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Solution of Noise-Vibration Problems of Urban Public Housing Adjacent to Railway

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ABSTRACT

Constructing urban public housing built adjacent railway site has the noise and vibration problem coming from operation of trains. Thus, anti-vibration plans utilizing anti-vibration pads must be established to minimize the impact of train noise and vibration from the tunnels on the residents of the public housing. Under various difficulties and expectation from the citizens, many efforts were taken to satisfy the amenity requirements on noise and vibration for the residential area. As a results, it can be recognized that amenity standards can be satisfied. But great caution is required to prepare ourselves for various situations that might occur during construction, especially considering that the relevant railroads are still under operation.

Key words: Noise, Vibration, Railway site, Anti-vibration Measure, Noise Criteria

1. Introduction

Urban public houses are built for the purpose of relieving housing-related anxieties of households with unstable income or younger generation, many of whom cannot afford to own houses with their low income. The main targets include people who just started their career, newly-weds, university students and other classes disadvantaged in terms of housing. The purpose of urban public housing policy is to provide houses at lower prices than the relevant market prices to those groups of citizens, based on their levels of income. Supplying houses at lower prices require reducing the land purchase expense as it accounts for the larges portion of the construction budget. Thus, public housing construction projects are implemented using railroad sites, unused national/public lands and unsold public facility sites owned by the public sector.

Railroad sites are expected to be the first sites where the urban public housing will be built, but they pose the issue of having to secure safety of the housing while not affecting the existing railroads. The site also pose the technical issue of having to minimize the impact of noise and vibration caused by trains under operation on the urban public housing residents. As amenity constitute the most basic requirements for residential districts, explaining the efforts to solve the technical issues in this paper, we hope to relieve the worries that the citizens have towards the issues.

2. Measures for Securing the Residential Amenity of Urban Public Housing

Noise and vibration caused by trains is one of the main concerns of residents living in urban public housing to be built on railroad sites. Recent enhancement of overall life quality resulted in increased concern regarding residential environment and amenity, and residents around railroad areas are highly concerned about the noise and vibration generated when the train passes through the area.

When a train moves along the railroad, the vibration generated by the train is delivered through the structures and ground to the buildings nearby. These vibrations can be directly felt by the residents, or are emitted as noise within the building through air and structures. Excessive vibration not only affects the safety of the structures, but also affect the lives of the residents with the

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Table 1. Various Cases for Using the Railway Sites and Reducing Noise and Vibration (Jang, 2013)

No.	Location	Project Name	Size	Usage	Construction Period	Features
1	Yangchongu, Seoul	Yangcheon Apt.	15 flrs, 16 bldgs	residence education commerce	1990~1995	■ Train speed at 5km/h ■ Rubber roadbed under the rail, separated from columns.
2	Yongsangu, Seoul	Yongsan station (PC*)	1 bldg 3 flrs under ~9 flrs above	history commerce	2000~2005	■ Column intervals of east-west direction are uneven from 15.9m to 24.45m, and 1.5~2 times longer than those of south-north direction
3	Guonseongu, Suwon	Suwon station (PC*)	3 flrs under ~6 flrs above	commerce business leisure	1999~2003	■ Front Jacking in underground passage, travelling method in mega truss block, and spancrete composit slab method, and other state-of-the-art method applied
4	Nisidai, Japan	Residential area in Nisidai	14 flrs 4 bldgs	residence education commerce	1969~1972	■ Use noise absorption material, train speed at 15km/h, install double floor panel
5	Kitagushu, Hukuoka	Gukura station bldg**	2 flrs under ~3 flrs above	train business commerce accommodation	1995~1998	■ Long span of 30m or above
6	Hukuoka, Japan	River work, Kitagushu	2 flrs under ~15 flrs above	commerce business accommodation		■ Urban redevelopment project using rivers running through the area, for the purpose of redeveloping the area around the station
7	New Kowloon, Hong Kong	Kulongbay(Telford Garden)	26 flrs 12 bldgs 11 flrs 29 bldgs	residence commerce education	1979~1982	■ Measures taken regarding anti-vibration foundation, waterproof and electricity
8	Luk Yeung Sun Chuen Hong Kong	Tsuen King Garden station	less than 30th flrs, 17 bldg.	residence commerce	1982~1984	■ Built in + shape, using reinforced concrete
9	Rive Gauche, Paris, France	Paris Rive Gauche	6~8 flrs	business commerce education, residence	2002~2010	■ Construct artificial ground at railroad site of 100m wide and 3km long ■ Redevelopment area divided into sections, each area is designed by renowned architects

(Note) PC: private capital; bldgs: Number of Buildings; flrs: floors; under: underground; above: above ground

noise it causes. Therefore, appropriate actions need to be taken to address this issue.

