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A REVIEW ON VIBRATION CONTROL OF COMPOSITE SLAB USING TUNED MASS DAMPER

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Abstract — *Floors are highly susceptible to vibrations during its functional usage and owing to its lesser thickness as compared to the plan dimensions. The type of vibrations induced depends on the functionality of the floor. The induced vibrations can lead to serviceability issues and also can render psychological effects on the inhabitants. The services used in the building can also be badly affected due to the induced vibrations which can be due to machine running on the floors, walking, dancing activities and other human induced impact forces. This review has been undertaken to understand the ill effects caused by vibrations generated by various sources on floor systems. Many authors have worked to reduce these vibrations by installations of various control systems. A detailed study has been undertaken in this paper to study and understand the mitigations of these vibrations.*

Keywords- *Floor vibration, Vibration control, Composites slab, Tuned mass damper*

I. INTRODUCTION

Vibration in buildings is a common problem and major concern especially in urban areas because of the daily activities. Vibrations can occur at many place like car, plane, Elevators, and buildings. Structural Vibration covers the wind Storm vibration, Earthquake vibration, Floor vibration. When the term Vibration comes with floor it shows that building and occupant experienced an oscillatory motion from their daily life. [12] Direction of the floor vibration may be vertical like up down movement and horizontal in terms of earthquake. The sources of this type of vibration is human activity like dancing, aerobics, jumping, walking and other than that vibrating machinery placed at the industrial floors. Floor vibration can be stated as excessive or intemperate when they disable the function of building in some manner. Vibration is a dynamic parameter that can experience with very small amount. When vibration increases up to the certain level like above human perception, from walking it will annoy to occupant and this is the serviceability problem. Second thing is that the loads from rhythmic activities like dancing/aerobics are generating the resonating frequency which leads to the excessive moment of the floor hence it is the safety as well as serviceability problem. [8] Floor vibration can occur in the structure which has light weight floor and long span floor. As the span increases the floors natural frequency are decrease to lower frequencies.

S. C. Chung [18] has study regarding the prediction of the influencing parameters for the floor vibration which are as under 1) No of beams 2) Location of beams 3) Slab thickness 4) compressive strength of concrete. Floor vibration impact simulated by the combining FEM structural analysis with the help of Fast Fourier Transformation. It was found from the conclusion that vibration reduction can be done with increasing the floor thickness and by changing the position of beams and number of beams.

According to Fredrik Ljunggren [1] short span has the frequency range between 15-20Hz and the for long span it has 8-10Hz. Researcher has concluded that as the frequency drove lower to its limiting value humans are very sensitive to lower frequencies than the higher one. The author has presented the ISO base curve which shows the vibration criteria. Local deflection appears when the induced force generates a local deflection in the direct vicinity of the occupant.it occurs when structure has low stiffness and generally found in the light weight construction. Resonant vibration is a result of low damping where the induced force generates a long lasting vibration of the floor.

Jae Ho Kim and Jin Yong Jeon [5] has done the mock-up floor test to analyze the vibration characteristics of concrete slab due to walking discomfort. Seven floor with panels of different sizes and beams with various joist spacing were casted based on the actual condition of the site. For measurement of the acceleration rubber ball has been used as impact resource which was thrown at the height of 20cm from the base. After performing the experiment it was found that vibration acceleration value and walking discomfort varied with the changing support condition of floor. From the result it can be said that vibration dose value (VDV), were highly correlated to the subjective responses.

