Influence of Construction Details on Vibration Characteristics of Cold-Formed Steel Floor Systems

by

Brian W. Davis

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AUTHOR'S DECLARATION

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners. I understand that my thesis may be made electronically available to the public.

Abstract

Over the last decade, cold-formed steel has become an increasingly popular building material for residential and commercial construction. This increased use can be attributed to the numerous advantages that cold-formed steel has over traditional residential building materials. Cold-formed steel offers resistance to termites and rot, design flexibility, rapid construction, and a strength-to-weight ratio greater than any other common building material. This high strength-to-weight ratio allows cold-formed steel floor systems to span great distances, but the weight of the floors is a fraction of that of traditional floor systems. The large spans are architecturally pleasing, and the lightweight is an asset during design, but the combination can lead to vibration problems.

Vibrations associated with lightweight floor systems, as a serviceability criterion, are not well addressed in current residential construction practice. Cold-formed steel floor systems are usually lighter and have less inherent damping. If designers are going to use the current span deflection criteria when designing residential floor systems, it is imperative to find the construction and design details that will limit these annoying vibrations in cold-formed steel floor systems.

This thesis presents the results from a recent investigation on the vibration characteristics of floor systems supported by cold-formed steel joists. The main objectives of this research were to determine the construction details that improve the vibration performance of cold-formed steel floor systems, and compare the tested floor systems against current acceptability criteria. The construction details analyzed were: span length, 14.5' (4.42 m), 17.0' (5.18 m), 19.5' (5.94 m) and 21.8' (6.64 m) spans were tested; joist types, C-shape and TradeReady joists were examined; subfloor materials, OSB, Fortacrete and metal deck subfloors were tested; toppings, the influence of a LevelRock topping was determined; ceilings, the influence of Type X and Type C ceilings were examined; strongbacks; live loads; and framing conditions, balloon framing and platform framing conditions were tested.

Laboratory floor systems, with varying construction details, were constructed and tested in the Structures Laboratory at the University of Waterloo. Field floor systems were also tested to verify the laboratory results and to ensure the laboratory floor systems represented a conservative model. Dynamic and static tests were performed on each floor system. The purposes of the dynamic tests were to determine the natural frequencies, damping ratios and RMS acceleration of the floor systems. The purposes of the static tests were to determine the deflection and load sharing capabilities of the floor systems.

Observations based on the static and dynamic response of the floor systems tested provided several conclusions on the influence of construction details on performance. If using span deflection limitations to design residential floor systems, the following construction details are recommended to limit floor vibrations: minimize span length; specify a metal deck subfloor, with a minimum of 1.5” (38.1 mm) thick layer of LevelRock topping; include a ceiling on the underside of the floor system, with the gypsum board attached to the bottom flange of the floor joists using resilient channel; include strongbacks with the ends fixed to wall studs, spaced 8’ along the joist length; and specify balloon framing instead of traditional platform framing.

The responses of the floor systems tested in this study were evaluated using the AISC resonance model for walking vibration and the ATC/NBC point-deflection model.

The AISC criterion was presented as a lower limit to the fundamental frequency of the floor as a function of mass and damping. All but three of the laboratory test floor systems and two of the field floors evaluated met this acceptability criterion, when measured damping was considered. Typically, measured damping was below the 6% value suggested in the design guide. All of the test floor systems except one field floor met this acceptability criterion when their damping was estimated to be 6%.

The ATC criterion was presented as an upper limit to the mid-span deflection of the floor system under a 225 lb (1 kN) point load as a function of span length. All of the test floor systems in the laboratory, and in the field, met this acceptability criterion when their measured mid-span deflection under the specified load was used.

Acknowledgements

There are many people I would like to thank who helped make this research possible. Firstly, I would like to thank my supervisor Dr. Lei Xu. His guidance, expertise and support made this research possible.

I would also like to extend a special thank you to Russ Parnell. The amount of testing performed for this research was far too much for one person, and his help throughout the experimentation portion of this research was greatly appreciated.

The testing program was partially funded by Dietrich Metal Framing, Worthington Integrated Building Systems, and United States Gypsum. I am very grateful for the assistance from all companies. They provided essential materials for the completion of the testing program. I would also like to thank Dietrich Metal Framing for providing access to their construction sites to perform the field testing.

This research would have been much more difficult without the assistance of the Structures Lab Technicians. Thanks to Doug Hirst, Rob Sluban, and Richard Morrison for their time, effort, and patience during the laboratory testing.

Finally, I would like to extent my deepest thanks to my wife, Marie-Pier. Without her encouragement and support, I would not have been able to complete this research.

Dedication

I dedicate this thesis to my wife Marie-Pier. Her support and tremendous patience made this thesis possible.

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Chapter 1

Introduction

1.1 General

Over the last decade, cold-formed steel has become an increasingly popular building material for residential and commercial construction. This increased use can be attributed to the numerous advantages that cold-formed steel has over traditional residential building materials. Cold-formed steel offers resistance to termites and rot, design flexibility, rapid construction, and a strength-to-weight ratio greater than any other common building material. This high strength-to-weight ratio allows cold-formed steel floor systems to span great distances, but the weight of the floors is a fraction of that of traditional floor systems. The large spans are architecturally pleasing, and the lightweight is an asset during design, but the combination can lead to vibration problems.

There is a perception in the residential construction industry that cold-formed steel floor systems are more susceptible to annoying vibrations produced by normal human activity than traditional wood, structural steel and concrete systems. Designing a floor system to control these annoying vibrations can be difficult, and correcting inadequacies after construction is usually very costly.

When designing residential floor systems, most North American homebuilders use span deflection limits provided by the National Association of Home Builders in the United States. The most stringent span deflection ratio provided is $L/480$, where L is the span length and the deflection is determined when the floor is subjected to uniform live loads. These span deflection limitations were established based on long term practices for residential, timber floor systems. However, the vibration characteristics of timber floors do not match the vibration characteristics of cold-form steel floor systems. The L/480 deflection limit is an over simplified criterion which does not reflect the floor response to vibration, and it is not appropriate for designing floor systems.

1.2 Description of Problem

Vibrations associated with lightweight floor systems, as a serviceability criterion, have not been well addressed in current residential construction practice. Cold-formed steel floor systems are usually lighter and have less inherent damping. If the dynamic behaviour is not addressed at the design stage, they may be susceptible to human induced floor vibrations. If designers are going to use the current span deflection criteria when designing residential floor systems, it is imperative to find the construction and design details that will limit these annoying vibrations in cold-formed steel floor systems.

1.3 Objectives

Presented in this thesis are the results from a recent laboratory and field study, on the vibration characteristics of cold-formed steel floors, performed at the University of Waterloo. Several full-scale floor systems with varying construction and design details were constructed and tested, and several in situ floor systems were tested. Each floor system in the laboratory was tested in a balloon framing and a platform framing condition, and the in situ floor systems were tested in the balloon framing condition.

The objectives of this research are:

- To evaluate the dynamic response of residential floor systems supported by cold-formed steel joists;
- To investigate the influence of span length, joist types, subfloor materials, toppings, ceilings, strongbacks, live loads, and framing conditions on the vibration characteristics of cold-formed steel floor systems;
- To identify the critical construction details that will limit annoying floor vibrations;
- To compare the vibration characteristics of in situ floor systems and laboratory constructed floor systems; and
- To evaluate the vibration performance of laboratory and in situ floor systems based on current acceptability criteria.

1.4 Vibration Terminology

Throughout this thesis, structural dynamics terminology will be used. To better understand the terminology, this section will define the key terms used throughout this thesis.

Floor vibrations are primarily induced by two different sources, human activity and machinery. Each of these sources induces a different type of vibration. Human activity creates *transient* vibrations, and machinery usually creates *steady-state* vibrations. *Transient* vibrations dissipate with time and are caused by an impact force such as walking. *Steady-state* vibrations are constant over time and are usually caused by vibrating or rotating machinery.

After an object, such as a floor system, has been set into motion, there are a number of terms to describe the response from the excitation. Common terms used to describe and quantify the response are *frequency*, *period* and *amplitude*. Depending on a floor systems mass, stiffness and damping it will have a unique response. The *frequency* (f) of the response is measured in Hz, which is the number of full cycles of vibration per second. The *period* (T) is the time it takes to complete one full cycle. The *amplitude* of vibration of a floor system is the maximum response at a specified point on the floor, from a position of static equilibrium. *Amplitude* may describe the displacement, velocity, or acceleration of a floor system, and is often plotted with respect to time.

A floor system may have several natural frequencies at different modes of vibration. A mode of vibration is a pattern assumed by the system where every particle is in simple harmonic motion with the same frequency. More than one mode of vibration will exist in a multiple degree-of-freedom system, with each mode having a different natural frequency. The lowest natural frequency of a floor system is the fundamental frequency of the system. The corresponding mode of vibration is known as the fundamental mode of vibration.

Once an object has impacted a floor system, the floor system begins to absorb the energy and the vibrations are dissipated. The rate at which the vibrations are dissipated is dependent upon the *damping* present in the floor system. *Damping* is usually expressed as a *damping ratio*. The *damping ratio* is the actual *damping* of the floor system divided by the *critical* *damping* of the system. The *critical damping* of the floor system is the damping needed for the system to perform one cycle and stop after the excitation. There are three different types of damping, *viscous damping*, *structural damping* and *coulomb damping*. *Viscous damping* is a result of fluid or air resistance, *structural damping* is a result of internal friction of the floor system and *coulomb damping* is external friction between sliding surfaces.

1.5 Thesis Outline

This thesis is organized as follows:

- Chapter 2 provides a detailed literature review on past research performed in the area of floor vibrations. Chapter 2 includes sections on: human perceptibility of floor vibrations; important research in the area of floor vibrations; and an explanation of the acceptability criteria proposed by the Applied Technology Council (ATC), the National Building Code of Canada (NBC), and the American Institute of Steel Construction (AISC).
- Chapter 3 explains the experimental work performed in the laboratory and in the field. Chapter 3 includes sections on, the laboratory setup, a description of the laboratory and field floor systems, the laboratory and field testing procedures, and the data processing.
- Chapter 4 contains information on the influence of construction details on the vibration characteristics of cold-formed steel floor systems. Chapter 4 includes sections on the effect of span length, the effect of joist type, the effect of subfloor material, the effect of a topping, the effect of a ceiling, the effect of a strongback, the effect of a live load, the effect of the framing condition, and a comparison between the laboratory and field results.
- In chapter 5 the vibration performance of the laboratory and field floor systems is assessed. The AISC, ATC and NBC acceptability criteria are used to evaluate the vibration performance of each floor system.

- Chapter 6 provides the concluding remarks from this research, and a summary of the construction details that are recommended to control vibrations in floor systems supported by cold-formed steel joists.

Chapter 2

Literature Review

The vibration performance of floor systems has been a long standing serviceability issue when designing a residential structure. Some of the earliest issues with floor vibrations were recognized by Tregold in 1828. He stated that when constructing long span floors the girders should be made deep enough such that a person walking across the floor will not shake everything in the room (Tregold, 1828).

Provided in this chapter is a literature review of past research performed in the area of lightweight floor vibration analysis and performance. This review will accomplish the following: comment on human perceptibility to floor vibrations; comment on the validity of using sandbag drop, heel drop and walking tests to determine the vibration characteristics of a floor system; discuss applicable research performed in the area of floor vibrations; and discuss current acceptability criteria prescribed by the Applied Technology Council (ATC), the National Building Code of Canada (NBC), and the American Institute of Steel Construction (AISC).

2.1 Human Perceptibility to Floor Vibrations

Many studies have been performed to quantify the perceptibility limits of humans subjected to floor vibrations. Determining vibration limits can be a difficult task, due to the large number of factors that vibration perceptibility is dependent upon. Human perception of vibration is a combination of physical perception, movement of the floor system, and the psychological perception of vibration. The body position of the receiver, the activity of the receiver, and the reradiated noise (e.g. china rattling in a cabinet) all effect the perception of vibration (ISO, 1989).

A pioneer study in human vibration perception was performed by Reiher and Meister (Reiher & Meister, 1931). In this investigation, steady state vibrations were applied to floor systems for a period of five minutes. The perceptibility of these vibrations was evaluated by individuals on the floor systems. Using the information obtained from this study, a scale of human tolerance was defined based on deflection and imposed frequency. Figure 2.1 shows the perception plot developed by Reiher and Meister.

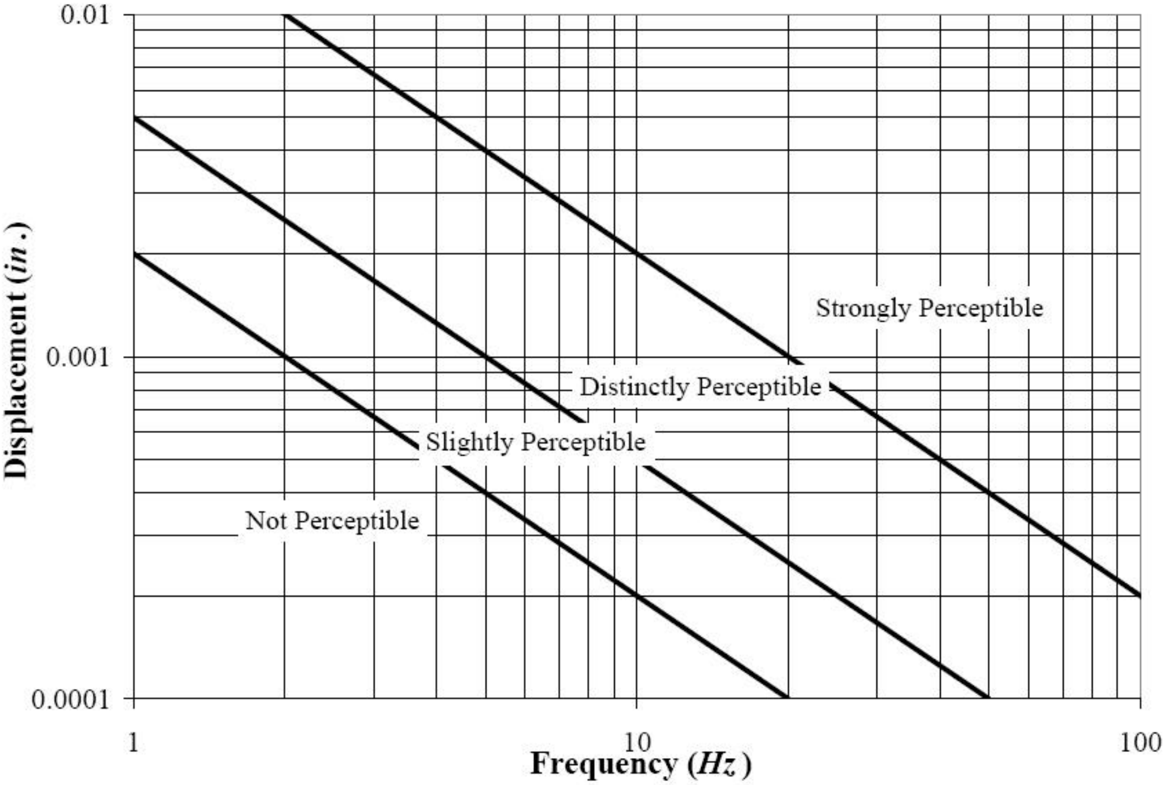


Figure 2.1: Reiher Meister Scale (Reiher & Meister, 1931)

In 1966, Lenzen performed perceptibility experiments on 46 concrete floor systems supported by steel joists (Lenzen, 1966). Lenzen subjected his test subjects to transient vibrations instead of steady state vibrations. From his research Lenzen found that more appropriate results were acquired when the Reiher Meister scale was multiplied by a factor of 10. Lenzen coined this new perceptibility scale the Modified Reiher Meister Scale. Figure 2.2 shows the Modified Reiher Meister Scale.

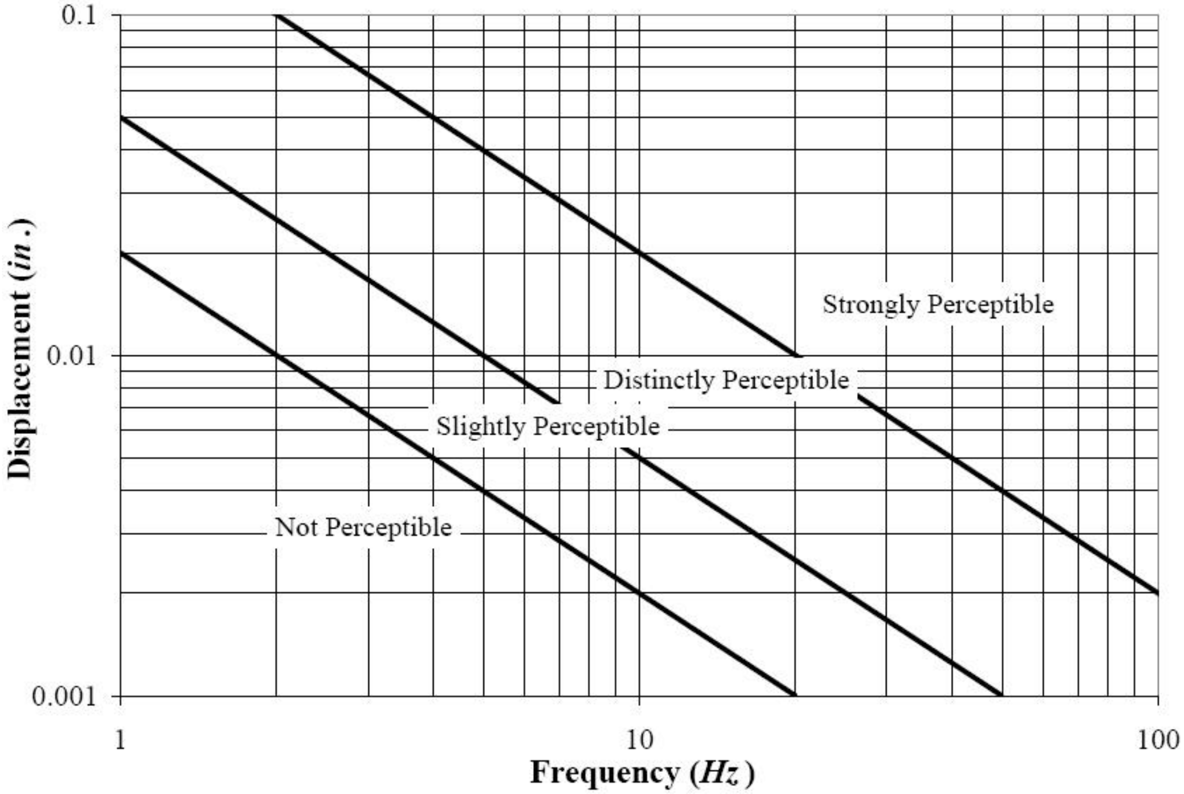


Figure 2.2: Modified Reiher Meister Scale (Lenzen, 1966)

In Figure 2.1and Figure 2.2 the x-axis corresponds to the fundamental frequency of the floor system and the y-axis corresponds to a calculated displacement found using the formula $\Delta = \frac{300l^3}{48EI_t}$, where, Δ is the centre deflection of the floor system (in), *l* is the joist span length, *E* is Young's Modulus, and I_t is the composite moment of inertia of the joist and floor slab.

Lenzen's research also gave rise to the heel drop test. Lenzen used the heel drop test as a worst case scenario for transient vibrations.

The International Standards Organization (ISO) produced an annoyance criteria scale that covers a number of occupancies (ISO, 1989). ISO produced a baseline curve and a series of multipliers that are applied to the baseline curve to represent the sensitivity of different occupancies. Examples of these multipliers are, 10 for offices and residential, 30 for shopping malls, and 100 for footbridges. The baseline curve is an upper limit to root mean square (RMS) acceleration (although typically labeled "Peak Acceleration" in literature), as a function of the fundamental frequency of the floor. The baseline curve reflects the fact that occupants are most sensitive to accelerations, associated with floor frequency, in the 4 – 8 Hz range, due to their physiology (Ohlsson S. V., 1982), and that walking excitations can contain forcing harmonics of 4, 6 and 8 Hz (ATC, 1999). For fundamental frequencies above 8 Hz, the acceleration limit is relaxed because of the reduction of occupant sensitivity. Figure 2.3 is a reproduction of the ISO vibration perceptibility curve with the ISO baseline, office/residential, operating room, and shopping mall limits shown

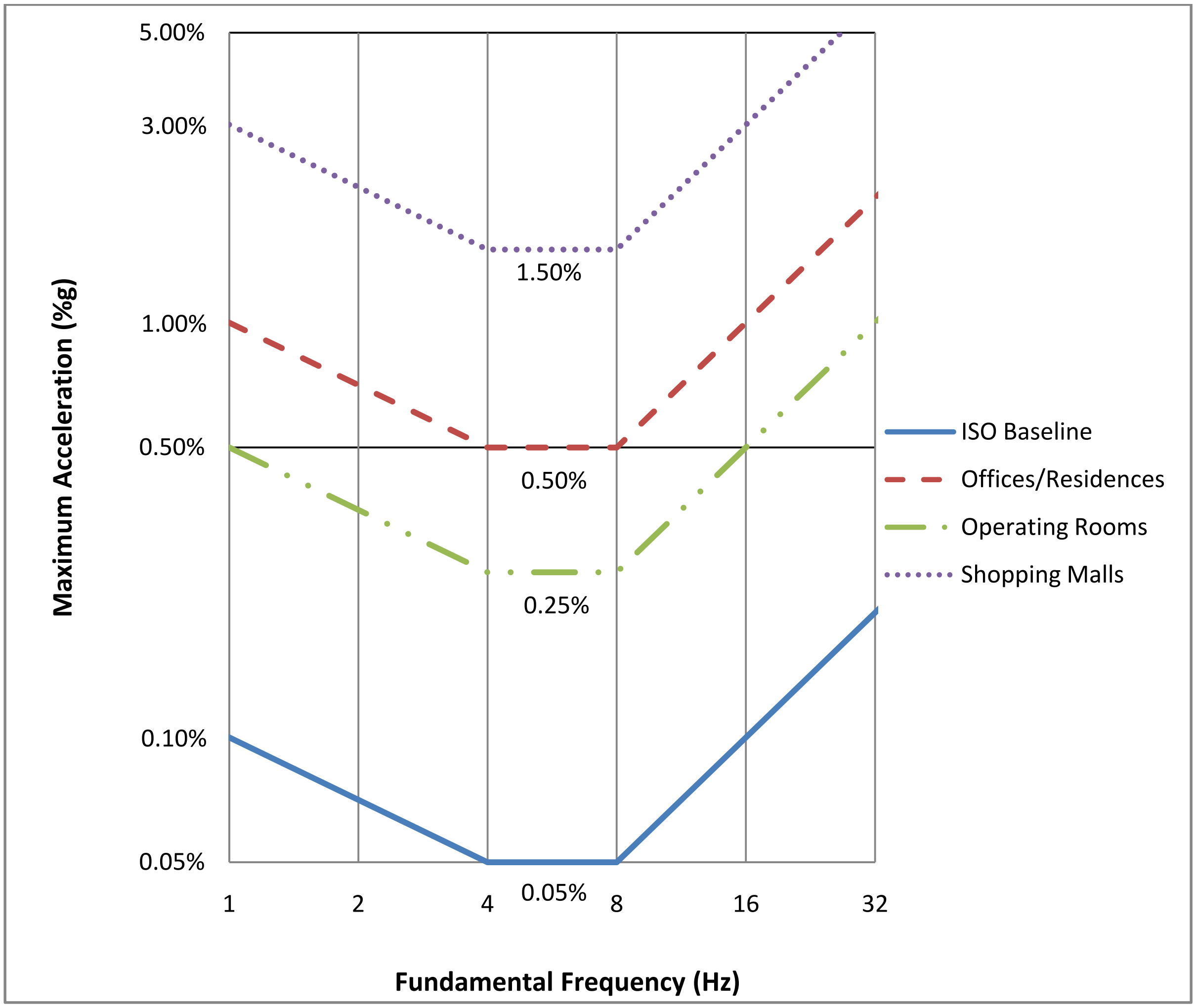


Figure 2.3: ISO Vibration Limitation Scale (ISO, 1989)

This extra sensitivity at vibrations in the range of 4 – 8 Hz is important to note. Floor systems with a fundamental frequency within this range should be avoided, or measures should be taken to raise the fundamental frequency away from this range.

2.2 Past Research in Floor Vibration

In 1970, Onysko performed a detailed literature review on the performance of wood-joist floor systems. The study was performed to identify the strength and stiffness requirements of a floor system needed to avoid annoying floor vibrations (Onysko D. M., 1970). Onysko continued his research in 1985 with an extensive field survey to evaluate the vibration performance of residential floor systems. This study involved the assessment of 646 wood floor systems. The assessment was made based on subjective evaluations made by the home owner, not from testing data. Results from this study show that the dynamic response due to an impact load (ex. heel drop or sandbag drop), and deflection due to a concentrated static load, were the two parameters that correlated best with perceived vibration acceptability (Onysko D. M., 1985). In 1995, Onysko further refined his acceptability criteria for wood-joist floor systems. This research provided a deflection limit based on a static load of 225lb (1 kN) applied to the centre of the floor system. This research also found that wood floor systems with a span length less than 9.84' (3 m) need to have a centre deflection less than 0.0787" (2 mm) in order to acceptable vibration performance (Onysko D. M., 1995).

Research was conducted by Ohlsson, in Sweden, in 1988. This research focused on determining the vibration performance of lightweight timber floor systems. Ohsson's research developed three parameters to ensure acceptable vibration performance of floor systems, independent of the construction materials. The three parameters were based on fundamental frequency, static flexibility and initial velocity due to an impulse excitation (heel drop). The first limitation was the fundamental frequency of the floor system needed to be greater than 8Hz, to avoid the increased sensitivity the human body has to vibration in the 4 – 8 Hz range. The second limitation was the floor system needed to have a centre deflection less than 0.059" (1.5 mm) when subjected to a 225 lb (1kN) load. The third limitation was imposed on the velocity of the floor system when subjected to an impulse excitation (Ohlsson S. V., 1988 a) (Ohlsson S. V., 1988 b). The velocity limitations are shown in Figure 2.4.

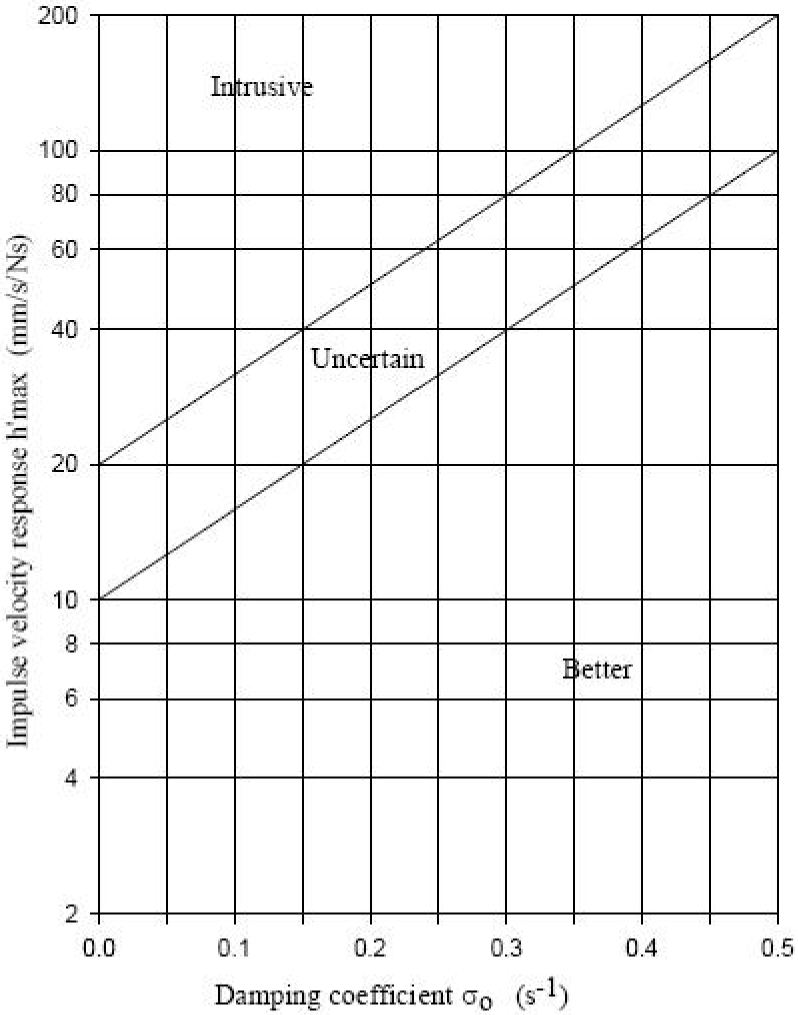


Figure 2.4: Ohlsson's Classification of Floor Response to an Impulse Load (Ohlsson S. V., 1988 a)

Ohlsson also suggested that limitations be set on the RMS acceleration due to walking excitations. Unfortunately, no specific limitations were provided in his research. It was suggested that the RMS acceleration response be compared to a similar floor system with acceptable vibration performance.

Murray performed a significant amount of research in area of floor vibrations and vibration performance of floor systems. Murray's research started in 1979 with the development of design and acceptability criteria. In this research, Murray investigated the vibration performance of 91 hot-rolled steel joist, concrete slab, floor systems when subject to a heel drop excitation. Murray compared the subjective reaction of these floor system to four previous design guidelines used in practice. From this research, Murray developed a design guideline based on damping, fundamental frequency, and peak displacement due to a heel drop impact (Murray T. , 1979). In 1997, Kraus and Murray conducted a series of laboratory tests on floor systems supported by cold formed steel joists. Full scale floor systems, as well as two joist models, were tested in this study. The study compared the results from these experiments to the Australian Standard, the Swedish Design Guide developed by Ohlsson, the U.S. Timber Floor Vibration Criteria developed by Johnson, and the Canadian Timber Floor Criterion developed by Onysko. The results from this study stated that the Canadian Timber Floor Criterion should be used to predict the vibration performance of cold-formed steel floor systems. This design guide was chosen due to its satisfactory agreement with testing results and the simplicity of use (Kraus & Murray, 1997). In 1997, the AISC and the CISC published a floor design guideline based on work performed by Murray, Allen and Unger in 1997. The guide provided basic principles and analytical tools to evaluate and design steel framed floor systems and footbridges. The guide evaluated the vibration performance of floor systems, by ensuring the ratio of maximum acceleration due to walking excitation, to acceleration due to gravity, did not exceed a certain limit for a given occupancy. Both human comfort and the control of movement for sensitive equipment were considered when selecting the vibration limits (Murray, Allen, & Unger, 1997).

In 1994, Johnson developed a design criterion for timber floors based on results from testing on 86 in situ floor systems. Johnson started his research with the intention of applying the acceptability criteria developed by Murray. Instead, Johnson developed his own acceptability criteria. Johnson proposed that the vibration performance of a floor system, supporting its own weight, would be acceptable if the fundamental frequency was found to be greater than 15 Hz. The 15 Hz criterion was intended to be used during the design stage (Johnson, 1994).

Chui proposed a floor vibration acceptability criterion in 1988. His research was based on laboratory built wood-joist floor systems as well as in situ wood floor systems (Chui, 1988). Smith and Chui continued this research and used the same criteria as Chui's original research. The criteria developed focused on a two prong approach. The first requirement was that the fundamental frequency of the floor system was greater than 8 Hz, to avoid the discomfort experience by humans in the range of 4 – 8 Hz. The second requirement was that the weighted RMS acceleration should be less than 0.45 m/s^2, when subjected to a heel drop. If both these criteria were met, the floor system was believed to have adequate vibration performance (Smith & Chui, 1988).

Extensive research in the area of vibration performance of floor systems supported by cold-formed steel joists has been performed at the University of Waterloo. Starting in 2000, research was performed by Xu and Rizwan. This study compared the results from the ATC design method, the Canadian Wood Council (CWC) design method, the Ohlsson design method, and the Smith and Chui design method, against results found from testing floor systems at Virginia Polytechnic Institute and the University of Waterloo (Rizwan & Xu, 2000). Research in the area of cold-formed steel floor system vibration was continued by Xu in 2000. This research was performed to find the construction details that influence the vibration performance of cold-formed steel floor systems. This study discussed the influence of span length, number of supported edges, joist end restraint, blocking type, screw pattern for subfloor, existence of a ceiling, gluing of subfloor and different excitation techniques (Xu L. , 2000). Similar research was also performed by Xu, Ling, Xie, Liu and Schuster in 2000. This study investigated the effects of ceiling materials, support conditions and bridging and blocking patterns on the vibration characteristics of cold-formed steel floors. This research found that supporting the floor system on all edges and decreasing the span length improved the vibration performance (Xu, Ling, Xie, Liu, & Schuster, 2002). In 2001, Liu developed a finite element model to determine the vibration characteristics of cold-formed steel floor system at the design stage. Liu also compared results from laboratory testing previously completed at the University of Waterloo to the developed finite element model (Liu W. , 2001). In 2002, Tangorra, Xu and Xie performed static and dynamic tests on cold-formed steel floor systems. The purpose of the research was to find the deflections, damping ratios, and frequencies of the floor systems, and compare the test results to five different design procedures. This study found that the ATC (1999) method predicted the frequencies and deflections better than the other four methods (Tangorra, Xu, & Xie, 2002). The most recent research in the area of floor vibrations at the University of Waterloo was performed by Tangorra in 2005. Tangorra performed dynamic and static tests on laboratory floor systems with varying construction details, as well as field experiments. The results from laboratory testing were used to determine the influence of certain construction details on the vibration performance of the floor system. The results from the laboratory experiments were also compared against current design methods, and a new design approach was proposed based on test results (Tangorra F. , 2005).

2.3 Acceptability Criteria

Several organizations have published design guides to assist structural designers in predicting whether the vibration performance of a floor system will satisfy criteria for occupant comfort. They are intended to be used in the pre-construction phase, or for retrofit of unacceptable floors. The three design guides examined in this study were chosen because they are commonly used in North America, the models and acceptability criteria are reasonable and based on accepted research, and their criteria can be applied easily to the dynamic properties of the floors measured in this study.

2.3.1 Resonance Model (AISC)

The resonance model is used to evaluate concrete or composite steel-concrete floors for walking and rhythmic activities. References for this model include Vibration Criteria of Assembly Occupancies (Allen, Rainer, & Pernica, 1985).

The resonance model is based on floor response from rhythmic activities. The loading function is described as a combination of sinusoidal forces (harmonics) with separate frequencies and dynamic amplification factors for each harmonic. Each activity has associated harmonic frequencies, amplification factors and a total participant weight based on occupant spacing. Rhythmic activities included in the design guides are dancing, aerobics, and concerts.

The model assumes that the floor system is an oscillating beam with one mode of vibration and one natural frequency. This is intended to be a worst-case result. The response of the floor is determined from this simple model and an assumed damping ratio (based on floor construction) under each applied harmonic, and the total acceleration predicted combination of all the responses.

The design guides provide two methods for determining floor acceptability using the resonance model. The simplest method is to solve for the minimum fundamental frequency a floor can have based on its weight and an acceleration limit, which is based on intended occupancy. This is done for each harmonic and the worst case is taken. This result is checked for acceptability against the predicted fundamental frequency of the floor. If that criterion is not met, the second method is applied. The floor response model is used to predict the total acceleration of the floor system, which is checked against the acceleration limit. If either method has an acceptable result, the floor is deemed acceptable.

The ATC, NBC and AISC design guides use a similar resonance model, based on many common references. The AISC guide is the only one which contains a loading function for walking excitation. As walking is the typical dynamic load for residential floors; the AISC resonance model was selected as one of the methods for evaluating the performance of floor systems in this study.

2.3.2 Point Deflection Model (ATC, NBC)

The point-deflection model is used to evaluate light-frame floors and walking loads. References for this model include Serviceability Design of Residential Wood-Framed Floors in Canada (Onysko, Hu, Jones, & Di Lenardo, 2000).

The point-deflection model is based on the assumption that a light-frame floor usually has a natural frequency greater than 10 Hz because of its short span and light weight. In addition, the occupants quickly damp out significant natural vibrations (ATC, 1999). Because of this, annoying floor response is generated by instantaneous deflections of the floor where footfalls from walking occur, and resonance is not a major concern for designers.

The method of determining floor acceptability is limiting static deflection, as a function of span length. The ATC design guide uses a modified version of Onysko's serviceability criteria, with a point load of 225 lbs (1 kN) at mid-span to determine the static deflection. The NBC design guide does not directly use the point-deflection model; however, the joist span tables found in Part 9 of Division B (NBC, 2005) incorporate a point-deflection model. The point-deflection model is not applicable to the AISC design guide, which is intended for heavier floors supported by structural steel beams or open web steel joists. The ATC point-deflection model was selected as one of the methods for evaluating the performance of floor systems in this study.

2.3.3 Impulse Vibration Model

The impulse-vibration model is used to evaluate all types of floors with heel-drop impacts. References for this model include Springiness and Human-Induced Floor Vibrations – A Design Guide (Ohlsson S. V., 1988).

The impulse-vibration model calculates the peak acceleration or displacement of a floor due to an impulse assuming the structure vibrates only in its fundamental mode, and compares it to a limiting value which is a function of damping (ATC, 1999). This method is typically achieved through experimental testing with a heel-drop impact.

The ATC method excludes the impulse-vibration model in order to have a simplified acceptability criterion, and suggests that the key characteristics are accounted for in both the resonance and point-deflection models (ATC, 1999). This reasoning was extended to this study, and an impulse-vibration model was not used to evaluate the floor systems.

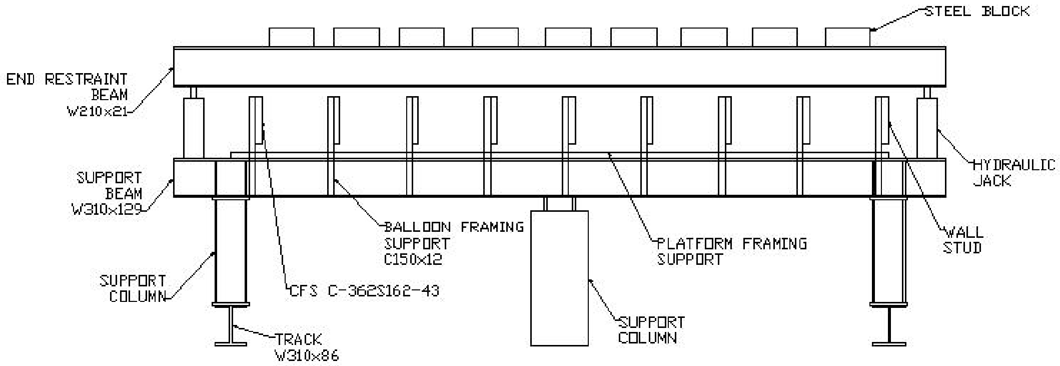
Chapter 3

Experimental Work and Procedures

Over an 11 month period, 14 full size floor systems, and 26 construction configurations were tested in the structural engineering laboratory at the University of Waterloo. In addition field tests were performed at three different locations. This section will describe the experimental apparatus used, the materials and construction of the floor systems, and the testing matrix used during the experimental period. This chapter will also include a description of the field floors tested, an explanation of the testing procedures, and discussion on the data processing techniques.

3.1 Experimental Apparatus

All laboratory floor systems were tested on a single experimental apparatus. The experimental apparatus consisted of a large steel frame constructed of 12” (305 mm) I-beams. The test frame elevated the floor system and allowed access to the underside of the floor. Figure 3.1 shows the experimental apparatus.



FRONT VIEW

SIDE VIEW

Figure 3.1: Experimental Apparatus

The experimental apparatus was designed to support the floor system on two sides and leave the other two sides free. The support-support, free-free support condition was chosen to ensure the laboratory results would represent a conservative scenario, when compared to in situ floor systems. Previous experiments performed at the University of Waterloo have shown that supporting four sides, instead of two sides, slightly increased the floor stiffness (Xu L. , 2000).

The hot rolled C-sections used for the balloon framing support were attached to the support beam using clip angles, and two 3/4” (19 mm) diameter bolts. The cold-formed steel stud sections were attached to the C sections using six #10, self drilling, and self tapping light gauge metal screws. There were nine steel blocks that were used to replicate a partial end restraint during platform framing experiments. The blocks were approximately, 14” (356 mm) long, by 8” (203 mm) wide, by 4” (101 mm) thick.

The experimental apparatus was designed to allow each floor system to be tested in three different end framing conditions. Each floor system was tested in a balloon framing condition, a platform framing condition without end restraint (no end beam – B0) and a platform framing condition with end restraint (with end beam – B1). Figure 3.2 shows an example of each framing condition.

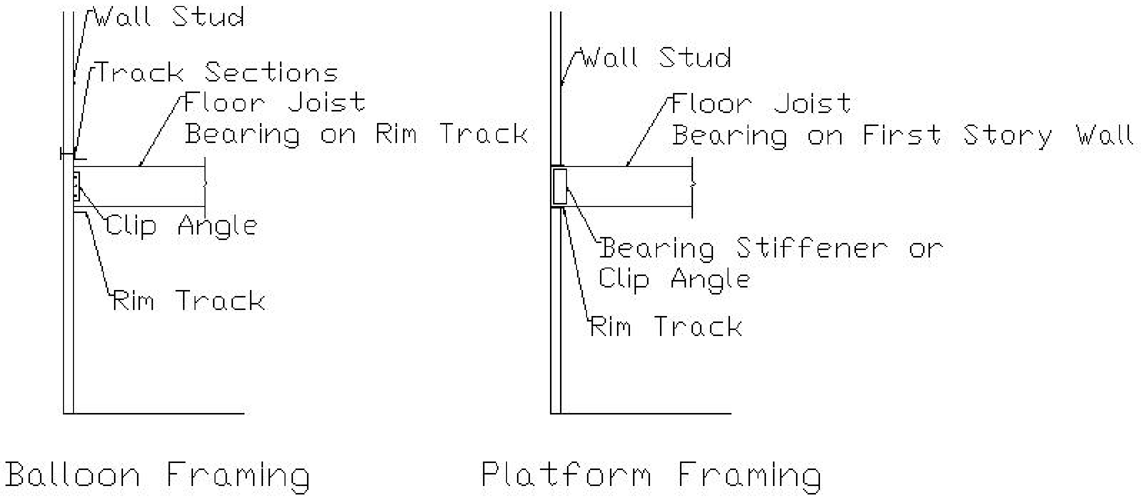


Figure 3.2: Framing Conditions

The balloon framing condition was tested because it is becoming increasingly popular in residential construction. The ease of assembly has contributed to the increased popularity. The platform framing was tested because this is the most widely used framing condition in multistory residential construction. When testing the platform framing condition with end restraint the end restraint was provided by a large I-beam with steel blocks welded to the top flange. The end restraint was designed to simulate the restraint provided from an above story wall. The line load provided by the restraint beam was 130.2 lb/ft (1.9 kN/m) (Liu W. , 2001).

When balloon framing is used a rim track is fastened to the interior face of the wall studs, and the floor joists are framed into the rim track. The stud spacing and joist spacing usually match when balloon framing is used, so each stud has a floor joist framed in at that point. The floor joists are framed into the rim track using a clip angle, attached to the web of the floor joists. This clip angle provides moment resistance at the joist end, creating a semi-rigid connection. There are no squash loads on the floor joists when balloon framing is used, and therefore, no web stiffeners are needed on the joist ends.

Platform framing requires segmented wall studs. The joists are framed into a rim track in the same fashion as the balloon framing, but the rim track is framed on top of the wall below the floor. The wall above the floor is framed on top of the floor joists, imparting squash loads on the floor joists. Therefore, when platform framing is used web stiffeners are needed to avoid web crippling of the floor joists. The platform framing does provide partial end restraint of the floor joists, but this research has found that the balloon framing provides more end restraint.

3.2 Materials and Construction of Laboratory Floor Systems

All floor systems tested in the laboratory were constructed with the same basic skeleton. Each floor consisted of nine, 12” (305 mm), cold-formed steel joists, spaced at 24” (610 mm) on centre. Throughout the testing the joists depth remained the same, but the joist type (Trade Ready Joist® (TDW) or C-Shape) was altered. The floor joists were connected to a rim track on both ends. The connection was made with three #12, self drilling, and self tapping light gauge metal screws. The rim track remained the same for each experiment. The rim track used was a TD24. The specification of the rim track are: 12” (305 mm) depth, 14 gauge (1.9 mm) material thickness, 1.25” (31.8 mm) top flange width, and a 2.5” (63.5 mm) bottom flange width. All floors were constructed with blocking and strapping occurring every 8’ (2.44 m) on centre along the length of the floor joists. The blocking used were 24” (610 mm) long cut sections of 12” (305 mm), 16 gauge (1.52 mm), cold-formed steel, C-shape sections. The blocking was attached to the web of the floor joists with clip angles and five, #12, light gauge metal screws per leg. The blocking was fastened between the first and second joist, the fourth and fifth joist and the eighth and ninth joist on every floor system. The strapping used was cold rolled channel, 2” (50.8 mm) wide, 14 gauge (1.9 mm) thickness, with a 1/4” (6.4 mm) leg length.

Every lab floor was constructed with a subfloor and some floors were constructed with gypsum based, self-leveling, lightweight concrete topping (LevelRock) and a ceiling on the underside of the floor. The different types of subfloor examined were 3/4” (19 mm) OSB, 3/4” (19 mm) Fortacrete® and 35” x 12’2” x 9/16” (889 mm x 3.71 m x 14.3 mm) 22 gauge (0.76 mm) metal form deck. Fortacrete is gypsum-based, cementitious board commonly used as a subfloor material where a fire-rated assembly is required. The OSB and Fortacrete were fastened to the floor joists using #8 self drilling, self tapping light gauge metal screws. The screw pattern used for the OSB and Fortacrete was 6” (152.4 mm) spacing on the perimeter of the sheet and 12” (305 mm) spacing internally.

The lightweight concrete topping was gypsum-based, self-leveling floor topping. The product used was LevelRock® 3500 pre-sanded floor underlayment. When the concrete topping was used on the Fortacrete, the thickness was 3/4” (19 mm); when the topping was used on the metal form deck, the thickness was 1.5” (38.1mm) from the bottom flute.

When a ceiling was installed, it was fastened to resilient channel running perpendicular to the floor joists. The resilient channel was spaced 12” (305mm) on centre, and was fastened to the floor joists using one, #12 self drilling, self tapping, light gauge metal screw per joist. The ceiling was fastened to the resilient channel with #6 light gauge metal drywall screws. The screw spacing was 12” (305 mm) on the perimeter and internally. Two different ceiling materials were used throughout the testing. The first was 5/8” (15.9 mm), Type X gypsum board and the second was 5/8” (15.9 mm), Type C gypsum board. The Type X gypsum board was only used on three floor systems. All other floor systems with a ceiling had type C gypsum board installed. Figure 3.3 shows an over head view and a cross section of a typical lab floor.

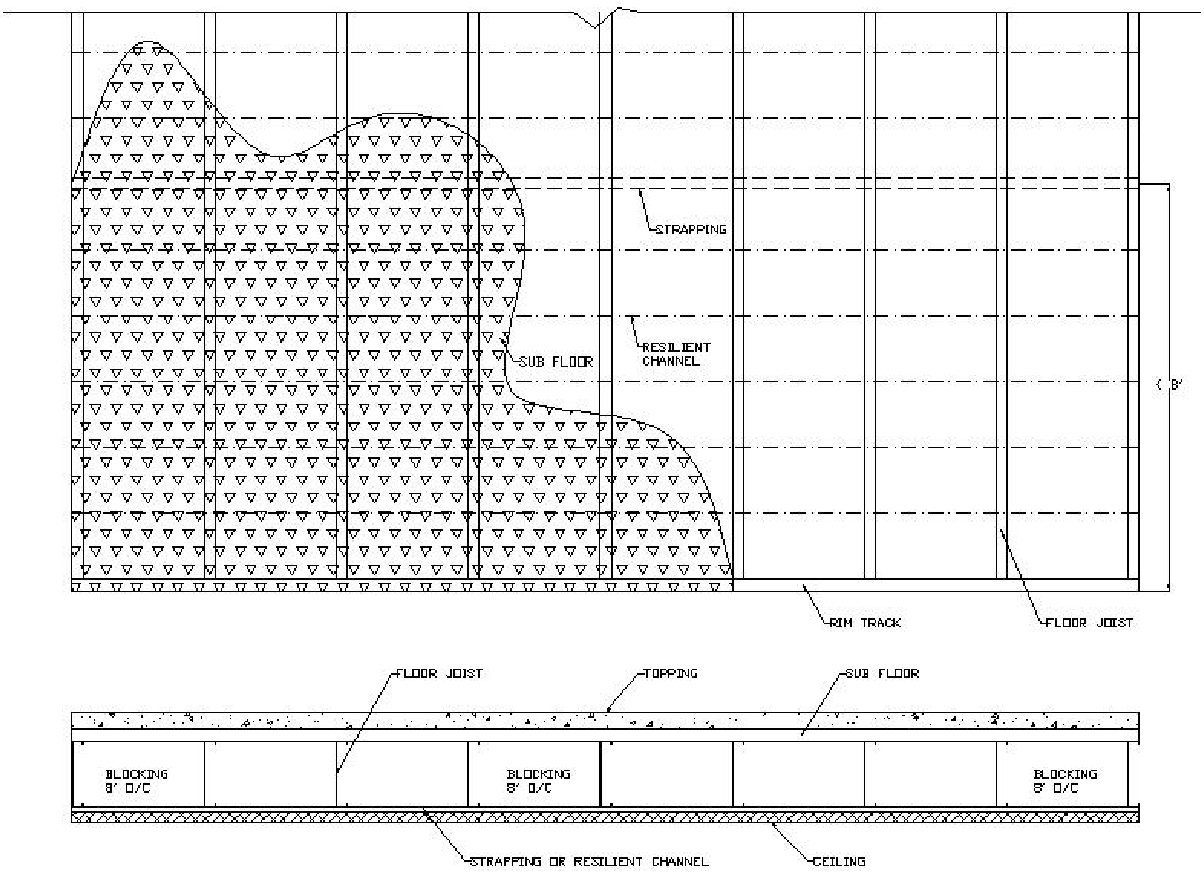


Figure 3.3: Overhead and Cross Section View of a Typical Floor System

An important point to note is that the blocking pattern is not perfectly symmetric. The centre section of blocking was installed between joist 4 and 5 on each floor system for consistency. Also, traditional web stiffeners were not installed at the ends of the joists during the platform framing tests. The rim tracks used in testing were a proprietary model with cutouts that act as web stiffeners. The loads applied to the floor system during testing were not substantial enough to cause local buckling, or crippling of the joist web. Detailed drawings of each floor system can be found in Appendix A of this report. The drawings show all the construction configurations and construction materials used during this study.

