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APPLICATIONS OF NOISE CONTROL ENGINEERING IN JAPAN

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INTRODUCTION

At the INTER-NOISE 94 held in Yokohama Japan last August, aboust 200 papers were submitted from Japan, covering nearly all fields of noise control engineering. Apart from the benefit of host country for the Congress, this fact shows the importance of noise control engineering in Japan. As is well known, there have been remarkable developments of noise control engineering in Japan and a large number of papers and technical reports have been published. However, it is regrettable that some of them are only written in Japanese. Through the detailed analysis of these Japanese activities, it would be possible to understand the peculialities existing in noise control problems and to review the special features in noise control engineering in Japan.

HISTRICAL BACKGROUND ON NOISE CONTROL PROBLEMS IN JAPAN

In general, noise problems are roughly divided into two categories, that is , the workplace noise problem and the general environmental noise problem. After the world war II, various kinds of noise problem have grouwn rapidly in connection with the economical growth in Japan.

During the 1950s. the impacts of industrial noise, traffic noise, construction noise and other kinds of noise on the environment have been the important social problems in Japan, as the "environmental pollution problem". Thus, the noise problem in Japan started as the general environmental problem. This may be due mainly to the large population, especially concentrated in city area. As the countermeasures for these noise problems, various national and local regulations and standards have been established from 1967 to 1975. The important ones are summarized in the following.

- 1967 Basic Law for Environmental Pollution Control Measures
- 1968 Noise Regulation Law
- 1971 Environmental Quality Standards for Noise (General areas including areas bordering on traffic road)
- 1973 Environmental Quality Standards for Aircraft Noise
- 1975 Environmental Quality Standards fos Shinkansen Railway Noise

The important provisions for above regulations and standards are shown in Annex A. Methods for the measurement adn evaluation of these noises are largely specified in Japanese Industrial Standards. In 1987, Koyasu reviewed the details of these basic measurement standards [1]. In 1993, the Basic Law for Environmental Pollution Control Measures was revised and the title was changed to the Basic Environment Law.

fulfil the requirements specified in the Environmental Noise Standards for Noise, it will be necessary to install extraordinarily high sound barriers, which have invrrse-L shape construction. Figure 1 shows the example of planned perspective drawing of such barrier construction. This may be huge in size and weight and it will be difficult to install in practical road construction. Thus, it is strongly required to develop some efficient noise control measures.

Recently, special attention has been set on the effect of noise reduction by the drainage asphalt pavement. Fundamental researches and test on tentative constructions have been carried out extensively in Japan [4]. Considerable amounts of noise reduction are expected. Only remaining theme to be solved will be the improvement of durability.

In spite of these efforts to reduce the road traffic noise, it is still not suggicient to accomplish the target required by the Environmental Quality Standards for Noise on areas bordering on traffic road. Thus, the noise control measures on roadside have been adopted in Japan. This action is based on the "Law on the Arrangements of Roadside along the Main Road" which was enacted in 1980. This is the compensation law for the purchase of buffer zones, construction of buffer buildings and sound proof improvement of existing dqellings. These procedures are effective not only for the noise control measures on highway but also on urban street where it is rather difficult to adopt noise control measures on road construction itself except for the application of drainage asphalt pavement.

One of the important items on road traffic noise control is the prediction method for road traffic noise. In Japna, ASJ Model-1975 has been used extensively, which was developed by the Acoustical Society of Japan based on the "uniform-spacing and identical source model". ASJ MOdel-1975 was developed for the calculation of L_{50}, 50 percentile A-weighted sound pressure level, corresponding to the road traffic noise descriptor specified in the Environmental Quality Standards for Noise. The new prediction method (ASJ Model-1993) which calculates L_{Aeq}, the equivalent continuous A-weighted sound pressure level, has been developed in 1993. This is the "energy-base prediction method" and is expected to be applicable for wider range of road constructions, roadside configurations and traffic conditions [5],[6].

