RESEARCH REPORT

Summary Report for Consortium on Fire Resistance and Sound Insulation of Floors: Sound Transmission Class and Impact Insulation Class Results

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Summary Report for Consortium on Fire Resistance and Sound Insulation of Floors: Sound Transmission Class and Impact Insulation Class Results

by A.C.C. Warnock and J.A. Birta

Internal Report IRC-IR-766

April 1998

This project was supported by a consortium including:

Boise Cascade
Canada Mortgage and Housing Corporation (CMHC)
Canadian Home Builder Association (CHBA)
Canadian Portland Cement Association (CPCA)
Canadian Sheet Steel Building Institute (CSSBI)
Canadian Wood Council (CWC)
Cellulose Insulation Manufacturers Association of Canada (CIMAC)
Forintek Canada Corporation (FORINTEK)
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Trus Joist MacMillan
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EXECUTIVE SUMMARY

The IRC Acoustics Laboratory has completed the measurement phase of a study of airborne and impact sound transmission through typical floor constructions used in Canadian housing. This summary provides in point form the major findings of the project.

- The major factor controlling the sound insulation of a given type of cavity floor is the sum of the masses per unit area of the floor and ceiling layers.
- Of lesser importance, but still significant, are the thickness and density of the sound absorbing material, the depth and spacing of the joists and the spacing of resilient metal channels. Increasing any of these variables increases sound insulation.
- Floors having resilient metal channels but no sound absorbing material provide about 8 STC points less than the same constructions containing about a 150 mm thickness of sound absorbing material.
- Joist floors without resilient metal channels do not achieve STC 50 in any practical configuration, with or without sound absorbing material in the cavity.
- Wood I-joist floors showed anomalously high variance in the sound insulation for nominally equivalent constructions.
- Using 22 mm deep U-channels to support the gypsum board gave about the same results as using 19 x 64 mm wood furring. Both are markedly inferior to resilient metal channels.
- Changing the joist length had no effect on the sound transmission.
- The tightness of the screws attaching the subfloor to the joists had no effect on sound transmission.
- Increasing the number of screws attaching the subfloor to the joists by a factor of four had no effect on sound transmission.
- Attaching the subfloor to the joists using both construction adhesive and nails gave the same results as attaching it using only screws.
- Moving 152 mm glass fiber batts from the top, to the middle and then to the bottom of a 240 mm deep cavity had no significant effect on sound insulation.

- There were no significant differences in STC or IIC between pairs of floors where a 35 mm thick concrete topping was poured on top and allowed to set or where an existing slab was lifted into place on the floor.

- There was no significant difference between a floor constructed using cross-bracing and one using wood strapping. Floors gave the same sound insulation with or without cross-bracing.

- Joist floors with ceiling assemblies having resilient metal channels between two layers of gypsum board give very poor sound insulation.

- Putting sound absorbing material in the cavity of a joist floor with a ceiling that is not resiliently suspended provides no significant increase in sound insulation.

- Floors with concrete toppings and no additional resilient surface or support, typically get IIC ratings less than 30.

- Adding resilient surface layers to floors with concrete surfaces greatly increases IIC ratings.

Areas requiring Additional Work

To a large extent the project has successfully established the major parameters affecting the sound insulation of floors. There are, however, some areas that need further work.

To maintain the fire resistance of floors with ceilings consisting of single layers of gypsum board, it was found necessary to add additional pieces of resilient metal channel to support the butt ends of the gypsum board. Tests showed that these additional channels reduced the sound insulation. Many floors, however, were not tested using these additional channels; consequently the STC has to be estimated. Some floors will have their STC reduced below 50 when the effect of the additional channels are taken into account, and some floors that achieved more than 50 will have an estimated value that is just below or at 50. For floors with STCs close to 50, it is important to build and test them to confirm by measurement what the correct rating is and to investigate what steps are necessary to increase economically the sound insulation to STC 50. These sets of marginal floors need to be constructed for each joist or truss type so all variables are considered.

More sound insulation tests are needed with 12.7 mm Type X gypsum board to more clearly define the differences, if any, relative to 15.9 mm gypsum board. In some cases there seemed little, if any, difference between a floor with a 15.9 mm Type X gypsum board ceiling and the same floor with a 12.7 mm Type X gypsum board ceiling.

If necessary for NBC purposes, more tests can also be done with regular 12.7 mm gypsum board. Very few tests were done using this material.

More tests are needed with steel joists to be sure that there is no unexpected behavior with untested structures.

More tests are needed with wood trusses to be sure that all variants of trusses are examined and to try to find a reason for the anomalously low impact insulation class ratings with these floors.

More tests are needed with wood I-joist floors to try to determine why there is so much variability with these floors. The consistency obtained with solid wood joist construction suggests that there is a real physical reason for the variability but only experiment will establish what this reason is.

More tests are needed with rock fiber batts and blown-in cellulose to more clearly define what advantage these materials have over less dense glass fiber batts.

Floors filled with a thickness of glass fiber greater than the cavity depth showed no change in sound insulation relative to a floor that was not over-filled. While perhaps not relevant to the National Building Code, at least one floor over-filled with rock fiber needs to be tested to deal with questions that arise on this topic. The higher density could mean that if floors were over-filled with rock fiber batts, the sound insulation would be reduced because of transmission through the fibrous material.

The impact insulation provided by a floor is, for the ISO tapping machine, extremely dependent on the compliance of the surface layer of the floor. Some work is being done in a separate project to study the influence of floor toppings on impact sound insulation but the topic is complicated and very extensive; more work would definitely be useful.

Résumé

Le laboratoire d'acoustique de l'Institut de recherche en construction (IRC) a achevé l'étape de la prise de lectures relative à l'étude de la transmission des sons aériens et des bruits d'impact à travers les assemblages de planchers habituellement utilisés dans les habitations au Canada. Le présent document en résume les principales constatations :

- Le facteur prépondérant qui détermine l'isolement acoustique de tout plancher à cavité est la somme des masses des couches de revêtement de sol et de plafond par unité de surface.
- Parmi les autres facteurs de moindre importance, mais néanmoins significatifs, on signale l'épaisseur et la densité du matériau absorbant, la hauteur et l'espacement des solives et l'espacement des profilés métalliques souples. Toute augmentation de ces variables aura pour effet d'améliorer l'isolement acoustique.

- Les assemblages dotés de profilés métalliques souples, mais dépourvus de matériau absorbant, affichent un ITS inférieur de 8 dB à celui d'un assemblage identique muni de 150 mm de matériau absorbant.

- Avec ou sans matériau absorbant, aucun des assemblages en solives dépourvus de profilés métalliques souples dans une configuration pratique n'atteint un ITS de 50.

- Des assemblages équivalents montés à l'aide de solives préfabriquées en I montrent une très grande variabilité dans les valeurs d'isolement acoustique obtenues.

- La pose de profilés métalliques en U de 22 mm de hauteur pour soutenir les plaques de plâtre produit à peu près les mêmes résultats que l'utilisation de lattes en bois de 19 x 64 mm. Les deux fournissent un rendement largement inférieur à celui des profilés métalliques souples.

- La portée des solives n'a aucun effet sur l'isolement acoustique.

- Le fait de serrer davantage les vis pour fixer le support de revêtement de sol aux solives n'a aucun effet sur l'isolement acoustique.

- Les résultats demeurent inchangés même si l'on pose quatre fois plus de vis pour fixer le support de revêtement de sol.

- La pose de vis jumelée à un adhésif à panneaux pour fixer le support de revêtement de sol aux solives n'a aucun effet sur les résultats.

- Il n'y a aucune différence dans les résultats, que les nattes de fibre de verre soient posées au sommet, au milieu ou dans le fond d'une cavité de 240 mm.

- On note très peu de différences au chapitre des indices ITS ou IIC entre deux assemblages dont le premier est muni d'une chape de béton de 35 mm coulée et mûrie

en place et le deuxième est constitué d'une chape de béton soulevée et déposée sur le plancher.

- Les résultats obtenus pour les assemblages de plancher sont identiques, qu'ils soient munis de contreventements ou de lattes continues.
- La pose de profilés métalliques souples entre deux plaques de plâtre diminue le rendement acoustique des planchers à solives.
- La pose d'un matériau absorbant dans la cavité d'un assemblage de plancher à solives dont la sous-face est dépourvue de profilés métalliques souples ne procure aucune augmentation notable de l'isolement acoustique.
- Les planchers dotés de chapes de béton, mais sans revêtement souple supplémentaire, affichent des IIC habituellement inférieurs à 30.
- La pose de couches additionnelles de revêtements souples sur les planchers comportant des surfaces en béton augmente considérablement leur indice IIC.

Domaines de recherches supplémentaires

C'est grâce à la présente recherche qu'on a réussi, dans une large mesure, à établir les principaux facteurs pouvant influer sur la performance acoustique des assemblages de plancher. Des recherches plus poussées dans certains domaines sont cependant nécessaires.

Pour maintenir la résistance au feu des assemblages dont la sous-face est revêtue d'une seule couche de plaques de plâtre, il faut poser des profilés souples additionnels pour soutenir les joints d'about des plaques de plâtre. Des essais ont montré que ces profilés souples supplémentaires diminuaient l'isolement acoustique. De nombreux planchers, cependant, ont été mis à l'essai sans la présence de ces profilés additionnels, ce qui fait que l'on a dû estimer les indices ITS. Certains planchers verront leur indice ITS diminuer sous les 50 dB, si on tient compte de l'effet produit par ces profilés additionnels, tandis que d'autres assemblages dont l'indice était supérieur à 50 se verront rétrogradés à 50 dB ou parfois moins. Dans le cas des assemblages qui affichent un ITS avoisinant 50 dB, il est important de les construire et de leur faire subir des essais pour confirmer l'indice, et également d'examiner les dispositions économiques qu'il y aurait lieu de mettre en œuvre pour porter l'ITS à 50 dB. Ces assemblages de planchers marginaux devront être construits avec chaque genre de solive de plancher afin de tenir compte de toutes les variables.

On devra effectuer d'autres essais d'isolement acoustique sur des assemblages munis de plaques de plâtre de type X de 12,7 mm d'épaisseur afin d'établir clairement les différences, s'il en existe, avec les plaques de plâtre de type X de 15,9 mm. Il y a très peu de différences, voire aucune, entre certains assemblages dont la sous-face est munie de plaques de plâtre de type X de 15,9 mm par rapport à d'autres dont la sous-face est constituée de plaques de plâtre de type X de 12,7 mm.

Si des essais supplémentaires s'avéraient nécessaires pour répondre aux exigences du CNB, ils pourront être effectués sur des assemblages dont la sous-face est revêtue de plaques de plâtre ordinaires de 12,7 mm d'épaisseur. Très peu d'essais ont été réalisés sur ce matériau.

On devra effectuer d'autres essais sur les assemblages montés en solives d'acier afin de s'assurer que les assemblages non évalués jusqu'à présent ne manifestent pas de comportements inattendus.

Des essais supplémentaires sont aussi requis dans le cas des solives préfabriquées en bois afin de découvrir pourquoi les résultats sont aussi variables. Les résultats uniformes que montrent les assemblages en solives de bois massif laissent croire qu'il existe vraiment une cause physique à cette variabilité. Il faudra donc recourir à d'autres essais pour en découvrir la cause réelle.

Il faut davantage d'essais portant sur des assemblages dont la cavité contient des nattes de fibre de roche ou un isolant cellulosique projeté afin d'établir les avantages de ces deux matériaux par rapport à l'isolant de fibre de verre qui possède une densité plus faible.

Les assemblages dont la cavité a été remplie d'isolant de fibre de verre en surépaisseur affichent les mêmes résultats qu'un assemblage qui a été rempli normalement. Bien que la situation ne soit pas une préoccupation à l'égard du Code national du bâtiment, il faudrait mettre à l'essai au moins un assemblage muni d'une surépaisseur de laine de fibre de roche afin de répondre aux interrogations à ce sujet. Le fait de poser ces nattes de laine plus dense en surépaisseur risque de réduire le niveau d'isolement acoustique en raison de la transmission du bruit via les fibres du matériau.

En ce qui a trait à la machine à chocs ISO, le niveau d'isolement aux bruits d'impact est étroitement lié au comportement des revêtements de sol. Des travaux en cours dans une autre recherche visent à déterminer l'influence des chapes de plancher sur le niveau d'isolement aux bruits d'impact. Puisque le domaine est complexe et très large, d'autres recherches seraient certainement utiles.

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INTRODUCTION

The IRC Acoustics Laboratory has completed the measurement phase of a study of airborne and impact sound transmission through typical floor constructions used in Canadian housing. A related project to study the fire resistance of floors was running simultaneously and is reported elsewhere[1].

As well as the Institute for Research in Construction of the National Research Council Canada (IRC/NRCC), both projects were supported by a consortium including

- Boise Cascade
- Canada Mortgage and Housing Corporation (CMHC),
- Canadian Home Builder Association (CHBA)
- Canadian Portland Cement Association (CPCA)
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- Ontario Home Warranty Program
- Ontario Ministry of Housing
- Owens Corning Fiberglas Canada Inc. (OCFCI),
- Roxul Inc. (ROXUL).
- Trus Joist MacMillan
- Willamette Industries

This report presents the sound transmission class (STC) and impact insulation class (IIC) ratings for all the floors in the project. Some of the specimens were chosen by IRC for

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[1] "Results of Fire Resistance Tests on Full-Scale Floor Assemblies", M.A. Sultan, Y.P. Seguin and P. Leroux.

technical reasons but the majority of the specimens were approved as part of a structured series established collectively by the consortium.

A second IRC report will present the measurements in one-third octave bands. Including the one-third octave band data in this report would have increased the complexity beyond that needed for building code purposes.

The acoustical measurements included impact sound measurements using experimental, non-standard devices. These measurements were made to provide extra information that might be used to improve the existing standardized tapping machine test or to develop new test procedures. A third IRC report will deal with these experimental impact measurements in detail.

The combined set of over 190 specimens provides

- data for systematic evaluation of sound transmission through joist floor systems,
- data for development of prediction methods,
- data for development of improved constructions, and
- a consistent assembly of STC and IIC data needed by builders and regulators to select constructions suitable for party floors in multi-family dwellings.

MEASUREMENT PROCEDURES

M59 test facility.

The M59 floor test facility (Figure 1) comprises two rooms with volumes of about 175 m^3 (Room volumes change when specimens of different thicknesses are installed.) The bottom room is constructed of 30 cm thick poured concrete and is supported on steel springs and neoprene placed under the floor. The upper room is constructed from steel studs and layers of particleboard. It is supported on steel columns that in turn rest on steel springs and neoprene supports.

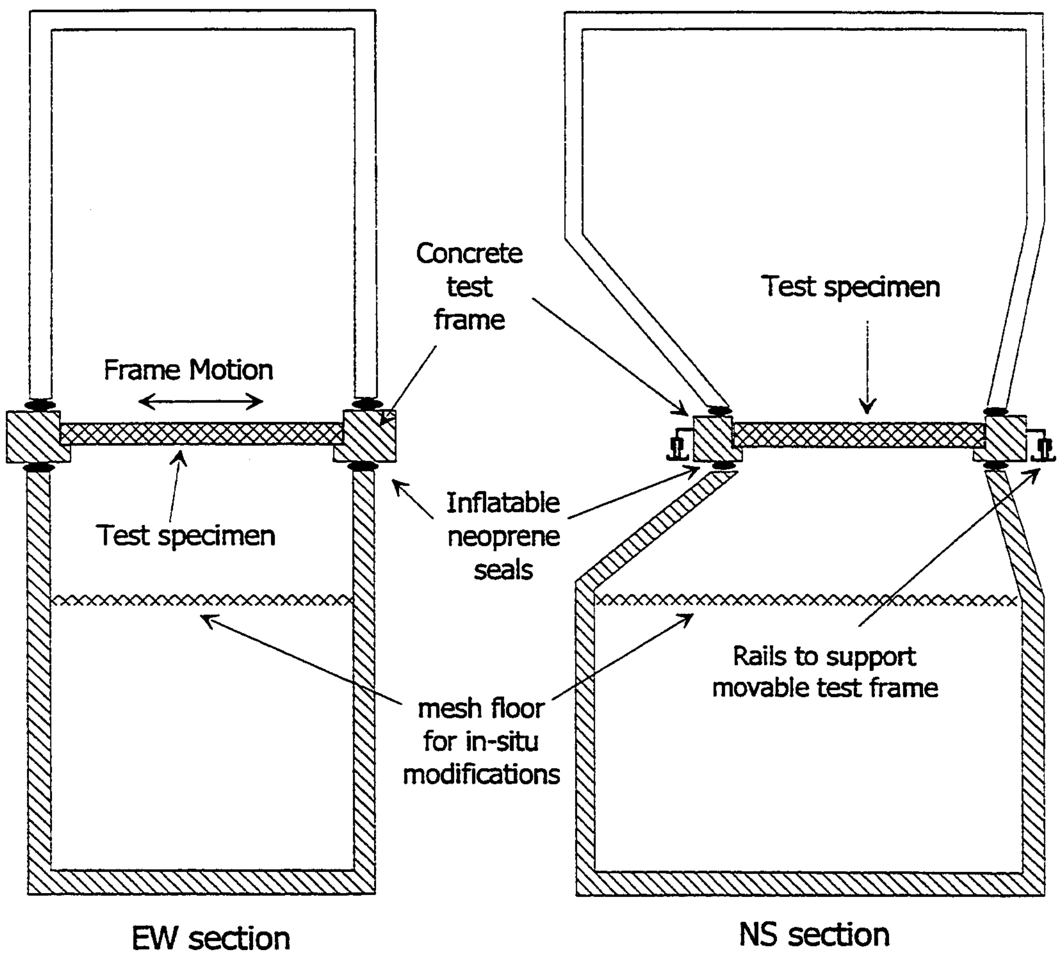

Figure 1: Sections through the M59 floor testing facility. (Not to scale)

Floor specimens are constructed in one of two concrete test frames that can be removed from between the reverberation rooms and lifted by a crane to a storage area or to the floor of the main laboratory. Figure 2 shows the frame partly inserted between the rooms.

The dimensions of the test frames are shown in Figure 3. The floor specimen opening measures 3.8 x 4.7 m. Gaps between the upper and lower chambers and the edges of the movable frame are sealed with inflatable gaskets. To reduce transmission around or through the frame, shields are placed over the exposed parts of the frame in the upper room after the frame and specimen are installed between the rooms. In addition to the inflatable gaskets, backer rod and tape are used to further seal the gap between the lower room lip and the test frame.

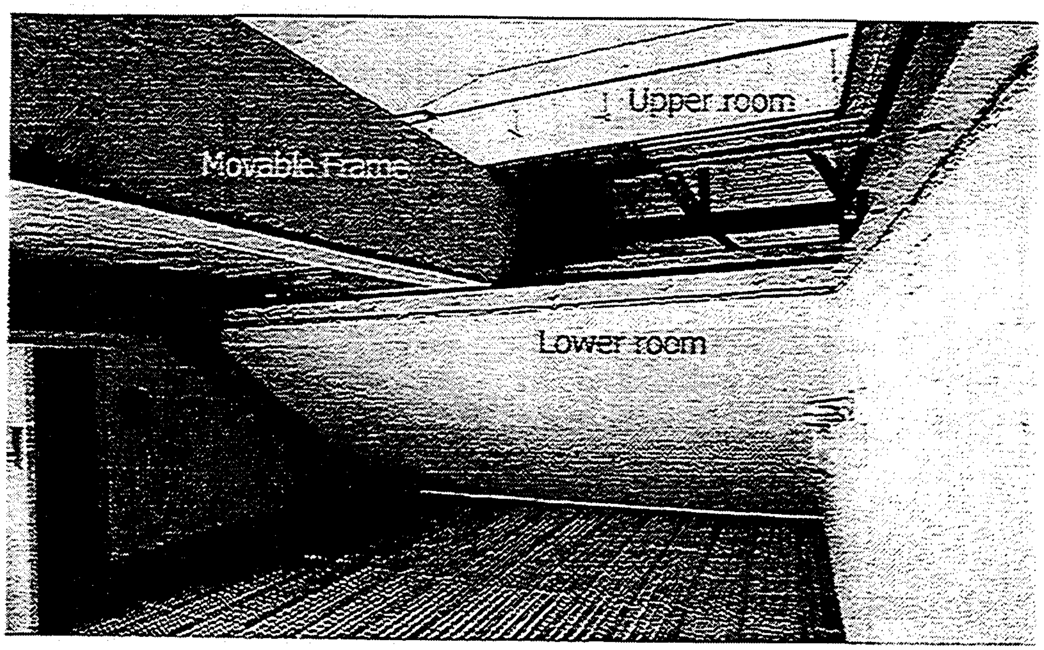

Figure 2: Insertion of floor frame between the upper and lower chambers.

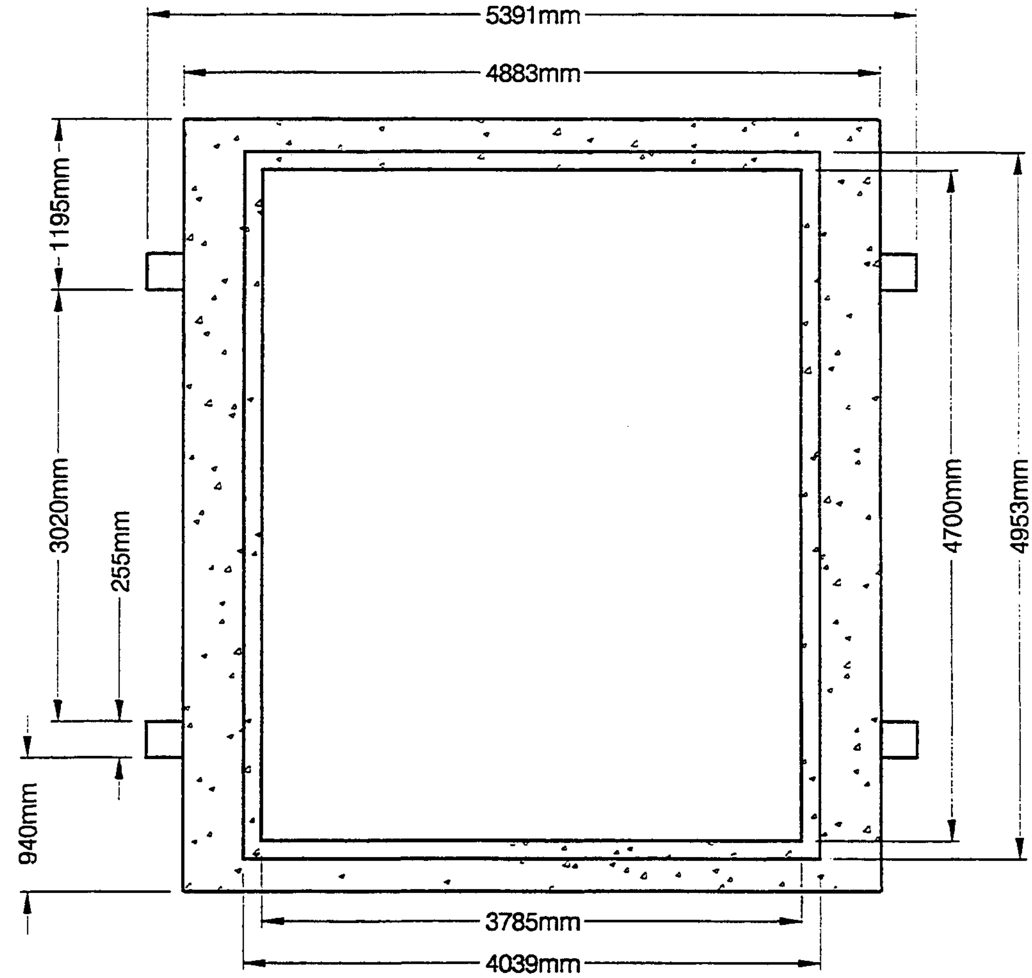

Figure 3: Plan and section of test frame for supporting specimens.

In each room a microphone is mounted at the end of a scissors-jack arrangement that is attached to a boom that turns about an axis near the middle of the ceiling. The scissors-jack moves along the boom and lowers and raises the microphone. Stepping motors set the microphone position and nine microphone positions are used in each room.

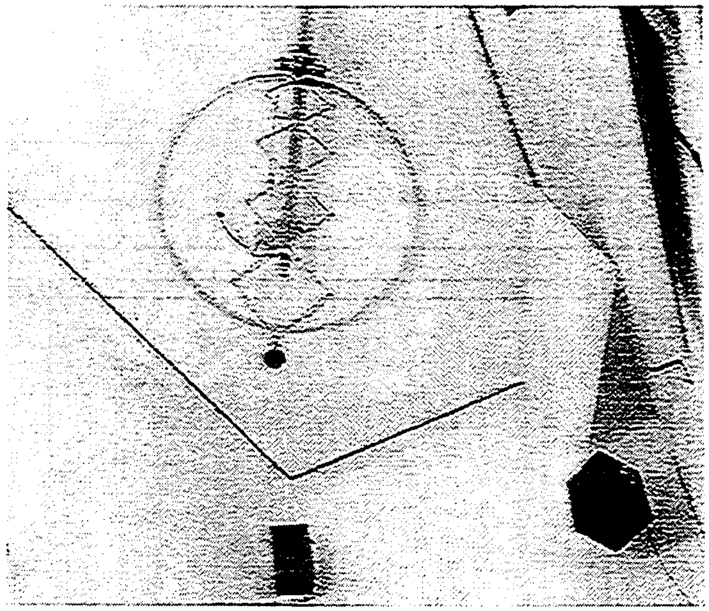

Figure 4: Automated system for moving the microphone in each room. Two of the four loudspeakers are also visible in the picture.

Airborne Sound — ASTM E90

Measurements of airborne sound transmission are made in accordance with ASTM E90[2]. In the M59 floor test facility sound is generated in one room using four loudspeaker systems, each with its own noise generator and amplifier. The movable microphone in each room measures the sound pressure levels and sound decay rates at frequencies from 50 to 6300 Hz. The information collected is used to calculate sound transmission loss (TL) and sound transmission class (STC) according to ASTM E413[3]. Measurements are made with each room in turn serving as the source room and the two sets of results are averaged.

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[2] ASTM E90 Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions.

[3] ASTM E413 Classification for Rating Sound Insulation.

Impact Sound — ASTM E492

Transmission of impact sound through floors is measured in accordance with ASTM E492[4]. A standardized tapping machine incorporating 5 steel-faced hammers is placed on the floor under test in four specified positions. The hammers are driven by a motor so they impact the floor surface twice per second each for a total rate of 10 impacts per second. Sound pressure levels and decay rates are measured in the room below. In this project, measurements were made from 25 to 6300 Hz. The information collected is used to calculate the normalized impact sound pressure level and the impact insulation class (IIC) according to ASTM E989[5].

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[4] ASTM E492 Standard Test Method for Laboratory Measurement of Impact Sound Transmission through Floor-ceiling Assemblies using the Tapping Machine.

[5] ASTM E989 Standard Classification for Determination of Impact Insulation Class.

REPEATABILITY AND REPRODUCIBILITY

Acoustical measurement in rooms involves sampling non-uniform sound fields, and consequently has associated with it a degree of uncertainty. By measuring at a number of microphone positions to determine a spatial average, the uncertainty due to room variations can be reduced below limits specified in the appropriate standards.

More important for comparing test results within a series of measurements or among laboratories are the concepts of *reproducibility* and *repeatability.*

Reproducibility is defined as the closeness of agreement between results obtained on nominally identical test specimens with the same test method in different laboratories. Obviously this includes the deviations due to systematic differences between facilities and equipment, any variations in implementation of the test procedures, and also any uncontrolled differences in the specimen and its installation. The reproducibility is a characteristic of the test method, which must be determined by an inter-laboratory comparison study. Reproducibility values are likely to depend on the kind of specimen being measured. For ISO 140, reproducibility has been shown to range from 3 dB at mid-frequencies to 7 dB at low frequencies. Values should agree within this range 19 times out of 20. It is because of this large uncertainty that systematic studies in one laboratory (like that reported here) are needed for clear comparisons. Reproducibility values for a reference steel panel tested according to ASTM E90 are given in ASTM E1289.

Repeatability may be defined as the closeness of agreement between independent results obtained with the identical test specimen in the same laboratory with the same equipment and test method by the same operator within a short time period.

Estimates of this repeatability can be made by running the same test several times in succession without disturbing the specimen in any way. Tests repeated in this manner using computer controlled instruments usually show negligible variation. Determined in this way, repeatability represents the limit associated with the measurement conditions specified by the computer program, for example, the integration time used to measure the sound pressure levels and the number of microphones used in each room.

In this project, as well as airborne sound transmission loss measurements, several different impact tests were routinely carried out on each floor specimen. Some of these used quite severe impacts that might have caused significant changes to the test specimen. So a more useful estimate of repeatability was obtained by running complete sets of the tests normally carried out several times over a period of several days. Thus any environmental effects and possible changes due to violent impacts are included in the estimate of repeatability. For convenience, this repeatability is termed the *re-test repeatability.* Tests were made in this way on the same specimen nine times over a period of 13 days. Eight of the STC ratings obtained were 50 and one was 51. Only 8 tapping machine tests were run; 4 gave IIC ratings of 45 and 4 gave ratings of 46.

Rebuild repeatability may be defined as the closeness of agreement between results obtained on nominally identical test specimens constructed with nominally identical materials with the same test method in the same laboratory. Since the laboratory, measurement methods and equipment remain constant, any variance found reflects variations in materials and installation techniques and possible unknown effects. This repeatability is of most relevance to this project where comparisons are being made among floors that were completely rebuilt and those that had minor changes made to them before re-testing. This repeatability represents the highest uncertainty associated with this project. For minor changes, for example adding an additional layer of gypsum board, the re-test repeatability would give more appropriate estimates of the uncertainty associated with the measurement.

Reference floor

To investigate *rebuild repeatability*, the same floor was constructed and tested eight times in the laboratory over a period of about 1 year using new materials each time. The floor construction consisted of

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<tr>
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• one layer of 15 mm thick OSB subfloor.
• 38 x 235 mm wood joists, 406 mm o.c.
• a layer of 152 mm thick glass fiber batts in the joist cavities.
• 13 mm deep resilient metal channels screwed 610 mm o.c. perpendicular to the joists
• one layer of Type X gypsum board, 15.9 mm thick, applied to the resilient metal channels.
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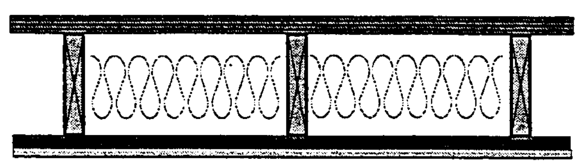
<td></td>
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This floor is referred to as the *reference floor* in the report and as *Mean ref* in the tables.

Four of the STC ratings obtained for the re-builds of the reference floor were 51 and four were 52. Four of the IIC ratings were 45 and four were 46. The data from these measurements were used to estimate rebuild repeatability for the STC and IIC ratings. For the purposes of this report, a change of more than 1 point in the STC or IIC rating may be taken as significant and can be attributed to a change in the specimen. A change of only 1 should be regarded as not significant unless an examination of the 1/3 octave band data shows significant changes.

It is perhaps worth reminding the reader that a statistically significant result may not have any practical significance.

SOUND TRANSMISSION AND IMPACT INSULATION CLASS TABLES

The tables on the following pages give the STC and IIC ratings for all the floors tested in the project that can be classified as using normal construction practices. Experimental constructions to investigate the effects of various factors are discussed in the appendices.

> *Users of this publication and these tables are reminded that in some situations, construction details that enhance sound insulation may not increase fire resistance or may even reduce it. The reverse is also true. These possibilities and costs ought to be considered when selecting floor systems.*

Unless otherwise indicated in the tables, resilient metal channels were spaced uniformly. Results from the fire research showed that best fire resistance was obtained for single layers of gypsum board when the butt ends of the board were supported using additional full-length or short pieces of channel. These additional channels reduce sound insulation (See *Other resilient metal channel arrangements* on page 92). The average reduction was about 2 dB for both STC and IIC.

> *Thus, where additional channels are to be used with a single layer of gypsum board, the STC and IIC values in the following tables for uniformly spaced channels should be reduced by 2.*

Additional channels did not significantly reduce the sound insulation when the ceiling comprised two layers of gypsum board. Thus values in the following tables for floors with such ceilings can be used directly.

Construction and material details are given in the sections following this. All the gypsum board used was of a fire-rated type except for the lightweight type 1500 board.

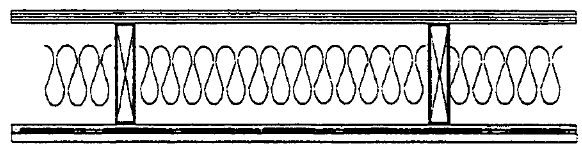
In some of the tables "Mean Ref" is used to identify the average STC and IIC for the reference floor described at the beginning of the report.

Two tables are included that give STC and, where appropriate, IIC for ceiling and floor layers tested alone except for necessary structural supports. This information is for general interest.

Table 1: Solid Wood Joists: Single layer subfloors and one or two ceiling layers

Joist Depth	235 mm
Joist Spacing	406 mm o.c.
Cavity filling	152 mm glass fiber batts
Resilient channels	610 mm o.c.

