RESEARCH REPORT

Flanking Sound Transmission in Wood Framed Construction

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FLANKING SOUND TRANSMISSION IN WOOD FRAMED CONSTRUCTION

Prepared for

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CLIENT REPORT

for

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Report #3:
Study of Flanking Sound Transmission in Wood Framed Construction

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FLANKING SOUND TRANSMISSION IN WOOD FRAMED CONSTRUCTIONS

In multi-family dwellings, the most obvious — and usually the most important — sound transmission path is through the wall or floor separating adjacent dwellings. Unfortunately, transmission along other paths (flanking transmission) often seriously reduces the sound insulation.

The basic purpose of this study, funded jointly by the Canada Mortgage and Housing Corporation and the Institute for Research in Construction of the National Research Council Canada, was to commission a facility for controlled flanking studies, and to determine the usefulness of conventional and more advanced test methods to identify flanking problems. Standard test methods (ASTM E336 for airborne sound and ASTM E1007 for impact sound) were compared with more detailed and sophisticated procedures. As discussed in the conclusions, there is no ideal simple solution. The standard methods can only roughly identify the flanking problem even with laborious re-measurement with a masking construction shielding each room surface in turn. The more sophisticated methods (acoustic intensity and structural vibration intensity) can pinpoint the problem, but require lengthy measurements and skilled use of expensive instrumentation that would exceed the capabilities of most acoustical consultants.

The resulting test methods have been used to investigate flanking transmission caused by specific construction faults. With very careful construction, wood-framed walls and floors can provide field performance very close to laboratory test results. However, these tests demonstrated that contractor errors and inappropriate construction details can wipe out the benefit of potentially excellent constructions.

- With typical wood, warping can cause contact between nominally separated studs or joists on the two sides of double wood stud assemblies. Bracing is needed to limit warping. It is also essential to caulk joints at the wall perimeter, to avoid leaks developing as the wood distorts.
- Resilient metal channels are only effective if the dominant sound transmission path is through the framing to which they are attached. If screws short out resilient channels, the STC and/or impact insulation will be reduced. For example, wrongly placed screws reduced a floor's STC by 3 in this case study.
- Correct design and implementation of fire stops is critical; they should provide the weakest possible vibration coupling. If the fire stop is formed by the continuation of a room's surface, then it should have the highest coincidence frequency, and highest mass possible. Two common fire stops were shown to severely reduce effective sound insulation — from STC 62 to STC 45 in one case.

SOMMAIRE

TRANSMISSION INDIRECTE DU SON DANS LES CONSTRUCTIONS À OSSATURE DE BOIS

Dans les collectifs d'habitation, la voie de transmission du son la plus évidente - et normalement la plus importante - est au travers des murs ou planchers séparant des logements attenants. En outre, la transmission indirecte du son par d'autres voies diminue dans un grande mesure l'isolation acoustique.

L'étude, dont le financement est partagé entre la Société canadienne d'hypothèques et de logement et l'Institut de recherche en construction du Conseil national de recherches Canada, visait la construction d'une installation pour des études contrôlées de transmission indirecte du son et la détermination de l'utilité des méthodes d'essai classiques et plus perfectionnées qui permettent d'isoler les problèmes de transmission indirecte du son. Les méthodes d'essai normalisées (ASTM E336 pour les bruits aériens et ASTM E1007 pour les bruits d'impact) ont été comparées à des méthodes plus détaillées et perfectionnées. Comme il est dit dans les conclusions, il n'existe pas de solution à la fois simple et idéale. Les méthodes ordinaires peuvent seulement identifier de manière approximative la présence d'un problème de transmission indirecte, même après de multiples et laborieuses mesures en masquant tour à tour chacune des surfaces d'une pièce. Les méthodes plus perfectionnées (intensité acoustique et intensité des vibrations structurales) permettent d'isoler le problème avec précision, mais nécessitent des mesures fastidieuses et l'emploi d'instruments coûteux dont la plupart des experts-conseils en acoustique ne savent pas se servir.

Les méthodes d'essai résultantes ont été employées pour l'investigation de transmission indirecte de son attribuable à des vices de construction précis. Avec une construction soigneuse, les murs et planchers à ossature de bois peuvent donner une performance in situ très proche des résultats d'essais en laboratoire. Ces essais ont cependant démontré que des erreurs commises par des entrepreneurs et des détails de construction qui ne conviennent pas neutralisent tout avantage qu'aurait pu apporter une construction bien exécutée.

- Le gauchissement du bois peut faire en sorte que des poteaux ou solives se touchent, des deux côtés d'assemblages de poteaux de bois doubles. Un contreventement est nécessaire pour atténuer le gauchissement. Il est également nécessaire de calfeutrer les joints sur le périmètre du mur, afin de prévenir les fuites que pourrait entraîner les flèches du bois.

- Des profilés souples sont aussi efficaces si la principale voie de transmission du son est l'ossature à laquelle ils sont fixés. Si les vis ne sont pas assez longues pour les profilés souples, il en résultera une réduction de l'ITS ou de l'isolement contre les bruits d'impact. En l'occurrence, des vis mal placées ont diminué de 3 l'ITS d'un plancher durant l'étude.

- La conception et l'exécution des cloisons coupe-feu sont des facteurs critiques; elles devraient assurer le plus faible couplage possible des vibrations. Si la cloison coupe-feu est le prolongement de la surface d'une pièce, elle devrait avoir la fréquence de coïncidence la plus haute, et la masse la plus élevée possible. Deux cloisons coupe-feu d'usage courant réduisent considérablement l'isolation acoustique effective - d'un ITS de 62 à 45 dans un cas.

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BACKGROUND

The net sound insulation between any two rooms is determined by all the sound propagation paths. In multi-family dwellings, the most obvious — and usually the most important — paths are through the walls and floors separating dwellings. However, sound also travels along other paths: flanking paths. Often the transmission along these flanking paths seriously reduces the sound insulation between homes. Flanking may arise due to poor design and/or poor construction. The purpose of this study, funded jointly by the Canada Mortgage and Housing Corporation and the Institute for Research in Construction of the National Research Council Canada, was to commission a flanking transmission measurement facility, and to develop test methods that will allow for the identification of flanking transmission and its measurement. The resulting test methods have been used to investigate flanking transmission caused by specific construction faults.

FACILITY

Figure 1 shows a sketch of the facility that was designed and constructed for the measurement of flanking transmission in wood-framed multi-family constructions.

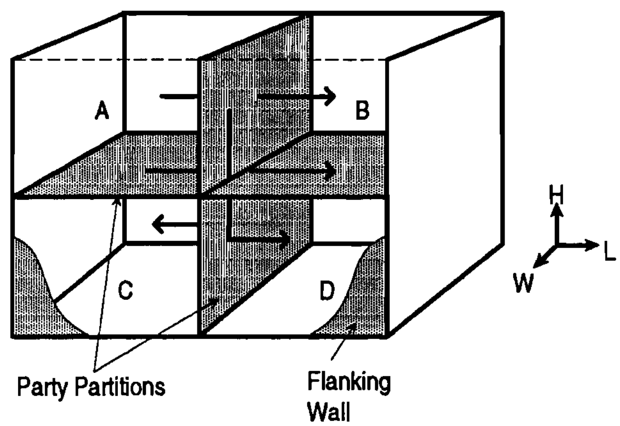


Figure 1: Schematic drawing of the flanking facility showing wall and floor specimens in grey. Some possible flanking paths are shown by arrows.

Room	Volume (m^3)	Length (m)	Width (m)	Height (m)
A	50.7	4.60	4.54	2.43
B	45.3	4.11	4.54	2.43
C	40.0	4.66	4.38	2.07
D	35.3	3.96	4.38	2.07

The permanent part of the facility comprises a floor, a roof, two end walls, and a back wall. All these surfaces are made of heavy materials and are resiliently mounted to stop them from acting as flanking surfaces. There are experimental party floors and party walls that are supported by load bearing walls exterior to the test chamber. There is also an experimental facade covering the front of the specimen. In such a facility, the sound insulation performance of the experimental surfaces can be accurately measured, and specific construction or design faults can be systematically introduced.

MEASUREMENT TECHNIQUES

Five test methods were used to examine the performance of each specimen. Computer programmes and hardware were assembled to control the measurement system, collect the data, and provide basic data analysis for all the tests. The five test methods are briefly discussed:

* Standard Airborne Sound Insulation (ASTM E336): This test method provides airborne sound transmission loss information for the individual third octave frequencies. Using ASTM E413, a single number rating (STC) can be obtained. The E336 test provides a measure of the net airborne sound insulation between two rooms since the test method cannot discriminate between sound transmitted through the separating wall or floor and that transmitted via a flanking path. The National Building Code of Canada (NBCC) and Ontario Building Code (OBC) require a minimum airborne sound insulation of STC 50 for a party wall or party floor.

* Standard Impact Sound Insulation (ASTM E1007): This test provides the impact sound insulation and, with ASTM E989, a single number rating (IIC) for the floor/ceiling assembly. Like the E336 test, the impact test cannot discriminate between sound transmission through the separating floor or via a flanking surface; it gives the net impact sound insulation between two rooms. Currently the NBCC does not have an impact criterion; however, it is generally recognized that one is required.

* Acoustic Intensity: This test method, unlike the previous two, allows for measurement of sound coming from each individual surface in situ. The acoustic intensity is measured over a specific surface, usually in third octaves. From the data it is possible to compare the sound energy radiated from each room surface in situ. For the separating wall or floor, transmission loss data obtained from the intensity technique can be compared directly to

results from the standard airborne test (E336) and can also be reduced to an STC rating. Unfortunately, the intensity method is prone to calibration errors and can produce misleading results unless sound fields meet rigorous criteria. In most cases, this requires that acoustic absorption be added to the receiving room when measurements are conducted.

* Surface Velocity: This test method, like acoustic intensity, enables the examination of a single surface. Using accelerometers, the acceleration of a surface can be measured. From the acceleration, the surface velocity can be easily calculated which is related to the resulting sound pressure level near the radiating surface. However, due to the different radiation characteristics of individual materials, sound insulation descriptors as defined in E336 and E1007 cannot be obtained accurately using this method. Therefore, it is only used as a tool to identify propagation paths.

* Structural Intensity: This test uses two accelerometers separated by a small distance to measure the acoustic power flow in a surface in a specific direction. This method is used only as a tool to identify and locate the sources of flanking transmission; it does not provide any information about the sound insulation offered by a building element.

