Experiment on the concrete slab for floor vibration evaluation of deteriorated building

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Abstract. Damages from noise and vibration are increasing every year, and most of which are noises between floors in deteriorated building caused by floor impact sound. In this study, the floor vibration of the deteriorated buildings constructed with the concrete slabs of thickness no more than 150 mm was evaluated by the vibration impact sound. This highly reliable study was conducted to assess floor vibration according with the serviceability evaluation standard of Reiher / Meister and Koch and vibration evaluation standard of ISO and AIJ. Designed pressure for the concrete slab sample of floor vibration assessment was 24MPa, and the sample was manufactured pursuant to KS F 2865 and JIS A 1440-2 with size of 3200 mm × 3200 mm × 140 mm. Tests were conducted twice with accelerometers, and Fast Fourier Transform was performed for comparative analysis by the vibration assessment criteria. The peak displacement from Test 1 was in the range of 0.00869 - 0.02540 mm; the value of peak frequency ranged from 18 to 27 Hz, and the average value was 22Hz. The peak acceleration value from Test 2 was in the range of 0.47 - 1.07 % g; the value of peak frequency was 18.5 - 22.57 Hz, and the average was 21Hz. The vibration was apparently recognizable in most cases according to the Reiher/Meister standard. In case of Koch graph for the damage assessment of the structure, the vibration was at the medium level and causes no damage to the building structure. The measured vibration results did not exceed the damage limit or serviceability limit of building according to the vibration assessment criteria of ISO and residential assessment guidelines provided by Architectural Institute of Japan (AIJ).

1. Introduction

The weights of the buildings at present were reduced in order to secure the large space by using high-strength lightweight concrete, design technology development, long span and high strength steel development. Therefore, the damping ratio and natural frequency of the building structure is decreasing. This phenomenon has caused the problem of dynamic load on the floor plate due to the vertical vibration. Thus, in the case of high-rise residential building, required to the effective standard for controlling the floor vibration that large space and long spanned is caused by the steel material, steel frame, high strength concrete [1]. For the modern architectures, the building spans are gradually increasing and the weight of the buildings become lighter with the development of structural analysis techniques and the improved strength of the construction materials. The rigidity of the floor plate reduces the natural frequency and damping capacity. to the problems of vibration comes from

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‘serviceability’, which causes residents to feel anxious and uncomfortable (Ad Hoc Committee on Serviceability Research, 1986) [2]. The recent high-rise building has serviceability problems caused by the wind-induced vibration acceleration. Therefore, accurate prediction of the dynamic characteristics is very important in the calculation of the reliability acceleration such as damping capacity and natural frequencies. In general, the natural frequency of the high-rise buildings can be calculated through the eigenvalue analysis at the design stage, but the prediction of the damping rate is difficult as the exact natural frequency is unpredictable. Detectable building vibration can cause anxiety of the residents. Such degree of building vibration that ordinary people cannot withstand is defined as ‘serviceability limit state’ [3]. For the passengers of the automobiles and airplanes which have the moving frequency of 5-8 Hz, their bodies suffer the most unpleasant experience due to the fact that the natural frequencies of the human ribs and abdomen overlap with these frequencies and thus create resonance. A vibration may not damage the structure, but it can cause discomfort for people and disturb working process of the sensitive machines. (Ellingwood, 1989) [4]. In case of the horizontal member (beams, slabs) of the structure to induce the vertical is no problem in the structural safety in the design of the stress examine and limits by static deflection, it is possible for the residents to generate anxiety and discomfort due to the vibration. Buildings are exposed to vibrations on a daily basis, and the effect of vibrations on structural safety of buildings differs according to various factors such as amplitude and cycle of vibration. Also in general, there is a substantial difference between human perception and safety of building. In case of Korea, the standard of heavy-weight impact noise interruption performance for standard floor structures was reinforced because of the damages from the noises between floors, and the slab thickness of wall type and mixed structure buildings was increased from 150 mm and below to 210 mm and above [5]. Regular inspections are performed on buildings that using slabs with thickness of 210mm or above such as newly constructed apartment houses, but the old apartment houses that using slabs with thickness of 150mm and below has not been inspected yet. In this study, the floor vibration of the deteriorated buildings constructed with the concrete slabs of thickness no more than 150 mm was evaluated by the vibration impact sound. This highly reliable study was conducted to assess floor vibration according with the serviceability evaluation standard of Reiher / Meister and Koch and vibration evaluation standard of ISO and AIJ.