Japan has been constructing residential complexes, e.g. Nishidai Complex, Tokyo, and multi complexes on railroad sites since the 1960's, and Hongkong, France and South Korea have been also building residential, business and commercial districts on railroad sites, and various efforts and methods designed to address the vibration and noise issues were applied to the construction of those complexes (see Table 1).

The methods applied to each case below include: noise/vibration reduction with anti-vibration foundation, distancing the vibration source, e.g. railroad, and the columns to reduce vibration delivered to the super structure, and reducing train speed.

2.1 Criteria of Noise and Vibration

As train speed increases and trains began to constantly pass through densely populated residential areas, the damage caused by train noise worsened. To address this issue, many countries including South Korea have established regulation on train noises.

Article 9 of Regulation on Housing Construction Standards, etc. under the Korean Housing Construction Promotion Act defines the noise regulation standard as below 65 dB(A). And the regulation also made it mandatory to construct housing at least 50m away from noise generating structures such as railroads, expressways and auto-only roads, or install anti-noise facilities.

The Noise·Vibration Control Act (No. 11669, September 23th, 2013) is an individual act for noise/vibration reduction control. The term 'train noise standard' had not been included in the Noise Vibration Regulation Act until recently in South Korea. However, the limit is provided as specified in the following table (applied from Jan. 1st, 2010) and is applied to the railroads constructed (transferred, changed) after the enforcement date of the revised Enforcement Ordinance for Noise Vibration Regulation (Prime Minister Ordinance, No. 474). Railroad noise standards for

Table 2. Limits of Transportation Noise and Vibration for Rail Road (Domestic Enforcement Ordinance for Regulating Noise and Vibration)

Object Area	Index	Limit (from Jan. 1st, 2010)	
		Day 06:00～22:00	Night 00～06:00
Residential area, green belt, settlement, tourism and resort area, nature protection area, area within 50m from the boundary of the area of school·hospital·public library	Noise Leq [dB(A)]	70	60
Commercial, industrial and agricultural area, the production management and the development area of industry and distribution, unnoticed area	Noise Leq [dB(A)]	75	65

(Note) Leq: Unit of Equivalent Noise Level

Table 3. Noise Criteria of Railroad for Residential Area in Various Countries

Country	Index for Noise Assessment	Target	Hours(H)	Standard [dB(A)]	Remark
France	Leq	New line including TGV	24	60	Recommended (residential area)
U.K.	Leq	New line	24	65	Standard
USA· German	L50	New line	06～22 22～06	45～50 55～60	Guide line of American transport association
Hong Kong	Leq Lmax	Existing and new line (for new resident plan)	24 23～07	65 85	Standard
Japan	Lmax	New line including Sinkansen	-	70	Standard (residential area)

Table 4. Suggested Value of Noise based on the Usage of Interior by ASHRAE

Types of Interior Usage	Criteria of Noise	
	NC value	dB(A)
Residential facility	30～35	40
Electricity room, parking lot	40～50	50～55
Multipurpose hall	30～40	40～45
Reading room	30～35	40
Community life facility	35～40	45

(Note) NC: Noise Criteria

residential areas of major countries are also shown in Table 2.

Table 2～3. represents standards for outdoor areas. The recommended interior noise levels across different usages suggested by ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) are shown in Table 4.

