STRUCTURAL ACOUSTIC COUPLING RESONANCE OF HINDU TEMPLES

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Abstract- Some ancient constructions over the world exhibit acoustic resonance chambers [1, 7]. Acoustic resonance of Pyramids [1], Stupas [2,6,7], Cathedrals [3,4,12] and Mosques [5] have been studied and they closely resembles the Alpha, Theta and Gamma waves of EEG spectrum [11]. Moreover, these EEG frequencies corresponds to the alert calmness that conducive for mental composure and general well being [6, 7]. Research has also showed that these frequencies are also closer to the Shumann resonance frequencies [9,10]. Even though, acoustic resonances are in the mechanical vibration domain the researchers have found these vibration energies may have transformed into equivalent electromagnetic frequencies (EEG and Shumann bandwidth) [1,6]. This conversion is mostly may have achieved in ancient resonance chambers by properly using special quartz crystals [2,6,7] and getting them to vibrate by acoustic energies. In addition, some of these acoustic resonance chambers also have vibrating frequencies which are octaves of 528 Hz and 432 Hz [13]. These frequencies are also known to be healing frequencies commonly used in sound therapies [14]. Limited research has been done to understand the acoustic resonance chambers of Hindu Temples. Two types of acoustic resonance chambers can be found in Hind Temples. The first one is the "Moolastana" chamber and the other is the inner core (path). We have studied, and measured acoustic resonance frequencies of inner core chamber in a Hindu Temple in Sri Lanka

Index Terms- Structural acoustic resonance, Hindu Temples, Finite element modelling and reverberation time

I. INTRODUCTION

The acoustic resonance was measured by using a microphone placed in selected locations of the inner core chamber while exiting the inner core with monotone frequencies. Frequencies from 35Hz to 1200Hz were used for the experiment and the sound levels at each tone is measured and the relative loudness spectrum is obtained reference to the loudness at the speaker. The locations are selected in the far field of the as shown in the Figure 1.0 maintaining a minimum distance from the sound source using the equation 1. A minimum of quarter wave length is preserved.

$$d_{min} = 2\sqrt{\frac{V}{cT}} \text{-----(1)}$$

Where, d_min is the minimum distance needs to be maintained and V is the volume of the inner core. C is the velocity of sound (345m/s) and T is the expected minimum reverberation time (taken as 100ms).

$$Relative\ Loudness = 10\log\left[\frac{Sound\ power\ at\ the\ location}{Sound\ power\ at\ the\ Speaker}\right] \text{---------(2)}$$

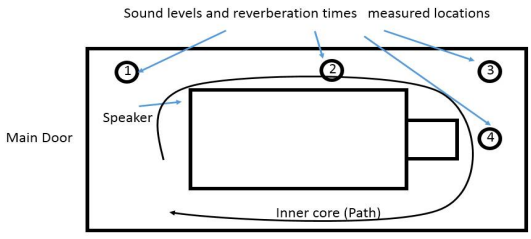


Fig 1.0 Plan of the Temple and the location of the speaker and sound level measurement points

Due to the symmetry of the inner core only one side sound level measurements were taken at points shown in Figure1.0 . Also the measurements were taken while the Temple doors were closed. Sound level at the speaker is taken as 0dB.

Reverberation times (RT) are measured in the inner core at the points shown in the Figure 1.0. Sound levels recordings were taken starting before the source is cut off and continued after the source is cut off until reverberation cannot be no longer detectable(more than 8 seconds). Frequencies from 35 Hz to 560Hz were used to energize the inner core during and three sound traces were recorded for each frequency and the average is taken

The RT is obtained when sound levels decay bellow 60dB by measuring the times at -5dB (t_{-5}) and -35dB(t_{-35}) levels and using the equation 2.

$$RT = \left[\frac{60}{(-5-(-35))/((t_{-5})-(t_{-35}))}\right] \text{-----(3)}$$

A typical measured acoustic signal and estimation of the RT is shown in the Figure 2.0