Many different construction configurations were examined. Table 3.1 shows each laboratory floor system tested and gives a description of the construction configuration.

Table 3.1: Laboratory Floor Construction Configurations

Floor Name	Joist	Joist Depth (in)	Joist Gauge (ga.)	Floor Span (ft)	Blocking Rows	Subfloor	Topping	Ceiling	Strongback
LF14.5A	Standard C	12	16	14.5	1	3/4" OSB	-	-	-
LF14.5A$_{i}$	Standard C	12	16	14.5	1	3/4" OSB	-	-	-
LF14.5B	Standard C	12	16	14.5	1	3/4" Fortacrete	-	-	-
LF14.5B$_{i}$	Standard C	12	16	14.5	1	3/4" Fortacrete	-	-	-
LF14.5C	TDW	12	16	14.5	1	3/4" OSB	-	-	-
LF14.5D	TDW	12	16	14.5	1	3/4" Fortacrete	-	Type X	-
LF14.5D$_{i}$	TDW	12	16	14.5	1	3/4" Fortacrete	-	-	-
LF14.5E	TDW	12	16	14.5	1	3/4" Fortacrete	3/4" LevelRock	Type X	-
LF14.5F	TDW	12	16	14.5	1	9/16" metal deck	1.5" LevelRock	Type X	-
LF17.0A	TDW	12	14	17	2	3/4" Fortacrete	3/4" LevelRock	Type C	-
LF17.0B	TDW	12	14	17	2	3/4" Fortacrete	3/4" LevelRock	Type C	Free
LF17.0C	TDW	12	14	17	2	9/16" metal deck	1.5" LevelRock	Type C	-
LF17.0D	TDW	12	14	17	2	9/16" metal deck	1.5" LevelRock	Type C	Free
LF19.5A	TDW	12	14	19.5	2	3/4" Fortacrete	3/4" LevelRock	Type C	-
LF19.5A$_{i}$	TDW	12	14	19.5	2	3/4" Fortacrete	3/4" LevelRock	-	-
LF19.5A$_{ii}$	TDW	12	14	19.5	2	3/4" Fortacrete	3/4" LevelRock	-	Supported
LF19.5A$_{iii}$	TDW	12	14	19.5	2	3/4" Fortacrete	3/4" LevelRock	Type C	Supported
LF19.5A$_{iv}$	TDW	12	14	19.5	2	3/4" Fortacrete	3/4" LevelRock	Type C	-
LF19.5B	TDW	12	14	19.5	2	9/16" metal deck	1.5" LevelRock	Type C	-
LF19.5B$_{i}$	TDW	12	14	19.5	2	9/16" metal deck	1.5" LevelRock	-	-
LF19.5B$_{ii}$	TDW	12	14	19.5	2	9/16" metal deck	1.5" LevelRock	-	Supported
LF19.5B$_{iii}$	TDW	12	14	19.5	2	9/16" metal deck	1.5" LevelRock	Type C	Supported
LF19.5B$_{iv}$	TDW	12	14	19.5	2	9/16" metal deck	1.5" LevelRock	Type C	-
LF21.8A	(2)TDW	12	16	21.83	2	9/16" metal deck	1.5" LevelRock	Type C	-

A unique naming convention for the floor systems was developed because of the large number of tests performed. All floor systems tested in the lab were labeled with “LF” (Lab Floor) at the beginning of the title. If “LF” does not precede the floor title then that floor was tested in the field. After LF, the span length of the floor is listed. All floor systems with the same span length were grouped into the same test panel. After the span length a letter (A-Z) was given to define the construction characteristics of the floor system. Finally, a subscript was given to some test iterations to denote that only a partial testing sequence was conducted on that floor system. For example a floor system with the name “LF14.5A” was a floor system tested in the laboratory, with a span length of 14’ 6”, and has construction details corresponding to the letter A.

3.3 Laboratory Testing Matrix

Presented in the following section is the laboratory testing matrix. This section includes information on the floor construction modifications tested and the comparisons between laboratory floors. The comparisons were made to find the construction details that influence the vibration characteristics of the floor system. The following list explains each floor detail that was examined:

- Span Length: 14.5’ (4.42 m), 17.0’ (5.18 m), 19.5’ (5.94 m) and 21.8’ (6.64 m) floor spans were tested.
- Framing Condition: Balloon framing, platform framing without end restraint, and platform framing with end restraint conditions were tested.
- Joist Type: Standard C-shape and Trade Ready Joists were tested.
- Sub Floor Material: 3/4” (19 mm) OSB, 3/4” (19 mm) Fortacrete and 35” x 12’2” x 9/16” (889 mm x 3.71 m x 14.3 mm) 22 gauge (0.76 mm) metal form deck were tested.
- Topping: LevelRock lightweight, gypsum-based, concrete topping and no topping conditions were tested.
- Ceiling: Type X gypsum board, Type C gypsum board and no ceiling conditions were tested.
- Strongback: Strongback free on ends, strongback connected to rigid support on ends and no strongback conditions were tested.
- Live Load: Live load of 6 psf (0.287 kPa) and no live load cases were tested.

The above floor modifications were used to develop a comparison matrix for the floor systems tested in the laboratory. Table 3.2 shows all the comparisons between laboratory floor systems that will be discussed in detail in Chapter 4 of this thesis.

Table 3.2: Comparison Summary for Laboratory Floor Systems

Comparisons for Effect of Span Length					
LF17.0A	vs.	LF19.5A	17' Span	vs.	19.5' Span
LF17.0C	vs.	LF19.5B	17' Span	vs.	19.5' Span
LF14.5E	vs.	LF17.0A	14.5' Span	vs.	17' Span
Comparisons for Effect Joist Type					
LF14.5A	vs.	LF14.5C	C-Shape Joists	vs.	TDW Joists
LF14.5B	vs.	LF14.5D$_i$	C-Shape Joists	vs.	TDW Joists
Comparisons for Effect of Subfloor Material					
LF14.5A	vs.	LF14.5B	OSB	vs.	Fortacrete
LF14.5C	vs.	LF14.5D$_i$	OSB	vs.	Fortacrete
LF14.5E	vs.	LF14.5F	Fortacrete	vs.	Metal Form Deck
LF17.0A	vs.	LF17.0C	Fortacrete	vs.	Metal Form Deck
LF17.0B	vs.	LF17.0D	Fortacrete	vs.	Metal Form Deck
LF19.5A	vs.	LF19.5B	Fortacrete	vs.	Metal Form Deck
Comparisons for Effect of LevelRock Topping					
LF14.5D	vs.	LF14.5E	No LevelRock	vs.	LevelRock
Comparisons for Effect of Ceiling					
LF14.5D	vs.	LF14.5D$_i$	Ceiling	vs.	No Ceiling
LF19.5A	vs.	LF19.5A$_i$**	Ceiling	vs.	No Ceiling
LF19.5B	vs.	LF19.5B$_i$**	Ceiling	vs.	No Ceiling
Comparisons for Effect of Strongback					
LF17.0A	vs.	LF17.0B	No Strongback	vs.	Strongback with free ends
LF17.0C	vs.	LF17.0D	No Strongback	vs.	Strongback with free ends
LF19.5A	vs.	LF19.5A$_{iii}$**	No Strongback	vs.	Strongback with ends supported by rigid column
LF19.5A$_i$**	vs.	LF19.5A$_{ii}$**	No Strongback	vs.	Strongback with ends supported by rigid column
LF19.5B	vs.	LF19.5B$_{iii}$**	No Strongback	vs.	Strongback with ends supported by rigid column
LF19.5B$_i$**	vs.	LF19.5B$_{ii}$**	No Strongback	vs.	Strongback with ends supported by rigid column
Comparisons for Effect of 6psf Live Load					
LF14.5B	vs.	LF14.5B$_i$	No Live Load	vs.	6psf Live Load
LF19.5A	vs.	LF19.5A$_{iv}$**	No Live Load	vs.	6psf Live Load
LF19.5B	vs.	LF19.5B$_{iv}$**	No Live Load	vs.	6psf Live Load
Comparisons for Effect of Framing Condition					
Almost all lab floors were tested in all three framing conditions					

The above table shows the comparisons performed to observe the effect of the various construction details on the floor systems vibration characteristics. The information gathered from the dynamic and static tests were used to make the comparisons. Only a partial testing sequence was performed on the laboratory floor systems listed in the table above with "**" following their name.

3.4 Description of Field Floor Systems

Field tests were performed to measure the vibration performance of in situ residential floor systems. Three different locations were chosen for field testing. The first was located in Columbus, Ohio, at the Carlyle's Watch Development. The second was located in North Myrtle Beach, South Carolina, at the Ocean Keys Development, and the third was located in Milwaukee, Wisconsin, at the City Green Development. The floor systems tested at all three locations were located in multistory residential buildings with construction details similar to the floors constructed and tested in the laboratory. The following section of this thesis will describe the floor systems tested in the field. A detailed field test sheet was prepared for each field floor system. The field test sheets describe the construction details of each floor and the location of the testing equipment. The field test sheets can be found in Appendix B.

3.4.1 Carlyle's Watch Development

The Carlyle's Watch Development was the first of three field sites visited. The Carlyle's Watch Development was an eight story, residential building. The floor systems were framed with cold-formed steel joists, and the walls were framed with cold-formed steel studs. Three different floor systems were tested at the Carlyle's Watch Development. The three floor systems were labeled CW708, CW709 and CW805. Floor CW708 was located on the seventh story in the eighth unit. Floor CW709 was located on the seventh story in the ninth unit, and CW805 was located on the eighth story in the fifth unit. Construction details at Carlyle's Watch limited the types of tests that could be performed on the floor systems. The dynamic tests (sandbag drop, heel drop and walking test) were performed on each floor system, but the existence of drop ceilings prohibited deflection tests on the floor systems.

Floor CW708 had a span length of 14.5' (4.42 m), and a floor width of 28.5' (8.69 m). The floor joists were 12" (305 mm) deep, 14 gauge (1.9 mm) TDW's, spaced at 24" (610 mm) on centre. The subfloor was 9/16" x 30" x 22ga. (14.3 mm x 762 mm x .76 mm) metal form deck with a 1.5" (38 mm) thick lightweight concrete topping. One row of blocking and strapping was installed at the mid span of the floor system. The blocking units were installed every fifth joist along the width of the floor. The blocking used were 24" (610 mm) long cut sections of 12” (305 mm), 14 gauge (1.9 mm), cold-formed steel, C-shape sections, and the strapping used was cold rolled channel, 2” (50.8 mm) wide, 14 gauge (1.9 mm) thickness, with a 1/4” (6.4 mm) leg length. Figure 3.4 shows floor CW708 in the condition that it was tested.

Figure 3.4: CW708

No partition walls were present when testing CW708. The floor was bare to the LevelRock topping. Three of the walls were framed with cold-form steel and had gypsum board installed and the back wall was glass.

With these construction details, this floor system was compared to LF 14.5F. The only differences in construction details between the floors were joist gauge, ceiling attachment and floor width. The laboratory floor system was constructed with 16 gauge (1.52 mm) joists, the ceiling was attached to resilient channel that was directly attached to the bottom of the floor joists and the floor width was 16’ (4.88 m).

Floor CW709 had a span length of 21.8’ (6.64 m), and a floor width of 26.3’ (8.02 m). The floor joists were two back to back 12” (305 mm) deep, 16 gauge (1.52 mm) TDW’s, spaced at 24” (610 mm) on centre. The subfloor was 9/16” x 30” x 22ga. (14.3 mm x 762 mm x .76 mm) metal form deck with a 1.5” (38 mm) thick lightweight concrete topping. Two rows of blocking and strapping were installed spaced 8’ (2.44 m) on centre. The blocking units were installed every fifth joist along the width of the floor. The blocking used were 24” (610 mm) long cut sections of 12” (305 mm), 16 gauge (1.52 mm), cold-formed steel, C-shape sections, and the strapping used was cold rolled channel, 2” (50.8 mm) wide, 14 gauge (1.9 mm) thickness, with a 1/4” (6.4 mm) leg length. Figure 3.5 shows floor CW709 in the condition that it was tested.

Figure 3.5: CW709

No partition walls were present when testing CW709. The floor was bare to the LevelRock topping. Two of the walls were framed with cold-form steel and had gypsum board installed and the other two walls were all glass.

With these construction details, this floor system was compared to LF 21.8A. The only difference in construction details between the floors are the floor width and ceiling attachment. The laboratory floor system had a floor width of 16’ (4.88 m), with the ceiling attached to the floor joists.

Floor CW805 had a span length of 19.3’ (5.89 m), and a floor width of 26.7’ (8.13 m). The floor joists were 12” (305 mm) deep, 14 gauge (1.9 mm) TDW’s, spaced at 24” (610 mm) on centre. The subfloor was 9/16” x 30” x 22ga. (14.3 mm x 762 mm x .76 mm) metal form deck with a 1.5” (38 mm) thick lightweight concrete topping. Two rows of blocking and strapping were installed at 8’ (2.44 m) on centre along the span of the floor system. The blocking units were installed every fifth joist along the width of the floor. The blocking used were 24” (610 mm) long cut sections of 12” (305 mm), 14 gauge (1.9 mm), cold-formed steel, C-shape sections, and the strapping used was cold rolled channel, 2” (50.8 mm) wide, 14 gauge (1.9 mm) thickness, with a 1/4” (6.4 mm) leg length. Figure 3.6 shows floor CW805 in the condition that it was tested.

Figure 3.6: CW805

No partition walls were present when testing CW805. The floor was bare to the LevelRock topping. Three of the walls were framed with cold-form steel and had gypsum board installed and the back wall was glass.

With these construction details, this floor system was compared to LF19.5B. The only differences in construction details between the floors were a slight difference in span length, ceiling attachment and floor width. The laboratory floor system was constructed with a 19.5’ (5.94 m) span length, the ceiling was attached to resilient channel that was directly attached to the bottom of the floor joists, and the floor width was 16’ (4.88 m).

3.4.2 Ocean Keys Development

The Ocean Keys Development was the second of three field sites visited. The Ocean Keys Development consisted of multiple, four story, residential units. The buildings were framed with cold-formed steel members. Two different floor systems were tested at the Ocean Keys Development. The two floor systems were labeled OK401 and OK402. Floor OK401 was located on the fourth floor in the first unit, and floor OK402 was located on the fourth floor in the second unit. Construction details at Ocean Keys limited the types of tests that could be performed on the floor systems. The dynamic tests (sandbag drop, heel drop and walking test) were performed on each floor system, but the existence of drop ceilings prohibited deflection tests on the floor systems.

Floors OK401 and OK402 had a span length of 14.2’ (4.33 m), and a floor width of 34.9’ (10.64 m). The floor joists were 12” (305 mm) deep, 16 gauge (1.9 mm) TDW’s, spaced at 24” (610 mm) on centre. The subfloor was 9/16” x 30” x 22ga. (14.3 mm x 762 mm x .76 mm) metal form deck with a 1.5” (38 mm) thick lightweight concrete topping. One row of blocking and strapping was installed at the mid span of the floor system. The blocking units were installed every fifth joist along the width of the floor. The blocking used were 24” (610 mm) long cut sections of 12” (305 mm), 16 gauge (1.52 mm), cold-formed steel, C-shape sections, and the strapping used was cold rolled channel, 2” (50.8 mm) wide, 14 gauge (1.9 mm) thickness, with a 1/4” (6.4 mm) leg length. Figure 3.7 shows floors OK401 and OK401 during the field investigation performed at the Ocean Keys Development.

Figure 3.7: OK401 and OK402

A partial partition wall was installed on the front side of the floor when testing OK401 and OK402. The partition wall was 10’ (3.05 m) in length and was installed 9.5’ (2.90 m) from the front wall. The floor was bare to the LevelRock topping. Three of the walls were framed with cold-form steel and had gypsum board installed, and the back wall contained glass slider doors and two large windows.

With these construction details, these floor systems were compared to LF14.5F. The only differences in construction details between the floors were a slight difference in span length, ceiling attachment and floor width. The laboratory floor system was constructed with a 14.5' (4.42 m) span length, the ceiling was attached to resilient channel that was directly attached to the bottom of the floor joists, and the floor width was 16' (4.88 m).

3.4.3 City Green Development

The City Green Development was the third of three field sites visited. The City Green Development consisted of two, eight story, residential buildings. Three different floor systems were tested at the City Green Development. A model unit was also tested at the City Green Development. A furnished version and an unfurnished version of the model unit were tested to determine the influence of flooring finishes and furniture on the vibration characteristics of the floor system. The five floor systems were labeled CG601, CG604, CG805, CG6MH and CG7MH. Floor CG601 was located on the sixth story in the first unit. Floor CG604 was located on the sixth floor in the fourth unit. Floor CG805 was located on the eighth floor in the fifth unit. Floor CG7MH was located on the seventh floor in the model unit and floor CG6MH was located on the sixth floor in the model unit. Construction details at City Green did not limit the types of tests that could be performed. The dynamic tests and deflection tests were performed on all floor systems tested at the City Green Development.

Floor CG601 had a span length of 17.5' (5.33 m), and a floor width of 13.8' (4.21 m). The floor joists were 12" (305 mm) deep, 14 gauge (1.9 mm) TDW's, spaced at 24" (610 mm) on centre. The subfloor was 3/4" (19 mm) Fortacrete with a 3/4" (19 mm) thick lightweight concrete topping. Before the lightweight concrete topping was applied, a 3/8" (9.5 mm) thick layer of sound reducing board was loosely laid on top of the Fortacrete. The lightweight concrete topping was then laid on the sound reducing board. Two rows of blocking and strapping were installed spaced 8' (2.44 m) on centre. The blocking units were installed every fifth joist along the width of the floor. The blocking used were 24" (610 mm) long cut sections of 12" (305 mm), 14 gauge (1.9 mm), cold-formed steel, C-shape sections, and the strapping used was cold rolled channel, 2" (50.8 mm) wide, 14 gauge (1.9 mm) thickness, with a 1/4" (6.4 mm) leg length. CG601 had a ceiling installed on the underside of the floor joists. The ceiling was 5/8” (15.9 mm) gypsum board attached to the floor joists by resilient channel that was run every 12” (305 mm) perpendicular to the joist direction. Figure 3.8 shows floor CG601 in the condition it was tested.

Figure 3.8: CG601

No partition walls were present when testing CG601. The floor was bare to the LevelRock topping. All of the walls were framed with cold-form steel and had gypsum board installed, and the back wall contained a large glass window.

With these construction details, this floor system was compared to LF17.0A. The only difference in construction details between the floors was the floor width. The laboratory floor system had a floor width of 16’ (4.88 m).

Floor CG604 had a span length of 14.8’ (4.51 m), and a floor width of 16.9’ (5.15 m). The floor joists were 12” (305 mm) deep, 14 gauge (1.9 mm) TDW’s, spaced at 24” (610 mm) on centre. The subfloor was 3/4” (19 mm) Fortacrete with a 3/4” (19 mm) thick lightweight concrete topping. Before the lightweight concrete topping was applied, a 3/8” (9.5 mm) thick layer of sound reducing board was loosely laid on top of the Fortacrete. The lightweight concrete topping was then laid on the sound reducing board. One row of blocking and strapping was installed at the centre line of the floor system. The blocking units were installed every fifth joist along the width of the floor. The blocking used were 24” (610 mm) long cut sections of 12” (305 mm), 14 gauge (1.9 mm), cold-formed steel, C-shape sections, and the strapping used was cold rolled channel, 2” (50.8 mm) wide, 14 gauge (1.9

mm) thickness, with a 1/4” (6.4 mm) leg length. CG604 had a ceiling installed on the underside of the floor joists. The ceiling was 5/8” (15.9 mm) gypsum board attached to the floor joists by resilient channel that was run every 12” (305 mm) perpendicular to the joist direction. Figure 3.9 shows CG604 in the condition that it was tested.

Figure 3.9: CG604

No partition walls were present when testing CG604. The floor was bare to the LevelRock topping. All of the walls were framed with cold-form steel and had gypsum board installed, and the back wall contained a small glass window.

With these construction details, this floor system was compared to LF14.5E. The only differences in construction details between the floors were slight differences in floor span and floor width. The laboratory floor system had a floor span on 14.5’ (4.42 m) and a floor width of 16’ (4.88 m).

Floor CG805 had a span length of 21.2’ (6.45 m), and a floor width of 28.0’ (8.53 m). The floor joists were two back to back, 12” (305 mm) deep, 14 gauge (1.9 mm) TDW’s, spaced at 24” (610 mm) on centre. The subfloor was 3/4” (19 mm) Fortacrete with a 3/4” (19 mm) thick lightweight concrete topping. Before the lightweight concrete topping was applied, a 3/8” (9.5 mm) thick layer of sound reducing board was loosely laid on top of the Fortacrete. The lightweight concrete topping was then laid on the sound reducing board. Two rows of blocking and strapping were installed spaced 8’ (2.44 m) on centre. The blocking units were installed every fifth joist along the width of the floor. The blocking used were 24” (610 mm) long cut sections of 12” (305 mm), 14 gauge (1.9 mm), cold-formed steel, C-shape sections, and the strapping used was cold rolled channel, 2” (50.8 mm) wide, 14 gauge (1.9 mm) thickness, with a 1/4” (6.4 mm) leg length. CG805 had a ceiling installed on the underside of the floor joists. The ceiling was 5/8” (15.9 mm) gypsum board attached to the floor joists by resilient channel that was run every 12” (305 mm) perpendicular to the joist direction. Figure 3.10 shows floor CG805 in the condition it was during the field testing performed at the City Green Development.

Figure 3.10: CG805

A partition wall was installed on the floor when testing CG805. The floor was bare to the LevelRock topping. All of the walls were framed with cold-form steel and had gypsum board installed and the back wall contained a large glass window and a fireplace that extended onto the floor. With these construction details, this floor system was not compared to any laboratory floor systems.

Model units CG6MH and CG7MH had a span length of 16.4’ (5.00 m), and a floor width of 23.75’ (7.24 m). The floor joists were 12” (305 mm) deep, 14 gauge (1.9 mm) TDW’s, spaced at 24” (610 mm) on centre. The subfloor was 3/4” (19 mm) Fortacrete with a 3/4” (19 mm) thick lightweight concrete topping. Before the lightweight concrete topping was applied, a 3/8” (9.5 mm) thick layer of sound reducing board was loosely laid on top of the Fortacrete. The lightweight concrete topping was then laid on the sound reducing board. One row of blocking and strapping was installed at the centre line of the floor system. The blocking units were installed every fifth joist along the width of the floor. The blocking used were 24” (610 mm) long cut sections of 12” (305 mm), 14 gauge (1.9 mm), cold-formed steel, C-shape sections, and the strapping used was cold rolled channel, 2” (50.8 mm) wide, 14 gauge (1.9 mm) thickness, with a 1/4” (6.4 mm) leg length. CG6MH and CG7MH had a ceiling installed on the underside of the floor joists. The ceiling was 5/8” (15.9 mm) gypsum board attached to the floor joists by resilient channel that was run every 12” (305 mm) perpendicular to the joist direction. Figure 3.11 shows the furnished model home (CG6MH) and Figure 3.12 shows the unfurnished model home (CG7MH).

Figure 3.11: Furnished Model Home (CG6MH)

Figure 3.12: Unfurnished Model Home (CG7MH)

The test results from these floor systems were compared against each other to find the influence of floor finishing and furniture on the fundamental frequency and damping ratio of the floor system.

3.5 Experimental Procedures

After reviewing previous work on floor vibration tests performed by Murray, Allen, Chui and Onysko (Kraus & Murray, 1997) (Allen, Rainer, & Pernica, 1985) (Chui, 1988) (Onysko D. M., 1985), a detailed testing procedure was developed. All of the tests performed can be grouped into two categories, dynamic tests and static tests. The dynamic tests include a sandbag drop, a heel drop, and a periodic walking test. The dynamic tests were performed to find the natural frequencies, damping ratio, peak acceleration and RMS acceleration. The static tests include a deflection test and a load sharing test. The static tests were performed to find the deflection profile and the load sharing capabilities of each floor system. The load sharing test could not be performed in the field due to a lack of access to the underside of the floor joists, and due to the fact that the joists needed to be unattached to perform the experiment.

The following section will describe the floor testing methods used in the laboratory and field investigations. This section will also include a brief discussion on the validity of the heel drop test and a comparison of the raw data gathered from the heel drop and the sandbag test. The experimental procedures used in the lab and in the field were relatively the same. The field testing procedures were slightly different than the lab testing procedures due to available testing equipment in the field, and the lack of control over construction details at the field sites.

3.5.1 Heel Drop Test

The purpose of the heel drop test was to determine the natural frequency and the damping ratio of the floor system. The heel drop test performed on all the floor systems, in the laboratory and in the field. The heel drop excitation was performed by a 180 lb (82 kg) man standing in the centre of the floor system. The man would stand on his toes then shift his weight backwards impacting the floor with his heels. The response of the floor system was then measured. The following figure shows the heel drop test being performed on a laboratory floor system.

Figure 3.13: Heel Drop Test

Though a standard test for floor vibration performance does not exist, the heel drop test is considered the standard test (Williams & Blakeborough, 2003). The heel drop procedure was first proposed by Ohmart in 1968. Initially he proposed the procedure to find the dynamic displacement of a floor system due to human occupancy (Ohmart, 1968). The procedure was further refined to find the dynamic response of a floor system. The heel drop is a common test and is useful for determining the system characteristics. However, damping is a function of the person standing on the floor to perform the test and heel drops are only used as a comparative tool (Allen, Rainer, & Pernica, 1985). The heel drop procedure was designed to idealize a triangular pulse load on the floor. The idealized time history produced by a heel drop is shown in Figure 3.14 below.

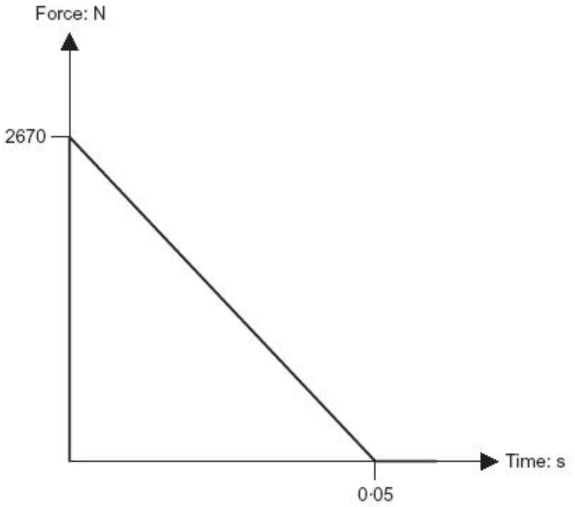


Figure 3.14: Idealized Heel Drop Time History (Williams & Blakeborough, 2003)

The heel drop time history shown above is a triangular pulse load. An equivalent impulse load can be found by integrating the force over the duration of the pulse. For the idealized heel drop time history the equivalent impulse was found to be 67 N-s. Some design guidelines such as the Canadian Steelwork Code and the Steel Construction Institute's design guide use an impulse of 70 N-s.

Once the individual on the floor had performed the heel drop, the response of the floor system was measured. To measure the floor response three ICP accelerometers, model number 353B33, were used. The accelerometers are produced by PCB Piezotronics. One accelerometer was placed at the centre of the floor, the second was placed at the quarter point along the centre joist line and the third accelerometer was placed at the quarter point of the floor perpendicular to the joist line. The accelerometers were connected to a signal conditioner, ICP Sensor Signal Conditioner model number 482A22. The signal conditioner provided a clean power supply for the accelerometers. The signal conditioner was connected to a filter-amplifier, Krohn-Hite Filter, model number 3364. The filter-amplifier was used to filter out signals over 50 Hz and amplify the filtered signal to provide a clean acceleration trace. The filter-amplifier was connected to our data acquisition system from National Instruments Inc., model number DAQCard-6024E. All of the above equipment was used to measure an acceleration trace of the floor system. Figure 3.15 shows a typical acceleration trace when a heel drop test was performed.

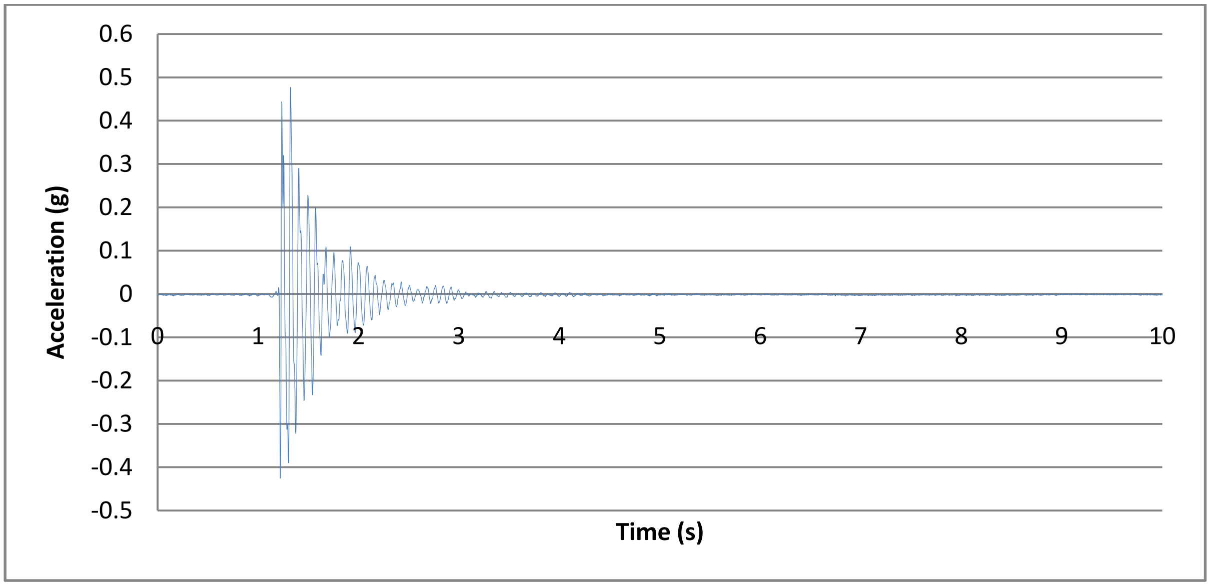


Figure 3.15: Typical Heel Drop Acceleration Trace

The above graph shows an example of the raw data collected when a heel drop was performed. Information on the data processing required to extract the frequency and damping ratio characteristics can be found in Section 3.6. The heel drop was performed three times for every floor configuration tested. After the raw data were processed, average values from the three trials were reported for the frequency and damping ratio.

3.5.2 Sandbag Test

The purpose of the sandbag test was the same as the purpose of the heel drop test, which was to determine the natural frequencies and damping ratio of the floor system. Performing the sandbag test provided conformation on the results from the heel drop test, as well as providing acceleration vs. time data that is independent of the individual that needs to be on the floor to perform the heel drop experiment.

The sandbag test was performed by suspending a 22 lb (10 kg) sandbag, at a height of 12” (305 mm), from the centre of the floor system. The sandbag was then released, exciting the floor system, and an acceleration trace was recorded. Figure 3.16 shows the sandbag test being performed in the laboratory.

Figure 3.16: Laboratory Sandbag Test

The sandbag test was performed differently in the laboratory and in the field because of the lack of equipment available in the field. In the laboratory and in the field the accelerometers were placed in the same configuration as the heel drop test and all the same equipment was used to acquire the raw data. The difference in laboratory and fields test was how the sandbag was dropped on the floor system. In the laboratory, the sand bag was suspended over the centre of the floor by a quick release mechanism that was attached to an overhead crane. The sandbag was then released by activating the quick release mechanism. In the field the sandbag was suspended over the centre of the floor by a tripod. The same quick release mechanism was used to drop the sandbag. Figure 3.17 shows the sandbag test being performed in the field.

Figure 3.17: Sandbag Test as Performed in the Field

Initially it was thought that using the tripod to release the sandbag would skew the results. Experiments were performed in the laboratory to test this theory. Three tests were performed using the overhead crane and three tests were performed using the tripod to release the sandbag. Table 3.3 shows the results from these tests.

Table 3.3: Tripod vs. Crane Release Results

Test	f_1 tripod	f_1 crane	f_2 tripod	f_2 crane	f_3 tripod	f_3 crane	ζ tripod	ζ crane
1	25.7	25.3	32.8	32.7	38.1	38.1	2.89%	3.27%
2	25.0	25.4	32.6	32.7	38.1	38.1	3.26%	2.67%
3	25.5	25.3	32.7	32.7	38.1	38.1	2.48%	2.47%
Average	25.4	25.3	32.7	32.7	38.1	38.1	2.88%	2.80%

The results from all experiments were almost identical and it was determined that the tripod did not affect the results from the dynamic testing.

The goal of the sandbag drop experiment was to excite the floor system and record the floor response in the form of an acceleration trace. Figure 3.18 shows a typical acceleration trace when a sandbag drop was performed.

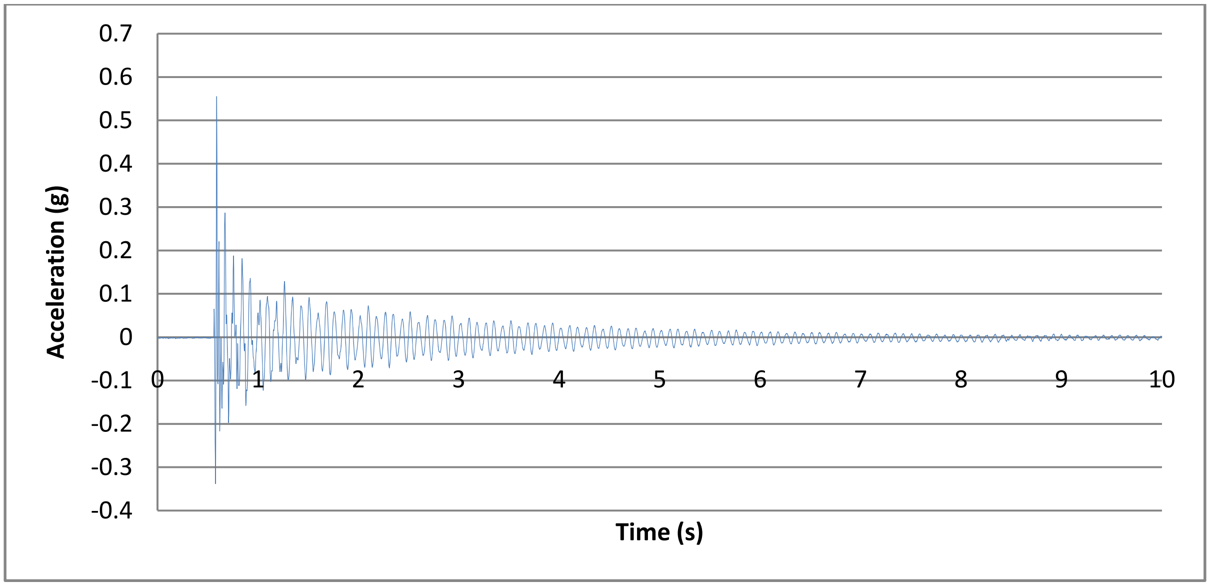


Figure 3.18: Typical Sandbag Acceleration Trace

The above graph shows an example of the raw data collected when a sandbag drop was performed. The sandbag drop was performed three times for every floor configuration tested. After the raw data were processed average values from the three trials were reported for the frequency and damping ratio.

The frequency results from the sandbag drop and the heel drop were almost identical in every case, but the damping ratio results were different. If the acceleration trace from the heel drop is compared to the sandbag drop, it can be seen that the initial acceleration of the floor is greater from the heel drop, and the heel drop acceleration dissipates more rapidly. The greater initial acceleration was present because the mass of the person performing the heel drop was much greater than the sandbag. The increased mass, impacting the floor system, caused a greater acceleration. The greater damping seen in the heel drop response was also a product of the person performing the heel drop. The person performing the heel drop acted like a large slosh damper placed in the centre of the floor. After the floor system was set in to motion, the energy in the floor was absorbed by the body in the centre of the floor.

3.5.3 Walking Parallel and Perpendicular to Floor Joists Test

Walking tests were performed on almost all laboratory and field floor systems. The purpose of the periodic test was to determine the maximum RMS acceleration for each floor system. This information was then used to assess the vibration performance of the floor system. The periodic walking tests were performed by a 180 lb (82 kg) man walking perpendicular and parallel to the direction of the joists. The equipment used to measure the response of the floor system was identical to the equipment used during the heel drop and sandbag drop experiments. The accelerometers were placed in the same orientation as the other dynamic experiments. The goal of the walking test was to excite the floor system with human induced walking vibrations. Figure 3.19 shows an example of the raw data collected from a walking test.

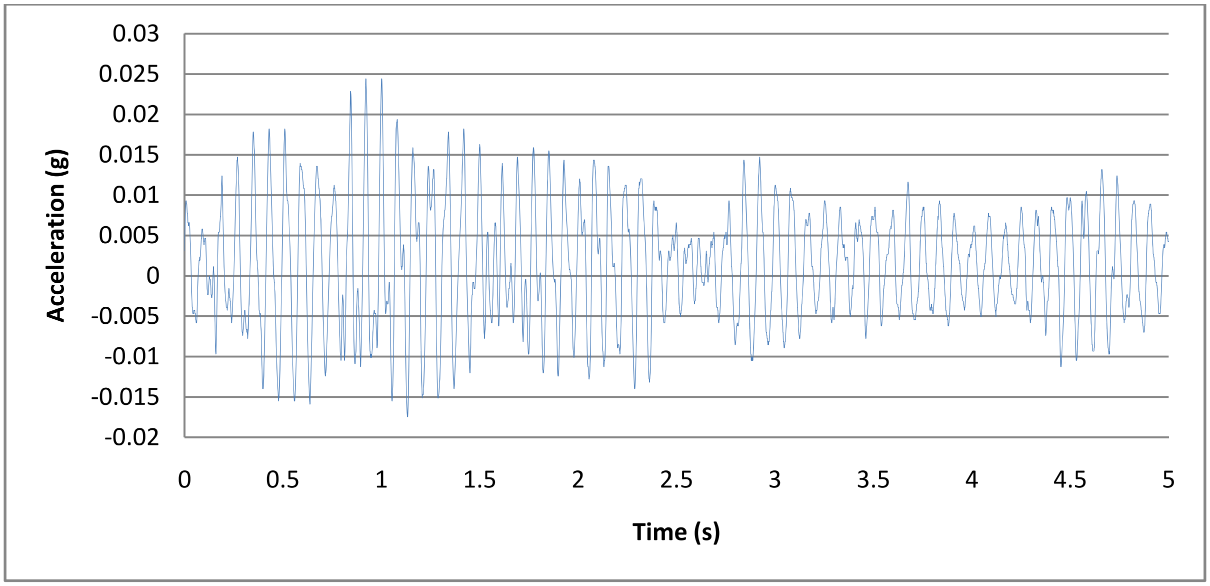


Figure 3.19: Typical Walking Acceleration Trace

The above graph shows an example of the raw data collected when a walking test was performed parallel to the joist direction. Information on the data processing required to extract the RMS acceleration can be found in Section 3.6. The walking test was performed twice for every floor configuration tested. After the raw data were processed average values from the two trials were reported for the RMS acceleration.

3.5.4 Deflection Test

The deflection test was one of two static tests that were performed on the floor systems. The deflection test was executed on almost all laboratory floor systems and the field floor systems tested at the City Green Development. Drop ceilings installed at the Ocean Keys and Carlyle's Watch field sites prevented the deflection test. The purpose of the deflection test was to find the deflection profile of the floor system when a static, concentrated load was applied. To perform the experiment, dial gauges were placed under the floor joists and a concentrated load of 225 lb (1 kN) was applied to the centre of the floor system. Figure 3.20 shows the dial gauge setup for the deflection test.

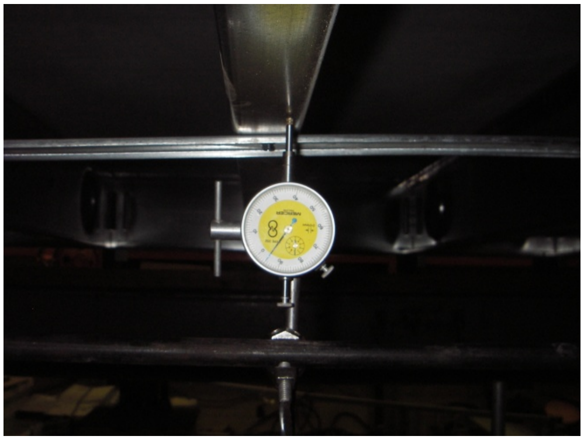


Figure 3.20: Dial Gauge Setup for Deflection Test

The above figure shows one of the dial gauges placed under a floor joist during a deflection test. The dial gauges were always situated so that the sensor was directly under the web of the joist to avoid errors from flange curling. Initially, only half of the deflection profile was measured, but after the third floor system dial gauges were placed under every joist. In the field experiments, only the centre three joist deflections were recorded. Figure 3.21 shows a typical deflection profile from a deflection experiment.

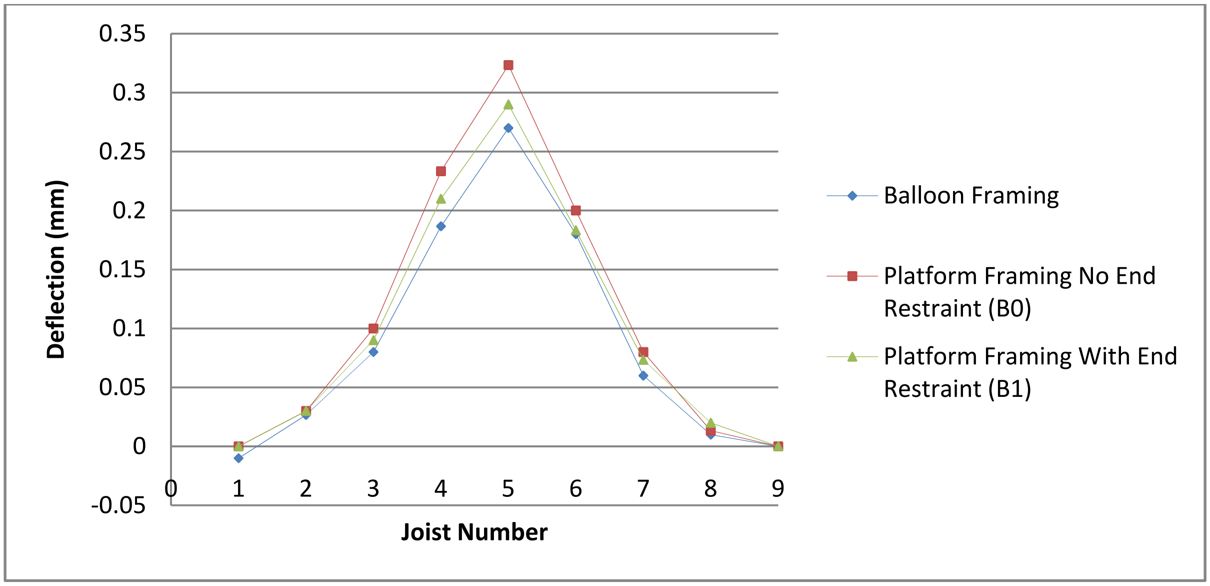


Figure 3.21: Typical Deflection Profile

The deflection test was performed three times for each framing condition, for a total of nine times for every floor system. In the field experiments, the deflection test was performed three times for the available framing condition. In each case the average values were reported.

3.5.5 Load Sharing Test

The purpose of the load sharing test was to ascertain the load sharing capability of each floor system. The load sharing test was performed by placing a load cell under the web of each joist in the floor system. The load cell was placed at the end of each joist flush with the bottom flange of the rim track. The floor was lowered onto the load cells, and each load cell was finely adjusted to ensure a completely level floor system. This was accomplished by adjusting the load cells so the interior load cells were supporting the same load and the two exterior load cells were supporting half the load of the interior load cells. After the load cells were adjusted, a 225 lb (1 kN) concentrated load was placed in the centre of the floor system. The joist end reactions were then recorded. Figure 3.22 shows the load sharing test being performed.

Figure 3.22: Load Sharing Test

The load sharing test was performed with nine load cells connected to a data acquisition system. The nine load cells were comprised of two different makes and three different models. Six of the load cells were produced by Tovey Engineering. Of those six, two were model number SW-5k-B000 and four were model number SW-2k-B000. The three remaining load cells were produced by Strainsert Universal and their model number was FL5U-2SPKT. The nine load cells were powered by a DC power supply produced by Hewlett Packard, model number 6204B. Each load cell required 10 volts of DC power. The load cells were connected to the data acquisition system which was a National Instruments, model number SCXI-1000. The data acquisition system described above was designed to measure the end reaction of each joist when the load sharing test was performed. Figure 3.23 shows the typical results from the load sharing test.

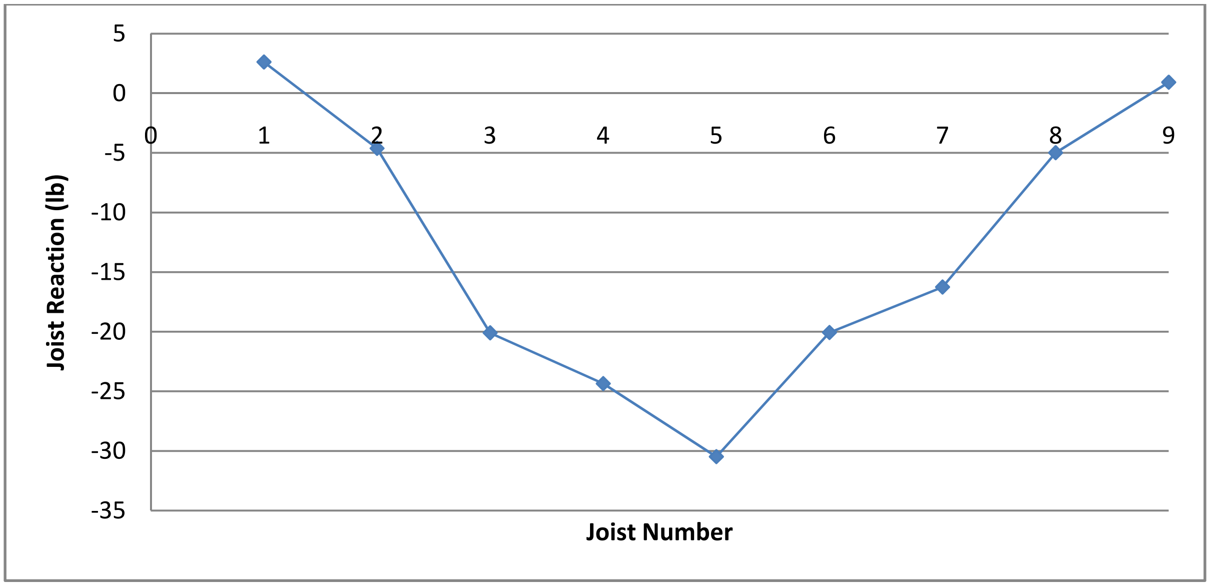


Figure 3.23: Typical Results from Load Sharing Test

The load sharing test was only performed on laboratory floor systems, due to the lack of access and construction conditions in the field. The load sharing experiment was only performed on the platform framing without end restraint and the platform framing with end restraint condition for each floor system. The experiment was executed three times for each framing condition, and the average values were reported. For the 19.5' (5.94 m) and 21.8' (6.64 m) lab floors, the load sharing experiment was only completed for the platform framing without end restraint. The weight of the floor and the end restraining beam would have overloaded the load cells in the platform framing with end rotational restraint condition. The goal of the load sharing test was to define the load sharing capability of each floor. Load sharing is the ability of the floor to disperse the 225lb (1 kN) concentrated load applied to the centre joist across the other joists. Information on determining the load sharing factor can be found in Section 3.6.

3.6 Data Processing

Discussed in this section are the techniques used to process the raw data collected from the dynamic and static tests performed in this investigation. The dynamic tests were performed to acquire the first three natural frequencies, damping ratio, peak acceleration, and RMS acceleration of each floor configuration. The Fast Fourier Transform (FFT) Technique was used to acquire the first three natural frequencies. Two different techniques were used to obtain the damping ratio; the first was the Bandwidth Method and the second was the Logarithmic Amplitude Decay Method. To find the RMS acceleration, the Unweighted RMS Method was used.

The static tests were performed to find the deflection and the load sharing capability of each floor system. The raw data from the deflection test did not require any further processing. The raw data from the load sharing test was processed to find a load sharing factor for each floor system. The data processing techniques used for the data collected from the laboratory and field floor systems were identical.

3.6.1 Determination of Frequency using Fast Fourier Transform Technique

To acquire the first three natural frequencies of a floor system, the FFT technique was used to process the raw acceleration trace. The FFT is a fast way of performing a Discrete Fourier Transform. The FFT technique was used to convert the raw data from a time domain to a frequency domain. The data set in the frequency domain is the power spectrum. The power spectrum characterizes how the energy passed to the floor system, from a sandbag drop or heel drop, is distributed throughout the floor system based on the frequency of vibration. Since it is known that resonance occurs when the frequency of excitation matches the natural frequency of the floor system, the maximum amount of power in the frequency domain will occur at the natural frequencies of the floor system. The natural frequencies of the floor system occur at peaks in the frequency domain. Figure 3.24 shows a typical power spectrum.

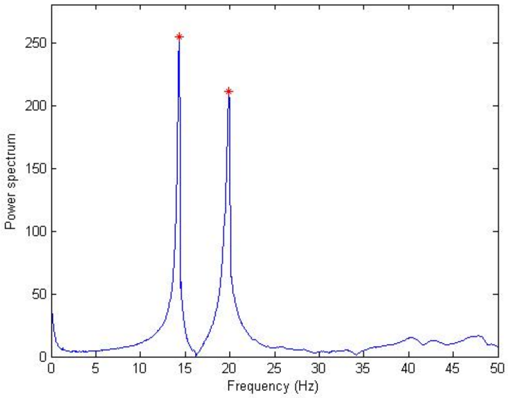


Figure 3.24: Typical Power Spectrum

The above figure shows a power spectrum from one of the laboratory floor systems. Three different measurement locations were used during the testing of the floor systems. The acceleration trace from each measurement location was different, but the power spectrum from each accelerometer was relatively the same. For each floor system, the frequencies reported were an average from all three accelerometers. The peaks in the power spectrum represent the natural frequencies of the floor system. The first peak corresponds to the fundamental frequency.