TEST RESULTS

This report is broken into two parts:

- The main body presents the single-number data from standard test methods (STC from airborne measurements by ASTM E336, and IIC from impact tests by ASTM E1007) for the five construction cases. It also presents and discusses the key conclusions about construction details and the test procedures.
- Discussions of technical issues are presented in appendices. Appendix A presents selected data from the other test methods along with a discussion of their effectiveness for determining the cause of flanking transmission. Appendices B and C are technical papers that have resulted from this research work.

Case I: Base Case

A specimen having party walls and party floors that might be found in a multi-family dwelling was constructed in the facility. The specimen was initially constructed without any deliberate flanking paths (Case I: Base Case — see Figures 2 and 3).

Figure 2: Base Case: Section through the party wall.

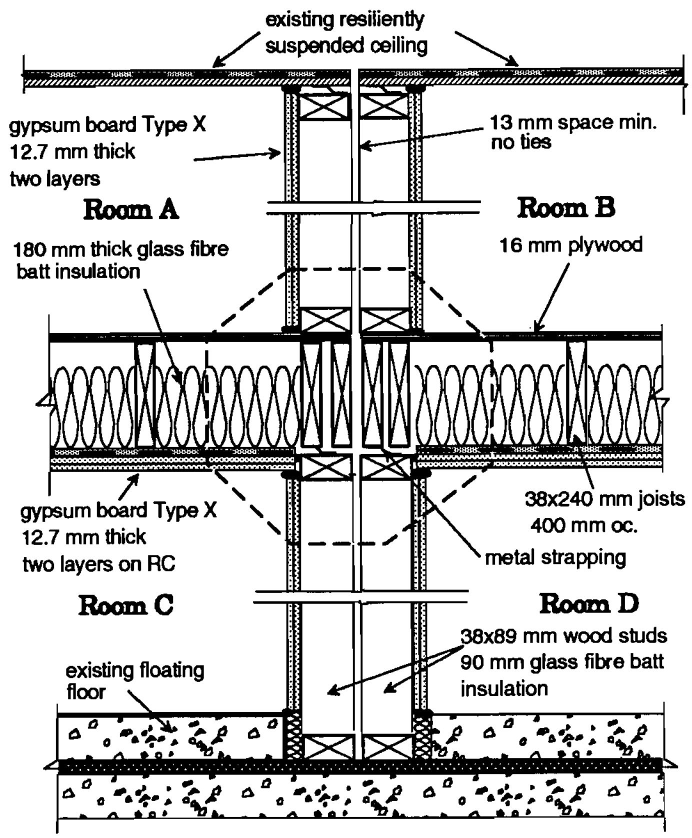
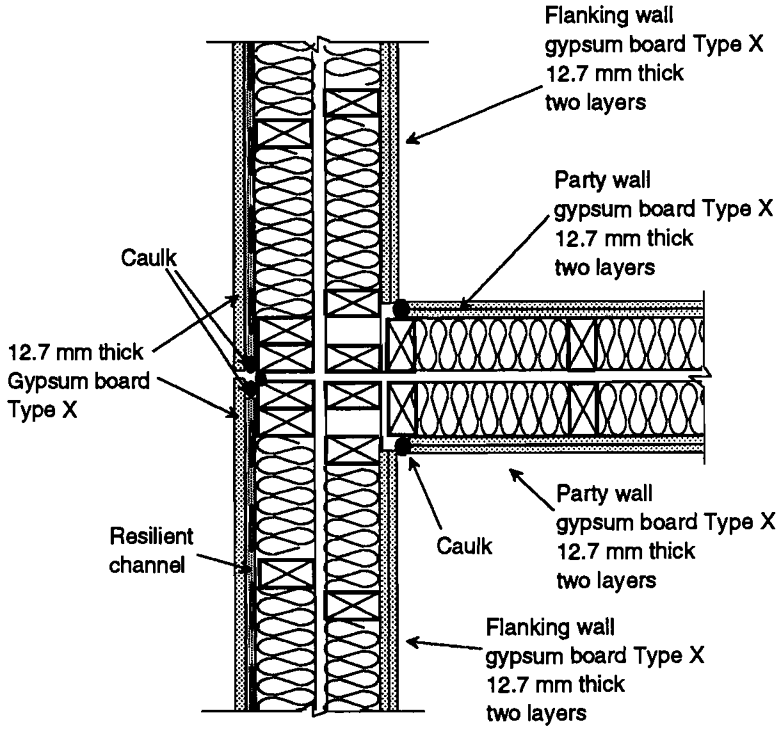


Figure 3: Base Case: Plan view of flanking and party walls.



The airborne sound insulation between the various room pairs was compared to laboratory data (that theoretically do not contain flanking transmission) in order to verify that the facility did not have inherent flanking and that the construction was free of faults. The measured results are shown in Table 1.

Table 1: Airborne sound insulation of the Initial Base Case construction and that expected from a similar construction under laboratory conditions.

Party Partition		Initial Base Case Construction	Similar Specimen in Laboratory Conditions
Wall	AB	62	65
	CD	62	65
Floor	AC	53	52
	BD	48	52

Comparing the airborne sound insulation in the horizontal direction between room pairs AB and CD (i.e., the sound insulation of the party wall in the absence of flanking transmission), it is evident that the sound insulation is lower than that of the laboratory specimen. This indicates that either the facility has some inherent flanking transmission or a construction fault in the specimen has some effect on the horizontal sound insulation. Later inspection of the floor joists that support either side of the upper party wall showed that the joists had warped, causing a physical contact and giving a weak flanking path between the upper two rooms via the floors. This is discussed in Appendix A: Airborne Sound Insulation.

Comparing the airborne sound insulation in the vertical direction, it can be seen that the room pair AC compares favourably with the laboratory data, but the room pair BD does not. The significant difference between room pairs AC and BD indicates that the initial specimen had an unexpected construction fault involving the floor/ceiling assembly of room pair BD.

The contractor had misplaced the screws in the ceiling's second layer of gypsum board of Room D such that the screws hit the joists, thereby "shorting-out" the resilient channels. Table 2 shows the effect on the airborne and impact sound insulation for the party floor/ceiling assembly. With correctly relocated screws, the performance was better but failed to match that of the nominally identical floor/ceiling between Rooms A and C. This may be because the resilient channels were damaged (physically deformed) when they were compressed between the joists and the gypsum board or because of some other (unidentified) minor structural flanking problem.

This specimen then became the 'Base Case' to which future tests involving deliberate faults would be compared. Although its performance was marginally compromised by the identified flanking where the floor joists made contact, this provided a realistic example of flanking for an initial test of measurement techniques.

Table 2: Showing the effect of incorrect installation of resilient channels on the airborne and impact insulation of the floor/ceiling assembly.

Floor/Ceiling Partition	Airborne Sound Insulation (STC)	Impact Sound Insulation (IIC)
Correct construction (rooms AC)	53	47
Screws "shorting-out" resilient channels	48	40
Short removed by repositioning the screws	51	45

Case II: Base Case with Resilient Channel Added to the Party and Flanking Walls

Resilient channels were added to the party and flanking walls of the Base Case specimen, as shown in Figure 4. From the measured airborne and impact sound insulations shown in Figures 5 and 6 it can be seen that for all room pairs, mounting the specimen wall surfaces on resilient channels improved the performance.

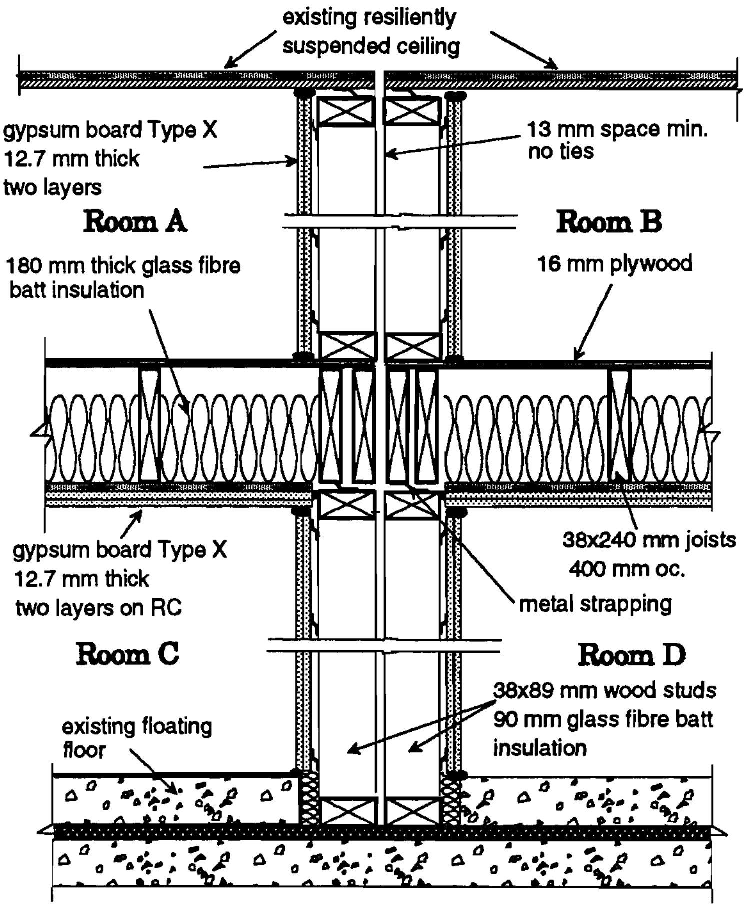
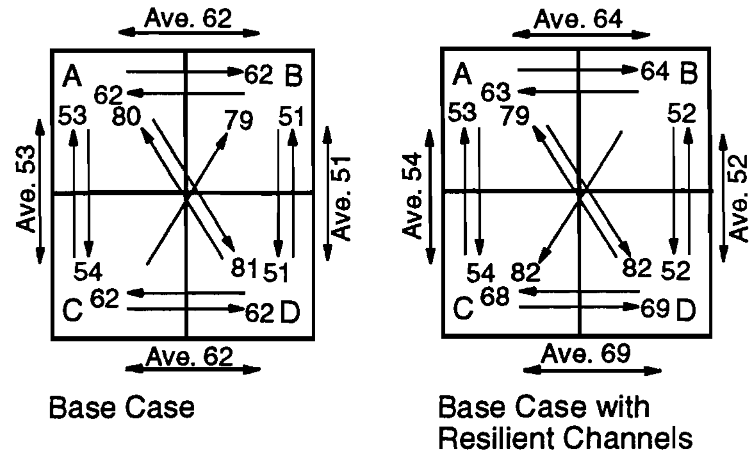


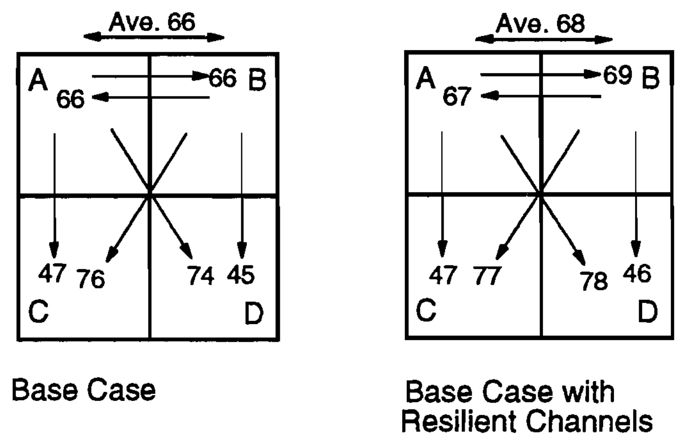
Figure 4: Base Case with resilient channel added to the party and flanking walls: Section through the party wall.

