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RESEARCH PROJECT ON THE NOISE PRODUCED BY DWV PIPES MADE OF CAST IRON, PVC AND ABS

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RESEARCH PROJECT ON THE NOISE PRODUCED BY SEWER PIPES MADE OF CAST IRON, PVC AND ABS

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1.0 INTRODUCTION

MJM ACOUSTICAL CONSULTANTS INC. has been retained by the CAST IRON SOIL PIPE ASSOCIATION to conduct a joint research project with the Cast Iron Soil Pipe Institute on the noise produced by several 3" diameter DWV pipes made of cast iron, PVC, and ABS, installed in a configuration most likely to be encountered in North American single and multiple dwelling buildings. The objective of the project was to study the noise emitted by DWV pipes as a function of the material entering in their fabrication.

During the course of this research project, eight series of acoustical measurements were conducted on seven types of North American DWV pipes: four with cast iron pipes, three with PVC pipes, and one with ABS pipes. All the pipes were installed in identical physical configuration and tested in the same acoustical conditions following strictly the same procedure to allow for direct comparison of the sound pressure levels emitted by each pipe during a 1.6 gallon (6 litres) water closet flush.

The acoustical measurements were conducted in the Domtar Acoustical Laboratory by the researcher in charge of the project, Mr. Jean-Marie Guérin, M.Sc.A., consultant, with the assistance and the supervision of Mr. Michel Morin, architect, President and Principal consultant of MJM ACOUSTICAL CONSULTANTS INC. The pipes were installed in the experimental set-up by a certified plumber at the employment of Plomberie Roland Bourbonnais.

This report is organized into an executive summary, a main report, and six annexes. The consumers, builders and construction professionals should find most of the information of interest to them in the **executive summary, in articles 2.0, 5.0 and 6.0**, respectively entitled: DESCRIPTION OF THE PIPES TESTED, ANALYSIS OF RESULTS, AND CONCLUSIONS.

The other articles of the report and **Annex I to VI** should be of interest to acousticians and to everyone interested in the experimental protocol which was followed during this research project and in the methods which were used to validate the acoustical data measured.

2.0 DESCRIPTION OF THE PIPES TESTED

Refer to **table 2.1** below for the description of the 3" diameter cast iron, PVC and ABS pipes tested during the present study.

Type of pipe	Diameter (in.)	Material	Length of pipe (ft)	Weight of pipe (lbs)	Colour	Hub	Applicable Standards	Type of couplings	Type of sweep
XH	3	Cast iron Extra heavy	10	80 to 85	Black	yes	ASTM A74	XH Charlotte seal gasket	long
SV	3	Cast iron service	10	60 to 75	Black	yes	ASTM A74	SV Quik-Tite gasket	long
Hubless No Hub	3	Cast iron hubless	10	53 to 58	Black	no	ASTM A888 CISPI 301 CSA B70	No Hub coupling (mechanical)	long and short
IPEX System 15	3	Solid wall PVC Type-1 Grade-1	12	17	Grey	no	CSA B181.2 ULC S-102.2M FSC-10	IPEX solvent cement	short
PVC 07300 ASTM D2665	3	Solid wall PVC Type-1; SCH 40	10	14	White	no	ASTM D2665 ASTM D1785	PVC solvent cement	short
PVC 04300 ASTM F891	3	Cellular core PVC IPS; SCH 40	10	9	White	no	ASTM F891-98	PVC solvent cement	short
ABS 03300 ASTM F628	3	Cellular core ABS SCH 40	10	9	Black	no	ASTM F628-95	ABS solvent cement	short

Description of the pipes tested

Table 2.1

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3.0 EXPERIMENTAL SET-UP

In order to allow for comparison between the noise radiated by the pipes tested, they had to be installed in identical physical conditions, and measured in the same acoustical conditions. This was achieved by constructing and validating an experimental set-up in the controlled environment of the Domtar Acoustical Laboratory, located in Senneville, Québec, Canada. The physical characteristics of the Domtar Acoustical Laboratory, the description of the experimental set-up, the instrumentation and the measurement procedure used to conduct this study are described in **articles 3.1 to 3.3** below.

3.1 Description of the Domtar Acoustical Laboratory

The Domtar Acoustical Laboratory consists of a control room and three reverberant rooms which are structurally decoupled from one another. Both the source room (90 m^3) and the receiving room (255 m^3) are equipped with rotating diffusers to maintain a proper reverberant field; all three rooms are also equipped with stationary diffusers. The dimensions, volume, construction, and weight of each room and the number of springs on which they rest (for the source and receiving room) appear below, along with the dimensions of the test openings.

There are ten microphone positions in each reverberant chamber; a stepping motor and a transverse chain carrier located along one diagonal of the room move the microphone from position to position.

You will find below the dimensions and characteristics of each reverberation chamber:

SOURCE ROOM

Room dimension	14'5" x 17'10" x 11'2" (4.394 m x 5.436 m x 3.404 m)
Room surface area	1 230 pi^2 (114.27 m^2)
Room volume	3 190 pi^3 (90.33 m^3)
Room weight	97 imperial tons (89 metric tons)

Wall thickness	1' (305 mm)
Number of springs	208

RECEIVING (REVERBERATION) ROOM

Room dimension	21'3" x 26'2" x 16' (6.477 m x 7.976 m x 4.877 m)
Room surface area	2 620 pi^2 (243.41 m^2)
Room volume	9 020 pi^3 (255.42 m^3)
Room weight	197 imperial tons (178.7 metric tons)
Wall thickness	1' (305 mm)
Number of springs	432

IMPACT ROOM

Room dimensions	16'5" x 18'6" x 11'4" (5.004 m x 5.639 m x 3.453 m)
Room surface area	1 400 pi^2 (130.1 m^2)
Room volume	3 440 pi^3 (97.41 m^3)
Wall thickness	1' (305 mm)

TEST OPENINGS

Walls	10' x 9' (3.05 mm x 2.743 mm)*
Floors and ceilings	8' x 10' (2.438 mm x 3.05 mm)*

More information can be found on the Domtar Acoustical Laboratory by visiting the internet site www.mjm.qc.ca.

3.2 Description of the experimental set-up

The experimental set up used to test each individual pipes under strictly the same experimental conditions is illustrated on **figures A1-1 to A1-5** and on pictures contained in **Annex I** of this report. As can be seen on the figures the experimental set-up used all three reverberant rooms of the Domtar Acoustical Laboratory: the source of water flow noise was located in the 97 m^3 room, the pipes under test were located in the 90 m^3 room, and the water was evacuated in the 250 m^3 room.

The source used to generate water flow noise inside the DWV pipes tested was a Cranada water closet manufactured by Crane, equipped with a 1.6 gallon (6 litres) tank. **Figures A1-1 and A1-2** illustrate in plan and in section the general set-up: the toilet was installed on an independent floor structure made of 3/4" thick particle board screwed to 2" x 8" joists spanning over the floor test opening and resting exclusively on the impact room floor structure. **Figure A1-3** illustrates the composition of the floor/ceiling assembly which was built in the floor test opening to prevent that the airborne noise generated in the 97 m^3 room by the flush of the water closet be transmitted to the 90 m^3 room where the pipes tested were installed. On **figure A1-1and A1-2**, one can follow the path of the water after the water closet had been flushed: the water had to travel through a horizontal section of pipe and then through a vertical section both located in the 90 m^3 reverberant room, before flowing in a container located in the 250 m^3 room and being evacuated by a sump pump to a municipal sewer. As for the water closet flush care was taken to minimize the transmission of the airborne noise produced by the sump pump from the 250 m^3 room to the 90 m^3 room: to that effect a high performance double-stud-double-gypsum sound isolating wall was built in the test frame separating the two rooms. Prior to measuring the noise emitted by each of the seven types of pipe assembly, the experimental set-up was validated to ensure that the noise measured in the 90 m^3 room was exclusively that irradiated by the pipes and by the pipe enclosure under test, without any contribution resulting from the airborne transmission of water closet or pump noise through the floor and the wall. During the construction of the pipe enclosures (permanent or removable) and the installation of the pipes, special precautions were taken to avoid rigid contact of the pipes with any structure: a clearance of 3/8" was left around the pipe at each penetration of wall, enclosure or floor and the 3/8" gap created was then sealed with a non-shrinking, non-hardening latex caulking compound. Finally, the horizontal section of the pipe assemblies under test was supported using rubber strappings and Armaflex sleeves to minimize the structural transmission of noise from the pipes to supporting structure.

Figures A1-4 and A1-5 illustrate the layout and the length of the pipes tested as well as the composition of the permanent and removable drywall enclosure built around the pipes. As can be seen on these figures, the removable panels of the enclosure consisted in one layer of 1/2" thick drywall with a surface mass of approximately 1.8 lb/ft^2; all the joints of the enclosure were sealed airtight using a latex caulking. In order to maintain an adequate signal to noise ratio inside the 90 m^3 room, batt insulation was not inserted inside the pipe enclosure cavity.

3.3 Description of the Instrumentation used to perform the sound pressure level measurements

Analyser:	Dual channel Larson Davis 2900, serial no 0456 Detector time: 35 ms Sampling time: 16.17 s (time necessary to perform a complete 6 litres water closet flush + a few seconds)
Digital filters:	1/3 octave band; frequency range = 25 Hz to 20 kHz
Pre-amplifier:	Larson Davis 900B
Microphone:	Prepolarized B&K Condenser Microphone Type 4155
Calibrator:	Brüel & Kjær Type 4230
Sound source:	Cranada standard water closet equipped with a 1.6 gal (6 litres) tank
Room where the sound pressure measurements were performed	90 m^3 reverberation chamber

4.0 MEASUREMENT PROCEDURE AND VALIDATION OF THE EXPERIMENTAL SET-UP

All throughout this research project, efforts have been made to ascertain the reliability of all the tests performed:

- The instrumentation used and the procedure followed to measure the sound pressure levels generated by the pipes was strictly the same for all measurements.

- The background noise in the 90 m^3 reverberation chamber in which the pipes were installed was monitored to ensure that it was always 10 dB below the noise radiated by unenclosed pipes for frequencies above 125 Hz; in the case of, enclosed pipes, especially at high frequencies, the noise radiated by the pipes was not always 10 dB higher than the background noise.

- For each type of pipe under test, a demonstration has been made that the noise measured in the 90 m^3 room was exclusively irradiated from the pipes under test and that there was no significant contribution resulting from airborne noise transmission from one chamber to another which could have altered the measurement results for the frequency range selected.

- Repeatability and reproducibility tests have been conducted on each type of pipe under test.

- All the measurements were performed from 25 Hz to 20 kHz. However since the low frequency limit above which the sound field is diffuse in the 90 m^3 room is 100 Hz, preliminary test results will then be presented starting at this frequency. The frequency range selected to compare pipes between themselves is discussed at length in **article 4.4** below.

4.1 Procedure to measure the noise radiated by the pipes under test during a water closet flush

.1 The analyser was set for a sampling duration of 16.17 seconds which corresponded to the time actually needed to completely evacuate from the pipes the 1.6 gallons (six litres) of water produced by a single flush, plus a few seconds;

.2 At each of the ten pre-determined microphone positions inside the 90 m^3 room, the analyser was first started and then, immediately after, the toilet flush was remotely activated from the control room;

.3 The space average of the sound pressure levels generated inside the 90 m^3 reverberant room during a water closet flush was calculated using the 1/3rd octave band SPLs measured at the ten pre-determined microphone positions; the 95% confidence limits on this average SPL were also calculated;

.4 The measurement procedures described in **4.1.1 to 4.1.3** were performed twice for each pipe assembly tested;

.5 Special care has been taken to perform measurement while the pump located in the 250 m^3 room was not in operation. However occasionally the pump was triggered automatically one or two seconds before the end of the 16.17 second sampling time with no significant consequences to the sound levels measured in the 90 m^3 room as demonstrated further in **article 4.3** of this report.

4.2 Background noise in the 90 m^3 chamber

An environment exempt of parasite noise was essential to permit accurate measurements of the noise created by the flow of water in the pipes under test. To achieve a very low background noise, the rotating diffuser inside the 90 m^3 room was turned off and all the mechanical equipments of the Domtar Research Centre susceptible to raise the background noise inside this room were also turned off.

The background noise has been measured at the ten pre-determined microphone positions along the microphone transverse of the 90 m^3 reverberant chamber with the analyser set as outlined in **article 4.1.1** above. The average of the background noise levels measured are plotted on **graph A2-1** in **Annex II** of this report and on **figure A5-1 to A5-8** of **Annex V**. As can be seen on these figures a signal to noise ratio of at least 10 dB was maintained in the case of the unenclosed pipes; for the enclosed pipes the signal to noise ratio was less than 10 dB at high frequencies.

4.3 Control of the noise transmitted in the 90 m^3 reverberant chamber during the operation of the pump and the water closet

Paragraphs 4.3.1 to 4.3.4 below describe the procedure followed to demonstrate that for each type of pipe, the sound pressure levels measured in the 90 m^3 reverberant chamber during a water closet flush resulted only from the noise radiated by the pipe or the pipe enclosure under test, with no contribution of airborne noise produced by the water closet or pump located in the 97 and 250 m^3 room ant transmitted through the floor or the wall separating these rooms from the 90 m^3 room where the pipes were installed.

.1 The sound transmission loss provided by the wall and floor/ceiling assemblies separating the 90 m^3 room from the other chambers of the laboratory were measured at least once for each type of pipe tested, following the prescriptions of ASTM E90-90[1]. When the transmission loss tests were performed on the wall and floor, the pipes in the 90 m^3 reverberant chamber were not enclosed. The sound Transmission Loss (TL) measured for the walls and floors with each type of pipe installed in the 90 m^3 room are presented on **graphs A2-2 to 5** in **Annex II** of this report.

1 Standard Methods for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions

On **graphs A2-2 and A2-3** the sound transmission loss of the wall separating the 90 m^3 chamber from the 250 m^3 chamber was approximately equivalent when Cast Iron, Ipex and PVC 7300 ASTM D2665 pipes were installed; with PVC 4300 ASTM F891 and ABS 3300 ASTM F628 pipes significant drops in the transmission loss curve of the wall for frequencies above 2000 Hz were noted.

On **graphs A2-4 and 5** one can observe that the sound transmission loss provided by the floor/ceiling assembly does not vary significantly from 50 Hz to 500 Hz; for frequencies higher than 500 Hz however, the transmission loss of the floor is affected by the type of pipe installed in the 90 m^3 chamber: the degradation of the transmission loss is significantly more important with plastic pipes than with cast iron pipes.

.2 The noise produced by the pump inside the 250 m^3 reverberant chamber ($L_{eq\,(16.17\,sec)}$) and the noise produced in the 97 m^3 chamber (L_{max} with a detector time of 35 ms) during a toilet flush were measured. The sound pressure levels measured at the ten microphone positions have been averaged and are plotted on **graph A2-6** of **Annex II** of this report.

.3 The noise produced by the pump in the 250 m^3 reverberant chamber and transmitted in the 90 m^3 reverberant chamber through the wall, and that generated by toilet flushes in the 97 m^3 reverberant chamber and transmitted to the 90 m^3 reverberant chamber through the floor/ceiling assembly were calculated with the SPL and TL plotted on **graphs A2-2 to 6** using **equation 1** below:

$$(1) \qquad Lp_2 = Lp_1 + 10Log(\frac{S}{A}) - TL$$

Lp_1: Average sound pressure level in the room where the sound source is located

Lp_2: Average sound pressure level to be evaluated in the 90m^3 reverberant chamber

S: Surface of the partition separating the two rooms (m^2)

A: Absorption in the 90 m^3 reverberant chamber

TL: Transmission loss of the partition

.4 Plotted on **graphs A2-7 to A2-10** are the calculated airborne noise levels transmitted to the 90 m^3 chamber during the operation of the toilet and of the pump along with the background noise measured in the 90 m^{3}chamber from 50 Hz to 5000 Hz. One can see, on **graphs A2-7 and A2-8**, that the noise radiated by the pump through the wall in the 90 m^3 reverberant chamber is equivalent to or lower than the background noise level above 200 Hz regardless of the pipe assembly installed; between 100 Hz and 200 Hz the noise radiated by the pump through the wall in the 90 m^3 reverberant chamber is 3 to 8 dB higher than the background noise. On **graphs A2-9 and A2-10** the maximum sound pressure level radiated by the water closet flush through the floor/ceiling assembly in the 90 m^3 reverberant chamber is 3 to 8 dB higher than the background noise between 100 Hz and 160 Hz; above 160 Hz maximum noise levels from toilet flush are in the same order or lower than the background noise.

4.4 Frequency range selected

For the reasons mentioned in **4.4.1 to 4.4.3** below, the frequency range selected to present the results in **article 5.0** of this study and to compare the pipe systems tested is 160 Hz to 10000 Hz:

.1 According to the diffuse field theory the precision of sound pressure levels measurements in a reverberant space is limited by the dimensions of this space and the sound absorption which it contains. The dimensions of the 90 m^3 reverberant chamber in which the pipes were installed, limits to 100 Hz the lower frequency for which sound pressure level measurements can be made with an acceptable uncertainty.

.2 At 100 Hz the noise transmitted through the floor/ceiling assembly during a flush could interfere with the noise radiated by the pipes.

.3 As mentioned earlier, for each pipe tested, two series of measurements were conducted at ten microphone positions from 25Hz to 20 kHz; the sound pressure levels ($Leq_{(16.17\ sec)}$) measured for each series were then averaged and the 95% confidence limits calculated. In our opinion, for a transient noise such as that produced by a water closet flush, the result of a measurement obtained by averaging the sound pressure levels measured at ten microphone positions can be considered reliable if the 95% confidence limits are within 3 dB of the average calculated. For all the measurements performed in this research project, the 95% confidence limits presented on **figure 4.1** below were inferior to 3 dB for the 1/3rd octave bands ranging from 160 Hz to 10000 Hz.

4.5 **Repeatability of measurements**

The following repeatability tests were performed:

.1 To verify the repeatability and consistency of the sound pressure levels generated by the toilet, the noise levels generated by five water closet flushes were measured at microphone position n° 5 inside the 90 m^3 chamber, for each type of pipe tested. The results of these tests appear in **Annex III** of this report; these tests demonstrated that the sound pressure levels generated by toilet flushes can be repeated with a reasonable degree of precision considering the transient nature of the noise produced by the source.

.2 For each configuration of pipe assembly (bare pipes, partially enclosed pipes and fully enclosed pipes) the sound pressure levels measurements were made twice, and compared. The average 1/3 octave sound pressure levels at ten microphone positions obtained for each series of measurements were compared and agreed generally within 1 dB with maximum differences of 3 dB. In terms of overall "A" weighted level, the variation between the two series of measurements is within 1 dBA. The 1/3 octave and overall sound pressure levels used to compare pipes in this report are the average of the two series of measurements performed representing twenty sound samples made at ten pre-determined positions.

4.6 Reproducibility of measurements

Reproducibility tests were conducted for each type of pipe studied. In order to do so, each pipe system was assembled three to four times using different pipes and couplings selected at random, and each assembly was tested using the test procedure outlined in **article 4.1** and **paragraph 4.5.2** above. The results of these tests are presented in **Annex IV** of this report: these results indicate that the experimental set-up and measurement method used in this research project provided test results with a good reproducibility: a variation of 1 dBA was noted between the overall noise level produced by the different samples.

5.0 ANALYSIS OF RESULTS

5.1 Comparing the acoustical performance of the pipe systems tested

To allow comparison between the different pipe systems tested we have plotted on **figures 5.1 to 5.4** below the average 1/3rd octave sound pressure levels measured on each pipe system installed in the four configurations listed below:

Figure 5.1: Bare pipes; the horizontal and vertical pipes were not enclosed
Figure 5.2: Horizontal pipe assembly exposed; the vertical pipe enclosed with drywall;
Figure 5.3: Vertical pipe assembly exposed; the horizontal pipe enclosed with drywall;
Figure 5.4: Enclosed pipes; both vertical and horizontal pipes were enclosed

.1 Bare pipes

The values plotted on **figure 5.1** for bare pipe assemblies are the average of the sound pressure levels measured on the three or four assemblies tested for each type of pipe (refer to **table 2.1** for more details on the types of pipes tested). As can be seen on this figure, for bare pipe assemblies, the cast iron pipes radiate less noise than the PVC and ABS pipes; the quietest assembly is that made with XH (extra heavy) cast iron pipes (40 dBA) and the noisiest that made with ABS pipes (55 dBA).

There is a 3 dBA variation in the noise radiated by the three types of bare PVC pipes measured in this study: the PVC pipe which radiates the least noise when unenclosed is the PVC 7300 ASTM D2665 and the one which radiates the most noise is PVC 4300 ASTM F891; Ipex System 15 ranked itself between PVC 7300 ASTM D2665 and PVC 4300 ASTM F891 with an average sound pressure level radiated of 49 dBA.

A 3 dBA variation was also noted in the noise level radiated by the four types of unenclosed cast iron pipe assemblies tested; the global sound pressure levels varied from 40 dBA to 43 dBA. In terms of global sound pressure level, bare cast iron pipe assemblies are 5 to 11 dBA quieter than bare PVC pipe assemblies, and 12 to 15 dBA quieter than the ABS assembly tested. Among all bare cast iron pipe assemblies tested the XH pipe assembly is the least noisy (40 dBA) and the SV (service) pipe assembly is the most noisy (43 dBA).

When comparing the noise levels produced by the No-Hub (Hubless) cast iron pipe assemblies, one notices that there is no significant differences between the noise levels produced by the assembly installed with a long radius bend and that installed with a short radius bend.

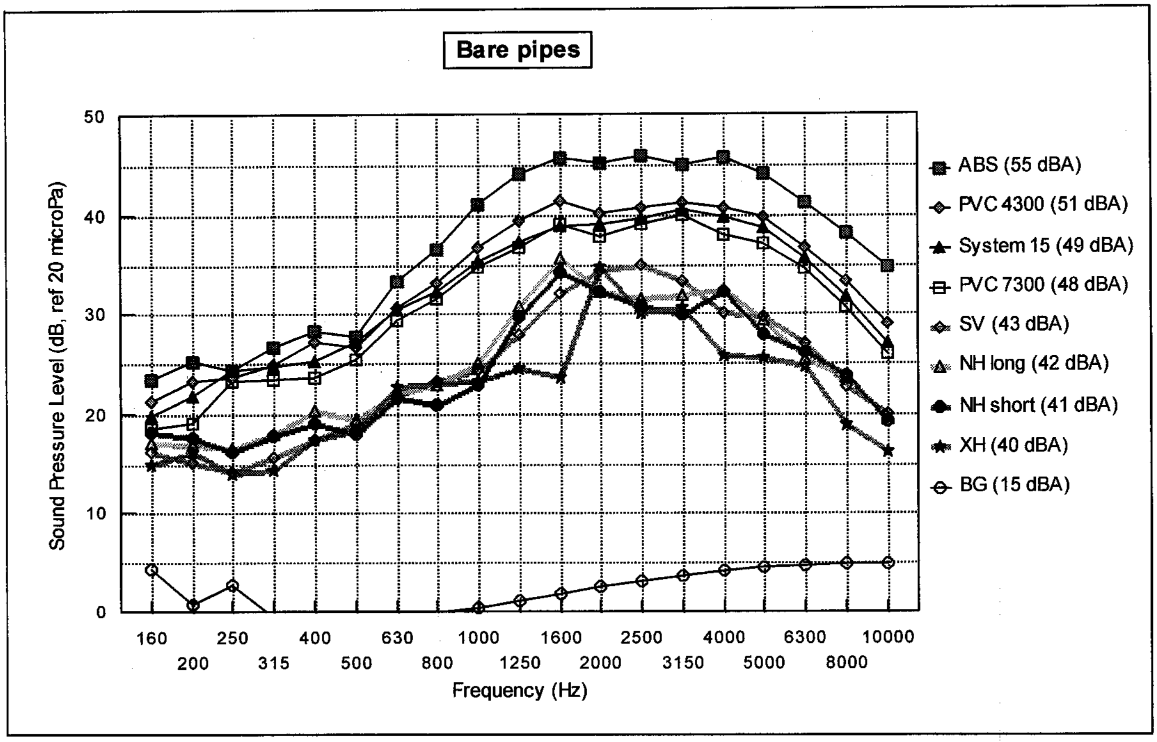


Figure 5.1: comparing unenclosed (bare) pipe assemblies

.2 Vertical pipe enclosed; Horizontal pipe exposed

The noise levels produced by a 1.6 gallon water closet flush in the horizontal pipe of the assemblies tested are plotted on **figure 5.2** below: these levels were measured when only the vertical pipe of the assembly was enclosed leaving the horizontal pipe exposed. Again, one notices that the cast iron pipes radiate less noise than the PVC and ABS pipes; the horizontal XH (extra heavy) cast iron pipe radiated the least noise (32 dBA) and the horizontal ABS the most noise (54 dBA).

There is a slight variation in the noise radiated by horizontal PVC pipes: the global sound pressure levels varied by only 1 dBA between the three systems tested (from 47 dBA to 48 dBA). For cast iron pipe assemblies however, the variation observed is more pronounced as the global sound pressure levels measured for horizontal pipes ranged from 32 dBA to 39 dBA. The horizontal cast iron pipe which radiated the least noise is the XH (extra heavy) (32 dBA) pipe and the one which radiated the most noise is the SV (service) pipe (39 dBA).

Below 2000 Hz and above 5000 Hz, there is no significant difference between the noise levels radiated by the No-Hub (Hubless) cast iron pipes whether they are installed with a short or a long radius bend; between 2000 Hz and 5000 Hz however, a difference in the order of 4 dB or less can be noted in the noise levels radiated depending on the turn or sweep installed. In terms of global sound pressure level, the noise radiated by horizontal No-Hub (Hubless) cast iron pipes is the same regardless of the radius of the bend installed (short or long): 36 dBA.

