Proceedings of the Institute of Acoustics

The Acoustics of a Pendopo : A Typical Open-sided Hall for Javanese Gamelan Music Performance

S. J. Sarwono University of Salford, School of Acoustics and Electronics Engineering, UK
Institute of Technology Bandung, Department of Engineering Physics, Indonesia
Y.W. Lam University of Salford, School of Acoustics and Electronics Engineering, UK

1. Introduction

Javanese *gamelan* is one of the Indonesian traditional music ensembles. Different from western classical orchestra, this ensemble which is originally an outdoor music is usually played in an open-sided hall called *Pendopo*. *Pendopo*, is a traditional building in Central Java, which is commonly used as a place for performing banquets and traditional dances accompanied by *gamelan* music.

Recently, Javanese *gamelan* is not only played in *Pendopo*, but also in a closed-room like a common concert hall or multi-purpose hall. Understanding the acoustical conditions of its typical performance hall is important to design a proper closed-room for the music.

Acoustic measurements of several *pendopos*, in the origin regions of Javanese *gamelan* have been carried out. The Initial Time Delay Gap (ITDG) and Subsequent Reverberation Time (T_{sub}) of four of them are presented in this paper. The results have also been confirmed with the opinions of Javanese *gamelan* experts and listeners

1.1. Javanese Gamelan

Gamelan gets its name from the low Javanese word *gamel*, which refers to a type of hammer, like a blacksmith's hammer. The name '*gamelan*' actually refers only to the instruments themselves, which are pre-dominantly percussion. Javanese have a separate word for the art of playing *gamelan* instruments namely *karawitan*, a noun formed from the word *rawit*, meaning 'intricate' or 'finely worked'.[1]

The bronze *gamelan* instruments are made from a mixture of tin and copper; three parts tin to ten parts copper. The word for '*gamelan*' in high Javanese is *gangsa*, a word in common Javanese etymology supposed to be formed from the two words ***tembaga*** (copper) and ***rejasa*** (tin), or from the numbers ***tiga*** (three) and ***sedasa*** (ten) expressing their proportions.

In a complete *gamelan* orchestra there are about twenty different types of instruments. However, the total number of instruments maybe as high as seventy-five, as there is need to be at least two of most of the one, for each of the two tuning systems. Some instruments (for example, the *kempul*) also exist as a set, and each item of that set may be counted separately.

Unlike the Western concert tradition where traditionally the function of the orchestra is to accompany the voice, in the Javanese *gamelan* orchestra the singing is no more or less important than any other instrument; its function is yet another melodic layer in the overall structure of music. A piece of *gamelan* music is usually complete when the singing is present, but it is possible, and quite satisfying musically, to play the same piece without it.

1.2. Pendopo

Pendopo, a large room, open-sided square veranda,[2] sheltered the functioning of Javanese states, with specific ones allotted to the law courts, the clergy and the king and his ministers for their public appearances. The symbolic importance of the buildings to the legitimacy of the rulers was carried out to new lengths in the late 18th century, when the court of *Pakubuwono II* of *Mataram* at *Kartasura* was transferred to a new capital near the village of *Solo*. Leading the grand procession of all court officials were the two *Waringin*, or Banyan trees, *Dewadaru* and *Jayadaru*, wrapped in silk and carried by officially appointed for the job. The descendants of these trees still stand square to the north of the court. Then the *pendopo* known as the *bangsal pengrawit* 'in its whole' was lifted and carried out to the new site by the *kalang* and *gowong* officials. Following were the elephants of the king, with their keepers and other officials, etc. By the same time the king had arrived, the *pendopo* had been set in its new place and the regalia and royal entourages were quickly moved to their proper positions around it. The king gave his audience, declaring that henceforth Solo, now to be called *Surakarta*, was to be his capital.[3]

Today the courts of Java preserve the ancient forms, though the trim is often modern. In the layouts of the *kratons* in *Yogyakarta* and *Solo*, some scholars see echoes of *Majapahit*. Ceremonials are still important to the *kratons*, and there is a busy life of courtiers as court-supported arts. Although the may not have any official roles in the running of the state today, the palace are still places of prestige, still able to arbitrate Java Style.

