CHAPTER II

LITERATUR REVIEW AND THEORETICAL BASIS

2.1 Literature Review

Banerji et al. (2000) conducted an experimental study on various parameters of TLD for structural response control of structures. The TLD parameter such as, frequency ratio, ratio of depth and mass ratio, which affect TLD performance in controlling earthquake response structures, are verified experimentally. Various values of frequency, base motion, and amplitude are considered in experiments to study the effectiveness of TLD for structures various movements of earthquake. Recent research studies have concentrated on innovative methods for controlling earthquake response structures by installing additional devices in the right locations in the structure.

A similar study by Banerji (2004) concluded that the main emphasis in writing results obtained using extensive experimental and numerical simulation results to illustrate that TLD, which is one of the control devices the most economical currently available, can be designed to effectively control the response of structures experiencing a large amplitude of broad banded basic Excitation, as experienced during earthquakes. There are two main conclusions in this study: a numerical simulation procedure based on the TLD formula proposed by Sun [5] can adequately predict structural responses in TLD systems — structures that experience a large amplitude of broad banded base excitation, although slightly underestimating the structural decline in response by TLD, perhaps due to underestimating energy dissipation by breaking waves during a strong shaking phase from the base of excitation . In addition The TLD-to-structure mass ratio and the ratio of depth (ratio of water depth to tank length in the direction of shaking) are TLD parameters which have a significant effect of TLD ability to control structural response to large amplitude base Excitation. A mass ratio of 4% and a ratio of 0.15 depths allow the TLD to be the most effective for wide banded soil movements. This optimal TLD can reduce the SDOF structure response usually around 30%, which is enough from a design point of view.

Bhattacharjee at el. (2013) a set of experiments were carried out for studying the sloshing phenomenon in a rectangular and a square tank under harmonic loading condition. Different water depth ratios varying from 0.05 to 0.3 and several excitation frequency ratios varying from 0.75 to 1.3 were considered. From this study, it has been observed that among all the water depth ratios for a given range of Excitation frequency ratios, there exists optimum water depth that corresponds to the minimum response amplitude for each damper. These values are 7.5, 5 and 7.5 cm, respectively, for TLD1, TLD2, and TLD3. It is seen that the square TLD is less effective in comparison with the rectangular TLD for the controlling response of the structure. Therefore, it is observed that TLD1 has better performance in comparison with TLD2. From this study, it has been found that TLD can be successfully used to control the response of the structure.

Pabarja at el. (2018) This study investigated experimentally the effectiveness of conventional Tuned Liquid Dampers (TLDs) for vibration mitigation of a vertically irregular structure. A three-story one-bay steel structure with the total height of 2.65 m was specifically designed and constructed in order to represent a vertically irregular structure. The test structure was subjected to free extracted. The test structure was equipped with TLDs that were tuned to its first and second resonance frequencies. The mass ratio for all studied TLDs was constant and equaled 3%. The TLDs were placed on each floor separately and the dynamic responses of the structure-TLD systems were measured for all floors. It was concluded that conventional TLDs were able to mitigate structural vibrations of a vertically irregular structure when it was excited at its first resonance frequency. However, TLDs were unsuccessful in reducing the peak displacement responses of all floors at the second resonance frequency.

2.2 . Shallow water theory

In the area of coastal hydrodynamics, concerned with modelling of flows in rivers, channels, estuaries etc, shallow water approximations of the incompressible Navier-Stokes equations are often used. The most popular model equations for studying near-shore hydrodynamics, Brocchini et al. (2001), and in general free surface flows in shallow water, are the Nonlinear Shallow Water Equations (NSW equations) also known as de Saint-Venant equations together with a large class of so-called Boussinesq-type equations (BT equations). A comprehensive overview and review of BT equations is given in Madsen (1999). In the shallow water models the momentum and mass conservation equations are depth-integrated resulting in a reduction of variables by one compared to the full problem described earlier. But more importantly, by substituting the nonlinear kinematic boundary condition into the depth integrated mass and momentum equations, the full nonlinear description of the free surface is retained *exactly* leaving only, for the 3D case, two equations for the conservation of momentum and one equation for the conservation of mass. The variable describing the free surface enters into the mass conservation equation and thus requires no special treatment. While these simplified models fail to give a detailed description of the local fluid behavior, a natural consequence of the averaging, they are very well suited for providinga description of the overall fluid behavior. The models though are by construction limited to the shallow water case which might be a serious limitation. However, and imperative for use in connection with describing TLDs, the models are often very fast to solve.

