Optimal Parameter of Tuned Liquid Column Damper attached to SDOF System Subjected to periodic loading

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Abstract**—**Optimal parameter of tuned liquid column damper (TLCD)namely Frequency Ratio, Length ratio and Mass ratio are evaluated for single Degree of Freedom (SDOF) system fitted with TLCD. Equation of motion for the SDOF-TLCD system has written, it is dynamically coupled equation. Coupled equation of motion is uncoupled by applying orthogonally condition and each uncoupled equations are solved and response are combined to get maximum displacement. Response of system for different values of frequency ratio, Mass ratio and length ratio are evaluated and graphs are plotted. From the graph optimal parameters are evaluated and finally conclusions are drawn.

Keywords*-Tuned Liquid Column Damper, Single degree of Freedom system etc.*

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I. INTRODUCTION

Response control of structures for lateral loads is always a major issue in structural Engineering. Various types are damper are used for response control of structure, Tuned liquid Column Damper is an emerging class of liquid damper in structural Engineering field. TLCD some benefits over the other dampers Such as: 1) less initial cost (only a U-Shaped tube fitted with orifice is required). 2) Frequency of TLCD can be adjusted by length of liquid only which provide better control on tuning. 3) TLCD has negligible maintenance cost. For application of TLCD system in structural system first it is necessary to know optimal Dynamic and geometric parameters of TLCD. These parameters are defined as follows:

Frequency Ratio (β): It is ratio of Frequency of TLCD to natural frequency of Structure. ($\beta=\omega_d/\omega_s$)

Length Ratio (α): It is the ratio of Width of TLCD to total length of Liquid in TLCD ($\alpha=b/l_e$).

Mass Ratio (μ): It is the ratio of mass of TLCD to mass of Structure.($\mu=m/M$)

In this work optimal values for above parameter are evaluated.

II. LITERATURE REVIEW

Equation of motion of TLCD fluid was first given by Sakai et al.(1989) afterward optimal absorber parameter for TLCD system were derived by Yalla and Ahsaan Kareem[5] for white noise excitations. Study on dynamic characteristics was done by Shyong Wu et al. [8] using Lagrange's equation. Study of vibration control of 76 Storey building using liquid column vibration absorber was done by B. Smali [2] et al they found that TLCD fitted with orifice provide better energy dissipation. Performance of TLCD system for response control of 76 Storey building was done by Kyung-Won Min et al [1]. Design guidelines for Structure-TLCD system was given by Jong-Cheng Wu et al [3] for white noise excitations. Also Damping effect of different fluids of TLCD such as Water, Glycol and MR fluids was done by Shane colwell et al [10].

The purpose of this study is to evaluate optimal parameter of TLCD for periodic loading. First response of SDOF system without TLCD is evaluated and then SDOF-TLCD system response for different mass ratio, frequency ratio and mass ratio are evaluated. Based on results graphs are prepared and conclusion a are made.

III. MATHEMATICAL MODDELING

In the system shown in figure there are two subsystem one is liquid in TLCD and another is Structure on which TLCD is fitted. Fluid is going to move within the TLCD in vertical direction and primary structure will be move in horizontal direction therefore there will be two equation of motions in system one for fluid inside the tube and another for structure.

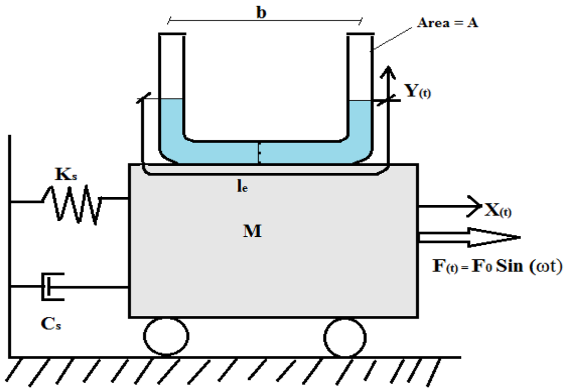

Fig: 1 SDOF attached with Tuned liquid column dampers

The equation of motion of fluid inside the TLCD is given as (Sakai et al 1989)

$$\rho A l\,\ddot{Y}(t)+\frac{1}{2}\xi A\left|\dot{Y}(t)\right|\dot{Y}(t)+2\rho A g Y(t)=-\rho A b\,\ddot{X}(t)\;\cdots(1)$$

