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RESEARCH AND DEVELOPMENT OF FLOOR IMPACT SOUND INSULATION OF MULTI-FAMILY DWELLINGS IN JAPAN

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ABSTRACT
In Japan, the problem of floor impact sound caused by such heavy impacts as human walking and stepping is still of frequent occurrence and the reduction of this acoustic problem is regarded as the most important condition in the structural design of floors of multi-family dwellings. In this paper, the state of development researches of floor impact sound insulation and typical examples of the specification of floor construction of actual buildings in Japan are introduced.

1 - INTRODUCTION
Multi-family dwellings in Japan prior to 1960 consisted primarily of the so-called "nagaya" (wooden tenement-style structures made up of contiguous dwelling units in the lateral direction); beginning in the 1960s, however, concrete structures began to become more wide spread, bringing about an increase in a residential format in which dwelling units are situated contiguously in the vertical direction. Quantity was more important in multi-family dwellings in those days than quality and, given the thin floor slabs, there were many complaints about floor impact sound from the unit above, eventually developing into a social problem. In order to resolve such problems, academic societies, industries and other concerned parties became vigorously involved in research and development, eventually realizing the design and supply of multi-family dwellings with considerable improvements in the performance of floor impact sound insulation.

Floor impact sound can be given as the type of noise that causes the most serious problems in multi-family dwellings and, since in Japan, in particular, where people remove their shoes before entering, the heavy, soft impact (heavy impact sound) that originates in the sound of people walking, stepping, running around and so forth is frequently targeted.

Floor impact sound by heavy weight impact source refers to the impact sound that is generated in the dwelling unit below when people running, etc., on the floor barefoot. In short, since the impact source itself is heavy and soft, the impact force that is applied to the floor is of considerable magnitude, including primary components in the range of 20 Hz − 100 Hz, and, therefore, the performance of floor impact sound insulation itself is dominated by the performance (mass, flexural rigidity, etc.) of the floor structure.

In this paper, we introduce the evaluation of residents toward the sound environment of multi-family dwellings, methods for evaluating heavy floor impact sound insulation performance, the current state of research and development of floor structure and floor impact sound, etc., in Japan.

2 - EVALUATION BY RESIDENTS OF INTERIOR NOISE
More than forty years have passed since concrete multi-family dwellings generally penetrated the market in Japan and the authors have continued to conduct large-scale questionnaire surveys of multi-family dwelling residents at an interval of every 10 − 15 years. Figs. 1, 2 and 3 shows a portion of the results of the questionnaire survey of the sound environment that the authors conducted targeting about

2,400 individual dwelling units in public multi-family residential buildings either for purchase or rental constructed mainly in the period 1985 – 92. The "rate of satisfaction of residents with the sound environment" indicates that some 70% of the residents of both purchased and rented units responded affirmatively regarding "satisfaction" from their actual experiences in everyday life, which could be considered favorable in terms of the overall sound environment. However, Fig. 1 and Fig. 2 indicate that room layout, sunlight exposure and so forth were given as the reasons for selection of the unit before taking up residency; after moving in, however, there was a high proportion of residents who pointed out a desire for improvements in "sound insulation properties" and "condensation and moisture proofing". The performance of spaces with respect to sound in particular is an element that cannot be definitely comprehended without actual experience in living in the dwellings and considerable disparities in the reaction of residents after taking up residency are apparent.

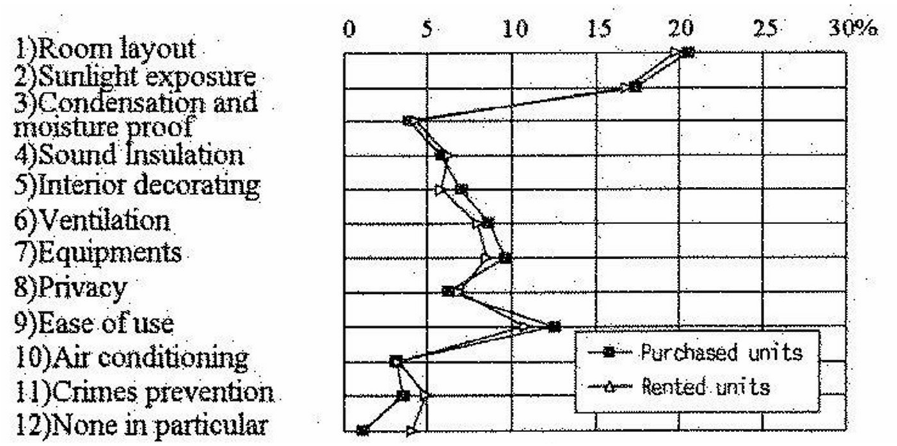

Figure 1: Reasons for selecting the current unit.

