Field Impact Isolation Performance of a High-End Apartment Floor

[1] Peter Ibbotson and [1] Malcolm Dunn

[1] Marshall Day Acoustics, PO Box 5811, Wellesley Street

peter.ibbotson@marshallday.co.nz

Abstract

A timber floor was constructed on a 100mm thick Interspan concrete slab within a high-end residential apartment. The finished timber was nailed using concealed fixings to a plywood substrate. The substrate was atop a 6 mm thick rubber underlay mat which was affixed to the concrete floor system using a polyurethane adhesive.

Impact testing on the completed timber floor / concrete slab was completed prior to the construction of the ceiling in the apartment below. Testing showed that the impact isolation class of the timber floor was much lower than the adjacent tiled areas. The measured impact isolation class (IIC) of the flooring system suggested a shortfall in performance of around ΔIIC 10 in comparison to that calculated for the timber floor system based on available data and theory. Vibration measurements on building elements in the apartment below showed that the floor transmission was the primary, though not only, path of noise transfer.

To determine the reason for the performance shortfall, a hole was cut in the completed floor and testing carried out using a tapping machine. Impact testing on the bare concrete slab showed that the slab was underperforming at high frequencies by around ΔIIC 6when compared to a theoretical prediction model. An initial comparison of IIC values could have lead to the erroneous conclusion that the poorer than expected performance of the slab was the reason for the overall shortfall in performance of the system, however analysis of the measured impact sound pressure levels showed that the timber, substrate and underlay were resulting in a higher level of impact noise at 1 kHz and 1.25 kHz than compared to the bare concrete slab alone. An inspection of the substrate and underlay showed that the adhesive used was significantly harder than expected. The adhesive had also penetrated the rubber matting which had likely resulted in an overall stiffening of the floor system. It was also noted that the use of the adhesive had formed small interstitial voids on both sides of the underlay. It was determined that one of these mechanisms was the primary cause of the shortfall in performance. In order to compensate for the shortfall in performance and to achieve the Building Code minimum level of performance (FIIC 50), a heavy, resilient ceiling and isolated wall linings were specified in the apartment below.

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1. Introduction

The construction of quality apartments with appropriate levels of sound insulation requires the design of suitable intertenancy wall and floor systems, the specification of suitable "acoustic" materials and, perhaps most importantly, good on-site workmanship and a strict adherence to the installation guidelines of the product supplier.

This paper summarises an investigation into why a timber floor in a high-end apartment was transmitting significantly more impact sound than would be theoretically expected for the system. This case study is considered to be of interest as it provided a unique opportunity to study the impact isolation class of each element of a floor system insitu, and to compare the measured results with a visual inspection of the floor construction. The case is also considered to be of interest given the potential erroneous conclusions that could have been reached without a careful analysis of the measured impact noise levels in each one-third octave band.

This paper presents the results of our field investigation, dis-cusses our analysis of the measured data and provides an explanation for why this shortfall occurred. The paper con-cludes that the shortfall in performance was due to: the use of a rigid adhesive; adhesive penetration through the resilient underlay; and/or the formation of interstitial voids within the subfloor.

2. Background

2.1 Apartment Shell

In 2006, Marshall Day Acoustics provided recommendations on the construction of a four level mixed-use building in Auckland CBD.

The building was designed to allow apartments to be fitted out on the third and fourth floor of the building, with office and retail spaces on the second and ground floor levels re-spectively. The building was located in a desirable city area and thus a "high quality" level of finish was proposed. In order to ensure this level of quality was achieved, Marshall Day Acoustics recommended that the apartments be designed to improve on the minimum impact isolation requirements of Section G6 of the New Zealand Building Code (i.e FIIC 50 minimum) [1]. The recommended acoustical criterion for the apartments was FIIC 60 to 65.

An Interspan concrete floor system was proposed for the apartments; Marshall Day Acoustics recommended a minimum 100mm concrete topping. The Interspan system consists of precast concrete ribs with timber infill between the ribs. The topping slab is poured on top of this system. The predicted impact isolation class of this system was IIC22 [2].