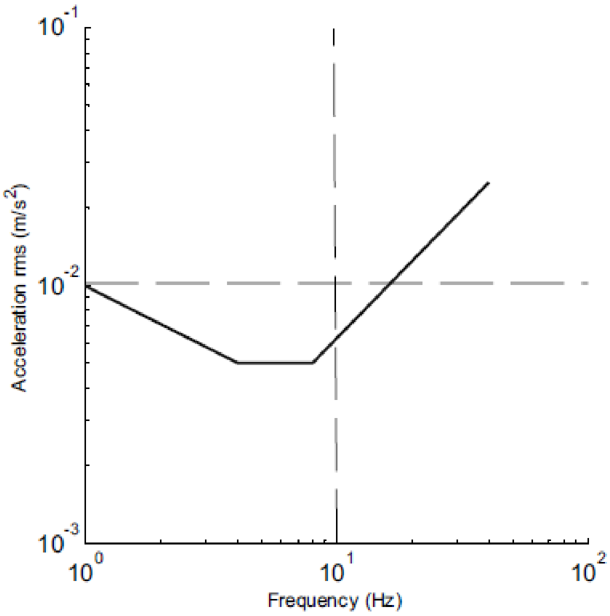

Figure 1- ISO base curve

Tuan Norhayati Tuan Chik [22] also presented that the level of vibration at the Register Office situated in University of TUN Hussein Malaysia on every floor of a high rise structure due to ground borne vibration from road traffic flow and to evaluate the vibration response data using MATLAB and ANSYSv14. Physical contribution of vibration from vehicles were measured and obtained using Laser Doppler Vibrometer. From the vibration criteria guideline researcher has found the vibration level from vehicles and footsteps on office floor. From the result it was found that level of vibration is 99% above the ISO level which surpasses the acceptable limit of vibration for the office building.

II. Control of Floor vibration

Ways to control the floor vibration problem depends upon the source. If there is a machine vibration the best solution is to put an isolators to the source. For primary reduction rotating equipment such as fans and pumps can be fixed at flexible support to neglect the risk of resonance with supporting structure. For human induced vibration this type of controlling device is not used. Basic method known to reduce the floor vibration is add column, add the partition that span from the floor to ceiling, provide additional thickness to floor , increasing the stiffness of the structure, providing dampers to the structure.
Most of the research for the vibration control of wooden floor has been given. Since Light weight floors show such a high propensity to create irritating vibration, many other researcher has tried to find the solution for that which can control the vibration level. Numerous method are found in the literature. Tuned mass damper, semi-active tuned vibration absorber and active control system are most popular systems among all of them.

III. ACTIVE CONTROL SYSTEMS

Ricardo Foschi [17] showed the experimental and theoretical result for the vibrant response of wooden floors under residence mainly for impulse due to heel drop test. With the help of reliability analysis static design guidelines can be established when suitable vibration acceptance criterion has been accepted. Criteria for this paper is taken from the researcher Wiss and Parelee and permissible span have been taken with verity in floor construction. Paper describe that the response must be calculate as a coupled system floor and oscillators. For the heel drop test it is suggested that the allowable span be calculated as vibrations" be less than or equal to 0.50, and that this requirement be met for 90% of the floors.

By Brace Ellingwood [21] it was clear that with the human activity floor vibration is generated which affect the serviceability criteria. Here existing serviceability criteria for floor are studied for the research dealing with the human perception of structural motion. Pedestrian movement excitation model in the terms of dynamic response of floor is analysed. Vibration can be reduced by the simple static deflection check in which the deflection limit depends on occupancy but it is independent of span.

For the controlling of floor vibration Linda M. Hanagan, Kirthi S. Walgama[11**]** utilized the active control system and present a method for integrated determination of actuators and signals and output feedback controller gains. Suggested algorithm gave the controller design. Result is obtained with the help of mitigation process that uses a quadratic PI penalizes the total flexible energy of the floor.

Thomas M. Murray[10] also gave the methodology to control the vibration with the help of Active control approach. For the convey control forces on floor electromagnetic proof mass actuator is used with the velocity feedback scheme, thus how reducing the amplitude of floor motion. Experimental and analytical study presented over in this paper which conclude the floor response to transient excitation show an increase in damping in the range of 2.5% to 40%.

C.R. Fuller[05] also discussed about the active sound and vibration Control field by displaying relevant control theory and its execution and describing some current practical application.