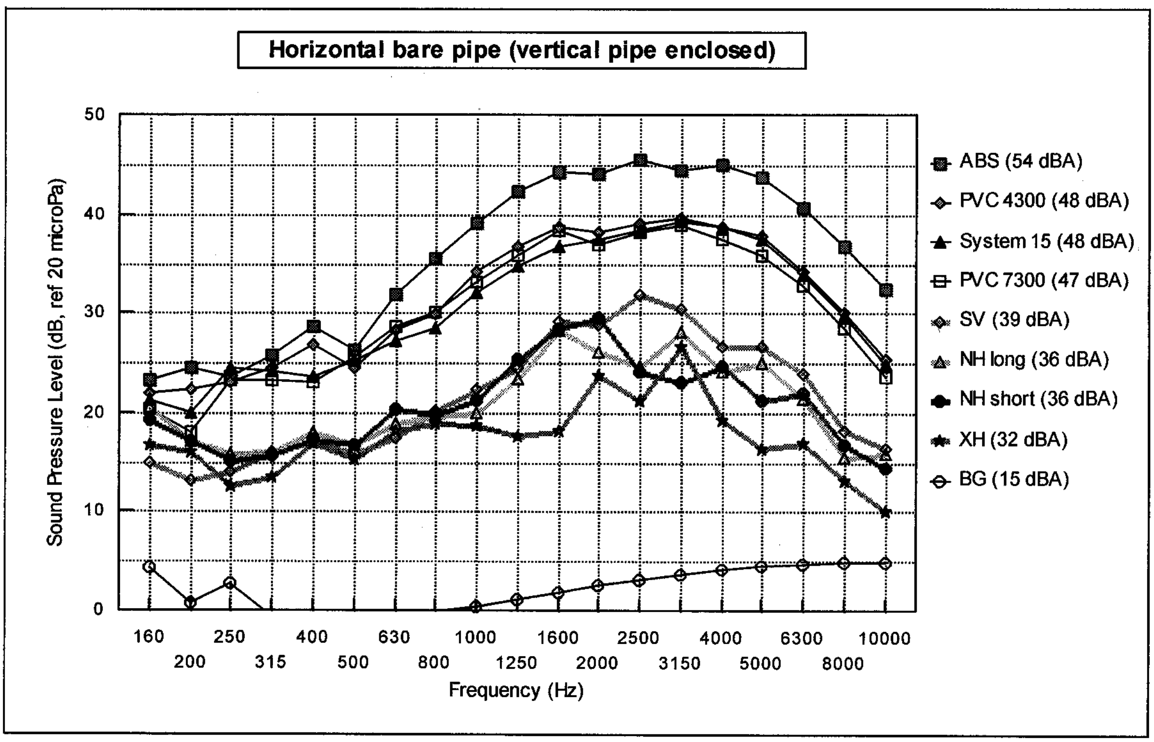


Figure 5.2: comparing unenclosed Horizontal pipes

.3 Horizontal pipe enclosed; Vertical pipe exposed

Figure 5.3 below present the noise levels radiated by the vertical pipe of each assembly when the horizontal pipe was enclosed. Again, the vertical cast iron pipes radiate less noise than the PVC or ABS pipes. The vertical XH (extra heavy) cast iron pipe radiated the least amount of noise (39 dBA) and the vertical ABS pipe the most noise (49 dBA).

As noted for bare pipes, there is a 3 dBA variation in the noise radiated by the three vertical pipes made of PVC: the global measured sound pressure levels varied from 42 dBA to 45 dBA. The Ipex System 15 is the vertical PVC pipe which radiates the least noise when unenclosed. The noise emitted by the vertical cast iron pipes varied by 2 dBA depending on the assembly tested: from 39 to 41 dBA.

As seen on **figure 5.3,** there is virtually no difference between the noise generated by the No-Hub (Hubless) cast iron vertical pipes when fitted with short or long radius bends (40 vs 41 dBA); this was expected since the turns located in the horizontal section of the pipe assembly tested were enclosed and the vertical assemblies did not contain any sweep.

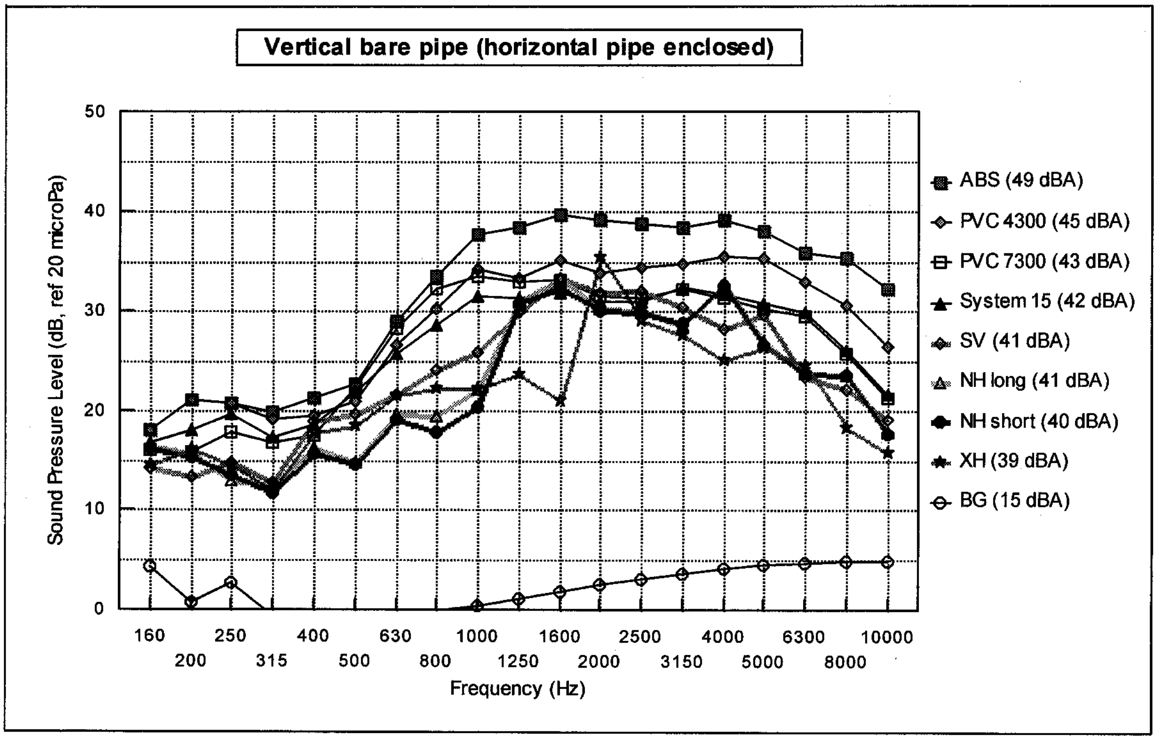


Figure 5.3: comparing unenclosed vertical pipes

.4 Enclosed pipes

The results of the measurements performed on enclosed pipe assemblies are presented on **figure 5.4** below. Again, cast iron pipe assemblies radiated less noise than PVC and ABS assemblies. The enclosed pipe assemblies which produced the least noise are made with cast iron (24 to 26 dBA); the assembly which radiated the most noise is that with ABS pipes (39 dBA); pipe assemblies made of PVC pipes ranked between cast iron and ABS (32 to 34 dBA).

The variation in the noise produced by enclosed pipe assemblies made of PVC is only 2 dBA; the PVC pipe assemblies which generated the least noise when enclosed is Ipex System 15. The variation in the noise radiated by enclosed cast iron pipes is also only 2 dBA.

In terms of global sound pressure level, the average noise radiated by enclosed cast iron pipe assemblies is 8 dBA less than that radiated by enclosed PVC pipe assemblies, the same difference exists between the average sound pressure levels measured on unenclosed cast iron pipes and PVC pipes. Among all enclosed cast iron pipe assemblies tested the XH (extra heavy) pipe assembly and the No-Hub (Hubless) cast iron with short radius bend radiated the least noise; the one which radiates the most noise is the enclosed SV (service) pipe assembly.

When enclosed, there is virtually no difference between the noise levels radiated by the No-Hub (Hubless) cast iron pipes installed with short and long sweep 90° bends. When comparing **figure 5.1** with **figure 5.4** the peaks noticed in the noise spectrum emitted by the bare cast iron pipes also occur at the same frequencies when the pipes are enclosed.

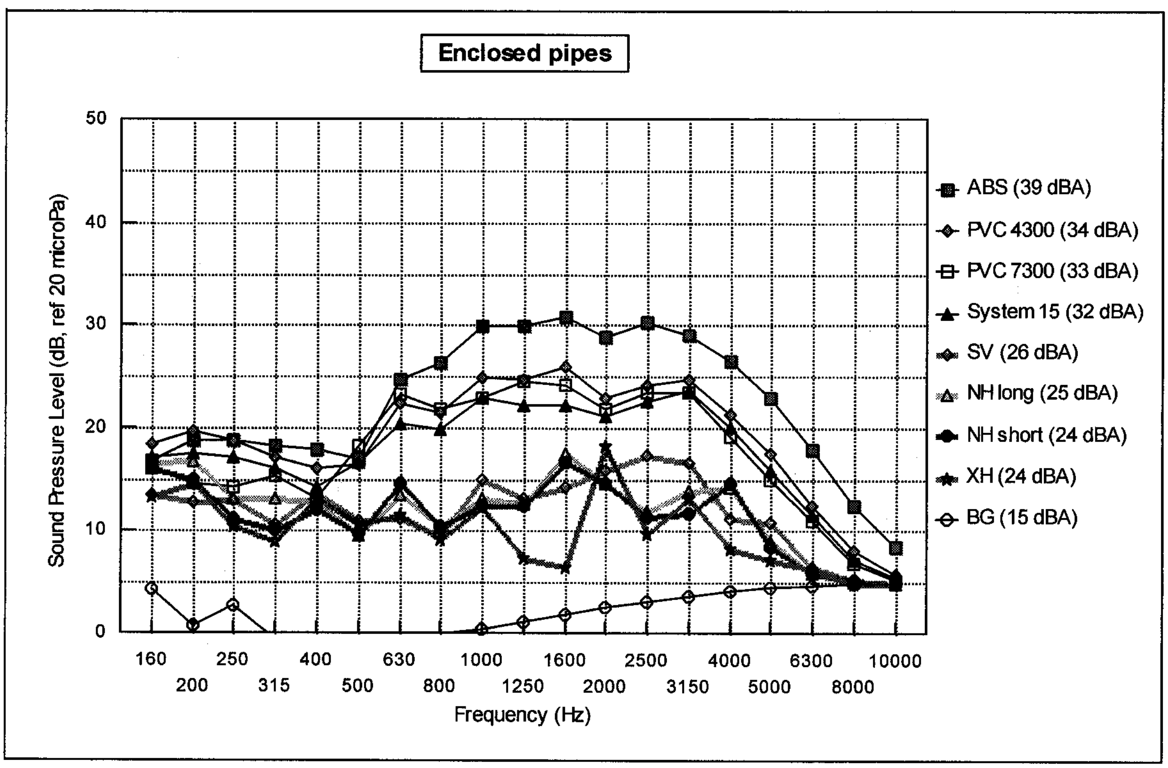


Figure 5.4

.5 Summary

Table 5.1 below summarizes the results obtained for all type of pipes assemblies in terms of overall "A" weighted levels:

	Global sound pressure level (dBA, ref 20 microPa)			
Type of pipe	Bare pipes	Enclosed pipes	Vertical pipe unenclosed	Horizontal pipe unenclosed
XH (extra heavy) - ASTM A74	40	24	39	32
No-Hub long - CISPI 301, CSA B70, ASTM A888	42	25	41	36
No-Hub short - CISPI 301, CSA B70, ASTM A888	41	24	40	36
SV (service) - ASTM A74	43	26	41	39
System 15 (solid wall)	49	32	42	48
PVC 7300 - ASTM D2665 (solid wall)	48	33	43	47
PVC 4300 - ASTM F891 (cellular core)	51	34	45	48
ABS 3300 - ASTM F628 (cellular core)	55	39	49	54
Average cast iron	41	25	40	36
Average PVC	49	33	43	48

Table 5.1: Overall "A" weighted sound pressure level radiated by pipe assemblies tested

5.2 <u>Comparing the noise produced by water flow in each type of pipe tested</u>

The sound pressure levels measured for each pipe system tested, with the pipes unenclosed, partially enclosed and fully enclosed are plotted on **figures A5-1 to A5-8** of **Annex V**. As mentioned earlier, for each types of pipe tested, three to 4 pipe assemblies were installed inside the experimental set-up and tested in unenclosed conditions. However the last assembly of each type of pipe tested was used to compare the acoustical performance of the pipes when unenclosed, partially enclosed and fully enclosed. The assembly used to make this comparison for each type of pipe tested appears in the titles of **figures A5-1 to A5-8** of **Annex V**. By analysing the curves plotted on **figures A5-1 to A5-8**, one notices that:

- For cast iron pipes, water generates more noise when flowing inside the vertical pipes than in horizontal pipes. For plastic pipes it is the contrary: more noise is generated with horizontal pipes than in vertical pipes.

- Peaks between 1600 and 5000 Hz are noticeable in the spectrum of the noise emitted by cast iron pipes. The most pronounced peak were noted in the case of the XH pipes. These peaks are not present in the noise spectrum emitted by plastic pipes, which is indicative that plastic pipes exhibit a more damped behaviour when radiating noise.

5.3 Sound insertion loss provided by a drywall enclosure

As can be seen on **figures A5-1 to A5-8** of **Annex V**, between 160 and 250 Hz, the pipe enclosure provides very little if any sound attenuation; the attenuation provided by the enclosure is significant above 250 Hz. The overall insertion loss measured for the pipe enclosure is consistent from one pipe system to another and is in the order of 15 to 17 dBA.

5.4 Validating the measurements made on partly enclosed pipes

In order to validate the measurements made with partly enclosed pipes: we have calculated the sum of the noise radiated in the 90 m^3 reverberant chamber by the vertical pipe only (the horizontal pipe was enclosed) and by the horizontal pipe only (the vertical pipe was enclosed) and compared the results to the measurement made on unenclosed pipes. The results are presented on **figures 6.1 to 6.8** in **Annex VI**; these figures indicate very good agreement above 250 Hz (differences in the order of one dB); the greater differences noted below 250 Hz are deemed to be due to the poor insertion loss provided by the pipe enclosure at these frequencies.

6.0 CONCLUSIONS

The objective of this research project was to measure and compare the noise emitted by seven types of DWV pipes fabricated with different materials: four systems were fabricated with cast iron, three with PVC, and one with ABS. The experimental set-up used during this study is typical of a DWV pipe installation which can be found in most North American single or multi-dwelling homes: a water closet discharging in a 3" horizontal drain pipe connected to a 3" vertical waste stack, enclosed in a wall made with 1/2" gypsum board. This study establishes clearly that DWV pipes made of cast iron are quieter than PVC pipes (by 6 to 10 dBA with an average difference of 8 dB), or ABS pipes (by as much as 15 dBA) whether the pipes are enclosed or not.

There is little variation in the noise levels radiated during a flush by different types of PVC pipes; the variation did not exceed 3 dBA in terms of global sound pressure level. The same 3 dBA variation also exists between vertical cast iron pipes; for horizontal cast iron pipes however, differences of up to 7 dBA were noted.

The tests performed on partially enclosed assemblies highlighted significant differences in the radiation pattern of horizontal pipes and vertical DWV pipes. With cast iron pipe assemblies the vertical stacks radiated more noise than the horizontal part during a water closet flush. In the case of PVC and ABS pipes the opposite behaviour was noted: the horizontal drains produced significantly more noise that the vertical stacks.

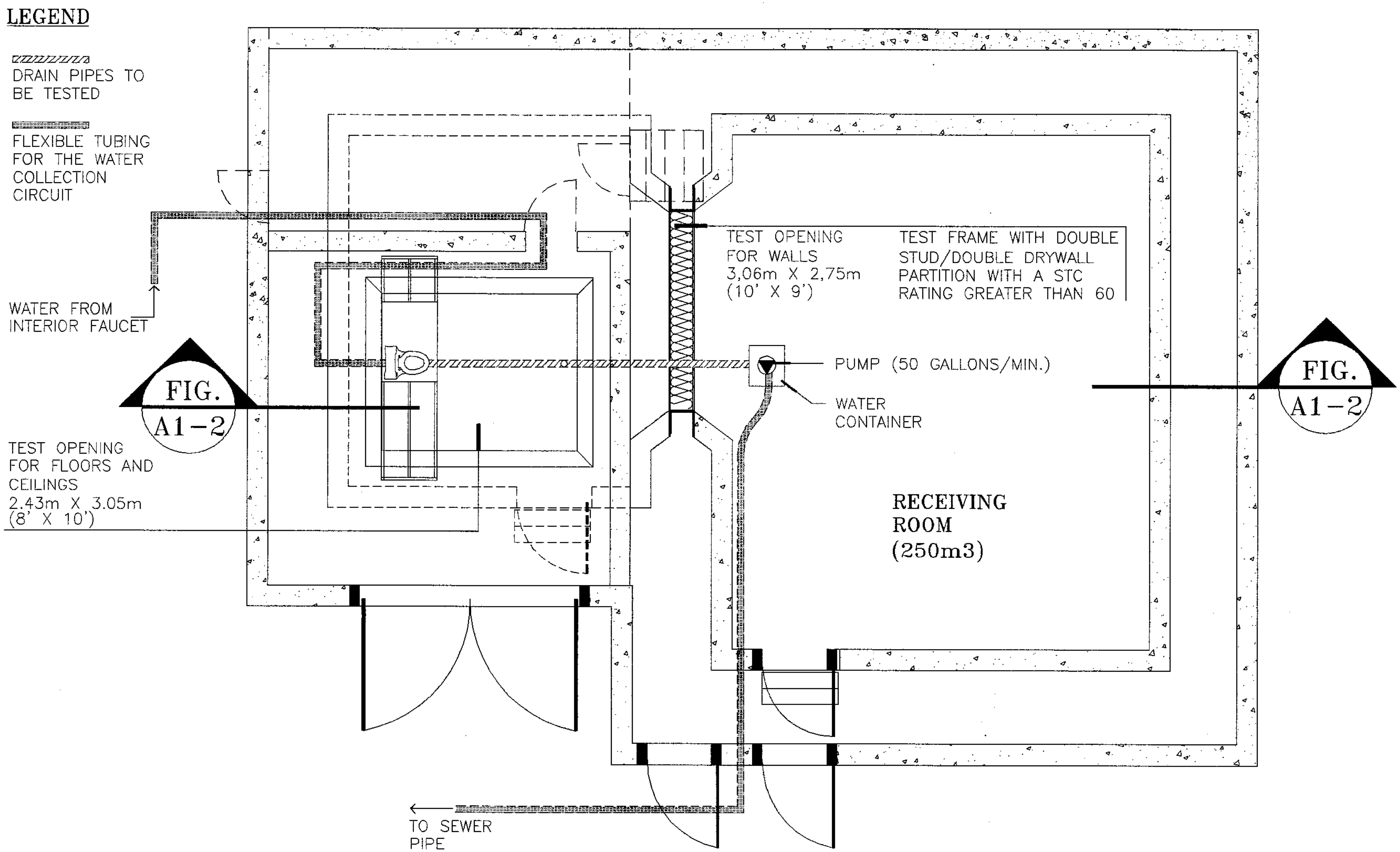
The insertion loss provided by the drywall enclosure does not seem to be dependent on the pipe assembly tested: the global insertion losses measured vary from 15 dBA to 17 dBA.