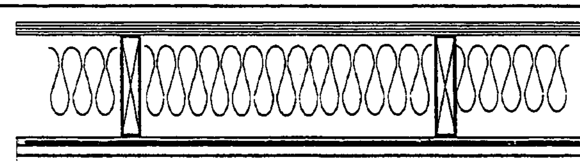
(a) Single layer subfloor and ceiling



Subfloor material	Subfloor thickness, mm	Gypsum board thickness, mm	Test ID	STC	Test ID	IIC
OSB	15	12.7[1]	TLF-95-155a	49	IIF-95-059	43
OSB	15	12.7	TLF-95-113a	51	IIF-95-040	45
OSB	15	15.9	Mean Ref	52	Mean Ref	46
OSB	19	15.9	TLF-95-127a	52	IIF-95-045	46
Plywood	15	15.9	TLF-95-133a	50	IIF-95-048	43
Plywood	25	15.9	TLF-96-061a	52	IIF-96-018	44

[1] 1.5 lb/sq.ft, 7.4 kg/m²

(b) Single layer subfloor and double layer ceiling



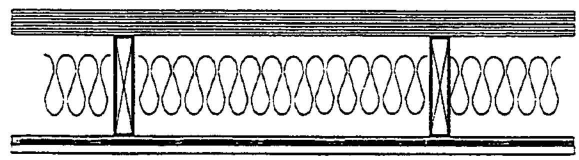
Subfloor material	Subfloor thickness, mm	Gypsum board thickness, mm	Test ID	STC	Test ID	IIC
OSB	15	2*12.7	TLF-95-157a	54	IIF-95-060	48
OSB	15	2*12.7	TLF-95-115a	56	IIF-95-041	50
OSB	15	2*15.9	TLF-95-107a	55	IIF-95-039	49
Plywood	15	2*15.9	TLF-95-145a	55	IIF-95-054	49
Plywood	25	2*15.9	TLF-96-065a	56	IIF-96-020	48

[1] 1.5 lb/sq.ft, 7.4 kg/m²

Table 2: Solid Wood Joists: Double layer subfloors and one or two ceiling layers

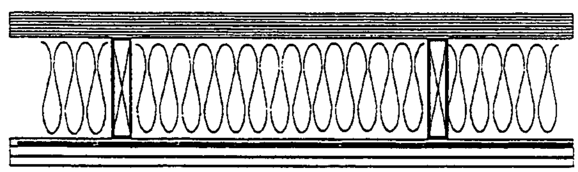
Joist Depth	235 mm
Joist Spacing	406 mm o.c.
Cavity filling	152 mm glass fiber batts
Resilient channels	610 mm o.c.

(c) Double layer subfloor and single layer ceiling



Subfloor material	Subfloor thickness, mm	Gypsum board thickness, mm	Test ID	STC	Test ID	IIC
OSB	2*15	15.9	TLF-95-123a	55	IIF-95-043	47
Plywood	2*13	15.9	TLF-95-129a	51	IIF-95-046	46
Plywood	2*15	15.9	TLF-95-149a	53	IIF-95-056	46

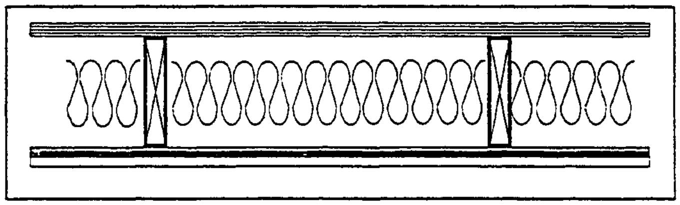
(d) Double layer subfloor and double layer ceiling



Subfloor material	Subfloor thickness, mm	Gypsum board thickness, mm	Test ID	STC	Test ID	IIC
Plywood	2*13	2*15.9	TLF-95-131a	58	IIF-95-047	53
Plywood	2*15	2*15.9	TLF-95-147a	58	IIF-95-055	51
OSB	2*15	2*15.9	TLF-95-125a	60	IIF-95-044	53

Table 3: Solid Wood Joists: Varying depth and spacing of joists

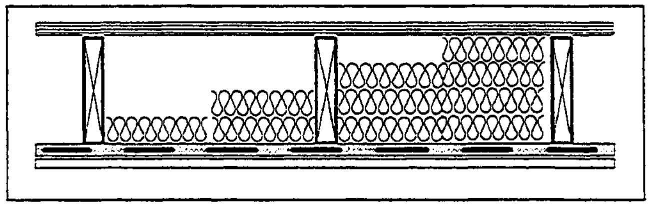
Subfloor	15 & 19 mm OSB
Cavity filling	152 mm glass fiber batts
Resilient metal channels	610 mm o.c.
Ceiling	1 layer 15.9 mm gypsum board



Joist Depth, mm	Joist Spacing, mm	OSB thickness, mm	Test ID	STC	Test ID	IIC
184	406	15	TLF-95-159a	50	IIF-95-061	44
235	300	15	TLF-96-031a	50	IIF-96-007	44
235	406	15	Mean Ref	52	Mean Ref	46
235	500	15	TLF-96-043a	52	IIF-96-013	46
235	610	15	TLF-96-035a	54	IIF-96-009	46
235	610	19	TLF-96-039a	53	IIF-96-011	46
286	406	15	TLF-95-215a	52	IIF-95-075	46

Table 4: Solid Wood Joists: Variable cavity fillings

Joist Depth	235 mm
Joist Spacing	406 mm o.c.
Subfloor	15 mm OSB
Resilient metal channels	610 mm o.c.
Ceiling gypsum board	1 layer 15.9 mm

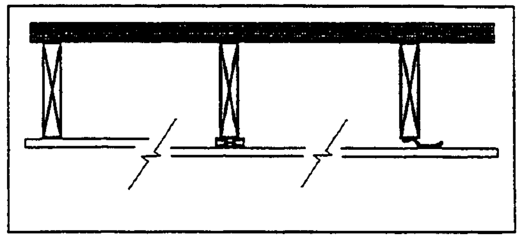


Cavity Filling					
Type[1]	Thickness	Test ID	STC	Test ID	IIC
None	Empty	TLF-96-063a	43	IIF-96-019	37
GFB	65	TLF-95-063a	50	IIF-95-019	45
GFB	90	TLF-95-085a	51	IIF-95-030	45
GFB	152	Mean ref	52	Mean ref	46
GFB	202	TLF-95-089a	53	IIF-95-032	46
GFB	217	TLF-95-061a	53	IIF-95-018	46
GFB	270	TLF-96-059a	53	IIF-96-017	46
RFB	90	TLF-95-065a	51	IIF-95-020	46
RFB	210	TLF-95-067a	54	IIF-95-021	48
CFS	59	TLF-95-143a	49	IIF-95-053	42
CFS	90	TLF-96-033a	52	IIF-96-008	45

[1]GFB = glass fiber batts, RFB = rock fiber batts, CFS = sprayed on cellulose fiber.

Table 5: Solid Wood Joists: Variable ceiling supports, empty cavity

Joist Depth	235 mm
Joist Spacing	406 mm o.c.
Subfloor	15 mm OSB
Cavity filling	None
Ceiling gypsum board	1 layer 15.9 mm

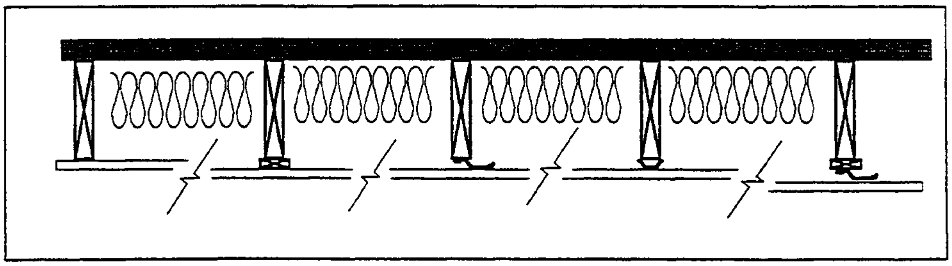


Furring type[1]	Test ID	STC	Test ID	IIC
None	TLF-95-095a	33	IIF-95-035	28
RC 610 mm o.c	TLF-96-063a	43	IIF-96-019	37
WF 610 mm o.c	TLF-95-097a	39	IIF-95-036	32

[1]RC = 13 mm resilient metal channels, UC = 22 mm deep U-channels, WF = 19 x 64 mm wood furring

Table 6: Solid Wood Joists: Variable ceiling supports, absorption in cavity

Joist Depth	235 mm
Joist Spacing	406 mm o.c.
Subfloor	15 mm OSB
Cavity filling	152 mm glass fiber batts
Ceiling gypsum board	1 layer 15.9 mm

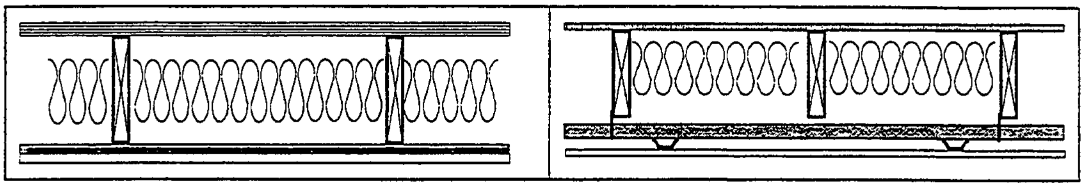


Furring type[1]	Test ID	STC	Test ID	IIC
none	TLF-95-073a	34	IIF-95-024	30
RC 200 mm o.c.	TLF-95-077a	47	IIF-95-026	40
RC 300 mm o.c.	TLF-95-079a	49	IIF-95-027	42
RC 406 mm o.c.	TLF-95-075a	50	IIF-95-025	42
RC 610 mm o.c.	Mean ref	52	Mean ref	46
UC 610 mm o.c.	TLF-95-081a	43	IIF-95-028	36
WF 610 mm o.c	TLF-95-083a	42	IIF-95-029	35
WF 610 mm o.c and RC 610 mm o.c	TLF-95-087a	52	IIF-95-031	45
WF 610 mm o.c and RC 610 mm o.c, no cross-bracing	TLF-95-091a	52	IIF-95-033	45

[1]RC = 13 mm resilient metal channels, UC = 22 mm deep U-channels, WF = 19 x 64 mm wood furring

Table 7: Solid Wood Joists: Alternative ceiling support

Joist Spacing	406 mm o.c.
Subfloor	15 mm OSB
Cavity filling	152 mm glass fiber batts
Ceiling gypsum board	1 layer 15.9 mm

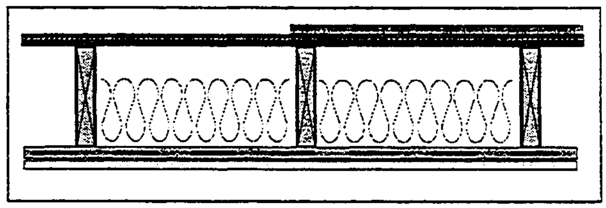


Note: the cavity depth is approximately the same in these two cases.

Joist depth, mm	Ceiling support	Test ID	STC	Test ID	IIC
286	Resilient metal channels, 610 mm o.c.	TLF-95-215a	52	IIF-95-075	46
235	Wire, C- and U-channels	TLF-96-089a	54	IIF-96-038	49

Table 8: Solid Wood Joists: Different floor coverings

Joist Depth	235 mm
Joist Spacing	406 mm o.c.
Subfloor	15 mm OSB
Cavity filling	152 mm glass fiber batts
Resilient Metal Channels	610 mm o.c.
Ceiling gypsum board	1 layer 15.9 mm

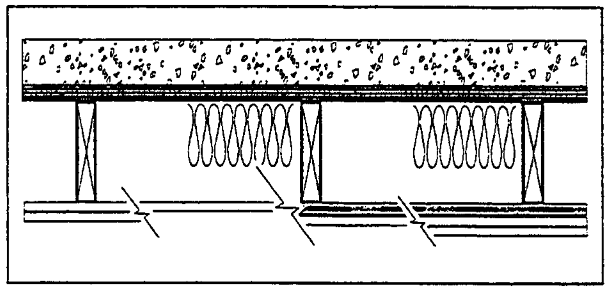


Covering	Test ID	STC	Test ID	IIC
None	Mean Ref	52	Mean Ref	46
Carpet and 9 mm foam underpad	TLF-96-057a	53	IIF-96-016	67
1.2 mm vinyl, inexpensive	No Test		IIF-96-029	44
1.9 mm vinyl, expensive	No Test		IIF-96-030	45
1.2 mm vinyl, medium priced	No Test		IIF-96-031	45

Note that the vinyl layers were glued to the floor but tests with the vinyl stapled to the floor give the same IIC ratings although there were significant differences between the two methods of installation at frequencies around 2500 Hz.

Table 9: Solid Wood Joists: 35 mm thick concrete topping with varying ceilings and cavity fillings

Joist Depth	235 mm
Joist Spacing	406 mm o.c.
Subfloor	15 mm OSB
Cavity filling	152 mm glass fiber batts



(a) pre-poured, reinforced 35mm concrete slab placed on top of OSB

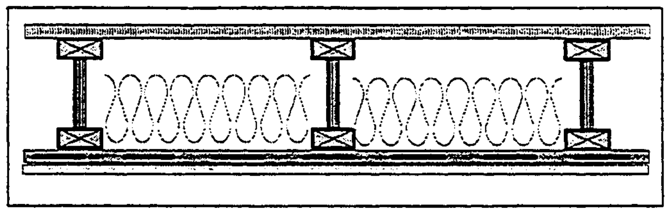
Gypsum Board Thickness, mm	Resilient Channels	Cavity Filling	Test ID	STC	Test ID	IIC
15.9	None	152 mm glass fiber batts	TLF-96-111a	48	IIF-96-049	35
15.9	610 mm o.c.	152 mm glass fiber batts	TLF-96-107a	68	IIF-96-047	48

(b) 35mm concrete poured directly on to the OSB sub-floor and allowed to set

Gypsum Board Thickness, mm	Resilient Channels	Cavity Filling	Test ID	STC	Test ID	IIC
15.9	None	152 mm glass fiber batts	TLF-96-139a	48	IIF-96-061	28
15.9	610 mm o.c.	152 mm glass fiber batts	TLF-96-143a	67	IIF-96-063	40
2*15.9	610 mm o.c.	152 mm glass fiber batts	TLF-96-147a	70	IIF-96-065	46
15.9	610 mm o.c.	None	TLF-96-151a	61	IIF-96-067	32
2*15.9	610 mm o.c.	None	TLF-96-155a	65	IIF-96-068	38
15.9	None	None	TLF-96-157a	46	IIF-96-069	25
2*15.9	None	None	TLF-96-161a	47	IIF-96-071	30

Table 10: Wood I-Joists: Different manufacturers

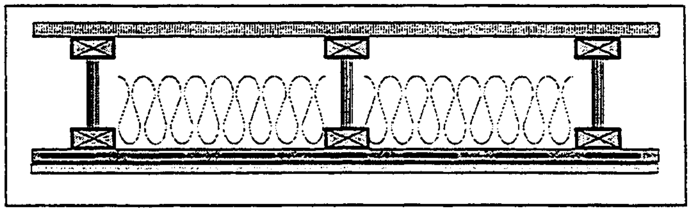
Joist Depth	241 mm
Joist Spacing	406 mm o.c.
Subfloor	15 mm OSB
Cavity filling	152 mm glass fiber batts
Resilient metal channels	610 mm o.c.
Ceiling gypsum board	1 layer 15.9 mm



	Flange dimensions, mm					
Manufacturer	**Horizontal**	**Vertical**	**Test ID**	**STC**	**Test ID**	**IIC**
A	64	38	TLF-96-069a	51	IIF-96-022	45
A	38	64	TLF-96-071a	51	IIF-96-023	46
A	89	38	TLF-96-073a	52	IIF-96-024	45
B	38	38	TLF-96-127a	52	IIF-96-055	45
B	57	38	TLF-96-131a	53	IIF-96-057	46
C	38	38	TLF-96-159a	50	IIF-96-070	44
D	38	38	TLF-97-007a	48	IIF-97-004	42
E	64	38	TLF-97-029a	48	IIF-97-015	42

Table 11: Wood I-Joists: 89 wide x38 mm thick flanges, different joist depths

Joist Spacing	406 mm o.c.
Subfloor	15 mm OSB
Cavity filling	152 mm glass fiber batts
Resilient metal channels	610 mm o.c.
Ceiling gypsum board	1 layer 15.9 mm

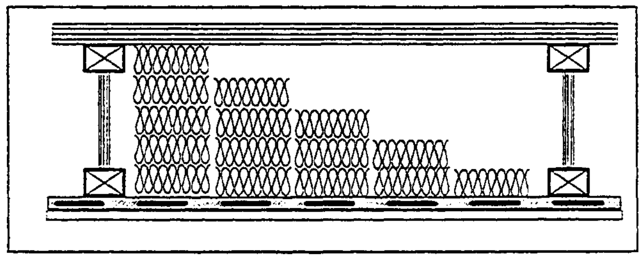


Joist Depth, mm	Test ID	STC	Test ID	IIC
241	TLF-96-073a	52	IIF-96-024	45
355	TLF-96-075a	53	IIF-96-028	45
457[1]	TLF-96-077a	53	IIF-96-032	46
457	TLF-96-101a	53	IIF-96-044	47

[1] 15 mm Waferboard, not OSB

Table 12: Wood I-Joists: Variable Cavity Filling

Joist Depth	457 mm
Joist Spacing	406 mm o.c.
Subfloor	15 mm OSB
Resilient metal channels	610 mm o.c.
Ceiling gypsum board	1 layer 15.9 mm

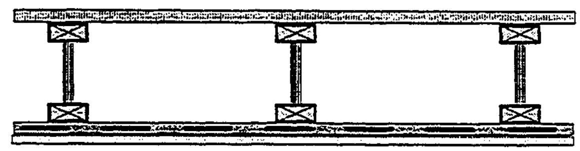


Material[1]	Thickness	Test ID	STC	Test ID	IIC
GFB	90	TLF-96-105a	52	IIF-96-046	46
GFB	152	TLF-96-101a	53	IIF-96-044	47
GFB	180	TLF-96-109a	54	IIF-96-048	47
GFB	292	TLF-96-113a	55	IIF-96-050	48
GFB	354	TLF-96-115a	56	IIF-96-051	49
GFB	456	TLF-96-117a	57	IIF-96-052	49
RFB	90	TLF-96-119a	53	IIF-96-053	47
RFB	456	TLF-96-121a	59	IIF-96-054	51

[1]GFB = glass fiber batts, RFB = rock fiber batts.

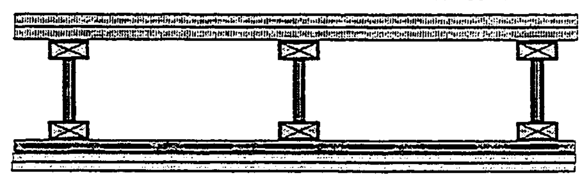
Table 13: 241 mm deep Wood I-Joists, 89 wide x 38 mm high flanges, empty cavity: Variable joist spacing, subfloors, ceilings and resilient metal channel spacings

(a) Single layer of 15 mm OSB, single layer of 12.7 mm gypsum board.



I-joist spacing, mm	Resilient channel spacing, mm	Test ID	STC	Test ID	IIC
406	610	TLF-96-165a	43	IIF-96-073	36
406	406	TLF-96-193a	42	IIF-96-085	36
610 (10 joists)	406	TLF-96-201a	44	IIF-96-089	35

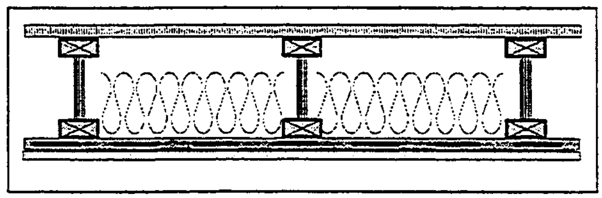
(b) Double layer of 15 mm OSB, double layer of gypsum board.



double layer of 12.7 mm gypsum board					
406	406	TLF-96-187a	51	IIF-96-082	43
406	610	TLF-96-177a	51	IIF-96-079	41
610 (10 joists)	406	TLF-97-001a	53	IIF-97-001	44
double layer of 15.9 mm gypsum board					
406	406	TLF-96-197a	49	IIF-96-087	41
406	610	TLF-96-181a	51	IIF-96-081	45
610 (10 joists)	406	TLF-97-005a	53	IIF-97-003	45

Table 14: Wood I-Joists: Different resilient metal channel (RC) spacing

Joist Depth	241 mm
Joist Spacing	406 mm o.c.
Subfloor	15 mm OSB
Cavity filling	152 mm glass fiber batts
Ceiling gypsum board	1 layer 15.9 mm

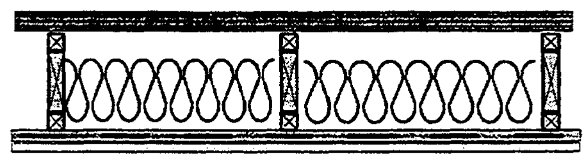


Resilient channel spacing	Test ID	STC	Test ID	IIC
406 mm	TLF-97-003a	50	IIF-97-002	44
610 mm	TLF-97-007a	48	IIF-97-004	42

Table 15: Wood Truss Floors: Varying joist depth and spacing and varying subfloor

Cavity filling	152 mm glass fiber batts
Resilient Metal Channels	610 mm o.c.
Ceiling gypsum board	1 layer 15.9 mm

Trusses constructed from 38 x 89 mm lumber with largest dimension vertical.

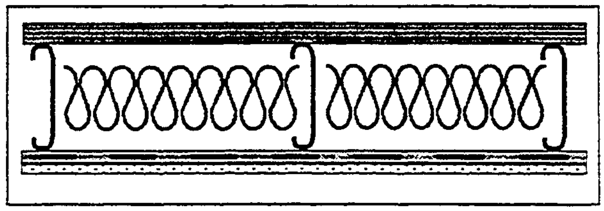


OSB thickness	Truss depth	Truss spacing	Test ID	STC	Test ID	IIC
15	356	406	TLF-97-033a	54	IIF-97-017	42
15	356	488	TLF-97-039a	52	IIF-97-019	41
15	356	610	TLF-97-045a	54	IIF-97-022	42
15	457	488	TLF-97-041a	55	IIF-97-020	44
15	457	610	TLF-97-043a	53	IIF-97-021	42
19	356	610	TLF-97-047a	54	IIF-97-023	42
19	356[1]	610	TLF-97-053a	55	IIF-97-026	43
19	457	610	TLF-97-049a	53	IIF-97-024	42
19	610	610	TLF-97-051a	55	IIF-97-025	43

[1] Truss formed from 38 x 64 mm lumber with largest dimension horizontal

Table 16: Steel Joist Floors: Varying joist depth, spacing and metal gauge, varying subfloor

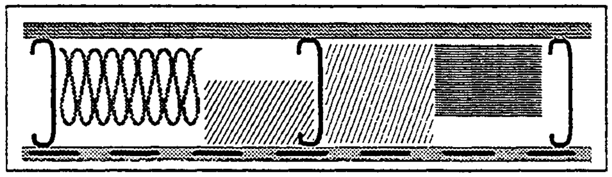
Cavity filling	152 mm glass fiber batts
Resilient metal channels	610 mm o.c.
Ceiling gypsum board	1 layer 15.9 mm



Steel Gauge	Joist Depth	Joist Spacing	OSB thickness	Test ID	STC	Test ID	IIC
14	203	406	16 mm OSB	TLF-97-057a	52	IIF-97-028	45
16	203	406	16 mm OSB	TLF-97-059a	51	IIF-97-029	45
18	203	406	16 mm OSB	TLF-97-061a	50	IIF-97-030	44
16	203	610	16 mm OSB	TLF-97-063a	53	IIF-97-031	44
16	254	406	16 mm OSB	TLF-97-065a	51	IIF-97-032	44
16	305	406	16 mm OSB	TLF-97-069a	52	IIF-97-034	44
16	203	610	19 mm OSB	TLF-97-067a	53	IIF-97-033	44

Table 17: Steel Joists, 16 gauge: Varying cavity absorption

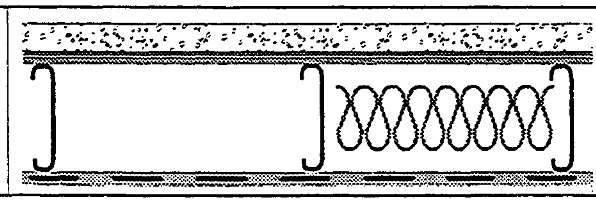
Subfloor	15 mm OSB
Joist Depth	203 mm
Joist Spacing	406 mm
Resilient metal channels	610 mm o.c.
Ceiling gypsum board	1 layer 15.9 mm



Cavity filling	Test ID	STC	Test ID	IIC
none	TLF-98-009a	44	IIF-98-004	35
152 mm glass fiber batts	TLF-98-001a	50	IIF-98-001	43
140 mm rock fiber batts	TLF-98-005a	51	IIF-98-002	45
90 mm Cellulose fiber	TLF-98-011a	51	IIF-98-005	44
140 mm Cellulose fiber	TLF-98-013a	52	IIF-98-006	45

Table 18: Steel Joists, 16 gauge: Gypsum concrete topping

25 mm Gypsum concrete topping on 15 mm OSB, 16 gauge joists



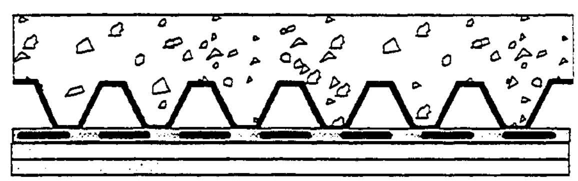
Subfloor	15 mm OSB
Joist Depth	203 mm
Joist Spacing	406 mm
Resilient metal channels	610 mm o.c.
Ceiling gypsum board	1 layer 15.9 mm

Cavity filling	Test ID	STC	Test ID	IIC
None	TLF-97-079a	55	IIF-97-039	24
152 mm glass fiber batts	TLF-97-081a	60	IIF-97-040	28

Table 19: Concrete Floors: Uniform and ribbed slabs

Slab Thickness	Test ID	STC	Test ID	IIC
145 mm	TLF-95-025a	53	IIF-95-004	27
95 mm	TLF-98-007a	47	IIF-95-003	20
Ribbed 75 – 150 mm	TLF-97-101a	51	IIF-97-045	21

Ribbed concrete slab with two layers of 12.7 mm gypsum board suspended from Resilient metal channels spaced 406 mm o.c.



Thickness	Test ID	STC	Test ID	IIC
Ribbed 75 – 150 mm	TLF-97-109a	57	IIF-97-049	36

Table 20: Ceiling Layers Only

Joist Depth	235 mm, solid wood
Joist Spacing	406 mm o.c.
Ceiling support	Resilient metal channels

Ceiling	Test ID	STC
1 sheet of 15.9 mm gypsum board	TLF-95-103a	29
2 sheets of 15.9 mm gypsum board	TLF-95-105a	35
1 sheet of 12.7 mm gypsum board	TLF-95-119a	29
2 sheets of 12.7 mm gypsum board	TLF-95-117a	33
1 sheet of light† 12.7 mm gypsum board	TLF-96-183a	27
2 sheets of light† 12.7 mm gypsum board	TLF-96-185a	32

† 1.5 lb/sq. ft. (7.4 kg/m^2)

Table 21: Floor Layers Only

Solid 38 x 235 mm wood joists, 406 mm o.c.

Subfloor	Test ID	STC	Test ID	IIC
15 mm OSB[1]	TLF-95-101a	24	IIF-95-038	20
16 mm plywood	TLF-96-137a	22	IIF-96-060	18
2 sheets of 16 mm plywood	TLF-96-141a	26	IIF-96-062	22
13 mm plywood	TLF-96-145a	22	IIF-96-064	20
2 sheets of 13 mm plywood	TLF-96-149a	26	IIF-96-066	22
25 mm plywood	TLF-96-067a	22	IIF-96-021	14
35 mm normal weight concrete on 15 mm OSB	TLF-96-163a	41	IIF-96-072	15

[1]Caulking and taping the joints between the sheets of OSB had no effect on the sound insulation.

Solid 38 x 235 mm wood joists, 610 mm o.c.

15 mm OSB	TLF-96-037a	25	IIF-96-010	19
19 mm OSB	TLF-96-041a	24	IIF-96-012	18

Wood I-joists, 457 mm deep, 406 mm o.c.

Subfloor	Test ID	STC	Test ID	IIC
15 mm OSB	TLF-96-081a	25	IIF-96-034	20
15 mm OSB	TLF-96-097a	25	IIF-96-042	21

Wood I-joists, 241 mm deep, 406 mm o.c.

Subfloor	Test ID	STC	Test ID	IIC
15 mm OSB	TLF-97-009a	24	97-005	18

CONSTRUCTION DETAILS

The figures in this section show construction details for the floors used. The captions explain the relevance of each figure.

Joist and beam layouts

For some of the constructions, the ratio of the length of the test frame and the joist spacing was not an integer. This results in there being small cavities at each end of the floor. Cavities such as these can increase sound transmission to a degree that depends on the details in each case. This effect was not extensively investigated during the project. Information is provided in the tables of STC and IIC to allow identification of the joist layout where confusion might arise.

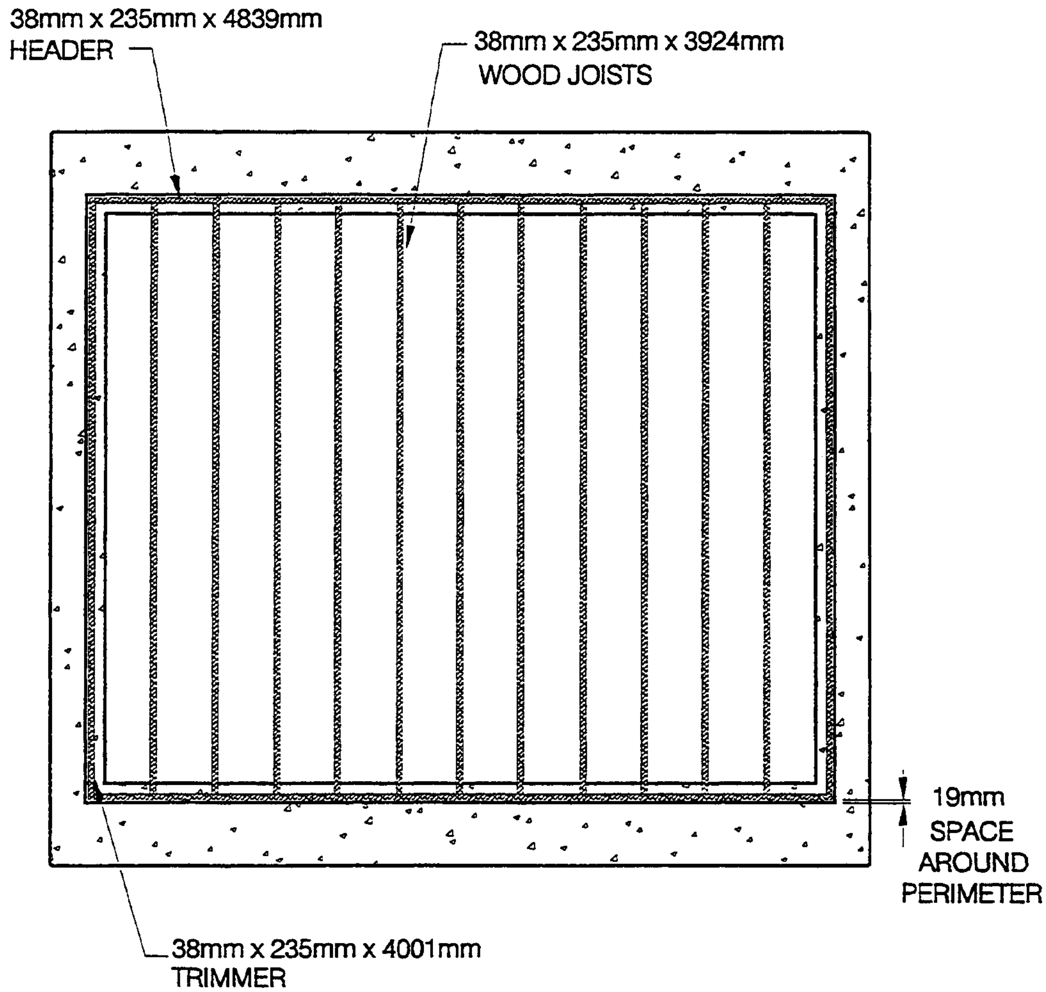


Figure 5: Layout for joists 406 mm o.c. with joist on mid-line of the floor opening — 13 joists.

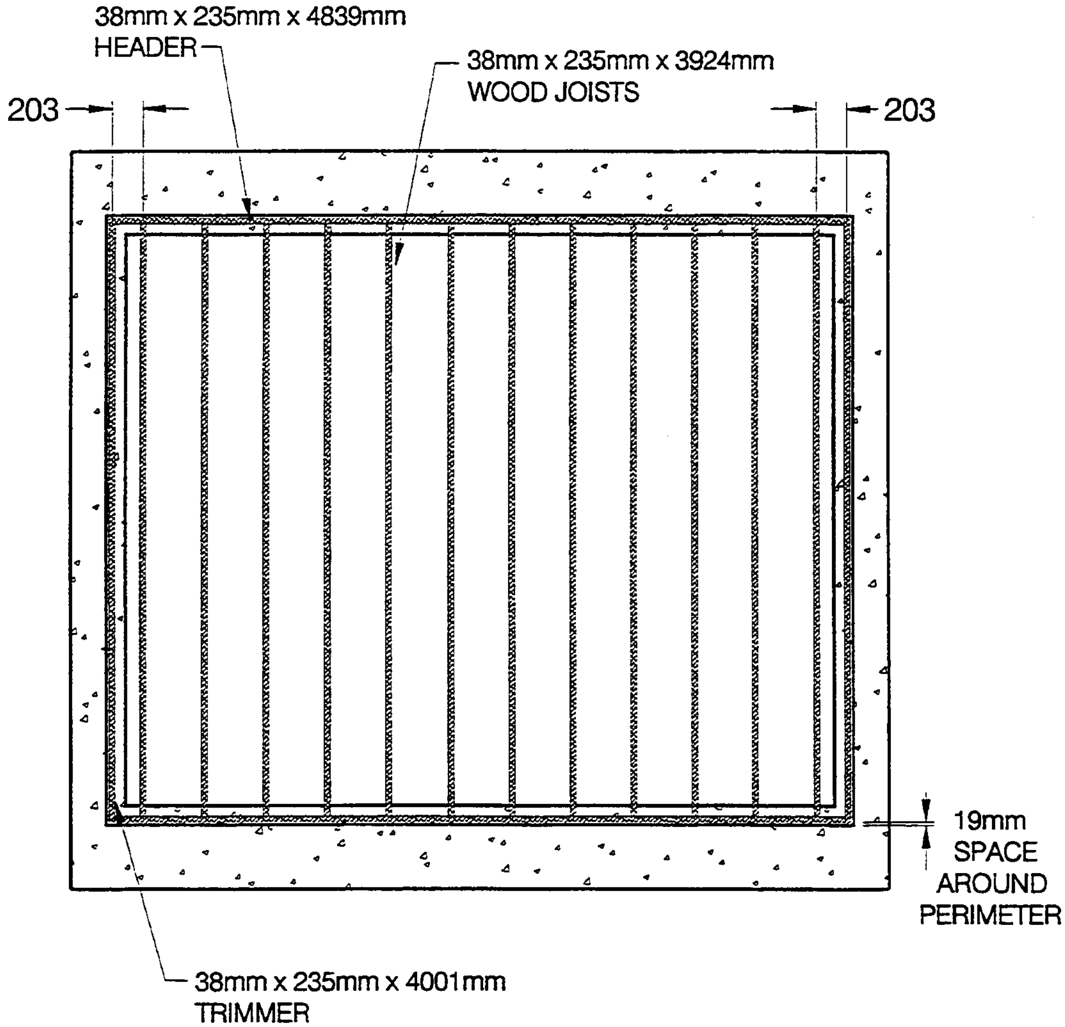


Figure 6: Layout for joists 406 mm o.c. with joists symmetrically disposed about the mid-line of the floor opening — 14 joists.