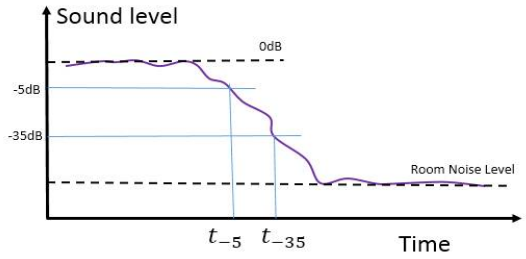


Figure 2.0 RT measurement

II. STRUCTURAL ACOUSTIC RESONANCE MODELLING

In this research Hindu Temples which are fully constructed with granite stones and concrete are considered. A selected Hindu Temple structure was meshed and estimating the acoustic resonance modes using Finite Element Methods (FEM). A Temple cavity with internal mass and texture is modeled with a general purpose FEM, for analyzing it under two categories namely structural vibrations and resonance modes. A complete model of two dimensional structure of the selected Temples is modeled and analyzed for its fundamental modes and their interactions with the cavity medium.

The free vibrating acoustic cavity of the inner core can be considered as an elastic structure completely filled with homogeneous, inviscid and compressible fluid, neglecting the gravity effects (structural acoustic coupling problem)[16]. The finite element solution of structural acoustic coupling problem was formulated by Carlsson[16].

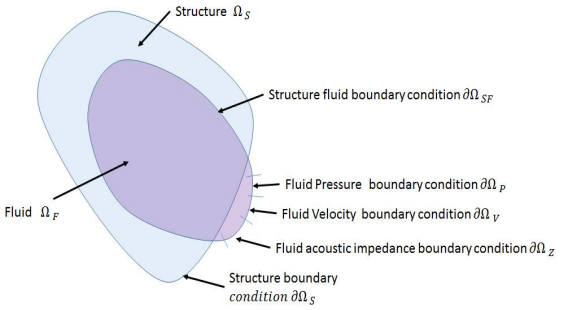


Figure 3.0 Diagram of structural acoustic coupling problem

The sketch of the structural acoustic coupling problem is shown in the Figure 2.0. The problem consist of two mediums structure and fluid namely and their respective boundary conditions are marked in the Figure 2.0. Mathematical formulation is done with the following force equation in elastic solid continuum medium and the boundary conditions. The strains of structure and fluid boundary condition where assumed to be equal and the pressure and the normal stress are also assumed to be equal.

Structural medium $\vec{\nabla}^T\sigma_S + b_s = \rho_s\frac{d^2u_S}{dt^2}$ $in\ \Omega_S$ and $\partial\Omega_S$ and initial conditions ----(4)

Where, σ_S is the stresses, $b_s$is the body force density, $\rho_s$is the density and $U_S$is the displacement.

Fluid medium $\frac{\partial^2 P}{\partial^2 t} - c_0^2\vec{\nabla}^2 P = c_0^2\frac{\partial q_F}{\partial t}$ $in\ \Omega_F$ and $\partial\Omega_P, \partial\Omega_V, \partial\Omega_Z$ and initial conditions. –(5)

Where, P is the pressure, c_0 is the acoustic velocity, $q_F$is the mass added for a unit volume.

Coupling boundary $U_S|_n = U_F|_n$ displacement at the boundary and $\sigma_S|_n = -P$ is the stress at the boundary. ---(6)

The finite element solution is given by the Equation 7 [16]. In the solution of the model problem Linear Lagrange multiplier methods (LLM) is employed. A set of super nodes which facilitates direct coupling with the structure and the cavity mass is employed.

$$\begin{bmatrix} M_s & 0 \\ \rho c^2 H^T & M_F \end{bmatrix}\begin{bmatrix} \ddot{U} \\ \ddot{P} \end{bmatrix} + \begin{bmatrix} K_S & -H \\ 0 & K_F \end{bmatrix}\begin{bmatrix} U \\ P \end{bmatrix} = \begin{bmatrix} F_b \\ F_q \end{bmatrix} \quad \text{----(7)}$$

Where, M_S *is the assembled structural mass matrix*

M_F *is the assembled fluid mass matrix*

$\rho c^2 H^T$ is the assembled fluid structure coupling mass matrix

K_S is the assembled structural stiffness matrix

K_F *is the assembled fluid equivalent stiffness matrix*

$-H$ is the assembled coupling stiffness matrix

F_b is the assembled body force matrix

F_q *is the assembled fluid flow force matrix*

U and P are nodal displacement and pressure matrices For acoustic resonance simulations only steady state natural vibration modes are considered and then the equation 7 reduce to Eigen equation 8 [15].