Railway Noise As to railway noise in Japan, special attentions have been paid on the Shinkansen (Super express train) noise, because of their serious influences on the sound environments along the railways. Tsuda et. al. revieqed the importantnoise sources, their contributions and countermeasures for Sshinkansen [7]. For the practical noise control measures on Shinkansen railway, the special types of sound barrier, the so-called inverse-L type barrier, have been adopted extensively. Because of their special feature in constructions, they are mainly effective o the reduction of noise emitted from lower parts of the train, especially emitted from rail and wheel. When the maximum speed of the Shinkansen train had been 200 km/h, this type of noise control measure had sufficient functions for attainng the noise environment which conformed to the Environmental Quality Standards for Shinkansen Railway Train. Recently, Japan Rail Companies have special interests on the increase of maximum speed for business service, for example more than 300 km/h must be "noise control measures". Thus, JR Companies and related organizations have been working hard for the development of low noise Shinkansen train. For these speed ranges, the most important factor for the noise emission from Shinkansen train is the aerodynamic noise generated from various parts of the train body, especially at the electric-current collector (pantograph). Research and development of low-noise pantograph were reported at the INTER-NOISE 94 [8],[9].

Also, as the future hifh-speed train, the developments of maglev cars have been carried out in Japan, where the aerodynamic noise must be the most important research items [10].

In parallel with the noise control of high-speed trains, the noise problem on the old railway lines has been paid attention as on eof the traffic noise problems. Until now, the noise from old railway lines has been excluded from the scope of the Environmental Quality Standards for Shinkansen Railway Noise. In the case of the old railway trains, maximum speed is far slower than that of the Shinkansen railway train, below 100 km/h. There are various kinds of noise sources for the old railway trains, that is the driving system, rail and wheel system including rail joint and wavelike defacement on the rail surface, auxiliary equipments, electric-current collectors and so on. In near future, it is expected that Environment Agency, Japan will take some action for the noise control of the old railway lines.

Aircraft & Airport Noise In Japan, there are serious noise problems around airport, mainly because of small countru with limited flat lands and in many cases, because of the densely populated areas adjacent to airports. Osaka Intl. Airport which situates in the midst of city area, has been for a long time the world-famous airport due to complaints from residents living around airport. Residents started lawsuits against the Fovernment from 1969, demanding the ban of night-time operations and the compensation. Extensive noise control measures, such as introduction of low-noise aircrafts, limitation of total number of flights, ban of night-time flight, flight path control and so on, had been adopted. As the results of these efforts, noise situations around airport had been improved markedly. For example, areas includedin the predicted equal noise level contours (75 WECPNL) decreased to 1600 ha in 1983 from 4600 ha in 1973. Also, sound-proof reconstruction of existing schols, hospitals, dqellings etc. had been adopted.

In parallel with these noise control actions for existing Osaka Intl. Airport, the construction of new airport in Osaka area free from noise problems had been planned from 1968. There, it had been considered that the most effective way for airport noise control was to build airports offshore. Already two airports, Nagasaki and Oita Airports, were constructed offshore. To supplement Osaka Intl. Airport, Kansai International Airport was constructed on an artigicial island in Osaka Bay Area and opened as the first stage construction on September 4, 1994. Kitazawa reviewed the outline on the construction of this airpor including histrical view of Osaka Intl. Airport [11]. All of the area includedin the predicted noise contour line 70 WECPNL is completely on sea surface (**Fig.2**). He mentioned that "It is the best solution to airport noise problems".

As to the control of aircraft noise source, there has been alittle contribution in Japan. More than 10 years ago, the mational project for the development of lownoise and clean jet aircraft had been carried out in Japan. However, it was only the research project and not the practical oriduction project.

CONSTRUCTION WORKS NOISE CONTROL

The Noise Regulation Law specifies the regulation of construction works noise by several ways, that is the emission noise limit for specified construction machinery and equipment, working time limit and so on. In the case of construction works along the road in city area, it had been necessary to work during the night time because of difficulties due to heavy traffic conditions in the day time. For such construction works, only very short working time has been allowed. Also, in general construciton works in city area, the use of diesel pile hammer was prohibited stictly.

On of the practical noise control measures for construction works, the Ministry of Construction established the designation system for low-noise/low-vibration construction machinery and equipment. Noise labelling was introduced ofr construction machinery and equipment which conformed to the noise limits for respective machinery and equipment. It was strongly recommended to use such machinery and equipment for construction works where the careful considerations for nosie control were required.

BUILDING NOISE CONTROL

In Japan, building noise control measures have been playing important roles in various noise problems. As mentioned in the histrical view, even in the case of factory noise control, the most important noise control measures had been the application of sound insulation on factory buildings, silencer systems on air moving devices and so on. This is mainly due to the fact that the Noise Regulation Law had specified the noise limits of industrial noise at the boundaries of factory sites.

As one of the important noise control measures on traffic noise, the applications of sound insulation treatment on various kinds of building facades, such as dwellings, hospitals, schools and other public buildings, along the main road including highway, along the Shinkansen railway and around airport, have been carried our extensively in Japan. These noise control procedures have been financially supported by the relevant authorities, if the noise aituations outside buildings would exceed specified levels or buildings around airport would be located within noise contour line for some specified values of WECPNL. In addition to the direct sound insulation of facade elements, special types of sound proof ventilation unit had been developed and installed.

In the above-mentioned examples of soun dinsulation inbuildings, noise sources are situated inside or outside of buildings. Thhrough these experiences, general interests on sound insulation in buildings have grown gradually. After the world war II, dwellings, in order to solve the concentration of population in city area. Complaints against neighbours' noise have become serious problems in Japan, resulting in the violawsuit. It had become important problems to upgrade the sound insulation in these dqellings. Concerning the sound insulation in buildings, mainly in multi-family dwellings, there still remain some important problems to be solved urgently. Some of them are reviewed in the following.

Airborne Sound Insulation In Japan, Building Standard Code was revised to include the allowable limit on airborne sound insulation between adjacent dwellings in multi-family dwellings and tenement houses in 1971. This was an important starting point for the application of sound insulation constructions in dwellings.

Developments of building constructions with high airborne sound insulation efficiencies have been mainly concentrated on the light-weight complex constructions. During past 20 years, the remarkable progress on the sound insulation constructions has been achieved. For example, it is now possible to get the wall construction with surface density of the order of and the sound transmission loss of higher than 50dB at the frequency of 500 Hz for practical use.

In parallel with the development of sound insulation construction, it has been an important item to establish the method for the assessment of sound insulation efficiencies of wall constructions. Until now, the assessment method specified in Japanese Industrial Standard JIS A 1419 (Classification of airborne and impact sound insulation for buildings) has been widely used in Japan. This method is so-called "curve-fitting method" which is similar to that specified in ISO 717/1 and 3. However, the reference curve and the fitting method in JIS A 1419 are somewhat different from ISO method. These situations might be common in more or less extent through respective countries, mainly because of their histrical background. Basic researches on this subject have been extensively carried out in Japan, especially from the psychoacoustic viewpoint. Tachibana *et. al.* reported that the arithmetic mean values of sound transmission loss or sound pressure level difference between rooms in octave band would be effective for the single number index of sound insulation efficiencies [12].

Impact Sound Insulation As to the floor impact sound insulation in dwellings, there have been some special features in Japan due to different living styles from those of American and European countries. Usually in Japan, residents take off their shoes in dwellings. So, the important source of floor impact would be soft and heavy impact, such as running or jumping of children in their rooms. Based on these experiences, JIS A 1418 (Method for field measurement of floor impact sound level) specifies two types of impact sources, that is light-weight impact source and heavy-weight impact source. Here, light-weight impact source is completely the same with tapping machine soecified in ISO 140/6. On the other hand, heavy-weight impact source was developed soft impact, such as running or jumping of children. The heavy and soft impact source is specified by the impact force-time characteristics. As the practical heavy-weight impact source, some type of automobile tire has been extensively used.