The Javanese houses are classified according to their roof forms, and houses are organized by the placement of the columns, which support roofs. Walls, it bear repeating, are secondary: their placement is determined by the roof-carrying columns. In the simplest Javanese house, four columns of equal height are braced a double layer of trusses. From the center of two of the trusses rise two columns, which in turn support a roof beam. This *kampung* roof falls away in two directions on either side of the beam. Of course, this simple shape may often be extended, added to and combined with other roof shapes.[3]

The most common roof type in Javanese houses is the *limasan*, created by extending the *kampung* model to a rectangular plan, with additional pairs of columns at either end. The basic shape is

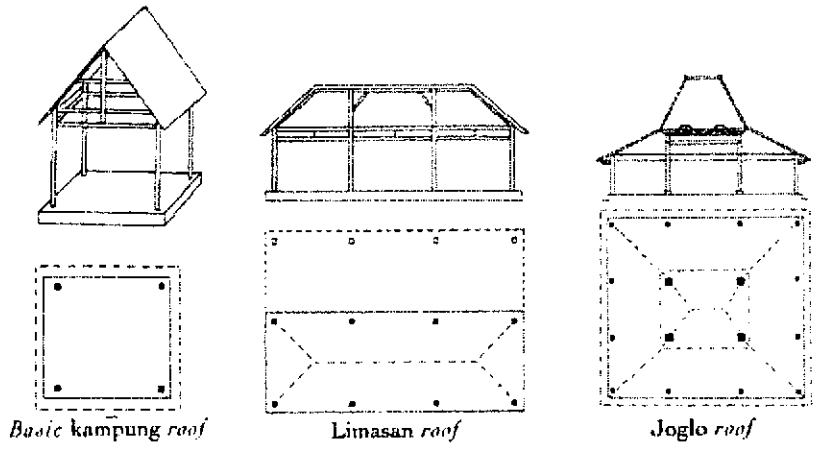

Figure 1. Roof Shapes of Javanese House[3]

created by the fact that the roof beam does not run the full length of the rectangular building, rather it extends over the inner most set of columns. This means the *limasan* roof has four slopes, two along the shorter axes. The typical *limasan* has four slopes and five ridges, and it begins to give emphasis to the central area between the innermost four columns.[3]

The most characteristic Javanese roof form for houses, and the most complex, is the *Joglo*. The

portion of the roof that sites over the innermost four columns, is much steeper, almost a pyramid, except that it comes to two points rather than a single one. The *joglo* does not use king posts as does the *limasan* or *kampung* roof. Rather, the master pillars are sometimes taller than the outer ones. And they resting on the top of the central four pillars are layers of wooden blocks, which step back into the center, and out to the sides. The outermost blocks support the roof that rises steeply above, the inner layers form a stepped pyramidal ceiling. The timbers of the inner layers are often heavily worked, carved, and gilded. This ceiling of stepped timber, the *tumpang sari*, is usually the most intensely decorated area of the traditional Java house.[3]

The *pendopos*, palace audience hall, or kind of pavilion which usually houses at least one set *gamelan*,[2] feature in many wealthier homes, including the *kratons*. Most of their roof shapes are the *Joglo*, however some of them are *Limasan*. A set of *gamelan* usually placed in one corner or side of *pendopo*. The center, under the *tumpang sari*, is kept clear for the dancer. The audience area is placed in main hall, left and right sides, or in the veranda. In some crowded urban areas, masonry walls might be erected around the *pendopo*.

1.3. Orthogonal Parameter

Extensive investigations have indicated that all of the significant objective parameters that are used to describe the sound signals at both ears of audiences in a room can be reduced to the following four factors [4] :

1. The Level of Listening
2. The Initial Time Delay Gap
3. The subsequent reverberation time, and
4. The Interaural Cross Correlation (IACC).

The paper will only evaluate the second and third parameter of each *pendopo*.

2. Data Collection

2.1 Objects of Measurement

Measurement was conducted in *Yogyakarta* and *Surakarta*. Several *pendopos* have been evaluated, four of them are presented in this paper. The four *pendopos* are *Pendopo Puro Pakualaman, Pendopo Tegalrejo, Pendopo Kepatihan,* and *Pendopo Mangkunegaran*.

