

ANALYSIS OF SLAB THICKNESS REQUIREMENT OF RCC SLAB IN ORDER TO PREVENT UNDESIRABLE FLOOR VIBRATION

M. M. Orvin*, K.M. Amanat & A. A. Kawsar

Department of Civil Engineering, Bangladesh University of Engineering and Technology, Dhaka, Bangladesh

**Corresponding Author: mmceorvin@gmail.com*

ABSTRACT

Now-a-days, modern structures are becoming slender, irregular shaped and long spanned which are susceptible to floor vibration phenomena. The purpose of this study is to determine the minimum slab thickness of a RCC slab to prevent undesirable vibration that will not cause discomfort to occupants and compare the obtained result with (Rakib, 2013) who investigated on this previously. Though American Concrete Institute (ACI) provided code for minimum slab thickness requirement from static deflection criteria, it might not be sufficient for dynamic serviceability like vibration. An investigation based on 3D finite element modeling of a reinforced RCC floor subjected to gravity load including partition wall load is carried out to study the natural floor vibration. The ANSYS model verification is done and is validated by ETABS modeling. The variation of the floor vibration is studied for several parameters such as different slab thickness, span length and floor panel aspect ratio.

Keywords: Floor vibration; RCC floor; slab thickness; ANSYS modeling of RCC Floors

INTRODUCTION

Modern construction techniques make use of lightweight materials to create long-span floors. These floors sometimes result in annoying levels of vibration under ordinary loading situations. In extreme cases this vibration can render the floor unusable by the human occupants of the building if it creates excessive discomfort to them. If the structures have the frequency below 10 Hz, then it creates resonance with human body. This resonance may cause discomfort to the people (Murray et al. 1993). The aim of the current study is to enlarge knowledge regarding the vibration response of a RCC building floor with change of different parameters. The variation of floor vibration is analyzed with change of slab thickness, floor panel aspect ratio and span length. A 3D finite element model of floor having three spans and bay will be developed. Verification of the built model is done by ETABS. Modal analysis is to be executed to determine mode shape and frequency. Analysis of the variation of natural floor frequency with variation of slab thickness, span and floor panel aspect ratio as well as analysis of the slab thickness with variation of span length and floor panel aspect ratio will be rendered. Finally the analyzed data is compared with M. Rakib (2013).

METHODOLOGY

American Institute of Steel Constructions (AISC) Steel Design Guide, Series 11: Floor Vibrations Due to Human Activity (Murray et al. 1997) states that the floor system is satisfactory if the peak acceleration, due to walking excitation as a fraction of the acceleration of gravity, g , does not exceed the acceleration limit. DG11 states that from experience and records, if the natural frequency of a floor is greater than 9-10 Hz, significant resonance with walking harmonics does not occur. Bachman and Ammann (1987) recommend that concrete slab-steel framed floor systems have a minimum first natural frequency of 9 Hz. Wyatt (1989), however, has recently proposed design criteria for walking vibration for fundamental natural frequencies not less than 7 Hz. Ohlsson (1988) has recommends that floors not to be designed with fundamental frequencies below 8 Hz. Vibration design of floors guideline incorporated in RFCS report suggested that frequency is related to modal mass. This guideline sums up that for a certain modal mass of floor, safe zone is reached beyond a frequency in the range of 3-10 Hz.

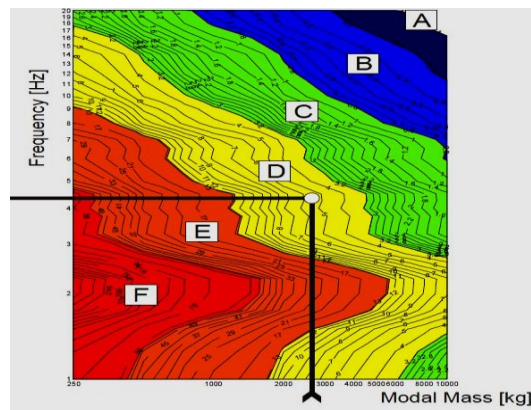


Fig. 1: Typical Frequency v/s Modal mass curve

Floors that have a natural frequency at or near 4-8 Hz may exhibit an excessive response because the input force component of the harmonic may coincide with the resonant frequency of the floor. The following Fig. 2 explains that human walking frequency mostly varies from 1.6 Hz to 8.8 Hz (Setareh, 2010). So building floor modes with natural frequencies in excess of 10 Hz is not usually excited by people walking. If the natural frequency of floor is more than 10 Hz, resonance will not occur for human excitation and discomfort to occupant is prevented.