Paul Reynolds [16] described about the Active vibration control of the office type building situated at north of England. To establish the experimental modal properties modal testing of floor is presented with the help of SISO- on off NLVFC using an electrodynamics proof mass actuator. The frequency which shows the maximum vibration is 6.4Hz which had damping 3% and modal mass was 20tonne. Floor vibration reduction were observed 50% experimentally.

NO of passive control device is also used to mitigate the floor vibration. Number of research has been carried out in this type of control of system.

Murray [22] presented semi active tuned vibration absorber which was different from the conventional type Tuned mass damper. This type of semi active tuned mass damper works under the control unit and it is able to change the damping force. Displacement relative velocity control procedure has been used in which sensor measure the displacement of floor with the comparison of velocity of damper.

IV. PASSIVE CONTROL SYSTEM

Saidi [06] presented a summary of the new viscoelastic tuned mass damper for floor application. This damper is based on the concept of sandwich beam with the energy dissipated by shearing of rubber layer. For the need of the experimental setup 2 no of dampers has been developed 1 was for steel beam which has 3m span and other one is for RC T beam with 9.5m span. Predicted analytical value of the damper were in excellent agreement with test in terms of natural frequency and damping ratio. With addition of this damper to steel beam damping was increased by 0.3 % to 3% and for the t beam it was 2.9% increment shows. So overall 6.1% damping increase with addition of viscoelastic damper.

Tuned mass damper is the best suitable passive control system to mitigate the vibration. So the some of the researcher has presented the design parameters for the TMD for different floor, different type of vibration.

John R. Sladek and Richard E. Klingner et al. [13] presented that to improve the effectiveness of the Tuned mass Damper and reduce the wind response of high Rise building john Hancock (Boston) or the Citicorp center in New York city has been installed and also found that it reduces the wind effect as much as 40%. Aim of this study to investigate that whether the TMD or similar device could reduce the effect of earthquake ground motions or not. In this paper design of tuned mass damper is taken with the mass ratio as 65% which shows negligible effect on the two structure. It was found that damper did not made any satisfactory contribution towards the reducing lateral forces at base of building. Graph has been shown in the paper that claims the result.

The study about to find the essential parameter of Tuned mass damper by Mehdi Setareh and Robert D. Hanson [15] which was obtained by component mode synthesis (CMS) method which is advantageous because of its response of a system with dampers can be found using a reduced number of mode shapes of the original structure. They have developed single degree of freedom structure (SDOF) model and tuned mass damper parameter which represent the vibration characteristics of a multiple degree of freedom system are compared. For better result they attached a TMD at different location like single node and multiple nodes at time and evaluate the response.

Chien-Liang Lee [02] carried out the study regarding the theories which conducted to be design the tuned mass damper to reduce the floor vibration. Paper present the dynamic system of MDOF structures, multiple tuned mass damper at different stories of the building and power spectral density function of environmental disturbances are taken into account. Researcher has described numerical methods for obtaining the optimal design parameters and also gave the numerical verifications. Optimal design parameter like equation for frequency for SDOF and Single tuned mass damper.

- $fopt = \frac{\sqrt{1+\frac{\mu}{2}}}{\sqrt{1+\mu}}$ and $\zeta opt = \sqrt{\frac{\mu(1+\frac{3\mu}{4}}{4(1+\mu)(1+\frac{\mu}{2}}}$

They have done analysis for the SDOF with single tuned mass damper, MDOF with STMD, and MDOF with multiple tuned mass damper. With the proposed numerical method, the numerical solution converges monotonically and very effectively toward the exact solutions as the number of iterations increases.