2.2 Regulation Standard for Vibration

Prime Minister Ordinance No. 473 announced the railroad vibration limit in 1994, in order to prevent damages caused by railroad vibration and appropriately manage/regulate railroad vibration. Although the ordinance came into effect on January 1st 2000, the limits are applied starting from January 1st, 2010, to railroads constructed after the date of announcement. The ordinance also states that necessary measures including anti-vibration facilities must be taken if the vibration generated by railroads exceeds the limits provided in Table 5. Table 6 shows the vibration standards based on the usage of building suggested by ISO 2361-2, 1989).

2.3 Selection of Alternative Measures for Protecting Vibration

The Gajwa urban public housing district requires anti-vibration measures, as it is located in the vicinity of Gyeongeui Line and Susaek Line of on the ground section as well as New Gyeongeui Line and Airport Railroad in underground section), and the vibration and noise from the train under operation are expected to affect the housing buildings.

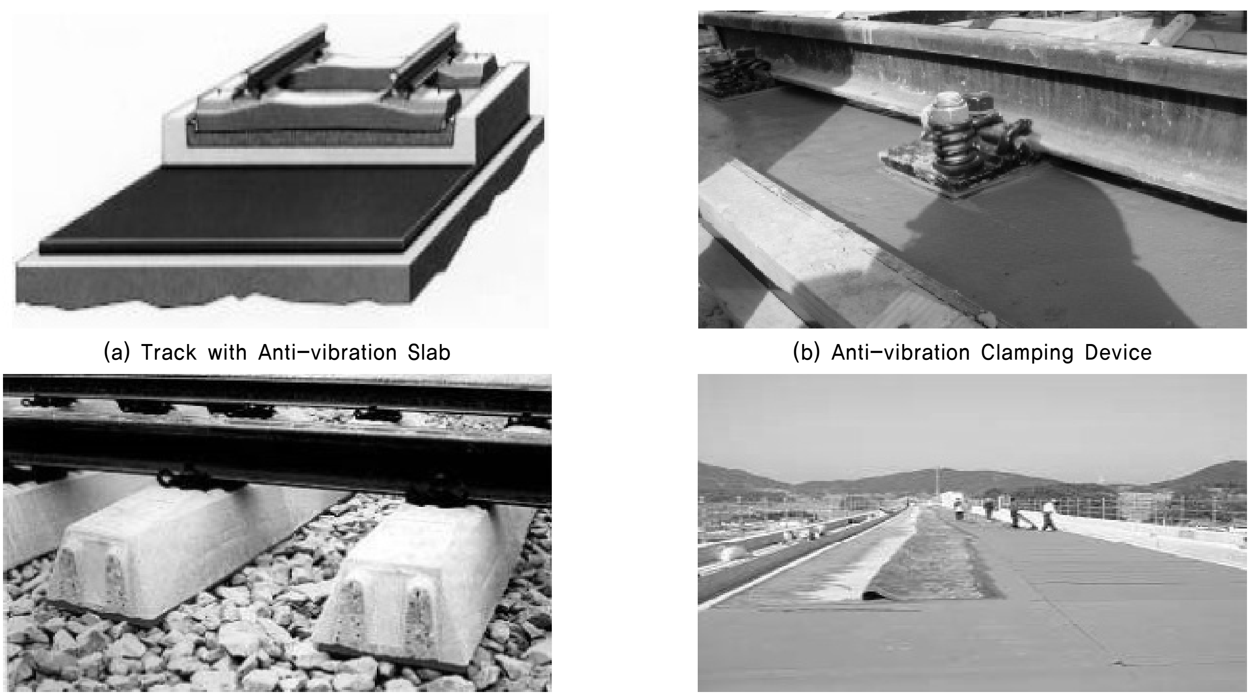
In general, anti-vibration measures are classified in terms of the applied locations. Those are ‘measure for vibration source’ applied to the source of vibration and ‘measures for delivery path’ applied at the location where the generated vibration is

Table 5. Vibration Standards for Railroad Areas

Object Area	Index	Limit (from Jan. 1st, 2010)	
		Day 06:00～22:00	Night 00～06:00
Residential area, green belt, settlement, tourism and resort area, nature protection area, area within 50m from the boundary of the area of school·hospital·public library residence	Vibration [dB(V)]	65	60
Commerce area, industry area, agriculture area, production control area and industry/distribution development promotion area, unannounced area	Vibration [dB(V)]	70	65

