Acoustics and Building Construction Technology in Medieval India: 14th To 17th Centuries

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***Abstract*—**History as a discipline studies the actions of the past and tries to understand the formation of future courses of actions in society. Archaeology is one of the disciplines whose findings help the historian in establishing the co-relation of truth with the past society. Many a times the structures are not complete in themselves as they have not been able to withstand vagaries of time, weather and human nature. Generally seen as a form of art reflecting the taste of time, Structures carry the knowledge and become an evidence of the erudition of the past. Medieval archaeology takes into account the structures, standing on the surface and speak eloquently of the cultural movements and integration through the ages. The paper attempts to look into the architecture of structures located in the regional empires of Mandu, Gulbarga and Golconda and explain the system of acoustics working in them by bringing out the level of contemporary technology incorporated in the construction.

***Keywords*—** Acoustics, Building construction, Medieval Indian Regional structures, Technology

I. INTRODUCTION

HISTORY as a discipline studies the actions of the past and tries to understand the formation of future courses of actions in society. Historians study actions as developments in the context ofsociety. In his endeavour for search of truth he is also guided by the growth of knowledge in different relevant areas of science. Archaeology is one of the disciplines whose findings help the historian in establishing the co-relation of truth with the past society. It seeks to promote "a better understanding of past human behaviour through the study of the physical remains associated with any such behaviour" [1]. It is no longer limited to excavations only and also takes into account the structures, which are standing on the surface and "speak eloquently of the cultural movements and integration through the ages" [2]. However, many a times the structures are not complete in themselves as they have not been able to withstand vagaries of time, weather and human nature. Thus, interpretations of a culture are developed even without direct access to all parts of that culture [3]. Nonetheless, the surviving artefacts are evidence of past technologies and are often termed as 'Physical history' [4]. The physical evidence available through fieldwork has a vital contribution for historical scholarship. Structures of historical age are generally seen as a form of art which reflects the taste of the time. However, like other creations they also carry the knowledge and become an evidence of the erudition of the past. Medieval archaeology takes into account the structures, which are standing on the surface and speak eloquently of the cultural movements and integration through the ages. These structures are also signified as cultural heritage and stand as physical representatives of the past. . The importance of these artefacts can be gauged from the fact that every era reflects its own distinct style and monuments stand as evidence of the past for future generation of historians. Since long the study of medieval structures has been limited to study of their architectural features and have often been seen as a form of art rather than as representative of contemporary knowledge and technology. It would be difficult to use the word 'science' in the medieval context in the same sense as it is used today [5]. The word technology is derived from the Greek word 'technologia' meaning systematic treatment of art. The modern usage of the word technology has extended the meaning to all kinds of mechanical devices and forms of practical activity, by which certain material objectives are attained. It includes, but is not confined to, practical applications of theoretical knowledge [6]. However, in case of medieval India we would be looking into the laws of nature known to the people and their application in the sphere of building construction.

While giving regulations on house buildings, Abul Fazl writes that "Regulations for house building in general are necessary; they are required for the comfort of the army, and are a source of splendour for the government. People that are attached to the world will collect in towns, without which there would be no progress. Hence, His Majesty plans splendid edifices, and dresses the work of his mind and heart in the garment of stone and clay. Thus, mighty fortresses have been raised, which protect the timid, frighten the rebellious, and please the obedient. Delightful villas and imposing towers have also been built. They afford excellent protection against cold and rain, provide for the comfort of the princesses of the Harem, and are conducive to that dignity which is so necessary for worldly power….Many tanks and wells are being dug for the benefit of the men and the improvement of the soil….He has passed new regulations, kindled the lamp of honesty, and put a stock of practical knowledge into the hands of simple and inexperienced men" [7]. Abul Fazl's assertion that Akbar put practical knowledge into stone and clay gives

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us an idea that the medieval society was aware of the laws of nature which are known to modern society as different theories of science. Hence, in order to understand the functioning of the medieval structures we need to see in what way the laws of nature were integrated in the building construction. The paper attempts to look into the architecture of structures located in the regional empires of Mandu, Gulbarga and Golconda and explain the system of acoustics working in these structures by bringing out the level of contemporary technology incorporated in the construction.