2. Methodology

Sources of vibration impact are generated in the form of shock wave and converted to elastic wave with amplitude and cycle. Here, the elastic wave generated inflicts damage on nearby structures and facilities. Ground vibration is described with displacement, velocity, acceleration and frequency. When a typical form of ground vibration is assumed to be a simple harmonic motion with constant cycle, the correlation shown in Eq. (1) - (4) is established among displacement, velocity and acceleration at maximum amplitude [10].

\[
\begin{align*}
\mu &= \mu_0 \sin(\omega t + \theta) ; \int \mu \, dx \\
\frac{d\mu}{dt} &= \omega \sin \left(\omega t + \theta + \frac{\pi}{2}\right) ; \int \frac{d\mu}{dx} \\
\ddot{\mu} &= \frac{d^2\mu}{dt^2} = d^2 \frac{\mu}{dx^2} = \omega^2 \mu_0 \sin(\omega t + \theta + \pi) \\
\omega &= 2\pi f = 2\pi \left(\frac{1}{T}\right)
\end{align*}
\]

Where, \(\mu, \mu_0 \text{ and } \theta\) are displacement, maximum displacement (mm) and phase angle (rad) respectively. \(\dot{\mu} \text{ and } \ddot{\mu}\) are particle velocity (mm/sec, cm/sec, kine) and acceleration (gal, cm/sec²), \(f \text{ and } T\) are frequency (Hz) and cycle (sec).
Since the absolute value of maximum particle motion is important in most situations related to characteristics of ground vibration, it can be represented as an absolute value as shown in the following two equations where $\mu_{\text{max}} = \mu_0$, $\dot{\mu}_{\text{max}} = v$, $\ddot{\mu}_{\text{max}} = a$ (better have real equations here instead of an image). As they have a functional relationship, the variable of maximum particle velocity can be computed by Eq. (5) - (7) once vibration frequency is known and the vibrational wave is approximately a simple sinusoidal wave.

$$v = \omega \mu_0 = 2\pi f \mu_0 ; \mu_0 = \frac{v}{2\pi f}$$  \hspace{1cm} (5)

$$\alpha = \omega^2 \mu_0 = (2\pi f)^2 \mu_0 = 2\pi f v ; v = \frac{a}{2\pi f}$$  \hspace{1cm} (6)

Also, the relationship among wavelength ($\lambda$), propagation velocity of elastic wave $c$, and cycle $T$ was presented in Eq. (7).

$$\lambda = c T = c \left( \frac{1}{f} \right)$$  \hspace{1cm} (7)

The functional relationship of the attenuation relation for the ground vibration was shown in Eq. (8).

$$V = V(D)^n$$  \hspace{1cm} (8)

Where $V$ is the ground vibration velocity (mm/sec, cm/sec) and $D$ is the distance between station point and vibration source and $n$ is the location constant by soil conditions.

3. Experimental

Designd pressure of the concrete slab sample for floor vibration assessment was 24MPa, and the sample was manufactured pursuant to KS F 2865 and JIS A 1440-2 with the size of $3200 \times 3200 \times 140$ mm\cite{12-13}. D13 rebar was arranged for 28 days of atmosphere curing. In this study, a 70kg adult male was allowed to jump for every second at the center of the floor to inflict impacts that were measured at different points. The tests were conducted twice with the accelerometers, and Fast Fourier Transform was performed for comparative analysis according with the vibration assessment criteria. The concrete slab sample was shown in Fig. 1. 1(a) was the sample of floor vibration and 1(b) was the measurement points. The conceptual diagram of the acceleration vibration measurement of Test 1 was shown in Fig. 2(a). 2(b) was the process of this experiment. Two tests were run to evaluate the respective measurements at each point with different standard. Test 1 was analyzed with standard of Koch and Reiher / Meister, Test 2 was analyzed with standard of ISO and AIJ. Fig. 3 showed the measured data from the accelerometer \cite{6-9}.
4. Results and Discussion