2.3. Sloshing in rectangular tanks

For accurately capturing the motion of sloshing water in a vibrating tank, nonlinear functions must be employed. If the conventional spring mass formula is used for modeling liquid sloshing behavior, then all the constants and will no longer be constants m, k and c, but rather functions of displacement i.e $m(x)$, $k(x)$ and $c(x)$. Most often, the numerical modeling is coupled with CFD (Computer Fluid Dynamics) software simulations and/or actual experimental setup simulations to obtain various curve fits for m, k and c and as functions of x. This is could be further complicated if water is confined in a complex geometry. Mondal, J. (2014)

In experimental case, water was confined in a simple rectangular container. At high water amplitudes, the linear models are no longer valid, since various non linearities enter the system, such as wave breaking and slamming (instead of sloshing). In this paper, a rather simple approach has been taken to model the system. Linear theory existing in literature has been used to find the natural frequency of water confined rectangular, which is given by (Abramson, 1966):

$$\omega = \frac{1}{2\pi} sqrt\left(\frac{g\pi}{a}\tanh\left(\frac{\pi h}{a}\right)\right) \tag{2.1}$$

where, ω =the natural frequency of sloshing in Hz

h =height of the water in the container

a =the length of the container in the direction of excitation

The dampening factor was also modeled linearly using the equation.

$$\zeta = sqrt\left(\frac{v}{a^{\frac{3}{2}}\sqrt{g}}\right) \tag{2.2}$$

where, v =kinematic viscosity of the liquid Equations (1) and (2) are only valid for shallow water cases (cases when $\frac{h}{a} > 0.15$)

2.4. Numerical method

After establishing a mathematical model, equations must be solved to provide a solution. Analytical solutions are always preferred, but building analytical solutions for nonlinear partial differential equations is very difficult, time-consuming and often impossible. Instead the equation must be solved approximately using numerical methods.

After building and applying numerical methods, it is important to verify that this method provides reliable results, namely solving mathematical problems with acceptable accuracy. The only way to verify this is to test the numerical method for the problem where the analytical solution exists. If there is no analytical solution then it must be built.

This chapter focuses on the choice, development and verification of numerical methods.

2.5. Genetic algorithm (GA)

Genetic algorithm (GA) is a stochastic algorithm that mimics natural phenomena as operators in the processing. The idea behind the mechanics of GA is to resemble the adaptive process in nature based on Darwinian's survival of the fittest mechanisms. GA has been used to obtain the optimum design of the function and has shown its superiority in obtaining nearly global optimum solution of the complex problems. Originated by Hollandin 1960s (Goldberg, Holland ,Michalewicz). GA has been used to obtain optimum value in many areas.

2.6. Comparison with Den Hartog Method

The comparison result with Den Hartog (1947) were calculated. In Den Hartog methods, the structure is converted to a single degree of freedom system then damper parameters are computed. The formula of Den Hartog [30] was based on the SDOF undamped structure with harmonic external load. According to Den Hartog the optimum tuning frequency ($\alpha opt=\omega TMD/\omega structure$) can be expressed as :

$$\alpha_{opt} = \frac{1}{1+\mu} \tag{2.3}$$

whereas the optimum damping ratio of the damper ξ *dopt* is formulated as:

$$\xi_{dopt} = \sqrt{\frac{3\mu}{8(1+\mu)}} \tag{2.4}$$

μ is the mass ratio of damper. To use the formula, the MDOF structure is then converted to SDOF structure following procedure in Soong and Dargush [1] by normalizing the mode shape at the location of TMD to be 1 unit.