The *pendopo agung* of the *Mangkunegaran* was originally built in 1810, but rebuilt earlier this century to a much more dramatic height, by Dutch architect, working in close collaboration with Prince *Mangkunegara VII*. Being the largest *pendopo* in the island, it is still the site of public ceremonies of the palace. The building now think as being one of the classic Javanese spaces was designed by a Dutch architect.[3]

It is in the center of the Palace Compound. Its 3270 sq.m *pendopo* is a place to perform banquets and traditional dances accompanied by *gamelan* music. The *gamelan* (heirlooms) called *'Kyai Kanyut Mesem'* (Drifting in smiles) is one of the best *gamelan* set in the country. There are also other sets kept here such as *Monggang, Kyai Udan Asih, Udan arum*, etc, and also a golden lion statue as a guard. The *Pendopo Ageng* is a traditional Javanese *Joglo* house, it has four main big pillars in the center. Its high rounded ceiling was painted with ornaments contains Javanese philosophycal teachings.[5]

K.G.P.A.A *Mangkoenagoro IX* had instructed the renovation at these ornaments and completed in September 1993. Javanese architecture is recognized as simple but elegant. The wooden pillars which support the *Pendopo Agung* were taken from the forest of *Danalaya* (Danalaya woods are preserved only for the *kratons* of *Yogya* and *Solo*, it is believed to contain supernatural power).
The golden-color of *Mangkunagaran* is yellowish-green (*pareanom*) combination as the identity of

this *kadipaten Anom* (Crown Prince) of *Mangkunagaran*.[5]

The *pendopo Pakualaman*, a *joglo* roof shape, is located in the magnificent, well preserved *Pakualaman* Palace or locally known as *Puro Pakualaman*, located 2 km east of the city main Post office at *Sultan Agung* street. This palace belongs to *Pakualaman* principality (*Kadipaten*). Its story dated back to March 17, 1813 when Prince *Notokusumo*, the son of Sultan *Hamengku Buwono I*, with Princess *Srenggorowati*, was throned by the British Lieutenant Governor General Sir Thomas Raffles as *Kanjeng Gusti Pangeran Adipati Arya* (K.G.P.A.A.) *Paku Alam I*. This brilliant Prince was coronated as *'Pangeran Merdiko'* (Free Prince) on June 1812 as proposed by Sultan *Hamengku Buwono II*.

The 5.4238 ha palace compound reflects a strong center of Javanese culture. The architect of this *puro* was K.G.P.A.A. *Paku Alam I* himself, who was an expert in culture and literature. Before entering the palace, one should cross the square, by passing : The main *'Wiworo Kusumo'* gate (1), here stands elegantly the *Joglo* style of *Pakualaman* mansion (the complete words are "*Wiworo Kusumo Winayang Reko*" means safety, justice and freedom). In the front part is a *'kuncungan'* (canopy) then the front hall called *Pendopo* or *Bangsal Utomo 'Sewotomo'* with its four main pillars in the center. These pillars are from special jati/teak wood from the village of *Karang Asem, Paliyan, Gunung Kidul*, south of *Yogyakarta*. All pillars in the *pendopo* are beautifully carved and painted. Huge crystal lamps are hanging on the ceiling.[5]

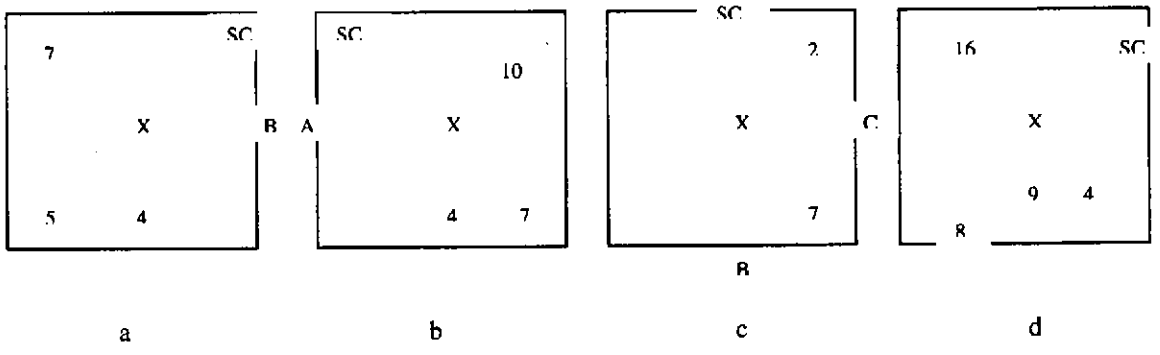

Figure 2. Measurement points : a. Pakualaman, b. Tegalrejo, c. Kepatihan, d. Mangkunegaran