Table 6. Vibration Standards based on the Usage of Building(ISO 2361-2, 1989)

Area	Time	Continuous Vibratory Acceleration Amplitude		Impact Acceleration Amplitude	
Hospital, surgery room, other crucial area	day night	0.0036 0.0036	(51dB) (51dB)	0.005 0.005	(54dB) (54dB)
Residential area	day night	$0.072/\sqrt{t}$ 0.005	(57dB) (54dB)	$0.1/\sqrt{n}$ 0.01	(60dB) (60dB)
Office	always	$0.14/\sqrt{t}$	(63dB)	$0.2/\sqrt{n}$	(66dB)
Factory, workshop	always	$028/\sqrt{t}$	(69dB)	$0.4/\sqrt{n}$	(72dB)



(a) Track with Anti-vibration Slab

(b) Anti-vibration Clamping Device

(c) Anti-vibration Roadbed

(d) Mat on the Rail Road Track

Fig. 1. Types of Anti-vibration Measures Using Rail Road Tracks

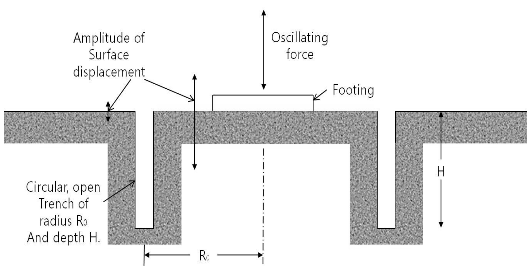
delivered, and the ‘measure for receiving point of vibration’ applied at the locations where damage is expected or vibration is actually felt.

2.3.1 Measures for Vibration Source

Measures for vibration source are further classified into those vehicles as well as for tracks, but currently there are no applicable noise reduction measures for vehicles. Measures for tracks include anti-vibration mat, anti-vibration pad and anti-vibration clamp (see Fig. 1). However, these measures were found difficult to apply in this case, as the railroads in the area are already under operation.

2.3.2 Measures for Delivery Path

Measures for delivery path involve preventing vibration from being delivered to the ground, by reducing or absorbing the



(a) Open Trench

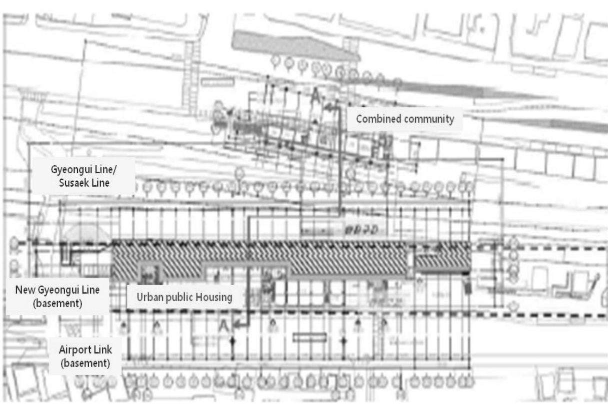
(b) Solid Wall

Fig. 2. Types of Measures for Delivery Path of Vibration

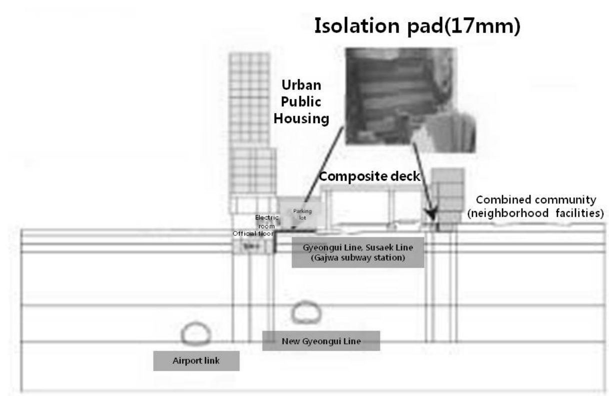
(a) Coil Spring+Damper

(b) Anti-vibration Pad

Fig. 3. Types of Alternative Measures for Receiving Point of Vibration



(a) Plan of Applying Protective Measures



(b) Location of Applying Protective Measures (section A–A')

Fig. 4. Application of Protective Measures of Vibration

energy delivered to the ground with anti-vibration materials. Open trench, solid walls and other vibration screen obstacles are installed between the source and the noise-receiving structures so as to reduce the intensity of vibration delivered to the structures. Fig. 2 shows open trenches and solid walls.