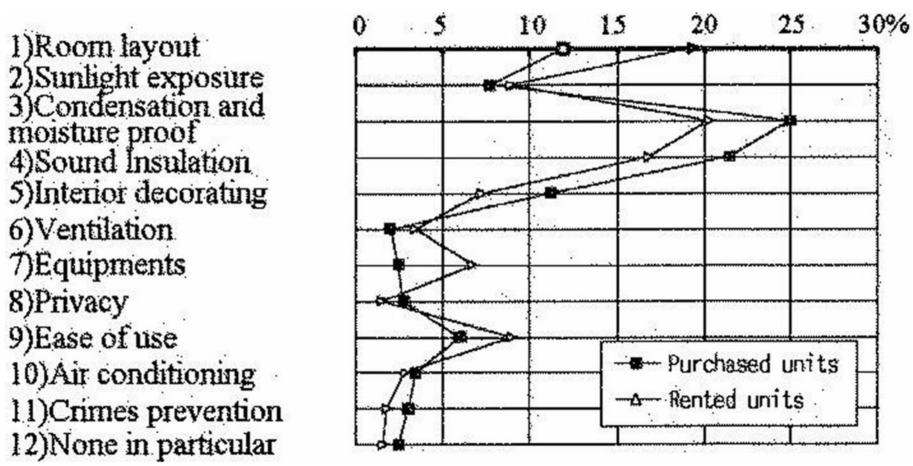

Figure 2: Desired improvements in the current unit.

Meanwhile, the results of the "indication rate of noise that result in poor evaluation of the insulation properties of dwelling units" (Fig. 3) in the same survey show that floor impact sound judged to be heavy floor impact sound, including footsteps and children jumping or running around, from the dwelling unit above shows the highest rate of inadequacy in current dwelling units. The claim rate is about 20% at maximum and this indicates that, as sounds in everyday life in multi-family dwellings, the sound of children jumping or running around continues to be the most important source of noise.

3 - CURRENT STATE OF FLOOR IMPACT SOUND INSULATION PERFORMANCE

There was a persistent lack of housing in postwar Japan and demands for housing in large quantities seemed to have priority over demands for quality in the performance of the living spaces. Within this context, the Architectural Institute of Japan published the *Standards for Sound Insulation Performance and Planning Guide for Architecture* in 1979, defining recommended standards and design guidelines

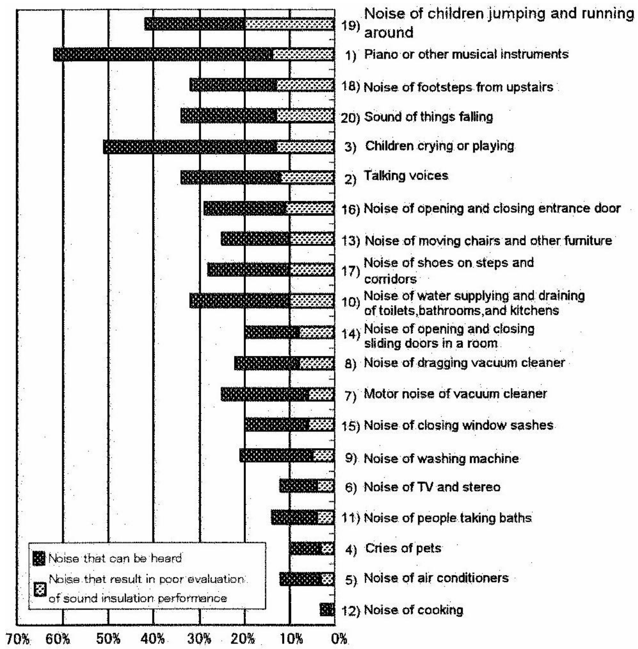

Figure 3: Indication rate of noise in everyday life.