In general, the power spectrum is a combination of all modes of vibration of the floor system, which includes the bending modes, torsional modes and others. Work carried out by Johnson (1994), demonstrated that multiple and torsional frequencies contributed very little to the floor response due to a sandbag excitation (Johnson, 1994). Therefore, the fundamental frequency is the dominant vibration component that influences the floor system response.

During testing, precautions were taken to avoid the Nyquist frequency. The Nyquist theory states that valid Fourier coefficients exist up to the (N/2) coefficient in the series.

$$f_{Nyquist} = \frac{N}{2T} = \frac{N}{2}\frac{1}{N\Delta t} = \frac{1}{2}f_s \tag{1}$$

In the above formula $f_{Nyquist}$ is the Nyquist frequency, N is the total number of sample points, T is the length of time and f_s is the sampling frequency. Using the above criteria if data were sampled at a rate of 1000 Hz the analysis would only be valid up to 500 Hz. For the floor testing, data were sampled at 500 Hz, so the analysis is valid up to 250 Hz. None of the floors tested had a natural frequency over 40 Hz so the Nyquist frequency was avoided.

3.6.2 Determination of Damping Ratios

Determining the damping ratio of a floor system is typically more difficult than determining the natural frequency (CSA-S16-01, 2004). For this study, two different methods were used to determine the damping ratio for each floor system. The bandwidth method was used to compute the damping ratio in the frequency domain, and the logarithmic decay method was used to compute the damping ratio in the time domain. Both methods are discussed in the following section.

3.6.2.1 Bandwidth Method

The bandwidth method is used to obtain the damping ratio of a system when that system is excited by an impulse load. The sandbag drop and heel drop were idealized impulse excitations, so the bandwidth method is valid for both of these tests. The derivation of the bandwidth method can be found in most dynamics text books. An explicit derivation for lightweight floor systems was performed by Liu (2001).

The damping ratio was found using the following equation:

$$\xi = \frac{\Delta f}{2 f_o} \tag{2}$$

Where

$\Delta f =$ Bandwidth of the frequency corresponding to the spectral value of $\frac{f_{max}}{\sqrt{2}}$

$f_o =$ Natural frequency corresponding to the peak value f_{max}

Figure 3.25 shows a power spectrum plot with the above parameters shown.

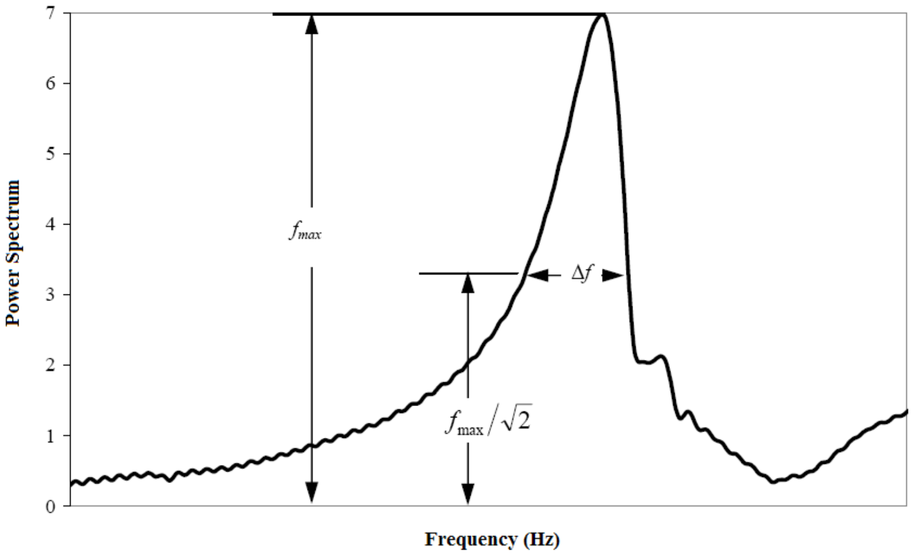


Figure 3.25: Typical Power Spectrum Showing Bandwidth Parameters

The bandwidth method was used to evaluate the damping ratio for all floors tested in the laboratory and in the field. A MATLAB program was developed in this study to facilitate the large number of tests that needed to be processed. However, there were some problems using the bandwidth method to obtain damping ratios. In the figure shown above, the peak of the power spectrum corresponding to the first natural frequency is clearly defined from any other peaks in the power spectrum. In this case, the bandwidth method works flawlessly. For some floors, the peaks of the power spectrum were not clearly defined, and Δf stretched from the up ramp of the first peak, to the down ramp on the second peak. This created a problem determining the appropriate value for Δf. In these cases, the damping ratio found using the bandwidth method may not be appropriate and was discarded. This is one of the reasons that two methods were used to acquire the damping ratio.

3.6.2.2 Logarithmic Amplitude Decay Method

The logarithmic amplitude decay method (log decay) is used to obtain the damping ratio of a system when that system was excited by an impulse load. The sandbag drop and heel drop were idealized impulse excitations so the log decay method is valid for both of these tests.

The derivation of the log decay method can be found in most dynamics text books. An explicit derivation for lightweight floor systems was performed by Liu (2001).

When utilizing the logarithmic amplitude decay method, the damping ratio was found using the following equation:

$$\xi = \frac{1}{2n\pi} \ln \left(\frac{A_i}{A_{i+n}}\right) \tag{3}$$

Where

$A_i =$ Initial amplitude of peak acceleration; and

$A_{i+n} =$ Amplitude of peak acceleration after *n* cycles

Figure 3.26 shows an acceleration trace with the above parameters shown.

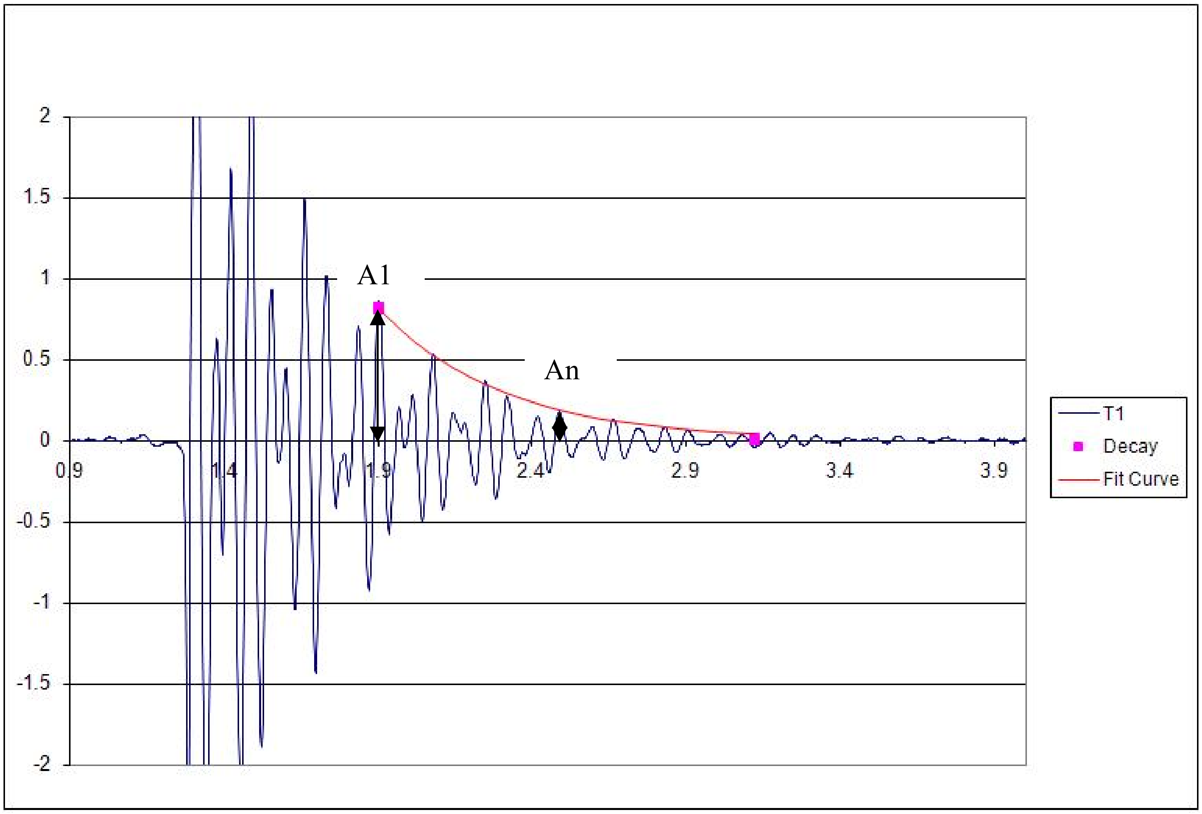


Figure 3.26: Typical Acceleration Trace Showing Log Decay Parameters

In general terms, the logarithmic decay method consists of determining the slope of the exponential function banding a decaying sinusoidal function to obtain the energy loss per cycle as a function of damping. Due to interference from other vibration modes the first five peaks were ignored when curve fitting (Liu W. , 2001). Ignoring the first five peaks improved the agreement between the bandwidth method and the logarithmic decay method.

3.6.3 Unweighted RMS Method

The RMS value of the acceleration measured from walking tests was calculated based on a procedure described by the International Standards Organization (ISO, 1997). The RMS value of acceleration was calculated using the following equation:

$$a_{RMS} = \left[\frac{1}{T}\int_0^T a(t)^2 dt\right]^{\frac{1}{2}} \tag{4}$$

where a_{RMS} is the unweighted RMS acceleration over the entire acceleration time history *a(t)*, with a sample period *T*. The entire 50 s time history was used for the RMS calculation. It should be noted that the procedure described in the reference is for a frequency weighted RMS, but as the acceptability criterion for acceleration is already weighted for frequency it is appropriate to use the unweighted RMS.

3.6.4 Determining the Load Sharing Factor

The load sharing factor was used to quantify the load sharing capability of the floor systems. The load sharing capability can be described as the ability of the floor to disperse the concentrated load transversely across the floor joists. To determine the load sharing factor, the end reactions from the centre three joists were divided by the sum of the end reactions for the nine floor joists. If the sum of the reactions from the centre three joists was a relatively small number, this implied that more of the load was dispersed to the remaining six joists. Therefore, the smaller the load sharing value, the better the load sharing capability of the floor system.

Chapter 4

Influence of Construction Details and Comparison between Laboratory and Field Results

The following section of this thesis discusses the influence of the construction details on the vibration characteristics of the lightweight floor systems supported by cold-formed steel joists. It will also include the results from the field testing, and comparison between the laboratory and field results. To determine the influence of the construction details, comparisons were made between floor systems with identical construction details except for the detail being analyzed. The construction details analyzed were span length, joist type, subfloor material, existence of a topping, existence of a ceiling, existence of a strongback (free and fixed ends), existence of a 6psf (0.287kPa) live load and framing condition. The vibration performance of the floor system was judged based on fundamental frequency, damping ratio, centre joist deflection and load sharing capabilities. Summary sheets detailing the testing results from each laboratory and field floor system can be found in Appendix C.

4.1 Effect of Span Length

To determine the effect of span length the results from six different laboratory floor systems were used, for a total of three comparisons. A 14.5’ (4.42 m) floor system was compared to a 17.0’ (5.18 m) floor system, and two comparisons of a 17.0’ (5.18 m) floor system vs. a 19.5’ (5.94 m) floor system were made. All three comparisons were made in the balloon framing, platform framing without end restraint, and platform framing with end restraint conditions. The following tables show the results of these comparisons in each framing condition.

Table 4.1: Span Length Comparison

Floor Name	Span (ft)	Joist Type	Sub floor	f_1 (Hz) Heel Drop	f_2 (Hz) Heel Drop	ζ (%) Heel Drop	Δ_{centre} (mm)	Δ_{centre} (in)	Load Sharing Factor
Balloon Framing									
LF14.5E	14.5	TDW 16ga.	2	17.7	22.6	2.56	0.22	0.009	N/A
LF17.0A	17.0	TDW 14ga.	2	14.7	20.0	4.17	0.30	0.012	N/A
LF17.0A	17.0	TDW 14ga.	2	14.7	20.0	4.17	0.30	0.012	N/A
LF19.5A	19.5	TDW 14ga.	2	11.9	17.0	2.95	0.33	0.013	N/A
LF17.0C	17.0	TDW 14ga.	3	14.3	18.4	3.29	0.25	0.010	N/A
LF19.5B	19.5	TDW 14ga.	3	11.4	16.8	3.63	0.28	0.011	N/A
Platform Framing No End Restraint (B0)									
LF14.5E	14.5	TDW 16ga.	2	15.2	21.2	4.81	0.25	0.010	0.70
LF17.0A	17.0	TDW 14ga.	2	13.2	18.8	4.37	0.34	0.013	0.67
LF17.0A	17.0	TDW 14ga.	2	13.2	18.8	4.37	0.34	0.013	0.67
LF19.5A	19.5	TDW 14ga.	2	11.2	16.3	4.13	0.35	0.014	0.58
LF17.0C	17.0	TDW 14ga.	3	12.7	18.3	3.36	0.26	0.010	0.61
LF19.5B	19.5	TDW 14ga.	3	10.4	16.1	3.67	0.30	0.012	0.58
Platform Framing With End Restraint (B1)									
LF14.5E	14.5	TDW 16ga.	2	15.8	21.7	4.54	0.24	0.009	0.67
LF17.0A	17.0	TDW 14ga.	2	13.4	19.3	3.68	0.32	0.013	0.54
LF17.0A	17.0	TDW 14ga.	2	13.4	19.3	3.68	0.32	0.013	0.54
LF19.5A	19.5	TDW 14ga.	2	11.7	17.2	3.44	0.34	0.013	N/A

LF17.0C	17.0	TDW 14ga.	3	12.7	19.8	3.26	0.25	0.010	0.49
LF19.5B	19.5	TDW 14ga.	3	10.8	16.9	3.42	0.28	0.011	N/A

Note: For the load sharing value, a smaller value indicates better load sharing

For Subfloor Column:
1: 3/4" (19 mm) OSB
2: 3/4" (19 mm) Fortacrete
3: 9/16" x 30" x 22 ga. (14.3 mm x 762 mm x 0.76 mm) metal form deck

From the results shown above, altering the span length of a floor system had a conclusive effect on the fundamental frequency, deflection, and load sharing capabilities the floor systems. As the span length increased the first natural frequency of the floor system decreased in all cases. On average, as the span length increased the fundamental frequency decreased by 20.7%, 16.8% and 15.4%, over the span lengths tested, for balloon framing, platform framing with no end restraint and platform framing with end restraint respectively. The decrease in frequency can be attributed to the added mass from the longer span and the increase in flexibility in longer spans. Adding mass to a system without adding stiffness will lower the natural frequency of the system. The fundamental equation for frequency is

$$\omega = \sqrt{\frac{k}{m}} \tag{5}$$

where, ω is the natural frequency of a system, m is the mass of the system, and k is the stiffness of the system. As the span length increased the centre deflection due to a 225lb (1kN) load also increased. The increased flexibility can be attributed to the increase in length of the system. Consider a single joist of the system; the stiffness can be found using the following equation:

$$k = \frac{3EI}{L} \tag{6}$$

where, k is the stiffness, E is Young's modulus, I is the moment of inertia, and L is the span length. Stiffness is inversely proportional to span length; therefore, as span length increases stiffness of the system decreases. On average, as the span length increased the centre deflection increased by 17.2%, 15.9% and 15.3% for balloon framing, platform framing with no end restraint and platform framing with end restraint respectively. This result agrees well with the decrease in frequency due to a longer span. As the span length increased the load sharing capability of the floor system also increased. On average, as the span length increased the load sharing factor increased by 7.9% and 21.5% for platform framing with no end restraint and platform framing with end restraint respectively. The load sharing capability increased because the longer span provided more area for the point load to distribute. Changing the span length had no significant influence on the damping ratio.

4.2 Effect of Joist Type

To determine the effect of the joist type, the results from four different laboratory floor systems were used for a total of two comparisons. Two different joist types were analyzed. The first was a typical C-shape joist with small, elliptical, punch-out openings along the neutral axis. The holes were 4” x 1.5” (101.6 mm x 38.1 mm) spaced at 4’ (1.22 m) on centre. The punch-out openings are usually used for running wiring and small services. The second cold-formed steel joist type was a proprietary product called TradeReady® Joists (TDW) manufactured by Dietrich Metal Framing. The TDW joists were a typical C-shape with large, circular, lip reinforced holes along the neutral axis. The holes were 8” (203 mm) in diameter and the holes were spaced at 4’ (1.22 m) on centre. The following figures show the typical C-shape and TDW joists.

Figure 4.1: C-Shape Joist

Figure 4.2: TDW Joist

The joist type comparisons were made in the balloon framing, platform framing without end restraint and platform framing with end restraint conditions. The following table shows the results of these comparisons in each framing condition.

Table 4.2: Joist Type Comparison

Floor Name	Joist Type	Subfloor	f_1 (Hz) Heel Drop	f_2 (Hz) Heel Drop	ζ (%) Heel Drop	Δ_{centre} (mm)	Δ_{centre} (mm)	Load Sharing Factor
Balloon Framing								
LF14.5A	C-Shape 16ga.	1	25.8	33.1	1.90	0.52	0.020	N/A
LF14.5C	TDW 16ga.	1	25.9	34.0	2.00	0.59	0.023	N/A
LF14.5B	C-Shape 16ga.	2	22.4	25.0	2.40	0.44	0.017	N/A
LF14.5Di	TDW 16ga.	2	24.0	29.2	1.78	0.38	0.015	N/A
Platform Framing No End Restraint (B0)								
LF14.5A	C-Shape 16ga.	1	19.5	30.0	2.29	0.67	0.026	0.69
LF14.5C	TDW 16ga.	1	17.7	26.0	2.00	0.71	0.028	0.72
Platform Framing With End Restraint (B1)								
LF14.5A	C-Shape 16ga.	1	17.9	29.8	3.68	0.55	0.022	0.64
LF14.5C	TDW 16ga.	1	16.4	27.0	1.62	0.62	0.024	0.64

Note: For the load sharing value, a smaller value indicates better load sharing

For Subfloor Column:
1: 3/4” (19 mm) OSB
2: 3/4” (19 mm) Fortacrete
3: 9/16” x 30” x 22 ga. (14.3 mm x 762 mm x 0.76 mm) metal form deck

From the results shown above, it is conclusive that the performance of the two joist types is comparable. The TDW joists have other advantages over the traditional C-Shape joists. The large lip reinforced opening can be used for the passage of mechanical services such as duct work, piping and electrical wires. Also, the large elliptical openings allow the installation of strongbacks when using the TDW joists.

4.3 Effect of Subfloor Material

To determine the effect of subfloor material the results from 12 different laboratory floor systems were used for a total of six comparisons. Three different subfloor materials were tested, OSB, Fortacrete and metal form decking. The comparisons made were OSB vs. Fortacrete, and Fortacrete vs. metal form deck. OSB was not compared to metal form deck because of the differences in uses of the subfloor materials and the fact that metal deck requires a concrete topping. All six comparisons were made in the balloon framing, platform framing without end restraint and platform framing with end restraint conditions. The following table shows the results of these comparisons in each framing condition.

Table 4.3: Subfloor Comparison

Floor Name	Subfloor	Joist Type	f_1 (Hz) Heel Drop	f_2 (Hz) Heel Drop	ζ (%) Heel Drop	Δ_{centre} (mm)	Δ_{centre} (in)	Load Sharing Factor
Balloon Framing								
LF14.5A	1	C-Shape 16ga.	25.8	33.1	1.90	0.52	0.020	N/A
LF14.5B	2	C-Shape 16ga.	22.4	25.0	2.40	0.44	0.017	N/A
LF14.5C	1	TDW 16ga.	25.9	34.0	2.00	0.59	0.023	N/A
LF14.5Di	2	TDW 16ga.	24.0	29.2	1.78	0.38	0.015	N/A
LF14.5E	2	TDW 16ga.	17.7	22.6	2.56	0.22	0.009	N/A
LF14.5F	3	TDW 16ga.	16.0	22.6	3.38	0.18	0.007	N/A
LF17.0A	2	TDW 14ga.	14.7	20.0	4.17	0.30	0.012	N/A
LF17.0C	3	TDW 14ga.	14.3	18.4	3.29	0.25	0.010	N/A
LF17.0B	2	TDW 14ga.	14.7	19.6	3.65	0.27	0.011	N/A

LF17.0D	3	TDW 14ga.	14.2	19.9	3.32	0.22	0.009	N/A
							0.000	
LF19.5A	2	TDW 14ga.	11.9	17.0	2.95	0.33	0.013	N/A
LF19.5B	3	TDW 14ga.	11.4	16.8	3.63	0.28	0.011	N/A
Platform Framing No End Restraint (B0)								
LF14.5A	1	C-Shape 16ga.	19.5	30.0	2.29	0.67	0.026	0.69
LF14.5B	2	C-Shape 16ga.	17.6	22.3	2.86	0.54	0.021	0.74
LF14.5E	2	TDW 16ga.	15.2	21.2	4.81	0.25	0.010	0.7
LF14.5F	3	TDW 16ga.	14.3	21.0	3.07	0.20	0.008	0.51
LF17.0A	2	TDW 14ga.	13.2	18.8	4.37	0.34	0.013	0.67
LF17.0C	3	TDW 14ga.	12.7	18.3	3.36	0.26	0.010	0.61
LF17.0B	2	TDW 14ga.	13.1	18.0	3.76	0.32	0.013	0.64
LF17.0D	3	TDW 14ga.	12.9	18.3	3.87	0.24	0.009	0.64
LF19.5A	2	TDW 14ga.	11.2	16.3	4.13	0.35	0.014	N/A
LF19.5B	3	TDW 14ga.	10.4	16.1	3.67	0.30	0.012	0.58
Platform Framing With End Restraint (B1)								
LF14.5A	1	C-Shape 16ga.	17.9	29.8	3.68	0.55	0.022	0.64
LF14.5B	2	C-Shape 16ga.	17.2	18.7	1.48	0.48	0.019	0.72
LF14.5E	2	TDW 16ga.	15.8	21.7	4.54	0.24	0.009	0.67
LF14.5F	3	TDW 16ga.	14.7	20.8	3.13	0.17	0.007	N/A
LF17.0A	2	TDW 14ga.	13.4	19.3	3.68	0.32	0.013	0.54
LF17.0C	3	TDW 14ga.	12.7	19.8	3.26	0.25	0.010	0.49
LF17.0B	2	TDW 14ga.	13.1	19.3	5.15	0.29	0.011	0.52
LF17.0D	3	TDW 14ga.	13.1	20.2	3.55	0.23	0.009	0.51
LF19.5A	2	TDW 14ga.	11.7	17.2	3.44	0.34	0.013	N/A
LF19.5B	3	TDW 14ga.	10.8	16.9	3.42	0.28	0.011	N/A

Note: For the load sharing value, a smaller value indicates better load sharing

For Subfloor Column:
1: 3/4” (19 mm) OSB
2: 3/4” (19 mm) Fortacrete
3: 9/16” x 30” x 22 ga. (14.3 mm x 762 mm x 0.76 mm) metal form deck

From the results shown above, altering the subfloor material had a conclusive effect on the first natural frequency, deflection, and load sharing capabilities the floor systems. The Fortacrete floor systems had a lower fundamental frequency than the OSB floor systems. On average, the Fortacrete floor systems had a lower fundamental frequency by 10.9%, 10.2% and 4.0% for balloon framing, platform framing with no end restraint and platform framing with end restraint respectively. This decrease in frequency can be attributed to the added mass when the Fortacrete was used. The Fortacrete is approximately 164 lbs (74.5 kg) per sheet and the OSB is approximately 80 lbs (36.36 kg) per sheet. The Fortacrete and the OSB sheets are the same size. The Fortacrete floor systems were found to be flexurally stiffer than the OSB systems and a decrease in centre deflection was seen in all cases. On average, the Fortacrete floor systems had a lower deflection by 30.0%, 21.5% and 13.6% for balloon framing, platform framing with no end restraint and platform framing with end restraint respectively. Though the Fortacrete was stiffer the added mass outweighed the stiffness effects and the fundamental frequency was still decreased. The load sharing capability of the floor system was not affected by altering the subfloor material between Fortacrete and OSB.

The metal deck slightly lowered the fundamental frequency, when compared to the Fortacrete. On average, the metal deck floor systems had a lower fundamental frequency by 3.5%, 4.7% and 5.1% for balloon framing, platform framing with no end restraint and platform framing with end restraint respectively. The decrease in frequency can be attributed to the added mass from the metal deck system. The metal deck system had a density of approximately 120 pcf (1922 kg/m^3), and the Fortacrete system had an average density of approximately 101 pcf (1618 k/m^3). The metal deck provided a much stiffer floor system than the Fortacrete, and a decrease in centre deflection was seen in all cases. On average, the metal deck floor systems had a lower centre deflection by 18.3%, 23.2% and 25.3% for balloon framing, platform framing with no end restraint and platform framing with end restraint respectively. The load sharing capability of the floor system was increased when the metal deck subfloor was used. On average, the metal deck floor systems had a greater load sharing capability by 13.6% and 5.8% for platform framing with no end restraint and platform framing with end restraint respectively. This increase in load sharing capability can be attributed to the added transverse stiffness provided by the metal form deck over the Fortacrete. The flutes of the metal form deck were laid perpendicular to the joist direction, providing the increased transverse stiffness.

The metal deck subfloor with 1.5” (38.1 mm) layer of LevelRock topping provided the greatest improvement in vibration performance out of the three subfloors examined. The metal deck and LevelRock combination provided extra mass to the system, but also provided enough stiffness to maintain a comparable fundamental frequency with the Fortacrete with LevelRock floors. The metal deck also provided an increase in longitudinal and transverse stiffness, further increasing the vibration performance.

4.4 Effect of Topping

To determine the influence of a topping, the results from two different laboratory floor systems were used. One of the floor systems was tested with a 0.75” (19mm) lightweight concrete topping and the other floor system was tested without a concrete topping. All other construction details were identical. The comparison was made in the balloon framing, platform framing without end restraint and platform framing with end restraint conditions. The following tables show the results of the comparison in each framing condition.

Table 4.4: Lightweight Concrete Topping Comparison

Floor Name	LevelRock (yes/no)	Subfloor	Joist Type	f_1 (Hz) Heel Drop	f_2 (Hz) Heel Drop	ζ (%) Heel Drop	Δ_{centre} (mm)	Δ_{centre} (in)	Load Sharing Factor
Balloon Framing									
LF14.5D	No	2	TDW 16ga.	19.7	24.1	3.30	0.34	0.013	N/A
LF14.5E	Yes	2	TDW 16ga.	17.7	22.6	2.56	0.22	0.009	N/A
Platform Framing No End Restraint (B0)									
LF14.5D	No	2	TDW 16ga.	16.3	22.9	2.59	0.40	0.016	0.72
LF14.5E	Yes	2	TDW 16ga.	15.2	21.2	4.81	0.25	0.010	0.70
Platform Framing With End Restraint (B1)									
LF14.5D	No	2	TDW 16ga.	16.7	22.7	2.43	0.37	0.015	0.64

LF14.5E	Yes	2	TDW 16ga.	15.8	21.7	4.54	0.24	0.009	0.67

Note: For the load sharing value, a smaller value indicates better load sharing

For Subfloor Column:
1: 3/4” (19 mm) OSB
2: 3/4” (19 mm) Fortacrete
3: 9/16” x 30” x 22 ga. (14.3 mm x 762 mm x 0.76 mm) metal form deck

From the results shown above, adding a lightweight concrete topping had a conclusive effect on the first natural frequency and deflection of the floor systems. The floor systems with a topping had a lower fundamental frequency than floor systems without a topping. On average, the floor systems with a concrete topping had a lower fundamental frequency by 10.7%, 6.98% and 5.54% for balloon framing, platform framing with no end restraint and platform framing with end restraint respectively. The decrease in frequency can be attributed to the added mass when a topping was added. The floor system with a topping was found to be stiffer than the floor system without a topping and a reduction in centre deflection was seen in all cases. On average, the floor systems with a concrete topping showed a decrease in centre deflection by 42.9%, 46.2% and 42.6% for balloon framing, platform framing with no end restraint and platform framing with end restraint respectively. Though the concrete topping increased stiffness, the added mass outweighed the stiffness effects and the fundamental frequency was still decreased.

The addition of a LevelRock topping has both positive and negative impacts on the vibration performance of the floor systems. The decrease in fundamental frequency is seen as a negative impact. This decrease may bring the fundamental frequency closer to the increased human sensitivity range of 4 – 8 Hz. The decrease in centre deflection is seen as a positive impact on the vibration performance. If the centre deflection is decreased then the amplitude of deflection under a walking excitation will be decreased, and therefore, less noticeable to the occupants. A lightweight concrete topping should be applied to floor systems to improve the vibration performance as long as the fundamental frequency remains above 10 Hz.

4.5 Effect of Ceiling

To determine the influence of a ceiling on the vibration characteristics, the results from six different laboratory floor systems were used for a total of three comparisons. Three of the floors were tested with a 5/8” (15.9mm) gypsum board ceiling attached to the underside of the floor (with resilient channel), and three floors were tested without a ceiling. Two different types of ceilings were tested. One comparison was made between floors with Type X gypsum board and two comparisons were made between floors with Type C gypsum board. All three comparisons were made in the balloon framing condition. The following tables show the results of these comparisons in each framing condition.

Table 4.5: Ceiling Comparison

Floor Name	Ceiling (yes/no)	Joist Type	Subfloor	f_1 (Hz) Heel Drop	f_2 (Hz) Heel Drop	ζ (%) Heel Drop	Δ_{centre} (mm)	Δ_{centre} (in)
Balloon Framing								
LF14.5D	Yes+	TDW 16ga.	2	19.7	24.1	3.30	0.34	0.013
LF14.5Di	No	TDW 16ga.	2	24.0	29.2	1.78	0.38	0.015
LF19.5A	Yes+	TDW 14ga.	2	11.9	17.0	2.95	0.33	0.013
LF19.5Ai	No	TDW 14ga.	2	12.7	18.6	3.60	0.37	0.015
LF19.5B	Yes	TDW 14ga.	3	11.4	16.8	3.63	0.28	0.011
LF19.5Bi	No	TDW 14ga.	3	11.9	17.6	2.92	N/A	N/A

For Subfloor Column:
1: 3/4” (19 mm) OSB
2: 3/4” (19 mm) Fortacrete
3: 9/16” x 30” x 22 ga. (14.3 mm x 762 mm x 0.76 mm) metal form deck
+ indicates Type X gypsum board was used

The effect of a gypsum board ceiling was only determined in the balloon framing condition. From the results shown above, adding a gypsum board ceiling had a conclusive effect on the fundamental frequency and deflection of the floor systems. The floor systems with a ceiling had a lower fundamental frequency than floor systems without a ceiling. On average, the floor systems with a ceiling had a lower fundamental frequency by 10.2% for balloon framing. This decrease in frequency can be attributed to the added mass when a ceiling was added. The floor system with a ceiling was found to be stiffer than the floor system without a ceiling and a decrease in centre deflection was seen in all cases. On average, the floor systems with a ceiling showed a decrease in centre deflection by 11.3% for balloon framing.

The increased stiffness can be attributed to the construction details of the ceiling. Adding a drop ceiling would not increase the stiffness of the system. The ceilings in this study were attached to resilient channel that was directly attached to the underside of the floor joists. The resilient channel was run perpendicular to the joist direction and spaced 12" (305 mm) on centre. The resilient channel braced the bottom flange of the joists and increased the continuity of the floor system. This stiffness was further increased by installing the gypsum board to the resilient channel. Though the ceiling increased stiffness, the added mass outweighed the stiffness effects and the fundamental frequency was still decreased. The addition of a ceiling did not conclusively influence the damping of the floor systems.

Previous research performed at the University of Waterloo examined the influence of a ceiling on the vibration characteristics of floor systems supported by cold-formed steel joists. In this study the ceiling was directly attached to the bottom flange of the joist, without using resilient channel. This research also found that adding a ceiling reduced the fundamental frequency and decreased the centre deflection of the floor system (Tangorra F. , 2005).

The addition of a ceiling has both positive and negative influences on the vibration performance of the floor systems. The decrease in fundamental frequency is seen as a negative impact. This decrease may bring the fundamental frequency closer to the increased human sensitivity range of 4 – 8 Hz. The decrease in centre deflection is seen as a positive impact on the vibration performance. If the centre deflection is decreased then the amplitude of deflection under a walking excitation will be decreased, and therefore, less noticeable to the occupants. During the floor design stage a drop or suspended ceiling should not be specified. A drop ceiling will negatively impact the vibration performance by lowering the fundamental frequency, but the stiffness of the floor will not be increased. If a ceiling is required, it should be attached to resilient channel that is directly fastened to the bottom flange of the floor joists.

4.6 Effect of Strongback

To determine the effect of a strongback, the results from 12 different laboratory floor systems were used for a total of six comparisons. Two different strongback configurations were tested. The first configuration was a strongback fastened to each floor joist, and the ends of the strong back were free to deflect. Four floor systems were tested in this configuration and two comparisons were made. The second configuration was a strongback attached to each floor joist, and the ends of the strongback were fastened to rigid columns. The attachment of the ends of the strongback restricted the deflection of the ends. The strongback with fixed ends configuration was tested to reflect real word conditions. When a strongback is used on a floor system in the field, the ends of the strongback are connected to the wall studs. In testing, the wall studs were simulated by metal columns fastened to the testing apparatus. Eight floor systems were tested in this configuration and four comparisons were made. All six comparisons were made in the balloon framing, platform framing without end restraint and platform framing with end restraint conditions. The following table shows the results of these comparisons in each framing condition.

Table 4.6: Strongback Comparison

Floor Name	Strongback (yes/no)	Joist Type	Subfloor	f_1 (Hz) Heel Drop	f_2 (Hz) Heel Drop	ζ (%) Heel Drop	Δ_{centre} (mm)	Δ_{centre} (in)	Load Sharing Factor
Balloon Framing									
LF17.0A	No	TDW 14ga.	2	14.7	20.0	4.17	0.30	0.012	N/A
LF17.0B	Yes	TDW 14ga.	2	14.7	19.6	3.65	0.27	0.011	N/A
LF17.0C	No	TDW 14ga.	3	14.3	18.4	3.29	0.25	0.010	N/A
LF17.0D	Yes	TDW 14ga.	3	14.2	19.9	3.32	0.22	0.009	N/A
LF19.5A	No	TDW 14ga.	2	11.9	17.0	2.95	0.33	0.013	N/A
LF19.5Aiii	Yes++	TDW 14ga.	2	12.9	22.7	3.88	0.30	0.012	N/A
								0.000	
LF19.5Ai	No	TDW 14ga.	2	12.7	18.6	3.60	0.37	0.015	N/A
LF19.5Aii	Yes++	TDW 14ga.	2	13.2	24.3	4.25	0.35	0.014	N/A

LF19.5B	No	TDW 14ga.	3	11.4	16.8	3.63	0.28	0.011	N/A
LF19.5Biii	Yes++	TDW 14ga.	3	9.9	14.8	2.48	0.26	0.010	N/A
LF19.5Bi	No	TDW 14ga.	3	11.9	17.6	2.92	N/A	N/A	N/A
LF19.5Bii	Yes++	TDW 14ga.	3	12.6	18.9	3.94	0.29	0.011	N/A
Platform Framing No End Restraint (B0)									
LF17.0A	No	TDW 14ga.	2	13.2	18.8	4.37	0.34	0.013	0.67
LF17.0B	Yes	TDW 14ga.	2	13.1	18.0	3.76	0.32	0.013	0.64
LF17.0C	No	TDW 14ga.	3	12.7	18.3	3.36	0.26	0.010	0.61
LF17.0D	Yes	TDW 14ga.	3	12.9	18.3	3.87	0.24	0.009	0.64
Platform Framing With End Restraint (B1)									
LF17.0A	No	TDW 14ga.	2	13.4	19.3	3.68	0.32	0.013	0.54
LF17.0B	Yes	TDW 14ga.	2	13.1	19.3	5.15	0.29	0.011	0.52
LF17.0C	No	TDW 14ga.	3	12.7	19.8	3.26	0.25	0.010	0.49
LF17.0D	Yes	TDW 14ga.	3	13.1	20.2	3.55	0.23	0.009	0.51

Note: For the load sharing value, a smaller value indicates better load sharing

++ indicates strongback ends were connected to columns (simulating wall studs), during testing
For Subfloor Column:
1: 3/4” (19 mm) OSB
2: 3/4” (19 mm) Fortacrete
3: 9/16” x 30” x 22 ga. (14.3 mm x 762 mm x 0.76 mm) metal form deck

From the results shown above, adding a strongback with free ends had a conclusive effect on the centre deflection of the floor systems. Adding a strongback with fixed ends had a conclusive effect on the first natural frequency, damping ratio and deflection of the floor systems. When a strongback with free ends was added to the floor system the centre deflection was decreased in all cases. On average, the floor systems with a strongback with free ends showed a decrease in centre deflection by 11.7%, 7.0% and 9.1% for balloon framing, platform framing with no end restraint and platform framing with end restraint respectively. The decrease in centre deflection can be attributed to the added transverse stiffness from the strongback. The strongback with free ends had no conclusive effect on the fundamental frequency of the floor system because there was no increase in the longitudinal stiffness of the floor system. The first mode of vibration for the floor system is a half sine wave along the joist direction, which corresponds to the fundamental frequency. If the longitudinal stiffness is not affected, and there is no mass added, there will be no change in the fundamental frequency.

When a strongback with fixed ends was added to the floor system, the vibration performance of the floor system was greatly improved. The strongback with fixed ends increased the fundamental frequency of the floor system in almost all cases. On average, the floor systems with a strongback with fixed ends showed an increase in fundamental frequency by 6.0% for balloon framing. This increase in frequency can be attributed to the increased longitudinal stiffness, and the interruption of the first mode of vibration caused by the strongback. The strongback with fixed ends also increased the damping ratio of the floor system in most cases. On average, the floor systems with a strongback with fixed ends showed an increase in damping ratio by 9.0% for balloon framing. This increase in damping can be attributed to the increase in mechanical connections within the floor system and the bending energy absorbed by the strongback. As the floor system vibrates, the fixed ends of the strongback remain static and flexural bending occurs, in the strongback, as the floor oscillates. The increased damping was seen in the fixed end strongback and not in the free end strongback because the free end strongback did not undergo flexure. The strongback with fixed ends also increased the stiffness of the floor system causing a decrease in the centre deflection in all cases. On average, the floor systems with a strongback with fixed ends showed a decrease in centre deflection by 7.5% for balloon framing. The strongback with fixed ends acted like a small, intermediate, transverse support for the floor system, and increased the stiffness.

The strongback with fixed ends greatly improved the vibration performance of the floor systems. The fundamental frequency was increased, the centre deflection was decreased and the damping ratio was increased. The increase in fundamental frequency improves the vibration performance by reducing the chances that resonance will occur due to walking excitation, and distancing the fundamental frequency from the sensitive range of 4 – 8 Hz. The decrease in centre deflection is seen as a positive impact on the vibration performance. If the centre deflection is decreased then the amplitude of deflection under a walking excitation will be decreased, and therefore, less noticeable to the occupants. Increasing the damping present in the floor system will always improve the vibration performance. With more damping the vibration amplitude will decay more quickly, and vibrations will be less noticeable to occupants.

4.7 Effect of Live Load

To determine the effect of a live load, the results from six different laboratory floor systems were used for a total of three comparisons. Three floor systems were tested with a 6psf (0.287kPa) live load and three floor systems were tested without a live load. The live load was added to the floor evenly distributing 50lb (22.7kg) barbell weights along the floor joists. The following figure shows a floor system with the live load applied.

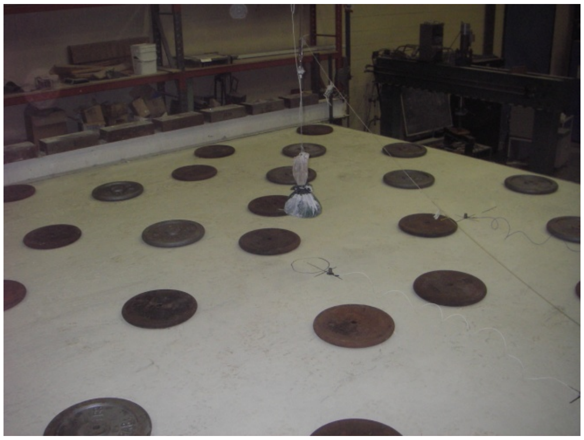


Figure 4.3: Live Load Applied to Laboratory Floor System

It is important to note how the live load was applied during this investigation. Steel weights were placed on the floor in a symmetrical pattern to simulate a 6 psf (0.287 kPa) live load. In most residential floor systems, the live load would be applied by furniture and occupants. The steel weights do not absorb energy during vibration, whereas, furniture and occupants may absorb and dissipate energy. Therefore, no conclusions can be drawn on the influence of this live load on the damping of the floor systems.

All three comparisons were made in the balloon framing, platform framing without end restraint, and platform framing with end restraint conditions. The following table shows the results of these comparisons in each framing condition.

Table 4.7: Live Load Comparison

Floor Name	Live Load (yes/no)	Joist Type	Subfloor	f_1 (Hz) Heel Drop	f_2 (Hz) Heel Drop	ζ (%) Heel Drop	Δ_{centre} (mm)	Δ_{centre} (in)	Load Sharing Factor
Balloon Framing									
LF19.5A	No	TDW 14ga.	2	11.9	17.0	2.95	0.33	0.013	N/A
LF19.5Aiv	Yes	TDW 14ga.	2	10.3	14.8	2.82	0.33	0.013	N/A
LF19.5B	No	TDW 14ga.	3	11.4	16.8	3.63	0.28	0.011	N/A
LF19.5Biv	Yes	TDW 14ga.	3	9.9	14.8	2.48	N/A	N/A	N/A
Platform Framing No End Restraint (B0)									
LF14.5B	No	C-Shape 16ga.	2	17.6	22.3	2.86	0.54	0.021	0.74
LF14.5Bi	Yes	C-Shape 16ga.	2	16.4	24.8	4.00	N/A	N/A	N/A
LF19.5A	No	TDW 14ga.	2	11.2	16.3	4.13	0.35	0.014	N/A
LF19.5Aiv	Yes	TDW 14ga.	2	9.9	14.6	3.17	0.35	0.014	N/A
Platform Framing With End Restraint (B1)									
LF19.5A	No	TDW 14ga.	2	11.7	17.2	3.44	0.34	0.013	N/A
LF19.5Aiv	Yes	TDW 14ga.	2	10.3	15.2	2.33	0.34	0.013	N/A

Note: For the load sharing value, a smaller value indicates better load sharing

For Subfloor Column:
1: 3/4" (19 mm) OSB
2: 3/4" (19 mm) Fortacrete
3: 9/16" x 30" x 22 ga. (14.3 mm x 762 mm x 0.76 mm) metal form deck

From the results shown above, adding 6psf (0.287kPa) live load had a conclusive effect on the fundamental frequency of the floor systems. The added mass from the live load lowered the fundamental frequency of the floor system in all cases. On average, the floor systems with a live load had a lower fundamental frequency by 14.3%, 9.7% and 12.7% for balloon framing, platform framing with no end restraint and platform framing with end restraint respectively. The live load had no conclusive effect on the deflection or damping of the floor systems tested.

4.8 Effect of Framing Condition

To determine the effect of the joist end framing condition, results from four different laboratory floor systems were used for a total of four comparisons. The three types of framing conditions examined were balloon framing, platform framing without end restraint, and platform framing with end restraint. Almost all floor systems tested in the laboratory were tested in all three framing conditions. Four floor systems were chosen for comparison to show the effects of the framing condition on the vibration characteristics of the floor. The following table shows the results from the comparisons.

Table 4.8: Framing Condition Comparison

Floor Name	Framing Condition	Joist Type	Subfloor	f_1 (Hz) Heel Drop	f_2 (Hz) Heel Drop	ζ (%) Heel Drop	Δ_{centre} (mm)	Δ_{centre} (in)	Load Sharing Factor
LF14.5E	BF	TDW 16ga.	2	17.7	22.6	2.56	0.22	0.009	N/A
	B0	TDW 16ga.	2	15.2	21.2	4.81	0.25	0.010	0.70
	B1	TDW 16ga.	2	15.8	21.7	4.54	0.24	0.009	0.67
LF17.0A	BF	TDW 14ga.	2	14.7	20.0	4.17	0.30	0.012	N/A
	B0	TDW 14ga.	2	13.2	18.8	4.37	0.34	0.013	0.67
	B1	TDW 14ga.	2	13.4	19.3	3.68	0.32	0.013	0.54
LF19.5A	BF	TDW 14ga.	2	11.9	17	2.945	0.33	0.013	N/A
	B0	TDW 14ga.	2	11.2	16.3	4.13	0.35	0.014	0.58
	B1	TDW 14ga.	2	11.7	17.2	3.44	0.34	0.013	N/A
LF21.8A	BF	(2) TDW 16ga.	3	11.7	16.9	3.295	0.28	0.011	N/A
	B0	(2) TDW 16ga.	3	9.7	14.3	3.53	0.34	0.013	0.71
	B1	(2) TDW 16ga.	3	9.9	15.4	3.525	0.31	0.012	N/A

Note: For the load sharing value, a smaller value indicates better load sharing
BF: Balloon Framing
B0: Platform framing without end rotational restraint

B1: Platform framing with end rotational restraint
For Subfloor Column:
1: 3/4” (19 mm) OSB
2: 3/4” (19 mm) Fortacrete
3: 9/16” x 30” x 22 ga. (14.3 mm x 762 mm x 0.76 mm) metal form deck

From the results shown above, the framing condition had a conclusive effect on the fundamental frequency, damping ratio, centre deflection and load sharing capabilities of the floor system. The balloon framing condition provided the most end restraint and created the stiffest floor configuration. The increased stiffness increased the fundamental frequency and decreased the centre deflection of the floor system. On average, the balloon framing condition increased the fundamental frequency by 12.7% and 9.7% when compared to platform framing without end rotational restraint, and platform framing with end rotational restraint respectively. The centre deflection was decreased when the balloon framing technique was used. On average, the balloon framing condition decreased the centre deflection by 12.6% and 7.1% when compared to platform framing without end rotational restraint, and platform framing with end rotational restraint respectively. The end restraint provided by the balloon framing is associated with the connection technique at the joist end. The rim track had a punch-out tab that was fastened to the web of the joist with three, #10, light gauge metal screws. The balloon framing connection technique provided the most end rotational stiffness, out of all the framing techniques tested.

The platform framing without end restraint was found to be the most flexible floor configuration. The increased flexibility and the free ends of the floor system absorbed more energy during vibration, and provided the highest damping ratio of the three framing conditions. On average, platform framing without end rotational restraint increased the damping ratio by 26.5% and 10.3% when compared to balloon framing and platform framing with end rotational restraint respectively. The load sharing capability was only examined on the two platform framing conditions. The increased transverse stiffness provided by the platform framing with end restraint increased the load sharing capability over the platform framing without end restraint in every case. On average, the platform framing with end rotational restraint increased the load sharing by 12.9% when compared to platform framing without end rotational restraint.

Out of the three framing conditions tested, the balloon framing condition improved the vibration performance. The balloon framing condition increased the fundamental frequency, and decreased the centre deflection, thereby improving the vibration performance.

4.9 Recommended Construction Practices Based on Findings

When designing residential floor systems where vibration performance is a concern, it is very important to consider the construction materials and construction details that will be implemented. From the research performed on laboratory floor systems and field floor systems, the following construction materials and details are recommended to designers who want to limit annoying floor vibrations that can occur in residential floor systems. When using current vibration design criteria, the results are very sensitive to the amount of damping assumed in the floor system. This section proposes a conservative design value for damping in residential floor systems supported by cold-formed steel joists.

1. Installing a metal deck subfloor, rather than an OSB or Fortacrete subfloor, will decrease the deflection of the floor system and increase the load sharing capabilities. The metal deck should be finished with a lightweight concrete topping to substantially stiffen the floor system and increase the mass. Increasing the stiffness, load sharing capability, and mass of the floor system will improve the vibration performance. If choosing between an OSB and Fortacrete subfloor, the Fortacrete subfloor should be chosen to improve the vibration performance of the floor system. The Fortacrete will increase the floor stiffness and increase the mass, when compared to OSB.
2. To further increase the stiffness and mass, and decrease the centre deflection of the floor system a gypsum board ceiling should be specified for the underside of the floor. Specifying a drop ceiling will not increase the stiffness and should be avoided where vibration performance is a concern. The ceiling should be attached directly to the underside of the joists by specifying resilient channel running perpendicular to the joist direction spaced 12” (305 mm) on centre.

3. The joist end framing condition was found to have a substantial influence on the vibration performance a floor system. It is recommended that joist end restraint be provided to improve the vibration performance. From this study it was found that balloon framing provided the greatest joist end restraint and increased the stiffness of the floor system. This added stiffness increased the fundamental frequency and decreased the centre deflection of the floor system. Increasing the fundamental frequency is the best way to improve the vibration performance of a floor system.
4. The design detail that most effectively improved the vibration performance of a floor system was the addition of a strongback with the ends fixed to wall studs. The application of a strongback with fixed ends increased the fundamental frequency, decreased the deflection, and increased the damping of the floor system. The strongback was the only design detail that was found to increase the damping of a floor system. The increased fundamental frequency and the increase in damping provided by the strongback, will significantly limit the annoying vibrations present in residential floor systems. However, the effectiveness of the strongback with fixed ends is expected to decrease as the floor width increases. This is because as the floor width increases, the distance between the fixed ends of the strongback increases. When the length of the strongback increases, flexural stiffness decreases, and the benefits seen from the strongback with fixed ends will decrease.
5. When designing lightweight floor systems supported by cold-formed steel joists, it is important to select the correct damping ratio used in calculations. The calculation methods used in the AISC and ATC are extremely sensitive to the damping ratio chosen (Kraus & Murray, 1997), and choosing an incorrect damping ratio can result in unconservative floor designs.

   Based on the findings from this research, it is recommended that 4% damping be used in calculations for residential floor systems supported by cold-formed steel joists. This value was based on results from field testing and laboratory testing, and previous vibration testing performed on cold-formed steel joist floor systems. From the research performed for this thesis, the average damping ratio for the laboratory floor systems was found to be 3%, and the average damping ratio for field floor systems was found to be 5%. More field testing was performed in 2006 at the University of Waterloo. Five in situ floor systems were tested and the average damping ratio was found to be 6% (Xu & Tangorra, 2007). The recommended design value of 4% is a conservative estimate. All of the laboratory and field tests were performed on bare, unfinished floor systems. One model home was tested with finished floors and furniture. The damping ratio found from this experiment was 7%.