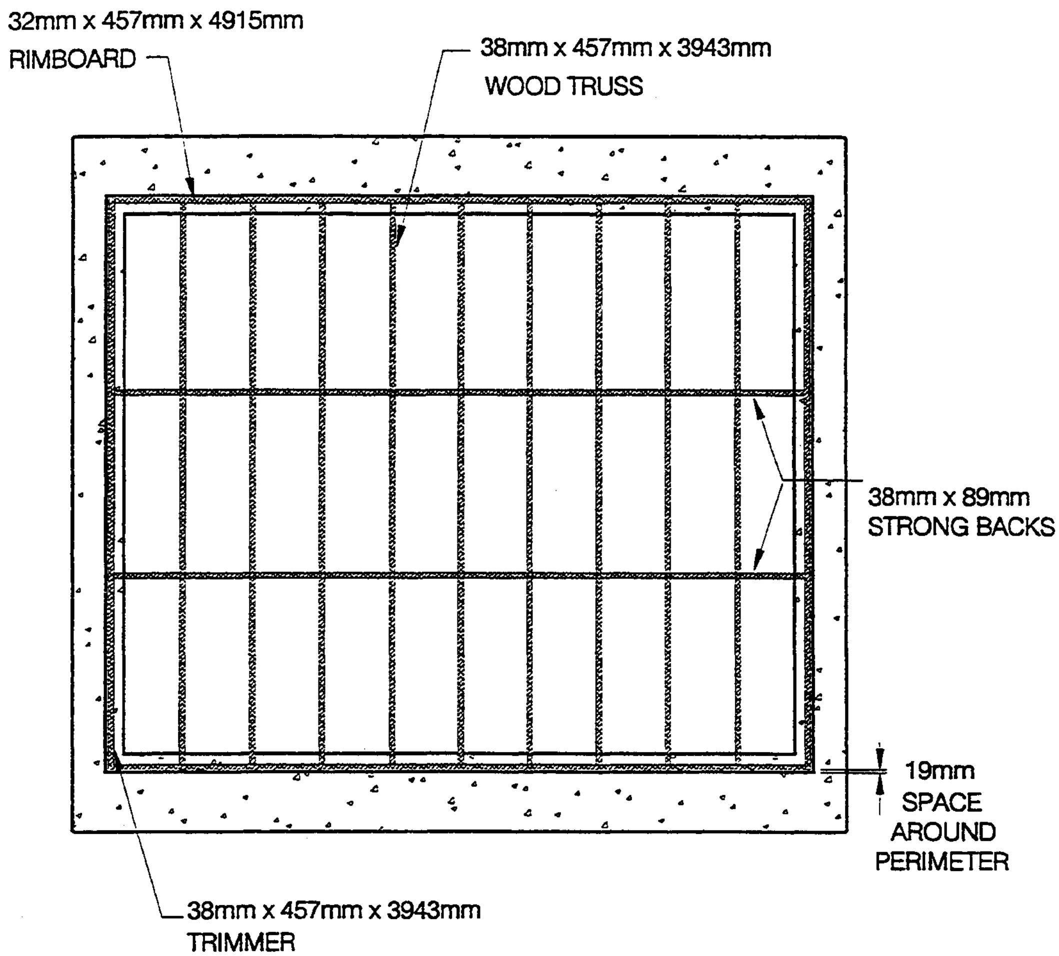


Figure 7: Layout for trusses 488 mm o.c.

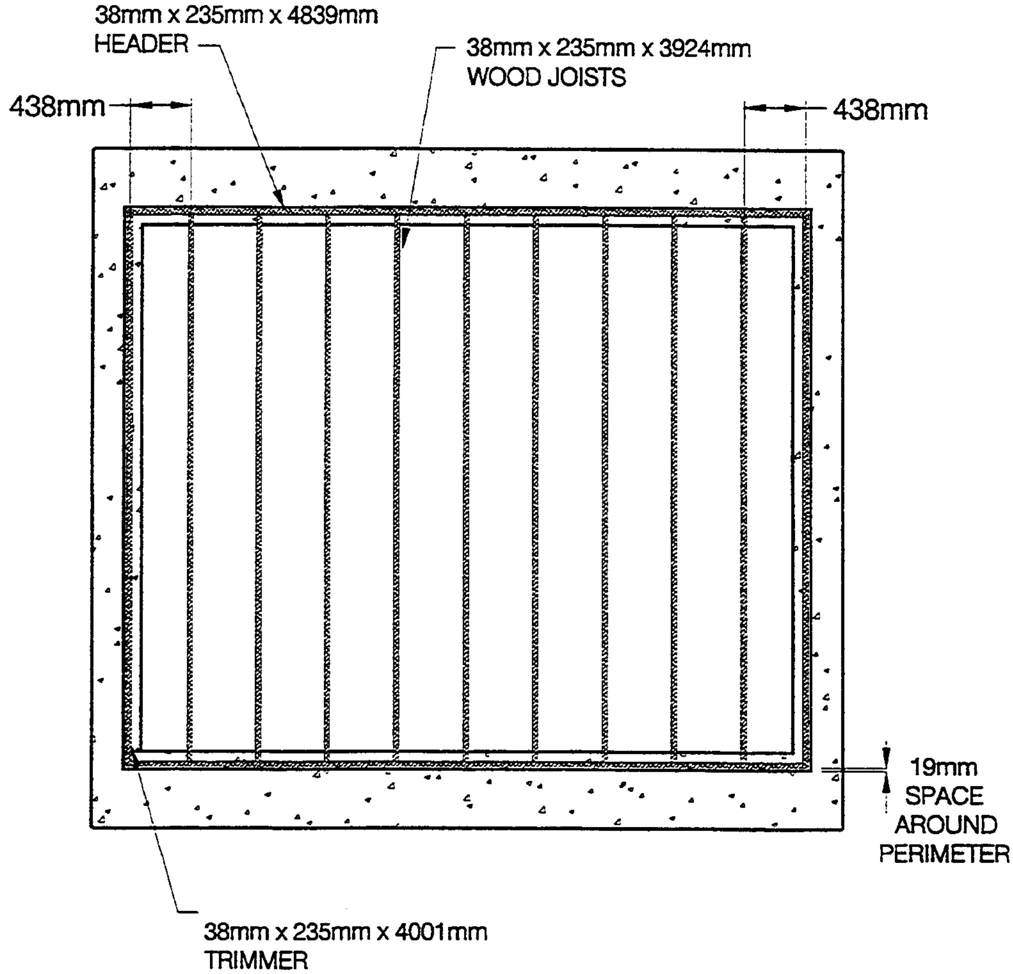


Figure 8: Layout for joists 500 mm o.c.

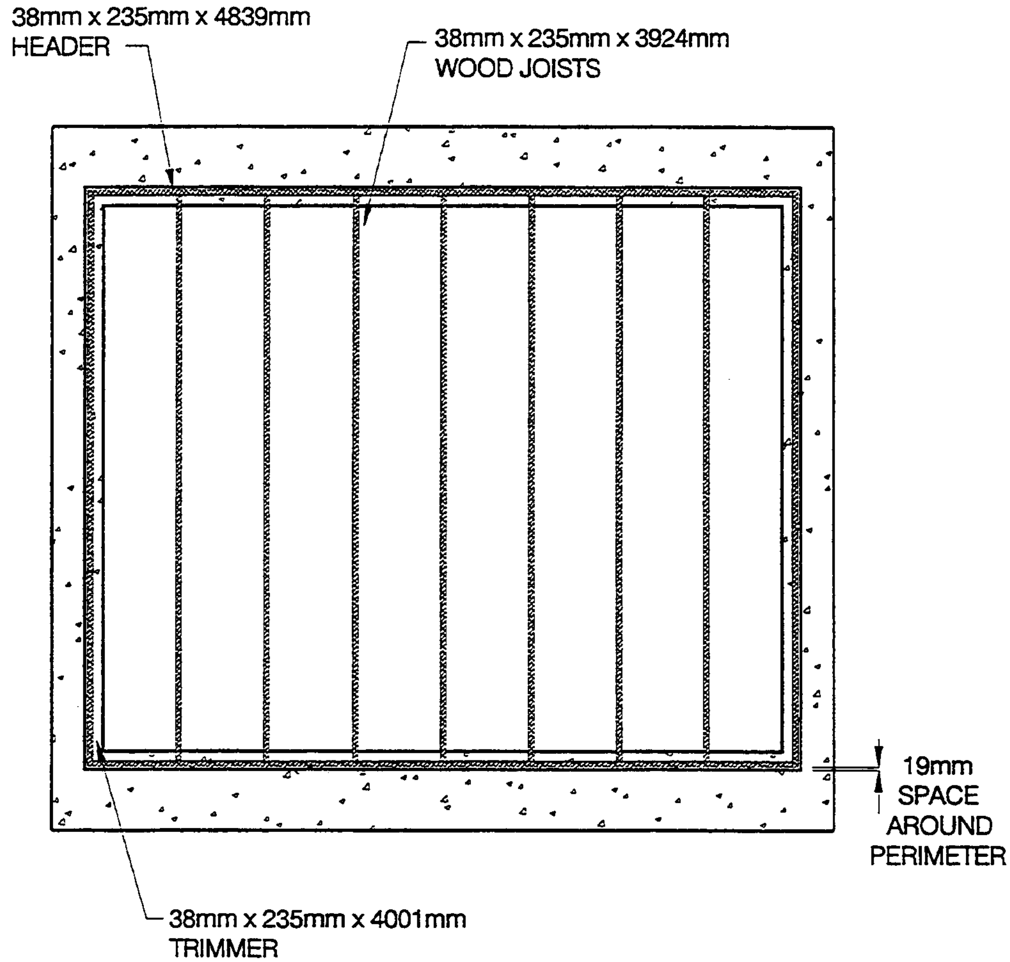


Figure 9: Layout for joists 610 mm o.c with joist on mid-line of the floor opening (9 joists).

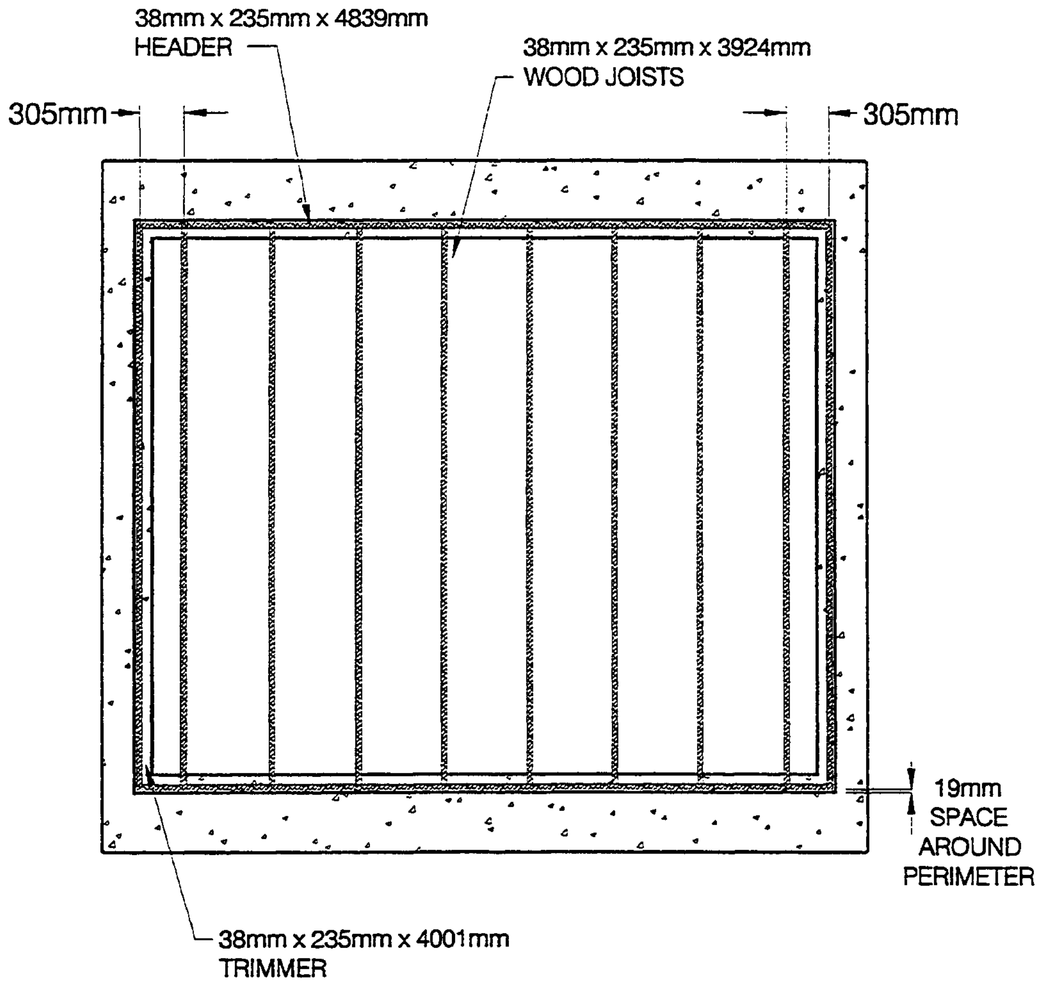


Figure 10: Layout for joists 610 mm o.c with joists symmetrically disposed about the mid-line of the floor opening (10 joists).

Gypsum board layouts

Caulking and finishing

All gypsum board joints were caulked and covered with metal tape. Tests in this laboratory have shown that this method of finishing gives identical results to those obtained when the gypsum board is finished with paper tape and gypsum compound. In the captions that follow, the terms base and face layer are used to denote the first layer attached to resilient metal channels or joists and the second, exposed layer respectively.

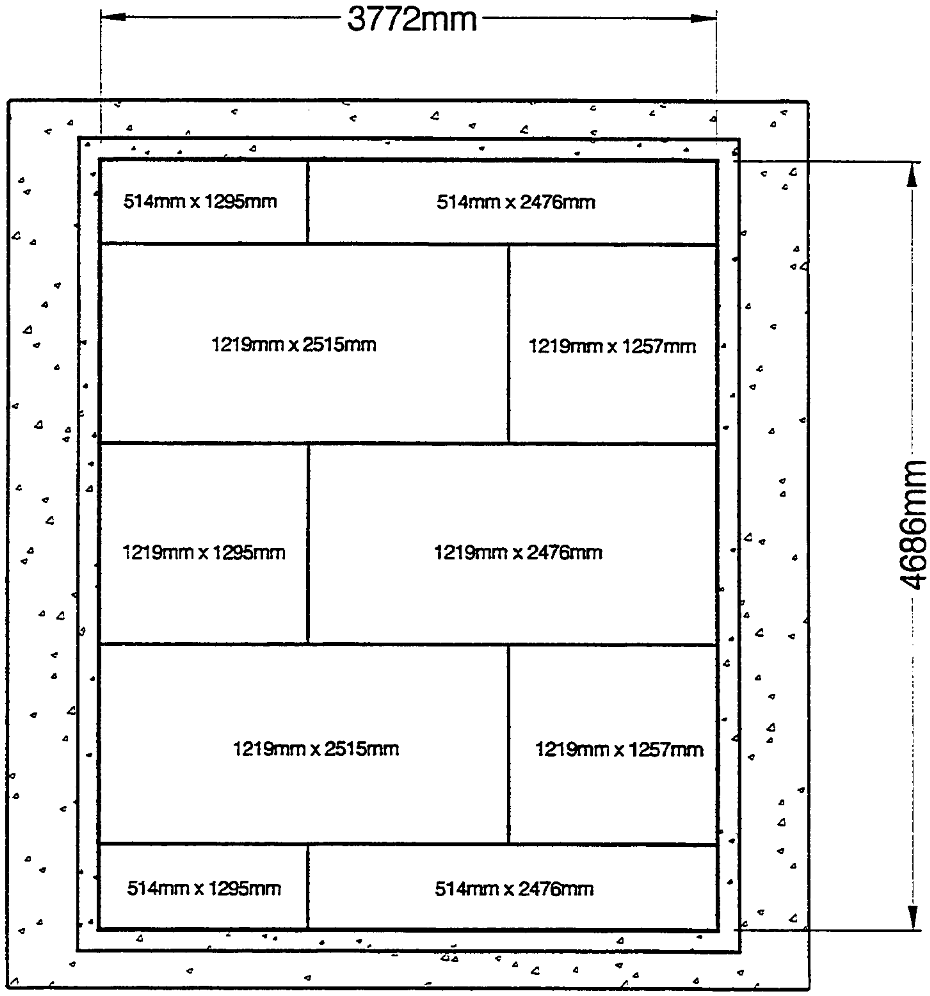


Figure 11: Single layer or base layer of gypsum board layout, resilient metal channels 610 mm o.c.

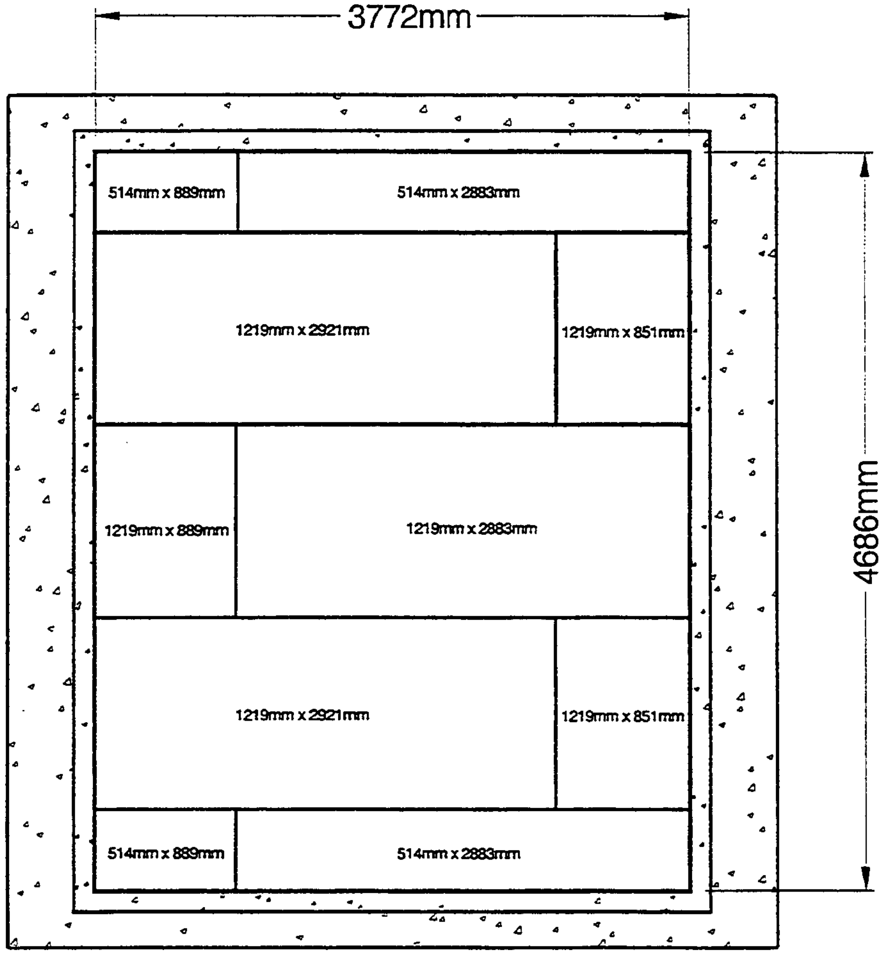


Figure 12: Single layer or base layer gypsum board layout, resilient metal channels 406 mm o.c.

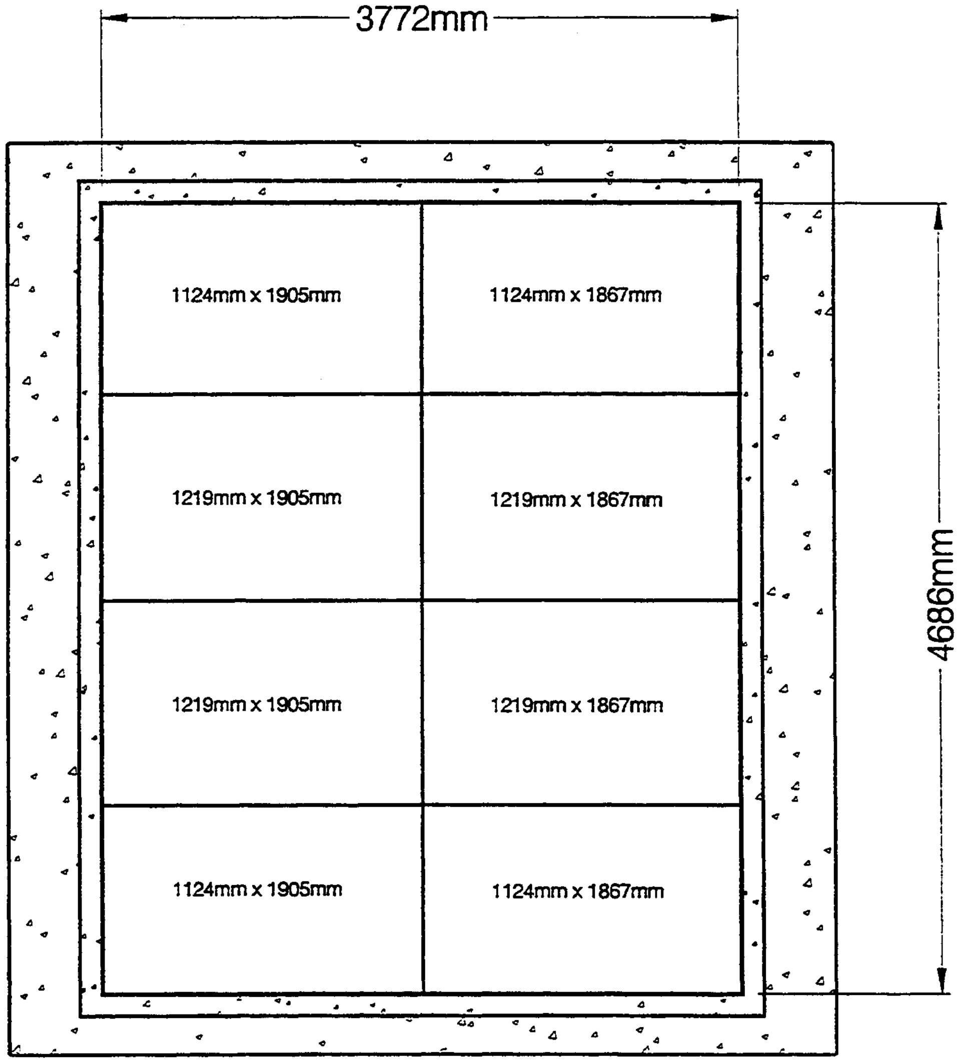


Figure 13: Face layer gypsum board layout, resilient metal channels 610 mm o.c.

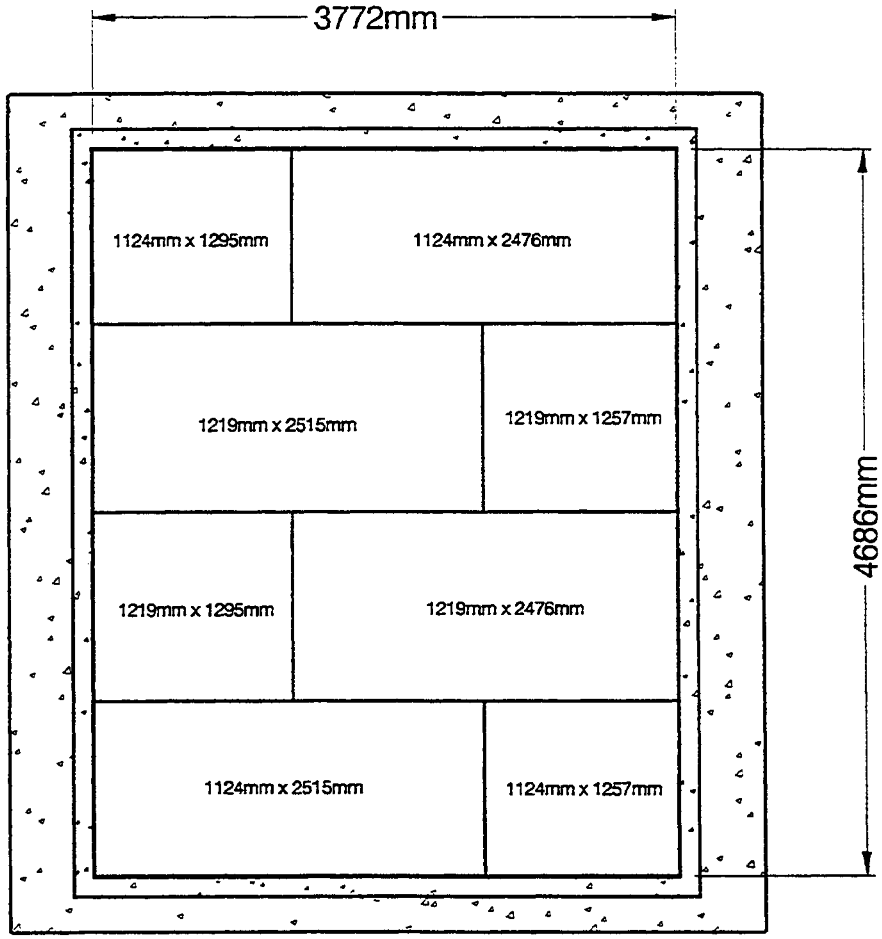


Figure 14: Face layer gypsum board layout, resilient metal channels 406 mm o.c.

Gypsum board screw patterns

Gypsum board was applied with the long axis perpendicular to the resilient metal channels, furring or joists as appropriate and screwed 305 mm o.c.

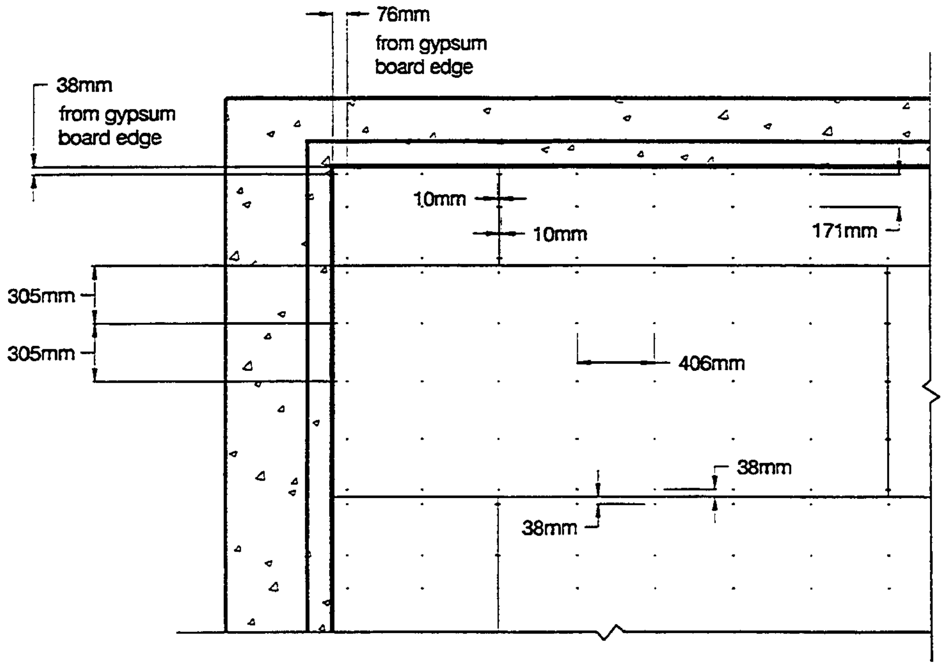


Figure 15: Screw pattern for single layer gypsum board layout, resilient metal channels 406 mm o.c.

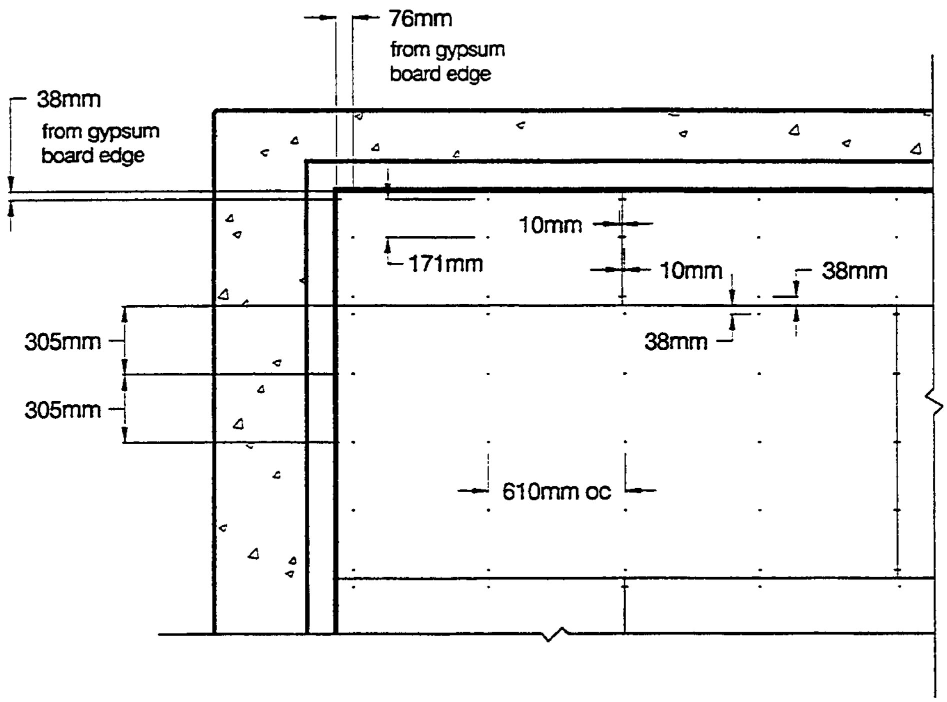


Figure 16: Screw pattern for single layer gypsum board layout, resilient metal channels 610 mm o.c.

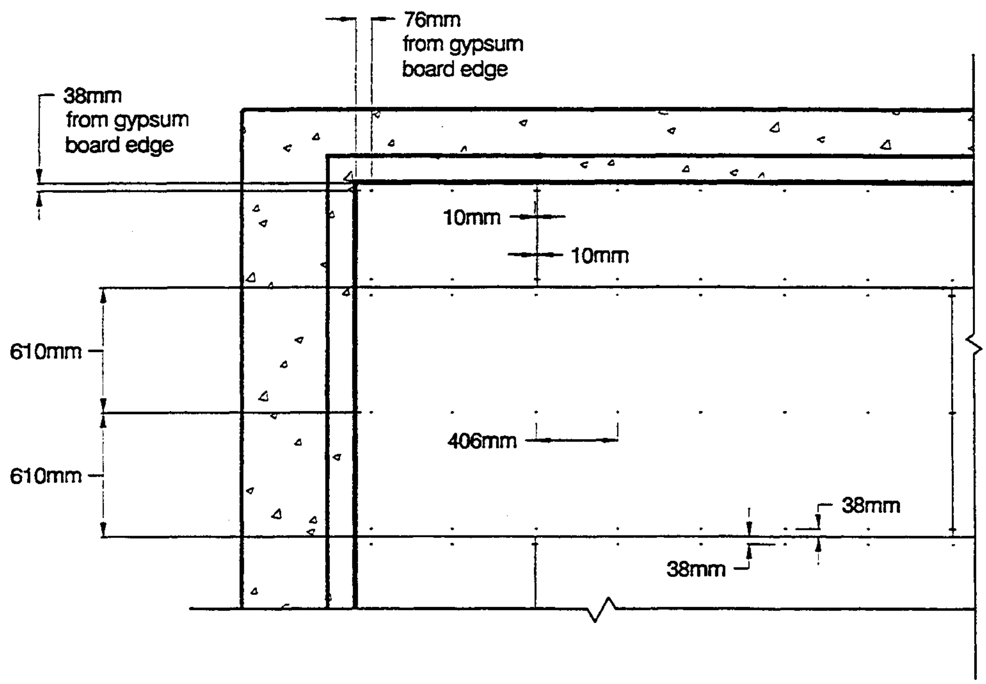


Figure 17: Screw pattern for base layer gypsum board layout, resilient metal channels 406 mm o.c.