Mandu, capital city of Hoshang Shah in the 15th century, lies in Malwa Plateau region. It is situated at the top of Vindhya range and acted as passage to Deccan from Delhi during medieval period. Mandu became the capital of the Ghori and Khalji rulers of Malwa from the beginning of the 15th century until it was annexed by the Akbar in 1564 and was made a part of the Mughal empire. Malwa, a tract between the Narmada and Tapti rivers, was ruled by the Paramara dynasty during the early medieval period with Dhar as their capital. It was during the reign of Devapala (early 13th century), the last of the Paramara ruler, that Iltumish attacked and plundered Malwa. But it was under Alauddin Khalji that the conquest of Malwa was completed and it was made a province of the Delhi Sultanate with Dhar as its capital which remained the headquarters of the governor of Malwa until Dilawar Khan Ghori declared independence in 1401 A.D. Although, Dilawar khan frequently visited Mandu [8] Dhar remained the seat of the government until Hoshang Shah (Also known as Alp Khan), Dilawar Khan’s son, shifted his capital to Mandu after succeeding to the throne after his father’s death [9]. The Jami Masjid and the

Hoshang Shah’s tomb, were started by Hoshang Shah but were completed by Mahmud Khalji, who put an end to the Ghori dynasty of Malwa and in 1435 ascended the throne and assumed the title of Sultan Mahmud Khalji [10]. The royal buildings of Mandu which survive to us today were given fresh lease of life during Jahangir’s period and carry the past with present in them. These buildings are distributed on North South axis and supported by three water bodies, Munj Talab, Kapoor Talab and Sagar Talab. Jahaz Mahal probably dates to the period of Ghiyath al-Din (1469-1500) and is named so as it looks like a ship situated between two strips of water, Munj Talab and Kapoor Talab. Outside the Jahaz Mahal complex situated on the southern side of the axis, there are two royal enclosures on the east of Sagar Talab, Baz Bahadur palace and Rani Rupmati pavilion. Baz Bahadur‟s palace was built by Sultan Nasir al-Din Khilji in 1508/09 with Rupmati‟s pavilion set above it on a hill. Standing between two water bodies, the Kapoor Talao and the Munja Talao, the palace looks like a ship, and hence gets its name Jahaz. It is about 360 ft in length and 40 ft in height [11] Jahaz Mahal which appears to be a single layered structure is actually a three layered structure. From the front, only one layer and the terrace is visible whereas other two layers can be seen from the backside.

Plate 1 Jahaz Mahal, Mandu

The ground layer is divided into fifteen aiwans and all these aiwans have either vault shaped ceilings or concave shaped ceilings in alternate pattern. The vault shaped ceilings have narrower dimension enclosures whereas concave shaped ceiling enclosures are of wider dimension [12]

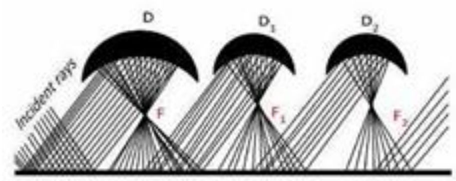

Fig. 1 : Reflection pattern of sound waves from Curved Parabolic and Plane Surfaces

The construction of Jami Masjid, according to an inscription carved on the doorway of the mosque, was started by Hoshang Shah and was completed by Mahmud Khalji in 1454 A.D. A rectangular domed porch is the entrance to this Mosque whose interior has a squared courtyard which is surrounded on each side by arcades of eleven pointed arches. The prayer hall is divided into four bays by series of pillars of uniform height and width. The roof of the prayer hall comprises of three larger domes and cylindrical cupolas forming a symmetrical pattern, one on each bay of the interior and these cupolas are located above an arch that are constructed along the bay giving the interiors a hollowness. Along the Qibla wall, there are sculpted Mihrabs made of polished black stone at regular intervals which are divided into two by a pulpit which is eleven steps high with a canopy which supported by four arches and is covered with a dome. In front of the pulpit is a platform, which gives it a throne like look and further making the area look like a court. Adjoining the western wall of Jami Masjid is the white marbled tomb of Hoshang Shah whose entrance is an octagonal pavilion with domed roof. Entering through the pavilion one gets the first glimpse of the resting place of the founder of Mandu, Hoshang Shah Ghori, which stands on a marble basement which is to be entered after passing through a pillared pavement which is made of red sandstone. This is designated as Dharmasala or hall which is supported by three sections of pillars [13] and steps from this hall lead to the court of the mausoleum.