Respectfully submitted July 10, 2000
MJM ACOUSTICAL CONSULTANTS INC., by

Michel Morin, OAQ, ASA
President and principal consultant

Jean-Marie Guérin, B.Ing. M.Sc.A.
Consultant

ANNEX I



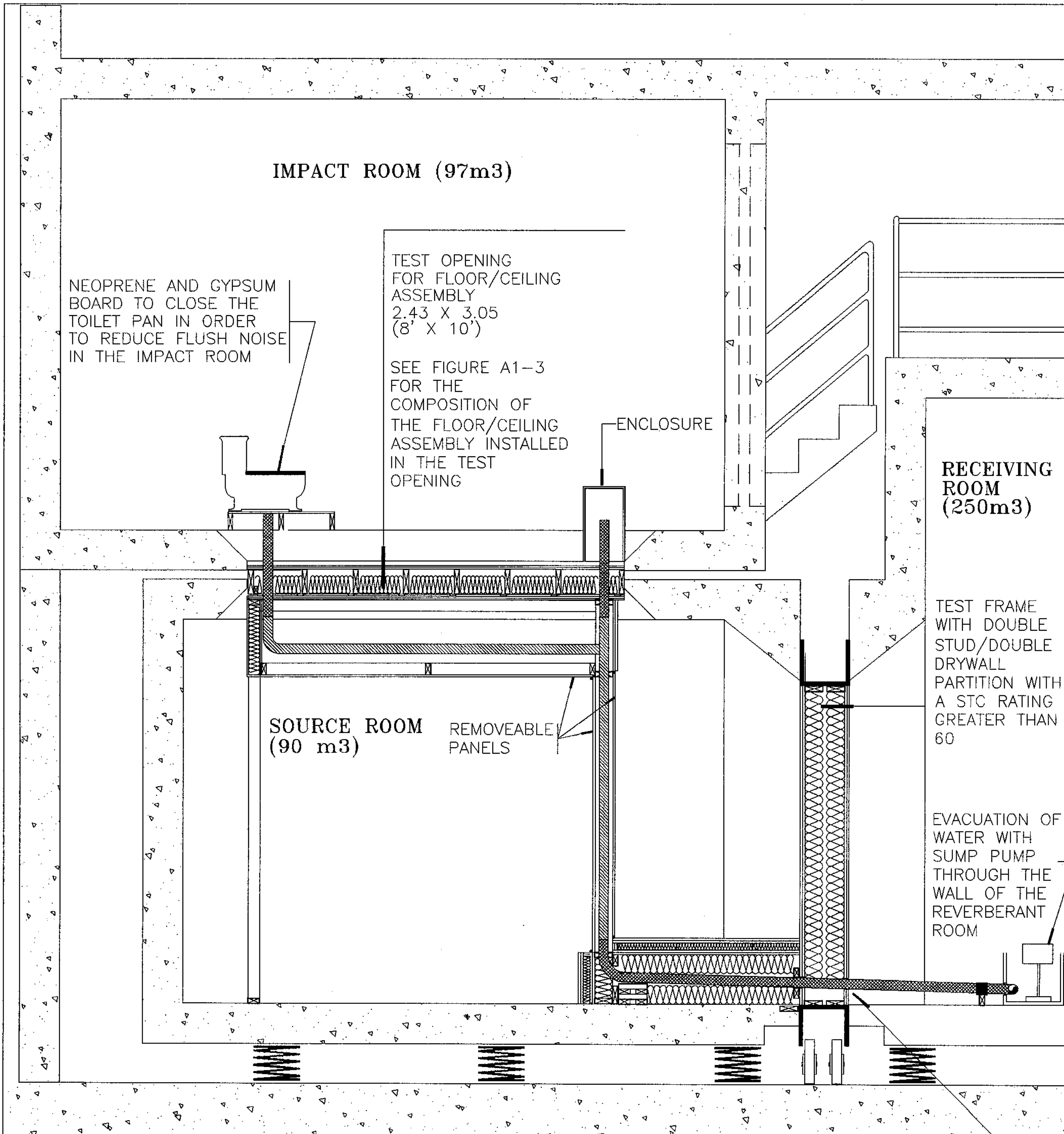
PLAN VIEW

CISPA EXPERIMENTAL SET-UP AT DOMTAR ACOUSTIC LABORATORY

PROJET 612.991
612991AA

FIGURE A1-1

2000 07



LEGEND

3 " DIAMETRE CAST IRON PIPE. THESE PIPES WILL REMAIN IN PLACE DURING THE ENTIRE DURATION OF THE EXPERIMENT

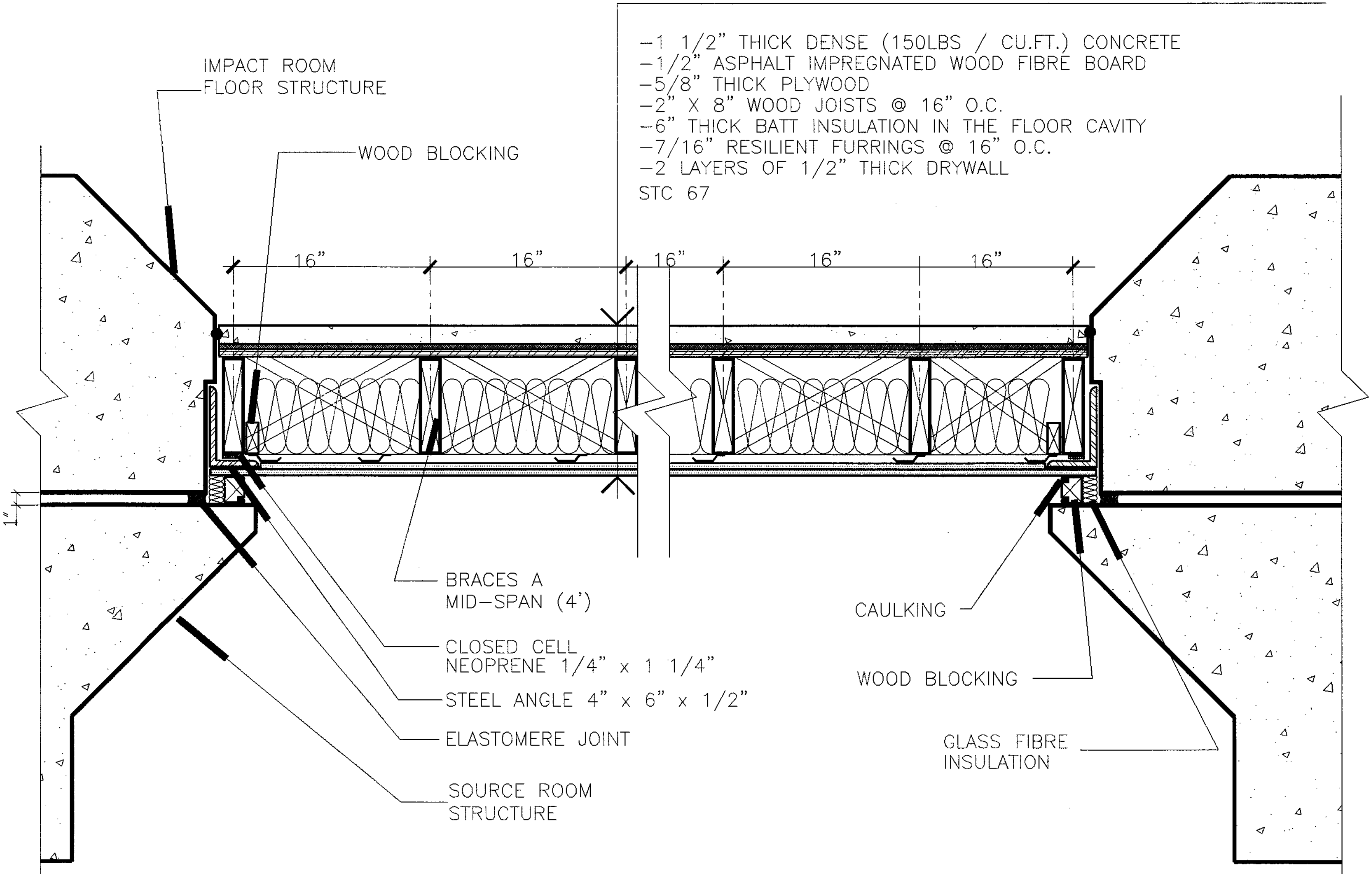
PIPES UNDER TEST

CISPA EXPERIMENTAL SET-UP AT DOMTAR LABORATORY

PROJET 612.991
612991BB

FIGURE A1-2

2000 07

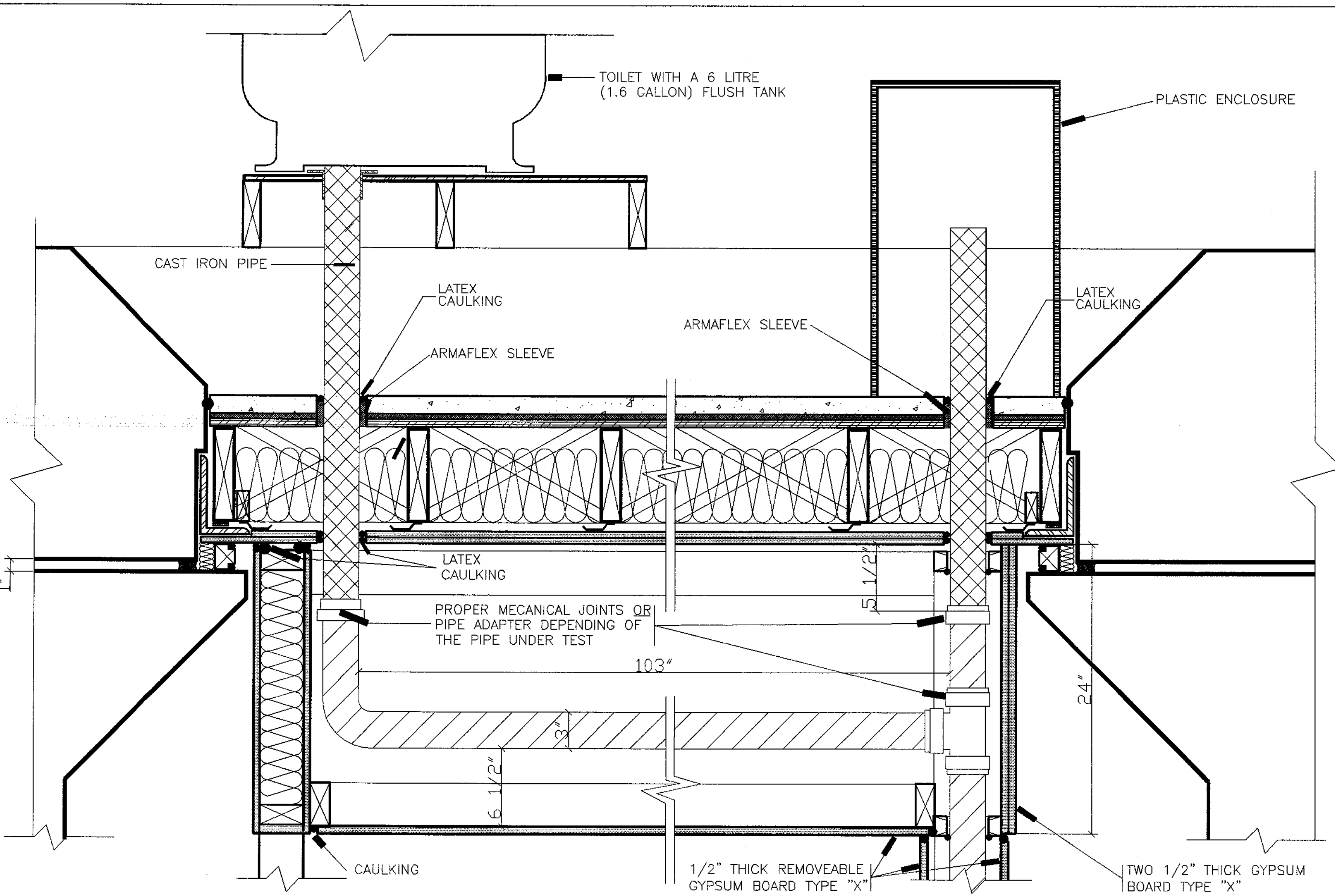


FLOOR/CEILING ASSEMBLY PRESENTLY CONSTRUCTED
AT THE DOMTAR ACOUSTICAL LABORATORY

PROJET 612.991
612991C

FIGURE A1-3

2000 07

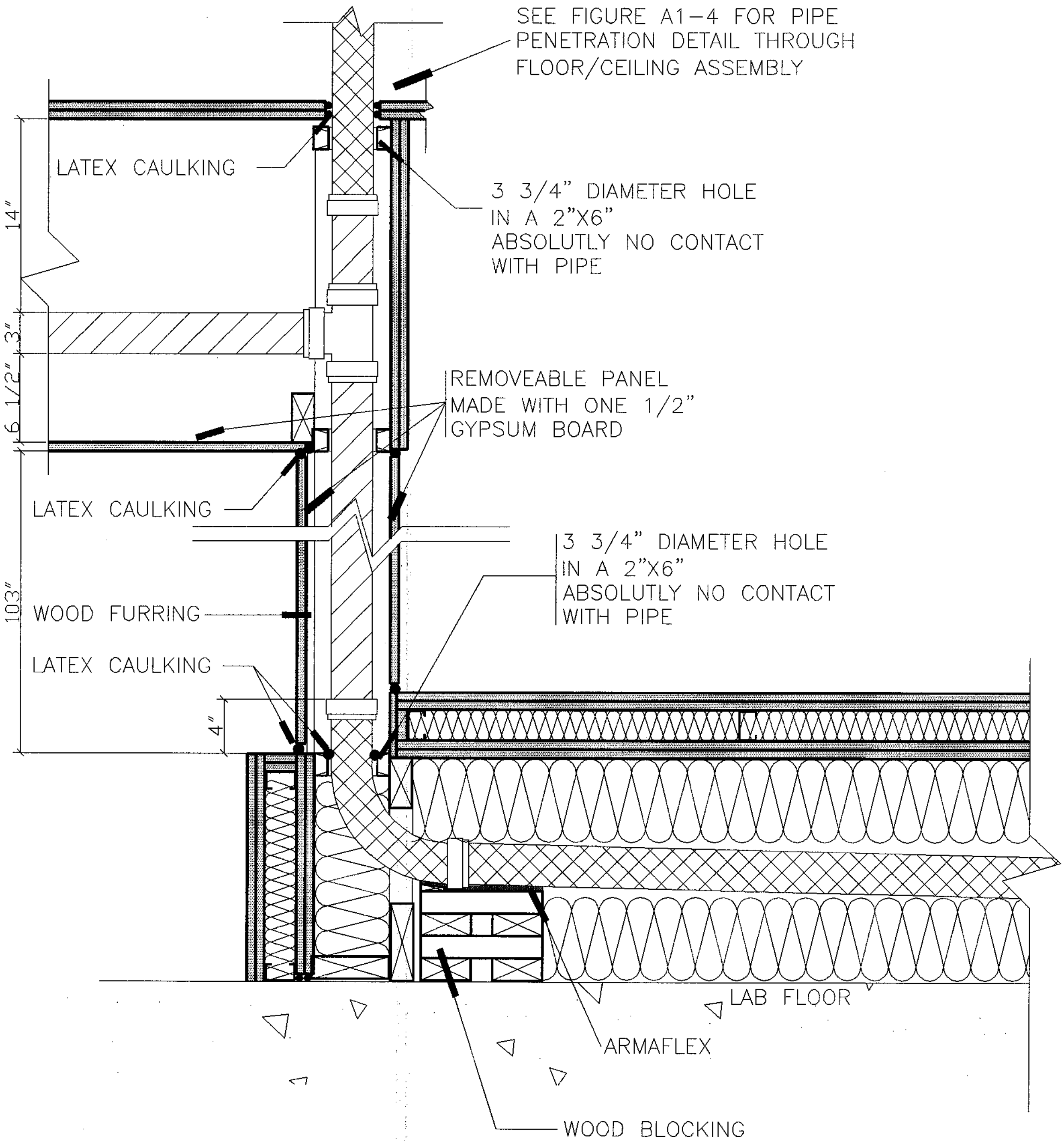


PIPE PENETRATION TROUGH THE FLOOR CEILING ASSEMBLY OF THE DOMTAR ACOUSTICAL LABORATORY

FIGURE A1-4

PROJET 612.991
612991DD

2000 07

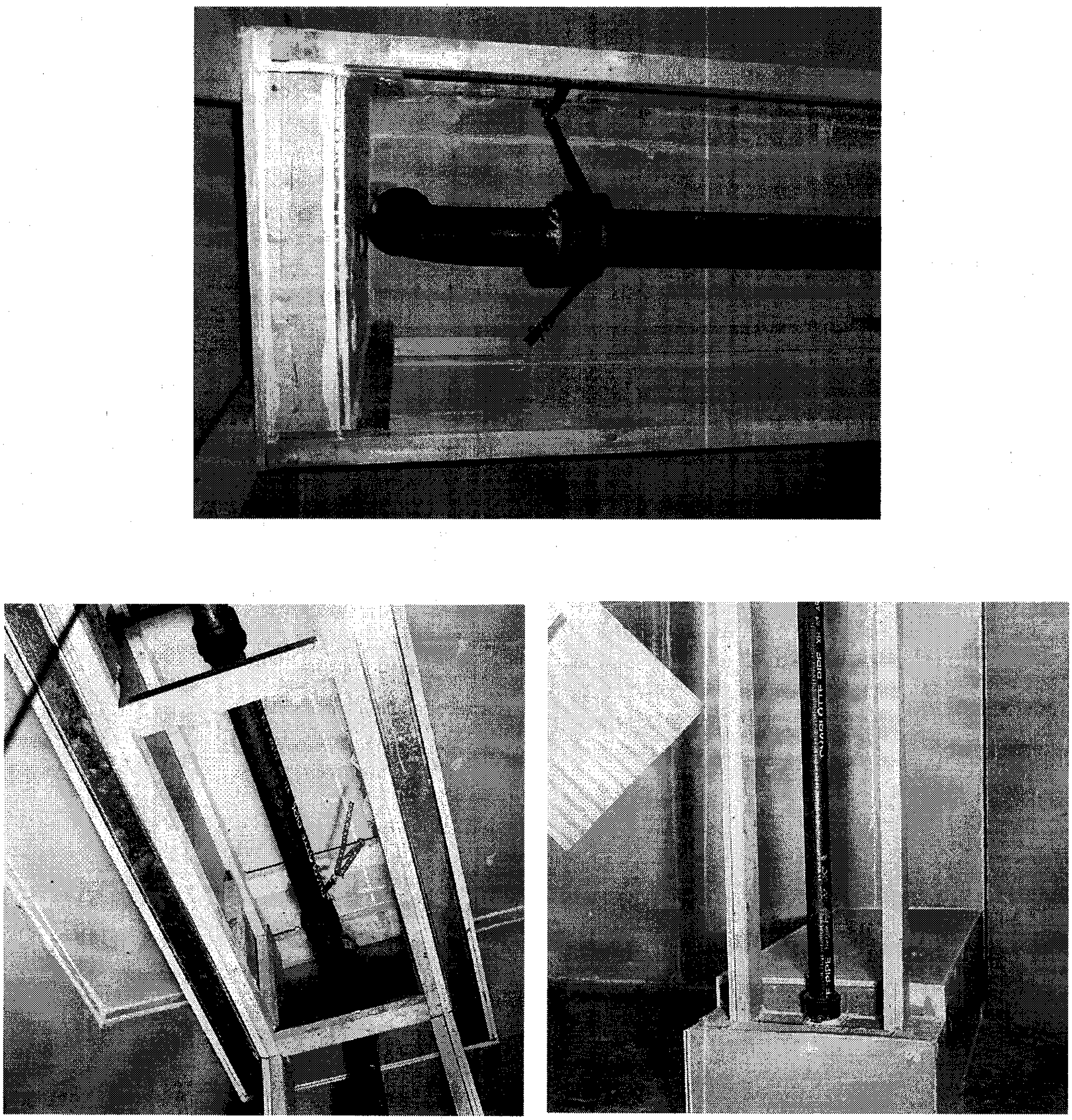


PIPE ENCLOSURE DETAIL

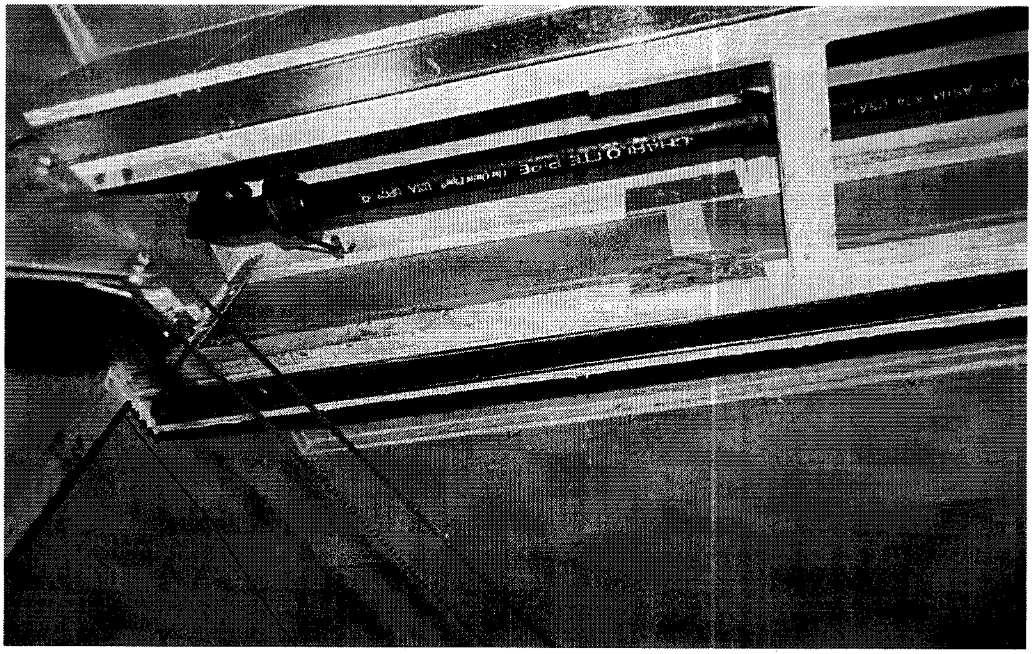
PROJET 612.991
612991EE

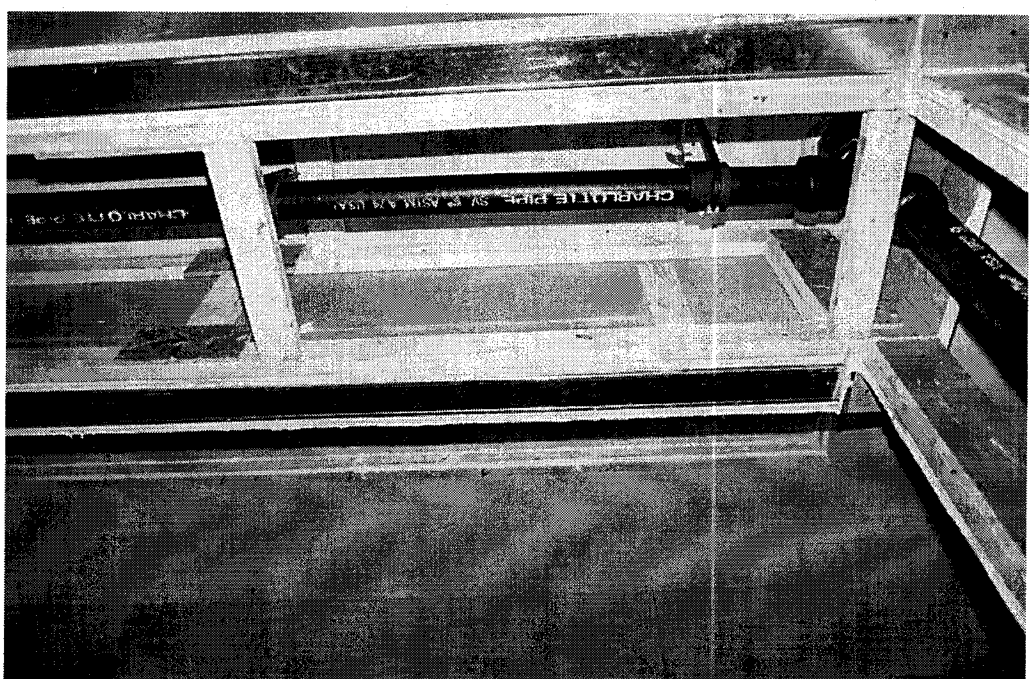
FIGURE A1-5

2000 07

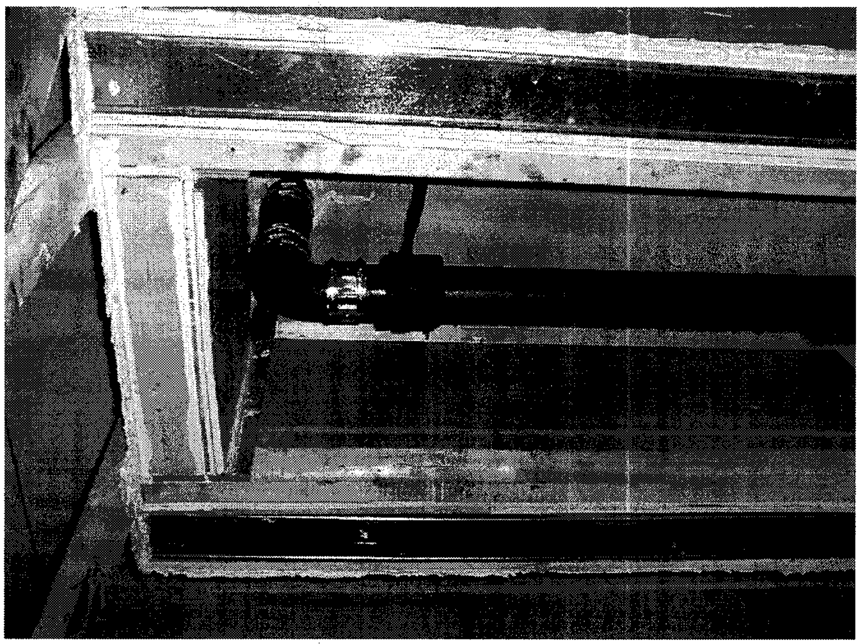


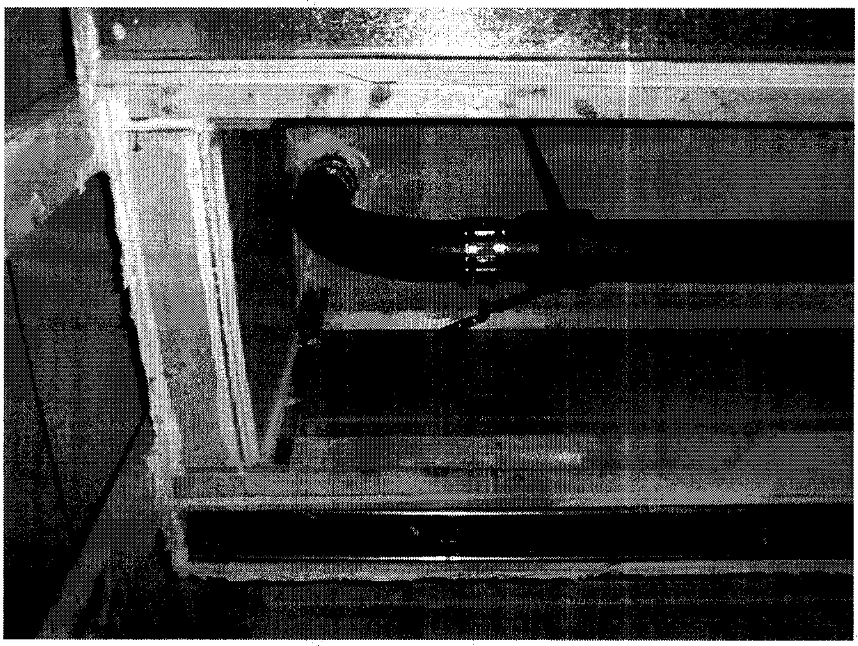
XH pipe assembly

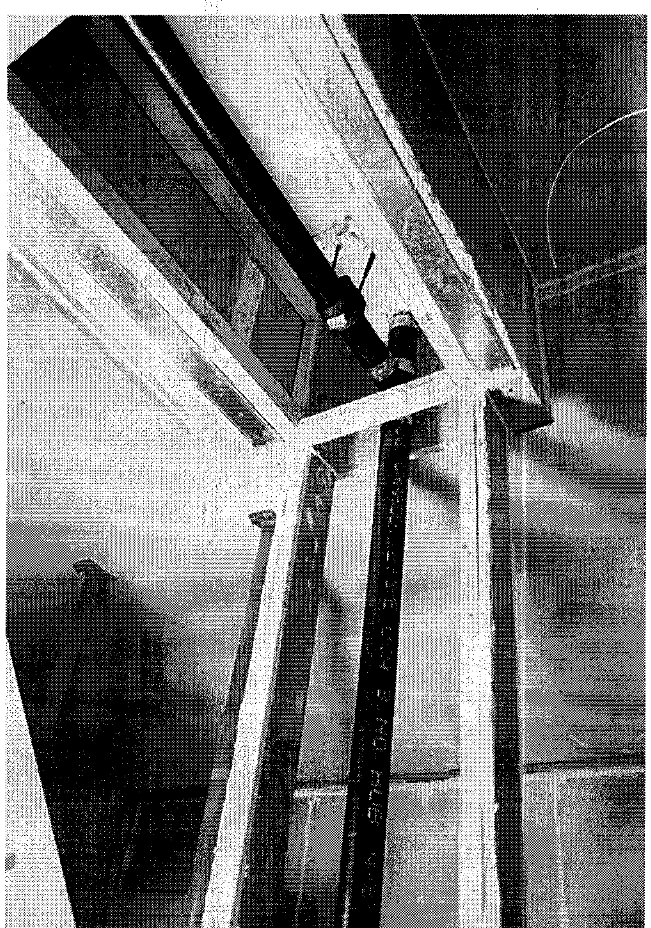




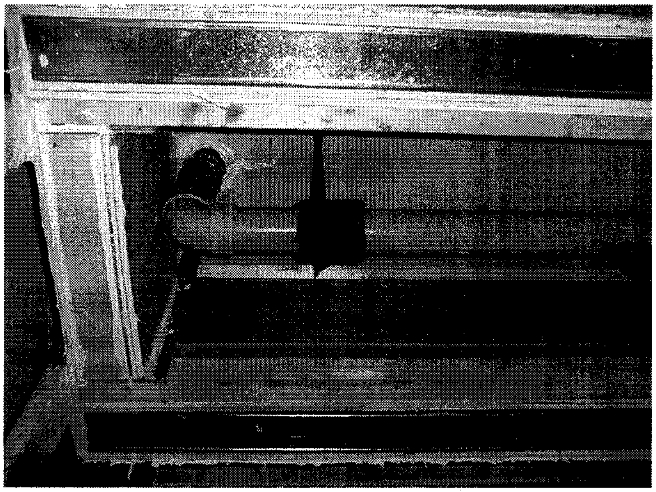
SV pipe assembly

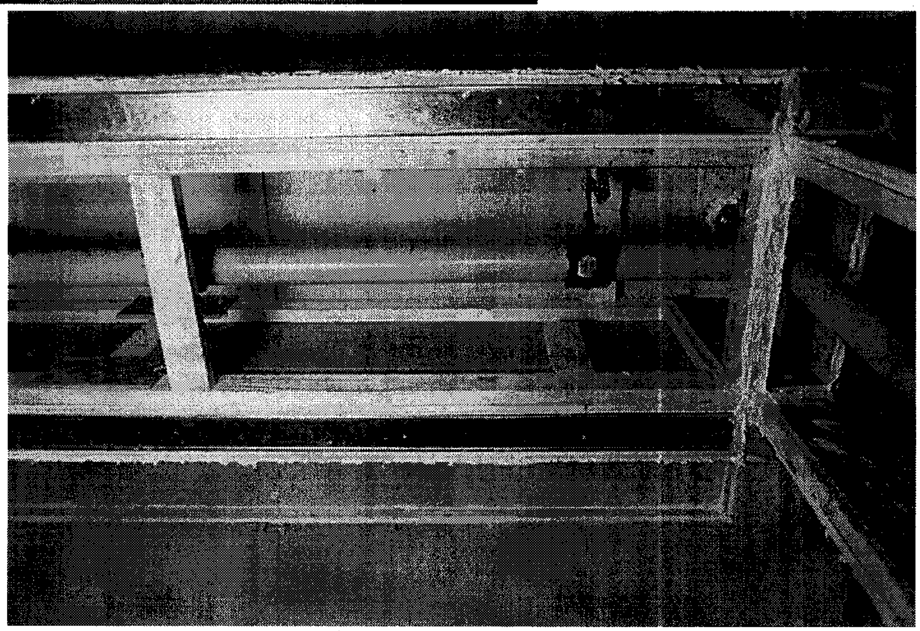


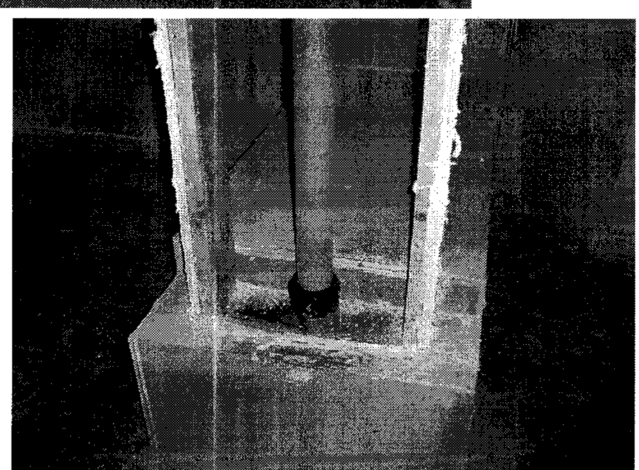




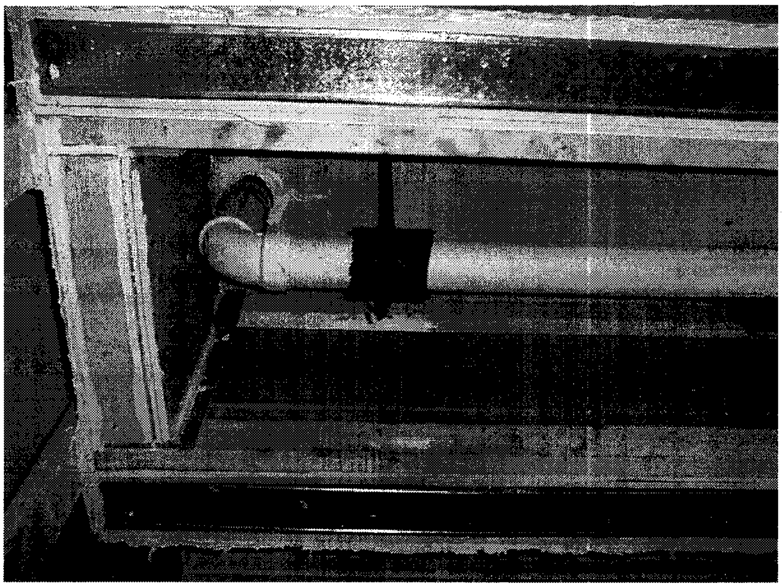
No Hub pipe assembly (Long sweep)