$$\begin{bmatrix} M_s & 0 \\ \rho c^2 H^T & M_F \end{bmatrix}\begin{bmatrix} \ddot{U} \\ \ddot{P} \end{bmatrix} + \begin{bmatrix} K_S & -H \\ 0 & K_F \end{bmatrix}\begin{bmatrix} U \\ P \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \quad \text{----(8)}$$

III. TWO DIMENSIONAL (2D) FINITE ELEMENT (FE) MODELLING

The numerical model of the Temple structure together with its cavity filled with air mass is analyzed using coupled fluid structure interaction (FSI) modules. The modal solutions are obtained for fully direct coupling between the structure and the fluid medium (air mass). The moving structures such as humans and other objects inside the cavity are not considered for the model. Also the inner core assumed to be a close enclosure. Both two dimensional and three dimensional models are developed for the compassion with the measurements. In 2D formulation the meshing was done according to the following Figure 4. Rectangular quadrature two dimensional elements are used for the solution. The boundaries are assumed to be hard boundaries for our initial solution.

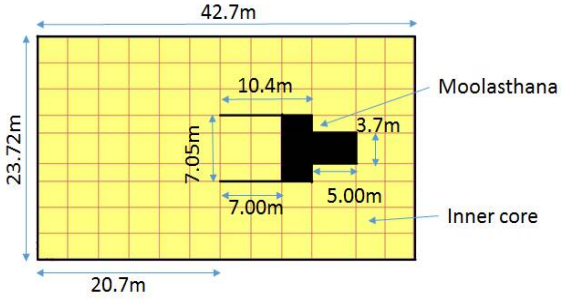


Figure 4.0 Meshed grid and the hard boundaries in black

The numerical model is compared with the acoustic measurements in the inner core of the Temple.

Material properties of the cavity are selected as, speed of sound(c) $345ms^{-1}$, density(ρ)$1.18kgm^{-1}$, thickness (t) 3.6m(height of the chamber) and Integration rule 3X3. Boundaries are modelled with 2D beam elements internal chamber is modelled with acoustic 2D quad isoperimetric elements. The formulation is done with three steps.

First step was the formulation of the M_S and K_S by assembling all the structural elements. The second step was the formulation of M_F and K_F by assembling the acoustic elements. Third step was the formulation of H by using the coupling between the solid and the fluid. At the boundary it is assumed that the degree of freedom (DOF) of the acoustic element is tangential due to the pressure and that of the solid element is three degrees. The fourth and the final step of the formulation was the assembling the Eigen equation 8 for obtaining the resonance modes of acoustic vibrations. The initial conditions assumed to be zero at the boundaries.

IV. THREE DIMENSIONAL (3D) FINITE ELEMENT (FE) MODELLING

Acoustic resonance chamber dimensions are modelled as shown in Figure 5.0 and direct coupled elements are used at the boundary between the solid and the acoustic cavity. Same material properties that are used for 2D model are used for the simulation of the 3D model. Tetrahedral acoustic elements are used for the meshing the acoustic cavity and 8 node quad elements are used for the solid structure. The Figure 6.0 shows the mesh of the acoustic resonance chamber.