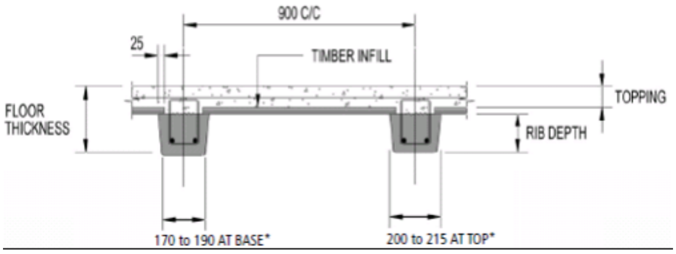

Figure 1. Interspan Flooring System

Based on the above system, it was expected that FIIC60 to FIIC65 could be achieved in the apartment below with the following [2]:

- Solid timber floor or tiles on suitable impact isolating underlay (i.e. ΔLw 16)
- Interspan slab system with 100 mm thick concrete top-ping
- 300 to 500 mm cavity below slab
- Cavity absorption
- Rubber isolation clip between joist and ceiling
- Two layers of 13 mm thick plasterboard (i.e Gib Ultraline or similar)

An alternative construction of 1 x 13 mm Gib Ultraline on a steel suspension system was also suggested as suitable to meet the Building Code minimum requirements.

2.2 Fitout

Fitout of the apartment occurred in 2010. The majority of the apartment floor was proposed to be finished in solid timber, though tiles were proposed in the bathroom areas. A raised flooring system was considered likely to result in the best overall impact isolation class, however this was not considered practicable to accommodate within the apartment shell. Instead the architect and developer proposed to construct the finished floor as follows:

- 19mm thick bleached Canadian Maple timber
- 9mm plywood substrate.
- 6mm thick rubber acoustic underlay bonded to floor slab using polyurethane adhesive.

It was expected that this system would achieve IIC 41 without a ceiling in place [2]. This was based on a theoretical prediction of impact noise transmission together with the claimed impact sound pressure level reduction provided by the underlay [2, 3, 4]. The claimed performance of the underlay was similar to that measured by Marshall Day Acoustics on other projects with similar systems. The claimed reduction was based on field tests performed by the manufacturer rather than laboratory measurements. The field test data appeared to be in accordance with ASTM E1007-97 and ISO 140-7:1998 standards.

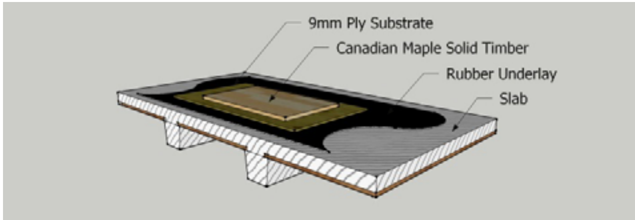

Figure 2. Floor construction schematic

3. Resilient Floor Covering

A rubber underlay was specified for this project. This product consists of flexible rubber sheets made by bonding long, thin rubber granules together to form a rubber mat. The granules are bound in a relatively open matrix with air spaces between the chips [5]. The resilience of the product is considered to depend on the resilience of the rubber itself and the air spaces between the chips. Field test data provided by the manufacturer showed that an improvement of ΔIIC 14 could be expected when the performance of a bare slab is compared to a floor covering of 12 mm Tasmanian Oak floor on a resili-ent underlay[4].

Figure 3. Rubber underlay

Based on the manufacturers data, it was calculated the floor system would achieve an impact isolation class of FIIC62 with the ceiling system discussed previously [2]. This was deemed to be acceptable for the project given the constraints, notwithstanding that it was considered less than ideal for large floor areas.

4. Preliminary Testing Results

4.1 Impact Testing

Auckland Council directed the impact isolation class of the finished floor be tested once completed. Auckland Council required that this testing be completed even though a ceiling was not yet constructed in the Level 3 apartment below. It is understood that no building consent had been lodged for the fitout of the Level 3 apartment at the time the Level 4 apartment was completed.

This testing was completed by an Auckland Council contrac-tor. These results showed that the impact isolation class of the timber floor was between FIIC32 and 34. The same testing on the bathroom tiles (ceramic tiles on Mapefonic underlay) resulted in FIIC40. The Auckland Council contractor noted this discrepancy and raised the potential shortfall in performance of the timber floor as of concern.

Table 1. Comparison of measured and theoretical performance (as tested by Council contractor)

	Measured FIIC	Predicted IIC
Timber floor area	32 -34	41
Tiled floor area	40	42

Subsequent to the receipt of this testing data, Marshall Day Acoustics visited the site and carried out our own testing. This testing gave results consistent with the above. Measurements were conducted and analysed using a tapping machine in general accordance with ASTM E1007-04e1 & E989-06 standards [6, 7].