Open trench is the most widely used anti-vibration structure. The trench is installed in the ground, so as to block the horizontal delivery of ground vibration wave. Solid walls are constructed by excavating trenches and building high rigidity walls pouring concrete inside. Solid walls can be constructed in various shapes, and allow for easy maintenance as they are installed as permanent structures in the ground.

2.3.3 Measures for Receiving Point of Vibration (buildings)

Measures for noise-receiving point are the most passive anti-vibration measure. It is designed to reduce noise inside the

Table 7. Property Values of Anti-vibration Pad

Classification	Property Values
Material and size	- Material : foam urethane - width: 1,500mm, - thickness : 17mm
Demanded performance	- Static elastic modulus for size of 200mm×200mm anti-vibration area A : 3,600±720N/mm anti-vibration area B : 6,000±1,200N/mm(elasticity buffer area) - Dynamic elastic modulus : within 200% of static elastic modulus(test method : KS M 6604)
	- Permanent compressibility rate : within 10%(test method : KS M ISO 1856, temperature 70°C, test hours 22)

buildings. This method can be applied during construction of the buildings, and includes the following methods: reducing ground vibration energy by reinforcing the foundation system, installing rubber pads or spring dampers into the connection between foundations, underground walls and superstructure, installing anti-vibration materials between columns and beams of the building. Fig. 3 shows an example of reducing vibration delivery to the building by (a) installing coil springs and dampers between columns and superstructure, and (b) installing anti-vibration pads on the foundation floor.

Anti-vibration methods were selected considering the structural characteristics of the new buildings and the site conditions, in order to satisfy anti-vibration capability, economic feasibility and constructability requirements. For the sites in this study, the 'measure for receiving point of vibration' is selected, by which 17mm-thick foam urethane anti-vibration pads are to be installed on the lower floor and sides of the buildings as shown in Fig. 4.

In order to secure the safety of floor slabs in the anti-vibration areas, elastic buffer areas of 1.5m wide were applied, using anti-vibration pads with high spring constant, at the connection between the installation area and the non-installation area. This measure could prevent stress concentration on the slab. The property values of anti-vibration pads are shown in Table 7.

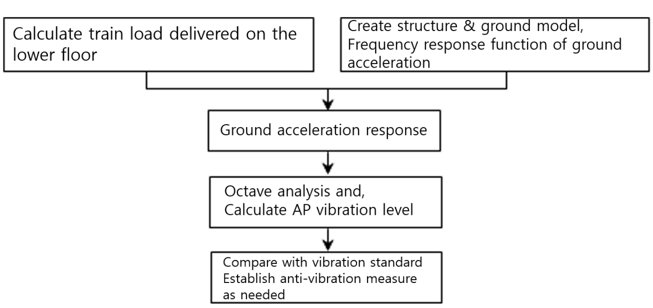


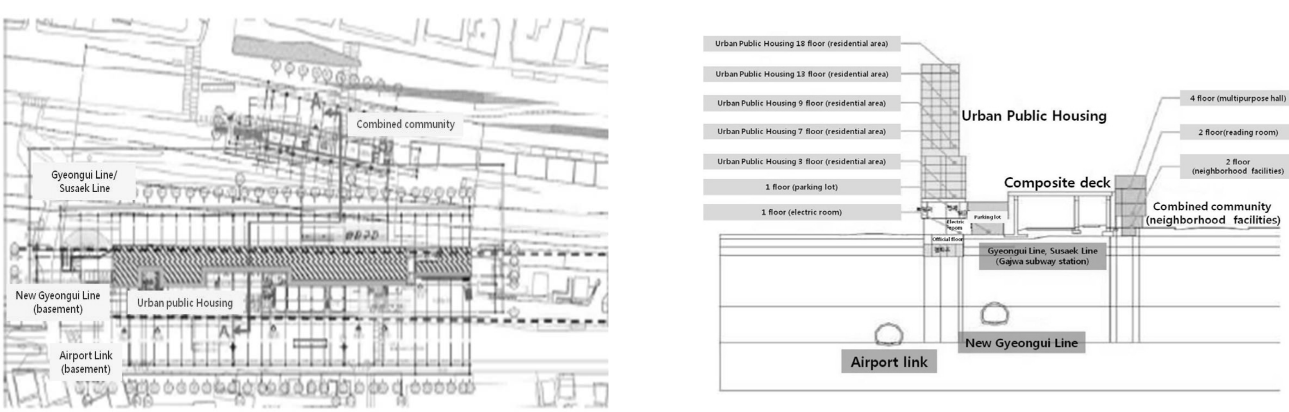
Fig. 5. Process of Assessing the Influence of Vibration