Recently, it has become the important item to measure the heavy and soft impact sound insulation for light-weight wood-joist floor construction. In this case, it is required to use impact source giving weaker force. Investigations into the development *et. al.* reported the basic characteristics of various kinds of rubber ball for heavy and soft impact source [13]. Round robin tests have been carried out in Japan. In near future, new type of heavy and soft impact source will be proposed from Japan to ISO/TC 43/SC 2 in order to be included in International Standards.

In parallel with the method for measurement of impact sound insulation, the method for evaluation must be an important problem. In JIS A 1419, the method for evaluation of impact sound insulation is also specified. It is the curve-fitting method which is similar to the method soecufued ub USI 717/2. However, the reference curve in JIS A 1419 (**Fig.3**) is quite different from that specified in ISO 717/2. As shown in Fig.3, the reference curve is given by approximate inverse-A curve. This means that the evaluation by this reference curve corresponds to evaluate the impact sound transmitted to the receiving room by the A-weighted sound pressure level.

As to the floor impact sound control measures, there have been two lines of procedures, for heavy and soft impact and for light weight impact. In the case of reinforced concrete floor construction, the important measures for the reduction of heavy and soft impact must be to increase the stiffness of floor constructions, mainly through the increase of thickness. On the other hand, so far in Japan the surface finishing of floors in dwellings had been so-called "Tatami", that is the straw mats. They are excellent measures for light weight impact sound. However, the principal floor surface coverings in dwelings have been changing to wood coverings in Japan. In this case, the important source of impact sound would be various kinds of light-weight impact. For the effectibe control of impact sound, various types of wood floor covering constructions habe been developed. The important subjects for the development of such floor cobering constructions would be not only the reduction of impact sound but the maintenance of good feeling for walking.

In parallel with these impact noise control procedures, reently the impact noise problems for the light-weight wood-joist floor constructions are being more important problems in Japan. Extensive research and development works have been carring out for the noise control of these floor constructions.

Structureborne Sound Insulation Owing to the technical progress in airborne sound insulation in buildings, the recent emphasis in building noise control is laid on the structureborne sound insulation. The important sources of structureborne sound in buildings are various kinds of machinery and equipment installed in buildings, such as HVAC systems, water supply and drainage installations, sanitary facilities, elevators, household appliances and so on. For these structureborne sound spurces, various kinds of noise control measures, mainly vibration isolations, have been applied extensively. Also, for the prediction of structureborne sound and of their noise control measures, methods for determination of vibromotive forces have been investigated.

There are another importantstructureborne noise sources in Japan, which usually exist outside of buildings. The most important ones are railway trains. In big cities, lines are under construction. Vibrations caused by these railway trains are transmitted to nearby buildings. Through the foundation of building, vibrations of trains propagate in the construction and emit the structureborne noise from somewhere in the building. Of course, the basic noise control measures for these structureborne noise caused by railway vibration must be the vibration isolation procedures adopted to the railway constructions. However, in many cases, especially if the neq building will be built at the site adjacent to the building itself. Various kinds of vibration control measures have been developed and practically adopted during the construction of building. In the extreme case, if there are auditorium, studios or other special rooms in the building where the quiet situations are strongly required, the floating constructions mainly using rubber vibration isolators will be adopted. Hiramatsu *et. al.* reported the practical example of such floating constructions in the building located near the subway line in Tokyo [14].

For the development of structureborne sound control in buildings, it is important to establish the prediction method including the determination of vibromotive force of the souce, vibration propagation in buildings and radiation characteristics of sound from vibrating surface. In 1994, Symposium organized by the Architectural Institute of Japan o the prediction method of structureborne sound in buildings was held in Tokyo, where the present situations on the prediction method were summarized and discussed extensively [15]. Representative design flow chart for structureborne sound insulation in buildings is shown in **Fig.4**.