It is important to note that 4% damping is only recommended for residential floor systems supported by cold-formed steel joists. To determine the damping ratio for other cold-formed steel floor systems, the use of the floor needs to be taken into consideration. For example, the damping present in an office floor system with no partitions will be significantly less than a typical residential floor system with partitions and furniture.

4.10 Comparison between Laboratory and Field Results

The purpose of the field testing was to obtain the vibration characteristics of in situ floor systems, and validate the results from the laboratory experiments to ensure that the laboratory results represented a conservative model, with regards to vibration performance. The testing procedure for the field floor system can be found in Chapter 3.

Two model units were tested at the City Green Development. One model home was furnished (CGMH6) and the other was unfurnished (CGMH7). The purpose of testing the model unit was to evaluate the effects of the furnishings on the vibration characteristics of the floor system. The following table displays the results from the field tests, as well as a comparison between the results from field tests and the matching laboratory floor system results. The results were compared based on the fundamental frequency, damping ratio and centre deflection. These characteristics were chosen because they provide insight into the vibration performance of the floor systems.

Table 4.9: Comparisons Between Field and Laboratory Results

Floor Name	Span (ft)	Joist Type	Subfloor	f_1 (Hz) Heel Drop	f_2 (Hz) Heel Drop	ζ (%) Heel Drop	Δ_{centre} (mm)	Δ_{centre} (in)
CW708	14.5	TDW 14ga.	3	18.7	23.2	4.26	N/A	N/A
LF14.5F	14.5	TDW 16ga.	3	16.0	22.6	3.38	0.18	0.007
CW709	21.8	(2) TDW 16ga.	3	9.9	13.1	5.16	N/A	N/A
LF21.8A	21.8	(2) TDW 16ga.	3	11.7	16.9	3.30	0.28	0.011
CW805	19.3	TDW 14ga.	3	11.8	24.3	2.54	N/A	N/A
LF19.5B	19.5	TDW 14ga.	3	11.4	16.8	3.63	0.28	0.011
OK401	14.2	TDW 16ga.	3	18.9	23.5	2.27	N/A	N/A
LF14.5F	14.5	TDW 16ga.	3	16.0	22.6	3.38	0.18	0.007
OK402	14.2	TDW 16ga.	3	20.0	27.1	4.03	N/A	N/A
LF14.5F	14.5	TDW 16ga.	3	16.0	22.6	3.38	0.18	0.007
CG601	17.5	TDW 14ga.	2	13.6	23.4	4.25	0.46	0.018
LF17.0A	17.0	TDW 14ga.	2	14.7	20.0	4.17	0.3	0.012
CG604	14.8	TDW 14ga.	2	16.0	24.0	5.48	0.29	0.011
LF14.5E	14.5	TDW 16ga.	2	17.7	22.6	2.56	0.22	0.009
CGMH6	16.8	TDW 14ga.	2	15.0	22.5	7.28	N/A	N/A
CGMH7	16.8	TDW 14ga.	2	15.4	24.5	7.89	0.35	0.014

For Subfloor Column:
1: 3/4" (19 mm) OSB
2: 3/4" (19 mm) Fortacrete
3: 9/16" x 30" x 22 ga. (14.3 mm x 762 mm x 0.76 mm) metal form deck

The above table shows the comparisons between the field and laboratory results as well as the comparison between the furnished and the unfurnished model home. In almost all cases the floor systems tested in the field had a greater fundamental frequency and a greater damping ratio. In some cases the laboratory floor systems displayed more conservative results, but the difference in frequency, damping ratio and centre deflection in those cases was slight. A conservative floor system would be one that has a higher fundamental frequency, more damping, and less centre deflection. For field floors CG601 and CG604, the fundamental frequency was slightly less, and the centre deflection was greater than the laboratory floors. This decrease in frequency and increase in centre deflection can be attributed to the difference in span length and the application of a sound reducing board between the subfloor and topping layers. In both cases the field floors have a greater span length than the laboratory floors. It was shown in Section 4.1 that an increase in span length will result in a decrease in frequency and an increase in deflection. The sound reducing board was loosely installed on the subfloor layer, and the lightweight concrete topping was installed on top of the sound board. The sound reducing board decreased the shear transfer between the subfloor and the topping. This caused a decrease in floor stiffness which resulted in an increased centre deflection and a decreased fundamental frequency. Floor CW709 has a lower fundamental frequency than LF21.8A. This discrepancy can also be attributed to the installation of the sound reducing board.

The construction details of the field floor systems can be found in Section 3.4. The comparisons made in the above table are between floor systems with similar construction details. The discrepancies in construction details are also explained in Section 3.4. On average the field floor systems had a 5.5% increase in fundamental frequency, a 19.8% increase in damping and a 13.7% decrease in centre deflection over the laboratory floor systems. Therefore, the laboratory floor systems provide a conservative model and the results are valid for practice. The floor systems in the field were supported on all four sides and the floor systems in the laboratory were only supported on two sides. The increased stiffness from the extra support increased the fundamental frequency, and decreased the centre deflection of the field floor systems. The increased damping in the field floor systems can be attributed to the added mechanical connections in the support walls and the presence of small partition walls in some cases. The field floors were constructed with walls above and below the floor edges. The mass of the walls, and the gypsum board on the walls improved the vibration performance of the field floors. The comparisons between field and laboratory results presented in this thesis agree well with previous research performed at the

University of Waterloo (Xu & Tangorra, 2007). Research performed by Xu and Tangorra found that field floor systems generally display higher fundamental frequencies, decreased centre deflection and greater damping than equivalent laboratory floors (Xu & Tangorra, 2007).

The model homes were examined to determine the effects of furnishings and finishes on the vibration characteristics of a floor system. CGMH6 was furnished with two couches, a coffee table, two standing light fixtures and the floor was finished with tile. CGMH7 was the exact same structural configuration and layout as CGMH6, but there were no furnishings or floor finishes. The results from the two tests are very similar with regards to fundamental frequency and damping ratio. The deflection was only measured in CGMH7 to avoid damage to the furnished model home. The results from this comparison show that floor finishes and furnishing provide little, to no improvement in the vibration performance of a floor system. It is important to note that this conclusion is only based on one experimental investigation, but the results agree with previous field studies performed at the University of Waterloo. Xu and Tangorra performed dynamic and static testing on furnished an unfurnished model homes. They found that the vibration characteristics of field floor systems were relatively the same between finished and unfinished floor systems. (Xu & Tangorra, 2007).

Chapter 5
Acceptability Criteria

A key aspect of this investigation was to establish whether the floor systems and construction details achieved acceptable levels of vibration for occupant comfort. The previous section discussed how certain construction details could influence the dynamic characteristics of floor systems, and their response. This section will evaluate the performance of each floor system based on the acceptability criteria and vibration models presented in the floor design guides published by the Applied Technology Council (ATC, 1999), National Building Code of Canada (NBC, 2005) and American Institute of Steel Construction (AISC, 1997).

Several organizations have published design guides to assist structural designers in predicting whether the vibration performance of a floor system will satisfy criteria for occupant comfort. The design guides are intended to be used in the pre-construction phase, or for retrofit of unacceptable floors. The three design guides examined in this study were chosen because they are commonly used in North America; the models and acceptability criteria are reasonable and based on accepted research; the criteria can be conveniently applied to the dynamic characteristics of the floors tested in this study; and they vary from other design methods previously examined. Previous research performed at the University of Waterloo, compared the results from experimentation against the Swedish Design Method, Australian Standard, Canadian Wood Council Design Method, ATC and Johnson's Design Method (Tangorra F. , 2005). The authors' omission of other design guides and acceptability criteria is not to be interpreted as a commentary on their quality or suitability for predicating acceptable floor vibrations.

5.1 Resonance Model Acceptability Criteria

The AISC and ATC design guides use the following equation (7) to determine the acceleration (as a fraction of gravity) response of a floor under walking excitation:

$$\frac{a_p}{g} = \frac{P_o e^{-0.35fn}}{\beta W} \tag{7}$$

where P_o is a constant excitation force (65 lb for offices and residences), f_n is the fundamental frequency of the floor, and βW is the product of the modal damping ratio and effective weight of the floor (AISC, 1997). This equation was taken from work performed by Murray, and was intended for use on concrete floors supported by structural steel members (Murray, Allen, & Unger, 1997).

The equation was rearranged to determine a minimum acceptable f_n as a function of βW with a maximum allowable a_p of 0.5 %g as show below:

$$f_n \geq \frac{-ln\left(\frac{a_p \beta W}{g\ P_o}\right)}{0.35} \tag{8}$$

The measured floor dynamic characteristics (frequency, mass and damping ratio) for the tested floors in balloon and platform framing are plotted on the same axes as this lower frequency limit. The measured floor properties (frequency and damping ratio) for the field test floor systems are also plotted against the minimum frequency limit.

The floor weight is a function of the effective width of the floor systems. The effective widths of the laboratory floor systems were found to be from 7 to 9 joists. The effective widths of the laboratory floors were determined by examining the deflection profile of the floor system when subject to a 225 lb (1 kN) load. The effective width was taken as the distance between inflection points in the deflection profile. The effective widths of the field floor systems were found by applying the procedure found in the AISC Design Guide 11. Table 5.1 shows the calculated effective widths for the field floor systems.

Table 5.1: Field Floor Systems Effective Widths

Floor Name	Effective Width (ft)	Effective Width (m)
CW708	8.09	2.47
CW709	10.37	3.16
CW805	10.78	3.29
OK401	7.90	2.41
OK402	7.90	2.41
CG601	9.22	2.81

CG604	9.32	2.84
CG805	11.36	3.46
MH7	10.36	3.16

When the AISC effective width calculation is used, there are two different panels to consider. The effective width can be evaluated based on the joist panel alone or the combined joist and girder panel. In most cases, the combined joist and girder panel mode is used when calculating the effective width. For this study, the only applicable panel is the joist panel. Figure 5.1 shows the results from the laboratory and field results plotted against the minimum frequency curve found using the AISC criteria.

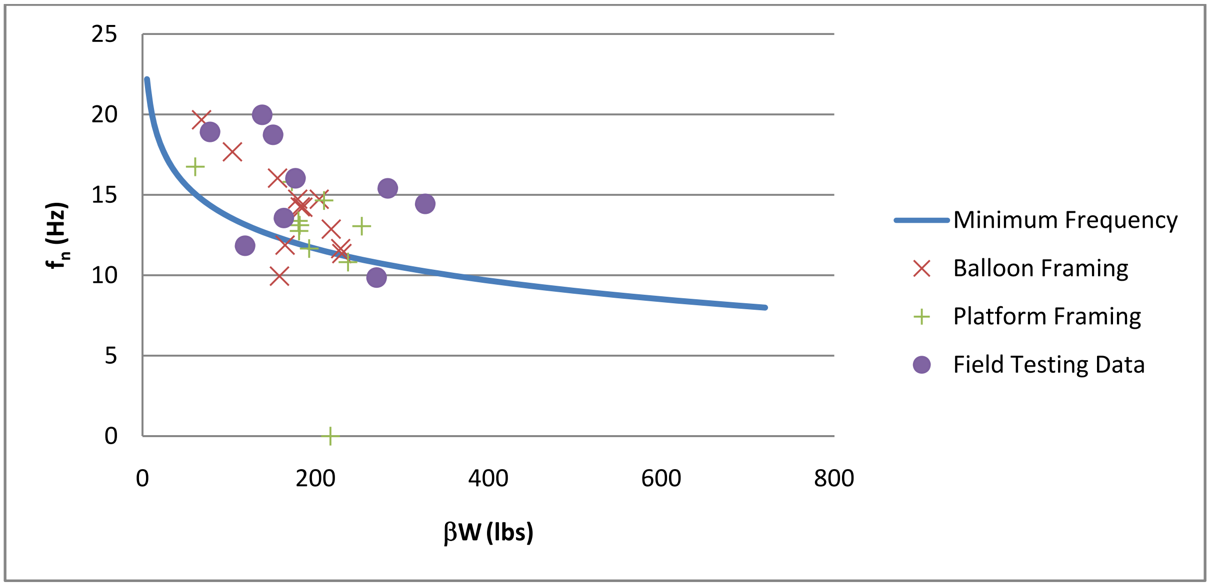


Figure 5.1: Resonance Model Acceptability Criteria (Measured Damping)

It can be seen that for the laboratory floor systems all but two floors in balloon framing (LF19.5A, LF19.5Biii) and three floors in platform framing (LF19.5A, LF19.5B, LF21.8A) meet the minimum frequency criterion. For the field testing floor systems all but two floors (CW709 and CW805) meet the minimum frequency criterion.

Damping ratio can have a significant impact on the performance of a floor under walking excitation in the resonance model. The damping ratios determined for the test floors range between 1 – 5 %. Studies have shown that a value for damping of 12% is appropriate for light-frame construction and 6% for composite steel-concrete construction (ATC, 1999). When an estimate of 6% is used in place of the measured damping ratio, every floor tested in the laboratory and all but one field floor system meet the minimum frequency criterion, as seen in Figure 5.2.

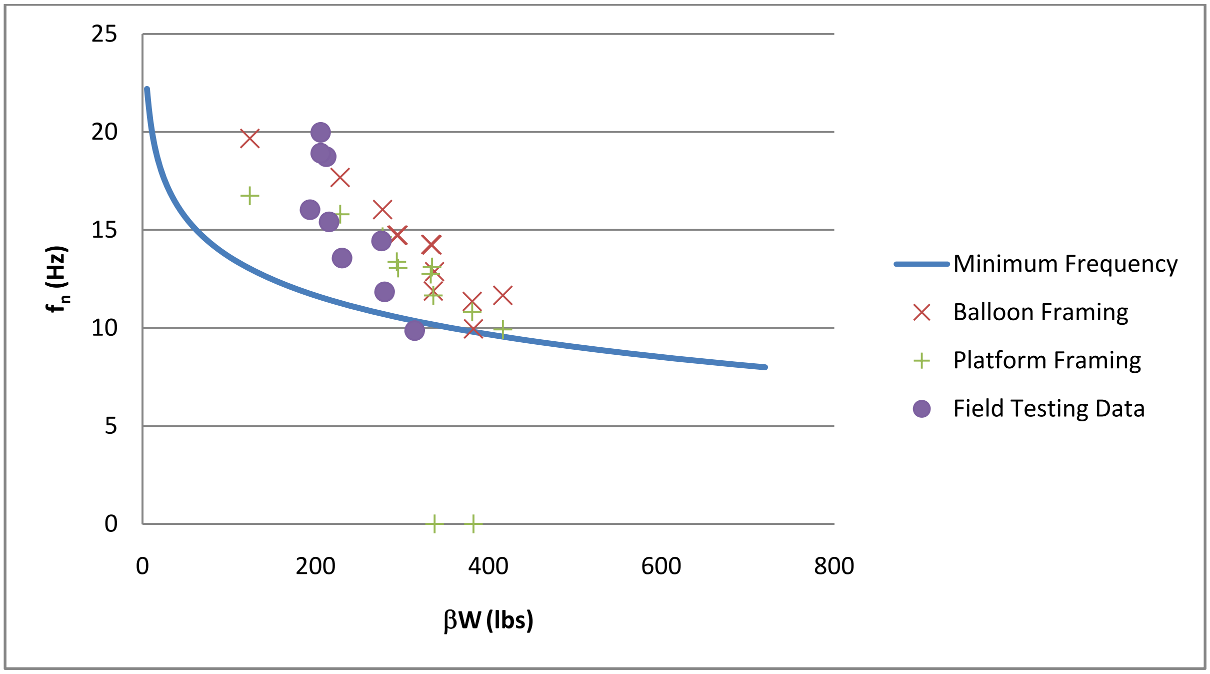


Figure 5.2: Resonance Model Acceptability Criteria (6% Assumed Damping)

5.2 Point-Deflection Model Acceptability Criteria

The ATC and NBC design guides have adopted a deflection criterion based on work by Onysko (first adopted by the 1995 NBCC) for wood floors and adjustments made for engineered wood products (CCMC, 1997). For light-frame floors with a natural frequency greater than 8 Hz, the following limit is used for deflection under a 225 lb (1 kN) point load:

$$\Delta_p \leq 0.024 + 0.1e^{-0.18(L-6.4)} \leq 0.08\ in \qquad (9a)$$

$$\Delta_p \leq 0.61 + 2.54e^{-0.59(L-1.95)} \leq 2.0\ mm \qquad (9b)$$

where *L* is the joist span (ft/m) and deflection is in inches/milimeters (ATC, 1999).

The deflection and span of each laboratory test floor and each field test floor was plotted on the same axes as the maximum deflection allowed from Equation 9. Every floor in the laboratory and in the field satisfies the maximum deflection criterion, as seen in Figure 5.3.

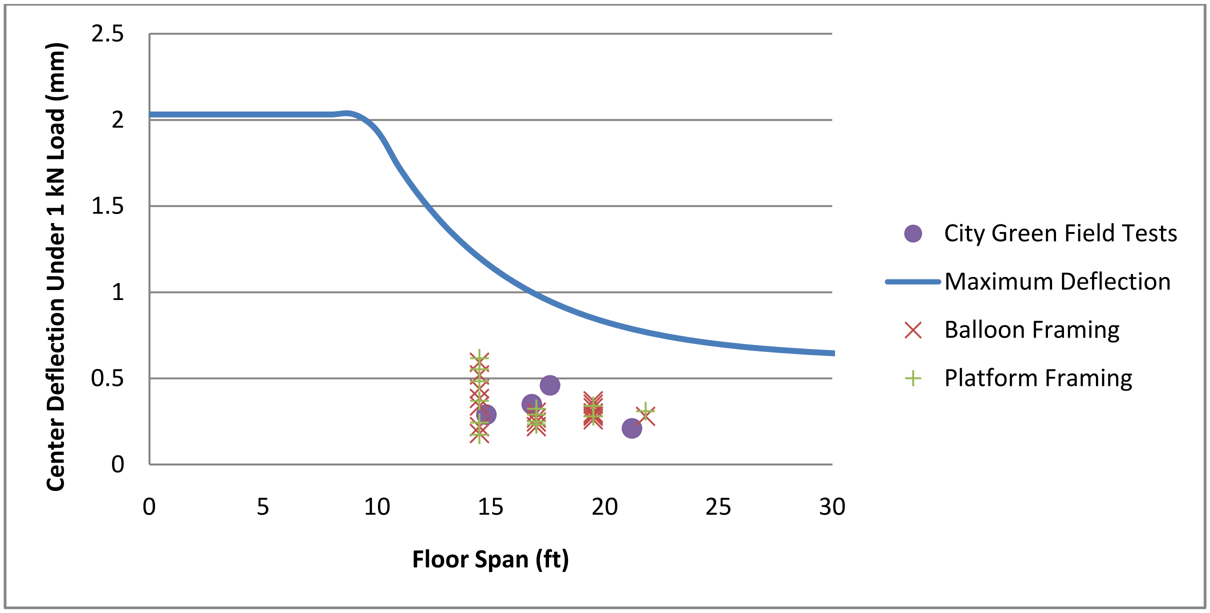


Figure 5.3: Point-Deflection Acceptability Criteria

The point-deflection limitation shown above is based on the assumption that a light-frame floor usually has a natural frequency greater than 10 Hz because of its short span and light weight. In addition, the occupants quickly damp out significant natural vibrations (ATC, 1999). Because of this, annoying floor response is generated by instantaneous deflections of the floor where footfalls from walking occur, and resonance is not a major concern for designers.

Only the City Green field testing results were plotted against the ATC criteria. This is because the City Green field tests were the only field tests where deflection data were recorded.

5.3 Acceptability Criteria Summary

The AISC resonance model and ATC point-deflection model were used as acceptability criteria for evaluating the vibration perceptibility performance of the floors in this study. The criteria were presented as a limiting value to be plotted against measured properties of each floor system. The majority of the test floors met the AISC criterion when the measured damping ration was used. All the laboratory test floors met the AISC criterion when an estimated damping ratio of 6% was used and only one field test did not meet the AISC criterion. All the test floors met the ATC criterion. A summary of the measured and limiting values is shown in Table 5.2 for balloon framing and field tests and Table 5.3 for platform framing.

Table 5.2: Acceptability Summary (Balloon Framing and Field Data)

	AISC Criterion			ATC Criterion	
Floor	**Floor Frequency (Hz)**	**Minimum Required Frequency (Hz)**	**Minimum Required Frequency 6% Damping (Hz)**	**Deflection (mm)**	**Maximum Allowable Deflection (mm)**
LF14.5D	19.7	14.7	13.0	0.34	1.20
LF14.5E	17.7	13.5	11.3	0.22	1.20
LF14.5F	16.0	12.4	10.7	0.18	1.20
LF17.0A	14.7	11.6	10.6	0.30	0.99
LF17.0B	14.7	13.2	10.5	0.27	0.99
LF17.0C	14.3	10.3	10.2	0.25	0.99
LF17.0D	14.2	10.3	10.2	0.22	0.99
LF19.5A	11.9	10.3	10.2	0.33	0.85
LF19.5Aiii	12.9	11.4	10.2	0.30	0.85
LF19.5B	11.4	11.2	9.8	0.28	0.85
LF19.5Biii	9.9	10.3	9.8	0.26	0.85
LF21.8A	11.7	6.0	9.6	0.28	0.77
CW708	18.7	12.5	11.5	N/A	N/A
CW709	9.9	10.8	10.4	N/A	N/A
CW805	11.8	13.2	10.7	N/A	N/A
OK401	18.9	14.3	11.6	N/A	N/A
OK402	20.0	12.7	11.6	N/A	N/A
CG601	13.6	12.2	11.2	0.46	1.50
CG604	16.0	12.0	11.7	0.29	1.54
CG805	14.4	10.3	10.7	0.21	1.88
MH7	15.4	10.7	11.4	0.35	1.79

Note: To reflect in situ conditions only floor systems with ceilings were evaluated with the acceptability criteria

Table 5.3: Acceptability Summary (Platform Framing)

	AISC Criterion			ATC Criterion	
Floor	**Floor Frequency (Hz)**	**Minimum Required Frequency (Hz)**	**Minimum Required Frequency 6% Damping (Hz)**	**Deflection (mm)**	**Maximum Allowable Deflection (mm)**
LF14.5E	15.8	12.1	11.3	0.24	1.20
LF14.5F	14.7	11.5	10.7	0.17	1.20
LF17.0A	13.4	12.0	10.6	0.32	0.99
LF17.0B	13.1	11.0	10.5	0.29	0.99
LF17.0C	12.7	11.9	10.2	0.25	0.99
LF17.0D	13.1	11.9	10.2	0.23	0.99
LF19.5A	11.7	11.8	10.2	0.34	0.85
LF19.5Aiii	N/A	N/A	10.2	N/A	0.85
LF19.5B	10.8	11.4	9.8	0.28	0.85
LF19.5Biii	N/A	N/A	9.8	N/A	0.85
LF21.8A	9.9	11.2	9.6	0.31	0.77

Note: To reflect in situ conditions only floor systems with ceilings were evaluated with the acceptability criteria

Chapter 6

Conclusions

Observations based on the static and dynamic response of the floor systems tested provided several conclusions on the effects of construction details on performance. As span length increases, fundamental frequency decreases, center deflection increases and load sharing capability increases. The use of standard or propriety joists does not affect the static and dynamic response. Compared to OSB subfloor, Fortacrete subfloor results in a floor system with less center deflection and a lower fundamental frequency. Compared to Fortacrete subfloor, metal form deck subfloor results in a floor system with less center deflection and a better load sharing capability. The influence on the fundamental frequency was negligible. The use of a strongback with free ends will reduce center deflection. The use of a strongback with fixed ends will increase the fundamental frequency and damping ratio of the floor system, while decreasing the center deflection. A floor system with balloon framing will have an increased fundamental frequency and decreased center deflection when compared to platform framing. A floor system with platform framing will have a higher damping ratio when compared to balloon framing.

From the research performed on laboratory floor systems and in situ floor systems the following construction materials and details are recommended to designers who want to limit annoying floor vibrations that can occur in residential floor systems. Specify a metal deck with a lightweight concrete topping as the subfloor for the floor system. Specify a ceiling on the underside of the floor system and ensure that the ceiling is attached to the joist through resilient channel. Specify balloon framing for the floor system to provide additional joist end restraint and the most influential design detail to improve the vibration performance of a floor system was the addition of a strong back with ends fixed to wall studs.

Three design guides were selected for evaluating the acceptability of the floor systems tested in this study ATC, NBC and AISC. These design guides were selected because their vibration models and acceptability criteria are reasonable and can be easily used with the measured data from this test program. The main vibration models used for floor performance are the resonance model, point-deflection model, and impulse-response model. Each model has a unique acceptance criterion: limiting acceleration as a function of frequency (resonance), limiting static deflection under a point load (point-deflection), and limiting acceleration or velocity as a function of damping (impulse-response). The responses of the floor systems tested in this study were evaluated using the AISC resonance model for walking vibration and the ATC point-deflection model.

The AISC criterion was presented as a lower limit to the fundamental frequency of the floor as a function of mass and damping. All but three of the laboratory test floor systems and two of the in situ floors evaluated met this acceptability criterion when measured damping was considered. Typically, measured damping was below the 6% value suggested in the design guide. All of the test floor systems except one in situ floor met this acceptability criterion when their damping was estimated to be 6%.

The ATC criterion was presented as an upper limit to the mid-span deflection of the floor system under a 225 lb (1 kN) point load as a function of span length. All of the test floor systems in the laboratory, and in the field, met this acceptability criterion when their measured mid-span deflection under the specified load was used.

6.1 Future Research

After performing the research, testing, and analysis outlined in this research, the following recommendations for future research are made:

- Using the information gained from this study, design equations should be developed that take into account the influence of construction details on the vibration characteristics of cold-formed steel floor systems. Construction details such as strongbacks, and end rotational restraint are not well addressed in current design criteria.
- A database needs to be developed for the laboratory and field testing performed on floor systems supported by cold-formed steel joists. The data base should include testing performed at the University of Waterloo, and other educational institutions

performing research in the area of floor vibrations. The data base could include: construction details of the floor systems; testing performed; and the key dynamic characteristics, such as fundamental frequency, damping ratio and deflection.

- More testing should be performed on under-designed floor systems. The floor systems tested in this study were all constructed with 12” (305 mm) deep joists. The 14.5’ (4.42 m) spans were over-designed, and the influence of certain construction details was not pronounced. Other joist sizes should be tested in order to examine the influence of construction details on shorter spans.
- More research should be performed to quantify influence of partial and full partition walls, on the vibration characteristics of floor systems. Partial and full partition walls could be constructed above and below the floor system, as well as, along the joist direction and perpendicular to the joist direction. The most effective partition wall could be found to improve the vibration performance of floor systems.
- Investigation in improvements to field testing equipment should be performed. For the field testing performed in this study, a large amount of equipment was transported to and from field testing sites. With advancements in software technology, much of the equipment could be reduced, and the ease of field testing could be increased.

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Xu, L., & Tangorra, F. M. (2007). Experimental Investigation of Lightweight Residential Floors Supported by Cold-Formed Steel Joists. *Journal of Contructional Steel Research , 63*, 422-435.

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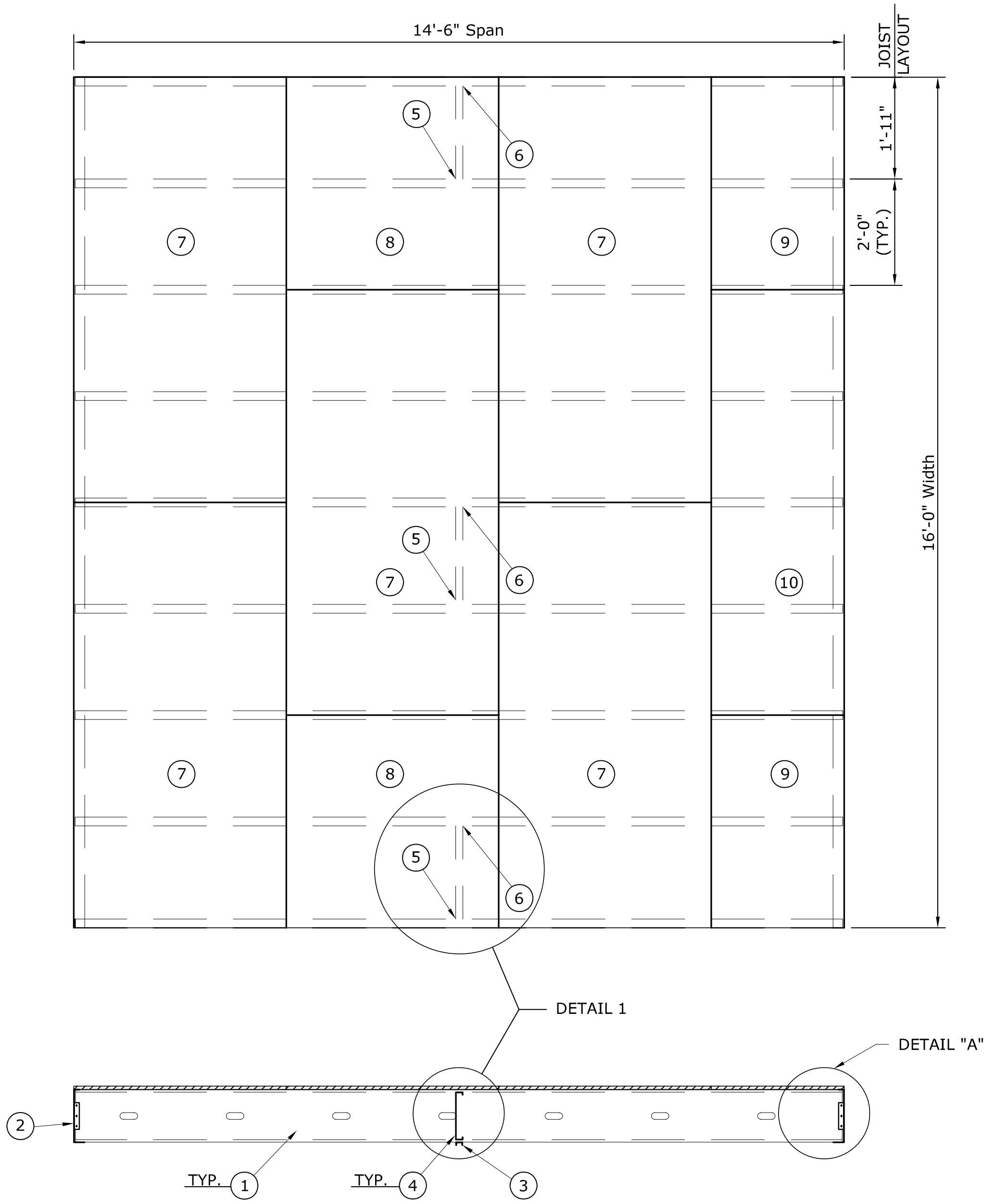
Appendix A

Floor Drawings



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2	2	12" TD24 14GA. RIM TRACK	16'-0"	NOTE 2,3
3	1	CRC BRIDGING	16'-0"	DETAIL 1
4	3	12" CSW 16GA.	1'-9 ¾"	DETAIL 1
5	3	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
6	3	4" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
7	5	3/4" T&G OSB	4'-0" x 8'-0"	NOTE 1
8	2	3/4" T&G OSB	4'-0" x 4'-0"	NOTE 1
9	2	3/4" T&G OSB	4'-0" x 2'-6"	NOTE 1
10	1	3/4" T&G OSB	8'-0" x 2'-6"	NOTE 1

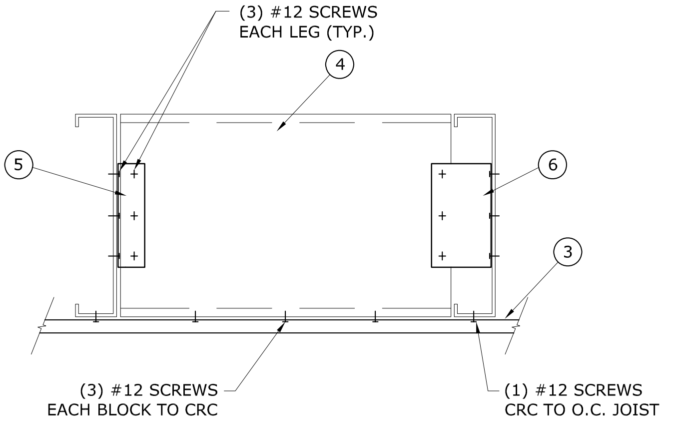
BILL OF MATERIAL

NOTES:

1.) SHEATHING TO FLOOR JOISTS: #10 SCREW - 6" PERIMETER / 12" FIELD

2.) RIM TRACK TO FLOOR JOIST: (3) #12 x 3/4" HWH

3.) RIM TRACK TO STUD: (3) #12 x 3/4" HWH



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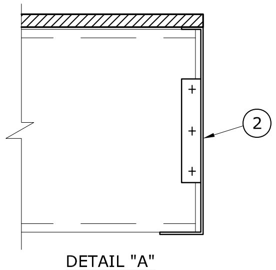

DETAIL "A"

Project Name
PERCEPTIBILITY TEST (12 CSW 16
with ¾" OSB Sheathing)
Location

Project Number

Drawn by
CAD 7

Approved by

Date
6/4/2007

Revisions

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WIBS
WORTHINGTON INTEGRATED BUILDING SYSTEMS
MID-RISE CONSTRUCTION
3100 E. 45th Street
Suite 400
Cleveland, OH 44127
Phone: 216.472.1511
Fax: 216.472.1517

Sheet Description
PANEL A1
LF14.5A

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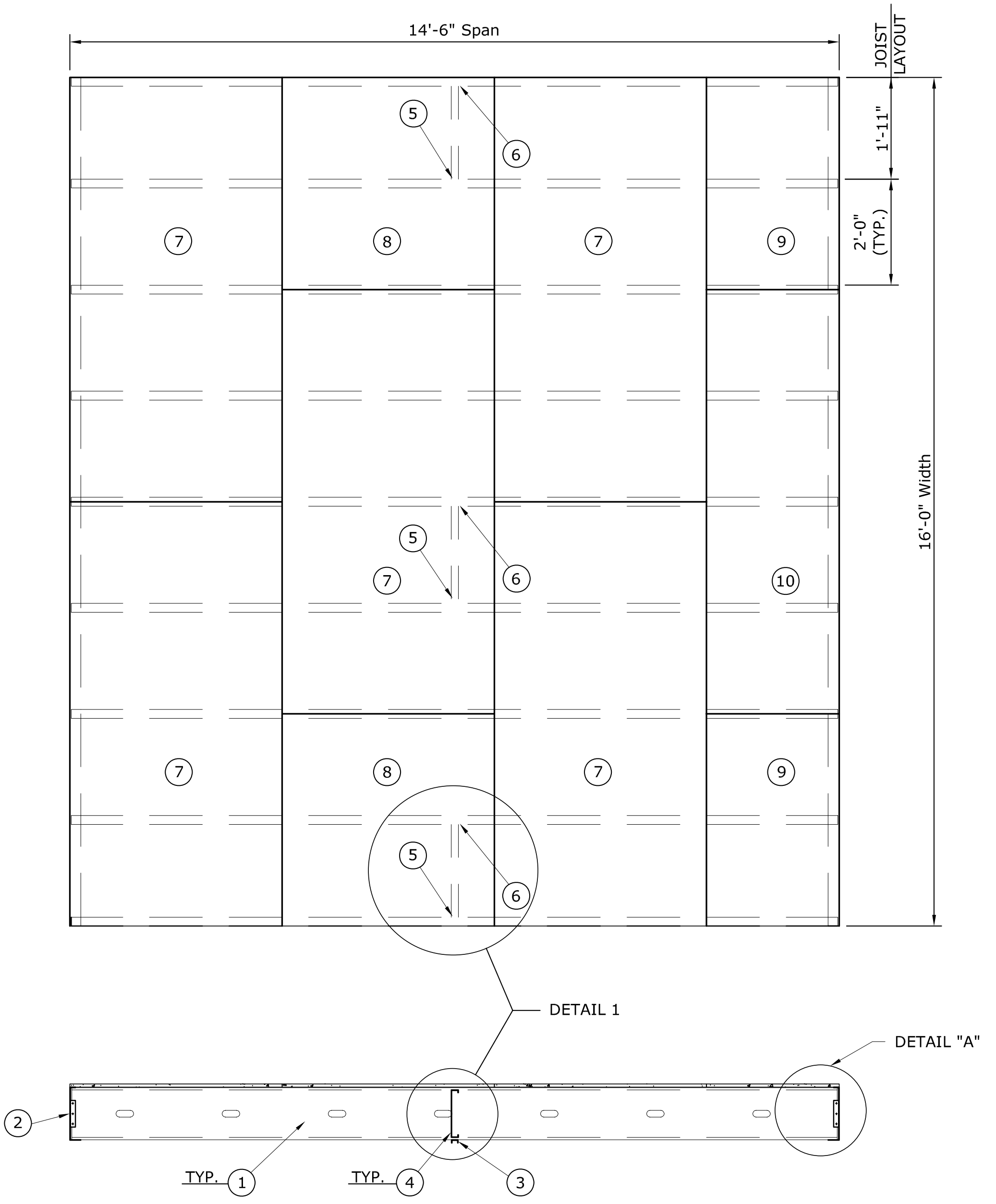

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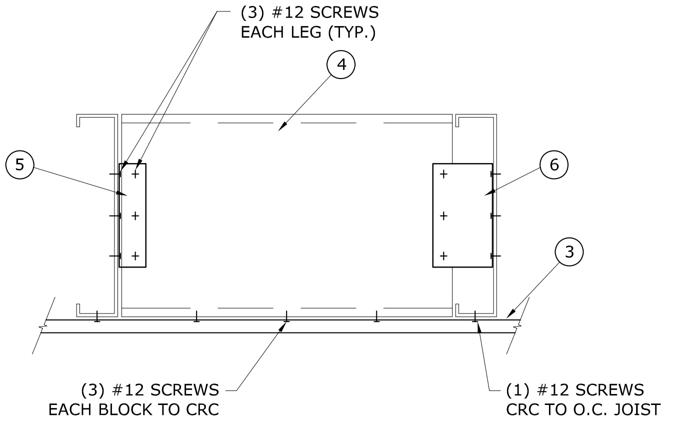
3	1	CRC BRIDGING	16'-0"	DETAIL 1
4	3	12" CSW 16GA.	1'-9 $\frac{3}{4}$"	DETAIL 1
5	3	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
6	3	4" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
7	5	3/4" T&G FORTACRETE	4'-0" x 8'-0"	NOTE 1
8	2	3/4" T&G FORTACRETE	4'-0" x 4'-0"	NOTE 1
9	2	3/4" T&G FORTACRETE	4'-0" x 2'-6"	NOTE 1
10	1	3/4" T&G FORTACRETE	8'-0" x 2'-6"	NOTE 1

NOTES:

1.) SHEATHING TO FLOOR JOISTS: #10 SCREW -
6" PERIMETER / 12" FIELD

2.) RIM TRACK TO FLOOR JOIST: (3) #12 x 3/4" HWH

3.) RIMTRACK TO STUD: (3) #12 x 3/4" HWH



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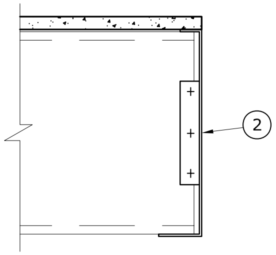

DETAIL "A"

Project Name
PERCEPTIBILITY TEST (12 CSW 16 Joist
With ¾" FortaCrete Sheathing)

Location

Project Number

Drawn by
CAD 7

Approved by

Date
6/4/2007

Revisions

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MID-RISE CONSTRUCTION
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Suite 400
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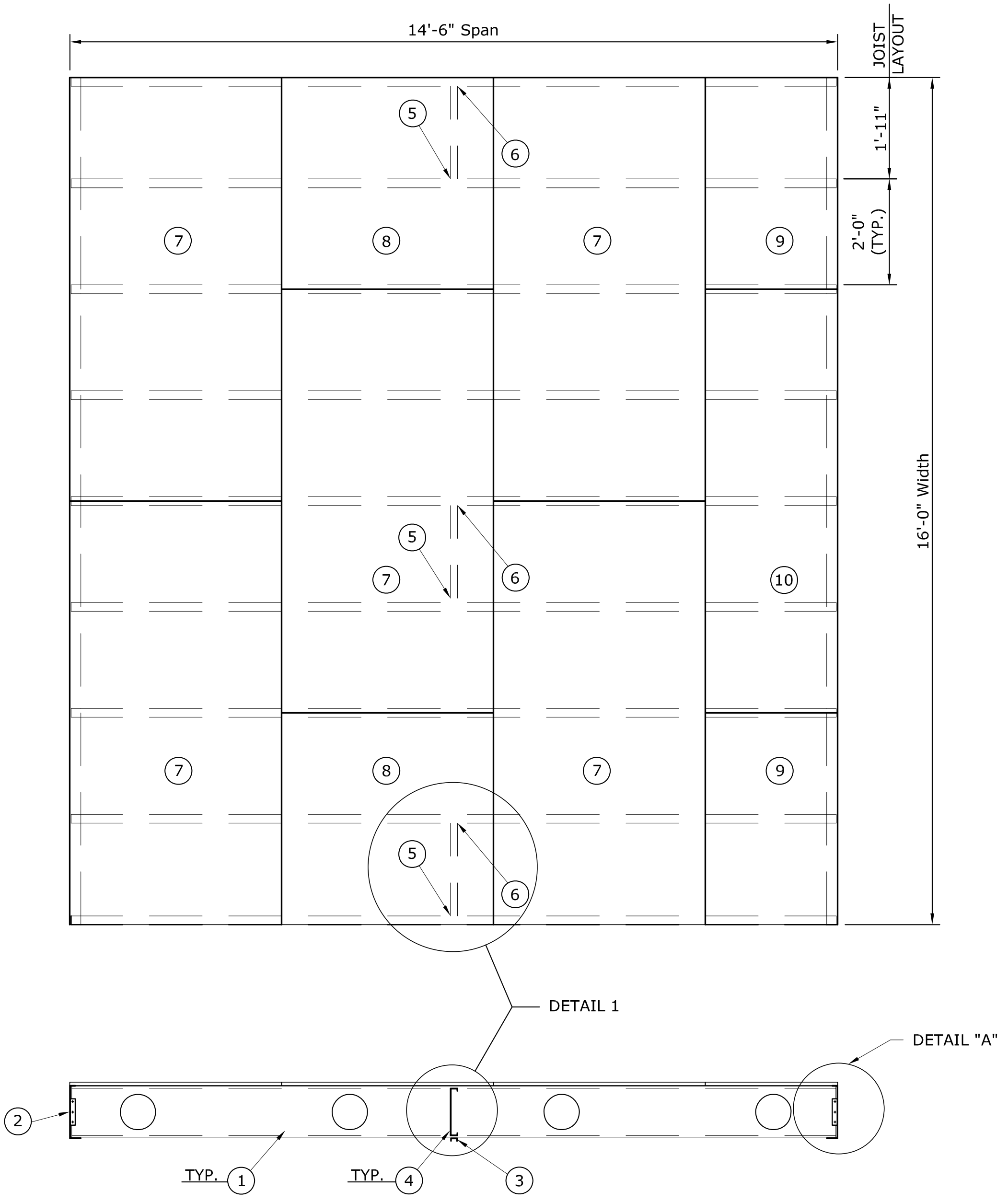

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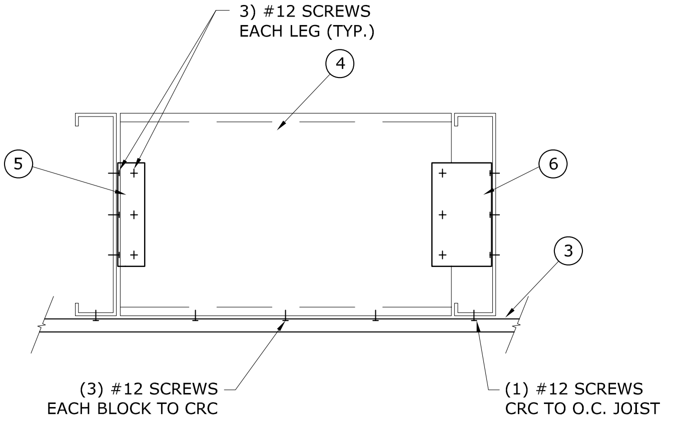
3	1	CRC BRIDGING	16'-0"	DETAIL 1
4	3	12" CSW 16GA.	1'-9 $\frac{3}{4}$"	DETAIL 1
5	3	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
6	3	4" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
7	5	3/4" T&G OSB	4'-0" x 8'-0"	NOTE 1
8	2	3/4" T&G OSB	4'-0" x 4'-0"	NOTE 1
9	2	3/4" T&G OSB	4'-0" x 2'-6"	NOTE 1
10	1	3/4" T&G OSB	8'-0" x 2'-6"	NOTE 1

NOTES:

1.) SHEATHING TO FLOOR JOISTS: #10 SCREW - 6" PERIMETER / 12" FIELD
2.) RIM TRACK TO FLOOR JOIST: (3) #12 x 3/4" HWH
3.) RIM TRACK TO STUD: (3) #12 x 3/4" HWH



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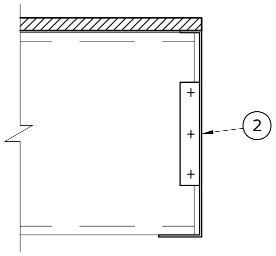

DETAIL "A"

Project Name
PERCEPTIBILITY TEST (12 TDW 16
TradeReady Joist with $\frac{3}{4}$" OSB Sheathing)
Location

Project Number

Drawn by
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Approved by

Date
6/4/2007

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Cleveland, OH 44127
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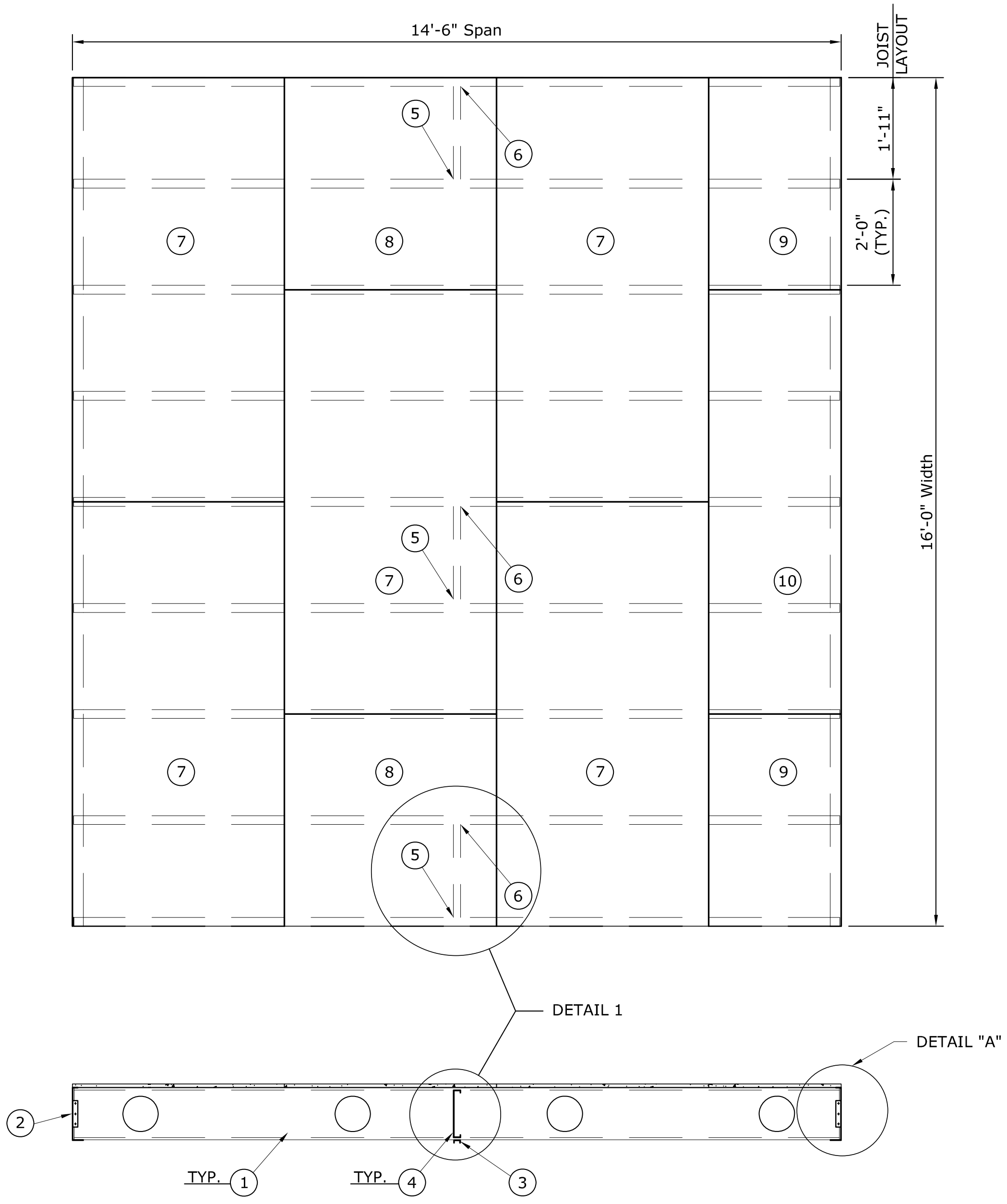

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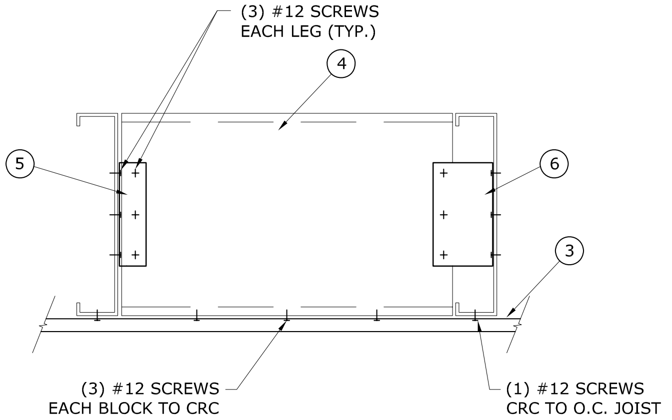
4	3	12" CSW 16GA.	1'-9 $\frac{3}{4}$"	DETAIL 1
5	3	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
6	3	3" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
7	5	3/4" T&G FORTACRETE	4'-0" x 8'-0"	NOTE 1
8	2	3/4" T&G FORTACRETE	4'-0" x 4'-0"	NOTE 1
9	2	3/4" T&G FORTACRETE	4'-0" x 2'-6"	NOTE 1
10	1	3/4" T&G FORTACRETE	8'-0" x 2'-6"	NOTE 1