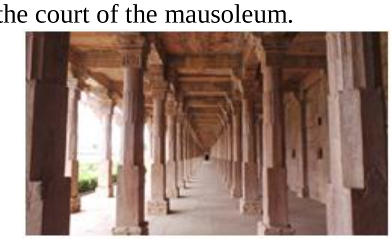

Plate 2 Dharmshala within Hoshang Shah’s tomb enclosure

Baz Bahadur Palace located on the southern axis is adjacent to Rewa Kund. A fleet of forty broad steps lead to the entrance of the palace where one could see a Persian inscription which reads that this was built by Nasir ud-Din in 1508 A.D. This must have been taken up by Baz Bahadur for its close proximity to Rewa Kund. The main entrance comprises of a covered passage with a vaulted roof and on either sides of the passage there are rooms for the guards which are rectangular in plan and their ceiling are vaulted [14].

Plate3 Baz Bahadur Palace

The royal buildings of Mandu which survive to us today were given fresh lease of life during Jahangir's period and carry the past with present in them.

In the medieval structures of Mandu, system of acoustics seems to be functional in three monuments, Jahaz Mahal, Dharmshala within Hoshang Shah's tomb enclosure and Baz Bahadur Palace. The ground floor of Jahaz Mahal which was a part of the royal palace had acoustics working to meet the requirement of the royalty. Similar kind of requirement in Baz Bahadur Palace too was met where the enclosure in the palace probably served as Music room of the complex. However, the system of acoustics working in the Dharmshala leads one to conjecture that Jami Masjid could have served as court in the beginning and later on converted into a mosque. Except for the Dharmshala all the structures have concave shaped ceiling, whereas Dharmshala has vault shaped ceiling. Before venturing into the explanation of the system in these structures, authors would like to discuss the other site and explain the system accordingly. The paper also attempts to look into the architecture of two covered Mosques in Gulbarga and Bidar and residential enclosures in Golconda fort and understand the functional part of it. The structures chosen belong to the period between 14th and 17th century which covers both Pre and Post Akbar period. The Golconda fort has mechanism of sound working in an open area whereas in Gulbarga and Bidar the resonance of sound is within a closed enclosure. The paper would be looking into the system of acoustics and make an attempt to explain them through modern principles of science.

The Bahmanis built Gulbarga as their capital in the 14th century and the mosque under study is located within the fort palace area. It is a covered mosque measuring 430" x 271" and has a system of acoustics working within it. Both the mosques in Gulbarga and Bidar have been chosen because they happen to be a closed structure mosque and likes of them are not to be easily found in India. Medieval India had generally followed the concept of open mosque with western side of the mosque being closed leaving a large area in the middle known as 'Sahn' open and used for offering prayer. The masque has nave of 40'x40' with a dome of diameter 40' and total height of the dome is around 80'. The main central hall which was also used for public address and prayer has number of arches on all directions. The mosque has 15 numbers of small sized domes at the centre and semi cylindrical domes on the extreme sides of central dome.

Bidar flourished as a provincial town during the reigns of the early Bahmani kings and is listed by Ferishta amongst great towns of the Deccan where schools for orphans were established during the reign of Mahmood Shah Bahmani I [15]. Ahmad Shah Bahmani, after a campaign against the Sultan of Malwa in 1426, arrived at Bidar on his return from the campaign. He took to the amusement of hunting and coming to a beautiful spot, resolved to found a city to be called Ahmudabad Bidar. A stone citadel of great extent and strength was erected on the site of Bidar [16].The fort of Bidar was completed in the year 1432 [17] and the capital city of Bahmanis was also shifted from Gulbarga to Bidar. Bidar continued to be the centre of power till 1619 when the

Barid kingdom was absorbed by Adil Shahis of Bijapur. Bidar fort, which stands today, has material evidence of both Bahmanis as well as Barid sultans. The construction is of stone using lime mortar and the style is influenced by Iranian and Central Asian patterns [18].

Plate 4

Plate 5

The palace fort area of Bidar too has a covered mosque known as Solah Khamba Mosque. The principle of reverberation of sound in Bidar mosque is same as that of Gulbarga mosque.

