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NUMERICAL ANALYSIS FOR FREQUENCY AND DISPLACEMENT IMPROVEMENT OF A LONG SPAN FLOOR BUILDING

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Abstract. In the last decade many buildings such as multipurpose buildings, malls, auditoriums, sports halls which have long-span building floor structure. Various research results indicate that in general long-span concrete floor structures have a fundamental frequency of less than 7 Hz. This will risk a resonance if this floor receives dynamic loads of people jogging to follow the song with a frequency of 2-3 Hz. This research was conducted to numerically analyze the long-span building floor model using SAP2000, to determine the fundamental frequency and maximum displacement of the floor structure model. It was also investigated how to increase its fundamental frequency and reduce the maximum displacement. The results have shown that the numerical analysis of the plate model long-span floor building using SAP2000 produces a fundamental frequency of 5.19 Hz. Model III with Reinforcing double equal angles (84x37x10x2.5) steel truss provides the best results, increases the fundamental frequency to be 7.93 Hz, and with a variety of static and dynamic loads, decreases the value of the displacement and far from the allowable displacement.

Keywords: fundamental frequency; displacement, dynamic loads, long-span floor

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1 INTRODUCTION

In the last decade many buildings, such as multipurpose buildings, malls, auditoriums, sports halls have been constructed as a long-span building floor structure. These buildings must meet the requirement for static and dynamic resistance design. In Indonesia, for the example, Supriyadi et al. [1], [2] found that the second-floor structure of Grha Sabha Pramana were remaining withstand due to earthquake loads and static live loads (e.g. graduation, weddings, and music concerts with a sitting audience of 5,000 people). Whereas, the floor experienced to a large deflection when a dynamic live load (e.g. 35 people danced following the music) was applied in the middle of the span of the floor structure. It was noticed that the natural frequency of the floor structure was 4.7 Hz which was almost gained by the frequency of movement of a group of dancing people. A similar result was also obtained by Pernica [3] in which measured directly the dynamic response of a stand area floor structure. The floor structure was built of a prestressed concrete block which the fundamental frequency was lesser than 5 Hz during the three-hour rock concert. The results indicated that the visitor movements from pounding feet and applause created a rhythmic dynamic load with frequencies ranging from 2 to 3 Hz.

Human annoyance criteria for vibration have been known for many years [4], but the criteria was applied recently for designing the floor structures. Applying the loading on the structure was complex as well as the response complicated, involving a large number of modes of vibration [4]. Ljunggren [5] provided an argument for the need to consider the effect of natural frequencies other than the fundamental as for the application to floor serviceability. Depending on the frequency and amplitude of these natural frequencies relate to the fundamentals, they could have a significant effect on the perceived vibration of the floor. However, the characteristics of the inducing force must be also considered. If the natural frequency of a floor was a tendency to exceed the limit, it was not likely to be excited by normal human activity even though it could cause severe regarding other possible input forces. Lee et al. [6] discussed about the damages from noise and vibration which increased yearly. Most of noises between floors in deteriorated building was caused by floor impact sound. In his study, the concrete slab measured vibration impact sound for evaluation floor vibration of the deteriorated buildings that fails to satisfy with the minimum thickness, and the vibration scale by impact sound was calibrated and compared with ISO and AIJ standard for vibration. The results showed that vibration in the slab with thickness used in existing building reach human perception levels.

Saidi et al. [7] demonstrated the need for the development of simple passive multi tuned mass dampers for retrofitting applications. By using multi dampers, several modes of vibrations can be treated. Furthermore, having a distributed system would result in the individual units being physically smaller in size. Finally, a multi damper system may be more accommodating if one specific damper is off-tuned due to changes to the floor such as those associated with redistribution of live loads. Murray [8] used Finite Element Analysis to Overview of Evaluation Procedure for Develop 3D model with Specialized for extremely low amplitude motion, Predict natural modes, Predict response to human activity and Compare to tolerance limit. Allen et al. [9] presented a calculation method, which was based on the selected load frequency, for the floor structure burdened with a movement of a group of people dancing or jumping rhythmically. This method is applied to the floor of the building with multi-use loads and minimum natural frequencies are obtained. This procedure was subsequently included as an additional regulation in the National Building Code of Canada 1985