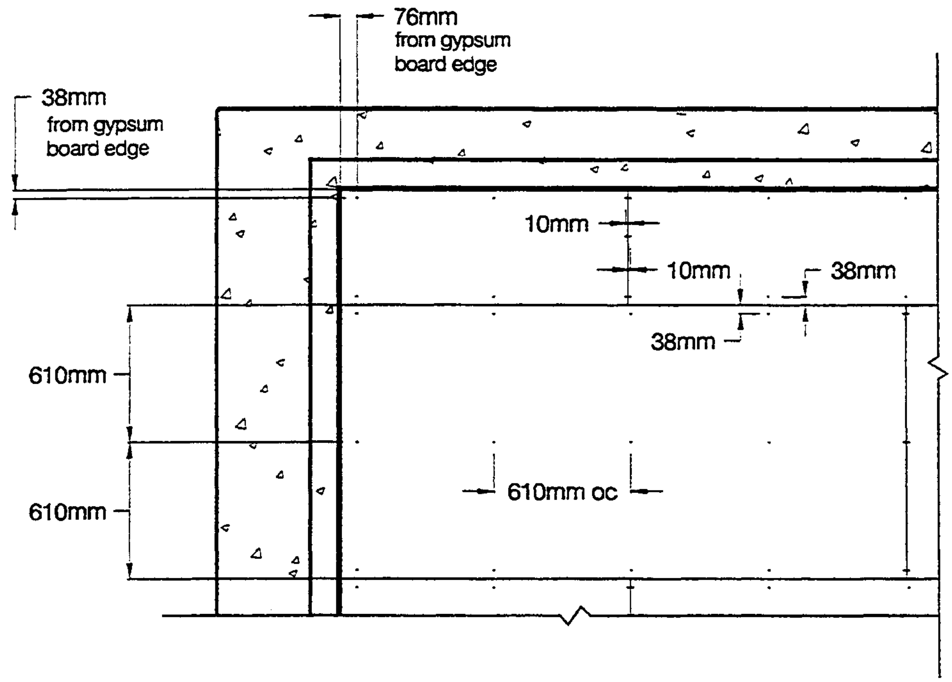


Figure 18: Screw pattern for base layer gypsum board layout, resilient metal channels 610 mm o.c.

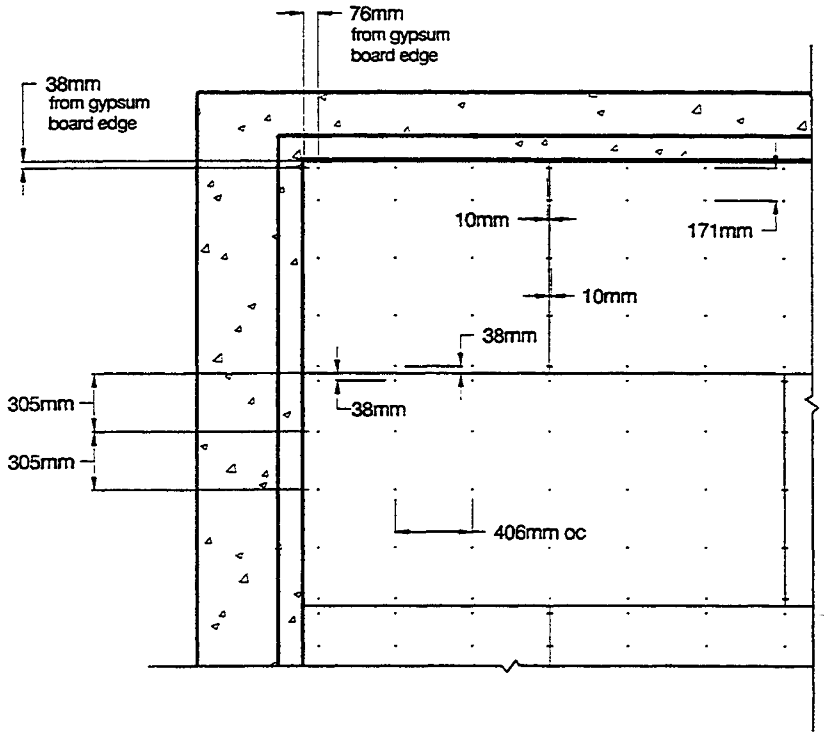


Figure 19: Screw pattern for face layer gypsum board layout, resilient metal channels 406 mm o.c.

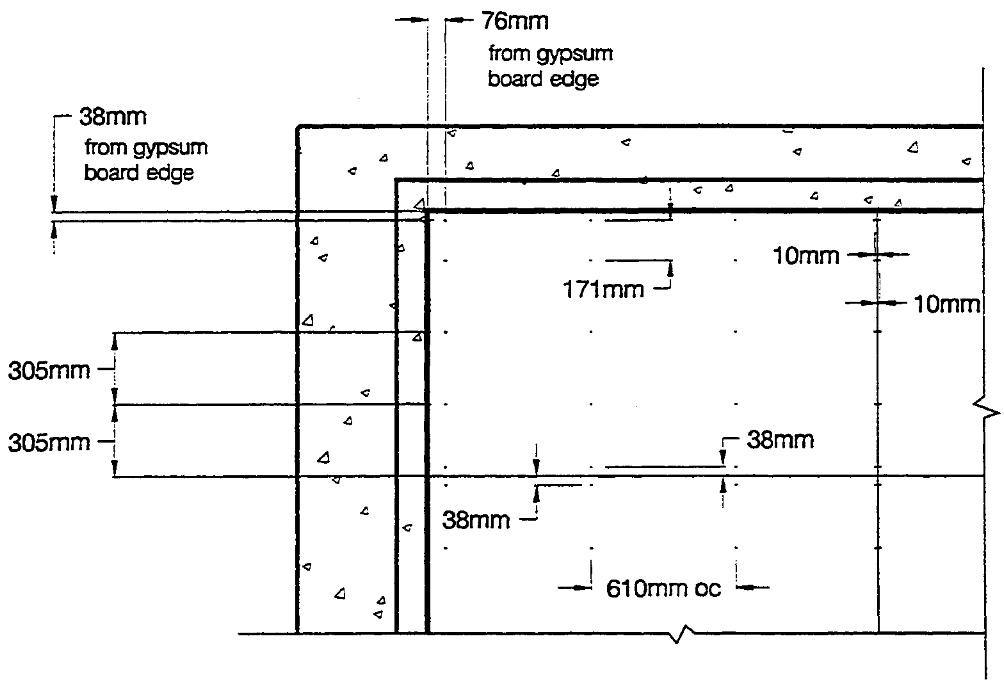


Figure 20: Screw pattern for face layer gypsum board layout, resilient metal channels 610 mm o.c.

Subfloor layouts

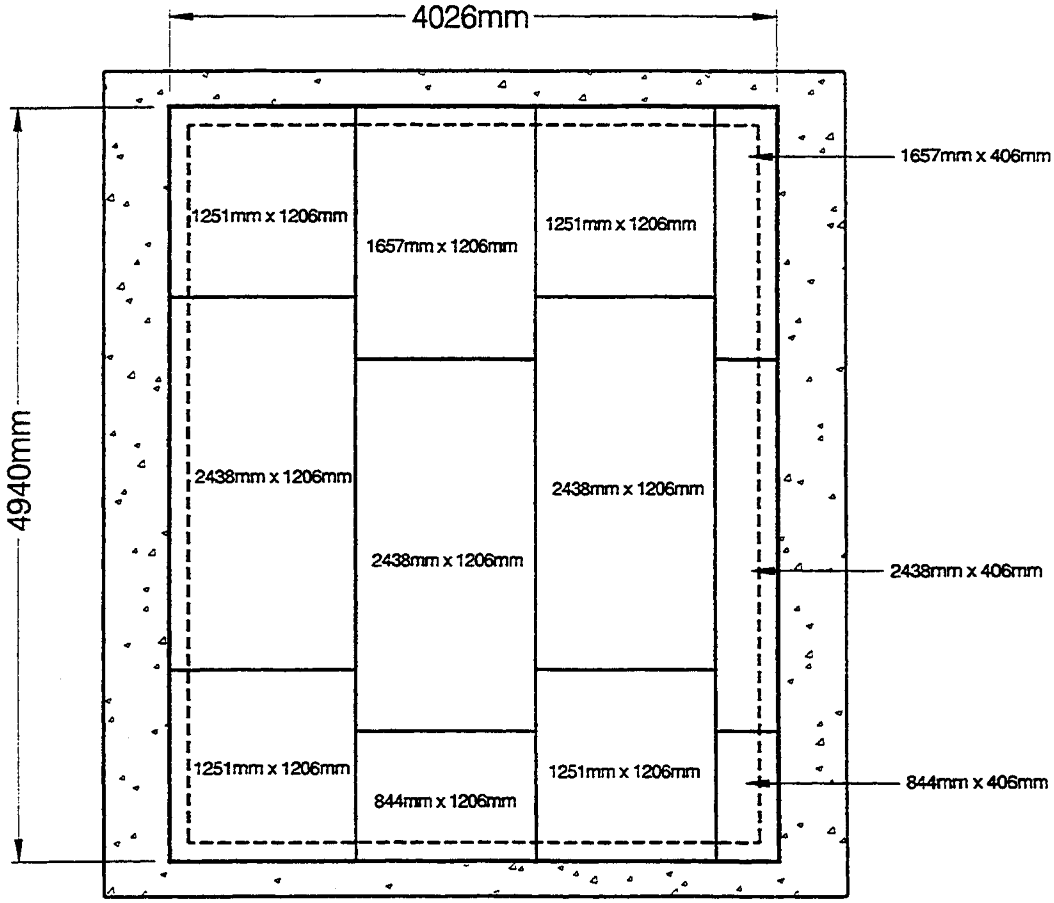


Figure 21: Single layer or base subfloor layout, joists 406 mm o.c.

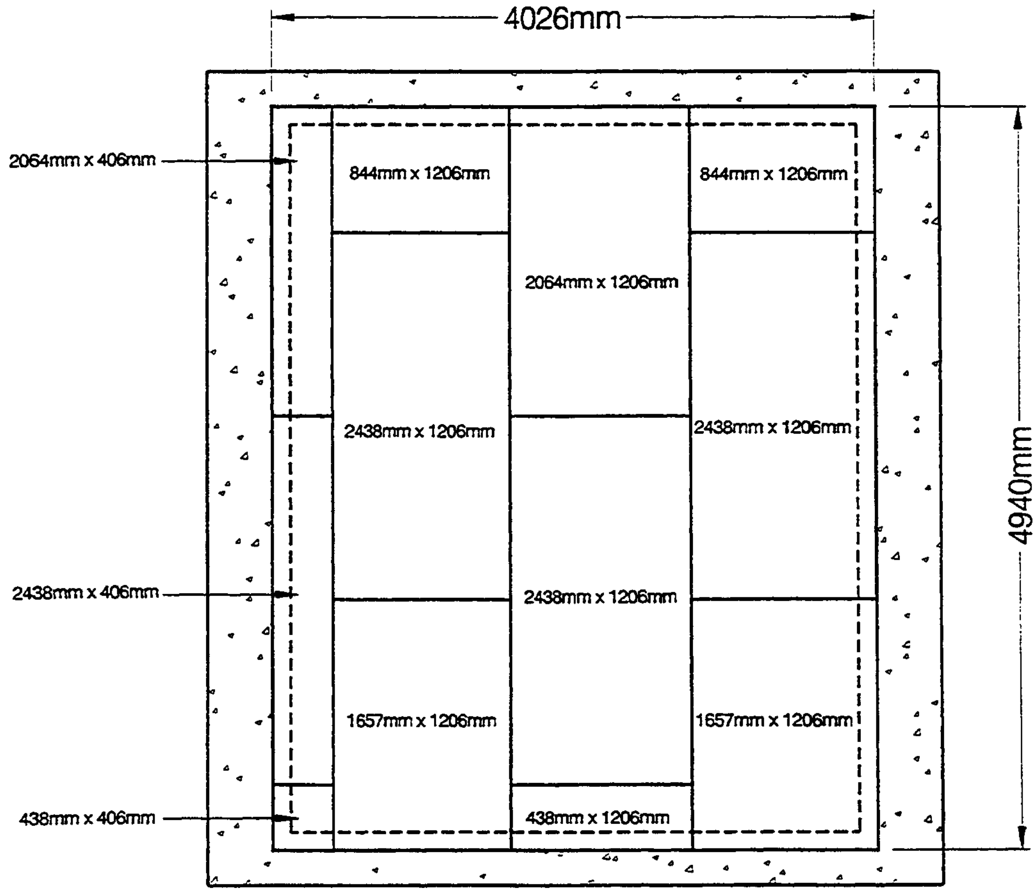


Figure 22: Face layer subfloor layout, joists 406 mm o.c.

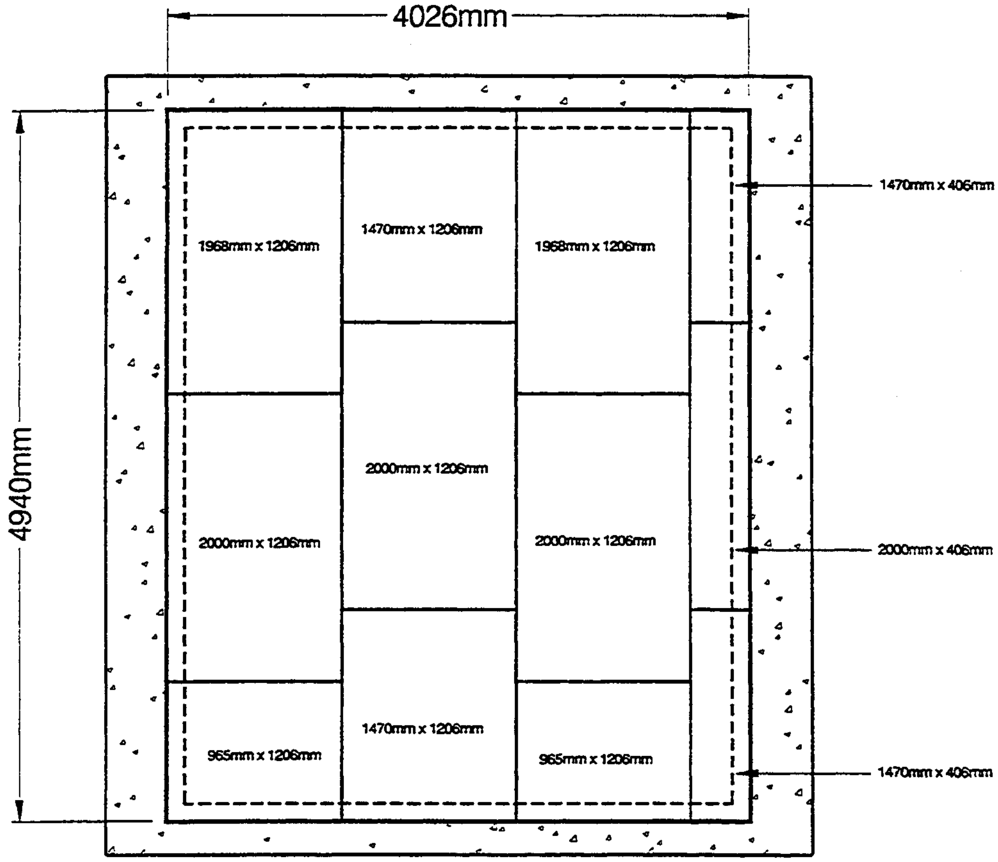


Figure 23: Face layer subfloor layout, joists 500 mm o.c.

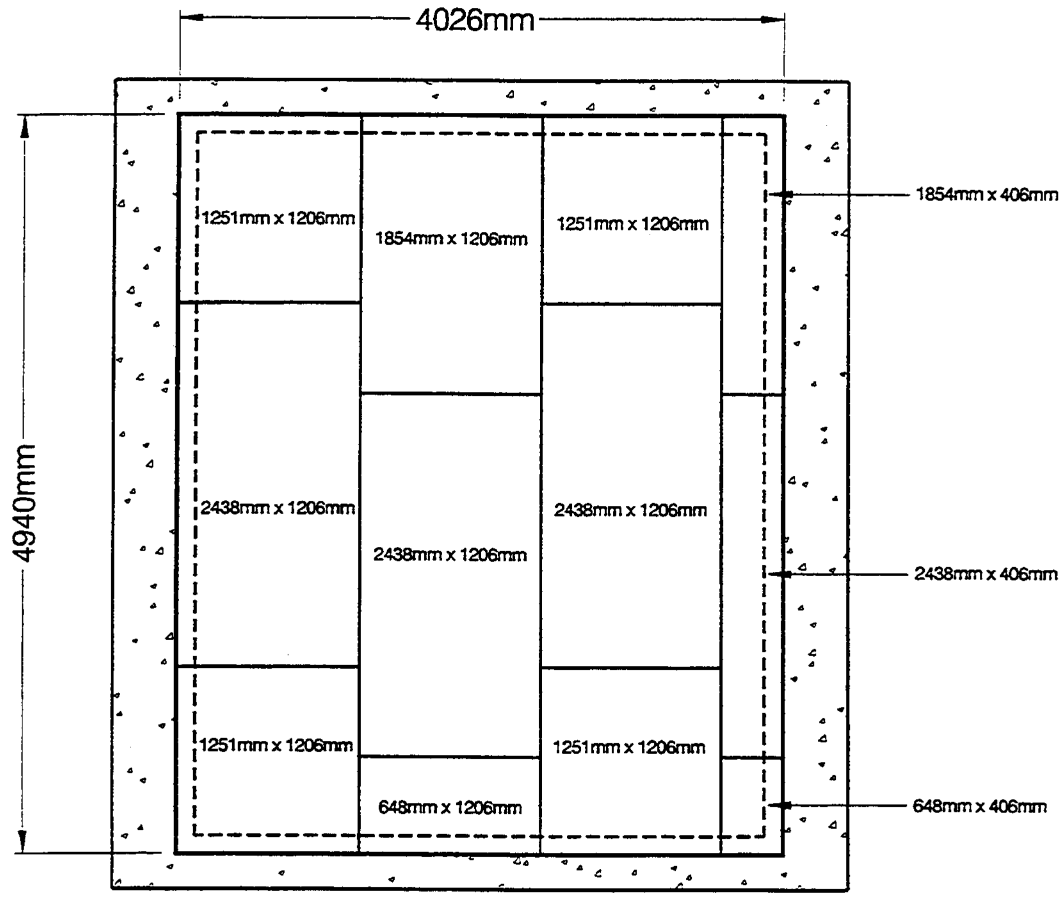


Figure 24: Single layer subfloor layout, joists 610 mm o.c.

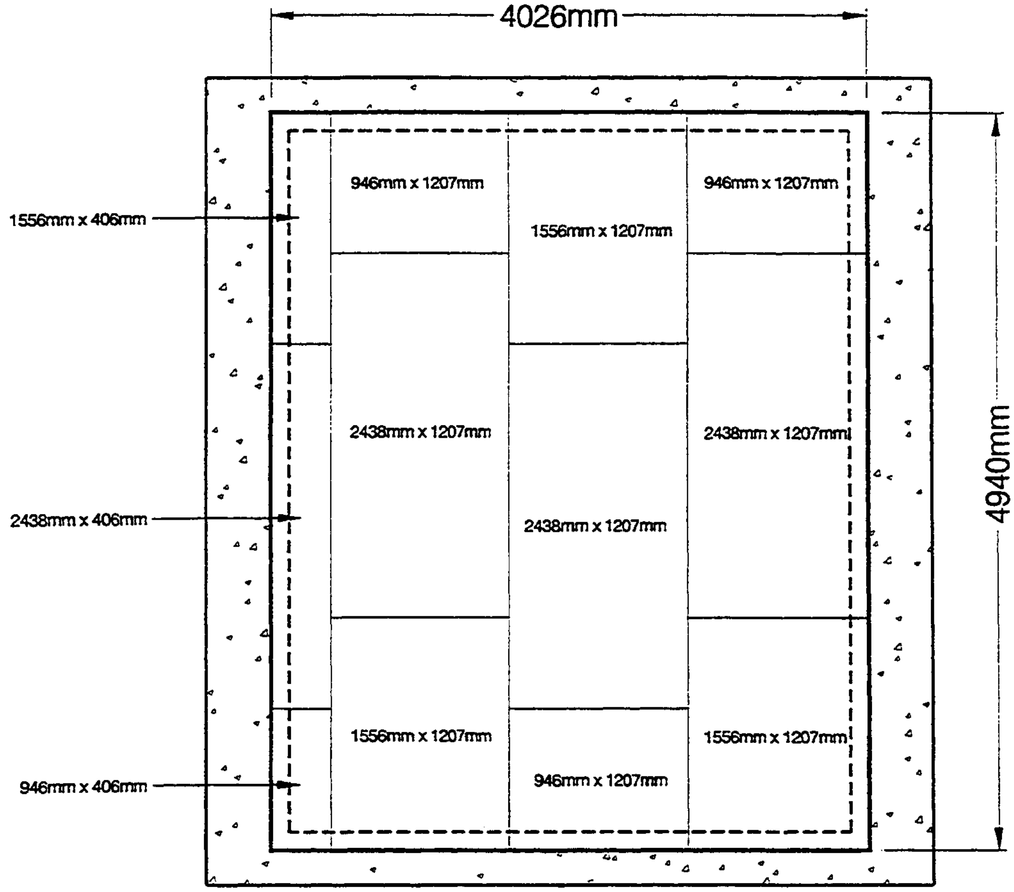


Figure 25: Base layer subfloor layout, joists 610 mm o.c.

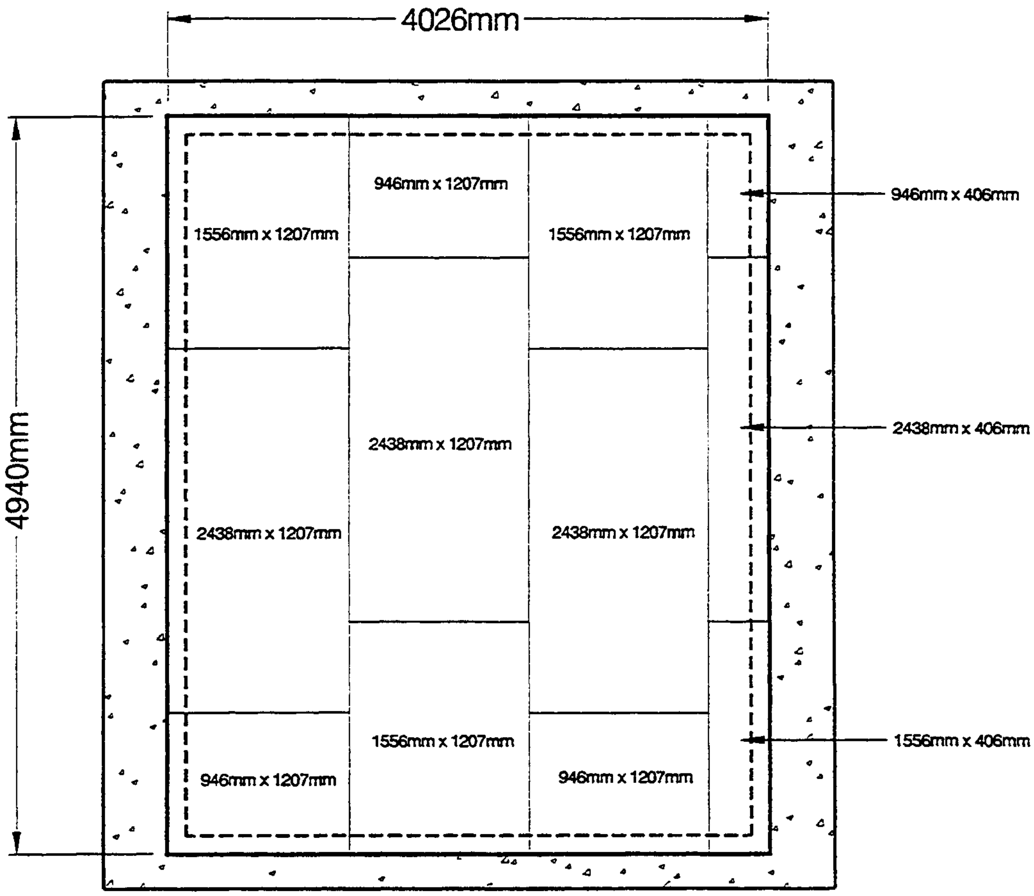


Figure 26: Face layer subfloor layout, joists 610 mm o.c.

Screw patterns for subfloors

OSB, plywood and particle-board sheets were applied with the long axis perpendicular to the joists. The sheets were screwed 150 mm o.c. around the edges and 305 mm o.c. in the field using #10 50 mm non-tapered wood screws.

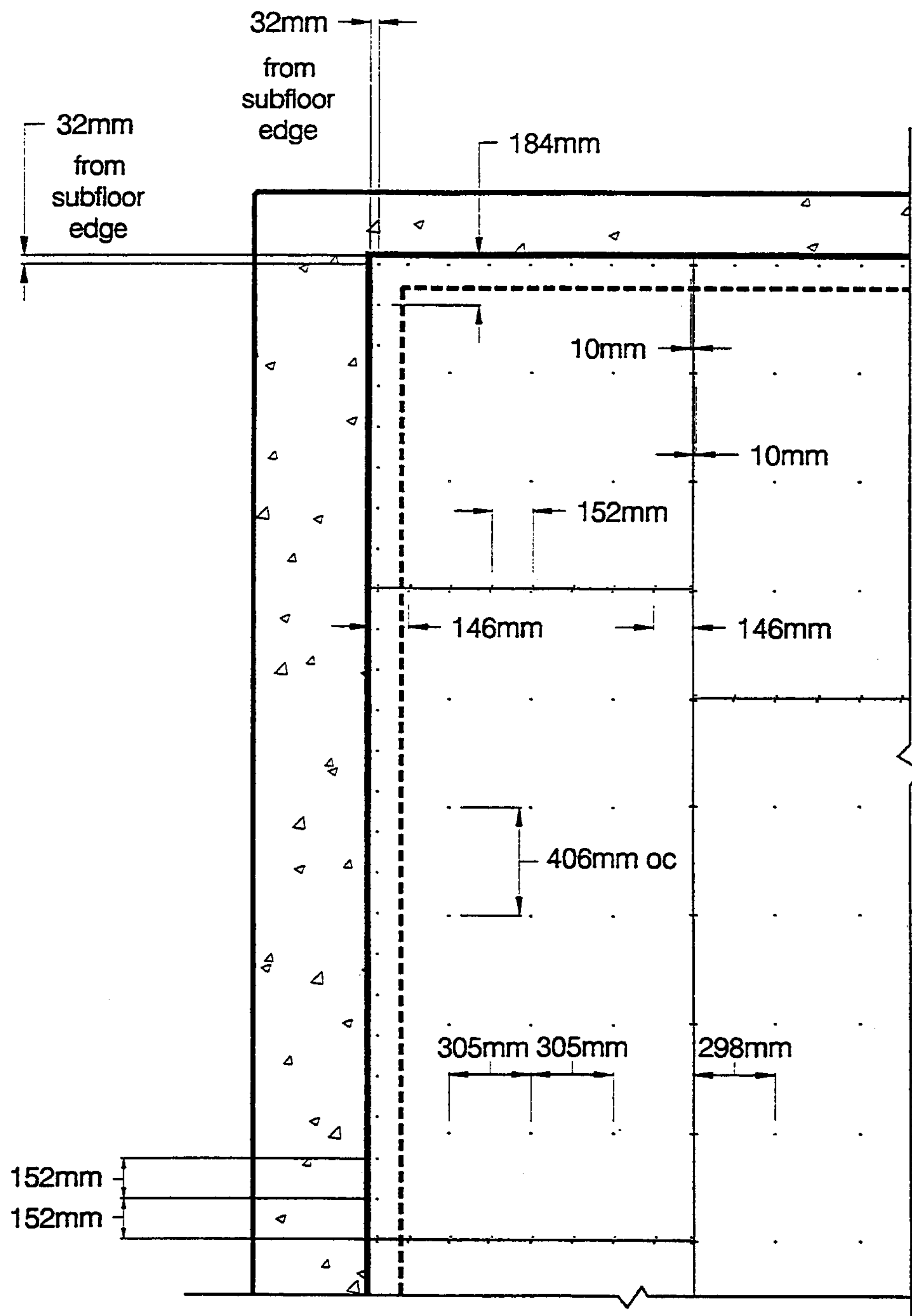


Figure 27: Screw pattern for single layer subfloor, joists 406 mm o.c.

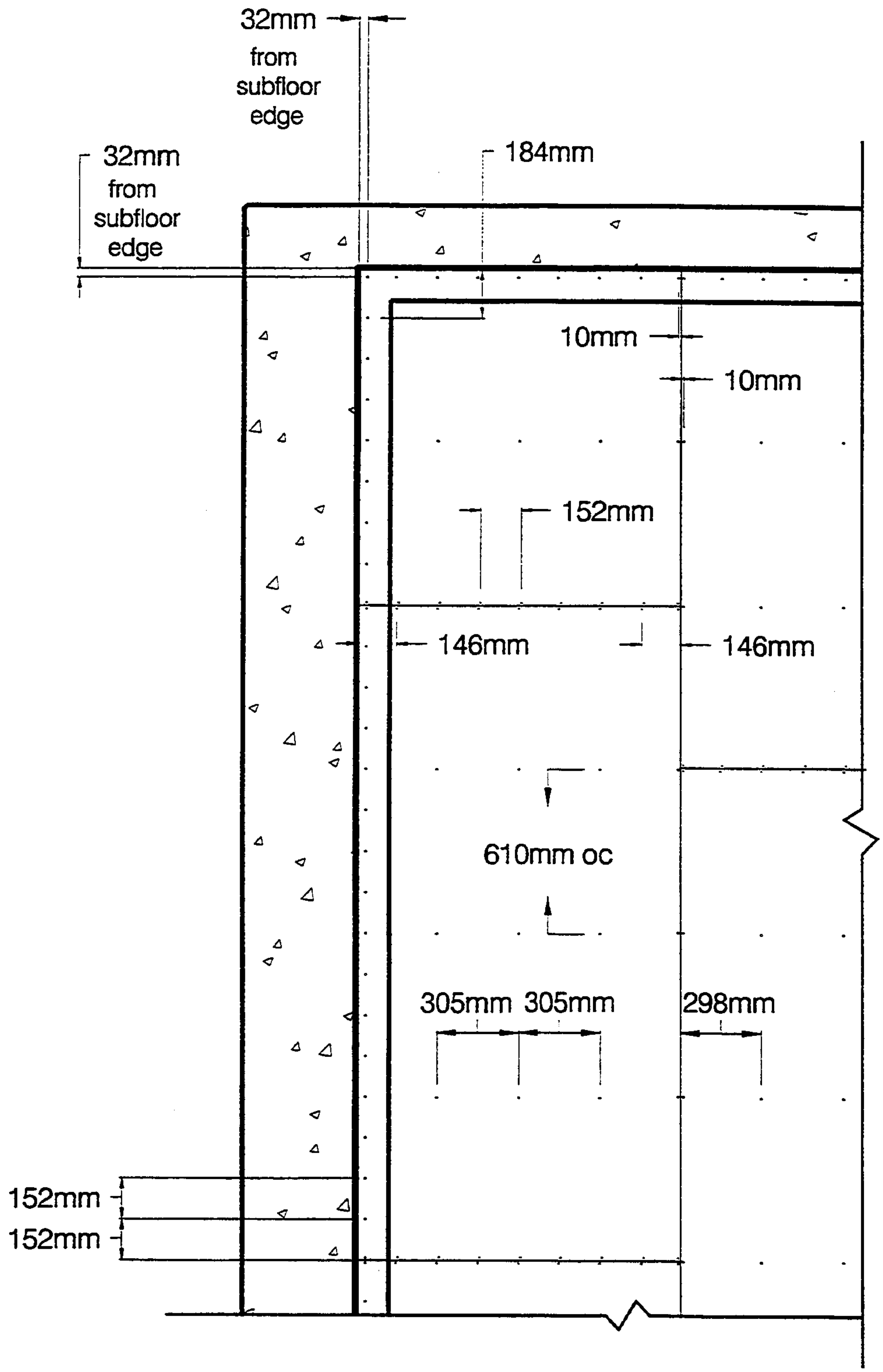


Figure 28: Screw pattern for single layer subfloor, joists 610 mm o.c (9 joists).

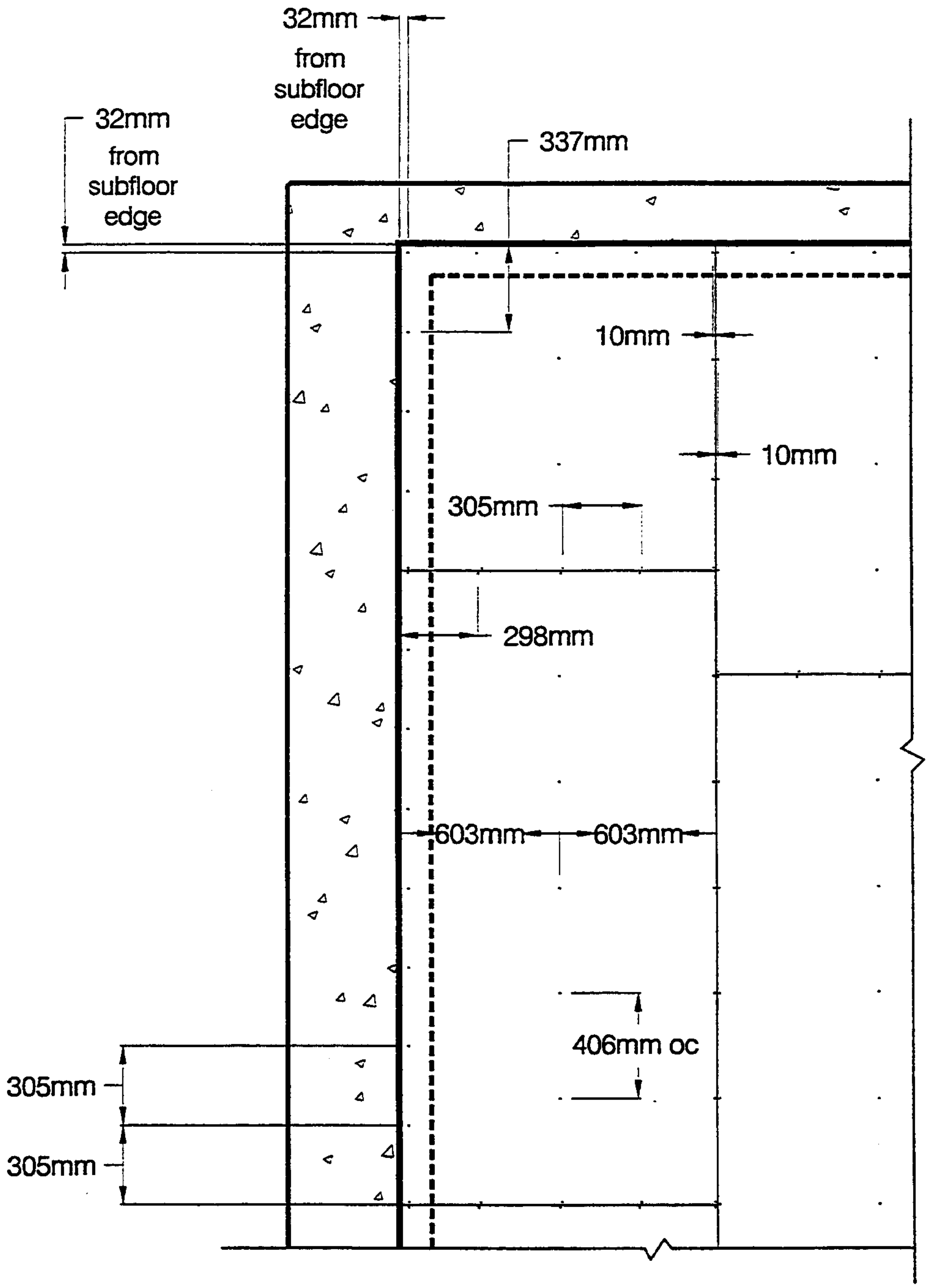


Figure 29: Screw pattern for single layer subfloor, joists 406 mm o.c.

