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Hyun-Suk Chung

Gap-Deug Kim

Kwan-Seob Yang

Kyung-Woo Kim

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Hyun-Suk Chung[i], Gap-Deug Kim[ii], Kwan-Seob Yang[iii] and Kyung-Woo Kim[iv]

ABSTRACT

With the recent introduction of light gauge steel framing systems in the concrete-dominated Korean construction industry, more buildings are built with drywall that is mainly composed of steel studs and gypsum boards. While load-bearing steel studs are extensively applied in residential construction, non load-bearing steel studs are applied in various building fields such as commercial, educational, as well as residential. As building projects involving steel stud walls are becoming to increase, higher demands in performance are requested from architects and builders, especially in the field of sound performance. A series of acoustic test were performed in the nationally certified sound-testing laboratory at Korean Institute of Construction Technology (KICT) in order to evaluate and analyze factors that influence acoustic performance of steel stud wall assemblies. Factors affecting the acoustic performance of steel stud walls that are analyzed in this paper include among others, the composition and structure of steel studs, stud spacing, stud thickness, stud size, use of resilient channel, screw spacing, etc. Factors relating to gypsum boards that were tested as part of the evaluation of acoustic performance are not included in this paper. Results of this study, which is co-funded by 3 major gypsum board companies in Korea, are being used to develop stud wall assemblies that meet the required acoustic performance for unit-to-unit separating walls, as well as present architects and builders with a better understanding on the sound behavior of steel stud drywall.

[i] Assistant Researcher, Research Institute of Industrial Science and Technology, South Korea
[ii] Senior Researcher, Research Institute of Industrial Science and Technology, South Korea
[iii] Senior Researcher, Korea Institute of Construction Technology, South Korea
[iv] Assistant Researcher, Korea Institute of Construction Technology, South Korea

1. INTRODUCTION

Drywall, which is mainly composed of light-gauge steel stud and gypsum wallboard, offe architects and builders a competitive alternative to the traditional wet construction method such concrete or masonry. More buildings in Korea are now using light-gauge steel to frame for n load-bearing as well as load-bearing walls. Drywall is not only simple to build and easy to hanc at the jobsite, but it can also enhance the performance of the building where traditional buildi methods cannot fully achieve.

With an increase application of light-gauge steel in commercial as well as residential building there is higher demand for its performance, especially in the fields of fire and acoustic performanc when applied in wall systems. The performance of a steel stud and gypsum wallboard assemb can be very diverse sine the performance is highly dependent on the type and nature of materia and subcomponents used to frame the wall, and also the different construction methods. It therefore important to exactly understand and evaluate how each wall component contributes to t performance of drywall, and use this information to develop optimal systems for use in vario types of buildings that have different performance requirements.

1.1 SCOPE AND OBJECTIVE

This paper focuses on evaluating the various factors that contribute to the acoustic performance o drywall through laboratory measurement of airborne sound insulation. Although fire and acoust performances cannot go without the other, the scope of this project is centered on the acoust performance since it is highly dependent on various factors and the building components than fi performance. Fire performance of a drywall can be usually achieved by considering the type a number of gypsum boards applied to steel studs, while the sound performance involves mo complicated issues other than the gypsum board.

The scope of this paper includes the selection of factors contributing to the acoustic performance drywall, analysis of importance factors, and evaluation of the influence that factors have on t acoustic performance through test results. Sound factors are evaluated for non load-bearing wal that can be applied as unit separating or within dwelling. Although tests performed under th study evaluate the different factors contributing to the acoustic performance of drywall, test resul from steel-related factors are only presented in this paper. Results relating to the gypsum boa and insulation are not included in this paper.

1.2 MARKET TRENDS & CONSTRUCTION PRACTICES

Korean residential construction industry is highly characterized by the use of reinforced concrete or masonry and the application of mid-rise to high-rise apartment buildings, which share more than 90% of the market. A concrete high-rise apartment or mid-rise multi-family housing is the usual type of dwelling for most Koreans, with a little market share of low-rise single-family housing.