The natural frequency of a floor can be calculated by the following formula that describes that with increase in stiffness the natural frequency of the system increases and

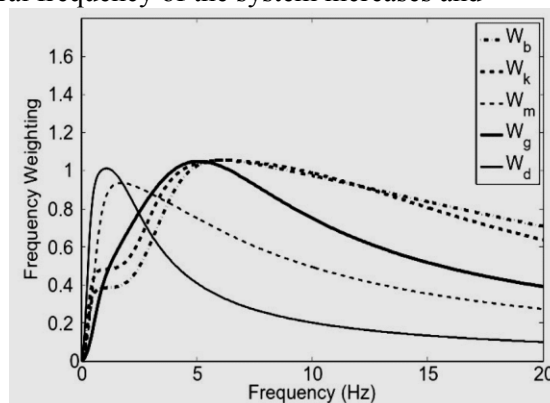


Fig. 2: Variation of the frequency weighting versus frequency (Setareh, 2010)

frequency decreases with the increase in mass of the structure. The formula follows:

$$\text{Natural Frequency, } f = \frac{1}{2\pi} \sqrt{\frac{\text{Stiffness}}{\text{Mass}}} \dots (1)$$

Finite element methods can be used to accurately predict the dynamic properties of reinforced concrete structure. ANSYS 11.0 is used in this study for its relative ease of use, detailed documentation, flexibility and vastness of its capabilities. ANSYS 11.0 is one of the most powerful and versatile packages available for finite element structural analysis. The verification of the model built in ANSYS 11.0 is done by building the model in ETABS 9.7. The x-z plane is acting as the horizontal plane in global co-ordinate system. To find the dynamic behavior of multistoried RC framed building, basic un-factored load case is considered as DL (self-weight, partition wall, floor finish). In calculation of column size determination, factored dead and live load is used.

Only self-weight of beams, columns and slabs and nonstructural load (Partition wall, floor finish) are considered as dead load case of the structure. All vertical loads except self-weight of beams, columns and slab are applied as mass on the structure. Total vertical load applied on the structure is $25 \times 4.786 \times 10^{-5}$ N/mm² (25 psf) and $50 \times 4.786 \times 10^{-5}$ N/mm² (50 psf) for floor finish and partition wall load respectively. Total live load applied on the structure is $100 \times 4.786 \times 10^{-5}$ N/mm² (100 psf). This live load will only be used in determining the beam, column size. In modal analysis live load is not used.

In this study author made reinforced floor model with ANSYS 11. The model was analyzed with modal analysis to get the dynamic behavior such as frequency of that floor for different span length and floor panel aspect ratio (beta). The floor should be modeled as a three dimensional space frame with joints and nodes selected to realistically model the stiffness and inertia effects of the structure. Each joints or nodes should have six degrees of freedom, three translational and three rotational.

For this study, a building frame of one floor with three span and three bay (bay is the longer floor panel) has been analyzed for 3m, 4m, 5m, 6m, 7m, 8m, 9m,10m span length. Floor panel aspect ratios are considered as 1, 1.2, 1.4, 1.6, 1.8. The slab thickness is takes as 50 mm increment starting from 50 mm. The column size is calculated from the load imposed on the floor assuming that the floor is a typical floor of a 5 storied building. Beam size is taken as the function of slab thickness and span length. The plan, elevation and three dimensional view of model are shown in following Fig. 3:

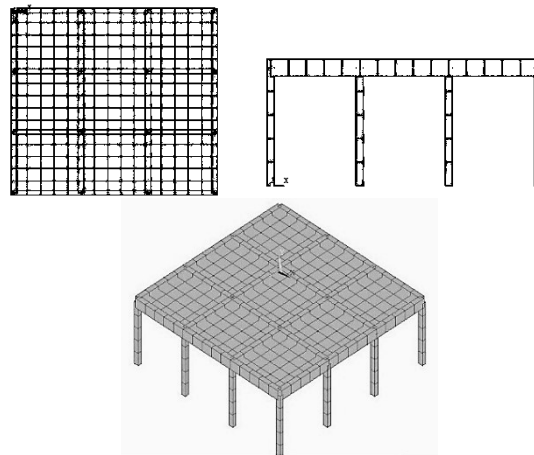


Fig. 3: Plan, 3D and Elevation of the Model

Modal analysis is used to calculate dynamic behavior of the floor (frequency). Every mode shape have a particular frequency. We have to be careful in determining the proper mode shape corresponding to the natural frequency of the floor. Initial shapes generally corresponds to sway shapes. The minimum natural frequency from mode shape must be defined carefully. Typical mode shapes are provided following in Fig. 4.

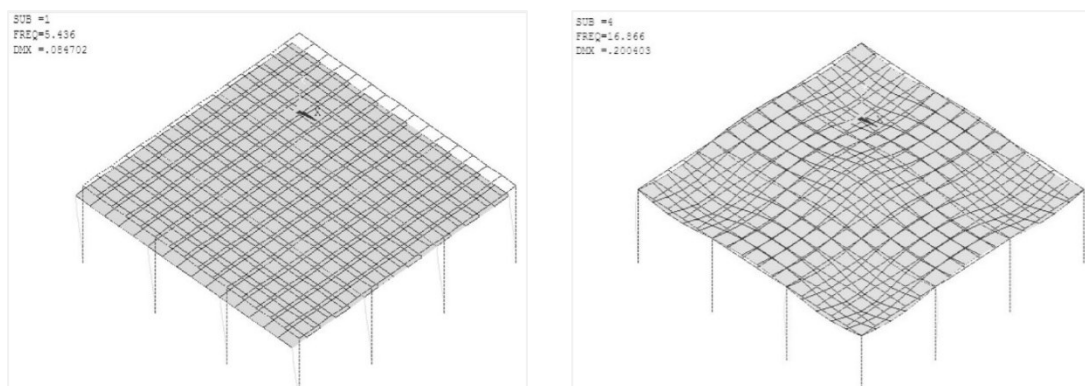


Fig 4: 1st Mode Shape, frequency 5.43 Hz and 4th Mode Shape frequency 16.87 Hz respectively

Validation of the ANSYS model is necessary in order to check whether the result found from ANSYS is accurate or not. A model is generated in software ETABS 9.7 and a particular mode shape frequency is checked whether it matches with that particular mode shape frequency of ANSYS model. From ANSYS, the natural frequency of the model floor (4th mode shape frequency) is 22.295 Hz. Three dimensional and elevation views are shown in Fig 3. From ETABS, the natural frequency of the model floor (4th mode shape frequency) is $(1/0.0405)$ Hz = 23.25 Hz.

RESULTS AND DISCUSSIONS

Analysis of determining minimum slab thickness for 10 Hz limit (Murray, 1997) for a building floor is modeled and parametric study with results will be discussed now. Parameters are taken based on practical values so that the actual building behavior under vibration will be same as the 3-D modeling frame. Only natural vibration of floor including 10 Hz criteria is studied. Comparison of ACI limit with 10 Hz criteria requirement including both present study and Rakib, (2013) is also discussed here. Typical curves are following:

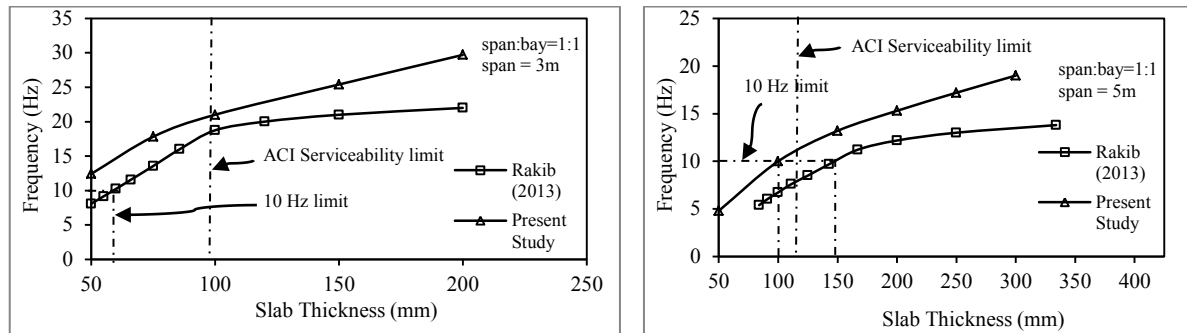


Fig. 5: Frequency v/s Slab thicknesses for floor panel aspect ratio 1.0 for 3m and 5m span