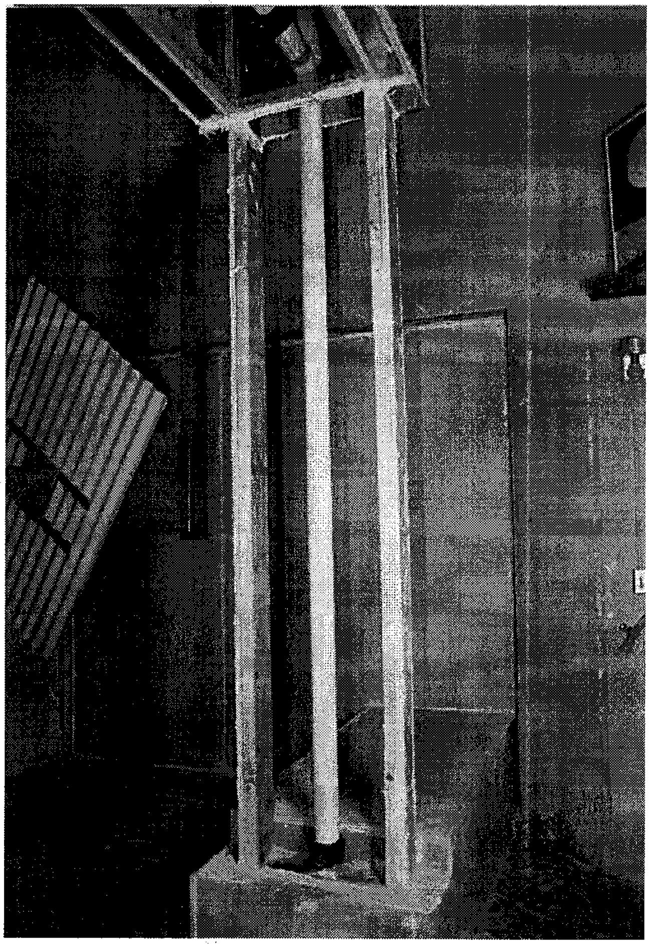




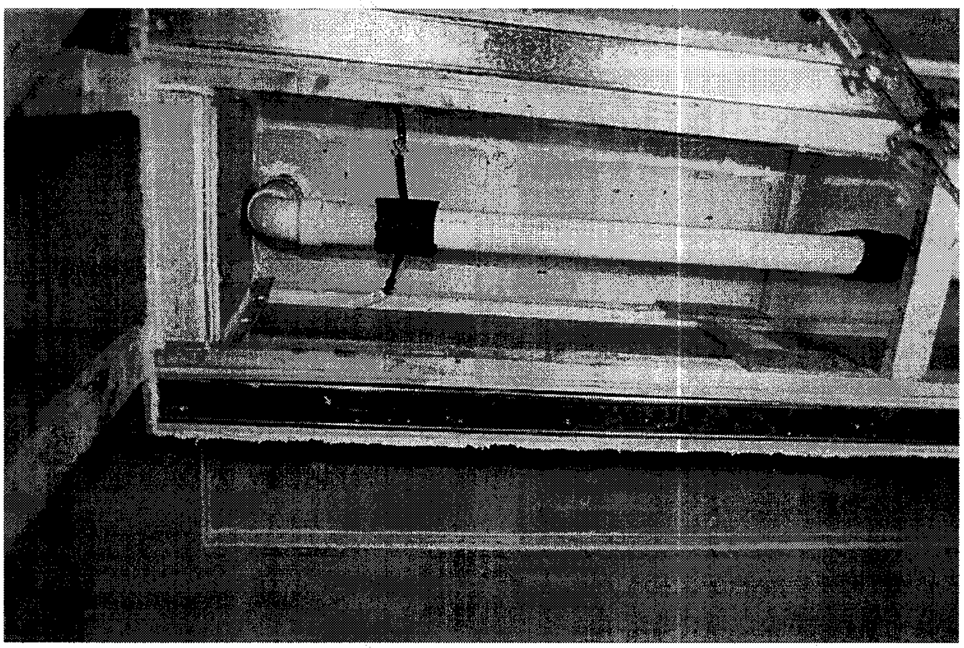


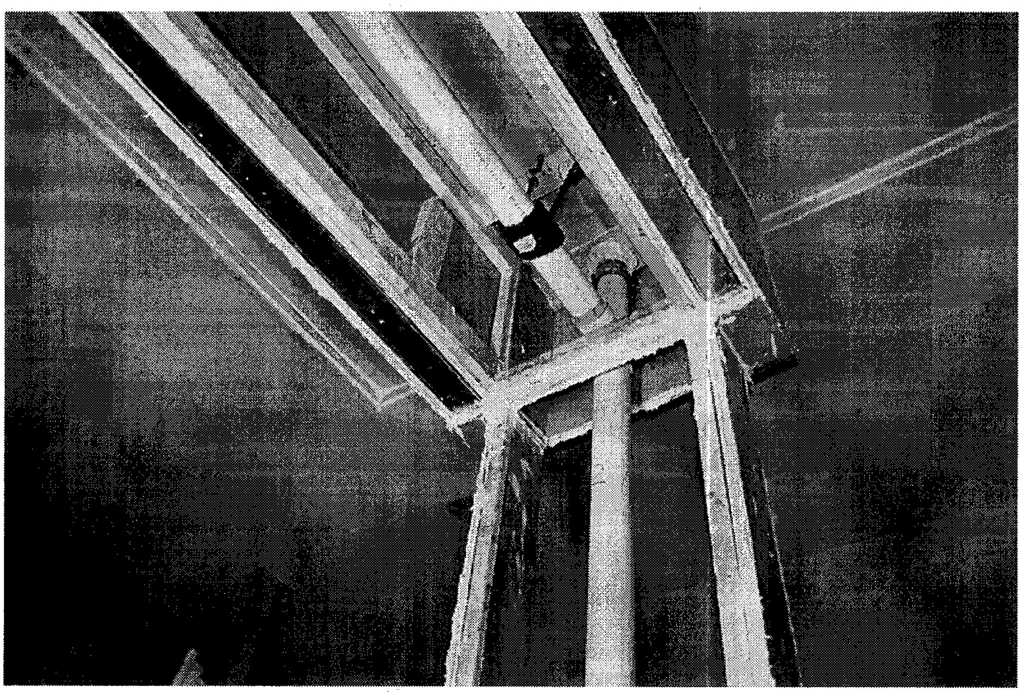
IPEX PVC System 15 pipe assembly



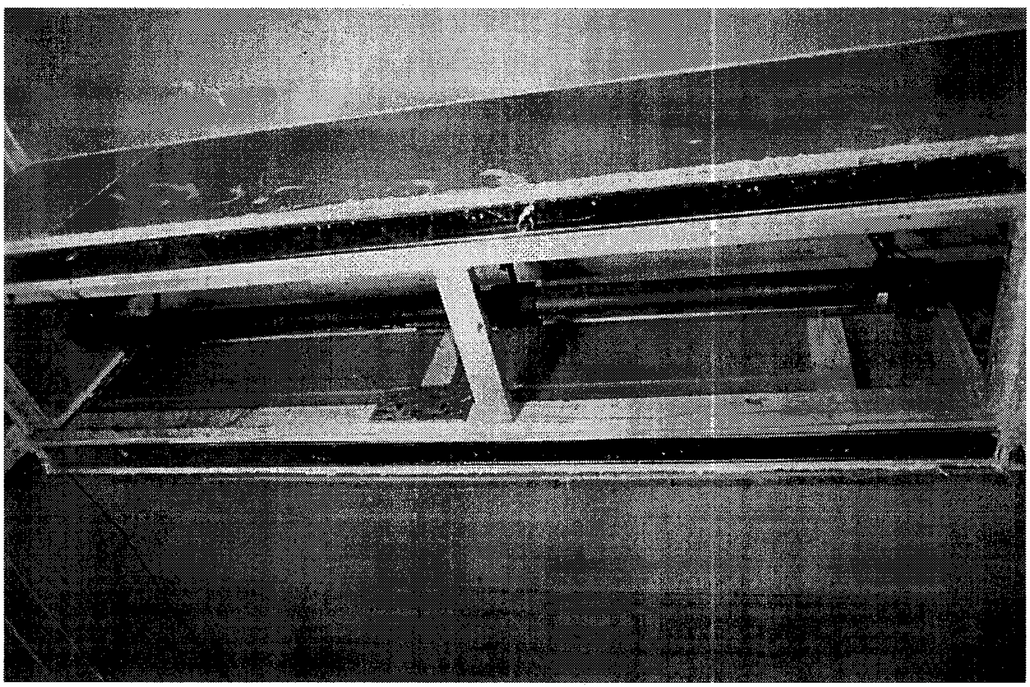


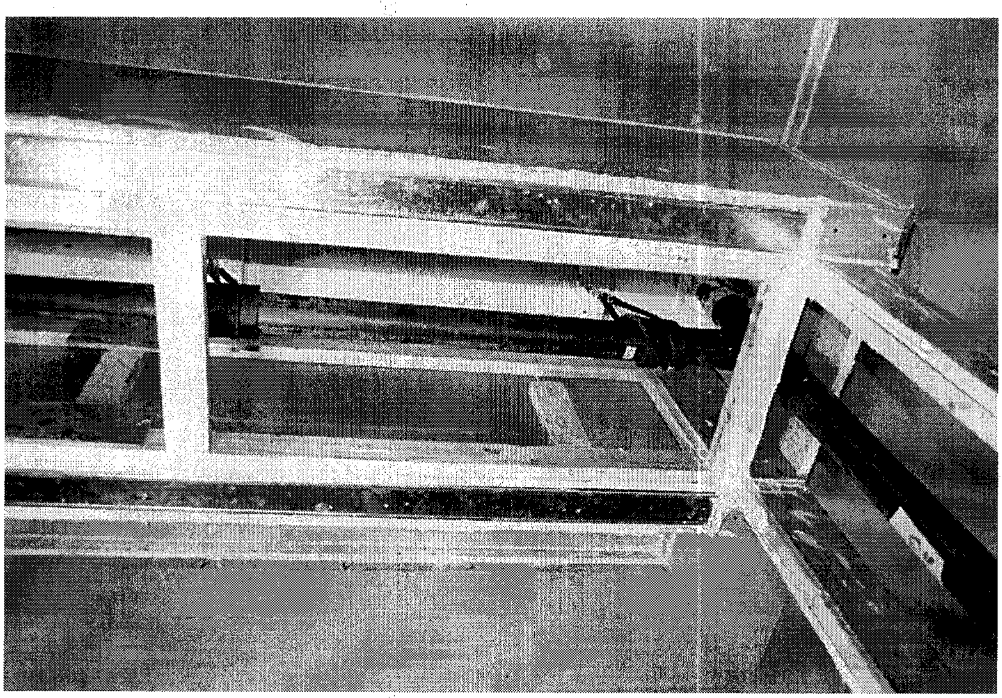
PVC 7300 - ASTM D2665 pipe assembly





PVC 4300 - ASTM F891 pipe assembly

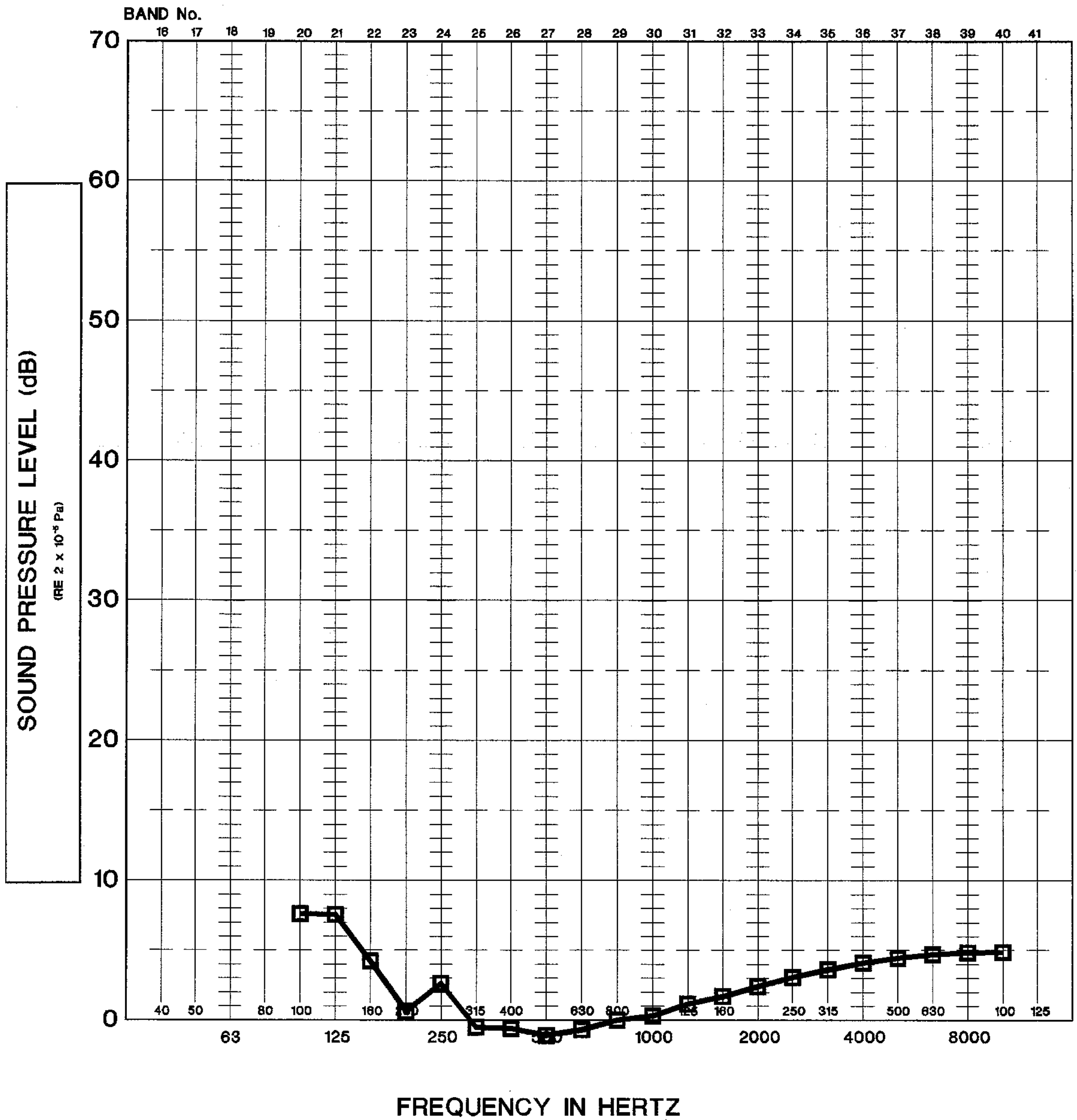




ABS - ASTM F628 pipe assembly

ANNEX II

NOTE: THIS GRAPH ALONE DOES NOT REPRESENT A COMPLETE REPORT



LEGEND

AVERAGE OF THE BACKGROUND SOUND PRESSURE LEVELS MEASURED IN THE 90 m3 ROOM (15 dB(A))

PROJECT DESCRIPTION

NOISE PRODUCED BY DWV PIPES

GRAPH TITLE

BACKGROUND NOISE MEASURED IN THE 90 m3 ROOM

GRAPH NUMBER A2-1

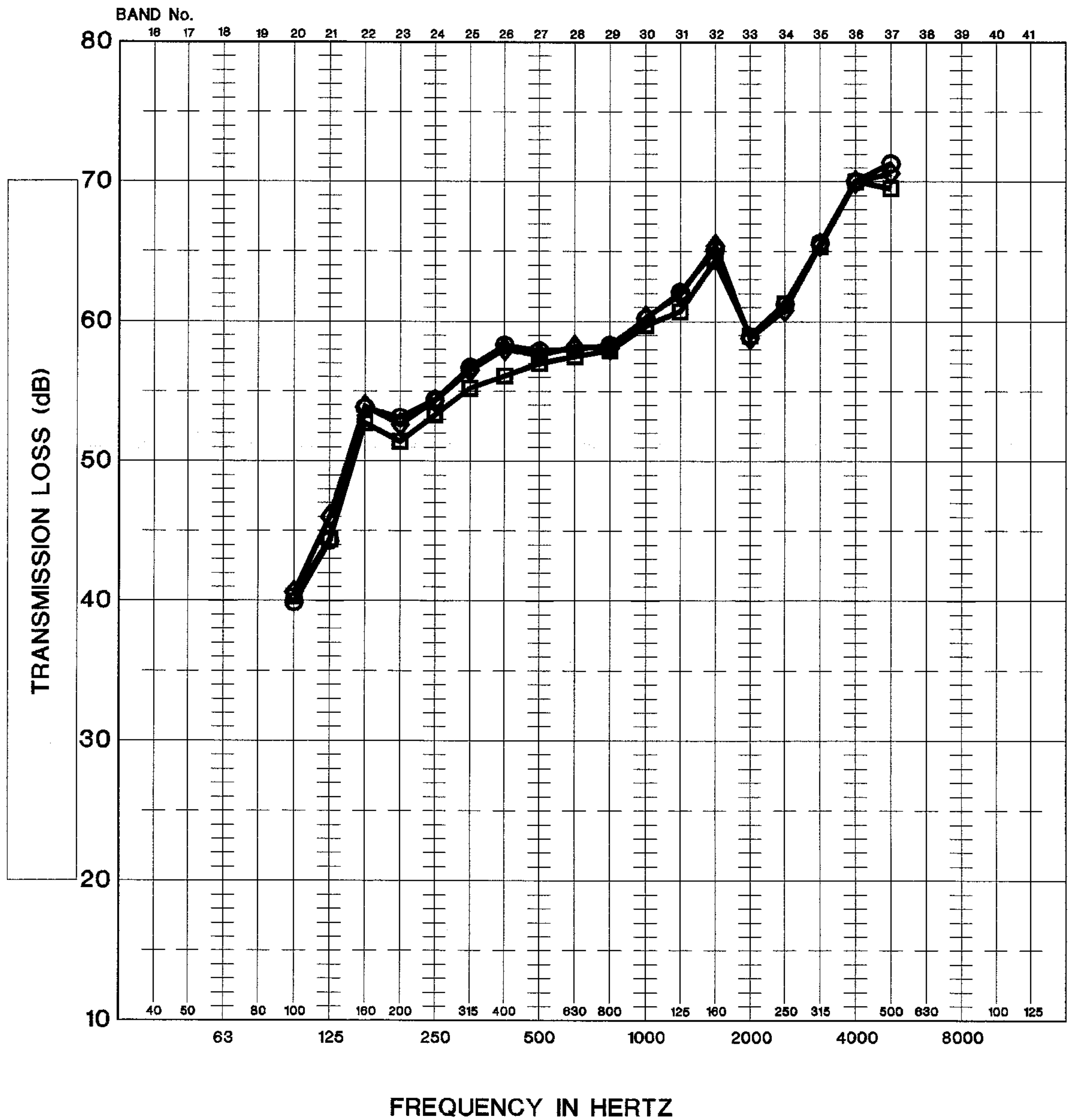
FILE 612-BG

PROJECT NUMBER 612.991

DATE 2000 07

mjm

NOTE: THIS GRAPH ALONE DOES NOT REPRESENT A COMPLETE REPORT



LEGEND

SOUND TRANSMISSION LOSS OF THE WALL BETWEEN THE 90m3 ROOM WHERE THE PIPES WERE INSTALLED AND THE 250m3 ROOM WHERE THE EVACUATION PUMP WAS INSTALLED

◇——◇ WITH NO HUB PIPES INSTALLED IN THE 90m3 ROOM; STC 61

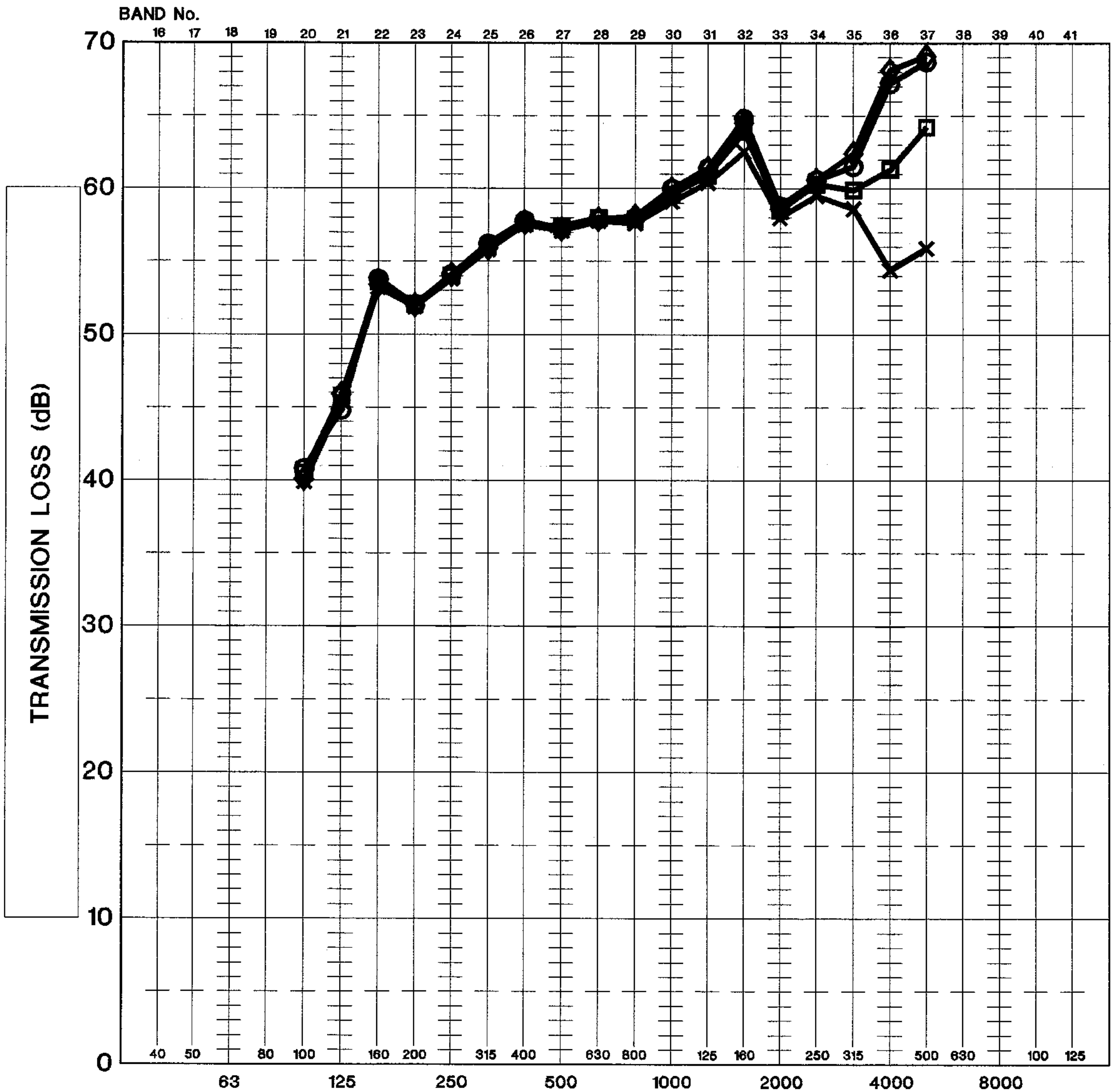
○——○ WITH XH PIPES INSTALLED IN THE 90m3 ROOM; STC 61

□——□ WITH SV PIPES INSTALLED IN THE 90m3 ROOM; STC 60

PROJECT DESCRIPTION NOISE PRODUCED BY DWV PIPES	
GRAPH TITLE SOUND TRANMISSION LOSS MEASUREMENT OF THE WALL WITH CAST IRON PIPES INSTALLED IN THE 90m3 ROOM	
GRAPH NUMBER A2-2	**FILE NAME:** 612-TL1
PROJECT NUMBER 612.991	**DATE** 2000 07