Figure 5: Measured airborne sound insulation (E336) of the Base Case with and without specimen wall surfaces mounted on resilient channels.



Room Pairs	Base Case Measured (STC)	Base Case with RC Measured (STC)	Base Case with RC Change
A↔B Ave.	62	64	+2
C↔D Ave.	62	69	+7
A↔C Ave.	53	54	+1
B↔D Ave.	51	52	+1
A↔D Ave.	80	81	+1
B↔C Ave.	80	82	+2

Figure 6: Measured impact sound insulation (E1007) of the Base Case with and without specimen wall surfaces mounted on resilient channels.



Room Pairs	Base Case Measured (IIC)	Base Case with RC Measured (IIC)	Base Case with RC Change
A→B	66	69	+3
B→A	66	67	+1
A→C	47	47	0
B→D	45	46	+1
A→D	74	78	+4
B→C	76	77	+1

The improvement was large for the lower room pair CD, but was not as great for the other cases. The small improvement in performance between other room pairs may have resulted for three reasons:

1. There is already adequate structural isolation between the source and receiving rooms;
2. The sound insulation is being controlled by airborne flanking due to leaks and cracks around the wall(s);
3. A structural flanking path exists that controls the sound insulation and this path does not involve the wall(s).

Unfortunately, in the case of the room pair AB, the third was true — flanking via the warped floor joists was controlling the sound insulation (see the Appendix A: Airborne Sound Insulation).

Mounting the wall surfaces on resilient channels will only offer a significant improvement in sound insulation when the dominant path of transmission is structural vibration via the wall framing. Under these conditions, resilient channels are likely to be very effective at increasing both the airborne and impact sound insulation (as observed for rooms CD).

The small changes observed for the other room pairs were evidence of flanking transmission by other paths, as discussed in more detail in Appendix A. Although the basic ASTM E90 and E492 tests did not pinpoint the flanking path, they clearly indicated the presence of flanking.

Case III: Base Case with a Fire Stop Under Party Wall

In multi-family dwellings, fire stops are required at various locations in the construction (e.g., at the base of the party wall) to slow the spread of fire to adjacent dwellings. According to the NBCC, one of the many ways to obtain an acceptable fire stop is to continue the plywood floor decking (having thickness greater than 13 mm) under the party wall, as shown in Figure 7.

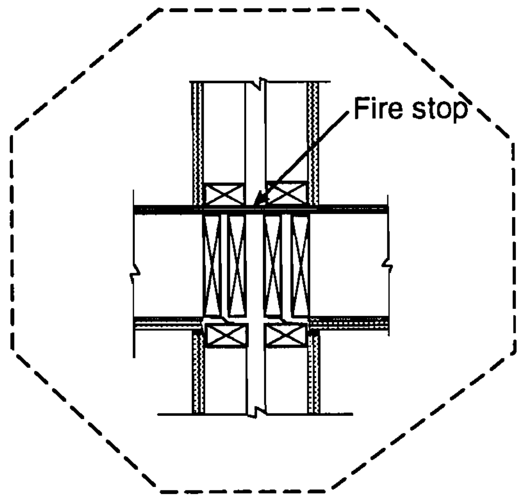
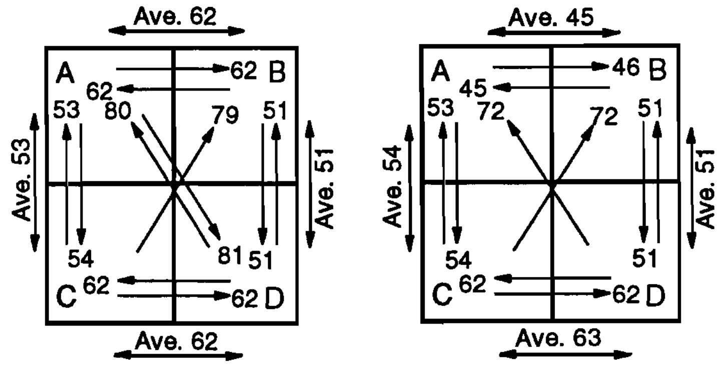


Figure 7: Base Case with a fire stop under the party wall. Section through party wall. Also refer to Figure 2.

For fire stops to be effective, they must bridge the air spaces between two adjacent dwellings. Unless the fire stop material is compressible and flexible, it will create an efficient path by which vibratory energy can travel from one dwelling to the other. The effects of such a flanking path on the airborne and impact insulations are shown in Figures 8 and 9, respectively.

Figure 8: Measured airborne sound insulation (E336) for Base Case with and without the fire stop under the party wall.



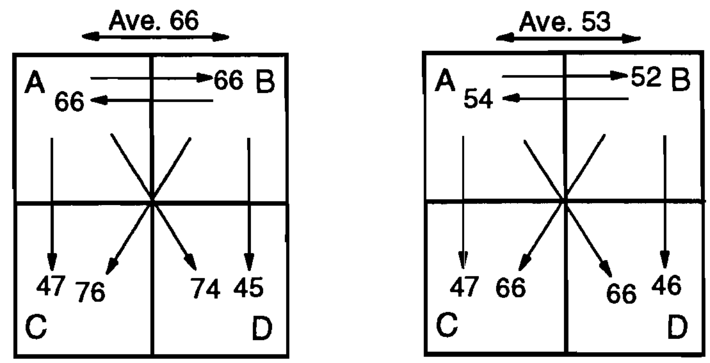
Base Case

Base Case with Fire Stop Under Party Wall

Room Pairs	Base Case	Base Case with Fire Stop Under Party Wall	
	Measured (STC)	Measured (STC)	Change
A↔B Ave.	62	45	-17
C↔D Ave.	62	63	+1
A↔C Ave.	53	54	+1
B↔D Ave.	51	51	0
A↔D Ave.	80	72	-8
B↔C Ave.	80	72	-8

This required building safety element has considerably reduced the sound insulation performance of the specimen. Without the fault, the sound insulation between rooms A and B might be described as outstanding (STC 62 as measured by the E336 test). However, with the fire stop (floor decking continued under the party wall), the sound insulation was reduced to sub-standard performance (STC 45 as measured by the E336 test). With the fire stop, the party wall assembly separating rooms A and B does not meet the NBCC criterion of STC 50.

Figure 9: Measured impact sound insulation (E1007) for the Base Case with and without the fire stop under the party wall.



Base Case

Base Case with Fire Stop Under Party Wall

	Base Case	Base Case with Fire Stop Under Party Wall	
Room Pairs	Measured (IIC)	Measured (IIC)	Change
A→B	66	52	-14
B→A	66	54	-12
A→C	47	47	0
B→D	45	46	+1
A→D	74	66	-8
B→C	76	66	-10

The impact insulation between rooms sharing a common floor/ceiling partition remains virtually unchanged. However, there is greatly reduced impact insulation between the two upper rooms. Normally, impact insulation is not measured in the horizontal direction, but with this type of strong physical coupling impact noises might be audible between the upper two rooms.

Case IV: Fire Stop Under Party Wall and Floating Floor in Room B

A simple floating floor was installed in Room B (one of the rooms sharing the floor decking) to investigate the effectiveness of a retrofit rather than fixing the problem at source. Figure 10 shows the construction used.

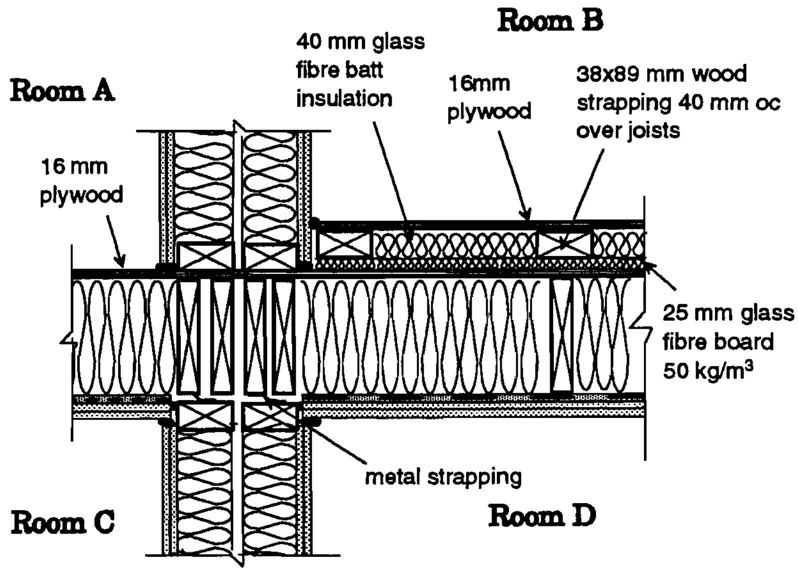


Figure 10: Fire stop under the party wall and floating floor. Section through the floor of Room B.

Figures 11 and 12 show the measured airborne and impact performance, respectively.