Pendopo Kepatihan, a *Limasan* roof styled with four main pillars at the centre, located in *Kepatihan*, the office of the *patih*, the sultan's chief-officer. It's a place where power is executed; rank, promotion of officers is decided and finance is arranged. It was the *dalem* (mansion) and office of the Patih (Sultan's Chief Minister) during feudal (colonial time). The official name of every *patih* of *kraton Yogyakarta* was *Danurejo*, so the building is locally known as *Kepatihan Danurejan*, and is now the office of the Governor of *Yogyakarta* Special Region, located North of *Beringharjo* Market.

Pendopo Tegalrejo, a *Joglo* roof shape located in *Diponegoro* museum. It is the youngest *pendopo* compared to the other three. This *pendopo* is also has four main pillars, but it is not fully open-sided, since there is one side covered with concrete wall and the other side half-closed by a wood bar wall. A brief detail of the fourth *pendopos* is shown in Table 1.

Table 1. A Brief Details of the Pendopos.

	Ceiling	Floor	Main hall sq. m	Inner centre height
Pakualaman	metal	tile	1600	5.5 m
Tegalrejo	wood	tile	900	5.5 m
Kepatihan	wood	ceramic	850	7.5 m
Mangkunegaran	wood	ceramic	3000	10.5 m

2.2 Method

Measurements were carried out using Impulse Response Technique, with an MLS signal. The MLS signal was send to a loudspeaker through a full duplex sound card, and the room response was recorded by using a Sound Level Meter's microphone, then fed back to the PC through the sound card. The calculation of ITD and T_{sub} was carried out off line.

Measurement points in the four *pendopos* are shown in Figure 2.

3. Results and Discussion

3.1 Initial Time Delay Gap

The acoustical measure of intimacy is called the Initial Time Delay Gap (ITDG). It is defined as the interval in milliseconds between the arrival of direct sound and the first reflection to the listener.[6] The smaller the interval, the more intimate the hall, or the more involved the listener feels with the performance.