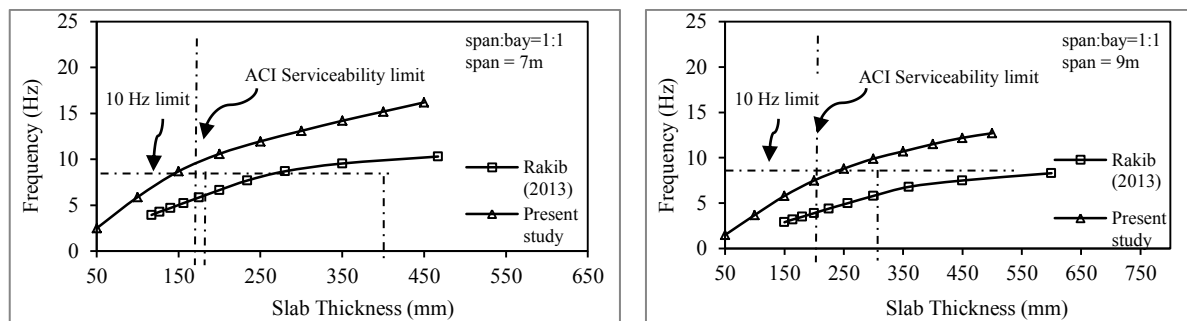


Fig. 6: Frequency v/s Slab thicknesses for floor panel aspect ratio 1.0 for 7m and 9m span

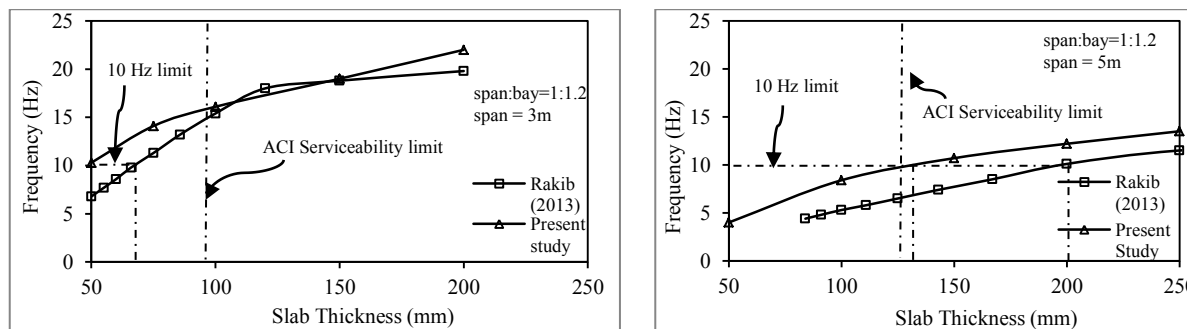


Fig. 7: Frequency v/s Slab thicknesses for floor panel aspect ratio 1.2 for 3m and 5m span