MJM

NOTE: THIS GRAPH ALONE DOES NOT REPRESENT A COMPLETE REPORT



LEGEND

SOUND TRANSMISSION LOSS OF THE WALL BETWEEN THE 90m3 ROOM WHERE THE PIPES WERE INSTALLED AND THE 250m3 ROOM WHERE THE EVACUATION PUMP WAS INSTALLED

o———o WITH IPEX PVC SYSTEM 15 PIPES INSTALLED IN THE 90m3 ROOM; STC 60

◇———◇ WITH PVC 7300 ASTM D2665 PIPES INSTALLED IN THE 90m3 ROOM; STC 60

□———□ WITH PVC 4300 ASTM F891 PIPES INSTALLED IN THE 90m3 ROOM; STC 59

×———× WITH ABS 3300 ASTM F628 PIPES INSTALLED IN THE 90m3 ROOM; STC 58

PROJECT DESCRIPTION

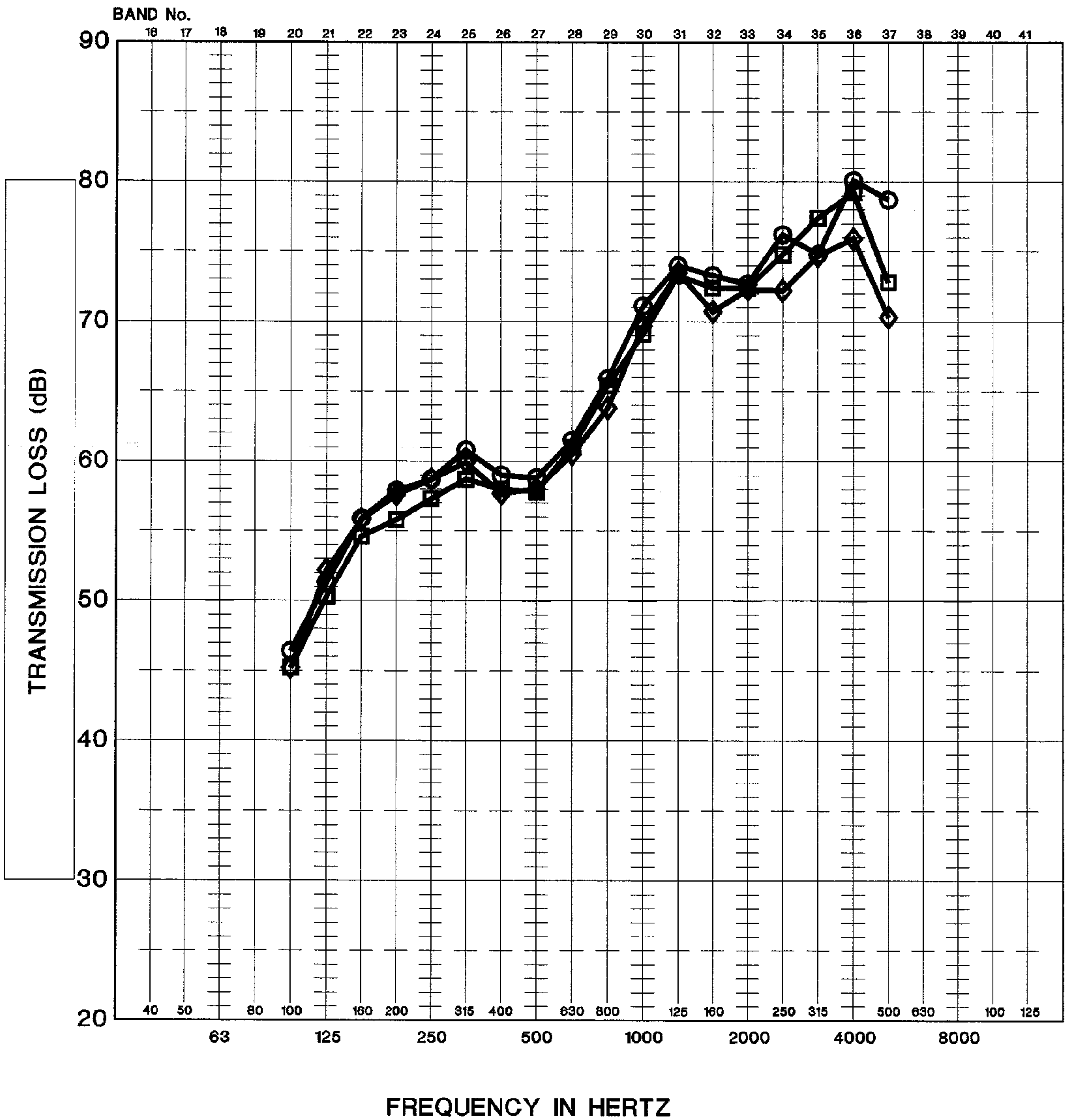
NOISE PRODUCED BY DWV PIPES

GRAPH TITLE

SOUND TRANMISSION LOSS MEASUREMENT OF THE WALL WITH PVC AND ABS PIPES INSTALLED IN THE 90m3 ROOM

GRAPH NUMBER A2–3	**FILE NAME:** 612–TL2
PROJECT NUMBER 612.991	**DATE** 2000 07

NOTE: THIS GRAPH ALONE DOES NOT REPRESENT A COMPLETE REPORT



LEGEND

SOUND TRANSMISSION LOSS OF THE FLOOR/CEILING ASSEMBLY BETWEEN THE 97m3 AND THE 90m3 ROOMS

○—○ WITH XH PIPES INSTALLED IN THE 90m3 ROOM; STC 67

□—□ WITH SV PIPES INSTALLED IN THE 90m3 ROOM; STC 66

◇—◇ WITH NO HUB PIPES INSTALLED IN THE 90m3 ROOM; STC 66

PROJECT DESCRIPTION

NOISE PRODUCED BY DWV PIPES

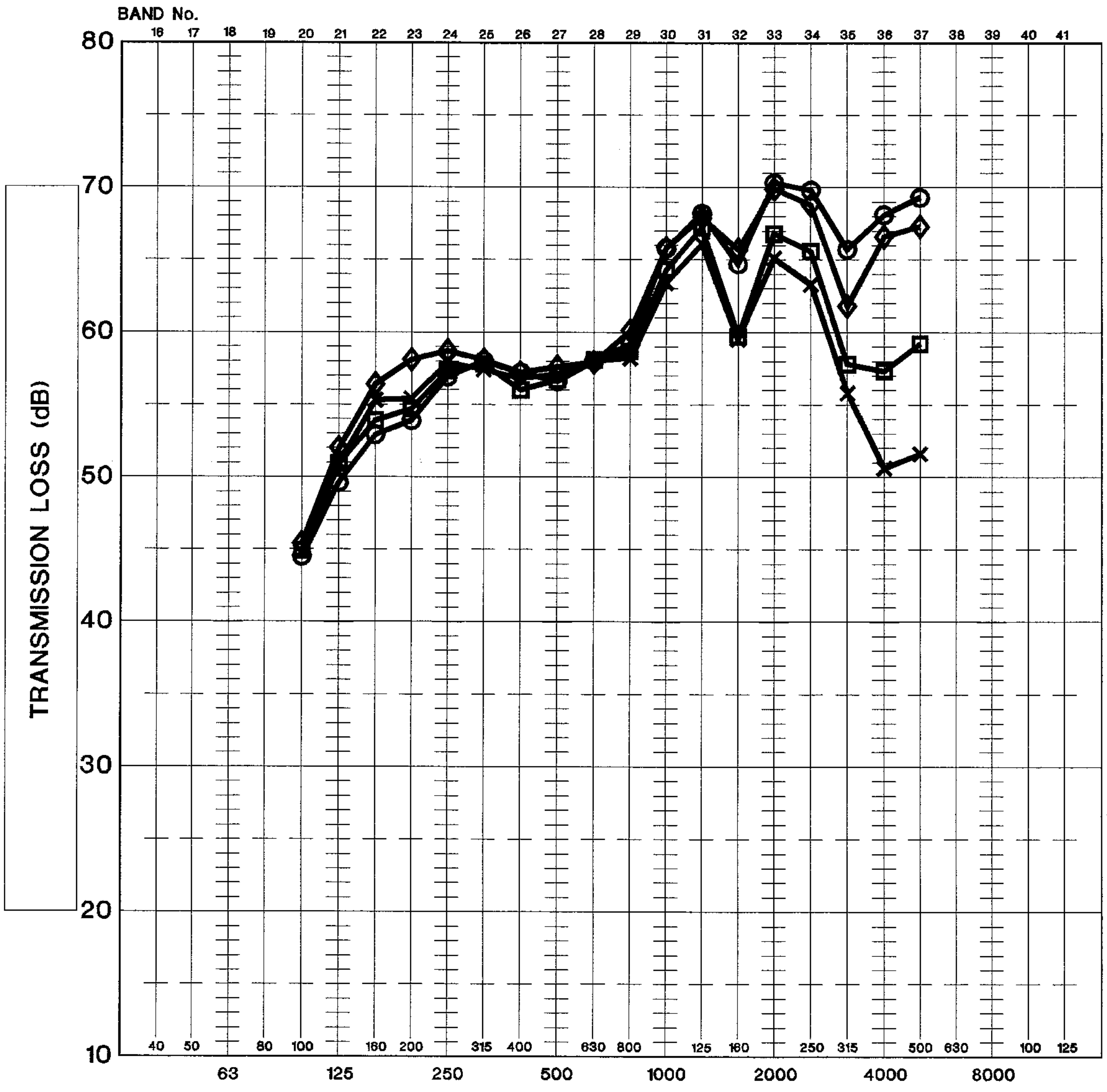
GRAPH TITLE

SOUND TRANMISSION LOSS MEASUREMENT OF THE FLOOR/CEILING ASSEMBLY WITH CAST IRON PIPES IN THE 90m3 ROOM

GRAPH NUMBER A2-4	**FILE NAME:** 612-TL3
PROJECT NUMBER 612.991	**DATE** 2000 07

mjm

NOTE: THIS GRAPH ALONE DOES NOT REPRESENT A COMPLETE REPORT



LEGEND

SOUND TRANSMISSION LOSS OF THE FLOOR/CEILING ASSEMBLY BETWEEN THE 97m3 AND THE 90m3 ROOMS

◇——◇ WITH PVC 7300 ASTM D2665 PIPES INSTALLED IN THE 90m3 ROOM; STC 63

○——○ WITH IPEX PVC SYSTEM 15 PIPES INSTALLED IN THE 90m3 ROOM; STC 63

□——□ WITH PVC 4300 ASTM F891 PIPES INSTALLED IN THE 90m3 ROOM; STC 60

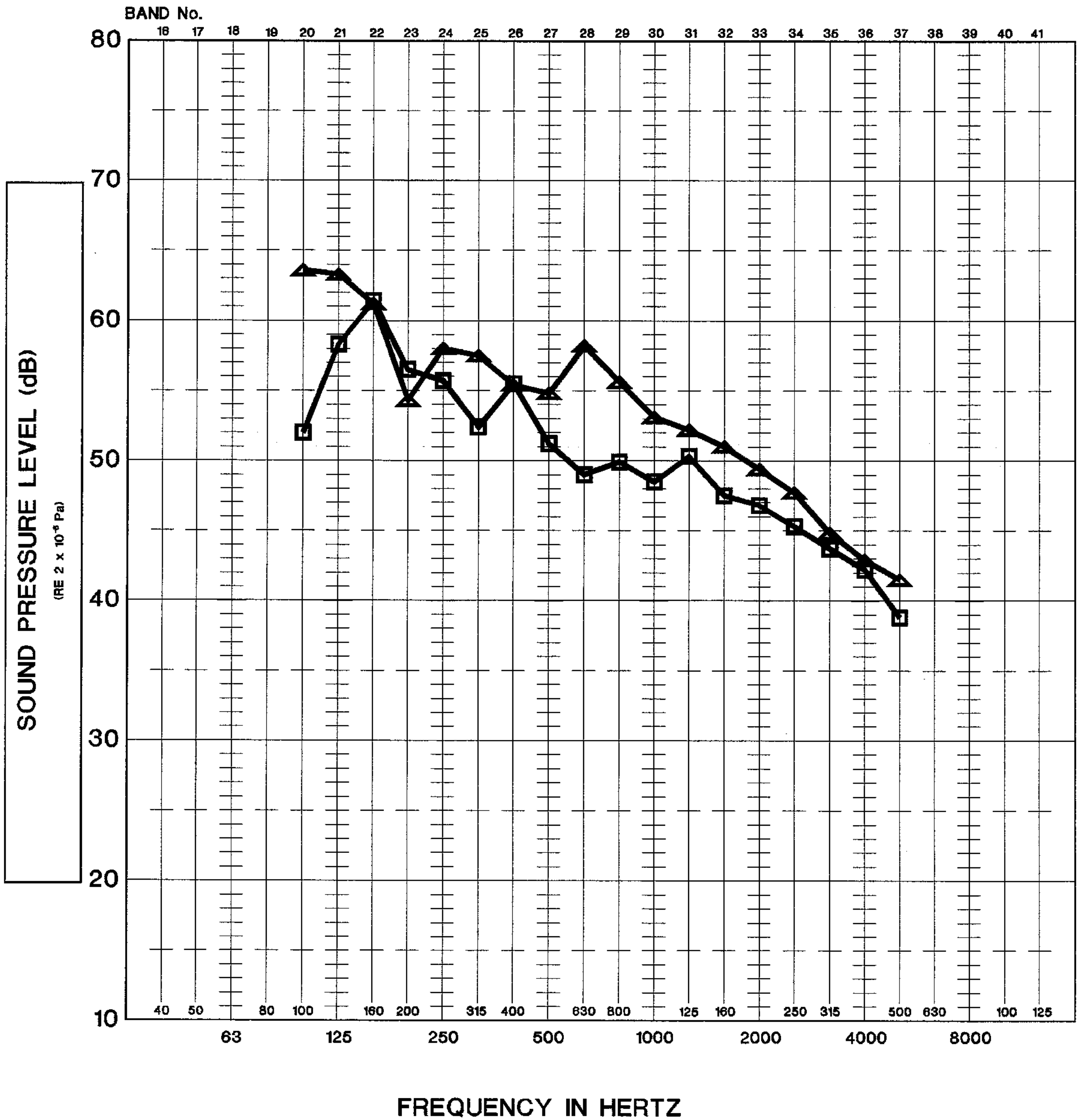
×——× WITH ABS 3300 ASTM F628 PIPES INSTALLED IN THE 90m3 ROOM; STC 55

PROJECT DESCRIPTION
NOISE PRODUCED BY DWV PIPES

GRAPH TITLE
SOUND TRANMISSION LOSS MEASUREMENT OF THE FLOOR/CEILING ASSEMBLY WITH PVC AND ABS PIPES IN THE 90m3 ROOM

GRAPH NUMBER A2-5	**FILE NAME:** 612-TL4
PROJECT NUMBER 612.991	**DATE** 2000 07

NOTE: THIS GRAPH ALONE DOES NOT REPRESENT A COMPLETE REPORT



LEGEND

△——△ TOILET FLUSH NOISE

AVERAGE OF THE MAXIMUM SOUND PRESSURE LEVELS (DETECTOR TIME = 35ms) MEASURED AT TEN POSITIONS IN THE 97m3 ROOM DURING TOILET FLUSHES (64 dB(A))

(THE TOILET BOWL OPENING WAS COVERED BY A NEOPRENE AND GYPSUM BOARD TO REDUCE THE AIRBORNE NOISE LEVELS GENERATED IN THE 97m3 ROOM DURING TOILET FLUSHES)

□——□ PUMP NOISE

AVERAGE SOUND PRESSURE LEVELS MEASURED AT TEN POSITIONS IN THE 250m3 ROOM (60 dB(A))

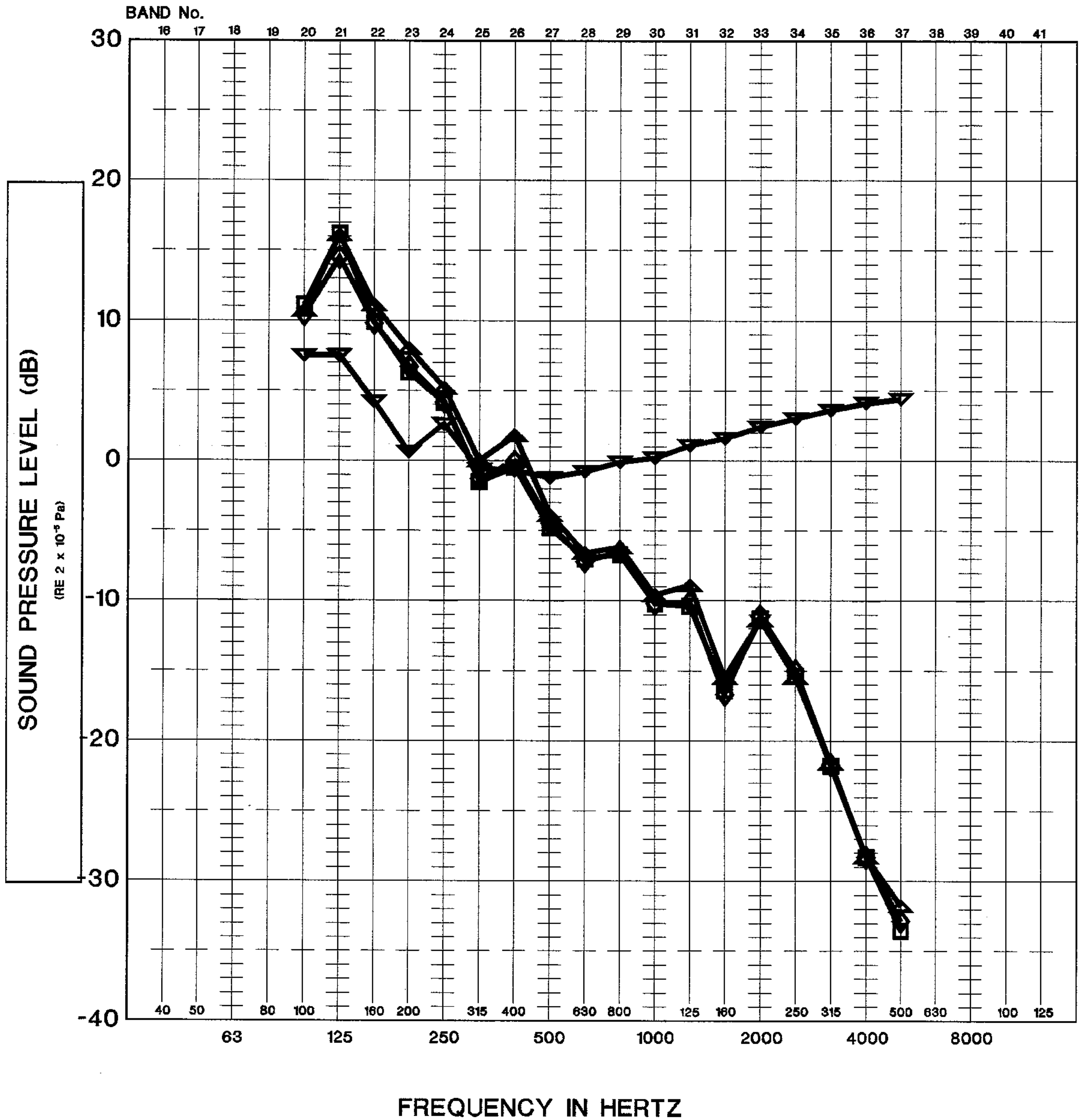
PROJECT DESCRIPTION
NOISE PRODUCED BY DWV PIPES

GRAPH TITLE
REVERBERANT SOUND PRESSURE LEVEL PRODUCED BY THE PUMP AND THE TOILET

GRAPH NUMBER A2-6	**FILE** 612-LP1
PROJECT NUMBER 612.991	**DATE** 2000 07

mjm

NOTE: THIS GRAPH ALONE DOES NOT REPRESENT A COMPLETE REPORT



LEGEND

CAST IRON PIPES

EVALUATION OF THE REVERBERANT SOUND PRESSURE LEVELS TRANSMITTED TO THE 90m3 ROOM WHILE THE PUMP IS OPERATING IN THE 250m3 ROOM:

- WITH SV PIPES INSTALLED IN THE 90m3 ROOM
- WITH XH PIPES INSTALLED IN THE 90m3 ROOM
- WITH NO HUB PIPES INSTALLED IN THE 90m3 ROOM
- AVERAGE BACKGROUND NOISE LEVELS MEASURED AT TEN POSITIONS IN THE 90m3 ROOM (15 dB(A))

PROJECT DESCRIPTION

NOISE PRODUCED BY DWV PIPES

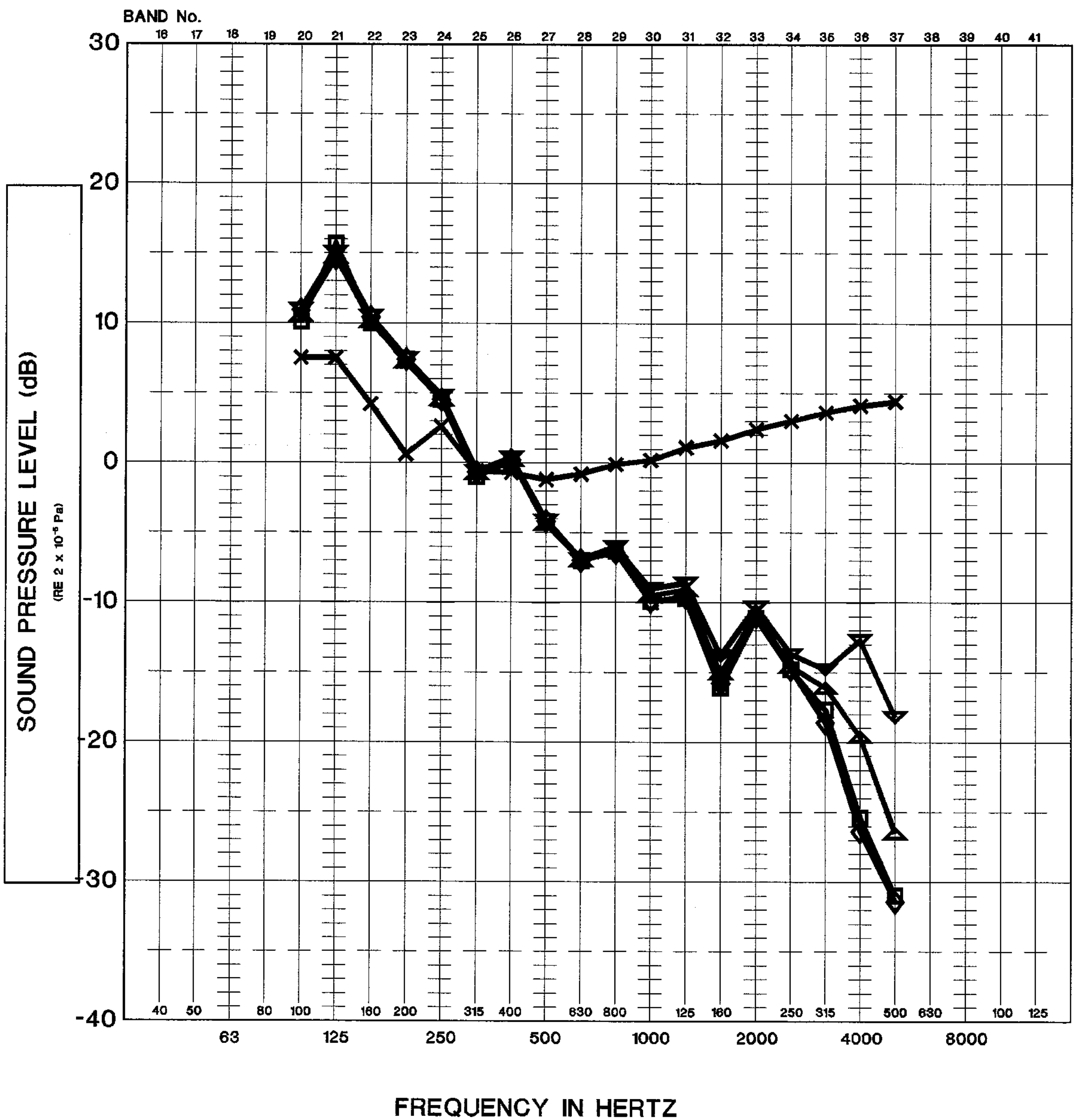
GRAPH TITLE

PUMP AIRBORNE NOISE LEVELS TRANSMITTED TO THE 90m3 ROOM THROUGH THE WALL – CAST IRON PIPES UNENCLOSED

GRAPH NUMBER A2–7	**FILE** 612–EVA1
PROJECT NUMBER 612.991	**DATE** 2000 07

mjm

NOTE: THIS GRAPH ALONE DOES NOT REPRESENT A COMPLETE REPORT



LEGEND

PLASTIC PIPES

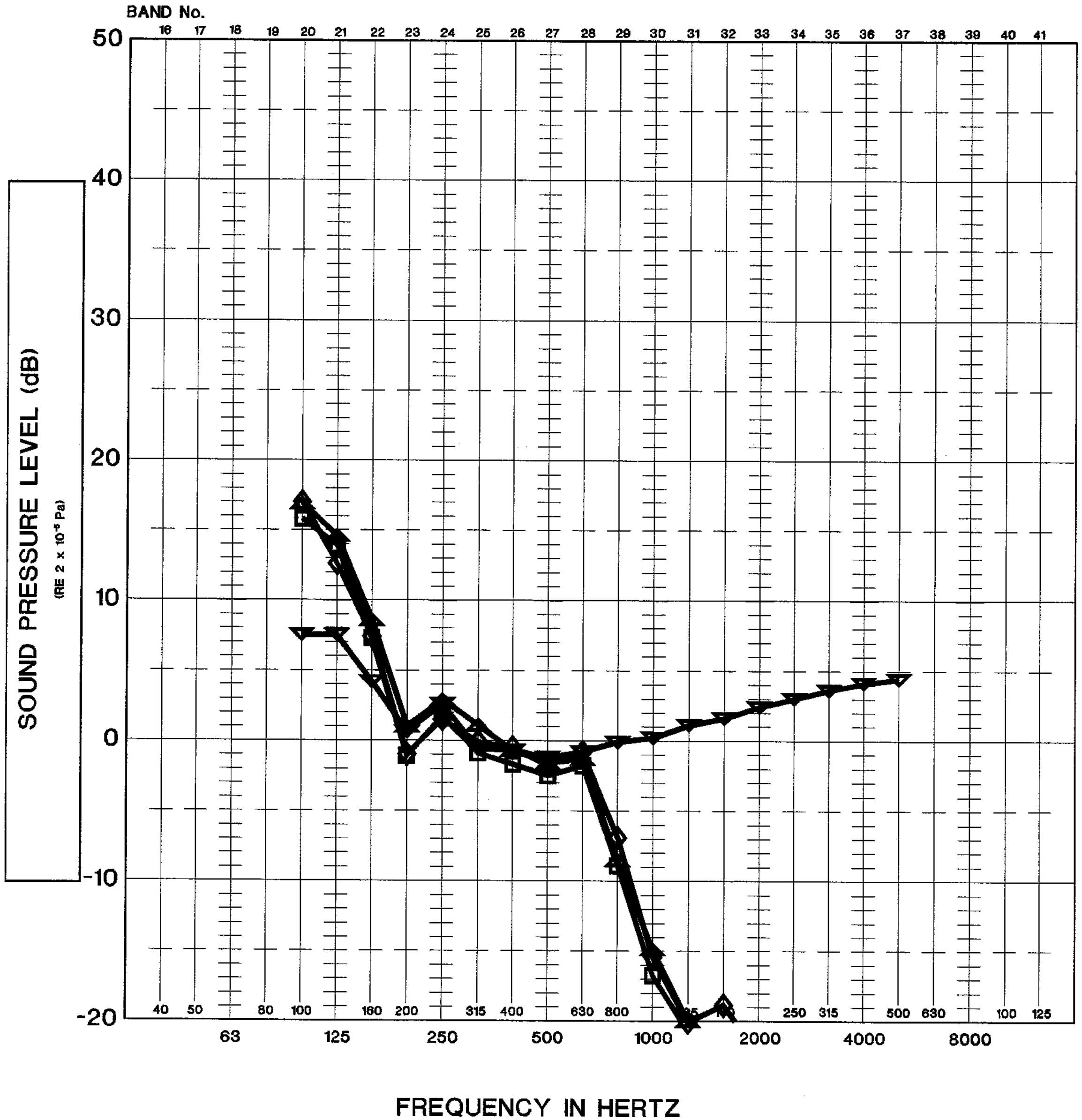
EVALUATION OF THE REVERBERANT SOUND PRESSURE LEVELS TRANSMITTED TO THE 90m3 ROOM WHILE THE PUMP IS OPERATING IN THE 250m3 ROOM:

- WITH ABS 3300 ASTM F628 PIPES INSTALLED IN THE 90m3 ROOM
- WITH PVC 4300 ASTM F891 PIPES INSTALLED IN THE 90m3 ROOM
- WITH PVC 7300 ASTM D2665 PIPES INSTALLED IN THE 90m3 ROOM
- WITH IPEX PVC SYSTEM 15 PIPES INSTALLED IN THE 90m3 ROOM
- AVERAGE OF THE BACKGROUND NOISE LEVEL MEASURED AT TEN POSITIONS IN THE 90m3 ROOM (15 dB(A))

PROJECT DESCRIPTION	
NOISE PRODUCED BY DWV PIPES	
GRAPH TITLE: PUMP AIRBORNE NOISE LEVELS TRANSMITED TO THE 90m3 ROOM THROUGH THE WALL – PLASTIC PIPES UNENCLOSED	
GRAPH NUMBER A2-8	FILE 612-EVA2
PROJECT NUMBER 612.991	DATE 2000 07

mjm

NOTE: THIS GRAPH ALONE DOES NOT REPRESENT A COMPLETE REPORT



LEGEND

CAST IRON PIPES

EVALUATION OF THE MAXIMUM AIRBORNE SOUND PRESSURE LEVEL TRANSMITED IN THE SOURCE ROOM THROUGH THE FLOOR/ CEILING ASSEMBLY DURING TOILET FLUSHES

◇——◇ WITH NO HUB PIPES INSTALLED IN THE 90m3 ROOM

△——△ WITH SV PIPES INSTALLED IN THE 90m3 ROOM

□——□ WITH XH PIPES INSTALLED IN THE 90m3 ROOM

▽——▽ AVERAGE BACKGROUND NOISE LEVELS MEASURED AT TEN POSITIONS IN THE 90m3 ROOM (15 dB(A))

PROJECT DESCRIPTION

NOISE PRODUCED BY DWV PIPES

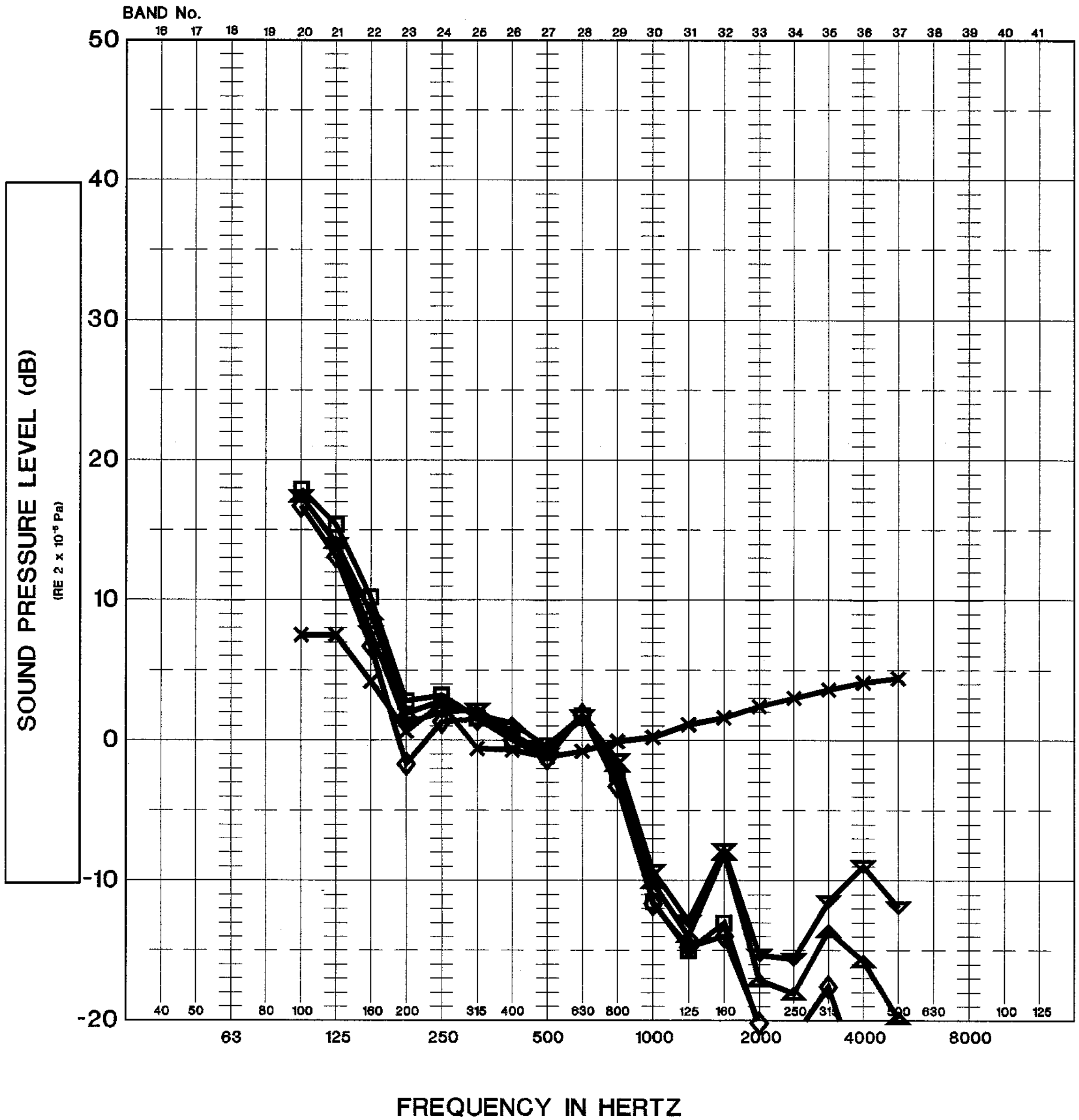
GRAPH TITLE

TOILET FLUSH AIRBORNE NOISE TRANSMITTED TO THE 90m3 ROOM – CAST IRON PIPES UNENCLOSED

GRAPH NUMBER A2–9	**FILE** 612–EVA3
PROJECT NUMBER 612.991	**DATE** 2000 07

mjm

NOTE: THIS GRAPH ALONE DOES NOT REPRESENT A COMPLETE REPORT



LEGEND

PLASTIC PIPES

EVALUATION OF THE MAXIMUM AIRBORNE SOUND PRESSURE LEVEL TRANSMITED IN THE SOURCE ROOM THROUGH THE FLOOR/ CEILING ASSEMBLY DURING TOILET FLUSHES

▽——▽ WITH ABS 3300 ASTM F628 PIPES INSTALLED IN THE 90m3 ROOM

△——△ WITH PVC 4300 ASTM F891 PIPES INSTALLED IN THE 90m3 ROOM

□——□ WITH IPEX PVC SYSTEM 15 PIPES INSTALLED IN THE 90m3 ROOM

◇——◇ WITH PVC 7300 ASTM D2665 PIPES INSTALLED IN THE 90m3 ROOM

×——× AVERAGE BACKGROUND NOISE LEVELS MEASURED AT TEN POSITIONS IN THE 90m3 ROOM (15 dB(A))

PROJECT DESCRIPTION NOISE PRODUCED BY DWV PIPES	
GRAPH TITLE TOILET FLUSH AIRBORNE NOISE TRANSMITTED TO THE 90m3 ROOM – CAST IRON PIPES UNENCLOSED	
GRAPH NUMBER A2-10	**FILE** 612-EVA4
PROJECT NUMBER 612.991	**DATE** 2000 07

ANNEX III

ANNEX III

REPEATABILITY TESTS

The repeatability of the noise radiated during a water closet flush in the 90 m^3 room has been assessed for each type of pipe tested. This repeatability test consisted in flushing the water closet five times while the microphone was located at position 5 along the microphone transverse of the 90 m^3 room where the pipes were installed.

The results obtained for each type of pipe tested while unenclosed are presented on **figures A3.1 to A3.8** below. The measured sound pressure levels appearing on these figures indicate that the water closet used to produce water flow noise in pipes was relatively stable and that the sound pressure levels generated in the 90 m^3 room by the different pipes tested can be repeated with a reasonable degree of precision.

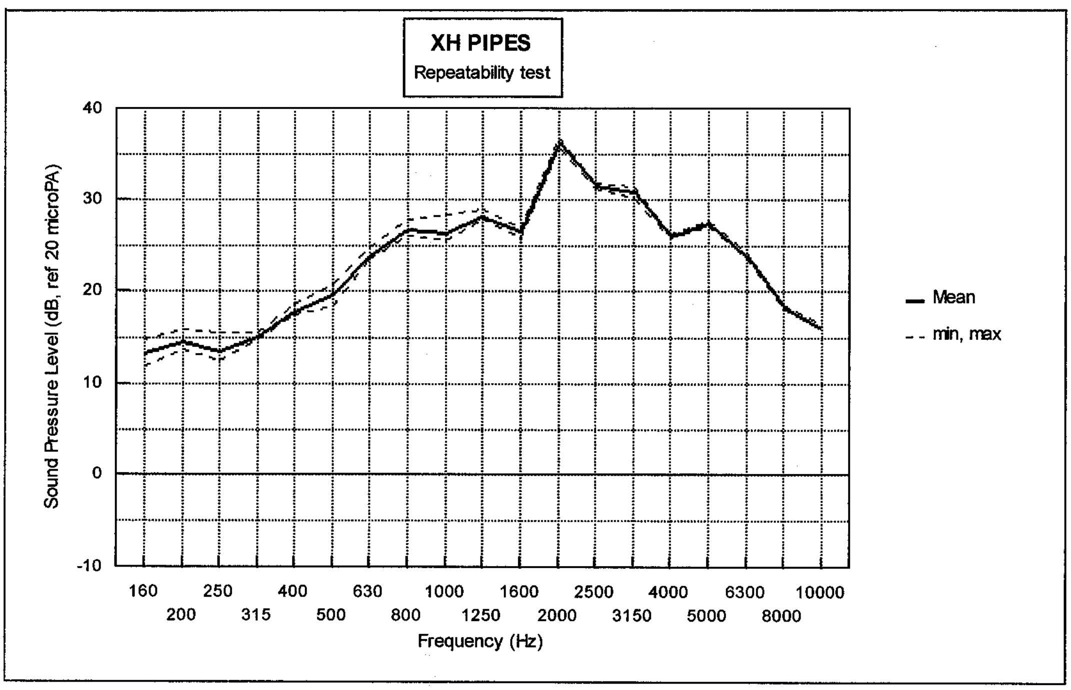


Figure A3.1: Repeatability test on XH pipe

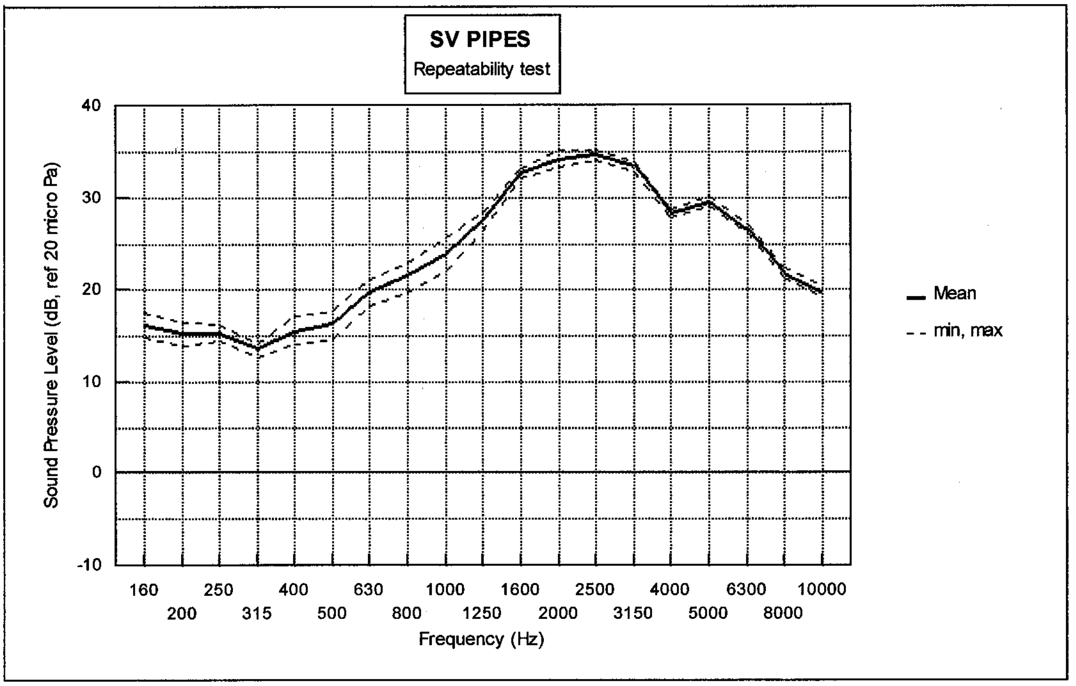


Figure A3.2: Repeatability test on SV pipe

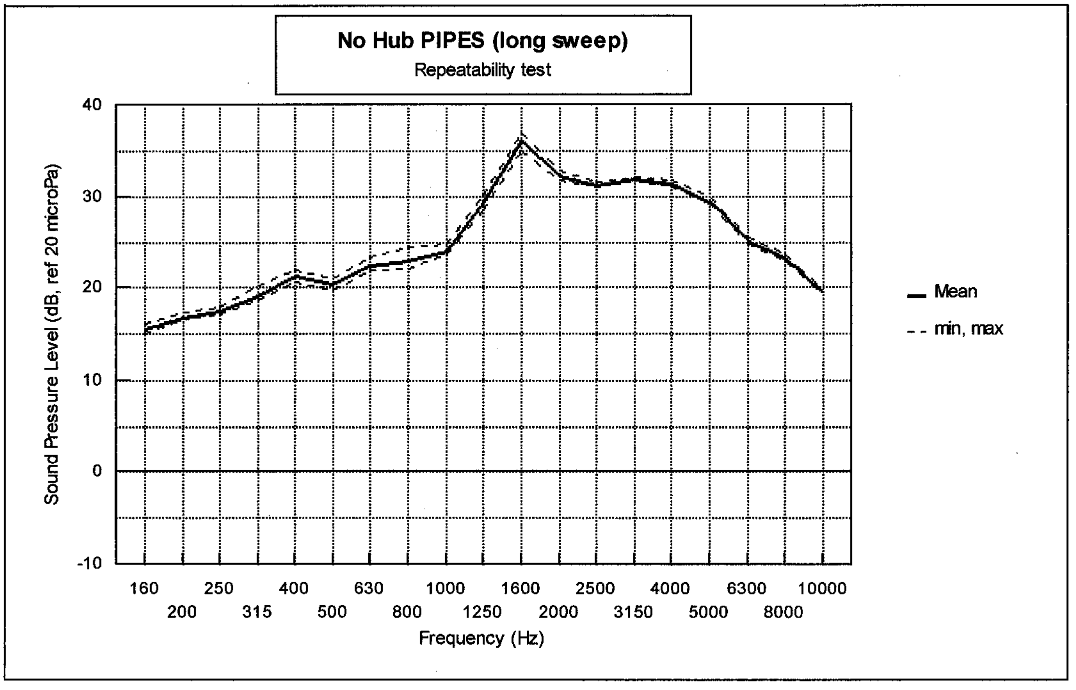


Figure A3.3: Repeatability test on No Hub pipe (long sweep)

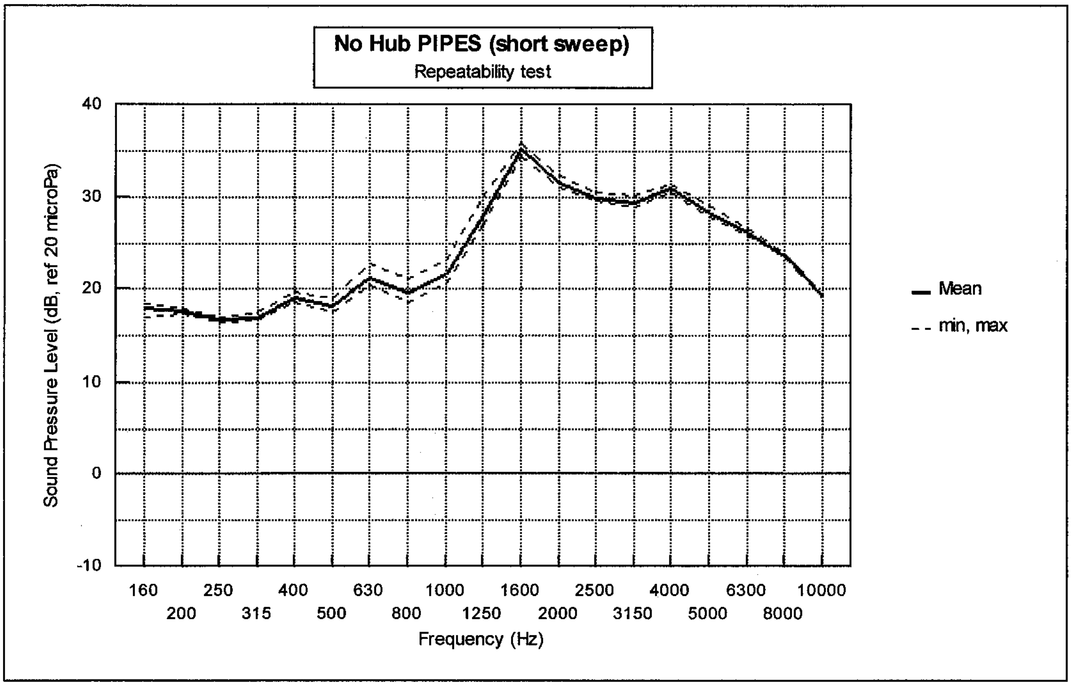


Figure A3.4: Repeatability test on No Hub pipe (short sweep)

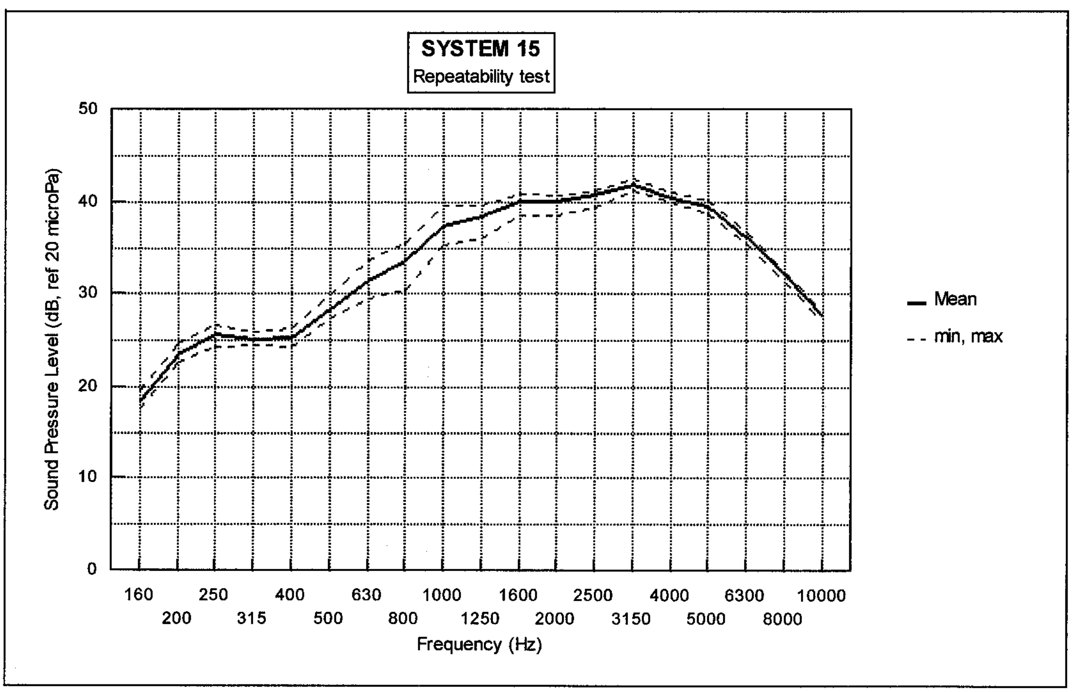


Figure A3.5: Repeatability test on IPEX PVC System 15 pipe

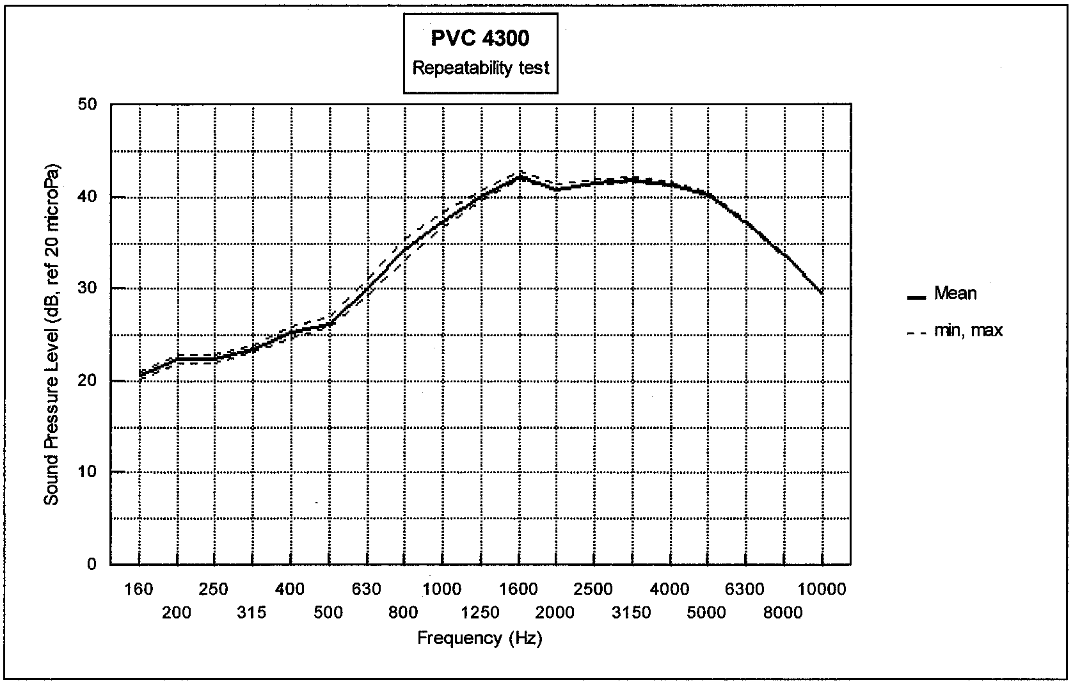


Figure A3.6: Repeatability test on PVC 4300 ASTM F891 pipe

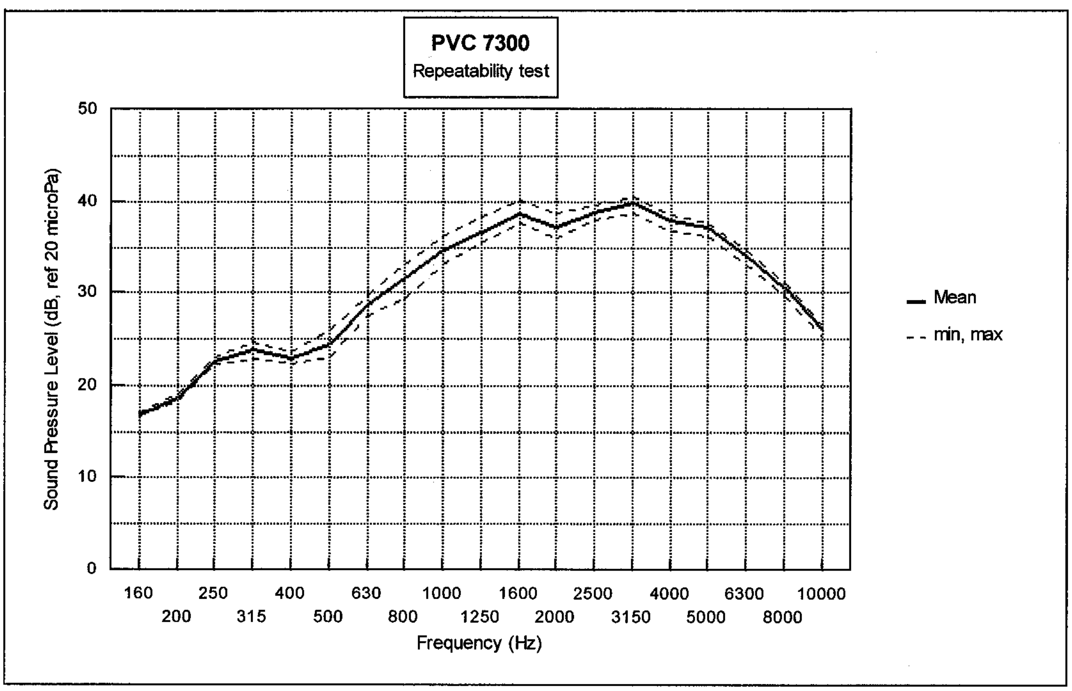


Figure A3.7: Repeatability test on PVC 7300 ASTM D2665 pipe

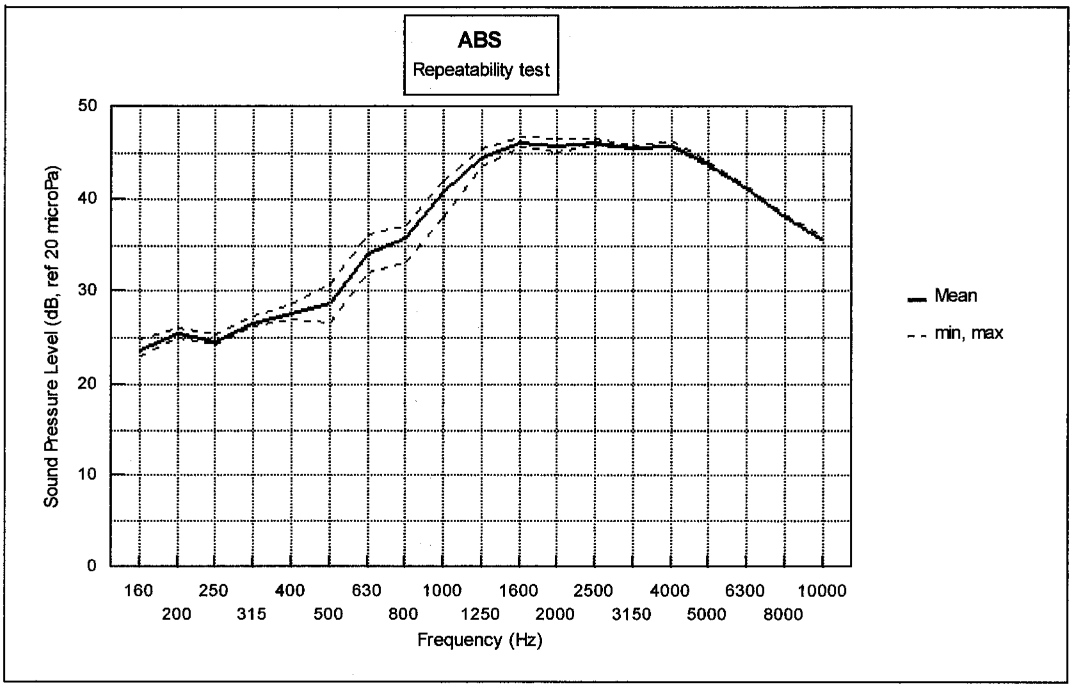


Figure A3.8: Repeatability test on ABS ASTM F628 pipe

ANNEX IV

ANNEX IV

REPRODUCIBILITY TESTS

Reproducibility tests were carried to demonstrate that sound pressure levels radiated by pipes inside the 90 m^3 reverberant chamber were truly representative of each type of pipes studied: for each type of pipe tested, three assemblies made with different pipes, couplings and fittings selected at random, were installed in the experimental set-up and tested.