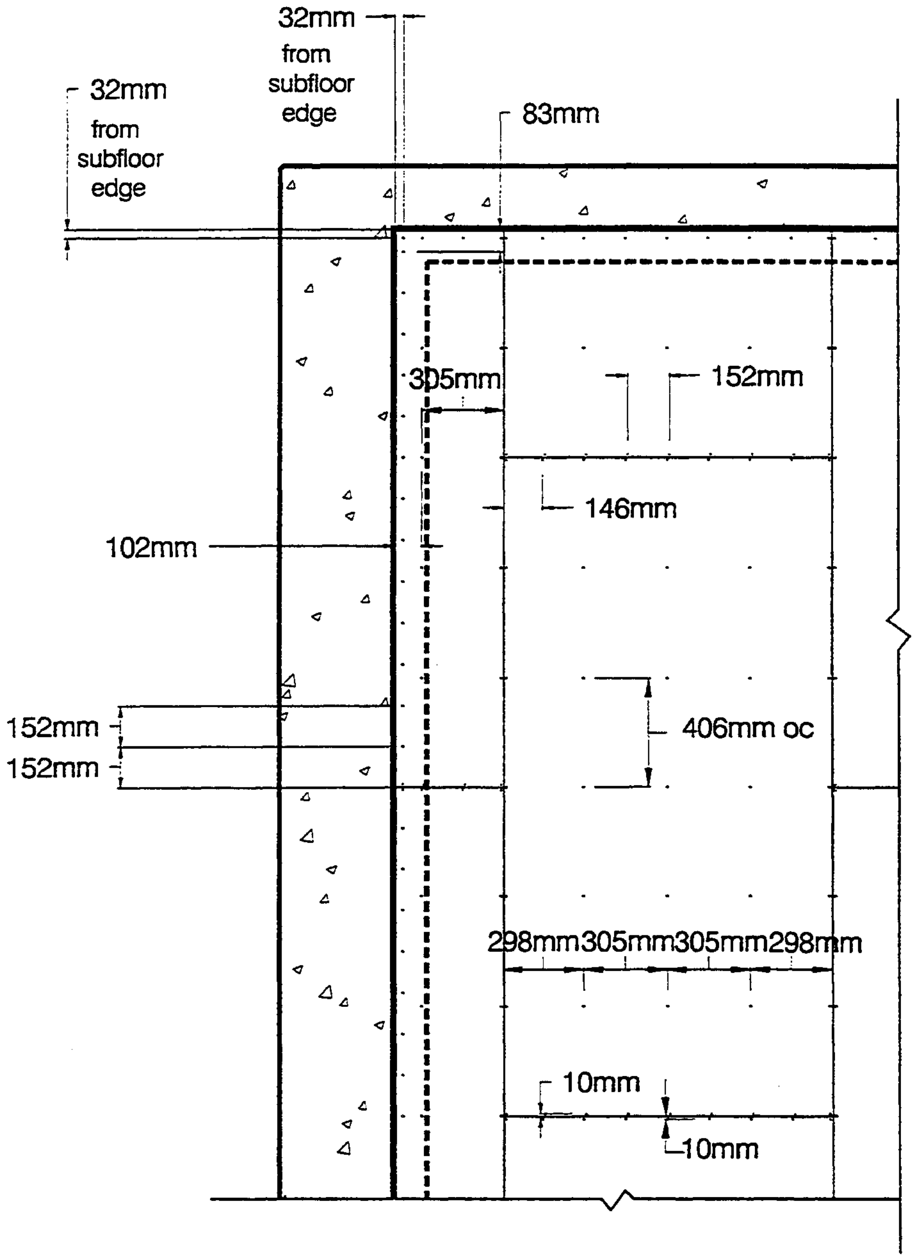


Figure 30: Screw pattern for face layer subfloor, joists 406 mm o.c.

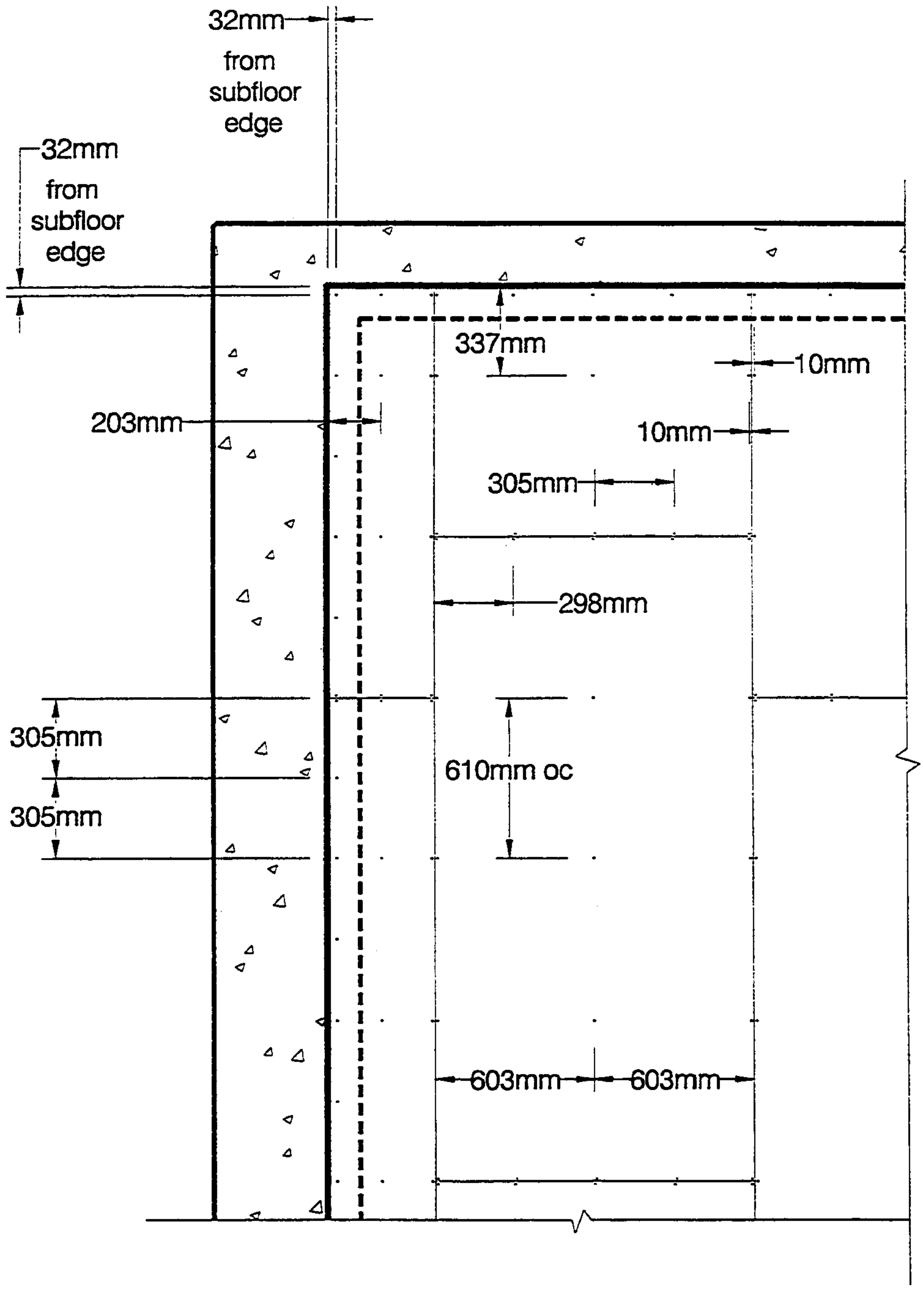


Figure 31: Screw pattern for base layer subfloor, joists 610 mm o.c (10 joists)

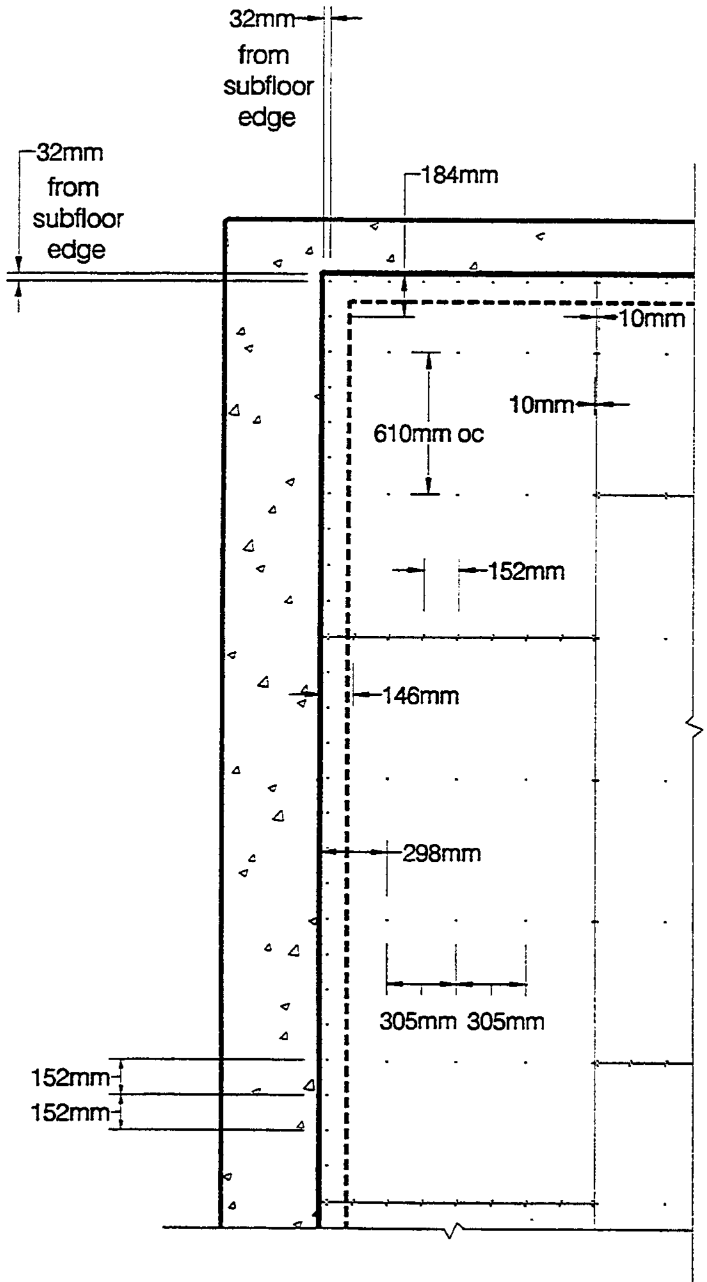


Figure 32: Screw pattern for face layer subfloor, joists 610 mm o.c (10 joists)

Screw patterns for gypsum board

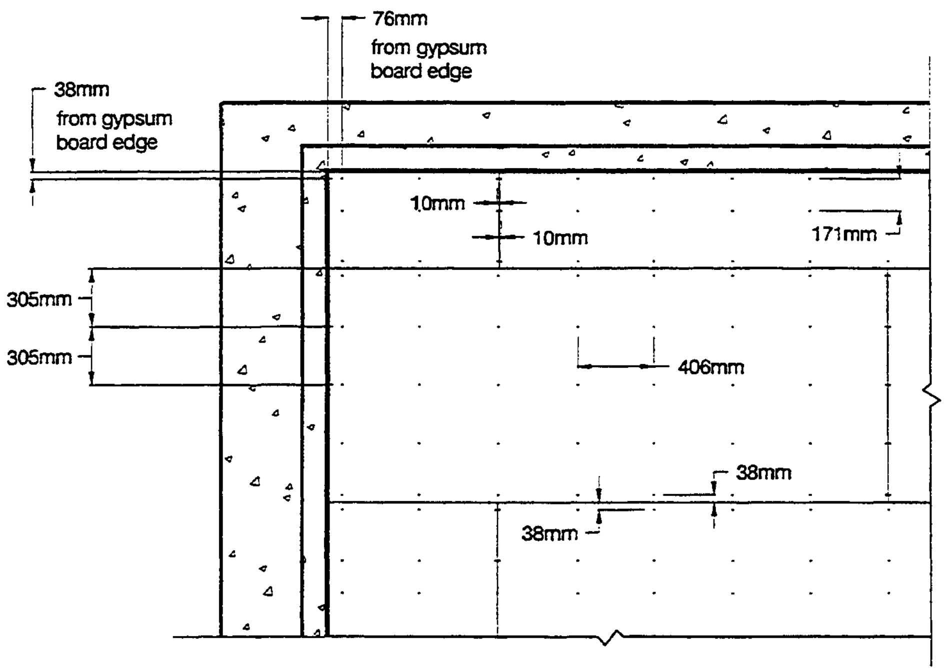


Figure 33: Screw patterns for single layer of gypsum board with resilient metal channels 406 mm o.c.

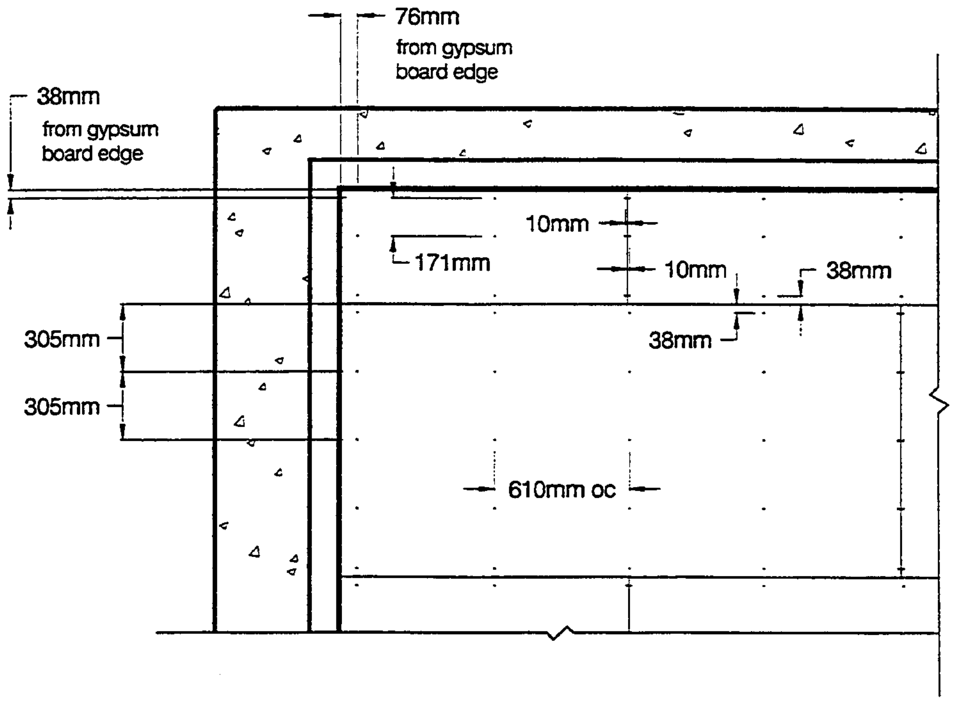


Figure 34: Screw patterns for single layer of gypsum board with resilient metal channels 610 mm o.c.

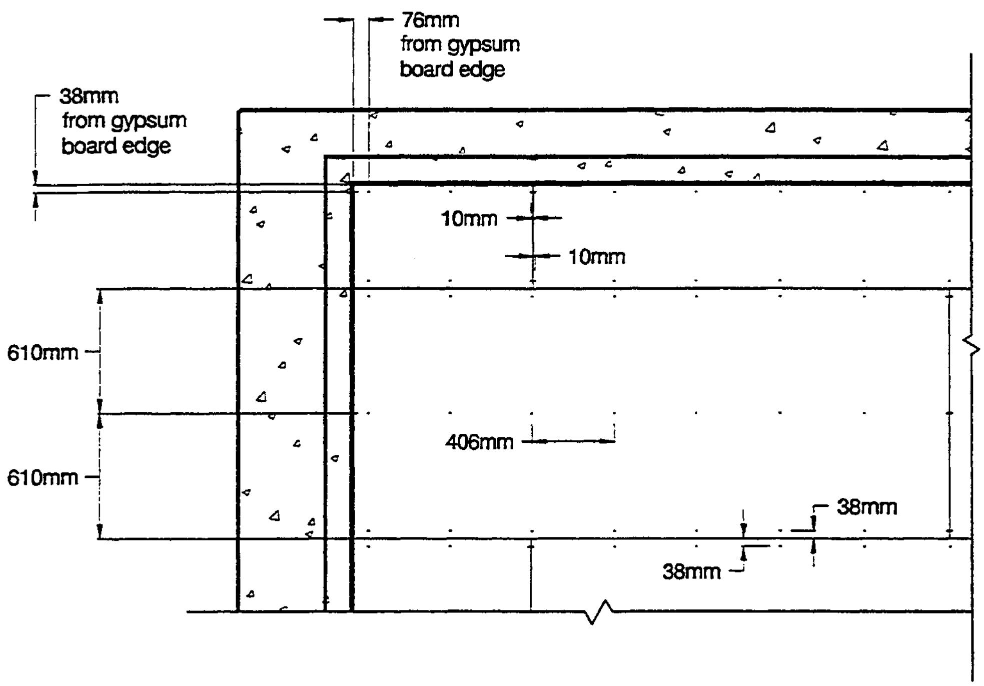


Figure 35: Screw patterns for base layer of gypsum board with resilient metal channels 406 mm o.c.

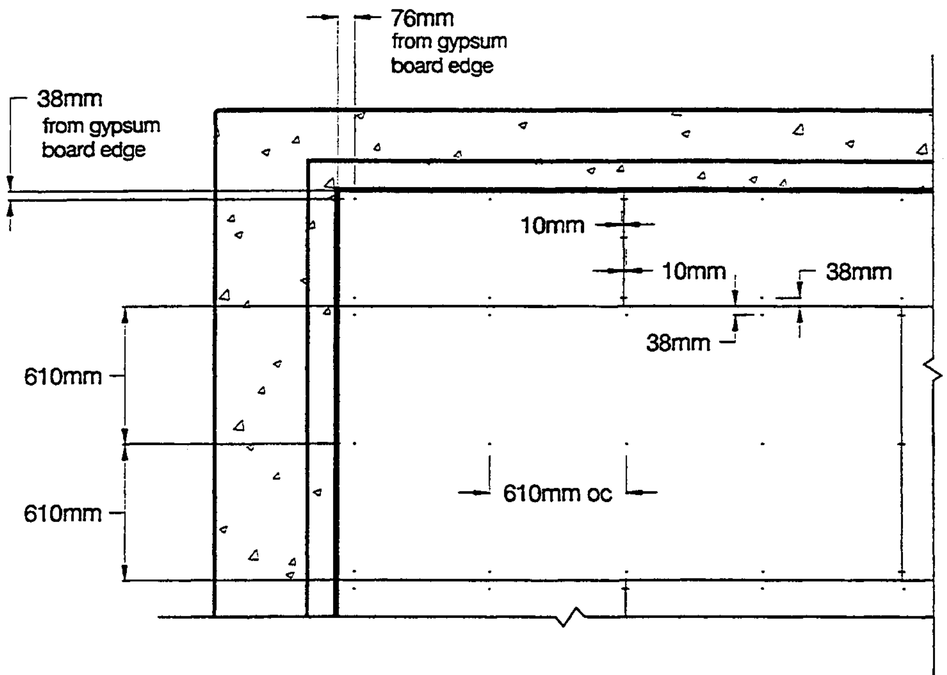


Figure 36: Screw patterns for base layer of gypsum board with resilient metal channels 610 mm o.c.

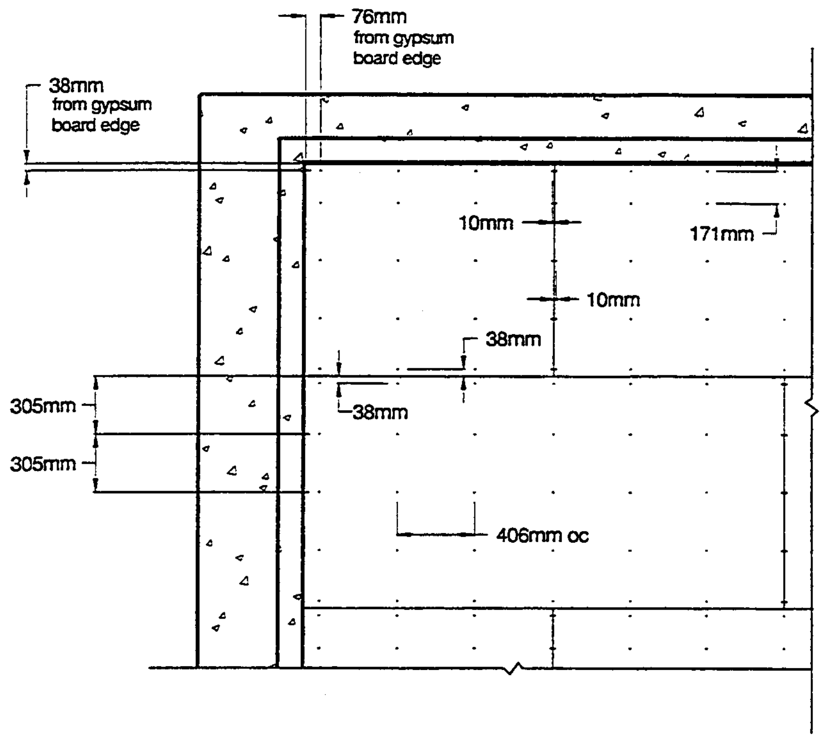


Figure 37: Screw patterns for face layer of gypsum board with resilient metal channels 406 mm o.c.

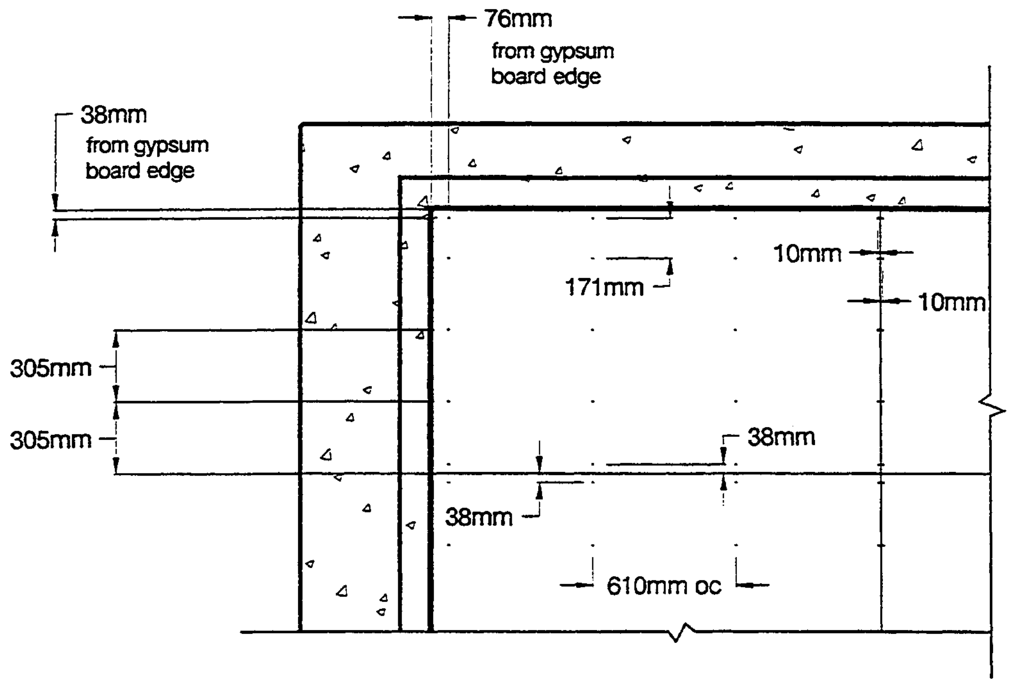


Figure 38: Screw patterns for face layer of gypsum board with resilient metal channels 610 mm o.c.

Resilient metal channel layouts

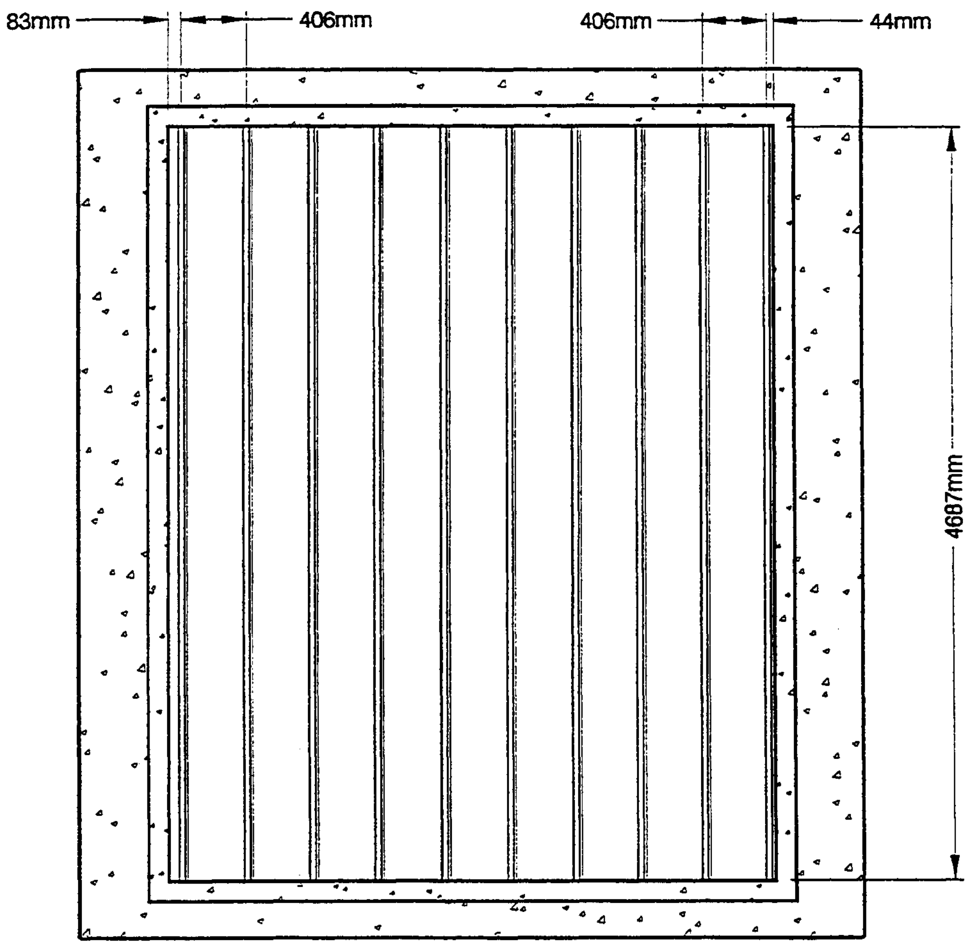


Figure 39: Resilient channel layout 406 mm o.c.

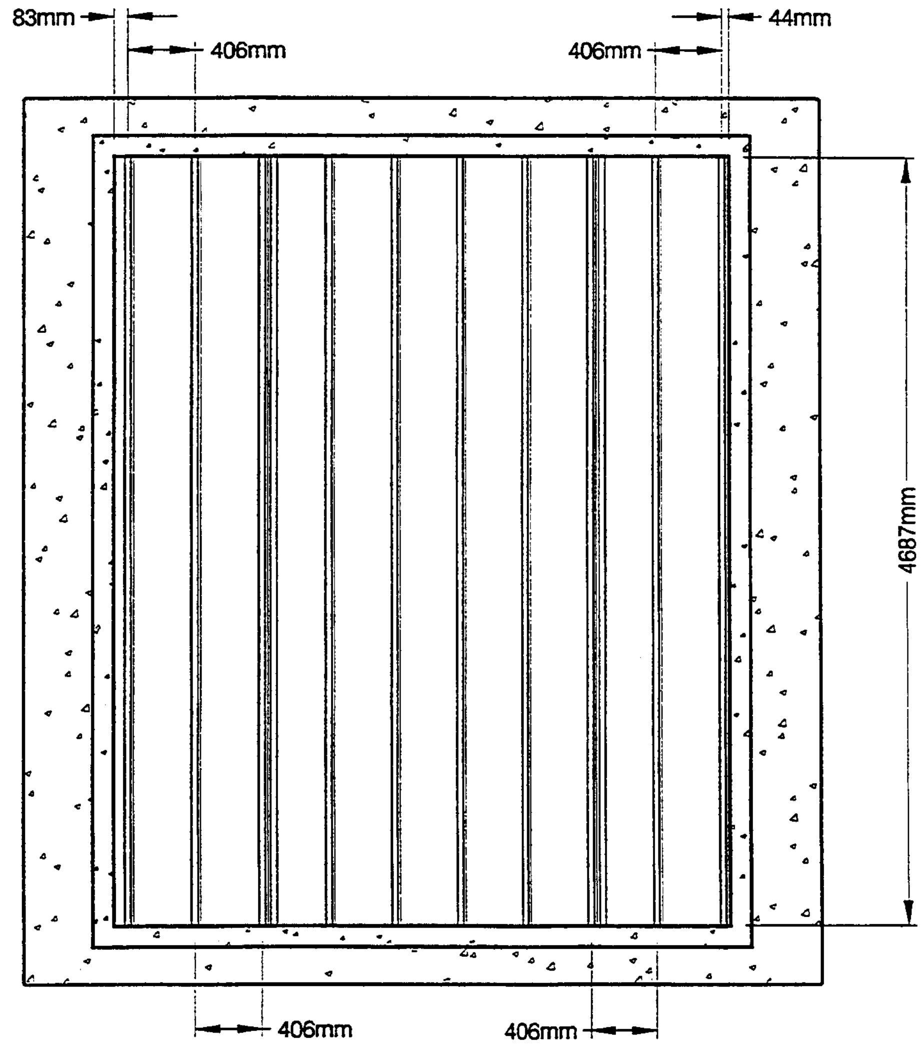


Figure 40: Resilient channel layout 406 mm o.c. with extra full length channels – 406+2 arrangement.

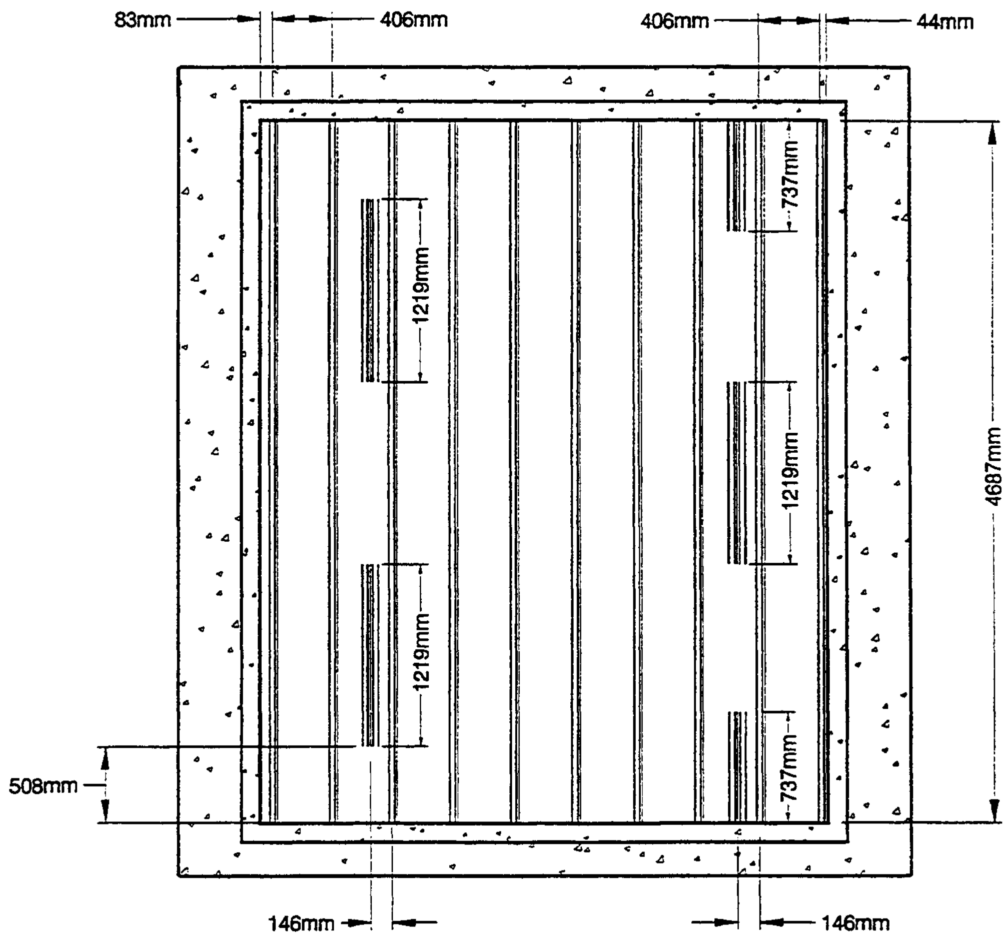


Figure 41: Resilient channel layout 406 mm o.c. with extra short channels – 406+short arrangement.