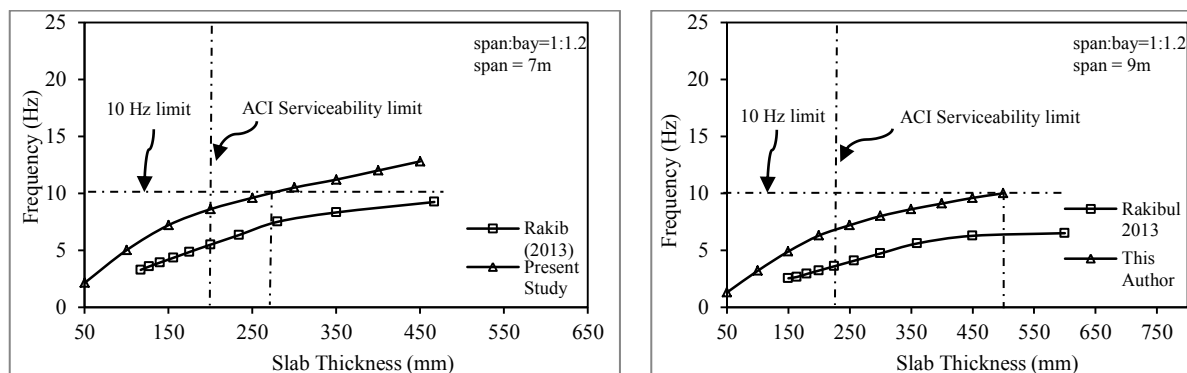


Fig. 8: Frequency v/s Slab thicknesses for floor panel aspect ratio 1.2 for 7m and 9m span

The natural frequency of floor is increasing with increase of slab thickness due to the fact that with increasing slab thickness, the beam and column size is also increased, due to self-weight of the slab. Hence increase the moment of inertia of structural elements and consequently increases the natural frequency of the floor. With increase of span length, the stiffness of the floor decreases, as a result the floor frequency is reduced. With increase of floor panel aspect ratio, the natural frequency of floor is decreasing. Increase of mass means decrease of natural frequency of the structure. But increased slab thickness increases the beam and column size that increases the moment of inertia and stiffness that increases the floor frequency.

For a particular curve, due to these two contradictory conditions, the initial part of the curves mentioned above in the figures are steeper when mass is small and when the mass is higher the curve becomes less steep. The frequency still increases due to increased stiffness. The typical shape of the curve obtained in this study is almost same as provided by Rakib (2013) but in comparison with Rakib (2013), it is seen that natural frequency is in the higher range found in this study than by Rakib (2013). In some curves provided by Rakib (2013), the frequency is very low resulting unrealistic slab thickness requirement.

Slab thickness fulfilling 10 Hz limit is plotted against various span length for various aspect ratio for both Present study and Rakib (2013) and compared with ACI Serviceability limit. Typical figures are shown in Fig. 9. Slab thickness fulfilling 10 Hz limit can also be plotted against various aspect ratio for various span for both 10 Hz limit and ACI limit. The slab thickness required for satisfying the 10 Hz limit, is increasing with the increase of span for a particular floor panel aspect ratio. Also, the larger the aspect ratio, the higher the slab thickness required for satisfying 10 Hz criteria. In comparison with Rakib (2013), it is seen that the 10 Hz limit curves provided by Rakib (2013) is higher than the curve provided by this author. It means that minimum slab thickness requirement is larger for Rakib's (2013) analysis and if the span length is large, the minimum slab thickness is sometimes found unrealistic.

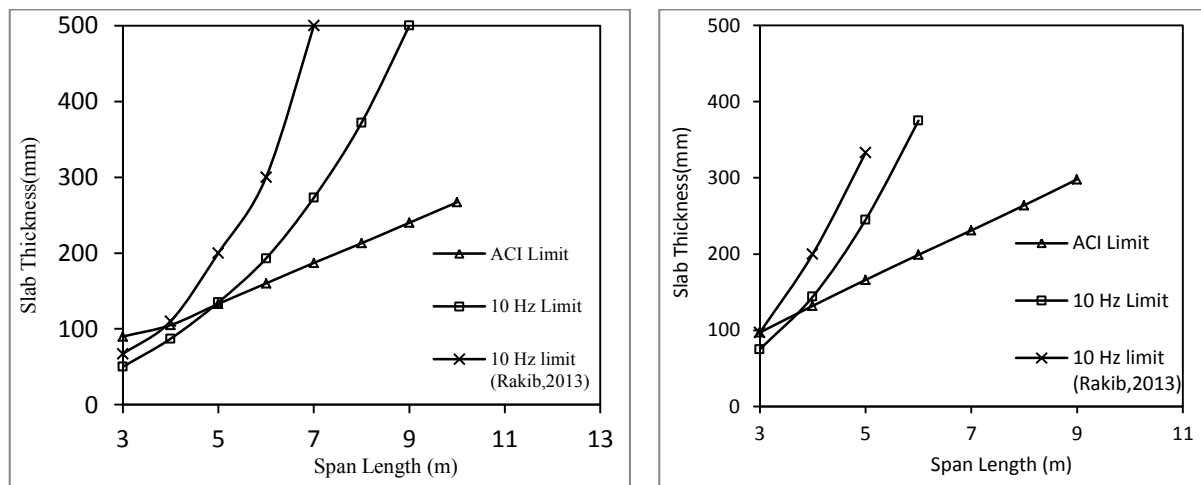


Fig. 9: Minimum Slab Thickness v/s Span length for aspect ratio of 1.2 and 1.6 respectively