Equation of structure is given by

$$(M_s+\rho A l)\,\ddot{X}(t)+\rho A b\ddot{Y}(t)+C_s\,\dot{X}(t)+K_s X(t)=F(t)\;\ldots(2)$$

By taking nonlinear damping as equivalent linear damping equation of structure in matrix form can be written as

$$\begin{bmatrix} M(1+\mu) & \alpha m \\ \alpha m & m \end{bmatrix}\begin{bmatrix} \ddot{X}(t) \\ \ddot{Y}(t) \end{bmatrix}+\begin{bmatrix} C_s & 0 \\ 0 & C_d \end{bmatrix}\begin{bmatrix} \dot{X}(t) \\ \dot{Y}(t) \end{bmatrix}+\begin{bmatrix} K_s & 0 \\ 0 & k_f \end{bmatrix}\begin{bmatrix} X(t) \\ Y(t) \end{bmatrix}=\begin{bmatrix} F(t) \\ 0 \end{bmatrix}$$

……..(3)

IV. Solution of Equation of Motion

Following steps are the steps to solve above dynamically coupled equation:

- Determine the frequency of modes neglecting damping of system [K-ω^2M] = 0
- Find the modal shapes and Normalize the modal shape

$$\phi_{ij} = \frac{a_{ij}}{\sqrt{\{a\}^T [M]\{a\}}} \quad \phi = \begin{bmatrix} \phi_{11} & \phi_{12} \\ \phi_{21} & \varphi_{22} \end{bmatrix}$$

- The equation can be written in matrix notation by introducing transformation of coordinates i.e.{u}=[φ]{z} and Pre multiplying equation of motion by Transpose of nth modal vector $[\varphi]^T$

$$\{X\} = \{\phi\}^T [M][\phi]\{\ddot{z}\} + \{\phi\}^T [C][\phi]\{\dot{z}\} + \{\phi\}^T [K][\phi]\{z\} = \{\phi\}^T \{F(t)\}$$

- Now applying orthogonality property of modal shape we get two uncoupled equation in following form

$$\ddot{z}_1 + 2\xi_1\omega_1 \dot{z}_1 + \omega_1^2 z_1 = P_1(t)$$

- $$\ddot{z}_2 + 2\xi_2\omega_2 \dot{z}_2 + \omega_1^2 z_2 = P_2(t) \quad ......(4)$$

- If the forces P_1(t) & P_2(t) = P_0.Sin(ωt) the steady State solution of each equation can be given by
- U(t)=Csin(wt)+DCos(wt)

- Where, $C = \frac{F_{0i}}{K_i} \frac{(1-r^2)}{(1-r^2)^2 + (2\xi_i r)^2}$ $D = \frac{F_0}{K_i} \frac{(-2\xi_i r)}{(1-r^2)^2 + (2\xi_i r)^2}$

V Steady State Response of SDOF System without TLCD

SDOF adopted for has following parameters:
Mass of structure (M) = 76500 kg, Stiffness of Structure (Ks) = 500000 N/m, Damping ratio = 0.05, Periodic Loading F (t) = 78500 Sin (ωt) and Natural Frequency =√(K/m) = 2.565 rad/s. Response of structure for resonant condition can be find by using equation No. and response of structure is plotted in fig No. 2