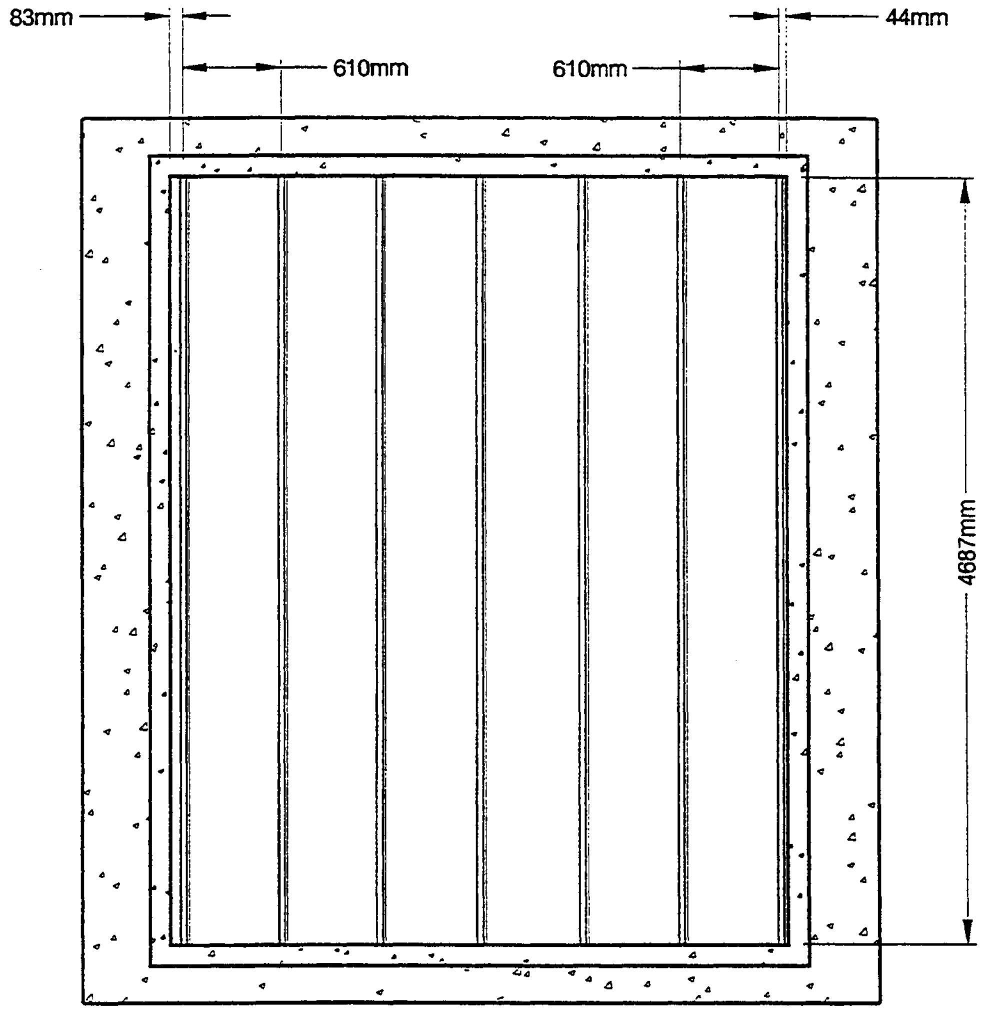


Figure 42: Resilient channel layout 610 mm o.c.

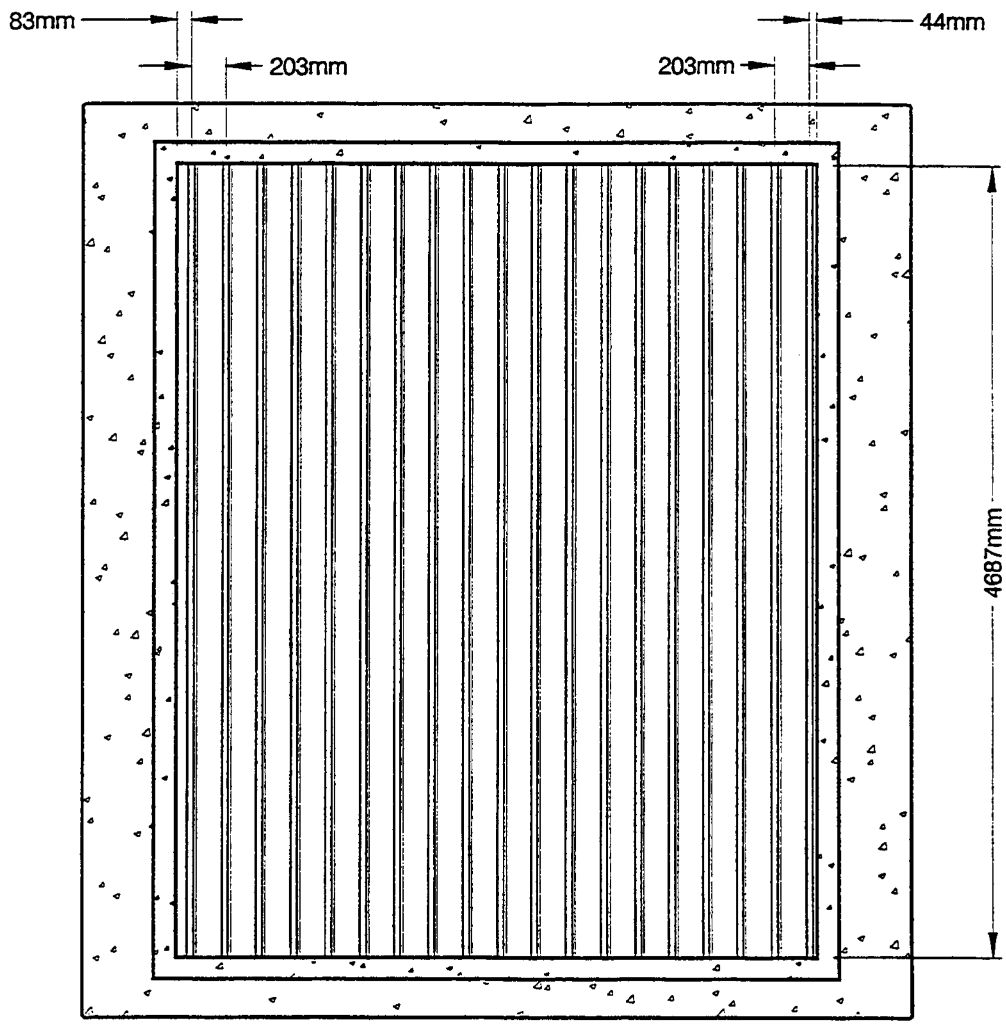


Figure 43: Resilient channel layout 200 mm o.c.

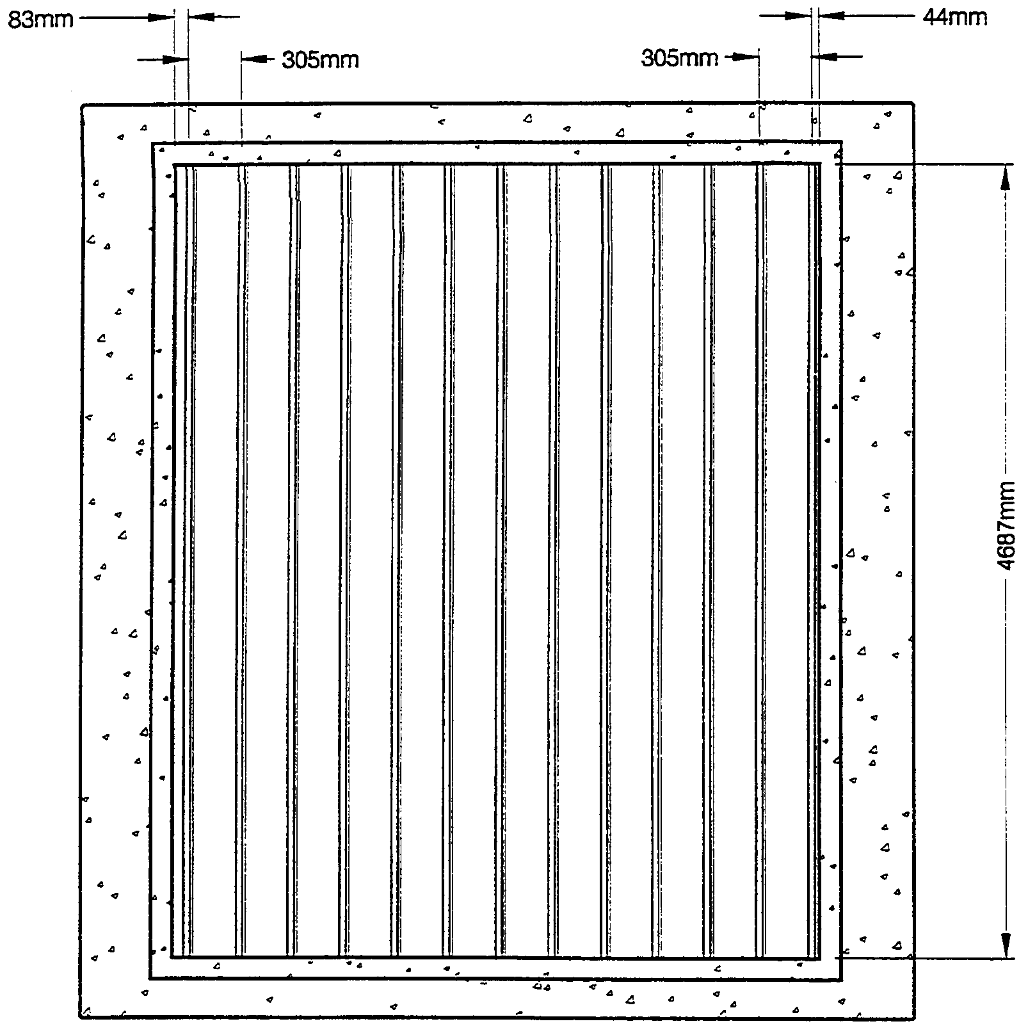


Figure 44: Resilient channel layout 305 mm o.c.

MATERIAL PROPERTIES

Dimensions, Weights and Densities

A certain amount of variation in the physical properties of building materials is inevitable. The values given below are typical. In detailed calculations, measured values were used.

Solid Wood Joists

Dimensions	Density, kg/m^3	kg/m
38 x 184	390	2.8
38 x 235	401	3.7
38 x 286	404	4.4

Wood I-joists

Manufacturer ID	Flange Horizontal x vertical	Flange material	Web	Joist Depth, mm	Weight, kg/m
A	64 x 38	solid wood	10 mm OSB	241	3.4
A	38 x 64	solid wood	10 mm OSB	241	3.1
A	89 x 38	solid wood	11mm OSB	241	4.3
A	89 x 38	solid wood	11mm OSB	356	5.2
A	89 x 38	solid wood	12mm OSB	457	5.8
B	38 x 38	LVL*	9.5 mm OSB	241	3.0
B	57 x 38	LVL	9.5 mm OSB	241	4.1
C	38 x 38	LVL	9.5 mm plywood	241	2.5
D	38 x 38	LVL	9.5 mm OSB	241	3.1
E	64 x 38	solid wood	9.5 mm OSB	241	3.4

* Laminated veneer lumber

Wood Trusses

All trusses were formed from 38 x 89 mm lumber with the exception of the case marked with an asterisk which used 38 x 64 mm lumber. In the latter case, the bearing surface was 64 mm wide. In all other cases, the bearing surface was 38 mm wide. The following table and figures give relevant construction details.

Depth, mm	Width, mm	mass/unit length (kg/m)
356	38	4.8
356	38	4.8
356	38	5.4
457	38	5.1
457	38	5.2
610	38	5.4
356	64	4.5

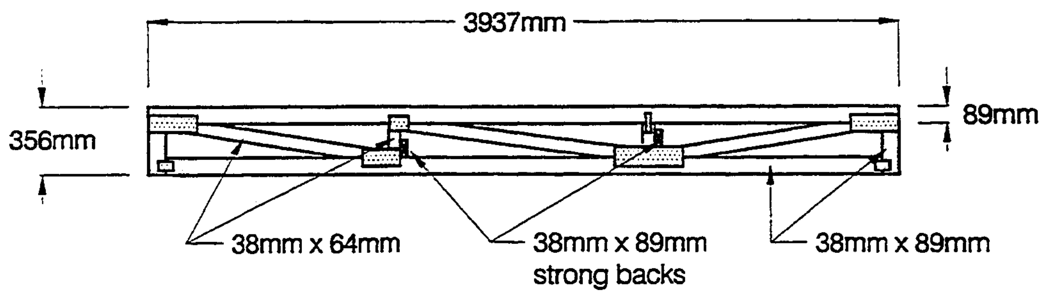


Figure 45: Construction of 356 mm deep wood trusses using 38 x 89 mm lumber.

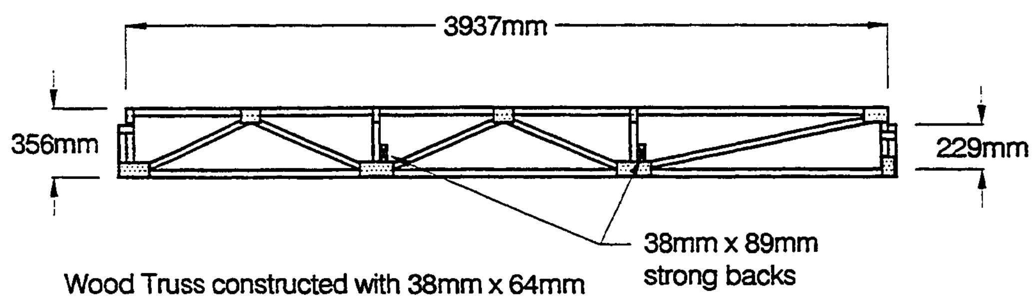


Figure 46: Construction of 356 mm deep wood trusses using 38 x 64 mm lumber

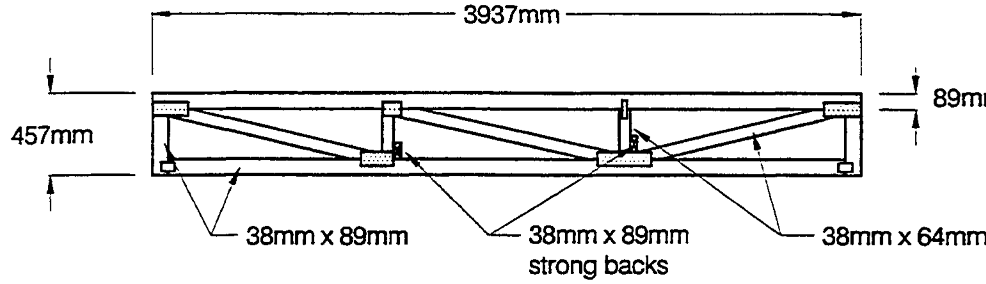


Figure 47: Construction of 457 mm deep wood trusses using 38 x 89 mm lumber.

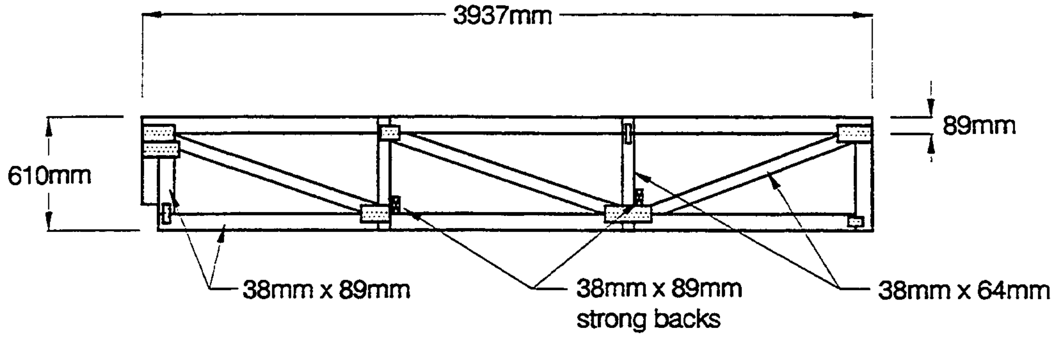


Figure 48: Construction of 610 mm deep wood trusses using 38 x 89 mm lumber.

Steel Joists, C section

Depth, mm	Gauge of steel	mass/unit length (kg/m)
203	14	4.3
203	16	3.5
203	18	2.8
203	16	3.5
254	16	4.4
305	16	5.0

Floor Layers

OSB 15.1 mm thick = 8.8 kg/m^2

OSB 19 mm thick =10.3 kg/m^2

Wood particle board, 9.5 kg/m^2

Plywood 13 mm thick = 5.7 kg/m^2
Plywood 15.1 mm thick = 7.1 kg/m^2
Plywood 25 mm thick = 12.1 kg/m^2

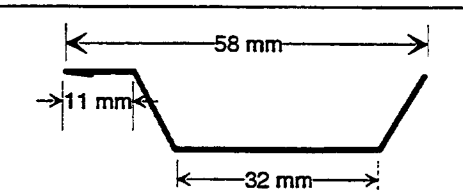
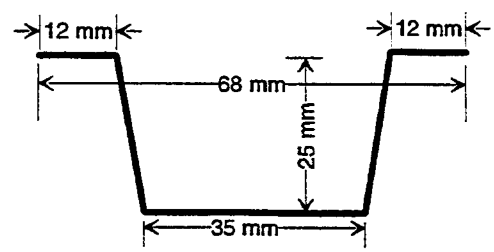
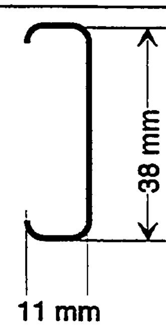
Sound Absorbing Material

65 mm thick glass fiber, 10.8 kg/m^3
89 mm thick R12 glass fiber. 10.6 kg/m^3
152 mm thick R20 glass fiber, 11.1 kg/m^3
202 mm thick R28 glass fiber. 13 kg/m^3

89 mm thick R13 rock fiber, 28.3 kg/m^3
210 mm thick R32 rock fiber, 36 kg/m^3

30 mm sprayed-on cellulose fiber, 52 kg/m^3
72 mm sprayed-on cellulose fiber, 48 kg/m^3
blown-in cellulose fiber, 23 kg/m^3

Metal Furring

resilient metal channels 13 mm deep 25 Ga., 0.26 kg/m	
U-channels, cold-rolled, 25 mm deep, 25 Ga. 0.37 kg/m	
C-channels, cold-rolled, 11 x 38 mm, 0.42 kg/m	

Wood furring strips and cross-bracing

Nominally 1" x 3" actually 19 x 64 mm, 0.47 kg/m

Gypsum Board

15.9 mm thick, fire-rated Type X gypsum board, surface weight = 11.3 kg/m^2
12.7 mm thick fire-rated Type C gypsum board, surface weight = 9.1 kg/m^2
12.7 mm thick Type 1500 gypsum board, surface weight = 7.4 kg/m^2

Concrete

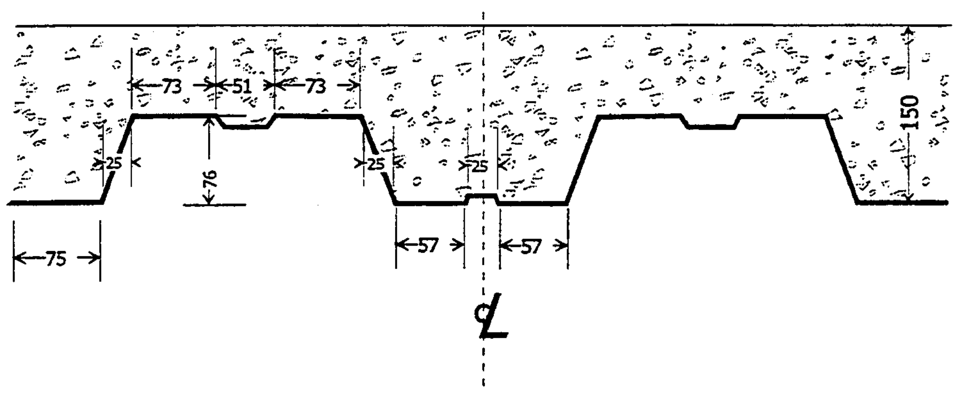
Gypsum concrete, 1862 kg/m^3

150 mm IRC reference concrete slab, 2375 kg/m^3.

35 mm thick IRC reference concrete slab, 2101 kg/m^3

35 mm thick concrete slab poured on top of floor, 2448 kg/m^3

The metal pan for the ribbed concrete floor was 0.9 mm thick with the dimensions shown here.



Young's modulus

Some measurements of Young's modulus have been made on the major materials used in the project. These measurements will be supplemented as needed in further work to develop analytical models for predicting sound insulation. The measurements were made in two ways: by measuring the resonance of a bar of the material and by measuring the longitudinal wave speed across a sample of the material. The values are given in Table 22.

Table 22: Values of Young's modulus for some materials in project

		Young's modulus, N/m^2	
Material	Cut	Mean	Standard deviation
15.9 mm Gypsum board	Across long axis	2.0×10^9	1.5×10^8
	Along long axis	3.2×10^9	1.3×10^8
OSB	Across long axis	2.1×10^9	1.3×10^8
	Along long axis	6.8×10^9	1.5×10^8
Plywood	Across long axis	2.4×10^9	3.1×10^8
	Along long axis	7.6×10^9	2.7×10^8
Concrete		3.3×10^{10}	
Steel		2.2×10^{11}	

PRELIMINARY INVESTIGATIONS

Before embarking on a long series of measurements, several construction variables had to be investigated to determine whether they had a significant effect on sound transmission. The reference floor construction was used to investigate them.

As well, during the project, some other variables were investigated to determine their effect on sound insulation. These investigations are discussed here.

Effects of Joist Length

Some theoretical considerations and published experimental data suggested that the length of the joists in a floor would have a highly significant effect on the sound transmission. To test this hypothesis a movable concrete support was constructed that allowed the test frame to support wood-joist floors with different joist lengths. This device is sketched in Figure 49 and Figure 50. A dimensioned drawing of the test frame is shown in Figure 3. The filler section shown in Figure 50 held pieces of a 150 mm thick concrete slab, sound absorbing material and gypsum board so sound transmission through this section was negligible relative to that through the test floor.

The reference floor was first constructed to completely fill the test frame with joists measuring 4.85 m and parallel to the long axis of the frame. Two sets of 19 x 64 mm cross bracing were installed between the joists 1617 mm from each edge of the floor. After testing, part of the OSB layer and the gypsum board were removed at one end and the joists cut to the new length. The movable support was inserted, the floor repaired and the filler section constructed and sealed. This process was repeated for joist lengths of 4.34, 3.45 and 2.92 m. The floor was also re-constructed as a full-size floor with the joists perpendicular to the long axis of the specimen frame giving a joist length of 3.92 m. It was surprising that there was so little change in the results when the joist length ranged from 2.92 to 4.85 m, but the data are clear. One-third octave band plots of these tests are not shown here but they too showed no significant variations. On the basis of this work, it was decided that joist length was not an important factor and that for convenience, all floors would be constructed with joists or trusses parallel to the short axis of the specimen frame.

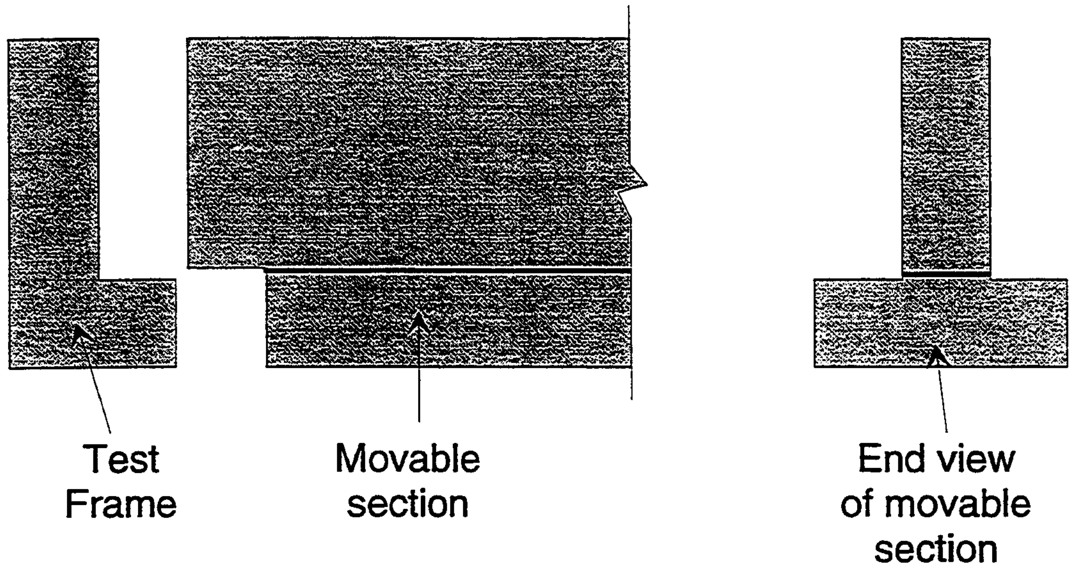


Figure 49: The movable concrete support used to change the floor size by supporting different joist lengths.

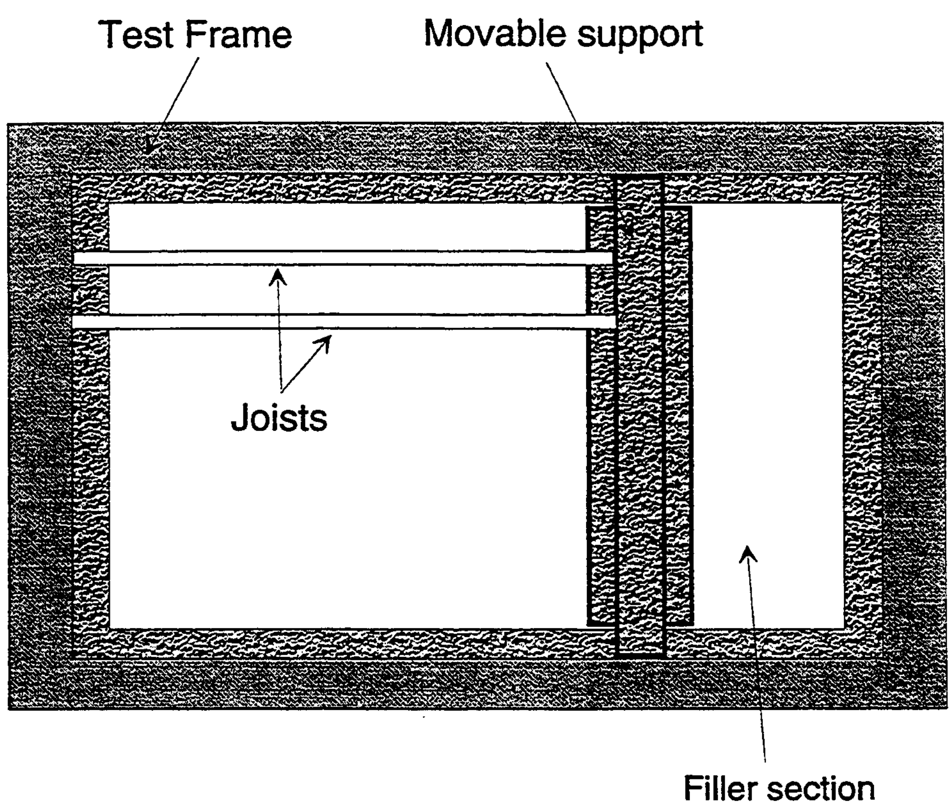


Figure 50: Illustration of the use of the movable concrete support when testing floors with different joist lengths.

Table 23: Effects of joist length. (Mean ref is the average result of tests on the reference specimen)

Joist Length	TestID	STC	TestID	IIC
4.85	TLF-95-035a	51	IIF-95-005	44
4.34	TLF-95-037a	52	IIF-95-006	46
3.45	TLF-95-039a	51	IIF-95-007	46
2.92	TLF-95-041a	51	IIF-95-008	46
3.92	Mean ref.	52	Mean ref.	46

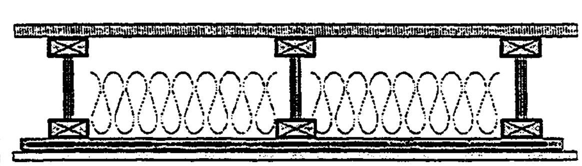
Number of I-joists in floor

The intent of a laboratory test is to provide a rating for a system that will characterize the values obtained in practice. Countless minor variations in construction occur in practical situations. In the laboratory it is important to be sure that the construction practices used are consistent and do not introduce bias. Experience is needed to decide when a variation is important and when it is not.

In acoustical testing it is important to avoid having sections of the floor or wall where the joist or stud separation is much different from the nominal value. This can happen when the width of the test opening is not an integer multiple of the joist or stud spacing. Research has shown that such atypical cavities can significantly reduce the transmission loss for wall systems and can introduce variability in a test series.

There are two possible methods of constructing a floor with joists spaced 406 mm o.c. in the M59 test frame: one using thirteen joists with no joist on the midline of the floor (Figure 5) and one using fourteen joists with one placed on the midline of the floor (Figure 6). The second arrangement results in two smaller cavities at each end of the floor and was expected, by extrapolation from other work, to give lower sound insulation. To verify this hypothesis, two floors were constructed using 13 and then 14 wood I-joists with the rest of the construction being

- 1 layer of 15 mm OSB subfloor
- 241 mm deep wood I-joists, 406 mm o.c.
- 152 mm glass fiber batts
- resilient metal channels, 406 mm o.c.
- one layer of 15.9 mm gypsum board



The effect on the STC and IIC ratings can be seen in Table 24. Examination of the detailed sound insulation plots shows that these differences are due to significant differences at all frequencies.

Table 24: 13 versus 14 I-joists

	TestID	STC	TestID	IIC
14 I-joists	TLF-97-025a	47	IIF-97-013	41
13 I-joists	TLF-97-029a	48	IIF-97-015	42

Sub-Floor attachment

Screw Tightness

One issue that was addressed was the possibility of changes in sound reduction caused by changes in the tightness of the screws attaching the sub-floor to the joists. In practice, changes in tightness could be caused by changes in the moisture content of the wood after installation, or by variations in workmanship during installation. To test the significance of screw tightness, the reference floor was constructed with screws tightened normally and then loosened in 1/4 turn increments until they had been loosened by 1 full turn. Measurements were made at each stage. There were no significant differences in the STC or the IIC ratings, but there were differences in the transmitted sound energy at the frequencies above 500 Hz; as the screws were loosened, less sound was transmitted.

When this experiment was repeated with a 15 mm thick plywood subfloor instead of the OSB subfloor, all the STC values were 50, two IIC values were 43 and three were 44.

Table 25: Effects of tightness of screws attaching OSB subfloor to joists on the sound insulation of the reference floor.

	TestID	STC	TestID	IIC
fully tightened	TLF-95-043a	51	IIF-95-009	46
-1/4 turn	TLF-95-045a	50	IIF-95-010	46
-1/2 turn	TLF-95-047a	50	IIF-95-011	45
-3/4 turn	TLF-95-049a	50	IIF-95-012	45
-1 turn	TLF-95-051a	51	IIF-95-013	45

Screws vs. Construction adhesive and Nails

The possibility that there might be a difference between screwing the OSB subfloor to the joists and attaching it with construction adhesive and nails was also examined. The number of screws used to attach the OSB subfloor to the joists was doubled and then doubled again. The OSB subfloor was then removed and re-attached using construction adhesive and nails. The hope was that, if attaching the OSB using construction adhesive and nails gave a different result from the normal number of screws, with more screws the two systems might become equivalent. Being able to use screws to attach the floor sheathing greatly simplifies changes to constructions.

As it happened, the tests showed that the attachment methods were essentially identical. The STC and IIC values are listed in Table 26 where it can be seen that there are no significant differences. The conclusion that may be drawn from this is that normal application of screws is equivalent to gluing and nailing as far as sound transmission is concerned. Consequently, during the project all floors were screwed to the joists.

Table 26: Effect of methods of attaching OSB subfloor to the joists on the sound insulation of the reference floors: construction adhesive and nails versus different screw arrangements.

Screw separation, edge & field	TestID	STC	TestID	IIC
150 & 305 mm	TLF-95-043a	51	IIF-95-009	46
75 & 150 mm	TLF-95-053a	50	IIF-95-014	46
38 & 75 mm	TLF-95-055a	50	IIF-95-015	46
Adhesive and nails	TLF-95-057a	51	IIF-95-016	46

Position of sound absorbing material in the floor cavity

To test the effect of moving the sound absorbing material inside the floor cavity, 152 mm thick glass fiber batts were placed at the bottom (against the ceiling), in the middle and at the top (against the subfloor) of the 235 mm deep cavity of the reference floor. As expected, changing the position did not change the results.

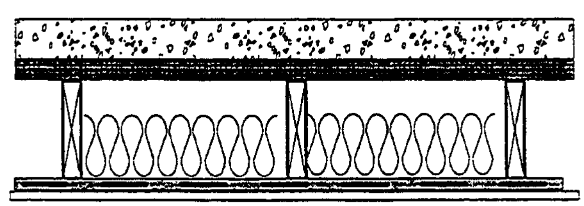
Table 27: Effect on sound insulation of position of sound absorbing material in cavity of reference floor

Location of sound absorbing material	TestID	STC	TestID	IIC
bottom	TLF-95-043a	51	IIF-95-009	46
Centre	TLF-95-069a	51	IIF-95-022	45
top	TLF-95-071a	52	IIF-95-023	45

Drying of concrete slab

According to ASTM acoustical testing standards, concrete constructions should be allowed to cure for 28 days before testing unless data are available to show that a shorter period of curing will suffice. When a 35mm concrete slab was poured on top of a wood joist floor, we had the opportunity to measure the sound transmission through the floor as it was drying. Such data are useful within the laboratory, the project, and to other laboratories that might wish to use a shorter curing time for similar specimens. The construction of the floor was

- 35 mm concrete
- 1 layer of 15 mm OSB subfloor
- 38 x 235 mm wood joists, 406 mm o.c.
- 152 mm glass fiber batts in the joist cavities
- 1 layer of 15.9 mm gypsum board.