CONCLUSION

In the present study an investigation has been done to determine the required minimum slab thickness from dynamic serviceability. Minimum slab thickness determination and comparison with slab thickness requirement investigated by Rakib (2013) is done. Floor frequency is dependent to mass of floor as well as the stiffness of the floor system. Increasing mass decreases the frequency and increasing stiffness increases the floor frequency. Floor frequency decreases with increase of span length and floor panel aspect ratio. ACI serviceability limit may not be sufficient for preventing floor vibration while span and aspect ratio is larger.

The minimum slab thickness requirement provided by Rakib (2013) is in the higher side in comparison with this present study. It may be due to the fact that this study only considers single floor for the vibration analysis. Only a single floor vibration is analyzed here and understanding the proper mode shape and corresponding frequency is easier. On the other hand Rakib (2013) considered 3 floors, building vibration characteristics may be merged with the floor vibration phenomena. Also the column axial stiffness may be included in the analysis of Rakib (2013).

The current study has some limitations. The results are not sufficient to apply for all type of situations as so many other factors have not been considered. Advancement of current study can be done combining some other variables. The model was considered to be linearly elastic. To be more realistic with the results a finite element analysis with nonlinearly material properties can be performed. The asymmetric floor frames can be studied under the variables considered for symmetric frames. Different number of span and bay other than three can be studied. Study can be carried out for without partition wall load. Effect of result due to floor height change can be another part of study. Vibration effect due to other sources (machinery, traffic) can be studied. Only gravity load on floor is considered in the study.

ACKNOWLEDGMENTS

The author wishes to express his deepest gratitude to Dr. Khan Mahmud Amanat, Professor, Department of Civil Engineering, BUET, Dhaka, for his continuous supervision all through the study. His systematic guidance, invaluable suggestions and affectionate encouragement at every stage of this study have helped the author greatly. A very special debt of deep gratitude is offered to the author's parents and his younger sister for their continuous encouragement and cooperation during this study.

REFERENCES

- Allen, D.E. and Murray, T.M. 1993. Design Criteria For Vibration Due To Walking. *AISC Engineering J.*, 40(4), 117-129.
- Bachmann H. and Ammann W. 1987. Vibrations in Structures Induced by Man and Machine. *Structural Engineering Document 3e*, Chapter 1, 2, 3.
- European Commission – Technical Steel Research: Generalization of criteria for floor vibrations for industrial, office, residential and public building and gymnastic halls, *RFCS Report EUR 21972 EN, ISBN 92-79-01705-5, 2006, <http://europa.eu.int>*
- Murray T.M., Allen D.E. and Ungar E.E. 1997. *Design Guide No. 11*. "Floor Vibrations Due to Human Activity", American Institute of Steel Construction (AISC), Chicago, IL, Chapter 2, 4.
- Murray, T.M.; Allen, D.E. and Uger, E.E. 2003. Floor Vibration Due To Human Activities. *Steel Design Guide Series, AISC, Chicago*.
- Nilson A.H., Darwin D., Dolan C.W., "Design of Concrete Structures", 13th edition, Chapter 13, Page 437.
- Ohlsson S.V. (1988), "Springiness and Human-Induced Floor Vibrations- A Design Guide", D12:1988, Swedish Council for Building research, Sweden.
- Rakib, M. 2013. Minimum slab thickness of RC slab to prevent undesirable floor vibration. *BSc Thesis*, Bangladesh University of Engineering And Technology (BUET), Dhaka, Bangladesh.
- Setareh M. (2010), Vibration Serviceability Of A Building Floor Structure I: Dynamic Testing And Computer Modeling. *Journal Of Performance Of Construction Facilities*, ASCE.
- Wyatt T.A. 1989. Design Guide on the vibration of floors. *ISBM: 1 870004 34 5, The Steel Construction Institute*, Berkshire, England.