Figure 4 illustrates the difference between the measured and expected impact isolation provided by the floor system.

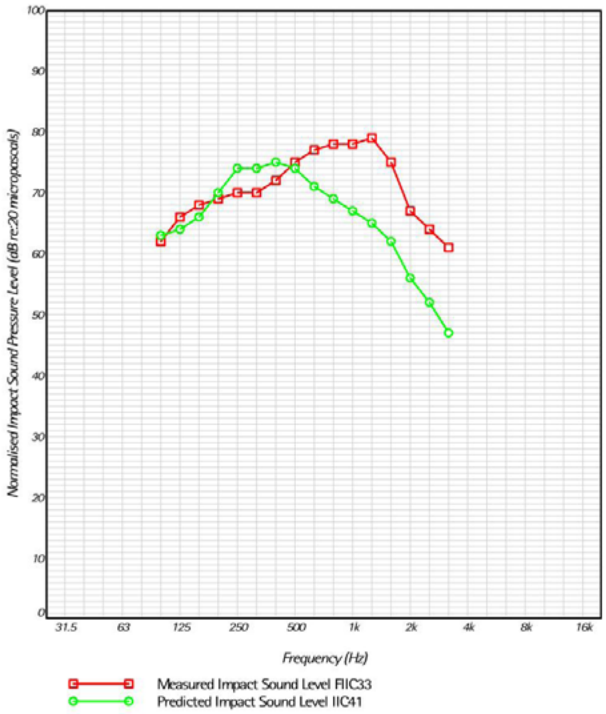

Figure 4. Comparison between measured and expected impact sound pressure levels

It can be seen that the level of impact isolation for the floor system insitu is significantly lower than expected between 630 and 3150 Hz. The shortfall in performance is around 20 dB at 1 kHz.

Impact noise levels would be expected to decrease from around 250Hz onwards, however in this case impact noise levels increase with frequency between 250 Hz and 1 kHz.

4.2 Vibration Testing

In order to determine the reason for this shortfall in performance, vibration analysis of the structure was undertaken. An accelerometer was used to measure the level of vibration in each building element of the downstairs apartment and the contribution to the overall level determined through a consideration of the radiating surface area, frequency and radiation efficiency of the building material as follows:

$$L_w = \alpha + 10\log S - 10\log f^2 + 10\log X + 10 \text{ dB}$$

Where:

S = radiation area (m^2),
f = frequency (Hz),
X = radiation efficiency,
α = Acceleration in dB rel. 10^{-6} m/s^2

The results showed that the main path of impact noise transmission was via the floor slab. However it was noted that flanking transmission was occurring via the plasterboard and masonry walls and other building elements (e.g glazing) and that these may contribute to the overall level once the ceiling was in place. Figure 5 illustrates the measured and calculated contributions to the overall impact sound pressure level without a ceiling in place.

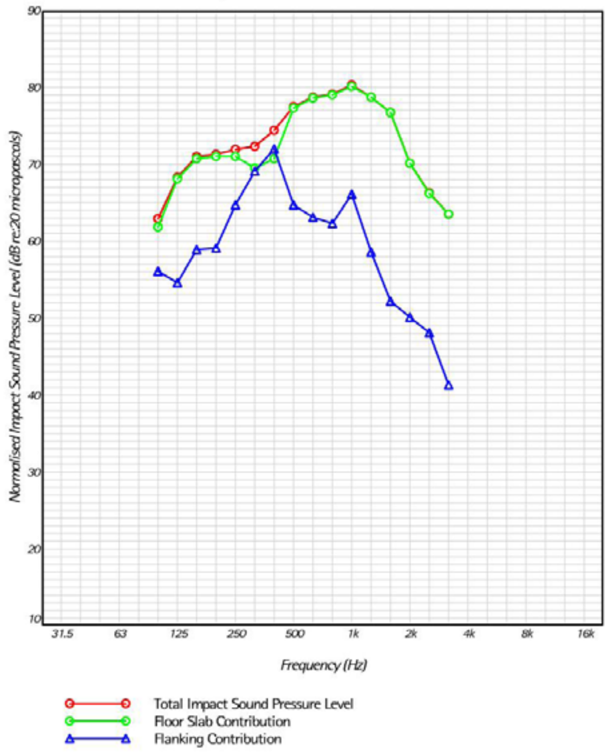

Figure 5. Calculated vibration contribution (from measurements)

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5. Determination of Cause of Shortfall

In order to determine the cause of the shortfall in performance of the floor system it was determined that a section of the floor would be removed and the impact isolation of the slab measured. It was determined that the bed could be removed and a small area of finished floor below the bed frame could be chiselled out for impact testing. Once the testing was complete, the reinstalment of the bed would conceal the hole in the floor.