4.1 Test 1

The experimental data in Table 1 was compared with the Meister and Reiher serviceability evaluation standard for building. The peak displacements ranged from 0.00869 to 0.02540 mm, and the peak frequency of vertical vibration had a range of 18 - 27 Hz and an average of 22 Hz. The vibration correspond with most of the measured data can be identified as clearly sensible. The measured vibration was at the medium level and would cause no damage to the building structure according to the Koch Standard. The analysis result of the vibration measurement, the vibration about damage to the structure was not measured. However, the vibration was measured vibration enough to detect in general. The vibration measurement and the damage to the structure was not analysed in details. The vibration can be detected in general however.

4.2 Test 2

Serviceability value at which people feel discomfort was based on the recommended value of ISO 2603. As in Table 2, peak frequencies at points 1 to 5 were 19, 20, 23, 20 and 22 Hz, and the average was 21 Hz. Serviceability limit for office and residential spaces at predominant frequencies of 18.5, 19.6, 22.6, 20.0 and 22.3 Hz for Points 1~5 are 0.7 %, 0.5 %, 0.9 %, 1.1 % and 0.9 % g of gravitational
acceleration. Accordingly, 0.7 %, 0.5 %, 0.9 %, 1.1 % and 0.9 % g were set as reference values. The highest acceleration amplitudes measured were 0.73 %, 0.47 %, 0.87 %, 1.07 % and 0.87% respectively. These values were not close to the recommended values for office and residential spaces. The range of vibration was 19% - 23% g, which was within the limit of serviceability. The results from Test 1, the serviceability standard of Reiher/Meister and the damage assessment by Koch were shown in Fig. 4(a) and 4(b). The data from Test 2, the serviceability standard of ISO and residential performance assessment of AIJ were shown in Fig. 4(c) and 4(d).

| Test 1 | Peak Frequency (Hz) | Peak Displacement. (mm) | PVS (mm/s) | Serviceability standard | Structure damage standard |
|--------|---------------------|-------------------------|------------|--------------------------|--------------------------|
|        |                     |                         |            | Reiher/Meister<sup>1)</sup> | Koch<sup>2)</sup>           |
| Point 1| 24                  | 0.01080                 | 2.52       | Surely recognition       | Moderate vibration (Nothing) |
| Point 2| 18                  | 0.02540                 | 3.30       | Surely recognition       | Moderate vibration (Nothing) |
| Point 3| 27                  | 0.00869                 | 1.78       | Pretty recognition       | Moderate vibration (Nothing) |
| Point 4| 21                  | 0.01570                 | 2.66       | Surely recognition       | Moderate vibration (Nothing) |
| Point 5| 21                  | 0.01830                 | 2.77       | Surely recognition       | Moderate vibration (Nothing) |

1) Standard level : Incognizance - Pretty recognition - Surely recognition – Slightly unpleasant - Extremely unpleasant - Unbearable
2) Standard level : Light vibration (Nothing) - Moderately vibration (Nothing) - Wildness vibration (plastering crack) - Serious vibration (wall damage) - Extremely serious vibration (destruction)

| Table 1. Measurement result of Test 1 |
|--------------------------------------|
| Test 2 | Peak Acceleration (%g) | Peak Frequency (Hz) | Time (sec) | Serviceability | Residential performance assessment |
|--------|------------------------|---------------------|------------|----------------|-----------------------------------|
|        |                        |                     |            | ISO            | AIJ                               |
| Point 1| 0.73                   | 19                  | 36         | Baseline       | Baseline                          |
| Point 2| 0.47                   | 20                  | 29         | Baseline       | Baseline                          |
| Point 3| 0.87                   | 23                  | 47         | Baseline       | Baseline                          |
| Point 4| 1.07                   | 20                  | 19         | Baseline       | Baseline                          |
| Point 5| 0.87                   | 22                  | 60         | Baseline       | Baseline                          |