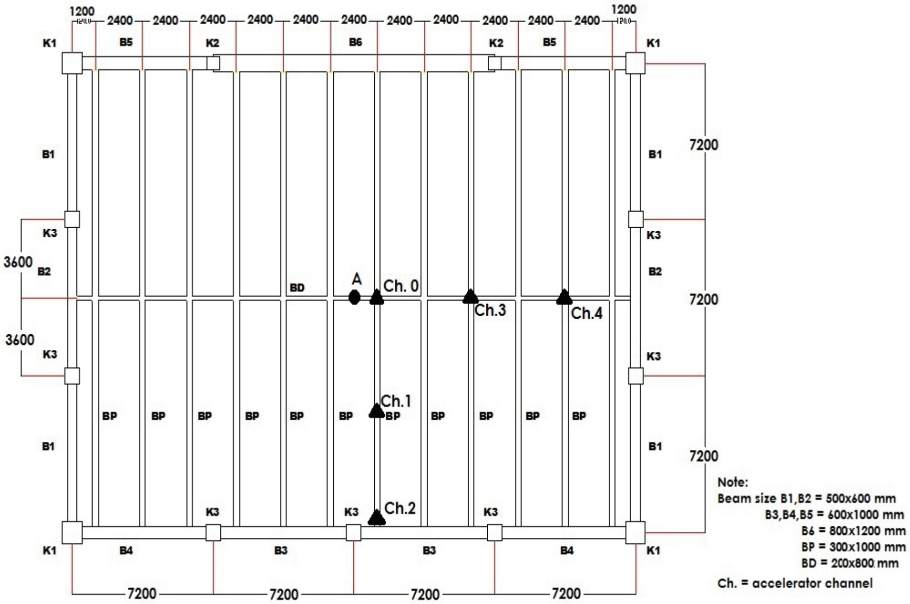
According to Bachmann and Pretlove [10] the fundamental frequency of long span floor systems designed using only static loads as is commonly done in Indonesia ranges from 4.5 to 5.5 Hz. While the dynamic burden is caused by a group of people jogging, dancing and moving together with a certain rhythm that lasts more than 20 seconds, has a frequency of around 2.0 to 3.0 Hz. The main design criteria that are suitable for floor systems that might be used for movement with a group of people with a certain rhythm, should be greater than twice the frequency of dynamic loads that work. Bachman also requires that floor systems with prestressed beams must have a minimum fundamental frequency of 7.0 Hz. Limitation of deflection of maximum permits and minimum height of beams listed in various Concrete Structure Design Guidelines in Indonesia, SNI 2847-2013 [11], as well as guidelines for the amount of live load that works in cargo regulations is considered insufficient to be used as a guideline for the design of long-span room structure, because in the process all of which are assumed to be static loads. In addition, the problem of excessive vibration in long-span floor structures has not received serious attention from structural planners in Indonesia, as has been done to overcome the dynamic burden of the earthquake.

Erlina et al. [12] illustrated that the additional damper improved the vibration serviceability of the floor system. This study also indicates that the use of additional damper can reduce the response of vertical acceleration. Liu and Davis, [13] presented a new method for predicting the waveform peak acceleration, narrowband spectral acceleration maximum magnitude, and one-third octave spectral velocity maximum magnitude. A total of 89 walking vibration tests were performed on five high-frequency floor bays. The measurements are used to assess the precision of the proposed methods and to calibrate the prediction methods to provide a specific probability that the actual response will exceed the predicted response. The measurements are compared to predictions by the proposed method and five established methods. According to Rainer and Pernica [14], the dynamic parameters of the slab so far have received little attention, so that many plates behave unsatisfied when receiving unwanted vibrations. Efficient design and the use of high quality materials tend to make the structure lighter and not stiff so that it is more sensitive to the vibration loads of walking people and machine tools.

Supriyadi et al. [1], [2] show how dangerous it is if the second floor of the Graha Sabha Pramana UGM building is burdened with a certain number of people who jump or dance following the sounds of music. Some researches [15], [16], [17] have examined experimentally and numerically using plate reduction models to increase the frequency of the second-floor building of the Grha Sabha Pramana UGM. The problem arose next is to find a way to add stiffeners without overlapping at the limit state, the combined structure of the other systems, and stiffeners to avoid overdesigning. As can be ascertained that the existing structure in the form of a slab system that has fulfilled several limit state structures in the form of strength (ductility) and resilience (durability), but need to be added stiffener to meet the other limit state in the form of stiffness, stability, and serviceability due to dynamic loads, without excessive overlap at the limit state that has been fulfilled. The purpose of this study was to find a solution for the long-span floor structure by taking the example of the second floor of the Grha Sabha Pramana building which included long-span floors which were built with the ability to withstand dynamic loads less and also to clarify the limits of their natural frequencies to avoid the danger of resonating with dynamic live load frequencies witch might work or vibrate the building. Besides, the results can be proposed to be additional regulations in multi-story buildings in the control of building strength due to the burden of dynamic life. Simultaneously with the study, the displacement was also examined to examine whether it exceeded the allowable displacement.