NOTES:

1.) SHEATHING TO FLOOR JOISTS: 6" PERIMETER / 12" FIELD WITH #10 SCREW

2.) RIM TRACK TO FLOOR JOIST: (3) #12 x 3/4" HWH

3.) RIM TRACK TO STUD: (3) #12 x 3/4" HWH



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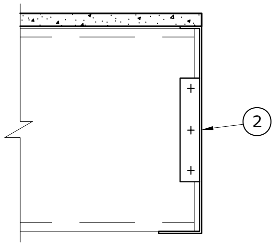

DETAIL "A"

Project Name
PERCEPTIBILITY TEST (12 TDW 16 TradeReady Joist with $\frac{3}{4}$" FortaCrete Sheathing)
Location

Project Number

Drawn by
CAD 7

Approved by

Date
6/4/2007

Revisions

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WORTHINGTON INTEGRATED BUILDING SYSTEMS
MID-RISE CONSTRUCTION
3100 E. 45th Street
Suite 400
Cleveland, OH 44127
Phone: 216.472.1511
Fax: 216.472.1517

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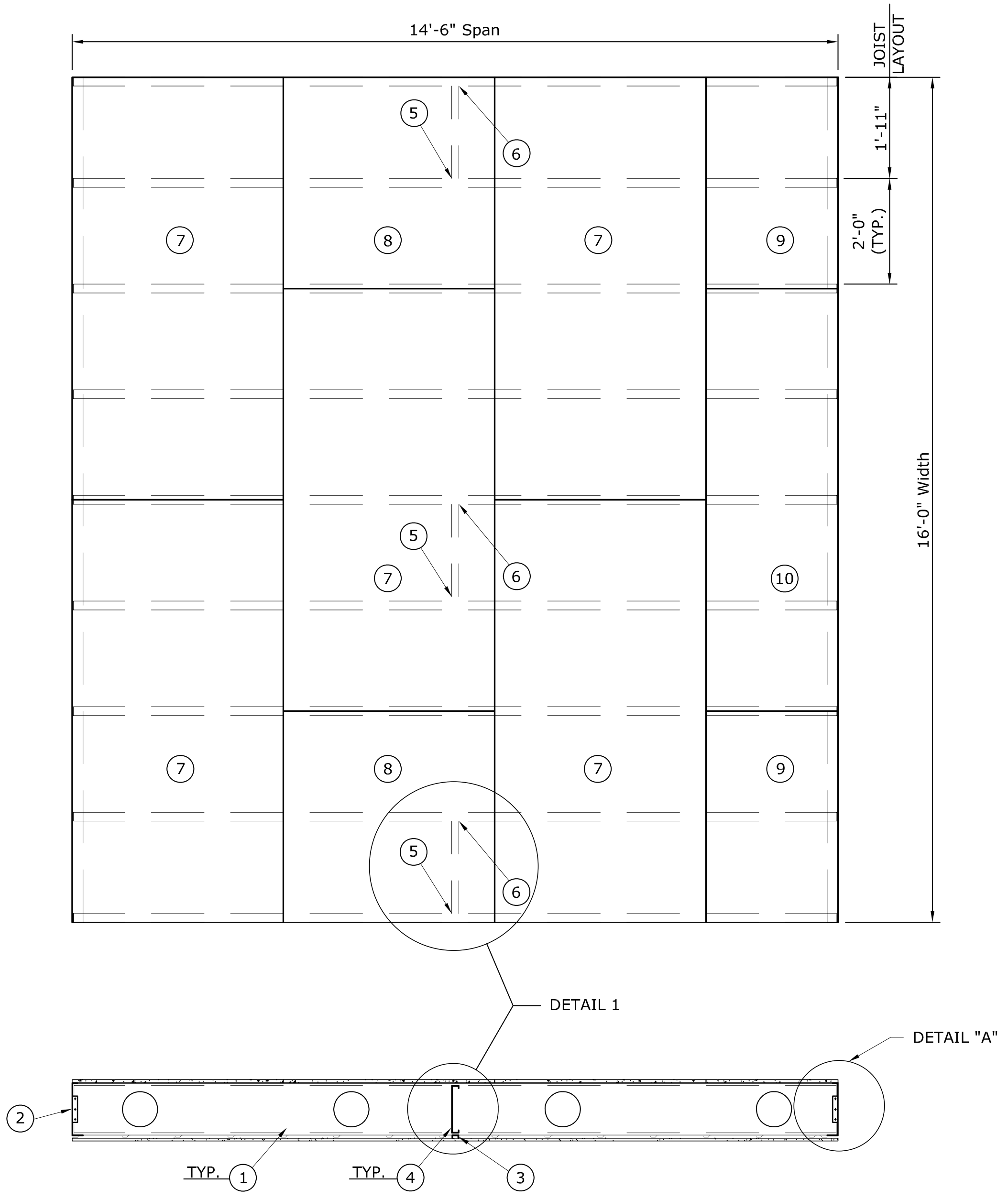

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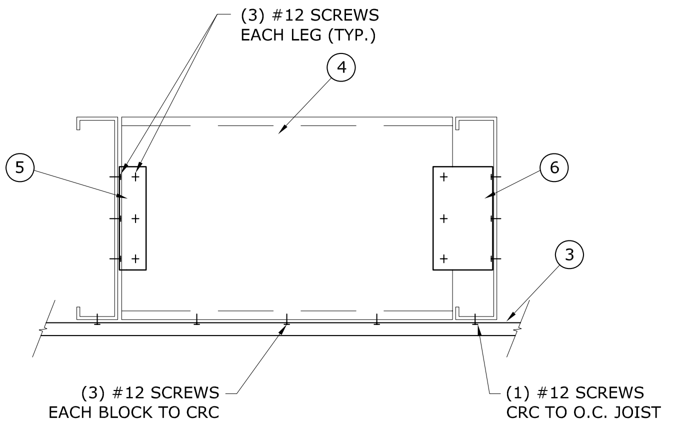
5	3	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
6	3	4" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
7	5	3/4" T&G FORTACRETE	4'-0" x 8'-0"	NOTE 1
8	2	3/4" T&G FORTACRETE	4'-0" x 4'-0"	NOTE 1
9	2	3/4" T&G FORTACRETE	4'-0" x 2'-6"	NOTE 1
10	1	3/4" T&G FORTACRETE	8'-0" x 2'-6"	NOTE 1
11	14	RESILIENT CHANNEL @ 12" OC	16'-0"	NOTE 4
12	8	5/8" DRYWALL TYPE C (4' x 8')	232 SF.	NOTE 5

BILL OF MATERIAL

NOTES:

1.) SHEATHING TO FLOOR JOISTS: 6" PERIMETER / 12" FIELD WITH # 10 SCREW
2.) RIM TRACK TO FLOOR JOIST: (3) #12 x 3/4" HWH
3.) RIM TRACK TO STUD: (3) #12 x 3/4" HWH
4.) RC TO JOIST: (1) #10 SCREW
5.) TYPE C DRYWALL TO RC: 12" PERIMETER/12" FIELD WITH #6 SCREWS



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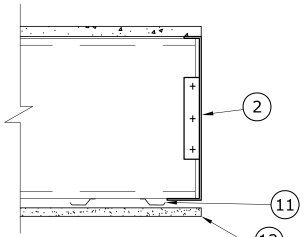

DETAIL "A"

Project Name
PERCEPTIBILITY TEST (12 TDW 16
TradeReady Joist with FortaCrete
Sheathing and Ceiling)
Location

Project Number

Drawn by
CAD 7

Approved by

Date
6/4/2007

Revisions

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WORTHINGTON INTEGRATED BUILDING SYSTEMS
MID-RISE CONSTRUCTION
3100 E. 45th Street
Suite 400
Cleveland, OH 44127
Phone: 216.472.1511
Fax: 216.472.1517

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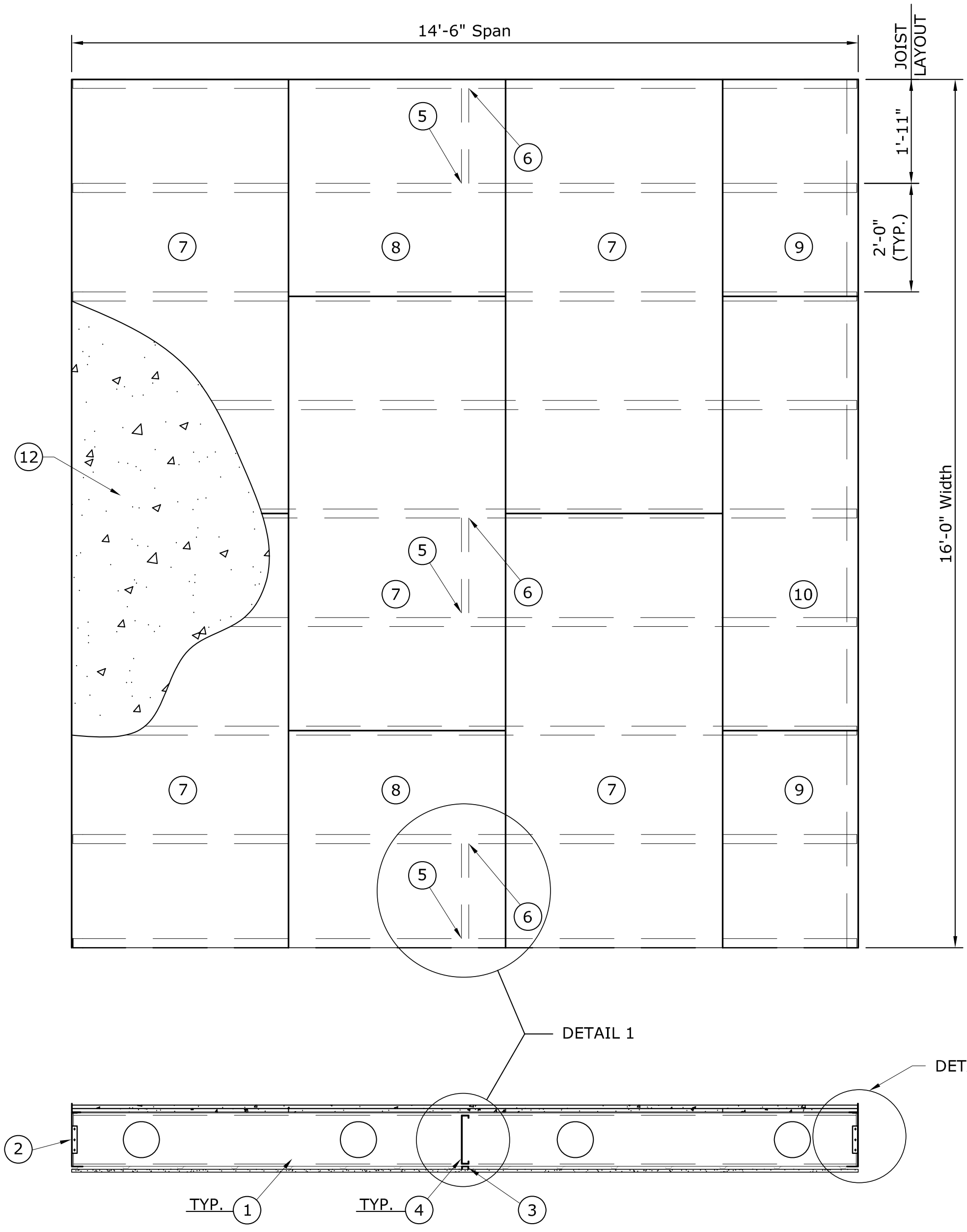

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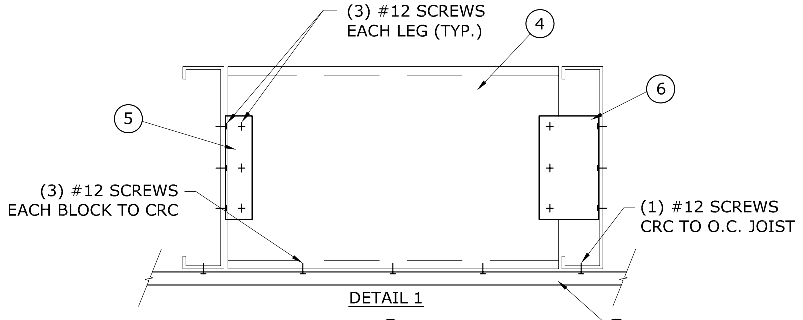
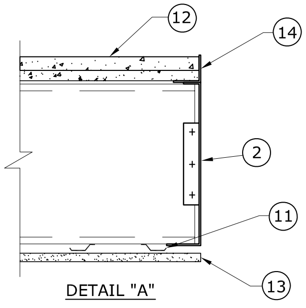
2	2	12" TD24 14GA. RIM TRACK	16'-0"	NOTE 2,3
3	1	CRC BRIDGING	16'-0"	DETAIL 1
4	3	12" CSW 16GA.	1'-9 ¾"	DETAIL 1
5	3	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-11"	DETAIL 1
6	3	4" x 1 1/2" x 16GA. CLIP ANGLE	0'-11"	DETAIL 1
7	5	3/4" T&G FORTACRETE	4'-0" x 8'-0"	NOTE 1
8	2	3/4" T&G FORTACRETE	4'-0" x 4'-0"	NOTE 1
9	2	3/4" T&G FORTACRETE	4'-0" x 2'-6"	NOTE 1
10	1	3/4" T&G FORTACRETE	8'-0" x 2'-6"	NOTE 1
11	14	RESILIENT CHANNEL	16'-0"	NOTE 4
12	-	3/4" LEVELROCK	15 CU. FT.	NOTE 7
13	8	5/8" DRYWALL (4' x 8')	232 SF.	NOTE 5
14	4	2" x 2" x 20GA. ANGLE	16'-0"	NOTE 6

NOTES:

1.) SHEATHING TO FLOOR JOISTS: 6" PERIMETER / 12" FIELD WITH # 10 SCREW
2.) RIM TRACK TO FLOOR JOIST: (3) #12 x 3/4" HWH
3.) RIM TRACK TO STUD: (3) #12 x 3/4" HWH
4.) RC TO JOIST: (1) #10 SCREW
5.) TYPE C DRYWALL TO RC: 12" PERIMETER/12" FIELD WITH #6 SCREWS
6.) PLACE ANGLE POURSTOP ON ALL 4 SIDES BEFORE INSTALLING FORTACRETE TO RIM TRACK AND END JOIST. TAPE CORNERS BEFORE LEVELROCK IS POURED.
7.) ¾" LEVELROCK INSTALLED BY USG CERTIFIED PROVIDER. CREATE TEST CUBES FOR COMPRESSION TEST ON DAY OF FLOOR TESTING.



DETAIL 1



DETAIL "A"

Project Name
PERCEPTIBILITY TEST (12 TDW 16
TradeReady Joist with FortaCrete
& ¾" LevelRock, Ceiling)
Location

Project Number

Drawn by
CAD 7

Approved by

Date
6/4/2007

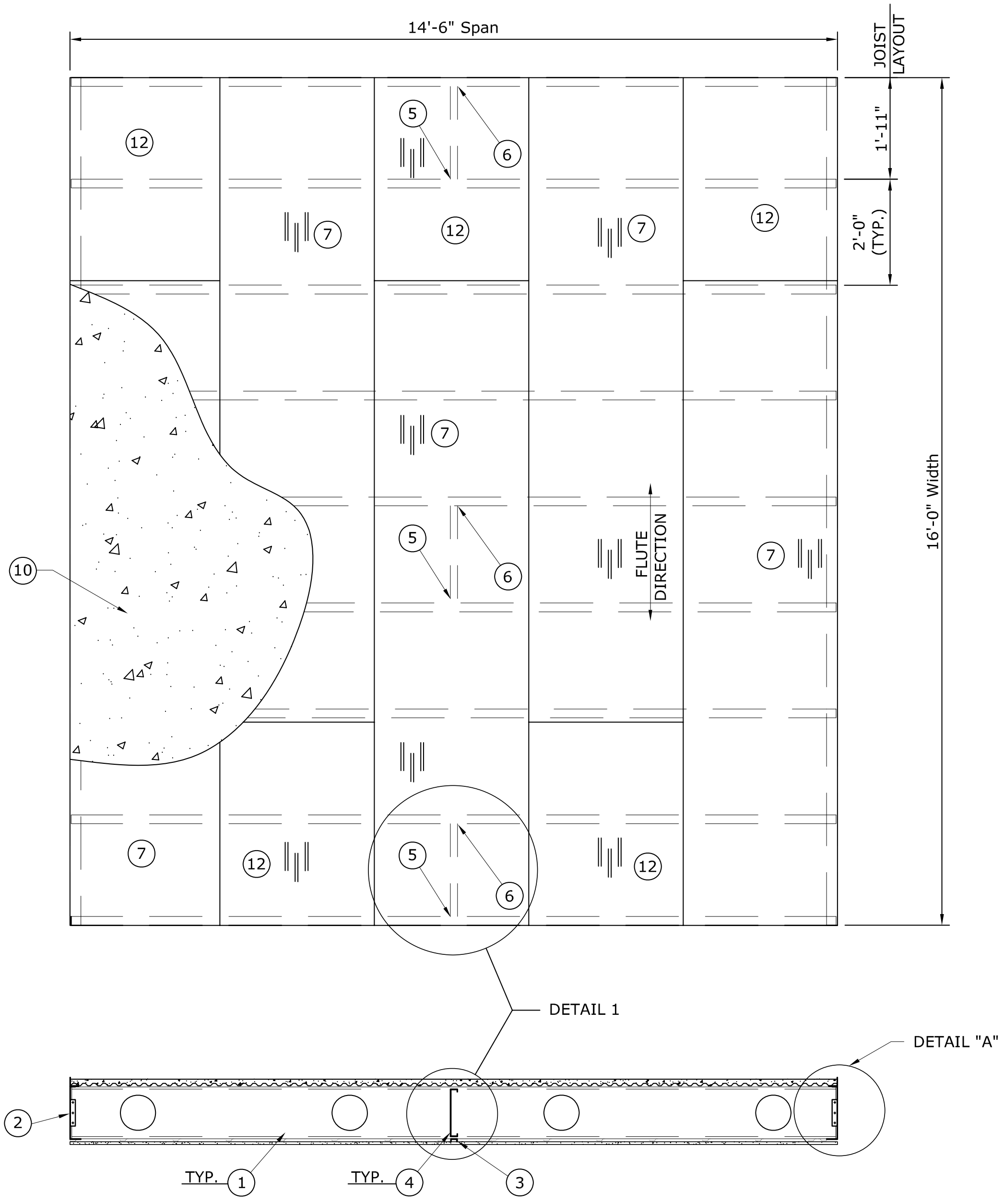
Revisions

A WORTHINGTON INDUSTRIES COMPANY
WIBS
WORTHINGTON INTEGRATED BUILDING SYSTEMS
MID-RISE CONSTRUCTION

3100 E. 45th Street
Suite 400
Cleveland, OH 44127
Phone: 216.472.1511
Fax: 216.472.1517

Sheet Description
PANEL B5
LF14.5E

Sheet
CFD
B5

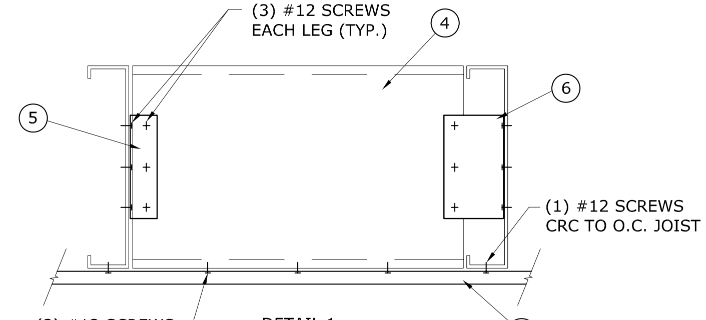


BILL OF MATERIAL

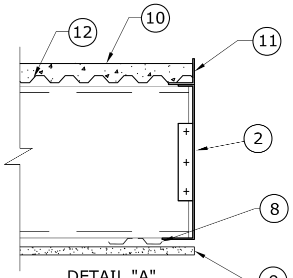
ITEM	QTY.	MATERIAL	LENGTH	NOTES
1	9	12" TDW 16GA.	14'-5 3/8"	NOTE 2
2	2	12" TD24 14GA. RIM TRACK	16'-0"	NOTE 2,3
3	1	CRC BRIDGING	16'-0"	DETAIL 1
4	3	12" CSW 16GA.	1'-9 $\frac{3}{4}$"	DETAIL 1
5	3	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
6	3	4" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
7	7	22GA 9/16" FORM DECK	2'-11" x 12'-2"	NOTE 1
8	14	RESILIENT CHANNEL @ 12" OC	16'-0"	NOTE 4
9	8	5/8" TYPE C DRYWALL (4' x 8')	232 SF.	NOTE 5
10	-	1 1/2" LEVELROCK	25 CU. FT.	NOTE 7
11	2	2" x 2" x 20GA. ANGLE	16'-0"	NOTE 6
12	5	22 GA $\frac{9}{16}$" FORM DECK	2'-11" x 4'-2"	NOTE 1

NOTES:

1.) DECK TO FLOOR JOISTS: $\frac{35}{3}$ FASTENER PATTERN (NO SIDELAP FASTENER)
2.) RIM TRACK TO FLOOR JOIST: (3) #12 x 3/4" HWH
3.) RIM TRACK TO STUD: (3) #12 x 3/4" HWH
4.) RC TO JOIST: (1) #10 SCREW
5.) TYPE C DRYWALL TO RC: 12" PERIMETER/12" FIELD WITH #6 SCREWS
6.) PLACE ANGLE POURSTOP ON ALL 4 SIDES BEFORE INSTALLING FORTACRETE TO RIM TRACK AND END JOIST. TAPE CORNERS BEFORE LEVELROCK IS POURED.
7.) 1 $\frac{1}{2}$" LEVELROCK INSTALLED BY USG CERTIFIED PROVIDER. CREATE TEST CUBES FOR COMPRESSION TEST ON DAY OF FLOOR TESTING.



DETAIL 1



DETAIL "A"

Project Name
PERCEPTIBILITY TEST (12 TDW 16
TradeReady Joist with $\frac{9}{16}$" Form Deck,
1 $\frac{1}{2}$" LevelRock, Ceiling)
Location

Project Number

Drawn by
CAD 7

Approved by

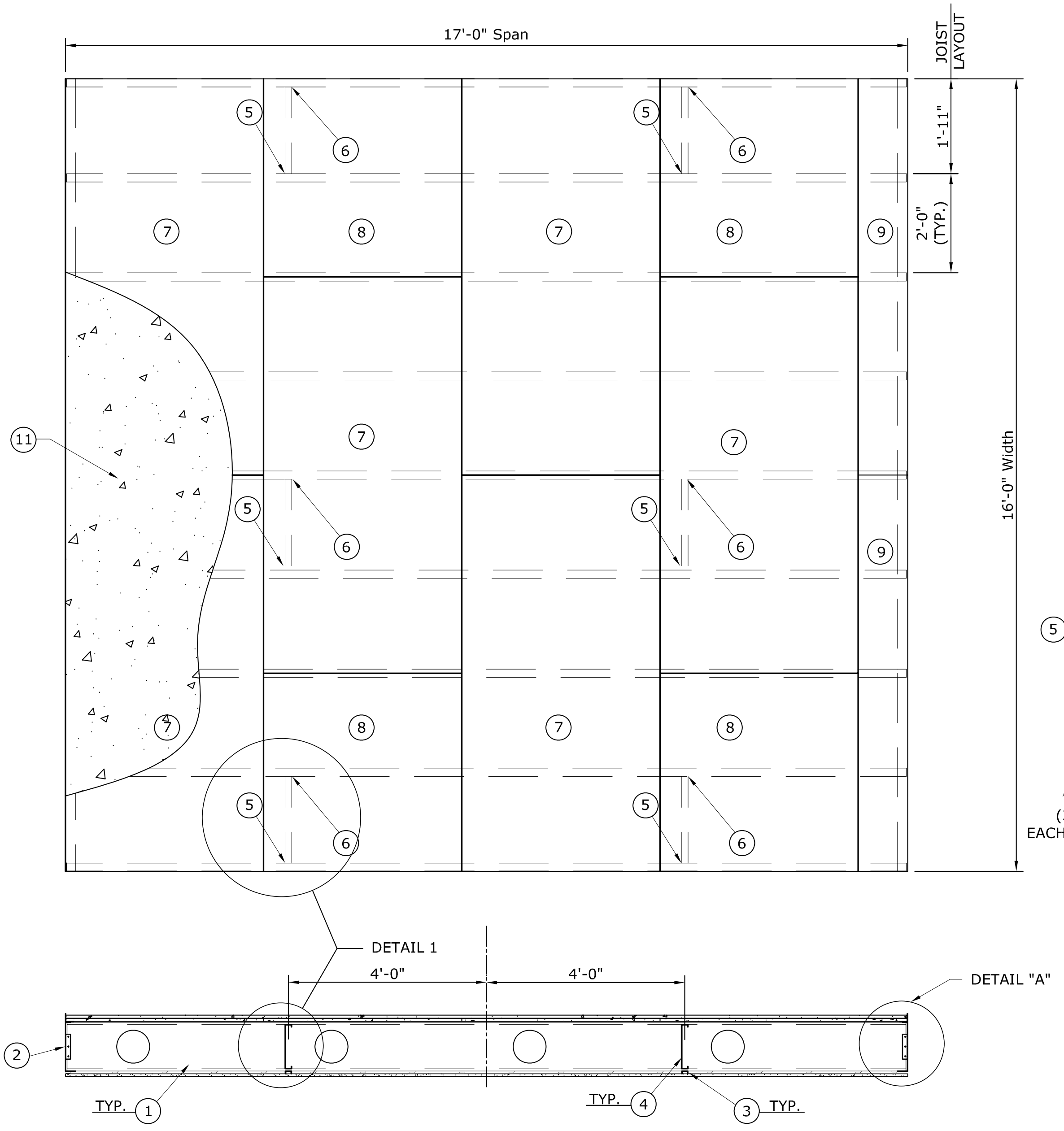
Date
6/4/2007

Revisions

A WORTHINGTON INDUSTRIES COMPANY
WIBS
WORTHINGTON INTEGRATED BUILDING SYSTEMS
MID-RISE CONSTRUCTION
3100 E. 45th Street
Suite 400
Cleveland, OH 44127
Phone: 216.472.1511
Fax: 216.472.1517

Sheet Description
PANEL B6
LF14.5F

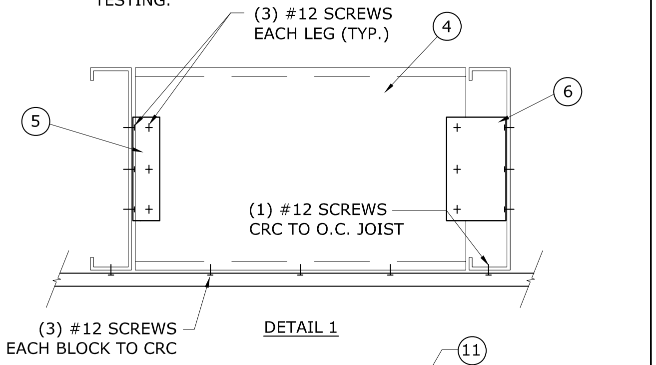
Sheet
CFD
B6



ITEM	QTY.	BILL OF MATERIAL MATERIAL	LENGTH	NOTES
1	9	12" TDW 14GA.	16'-11 3/8"	NOTE 2
2	2	12" TD24 14GA. RIM TRACK	16'-0"	NOTE 2,3
3	2	CRC BRIDGING	16'-0"	DETAIL 1
4	6	12" CSW 14GA.	1'-9 $\frac{3}{4}$"	DETAIL 1
5	6	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
6	6	4" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
7	6	3/4" T&G FORTACRETE	4'-0" x 8'-0"	NOTE 1
8	4	3/4" T&G FORTACRETE	4'-0" x 4'-0"	NOTE 1
9	2	3/4" T&G FORTACRETE	8'-0" x 1'-0"	NOTE 1
10	16	RESILIENT CHANNEL @ 12" OC	16'-0"	NOTE 1
11	-	3/4" LEVELROCK	17 CU. FT.	NOTE 7
12	10	5/8" TYPE C DRYWALL (4' x 8')	272 SF.	NOTE 5
13	4	2" x 2" x 20GA. ANGLE	16'-0"	NOTE 6

NOTES:

1.) SHEATHING TO FLOOR JOISTS: 6" PERIMETER / 12" FIELD WITH # 10 SCREW
2.) RIM TRACK TO FLOOR JOIST: (3) #12 x 3/4" HWH
3.) RIM TRACK TO STUD: (3) #12 x 3/4" HWH
4.) RC TO JOIST: (1) #10 SCREW
5.) TYPE C DRYWALL TO RC: 12" PERIMETER/12" FIELD WITH #6 SCREWS
6.) PLACE ANGLE POURSTOP ON ALL 4 SIDES BEFORE INSTALLING FORTACRETE TO RIM TRACK AND END JOIST. TAPE CORNERS BEFORE LEVELROCK IS POURED.
7.) $\frac{3}{4}$" LEVELROCK INSTALLED BY USG CERTIFIED PROVIDER. CREATE TEST CUBES FOR COMPRESSION TEST ON DAY OF FLOOR TESTING.



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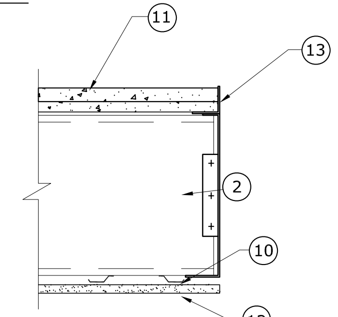


DETAIL "A"

Project Name
PERCEPTIBILITY TEST (12 TDW 14
TradeReady Joist with FortaCrete,
$\frac{3}{4}$" LevelRock, Ceiling)
Location

Project Number

Drawn by
CAD 7

Approved by

Date
6/4/2007

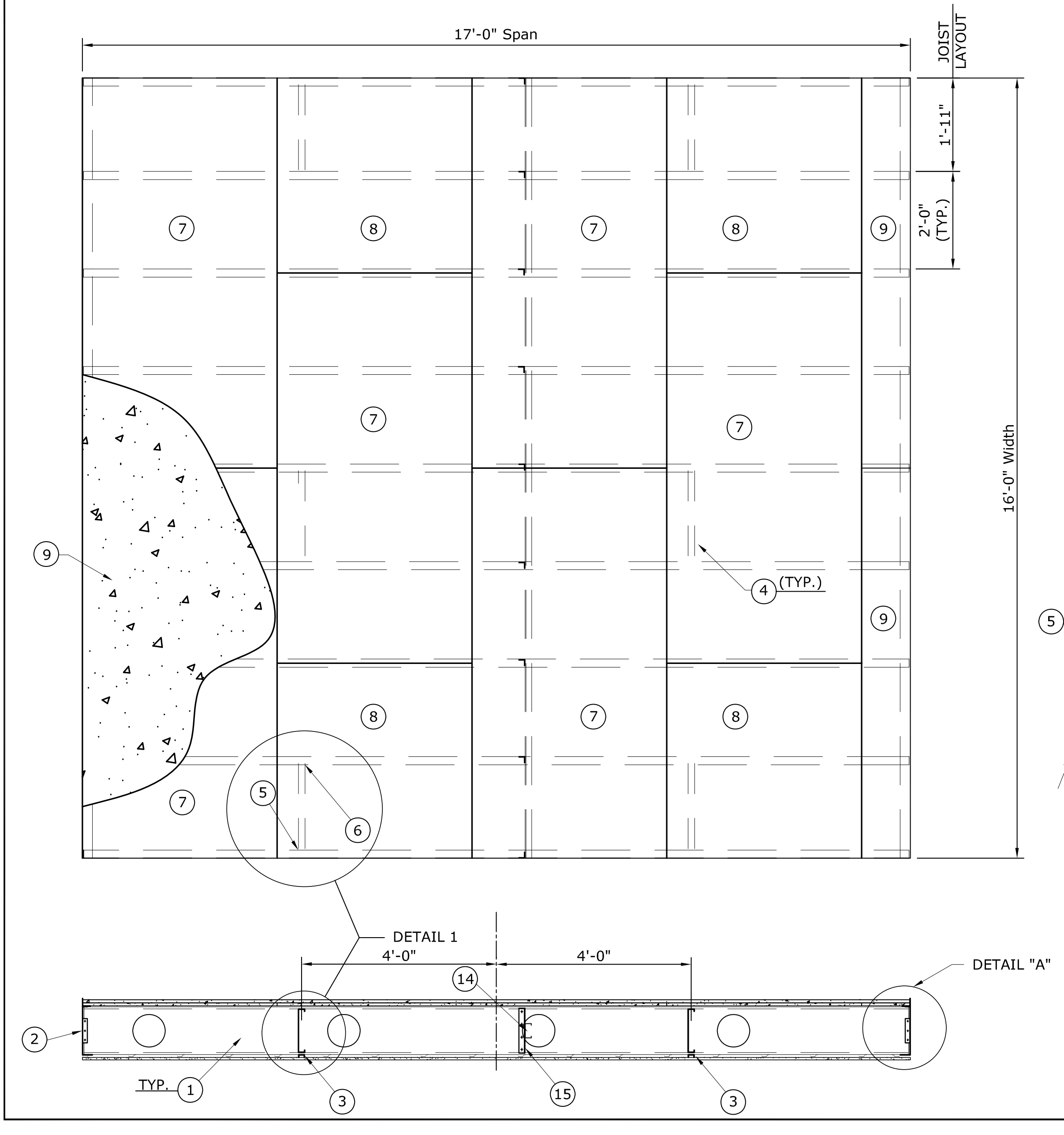
Revisions

A WORTHINGTON INDUSTRIES COMPANY
WIBS
WORTHINGTON INTEGRATED BUILDING SYSTEMS
MID-RISE CONSTRUCTION

3100 E. 45th Street
Suite 400
Cleveland, OH 44127
Phone: 216.472.1511
Fax: 216.472.1517

Sheet Description
PANEL C7
LF17.0A

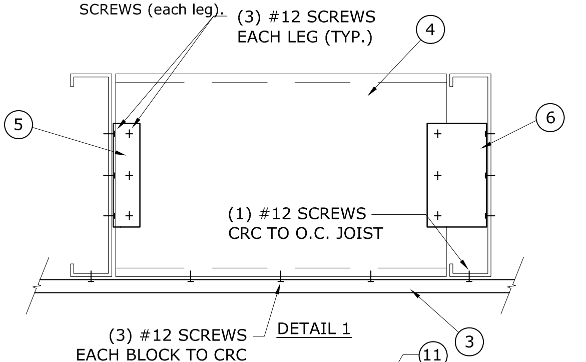
Sheet
CFD
C7



ITEM	QTY.	MATERIAL	LENGTH	NOTES
1	9	12" TDW 14GA.	16'-11 3/8"	NOTE 2
2	2	12" TD24 14GA. RIM TRACK	16'-0"	NOTE 2,3
3	2	CRC BRIDGING	16'-0"	DETAIL 1
4	6	12" CSW 14GA.	1'-9 $\frac{3}{4}$"	DETAIL 1
5	6	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
6	6	4" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
7	6	3/4" T&G FORTACRETE	4'-0" x 8'-0"	NOTE 1
8	4	3/4" T&G FORTACRETE	4'-0" x 4'-0"	NOTE 1
9	2	3/4" T&G FORTACRETE	8'-0" x 1'-0"	NOTE 1
10	16	RESILIENT CHANNEL @ 12" OC	16'-0"	NOTE 4
11	-	3/4" LEVELROCK	17 CU. FT.	NOTE 7
12	10	5/8" TYPE C DRYWALL (4' x 8')	272 SF.	NOTE 5
13	4	2" x 2" x 20GA. ANGLE	16'-0"	NOTE 6
14	1	3.625 CSJ 16 STRONGBACK	16'-0"	NOTE 8
15	9	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-11"	NOTE 8

NOTES:

1.) SHEATHING TO FLOOR JOISTS: 6" PERIMETER / 12" FIELD WITH #10 SCREW
2.) RIM TRACK TO FLOOR JOIST: (3) #12 x 3/4" HWH
3.) RIM TRACK TO STUD: (3) #12 x 3/4" HWH
4.) RC TO JOIST: (1) #12 SCREW
5.) TYPE C DRYWALL TO RC: 12" PERIMETER/12" FIELD WITH #6 SCREWS
6.) PLACE ANGLE POURSTOP ON ALL 4 SIDES BEFORE INSTALLING FORTACRETE TO RIM TRACK AND END JOIST. TAPE CORNERS BEFORE LEVELROCK IS POURED.
7.) $\frac{3}{4}$" LEVELROCK INSTALLED BY USG CERTIFIED PROVIDER. CREATE TEST CUBES FOR COMPRESSION TEST ON DAY OF FLOOR TESTING.
8.) ATTACH STRONGBACK TO EACH JOIST VIA CLIP ANGLE WITH (3) #10 SCREWS (each leg).



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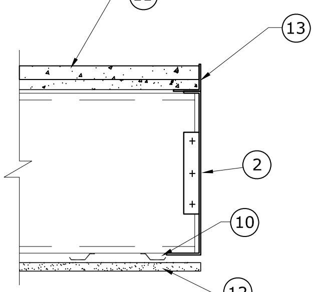


DETAIL "A"

Project Name
PERCEPTIBILITY TEST (12 TDW 14 TradeReady Joist with FortaCrete, $\frac{3}{4}$" LevelRock, Strongback, Ceiling)
Location

Project Number

Drawn by
CAD 7

Approved by

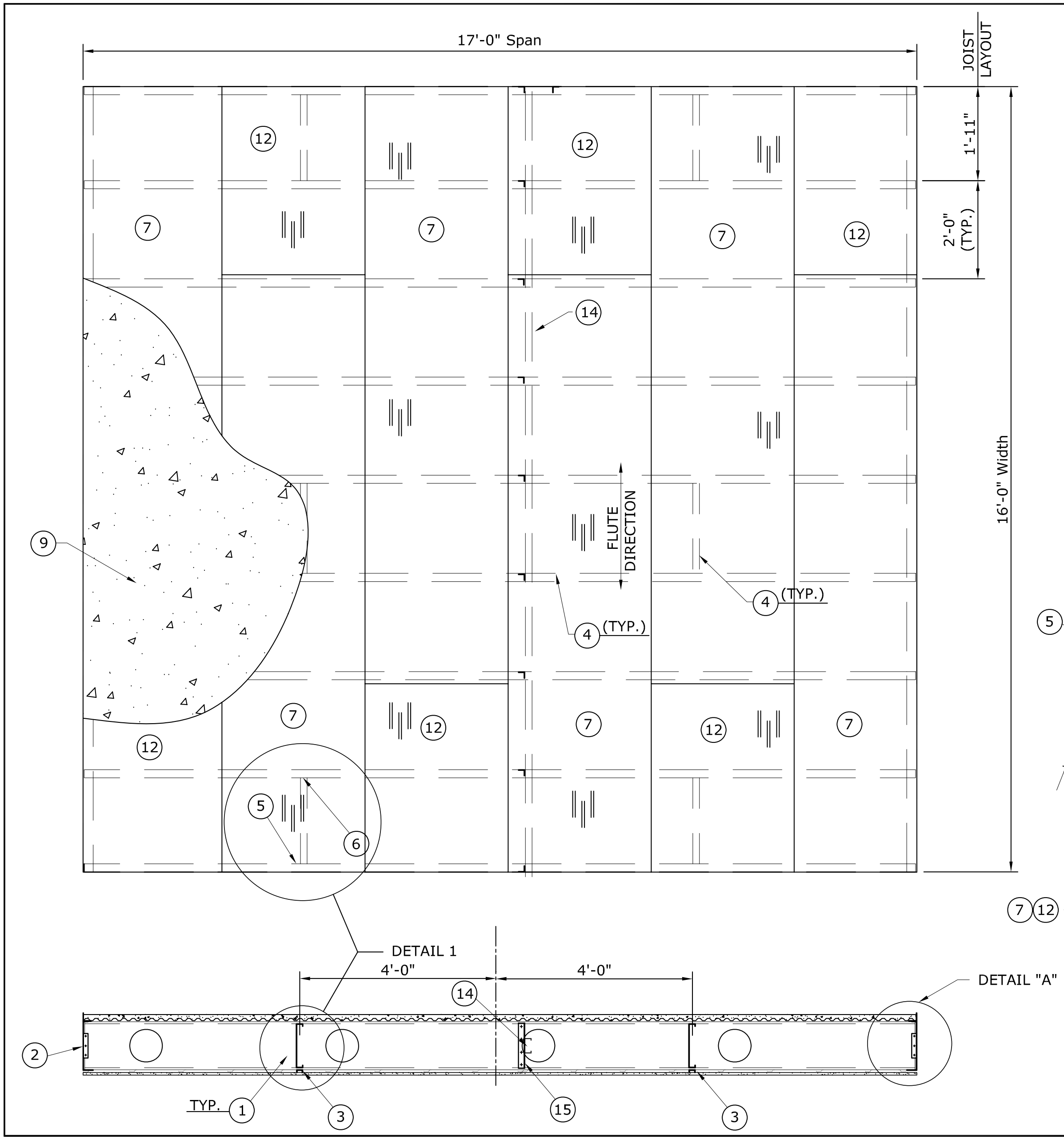
Date
6/4/2007

Revisions

A WORTHINGTON INDUSTRIES COMPANY
WIBS
WORTHINGTON INTEGRATED BUILDING SYSTEMS
MID-RISE CONSTRUCTION
3100 E. 45th Street
Suite 400
Cleveland, OH 44127
Phone: 216.472.1511
Fax: 216.472.1517

Sheet Description
LF17.0B
PANEL C8

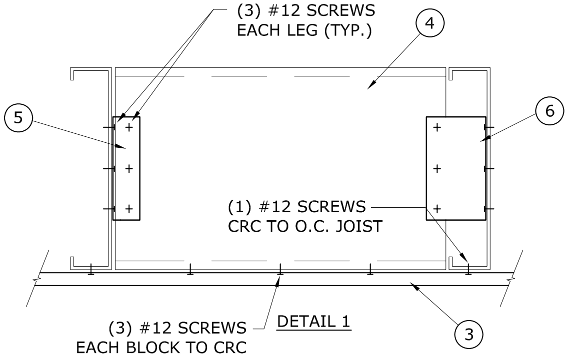
Sheet
CFD
C8



ITEM	QTY.	MATERIAL	LENGTH	NOTES
1	9	12" TDW 14GA.	16'-11 3/8"	NOTE 2
2	2	12" TD24 14GA. RIM TRACK	16'-0"	NOTE 2,3
3	1	CRC BRIDGING	16'-0"	DETAIL 1
4	3	12" CSW 16GA.	1'-9 $\frac{3}{4}$"	DETAIL 1
5	6	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
6	6	4" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
7	7	22GA 9/16" FORM DECK	2'-11" x 12'-2"	NOTE 1
8	14	RESILIENT CHANNEL @ 12" OC	16'-0"	NOTE 4
9	9	5/8" TYPE C DRYWALL (4' x 8')	232 SF.	NOTE 5
10	-	1 1/2" LEVELROCK	29 CU. FT.	NOTE 7
11	2	2" x 2" x 20GA. ANGLE	16'-0"	NOTE 6
12	5	22 GA $\frac{9}{16}$" FORM DECK	2'-11" x 4'-2"	NOTE 1
14	1	3.625 CSJ 16 STRONGBACK	16'-0"	NOTE 8
15	9	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-11"	NOTE 8

NOTES:

1.) DECK TO FLOOR JOISTS: $\frac{35}{3}$ FASTENER PATTERN (NO SIDELAP FASTENER)
2.) RIM TRACK TO FLOOR JOIST: (3) #12 x 3/4" HWH
3.) RIM TRACK TO STUD: (3) #12 x 3/4" HWH
4.) RC TO JOIST: (1) #12 SCREW
5.) TYPE C DRYWALL TO RC: 12" PERIMETER/12" FIELD W/#6 SCREWS
6.) PLACE ANGLE POURSTOP ON ALL 4 SIDES BEFORE INSTALLING FORTACRETE TO RIM TRACK AND END JOIST. TAPE CORNERS BEFORE LEVELROCK IS POURED.
7.) 1 $\frac{1}{2}$" LEVELROCK INSTALLED BY USG CERTIFIED PROVIDER. CREATE TEST CUBES FOR COMPRESSION TEST ON DAY OF FLOOR TESTING.
8.) ATTACH STRONGBACK TO EACH JOIST VIA CLIP ANGLE WITH (3) #10 SCREWS (each leg).



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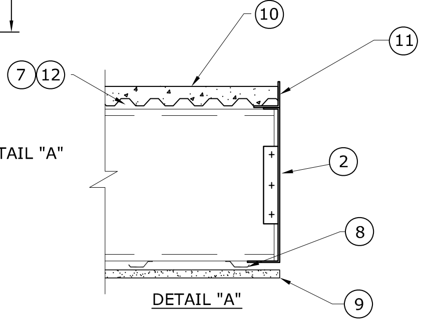


DETAIL "A"

Project Name
PERCEPTIBILITY TEST (12 TDW 14 TradeReady Joist with $\frac{9}{16}$" x 22ga Form Deck, 1 $\frac{1}{2}$" LevelRock, Strongback, Ceiling)
Location

Project Number

Drawn by
LAP

Approved by

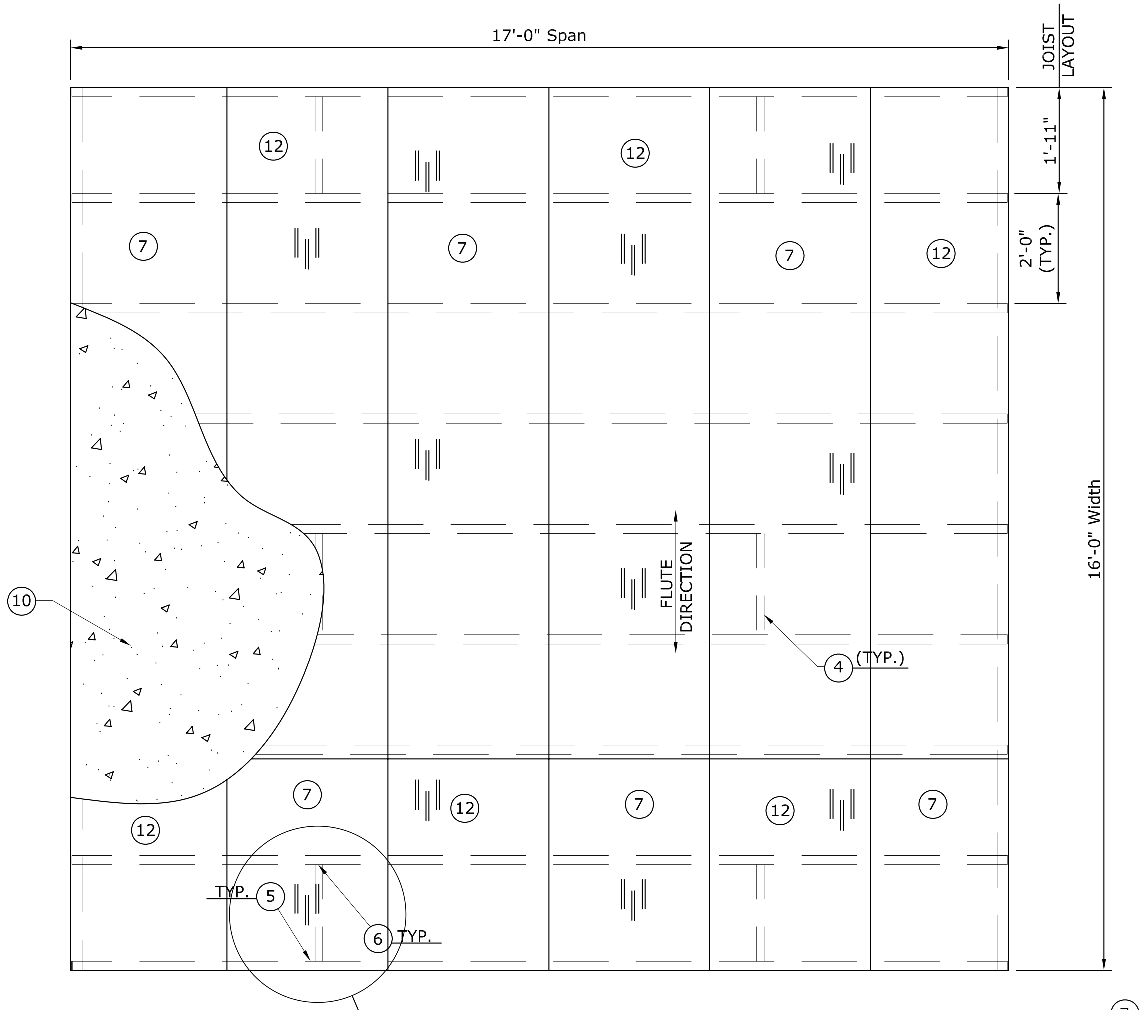
Date
12/31/2007

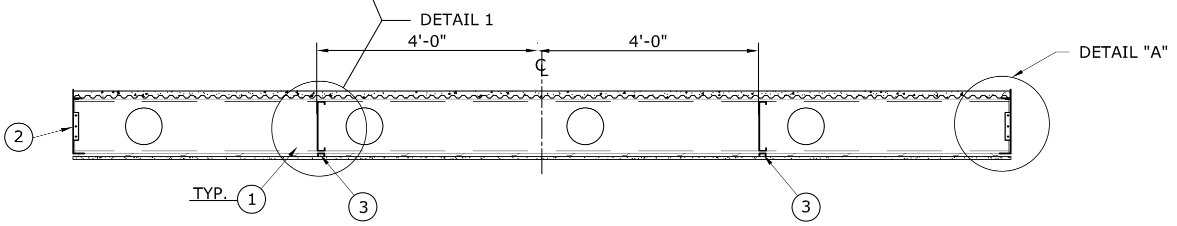
Revisions

A WORTHINGTON INDUSTRIES COMPANY
WIBS
WORTHINGTON INTEGRATED BUILDING SYSTEMS
MID-RISE CONSTRUCTION
3100 E. 45th Street
Suite 400
Cleveland, OH 44127
Phone: 216.472.1511
Fax: 216.472.1517

Sheet Description
PANEL C9
LF17.0C

Sheet
CFD
C9



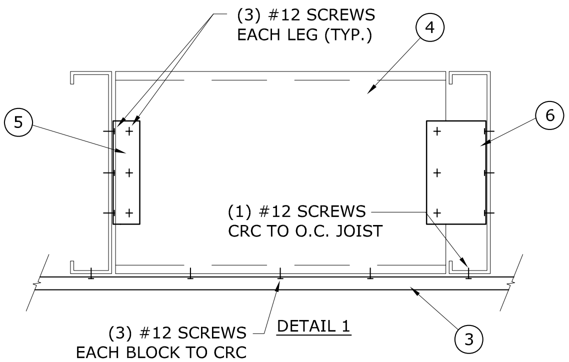


ITEM	QTY.	MATERIAL	LENGTH	NOTES
1	9	12" TDW 14GA.	16'-11 3/8"	NOTE 2
2	2	12" TD24 14GA. RIM TRACK	16'-0"	NOTE 2,3
3	1	CRC BRIDGING	16'-0"	DETAIL 1
4	3	12" CSW 16GA.	1'-9 $\frac{3}{4}$"	DETAIL 1
5	6	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
6	6	4" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
7	7	22GA 9/16" FORM DECK	2'-11" x 12'-2"	NOTE 1
8	14	RESILIENT CHANNEL @ 12" OC	16'-0"	NOTE 4
9	9	5/8" TYPE C DRYWALL (4' x 8')	232 SF.	NOTE 5
10	-	1 1/2" LEVELROCK	29 CU. FT.	NOTE 7
11	2	2" x 2" x 20GA. ANGLE	16'-0"	NOTE 6
12	5	22 GA $\frac{9}{16}$" FORM DECK	2'-11" x 4'-2"	NOTE 1

BILL OF MATERIAL

NOTES:

1.) DECK TO FLOOR JOISTS: $\frac{35}{3}$ FASTENER PATTERN (NO SIDELAP FASTENER)
2.) RIM TRACK TO FLOOR JOIST: (3) #12 x 3/4" HWH
3.) RIM TRACK TO STUD: (3) #12 x 3/4" HWH
4.) RC TO JOIST: (1) #12 SCREW
5.) TYPE C DRYWALL TO RC: 12" PERIMETER/12" FIELD W/#6 SCREWS
6.) PLACE ANGLE POURSTOP ON ALL 4 SIDES BEFORE INSTALLING FORTACRETE TO RIM TRACK AND END JOIST. TAPE CORNERS BEFORE LEVELROCK IS POURED.
7.) 1 ½" LEVELROCK INSTALLED BY USG CERTIFIED PROVIDER. CREATE TEST CUBES FOR COMPRESSION TEST ON DAY OF FLOOR TESTING.