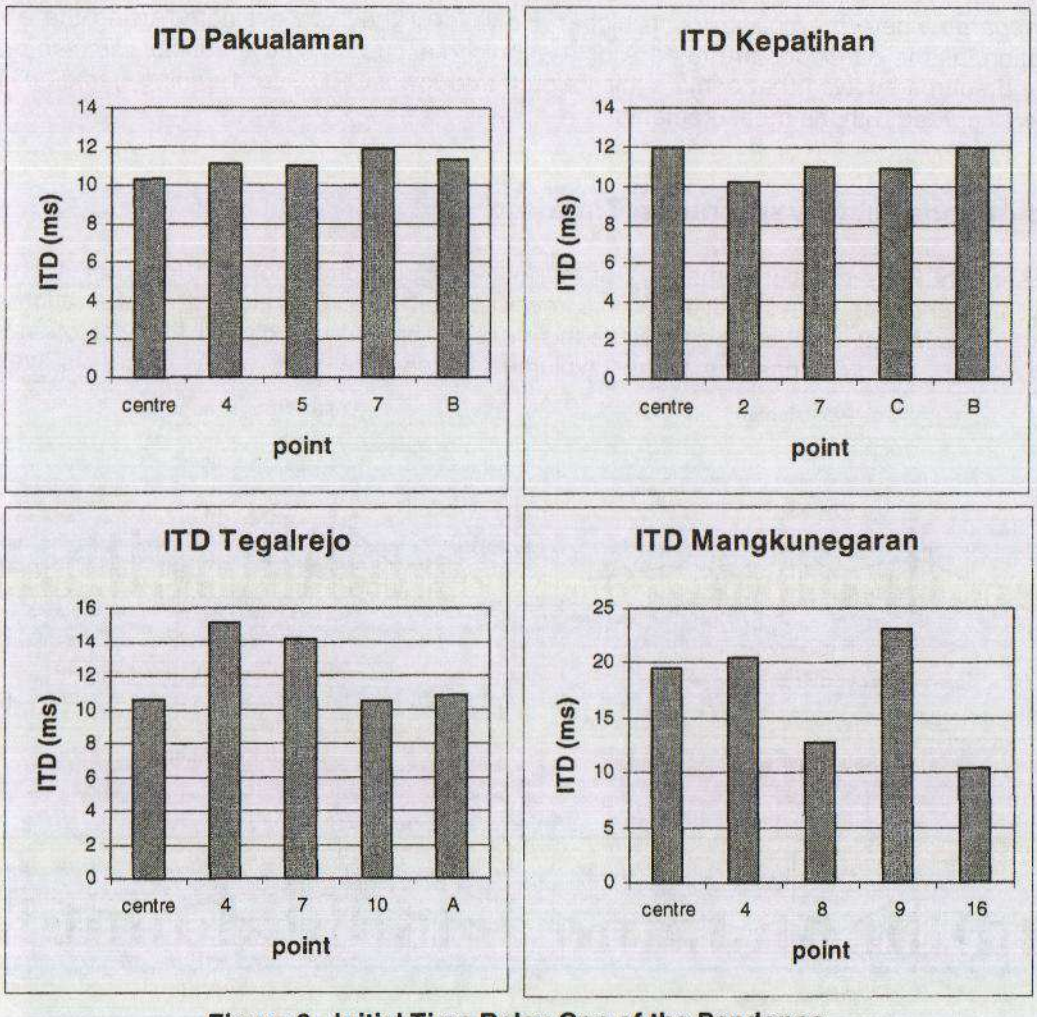

Figure 3. Initial Time Delay Gap of the Pendopos

ITDG is obviously a function of size of the hall. Our ears and brains are exquisitely sensitive to very fine time differences. Therefore ITDG is a means of mentally establishing whether one is in an acoustically small or large space.

In a wide hall or in an open air-music space, the intimacy can be improved by use of an orchestral enclosure. The enclosure provides early reflection of sound at the listener.

The appropriate ITDG depends on the type of music. Music whose harmonies and timings were written for spaces having a certain degree of intimacy tend to sound unnatural when played in spaces with a markedly different intimacy.

For concert hall, studies indicate a preference of a low ITDG.[6] Rate A and A+ are in between 10 to 25 ms, rate B and B+ are in between 20 to 40 ms. Since ITDG varies with the location in a hall, these values were measured at the centre of the halls.

The Initial Time Delay Gaps in the four *pendopos* are shown in Figure 3. It can be seen that *pendopo Pakualaman*, *Tegalrejo* and *Kepatihan* have ITDG around 10 ms, while *Mangkunegaran* has around 15-20 ms. The nearest reflector from the source is the ceiling. The ceiling above the source, in the first three *pendopos* is lower than the *Mangkunegaran*. It is why the ITDG of the three *pendopos* is smaller than the last one. It is also can be seen from the ITDG graphics (Figure 3), the distribution of ITDG in the first three *pendopos* relatively uniform, but not in the case of *Mangkunegaran* where the ceiling much higher. However if they are evaluated using the above classification, all the *pendopos* are rated A or A+. Psycho-acoustics study,[7] using *gamelan* music as a sound source showed that some subjects preferred lowest ITDG for listening *gamelan*. This result is well agreed with the measurements.

3.2 Subsequent Reverberation Time

The Subsequent Reverberation Time, T_{sub} of the four *pendopos* are shown in Figure 4. It can be seen that all *pendopos* have relatively similar reverberation time. The highest reverberation time belongs to *Tegalrejo*. It is not surprising since this *pendopo* is the most 'closed' than the other. The *Mangkunegaran*, although has the biggest volume, settled in a very open space, as well as