for the performance of sound insulation in multi-family dwellings, hotels, offices, schools, hospitals and other buildings. Building design and construction have subsequently been carried out in line with those recommended standards and an awareness of the importance of assuring sound insulation performance has become firmly rooted in the construction industry and among consumers, while much technological research and development have also been carried out for the purpose of realizing improvements in performance. The conditions during the last twenty years or so indicate that we have entered a stage marked by an increase in demands from consumers for improvements in sound insulation for living spaces while the quality of housing is being called into question. Prompted by such changes in conditions, the recommended sound insulation standards of the Architectural Institute of Japan mentioned above were amended in 1997 and new recommended standards were issued as we advance on to a new age in which a strong awareness of globalization has led to the incorporation of ISO standards into measurement, evaluation and other methods relating to sound insulation and standards began being developed in a form for use in conjunction with the existing JIS standards [2], [3], [4].

The evaluation curves of Fig. 4 stipulated in JIS standards and in the above standards of the Architectural Institute of Japan are used in the evaluation of floor impact sound in Japan. This curve is the inversed characteristics of the frequency-weighting 'A' and, with the sound pressure level in the 500Hz band of each curve as the representative value, it is expressed as L-∞. The floor impact sound level by measured octave band is plotted in Fig. 4 and it is evaluated by the maximum L value for each band.

Since the inversed frequency-weighting 'A' curves are used, the L values and dBA values indicate an extremely strong correlation and it is possible to establish relationships such as those indicated in Fig. 5. It could be said that the L values indicate an extremely good correspondence to dBA. The method of measuring floor impact sound using a tapping machine is stipulated as JIS A 1418-1:2000 in a form that is in conformity with ISO 140-7; however, in regard to heavy floor impact sound, since the sound has a single transient response waveform, the method for measuring the maximum sound pressure level according to time weighting characteristic 'Fast' of a sound level meter is stipulated as JIS A 1418-2:2000. Furthermore, the L curves of Fig. 4 are extremely useful when used as sound insulation design indexes since the floor impact sound level is stipulated in each band.

The floor structures of multi-family dwellings currently being constructed in Japan are mostly ordinary concrete homogeneous single slabs and void slabs. Fig. 6 shows the outcome of a classification of the performance of the heavy floor impact sound insulation of those floor slabs according to the L value. Under current conditions, ordinary concrete single slabs that are generally used have a thickness of 180 $-$ 200 mm and insulating performance is L50 $-$ L55. In addition, void slabs are used in such cases as when realizing slabs with a broad surface area or when there are no beams in the dwelling unit and there is only one slab per unit and the thickness of the concrete in a cross-section of the floor is usually 250 $-$

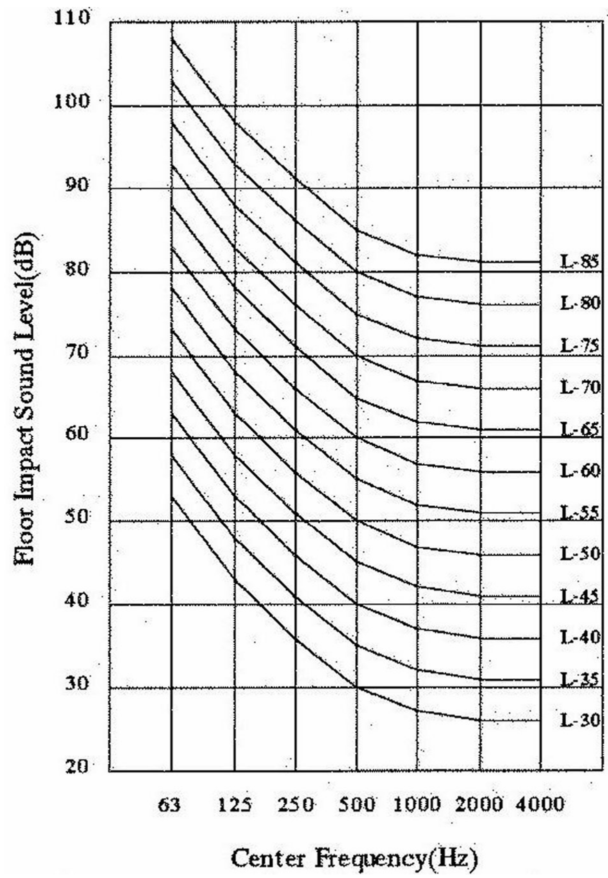

Figure 4: Evaluation curves for floor impact sound stipulated in JIS and the standard of the AIJ.