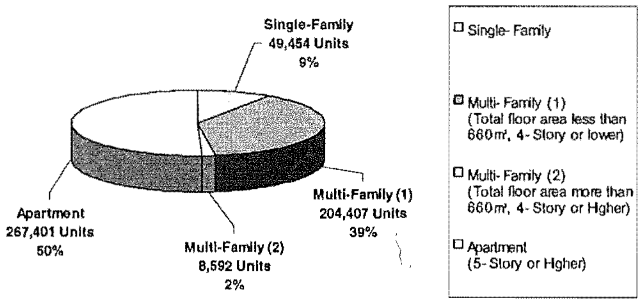
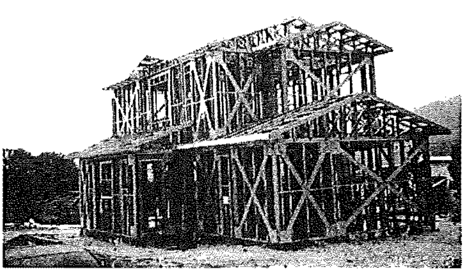


Figure 1. Completed housing units (2001, Ministry of Construction and Transportation)

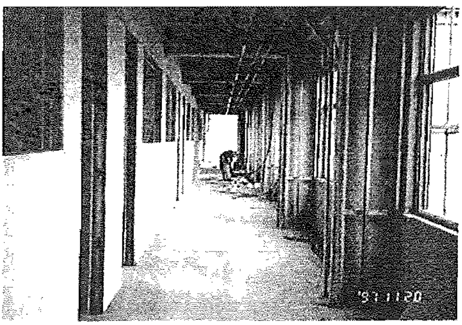
It was not until POSCO (Pohang Iron and Steel Company) began to introduce Steel House in the late 1990s that light-gauge steel was used for load-bearing structures of residential buildings as well as other types of buildings. And it was not until major construction firms began to build high-rise steel apartments that light gauge steel was extensively applied as non load-bearing walls. Hence, the application of dry construction method such as drywall was not widely used until mid 1990s.

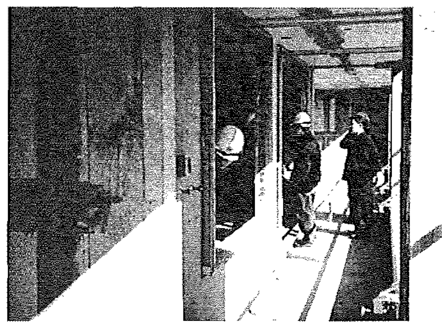


< Single-Family House > < Multi-Family House >

Figure 2. Examples of Light Gauge Steel Framed Construction (Load-Bearing)

Benefits of light gauge steel framing have nowadays been widely accepted by many architects a builders in Korea, and more companies are building with light gauge steel for their interior n load-bearing walls as well as exterior curtain walls. The application of light gauge steel includ commercial buildings such as hotel, exhibition center, shopping mall, educational buildings such school, public buildings such as post office, hospital, as well as government buildings. Lig gauge steel was first applied to steel framed buildings but nowadays, there is a vast increase application to reinforced concrete structures. Major examples that can be noted are concrete hig rise apartments with interior non load-bearing walls using steel stud.





< Steel Framed School > < Concrete High-Rise Apartment >

Figure 3. Examples of Light Gauge Steel Framed Construction (Non Load-Bearing)

2. REGULATORY FRAMEWORK

Building components, such as walls, that need to be acoustically approved for application buildings, need to be approved for different fire-resistance performances set forth in the Korea building code. It is therefore indispensable to understand the fire requirements of buildings befo studying the regulations on acoustic performance.

2.1 FIRE REQUIREMENTS

The Korean building code requires all buildings and their structural components to have a fi resistant performance in compliance with the criterion established by the Ministry of Constructi and Transportation. **Table 1** describes the buildings that have to meet fire requirements according building use and size of floor area. **Table 2** describes the fire requirements for exterior ar interior walls of buildings according to building type, building height, etc.