The ratings in Table 28 show that the floor had stabilized acoustically after only 14 days. In fact, the STC and the TL spectrum did not change significantly after the 5th day. The IIC might well have stabilized by this time too, but to avoid potential damage to the concrete, the first impact test using the ISO tapping machine was not done until the

14th day. The impact spectra were not significantly different. The changes in IIC rating are due to small variations around 100 Hz that can be considered random.

Table 28: STC and IIC ratings measured while 35 mm thick concrete slab was drying.

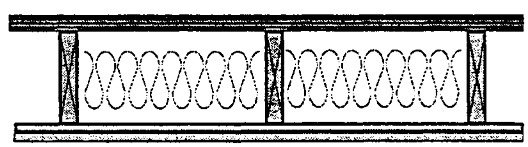
Days	TestID	STC	TestID	IIC
5	TLF-96-123a	48		
10	TLF-96-125a	48		
14	TLF-96-129a	48	96-056	27
20	TLF-96-133a	48	96-058	27
25	TLF-96-135a	48	96-059	28
28	TLF-96-139a	48	96-061	28

Presence of cross-bracing in floors

To determine whether the presence of cross-bracing in the floors had any significant effect on the sound insulation, two floor specimens were constructed. Each pair of specimens was identical except for the absence of cross-bracing in one case.

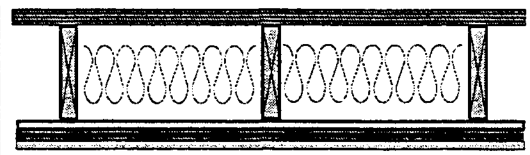
The first floor consisted of

- one layer of 15.1 mm thick OSB flooring.
- 38 x 235 mm wood joists, 406 mm o.c.
- a layer of 152 mm thick glass fiber batts in the joist cavities.
- 19 x 64 mm wood furring attached to the joists, 610 mm o.c.
- one layer of Type X gypsum board, 15.9 mm thick, applied to the furring.



The second floor consisted of

- one layer of 15.1 mm thick OSB flooring.
- 38 x 235 mm wood joists, 406 mm o.c.
- a layer of 152 mm thick glass fiber batts in the joist cavities.
- 19 x 64 mm wood furring attached to the joists, 610 mm o.c.
- 13 mm deep resilient metal channels screwed 610 mm o.c. perpendicular to the wood furring.
- one layer of Type X gypsum board, 15.9 mm thick, applied to the resilient metal channels.



Each floor was constructed with a single row of cross-bracing on the mid-line and tested. The cross-bracing was then removed, the floor re-assembled and tested again. The results in Table 29 show that the cross-bracing had no effect on the sound insulation in either case.

Table 29: Sound insulation for floors with and without cross bracing between joists.

Furring	Cross-bracing	TestID	STC	TestID	IIC
19 x 64 mm wood, 610 mm o.c.	1 row	TLF-95-083a	42	IIF-95-029	35
19 x 64 mm wood, 610 mm o.c	None	TLF-95-099a	42	IIF-95-037	35
resilient metal channels, 610 mm o.c.	1 row	TLF-95-087a	52	IIF-95-031	45
resilient metal channels, 610 mm o.c.	None	TLF-95-091a	52	IIF-95-033	45

ANALYSIS OF INDIVIDUAL VARIABLES

Resilient channel effects

Uniformly spaced resilient metal channels

The positioning of resilient metal channels is an important issue for fire resistance ratings and for sound insulation. Acoustical tests with resilient metal channels spaced uniformly at different separations showed a dependence of STC on channel separation or, the total length of channels in the floor. The straight line in Figure 51 connects those points where the channels were evenly spaced.

Similar data for the IIC rating are shown in Figure 52. In this case the points for those floors where the resilient metal channels were spaced uniformly do not lie on a straight line but a trend line for the four points is shown.

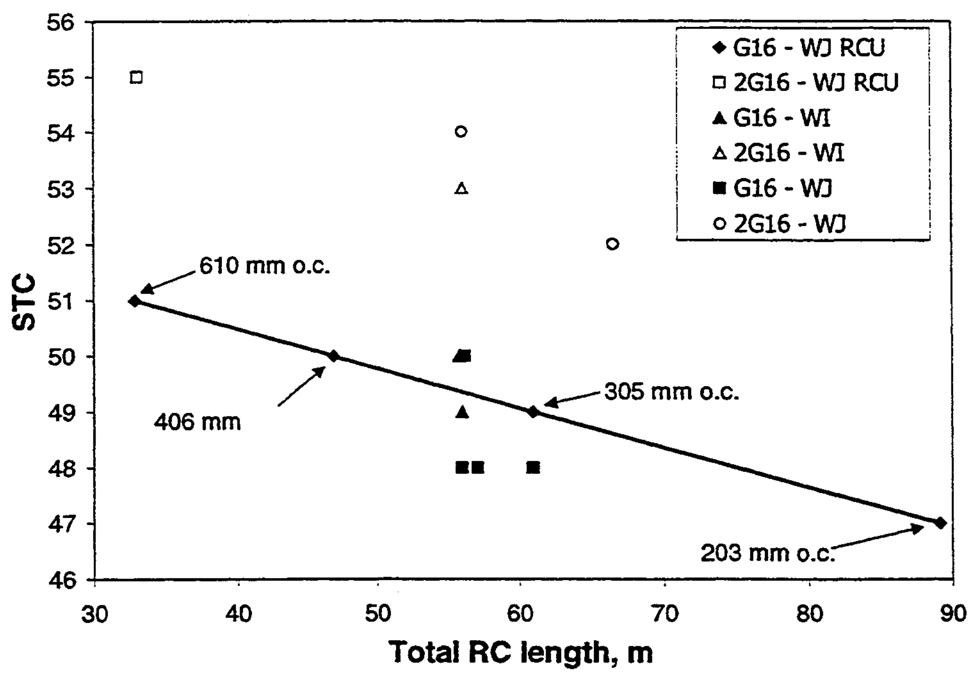


Figure 51: Variation of STC with total length of resilient metal channel in the floor. All floors have 15 mm OSB sub-floor and 150 mm of glass fiber batts in the cavity. WJ denotes a measurement made with 235 mm deep wood joists. WI denotes a measurement made with 241 mm deep I-joists. G16 denotes a single layer and 2G16 two layers of 15.9 mm gypsum board. RCU means that resilient metal channels were spaced uniformly, otherwise additional channels were used to support the butt ends of the gypsum board. All joists were nominally 406 mm o.c.

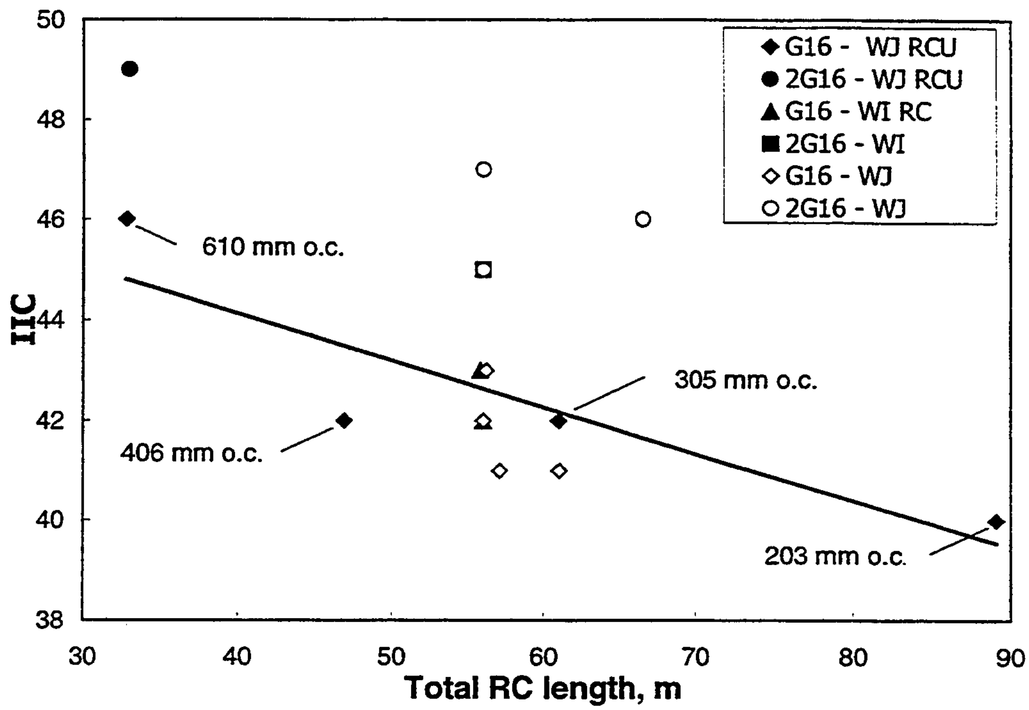


Figure 52: Variation of IIC with total length of resilient metal channel in the floor. See previous caption for explanation of codes.

Other resilient metal channel arrangements

To improve fire resistance, some means of attaching the butt ends of the face layer of gypsum board more firmly to the ceiling was needed. So, with a uniform array of resilient metal channels spaced 406 mm o.c., additional short pieces of channel were added to support the butt ends. The layout of channels to support a single layer of gypsum board is shown in Figure 53. For a double layer of gypsum board, more pieces of channel were added. The layout for this case is shown in Figure 54.

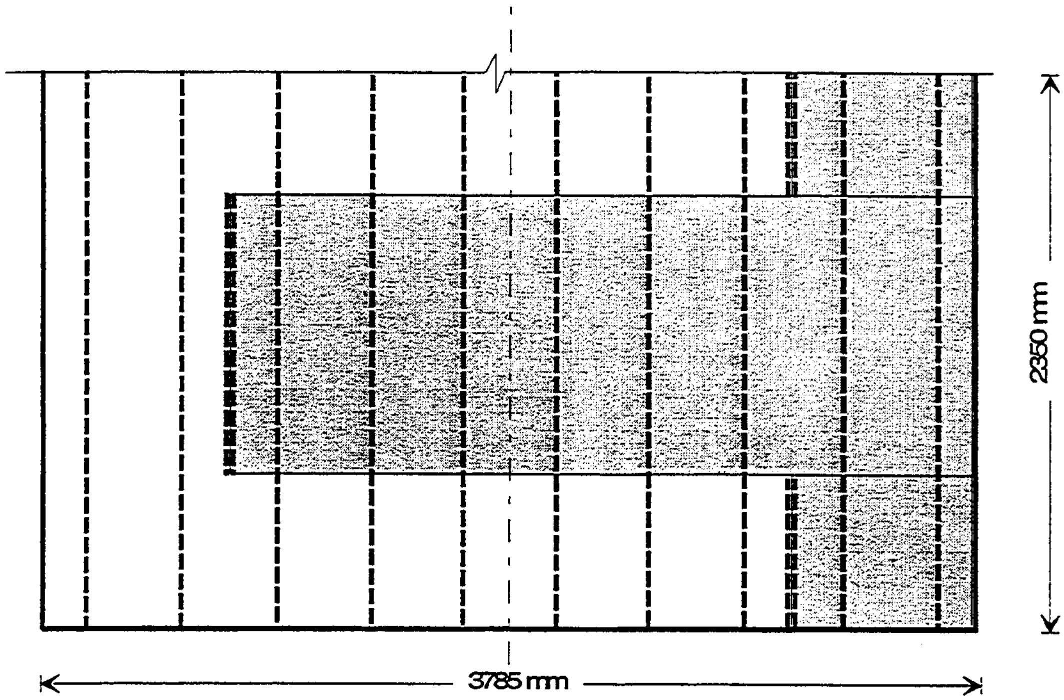


Figure 53: Attachment of single layer of gypsum board to channels with additional butt-end supports. Shaded areas represent gypsum board and dashed lines are channels. Denoted '406 + short' in the text.

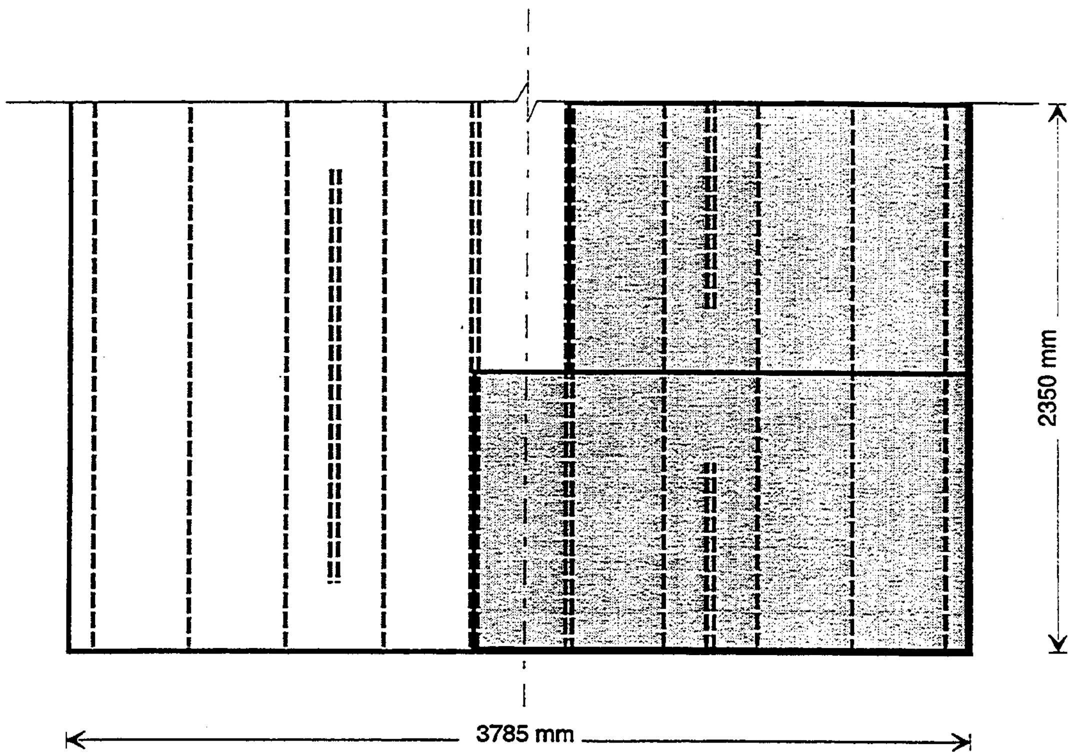


Figure 54: Layout of face layers of gypsum board and channels on system with additional short pieces of channel to support the butt-ends of the base layer of gypsum board. Shaded areas represent face layers of gypsum board and dashed lines are channels. Denoted '406 + short' in the text.

Test results with these additional short pieces of channels present showed reduced sound insulation. This was attributed to channels being too close together where the additional short pieces were installed. An alternative system using additional full-length channels to support the ends of the gypsum board was tried. This system is depicted in Figure 55 and Figure 56. In this system, the butt joints of the second (face) layer of gypsum board were screwed into the first (base) layer using type G screws spaced 305 mm o.c. Elsewhere, regular screws were used. Data from tests using these non-uniform channel arrangements are included in Figure 51. More details can be found in Table 30 where the channel arrangement using additional short pieces is denoted 406 + short, the regular arrangement is denoted 406 and the arrangement using additional full length channels is denoted 406 + 2.

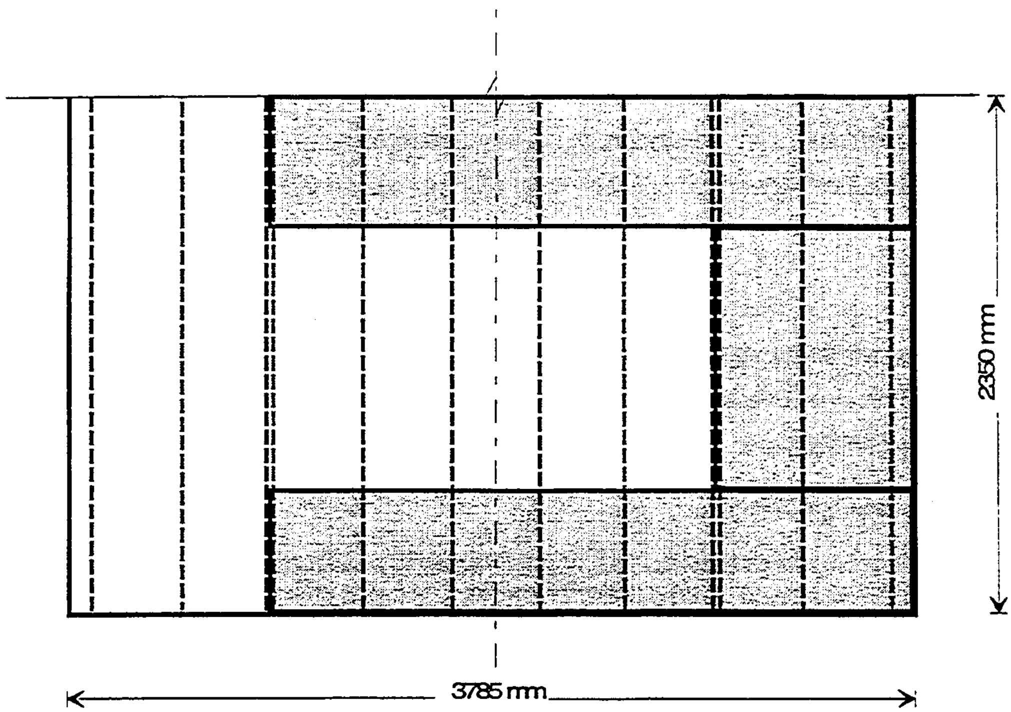


Figure 55: Continuous additional channel system for supporting butt-ends of single layer of gypsum board. Denoted '406 + 2' in the text.

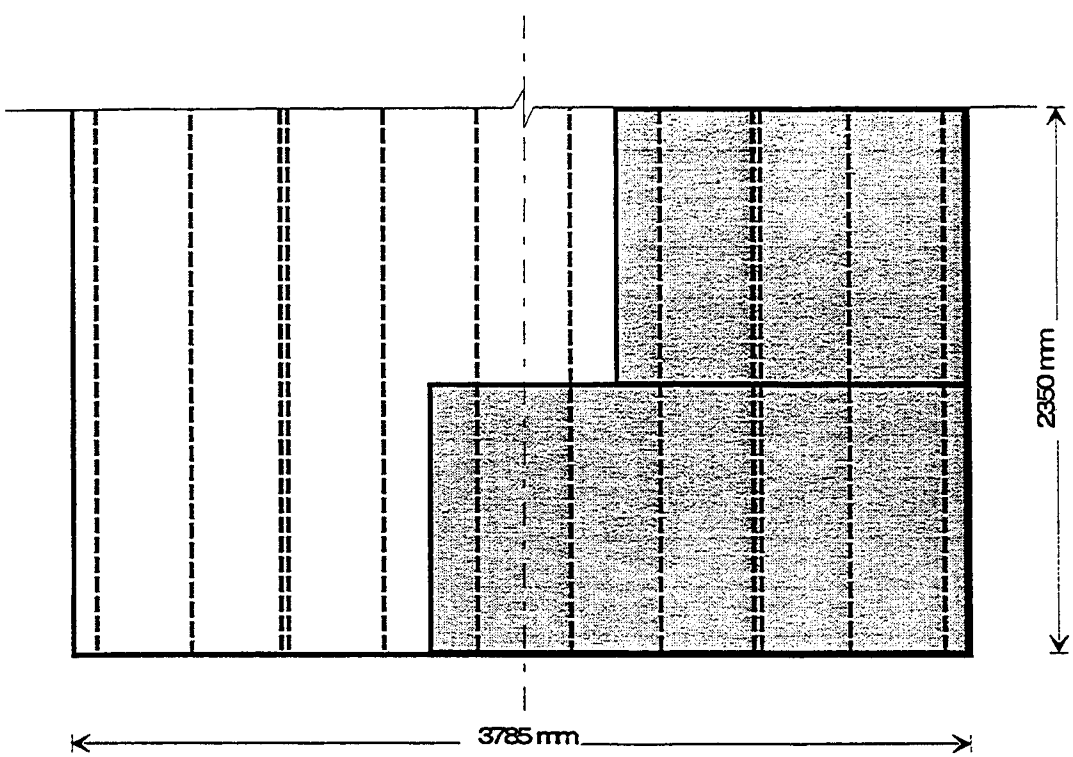


Figure 56: Layout of channels and face layers of gypsum board for continuous butt-end support. Face layer attached using Type G screws. Denoted '406 + 2' in the text.

The major conclusion drawn from these tests using was that additional resilient metal channels reduce sound insulation, but in no predictable way. The second arrangement using additional full length channels close together had no significant detrimental effect on sound insulation.

Comparing the 2nd and 3rd rows of Table 30 reveals a result of some interest. The only change between these two tests was to add additional screws to the gypsum board to reduce the screw spacing from 610 mm to 305 mm. This resulted in a reduction of 2 in the STC rating and 1 in the IIC rating. Further down, the table shows that such changes in screw spacing are not important when two layers of gypsum board are used.

Table 30: Sound insulation ratings for joist floors with different arrangements of resilient metal channels. In each case the subfloor was 15 mm OSB and the cavity contained 152 mm of glass fiber batts. The shaded areas indicate floors constructed using 241 mm wood I-joists, non-shaded rows are for 235 mm wood joists, both 406 mm o.c.

resilient metal channels								
		Screw Spacing						
layout	**Length**	**1st layer**	**2nd layer**	**Joist Type**	**Test ID**	**STC**	**Test ID**	**IIC**
Single layer of 15.9 mm gypsum board								
406	46.9	305		WJ	TLF-95-075a	50	IIF-95-025	42
406+2	56	610		WJ	TLF-96-167a	50	IIF-96-074	43
406+2	56	305		WJ	TLF-96-169a	48	IIF-96-075	42
406+short	57.1	305		WJ	TLF-96-099a	48	IIF-96-043	41
406+short	61	305		WJ	TLF-96-175a	48	IIF-96-078	41
406	46.9	305		WI	TLF-97-003a	50	IIF-97-002	44
406+2	56	305		WI	TLF-96-195a	50	IIF-96-086	43
406+2	56	305		WI	TLF-96-199a	49	IIF-96-088	42
Double Layer of 15.9 mm gypsum board								
406	46.9	610	305	WJ	TLF-96-179a	53	IIF-96-080	47
406+2	56	305	305	WJ	TLF-96-171a	54	IIF-96-076	45
406+2	56	610	305	WJ	TLF-96-173a	54	IIF-96-077	47
406+short	66.5	305	305	WJ	TLF-96-103a	52	IIF-96-045	46
406+2	56	610	305	WI	TLF-96-189a	53	IIF-96-083	45
406+2	56	610	305	WI	TLF-96-191a	53	IIF-96-084	45

Fire resistance tests eventually showed that there was no real need for the additional channels when two layers of gypsum board were used; using type G screws to secure the butt ends of the 2nd layer of gypsum board to the 1st ensured adequate fire resistance.

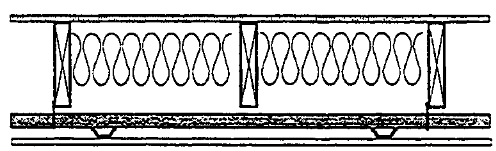
When only a single layer of gypsum board is used for the ceiling, additional channels to support the butt ends of the gypsum board are still needed. These reduce the sound insulation and many of the floors tested that achieved slightly more than STC 50, can be expected to fall below this value or perhaps only just achieve it. To be sure of the results when this channel arrangement is used, tests are needed to establish the correct values.

Wire support vs. resilient metal channels.

The dependence of sound insulation on resilient metal channel spacing and the spacing of the screws attaching the gypsum board to the channels indicates that energy transmission through the channels is an important limiting mechanism for floor sound insulation. To investigate possible improvements in methods of suspending the gypsum board, a floor was built where the gypsum board was suspended from the joists using 12 gauge wire, U- and C-channels. (See the materials section for a description of these channels).

The floor consisted of

- One layer of 15 mm OSB subfloor
- 38 x 235 mm joists, 406 mm o.c.
- glass fiber batts, 152 mm thick
- 32 mm deep C-channels, 610 mm o.c with tops held 6 mm below bottom of the joists by the wire
- 25 mm deep U-channels, attached with wire 610 mm o.c. at right angles to the C-channels
- A layer of 15.9 mm thick gypsum board screwed to the U-channels



The wires supporting the C-channels were attached to every second joist and so were 812 mm apart in one direction and 610 mm apart in the other. The overall cavity depth was 298 mm. To get some estimate of the effect of the wire, C-, and U-channel system, a construction with the same subfloor, ceiling, sound absorbing material, joist spacing and overall cavity depth but using resilient metal channels to support the gypsum board needs to be used for comparison. The closest equivalent construction had 286 mm deep wood joists; all other elements were the same. This difference in cavity depth is negligible. STC and IIC ratings for the two systems are shown in Table 31 where it can be seen that the wire supports resulted in a 2 point increase in STC and a 3 point increase in IIC.

The improvement in STC and IIC is due to improved sound insulation at frequencies above 500 Hz. This single test suggests that ceiling suspension systems might be developed that would increase sound insulation. The improvements seen here, however, while statistically significant are not very large. Fire resistance and installation costs must also be considered for potential new ceiling support systems.

Table 31: Using 12 gauge wire, C channels and U channels instead of resilient channels to support gypsum board.

Gypsum board support	Test ID	STC	Test ID	IIC
286 mm wood joists, and resilient metal channels, 610 mm o.c.	TLF-95-215a	52	IIF-95-075	46
235 mm wood joists, wire, C-channels and U-channels	TLF-96-089a	54	IIF-96-038	49

Thickness and type of sound absorbing material

The effects of different thicknesses and types of sound absorbing material were examined in a 235 mm deep wood joist floor and in a 457 mm deep wood I-joist floor. The joists and the I-joists were 406 mm o.c. These floor systems had subfloors of 15 mm OSB, resilient metal channels spaced 610 mm o.c. and a single layer of 15.9 gypsum board. The dependence of STC and IIC on thickness is shown in Figure 57 and Figure 58. The results show that the sound transmission class and the impact insulation class increase fairly linearly with the amount of sound absorbing material.

The second point to note from these graphs is that the more dense rock fiber batts give small but definite improvements in sound insulation. It is not possible to say whether the sound insulation given by cellulose fiber is much different from that given by the other fibrous sound absorbing materials. The material had to be wet-sprayed on to the underside of the floor; only two thicknesses were tested with the larger thickness being about 90 mm.

Other tests in a steel joist floor with blown-in cellulose, glass fibre and rock fibre batts of the same thickness showed that, when detailed spectra were examined, the cellulose was significantly better than the glass fibre and slightly better than the rock fibre at frequencies

frequencies above 500 Hz. The higher values of sound insulation resulted in higher STC and IIC ratings.

Overfilling the floor cavity

In one of the tests in the wood joist floor, the 250 mm deep cavity was overfilled with three 90 mm thick glass fiber batts (100% full results). A detailed comparison of the results for this construction with the case where the same floor was 87% full shows that the additional thickness and the compression of the glass fiber does not significantly change the sound transmission loss nor the impact sound levels from the ISO tapping machine.

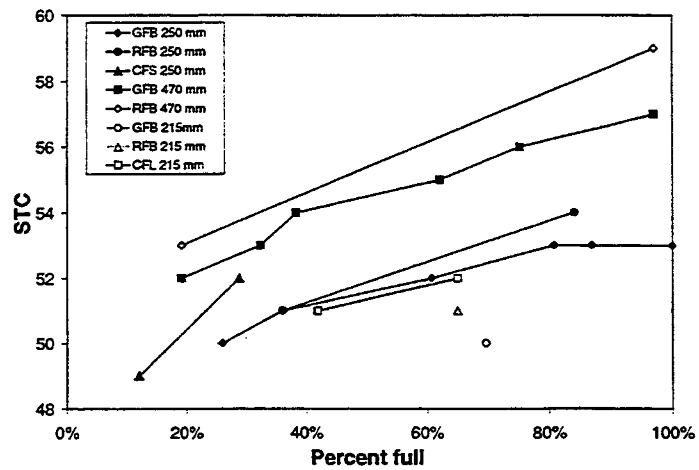


Figure 57: Dependence of STC on thickness of layer of sound absorbing material in a 235 mm wood joist floor and a 457 mm deep wood I-joist floor. GFB = glass fiber batts, RFB = rock fiber batts, CFS = sprayed on cellulose fiber. The dimensions following these codes give the cavity depth.

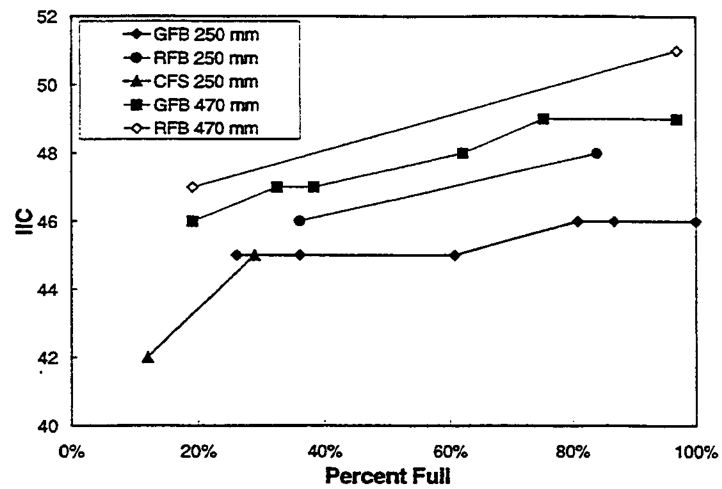


Figure 58: Dependence of IIC on thickness of layer of sound absorbing material in a 235 mm wood joist floor and a 457 mm deep wood I-joist floor. GFB = glass fiber batts, RFB = rock fiber batts, CFS = sprayed on cellulose fiber. The dimensions following these codes give the cavity depth.

Type of Joist or truss, depth and spacing

To display graphically the differences in sound insulation that can be attributed to the type of joist or truss used, requires comparisons among floors that are practically identical in all details of their construction except for the type of joist or truss. The same is true for differences due to joist depth or spacing. Practical considerations required that during the project not all joist depths, spacings and types were tested with the same subfloor, ceiling, sound absorbing material and resilient metal channel arrangements. However, some data are available for comparison; most for a joist or truss spacing of 406 mm. Figure 59 shows STC values for a number of floors with a subfloor of one layer of 15 mm OSB, 152 mm of glass fiber batts in the cavity, resilient metal channels, 610 mm o.c. and a single layer of 15.9 mm gypsum board for the ceiling. Figure 60 shows IIC values for the same floors. Note that as the joist depth increases, the fraction of the cavity volume occupied by the glass fiber batts decreases. As seen earlier, reducing the fraction of the cavity filled with sound absorbing material, reduces the sound insulation; this will reduce any increase in sound insulation due to increasing joist depth.

While plots of this type give some overview of the importance of some of the individual physical factors, a better understanding of the combined effect of the various factors is obtained by doing a more complete, multi-variate regression analysis as described later. One point that is worth noting in these figures is the large range in STC and IIC for the

241 mm deep wood I-joist floors. Another is the unusually low IIC rating for the wood truss floor, a characteristic of all of the truss floors in the project.

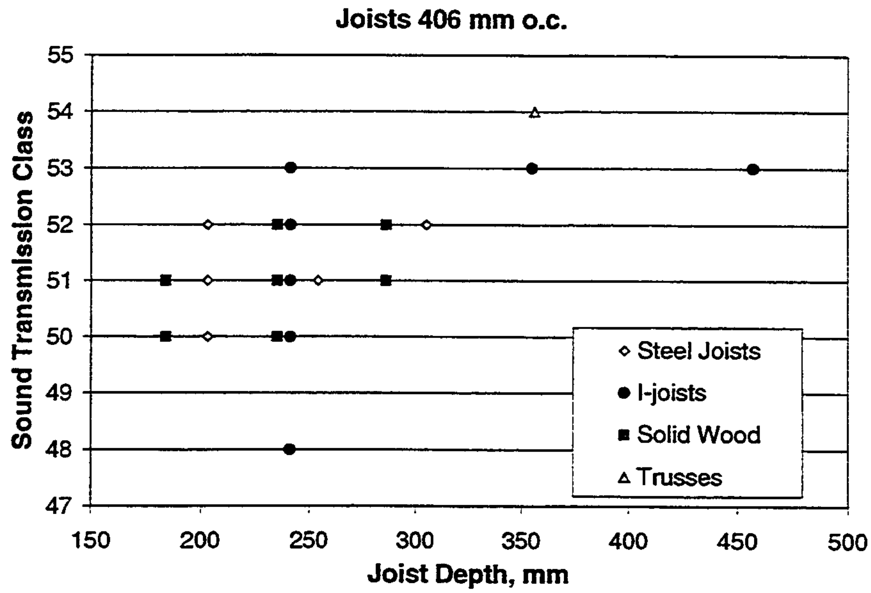


Figure 59: Sound transmission class for floors with joists 406 mm o.c, a single layer of 15 mm OSB subfloor, 152 mm of glass fiber batts, resilient metal channels, 610 mm o.c. and a single layer of 15.9 mm gypsum board.