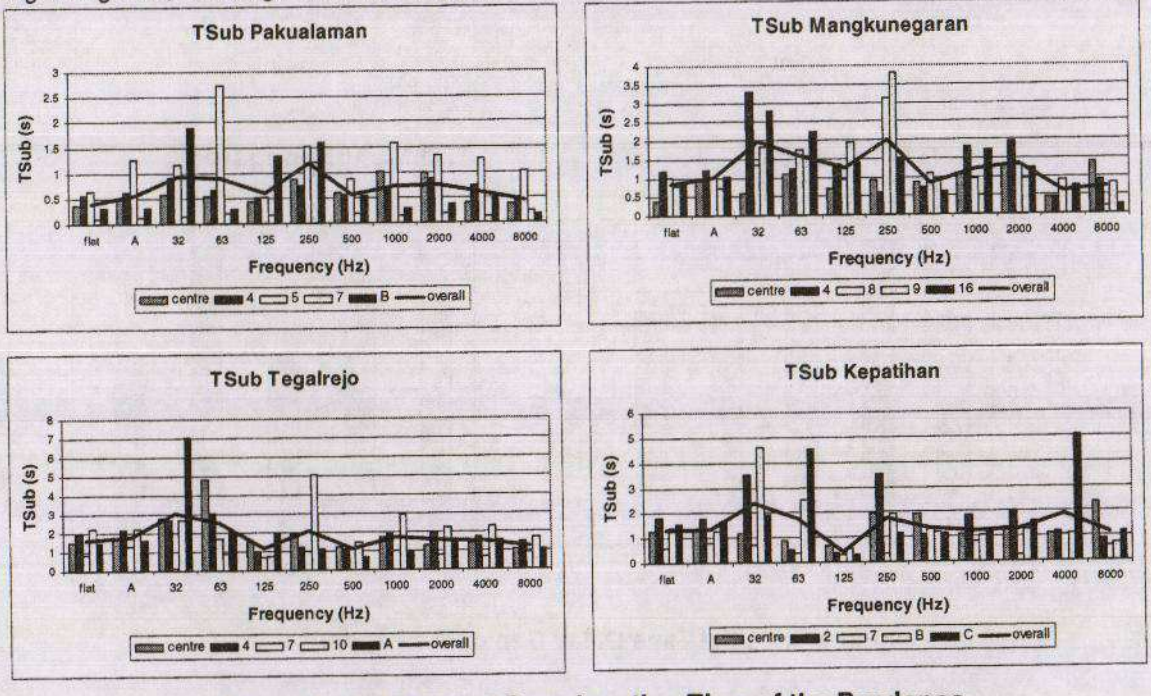

Figure 4. Subsequent Reverberation Time of the Pendopos

Pakualaman and *Kepatihan*. If we look at the trend on each graphics, trends of T_{sub} for each *pendopos* are similar though they have different values. They all have the highest value in the lowest frequency and the lowest value in 125 Hz, except in *Mangkunegaran* where the minimum T_{sub} was in the 8 kHz.

The dominant frequency of most instruments in a *gamelan* ensemble is in between 250 and 1250 Hz, with sounding duration (instrument reverberation time) 1 to 3 s, on average. They also have a special instrument, called Gong, which has a dominant frequency around 40 Hz and sounding duration about 4.5 s.

The average reverberation time at 500 Hz of *pendopo Pakualaman*, *Tegalrejo*, *Kepatihan* and *Mangkunegaran* were 0.60 (0.60 at the centre), 1.12 (1.20), 1.32 (1.92) and 0.86 (0.87) second, respectively. Although it can not be directly compared, the suggested reverberation time of a concert hall for orchestral music with a similar room 'volume' of those *pendopos* is around 1.9, 1.8, 1.9 and 2 second, respectively.

Reverberation time should be (reasonably) constant over the entire frequency range.[6] However, to provide a greater amount of reflected sound in the low frequency region, where the ear's sensitivity is low, an increase in low frequency reverberation (125 Hz and 250 Hz) is considered desirable. The