300 mm. The insulating performance is generally in the range of about L50.

Fig. 7 shows examples of driving point impedance measurements of ordinary concrete single slabs and void slabs. These indicate that, in the case of single slabs, there is a conspicuous fall in impedance in the natural frequency band of floor slabs and its influence becomes very strong in particular in the vicinity of 63 Hz, which is a problem in heavy floor impact sound. Therefore, when dealing with heavy floor impact sound, it can probably be said that the design of the slab natural frequency is important. Meanwhile, in the case of void slabs, the slab ratio (length of the long side/length of the short side) will frequently be large and, since the density of the natural frequency will increase in the long direction, the fall of the impedance is restrained, and impedance will be considerably restrained compared to single slabs and show good vibration characteristics.

Next are the current conditions of the performance of heavy floor impact sound insulation of wooden and lightweight steel frame structures. In ordinary residential floors, floor cross-section specifications, having low rigidity and low mass are used. The sound insulation performance is extremely low in the range of L75 − L80. Wooden structures are frequently used in rental multi-family dwellings and demands are not as severe as in the case of multi-family dwellings for purchase; however, various active efforts are being made to develop methods for devising measures for the entire structure in order to improve insulation performance.

Fig. 8 shows an example of an examination of methods for countermeasure with heavy floor impact sound of steel frame and wooden residential housing carried out experimentally by the authors. The basic approach of improvement methods is increasing the flexural rigidity, increasing mass, improving the sound insulating properties of the ceiling of the room below, increasing the flexural rigidity of the walls of the room below, incorporating vibration control and so forth and this indicates that, by carrying out all of the countermeasures, it is possible to improve performance to about L50.

Meanwhile, floor impact sound insulation properties using a tapping machine is also basically determined by the flexure rigidity of the floor structure and mass or, in other words, by the driving point impedance; however, the influence of the shock absorbing effect of the floor finishing material is far greater. Fig. 9 shows the results of estimates based on the L value of the performance of floor impact sound insulation

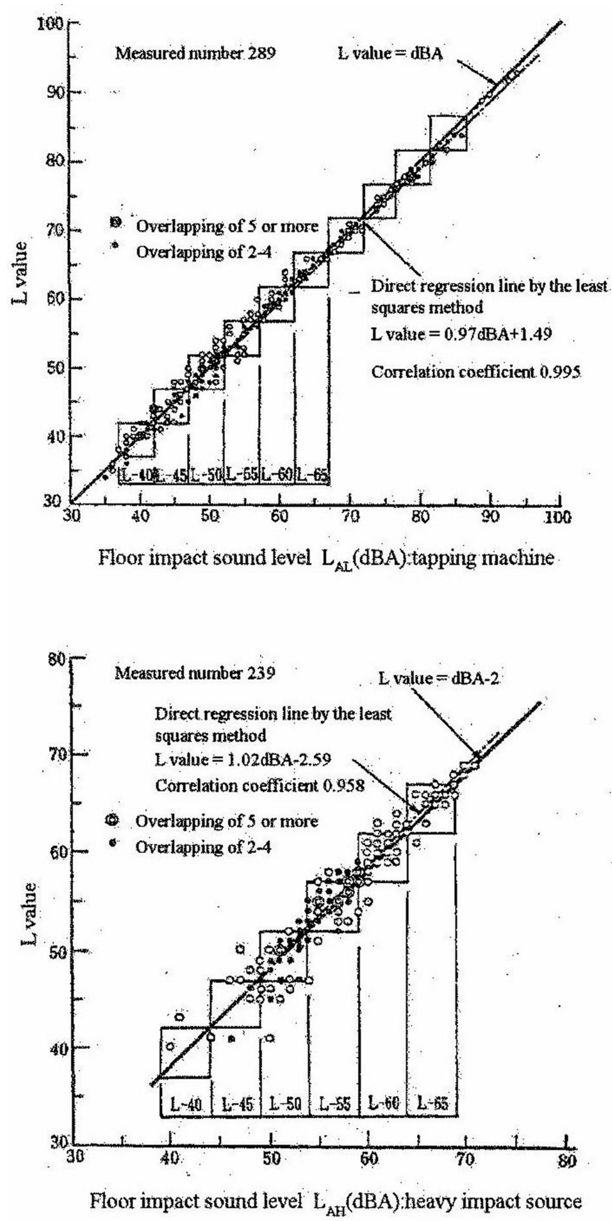

Figure 5: Relationship between dBA and L-value.

using a tapping machine when a concrete slab (ordinary concrete slab: 200 mm thick) is covered with various floor finishing materials; it can be seen, however, that performance varies greatly depending on the type of floor finishing material. Direct-pasted wood flooring and dry-type two-layer flooring are currently in use in Japan as floor finishing materials and the performance of floor impact sound insulation using tapping machine frequently shows a value of L45 − L65.