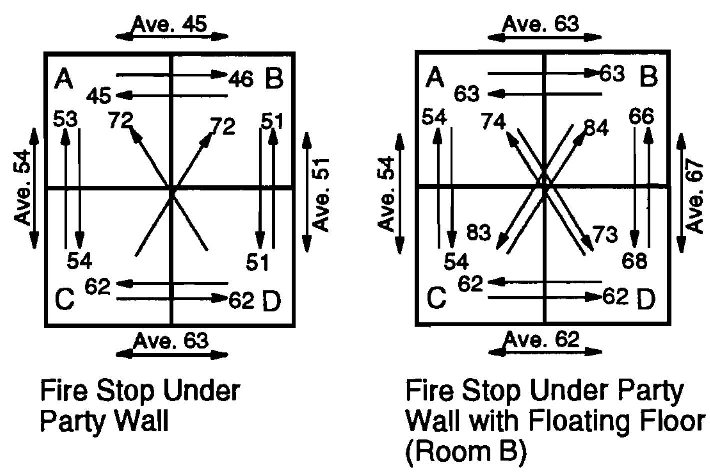
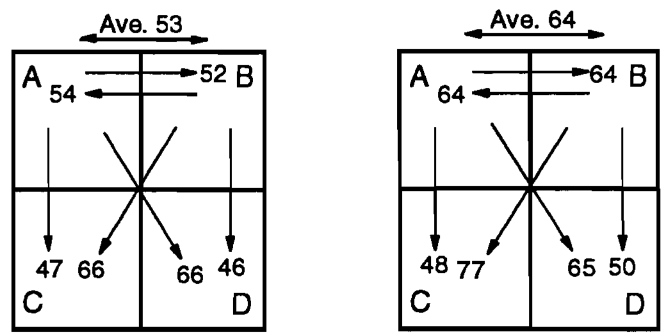


Figure 11: Comparison of the measured airborne sound insulation (E336) for the fire stop under the party wall with and without the floating floor. Base Case data are listed in the Table, and shown in more detail in Fig. 5.

Room Pairs	Base Case	Base Case with Fire Stop Under Party Wall		Fire Stop with Floating Floor Room B	
	Measured	Measured	Change	Measured	Change
A↔B	62	45	-17	63	+1
C↔D	62	63	+1	62	0
A↔C	53	54	+1	54	+1
B↔D	51	51	0	67	+16
A↔D	80	72	-8	74	-6
B↔C	80	72	-8	84	+4

From Figure 11 it is evident that in all but one set of the room pairs (A↔D) the airborne insulation was better than the Base Case (i.e., without the fire stop). This is especially true for the room pair BD where the airborne insulation increased by 16 points. The diagonal room pair AD which did not have the benefit of the floating floor received only a very marginal improvement.

Figure 12: Comparison of the measured impact sound insulation (E1007) for the fire stop under the party wall with and without the floating floor. Base Case data are listed in the Table, and shown in more detail in Fig. 6.



Fire Stop Under Party Wall

Fire Stop Under Party Wall with Floating Floor (Room B)

Room Pairs	Base Case	Base Case with Fire Stop Under Party Wall		Fire Stop with Floating Floor Room B	
	Measured	Measured	Change	Measured	Change
A→B	66	52	-14	64	-2
B→A	66	54	-12	64	-2
A→C	47	47	0	48	+1
B→D	45	46	+1	50	+5
A→D	74	66	-8	65	-9
B→C	76	66	-10	77	+1

Figure 12 shows that the floating floor also significantly increased the impact insulation performance especially of the floor/ceiling assembly separating rooms B and D.

For this specimen construction, it could be argued that adding a floating floor is a better solution than trying to improve the acoustic performance of the fire stop since the airborne sound insulation was, for all cases except one, better than the Base Case which did not have a fire stop. The reduced sound insulation caused by fire stops is an important issue since every multi-family dwelling must have them. Further research is required to develop fire stop details and verify that they will produce adequate acoustical and fire performance as intended by the National Building Code of Canada.

Case V: Base Case with a Fire Stop at the Flanking Wall

A fire stop that ran across the end of the party wall in the upper room was added to the Base Case. A plan view of the fire stop installed between rooms A and B is shown in Figure 13.

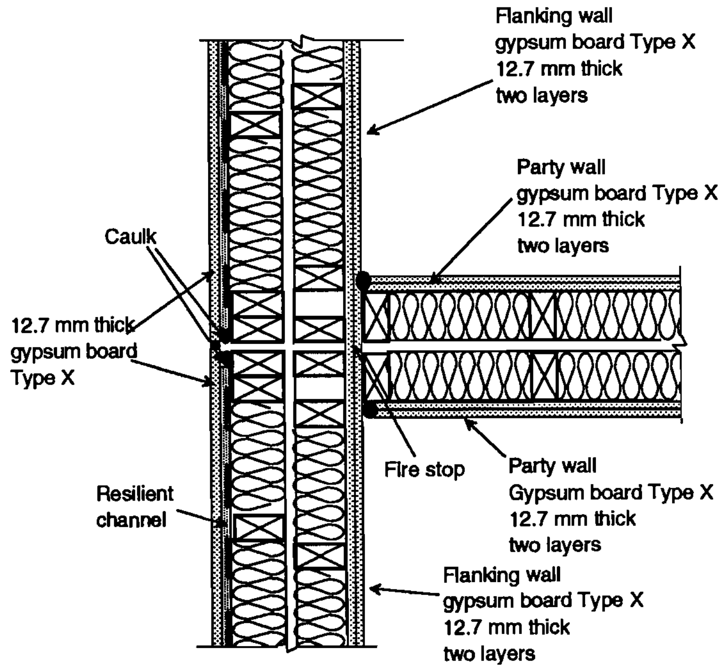
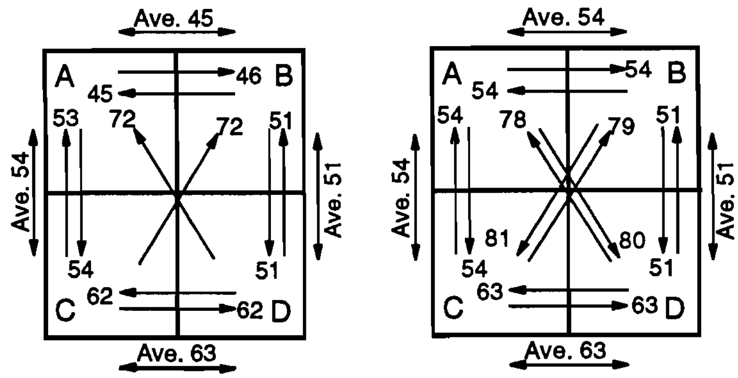


Figure 13. Base Case with a fire stop at the flanking wall: Plan view of the flanking and party walls.

Note that the lower rooms were left unchanged to provide a comparison of the sound insulation performance between room pairs with and without the fire stop. In this case, the material offering the fire resistance is the double layer of gypsum board. The head and base plate of the flanking wall were not continued across the party partition. Figures 14 and 15 show the measured performance for this case.

Figure 14: Measured airborne sound insulation (E336) for the fire stop across the end of the party wall is compared with results with the plywood floor fire stop across the party wall. The Base Case is listed in the Table, and shown in more detail in Fig. 5.

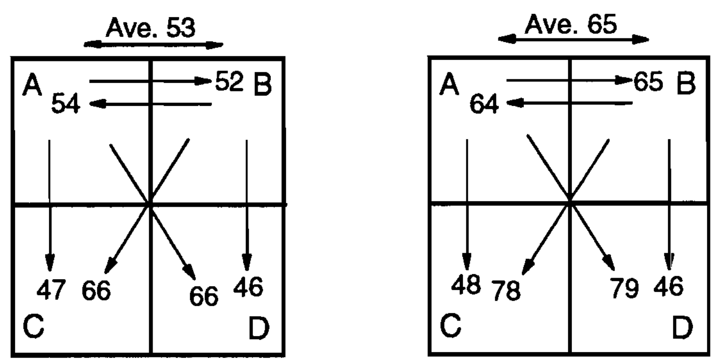


Fire Stop Under Party Wall

Fire Stop Across Party Wall End

Room Pairs	Base Case	Fire Stop Under Party Wall		Fire Stop Across the End of the Party Wall	
	Measured	Measured	Change	Measured	Change
A↔B	62	45	-17	54	-8
C↔D	62	63	+1	63	+1
A↔C	53	54	+1	54	+1
B↔D	51	51	0	51	0
A↔D	80	72	-8	79	-1
B↔C	80	72	-8	80	0

Figure 15: Measured impact sound insulation (E1007) for the fire stop across the end of the party wall is compared with results with the plywood floor fire stop across the party wall. The Base Case is listed in the Table, and shown in more detail in Fig. 6.



Fire Stop Under Party Wall

Fire Stop Across Party Wall End

Room Pairs	Base Case	Fire Stop Under Party Wall		Fire Stop Across the End of the Party Wall	
	Measured	Measured	Change	Measured	Change
A→B	66	52	-14	65	-1
B→A	66	54	-12	64	-2
A→C	47	47	0	48	+1
B→D	45	46	+1	46	+1
A→D	74	66	-8	79	+5
B→C	76	66	-10	78	+3

From the tables it is evident that this form of fire stop significantly degrades the airborne sound insulation between the upper rooms (A and B). The airborne sound insulation was reduced from superior performance (STC 62) to moderate performance (STC 54) — a reduction of 8 STC points. The airborne sound insulation between other room pairs was virtually unaffected.

With the exception of the room pairs along the diagonal, the impact sound insulation is nearly the same as for the Base Case. This indicates that, for all room pairs except those on the diagonal, the degree of mechanical coupling involving the floor was virtually unchanged. The increase in the impact sound insulation for the diagonals is due to the removal of an unintentional construction fault involving the floor joists of rooms A and B (the joists at the party line that are nominally separated by a 25 mm air gap warped causing a physical bridge between the two rooms; see Appendix A: Airborne Sound Insulation).

DISCUSSION OF FIRE STOPS

The effect on the airborne sound insulation by the fire stops in the type of walls considered here has been significant. The fire stops considered here — which are not typical of all fire stops — were formed by the continuation of a room surface under the party wall (in the case of the floor decking) or across the party wall (in the case of the gypsum board). This continued surface common to both rooms does not have any physical breaks. It provides an effective path for vibration propagation from one room to the other.

Figure 16: Comparison of the effect on airborne sound insulation (E336) due to plywood and gypsum board fire stops.