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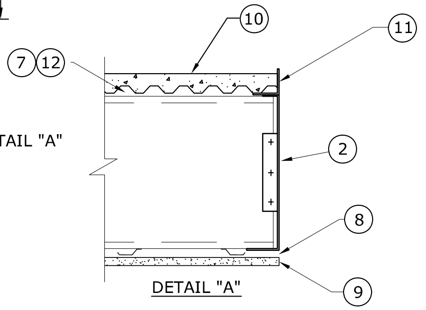

DETAIL "A"

Project Name
PERCEPTIBILITY TEST (12 TDW 14
TradeReady Joist with $\frac{9}{16}$" x 22ga Form
Deck, 1 $\frac{1}{2}$" LevelRock, Ceiling)
Location

Project Number

Drawn by
LAP

Approved by

Date
12/31/2007

Revisions

A WORTHINGTON INDUSTRIES COMPANY
WIBS
WORTHINGTON INTEGRATED BUILDING SYSTEMS
MID-RISE CONSTRUCTION
3100 E. 45th Street
Suite 400
Cleveland, OH 44127
Phone: 216.472.1511
Fax: 216.472.1517

Sheet Description
PANEL C10
LF17.0D

Sheet
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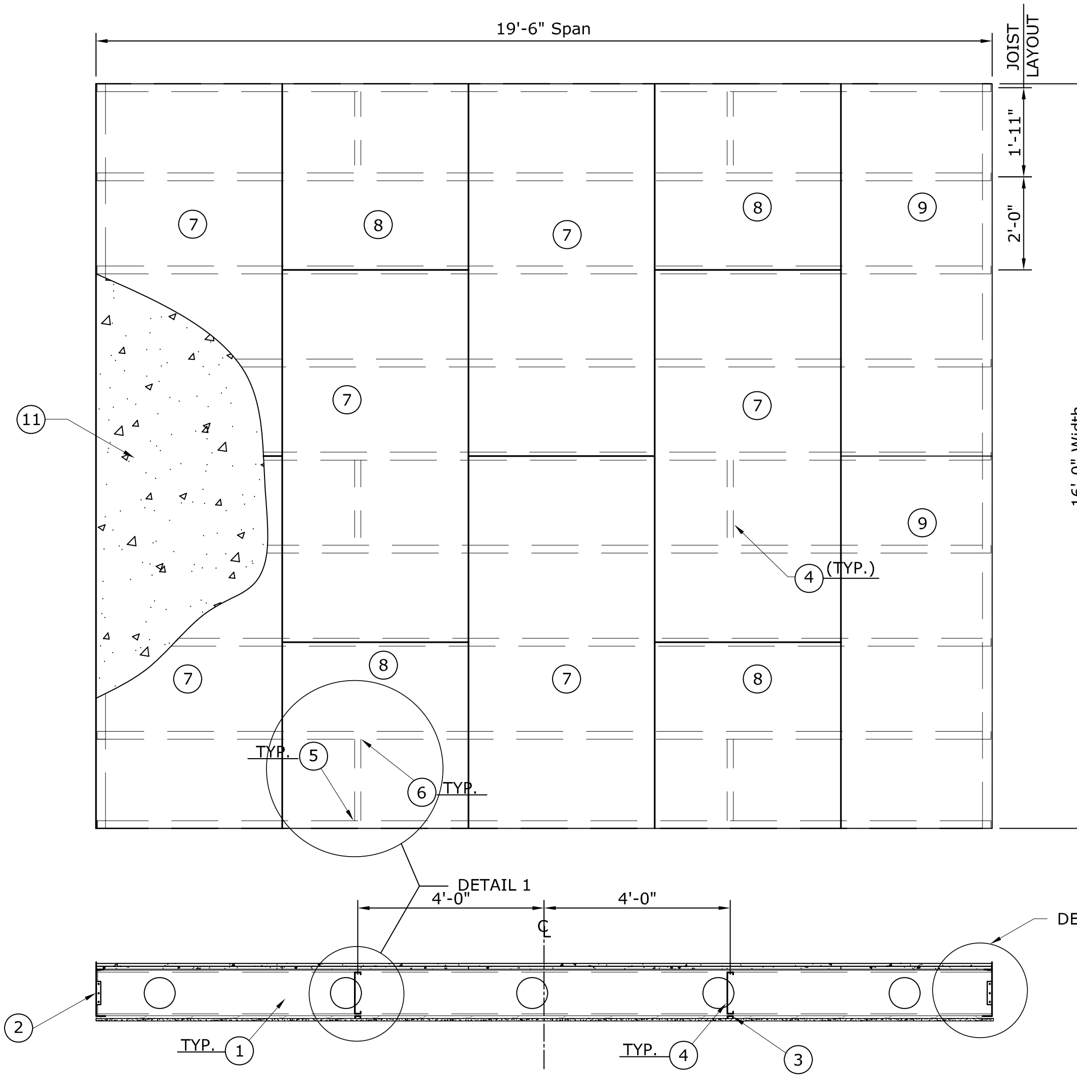
C10

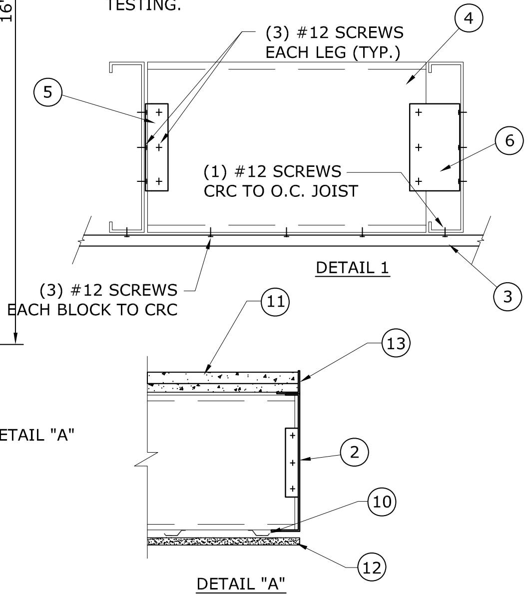


BILL OF MATERIAL

ITEM	QTY.	MATERIAL	LENGTH	NOTES
1	9	12" TDW 14GA.	19'-5 3/8"	NOTE 2
2	2	12" TD24 14GA. RIM TRACK	16'-0"	NOTE 2,3
3	2	CRC BRIDGING	16'-0"	DETAIL 1
4	6	12" CSW 14GA.	1'-9 $\frac{3}{4}$"	DETAIL 1
5	6	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
6	6	4" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
7	6	3/4" T&G FORTACRETE	4'-0" x 8'-0"	NOTE 1
8	4	3/4" T&G FORTACRETE	4'-0" x 4'-0"	NOTE 1
9	2	3/4" T&G FORTACRETE	8'-0" x 3'-6"	NOTE 1
10	20	RESILIENT CHANNEL @ 12" OC	16'-0"	NOTE 4,5
11	-	3/4" LEVELROCK	21 CU. FT.	NOTE 7
12	10	5/8" TYPE C DRYWALL (4' x 8')	312 SF.	NOTE 5
13	5	2" x 2" x 20GA. ANGLE	16'-0"	NOTE 6

NOTES:

1.) SHEATHING TO FLOOR JOISTS: 6" PERIMETER / 12" FIELD WITH # 10 SCREW
2.) RIM TRACK TO FLOOR JOIST: (3) #12 x 3/4" HWH
3.) RIM TRACK TO STUD: (3) #12 x 3/4" HWH
4.) RC TO JOIST: (1) #12 SCREW
5.) TYPE C DRYWALL TO RC: 12" PERIMETER/12" FIELD WITH #6 SCREWS
6.) PLACE ANGLE POURSTOP ON ALL 4 SIDES BEFORE INSTALLING FORTACRETE TO RIM TRACK AND END JOIST. TAPE CORNERS BEFORE LEVELROCK IS POURED.
7.) ¾" LEVELROCK INSTALLED BY USG CERTIFIED PROVIDER. CREATE TEST CUBES FOR COMPRESSION TEST ON DAY OF FLOOR TESTING.



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Project Name
PERCEPTIBILITY TEST (12 TDW 14
TradeReady Joist with FortaCrete,
$\frac{3}{4}$" LevelRock, Ceiling)
Location

Project Number

Drawn by
LAP

Approved by

Date
12/31/2007

Revisions

A WORTHINGTON INDUSTRIES COMPANY
WIBS
WORTHINGTON INTEGRATED BUILDING SYSTEMS
MID-RISE CONSTRUCTION

3100 E. 45th Street
Suite 400
Cleveland, OH 44127
Phone: 216.472.1511
Fax: 216.472.1517

Sheet Description
PANEL D12
LF19.5A

Sheet
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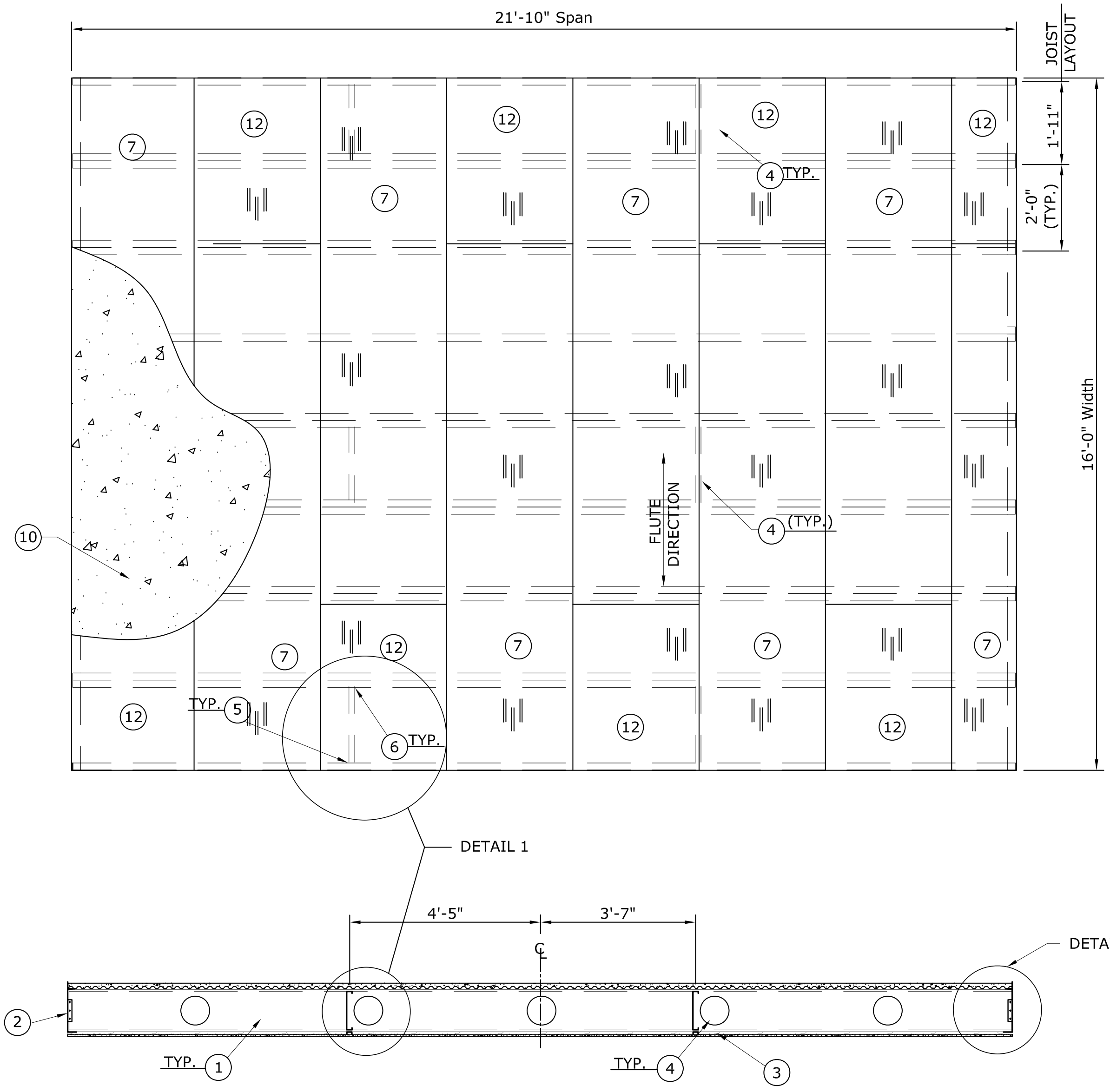
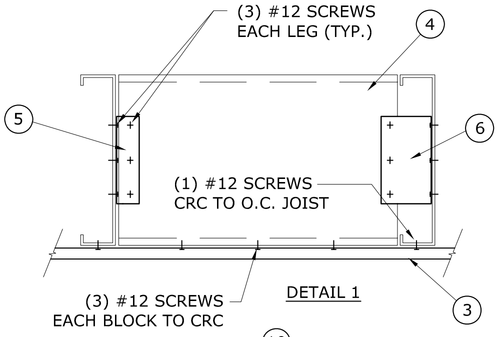
D12



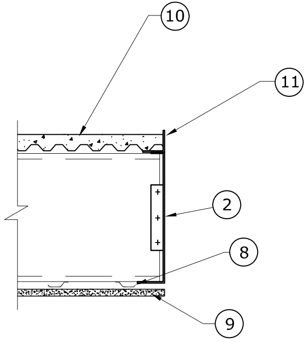
BILL OF MATERIAL				
ITEM	QTY.	MATERIAL	LENGTH	NOTES
1	9	(2) 12" TDW 16GA.	21'- 9 3/8"	NOTE 2
2	2	12" TD24 14GA. RIM TRACK	16'-0"	NOTE 2,3
3	1	CRC BRIDGING	16'-0"	DETAIL 1
4	3	12" CSW 16GA.	1'-9 $\frac{3}{4}$"	DETAIL 1
5	6	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
6	6	4" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
7	8	22GA 9/16" FORM DECK	2'-11" x 12'-2"	NOTE 1
8	23	RESILIENT CHANNEL @ 12" OC	16'-0"	NOTE 4
9	9	5/8" TYPE C DRYWALL (4' x 8')	350 SF.	NOTE 5
10	-	1 1/2" LEVELROCK	38 CU. FT.	NOTE 7
11	5	2" x 2" x 20GA. ANGLE	16'-0"	NOTE 6
12	8	22 GA $\frac{9}{16}$" FORM DECK	2'-11" x 4'-2"	NOTE 1

NOTES:

1.) DECK TO FLOOR JOISTS: $\frac{35}{3}$ FASTENER PATTERN (NO SIDELAP FASTENER)
2.) RIM TRACK TO FLOOR JOIST: (3) #12 x 3/4" HWH
3.) RIM TRACK TO STUD: (3) #12 x 3/4" HWH
4.) RC TO JOIST: (1) #12 SCREW
5.) TYPE C DRYWALL TO RC: 12" PERIMETER/12" FIELD W/#6 SCREWS
6.) PLACE ANGLE POURSTOP ON ALL 4 SIDES BEFORE INSTALLING FORTACRETE TO RIM TRACK AND END JOIST. TAPE CORNERS BEFORE LEVELROCK IS POURED.
7.) 1 ½" LEVELROCK INSTALLED BY USG CERTIFIED PROVIDER. CREATE TEST CUBES FOR COMPRESSION TEST ON DAY OF FLOOR TESTING.



DETAIL 1



DETAIL "A"

Project Name
PERCEPTIBILITY TEST ((2) 12 TDW 16
TradeReady Joist with $\frac{9}{16}$" x 22ga Form
Deck, 1 $\frac{1}{2}$" LevelRock, Ceiling)
Location

Project Number

Drawn by
LAP

Approved by

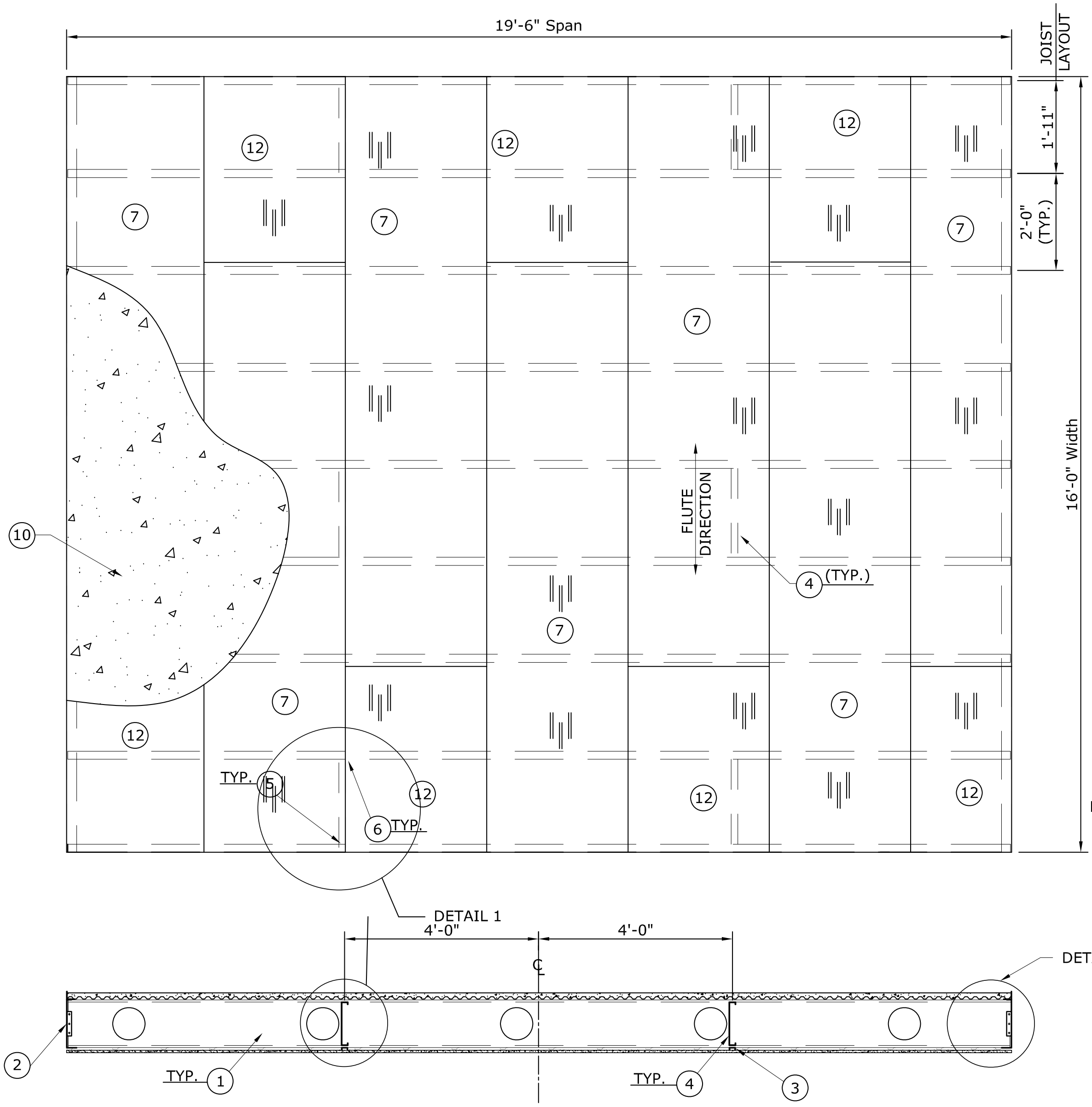
Date
12/31/2007

Revisions

A WORTHINGTON INDUSTRIES COMPANY
WIBS
WORTHINGTON INTEGRATED BUILDING SYSTEMS
MID-RISE CONSTRUCTION
3100 E. 45th Street
Suite 400
Cleveland, OH 44127
Phone: 216.472.1511
Fax: 216.472.1517

Sheet Description
PANEL E13
LF21.8A

Sheet
CFD
E13

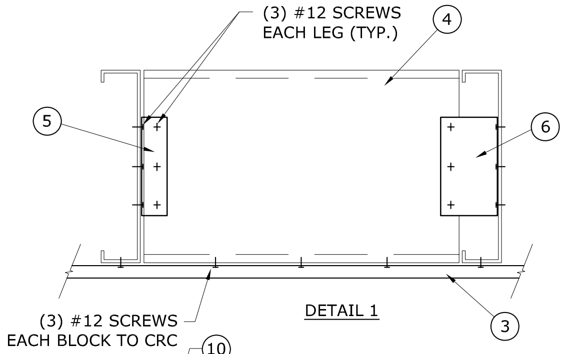


BILL OF MATERIAL

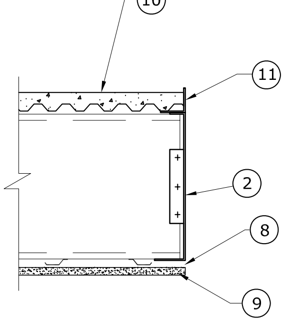
ITEM	QTY.	MATERIAL	LENGTH	NOTES
1	9	12" TDW 14GA.	19'-5 3/8"	NOTE 2
2	2	12" TD24 14GA. RIM TRACK	16'-0"	NOTE 2,3
3	1	CRC BRIDGING	16'-0"	DETAIL 1
4	3	12" CSW 16GA.	1'-9 $\frac{3}{4}$"	DETAIL 1
5	6	1 1/2" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
6	6	4" x 1 1/2" x 16GA. CLIP ANGLE	0'-9"	DETAIL 1
7	7	22GA 9/16" FORM DECK	2'-11" x 12'-2"	NOTE 1
8	14	RESILIENT CHANNEL @ 12" OC	16'-0"	NOTE 4
9	9	5/8" TYPE C DRYWALL (4' x 8')	232 SF.	NOTE 5
10	-	1 1/2" LEVELROCK	34 CU. FT.	NOTE 7
11	5	2" x 2" x 20GA. ANGLE	16'-0"	NOTE 6
12	5	22 GA $\frac{9}{16}$" FORM DECK	2'-11" x 4'-2"	NOTE 1

NOTES:

1.) DECK TO FLOOR JOISTS: $\frac{35}{3}$ FASTENER PATTERN (NO SIDELAP FASTENER)
2.) RIM TRACK TO FLOOR JOIST: (3) #12 x 3/4" HWH
3.) RIM TRACK TO STUD: (3) #12 x 3/4" HWH
4.) RC TO JOIST: (1) #12 SCREW
5.) TYPE C DRYWALL TO RC: 12" PERIMETER/12" FIELD W/#6 SCREWS
6.) PLACE ANGLE POURSTOP ON ALL 4 SIDES BEFORE INSTALLING FORTACRETE TO RIM TRACK AND END JOIST. TAPE CORNERS BEFORE LEVELROCK IS POURED.
7.) 1 ½" LEVELROCK INSTALLED BY USG CERTIFIED PROVIDER. CREATE TEST CUBES FOR COMPRESSION TEST ON DAY OF FLOOR TESTING.



DETAIL 1



DETAIL "A"

The drawings contained erein are supplied solely to assist in the selection and/or analysis of DIETRICH INDUSTRIES, INC. products. The drawings are preliminary in nature and are not intended to replace the drawings and services of the Architect or Engineer of Record. WORTHINGTON INTEGRATED BUILDING SYTEMS in rendering such drawings shall in no way be deemed to assume any professional responsibility and hereby disclaims any and all such liability or obligation.

Project Name
PERCEPTIBILITY TEST (12 TDW 14
TradeReady Joist with $\frac{9}{16}$" x 22ga Form
Deck, 1 $\frac{1}{2}$" LevelRock, Ceiling)
Location

Project Number

Drawn by
LAP

Approved by

Date
12/31/2007

Revisions

A WORTHINGTON INDUSTRIES COMPANY
WIBS
WORTHINGTON INTEGRATED BUILDING SYSTEMS
MID-RISE CONSTRUCTION

3100 E. 45th Street
Suite 400
Cleveland, OH 44127
Phone: 216.472.1511
Fax: 216.472.1517

Sheet Description
PANEL F15
LF19.5B

Sheet
CFD
F15

Appendix B

Field Test Sheets

Canadian Cold-Formed Steel Research Group

Floor Vibration Testing - Site Testing Checklist and Data Sheet

Date	Tested by	Test Site	Unit Number
7-Feb-07	BWD/RAP	Carlyle's Watch	708 (G)

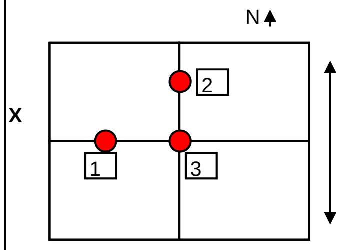
Floor Description

Floor Span	Joist Depth	Ceiling Type	Strong Back
174"	12"	drop	no
Floor Width	Blocking Pattern	Deck Type	Topping Type
342"	outer joists blocked at midspan	9/16"x30"x22ga metal form deck	1.5" Levelrock
Joist Spacing	Strapping Pattern	Additional Comments	
24" o/c	1 @ midspan	track and hanging fixtures	
Joist Designation	Screw Spacing		
12" TDW 14ga	30/4, #12 screws, 10 o/c on joists, stitch fasteners 6" o/c between joists at side laps	** Sketch of Floor Partitions, Joist Direction, Joist Location on Next Page	

~~Static Test~~

~~Number of Joists Tested~~	~~Floor Condition @ Dial Gauges~~ ~~bare joist / unfinished drywall / finished drywall / drop ceiling~~ ~~other:~~								
~~Deflection after 1kN~~	~~Joist 1~~	~~Joist 2~~	~~Joist 3~~	~~Joist 4~~	~~Deflection after 1kN~~	~~Joist 1~~	~~Joist 2~~	~~Joist 3~~	~~Joist 4~~
~~Test Location:~~					~~Test Location:~~				
~~N / E / S / W of centre~~					~~N / E / S / W of centre~~				
~~Joist Location~~					~~Joist Location~~				
~~Test 1 (mm)~~ ~~Deflection~~					~~Test 1 (mm)~~ ~~Deflection~~				
~~Reflex~~					~~Reflex~~				
~~Test 2 (mm)~~ ~~Deflection~~					~~Test 2 (mm)~~ ~~Deflection~~				
~~Reflex~~					~~Reflex~~				
~~Test 3 (mm)~~ ~~Deflection~~					~~Test 3 (mm)~~ ~~Deflection~~				
~~Reflex~~					~~Reflex~~				

Dynamic Test

Accelerometer Positioning  	Test 1 Sandbag 1	File Name: CW708_1 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1 Results found in Appendix C	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			
	Test 2 Sandbag 2	File Name: CW708_2 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			
	Test 3 Sandbag 3	File Name: CW708_3 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			
X indicates outside wall ↕ indicates joist direction	Test 4 Heel Drop 1	File Name: CW708HD_1 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			
	Test 5 Heel Drop 2	File Name: CW708HD_2 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			
	Test 6 Heel Drop 3	File Name: CW708HD_3 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			
	Test 7 Periodic	File Name: CW708PER_EW, CW708PER_NS Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			
	Test 8 Random	File Name: CW708_RAND Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			

Canadian Cold-Formed Steel Research Group
Floor Vibration Testing - Site Testing Checklist and Data Sheet

Date	Tested by	Test Site	Unit Number
7-Feb-07	BWD/RAP	Carlyle's Watch	709

Floor Description

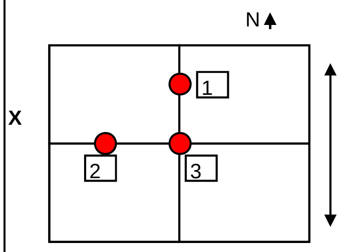
Floor Span	Joist Depth	Ceiling Type	Strong Back
262"	12"	drop	no
Floor Width	Blocking Pattern	Deck Type	Topping Type
315"	outer joists blocked	9/16"x30"x22ga metal form deck	1.5" Levelrock
Joist Spacing	Strapping Pattern	Additional Comments	
24" o/c	@ midspan and 8'	track and hanging fixtures, midspan crack	
Joist Designation	Screw Spacing		
Double 12" TDW 16ga	30/4, #12 screws, 10 o/c on joists, stitch fasteners 6" o/c between joists at side laps	** Sketch of Floor Partitions, Joist Direction, Joist Location on Next Page	

~~Static Test~~

~~Number of Joists Tested~~	~~Floor Condition @ Dial Gauges~~ ~~bare joist / unfinished drywall / finished drywall / drop ceiling~~ ~~other:~~								
~~Deflection after 1kN~~	~~Joist 1~~	~~Joist 2~~	~~Joist 3~~	~~Joist 4~~	~~Deflection after 1kN~~	~~Joist 1~~	~~Joist 2~~	~~Joist 3~~	~~Joist 4~~
~~Test Location:~~					~~Test Location:~~				
~~N / E / S / W of centre~~					~~N / E / S / W of centre~~				
~~Joist Location~~					~~Joist Location~~				
~~Test 1 (mm)~~ ~~Deflection~~					~~Test 1 (mm)~~ ~~Deflection~~				
~~Reflex~~					~~Reflex~~				
~~Test 2 (mm)~~ ~~Deflection~~					~~Test 2 (mm)~~ ~~Deflection~~				
~~Reflex~~					~~Reflex~~				
~~Test 3 (mm)~~ ~~Deflection~~					~~Test 3 (mm)~~ ~~Deflection~~				
~~Reflex~~					~~Reflex~~				

Dynamic Test

Accelerometer Positioning



X indicates outside wall

↕ indicates joist direction

Test		Freq 1	Freq 2	Freq 3	Damp	Peak Ampl/Comments
Test 1 Sandbag 1	File Name: CW709_1 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest					
Test 2 Sandbag 2	File Name: CW709_2 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest					
Test 3 Sandbag 3	File Name: CW709_3 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest					
Test 4 Heel Drop 1	File Name: CW709HD_1 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest					
Test 5 Heel Drop 2	File Name: CW709HD_2 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest					
Test 6 Heel Drop 3	File Name: CW709HD_3 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest					
Test 7 Periodic	File Name: CW709PER_EW1, CW709PER_NS Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest					
Test 8 Random	File Name: CW709RAND Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest					

Canadian Cold-Formed Steel Research Group
Floor Vibration Testing - Site Testing Checklist and Data Sheet

Date 7-Feb-07	Tested by BWD/RAP	Test Site Carlyle's Watch	Unit Number 805 C

Floor Description

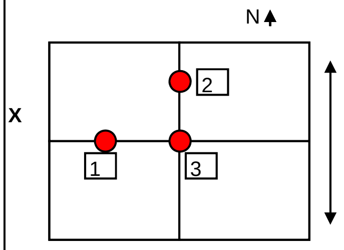
Floor Span 232"	Joist Depth 12"	Ceiling Type drop	Strong Back no
Floor Width 320"	Blocking Pattern outer joists blocked	Deck Type 9/16"x30"x22ga metal form deck	Topping Type 1.5" Levelrock
Joist Spacing 24" o/c	Strapping Pattern 1 @ midspan	Additional Comments track and hanging fixtures, midspan crack	
Joist Designation 12" TDW 16ga	Screw Spacing 30/4, #12 screws, 10 o/c on joists, stitch fasteners 6" o/c between joists at side laps	** Sketch of Floor Partitions, Joist Direction, Joist Location on Next Page	

~~Static Test~~

~~Number of Joists Tested~~	~~Floor Condition @ Dial Gauges~~ ~~bare joist / unfinished drywall / finished drywall / drop ceiling~~ ~~other:~~								
~~Deflection after 1kN~~	~~Joist 1~~	~~Joist 2~~	~~Joist 3~~	~~Joist 4~~	~~Deflection after 1kN~~	~~Joist 1~~	~~Joist 2~~	~~Joist 3~~	~~Joist 4~~
~~Test Location:~~					~~Test Location:~~				
~~N / E / S / W of centre~~					~~N / E / S / W of centre~~				
~~Joist Location~~					~~Joist Location~~				
~~Test 1 (mm)~~ ~~Deflection~~					~~Test 1 (mm)~~ ~~Deflection~~				
~~Reflex~~					~~Reflex~~				
~~Test 2 (mm)~~ ~~Deflection~~					~~Test 2 (mm)~~ ~~Deflection~~				
~~Reflex~~					~~Reflex~~				
~~Test 3 (mm)~~ ~~Deflection~~					~~Test 3 (mm)~~ ~~Deflection~~				
~~Reflex~~					~~Reflex~~				

Dynamic Test

Accelerometer Positioning



X indicates outside wall

↕ indicates joist direction

Test 1 Sandbag 1	File Name: CW805_1 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1 Results found in Appendix C	Freq 2	Freq 3	Damp	Peak Ampl/Comments
Test 2 Sandbag 2	File Name: CW805_2 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp	Peak Ampl/Comments
Test 3 Sandbag 3	File Name: CW805_3 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp	Peak Ampl/Comments
Test 4 Heel Drop 1	File Name: CW805HD_1 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp	Peak Ampl/Comments
Test 5 Heel Drop 2	File Name: CW805HD_2 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp	Peak Ampl/Comments
Test 6 Heel Drop 3	File Name: CW805HD_3 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp	Peak Ampl/Comments
Test 7 Periodic	File Name: CW805PER_EW1, CW709PER_NS Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp	Peak Ampl/Comments
Test 8 Random	File Name: CW805RAND Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp	Peak Ampl/Comments

Canadian Cold-Formed Steel Research Group
Floor Vibration Testing - Site Testing Checklist and Data Sheet

Date 21-Feb-07	Tested by BWD/RAP	Test Site Ocean Keys, Myrtle Beach, NC	Unit Number 401

Floor Description

Floor Span 170"	Joist Depth 12"	Ceiling Type drop	Strong Back no
Floor Width 419"	Blocking Pattern 8' o/c	Deck Type 9/16"x30"x22ga metal form deck	Topping Type 1.5" Levelrock
Joist Spacing 24" o/c	Strapping Pattern 1 @ midspan	Additional Comments accelerometers are placed at midspan for this test	
Joist Designation 12" TDW 16ga	Screw Spacing 30/4, #12 screws, 10 o/c on joists, stitch fasteners 6" o/c between joists at side laps	** Sketch of Floor Partitions, Joist Direction, Joist Location on Next Page	

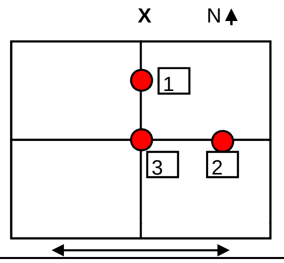
Static Test

Number of Joists Tested 3	Floor Condition @ Dial Gauges	**bare joist** / unfinished drywall / finished drywall / drop ceiling other:

Deflection after 1kN		Joist 1	Joist 2	Joist 3	Joist 4	Deflection after 1kN		Joist 1	Joist 2	Joist 3	Joist 4
Test Location:						Test Location:					
N / E / S / W of centre						N / E / S / W of centre					
Joist Location		centre	next to centre	2nd next to centre		Joist Location					
Test 1 (mm)	Deflection					Test 1 (mm)	Deflection				
	Reflex						Reflex				
Test 2 (mm)	Deflection					Test 2 (mm)	Deflection				
	Reflex						Reflex				
Test 3 (mm)	Deflection					Test 3 (mm)	Deflection				
	Reflex						Reflex				

Dynamic Test

Accelerometer Positioning



X indicates outside wall

↕ indicates joist direction

Test 1	File Name: OK401B_1	Freq 1	Freq 2	Freq 3	Damp
Sandbag 1	Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Results found in Appendix C			
		Peak Ampl/Comments			
Test 2	File Name: OK401B_2	Freq 1	Freq 2	Freq 3	Damp
Sandbag 2	Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest				
		Peak Ampl/Comments			
Test 3	File Name: OK401B_3	Freq 1	Freq 2	Freq 3	Damp
Sandbag 3	Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest				
		Peak Ampl/Comments			
Test 4	File Name: OK401BHD_1	Freq 1	Freq 2	Freq 3	Damp
Heel Drop 1	Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest				
		Peak Ampl/Comments			
Test 5	File Name: OK401BHD_2	Freq 1	Freq 2	Freq 3	Damp
Heel Drop 2	Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest				
		Peak Ampl/Comments			
Test 6	File Name: OK401BHD_3	Freq 1	Freq 2	Freq 3	Damp
Heel Drop 3	Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest				
		Peak Ampl/Comments			
Test 7	File Name: OK401BPER_EW, OK401BPER_NS	Freq 1	Freq 2	Freq 3	Damp
Periodic	Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest				
		Peak Ampl/Comments			
Test 8	File Name: N/A	Freq 1	Freq 2	Freq 3	Damp
Random	Acceleration Plot Data Check: OK / retest				

Canadian Cold-Formed Steel Research Group

Floor Vibration Testing - Site Testing Checklist and Data Sheet

Date	Tested by	Test Site	Unit Number
21-Feb-07	BWD/RAP	Ocean Keys, Myrtle Beach, NC	402

Floor Description

Floor Span	Joist Depth	Ceiling Type	Strong Back
170"	12"	drop	no
Floor Width	Blocking Pattern	Deck Type	Topping Type
419"	8' o/c	9/16"x30"x22ga metal form deck	1.5" Levelrock
Joist Spacing	Strapping Pattern	Additional Comments	
24" o/c	1 @ midspan	accelerometers are placed at midspan for this test	
Joist Designation	Screw Spacing		
12" TDW 16ga	30/4, #12 screws, 10 o/c on joists, stitch fasteners 6" o/c between joists at side laps	** Sketch of Floor Partitions, Joist Direction, Joist Location on Next Page	

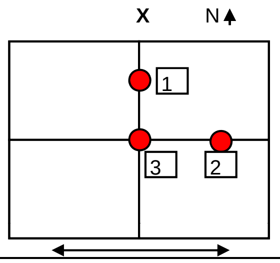
Static Test

Number of Joists Tested 3	Floor Condition @ Dial Gauges **bare joist** / unfinished drywall / finished drywall / drop ceiling other:

Deflection after 1kN	Joist 1	Joist 2	Joist 3	Joist 4	Deflection after 1kN	Joist 1	Joist 2	Joist 3	Joist 4
Test Location:					Test Location:				
N / E / S / W of centre					N / E / S / W of centre				
Joist Location	centre	next to centre	2nd next to centre		Joist Location				
Test 1 (mm) Deflection					Test 1 (mm) Deflection				
Reflex					Reflex				
Test 2 (mm) Deflection					Test 2 (mm) Deflection				
Reflex					Reflex				
Test 3 (mm) Deflection					Test 3 (mm) Deflection				
Reflex					Reflex				

Dynamic Test

Accelerometer Positioning



X indicates outside wall

↕ indicates joist direction

Test 1 Sandbag 1	File Name: OK402B_1 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 2 Sandbag 2	File Name: OK402B_2 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 3 Sandbag 3	File Name: OK402B_3 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 4 Heel Drop 1	File Name: OK402BHD_1 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 5 Heel Drop 2	File Name: OK402BHD_2 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 6 Heel Drop 3	File Name: OK402BHD_3 Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 7 Periodic	File Name: OK402BPER_EW, OK402BPER_NS Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 8 Random	File Name: N/A Acceleration Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp

Canadian Cold-Formed Steel Research Group
Floor Vibration Testing - Site Testing Checklist and Data Sheet

Date 18-Jul-07	Tested by BWD/RAP	Test Site City Green	Unit Number 601

Floor Description

Floor Span 211"	Joist Depth 12"	Ceiling Type 5/8" drywall on RC	Strong Back N/A
Floor Width 166"	Blocking Pattern 8' o/c	Deck Type 3/4" Fortacrete	Topping Type 3/4" LR
Joist Spacing 24" o/c	Strapping Pattern 8' o/c	Additional Comments 14 ga. Rim track full partition at kitchen No partitions	
Joist Designation 12" TDW 14ga	Screw Spacing 6" @ perimeter, 12" @interior	** Sketch of Floor Partitions, Joist Direction, Joist Location on Next Page	

Static Test

Number of Joists Tested

Floor Condition @ Dial Gauges   bare joist / unfinished drywall / **finished drywal**l / drop ceiling

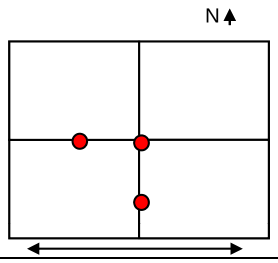
other:

Deflection after 1kN		Joist 1	Joist 2	Joist 3	Joist 4
Test Location:					
N / E / S / W of centre					
Joist Location		centre	next to centre right	next to centre left	
Test 1 (mm)	Deflection	0.48	0.29	0.28	
	Reflex	0	0	0	
Test 2 (mm)	Deflection	0.43	0.26	0.28	
	Reflex	0	0	0	
Test 3 (mm)	Deflection	0.46	0.26	0.28	
	Reflex	0	0	0	

Deflection after 1kN		Joist 1	Joist 2	Joist 3	Joist 4
Test Location:					
N / E / S / W of centre					
Joist Location		centre	next to centre	2nd next to centre	3rd Next to centre
Test 1 (mm)	Deflection				
	Reflex				
Test 2 (mm)	Deflection				
	Reflex				
Test 3 (mm)	Deflection				
	Reflex				

Dynamic Test

Accelerometer Positioning



X indicates outside wall

↕ indicates joist direction

Test 1 Sandbag 1	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1 Results found in Appendix c	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 2 Sandbag 2	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 3 Sandbag 3	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 4 Heel Drop 1	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 5 Heel Drop 2	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 6 Heel Drop 3	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 7 Periodic	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 8 Random	File Name: Acceleration Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp

Canadian Cold-Formed Steel Research Group

Floor Vibration Testing - Site Testing Checklist and Data Sheet

Date 18-Jul-07	Tested by BWD/RAP	Test Site City Green	Unit Number 604

Floor Description

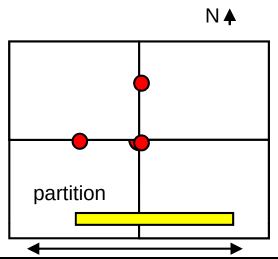
Floor Span 178"	Joist Depth 12"	Ceiling Type 5/8" drywall on RC	Strong Back N/A
Floor Width 203"	Blocking Pattern 8' o/c	Deck Type 3/4" Fortacrete	Topping Type 3/4" LR
Joist Spacing 24" o/c	Strapping Pattern 8' o/c	Additional Comments 14 ga. Rim track	 partition present f-c
Joist Designation 12" TDW 14ga	Screw Spacing 6" @ perimeter, 12" @interior	** Sketch of Floor Partitions, Joist Direction, Joist Location on Next Page	

Static Test

Number of Joists Tested	Floor Condition @ Dial Gauges	bare joist / unfinished drywall / **finished drywal**l / drop ceiling other:							
Deflection after 1kN	Joist 1	Joist 2	Joist 3	Joist 4	Deflection after 1kN	Joist 1	Joist 2	Joist 3	Joist 4
Test Location:					Test Location:				
N / E / S / W of centre					N / E / S / W of centre				
Joist Location	centre	next to centre right	next to centre left		Joist Location	centre	next to centre	2nd next to centre	3rd Next to centre
Test 1 (mm) Deflection	0.29	0.2	0.2		Test 1 (mm) Deflection				
Reflex	0	0	0		Reflex				
Test 2 (mm) Deflection	0.29	0.2	0.19		Test 2 (mm) Deflection				
Reflex	0	0	0		Reflex				
Test 3 (mm) Deflection	0.29	0.2	0.2		Test 3 (mm) Deflection				
Reflex	0	0	0		Reflex				

Dynamic Test

Accelerometer Positioning



X indicates outside wall

↕ indicates joist direction

Test 1 Sandbag 1	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1 results found in Appendix C	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 2 Sandbag 2	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 3 Sandbag 3	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 4 Heel Drop 1	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 5 Heel Drop 2	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 6 Heel Drop 3	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 7 Periodic	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 8 Random	File Name: Acceleration Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp

Canadian Cold-Formed Steel Research Group

Floor Vibration Testing - Site Testing Checklist and Data Sheet

Date	Tested by	Test Site	Unit Number
18-Jul-07	BWD/RAP	City Green	805

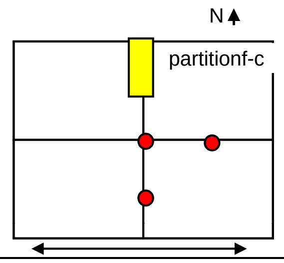
Floor Description

Floor Span	Joist Depth	Ceiling Type	Strong Back
21' 2"	12"	5/8" drywall on RC	N/A
Floor Width	Blocking Pattern	Deck Type	Topping Type
28' 0"	8' o/c	3/4" Fortacrete	3/4" LR
Joist Spacing	Strapping Pattern	Additional Comments	
24" o/c	8' o/c	12 ga. Rim track full partition at kitchen partition wall present f-c	
Joist Designation	Screw Spacing	** Sketch of Floor Partitions, Joist Direction, Joist Location on Next Page	
(2) btb 12" TDW 14ga	6" @ perimeter, 12" @interior		

Static Test

Number of Joists Tested	Floor Condition @ Dial Gauges	bare joist / unfinished drywall / finished drywall / drop ceiling other:							
Deflection after 1kN	Joist 1	Joist 2	Joist 3	Joist 4	Deflection after 1kN	Joist 1	Joist 2	Joist 3	Joist 4
Test Location:					Test Location:				
N / E / S / W of centre					N / E / S / W of centre				
Joist Location	centre	next to centre right	next to centre left		Joist Location	centre	next to centre	2nd next to centre	3rd Next to centre
Test 1 (mm) Deflection	0.2	0.17	0.11		Test 1 (mm) Deflection				
Reflex	0	0	0		Reflex				
Test 2 (mm) Deflection	0.22	0.18	0.11		Test 2 (mm) Deflection				
Reflex	0	0	0		Reflex				
Test 3 (mm) Deflection	0.2	0.17	0.1		Test 3 (mm) Deflection				
Reflex	0	0	0		Reflex				

Dynamic Test

Accelerometer Positioning 	Test 1	File Name:	Freq 1	Freq 2	Freq 3	Damp
	Sandbag 1	Acceleration Plot Data Check: OK / retest	Results found in Appendix C			
		FFT Plot Data Check: OK / retest	Peak Ampl/Comments			
	Test 2	File Name:	Freq 1	Freq 2	Freq 3	Damp
	Sandbag 2	Acceleration Plot Data Check: OK / retest				
		FFT Plot Data Check: OK / retest	Peak Ampl/Comments			
	Test 3	File Name:	Freq 1	Freq 2	Freq 3	Damp
	Sandbag 3	Acceleration Plot Data Check: OK / retest				
		FFT Plot Data Check: OK / retest	Peak Ampl/Comments			
X indicates outside wall	Test 4	File Name:	Freq 1	Freq 2	Freq 3	Damp
↕ indicates joist direction	Heel Drop 1	Acceleration Plot Data Check: OK / retest				
		FFT Plot Data Check: OK / retest	Peak Ampl/Comments			
	Test 5	File Name:	Freq 1	Freq 2	Freq 3	Damp
	Heel Drop 2	Acceleration Plot Data Check: OK / retest				
		FFT Plot Data Check: OK / retest	Peak Ampl/Comments			
	Test 6	File Name:	Freq 1	Freq 2	Freq 3	Damp
	Heel Drop 3	Acceleration Plot Data Check: OK / retest				
		FFT Plot Data Check: OK / retest	Peak Ampl/Comments			
	Test 7	File Name:	Freq 1	Freq 2	Freq 3	Damp
	Periodic	Acceleration Plot Data Check: OK / retest				
		FFT Plot Data Check: OK / retest	Peak Ampl/Comments			
	Test 8	File Name:	Freq 1	Freq 2	Freq 3	Damp
	Random	Acceleration Plot Data Check: OK / retest				

Canadian Cold-Formed Steel Research Group

Floor Vibration Testing - Site Testing Checklist and Data Sheet

Date	Tested by	Test Site	Unit Number
18-Jul-07	BWD/RAP	City Green	603 Model Home furnished