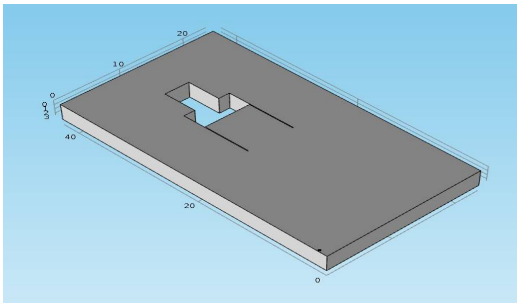


Figure 5.0 3D Diagram of the acoustic resonance chamber of the Temple

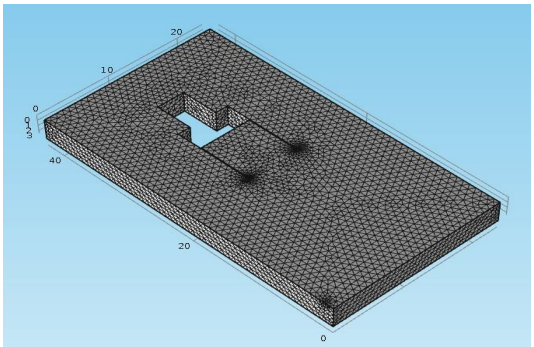


Figure 6.0 3D Mesh of the Temple acoustic chamber

The frequencies are investigated from 35Hz to 1200Hz. The formulated problem is solved by a popular finite element engine.

V. TWO DIMENSIONAL FEM RESULTS

For the 2D FE formulation, the resonance modes are obtained by using a popular 2D FE engine, and the results are shown in the following Figure 7.0.

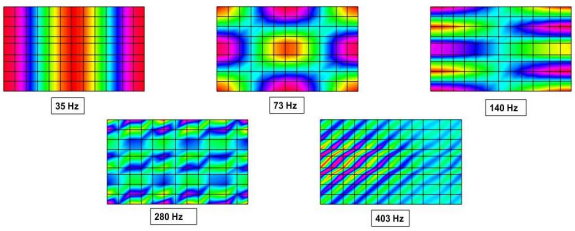


Figure 7.0 Acoustic pressure resonance modes

VI. THREE DIMENSIONAL FEM RESULTS

The acoustic pressure of the 3D simulated results are shown in the Figure 8.0 and It was fund from the simulation results that the peak values are significant at frequencies 65Hz,71Hz,90Hz,172Hz,230Hz,345Hz,402Hz,477Hz ,513Hz,537Hz,573,605Hz and 939Hz.

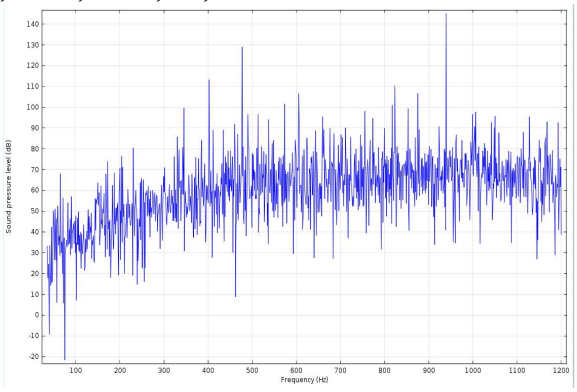


Figure 8.0 Frequency response of the acoustic pressure of the Temple resonance chamber

The resonance modes of the 3D simulation results are shown in Figure 9.0. It can be clearly seen that at higher frequencies complex modes are manifesting.

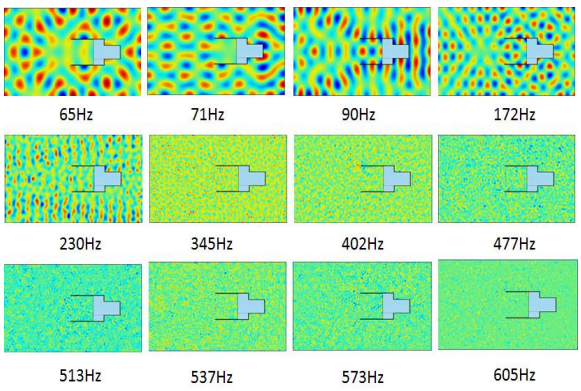


Figure 9.0 Resonance modes of the Temple resonance chamber

VII. ACOUSTIC MEASURMENTS

Figure 10.0 and Figure 11.0 show the measured sound levels of the four points of the inner core at frequencies from 35Hz to 1200Hz.Above 1200Hz frequencies are not measured as the attenuation is greater. It was observed peak value around 430Hz at all four points out of all four points measured. That is point 1 had the largest sound level values at frequency range considered.