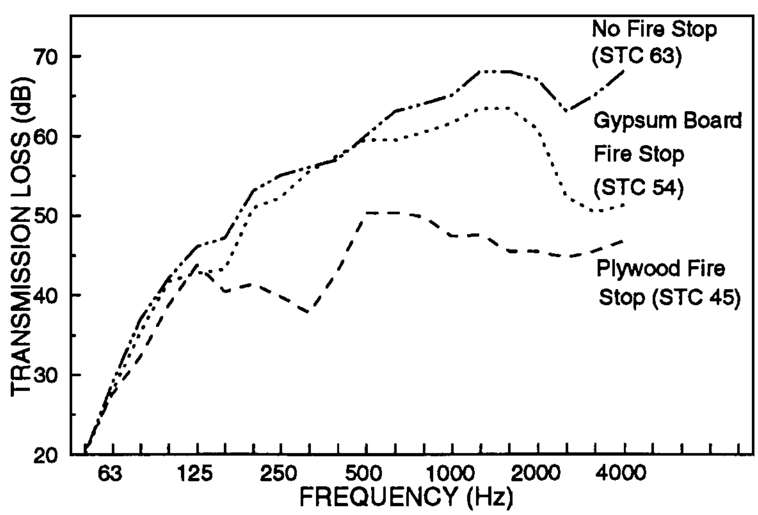


Figure 16 shows the effect on the measured sound transmission loss between rooms A and B for two fire stops made from a room surface continued across the party wall. From the figure it can be seen that continuing the gypsum board across the end of the party wall (i.e., gypsum board fire stop) gives greatly reduced sound insulation when compared to the Base Case (without fire stop). The reduced sound insulation starts at about 500 Hz and increases with frequency. Between about 2000 and 2500 Hz, the insulation is degraded more rapidly due to the onset of the coincidence dip.

The sound insulation of the party wall that had the plywood floor decking continued under it (i.e., plywood fire stop) exhibited greatly reduced insulation for all frequencies greater than 125 Hz when compared to either the gypsum board fire stop or the Base Case.

There are likely to be three important factors affecting the sound insulation between the two rooms sharing the common room surface acting as a fire stop. They are:

- Ability of the surface to accept airborne acoustic energy in the source room and convert it to vibration energy (i.e., bending waves);
- Effectiveness of the continued surface (i.e., fire stop) for transmitting vibration energy;
- Ability of the receiving room surface to convert the vibration energy into airborne acoustic energy.

The reduction in sound insulation caused by continuing the gypsum board surface across the party wall (with the gypsum board fire stop) is considerably less than continuing the plywood floor decking across the party wall (with the plywood fire stop). It suggests that one or more of the factors are significantly different for the two cases. However, in both cases the continued surfaces are likely to provide an effective path for the flow of vibration energy because there are no physical breaks. If the continued surface in each case allows vibration energy to propagate with similar efficiency, then the difference in sound insulation performance must be due to their relative ability to accept and radiate acoustic energy.

The efficiency with which each room surface can accept or radiate acoustic energy is determined by the material's stiffness which determines its coincidence frequency. In the frequency range above this, the surface is able to accept acoustic energy very efficiently from the air of the source room and convert it into bending waves that can travel in the surface to the receiving room.

When a fire stop is formed by the continuation of a room's surface across the party wall, the source room surface is an efficient acceptor of energy in exactly the same frequency range where the contiguous receiving room surface is an efficient radiator. Thus, a continuous common surface made from a material having a critical frequency that occurs near the middle of the frequency range for building acoustics (e.g., 16 mm plywood with f_c ~1000 Hz) will have a more significant impact on the sound insulation than would one constructed from a material that has a critical frequency near the high end of the range (e.g., double layer of 13 mm gypsum board with f_c ~2500 Hz). The higher mass of the double gypsum board surface is also important, and increases its sound transmission loss relative to the plywood.

The two fire stops considered here, both formed by the continuation of a room surface across the party wall, have significantly degraded the net sound insulation. In both cases the sound insulation of the nominal partition no longer was the dominant factor controlling the sound insulation — it was flanking via the continued surface that formed the fire stop. In such cases, efforts to provide increased sound insulation by adding materials to the party wall (i.e., additional layers of gypsum board and/or cavity absorption, resilient channels, etc.) would give little or no improvement to the net sound insulation.

Selection of the correct material and suitable construction details for this type of fire stop are therefore critical to the acoustic and fire separation between multi-family dwellings.

CONCLUSIONS Re: Building Practice

The findings of this study are briefly summarized below:

1. Given correct design and construction, partitions in wood-framed constructions can exhibit sound insulation similar to that obtained in a laboratory. However, to achieve this requires knowledgeable tradesmen, constant quality control, and engineered joint details.
2. "Shorting" of resilient channels (by having the gypsum board screws anchored to the studs/joists) can significantly reduce the partition performance — 3 STC degradation was experienced in the case examined.
3. Physical contact between floor joists on either side of a double stud party wall must be prevented. The joist(s) under each side of the party wall should be strapped to the nearest joist on the same side of the party wall.
4. Straight and dry lumber should be used so that the gypsum board wall surfaces will form an air-tight joint to both the top and bottom plates as well as the studs. Caulking around the perimeter of the framing is strongly recommended to help attain the rated acoustic performance.
5. Choosing a fire stop that meets both the fire and acoustical requirements is critical. The study has shown that a fire stop given in the NBCC can degrade the airborne sound insulation of a party wall from STC 62 to STC 45 — a reduction of 17 points. Thus, it is possible to degrade the performance of a superior partition to the point where it fails to meet the NBCC requirement of STC 50.

   The data in this report suggest that fire stops should not be formed by the continuation of a room's surface across a party wall. A comprehensive study is required to determine the details and the materials that should be used in fire stops. However, preliminary analysis suggests that the following are desirable acoustical characteristics for fire stops:

   Weakest possible physical coupling between the rooms sharing a fire stop (e.g., 0.38 mm steel with a cusp appears preferable to continuous floor decking);

   If the fire stop is to be formed by the continuation of a room's surface then the surface material should have as high a mass as possible and a coincidence dip that occurs at as high a frequency as possible (e.g., double layer of gypsum board is probably preferable to plywood).

Re: Test Methods

1. The Standard Sound Insulation Test Methods (Airborne; ASTM E336, Impact; ASTM E1007) provide a measure of the net sound insulation between two rooms as they do not discriminate between the radiating surfaces or transmission paths. However, results from the standard tests can be compared to tests of a similar specimen made under laboratory conditions to reveal the presence of a construction fault. Neither method alone can identify the propagation path or the type of fault until individual room surfaces are masked-off in turn. To obtain accurate results this can be very tedious and time consuming and may not be practical in many field applications. The test methods are well known by consultants and require only very basic equipment.

2. Sound intensity methods provide a way of determining the radiated sound energy from individual room surfaces. Room surfaces can be ranked in terms of their radiated energy to identify flanking faults. For party walls and floor/ceilings the transmission losses can be determined and expressed as a single number rating (STC). This allows for the measured field performance to be compared to field E336 test data or to laboratory data, providing another way of identifying faults in individual partitions. This very powerful method has some very significant drawbacks:

    - It requires very expensive equipment (two channel analyzer with an intensity probe and a specialized calibration device);
    - Very accurate calibrations are required to achieve accurate results;
    - The measurement room must not be too reverberant and should not have other noise sources in it;
    - There is a great potential for measurement error and thus a highly skilled operator is required who has considerable experience with intensity techniques.

    Sound intensity measurement procedures have not been adequately defined and standardized, especially for field applications. However, in the future it is likely to be the measurement tool of choice.

3. Surface velocity measurements cannot be used to provide the standard measures of sound insulation (IIC or STC). However, they can be used to investigate relative levels of vibratory energy either over a single room surface or over several. Abrupt changes or constant increases in vibratory levels can indicate both the presence and location of flanking paths. This technique requires only minimal equipment (sound level meter and an accelerometer) which is relatively inexpensive compared to intensity gear. It is very simple and relatively immune to operator error. Calibration is not an issue since the technique only requires the relative levels between the points on the measurement surface. It is therefore ideal as a simple diagnostic tool.
4. Structural intensity is a very powerful tool for determining flanking paths. The method is currently only used under laboratory conditions as its limitations have not been well quantified. The build-up of reverberant energy in the measurement surface, which was a serious problem when measuring heavy monolithic constructions (such as masonry and concrete), does not seem to be as important for the light weight constructions investigated here. The technique requires expensive equipment (two channel analyzer, a pair of phase matched accelerometers, and a special calibrator). Moreover, it requires a very knowledgeable person who is familiar with the technique's limitations. Currently, except for a very few experts in the research community, this method is impractical. More research is required to enable general use, but when this happens it will most likely be the tool of choice for practitioners to identify flanking paths.

MORE DETAILED DISCUSSION OF MEASUREMENTS

Five test methods were investigated as potential tools for determining the source and cause of flanking transmission. Selected measured data from the five test methods are presented in graphic form to illustrate their effectiveness as detection methods.

Airborne Sound Insulation:

Figure A1 shows the transmission loss performance as measured using ASTM E336 for the room pairs CD and AB for Case I (Base Case) and Case II (Base Case with resilient channels).

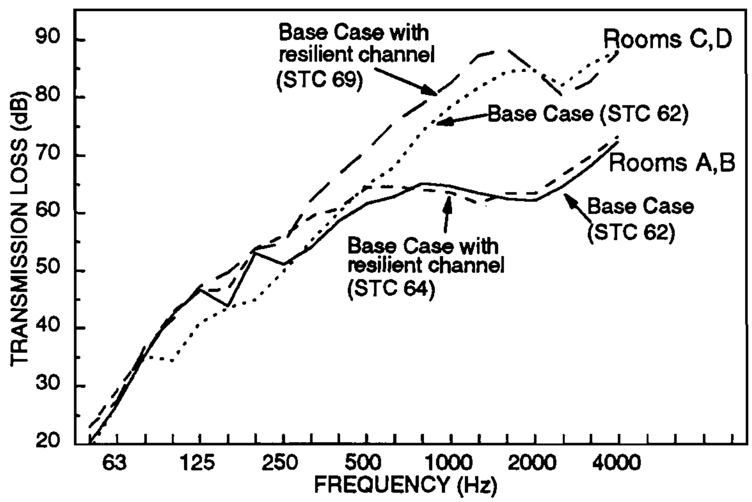


Figure A1: Measured transmission loss (E336) for room pairs AB and CD, Base Case with and without resilient channels (RC).

From the figure it is evident that adding the resilient channels caused a greater increase in sound insulation between the lower two rooms (C and D) than between the upper two rooms (A and B). Since both walls are of nominally identical construction, the improvement should be identical for the upper and lower rooms (provided that there are no flanking paths). Later inspection revealed that the 39x240 mm joists on either side of the upper double stud party wall had warped such that the bottom of the joists (which were not adequately strapped) bridged the 25 mm air gap. This strong physical connection between the upper two rooms created a flanking path that caused the floor to be the dominant radiator when compared to the very little energy transmitted by the superior party wall. Consequently, increasing the performance of the wall, by adding the resilient channels, had little effect on the net sound insulation.