Table 1. Buildings Requiring Fire-Rated Construction

Building Use	Floor Area	Remarks
Cultural and assembly centers, funeral homes, liquor stores, etc.	Not less than 2000m^2	Except: Exhibition, animal and botanic parks / Kiosks located outside buildings with areas exceeding 1000 m^2
Exhibition, animal and botanic park, business facilities, institutional and welfare facilities, sport facilities, storage facilities, storage facilities of hazard and treatment, car facilities, TV studio, telecommunication, etc.	Not less than 500m^2	Except: Liquor stores
Factory	Not less than 2,000 m^2	Except: Factories that have little combustible materials as specified by the Min. of Construction and Transportation
Multi-family houses, institutional, education and welfare accommodations	Not less than 400m^2	
Buildings under 3 stories and buildings with basements	All areas	Except: Single family houses, animal and botanic facilities, detaining facilities etc

Table 2. Fire-Resistance Requirements for Walls (Hours)

Building Use[i] \ Structural Elements				Wall					
				Exterior			Interior		
				Load-Bearing	Non Load-Bearing[ii]		Load-Bearing	Non Load-Bearing[ii]	
		Max. No. of Stories/Height (m)			A	B		A	B
1	1-1	12/50	Over	3	1	1/2	3	2	2
			Below	2	1	1/2	2	1 1/2	1 1/2
		4/20 Below		1	1	1/2	1	1	1
2	2-1	12/50	Over	2	1	1/2	2	2	2
			Below	2	1	1/2	2	1	1
		4/20 Below		1	1	1/2	1	1	1
3	3-1	12/50	Over	2	1 1/2	1/2	2	1 1/2	1 1/2
			Below	2	1	1/2	2	1	1
		4/20 Below		1	1	1/2	1	1	1

[i] Building use is defined as follows:

1 General Facility

1-1 Business facilities, retail and wholesale, military, broadcasting, power plant, tele-communicati studio, facilities related to sightseeing, sport facilities, cultural and assembly facilities, the 1st and life supporting facilities, amusement facilities, leisure facilities, cremation out of tomb faciliti educational and welfare facilities, motor car facilities (except for repair station).

2 Residential

2-1 Residential multi-family house, house for official, accommodation facilities, institutional faciliti low rise multi-family house

3 Industrial

3-1. Industrial - factory, storage facilities, waste treatment facilities, motor car repair station out of mo car facilities, storage and treatment facilities of hazard materials

[ii] A and B are defined as follows:

A. Portion of wall that is possible to catch fire

B. Portion of wall that is impossible to catch fire

2.2 ACOUSTIC REQUIREMENTS

As for acoustic performance of walls, the Korean building code requires unit-separating walls multi-family housing, separating walls of dormitory rooms, hospital rooms, classrooms educational and research facilities, and hotel rooms to be fire-resistant and acoustically approve While the acoustic performance of reinforced concrete structure can be achieved by the prescripti design method set forth in the building code, other methods such as the steel stud drywall must tested and approved individually by a national construction testing laboratory according to criteri set forth by the Ministry of Construction & Transportation.

In order to be acoustically approved for use as separating wall in the above-mentioned installatio the sound test results must meet the performance criteria described in **Table 3**.

Table 3. Performance Criterion for Acoustic System

Frequency	Sound Transmission Loss
125Hz	More than 30dB
500Hz	More than 45dB
2,000Hz	More than 55dB

3. ANALYSIS OF FACTORS AFFECTING ACOUSTIC PERFORMANCE OF STEEL STUD WALL ASSEMBLY

The acoustic performance of drywall is influenced not only by the material used to frame the wall but also by the method it is structured and installed. Various factors influencing the sound performance of steel stud drywall have been studied around the world in many countries for a long period of time. But with the development of new materials and construction methods, the increase in performance requirements, and other issues such as the difference of acoustic testing laboratory and test method, different construction materials and practices, there was a need to evaluate the factors contributing to the acoustic performance of drywall using Korean testing and building practices.

The acoustic factors to be evaluated were proposed and analyzed using expert judgment from the project participants that included, among others, staff from gypsum board companies and Korean Institute of Construction Technology, which provides nationally approved acoustic testing. In the first stage, a total of 18 factors and 28 test models were proposed during the course of the project. Factors are grouped into 5 categories: gypsum board, steel stud, insulation, resilient layer, and construction method. Each category includes 3~5 factors each, and each factor is subdivided into 1 ~ 3 test models. The factors and test models for evaluation are summarized in **Table 4**.