Optimum parameter for tuned mass damper by S. V. Bakre and R. S. Jangid [19] (2006) shows that system attached to viscously damped single degree of freedom main system are derived from various combination of excitation and response parameters. The vibration has given to the main system with the help of external force and Gaussian white noise random process. Study focuses on developing the formulae for dampers for the main system under various loading. Also one of the objective is to find out the explicit expressions for the optimum parameters of a TMD system for practical applications using a curve-fitting scheme, with error analysis conducted. Researcher has evaluated the response for three categories like 1) response to external force applied to main system 2) response to base acceleration. Study shall carried out for Damped and Undamped system. For the case when external force is applied to main mass and main system under base excitation researcher has taken a variable mass ratio ranges from 0.5% to 10% and damping ranges from that 1% to 10% and for that they evaluate the frequency. Result shows that optimum tuning frequency decreases with the increase in both the mass ratio as well as damping ratio of main system. Optimum damping ratio of the TMD increases in the mass ratio of TMD system.

No of equation was also adopted to design the TMD with viscous damper on flexible structure which represent over here from the paper by JanHøgsberg[19]**.** Design process for TMD with the 2 degree of freedom structure which consist a absorber kept on spring which was supported by mass. Furthermore they used classical frequency tuning. Damping value was determined by dynamic amplification of combined system. Also they have given the frequency response, frequency tuning, modal damping, Damper tuning in this paper.

1. Equivalent Damping (ζ_k) = $2 (\zeta_d – \zeta_s)$
2. Mass ratio (μ) = $2 (\zeta_k)^2/1- 2 (\zeta_k)^2$
3. Equivalent absorber stiffness (k_x) = $\mu^* k_s /(1+ \mu)^2$
4. Background flexibility factor (k) = $k_k /(k_o- k_k)$
5. Absorber natural frequency ($\dot{\omega}_d$) = $\sqrt{1 + k \frac{\dot{\omega}_s}{1+\mu}}$
6. Absorber damping ratio (ζ_d) = $\sqrt{1 + k \sqrt{\frac{\mu}{2(1+\mu)}}}$
7. Absorber mass, stiffnes, damping coefficients = $m_d = \mu\, m_s$

Study of this literature review further focuses on composite floor which comprises of prefabricated profiled sheet with the combination of in situ concrete. After hardening of the concrete monolithic action forms between those two element and concrete and sheet behaves like single structure unit. These composite slabs have much lesser thickness and as a result of that the floor vibrations is a major problem. Study related to control of these vibrations has been undertaken by many researchers. A review of these study has been presented in the following article.

Experimental and finite element modelling of Composite deck slabs with and without embossments presented by Basker R [01] in the composite slabs, mechanical interlocking in the form of embossments or shear connectors were used to transfer shear between the outer skin of the plate and the concrete core. For the experimental programme they conducted the flexure test which gives the flexure capacity of slab and relation between the load and deflection, load and strain. Finite element analysis is done with the help of ANSYS8. And for the experimental work they tested the composite slab at 2 point load at L/4 of the span. The generated results were quite nearer to each other. Results which lead to conclusion that slab without embossment attained early ultimate load due to the initialization of its delamination of deck sheets and with embossment load carrying capacity is 13% more than that of without embossment.

Experimental programme for the Dynamic vibration induced by human load in the composite slab by Wendell D. Varela[24] Three criteria in which 1st was one person walking at the time 2nd criteria is 6 people walking at the same direction onto the slab and 3rd criteria is that people walking randomly onto the slab. For each criteria they found different response for time and frequency is shown. Which produced discomfort to the occupant and generated low damping and for that they have designed a passive control device (tuned mass damper) and places at multiple location then they perform experiment again and results show that for any criterion of human load TMD provides significant reduction in vibrations amplitude and also improve the occupants comfort.