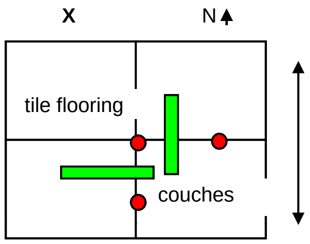
Floor Description

Floor Span 16' 5"	Joist Depth 12"	Ceiling Type 5/8" drywall on RC	Strong Back N/A
Floor Width 23' 9"	Blocking Pattern 8' o/c	Deck Type 3/4" Fortacrete	Topping Type 3/4" LR
Joist Spacing 24" o/c	Strapping Pattern 8' o/c	Additional Comments 14 ga. Rim track Static test performed on unfurnished 8th floor model so the model home was not damaged	
Joist Designation 12" TDW 14ga	Screw Spacing 6" @ perimeter, 12" @interior	** Sketch of Floor Partitions, Joist Direction, Joist Location on Next Page	

Static Test

Number of Joists Tested		Floor Condition @ Dial Gauges			bare joist / unfinished drywall / **finished drywal**l / drop ceiling other:				
Deflection after 1kN	Joist 1	Joist 2	Joist 3	Joist 4	Deflection after 1kN	Joist 1	Joist 2	Joist 3	Joist 4
Test Location:					Test Location:				
N / E / S / W of centre					N / E / S / W of centre				
Joist Location	centre	next to centre right	next to centre left		Joist Location	centre	next to centre	2nd next to centre	3rd Next to centre
Test 1 (mm) Deflection	0.35	0.21	0.24		Test 1 (mm) Deflection				
Reflex	0	0	0		Reflex				
Test 2 (mm) Deflection	0.34	0.21	0.22		Test 2 (mm) Deflection				
Reflex	0	0	0		Reflex				
Test 3 (mm) Deflection	0.35	0.22	0.22		Test 3 (mm) Deflection				
Reflex	0	0	0		Reflex				

Dynamic Test

Accelerometer Positioning 	Test 1 Sandbag 1	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1 Results found in Appendix C	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			
	Test 2 Sandbag 2	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			
	Test 3 Sandbag 3	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			
X indicates outside wall ↕ indicates joist direction	Test 4 Heel Drop 1	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			
	Test 5 Heel Drop 2	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			
	Test 6 Heel Drop 3	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			
	Test 7 Periodic	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
			Peak Ampl/Comments			
	Test 8 Random	File Name: Acceleration Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp

Canadian Cold-Formed Steel Research Group
Floor Vibration Testing - Site Testing Checklist and Data Sheet

Date 18-Jul-07	Tested by BWD/RAP	Test Site City Green	Unit Number 703 Model Home unfurnished

Floor Description

Floor Span 16' 5"	Joist Depth 12"	Ceiling Type 5/8" drywall on RC	Strong Back N/A
Floor Width 23' 9"	Blocking Pattern 8' o/c	Deck Type 3/4" Fortacrete	Topping Type 3/4" LR
Joist Spacing 24" o/c	Strapping Pattern 8' o/c	Additional Comments 14 ga. Rim track Static test performed on unfurnished 8th floor model so the model home was not damaged ** Sketch of Floor Partitions, Joist Direction, Joist Location on Next Page	
Joist Designation 12" TDW 14ga	Screw Spacing 6" @ perimeter, 12" @interior		

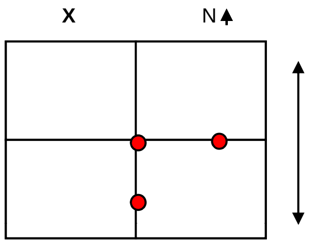
Static Test

Number of Joists Tested	Floor Condition @ Dial Gauges bare joist / unfinished drywall / **finished drywal**l / drop ceiling other:

Deflection after 1kN	Joist 1	Joist 2	Joist 3	Joist 4	Deflection after 1kN	Joist 1	Joist 2	Joist 3	Joist 4
Test Location:					Test Location:				
N / E / S / W of centre					N / E / S / W of centre				
Joist Location	centre	next to centre right	next to centre left		Joist Location	centre	next to centre	2nd next to centre	3rd Next to centre
Test 1 (mm) Deflection	0.35	0.21	0.24		Test 1 (mm) Deflection				
Reflex	0	0	0		Reflex				
Test 2 (mm) Deflection	0.34	0.21	0.22		Test 2 (mm) Deflection				
Reflex	0	0	0		Reflex				
Test 3 (mm) Deflection	0.35	0.22	0.22		Test 3 (mm) Deflection				
Reflex	0	0	0		Reflex				

Dynamic Test

Accelerometer Positioning



X indicates outside wall

↕ indicates joist direction

Test 1 Sandbag 1	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1 Results found in Appendix C	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 2 Sandbag 2	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 3 Sandbag 3	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 4 Heel Drop 1	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 5 Heel Drop 2	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 6 Heel Drop 3	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 7 Periodic	File Name: Acceleration Plot Data Check: OK / retest FFT Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp
		Peak Ampl/Comments			
Test 8 Random	File Name: Acceleration Plot Data Check: OK / retest	Freq 1	Freq 2	Freq 3	Damp

Appendix C

Master Results

Testing Master Sheet

LF14.5A (LF1)

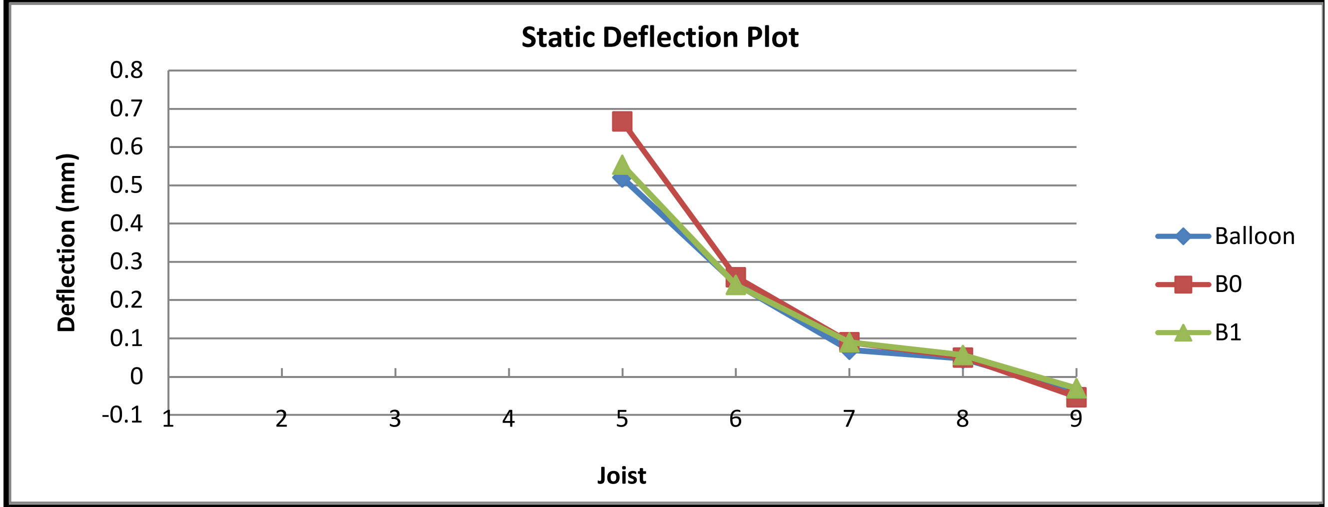
C-Joist | No Ceiling
OSB | No Strongback

Dynamic Testing

Heel Drop	**Balloon**			**B0**			**B1**		
f (Hz) avg	25.8	33.1	38.1	19.5	30.0	N/A	N/A	N/A	N/A
ζ_1 Mean(Min)	~~9.77%~~			~~14.44%~~			N/A		
ζ_2 Min(Mean)	~~11.04%~~			~~15.62%~~			N/A		
ζ_3 Log Dec	1.90%			2.29%			N/A		
a_{peak} (g) avg	1.44			1.48			N/A		
Sandbag Drop	**Balloon**			**B0**			**B1**		
f (Hz) avg	25.3	32.7	38.1	19.1	27.4	38.2	17.9	29.8	N/A
ζ_1 Mean(Min)	~~8.46%~~			~~6.80%~~			~~5.65%~~		
ζ_2 Min(Mean)	~~8.56%~~			~~6.97%~~			~~6.06%~~		
ζ_3 Log Dec	2.25%			3.02%			3.68%		
a_{peak} (g) avg	0.50			0.40			0.36		
Walking	**Balloon**			**B0**			**B1**		
a_{peak} (g) un wtd	0.168			0.129			0.146		
a_{RMS} (g) un wtd	0.0172			0.0151			0.0134		

Static Testing

Blocking Layout	Block			Block				Block	
Deflection	J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon (mm)					0.52	0.24	0.07	0.05	-0.04
B0 (mm)					0.67	0.26	0.09	0.05	-0.05
B1 (mm)					0.55	0.24	0.09	0.06	-0.03



Load Sharing	J1	J2	J3	J4	J5	J6	J7	J8	J9
B0 (lb) avg	2.49	-2.05	-18.02	-23.46	-29.40	-22.66	-10.76	-6.49	1.05
B1 (lb) avg	-3.33	-3.72	-9.65	-16.94	-25.99	-19.41	-8.52	-7.63	-1.74
Factor	B0	0.69	B1	0.64					

Measured Wt (lb)		Per Joist (lb)	0	
Calculated Wt (lb)	1012	Per Joist (lb)	126.5	

Testing Master Sheet

LF14.5B (LF2)

C-Joist	No Ceiling
Fortacrete	No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	22.4	25.0	28.6	17.6	22.3	29.5	17.2	18.7	26.0
ζ_1	Mean(Min)		2.21%			3.57%			~~3.48%~~	
ζ_2	Min(Mean)		2.30%			3.69%			~~3.63%~~	
ζ_3	Log Dec		2.58%			2.15%			1.48%	
a_{peak}	(g) avg		1.194			1.076			1.259	
Sandbag Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	22.5	25.1	28.2	17.2	21.4	28.7	17.2	18.8	26.1
ζ_1	Mean(Min)		3.00%			2.71%			~~2.76%~~	
ζ_2	Min(Mean)		3.20%			2.85%			~~3.12%~~	
ζ_3	Log Dec		3.01%			2.78%			1.88%	
a_{peak}	(g) avg		0.206			0.222			0.210	
Walking		**Balloon**			**B0**			**B1**		
a_{peak}	(g) un wtd		0.187			0.174			0.119	
a_{RMS}	(g) un wtd		0.0157			0.0176			0.0143	

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)					0.44	0.11	0.01	-0.03	0.03
B0	(mm)					0.54	0.18	0.03	-0.04	0.06
B1	(mm)					0.48	0.13	0.04	-0.03	0.05

Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg	11.08	-8.65	-18.65	-32.51	-45.27	-7.62	-11.11	-3.49	1.51
B1	(lb) avg	0.56	-8.65	-14.08	-22.34	-38.16	-14.44	-5.20	-0.12	-1.67
Factor		B0	0.74	B1	0.72					

Measured Wt (lb)		Per Joist (lb)	0
Calculated Wt (lb)	1446	Per Joist (lb)	180.75

Testing Master Sheet

LF14.5B (6 psf)

C-Joist
Fortacrete

No Ceiling
No Strongback

Dynamic Testing

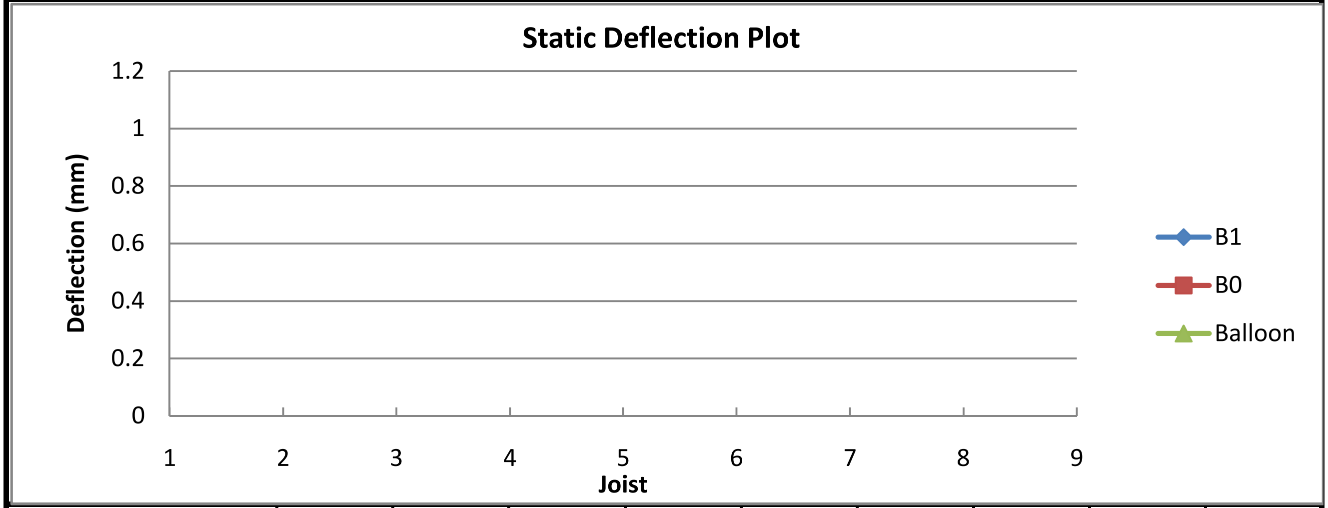
Heel Drop		Balloon	B0	B1
f	(Hz) avg		16.4 24.8 N/A	
ζ_1	Mean(Min)		0.79%	
ζ_2	Min(Mean)		2.43%	
ζ_3	Log Dec		N/A	
a_{peak}	(g) avg		0.960	

Sandbag Drop		Balloon	B0	B1
f	(Hz) avg			
ζ_1	Mean(Min)			
ζ_2	Min(Mean)			
ζ_3	Log Dec			
a_{peak}	(g) avg			

Walking		Balloon	B0	B1
a_{peak}	(g) un wtd			
a_{RMS}	(g) un wtd			

Static Testing

Blocking Layout	Block			Block				Block	
Deflection	J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon (mm)									
B0 (mm)									
B1 (mm)									



Load Sharing	J1	J2	J3	J4	J5	J6	J7	J8	J9
B0 (lb) avg									
B1 (lb) avg									
Factor	B0	N/A	B1	N/A					

Measured Wt (lb)	N/A	Per Joist (lb)	N/A	
Calculated Wt (lb)	2838	Per Joist (lb)	354.75	

Testing Master Sheet

LF14.5C (LF3)

TDW
OSB

No Ceiling
No Strongback

Dynamic Testing

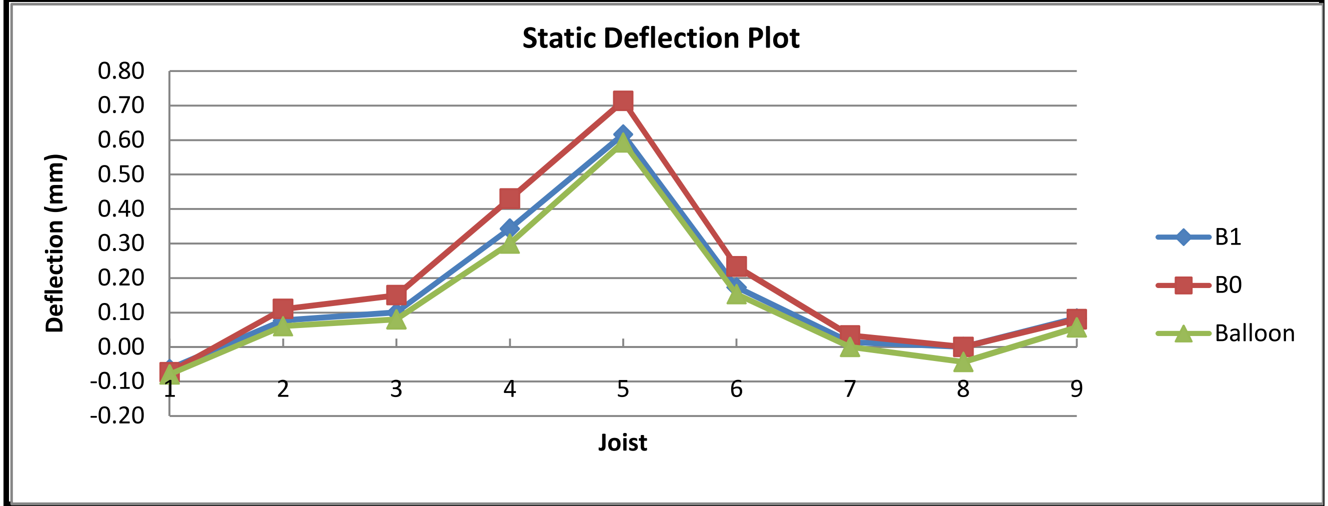
Heel Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	25.9	34.0	42.0	17.9	25.8	34.5	16.4	27.0	35.6
ζ_1	Mean(Min)	~~5.45%~~			~~7.12%~~			~~6.73%~~		
ζ_2	Min(Mean)	~~6.13%~~			~~8.68%~~			~~8.33%~~		
ζ_3	Log Dec	2.00%			2.00%			1.62%		
a_{peak}	(g) avg	0.688			0.930			0.965		

Sandbag Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	26.3	33.2	41.4	17.7	26.0	35.1	16.4	27.8	36.6
ζ_1	Mean(Min)	2.01%			2.20%			~~2.89%~~		
ζ_2	Min(Mean)	2.08%			2.28%			~~3.79%~~		
ζ_3	Log Dec	1.99%			1.67%			2.15%		
a_{peak}	(g) avg	1.202			1.073			1.061		

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd	N/A	N/A	N/A
a_{RMS}	(g) un wtd	N/A	N/A	N/A

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	-0.08	0.06	0.08	0.30	0.59	0.15	0.00	-0.04	0.06
B0	(mm)	-0.07	0.11	0.15	0.43	0.71	0.23	0.03	0.00	0.08
B1	(mm)	-0.06	0.08	0.10	0.34	0.62	0.17	0.01	0.00	0.08



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg	5.36	-4.42	-16.73	-26.05	-35.90	-17.27	-9.44	-2.61	-2.35
B1	(lb) avg	-1.47	-8.42	-11.96	-22.02	-27.66	-16.26	-5.25	-4.53	-5.65
Factor		B0	0.72	B1	0.64					

Measured Wt (lb)	1076	Per Joist (lb)	134.5
Calculated Wt (lb)	1012	Per Joist (lb)	126.5

Testing Master Sheet

LF14.5Di (LF4)

TDW	No Ceiling
Fortacrete	No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	24.0	29.2	34.4	N/A	N/A	N/A	N/A	N/A	N/A
ζ_1	Mean(Min)		~~3.04%~~			N/A			N/A	
ζ_2	Min(Mean)		~~3.58%~~			N/A			N/A	
ζ_3	Log Dec		1.78%			N/A			N/A	
a_{peak}	(g) avg		2.053			N/A			N/A	

Sandbag Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	24.1	28.8	33.9	N/A	N/A	N/A	N/A	N/A	N/A
ζ_1	Mean(Min)		1.29%			N/A			N/A	
ζ_2	Min(Mean)		1.63%			N/A			N/A	
ζ_3	Log Dec		2.13%			N/A			N/A	
a_{peak}	(g) avg		0.264			N/A			N/A	

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd	0.164	N/A	N/A
a_{RMS}	(g) un wtd	0.0220	N/A	N/A

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)					0.38	0.10	0.00	-0.02	0.01
B0	(mm)					N/A	N/A	N/A	N/A	N/A
B1	(mm)					N/A	N/A	N/A	N/A	N/A

Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg									
B1	(lb) avg									
Factor		B0	N/A	B1	N/A					

Measured Wt (lb)	N/A	Per Joist (lb)	N/A	
Calculated Wt (lb)	1446	Per Joist (lb)	180.75	

Testing Master Sheet

LF14.5D (LF4a)

TDW
Fortacrete

Type X Ceiling
No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	19.7	24.1	31.0	16.3	22.9	27.6	16.7	22.7	27.3
ζ_1	Mean(Min)		4.45%			~~6.44%~~			~~9.05%~~	
ζ_2	Min(Mean)		4.68%			~~7.05%~~			~~10.02%~~	
ζ_3	Log Dec		2.15%			2.59%			2.43%	
a_{peak}	(g) avg		1.341			1.198			1.521	

Sandbag Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	19.7	24.2	30.9	16.2	22.4	27.4	16.9	22.0	26.2
ζ_1	Mean(Min)		2.46%			2.84%			3.75%	
ζ_2	Min(Mean)		2.56%			2.91%			4.04%	
ζ_3	Log Dec		1.82%			2.65%			2.15%	
a_{peak}	(g) avg		1.743			1.451			1.581	

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd	0.094	0.189	0.119
a_{RMS}	(g) un wtd	0.0136	0.0140	0.0124

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)					0.34	0.22	0.06	0.03	-0.04
B0	(mm)					0.40	0.26	0.10	0.04	-0.04
B1	(mm)					0.37	0.23	0.08	0.04	-0.03

Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg	5.37	-6.09	-15.76	-27.93	-39.90	-13.63	-9.58	-4.44	-1.81
B1	(lb) avg	2.05	-5.82	-14.84	-25.52	-37.02	-10.96	-8.41	-6.08	-7.61
Factor		B0	0.72	B1	0.64					

Measured Wt (lb)	2276	Per Joist (lb)	284.5	
Calculated Wt (lb)	2002	Per Joist (lb)	250.25	

Testing Master Sheet

LF14.5E (LF5)

TDW
Fortacrete w/ LR

Type X Ceiling
No Strongback

Dynamic Testing

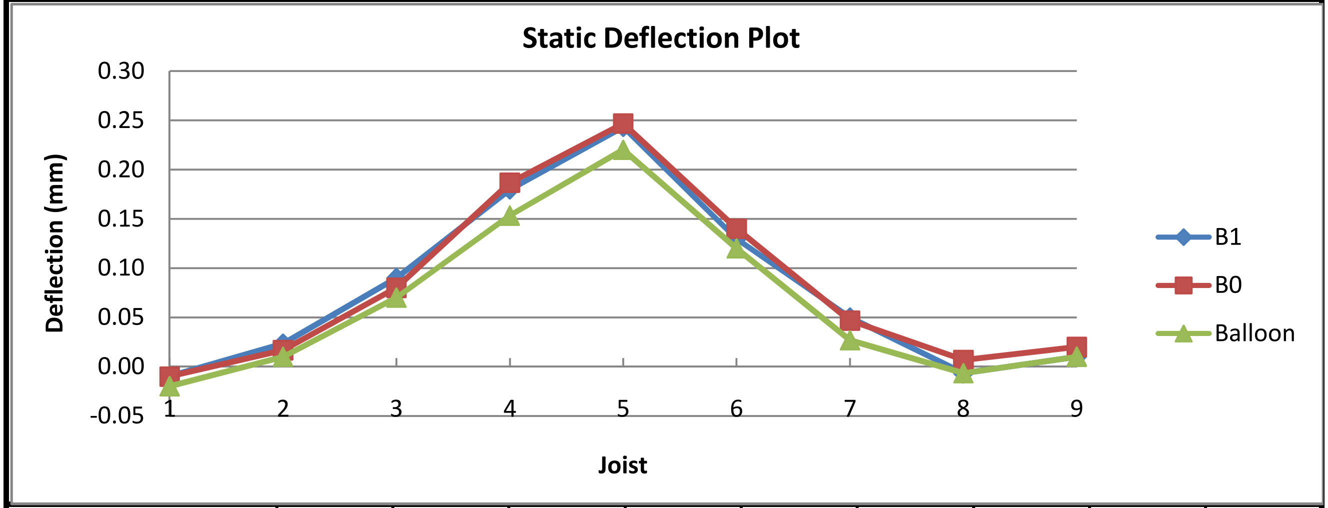
Heel Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	17.7	22.6	N/A	15.2	21.2	28.9	15.8	21.7	28.6
ζ_1	Mean(Min)	2.78%			5.61%			5.14%		
ζ_2	Min(Mean)	3.12%			5.69%			5.30%		
ζ_3	Log Dec	2.34%			4.00%			3.94%		
a_{peak}	(g) avg	0.696			0.561			0.649		

Sandbag Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	17.7	22.5	N/A	15.7	21.1	28.9	16.2	22.2	27.3
ζ_1	Mean(Min)	0.93%			2.26%			1.64%		
ζ_2	Min(Mean)	0.96%			2.52%			1.72%		
ζ_3	Log Dec	0.98%			1.96%			1.40%		
a_{peak}	(g) avg	0.902			0.708			0.726		

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd	0.166	0.166	0.169
a_{RMS}	(g) un wtd	0.0285	0.0292	0.0314

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	-0.02	0.01	0.07	0.15	0.22	0.12	0.03	-0.01	0.01
B0	(mm)	-0.01	0.02	0.08	0.19	0.25	0.14	0.05	0.01	0.02
B1	(mm)	-0.01	0.02	0.09	0.18	0.24	0.13	0.05	-0.01	0.01



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg	1.18	-5.61	-13.92	-31.04	-34.97	-14.27	-12.36	-5.39	1.02
B1	(lb) avg	-2.05	-6.14	-13.94	-27.02	-31.87	-12.89	-12.48	-3.19	2.98
Factor		B0	0.70	B1	0.67					

Measured Wt (lb)	4123	Per Joist (lb)	515.375	
Calculated Wt (lb)	3742	Per Joist (lb)	467.75	

Testing Master Sheet

LF14.5F (LF6)

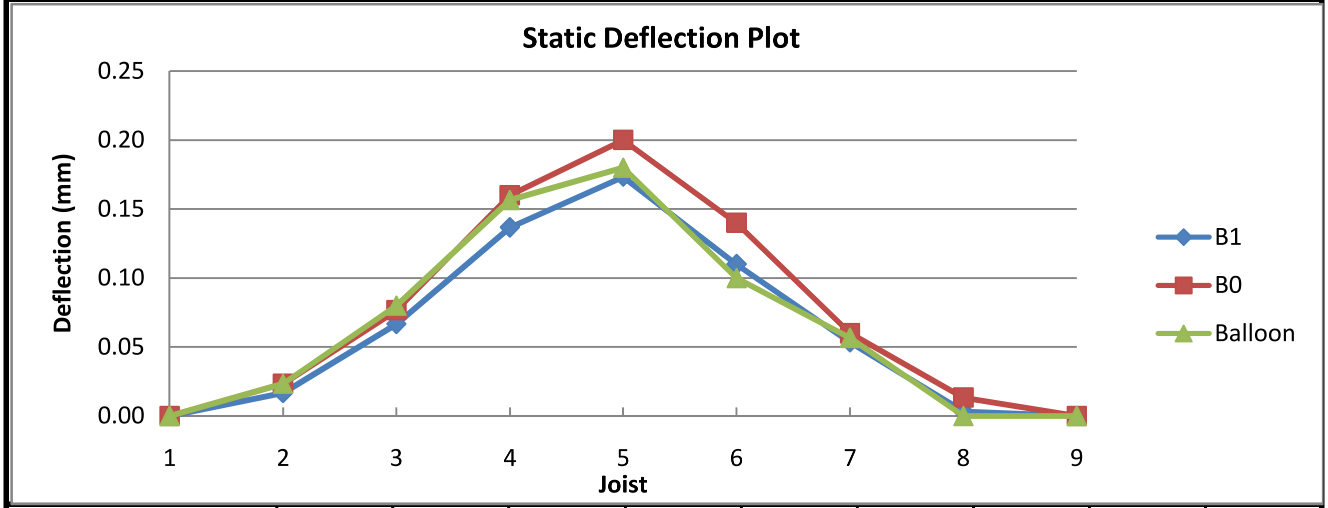
TDW | Type X Ceiling
Metal Deck w/ LR | No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	16.0	22.6	32.3	14.3	21.0	30.5	14.7	20.8	32.3
ζ_1	Mean(Min)		3.75%			3.07%			3.34%	
ζ_2	Min(Mean)		3.81%			3.19%			3.42%	
ζ_3	Log Dec		3.00%			3.07%			2.91%	
a_{peak}	(g) avg		0.717			0.550			0.599	
Sandbag Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	16.1	22.5	32.1	14.6	21.2	29.9	14.8	22.0	N/A
ζ_1	Mean(Min)		0.77%			1.28%			1.02%	
ζ_2	Min(Mean)		0.81%			1.30%			1.06%	
ζ_3	Log Dec		0.98%			1.32%			1.52%	
a_{peak}	(g) avg		0.457			0.444			0.438	
Walking		**Balloon**			**B0**			**B1**		
a_{peak}	(g) un wtd		0.226			0.212			0.223	
a_{RMS}	(g) un wtd		0.0373			0.0471			0.0391	

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	0.00	0.02	0.08	0.16	0.18	0.10	0.06	0.00	0.00
B0	(mm)	0.00	0.02	0.08	0.16	0.20	0.14	0.06	0.01	0.00
B1	(mm)	0.00	0.02	0.07	0.14	0.17	0.11	0.05	0.00	0.00



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg	-2.14	-8.41	-18.67	-19.46	-20.06	-19.63	-15.01	-9.00	-2.68
B1	(lb) avg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Factor		B0	0.51	B1	N/A					

Measured Wt (lb)	5129	Per Joist (lb)	641.125
Calculated Wt (lb)	4561	Per Joist (lb)	570.125

Testing Master Sheet

LF17.0A (LF7)

TDW

Fortacrete w/ LR

Type C Ceiling

No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	14.7	20.0	34.1	13.2	18.8	33.5	13.4	19.3	34.3
ζ_1	Mean(Min)		4.36%			4.61%			3.93%	
ζ_2	Min(Mean)		4.44%			4.80%			3.99%	
ζ_3	Log Dec		3.98%			4.13%			3.42%	
a_{peak}	(g) avg		0.891			0.717			0.624	
Sandbag Drop			**Balloon**			**B0**			**B1**	
f	(Hz) avg	14.9	19.1	34.3	13.5	17.9	33.6	13.6	19.4	34.2
ζ_1	Mean(Min)		0.79%			1.82%			1.40%	
ζ_2	Min(Mean)		0.82%			1.87%			1.45%	
ζ_3	Log Dec		0.93%			1.60%			1.31%	
a_{peak}	(g) avg		0.574			0.609			0.602	
Walking			**Balloon**			**B0**			**B1**	
a_{peak}	(g) un wtd		0.059			0.074			0.053	
a_{RMS}	(g) un wtd		0.0106			0.0107			0.0101	

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	-0.02	0.02	0.07	0.21	0.30	0.17	0.05	0.00	0.00
B0	(mm)	-0.01	0.03	0.09	0.23	0.34	0.20	0.07	0.02	0.00
B1	(mm)	0.00	0.03	0.09	0.21	0.32	0.18	0.06	0.01	0.01

Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg	3.81	-3.28	-19.10	-26.32	-30.71	-21.59	-15.71	-4.24	-0.47
B1	(lb) avg	-6.21	-5.91	-13.17	-19.73	-27.03	-16.93	-14.65	-8.29	-5.12
Factor		B0	0.67	B1	0.54					
Measured Wt (lb)		4935		Per Joist (lb)		616.875				
Calculated Wt (lb)		4835		Per Joist (lb)		604.375				

Testing Master Sheet

LF17.0B (LF8)

TDW
Fortacrete w/ LR

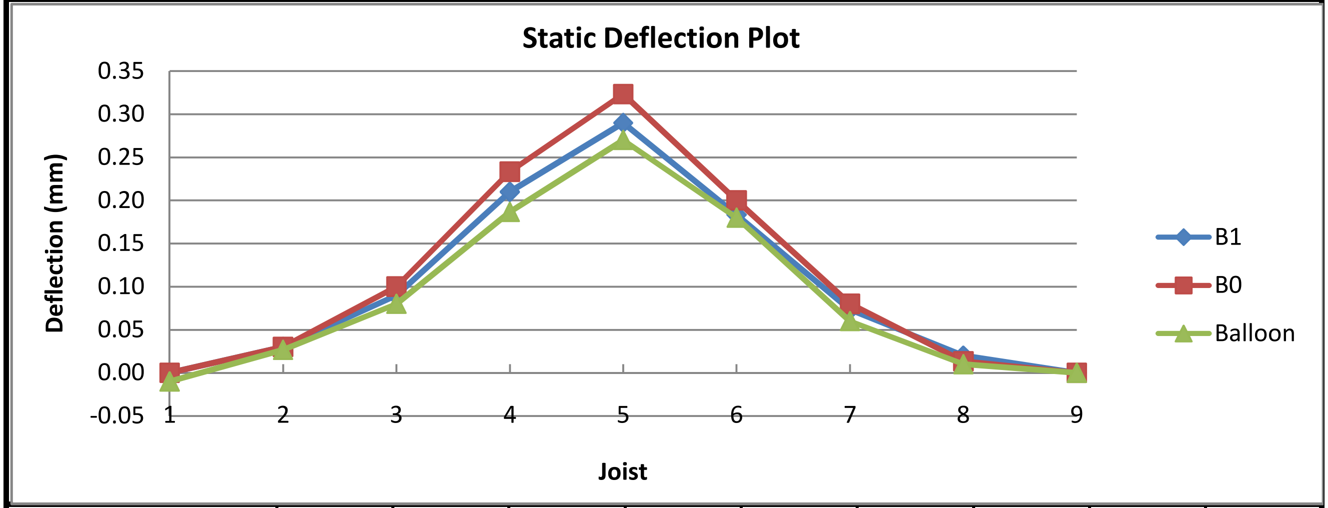
Type C Ceiling
Strongback - Free End

Dynamic Testing

Heel Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	14.7	19.6	35.7	13.1	18.0	N/A	13.1	19.3	N/A
ζ_1	Mean(Min)		3.69%			4.16%			5.60%	
ζ_2	Min(Mean)		3.86%			4.35%			5.71%	
ζ_3	Log Dec		3.60%			3.35%			4.70%	
a_{peak}	(g) avg		0.777			0.831			0.685	
Sandbag Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	14.9	19.7	35.9	13.3	18.1	N/A	13.3	19.3	N/A
ζ_1	Mean(Min)		0.74%			1.38%			2.34%	
ζ_2	Min(Mean)		0.75%			1.42%			2.41%	
ζ_3	Log Dec		0.89%			1.19%			2.54%	
a_{peak}	(g) avg		0.502			0.541			0.605	
Walking		**Balloon**			**B0**			**B1**		
a_{peak}	(g) un wtd		0.057			0.056			0.067	
a_{RMS}	(g) un wtd		0.0119			0.0099			0.0107	

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	-0.01	0.03	0.08	0.19	0.27	0.18	0.06	0.01	0.00
B0	(mm)	0.00	0.03	0.10	0.23	0.32	0.20	0.08	0.01	0.00
B1	(mm)	0.00	0.03	0.09	0.21	0.29	0.18	0.07	0.02	0.00



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg	2.62	-4.62	-20.10	-24.35	-30.48	-20.07	-16.25	-4.99	0.92
B1	(lb) avg	-4.35	-6.21	-14.97	-18.97	-25.88	-15.30	-15.61	-8.76	-5.25
Factor		B0	0.64	B1	0.52					

Measured Wt (lb)	4932	Per Joist (lb)	616.5	
Calculated Wt (lb)	4860	Per Joist (lb)	607.5	

Testing Master Sheet

LF17.0C (LF9)

TDW
Metal Deck w/ LR

Type C Ceiling
No Strongback

Dynamic Testing

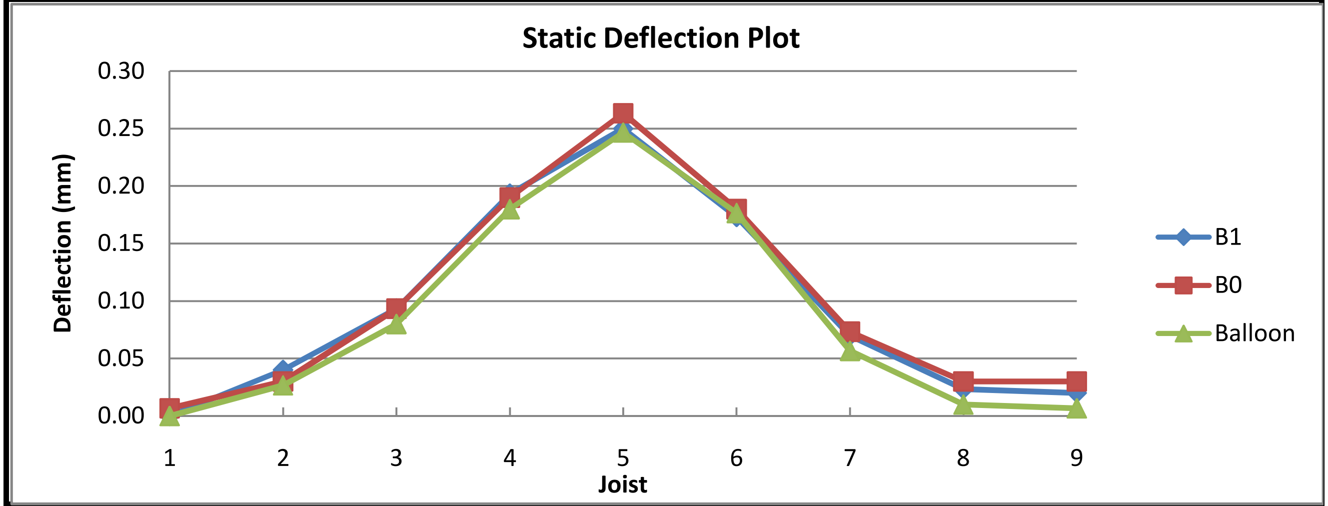
Heel Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	14.3	18.4	18.6	12.7	18.3	N/A	12.7	19.8	N/A
ζ_1	Mean(Min)		3.53%			3.08%			3.02%	
ζ_2	Min(Mean)		3.59%			3.23%			3.71%	
ζ_3	Log Dec		3.04%			3.64%			3.50%	
a_{peak}	(g) avg		0.599			0.630			0.581	

Sandbag Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	14.3	18.3	19.4	12.8	18.4	N/A	13.4	18.8	20.0
ζ_1	Mean(Min)		0.76%			0.81%			0.91%	
ζ_2	Min(Mean)		0.80%			0.88%			0.95%	
ζ_3	Log Dec		1.37%			1.52%			2.00%	
a_{peak}	(g) avg		0.441			0.406			0.441	

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd	0.059	0.063	0.049
a_{RMS}	(g) un wtd	0.0140	0.0135	0.0103

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	0.00	0.03	0.08	0.18	0.25	0.18	0.06	0.01	0.01
B0	(mm)	0.01	0.03	0.09	0.19	0.26	0.18	0.07	0.03	0.03
B1	(mm)	0.00	0.04	0.09	0.19	0.25	0.17	0.07	0.02	0.02



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg	1.38	-5.76	-16.91	-22.77	-25.56	-19.41	-11.40	-7.79	-2.36
B1	(lb) avg	-5.27	-6.89	-14.35	-18.59	-20.48	-15.21	-12.38	-11.25	-5.83
Factor		B0	0.61	B1	0.49					

Measured Wt (lb)	5741	Per Joist (lb)	717.625	
Calculated Wt (lb)	5489	Per Joist (lb)	686.125	

Testing Master Sheet

LF17.0D (LF10)

TDW
Metal Deck w/ LR

Type C Ceiling
Strongback - Free End

Dynamic Testing

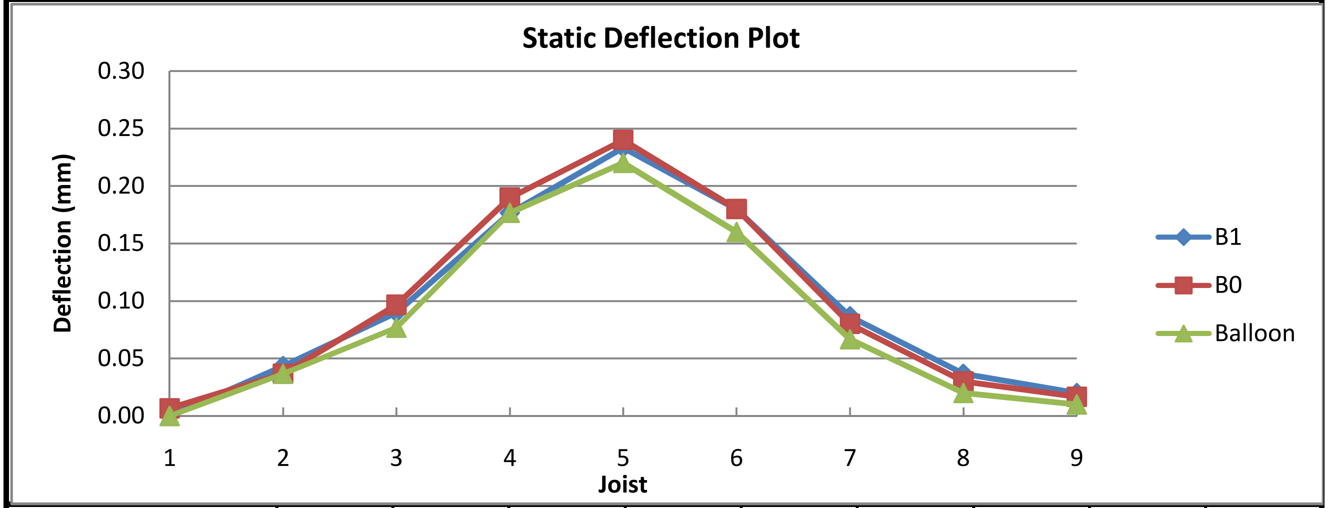
Heel Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	14.2	19.9	N/A	12.9	18.3	N/A	13.1	20.2	N/A
ζ_1	Mean(Min)		3.29%			4.45%			3.95%	
ζ_2	Min(Mean)		3.35%			4.52%			4.06%	
ζ_3	Log Dec		3.35%			3.29%			3.15%	
a_{peak}	(g) avg		0.676			0.680			0.583	

Sandbag Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	14.3	19.9	N/A	13.2	18.6	N/A	13.4	20.2	N/A
ζ_1	Mean(Min)		0.69%			0.93%			1.20%	
ζ_2	Min(Mean)		0.71%			1.08%			1.44%	
ζ_3	Log Dec		1.26%			1.58%			1.92%	
a_{peak}	(g) avg		0.404			0.407			0.387	

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd	0.059	0.045	0.045
a_{RMS}	(g) un wtd	0.0133	0.0094	0.0097

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	0.00	0.04	0.08	0.18	0.22	0.16	0.07	0.02	0.01
B0	(mm)	0.01	0.04	0.10	0.19	0.24	0.18	0.08	0.03	0.02
B1	(mm)	0.00	0.04	0.09	0.18	0.23	0.18	0.09	0.04	0.02



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg	0.78	-3.62	-16.58	-21.24	-24.57	-23.54	-11.79	-7.42	-0.83
B1	(lb) avg	-3.86	-6.42	-14.68	-18.28	-20.26	-17.31	-11.42	-9.54	-6.87
Factor		B0	0.64	B1	0.51					

Measured Wt (lb)	5529	Per Joist (lb)	691.125	
Calculated Wt (lb)	5514	Per Joist (lb)	689.25	

Testing Master Sheet

LF19.5A (LF12)

TDW

Fortacrete w/ LR

Type C Ceiling

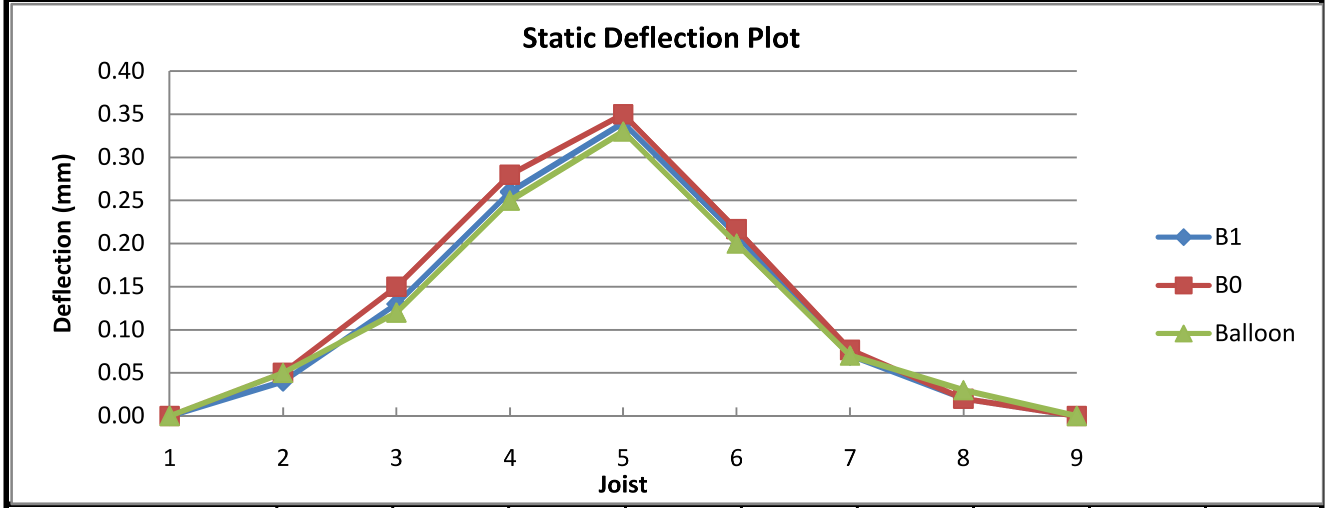
No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	11.9	17.0	N/A	11.2	16.3	N/A	11.7	17.2	N/A
ζ_1	Mean(Min)		3.04%			4.59%			3.70%	
ζ_2	Min(Mean)		3.10%			4.89%			3.77%	
ζ_3	Log Dec		2.85%			3.67%			3.18%	
a_{peak}	(g) avg		0.755			0.640			0.575	
Sandbag Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	12.0	16.9	N/A	11.4	16.4	N/A	11.8	17.3	N/A
ζ_1	Mean(Min)		0.68%			1.84%			1.06%	
ζ_2	Min(Mean)		0.71%			1.90%			1.08%	
ζ_3	Log Dec		0.86%			1.25%			1.14%	
a_{peak}	(g) avg		0.552			0.548			0.549	
Walking		**Balloon**			**B0**			**B1**		
a_{peak}	(g) un wtd		0.058			0.051			0.059	
a_{RMS}	(g) un wtd		0.0137			0.0104			0.0133	

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	0.00	0.05	0.12	0.25	0.33	0.20	0.07	0.03	0.00
B0	(mm)	0.00	0.05	0.15	0.28	0.35	0.22	0.08	0.02	0.00
B1	(mm)	0.00	0.04	0.13	0.26	0.34	0.21	0.07	0.02	0.00



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg	0.72	-5.40	-19.21	-21.83	-22.56	-17.19	-8.61	-5.94	-6.03
B1	(lb) avg									
Factor		B0	0.58	B1	N/A					

Measured Wt (lb)		5419		Per Joist (lb)		677.375				
Calculated Wt (lb)		5538		Per Joist (lb)		692.25				

Testing Master Sheet

LF21.8A (LF14)

Double TDW
Metal Deck w/ LR

Type C Ceiling
No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	11.7	16.9	28.5	9.7	14.3	N/A	9.9	15.4	N/A
ζ_1	Mean(Min)		3.27%			3.47%			3.53%	
ζ_2	Min(Mean)		3.36%			3.61%			3.58%	
ζ_3	Log Dec		3.32%			3.59%			3.52%	
a_{peak}	(g) avg		0.609			0.531			0.566	

Sandbag Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	11.8	16.0	28.8	9.9	14.5	N/A	10.1	15.5	N/A
ζ_1	Mean(Min)		1.17%			1.86%			2.28%	
ζ_2	Min(Mean)		1.21%			1.90%			2.34%	
ζ_3	Log Dec		1.56%			1.96%			2.00%	
a_{peak}	(g) avg		0.532			0.506			0.546	

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd	0.046	0.041	0.036
a_{RMS}	(g) un wtd	0.0114	0.0087	0.0081

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	0.00	0.04	0.10	0.21	0.28	0.18	0.09	0.03	0.00
B0	(mm)	0.01	0.06	0.13	0.24	0.34	0.23	0.11	0.05	0.01
B1	(mm)	0.02	0.06	0.12	0.23	0.31	0.22	0.10	0.05	0.02

Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg	3.95	-5.08	-17.49	-24.60	-34.81	-21.79	-15.91	-3.25	4.82
B1	(lb) avg									
Factor		B0	0.71	B1	N/A					

Measured Wt (lb)		Per Joist (lb)	0
Calculated Wt (lb)	6879	Per Joist (lb)	859.875

Testing Master Sheet

LF19.5B (LF15)

TDW
Metal Deck w/ LR

Type C Ceiling
No Strongback

Dynamic Testing

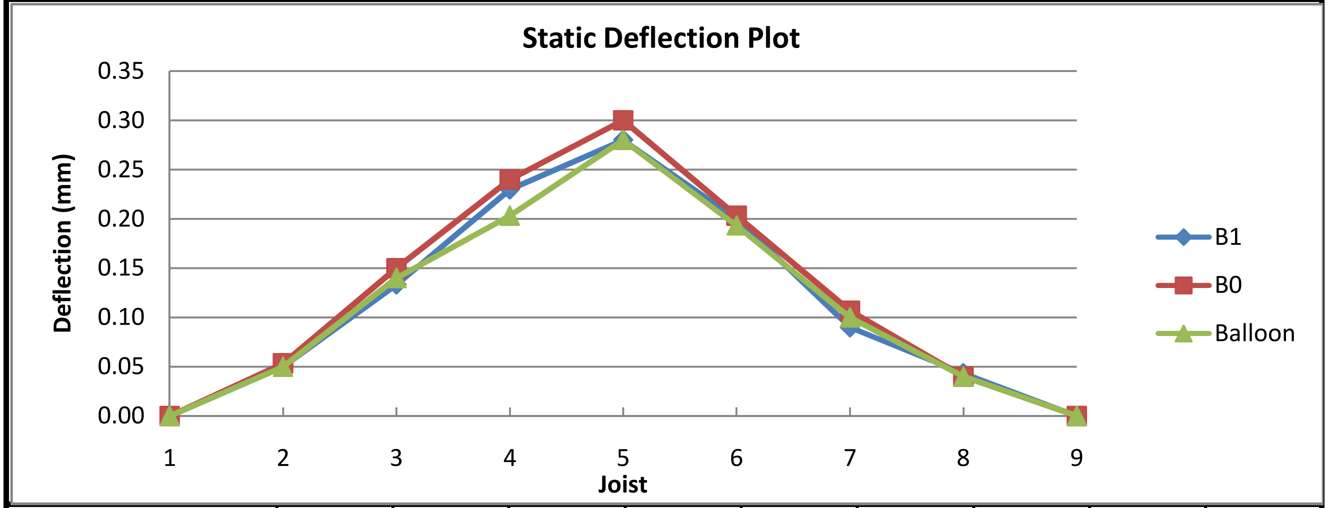
Heel Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	11.4	16.8	N/A	10.4	16.1	N/A	10.8	16.9	N/A
ζ_1	Mean(Min)		3.85%			3.53%			3.40%	
ζ_2	Min(Mean)		3.90%			3.73%			3.48%	
ζ_3	Log Dec		3.41%			3.80%			3.44%	
a_{peak}	(g) avg		0.756			0.762			0.740	