Among the 18 factors and 28 test models proposed, 16 factors in 26 test models were selected for evaluation. The two factors not considered were stud spacing and nailing method. The stud spacing factor was eliminated due to the construction practice in Korea where 900mm width wallboard is more extensively used than 1200mm width. As to the nailing method, it was eliminated because it was not proven for use in fire-resistant wall systems at the time. The 16 factors were then summarized into a list in order of importance, also evaluated using expert judgment from the project participants.

This paper deals with 9 factors among the 16 factors selected, based on the categories of steel stud, construction method and resilient layer, and not considering factors related to gypsum board and insulation.

Table 4. Acoustic Factors and Elements

Acoustic Factors		Test Models	
Category	Item	Basic Type	Alternative Type
Gypsum Board	Type of Board	Normal	Type-X
			Waterproof
			Soundproof
	Number of Board	1 Layer	2 Layers
			3 Layers
	Thickness of Board	9.5mm	12.5mm
			15mm
	Composition of Board	Same Layers	Different Thickness
			Different Type
			Different Number of Layers
Insulation	Use of Insulation	No	Yes (50mm)
			Yes (100mm)
	Size of Insulation	50mm	100mm
	Type of Insulation	Mineral Wool	Glass Wool
	Density of Insulation	MW 60K	MW 100K
		GW 24K	GW 48K
Steel Stud	Width of Stud	50mm	100mm
	Thickness of Stud	0.5mm	0.8mm
	Spacing of Stud*	450mm	600mm
	Type of Stud	C-Shaped	Box-Shaped
Construction Method	Method of Installation	Single Stud	Double Stud
			Staggered Stud
	Screw Spacing	300mm	150mm
	Nailing*	No	Yes (2^{nd} Layer)
Resilient Layer	Use of Rubber Pad	No	Yes (Both Sides)
	Use of Acoustic Sheet	No	Yes (One Side)
	Use of Resilient Channel	No	Yes (One Side)
			Yes (Both Sides)

* *Proposed, but not selected for review of acoustic performance*

4. ACOUSTIC TEST OF STEEL STUD WALL ASSEMBLY

4.1 TEST METHOD

The acoustic tests were performed in the reverberation room (**Figure 4**) at Korean Institute of Construction Technology. The tests were performed according to requirements set forth in the Korean Standard KS F 2808:2001 'Laboratory Measurements of Airborne Sound Insulation of Building Elements', which is mainly based on the ISO 140-3 Part 3. Temperature conditions of the reverberation room were set at -10°C ~ +25°C, and humidity conditions were maintained at a range of 45% ~ 60%.

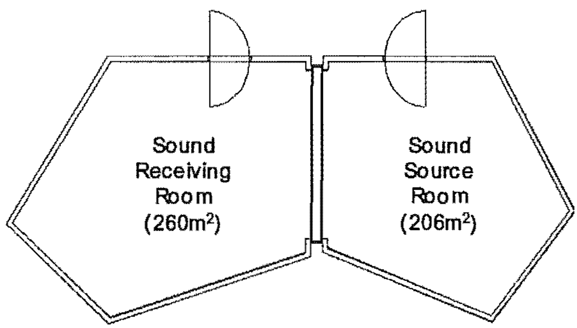
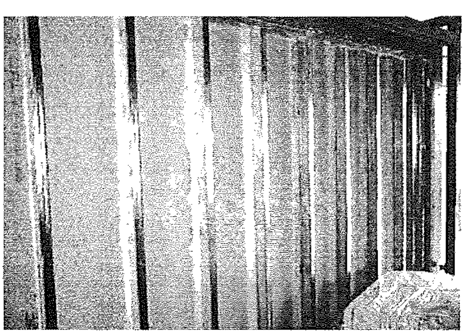
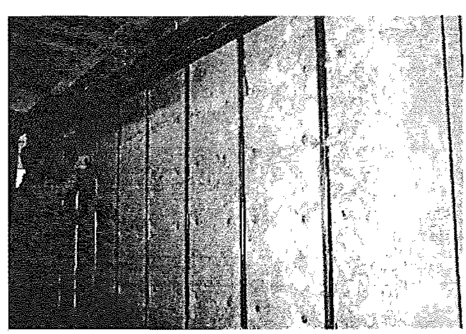