The first modal mass:

$$M1 = \phi_1^T M \phi_1 \tag{2.5}$$

The mass ratio:

$$\mu = \frac{m_d}{M_1} \tag{2.6}$$

The optimum frequency ratio from Eq.(3):

$$\alpha_{opt} = \frac{1}{1+\mu} \tag{2.7}$$

From which we can obtain:

$$\omega_d = \alpha_{opt}\,\omega_1 \tag{2.8}$$

and

$$k_d = m_d\,\omega_d^2 \tag{2.9}$$

From Eq.(4):

$$\xi_{dopt} = \sqrt{\frac{3\mu}{8(1+\mu)}} \tag{2.10}$$

Such that

$$C_d = 2\,m_d\,\omega_d\,\xi_d \tag{2.11}$$

2.7. Equation of Motion

The equations of motion for this building equipped with a dynamic absorber under wind-induced excitation can be written as chang and Qu[2] (1998) :

$$\mathbf{M\ddot{X}} + \mathbf{C\dot{X}} + \mathbf{KX} = \mathbf{F} - \mathbf{H}(G_3\ddot{w} + G_2\mathbf{H}^{\mathbf{T}}\mathbf{\ddot{X}}) \tag{2.12}$$

$$G_1\ddot{w} + C_t\dot{w} + K_t w = G_3\mathbf{H}^{\mathbf{T}}\mathbf{\ddot{X}} \tag{2.13}$$

where **M, C, K, X,** $\mathbf{\dot{X}}$ and $\mathbf{\ddot{X}}$ are the mass, damping and stiffness matrices, and the displacement, velocity and acceleration vectors for the tall building, respectively; **F** is the wind-induced loading vector; **H** is the location matrix for the dynamic absorber; the superscript **T** represents the matrix transpose; w, $\dot{w}$ and $\ddot{w}$ are the displacement, velocity and acceleration for the dynamic absorber, respectively; C_t and K_t are the damping and stiffness coefficients for the dynamic absorber, respectively; and G_1, G_2 and G_3 are the coefficients of the dynamic absorber.

For the case of a rectangular tuned liquid damper (R-TLD), the expressions of these five coefficients become :

m_cÜ + c_ců + k_cu + f (TLD) = - m ůj (TLD) (2.14)

[M]ů□ + [C]ů + [K]{ů} = F-

(2.16a, b, c) $C_t = 2\varsigma_t \omega_t M_t$; $K_t = \omega_t^2 G_1$

(2.16d, e)

With

$$d_1 = \frac{1}{\pi_1^2 - 1} \tag{2.16f}$$

$$F_1 = \frac{1}{\pi}\frac{\alpha}{h}\tanh\left(\pi_1 \frac{h}{\alpha}\right) \tag{2.16g}$$

$$M_t = \rho\alpha bh \tag{2.16h}$$

$$\omega_t^2 = \pi\frac{g}{\alpha}\tanh\left(\pi\frac{h}{\alpha}\right) \tag{2.16i}$$

From these equation we can formulate equation for find optimal h (L) :

$$\tanh\left(\frac{\pi h}{l}\right) = \frac{\omega tld^2}{\frac{\pi g}{l}} \tag{2.17}$$

$$\tanh\left(\frac{\pi h}{l}\right) = \frac{l\omega tld^2}{\pi g} \tag{2.18}$$

$$h = \frac{l}{\pi}\tanh\frac{l\omega tld^2}{\pi g} \tag{2.19}$$

To determine the model used for this research table 2.1 is made to see the range of optimum h depending on tank length (L) and structure fundamental Period (T).

Table. 2.1 Optimum h for period (T) in each tank length (L)

T/L	10cm	20cm	30cm	40cm	50cm	60cm	70cm	80cm	90cm
10.00	4.07747E-05	0.000163	0.000367	0.000652	0.001019	0.001468	0.001998	0.00261	0.003303
5.00	0.0001631	0.000652	0.001468	0.00261	0.004078	0.005873	0.007995	0.010444	0.01322
3.33	0.000366989	0.001468	0.003304	0.005876	0.009184	0.013232	0.018021	0.023553	0.029832
2.50	0.000652487	0.002611	0.005879	0.010462	0.016367	0.023606	0.032189	0.042134	0.053456
2.00	0.001019717	0.004083	0.009203	0.0164	0.025705	0.037159	0.050812	0.066726	0.084976
1.67	0.001468932	0.005888	0.013296	0.023758	0.037369	0.054258	0.074594	0.098593	0.126532
1.43	0.002000591	0.008034	0.018199	0.032666	0.051693	0.075649	0.105048	0.140608	0.183351
1.25	0.002615452	0.010533	0.023978	0.043355	0.069313	0.102857	0.145563	0.200029	0.270931
1.11	0.003314682	0.013406	0.030745	0.056236	0.091465	0.13926	0.205188	0.302616	0.48344
1.00	0.004099997	0.016681	0.038683	0.072061	0.120799	0.194206	0.324205		
0.91	0.004973831	0.020406	0.048096	0.092309	0.16436	0.316713			
0.83	0.005939548	0.024648	0.059515	0.120414	0.255321				
0.77	0.007001709	0.02951	0.073945	0.167637					
0.71	0.008166424	0.035152	0.093616						
0.67	0.009441815	0.041833	0.125241						
0.63	0.010838667	0.050007	0.229522						
0.59	0.01237134	0.060566							
0.56	0.014059114	0.075654							
0.53	0.015928247	0.103238							
0.50	0.018015245								