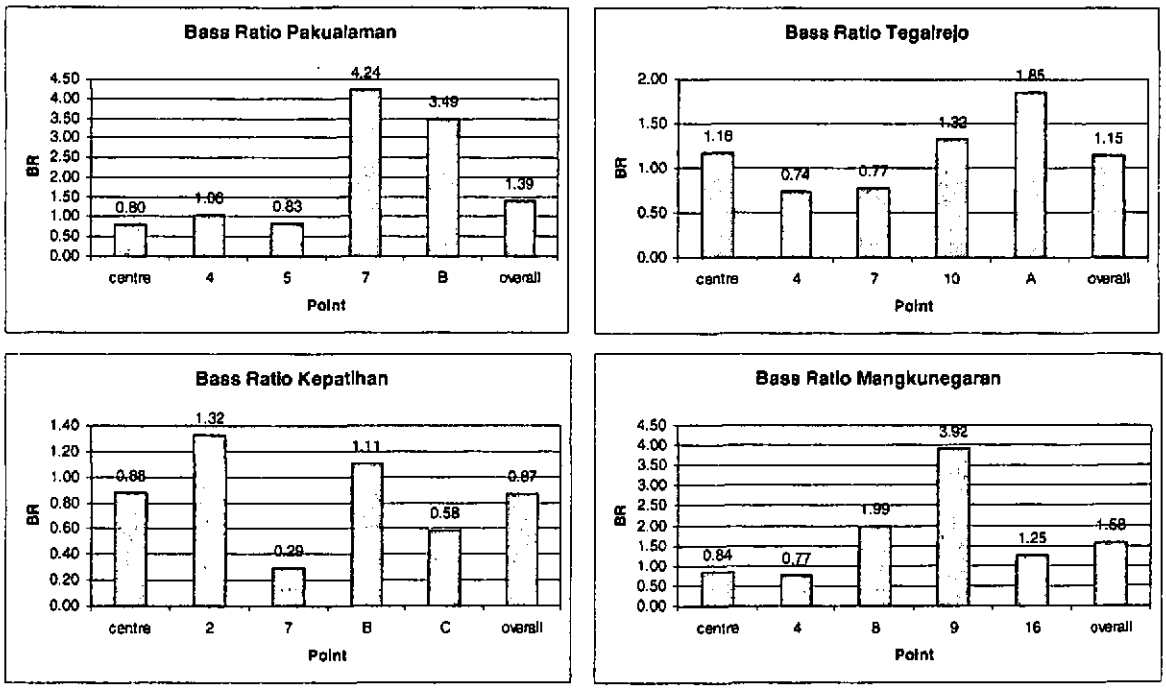

Figure 5. Bass ratio of the pendopos (unoccupied)

increase in low frequency reverberation time is particularly important in halls meant for music. For concert halls, a quantity called Bass Ratio (BR), which is defined by the following relationship, where RT is reverberation time.

$$BR = \frac{RT_{125} + RT_{250}}{RT_{500} + RT_{1000}} \qquad (1)$$

Bass Ratio is a measure of warmth in music. The preferred BR for a concert hall for music is 1.1 to 1.25 for highly RT hall and 1.1 to 1.45 for RT 1.8 s or less. A hall with BR less than 1.0 appears to have lack of warmth.[6]

It can be seen from the Figure 5, if the preference of classical music is used, the BR at most of the centre points, where dancers perform their action, except in *Tegalrejo*, have a lack of warmth. It is also the case on the audience area of *Kepatihan* (other point) except point 2 and B, *Tegalrejo* point 4 and 7, and *Mangkunegaran* point 4. However, It can not be concluded that all the *pendopos* have a lack of warmth, since *gamelan* has different characters of those in classical music.

Since the *gamelan* music itself has some dominant low frequency instruments with its own long reverberation times, there might be a special preference for this BR.

4. Expert Opinion

Some experts who are playing and/or listening to *gamelan* frequently were giving their opinion as follows.

Sapto Rahardjo : (Yogyakarta, gamelan expert/composer, player, listener)

I think *Pakualaman* is my best place for playing and listening to *gamelan* in *Yogyakarta*, I love the *reverberant* sound there. My second choice is *Tegalrejo*, the reverb also sounds good, while the reverberation time in *Kepatihan* is too long. I never have any experience in *Mangkunegaran* before....

Giovanni Sciarrino : (Italia, player, listener)

Puro Pakualaman - I would consider one of the best because the acoustic is balanced and not too resonant (as *Mangkunegaran* is). The cock did not bother too much. I wonder if in general the choice of the precise placement of the *gamelan* is made consciously, as it certainly influences the acoustic result of the music making.

Tegalrejo - I think it's where I attended *wayang*, not *klenengan*, and do not recall particular impressions with respect to sound.

Kepatihan - No special opinion.

Mangkunegaran - I may sing off the chorus, as the saying goes, but I consider it too resonant (too much reverberation) for normal *gamelan* playing. The sound becomes too muddy and you loose details. On the other hand, I find it nice for particular performances like the ceremonial *gamelans* (*Munggang, Kodok Ngorek, Carabalen)*, probably because in this case you have fewer instruments, and loud, and simple repetitive lines. I must add that any performance at *Mangkunegaran* becomes very nice and magical if the listener is FAR FROM THE PENDOPO (especially at night). And of course the architecture is outstanding, possibly the *nicest pendopo*.

Jody Diamond (USA, listener, player, moderator Gamelan mailing list)

My favorite *pendopo* by far is the *Mangkunegaran* -- for sound as well as mood. The *Paku Alaman* is nice, but seems a bit drier.