Figure 4. Reverberation Room for Acoustic Testing



< Installation of Gypsum Board on Steel Stud >



< Installation of Mineral Wool >

Figure 5. Fabrication of Wall Test Specimen

A total of 34 walls were fabricated (**Figure 5**) and tested in the reverberation room from August November of 2001. Test specimens were 4.4m wide and 2.4m high for a total wall surface area 10.12m^2. Although there was demand for testing multiple specimens for each test model to obta an average value of multiple test results, only one test specimen was tested for each test model this project due to time and resource limitations.

4.2 ACOUSTIC TESTING MODELS

The test models used for evaluation of the acoustic performance can be divided into the basic moc and evaluation models.

1) Basic Model

The basic model consists of 0.8mm thick steel studs with a width size of 100mm spaced at 450m on center, with 2 layers of 15mm thick type-X gypsum board on each side, and 50mm of mine wool(60K) installed in between studs. The screws are spaced at 300mm on center for the first a second layer. (**Figure 6**) 3 basic models from 3 different gypsum board companies were tested.

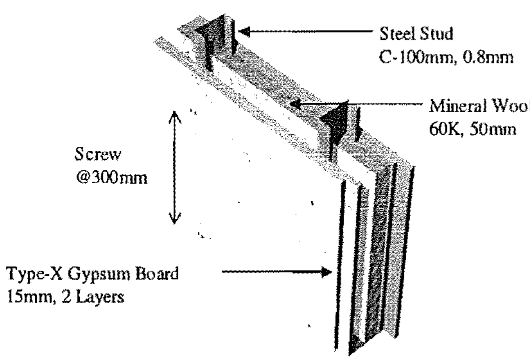


Figure 6. Basic Test Model (B-1)

The use of 2 layers of 15mm type-X gypsum board results from the achievement of 2 hours of fi resistance performance for use as non load-bearing walls installed in buildings that are more than stories high, in accordance with the Korean building code. Steel studs having a web size 100mm are used to achieve a total wall thickness of ±150mm, so that drywall can be competiti compared to traditional concrete or masonry walls that have a wall thickness of 200mm or so.

2) Evaluation Models

31 wall specimens, excluding 3 basic models from the total 34 wall specimens, were fabricated and tested as part of the evaluation for the influences that each factor has on the acoustic performance of drywall. Assuming that gypsum boards from different gypsum board companies differ slightly in performance, 4 series of tests that included 5 ~ 8 wall specimens were carried out using one type of gypsum board for the entire series. Hence, the wall specimens within one series were not compared with others that were in other series. All evaluation models were compared within the same series or with the basic model.

Table 5 shows the details of 13 wall specimens as evaluation models that were used to analyze the acoustic performance of drywall, that are related to steel stud, construction method and resilient layer, excluding factors related to gypsum board and insulation. The symbol of the wall specimen is decided by the factor category: S for stud, C for construction method and R for resilient layer.

For factors related to steel stud, the width influence is evaluated by comparing S-1 and S-2, the thickness influence by B-1 and S-3, the type influence by B-1 and S-4. For factors related to the construction method, the staggered effect is evaluated by comparing B-1 and C-1(C-2), the double effect by B-1 and C-3(C-4), screw spacing by B-1 and C-5. For factors related to the resilient layer, the effect of rubber pad is evaluated through comparison of B-1 and R-1, the resilient channel effect by B-1 and R-2(R-3), and soundproof sheet effect by B-1 and R-4.

Table 5. Evaluation Models Related to Steel Stud, Construction Method and Resilient Layer