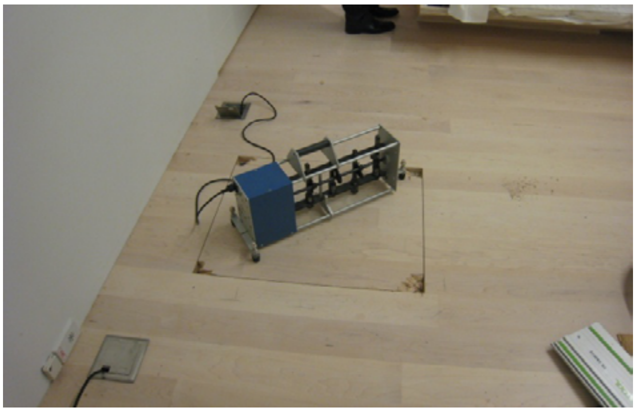

Photo 1. Floor test area with cuts & corners chiselled out

This approach allowed the impact sound level for the bare concrete floor slab to be measured. These measurements showed that the bare Interspan floor slab was achieving only FIIC16 whereas the level of impact isolation that would be expected for a 100 mm thick concrete slab would be IIC22.

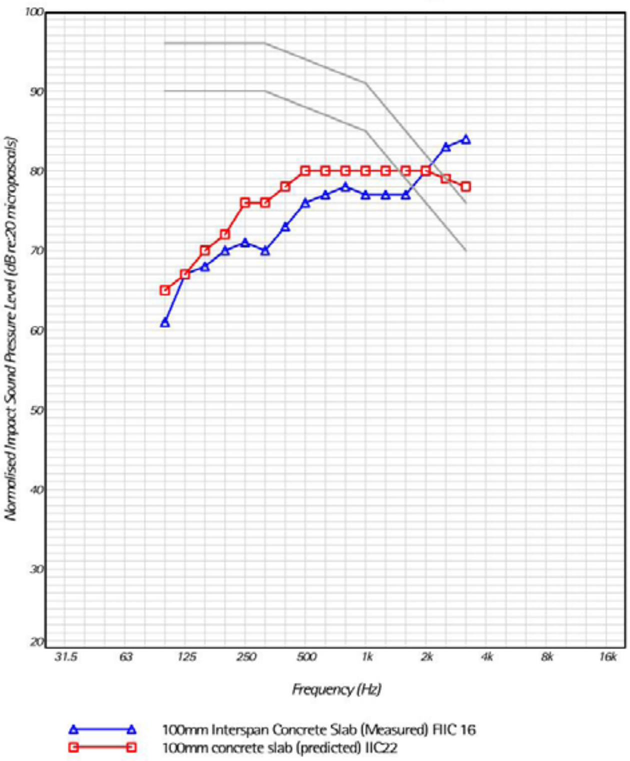

Figure 6. Theoretical vs. measured concrete slab performance

The insitu performance of the slab is compared with the theo-retical level of performance in Figure 6. The measured performance was generally better than that predicted for a 100 mm thick floorslab. However at frequen-cies above 2 kHz the opposite is true: the field performance of the slab is worse than predicted. The Impact Isolation Class of a bare slab is generally determined by the uppermost frequencies of interest and thus the insitu floor slab had a much lower FIIC than expected (FIIC 16 (measured) verses IIC22 (predicted)). A simple comparison of IIC values might have suggested that the shortfall in floor slab impact isolation class was the cause of the overall shortfall in performance of the floor. However this was later found not to be the case when the actual impact sound reduction of the underlay and floor was considered over the entire frequency range. This illustrates the risk of considering only single number rating systems in assessing field performance.

Because the impact isolation of the floor slab was known, the additional isolation provided by the solid timber floor and underlay could be determined through comparing the measured impact sound level from the finished floor with the measured impact sound level from the concrete slab. The difference in these values represents the impact isolation provided by the timber floor and resilient underlay.