Emad El-Dardiry, Tianjian Ji et al. [03] shows the dynamic behavior of composite floor with isotropic and orthotropic flat plate models. For isotropic flat plate models they used LUSAS finite element programme. To conduct the 3D analysis of composite floor they have used 1) Thin shell elements (QSL8) to model the steel sheet. 2) 3D-solid elements (HX20) to model the concrete slab. For orthotropic flat plate analysis there is no requirement of 3D analysis it can be simply done with the unit length 1.0 m in each of the two perpendicular directions is considered. They analyzed X and Y direction for that they have found different locations of eccentricities, neutral axis, Area and second moment of inertia which has more important to the dynamic analysis like as it can significantly affect the predicted frequencies and change the order of vibration modes. The study also covers the comparison between the 3D composite panel model and equivalent plate models. But for Equivalent plate they have made certain assumptions. The equivalent flat plate models are constructed on the basis that the 3D model of the composite panel has four edges simply supported and is subjected to uniformly distributed loads in addition that shear modulus for the orthotropic plate uses the one for an isotropic plate. So the study goes further to the effect of boundary condition and also effect of the shear modulus. And results for the effect of boundary condition is the thickness of a flat plate using the isotropic plate model varies about 5%–6% for the studied cases while the thickness of the orthotropic flat plate is almost constant. For displacement and frequency isotropic models is very good solution. But in orthotropic there is slight variation 10% in displacement and 5% in frequency. The steel sheet in a composite floor should be considered in modelling as its contribution to the global stiffness of the composite floor is not small, about 16% of the total stiffness in the 3D panel model

A slight modification in the conventional type of the dampers gave better result for mitigation the floor vibration. So this Modified damper for the vibration control of the floor is Tuned liquid damper, liquid column damper, momentum exchange damper, bidirectional and homogeneous tuned mass damper.

Modified new version of the Tuned liquid damper is Liquid column ball damper which is equipped with coated steel ball in place of orifice in liquid damper immersed inside the column of the damper. K.A.Al- Saif [10] new concept to f the tuned liquid column damper is proposed. The mathematical model of the absorber attached to a single degree of freedom structure is developed. The viscosity of the fluid used is included in the model. A comparative study between the responses of a structure with attached TLCBD and with attached TLCD is conducted. Two sets of optimum design parameters for TLCD that are available in the literature are used in the comparison. It was shown that the performance of the proposed absorber is excellent with up to 67%vibration reduction.

Makoto Kawachi[15] (2007) presented the study regarding the new Momentum exchange impact damper which controls floor impact vibration. In this research area computational model is formulated to simulate dynamic floor vibration induced by impact. Numerical model of flooring system was generated by FEM formulation. For the mass ratio of 1.2 the acceleration of slab reduced up to 25% and 63%. Comparison of this new damper with conventional added mass at center of floor with high impact load. And impact damper showed better result compare to the conventional one.

Jos´e L. Almaz´an) [09] presented another damper calls bidirectional homogeneous tuned mass damper. Mechanism of this damper is like pendular mass is supported by cables and linked to a unidirectional friction damper with its axis perpendicular to the direction of motion. Experimental test performed using a BH-TMD model confirms that equivalent oscillation period and damping ratio are independent of motion amplitude. Level of the response reduction in this new BH-TMD is similar to viscous damper. Author has also conclude that BH-TMD may reach displacement reduction factors that vary from few percentage point to 60% which depends upon the excitation of the structure.

V. CONCLUSION:

Floor vibration is a major problem as far as serviceability and human psychological effects are concerned. Following are the points that can be summarized based on the study of the past research that has been undertaken to understand the ill effects and control of these vibrations in a floor.

1) Active control system for the reduction has more advantage than the conventional tuned mass damper.
2) The active control systems are also less disturbing to the structure than other traditional methods. However, the disadvantages of this method is its initial and operating costs that are much larger as compared to other systems.
3) From the literature review it can be found for the passive control system was also helpful to control the vibration. Especially Tuned mass damper has gain more focus which depends upon stiffness and mass.
4) This damper is proven very effective compared to other passive control damper like viscous damper, lead exclusion damper.
5) Variation of the parameters like mass and stiffness in TMD can be done by increasing and decreasing the number of springs, steel plates as mass.

6) Major work for vibration control is proposed for normal RC slabs. However, further study needs to be conducted for composite floor system as they have much lesser thickness as compare to normal RC floor. Mitigation of these vibration for composite floor system still needs further investigations.

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