4 - FUTURE TRENDS

The mainstream of research currently consists of methods for reducing heavy floor impact sound and methods for making clear and estimating the generating system. The impedance method of Fig. 10 proposed by the authors is frequently used as a method for estimating floor impact sound level; however, among the various factors indicated in the flow of Fig. 10, the method for specifying the driving point impedance of the floor structure has been the subject of various studies and we anticipate improvements in the precision of the estimates.

In the meantime, the development of products for floor finishing materials is also being proceeding vigorously. The main objective of product development is to improve floor impact sound insulation using tapping machine as much as possible without causing a lowering in the performance of heavy floor

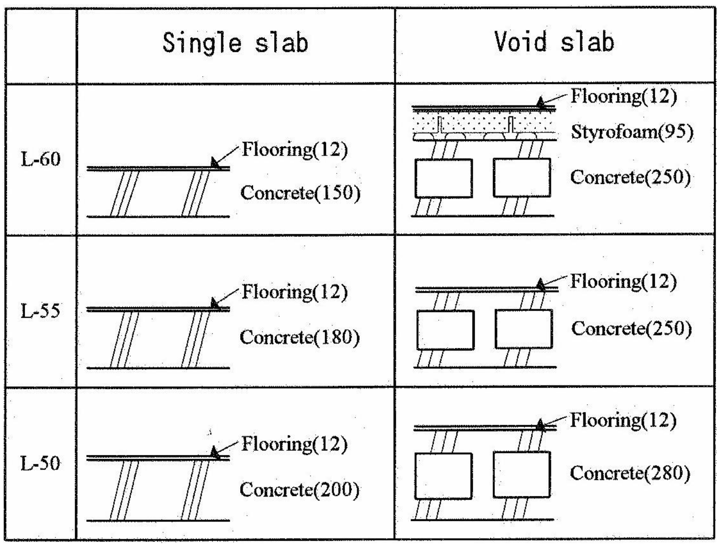

Figure 6: Classification of floor slabs according to the L-value.

impact sound insulation. In the case of dry-type two-layer flooring, in particular, since the floor has a double-layered structure, an important issue is the means for avoiding a lowering in performance due to resonance with the upper vibration system.

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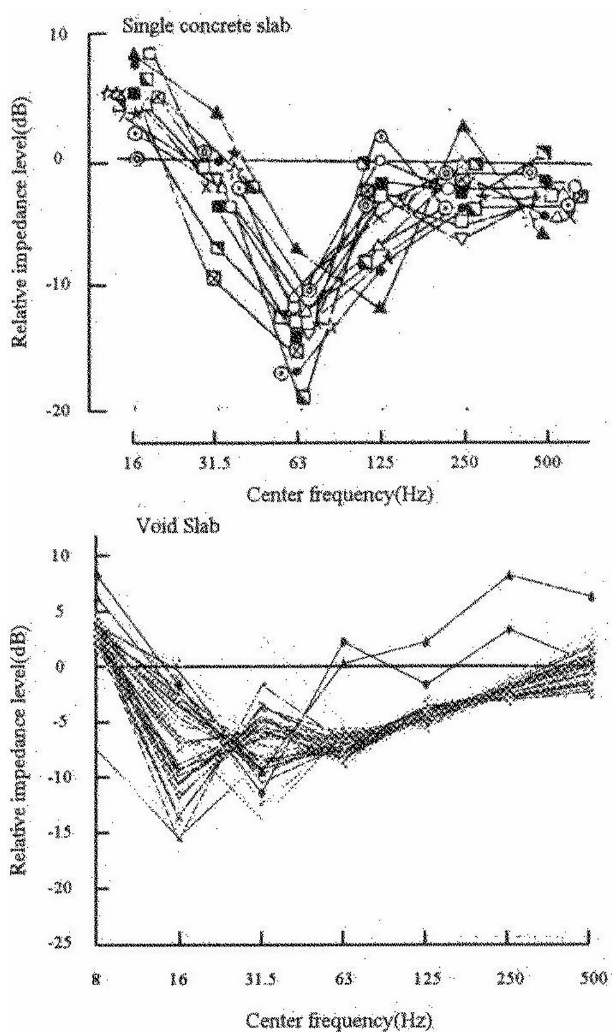

Figure 7: Examples of driving point impedance of concrete slabs.