Applications of Active Control Active control technologies, such as active noise control, active sound field control and active vibration control, are expected to be aoolicable to the field of building noise control. As to the practical applications of active control in building acoustics, so far there have been several results on the noise control in duct systems.

In 1991, International Symposium on Active Control of Sound and Vibration organized by the Acoustical Society of Japan was held in Tokyo [16]. At the INTER-NOISE 94, 25 papers presented from Japan in the special session onactive control. In these symposium and congress, interesting research works concerning the applications in building acoustics, especially the active sound field control, have been presented. Kobori reviewed the development of active vibration control technologies for architectural structures in Japan [17].

In near future, it is expected that some effective applications of active control technologies will be obtained.

MACHINERY NOISE CONTROL

In general, machinery noise control technologies have been playing important roles for the improvement of work environmental and general enbironemntal noise situations. In addition to the national regulations concerning machinery noise, recent trends on the interests and requirements on machinery noise control in Europe and America have set the strong impacts on Japanese indsutries forthe reduction of noise emitted from machinery. Thus, design and manufacture of low-noise machinery are now becoming the important themes for the machine manufacturing industries in Japan.

Noise Source Analysis For machinery nosie control, it is essential to identify the important noise source parts in machines and to clarify the basic mechanism of noise emission from machines. Various kinds of techniwues for noise source analysis have been developed and adopted extensively.

Techinical papers from industries on numerical and experimental analyses for these purposes have increased markedly during past few years. FEM, BEM and modal analysis techniques are widely used in practical machine design. Sound intensity and acoustic holography techniques are also used for noise source identifications.

Based on the results of noise source analysis, noise control technologies for various kinds of machinery and equpment have been developed. Some examples, concering noise control of centrifual fans, were presented at the INTER-NOISE94 [18], [19].

Noise Control Elements Research and development of various kinds of passive noise control elements, such as silencers, mufflers, enclosures and so on, have been widely carried out for the purpose of machinery noise control. Applications of damping materials and vibration isolators play an important role for the reduction of machinery noise emission. Ohishi *et. al.* reported the basic research on the application of damping treatment on enclosures [20].

Applications of Active Control Researches on active noise and vibration control technologies are in progress for the future practical design and construction of low-noise machinery and equipment. Until now, only few practical applications for machinery noise control habe been reported, such as the noise control of refrigerators and computor-related equipments [21], [22].

CREATION OF COMPORTABLE SOUND ENVIRONMENTS

The special feqture in recent noise control engineering in Japan is that the main theme is intended not only to the reduction of sound pressure level of noise sources or in some environments, but also to the creation of comfortable sound environments. The main theme of the INTER-NOISE 94 was "Noise-Quantity and Quality". This theme reflects Japanese considerations on the future important direction of noise control engineering. Namba gave the keynote lecture on this theme [23]. He mentioned that for the effective control of noise, it is necessary to consider not only the quantity of noise but also its quality, that is timbre or noise quality.

Of course, all existing refulations and standards in Japan are based directly or indiectly on A-weighted sound presure levels. This means that the present noise control enginerring is mainly directed to the reduction of noise quantity. However, recently in many cases, it is required to consider the improvement of noise quality in parallel with the reduction of sound pressure level. Background and various aspects on this subject in Japan were reviewed and discussed in detail in Namba's paper.

In relation to the main theme, several sessions were organized in the INTER-NOISE 94, such as "Sound quality of machinery noise", "Sound amenity & sound soundscape", "Perception of noise", "Subjective ecaluation of environmental noise", "Psychological effect of noise", "Noise & communication" and "Subjective response to vibration ".

Through these approaches in noise control engineering, it is expected that worldwide efforts of noise control engineers will be able to contribute the creation of the *comfortable sound enbironment* and the improvement of the *quality of life* from the acoustical point of view.