2 RESEARCH METHODS

The layout and dimensions of the second-floor plate of Grha Sabha Pramana (GSP) is shown in Fig. 1. In this study a numerical model was made using SAP2000 as shown in Fig. 2. The structure was modeled as 3D elements that have concrete material characteristics, dimensions, and spans such as those on the building's 2nd-floor plate prototype, henceforth referred to as Model I. The structure was loaded as required in Indonesian building code of minimum loads for building design [18]. There were two steps of analysis in this study: (1) determination for the appropriate number of elements, and (2) simulation of the reinforced floor structure.



Note:
Beam size B1,B2 = 500x600 mm
B3,B4,B5 = 600x1000 mm
B6 = 800x1200 mm
BP = 300x1000 mm
BD = 200x800 mm
Ch. = accelerator channel

Fig. 1 The beam - slab layout and dimension of the second floor of Grha Sabha Pramana [1,2]

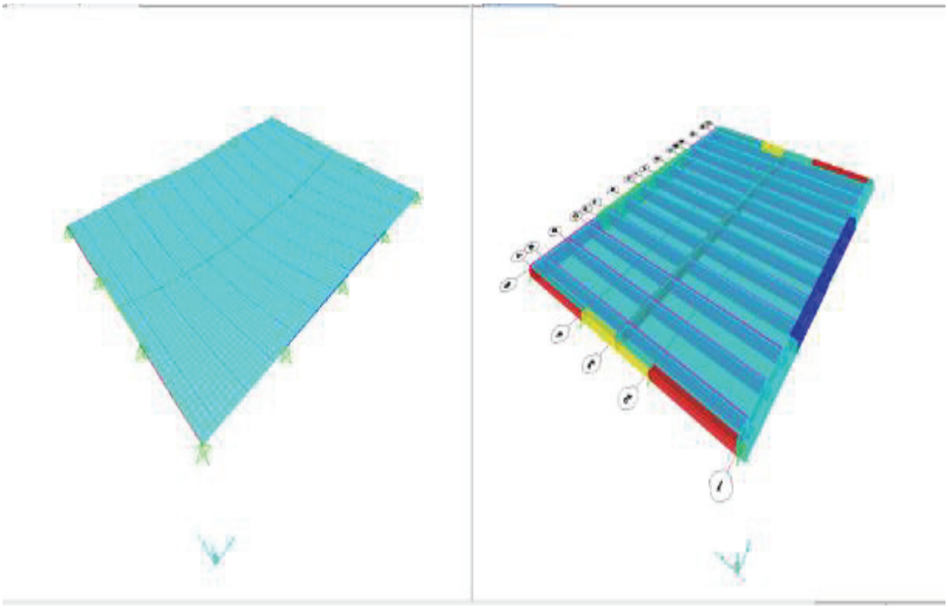
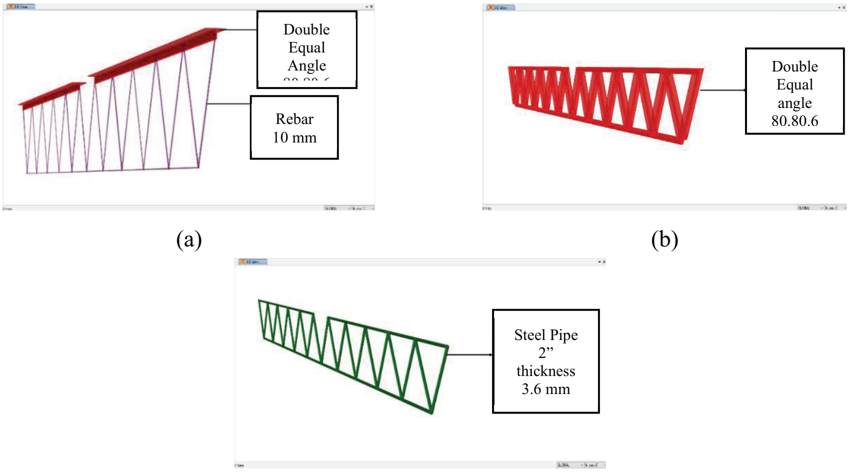


Fig. 2 Numerical Model of Second Floor of GSP

The floor system was modeled as solid material. The boundaries was set as fixed at the edge of the floor as shown in Fig. 2. Number of elements was a controlling parameter in the finite element method. To obtain an appropriate meshes in modeling, in this study, the SAP2000 analyzed eight models with the different numbers of the mesh sizes. Convergent value was marked when the analysis of the number of elements had a relatively same the value of maximum displacement or less deviation at the point A (see Fig. 1).