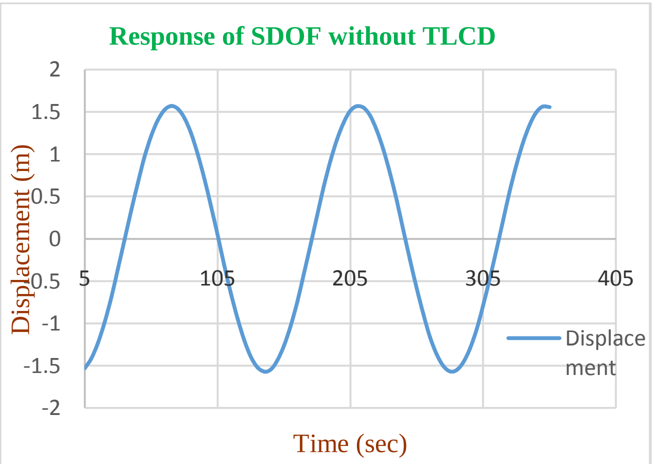

Fig: 2 Displacement vs. time of SDOF without TLCD

VI Steady State Response of SDOF System with TLCD

Following parameters are assume to evaluate response of SDOF-TLCD system to check the effectiveness of TLCD.

- 2% mass (μ=0.02), Frequency Ratio (β) = 1.0 and a length ratio (α)= 0.90 is adopted for check the effectiveness of TLCD system
- Therefore mass of Damper will be (m) = 1530 kg.
- Frequency of Damper = 2.565 rad/s
- Length of TLCD (le) can be evaluated by using equation of Frequency of TLCD = √(2.g/le) which is equal to 3.0 m
- Stiffness of Damper (Kd) = 2ρ.A.g = 10006.2 kN/m and assuming a ξd=15% damping provided by TLCD Damping Coefficient of TLCD (Cd) I= 2mωdξd =1173.43 N-m/sec
- Following procedure of solution in section IV results with above parameter are evaluated and overlapped on figure No. 2 and plotted in figure No. 3.
- Maximum displacement without TLCD is 1.53 m and by above parameter in TLCD a maximum displacement of 0.931 m is obtained. Which show a total 38% reduction in displacement.

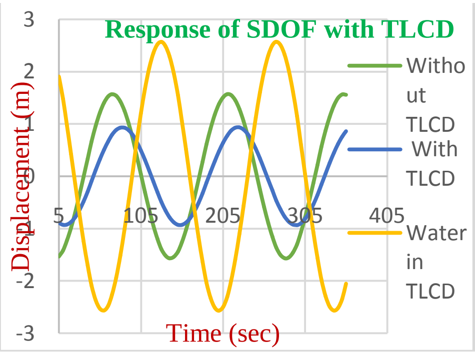

Fig: 3 Steady State Displacement vs. time of SDOF with TLCD

V. Response of SDOF-TLCD System for Constant Mass Ratio and Varying Length and Frequency Ratio

Mass ratio is kept constant and frequency ratio and length ratios are varied and graphs are plotted for mass ratio of 1.25, 1.5, 1.75, 2, 2.25% mass for frequency ratio range of 0.91 to 1.06 at an interval of 0.01 and length ratio range of 0.5 to 0.9with 0.05 interval. The obtained results are plotted in following graphs.