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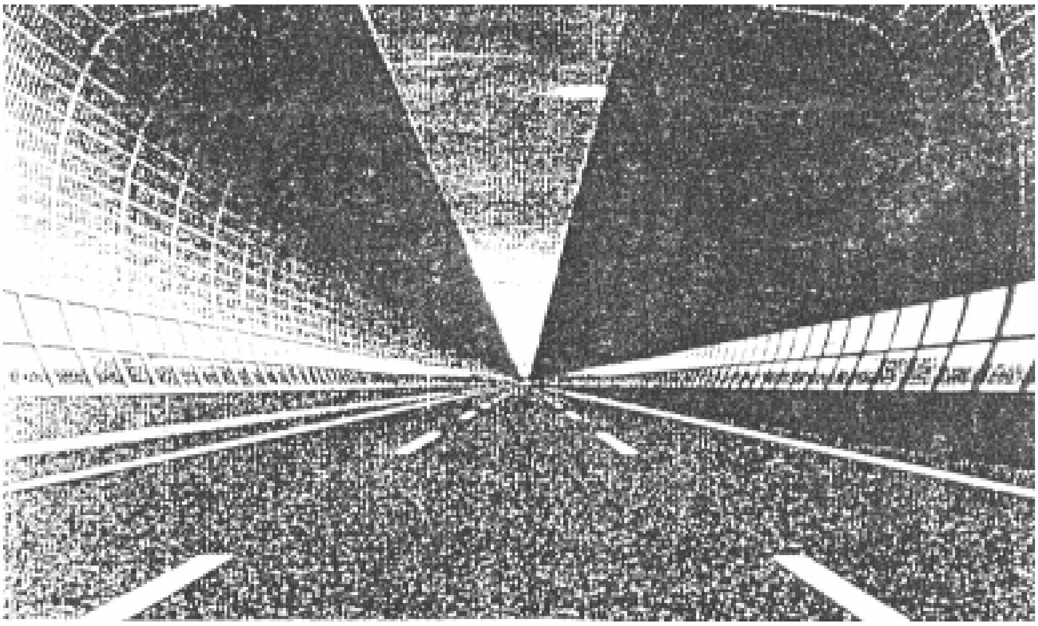

Fig. 1 Planned drawing of sound barrier for highway noise control

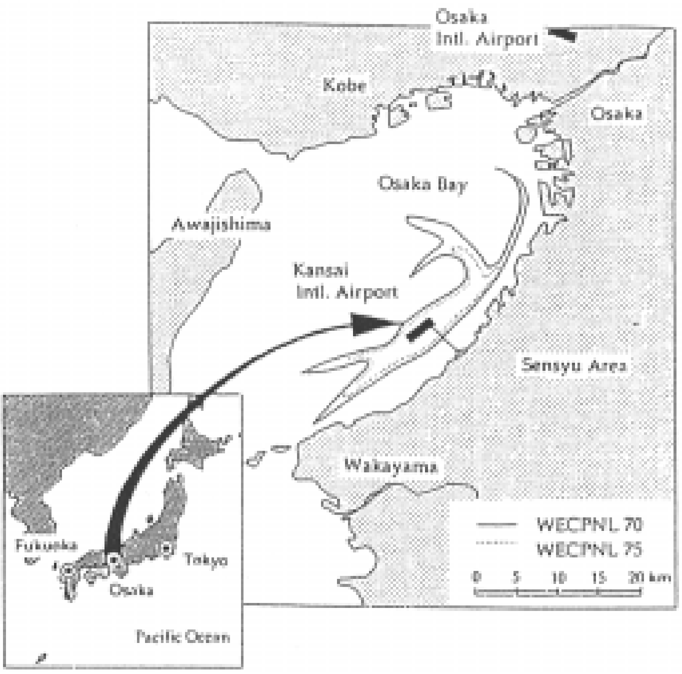

Fig. 2 Predicted noise contour for Kansai Intl. Airport (Kitazawa [11])