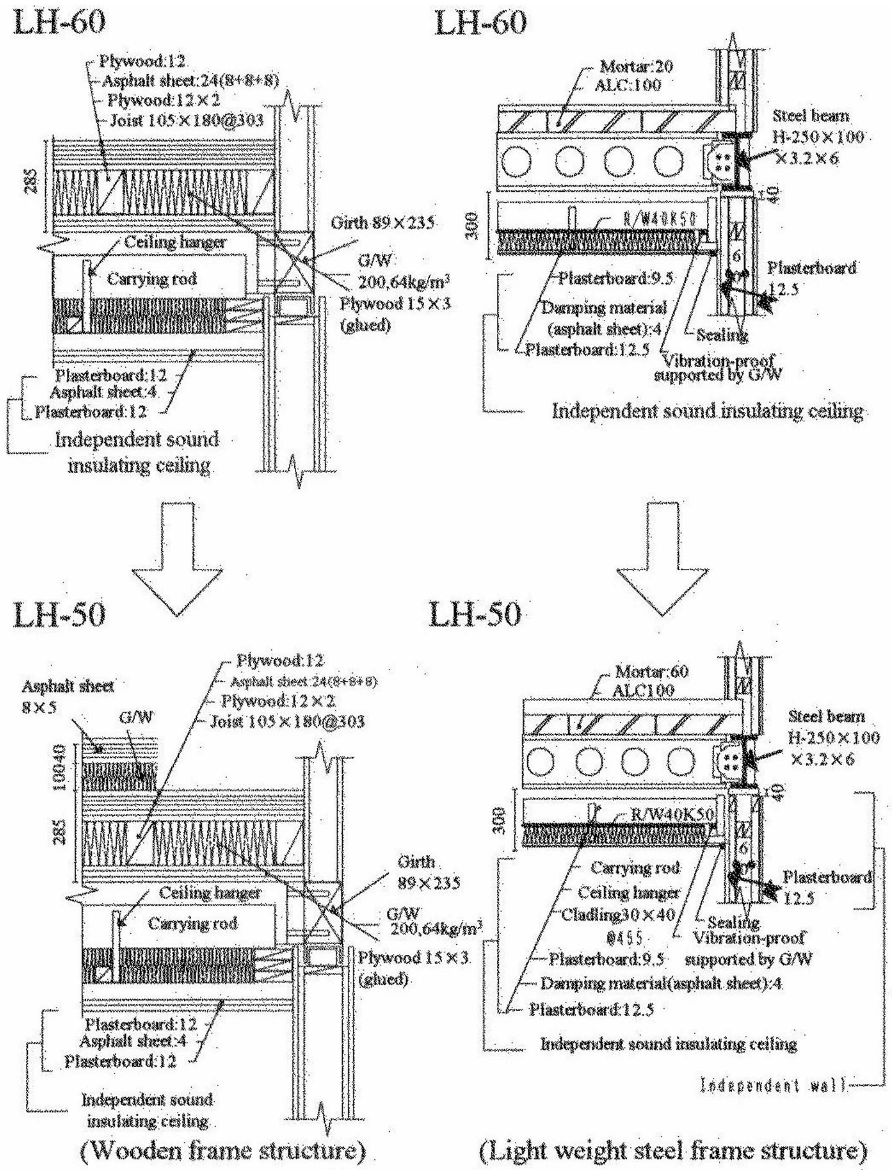

Figure 8: Examples of improvements in the performance of heavy floor impact sound insulation in wooden and light weight steel frame structure.