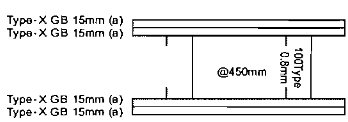
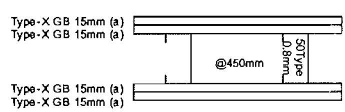
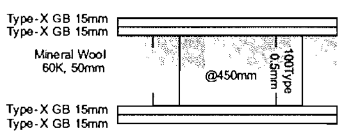
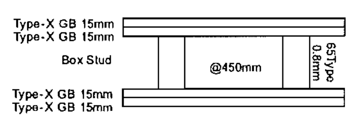
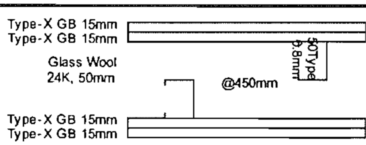
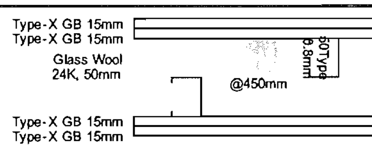
Symbol	Wall Detail	Symbol	Wall Detail
S-1		S-2	
S-3		S-4	
C-1		C-2	

Table 5. Evaluation Models - Continued

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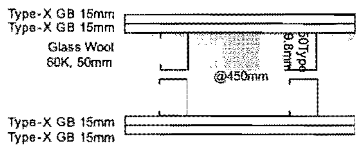
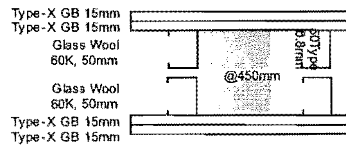
<tr><td>C-3</td><td>
</td><td>C-4</td><td>
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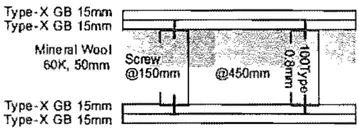
<tr><td>C-5</td><td>
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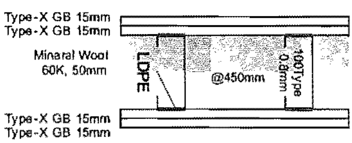
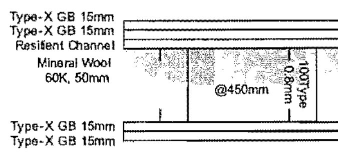
<tr><td>R-1</td><td>
</td><td>R-2</td><td>
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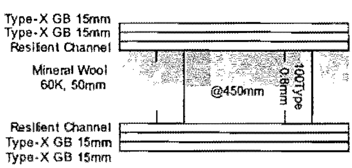
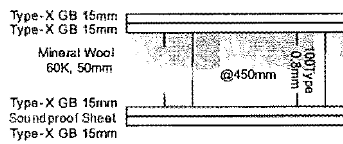
<tr><td>R-3</td><td>
</td><td>R-4</td><td>
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5. ANALYSIS OF ACOUSTICAL TESTING RESULTS

5.1 GENERAL

Test results of 3 basic models and 13 evaluation models are included in this paper to analyze factors that influence the acoustic performance of light gauge steel framed walls in the category steel stud, construction method and resilient layer.

Results of the acoustic tests show that 4 test models are satisfactory for application as ur separating walls according to the Korean building code. The staggered stud wall (C-1), the doul stud walls (C-3 & C-4), and double resilient channel wall (R-3) proved to be above the sou performance requirements shown in **Table 3**.

5.2 ANALYSIS OF RESULTS ACCORDING TO FACTORS

Results of the acoustic tests can be summarized as follows, according to the categories and factors. All results are expressed in STC (Sound Transmission Class) values. As mentioned previously, results are from single tests of each wall specimen, except for the basic model, which is an average of 3 test results of the same type but different gypsum board companies.

1) Steel Stud

① Width of Stud

The effect of having larger air cavity based on the web size of the steel stud from 50mm(S-2) to 100mm(S-1) proves that it can enhance the acoustic performance by 3dB. The 50mm-type stud wall showed 42dB, while the 100mm-type stud wall indicated 45dB.

② Thickness of Stud

Effects of using thinner steel studs proved to be trivial according to tests performed for a wall having a steel stud of 0.5mm thickness (S-3) and 0.8mm thickness (B-1). An increase of 3~6dB can be noted in the frequency range of 100Hz ~ 160Hz for the 0.5mm steel stud wall.

③ Type of Stud

When using a boxed-shape stud (S-4) compared to a C-shaped stud (S-1 & S-2), more oscillations are induced in such wall, which contribute to the deterioration of acoustic performance.