2.4 Assessment of Vibration and Noise

2.4.1 Method of Assessment for Influence of Vibration

Noise prediction was performed in order to assess the influence of vibration delivered to the new public houses and multi complexes. The program used for prediction was Plaxis-2D, and the assessment process is summarized in Fig. 5.

ISO 2631-2 in 1989 (see Table 5) was used as the railroad vibration standard to compare with the result of vibration analysis. Vibration analysis was performed on cross section A-A of Fig. 6, and the analysis points were selected based on the expected influence from railroad vibration. The analysis points were: 1st



(a) Ground Plan (b) Cross Section

Fig. 6. Schematic View of Influence Assessment of Vibration

floor at electricity room and parking lot, 3 7, 9, 13, 18th floor of the public housing, and 1, 2, 4th floor of the combined community building.

2.4.2 Results of Assessment for Influence of Vibration

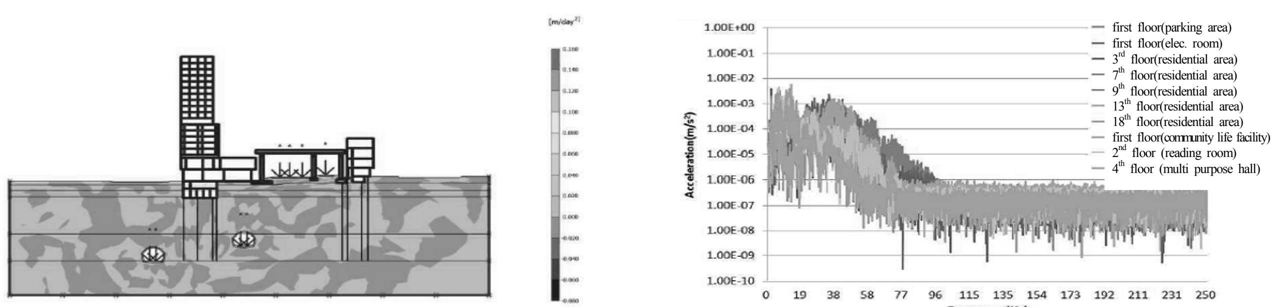
In order to assess the influence of railroad vibration on the apartment buildings and the combined community buildings, analysis was performed for two cases: a case where anti-vibration measure is not applied, and the other case where the anti-vibration measure is applied. The vibration analysis results and compliance with the standards before/after application of the measure are shown in Table 8 and the ISO 2631-2(1989) was used as the evaluation criteria for the level of satisfaction.

The measure applied was the one for receiving point of vibration,

Table 8. Assessment Result of Vibration from Railway Operation(before and after protection measure)

Location of Assessment		Standard of Vibration Level [dB]	Value of Vibration Analysis [dB]		Decision*	
			before measure	after measure	before measure	after measure
Public Housing	18th floor (residential area)	60 (residence)	55.2	46.2	satis.	satis.
	13th floor (residential area)		55.6	46.0	satis.	satis.
	9th floor (residential area)		58.0	45.4	satis.	satis.
	7th floor (residential area)		63.6	50.6	unsatis.	satis.
	3rd floor (residential area)		69.1	54.6	unsatis.	satis.
	first floor (electricity room)	72 (working hall)	70.3	62.0	satis.	satis.
	first floor (parking area)		70.3	59.5	satis.	satis.
Combined Community Building	4th floor (multi purpose hall)	66(office)	69.7	54.0	unsatis.	satis.
	2nd floor (reading room)	60(residence)	71.6	56.2	unsatis.	satis.
	first floor (community life facility)	66(office)	74.9	57.6	unsatis.	satis.