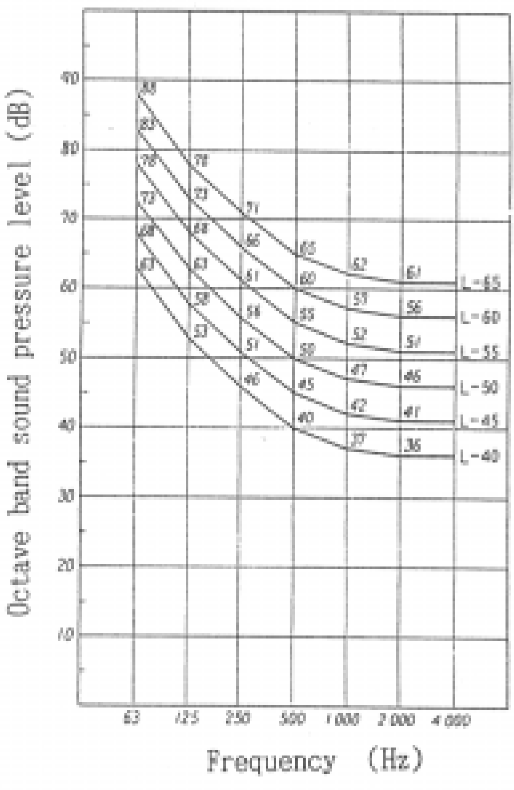

Fig. 3 Reference curves for the evaluation of impact sound insulation of floors (JIS A1419)