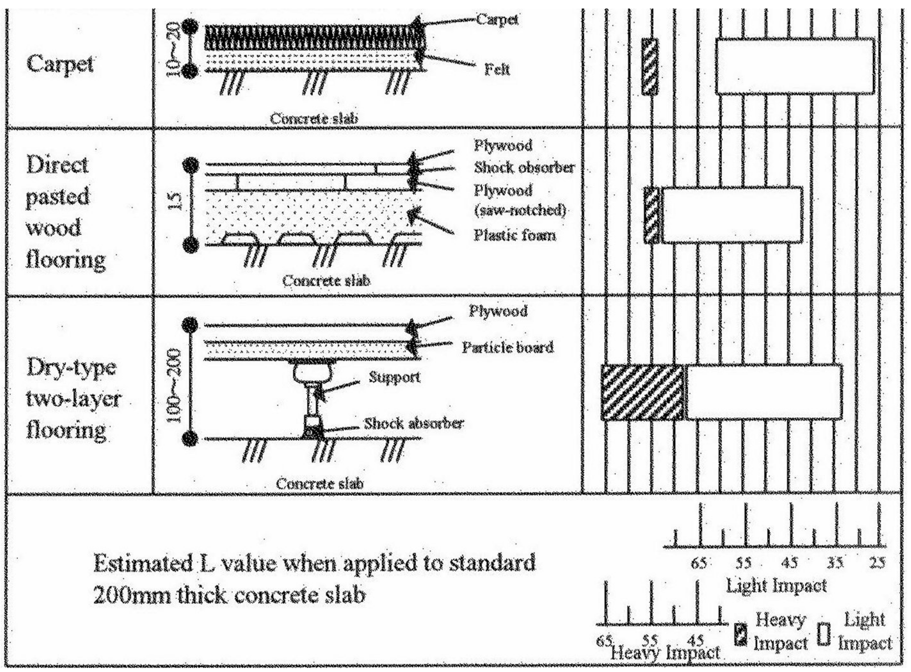

Figure 9: Improvement of L-value for floor finishing materials.

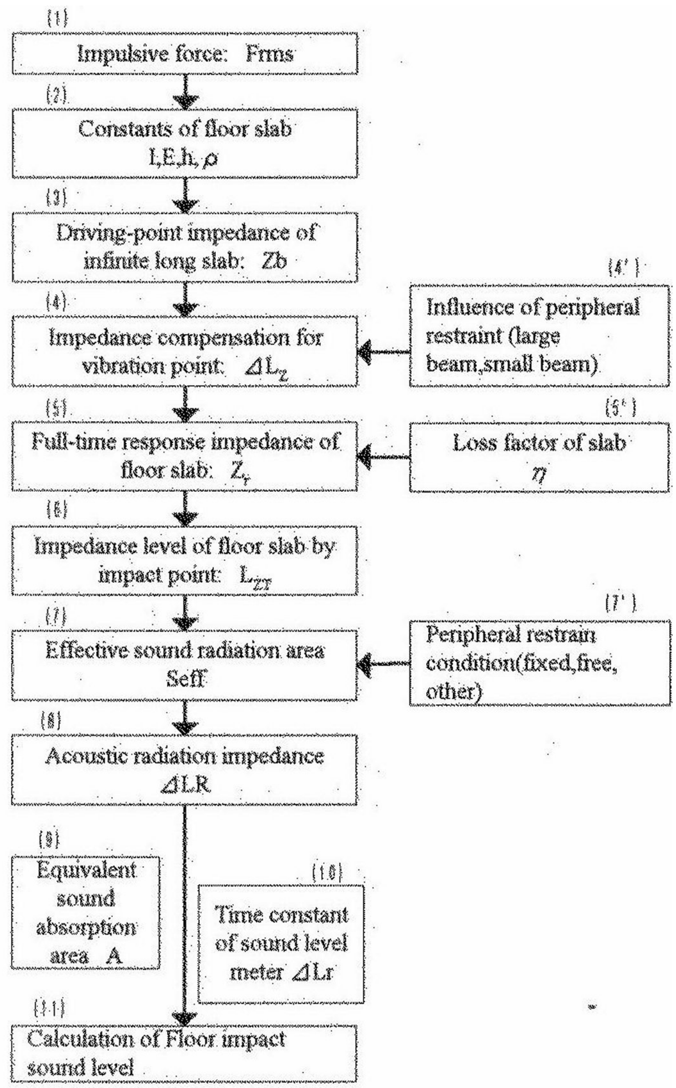

Figure 10: Calculation flow of floor impact sound level according to the impedance method.