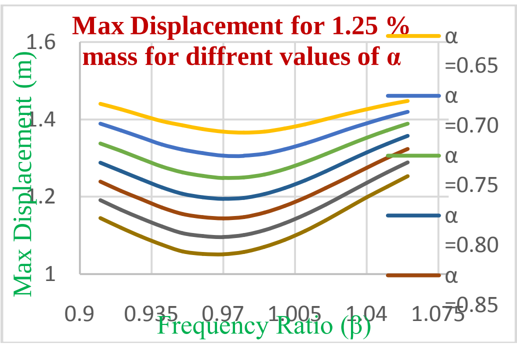

Fig 4 Max displacement for 1.25% mass and different β and α

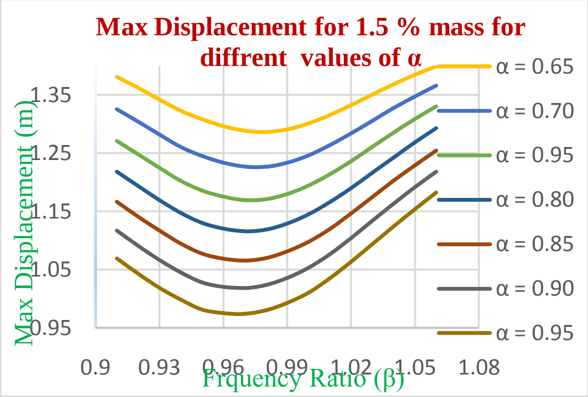

Fig: 5 Max Displacement for 1.5 % mass

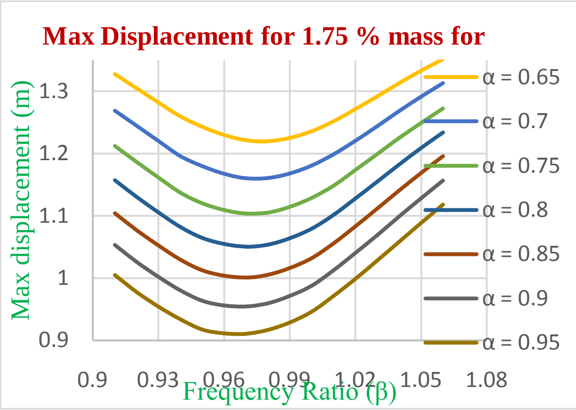

Fig: 6 Max Displacement for 1.75 % mass.

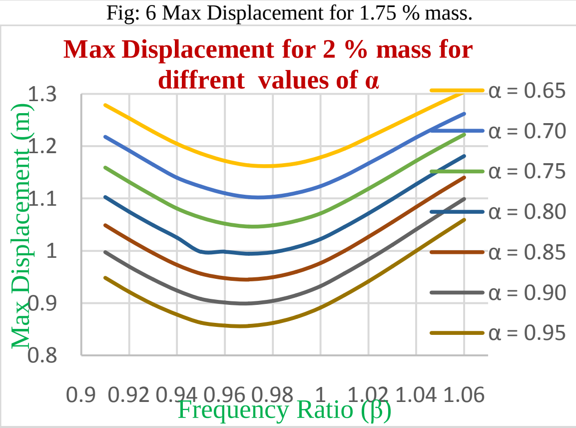

Fig: 7Max Displacement For 2.0% mass.

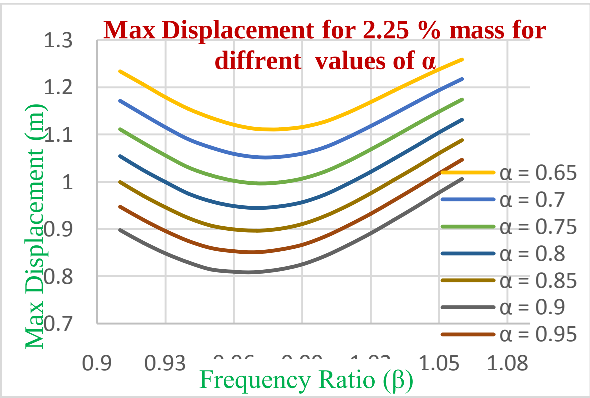

Fig: 8Max Displacement for 2.0% mass

VI. Response of SDOF-TLCD System for Constant Length Ratio and Varying %Mass and Frequency Ratio

length ratio is kept constant for one graph and maximum displacement are plotted for different mass having a range of 0.75 to 2.5 % at an interval of 0.25 % for frequency ratio range of 0.91 to 1.06 at an interval of 0.01. The obtained results are plotted in following graphs.