Tjahjono Rahardjo (Semarang, player, listener)

In *Surakarta* the best place is of course the *pendopo Mangkunegaran*.....

Hardjo Susilo (gamelan expert, player, Lecturer on gamelan in University of Hawaii USA)

With complete subjectivity (It simply means that I have performed or listened to performances on those pendhopo; and if I were to choose my preference I would go by that list in that order I would say *#Pendopo Puro Mangkunegaran, Solo #Pendopo Puro Pakualaman Yogyakarta, #Pendopo Agung Kepatihan (Bangsal Kepatihan) Yogyakarta, and finally #Pendopo Tegalrejo (Museum Diponegoro), Yogyakarta*

Nancy Cooper (player, listener)

I have heard performances at the first four *pendhopo* listed. By far my *favorite* is the *Pendhopo at Pura Pakualaman*. I have no expertise whatsoever in acoustics, I just like the way the sounds seems to float and resonate, without clashing. To me it sounds quite heavenly. I have made simple recordings there with a Walkman with no special microphone and the recording sounds better than some done in studios. I do not know how you could put this kind of response into scientific terms, however. I really have not

noticed the difference among the other three - they all sound good to me, although if pressed I guess I would like *Kepatihan* next best.
I just remembered that I once went to a rehearsal years ago at *Mangkunegaran*, but I do not have any particular memories about the sounds. I think that means that it did not impress me as much as the *pendhopo* at *Pakualaman.*

Elsje Plantema (Netherland, Gamelan Widosari Ensemble, player, listener)
From the *pendopo* I really know, *Mangkunagaran* is certainly number one. Wonderful acoustics!

Max Krausse (Canada, listener, player)
Mangkunegaran - It was the first *pendopo* I visited, the first time I had heard *karawitan* in Java and a really delicious experience. I think it is has the best acoustic environment of the three, possibly because it is the largest? Whatever the reasons, the one time I spent a few hours there (a Wednesday morning dance rehearsal) was a truly transcendental experience for me - the most beautiful music, a really welcoming atmosphere, everything I could ask for in a musical experience, except I could have listened for a few more hours if they had kept playing

Ernst L. Heins (Ethnomusicologist, University of Amsterdam, Netherlands)
The ones you mention are all equally excellent, of course....

Its apparently most of them prefer the *Mangkunegaran* and *Pakualaman* as the best place for *gamelan* performance, though most of them also never been in the other *pendopos.* However, It is also still not confirmed, whether some of player or listener prefer more reverb place or some other prefer less reverb for playing *gamelan.* It is become an interesting subjective study in this field.

5. Conclusion

It is shown that all the *pendopos* have a good ITDG and T_{sub}, however the *Mangkunegaran* and *Pakualaman* slightly better than the other, considering that it was a case of an open-sided hall and also the *gamelan* instruments have its own long reverberation times. The results were also agree with the opinion of some *gamelan* experts, and the subjective preference testing of the ITDG for listening a Javanese *gamelan* music,[7] using Indonesian and non-Indonesian subjects.

Acknowledgement

The authors would like to thank the Engineering Education Development Project – Asian Development Bank, for funding this research.

References

1. Lindsay, Jennifer, "*Javanese gamelan : traditional orchestra of Indonesia*", 2nd ed., Singapore; Oxford : Oxford University Press, 1992.
2. Becker, Judith, "*Traditional Music in Modern Java*", The University Press of Hawaii, 1980.
3. Sosrowardoyo, Tara and Schoppert, Peter, "*Java Style*", Thames and Hudson Ltd London, 1997.
4. Ando Y, "*Concert Hall Acoustics*", Springer Verlag, New York, 1985
5. http://www.joglosemar.co.id.
6. Mehta, Madan et. al., "*Architectural Acoustics, Principle and Design*", Prentice Hall, 1999. ch. 10 and 12.
7. J. Sarwono and Y.W. Lam, "*Initial Time Delay Gap for Javanese Gamelan Concert Hall : An Auto Correlation Function Approach*", proceeding of IoA, Volume 21 Pt 6, 1999, pp. 47 - 54.
8. J. Sarwono and Y.W. Lam, "*Auto-correlation Function Analysis of Javanese Gamelan Music Pieces*", proceeding of ISSM'99, Kassel, Germany, 8-9 October 1999.