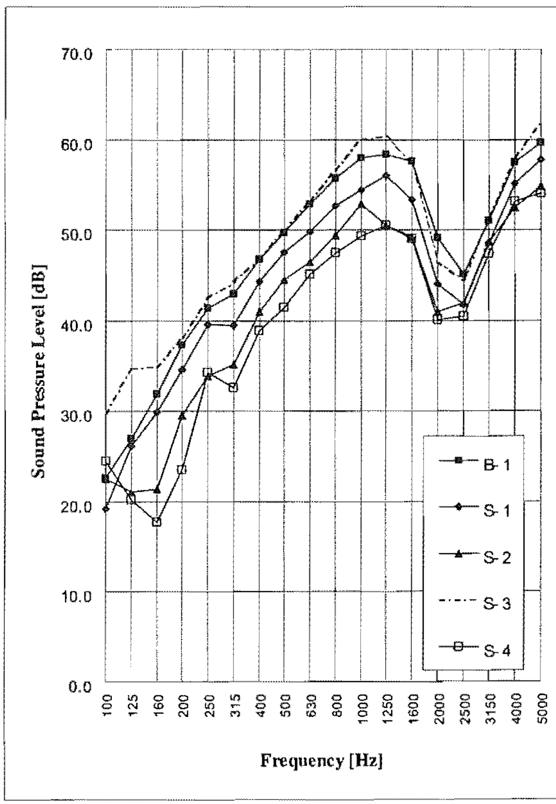

Figure 7. Acoustic Test Results – Steel Stud

An STC value of 38 is obtained for the boxed-shape stud having a web size of 65mm, while and STC value of 45 is obtained for the C-shaped stud having a web size of 100mm.

2) Construction Method

① Staggered Stud

Compared with the basic model (B-1), which has an STC value of 48dB, the staggered stud wall (C-1) proved to be highly superior in acoustic performance with an STC value of 54dB. The effect of staggering the insulation to minimize the transmittal of sound through steel studs contributed much to the higher performance. Result of the staggered stud wall having a straight insulation installation (C-2) supports such effect, which has significantly little or no enhancement compared with the basic model.

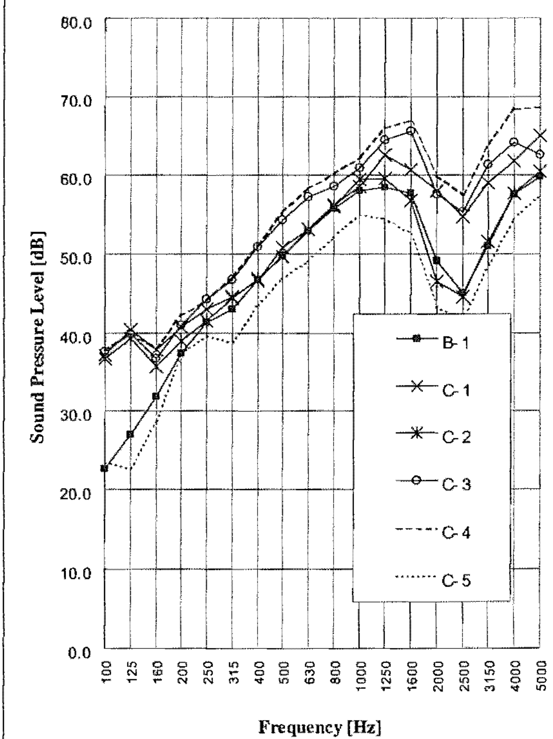

Figure 8. Acoustic Test Results – Construction Method

② Double Stud

Test results show that a drastic improvement can be obtained in acoustic performance when using a double stud wall system. Compared with the basic model (B-1) that uses a single 100mm-sized steel stud, the double structure, where two 50mm-sized steel studs are installed separately with each other with a 10mm gap in between, proved to b highly sound efficient. While the basic model has an STC value of 48dB, the double stud structu with one layer of insulation (C-3) is 55dB, and 2 layers of insulation (C-4) is 56dB.

③ Screw Spacing

When installing screws at a shorter spacing of 150mm (C-5) than 300mm (B-1), the acoust performance is reduced, with a result of 46dB compared to 48dB. The effect of shorter scre spacing contributed to more transmittal of sound through higher oscillations of wall componen that are joined together.