As discussed, the manufacturer had previously completed similar insitu testing for the underlay product on a 200 mm thick bare slab.

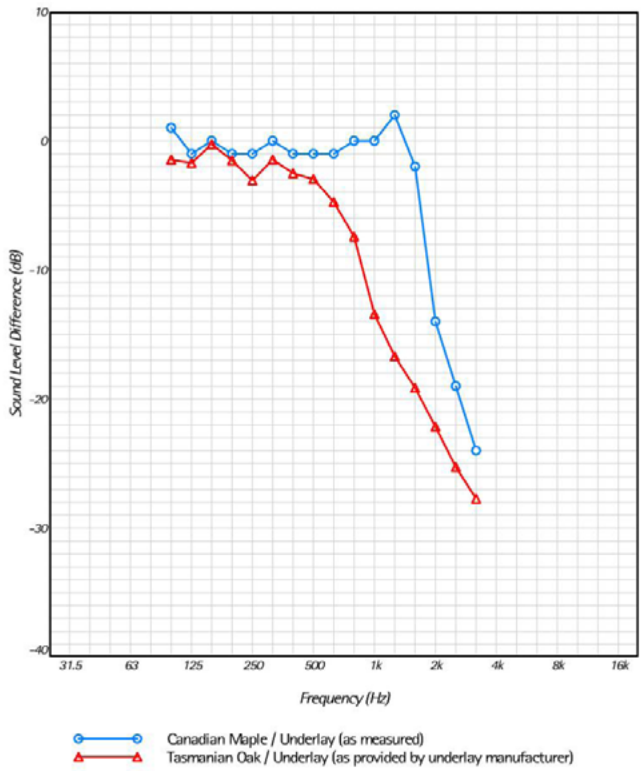

Figure 7. Measured floor / underlay performance vs. supplier test data.

These tests provided a comparison between the performance of a bare slab and the same slab with 12 mm thick Tasmanian Oak on resilient underlay in place.

The difference in sound pressure level for both the manufac-tures test and the subject test is shown in Figure 7. These results demonstrate that there was a significant differ-ence in impact isolation between the subject floor system and that previously measured by the manufacturer.

The difference in performance is most obvious at 1.25 kHz. At this frequency it was expected that the floor / underlay system would reduce impact sound levels by around 17 dB when compared to the bare slab alone, however the measured performance of the system at the subject apartment showed that the system actually increased impact sound transmission by 2 dB when compared to the bare slab alone. The overall difference between the measured and expected performance at this frequency is 19 dB.

The impact isolation provided by the floor system, while not as good as claimed by the manufacturer, does provide isolation between 2 to 3.15 kHz. Reductions in impact sound pressure levels of 14 to 24 dB were measured in this frequency range. This means that while the slab performance was poorer than expected at these frequencies, sufficient impact isolation was provided by the floor and resilient underlay to ensure that the overall Impact Isolation Class is not determined by these frequencies.

Figure 8 shows the effect of the timber and underlay in com-parison to the bare slab together with the fitted FIIC curves. It can be seen that the floor and underlay system (red line) provides negligible improvement over the bare slab (blue line) up to 630 Hz. The increase in impact transmission over the bare slab alone is obvious at 1.25 kHz. The improvement in sound insulation provided by the floor and underlay is significant only above 1.6 kHz.

Also shown is the impact sound level that would have been expected based on the measured performance of the floor slab together with the effect of the underlay as claimed by the manufacturer. There is a significant difference between what was measured and expected at mid and high frequencies.