In order to under the system of acoustics functioning in the medieval structure, one needs to understand the basic principles of sound on which the system of acoustic works. The acoustics within a room depend on the key issues of reverberation, room shape and interior noise control.

Reverberation is a result of repeated reflections of sound waves off all room surfaces. Reverberation in a room is affected by absorptive and reflective or diffusive materials. Whenever sound strikes a surface, some of it is absorbed, some of it is reflected and transmitted through the surface. Dense surfaces isolate sound well and reflect sound back into the room. Sound also bounces back and forth between hard and parallel surfaces. It generally follows line of sight and tends to travel in a straight line. Sound waves travel out from their source and impinge on to a surface where they are absorbed or reflected or both. Sound waves travel in straight lines and when they encounter a new medium, such as the wall of a room or any substance whose density or elasticity differs

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from that in which the sound originated, the waves are reflected and transmitted. The reverberation also depends on the absorptive material present in the room. The absorbers can be people, carpet, upholstery, furniture, plants, flags etc. They absorb sound and allow less diffusion of sound. Walls, ceiling etc. reflect the sound and help in reverberation. However, these are not the only prerequisite for the reverberation of the sound. The shape of the ceiling or wall also determines the reverberation of the sound. Apart from this, the frequency at which sound is produced also determines the quality of sound and the distance to which it can travel. The speed of any wave depends upon the properties of the medium through which the wave travels. Typically there are two essential types of properties which affect wave speed inertial properties and elastic properties. Elastic properties are those properties related to the tendency of a material to maintain its shape and do not deform whenever a force or stress is applied to it. Inertial properties are those properties related to the material's tendency to be sluggish to changes in its state of motion. The density of a medium is an example of an inertial property. The greater the inertia (ie. mass density) of individual particles of the medium, the less responsive they will be to the interactions between neighboring particles and the slower that wave will be. The inertial property of density tends to be the property which has greatest impact upon the speed of sound. The speed of a sound wave in air depends upon the properties of the air, namely the temperature and the pressure. The pressure of air affects the mass density of the air and the temperature affects the strength of the particle interactions. Since the speed of a wave is defined as the distance which a point on a wave travels per unit of time, it is often expressed in units of meters/second (m/s). At normal atmospheric pressure, the temperature dependence of the speed of a sound wave through air is approximated by the following equation:

$$V = 331\, m/s + (0.6\, m/s/C).T$$

Where T is the temperature of the air in degree Celsius (C), the speed of a sound wave in air at a temperature of 20 degrees Celsius can yield the following solution.

$$V = 331\, m/s + (\, 0.6\, m/s/C\,).T$$
$$V = 331\, m/s + (\, 0.6\, m/s\, C\,).(\, 20\, c\,)$$
$$V = 331\, m/s + 12\, m/s$$
$$V = 343\, m/s$$

This equation can be used to determine reasonably accurate speed values for temperatures between 0 and 100 Celsius. Hence, one can safely presume that in the Hyderabad climate, where evening temperature could be around 20 Celsius, under given circumstances, sound could travel at the speed of 343m/s. There are several frequencies or harmonics produced at the lips. The fundamental frequency (FO) is the number of times per second that the vocal folds vibrate (in Hertz). Females usually have higher pitched voices than males. The fundamental frequency (FO) of male voices typically ranges from 100 to 150 Hz while it ranges from 170 to 220 Hz in females. The conversational fundamental frequency is approximately 200 Hz for adult women and 125 Hz for adult men. The frequency and the wavelength determine the speed of the sound wave. The mathematical relationship between speed, frequency and wavelength can be understood by the following equation:

$$Speed = Wavelength.Frequency$$

Using the symbols v, ⎣ and f, the equation can also be written as v = f.

The concave shape in the ceiling helps the reflected sound to converge at a focal point. The concave catches the sound and distributes it in the shape of an umbrella. Similar kind of interface with the similar kind of ceiling would be capable of receiving and reflecting the sound to a distance as per the above given equation [19]. The sounds waves are longitudinal in nature and are treated as a mechanical waves. Due to wave nature it also follows many laws of physics and some of the properties of the sound waves are as similar to the optical waves. As a result it gets reflected from the smooth surface (law of reflection), focused from the curved parabolic surfaces and get attenuated due to obstacle in the path of propagation. The amount of energy carried by sound is measured in terms of intensity and most commonly it is measured in terms of Decibels (dB). Therefore, the intensity of the reflected sound depends on the quality of the surface. In addition, the sound waves restricted between two plane surfaces also form standing wave pattern and the waves have maxima and minima points at regular intervals which are known as nodes (Point of Maximum Disturbance) and anti-nodes (Minimum Disturbance). The distance between two nodes or antinodes are measured in terms of wavelength (ƛ). The human being can hear sound between 20- 20,000 Hz frequency range [20].