3) Resilient Layer

Resilient layers can be achieved by isolating the steel stud and gypsum board or by providing a soundproof sheet between the gypsum board layers. Both cases were studied in the tests.

① Use of Rubber Pad

Compared with the basic model (B-1), installing a rubber pad (LDPE, Low Density Polyethylene) along each stud where the gypsum board is attached (R-1) contributed to an acoustic performance enhancement of 3dB in STC. More enhancements were observed in lower frequencies.

② Use of Resilient Channel

Using a resilient channel proved to be one of the best methods to enhance the acoustic performance of a steel stud wall with gypsum board. The effect of having resilient channels on one side (R-2) is 53dB in STC value, while the effect of having resilient channels on both sides (R-3) is 54dB in STC value. This is an increase of 5~6dB compared with the basic model.

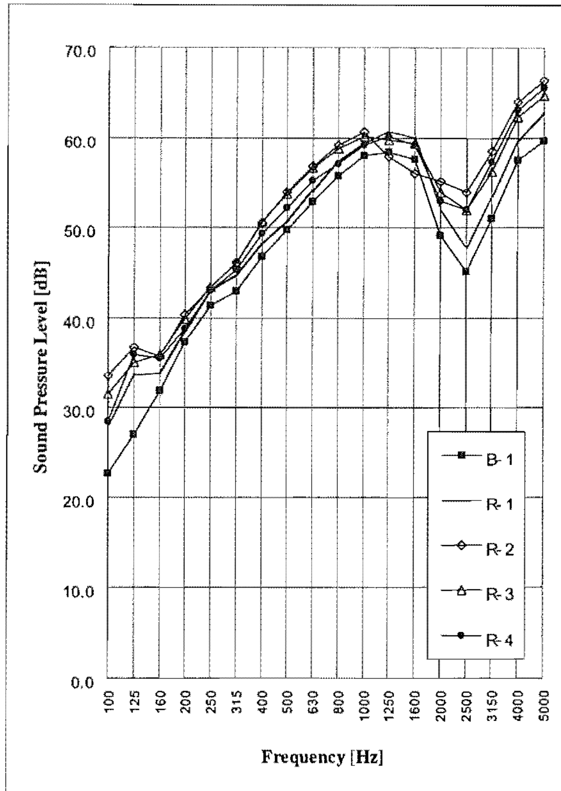

Figure 9. Acoustic Test Results – Resilient Layer

③ Use of Soundproof Sheet

Applying a rubber product soundproof sheet on an entire surface of one side of the test wall (R-4) contributed to an increase of sound performance, with an STC value of 54dB compared to 48dB for the basic model without a soundproof sheet. Results in high frequencies failed to surpass a sound pressure level of 55dB at 2000Hz, thus not making the wall approved for national certification as unit-separating wall. Though the sound performance can be increased with a soundproof sheet, higher cost and difficulty of construction must be overcome for application at the field site.

CONCLUSIONS

With wider application of drywall in the Korean construction industry, more demands are made regard to the system's performances, especially acoustic performance. In order to provide agreeable environment, the Korean building code, as in many other countries, requires the use of acoustically approved wall system for unit separating walls in multi-family housing, hotel roo hospital rooms, and others. While the sound performance of reinforced concrete and maso walls can be easily achieved through prescriptive methods, new construction methods such drywall must be individually tested and approved. But since drywall can be diverse according the material composition, construction method, etc., it is important to exactly know how e individual factor related to drywall, such as steel stud, gypsum board, and others, contribute to acoustic performance of the overall wall system, so that an optimal system can be developed t meets the acoustic requirements set forth by the Korean building code.

A total of 34 wall specimens were tested during a project that was jointly achieved w participation from 3 Korean gypsum companies, to review 16 factors contributing to the acous performance of drywall. This paper presents results of 9 factors among the total 16, focusing factors related to steel stud, construction method, and resilient layer. Results show that stagge and double stud walls enhance the acoustic performance, while a similar increase in sou performance can be also achieved through use of resilient channels. Gypsum board companies making efficient use of the test results of the project to develop a cost-effective and hi performance wall system. Results of the project will be published so that architects and build have a better understanding on the acoustic behavior of drywalls.

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