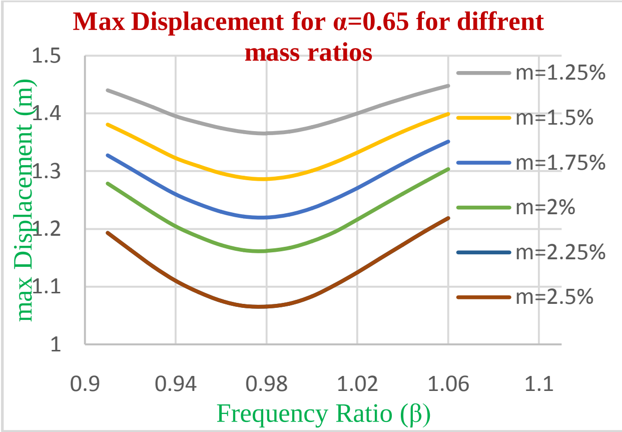

Fig 9Max Displacement for α=0.65 for Different mass ratios

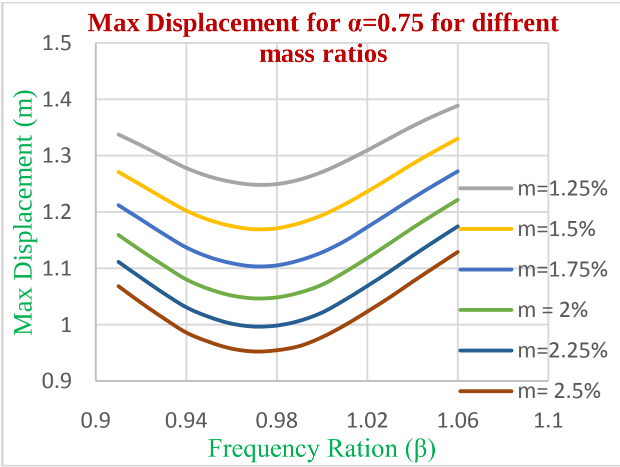

Fig 10Max Displacement for α=0.75 for Different mass ratios

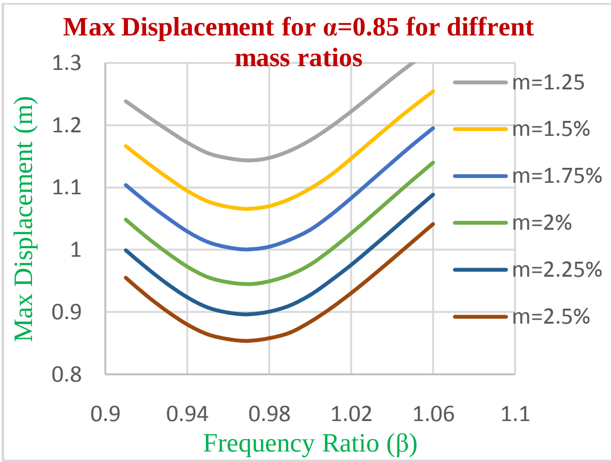

Fig: 11 Max Displacement for α=0.85 for Different mass ratios

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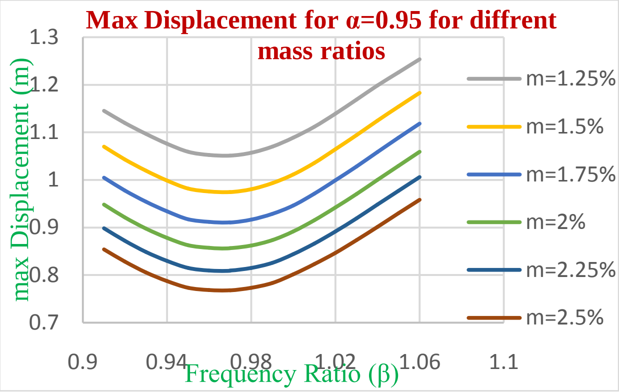

Fig 12Max Displacement for α=0.95 for Different mass ratios

VIII. RESPONSE OF SDOF-TLCD SYSTEM FOR CONSTANT FREQUENCY RATIO AND VARYING %MASS AND FREQUENCY RATIO

Frequency ratio is kept constant at one time and maximum displacement are plotted for different % mass having a range of 1.5% to 2.5 % at an interval of 0.25 % for length ratio range of 0.5 to 0.95 at an interval of 0.05. The obtained results are plotted in following graphs