The E336 tests do not immediately provide information about the cause of the fault as individual surfaces can not be examined. It is only when individual surfaces are masked-off (e.g., covered by a layer of 90 mm thick fiberglass and a layer of gypsum board) and the E336 test repeated with each surface covered in turn, that it becomes possible to identify the predominant radiating surface. However, examination of the transmission loss spectrum may provide some clues as to the presence and cause of flanking. For example, the coincidence dip for the wall separating room pair AB is not in the 2500/3150 Hz third octave bands (typical of 13 mm gypsum board), but occurs at a much lower frequency (about 1000 Hz) and has a broad plateau (typical of plywood).

Acoustic Intensity:

Figure A2 shows the measured airborne sound transmission loss between rooms A and B for Case III: Fire stop under the party wall.

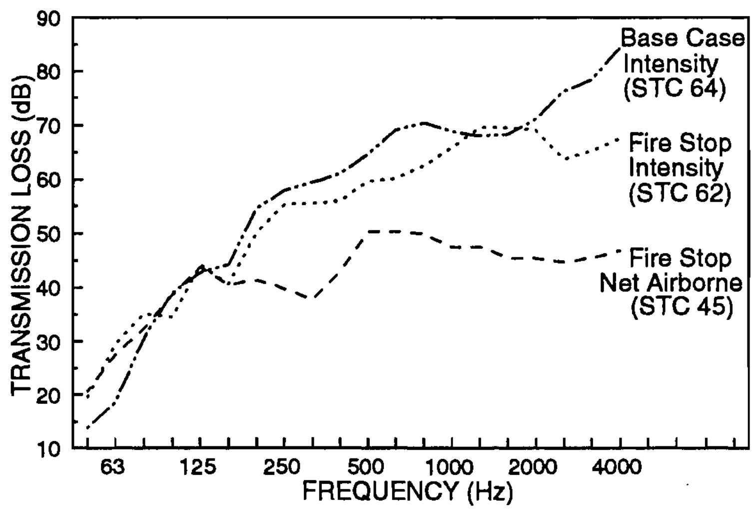


Figure A2: Measured party wall transmission loss between room pair AB with and without the fire stop under the party wall. Transmission loss data from intensity method are for the party wall only.

From the figure, it can be seen that the fire stop slightly altered the transmission loss of the party wall as shown by the change in the transmitted acoustic intensity. In terms of a single number rating, the sound insulation dropped from STC 64 to STC 62. Comparing the net transmission loss with the fire stop (E336 test, STC 45) to the transmission loss of the party wall with the fire stop (intensity method, STC 62), it is evident that above 160 Hz the party wall is transmitting only a small part of the sound energy. These observations allow us to make two statements. First, the intensity method allows us to measure the sound radiated from each individual surface in situ, and to determine sound transmission loss for the separating wall or floor itself, nominally ignoring sound radiated from the other surfaces. Second, the measured data strongly suggest that there is at least one very significant flanking path between rooms A and B and that the party wall is connected to the flanking path. It should be noted that difficulties can be encountered when measuring the intensity of a surface that is connected at right angles to a much more energetically radiating surface. In such a case, measuring near the common edge, it can become difficult to correctly identify the intensities of the two individual surfaces. Under such conditions, masking of adjacent radiating surfaces is recommended. (Appendix C discusses this in more detail.)

To get accurate results with this technique requires a very accurate calibration of the phase-matched microphones (using very expensive equipment) before and after each measurement. Quality control indicators as defined in the various sound intensity standards must be computed and continuously monitored throughout the measurement to ensure that the measured data are valid. Unfortunately, most intensity analyzers cannot provide this information directly. The user must write or obtain software to perform the calculations. Poor judgment by the user can lead to very large errors in the calculated transmission loss results. The technique should only be used by an experienced person.

Impact Sound Insulation:

This test method provides the specimen's net impact sound insulation and, with ASTM E989, a single number rating, IIC. Previously it was shown in Figure 9 that the fire stop under the party wall transmits floor impact energy horizontally under the party wall to the adjacent room. Since the IIC was 52 in rooms A to B and 54 in rooms B to A, it strongly suggests reciprocity of impact energy flow. This leads us to assume that the floors of both rooms A and B are involved in the flanking path. A general impact test method for measuring receiving room sound pressure levels, in response to impact excitation of any source room surface or sub-surface, has great potential in determining flanking paths. Alone, the E1007 test does not reveal the cause of the flanking transmission and it would, of course, completely fail to detect a flanking path that did not involve a floor surface (e.g., Case V).

Acceleration/Velocity:

Figure A3 shows a surface velocity contour plot of the floor in Room B (source Room A) with the fire stop under the party wall (Case III).

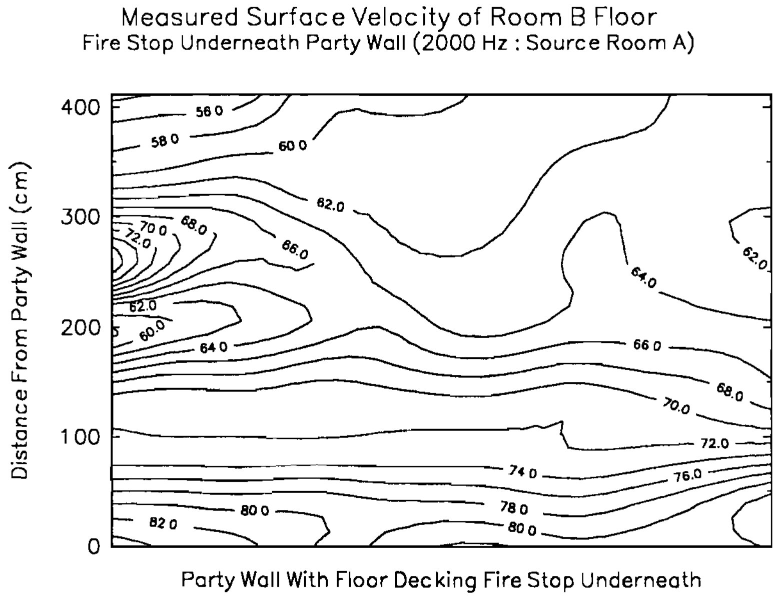


Figure A3: Surface velocity contour plot of Room B floor (source room A) with the fire stop under the party wall. Data expressed in dB RE: $1x10^{-9}$ m / s.

From the results, it is clear that the surface velocity of the receiving room floor rapidly increases as the observation point approaches the party wall. This strongly suggests that the floor is being driven by a point or points near the party wall. Since the vibration levels are relatively constant along the width of the floor, it also suggests that the floor is being driven by many points along the edge or even completely along the edge. By examining the change in vibratory energy with position, this method can suggest possible propagation paths, but does not allow for the determination of the sound insulation.

This method is ideal for field testing, as it does not require expensive equipment and in most cases should not require calibration because only the relative levels are important.

Structural Intensity:

Figure A4 shows the measured structural intensity vectors for Case IV: Fire stop under party wall with floating floor in Room B.

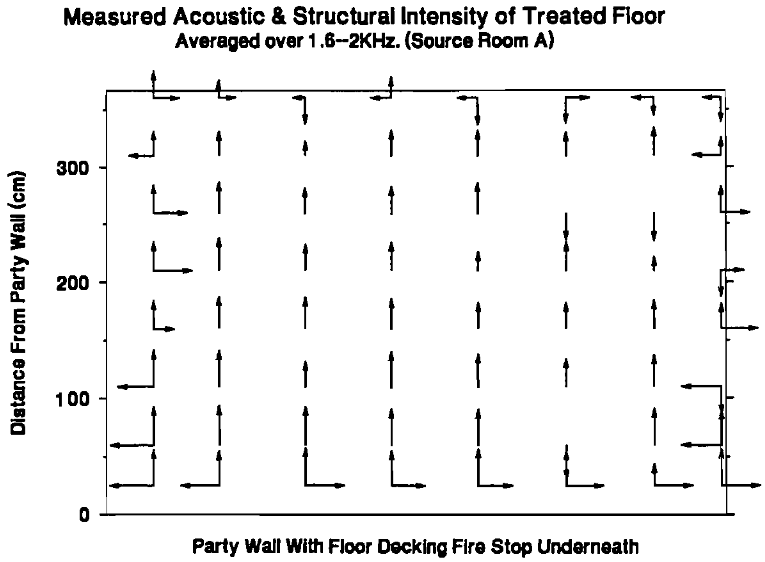


Figure A4: Measured structural intensity plot of the floating floor in room B (source room A) with the fire stop under the party wall.

The direction and the magnitude of the plotted vectors indicate the magnitude and direction of energy propagation in the floor. (Please note that data for both orthogonal directions was only measured for points around the perimeter. For the other points, energy flow was only measured in the direction parallel to the flanking wall.) From the figure, it is clear that the energy is propagating from the party wall to the rear of the room and that the amount of energy entering the floating floor is reasonably constant across the width of the room. This strongly suggests that the vibratory energy in the floating floor is entering along a line close to the party wall. This interpretation is consistent since the floating floor is driven by the 'sub-floor' below which was shown in Figure A3 to be most energetic near the party wall. Structural intensity is perhaps the most powerful tool for determining the cause(s) of flanking transmission. However, structural intensity does not provide complete information about the sound insulation performance of a surface but only how much energy it is transporting and in which direction.

This method is truly in its infancy. There is not even a draft standard telling of how to conduct the measurement or what its limitations are. Thus, issues such as calibration, quality control indicators, and when to apply the method must be addressed by the user based on his knowledge of the most recent advances in this field. It is likely to be unsuitable for practitioners to use until it becomes standardized.

METHODS FOR MEASURING AND IDENTIFYING FLANKING TRANSMISSION IN WOOD-FRAMED CONSTRUCTION

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INTRODUCTION

The net sound insulation between any two rooms is determined by all the sound propagation paths, which include flanking paths. In constructions having poor design or construction techniques, flanking paths can control the net sound insulation. In the first stage of IRC's programme to study the effects of flanking transmission that was jointly funded by Canada Mortgage and Housing Corporation, a new facility was constructed and various test methods were examined as diagnostic tools. To illustrate the effectiveness of the test methods, measured data are presented for two specimens, one with a potentially common fault and the other without. The results of the test methods and the change in sound insulation are discussed.