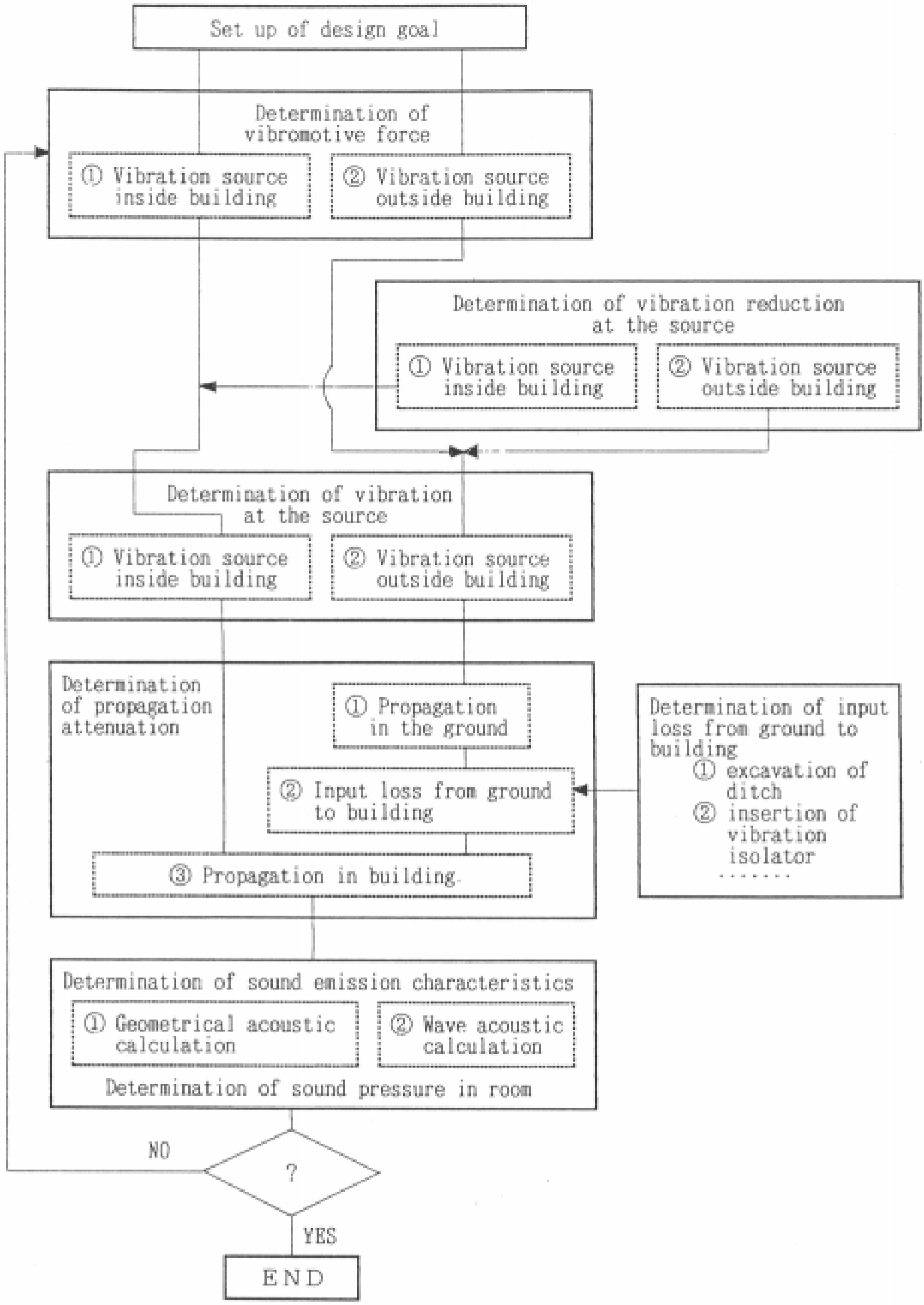

Fig. 4 Design flow chart for structureborne sound insulation in buildings

ANNEX A IMPORTANT PROVISIONS IN NOISE REGULATION AND ENVIRONMENTAL QUALITY STANDARDS FOR NOISE IN JAPAN

Ⅰ. Noise Regulation Law

(1) Enforcement standards for industrial noise

zone / time	exclusive residential area	residential area	residential use with commercial & industrial use	mainly indsutrial use
daytime	40 ~ 50dB(A)	50 ~ 60dB(A)	60 ~ 65dB(A)	65 ~ 70dB(A)
morning & evening	40 ~ 45dB(A)	45 ~ 50dB(A)	55 ~ 65dB(A)	60 ~ 70dB(A)
night	40 ~ 45dB(A)	40 ~ 50dB(A)	50 ~ 55dB(A)	55 ~ 65dB(A)

Standard values : 5 percentile A - erighted sound pressure level L_5 for the case of fluctuating noise

(2) Enforcement standards for construction works nois

(3) Maximum allowable limits for road vehicles

Ⅱ. Environmental quality standards for noise

(1) General area

category of area	time		
	daytime	morning & evening	night time
AA : areas which require particular quiet	not more than 45 dB(A)	not more than 40 dB(A)	not more than 35 dB(A)
A : primarily residential areas	50 dB(A)	45 dB(A)	40 dB(A)
B : areas where substantial number of residences are located among shops & factories	60 dB(A)	55 dB(A)	50 dB(A)

Standard value : 50 percentile A - weighted sound pressure level L_{50}

(2) area bordering on traffic roads

category of area	time		
	daytime	morning & evening	night time
A area : bordering on a two-lane road	not more than 55 dB(A)	not more than 50 dB(A)	not more than 45 dB(A)
A area : bordering on a more-than-two-lane road	60 dB(A)	55 dB(A)	50 dB(A)
B area : bordering on a not-more-than-two-lane road	65 dB(A)	60 dB(A)	55 dB(A)
B area : bordering on a more-than-two-lane road	65 dB(A)	65 dB(A)	60 dB(A)

Standard value: 50 percentile A-weighted sound level L_{50}

III. Environmental quality standards for aircraft noise

Category of area	Standard value (in WECPNL)
Ⅰ: area for exclusively residential use	70
Ⅱ: other area where normal living conditions should be reserved	75

NOTE: Target date for performance of standards is specified respectively according to airport catefories.

IV. Environmental quality standards for Shinkansen railway noise

Category of area	Standard value
Ⅰ: area for exculsively residential use	70 dB(A)
Ⅱ: other area where normal living conditions should be reserved	75 dB(A)

NOTE: Target date for performance of standards is specified respectively according to the situations of Shinkansen lines.