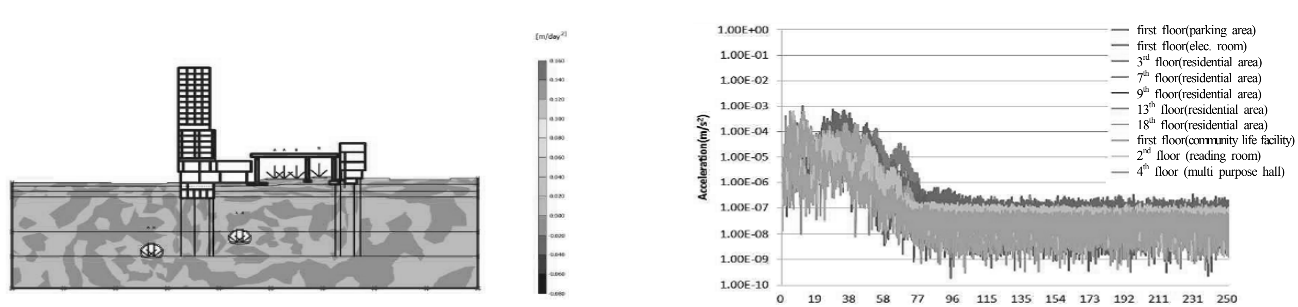
(Note) unsatis.: unsatisfactory; satis.: satisfactory



(a) Cross Section A-A'

(b) Frequency Characteristics during Train Service

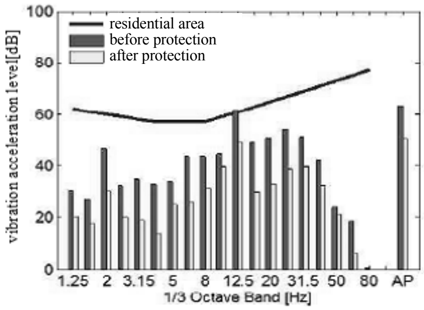
Fig. 7. Results of Vibration Analysis at Various Locations(before protection measures)



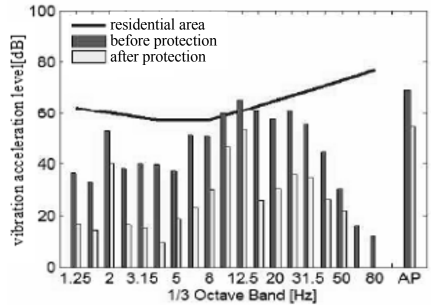
(a) Cross Section A-A

(b) Frequency Characteristics during Train Service

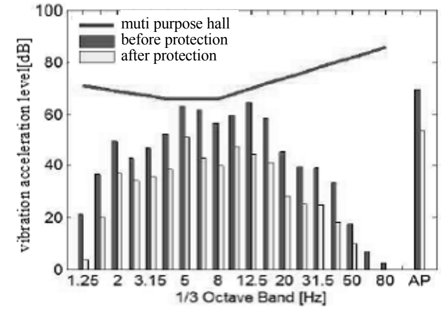
Fig. 8. Results of Vibration Analysis at Various Locations(after protection measures)



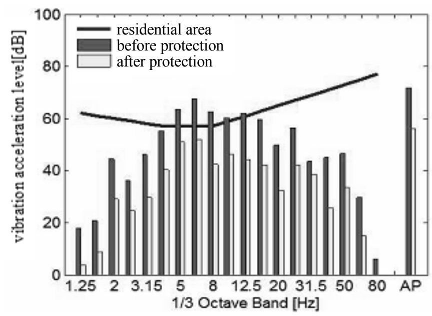
(a) 7th Floor (residential area)