In my study I have measured the diameter of size of the bigger dome in Gulbarga mosque, which is around 40' in diameter and the depth of the dome is admeasured around 10'. Therefore, the focal point (F) of the dome is located around 10' from the top [21].

Plate 6

As the total height of the building is 80', the sound thus produced in the central hall or nave, follows upward path and gets reflected and passes through the focal point (F) and moves another 70'' distance to reach up to the floor of the mosque. Fig.1 shows the focal point which forms a cusp of reflected sound waves and is treated as a point of high intensity. These waves further move away from the focal point and get diverged and strike to the smooth flooring. The entire reflected rays from the dome form another circle of rays .These reflected rays get another reflection from the flooring at certain angle (45 degree) and move once again in all the directions. I have measured the intensity of sound using decimeter. The intensity of the direct sound was found around 65 dB while intensity of the reflected sound from the dome was around 60 dB. This confirms the small absorption and reflection losses of sound waves from the dome surface. However, sound wave of intensity also confirms the good quality of external surface as well as perfectness of the parabolic shape of the dome. In the second step, the reflected sound from the smooth floor reflected at 45 degree moved in forward direction and got reflected from the small size domes of small focal lengths [Fig1].

The similar process of reflection, focusing and defocusing would get repeated in the subsequent domes .It is matter of fact that the sound waves moving in the forward direction and going through multiple reflection from different small chambers of domes suffer reflection, absorption and scattering losses. We once again measured the intensity of the sound at the end of the building and found direct intensity of the sound was of the order of 55dB while the intensity of the reflected sound was of the order of 45dB only. The loss in the sound measured could be probably because of the less smooth surface at the present. At present the original smoothness of the surface has weathered away and only small remains of it can be seen. The gypsum coating on the walls, pillars and floor would have certainly helped in transmission of sound without any loss or negligible loss. The extreme corners of the mosque do not have circular but cylindrical domes to prevent the escaping of sound through open arches. The cylindrical domes on the sides allow sound to travel in straight line only unlike concave shaped domes where sound gets distributed in all directions. The cylindrical kind of dome was required on the sides as there are large arches as openings adjoining it. If the sound was not allowed to travel in straight line, it would have escaped through the openings and got lost. Hence, the cylindrical domes on the sides allowed sound to maintain intensity and travel to the furthest corner of the mosque. Monuments in Mandu and Solah Khamba mosque in Bidar too worked on the same principle and the 'namazis' could listen to the 'muazzin' in any corner of the mosque without any 'modern gadget'.

Qutb Shahi rulers inherited Golconda fort from the Bahmanis, which they had got from Rajas of Warangal. It was an earthen fort in the beginning and was known as Mangal. It was ceded to Bahmanis by the Rajas of Warangal and fixed as the boundary between two kingdoms. It remained as an important outpost of the Bahmanid kingdom till 1512 A.D. when Quli Qutb Shah, the governor of the fort, declared independence and made it his capital. The fort was strengthened during the reign of Ibrahim Qutb Shah, who rebuilt it extensively with stone and mortar [22].