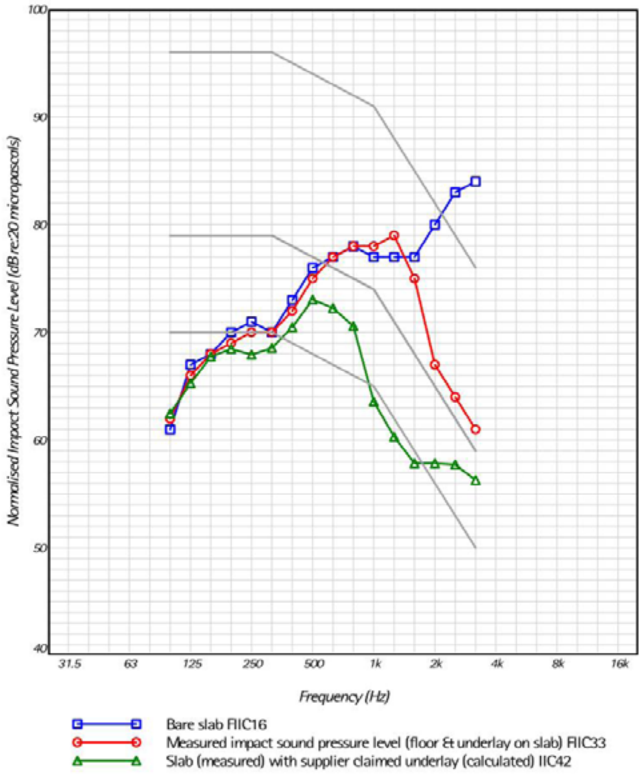

Figure 8. Comparison of a) bare slab; b) timber and underlay on bare slab (measured); and c) bare slab with expected performance of underlay as claimed by supplier

6. Site Observations

The removal of a test area of the floor enabled cross-sections of the floor, plywood, underlay and hardened glue to be removed and inspected as samples. Our inspections showed the following:

1. The adhesive used to bond the underlay to the concrete floor was very hard and stiff. The installation guidleines for the underlay specify that the adhesive should be an RLA Polymers RL1017 single part polyurethane adhesive [5]. The manufacturer field test data provided had been measured for a system with Bostik Ultraset as the adhesive. Both of these adhesives are understood to have a low hardness [8]; the Bostik Ultraset technical data sheet states a hardness of "Approx. 52 Shore 'A'" [9]. It is understood that a Selleys Liquid Nails timber flooring adhesive product was used instead of the above adhe-sive(s). This manufacturer is understood to supply several timber adhesives under the "Liquid Nails" brand and it is not clear which exact adhesive system was used. It is noted that some Liquid Nails floor adhesives are claimed to be very stiff while others are claimed to be very flexible. Our inspection showed that in this instance, the polyurethane was very rigid once set.

2. In addition to the above, the adhesive used to bond the resilient underlay to the concrete slab appeared that have been applied generously. A notched trowel had likely been used to apply the adhesive as thick adhesive "ribs" were clearly evident on the underside of the underlay. Because of the generous application, the adhesive had penetrated through the 6mm thick resilient underlay to the underside of the plywood substrate in some areas. The resilience of the underlay was subjectively much lower where the adhesive "ribs" had penetrated the un-derlay. The underlay supplier recommends that the RL1017 single part polyurethane adhesive be used using a 1.6 mm x 1.6 mm "V" notched trowel [5]. RLA polymers state a 3.2 mm "V" notched spreader be used [8]. By comparison, the Selleys Liquid Nails timber flooring guidelines states that a trowel with 5 mm wide by 6 mm high V notch at 25 mm centres should be used for strip flooring [9]. In this situation it is considered likely that a trowel with large, coarse notches was used leading to the significant penetration of adhesive through the underlay.

3. The liberal application of adhesive also resulted in small voids forming between the underside of the underlay and the concrete slab. These voids occurred between the ad-hesive "ribs" where the underlay was not resting in contact with the floor. It is possible that these voids were the cause of, or contributed to, the shortfall in performance observed.

On the basis of our field tests and observations, it was con-cluded that the installation of the resilient underlay was the cause of the shortfall in impact isolation provided by the flooring system.

7. Outcomes of Performance Shortfall

Based on the above results, it was determined that the Building Code minimum level of performance would not have been achieved with the ceiling in place. This was in part due to the level of flanking noise from walls and windows measured using the vibration accelerometer. In order to rectify this, the following was recommended:

- Ceiling to consist of 2 x 13 mm dense plasterboard (e.g. Gib Noiseline or similar) on steel suspension incorporating resilient clips at 900 mm centres (e.g. ST001 clips or similar). 75 mm thick thermal insulation in the cavity)
- External wall linings to be 13 mm thick standard plasterboard on resilient clips (e.g. ST001).
- Internal wall linings as standard. Any full height framing to be resiliently isolated at the head of partition using partition supports at 400 mm centres (e.g. Masons MPS)

It is understood that the above recommendations were not followed; specifically the resilient isolation of the wall linings and internal wall framing was omitted from the fit out of the downstairs apartment. It is understood that only the rec-ommendation relating to the apartment ceiling was followed.