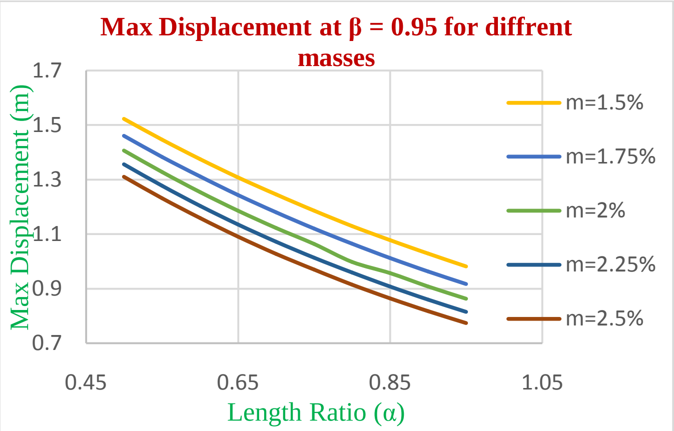

Fig: 13 Max Displacement for β=0.95 for Different % mass

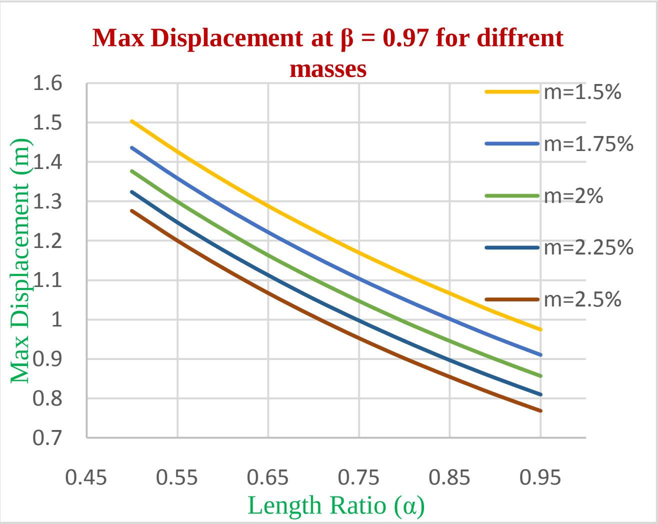

Fig: 14 Max Displacement for β=0.95 for Different % mass

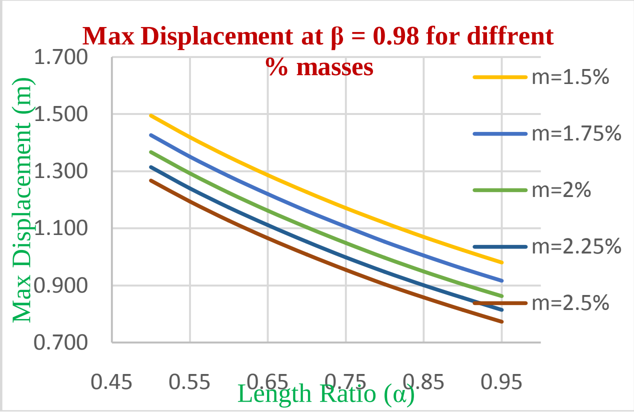

Fig: 15 Max Displacement for β=1.0 for Different %

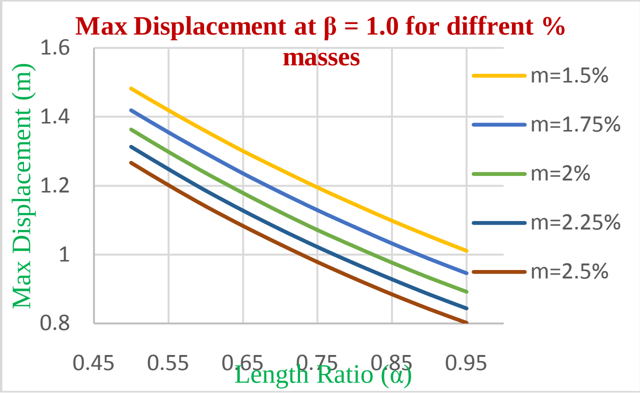

Fig: 16 Max Displacement for β=1.0 for Different % mass

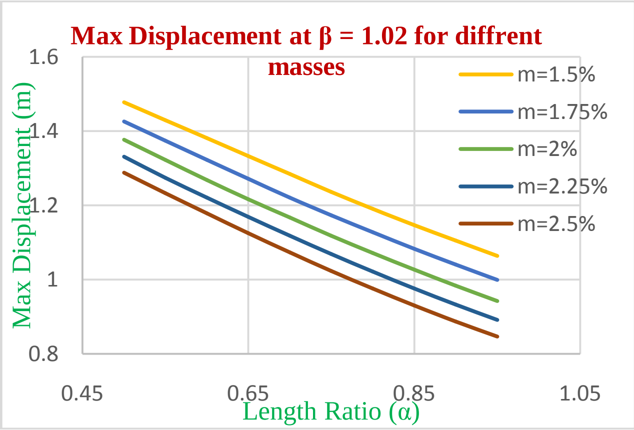

Fig: 17 Max Displacement for β=1.02 for Different % mass

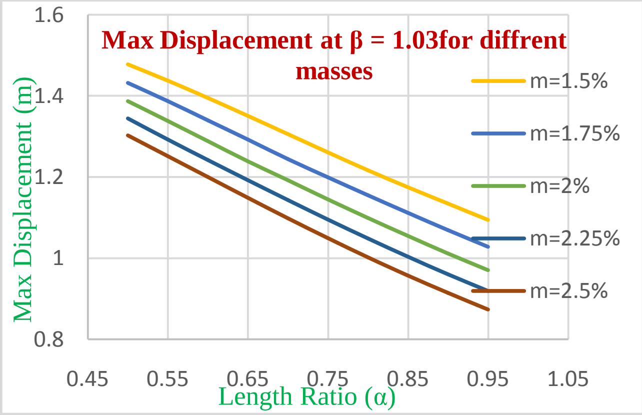

Fig: 18 Max Displacement for β=1.03 for Different % mass

IX. RESULTS AND DISCUSSION

Displacement of SDOF system without TLCD is 1.531 m by comparing it with above graphs it is observed that for higher length ratio optimal value of frequency ratio is near 0.97 and for lower length ratio optimal frequency is between 0.98 and 0.99. From graph 50 % reduction in displacement is observed with a mass ratio of 2.5 % and length ratio 0.95 and 45 % reduction in displacement with same length ratio and 2% mass, 37% reduction in displacement with a 1.5 % mass and 0.9 Alpha value and for 1% mass 25% reduction is observed with α =0.95.

By observing the graphs from fig 9 to fig 12 having constant value of length ratio for each graph it can be conclude that for a length ratio though mass is increased or decreased it will not effect to optimal frequency ratio for that length ratio, therefore optimal frequency ratio for a given length ratio will be constant. For lower values of length ratio and higher mass it gives good displacement control while with lower length ratio and lower mass ratio displacement control is very less. For lower mass ratio (0.75%) and lower length ratio (α = 0.65)only a reduction in displacement of 6.32 % is observed while for 1 % mass 14 % reduction in displacement is obtained. For higher value of α and for less mass ratio (0.75%) a displacement reduction of 19 % is obtained. Therefore it is always economical to use higher alpha and lower mass ratio.

Fig 13 to fig 18 shows that, for a particular frequency ratio as the length ratio increases displacement of structure reduces. It can be observed from graphs that as length ratio increases response get reduced linearly.

X. CONCLUSION

Response of SDOF system with and without TLCD system is evaluated for different % mass, frequency ratio and length ratio and graphs are plotted. Following conclusions are made by observing the graphs

- Optimal Frequency ratio for SDOF-TLCD system lies between 0.97 to 0.99 for different mass ratio
- Higher length ratio (α) above 0.85 provides good displacement control.
- Higher mass ratios provides better displacement control over lower mass ratio
- For a particular length ratio optimal frequency ratio is constant.
- It is economical to go with lower % mass and higher length ratio
- A well designed TLCD system provides better control on structural response for periodic loading.

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