(a) (b)

(c)

Fig. 3 (a) Reinforcing Steel bar truss of 10 mm diameter (Model II), (b) Reinforcing double equal angle (84x37x10x2.5) steel truss (Model III), (c) Reinforcing pipe truss of 2 inch diameter (Model IV)

Numerically, to get this solution, a reinforcing steel bar truss of 10 mm diameter, henceforth referred to as Model II (Fig. 3a), a reinforcing double equal angle (84x37x10x2.5) steel truss, henceforth referred to as Model III (Fig. 3b) and a reinforcing pipe truss of 2-inch diameter, henceforth referred to as Model IV (Fig. 3c) was added to the bottom of the second-floor plate model of Grha Sabha Pramana. The height of the third steel truss was 1 m. These three types of reinforcement as an alternative if the position of the reinforced floor is very high compared to the lower floor and does not disturb the lower floor space. The merging of the steel truss into the concrete floor slab is carried out using anchoring. Then the three reinforced models are analyzed with SAP2000 to find out the changes in fundamental frequency and displacement results. In the analysis to find out the maximum displacements, all plate models are loaded with dead load and live load statically and dynamically. For dynamic live loads, sinusoidal harmonic load was used with frequencies from 1-6 Hz. This load frequency was chosen mainly to find out people who danced and sang to follow the music with a frequency of 2-3 Hz.

3 RESULTS AND DISCUSSION

3.1 EFFECT OF THE NUMBER OF MESH ELEMENTS

From analysis with a combination of loading: dead load + live load, the maximum displacement values differ from the eight models but are located in the same coordinates. The relationship between the eight models with the value of maximum displacement can be seen in Table 1. The results in Table 1 shows that based on the eight models of calculation with mesh variation from 7200 mm to 400 mm, the frequency and displacements was relatively the same after the mesh size of 400 mm. Thus, the mesh element of 400 mm can be considered for further numerical simulation.

Table 1 Relationship between mesh size and the results of the analysis using SAP 2000

No	Mesh (mm)	Frequency (Hz)	Maximum Displacement (mm)	Mass (kg.s^2/cm)	Stiffness (kg/m)
1	7200	4.55	17.123	513.26	419488
2	3600	4.73	16.062	513.26	454294
3	2500	4.85	15.478	513.26	476040
4	2000	4.91	15.100	513.26	489889
5	1500	4.95	14.927	513.26	496948
6	1000	5.03	14.501	513.26	513684
7	500	5.16	13.894	513.26	539715
8	400	5.19	13.741	513.26	546429

Furthermore, Table 1 show that the results of the second-floor frequency of the Grha Sabha Pramana building is 5.19 Hz, closely to the results of a study conducted by Supriyadi et al. [1,2] and even close to the results of a study by Supriyadi et al. [15], in which also conducted experimentally in the Civil and Environmental Engineering Structural laboratory. In numerical and experimental research from Supriyadi et al. [15], showed that the fundamental frequency results ranging from 4.001 to 5.493 Hz. Based on these results, the fundamental frequency of the second floor of the Grha Sabha Pramana building was remaining smaller than 7 Hz as a minimum frequency requirement according to Bachmann and Pretlove [10]. Therefore, in this study, a solution was sought for increasing the frequency of the second floor of the Grha Sabha Pramana building to exceed the minimum frequency requirements.

3.2 EFFECT OF REINFORCING STRUCTURE

The results of the analysis of the plate model reinforced with 3 types of reinforcement using SAP 2000 could be seen in table 2. The results show that the fundamental frequency increases to 5.34 Hz, 7. 93 Hz and 6.17 Hz respectively for Model II, Model III, and Model IV. From the 3 ways of strengthening above, it appears that the most effective is the Model III. Beside increasing the frequency table 2 show also increases the value of the stiffness. From a non-reinforced plate Model I which rigidity value is 546429 kg/m, to be 581788 kg/m of Model II, to be 1302519 kg/m of Model III and to be 776188 kg/m of Model IV. It appears that there is a correlation between increasing frequency and stiffness.