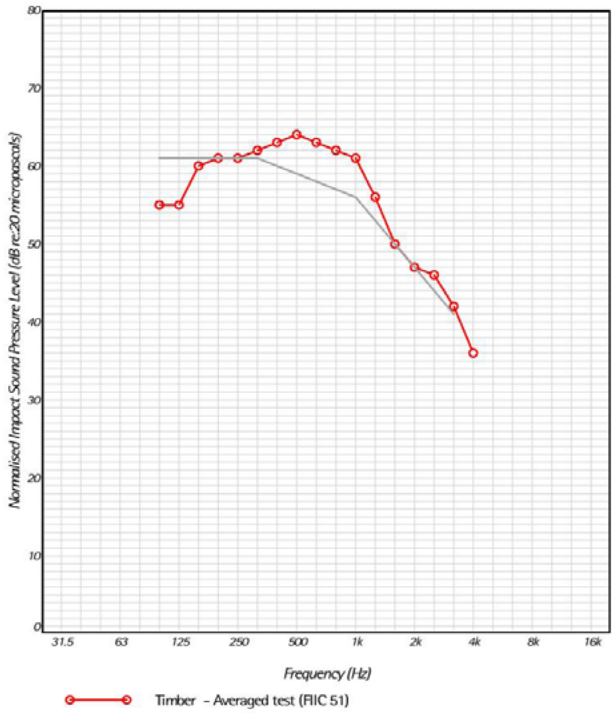

Figure 9. Normalised impact sound pressure levels with ceiling and wall linings in place (FIIC51)

Final measurements performed by Marshall Day Acoustics and the Council contractor showed that the above construc-tions achieved FIIC51. This performance just complied with the Building Code minimum of FIIC50 but did not achieve the high level of sound insulation recommended for the apartments.

8. Summary and Conculsions

This paper summarised an investigation into why a timber floor in a high-end apartment was transmitting significantly more impact sound than would be theoretically expected for the system.

The results of the study showed that adhesive penetration through the resilient underlay was the likely cause of the shortfall in performance. This shows the importance of careful workmanship on-site in ensuring that the project field performance ratings will be achieved.

The study also illustrates the importance of careful examination of field data and shows that simple comparisons of single number ratings (such as FIIC) may lead to erroneous conclusions.

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Happy New Year to all, we hope to you had a relaxing Christmas and we are looking forward to bringing you more Court decisions which involve acoustic issues throughout 2015.

It was a busy end to 2014 with the Court of Appeal decision being released involving Palmerston North City Council and New Zealand Windfarms Limited, as well as two High Court decisions involving the Waimakariri District Council and the North Canterbury Clay Target Association, and the NZ Aviation Museum Trust and Marlborough Aero Club against the Marlborough District Council and Colonial Vineyard Ltd. Following are brief summaries of these proceedings but full copies of the decisions can be found on the RMA Net website at www.rma.net

In the Court of Appeal

PALMERSTON NORTH CITY COUNCIL - Appellant

NEW ZEALAND WINDFARMS LIMITED - Respondent

[2014] NZCA 601, 38p, [104] paras, 9 December 2014

Summary of Facts

In 2005 New Zealand Windfarms Ltd (NZWL) was granted consent by the Council for a windfarm comprising 97 turbines in the hills to the east of Palmerston North, know as the Te Rere Hau Windfarm. After two thirds of the project was completed NZWL discovered that the consent application had significantly under predicted the actual noise generation characteristics of the turbines and their noise impact on surrounding residents. The Council wished to hold NZWL to its prediction of the noise effects under Condition 1 of the consent, and NZWL appealed. In decision [2012] NZEnvC 133 the Environment Court found that NZWL was bound by both its own predictions about sound levels generated (Condition 1) and by the specific noise standards contained in the consent conditions (Conditions 4 and 5). On appeal to the High Court, Williams J held that Condition 1 could not be used in that way and set aside the Environment Court decision ([2013] NZHC 1504) but in a further judgment, [2013] NZHC 2654, Williams J granted the Council leave to appeal to the Court of Appeal.

The Council appealed on three points of law;

(a) Did Condition 1 apply to either or both the noise generation characteristics and performance of the turbines, and the noise effects at receiver locations?

(b) Was it lawful for the High Court, rather than the Environment Court, to determine if the windfarm had been constructed, operated or maintained in a manner which complied with Condition 1?

(c) Was Williams J right as to scope of the application for the windfarm if the answer to a) was no and to b) was yes?

As such the appeal focused on whether Condition 1 enabled