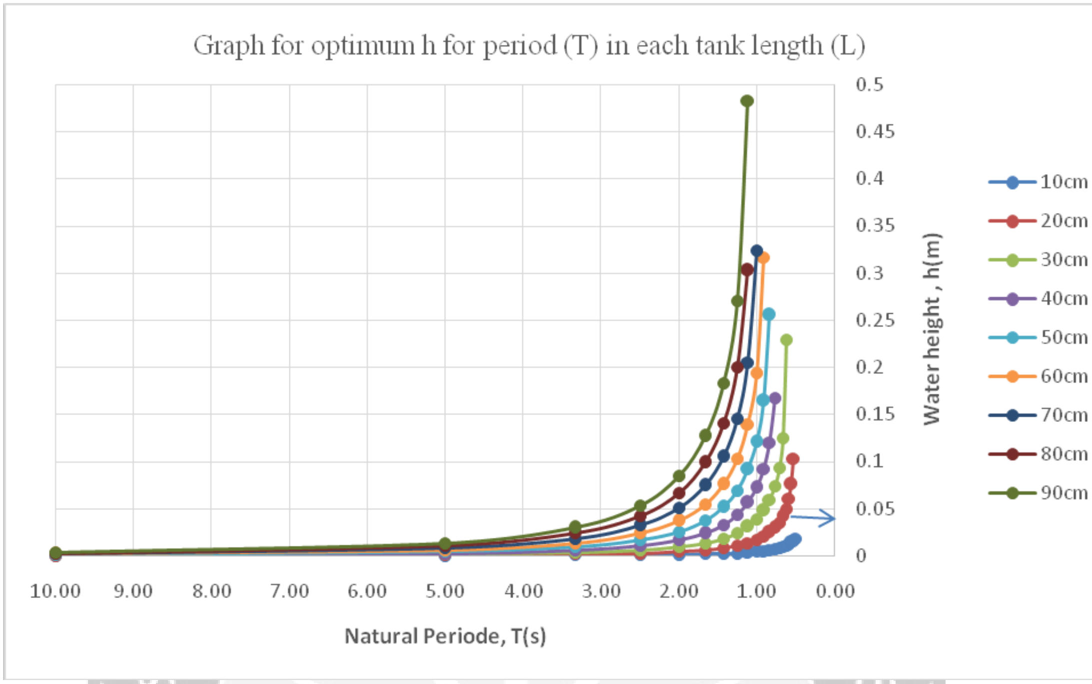

Figure. 2.1 Optimum *h* for period (T) in each tank length (L)

In table 2.1 the blank portion are the part where the equation cannot be calculated and the marked table are the value that favorable to be used as the target *h* (water height more than 0.04 m).

In Fig 2.1 we can observe that the shortest L that fulfill target water height, *h* more than 4 cm are 20 cm tank with structure period around 0.67 second. Based from these parameter the experimental model are made.