CONSTRUCTIONS

The double wood-stud specimens examined are common in multi-family row-housing. The first specimen was constructed without any deliberate flanking paths (base condition - see Figure 1). Then the potentially common construction fault was introduced. The plywood floor decking of the upper rooms was continued across the party line (see Figure 2).

MEASUREMENT TECHNIQUES AND TEST RESULTS

Standard Airborne Sound Insulation (ASTM E336): This test method provides the specimen's net field airborne sound transmission loss, FTL and, with ASTM E413, a single number rating, FSTC. The ASTM E336 test, whilst not identical to ISO 140-4, has the same intent. Comparing results shown in Figure 3, it is evident that the construction fault significantly degrades the sound insulation between rooms A and B (FSTC 62 without the fault, FSTC 45 with the fault). The E336 test method allows for the detection of significant flanking if the test results can be compared to laboratory data or similar specimen with a fault. However, it does not provide information about the cause or path of flanking propagation as individual surfaces cannot be examined. It is only when individual room surfaces are masked-off (covered by, say, a layer of 90 mm thick fiberglass insulation and a layer of gypsum board) and the E336 test repeated with each surface covered in turn that it becomes possible to identify the predominant radiating surface. It should be noted that unless one surface drastically dominates the radiated energy, measurement precision is likely to mask the rather small variation in results. If conducted properly, this masking method requires a significant amount of work. For these reasons the masking method is not recommended unless the E336 test is the only method available.

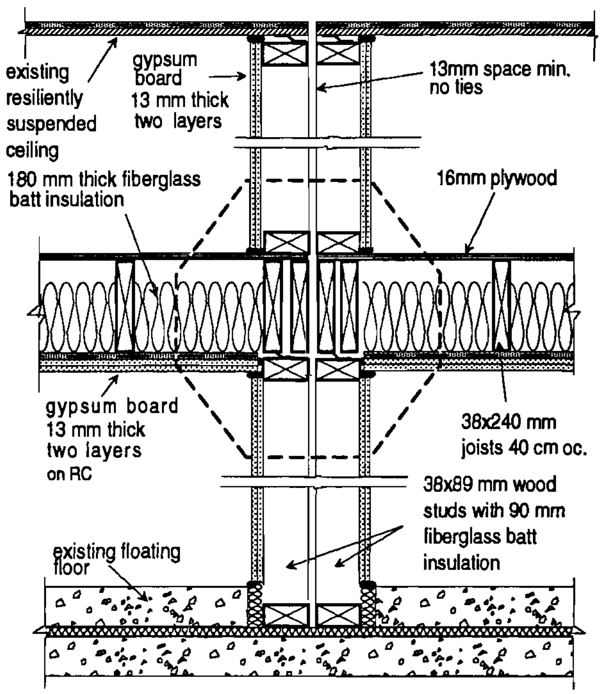


Figure 1: Section of base condition specimen at the party wall.

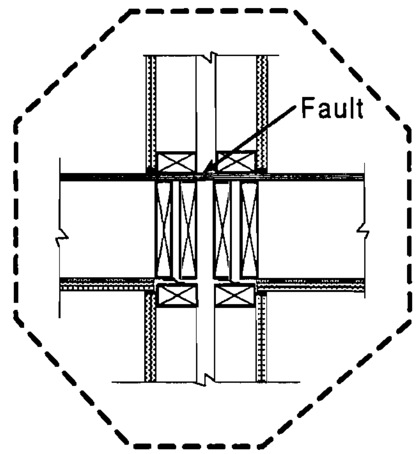
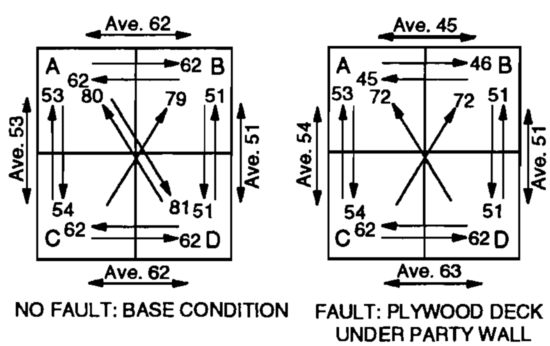


Figure 2: Section showing construction fault, floor decking continued under party wall.



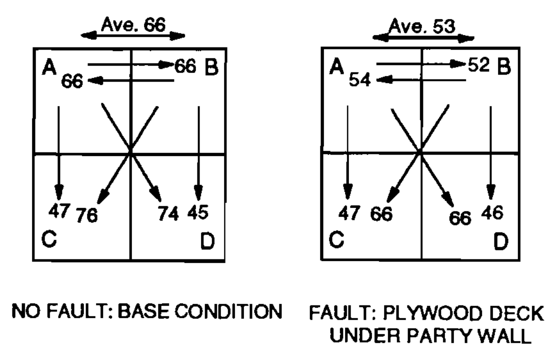


Figure 3: Measured airborne sound insulation class (FSTC: E336 test) between rooms A, B, C and D with and without the plywood decking continued under the party wall.

Figure 4: Measured impact insulation class (FIIC: E1007 test) between rooms A, B, C and D with and without the plywood decking continued under the party wall.

Standard Impact Sound Insulation (ASTM E1007): This test method provides the specimen's net field impact sound insulation and, with ASTM E989, a single number rating, FIIC. From Figure 4, it appears that the construction fault transmits floor impact energy horizontally under the party wall to the adjacent room. Since the FIIC for the specimen with the fault was 52 in room A to B and 54 in room B to A, it strongly suggests reciprocity of impact energy flow. This leads us to assume that the floors of both rooms A and B are involved in the flanking path. A general impact test method for measuring receiving room sound pressure levels in response to impact excitation of any source room surface or sub-surface has great potential in determining flanking paths. Wall impact insulation with a view to subjective annoyance has been investigated, [Boles and Gold, Applied Acoustics, Vol. 21, 1987, pp. 53-74], but was not extended as a method for determining flanking paths. This will be examined in the next phase of our flanking transmission study.

Acoustic Intensity: Figure 5 shows the measured airborne field sound transmission loss between rooms A and B. From the figure, it can be seen that the fault slightly altered the transmission loss of the party wall as derived from the transmitted acoustic intensity. In terms of a single number rating, the sound insulation dropped from FSTC 64 to FSTC 62. Comparing the net FTL with the fault (E336 test, FSTC 45) to the FTL of the party wall with the fault (intensity method, FSTC 62), it is evident that above 160 Hz, the party wall is transmitting only a small part of the sound energy. These observations allow us to make two statements. First, the intensity method allows us to measure the TL of an individual surface in situ. Second, the measured data strongly suggest that there is at least one very significant flanking path between rooms A and B and that the party wall is probably connected to the flanking path. It should be noted that difficulties can be encountered when measuring the intensity of a surface that is connected at right angles to a much more energetically radiating surface. In such a case, measuring near the common edge, it can become difficult to correctly identify the intensities of the two individual surfaces.

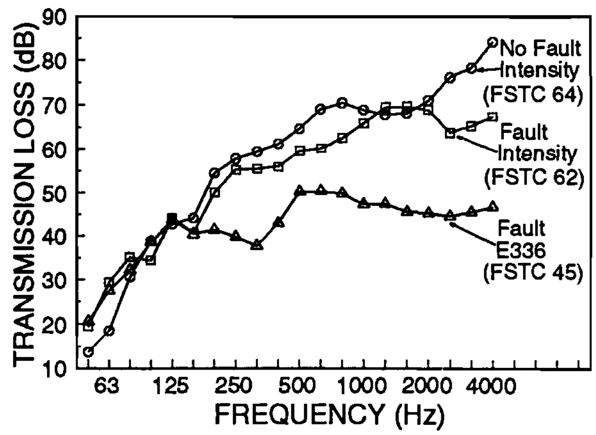


Figure 5: Measured airborne field sound transmission loss between rooms A and B. Transmission loss data from intensity method are for the party wall only.

Surface Velocity: Figure 6 shows the average measured acceleration of the floor along lines parallel to the party partition both with and without the fault. There were six measurement positions along each line. The figure reveals that the fault has caused a significant increase in vibration levels in the receiving room, especially for points near the party wall. This clearly indicates the fault has increased mechanical coupling and that it involves the floor and/or its support assembly near the party wall. This method can suggest possible propagation paths, but does not directly measure the sound insulation for each path. Using surface velocities, it is theoretically possible compute the sound power radiated by a surface and hence the transmission loss as long as the surface's radiation efficiency is known. ISO 140-4 suggests that for frequencies greater than the partition's critical frequency the radiation efficiency can be taken to be unity. However, this may not be very helpful especially when the critical frequency occurs near the upper end of the frequency bands of interest as is the case for gypsum board walls and other lightweight constructions.

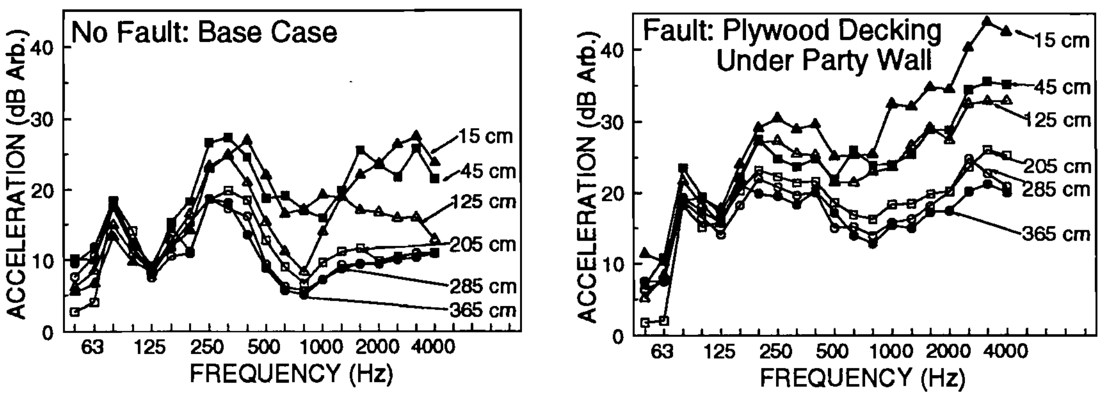


Figure 6: Average floor acceleration Room B, source Room A, with and without the fault. Data are an average of six points along parallel lines located at various distances from the party wall.

CONCLUSIONS

1. The standard sound insulation test methods (Airborne, ASTM E336; Impact, ASTM E1007) provide a measure of the net sound insulation between two rooms which can be compared to tests of a similar specimen made under laboratory conditions to reveal the presence of a construction fault. Either method alone cannot identify the propagation path or the type of fault.