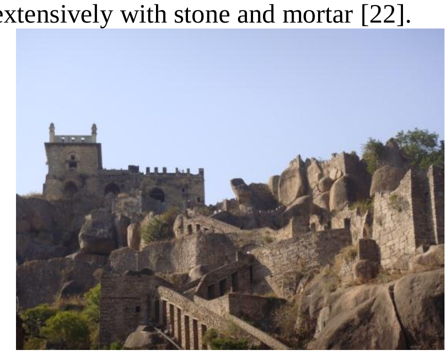

Plate 7

In the Golconda fort there are evidences of system of acoustics working near the Bala Hisar gate entrance, in the portico. The portico is connected to the Baradwari situated at the top of the fort area and the Baradwari is also connected to another Baradwari known as Taramati Baradwari located outside the fort area. The ceiling of the portico is concave shaped dome which helps in concentration and reverberation of the sound. The aerial distance between the portico and the Baradwari in the fort is approximately 500 to 600 meters. Hence, if we take the distance sound would travel in 20ºc to be 343m/sec. then probably one interface was required to reverberate the sound from the portico to the Baradwari. This mechanism was probably used to warn the ruler about the impeding danger as the Bala Hisar gate was the last point of defence and marked entry to the fort palace area. The aerial distance between Taramati Baradwari and the fort Baradwari is approximately one km. At the present there are no existing physical evidences of Interfaces in between. However, if the resonance of the sound had to take place, the concave dome of Taramati Baradwari [23] would have concentrated and distributed the sound to be again concentrated and distributed by the Interface having same properties.

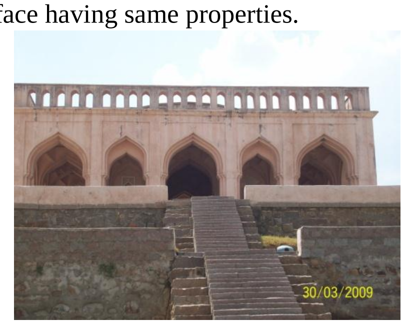

Plate 8

The mechanism would have allowed sound to travel in relay to the top of the Golconda fort, in the Baradwari with the help of three or four interfaces in between. One of the enclosures in the residential part of the fort has chambers where reverberation of sound takes place but not in the same manner as in the earlier discussed structures. It is in the south west of the fort or right side of the Taramati mosque. The structure has three layers. The first two layers are double storied while the third one is single storied. The middle one is the cooling chamber while the third one has the system of acoustics working in it. The enclosure is in square form with each side of the square measuring 28'4". The distance between two corners of the square is 40'16". In this enclosure, sound travels diagonally from one corner to the opposite corner and is not audible in the other two corners. Reflection of sound waves is also affected by the shape of the surface. Curved surfaces with a parabolic shape have the habit of focusing sound waves to a point. The sound thus reflected gets concentrated and focus at one focal point. Hence, because of the parabolic shape of the corners the sound emitted at one corner got concentrated and focused at the other corner resulting in the reverberation in that corner without getting reverberated in other two corners. This kind of reverberation can also be seen in the enclosure of Taramati Baradwari. The purpose of acoustics in both the cases was not of uniform nature and was determined by the exigencies. The portico would be resonating sound related to security and administrative matters whereas Taramati Baradwari and the other enclosure in the palace would be fulfilling the entertainment and pleasure aspect.

The indigenous technology used in the building construction speaks of the level of technology available during that period of time. We do not get any detailed reference of these kinds of technologies in the contemporary sources. Hence, it becomes more difficult to corroborate such kind of knowledge and one is totally dependent on the field work alone to reconstruct the knowledge of that time. It would not be out of the place to mention here that the medieval age too had its share of knowledge which was scientific and logical in nature. These structures stand as evidence of the past and help the present in reconstructing past society for the future. The society which met its requirement of modern times without having access to 'modern gadgets' showed how the laws of nature could be used in fulfilling its need and some of those get reflected in the technology of building construction.

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[12] See Figure 1.

[13] James Fergusson, *History of Indian And Eastern ArchitectureVol II*, London, 1910, p 250. See Plate 2 which shows the Pillared courtyard.

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[20] For general understanding of properties of sound also see class XI & XII NCERT Physics books.

[21] Calculating a parabolic Dish's focal point, http://www.downeastmicrowave.com. See Plate 6.

[22] See Mahomed Kasim Ferishta, Tarikh I Ferishta, Eng. Tr. By John Briggs, ***History of the Rise of the Mahomedan Power in India***, vol. iii, Delhi, Reprint 1981. (First Published in 1829). Also see S.A.A. Bilgrami, ***Landmarks of the Deccan***, New Delhi, Reprint 1992. (First Published in 1927). See Plate 7.

[23] See, Sanjay Subodh & Shatarupa Bhattacharya, 'Acoustic in Medieval Buildings: A Case Study of Golconda', ***Proceedings of Indian History Congress***, 70th Session, 2009-10. See Plate 8.