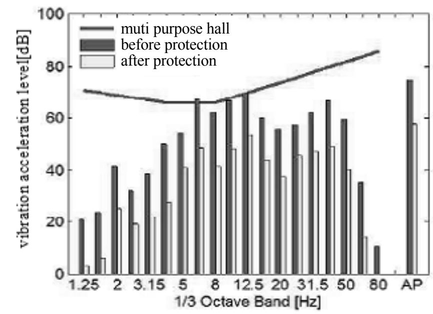
(b) 3rd Floor (residential area)



(c) 4th Floor(multi purpose hall)



(d) 2nd Floor (reading room)



(e) First Floor(community life facility)

Fig. 9. Analyzed Value of Vibratory Acceleration at the Representative Locations before and after Anti-vibration Measures

Table 9. Results of Noise Prediction Analysis on the Ground (before and after protection measures)

Location of Assessment		Standard of Noise Level [dB(A)]	Result of Noise Analysis [dB(A)]		Decision*	
			before measure	after measure	before measure	after measure
Public Housing	18th floor (residential area)	40	47.6	37.7	unsatis.	satis.
	13th floor (residential area)		47.9	38.4	unsatis.	satis.
	9th floor (residential area)		51.6	37.5	unsatis.	satis.
	7th floor (residential area)		52.5	37.4	unsatis.	satis.
	3rd floor (residential area)		58.6	34.1	unsatis.	satis.
	first floor (electric room)	50∼55	62.2	54.9	unsatis.	satis.
	first floor (parking area)		63.2	52.4	unsatis.	satis.
Building of Combined Community	4th floor (multi purpose hall)	45	43.1	41.7	satis.	satis.
	2nd floor (reading room)	40	52.9	43.7	unsatis.	unsatis.
	first floor(community life facility)	45	61.2	45.0	unsatis.	satis.

(Note) unsatis.: unsatisfactory; satis.: satisfactory

in which anti-vibration pads are installed at the lower part of the public houses and the combined community building. Fig. 7∼9 represent the summary of the vibration analysis results.

According to the analysis results, the standards were not satisfied at some locations before application of the anti-vibration measure. However, all locations satisfied the standards after application of the anti-vibration measure, demonstrating that the anti-vibration methods and materials applied to this site were suitable.

In the analysis, the influence from on-ground lines such as Susaek Line, Gyeongeui Line as well as the cargo trains was found to be dominant, while the influence of Airport Railroad and New Gyeongeui Line, located deep under the super structures was minimal.

2.4.3 Results of Assessment for Influence of Noise

The vibration delivered to public housing and combined community facility due to railroad operation was analyzed, and the vibratory acceleration calculated from Eqn (1) was used to predict noise emission.

$$L_{po} = L_a - 20\log f + 23 \quad (1)$$

where, L_{po} : level of emitted noise, L_a : level of vibratory acceleration (value of vibratory acceleration in Table 22), f : frequency (1/3 Octave band : 1.25～80Hz).

The results of noise analysis and the satisfaction level assessment performed at the same locations as the vibration influence assessment are shown in Table 9. ASHRAE standards in Table 6 were used as the standard values for the allowable noise.

According to the analysis results, the standards were not satisfied at most locations before application of the anti-vibration measure, but satisfied the standards at all locations after application of the anti-vibration measure, demonstrating that the anti-vibration method applied to the site were suitable. In addition, as the reading room on the 2nd floor of the combined community building is expected to receive noise slightly exceeding the standard, it is worthwhile to use the room for some different purposes.

3. Conclusions

Under various difficulties and the pressure of high concern and expectation from the citizens, many efforts were taken to satisfy the amenity requirements on noise and vibration for the residential area. As a results, it can be recognized the amenity standards can be satisfied.

The prediction analysis on noise and vibration showed that the noise levels are considerably reduced to below the standards after application of anti-vibration measures using anti-vibration pads, etc, while noise and vibration exceeds the standards without any anti vibration measure.

Although the amenity prediction for the two districts were carefully performed using the state-of-the-art techniques, various unexpected conditions may occur during the actual construction. Therefore, constant feedback from the construction site needs to be reflected into the design. In addition, as the trains are under operation during the construction period, special care is needed.

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