2. Sound intensity methods provide a way of determining the airborne sound insulation of a single surface. However, difficulties may be encountered when measuring near other radiating surfaces. The measured transmission loss data may be compared to field E336 test data or to laboratory data, making it easy to identify faults in individual partitions.

3. Surface velocity measurements can be used to investigate relative levels of vibratory energy either over a single room surface or over several. Abrupt changes or constant increases in vibratory levels with position can indicate both the presence and location of flanking paths.
4. Impact excitation of each individual source room surface and measuring the resulting sound pressure level in the receiving room has the potential to be a valuable and relatively easy test method for determining flanking paths.
5. Running the floor decking under the party wall was shown to dramatically reduce the sound insulation performance between the two rooms separated by the party partition. Such a fault degraded the net airborne sound insulation from FSTC 62 without the fault to FSTC 45 with the fault.
6. Running the floor decking under the party wall did not cause an appreciable reduction in the floor/ceiling impact insulation. However, the fault did cause a significant reduction in the impact insulation between the horizontally adjacent rooms separated by the party wall.
7. Given correct design and construction, party partitions in wood-frame constructions can exhibit sound insulation performance similar to that obtained under laboratory conditions. However, to achieve this requires knowledgeable tradesmen and constant quality control.

Determination of Flanking Transmission and Field Sound Transmission Loss in Wood-Framed Constructions Using Intensity Methods

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Introduction

The method of acoustic intensity is used to determine the presence and magnitude of flanking transmission in a common double wood stud construction. This work was conducted as part of a joint research project with Canada Mortgage and Housing Corporation. Two construction specimens are considered. The first, without a construction fault, represents the ideal case in which there should be no flanking, (base condition -- See Figure 1). The second specimen has a potentially common construction fault. The plywood floor decking of the upper rooms is continued across the party line, (see Figure 2). The results of the intensity measurements are presented for the various surfaces. Difficulties encountered when using the intensity technique in the presence of flanking transmission are also discussed.

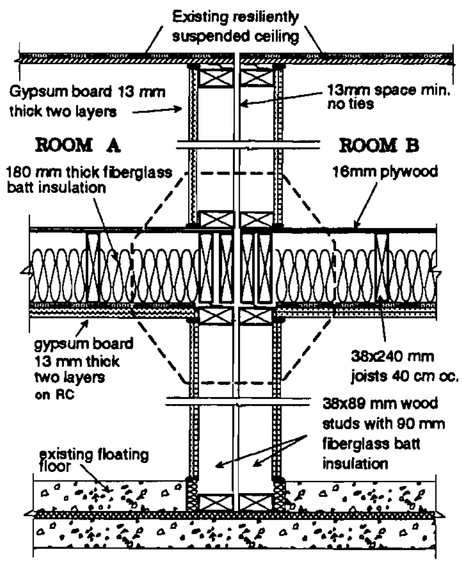

Figure 1: Section of base condition specimen at the party wall.

Measurement Technique

It is generally assumed that conventional measurement procedures involving either a P-P or P-V intensity probe will provide an accurate measure of an individual surface's radiated sound power. In fact, significant difficulties can be encountered when measuring the intensity of a surface that is physically connected at right angles to a much more energetically radiating surface. Consider measuring the

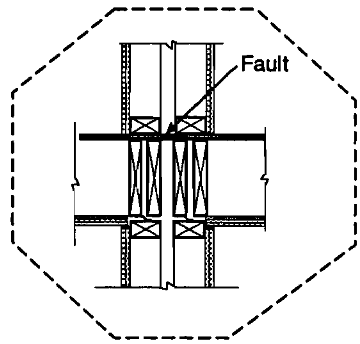

Figure 2: Section showing the construction fault.

transmission loss (TL) of the party wall shown in Figure 1 using the intensity technique when the floor is the dominant radiator, (i.e., under extreme flanking caused by the construction fault, Figure 2). Figure 3 shows the party wall transmission loss as computed from the measured intensity with and without the floor masked. The masking consisted of 1/2 inch thick gypsum board over 5/8 inch thick plywood separated from the measurement surface by 2 inch thick fiberglass batt insulation. A resilient air-tight joint between masking and measurement surfaces proved to be critical. The joint was made by using closed cell neoprene pipe lagging placed over the edge of the masking panels butting the measurement surface. The measurement surface was 4.54 m wide and 2.40 m high. Ninety-five points were used to sample the surface; using 10 columns over the width and 11 rows over the height. The probe was located at 6 cm from the measurement surface. The integration time was at least 60 seconds for each measurement point and the receiving room had at least 25 m^2 of 50 mm thick rigid fiberglass absorbing material. The results indicate that the P-P intensity probe is incapable of determining the normal radiated intensity of the measurement surface when there is an adjacent non masked radiating surface coupled at right angles. This has a significant impact on the usefulness of the method under extreme flanking conditions. Under these conditions, masking should be considered. In all subsequent intensity test data presented here, flanking surfaces were masked.

Party Wall Intensity

Figure 4 shows the measured TL between rooms A and B. From the figure, it can be seen that the fault affected the TL of the party wall as derived from the transmitted acoustic intensity. In terms of a single number rating the sound

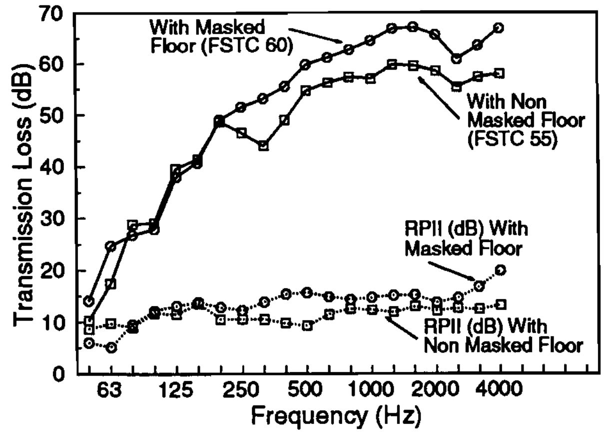

Figure 3: Party wall transmission loss obtained from the acoustic intensity with and without the floor masked.

$RPII = [L_p - |L_I|]_{calibration} - [L_p - L_I]_{measurement}$

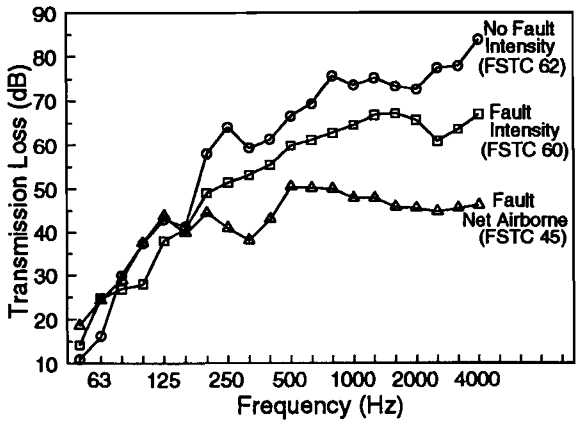

Figure 4: Party wall transmission loss obtained from the acoustic intensity with and without the fault. For the case of the fault, the net airborne sound insulation (which includes the flanking paths) is included for comparison.

insulation dropped from FSTC 62 to FSTC 60. Comparing the net airborne sound insulation with the fault (FSTC 45) to the TL of the party wall with the fault (intensity method, FSTC 60), it is evident that for frequencies greater than 200 Hz, the party wall provides much greater sound insulation. Thus, there is at least one very significant flanking path between rooms A and B, and the party wall is probably connected to the flanking path, but it is not the predominant radiator.

Floor

Figure 5 shows the measured radiated sound power for the floor and the party wall of room B when room A is the source. It is evident that the floor is the predominant radiator of acoustic energy for frequencies greater than 200 Hz. Figure 6 shows the average radiated intensity of

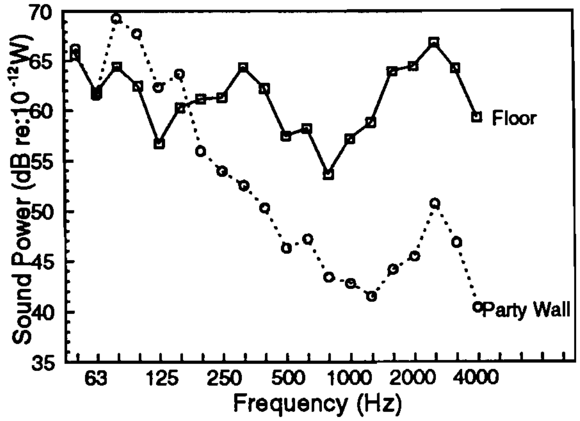

Figure 5: Measured total radiated sound power from the party wall and the floor.

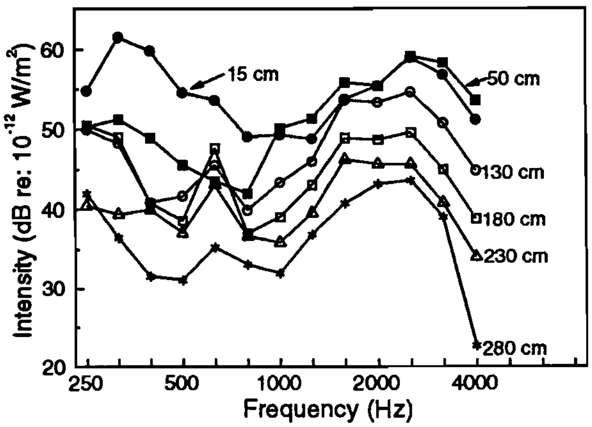

Figure 6: Measured floor intensity averaged along lines at the indicated distance from the party wall.

the floor along rows at the indicated distances from the party wall. Eight points were used in each row. There is a strong gradient in the radiated energy, indicating that the floor is more energetic near the party wall. This is especially true for frequencies greater than 800 Hz. The gradient in the radiated energy of the floor suggests that the floor is connected to the flanking path at or near the floor/party wall intersection.

Conclusions

1. Under conditions of extreme flanking, intensity methods fail to correctly isolate the normal component of the measurement surface. This can cause significant errors in the measured sound power and hence the transmission loss. For this reason, the use of masking is suggested when measuring next to a significant radiator.
2. Intensity methods allow for sound power measurement of surface sub-areas. This can be very useful to identify flanking paths.
3. Flanking transmission can significantly degrade and in severe cases control the net sound insulation.