Table 2 Frequency, mass, stiffness of plate with reinforcement

Plate Model	Frequency (Hz)	Mass ($kg.s^2/cm$)	Stiffness (kg/m)
Model I	5.19	513.26	546429
Model II	5.34	516.80	581788
Model III	7.93	524.66	1302519
Model IV	6.17	516.46	776188

Table 3 Maximum displacement on each plate model.

Plate Model	Maximum Displacement (mm)							The allowable displacement: L/360 (mm)
	1.2 DL+ 1.6LL Static	1.2DL+ 1.6LL Harmonic 1 Hz	1.2DL+ 1.6LL Harmonic 2 Hz	1.2DL+ 1.6LL Harmonic 3 Hz	1.2DL+ 1.6LL Harmonic 4 Hz	1.2DL+ 1.6LL Harmonic 5 Hz	1.2D+ 1.6LL Harmonic 6 Hz	
Model I	65.20 (81.5%)	67.08 (83.85%)	75.34 (94.18%)	92.00 (115%)	179.02 (223.78%)	445.63 (557%)	155.02 (193.8%)	80.00
Model II	60.97 (76.21%)	62.95 (78.69%)	69.18 (86.48%)	82.57 (103.2%)	120.94 (151.18%)	327.78 (409.7%)	194.39 (243%)	80.00
Model III	25.77 (32.2%)	26.28 (32.85%)	27.32 (34.15%)	29.08 (36.35%)	32.57 (40.7%)	39.66 (49.58%)	53.67 (67.1%)	80.00
Model IV	45.06 (56.32%)	46.28 (57.9%)	49.65 (62.1%)	56.47 (70.59%)	70.37 (87.96%)	112.02 (140%)	343.03 (428.8%)	80.00

Note: value in bracket ( ) was the percent of maximum displacement of the allowable displacement.

To examine the magnitude of the displacement that occurred, loading was applied to the 4 numerical models of plates with a combination of factored dead load and live load statically and a combination of factored dead load and live load dynamically with a sinusoidal frequency of 1-6 Hz and a safe allowable displacement were calculated based on SNI 2847-2013 [11]. As presented in Table 3, the displacement of all model were remaining less than the allowable displacement when the structures were loaded by a combination of factored dead load and live load statically. As well on the harmonic life loading with a frequency of 1-2 Hz, the displacement that occurred for all model were still less than the allowable displacement. But for model I and model II due to the harmonic life loading with a frequency of 3 Hz the displacements that occur at 92 mm and 82.7 mm exceeds 80 mm as allowable displacement. The largest maximum displacement occurs in Model I (445.63 Hz), when the resonance phenomenon occurs. That happens when the harmonic dead load and live load with a frequency of 5 Hz is charged to Model I which has a fundamental frequency of 5.19 Hz. That also happens to Model I and Model II displacement due to harmonic dead load live loads with a frequency of 6 Hz is 155.02 mm and 194.39 mm. On the other hand, the reinforcement models (Models III) the displacements that occur from all loading are still below the allowable displacement. The maximum displacement of the Model III was only 53.67 mm, which was 67% of the allowable desplacement of 80 mm. Although the Model IV which has fundamental frequency 6.17 Hz was safe to be loaded with harmonic loads with frequencies up to 4 Hz, but it was unsafe if the load frequency is 5-6 Hz so displacements that occur are more than 80 mm. So model III that shows displacement is safe for all type of loading and changes in fundamental frequency to be 7.93 Hz which means more than 7 Hz.

4 CONCLUSION

In this study, a numerical investigation concerning dynamic response of long span floor building has been presented. The results and discussion found that the second floor of the Grha Sabha Pramana building has a fundamental frequency of 5.19 Hz, which was smaller than that required by Bahman and Pretlove [10]. Although the second floor of the Grha Sabha Pramana building has been designed to be safe against dead loads and live loads statically and even safe from harmonic dynamic loads with load frequency up to 2 Hz, it was unsafe for 3 Hz load frequency. So that without reinforcing structure, the floor was at risk if there was a loading from a group of people dancing and singing follow the music with a frequency of 3 Hz. Based on simulation of the 3 types of reinforcement, Model III was recommended to be installed, because the double equal angle (84x37x10x2.5) steel truss increased the fundamental frequency up to 7. 93 Hz and the stiffness improved from 546429 kg/m to 1302519 kg/m. The reinforcing floor could reduce the value of the maximum displacement as 29.27 mm which was 64% lower than the allowable displacement.

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