The weight of the complete assemblies tested (pipes, fittings and coupling) are reported in **table A4.1** below. As can be seen in this table the weight of cast iron assemblies did not vary by more than 5 lbs with the exception of the Standard SV pipes for which a variation of 20 lbs was noted. The variations in weight for the plastic assemblies are considered negligeable.

	Weight of complete assembly (lbs)			
Assembly	1	2	3	4
XH - ASTM A74 cast iron	169	168	172	--
SV - ASTM A74 cast iron	130	130	153	130
No Hub - CISPI 301, CSA B70, ASTM A888, cast iron (long sweep)	104	108	105	--
No Hub - CISPI 301, CSA B70, ASTM A888, cast iron (short sweep)	105	110	105	--
IPEX PVC System 15	30	30	31	--
PVC 4300 - ASTM F891	22	23	22	--
PVC 7300 - ASTM D2665	17	17	18	--
ABS - ASTM F628	29	29	30	--

Table A4.1

The results of the reproducibility tests are presented on **figures A4.1 to A4.8** below. The data shown on these figures indicate a good reproducibility of the measurements performed during this study:

- The global sound pressure levels of the assemblies of the same type of pipes did not vary by more than one dBA.

- The maximum 1/3 octave sound pressure level difference between assemblies of the same type of pipes is less than 4 dB except for the service SV cast iron pipe, for which greater differences of up to 9 dB can be observed on **figure A4.2** for the 1600 Hz and 2000 Hz bands; this is due to the important variation of weight between SV pipes.

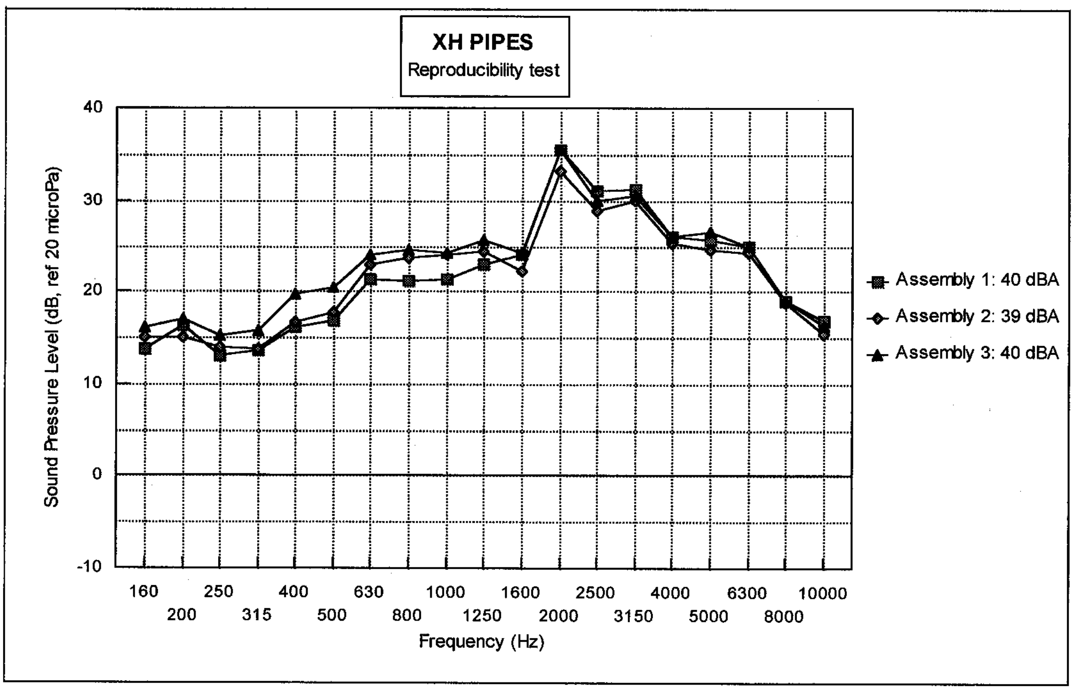


Figure A4.1: Reproducibility test on XH pipe

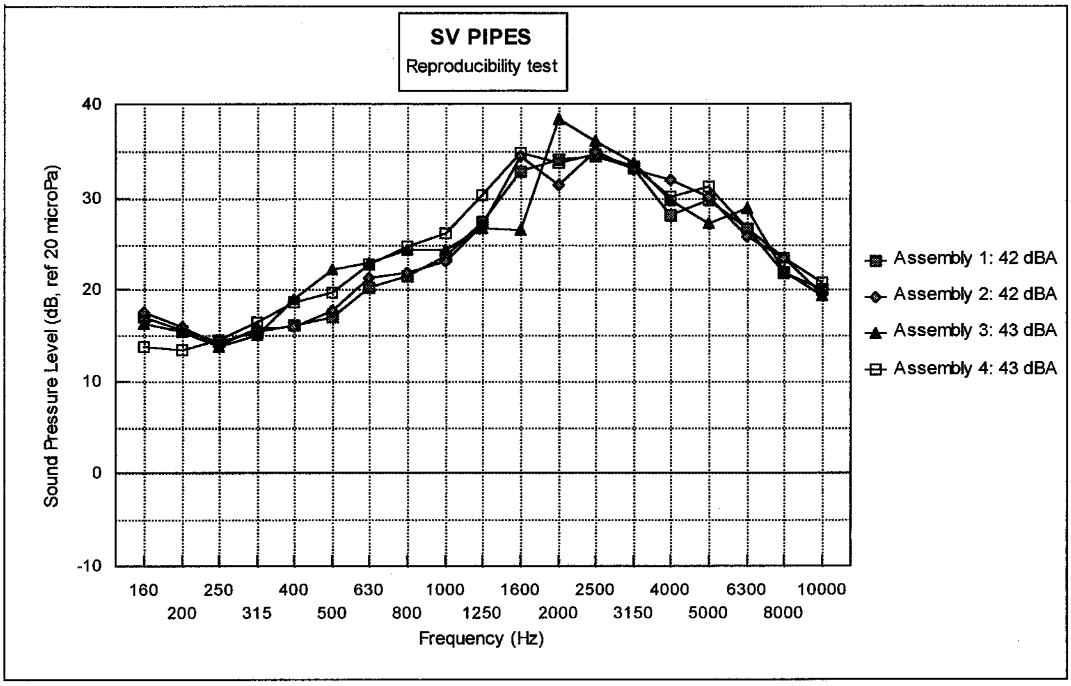


Figure A4.2: Reproducibility test on SV pipe

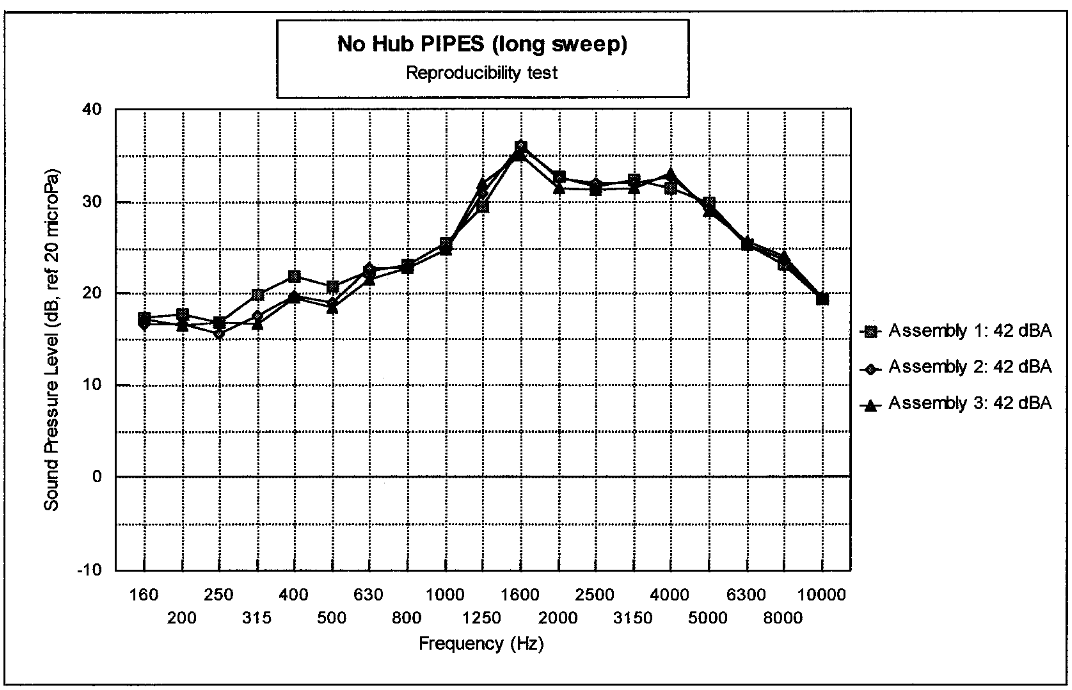


Figure A4.3: Reproducibility test on No Hub pipe (long sweep)

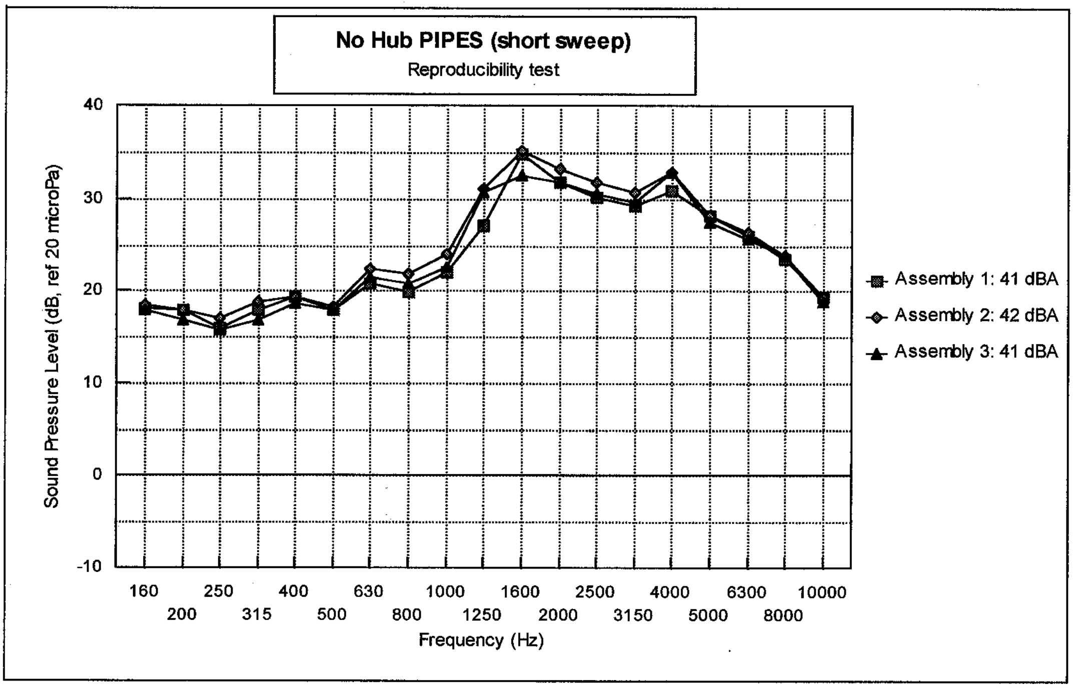


Figure A4.4: Reproducibility test on No Hub pipe (short sweep)

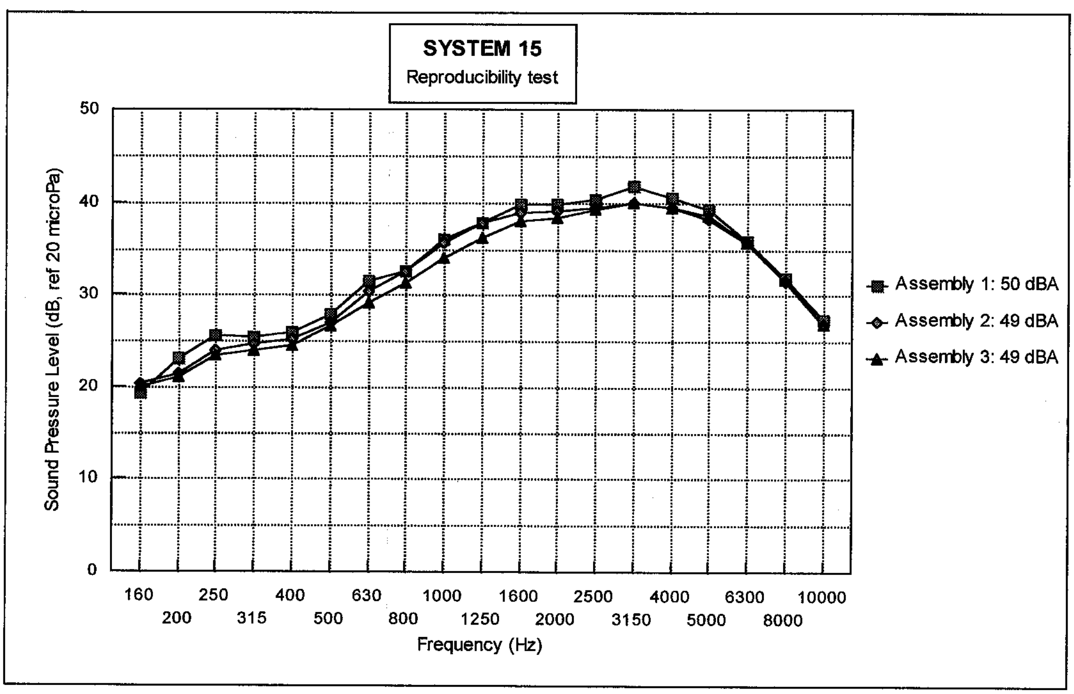


Figure A4.5: Reproducibility test on IPEX PVC System 15 pipe

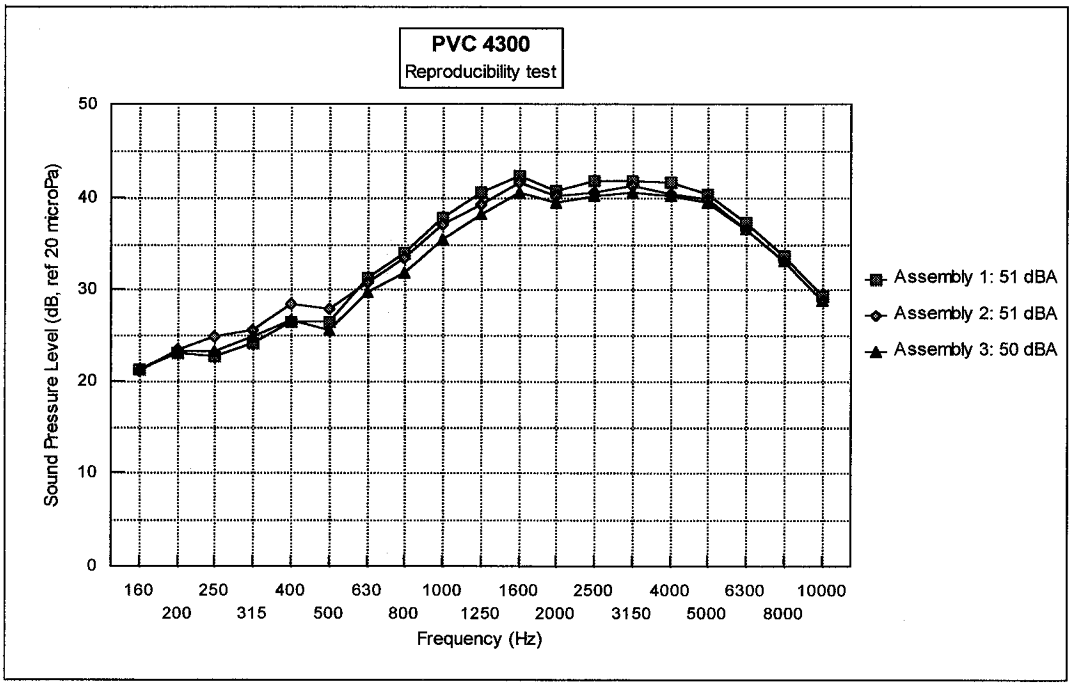


Figure A4.6: Reproducibility test on PVC 4300 ASTM F891 pipe

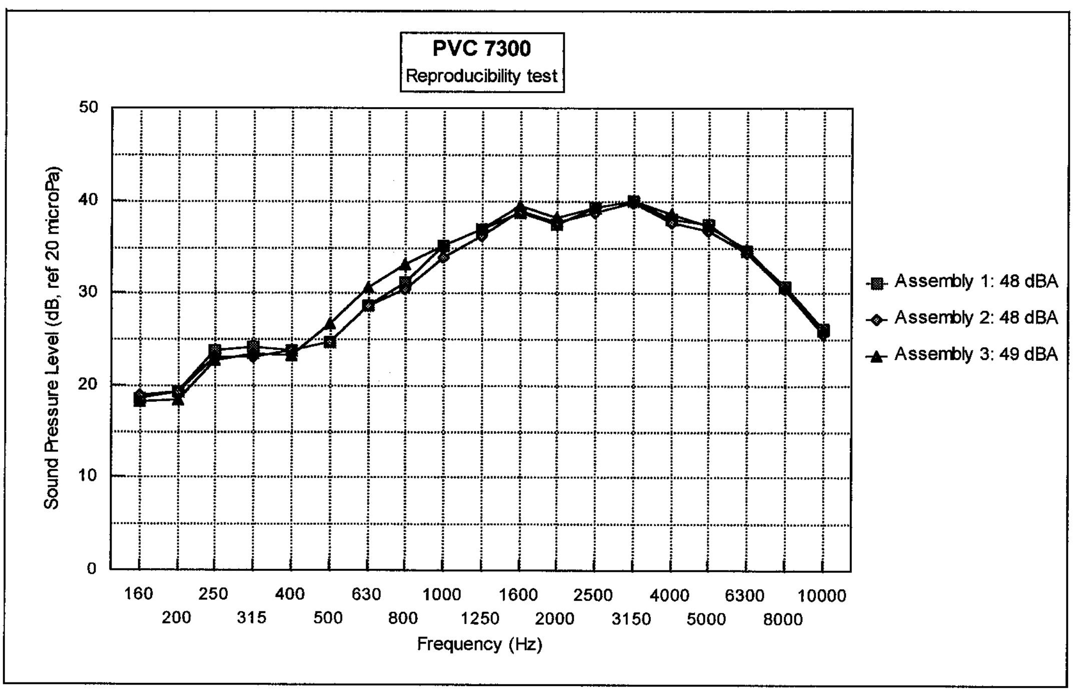


Figure A4.7: Reproducibility test on PVC 7300 ASTM D2665 pipe

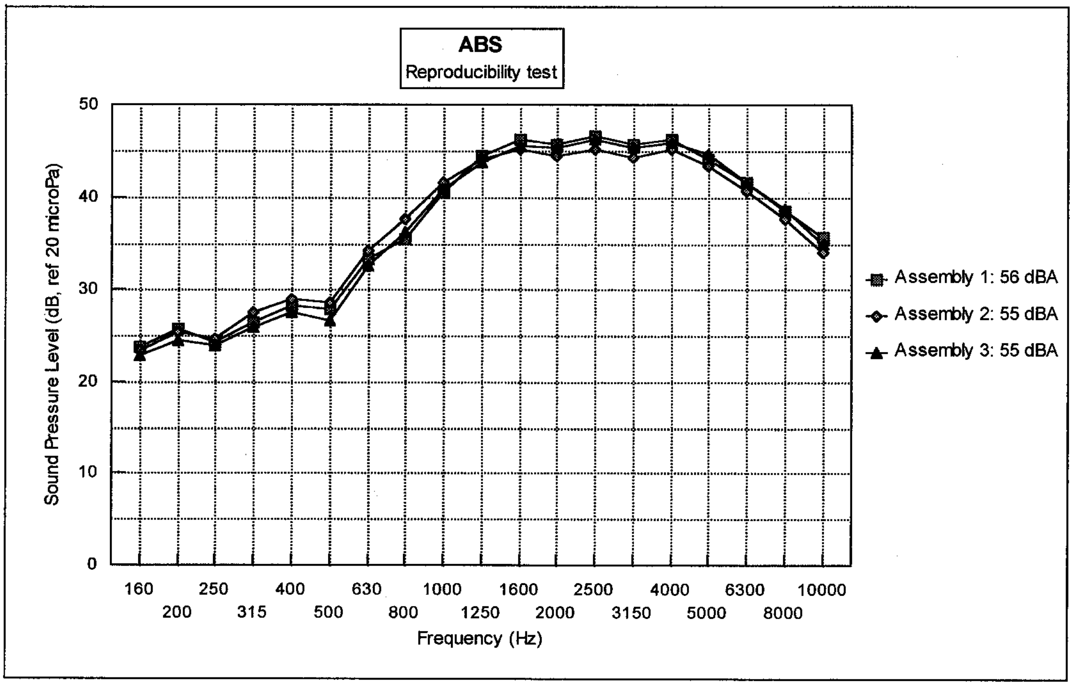


Figure A4.8: Reproducibility test on ABS ASTM F628 pipe

ANNEX V

ANNEX V

Sound pressure levels for the four configuration tested on each type of pipe.

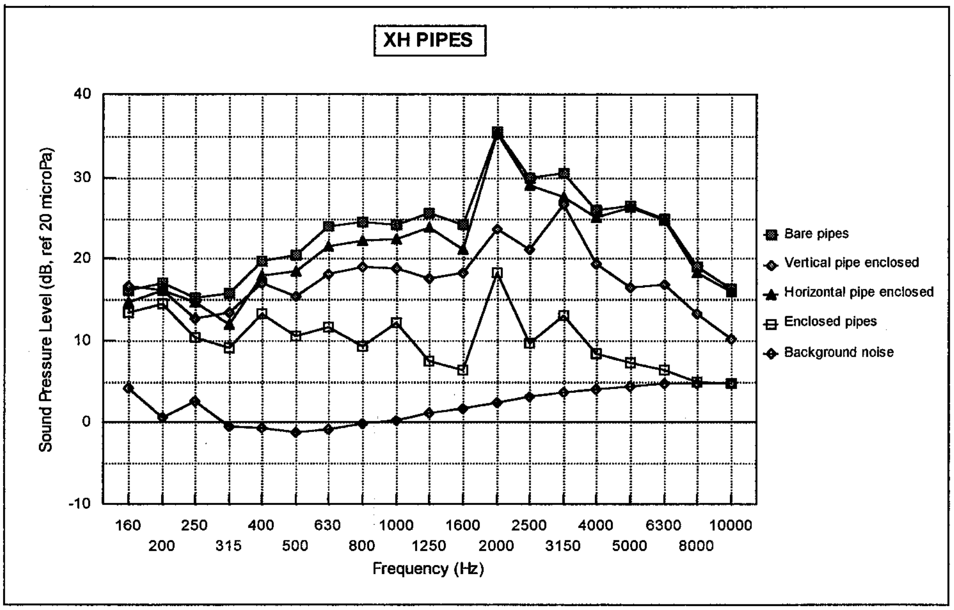


Figure A5-1: XH pipe test results (Assembly no 1)

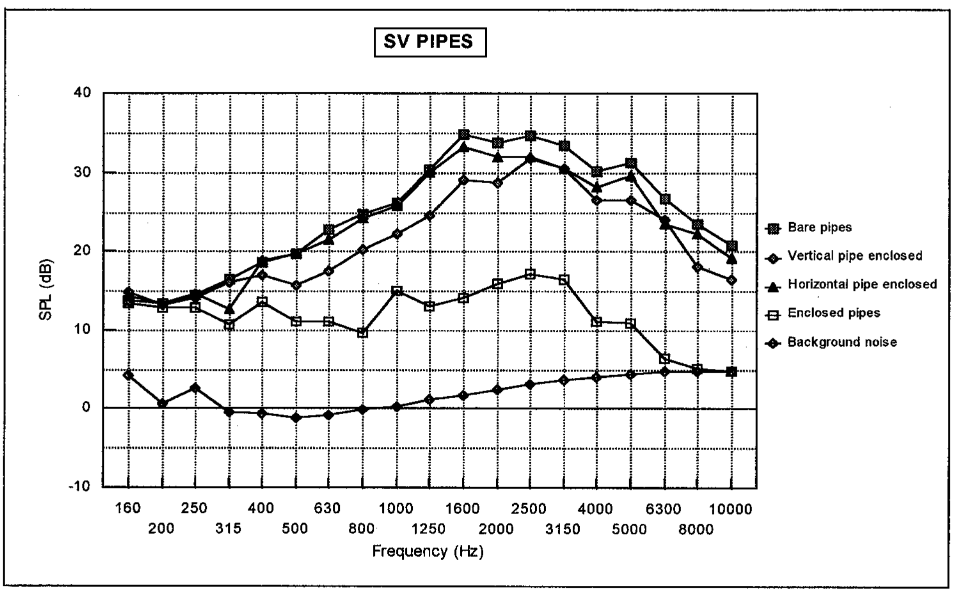


Figure A5-2: SV pipe test results (Assembly no 4)