Table. 2.2 Optimum tank width (B) for period (T) in each tank length (L)

Md = 0.00066 ton

T (s)/L (m)	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
10.00	161.8649115	20.23308	5.99497	2.529119	1.294902	0.74936	0.471897	0.316132	0.222027
5.00	40.46589586	5.058104	1.498632	0.632197	0.323659	0.187285	0.117927	0.078991	0.05547
3.33	17.98420316	2.247727	0.665845	0.280816	0.14372	0.083131	0.05232	0.035027	0.024582
2.50	10.11514579	1.263862	0.374215	0.157717	0.080648	0.046599	0.029291	0.019581	0.013718
2.00	6.472386027	0.808217	0.23906	0.10061	0.051351	0.029602	0.018556	0.012364	0.00863
1.67	4.493060942	0.560434	0.16546	0.06945	0.035323	0.020273	0.01264	0.008368	0.005796
1.43	3.299024581	0.410743	0.120887	0.050512	0.025535	0.014541	0.008975	0.005867	0.004
1.25	2.523464214	0.313289	0.091752	0.038058	0.019044	0.010694	0.006477	0.004124	0.002707
1.11	1.991141319	0.246164	0.071557	0.02934	0.014432	0.007899	0.004595	0.002726	0.001517
1.00	1.609757455	0.197824	0.056873	0.022897	0.010927	0.005664	0.002908		
0.91	1.326945068	0.161715	0.045741	0.017875	0.008031	0.003473			
0.83	1.11119572	0.133884	0.036965	0.013703	0.00517				
0.77	0.942626977	0.111826	0.029752	0.009843					
0.71	0.808187299	0.093878	0.0235						
0.67	0.699018118	0.078885	0.017566						
0.63	0.608930942	0.06599	0.009585						
0.59	0.53349113	0.054486							
0.56	0.469446375	0.04362							
0.53	0.414358203	0.031965							
0.50	0.366356391								

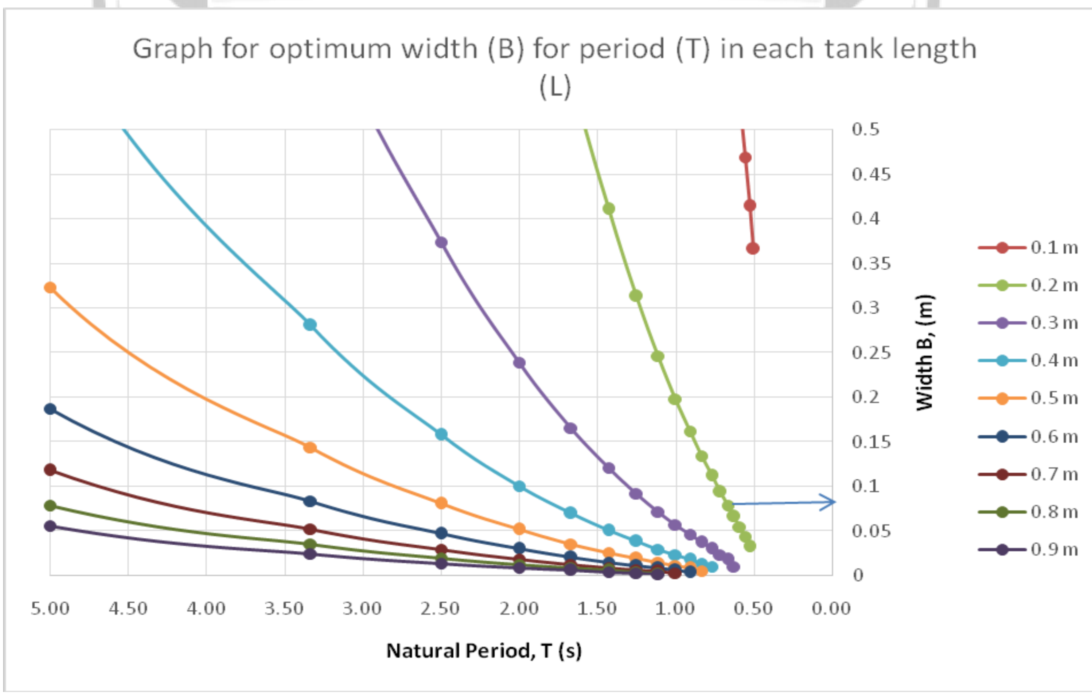

Figure. 2.2. Optimum tank width (B) for period (T) in each tank length (L)

In table 2.2 the blue shaded portion are the part where the result are reasonable for the dimension of the model which within range of 0 - 50 cm, therefore only these part will be shown in Fig 2.2.

In Fig 2.2 we can observe that tank width for length of 20 cm tank with structure period around 0.67 second is around 8 cm, which is proportional to the tank length. Therefore, The parameter which already chosen is sufficient for experimental model.