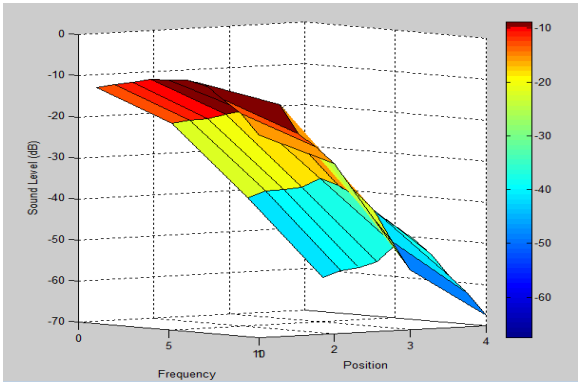
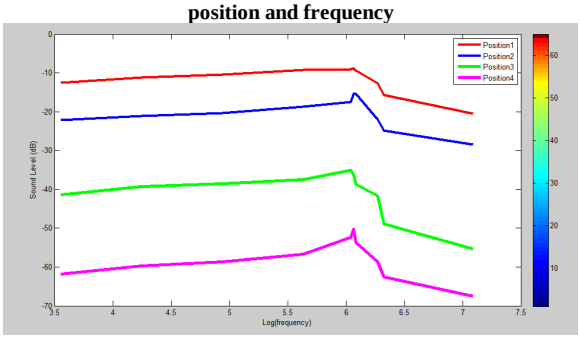


Figure 10.0 Surface plot of the sound levels with respect to position and frequency



F Figure 11.0 Sound levels at four points against log frequency

Figure 12.0 and Figure 13.0 show the reverberation times (RT_{60}) at 420,430 and 440 Hz frequencies other frequency reverberation times are not considered as they are bellow 50ms. A maximum RT_{60} of 1.2s observed at point 1 at 430Hz. At other three points it was observed that the $RT_{60}s$ were exponentially reducing with the distance from the source and the frequencies deviating from 430Hz.

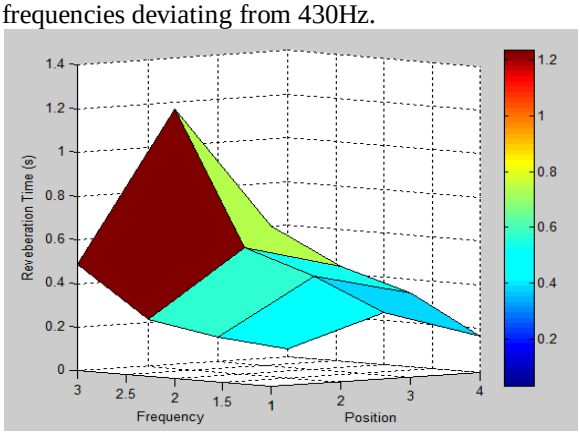


Figure 12.0 Surface plot of the Reverberation time of the inner core

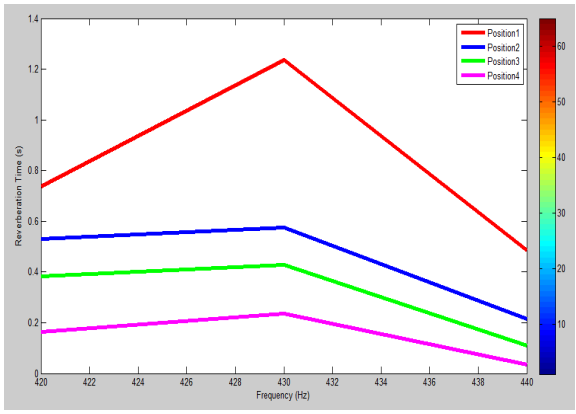


Figure 13.0 Reverberation time of the inner core

VIII. DISCUSSION & ACKNOWLADGEMENTS

The resonance frequency and maximum reverberation time observed near 430Hz and this frequency is closer to the 432Hz used in sound healing. However more research work is needed to be carried out with multiple of Hindu Temples around the world in order to understand the acoustic resonance of the Hindu Temples. The resonance modes of the simulated results and the measured values showed deviations and in future we are expecting to refine our models and also improve the measurements. In addition we are planning to model the reverberation of the Hindu Temple acoustic resonance chambers as well. More over in future further measurements and modelling are expected carried out at the "moolasthana" chamber as well.

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