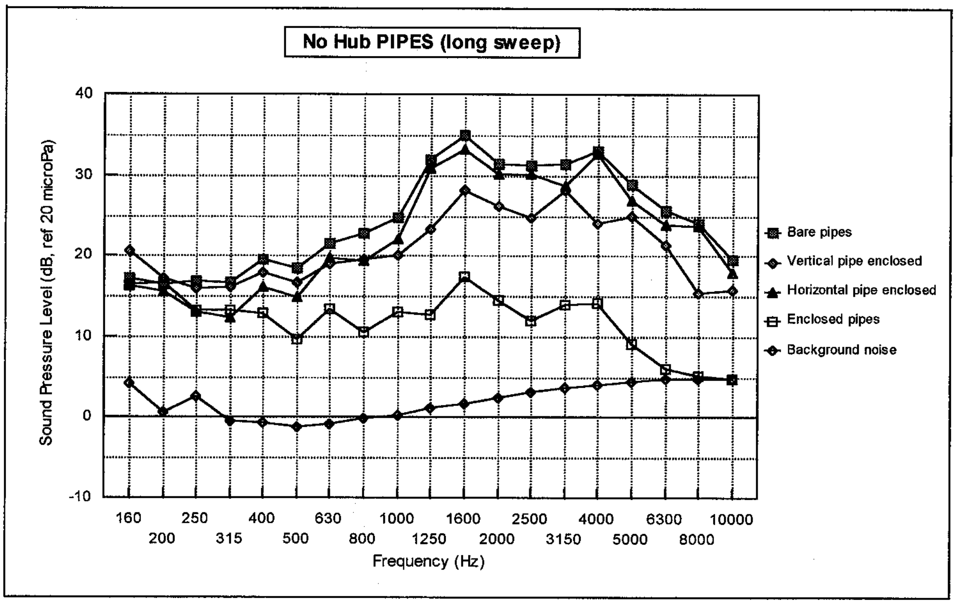


Figure A5-3: No Hub (long sweep) pipe test results (Assembly no 3)

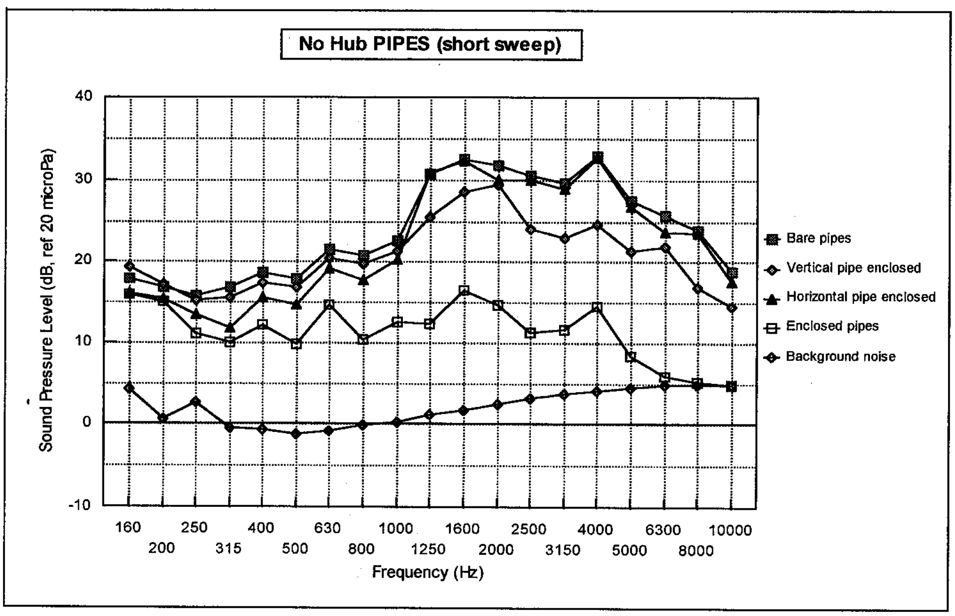


Figure A5-4: No Hub (short sweep) pipe test results (Assembly no 3)

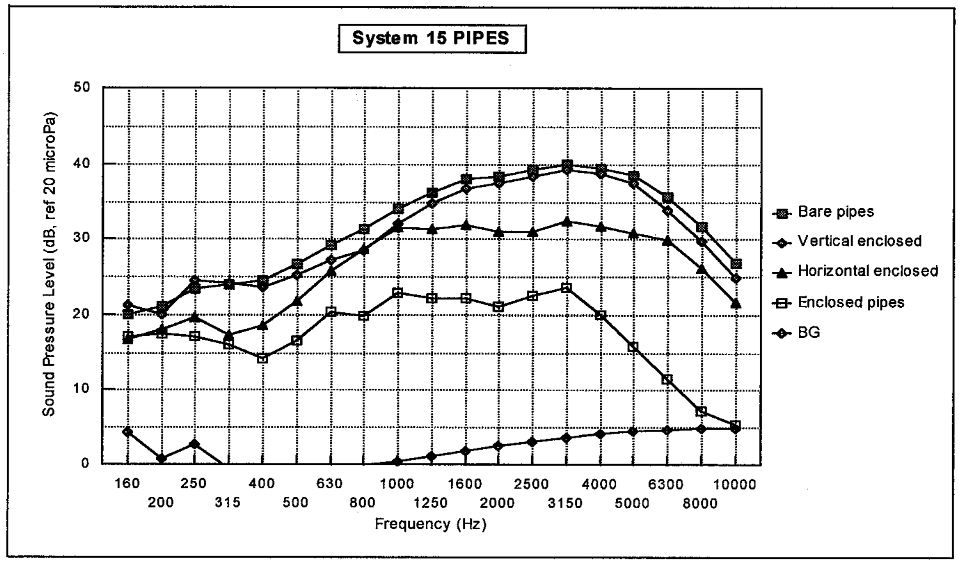


Figure A5-5: Ipex PVC System 15 pipe test results (Assembly no 3)

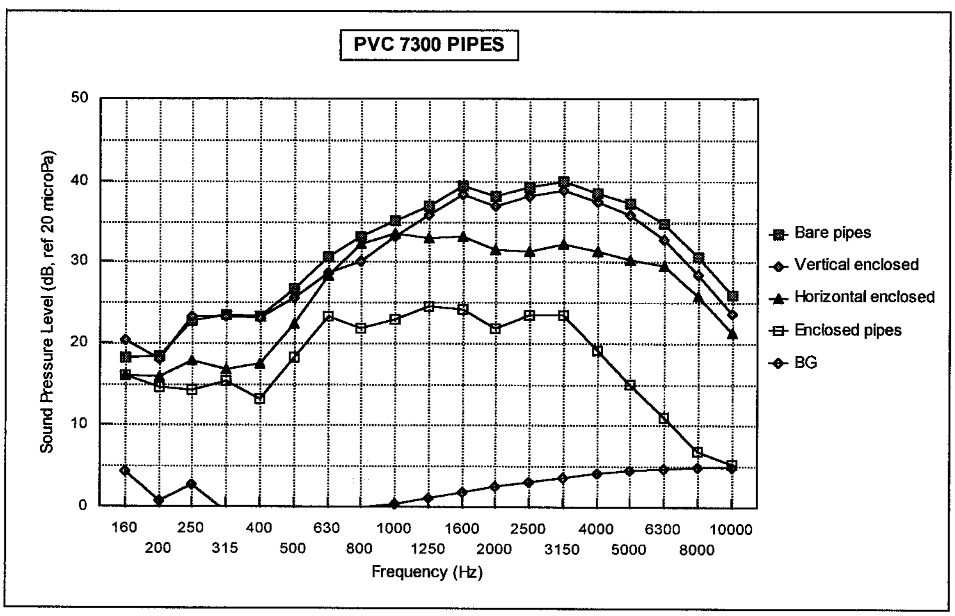


Figure A5-6: PVC 7300 ASTM D2665 pipe test results (Assembly no 3)

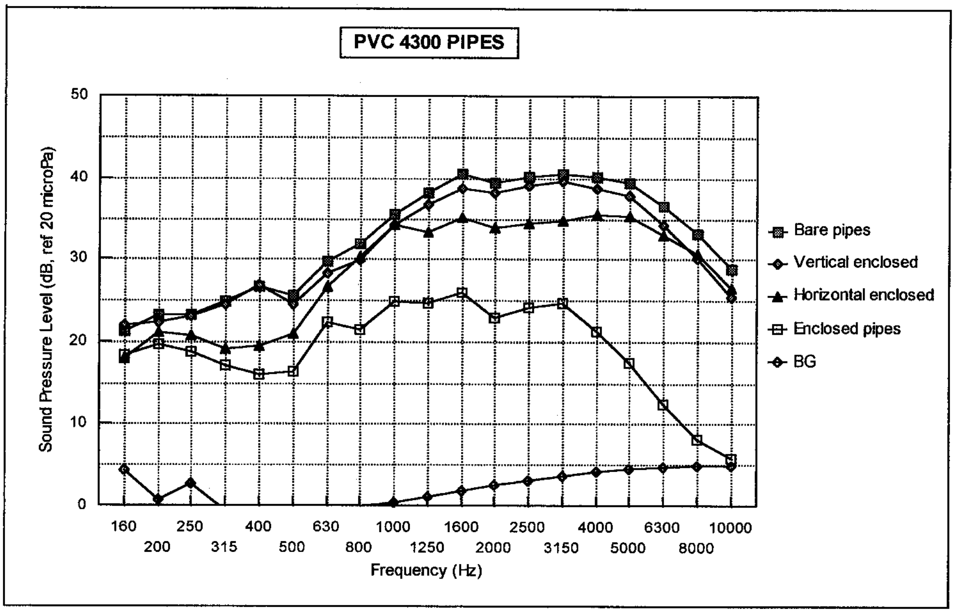


Figure A5-7: PVC 4300 ASTM F891 pipe test results (Assembly no 3)

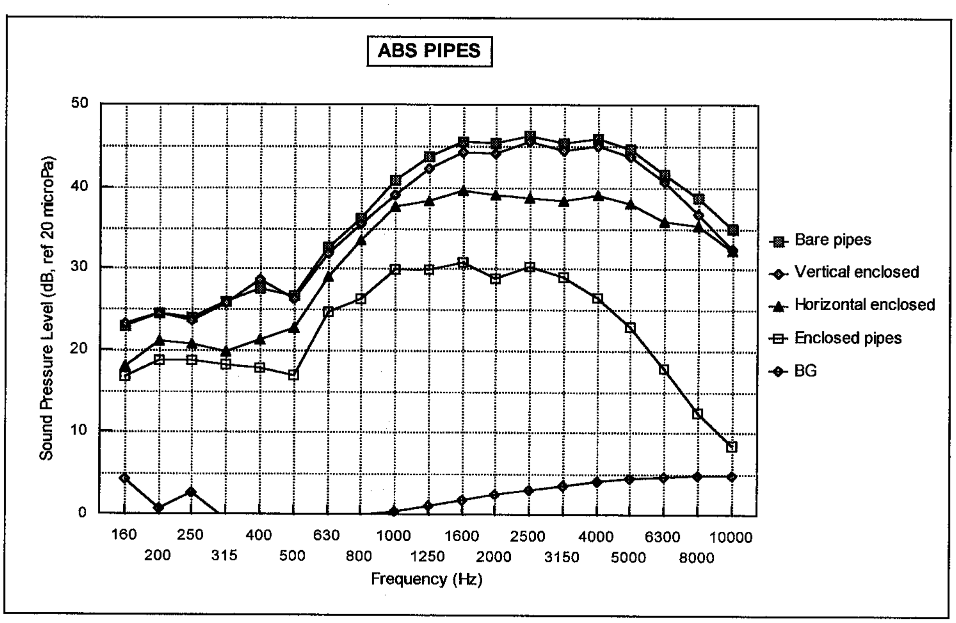


Figure A5-8: ABS 3300 ASTM F628 pipe test results (Assembly no 3)

ANNEX VI

ANNEX VI

Validating the measurements made with partly enclosed pipes.

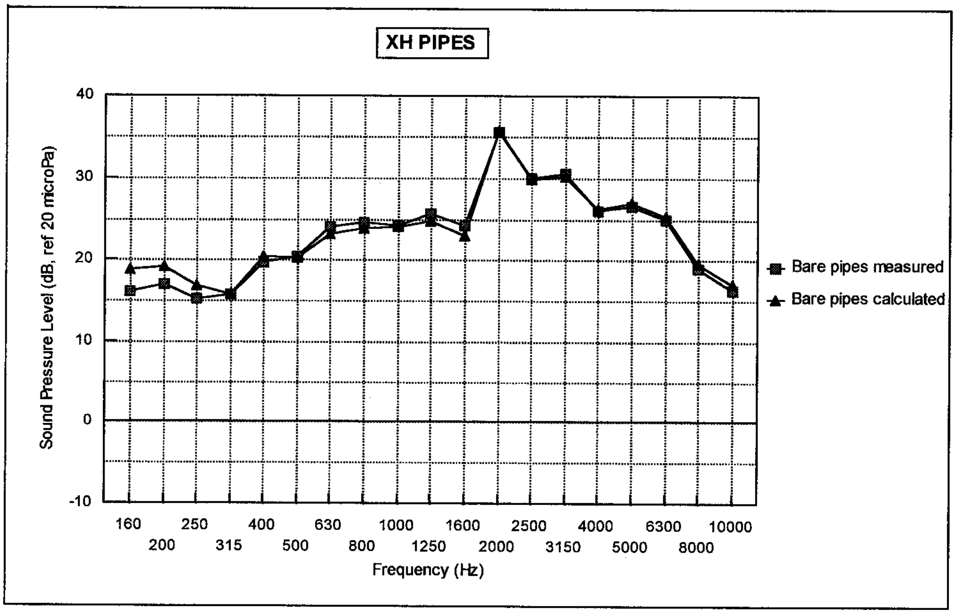


Figure A6-1: XH pipe tests validation

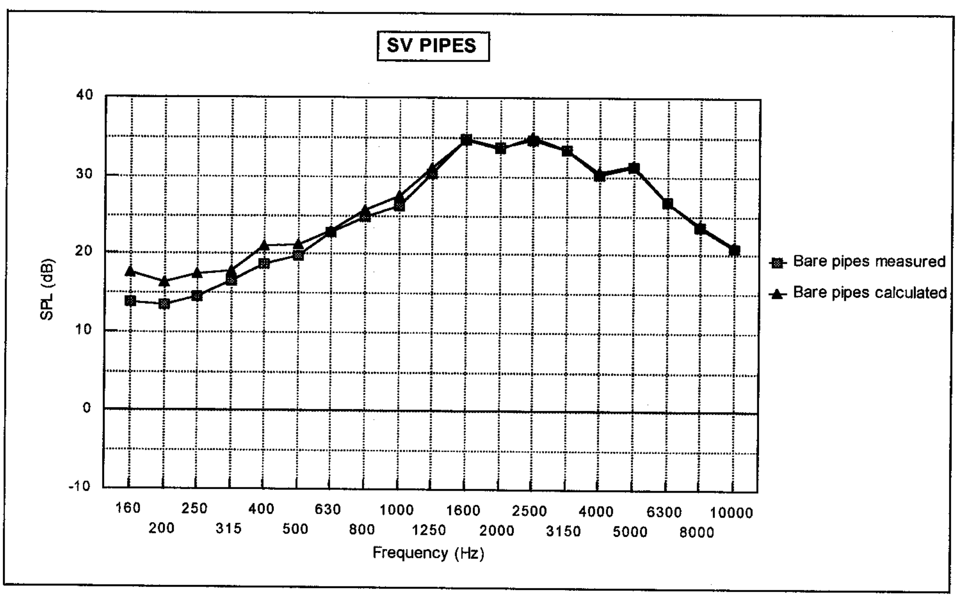


Figure A6-2: SV pipe test validation

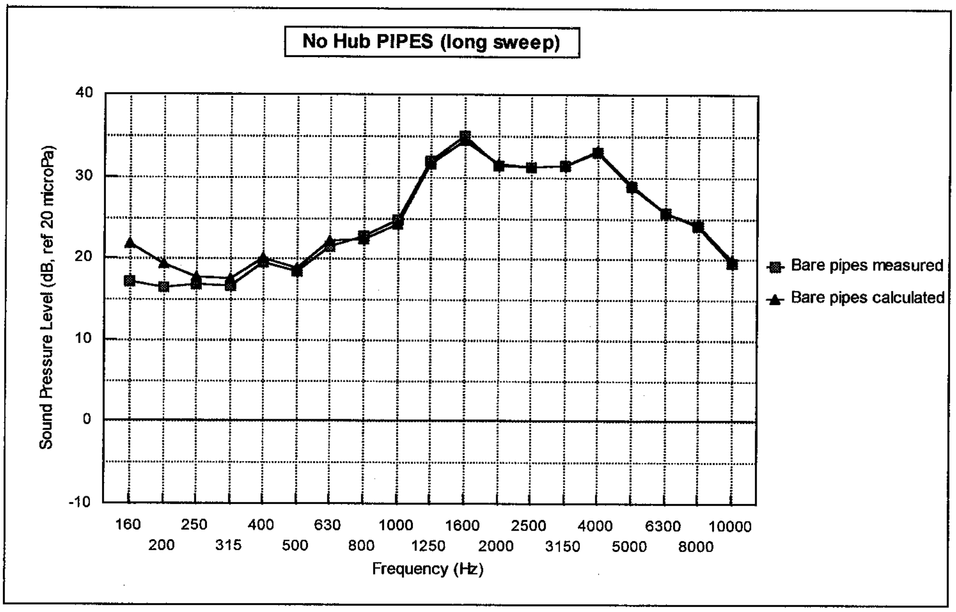


Figure A6-3: No Hub (long sweep) pipe test validation

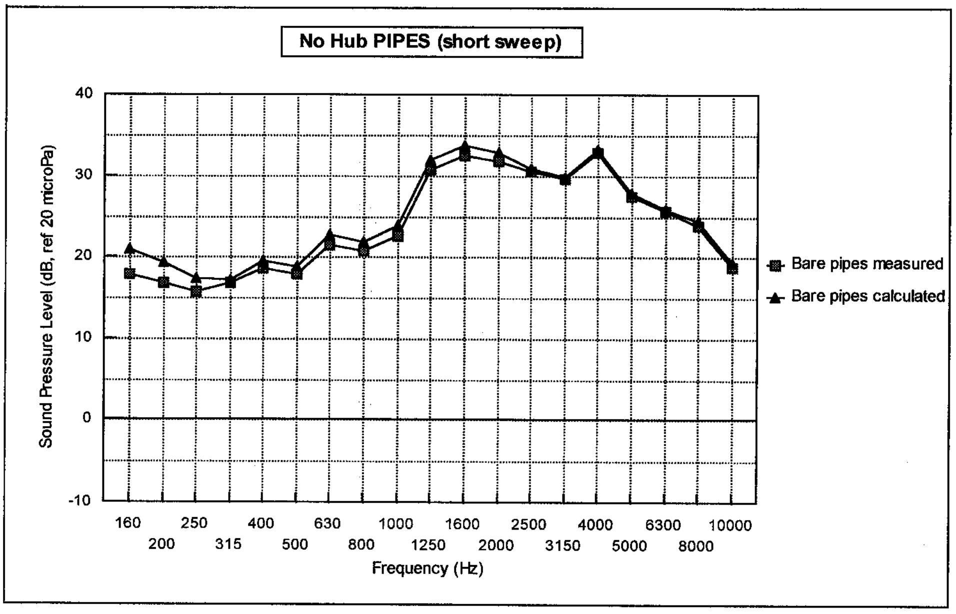


Figure A6-4: No Hub (short sweep) pipe test validation

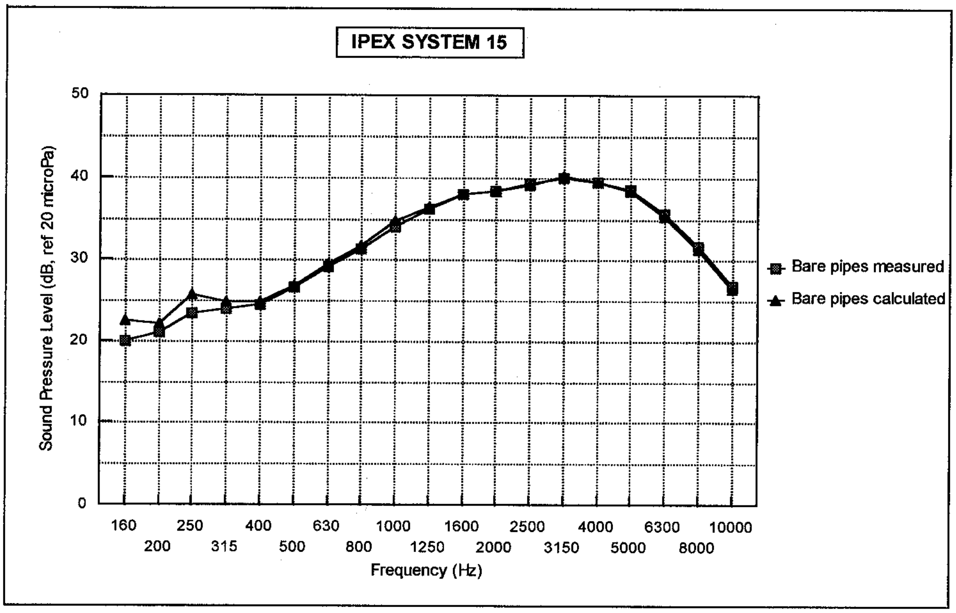


Figure A6-5: Ipex PVC System 15 pipe test validation

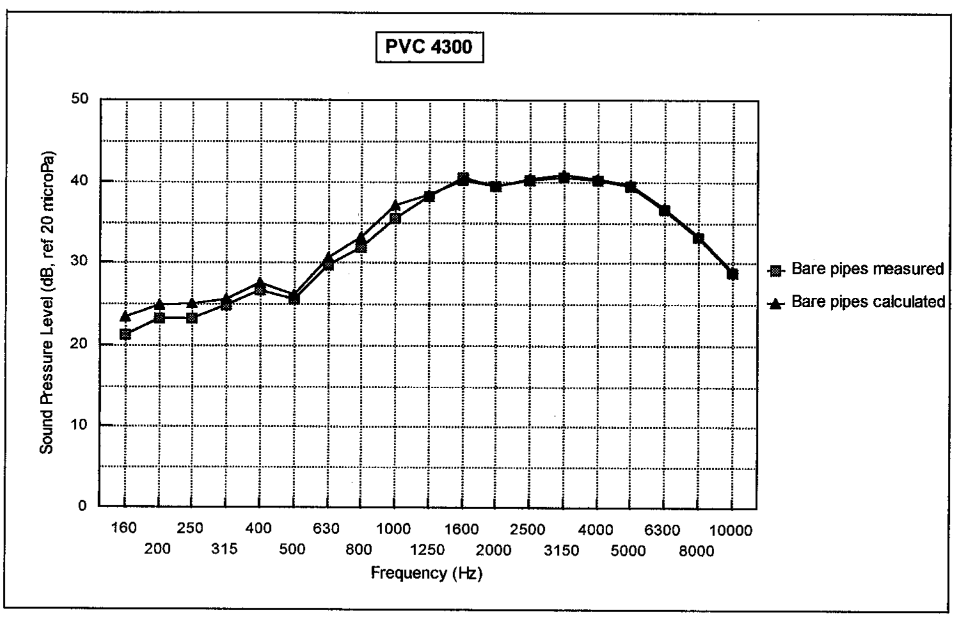


Figure A6-6: PVC 4300 ASTM F891 pipe test validation

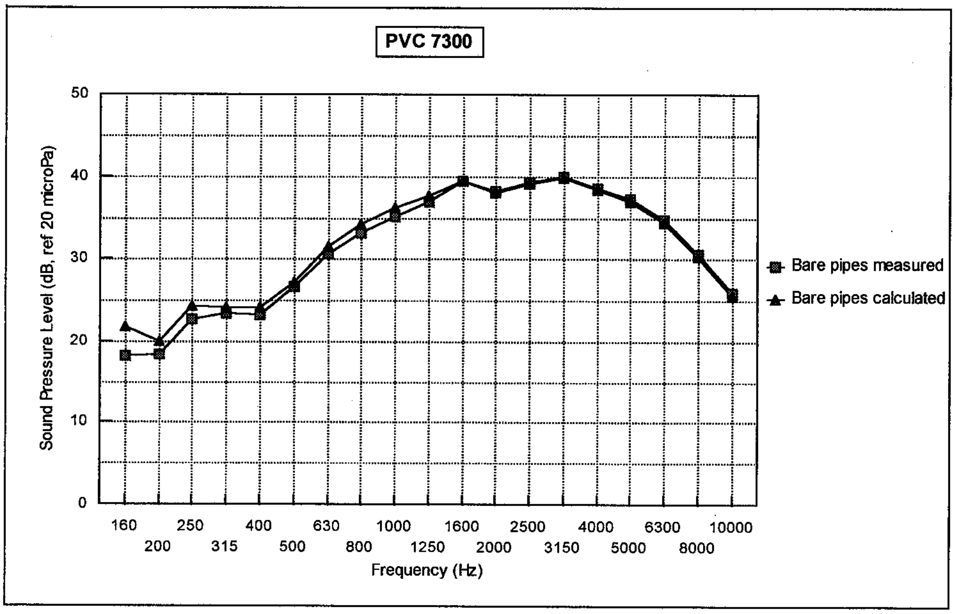


Figure A6-7: PVC 7300 ASTM D2665 pipe test validation

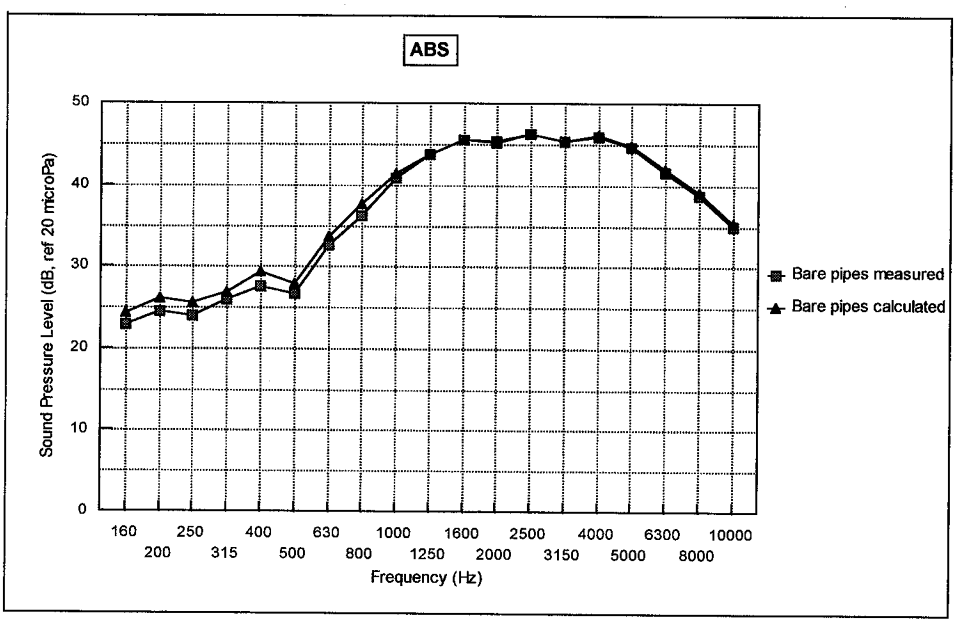


Figure A6-8: ABS 3300 ASTM F628 pipe test validation