Sandbag Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	11.4	16.8	N/A	10.6	16.3	N/A	11.1	17.0	N/A
ζ_1	Mean(Min)		1.52%			1.14%			0.80%	
ζ_2	Min(Mean)		1.59%			1.19%			0.84%	
ζ_3	Log Dec		1.32%			1.33%			0.99%	
a_{peak}	(g) avg		0.491			0.650			0.578	

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd	0.054	0.057	0.053
a_{RMS}	(g) un wtd	0.0114	0.0124	0.0138

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	0.00	0.05	0.14	0.20	0.28	0.19	0.10	0.04	0.00
B0	(mm)	0.00	0.05	0.15	0.24	0.30	0.20	0.11	0.04	0.00
B1	(mm)	0.00	0.05	0.13	0.23	0.28	0.20	0.09	0.04	0.00



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg	-1.48	-6.53	-14.19	-16.54	-25.61	-21.59	-15.09	-6.09	-2.18
B1	(lb) avg									
Factor		B0	0.58	B1	N/A					

Measured Wt (lb)	6200	Per Joist (lb)	775
Calculated Wt (lb)	6288	Per Joist (lb)	786

Testing Master Sheet

LF19.5Ai (ET 1)

TDW
Fortacrete w/ LR

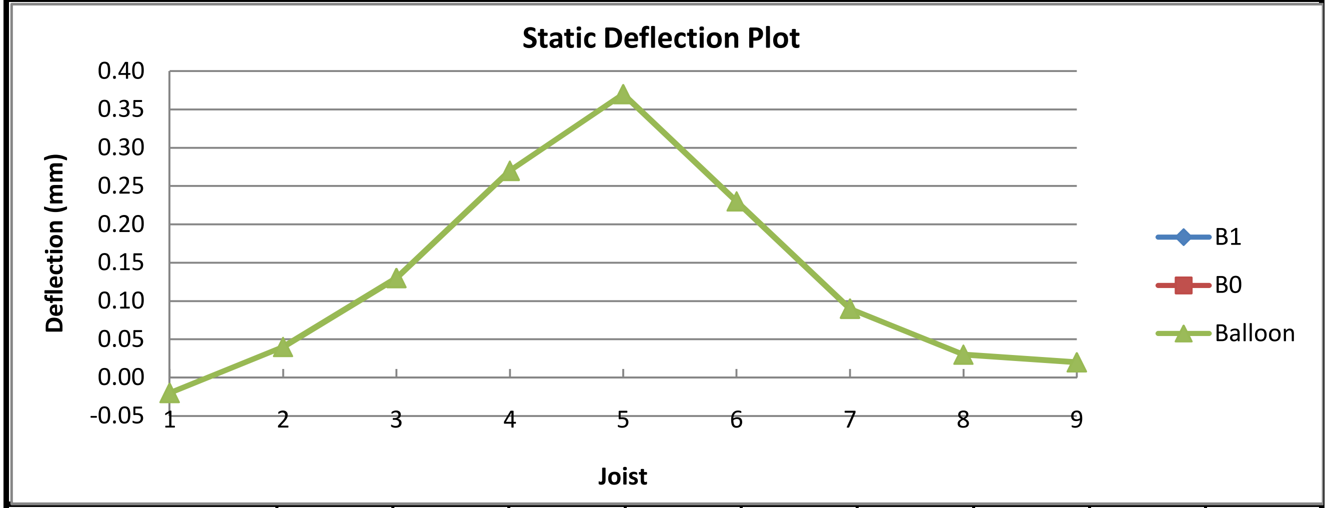
No Ceiling
No Strongback

Dynamic Testing

Heel Drop		Balloon			B0	B1
f	(Hz) avg	12.7	18.6	31.7		
ζ_1	Mean(Min)		4.36%			
ζ_2	Min(Mean)		4.38%			
ζ_3	Log Dec		2.83%			
a_{peak}	(g) avg		0.837			
Sandbag Drop			**Balloon**		**B0**	**B1**
f	(Hz) avg	12.7	17.4	31.3		
ζ_1	Mean(Min)		1.34%			
ζ_2	Min(Mean)		1.40%			
ζ_3	Log Dec		0.64%			
a_{peak}	(g) avg		0.666			
Walking			**Balloon**		**B0**	**B1**
a_{peak}	(g) un wtd					
a_{RMS}	(g) un wtd					

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	-0.02	0.04	0.13	0.27	0.37	0.23	0.09	0.03	0.02
B0	(mm)									
B1	(mm)									



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg									
B1	(lb) avg									
Factor		B0	N/A	B1	N/A					

Measured Wt (lb)	N/A	Per Joist (lb)	N/A
Calculated Wt (lb)	4788	Per Joist (lb)	598.5

Testing Master Sheet

LF19.5Bi (ET 1b)

TDW
Metal Deck w/ LR

No Ceiling
No Strongback

Dynamic Testing

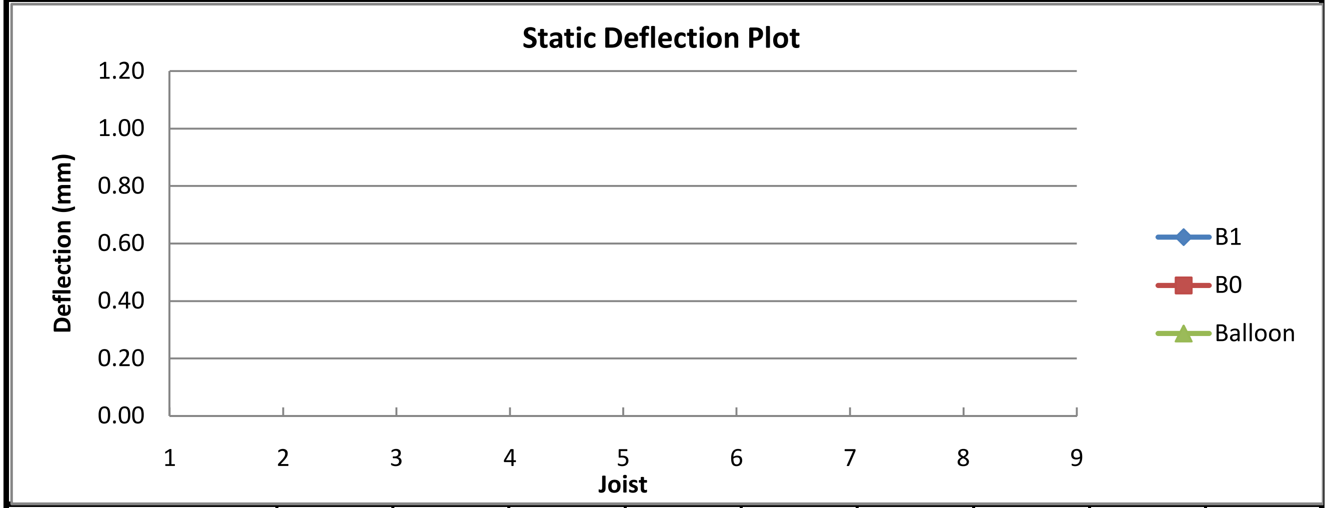
Heel Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	11.9	17.6	N/A		
ζ_1	Mean(Min)		2.93%			
ζ_2	Min(Mean)		2.98%			
ζ_3	Log Dec		2.92%			
a_{peak}	(g) avg		0.922			

Sandbag Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	12.0	17.5	N/A		
ζ_1	Mean(Min)		0.43%			
ζ_2	Min(Mean)		0.44%			
ζ_3	Log Dec		0.72%			
a_{peak}	(g) avg		0.798			

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd			
a_{RMS}	(g) un wtd			

Static Testing

Blocking Layout	Block			Block				Block	
Deflection	J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon (mm)									
B0 (mm)									
B1 (mm)									


Static Deflection Plot

Load Sharing	J1	J2	J3	J4	J5	J6	J7	J8	J9
B0 (lb) avg									
B1 (lb) avg									
Factor	B0	N/A	B1	N/A					

Measured Wt (lb)	N/A	Per Joist (lb)	N/A	
Calculated Wt (lb)	5538	Per Joist (lb)	692.25	

Testing Master Sheet

LF19.5Aii (ET 2)

TDW	No Ceiling
Fortacrete w/ LR	Strongback - Fixed Ends

Dynamic Testing

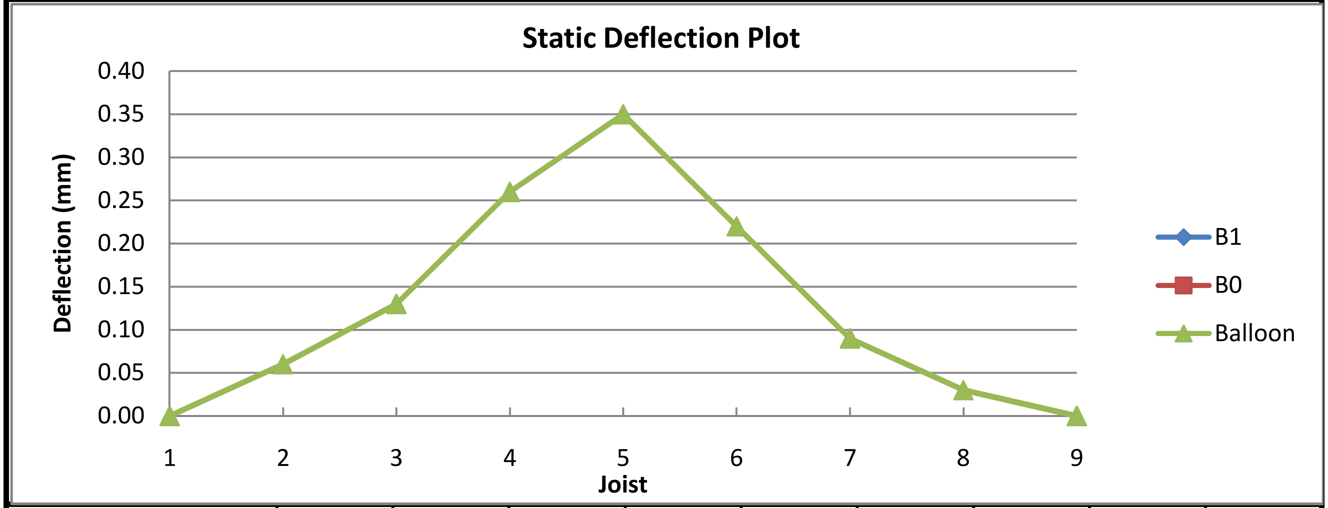
Heel Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	13.2	24.3	N/A		
ζ_1	Mean(Min)		4.40%			
ζ_2	Min(Mean)		4.54%			
ζ_3	Log Dec		4.10%			
a_{peak}	(g) avg		1.006			

Sandbag Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	13.2	24.0	N/A		
ζ_1	Mean(Min)		0.60%			
ζ_2	Min(Mean)		0.63%			
ζ_3	Log Dec		0.55%			
a_{peak}	(g) avg		0.791			

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd			
a_{RMS}	(g) un wtd			

Static Testing

Blocking Layout		Block			Block			Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	0.00	0.06	0.13	0.26	0.35	0.22	0.09	0.03	0.00
B0	(mm)									
B1	(mm)									



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg									
B1	(lb) avg									
Factor		B0	N/A	B1	N/A					

Measured Wt (lb)	N/A	Per Joist (lb)	N/A	
Calculated Wt (lb)	4813	Per Joist (lb)	601.625	

Testing Master Sheet

LF19.5Bii (ET2b)

TDW
Metal Deck w/ LR

No Ceiling
Strongback - Fixed Ends

Dynamic Testing

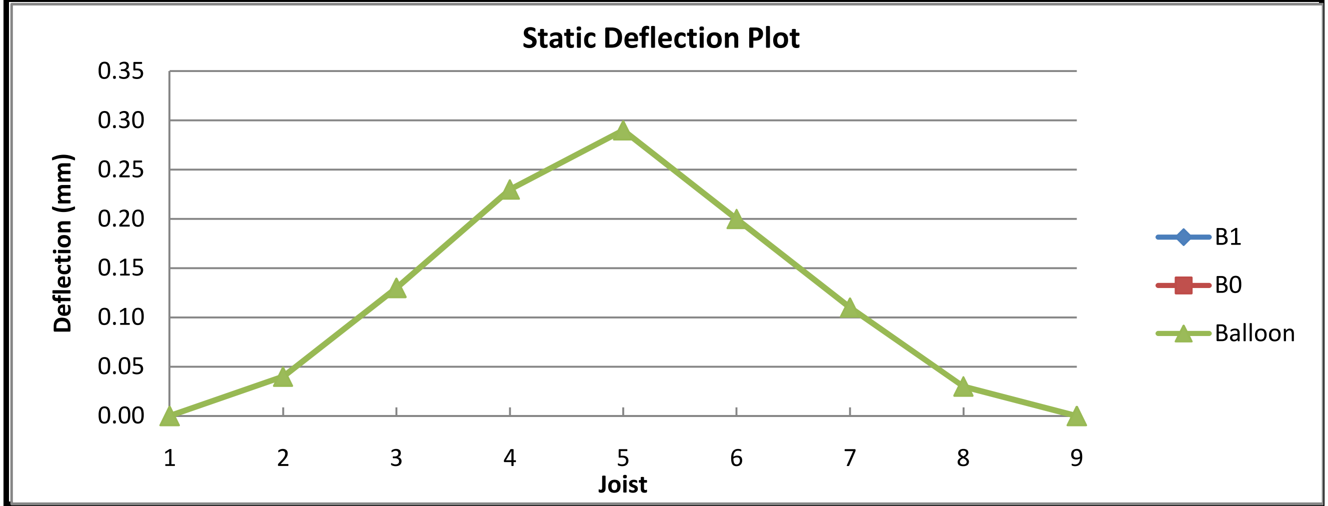
Heel Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	12.6	18.9	25.3		
ζ_1	Mean(Min)		4.30%			
ζ_2	Min(Mean)		4.34%			
ζ_3	Log Dec		3.57%			
a_{peak}	(g) avg		0.930			

Sandbag Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	12.7	25.0	N/A		
ζ_1	Mean(Min)		N/A			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		0.63%			
a_{peak}	(g) avg		0.576			

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd			
a_{RMS}	(g) un wtd			

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	0.00	0.04	0.13	0.23	0.29	0.20	0.11	0.03	0.00
B0	(mm)									
B1	(mm)									



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg									
B1	(lb) avg									
Factor		B0	N/A	B1	N/A					

Measured Wt (lb)	N/A	Per Joist (lb)	N/A	
Calculated Wt (lb)	5563	Per Joist (lb)	695.375	

Testing Master Sheet

LF19.5Aiii (ET 3)

TDW
Fortacrete w/ LR

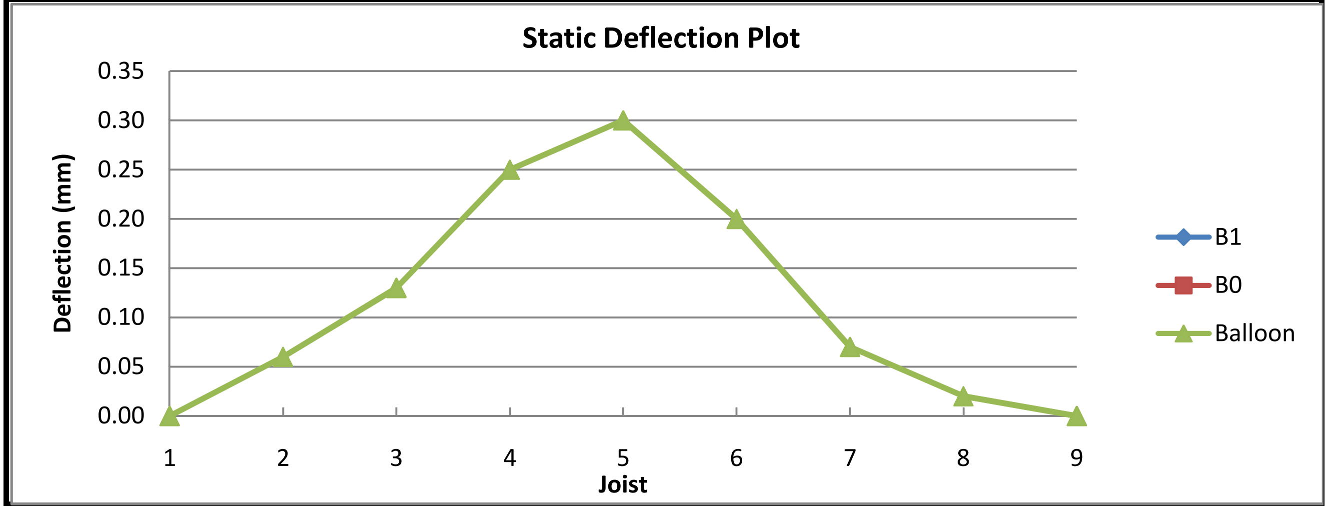
Type C Ceiling
Strongback - Fixed Ends

Dynamic Testing

Heel Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	12.9	22.7	N/A		
ζ_1	Mean(Min)		4.38%			
ζ_2	Min(Mean)		4.50%			
ζ_3	Log Dec		3.37%			
a_{peak}	(g) avg		0.855			
Sandbag Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	13.0	23.0	N/A		
ζ_1	Mean(Min)		0.73%			
ζ_2	Min(Mean)		0.74%			
ζ_3	Log Dec		0.83%			
a_{peak}	(g) avg		0.539			
Walking		**Balloon**			**B0**	**B1**
a_{peak}	(g) un wtd					
a_{RMS}	(g) un wtd					

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	0.00	0.06	0.13	0.25	0.30	0.20	0.07	0.02	0.00
B0	(mm)									
B1	(mm)									



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg									
B1	(lb) avg									
Factor		B0	N/A	B1	N/A					

Measured Wt (lb)	N/A	Per Joist (lb)	N/A
Calculated Wt (lb)	5563	Per Joist (lb)	695.375

Testing Master Sheet

LF19.5Biii (ET3b)

TDW
Metal Deck w/ LR

Type C Ceiling
Strongback - Fixed Ends

Dynamic Testing

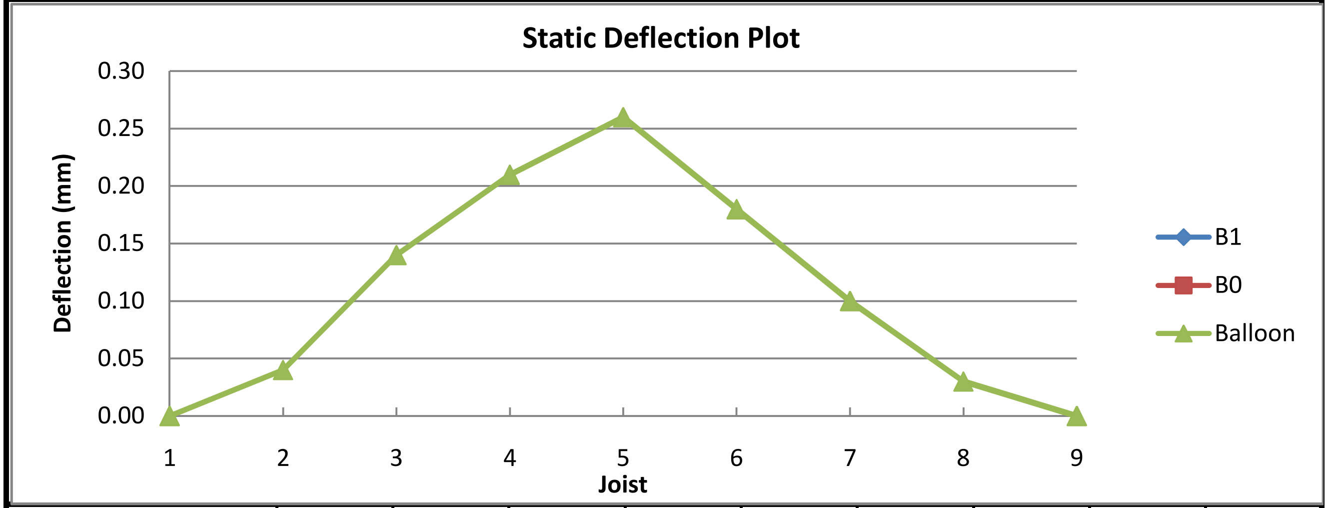
Heel Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	9.9	14.8	N/A		
ζ_1	Mean(Min)		2.30%			
ζ_2	Min(Mean)		2.37%			
ζ_3	Log Dec		2.66%			
a_{peak}	(g) avg		0.754			

Sandbag Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	10.0	14.9	N/A		
ζ_1	Mean(Min)		0.60%			
ζ_2	Min(Mean)		0.62%			
ζ_3	Log Dec		0.66%			
a_{peak}	(g) avg		0.450			

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd			
a_{RMS}	(g) un wtd			

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)	0.00	0.04	0.14	0.21	0.26	0.18	0.10	0.03	0.00
B0	(mm)									
B1	(mm)									



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg									
B1	(lb) avg									
Factor		B0	N/A	B1	N/A					

Measured Wt (lb)	N/A	Per Joist (lb)	N/A	
Calculated Wt (lb)	6313	Per Joist (lb)	789.125	

Testing Master Sheet

LF19.5Aiv 6 psf

TDW
Fortacrete w/ LR

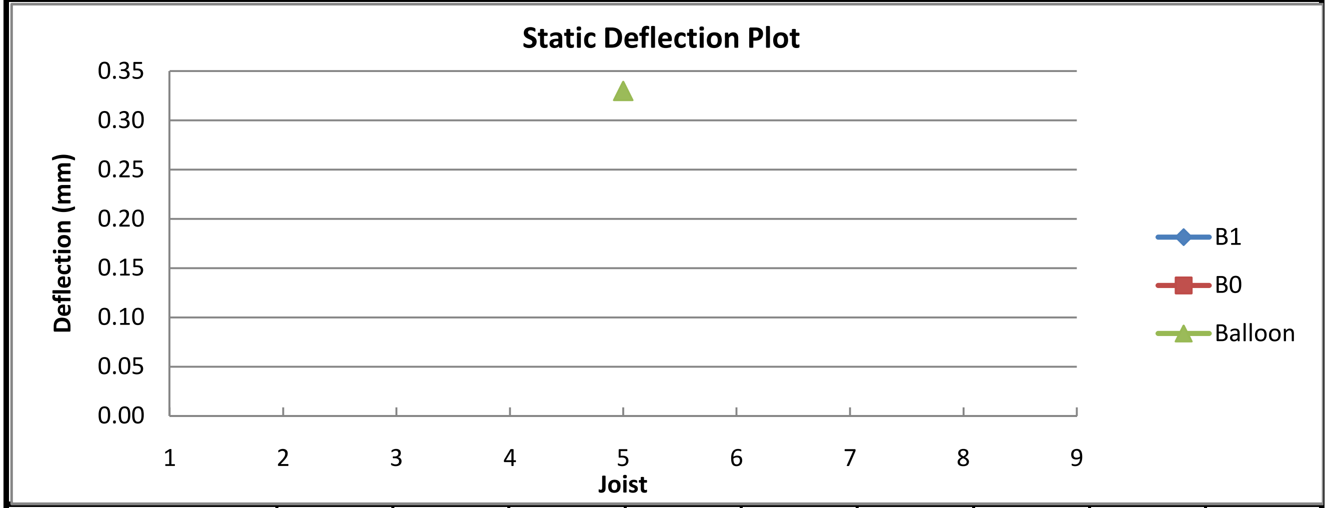
Type C Ceiling
No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	10.3	14.8	N/A	9.9	14.6	N/A	10.3	15.2	N/A
ζ_1	Mean(Min)		2.58%			3.36%			2.45%	
ζ_2	Min(Mean)		2.61%			3.51%			2.51%	
ζ_3	Log Dec		3.05%			2.82%			2.21%	
a_{peak}	(g) avg		0.528			0.491			0.436	
Sandbag Drop		**Balloon**			**B0**			**B1**		
f	(Hz) avg	10.4	14.8	N/A	10.1	14.7	N/A	10.6	15.3	N/A
ζ_1	Mean(Min)		0.42%			1.10%			0.79%	
ζ_2	Min(Mean)		0.57%			1.12%			0.81%	
ζ_3	Log Dec		0.87%			0.94%			0.75%	
a_{peak}	(g) avg		0.411			0.449			0.413	
Walking		**Balloon**			**B0**			**B1**		
a_{peak}	(g) un wtd									
a_{RMS}	(g) un wtd									

Static Testing

Blocking Layout		Block			Block				Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)					0.33				
B0	(mm)									
B1	(mm)									



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg									
B1	(lb) avg									
Factor		B0	N/A	B1	N/A					

Measured Wt (lb)	N/A	Per Joist (lb)	N/A	
Calculated Wt (lb)	7410	Per Joist (lb)	926.25	

Testing Master Sheet

LF19.5Biv 6 psf

TDW
Metal Deck w/ LR

Type C Ceiling
No Strongback

Dynamic Testing

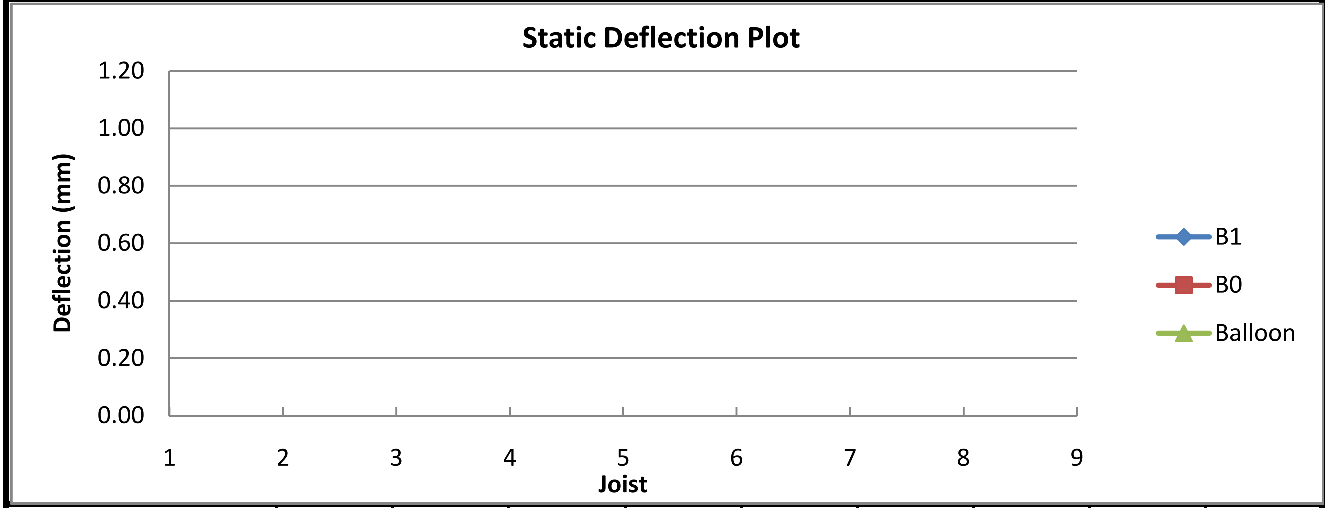
Heel Drop		Balloon			B0	B1
f	(Hz) avg	9.9	14.8	N/A		
ζ_1	Mean(Min)		2.30%			
ζ_2	Min(Mean)		2.37%			
ζ_3	Log Dec		2.66%			
a_{peak}	(g) avg		0.618			

Sandbag Drop		Balloon			B0	B1
f	(Hz) avg	10.0	14.9	N/A		
ζ_1	Mean(Min)		0.60%			
ζ_2	Min(Mean)		0.62%			
ζ_3	Log Dec		0.66%			
a_{peak}	(g) avg		0.412			

Walking		Balloon	B0	B1
a_{peak}	(g) un wtd			
a_{RMS}	(g) un wtd			

Static Testing

Blocking Layout		Block			Block			Block	
Deflection		J1	J2	J3	J4	J5	J6	J7	J8	J9
Balloon	(mm)									
B0	(mm)									
B1	(mm)									



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg									
B1	(lb) avg									
Factor		B0	N/A	B1	N/A					

Measured Wt (lb)	N/A	Per Joist (lb)	N/A	
Calculated Wt (lb)	8160	Per Joist (lb)	1020	

Testing Master Sheet

CW708(14.33')

TDW
Metal Deck w/ LR

Drop Ceiling
No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	18.7	23.2	30.6		
ζ_1	Mean(Min)		3.37%			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		5.14%			
a_{peak}	(g) avg		TBD			

Sandbag Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	18.7	22.9	30.6		
ζ_1	Mean(Min)		3.56%			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		3.62%			
a_{peak}	(g) avg		TBD			

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd	TBD		
a_{RMS}	(g) un wtd	TBD		

Static Testing

Blocking Layout										
Deflection					L of Centre	Centre	R of Centre			
Balloon	(mm)				N/A	N/A	N/A			
B0	(mm)									
B1	(mm)									

Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg									
B1	(lb) avg									
Factor										

Measured Wt (lb)		Per Joist (lb)		
Calculated Wt (lb)	8005	Per Joist (lb)		

Testing Master Sheet

CW709(21.8')

Double TDW
Metal Deck w/ LR

Drop Ceiling
No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	9.9	13.1	17.2		
ζ_1	Mean(Min)		4.80%			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		5.51%			
a_{peak}	(g) avg		TBD			
Sandbag Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	9.9	12.9	17.0		
ζ_1	Mean(Min)		3.58%			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		3.77%			
a_{peak}	(g) avg		TBD			
Walking		**Balloon**			**B0**	**B1**
a_{peak}	(g) un wtd		TBD			
a_{RMS}	(g) un wtd		TBD			

Static Testing

Blocking Layout									
Deflection				L of Centre	Centre	R of Centre			
Balloon	(mm)			N/A	N/A	N/A			
B0	(mm)								
B1	(mm)								

Load Sharing	J1	J2	J3	J4	J5	J6	J7	J8	J9
B0 (lb) avg									
B1 (lb) avg									
Factor									

Measured Wt (lb)		Per Joist (lb)		
Calculated Wt (lb)	11438	Per Joist (lb)		

Testing Master Sheet

CW805(19.3')

TDW
Metal Deck w/ LR

Drop Ceiling
No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	11.8	24.3	N/A		
ζ_1	Mean(Min)		N/A			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		2.54%			
a_{peak}	(g) avg		TBD			

Sandbag Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	11.9	23.0	40.3		
ζ_1	Mean(Min)		N/A			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		2.81%			
a_{peak}	(g) avg		TBD			

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd	TBD		
a_{RMS}	(g) un wtd	TBD		

Static Testing

Blocking Layout									
Deflection				L of Centre	Centre	R of Centre			
Balloon (mm)				N/A	N/A	N/A			
B0 (mm)									
B1 (mm)									

Load Sharing	J1	J2	J3	J4	J5	J6	J7	J8	J9
B0 (lb) avg									
B1 (lb) avg									
Factor									

Measured Wt (lb)		Per Joist (lb)		
Calculated Wt (lb)	10134	Per Joist (lb)		

Testing Master Sheet

OK401(14.2')

TDW	Drop Ceiling
Metal Deck w/ LR	No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	18.9	23.5	31.1		
ζ_1	Mean(Min)		N/A			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		1.55%			
a_{peak}	(g) avg		TBD			
Sandbag Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	22.3	28.6	35.2		
ζ_1	Mean(Min)		N/A			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		2.27%			
a_{peak}	(g) avg		TBD			
Walking		**Balloon**			**B0**	**B1**
a_{peak}	(g) un wtd		TBD			
a_{RMS}	(g) un wtd		TBD			

Static Testing

Blocking Layout									
Deflection				L of Centre	Centre	R of Centre			
Balloon (mm)				N/A	N/A	N/A			
B0 (mm)									
B1 (mm)									

Load Sharing	J1	J2	J3	J4	J5	J6	J7	J8	J9
B0 (lb) avg									
B1 (lb) avg									
Factor									

Measured Wt (lb)		Per Joist (lb)		
Calculated Wt (lb)	9713	Per Joist (lb)		

Testing Master Sheet

OK402(14.2')

TDW	Drop Ceiling
Metal Deck w/ LR	No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	20.0	27.1	34.3		
ζ_1	Mean(Min)		N/A			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		4.03%			
a_{peak}	(g) avg		TBD			

Sandbag Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	20.0	27.9	32.6		
ζ_1	Mean(Min)		N/A			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		5.24%			
a_{peak}	(g) avg		TBD			

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd	TBD		
a_{RMS}	(g) un wtd	TBD		

Static Testing

Blocking Layout									
Deflection				L of Centre	Centre	R of Centre			
Balloon (mm)				N/A	N/A	N/A			
B0 (mm)									
B1 (mm)									

Load Sharing	J1	J2	J3	J4	J5	J6	J7	J8	J9
B0 (lb) avg									
B1 (lb) avg									
Factor									

Measured Wt (lb)		Per Joist (lb)		
Calculated Wt (lb)	9713	Per Joist (lb)		

Testing Master Sheet

CG601(17.6')

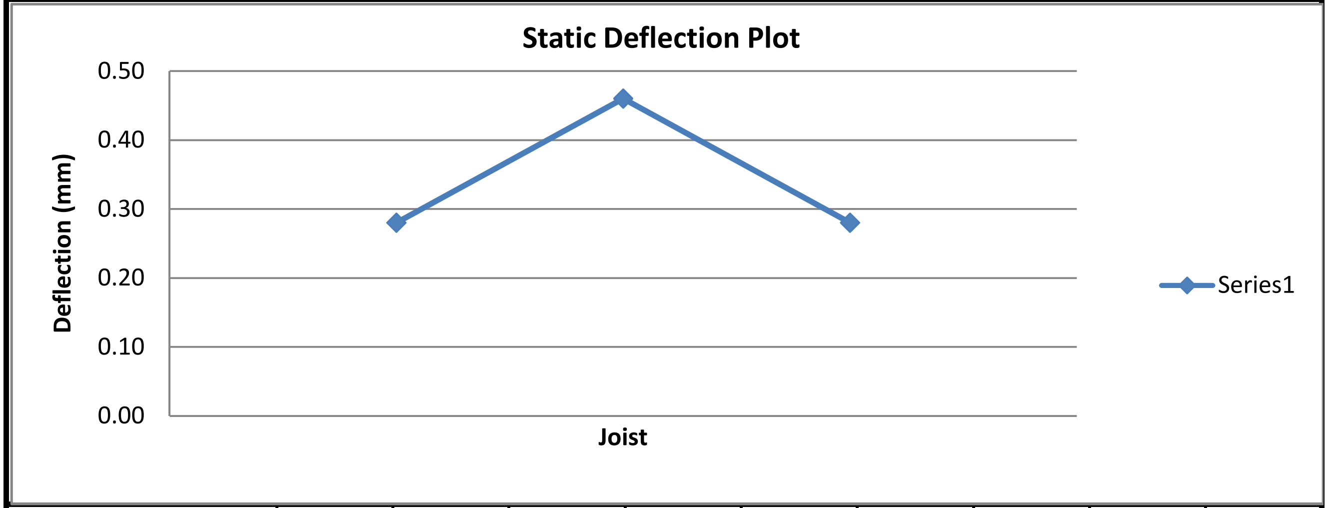
TDW	Ceiling on RC
Fortacrete w/ LevelRock	No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	13.6	23.4	N/A		
ζ_1	Mean(Min)		N/A			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		4.25%			
a_{peak}	(g) avg		TBD			
Sandbag Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	14.4	23.1	N/A		
ζ_1	Mean(Min)		N/A			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		3.58%			
a_{peak}	(g) avg		TBD			
Walking		**Balloon**			**B0**	**B1**
a_{peak}	(g) un wtd		TBD			
a_{RMS}	(g) un wtd		TBD			

Static Testing

Blocking Layout										
Deflection					L of Centre	Centre	R of Centre			
Balloon	(mm)				0.28	0.46	0.28			
B0	(mm)									
B1	(mm)									



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg									
B1	(lb) avg									
Factor										

Measured Wt (lb)		Per Joist (lb)		
Calculated Wt (lb)	4114	Per Joist (lb)		

Testing Master Sheet

CG604(14.8')

TDW
Fortacrete w/ LevelRock

Ceiling on RC
No Strongback

Dynamic Testing

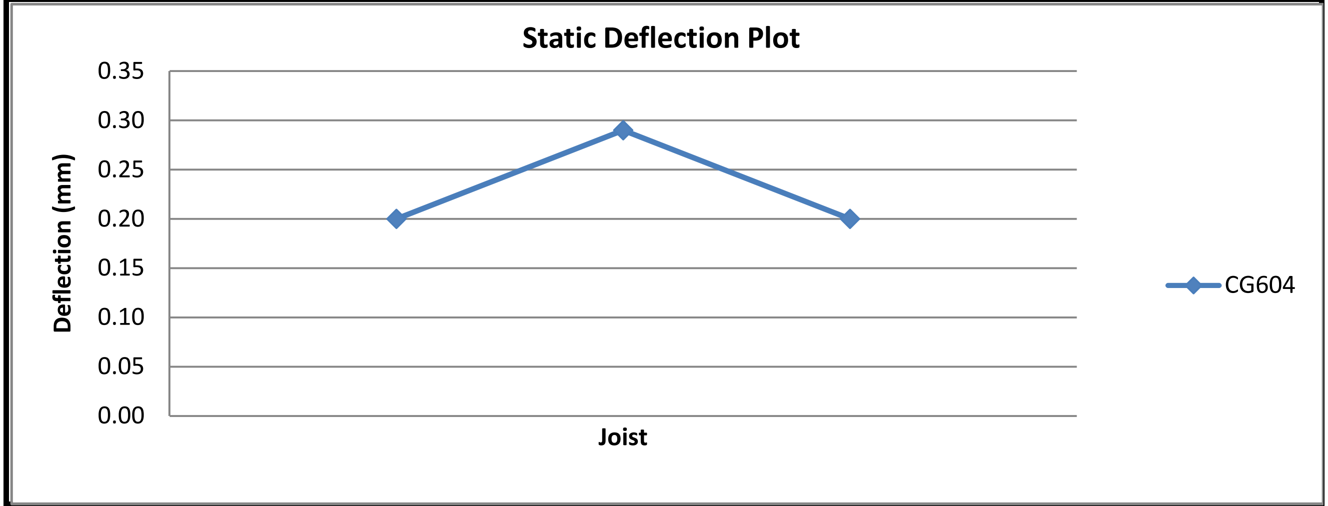
Heel Drop		**Balloon**	**B0**	**B1**
f	(Hz) avg	16.0 24.0 38.0		
ζ_1	Mean(Min)	N/A		
ζ_2	Min(Mean)	N/A		
ζ_3	Log Dec	5.48%		
a_{peak}	(g) avg	TBD		

Sandbag Drop		**Balloon**	**B0**	**B1**
f	(Hz) avg	16.3 23.1 38.5		
ζ_1	Mean(Min)	N/A		
ζ_2	Min(Mean)	N/A		
ζ_3	Log Dec	4.23%		
a_{peak}	(g) avg	TBD		

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd	TBD		
a_{RMS}	(g) un wtd	TBD		

Static Testing

Blocking Layout									
Deflection				L of Centre	Centre	R of Centre			
Balloon (mm)				0.20	0.29	0.20			
B0 (mm)									
B1 (mm)									



Load Sharing	J1	J2	J3	J4	J5	J6	J7	J8	J9
B0 (lb) avg									
B1 (lb) avg									
Factor									

Measured Wt (lb)		Per Joist (lb)			
Calculated Wt (lb)	4402	Per Joist (lb)			

Testing Master Sheet

CG805(21.2')

Double TDW
Fortacrete w/ LevelRock

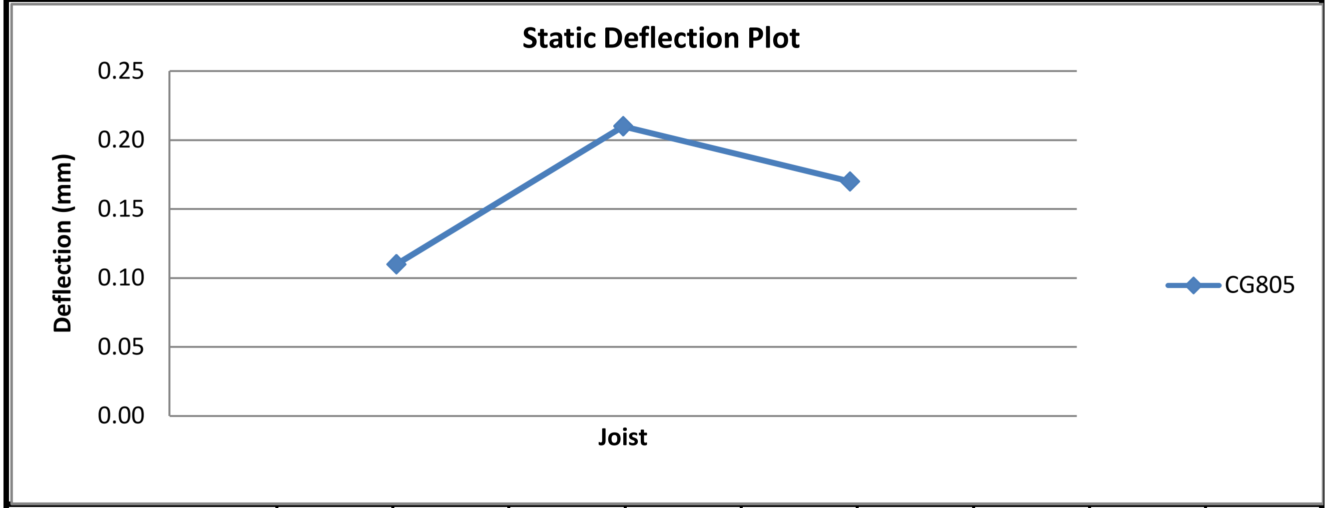
Ceiling on RC
No Strongback

Dynamic Testing

Heel Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	14.4	22.4	32.1		
ζ_1	Mean(Min)		7.82%			
ζ_2	Min(Mean)		8.01%			
ζ_3	Log Dec		6.37%			
a_{peak}	(g) avg		TBD			
Sandbag Drop		**Balloon**			**B0**	**B1**
f	(Hz) avg	15.2	22.8	33.8		
ζ_1	Mean(Min)		4.97%			
ζ_2	Min(Mean)		5.13%			
ζ_3	Log Dec		3.58%			
a_{peak}	(g) avg		TBD			
Walking		**Balloon**			**B0**	**B1**
a_{peak}	(g) un wtd		TBD			
a_{RMS}	(g) un wtd		TBD			

Static Testing

Blocking Layout										
Deflection					L of Centre	Centre	R of Centre			
Balloon	(mm)				0.11	0.21	0.17			
B0	(mm)									
B1	(mm)									



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg									
B1	(lb) avg									
Factor										

Measured Wt (lb)		Per Joist (lb)		
Calculated Wt (lb)	9766	Per Joist (lb)		

Testing Master Sheet

CGMH6(16.8')

TDW

Ceiling on RC

Fortacrete w/ LevelRock

Furnished

Dynamic Testing

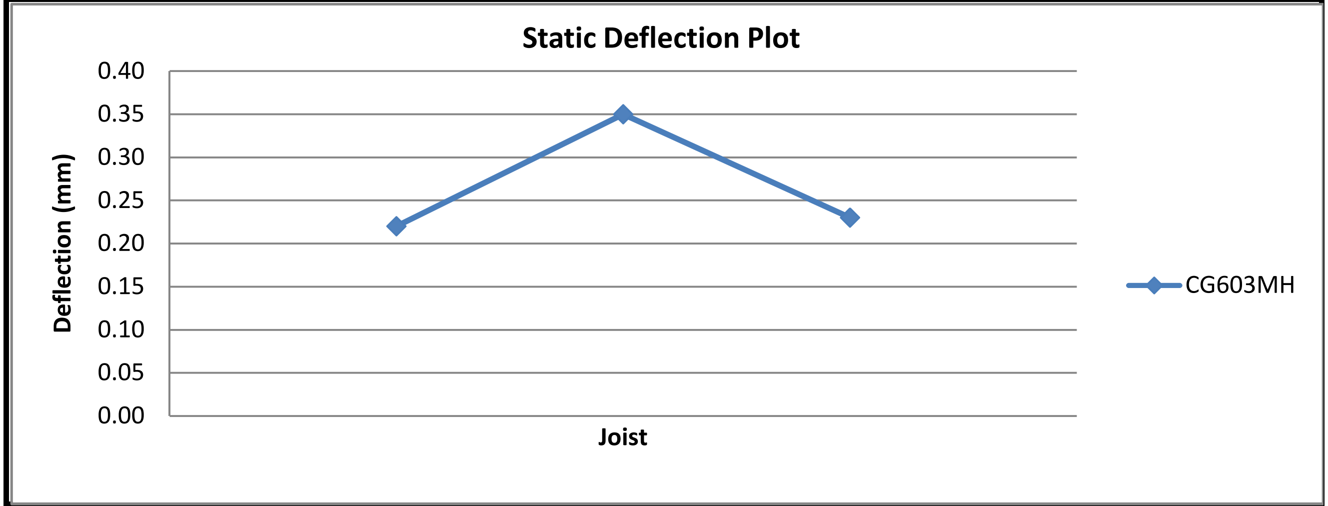
Heel Drop		Balloon			B0	B1
f	(Hz) avg	15.0	22.5	31.8		
ζ_1	Mean(Min)		N/A			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		6.60%			
a_{peak}	(g) avg		TBD			

Sandbag Drop		Balloon			B0	B1
f	(Hz) avg	15.7	23.8	33.8		
ζ_1	Mean(Min)		N/A			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		7.28%			
a_{peak}	(g) avg		TBD			

Walking		Balloon	B0	B1
a_{peak}	(g) un wtd	TBD		
a_{RMS}	(g) un wtd	TBD		

Static Testing

Blocking Layout									
Deflection				L of Centre	Centre	R of Centre			
Balloon (mm)				0.22	0.35	0.23			
B0 (mm)									
B1 (mm)									



Load Sharing	J1	J2	J3	J4	J5	J6	J7	J8	J9
B0 (lb) avg									
B1 (lb) avg									
Factor									

Measured Wt (lb)		Per Joist (lb)		
Calculated Wt (lb)		Per Joist (lb)		

Testing Master Sheet

CGMH7(16.8')

TDW
Fortacrete w/ LevelRock

Ceiling on RC
Unfurnished

Dynamic Testing

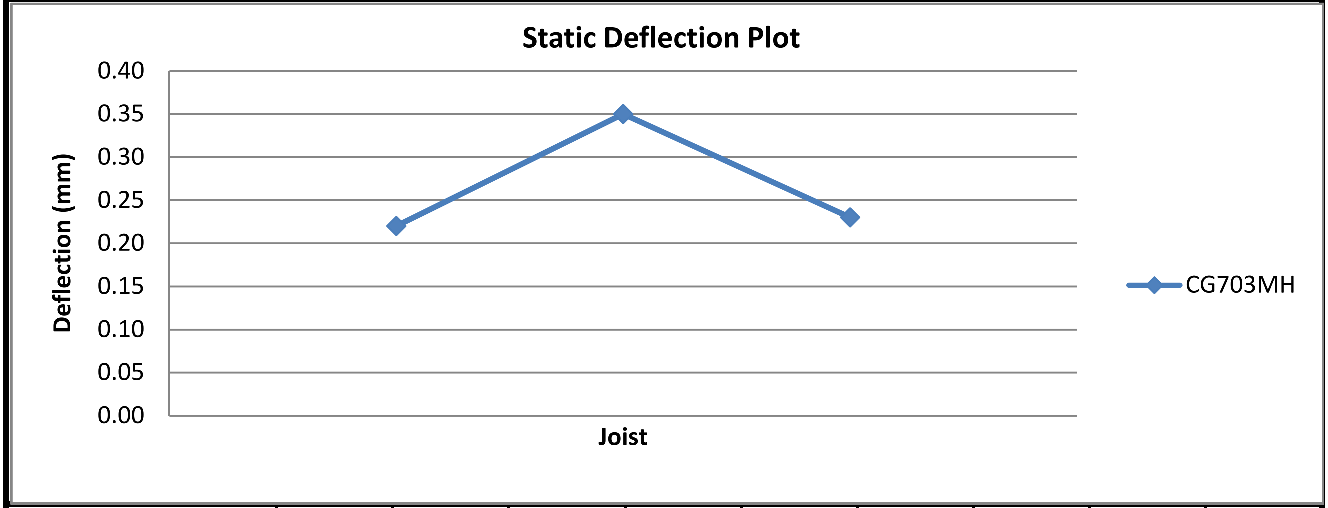
Heel Drop			**Balloon**		**B0**	**B1**
f	(Hz) avg	15.4	24.5	0.0		
ζ_1	Mean(Min)		N/A			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		7.89%			
a_{peak}	(g) avg		TBD			

Sandbag Drop			**Balloon**		**B0**	**B1**
f	(Hz) avg	17.3	25.6	34.1		
ζ_1	Mean(Min)		N/A			
ζ_2	Min(Mean)		N/A			
ζ_3	Log Dec		6.17%			
a_{peak}	(g) avg		TBD			

Walking		**Balloon**	**B0**	**B1**
a_{peak}	(g) un wtd	TBD		
a_{RMS}	(g) un wtd	TBD		

Static Testing

Blocking Layout									
Deflection					L of Centre	Centre	R of Centre		
Balloon	(mm)				0.22	0.35	0.23		
B0	(mm)								
B1	(mm)								



Load Sharing		J1	J2	J3	J4	J5	J6	J7	J8	J9
B0	(lb) avg									
B1	(lb) avg									
Factor										

Measured Wt (lb)		Per Joist (lb)		
Calculated Wt (lb)	6498	Per Joist (lb)		