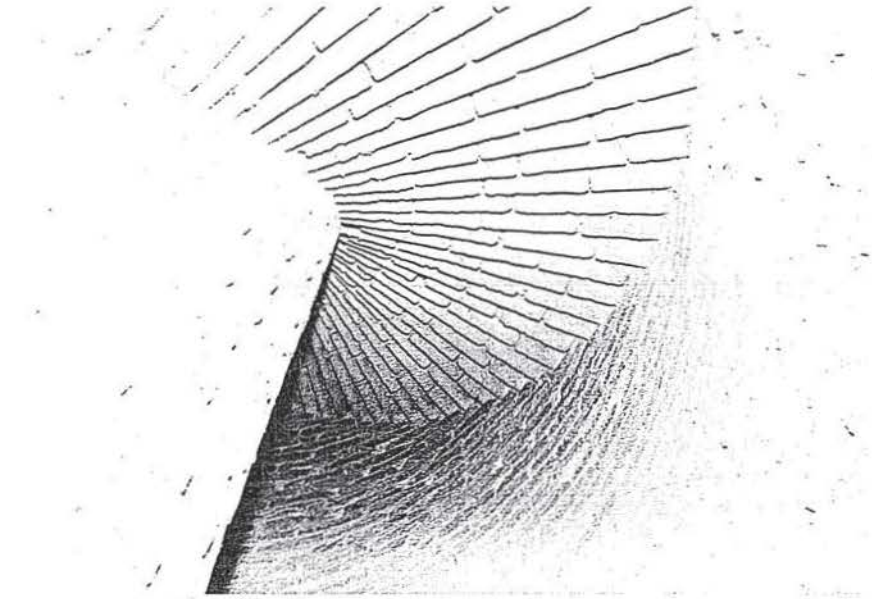

Photo 11 The detail of step underside of Van Red (Kızıl) Mosque.

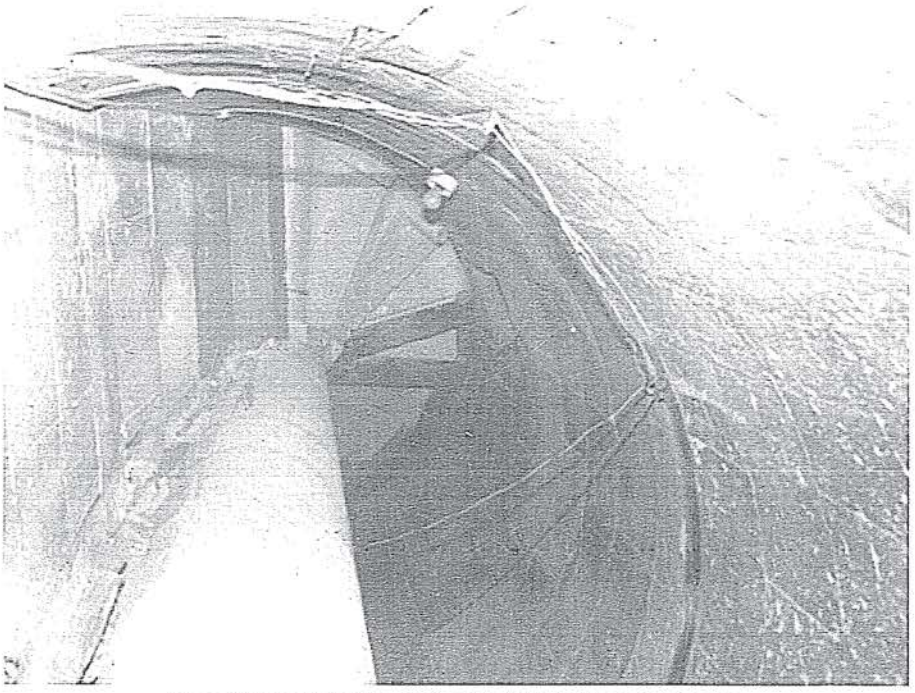

Photo 12 The detail of step underside of Niğde Alaeddin Mosque.

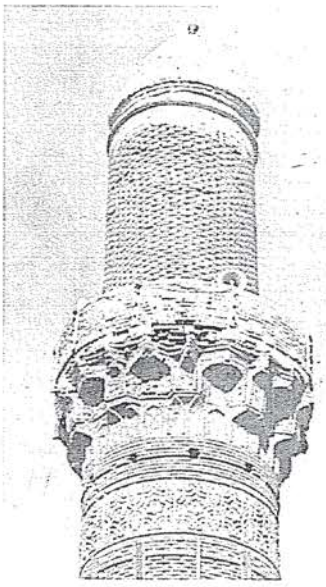

Photo 13 The hat section of Aksaray Red (Kızıl) Minaret.