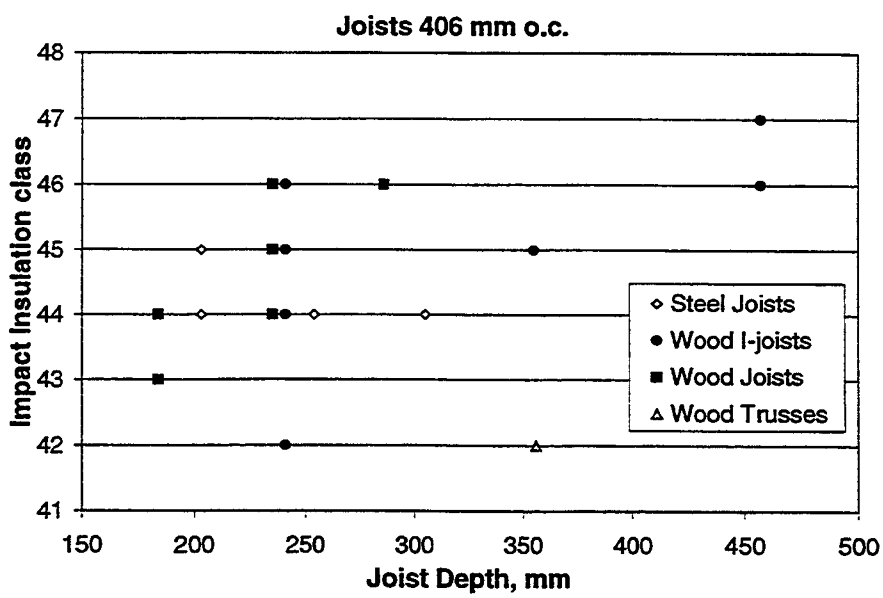
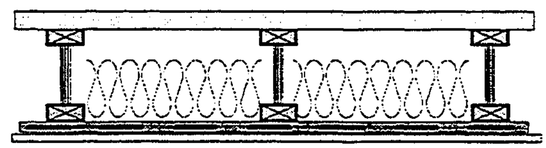


Figure 60: Impact insulation class for floors with joists 406 mm o.c, a single layer of 15 mm OSB subfloor, 152 mm of glass fiber batts, resilient metal channels, 610 mm o.c. and a single layer of 15.9 mm gypsum board

Wood I-joist type

Eight floors, nominally identical except for the type of I-joist, were tested to determine whether I-joist type had an effect on the sound insulation. All floors in this sub-set had the construction

- 15 mm OSB subfloor
- 241 mm deep I-joists, 406 mm o.c.
- 152 mm glass fiber batts
- resilient metal channels, 610 mm o.c.
- 1 layer of 15.9 mm gypsum board



Differences were only in the I-joist construction; these are detailed in Table 32. The range in STC values obtained is significant and perplexing. No reason has been found for these disparate ratings. None of the physical parameters in the table correlate with the STC or with the IIC ratings which are also quite dissimilar. The first and seventh joists in the table, for example, appear to be identical yet the STC ratings differ by 4 points. The expected STC difference in the table is calculated based on the results of the regression analysis described later using the masses of the subfloor and the ceiling as the major variables. These variables do not account for the differences seen.

Table 32: I-joist properties, STC and IIC ratings for nominally identical floors

		Flange			web		rimboard	
			dimensions					
TestID	Manu-facturer	Material	Horizontal	Vertical	material	thickness, mm	Material	Thickness, mm
TLF-96-069a	A	solid wood	64	38	OSB	10	OSB	22
TLF-96-071a	A	solid wood	38	64	OSB	10	OSB	22
TLF-96-073a	A	solid wood	89	38	OSB	11	OSB	22
TLF-96-127a	B	LVL	38	38	OSB	9.5	OSB	32
TLF-96-131a	B	LVL	57	38	OSB	9.5	OSB	32
TLF-96-159a	C	LVL	38	38	plywood	9.5	plywood	25
TLF-97-007a	D	LVL	38	38	OSB	9.5	OSB	25
TLF-97-029a	E	solid wood	64	38	OSB	9.5	OSB	28

Rimboard attachment

A: 3"x.14" diameter common nails, two in top flange of I-joist and two in bottom flange

B: 10d (3") common nails, one in top flange of I-joist and one in bottom flange

C: 8d (2-1/2") common nails, one in top flange of I-joist and one in bottom flange

D: 8d (2-1/2") common nails, one in top flange of I-joist and one in bottom flange

E: 8d (2-1/2") common nails, one in top flange of I-joist and one in bottom flange

TestID	Manu-facturer	avg. mass per unit length of beam kg/m	STC	IIC	OSB mass, kg	Frame mass, kg	Ceiling mass, kg	Expected STC difference
TLF-96-069a	A	3.4	51	45	179.9	202.9	196.8	0.0
TLF-96-071a	A	3.1	51	46	181.8	189.8	198.8	0.1
TLF-96-073a	A	4.3	52	45	188.6	251.9	198.2	0.3
TLF-96-127a	B	3	52	45	179.1	200.6	181.1	-0.6
TLF-96-131a	B	4.1	53	46	179.3	252.3	204.3	0.2
TLF-96-159a	C	2.5	50	44	181.2	163.2	200.7	0.2
TLF-97-007a	D	3.1	48	42	173.3	158.6	199.3	-0.1
TLF-97-029a	E	3.4	48	42	173.4	213.9	196.7	-0.2
Averages		3.4	50.6	44.4	179.6	204.2	197.0	

Another anomalous result can be seen in Table 14 which shows that reducing the spacing of the resilient metal channels in I-joist floor TLF-97-007a resulted in an *increase* in the STC by 2 points. This is in contrast to the findings for solid wood joists where reduced channel spacing gave decreased sound insulation. More work is needed to try to identify the variables responsible for these observations.

Wood Truss Type

Two floors were constructed, differing only in the type of truss used. In one case the trusses were constructed from 38 x 89 mm lumber with a 38 mm wide bearing surface. In the other case, the trusses were constructed from 38 x 64 mm lumber with a 64 mm wide bearing surface. The construction was

- 15 mm OSB subfloor
- 356 mm deep wood trusses, 610 mm o.c.
- 152 mm glass fiber batts
- resilient metal channels, 610 mm o.c.
- 1 layer of 15.9 mm gypsum board.

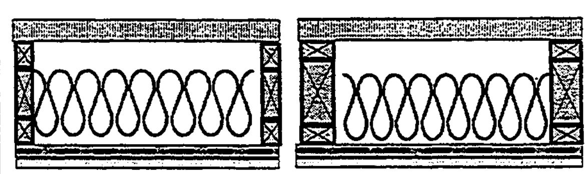
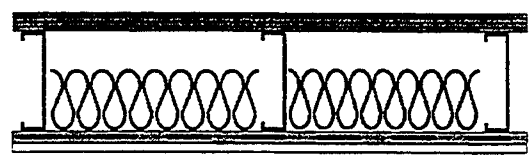


Table 15 shows that the STC and IIC were each 1 point higher in the second case. This is not a large enough difference to be considered significant. More measurements would be needed to determine whether the orientation of the lumber in the trusses has a significant effect on the sound insulation.

Steel Joist Gauge

203 mm deep steel joists formed from three gauges of metal were used to construct floors. The construction was

- 15 mm OSB subfloor
- 203 mm deep steel joists, 406 mm o.c. 14, 16 and 18 Ga.
- 152 mm glass fiber batts
- resilient metal channels, 610 mm o.c.
- 1 layer of 15.9 mm gypsum board.



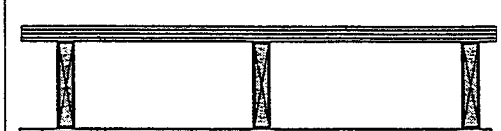
The results can be found in Table 16. The IIC ratings are not significantly different. The STC ratings range from 50 to 52; the lighter gauge joists get the lowest STC rating. This STC difference is just significant but it is difficult to explain; there is no obvious physical mechanism to account for the difference if it is real and not just random. More work is needed to clarify this result. In the meantime, it is best to assume that there is no significant effect on the sound insulation due to steel gauge for the range of gauges considered.

Improving an existing poor floor

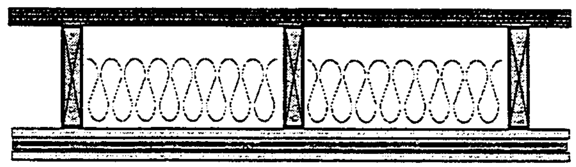
Four methods for improving an existing poor floor were examined. The base floor consisted of

- one layer of 15 mm OSB subfloor
- 38 x 235 mm wood joists, 406 mm o.c.
- one layer of 15.9 mm gypsum board screwed directly to the joists

STC 33, IIC 28



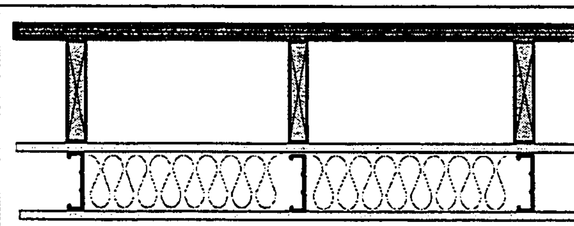
It is commonly believed that the adding resilient metal channels and a layer of gypsum board is an effective way to increase the sound insulation of a wall or floor. It is also thought that the addition of sound absorbing material in the cavity of a wall or floor which does not use resilient metal channels or some other means of isolating the layers on each side will significantly increase the sound insulation. Previous experience has shown that neither technique is effective. To provide a consistent set of data for comparison, both of these techniques were evaluated together. 152 mm glass fiber batts were added to the cavity of the base floor by removing then replacing the subfloor. (In practice, this might be done without removing the ceiling by blowing insulation into the cavity through holes cut in the gypsum board.) Resilient metal channels were then attached to the existing gypsum board and an extra layer of 15.9 mm gypsum board was added to the ceiling. These alterations resulted in STC and IIC values of 38 and 31.

Method 1: Adding sound absorbing material, resilient metal channels and gypsum board. STC 38, IIC 31	

Method 2 used resilient steel studs as follows:

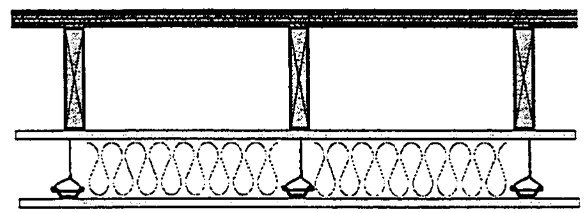
- 38 x 89 mm resilient steel studs were screwed to the joists through the existing gypsum board
- 89 mm glass fiber batts were placed in the cavities between the studs
- one layer of 15.9 mm gypsum board was screwed to the steel studs

The STC and IIC obtained were 53 and 46.

Method 2: Adding resilient steel studs sound absorbing material, and gypsum board. STC 53, IIC 46	

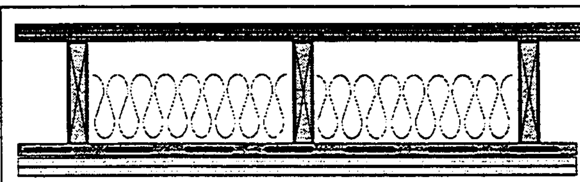
Method 3 used wire and U-channels to support the additional gypsum board at a distance of 90 mm from the existing ceiling. 89 mm glass fiber batts were placed in the cavity between the layers of gypsum board. The STC and IIC obtained were 52 and 46.

Method 3: Adding wire and U-channels to support additional gypsum board
STC 52, IIC 46



In the 4th case the existing ceiling was removed completely, 152 mm of glass fiber batts placed in the cavity and a new ceiling consisting of 2 layers of gypsum board on resilient metal channels was installed. The STC and IIC for this assembly are 55 and 49 respectively, demonstrating that it is best to follow good acoustical practice from the beginning or, when this has not been done, to correct the construction so it becomes properly designed.

Method 4: rebuild to conform to good acoustical practice.
STC 55, IIC 49



Examination of this set of data shows that essentially the same materials can be used in arrangements that provide quite different sound insulation.

MULTI-VARIATE REGRESSION ANALYSES

Regression analyses of the data collected permits interpolation and extrapolation of the results to cases that were not actually measured. Developing an analytical model would be more satisfactory in the long term but this would require much more work. Representative regression equations that are generally applicable are only obtained when there is a reasonably uniform distribution of the values of each predictor variable. This was not always possible in this study, so some anomalous results are to be expected. This section presents the some of the more useful results of the regression analyses.

A regression analysis of all the measured results as one collection of data would not be fruitful. The many variations in construction that are possible have too great an influence on sound insulation and are not easily dealt with using simple linear regression models. For example, simple regression models would not easily deal with floors having resilient metal channels separating two layers of gypsum board, floors with and without resilient metal channels as one class of floor system.

To gain some insight into those physical factors that are significant in determining sound insulation, the data were separated into major categories as follows:

- Solid wood joist floors with resilient metal channels directly attached to the joists and with sound absorbing material in the cavity (70 floors),
- Wood I-joist floors with resilient metal channels directly attached to the joists and with sound absorbing material in the cavity (23 floors),
- All cavity floors with resilient metal channels directly attached to the joists and with sound absorbing material in the cavity (110 floors), and
- All cavity floors with resilient metal channels directly attached to the joists and with *no* sound absorbing material in the cavity (11 floors).

Other categories did not contain enough data to allow meaningful analysis.

For the analyses with IIC as the dependent variable, floors with concrete toppings or resilient toppings were excluded from the regression analysis. The resilience of the floor layer struck by the tapping machine strongly influences the level of impact sound generated by the ISO tapping machine. For example, the addition of a layer of cork on top of a concrete layer can increase the IIC rating by 20 points or more. This important variable needs specific measurements for its characterization but such measurements were not made in this study. In fact the project deliberately did not focus on this aspect of sound insulation; it is a problem sufficiently complex that it needs a separate study.

For all the analyses, the physical variables found to be significant were the mass per unit area of the sub-floor and the ceiling, joist depth and spacing, resilient metal channel spacing, and the thickness and density of the sound absorbing material. Other parameters did not correlate with sound insulation. In particular, adding the mass of the floor framing as an independent variable or in combination with other variables decreased the square of the correlation coefficient. In many cases not all of these variables were significant especially when the number of cases was low.

All analyses were multiple stepwise regressions done using commercial software. For a variable to be included in a regression analysis, the "F" value was required to be 4 or greater.

Solid wood joist floors with resilient metal channels and sound absorbing material.

The range in values covered by the correlation analysis for solid wood joists is shown in Table 33.

Table 33: Maximum and minimum values of parameters used in regression analysis for solid wood joist floors with resilient metal channels and sound absorbing material (70 floors).

Variable	Minimum	Maximum
STC	47	70
IIC	40	53
Joists		
Depth, mm	184	286
Spacing, mm	305	610
Sound absorbing material		
Thickness, mm	59	270
Density, kg/m^3	10	58
Resilient metal channels		
spacing, mm	203	610
Total mass, kg	8.1	23.4
Flooring		
Layers, kg	140	1864
Framing, kg	165	271
Layers + Framing Mass, kg	347	2068
Ceiling Mass, kg	130	415

The logarithm of the total mass per unit area of the sub-floor and ceiling was the most significant variable. For STC, the regression equation found for the set of 70 wood joist floors was

$$\mathbf{STC = 1.31 + 24.4 * \log_{10}(\mathit{Layers}) + 0.02 * \mathit{JstDepth} + 0.01 * \mathit{JstSpace} + 0.02 * \mathit{InsThick} + 0.01 * \mathit{RCSpace} + 0.023 * \mathit{InsDensity},\ r^2 = 0.97,\ 70\ cases} \quad (1)$$

Where *Layers* is the sum of the subfloor and ceiling area masses in kg/m^2, *InsDensity*, the density of the sound absorbing material is in kg/m^3 and all dimensions are in mm. 67

of the 70 STC values predicted using this regression equation (96%) were within 1 point of the measured values. All predicted values were within 2 points of the measured value.

For IIC, the regression equation found for 64 of the 70 floors was

IIC = 1.51 + 21.8* log$_{10}$*(Layers)* + 0.027JstDepth* + 0.011**RCSpace* + 0.013**InsThick*, r^2 = 0.79, 64 cases**	(2)

56 of the 64 predicted IIC values (88%) were within 1 point of the measured values and all predicted values were within 3 points of the measured values.

In the case of IIC there was no significant dependence on the density of the sound absorbing material. While this might be correct for the data set used, it is not in accord with the data presented in Figure 58 which probably indicates that the data set is out of balance; it does not contain enough measurements for floors with rock wool in the cavity.

Wood I joists with resilient metal channels and sound absorbing material

For wood I-joists, 23 floors were available for regression analysis. The range in values covered by the tests is shown in Table 33. The regression equations based on this set of data predict with less precision than those for the solid wood joist floors do. They are

STC = 5.6 + 30*log$_{10}$(*Layers*) + 0.014JstDepth* + 0.016**InsThick*, r^2 = 0.86, 23 cases**	(3)
IIC = 29.7 + 7.0* log$_{10}$(*Layers*) + 0.01JstDepth* + 0.012**InsThick* + 0.094**InsDens*, r^2 = 0.78, 23 cases**	(4)

In both cases, 17 of 23 predicted values (74%) were within 1 point of the measured values. Since no I-joist floors were tested with concrete or soft layers on top, none had to be excluded for the IIC analysis.

Note that the STC apparently does not depend on the density of the sound absorbing material. This can be attributed to the anomalous variability seen for the wood I-joist floors and to the fact that only three of the floors used in the analysis contained rock fiber batts.

It would be convenient if the regression equations for the wood joist floors could be used to predict the STC and IIC ratings for the wood I-joist floors. Unfortunately, they overpredict. The average STC overprediction is 1.5 with some individual values overpredicted by around 4. The average IIC overprediction is 2.7 with some individual values overpredicted by around 5.

Table 34: Maximum and minimum values of parameters used in regression analysis for wood I-joist floors with resilient metal channels and sound absorbing material (23 floors)

Variable	Minimum	Maximum
STC	48	61
IIC	42	51
Joists		
Depth, mm	241	457
Spacing, mm	406	610
Sound absorbing material		
Thickness, mm	90	456
Density, kg/m^3	10.5	32.5
Resilient metal channels		
spacing, mm	406	610
Total mass, kg	8.1	12.4
Flooring		
Layers, kg	173	410
Framing, kg	121	387
Layers + Framing Mass, kg	332	578
Ceiling Mass, kg	181	364

Wood truss floors with resilient metal channels and sound absorbing material

Only 9 wood truss floors were constructed and measured: not enough to give reliable statistical information on their own. The solid wood joist regression equations overpredict the wood truss STC results as they did for the wood I-joists. In this case, the average overprediction is 2.9 with individual errors as high as 5 or 6. In the case of IIC, the wood joist regression equations overpredict even more, on average by 8.1. As a set, the wood truss floors all gave unusually low IIC ratings. This is another issue that needs further investigation.

Floors with resilient metal channels but no sound absorbing material

Only 14 floors fall into this category; three of these were constructed using wood joists, the rest using wood I-joists. The only variable found to be statistically significant was the sum of the masses per unit area of the floor and ceiling layers. The regression equations found were

STC = 8.8 + 26.7* $\log_{10}$*(Layers)*, *r* = 0.96, 14 cases	(5)
IIC = 5.43 + 23.6* $\log_{10}$*(Layers)*, r^2 = 0.82, 11 cases.	(6)

Only one joist depth was used, two joist spacings and two resilient metal channel spacings. The statistical analysis shows that there are not enough data to warrant concluding that any other physical parameter is significant. Again, the cases with concrete toppings were excluded from the IIC analysis.

Floors with no resilient metal channels

There were not enough floors in this category to permit any reasonable statistical analysis. Data for those floors that were tested are given in the section "Sound Transmission And Impact Insulation Class Tables" that begins on page 13.

All joist floors with resilient metal channels and sound absorbing material

The poor predictions obtained from the solid wood joist regression equations when they are used to predict sound insulation for other types of beams is perhaps no more than the result of extending the equations beyond the range of the original data; the I-joists and trusses had depths much greater than the deepest solid joist tested (286 mm). It is of interest to establish how well a regression analysis works when all joist types are assumed to be similar. Thus data for the solid wood joists, wood I-joists, wood trusses and steel joists were analyzed together. The range in values covered by the tests is shown in Table 35. The regression equations found were

$STC = 7.1 + 23.9 * \log_{10}(Layers) + 0.0086 * JstDepth + 0.0066 * JstSpace + 0.017 * InsThick + 0.0085 * RCSpace + 0.030 * InsDensity,\ r^2 = 0.92$, 110 cases	(7)
$IIC = 10.6 + 22.2 * \log_{10}(Layers) - 0.010 * JstSpace + 0.016 * InsThick + 0.012 * RCSpace,\ r^2 = 0.92$, 102 cases	(8)

It is surprising that the IIC rating shows a negative dependence on joist spacing. There is no obvious explanation to be found in this analysis. More detailed study using one-third octave band data may provide insight.

Table 35: Maximum and minimum values of parameters used in regression analysis for all joist floors with resilient metal channels and sound absorbing material (110 floors)

Variable	Minimum	Maximum
STC	47	70
IIC	40	53
Joists		
Depth, mm	184	610
Spacing, mm	305	610
Sound absorbing material		
Thickness, mm	59	456
Density, kg/m^3	10.5	58.4
Resilient metal channels		
spacing, mm	203	610
Total mass, kg	8.1	23.4
Flooring		
Layers, kg	140	1863
Framing, kg	121	387
Layers + Framing Mass, kg	332	2068
Ceiling Mass, kg	129	415

Some indication of the accuracy of prediction using these regression equations can be seen in Figure 61 for STC and Figure 62 for IIC. There are few data points for STC greater than 60 but the agreement between measured and predicted values seems reasonable. The predictions may seem less accurate for IIC but this is because the range of IIC values is much less than the range of STC values; thus the graph shows more detail.

Another method of presenting the accuracy of prediction is seen in Figure 63 and Figure 64. In these graphs the differences between measured and calculated values are presented in the form of histograms. For STC, 90% of all the predictions fell within ± 1 dB of the measured values, 96% within ± 2 dB, and 94% of the predictions were no more than 1 dB below the measured values. For IIC the corresponding values are 75%, 92% and 89%.

In Figure 63 and Figure 64 the 5 cases where Measured-Predicted = –3 include 3 wood I-joist floors and 2 wood truss floors. In Figure 63 there are 2 wood I-joist and I wood truss floors in +2 category. In Figure 64 there is a total of 6 wood I-joist floors in the +2 and +3 categories.

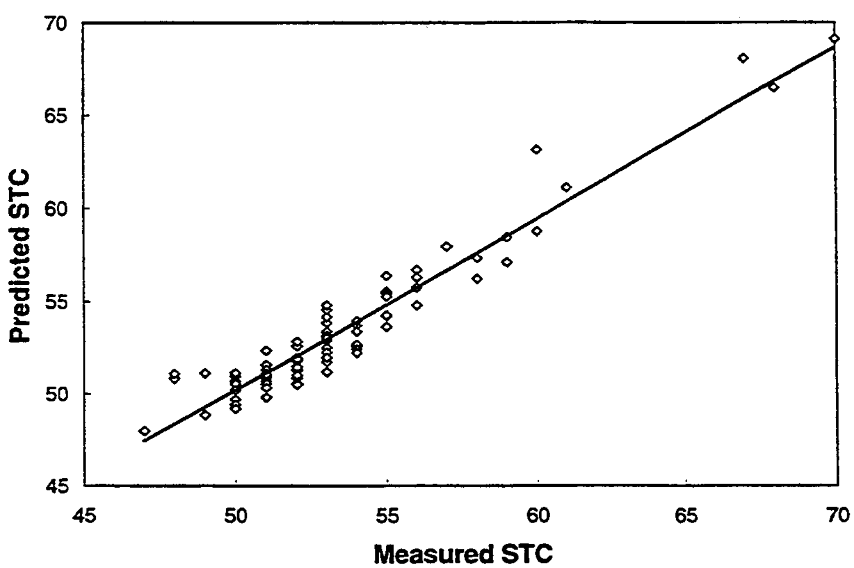


Figure 61: Predicted versus measured STC for all joist floors having resilient metal channels and sound absorbing material.

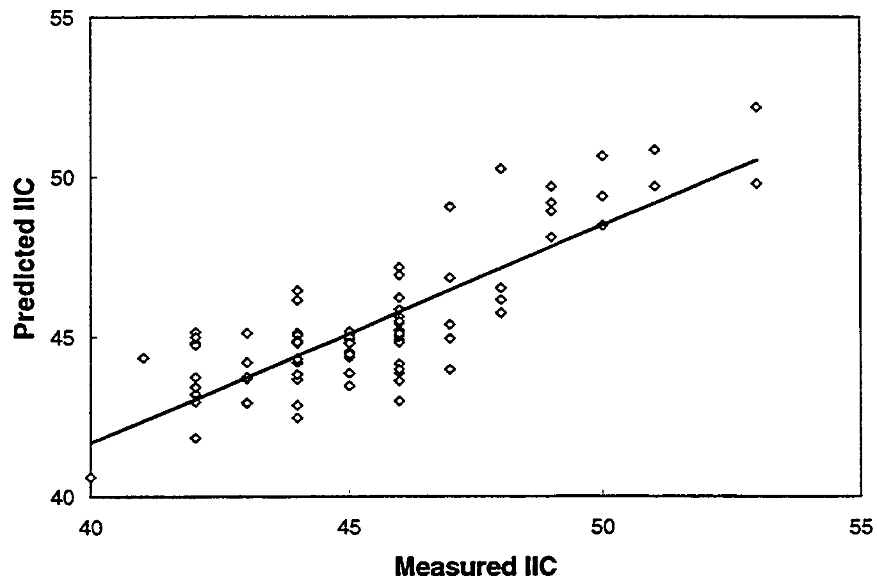


Figure 62: Predicted versus measured IIC for all joist floors having resilient metal channels and sound absorbing material.

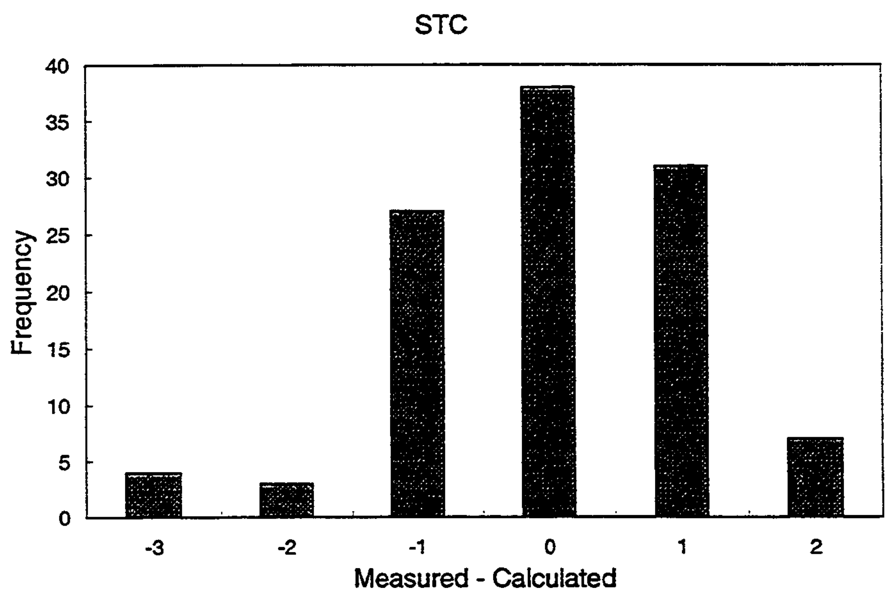


Figure 63: Histogram of measured-calculated STC differences for all joist floors having resilient metal channels and sound absorbing material

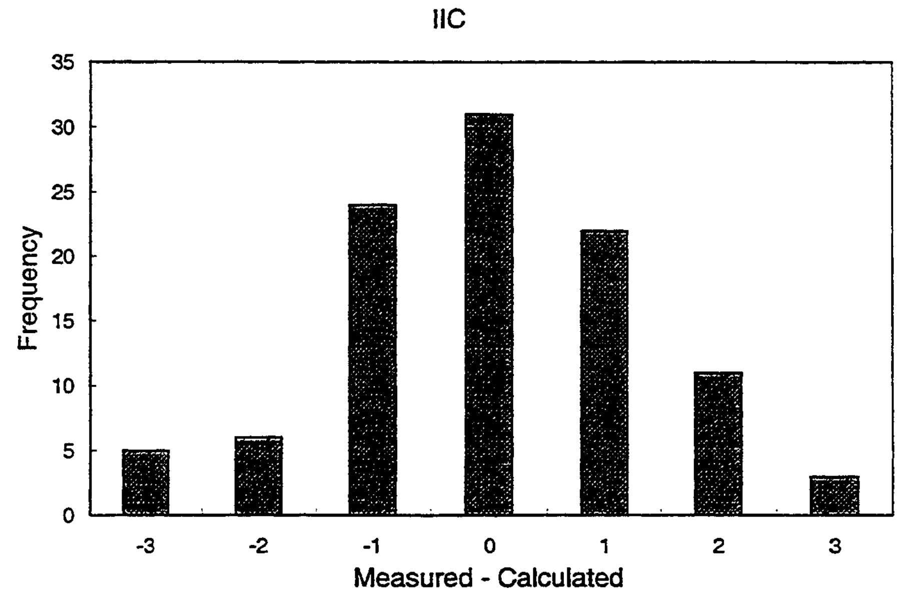


Figure 64: Histogram of measured-calculated IIC differences for all joist floors having resilient metal channels and sound absorbing material

Accuracy of prediction for different joist types

While the set of data used to develop equations (7) and (8) includes results for all joist types, the majority are for wood joist floors. If these equations are to be used to predict results for steel joists, wood I-joists and trusses, and even wood joists, the predictions for each type of joist need to be examined more closely to determine how well they agree with measurements. This is done below for each joist type. As well, some further discussion is given about the dependence of the sound insulation on the type of sound absorbing material.

The tables that follow present the mean, standard deviation (SD in the tables), minimum, and maximum for the measured data, the predicted data and the differences. This presentation is made for STC and IIC. Ideally, the mean difference between measured and predicted values would be zero with a very small standard deviation. If the mean difference is significantly different from zero but its standard deviation is small, the prediction is precise but biased. This would indicate that the particular type of joist was significantly different from the overall average.

Wood joists

Table 36 shows that there is good agreement between measured and predicted values for STC and IIC with standard deviations of the differences around 1 dB. The regression equations do a satisfactory job of prediction for this type of joist. The predictions are not substantially different from those made using the regression equations for wood joists only which are summarized in Table 37.

Table 36: Summary of predictive accuracy of regression equations (7) and (8) for solid wood joist floors.

	STC			IIC		
	Measured	**Predicted**	**Difference**	**Measured**	**Predicted**	**Difference**
Mean	52.5	52.5	0.0	45.6	45.5	0.1
SD	4.1	3.8	0.9	2.4	2.1	1.2
Minimum	47	48	-2	40	41	-2
Maximum	70	69	2	53	52	3

Table 37: Summary of predictive accuracy of regression equations (1) and (2) for solid wood joist floors.

	STC			IIC		
	Measured	**Predicted**	**Difference**	**Measured**	**Predicted**	**Difference**
Mean	52.5	52.5	0	45.6	45.6	0
SD	4.1	4.0	0.8	2.4	2.1	1.0
Minimum	47	48	-2	40	41	-3
Maximum	70	70	2	53	52	3

Wood I-joists

The predictions for wood I-joist based on equations (7) and (8) are shown in Table 38. Those made using the equations (3) and (4) derived from wood I-joist data only are shown in Table 39. It is evident that the precision of the prediction is worse in Table 38. A closer examination of the data shows that three of the STC ratings are overpredicted by 3 points, but this may be due entirely to the anomalous variability seen in the results for the wood I-joists.

Table 38: Summary of predictive accuracy of regression equations (7) and (8) for wood I-joist floors

	STC			IIC		
	Measured	**Predicted**	**Difference**	**Measured**	**Predicted**	**Difference**
Mean	53.1	53.1	0.2	45.9	45.7	0.6
SD	3.5	3.0	1.4	2.4	2.1	1.6
Minimum	48	49	-3	42	42	-3
Maximum	61	61	3	51	51	3

Table 39: Summary of predictive accuracy of regression equations (3) and (4) for wood I-joist floors

	STC			IIC		
	Measured	**Predicted**	**Difference**	**Measured**	**Predicted**	**Difference**
Mean	53.1	53.0	0.0	45.9	45.8	0.0
SD	3.5	3.3	1.22	2.4	2.1	1.2
Minimum	48	50	-2	42	44	-2
Maximum	61	60	2	51	51	2

Wood Trusses

Table 40 shows the summary for wood trusses. Although the range of differences for STC is about the same for wood joists in Table 36, the standard deviation is larger. It must be remembered that there are only nine wood truss floors in the data set. The main point to notice from this table is that the IIC is consistently underpredicted. All of the wood truss floors showed anomalously low IIC ratings.

Table 40: Summary of predictive accuracy of regression equations (7) and (8) for wood truss floors

	STC			IIC		
	Measured	**Predicted**	**Difference**	**Measured**	**Predicted**	**Difference**
Mean	53.9	54.1	-0.2	42.3	43.7	-1.3
SD	1.1	1.2	1.4	0.9	0.7	1.0
Minimum	52	52	-2	41	43	-3
Maximum	55	56	2	44	45	0

Steel Joists

Table 41 is the summary table for the predictions for the ten steel joist floors tested. For STC, with the exception of one floor topped with gypsum concrete, all the predicted values are within ±1 point of the measured values. All predicted IIC values were within ±1 point of the measured values.

Table 41: Summary of predictive accuracy of regression equations (7) and (8) for steel joist floors

	STC			IIC		
	Measured	**Predicted**	**Difference**	**Measured**	**Predicted**	**Difference**
Mean	52.8	52.9	-0.1	44.3	44.6	-0.3
SD	3.1	4.2	1.4	0.5	0.8	0.8
Minimum	50	51	-3.0	44	43	-1.0
Maximum	60	63	1.0	45	45	1.0

Accuracy of prediction for different types of sound absorbing material

Since the majority of the measurements were made using glass fiber batts as the sound absorbing material, the regression equations predict the results for this material well. Not enough data were collected for the other types of sound absorbing material to allow the same kind of regression analysis. The coefficient for the variable insulation density in the STC regression equation is 0.03. This means that increasing the density from 10 to 30 kg/m^3 increases the STC by 0.6 dB (This corresponds approximately to a change from glass fiber batts to rock fiber batts). There is no dependence on the density of the sound absorbing material in the regression equation developed for IIC. This is not in accord with the observations presented in the section "Thickness and type of sound absorbing material" on page 98. The data there suggest that changing from glass fiber batts to rock fiber batts should increase the STC and IIC by about 1 point, if not more. More measurements are needed to clarify this issue.

RATINGS FOR BUILDING CODES

Two methods are available for generating tables for building codes. One is to use the data as measured and by some means estimate values for constructions that were not measured. This method is direct but inevitably has experimental variance built in. The precision of the test methods is such that some results obtained contradict common sense or other results. Fortunately, such contradictions are not usually very large.

The second method is to use the regression equations developed to calculate the sound insulation ratings. This method has the advantage of internal consistency but will inevitably produce some data that conflict to a greater or lesser extent with measured data. In practice a combination of both will be necessary because there are still unanswered questions about the experiments that can only be resolved by further study.