5. Conclusion

In this study, an experiment was conducted to evaluate the floor vibration of deteriorated buildings. The impact sound of the concrete slab sample was measured and the results were stated as follow:

The peak displacement from Test 1 was in the range of 0.00869 - 0.02540 mm; the value of peak frequency ranged from 18 to 27 Hz, and the average value was 22Hz. The peak acceleration value from Test 2 was in the range of 0.47–1.07 % g; the value of peak frequency ranged from 18.5 to 22.57 Hz, and the average was 21Hz. Ranges of the vibration frequency from Test 1 and Test 2 were relatively consistent. When it is seen that the natural frequency values of floor slabs are concentrated in relatively the same range, it is known that occur temporary and intensive vibration on the specimen.
Concrete slab floor that was used in deteriorated building with thickness lower than the latest standards creates living noise at level that does not exceed the standard range, but the noise is sufficient enough to make people feel uncomfortable. The vibration was apparently recognizable in most cases according to the Reiher/Meister standard. In the case of Koch graph for the damage assessment of the structure, the vibration was at the medium level and cause no damage to the building structure. The measured vibration results did not exceed the damage limit or serviceability limit of building according to the vibration assessment criteria of ISO and residential assessment guidelines provided by Architectural Institute of Japan (AIJ). Vibration currently does not exceed damage limit or serviceability limit of building, but there is a problem of serviceability for temporary vibration. As the natural frequencies were similar to the frequencies measured at the test points from the experiment, buildings can possibly be damaged by vertical vibration and by the amplification of longitudinal
vibration. Further study was expected to confirm the experimental data for serviceability and to assess the applicability of floor vibration assessment criteria for aged buildings.

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Reference
[1] Colin Hansen, Scott Snyder, Xiaojun Qiu, Laura Brooks, Danielle Moreau, “Active Control of Noise and Vibration” second edition volume 1, 2013
[2] Ad Hoc Committee on Serviceability Research, “Structural serviceability : A critical appraisal and research needs.” J. Struct. Engrg., 112(12), 2646-2664, 1986
[3] H. Reiher and F.J Meister, “Human Sensivity to Vibrations”, Forsch. aufdem Geb. Des Ingen, vol. 2, no. 11, pp.381-386, 1931
[4] B. Ellingwood, “Probability-based codified design: past accomplishments and future challenges”, Structural Safety, 13, pp. 159–176, 1994
[5] Ministry of Land, Infrastructure and Transport, “Management standards and accreditation of floor impact sound of apartment building”, Republic of Korea, 2013
[6] Reiher W, Meister FJ. The effect of vibration on people (translated from German, originally published in 1931). Report, F-TS-616-RE, Headquarters Air Material Command, Wright Field, OH, 1946
[7] F. Koch, V. Petrova-Koch, T. Muschik, J. Lumin., 57, p. 271, 1993
[8] ISO, “ISO 2631 Mechanical vibration and shock-evaluation of human exposure to whole-body vibration”, 1997
[9] AIJ, “Residential performance assessment criteria guideline explanation””, Architectural Institute of Japan, 2004
[10] Anil K. Chopra., “Dynamics of Structures”, Theory and Applications to Earthquake Engineering. 
[11] BlastMate III Operation Manual, software version 4.3, Instantel, ISO 9001, 2001
[12] KS F 2865, “Laboratory measurements of the reduction of transmitted impact sound by floor coverings on a heavyweight standard floor”, 2012
[13] JIS A 1440-2 : Acoustics - Laboratory measurement of the reduction of transmitted impact sound by floor coverings on a solid standard floor - Part2 : Method using standard heavy impact sources, 2007References to preprints. For preprints there are two distinct cases: