The Effect of Lateral Bracing on the Dynamic Response of Wood Floor Systems.

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Thesis submitted to the Faculty of the Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

Master of Science

in

Civil Engineering

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May 1993

Blacksburg

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(ABSTRACT)

This thesis presents the results of an extensive study of several types of lateral bracing for solid-sawn and parallel-chord truss floor systems. Three solid-sawn floor bracing systems were evaluated: X-bridging, full-depth solid blocking, and finally, post-tensioned solid-blocking. Five different truss bracing systems were investigated: bottom-chord bracing, steel X-bracing, strong-back bracing, and the bracing combinations of X-plus bottom-chord bracing, and strong-back plus bottom chord bracing were evaluated. A total of seven, 4.9m x 4.9m floor specimens were constructed. Four 38 x 286 mm (2 x 12 inch nominal), solid-sawn wood joist floors were constructed for evaluation of the solid-sawn bracing systems. Three 305 mm (12 inch) deep, bottom-chord bearing, metal plate connected, parallel-chord truss floors were constructed to evaluate the truss floor bracing systems. Both floor systems utilized joist/truss spacings of 610 mm (24 inches) on center, and were covered with 18.3 mm (23/32 inch) thick, tongue-in-groove, plywood sheathing. The bracing systems were evaluated at different live load levels and boundary conditions.

The bracing systems were subjected to both static and dynamic loadings. The

effect of the bracing systems were determined based on four parameters: one static, and three dynamic. The percent change in concentrated load carried by the loaded joist was used as the static test parameter. The effect, if any, of the bracing systems on the modal resonant frequencies, separation of frequencies, and damping characteristics of the floor systems, were used as dynamic parameters. Future research and design recommendations were given in the conclusion chapter.

ACKNOWLEDGEMENTS

First, I would like to thank the United States Department of Agriculture - NRI Competitive Grants Program, USDA Project #91-37103-6541, for providing me the opportunity to become involved in this research project.

Next, I wish to express my deepest gratitude to my advisor's Dr. Dan Dolan, Dr. Tom Murray, and Dr. Frank Woeste, who gave me the guidance and support to produce the caliber of work presented in this thesis. I thank them for having confidence in my ability to get the job done. Also to all of my professors and teachers throughout my life who taught me what I needed to know to get to where I am today.

My thanks go out to Mr. J. W. Akers, Mr. Kenney Albert, Mr. Harold Vandivort, Mr. Carlisle Price, and Mr. Harrison Sizemore from the Brooks Forest Products Research Center, who helped turn our ideas into results. Also to Mr. Brett Farmer, and Mr. Dennis Huffman, from the Civil Engineering Structures Lab who literally "built the foundation" for this project. I also wish to thank Sharon Daley, Angie Riegel, and Ann Crate, the people behind the scenes who always had the time to help me out. My thanks, also, to all of the other faculty and staff at the Virginia Polytechnic Institute and State University who made my time in Blacksburg both pleasant and beneficial.

To my friends and colleagues in the Department of Wood Science and Forest Products, Tim Steiss, Xiaoming Li, Rob Kalkert, Maurice White, and Scott Gutshall, for helping me carry the weight down the long road I traveled, and for tolerating my sometimes unpleasant disposition. To Dave Runte, for his friendship, and for never letting me lose my sense of humor. Also to Linda Morley, Cameron Bryant, Jeff Driver, and Ron Shope, for their friendship and comradery during my stay in Blacksburg.

Finally, to my family, Irene and Kenney, Norma and Bill, Pat and John, and Clay, Lisa, Jessie and C.J., who are the source of strength in my life, and who gave, and still give, their love and support so freely. I am truly blessed to have so many good people in my life.

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I

INTRODUCTION

In order to better utilize timber resources in the United States, new structural systems, specifically new floor joist systems, are being developed which are lighter, stiffer, and carry the static design loads with less wood mass. As these new lighter and stronger joist systems are being used, floor span lengths are increasing, and serviceability criteria are becoming a more significant factor in floor system design. A major serviceability problem, and the cause of an increasing amount of litigation, is the susceptibility of wood floor joist systems to annoying vibrations.

Traditionally, floor systems are designed based on strength requirements, after which the serviceability of the floor is checked based on deflection under a uniform static loading. In other words, the deflection of the floor joist model under a uniform static load is calculated using a deflection equation derived from structural theory. The calculated deflection is then compared to an allowable value, usually some deflection per length criteria. For certain floor system configurations, this deflection limitation does not provide enough resistance to random dynamic loading, say for instance, rhythmic activities such as aerobics or dancing, hence the problem of floor vibrations. In addition, lighter and stronger joist systems have been developed which either supply the necessary strength with less wood mass (i.e. a more efficient cross-section), or allow for longer spans with the same mass, or both. These newer systems have equal or greater stiffness and less mass, and are associated with an occurrence of serviceability problems in floors.

As a sidenote, the problem of annoying floor vibrations has also arisen in concrete and steel systems due to the lighter structural elements allowed by load and resistance factor design methodology (LRFD). As load-factor design is integrated into the National Design Specification, the same increased occurrence of serviceability problems could arise, and when combined with lighter and stiffer wood-joist systems would provide an ideal environment for floor serviceability failures.

Annoying floor vibrations represent a structural failure of sorts, although not the catastrophic failure that one often thinks of when the phrase "structural failure" is mentioned. A structural design is based on two criteria: strength criteria, and serviceability criteria. Annoying floor vibration represents a failure in the latter; a failure of the serviceability requirements of the floor system. While no human life is lost in this type of failure, floor vibrations do cause human distress and uneasiness. It is the goal of this thesis to evaluate the effect of several between joist bracing systems on the static and dynamic behaviors of two different types of wood floor joist systems; solid-sawn lumber, and parallel chord truss floor systems. The bracing systems which will be evaluated in this study are bridging and blocking, and post-tensioning of the blocking, and their effect on the static and dynamic response of sawn lumber floor systems. The effect of using metal X-bracing and "strong-backs" in parallel chord truss systems will also be evaluated. Strong-back refers to a bracing system recommended for installation with parallel-chord floor truss systems. A strong-back consists of a piece of sawn lumber, usually 38 x 140 mm (2 x 6 nominal) or larger in cross-section, attached either to a vertical web member located at midspan along the centerline of the floor system, or at pre-defined spacings along the truss span.

Since the problem of annoying wood joist floor vibrations has resulted in a considerable amount of litigation recently, it follows that something should be done to reduce this problem in the wood construction industry. The expected results from this research will quantify the effect bracing systems have on the problem of wood-joist floor vibrations. With these results, building code modifications will be proposed if improvement in the floor response is observed. In addition, papers on this topic will be presented at national conferences, and published in technical journals and trade magazines. The organization of this thesis is as follows: Chapter two contains a review of pertinent literature, Chapter three presents a detailed explanation of the experimental methods and procedures, Chapter four presents results and discussion of results, and chapter five states conclusions derived from the results.

II

LITERATURE REVIEW

3.1 Introduction

This chapter will provide the reader with a summary of similar work completed prior to this thesis. The main areas to be focused upon are the static and dynamic evaluation of joist systems with particular emphasis placed on research of joist systems incorporating between joist bracing systems.

3.2 Review of Pertinent Literature

3.2.1 General Vibrational Characteristics of Wood Joist Floors

Polensek [1970] investigated human sensitivity to impact-induced vibration on twenty-eight wood-joist floor systems. The floors were 7.3m (24 ft.) wide with varied span lengths from 2.7m to 5.2m (9 to 17.2 ft) depending on size, grade, and species of the joists. Plywood sheathing of 12.7mm (1/2 inch) thickness was nailed to the joists, and the floor systems were supported by a 229mm (9 in) thick, 1.2m (4ft) high concrete wall. The floors were impacted with a 154kg (70 pound) weight dropped from varying heights, and deflection versus time plots were recorded. In addition to the mechanical monitoring of the floor, a human subject seated on the floor system in a chair rated the resulting vibrations. A rating system based on natural frequency versus deflection was proposed, and an analytical method for calculating the first natural frequency was presented. It was found that the magnitude of impact had no significant effect on duration of vibration, from which it was suggested that wooden floor systems provide higher inherent damping than those of concrete and steel. Damping is a measure of energy dissipation of the system. This study also recommended that building codes require vibrational criteria evaluation prior to construction.

Another study by Polensek [1971] evaluated the effect elastomeric adhesive had on the static and dynamic response of two wood-joist floor systems. Both floors were constructed with 38 x 184mm (2 x 8 inch nominal) Douglas Fir joists spaced at 406mm (16 inches) on center, and sheathed with 15.9mm (5/8 inch) thick, tongue-in-groove, touch sanded, plywood. The nailed only floor spanned 3.8m (12.6 ft) while the nailed and glued floor spanned 4.4m (14.4 feet). There were six different types of tests used to evaluate the effect of gluing the joist-to-sheathing connection. Among them was a vertical free-vibration test and a concentrated load test. Free-vibration was induced by the sudden release of a 91kg (200 pound) mass from the centroid of the floor. It was found that in a free-vibration mode there was no significant increase in fundamental frequency due to gluing. It was pointed out that while the gluing was thought to increase the fundamental frequency of each joist, the sheathing in turn combined each of the individual frequencies, and therefore, the resulting floor fundamental frequency depended on the relationship between adjacent joist frequencies. Based on this theory, a number of lower frequencies (nailed only joists) could combine to produce a floor frequency equal to that of the stiffer (glued and nailed) joist floor due to relative local stiffness. In the concentrated load test, a 1335N (300 pound) force was applied at midspan of each joist while the deflection of all the joists in the floor system were recorded. There was no significant difference between the nailed only, and the nailed and glued floors. However, when the floors were loaded with a uniform load to collapse, it was found that the glued and nailed floors were significantly stronger than the nailed only floors.

Then in 1972, Polensek et al. evaluated, among other things, load sharing of wood joist floor systems subject to various static load cases. Forty-four floor systems were tested, each constructed of either 38 x 140 mm (2 x 6 inch nominal), or 38 x 235 mm (2 x 10 inch nominal) floor joists. It was found that two-thirds of a 1335N (300 lb.) concentrated load was shared by the three adjacent joists on each side of the loaded member at midspan. It was also put forth that a localized uniform load would be a more rational design load for a floor system versus the more commonly used uniform load over the entire span. One reason given for this was that a crowd of eight people in 1.4 square meters (15 square feet) of floor area, would create a load of approximately 4788 Pa (100 psf), which could be a critical load case. This report also stated that in floor system design, a T-beam model, with a joist and an effective width of sheathing, was a better design model since it would take into account the additional strength and stiffness provided by the composite action of the two materials.

Polensek [1975] investigated damping capacity of wood joist floor systems, and the effect of mass and floor boundary conditions, on damping ratio and first natural frequency. The damping ratio is the fraction of critical damping present in the system. Critical damping can be defined as the level of damping (energy dissipation) present such that no oscillation of the system occurs after dynamic loading. This study was a continuation of Polensek et al. 1972, and used the same forty-four floors in this study. Experimental testing consisted of four types: (1) Vertical free vibration tests to determine a range of actual damping ratios of floor systems during dynamic loading, (2) Vertical vibration tests with live load (people) on the floor to quantify the effect of added mass on damping characteristics of floors, (3) Vertical vibration tests with partial support fixity (wall load), and added mass, to assess the effect of boundary conditions (partial fixity), and added mass on damping ratio, and natural frequency, respectively, and (4) Horizontal vibration tests to determine the contribution of wood-joist floors to damping in a lateral load case. It was found that live load increased the damping ratio by only 0.07. It was also found that adding mass at midspan reduced the natural frequency in the area of loading only, and had a negligible effect on the damping capacity. Also, the simulation of the wall load at the supports slightly increased the floor stiffness, and therefore slightly increased the floor frequency, but had no effect on damping.

In 1971, C.-T. Yeh (et al.) evaluated three sources of damping present in wood-joist floor systems. First, the damping of the wood itself was studied. Eighteen, 38.1 x 92.1 mm (2 x 4 inch nominal), hemlock joists were tested in free vibration using a resonance method. An average damping ratio of 0.0035 was found, which was independent of the number of members or method of testing. Next, damping due to slip between the floor sheathing and joist was evaluated. Both full bearing nails (bearing of nail shank on sheathing), and "negligible" shank bearing nail connections were tested. It was found that "negligible" shank bearing nails gave higher damping ratios than normal nail connections. It was also found that in the low amplitude of vibration range, the "negligible" shank bearing nails could provide damping ratio's on the order of twice those provided by full bearing nails. Finally, the effect of adhesive between the joist and the sheathing on the damping ratio was evaluated. The material damping ratio of wood-joist floor systems was more than doubled when viscoelastic adhesive was used [Yeh, et al. 1971].

In 1975, the performance characteristics of wood-joist panels was studied by S. Corder, and D. Jordan. In this study, nine different 38 x 184mm (2 x 8 inch nominal) joist systems were constructed and subjected to four different tests: (1) fixed line load deflection of both sheathed and unsheathed systems to determine the load sharing capabilities of each of the systems, (2) free-vibration deflection tests to determine average natural frequencies and average damping ratios, (3) concentrated static load tests to determine maximum load and deflections, and finally (4) an impact test to determine maximum drop height of a one-hundred and fifty pound bag of lead shot required for failure. Failure occurred when the sheathing between the joist was fractured due to the impact load. The modulus of elasticity and moisture content were determined before the floor systems were constructed. It was found from the fixed line load test that with the addition of sheathing, the stiffness of the systems increased between 47% to 131%. Panels with nailed connections between the sheathing and joist had, as one would expect, less increase in stiffness than those with nailed and glued joist to sheathing connections. From the free-vibration test, the damping was determined to be between 2.7 and 8.3 percent of critical. The greater the percent of critical damping present, the shorter the duration of vibration was, and therefore the vibrations were less noticeable to human beings. The average natural frequencies of the panels ranged from 14 to 20 hertz, with the wide ranges due to different span lengths. The concentrated load tests determined maximum concentrated load capacity, and deflection at failure. Failure occurred when the loading rod punched through the sheathing.

Onysko [1970], in a questionnaire survey of 107 houses in Canada, found that the noise produced by cabinets and other furniture was the prevalent reason for dissatisfaction with floor performance. He also stated that detection of annoying floor vibrations was room specific, i.e. a bedroom floor would be more critical than a bathroom floor.

3.2.2 Evaluation of Bridging

This section describes some of the investigations conducted on various bridging systems. Since the research in this thesis relates to X-bridging and solid-bridging, only previous research pertaining to these two systems was investigated. X-bridging can be defined as diagonal members which connect adjacent joists through the use of struts. These struts attach to the upper side of one joist at one end, usually by toe-nailing, and to the lower side of an adjacent joist at the other end, also by toe-nailing. Solid-blocking can be defined as a piece of sawn lumber, usually the same depth as the joists, attached between adjacent joists and often staggered for nailing purposes.

An extensive study of both X-bridging and solid-blocking was done in 1961 by a research group for the National Association of Home Builders. The research was conducted to evaluate the necessity of these types of bracing in floor systems. Both laboratory built and in-situ floors were tested, and a total of ten floors for the laboratory phase were constructed. Five single span floors and five double span floors (floors with an internal support) were tested both statically and dynamically in the laboratory. The loading for the static tests consisted of both a 113kg (250 pound), and a 159kg (350 lb.), mass applied at the centerpoint of the floors. Both free-vibration and forced-vibration were induced in the dynamic testing phase. Free-vibration was induced by the sudden release of both 41kg (90 pound), and 1163kg (250 pound), masses from either the center, or one of the central, joists. Forced-vibration was induced by dropping a 1.4kg (2.9

pound) steel ball from a height of 0.9m (3 feet) onto the centerpoint of the floor, for one impact only. Traces were also recorded for a person walking on the floor. Bridging was evaluated based on four criteria; 1) how the bridging affected the floor's ability to transfer concentrated a load away from the loaded joists, 2) whether or not bridging was needed for lateral stability of the joists, 3) how bridging affected the dynamic response of the floors, and 4) how bridging affected the deflection of the floor perpendicular to the span. As stated before, five single span and five continuous span floor systems were studied in the laboratory phase. Only the single span results will be focused on in this document since it best parallels the research done by the writer of this working plan. The first four floors had clear spans of 3.5m (11.4 feet), while the fifth floor had a clear span of 4.7m (15.4 feet). Each of the five floors had different joist depths and spacings. Depths were 197mm (7.75 inches), 187mm (7.35 inches), 137mm (5.41 inches), 235mm (9.25 inches), and 292mm (11.5 inches) respectively. All were 38mm (2 inch nominal) in width. The first three floors had seven joists spaced at 400mm (16 inches) on center, while the last two floors had six joists spaced at 400mm (16 inches) on center. The floors were sheathed (nailed only sheathing-to-joist connections) with both 12.7mm (1/2 inch) and 15.9mm (5/8 inch) thick sheathing, nailed with 8d common duplex nails, 3.3mm (0.131 inches) in diameter and 63.5mm (2.5 inches) in length, at 152mm (6 inch) exterior nail spacing or 254mm (10 inch) spacing on the interior of the sheathing. Both bridging and blocking were described, but only the X-bridging was actually tested with the dynamic loading. The X-bridging was 19 x 70mm (1 x 3 inch nominal) toe-nailed at each joist connection. The solid-bridging for the other tests was 38 x 140mm (2 x 6 inch nominal) in cross section and was attached to the joist with either 2 or 3 16d nails, 4.1mm (0.162 inches) in diameter, 88.9mm (3.5 inches) in length, at each end. One row of both types of bridging was installed along the midspan of each of the floor systems. In the lateral distribution of concentrated load test, it was determined that the plywood played a greater role in lateral load distribution than the bridging did, and that if plywood of sufficient thickness was used, no bridging would be necessary. For the X-bridging, reduction in deflection ranged from 1.5% (0.03mm or 0.001 inches) to 6.1% (0.18mm or 0.0007 inches) in the field tests. In the laboratory tests an average reduction of 8.2% (0.43mm or 0.017 inches) was observed. The solid- blocking gave a 2.6% (0.08mm or 0.003 inches) in the field and an 8.9% (0.48mm or 0.019 inches) average reduction in the laboratory. The greater effects in the laboratory were contributed to three reasons; 1) the bridging was carefully cut and fitted in the laboratory floors, 2) only eight hours elapsed between installation and testing in the laboratory, and 3) the bridging was continuous from span to span in the laboratory, whereas in the field it often had to be offset due to the presence of mechanical systems in the test houses. In the dynamic testing, the floor response was recorded using a single strain gauge placed at midspan on the underside of the loaded joist. When comparing the sheathed only joist floors, to the sheathed and bridged joist floors, the following changes were observed in the free-vibration tests. An 8.2% decrease in induced strain at the bottom of the central joist, a 2.2% increase in natural frequency and finally, an 8.2% increase in duration of vibration. In the forced vibration tests there was a 1.1% reduction in induced strain and negligible changes in natural frequency and duration of vibration. Since the duration of loading was increased in the free-vibration tests, the authors stated that bridging could have a detrimental effect on human perception of the floor vibration. Based on the above static and dynamic test results, this report stated that bridging should not be required in floor systems.

Y.H. Chui in a report for the Timber Research and Development Association, investigated the effect of changing construction variables on the dynamic response of solid sawn joist systems [Chui, 1986a]. According to the report, problems of annoying floor vibrations are related to three criteria: frequencies, amplitude, and duration of floor vibrations. The effect of changing construction variables was therefore based on these three criteria. Five floors were constructed using 47 X 194mm (2 X 8 inches nominal) Canadian Hem-Fir joists. Floor dimensions were 3.6m (11.8 ft) span by 4.8m width. After each of the floors were constructed and tested, they were retrofitted with one of the construction variables to be investigated, and retested. The following construction variables were investigated; 1) joist spacing, 2) between joist strutting (solid-blocking), 3) the effect of added dead load, 4) the sheathing to joist connection, 5) the effect of attaching plasterboard to the bottom of the joists, 6) the effects of sheathing stiffness,

7) the effect of added joist end fixity to simulate upper story loads, and finally, 8) the effect of edge and internal joist support. Six in-situ floors were also investigated to establish acceptable levels of the root-mean-square acceleration.

It was found that significantly reducing joist spacing had a negative effect on dynamic response because it reduced the spacing between the modes of vibration of the floors. However, it was also stated that joist spacings between 350 and 610mm (15.75 to 23.6 inches) had adequate dynamic characteristics. The study stated that by adding two rows of solid blocking to the floors, the fundamental mode of frequency remained approximately the same, however, the separation between the modes was increased, thereby reducing the possibility of modal interaction. By placing two-100kg (221 pound) loads, one along each of the outside joists, a 17% decrease in first natural frequency, and a 48% average increase in damping for the first five modes of vibration were observed. When plasterboard was fixed to the bottom of the floor, it had two effects on the floor. First, the self-weight of the floor system was increased which in turn decreased the lower mode frequencies (i.e. first, second and third modes). Secondly, the stiffness of the floor system was increased which in turn increased the higher modes of frequencies. Therefore, the overall effect of affixing the plasterboard was to separate the modes of vibration which was a beneficial effect. When the floors were supported along the outside and center joist(s), a 20% increase in the first mode was observed. This study also stated that the range of frequency to be avoided was between 4 to 8 hz, and that the root-mean-square acceleration threshold of sensitivity was 0.375 m/s/s, with an upper limit of 0.5 m/s/s. There were primarily two recommendations put forth, first that it is beneficial to increase the stiffness in the perpendicular to joist direction through blocking, stiffer sheathing, and/or perimeter and intermediate support of joists. Second, that for damping purposes, it is beneficial to allow relative movement to occur between the sheathing and the joist through a particular connection detail.

In another study, Chui [1990] stated that assigning a lower bound natural frequency limit may be sufficient for floor systems substantially heavier than timber floors, but that for light weight timber floors it is necessary to limit magnitude of vibration also.

Onysko [1988], based on results of his interviewing and inspection of 107 houses throughout Canada, found that the most important criteria for predicting floor performance are deflection under concentrated loads, floor span, damping ratio, natural frequency of vibration, and peak dynamic response to impulse loading. He went on to state that floor serviceability criteria based on floor response to uniform loading is a poor discriminator of human perception of vibration. This study proposed a new floor serviceability criterion based on a 1.75mm (approximately 1/16 of an inch) limit on deflection due to a 1 kN (225 pound) concentrated load applied at midspan of a joist. He states that the criterion accounts for the total floor response, not just for that of a floor joist alone as is usually the case.

In another paper, Onysko [1988b] summarized an extensive study of experimental, analytical, and field studies of floor systems for Forintek of Canada. It was noted that as floor systems have moved from the traditional multi-layered structural and semi-structural flooring, to that of single layer panels, transverse floor stiffness has been reduced, thereby increasing excessive deflections and vibration problems. In the experimental phase of this study, four different floor system components/aspects were extensively evaluated; bridging, continuous joist spans, composite action between joists and sheathing, and effect of partitions on floor response. The bridging evaluation will be focused on, and consisted of five parts; 1) contribution of bridging on static and dynamic response, 2) the relative importance of various bridging types, 3) the effect of bridging after reduction in moisture content, 4) the effect of bridging location, and 5) the effect of bottom strapping and ceiling on the underside of floors. Bottom strapping can be defined as a piece of lumber affixed to the underside of the joists perpendicular to the joist span. The bridging study was based upon both field and laboratory studies, and the floors were both statically and dynamically loaded. Static load was applied with a 100kg (220 pound) mass applied along the centerline of the floor while transverse deflection was recorded. Dynamic impulse load was induced by dropping a steel ball onto a neoprene slab. Response was monitored with accelerometers, and velocity or displacement transducers. Several different bridging types, and combinations thereof, were investigated. Since this report was a summary, each type was not explicitly described but the bridging systems were either classified as "bending" or "shear" type. Bending type bridging was described as a type of bridging which transmits force through the bending of the bridging itself, i.e. a bottom strap affixed to the underside of each of the joist in the floor. Shear type bridging was defined as an element which resists deformation of the space between joists, i.e. X and/or solid-blocking. Combinations of both types of bridging were also utilized , for instance, skewed solid blocking with a bottom strap attached underneath. It was stated that bridging did assist the sheathing in distribution of a concentrated and dynamic load to adjacent floor areas, and therefore, does have an effect on a floor's acceptability in its environment. Results from a joist floor with the minimum, "code allowed", sheathing thickness showed a reduction in static and dynamic response ranging from a negligible effect due to a 25x3mm (1 x 0.125 inch) steel strap, to a 49% reduction for the combination of skewed solid bridging plus a bottom strap, the most effective bridging system. Since this report was only a summary of experimental work, little raw data was presented. However, the paper was presented at an international symposium on serviceability of buildings in Ottawa, Canada. In summary, this report put forth that bridging can improve the static and dynamic response of "minimum performance" floors, or floors that provide the minimum required amount of strength and serviceability.

A considerable amount of work has been done in the area of timber floor research by Sven Ohlsson. Ohlsson [1986] differentiates between two orthogonal types of floor stiffness, each having it's own contribution to the floor's frequency of vibration. First, is the joist bending rigidity parallel to the joist span, which is said to mainly govern fundamental floor frequency. Second, is the transverse bending rigidity of the floor due to any transverse stiffening system (i.e. bridging, sheathing, etc..). The transverse stiffness is said to affect the spacing between the higher frequencies, and therefore determines the number of modes that contribute to floor response. Ohlsson [1988a] found that since light weight timber floors are highly orthotropic, their response to dynamic loading contains several closely spaced modes of vibration, and therefore, evaluation of fundamental frequency alone is insufficient in evaluating serviceability of a floor system.

In a 1988 floor design guide, Ohlsson [1988b] proposed a design method which was not material dependent, but frequency and span dependent. The proposed design method applies to both light-weight floors with a 6 - 8m (19.7 - 26.3 ft.) spans, as well as to heavier floors of shorter span lengths. The frequency criteria for the design method was for floors whose calculated first natural frequency was greater than 8 Hz. This guide proposed a design equation for calculation of the lowest natural frequency. Ohlsson stated that the parameter which best predicts human perception of floor vibration is the vibration velocity. He also notes that increased damping at all times improves floor performance. Regarding wood floor systems, Ohlsson considers floor stiffness perpendicular to the joist span of critical importance in predicting the dynamic response of a floor. He stated that the transverse stiffness affects both the number of modes of vibration, and what portion of the floor mass is set into vibration. Transverse stiffness is also said to be critical with respect to deflection due to static load.

In a paper presented at the 1988 International Timber Engineering Conference, Ohlsson [1988c] discussed static stiffness in relation to floor serviceability. Ohlsson noted that some pre-loading of a floor system was necessary before a floor could respond with the stiffness with which it was designed to provide. Often this pre-load is not provided which could produce some serviceability problems. Two types of stiffness were defined in this paper. Global stiffness was defined as that stiffness related to maximum deflection due to a uniform loading. This is the stiffness criteria used in some current design codes, and is essentially the flexural rigidity in the direction of the floor span. Often researchers look to improve this type of stiffness to reduce serviceability problems through either improving composite action between the joist and sheathing, or through the use of a stiffer joist system. Local stiffness is the second type of stiffness described and was defined as the ratio of concentrated load to deflection under that load. Local stiffness is composed of two components; the stiffness of the sheathing across the joist span, i.e. local board stiffness, and the stiffness due to deflection of adjacent joists. It is noted that floors have, traditionally, not been designed to transmit bending moments perpendicular to the joist span and that if they were, an improvement in floor serviceability could be obtained. Some comments on X-bridging were also made in this paper. It was stated that X-bridging is fairly ineffective in supplying the necessary transverse stiffness for several reasons. First, due to the fact that force is applied to the joist in a direction of low stiffness, the perpendicular to grain direction. Second, that since the joist-to-bridging connection usually occurs over a relatively small area, a stress concentration can result. Third, that shrinkage, and loading render the bridging useless with the passage of time. Finally, he stated that often the installation of the bridging is done with less than adequate construction practices which reduces any effectiveness the bridging may have.

As can be seen from this literature review, there were many conflicts in the evaluation of between joist bridging systems. However, the general trend seems show that X-bridging has only minor effects on the static and dynamic response of floor joist systems, while solid-blocking seems to be more effective.

3.2.3 Effect of Post-Tensioning Solid Blocking

The author could locate only one reference which investigated post-tensioning of wood joist floor systems. In a very general and non-specific study, Arapetyan et al. investigated vibration reduction due to post-stress of a floor system. In this study, a constant concentrated load was applied while a post-tension force was incremented up to 8900N (2000 pounds). Deflection of the joists was monitored at each increment using a dial strain gauge. The concentrated load was scaled to represent an equivalent dynamic load due to the impact of a person walking on the floor, using the equation:

$$P_{dyn} = P_{st}[1 + (1 + 2h/D_{st})^{1/2}]$$

where P_{dyn} = dynamic impact load

P_{st} = gradually applied static load

h = height

D_{st} = deflection due to static load

It was stated that a 50% reduction of deflection was observed for an 8900N (2000 pound) pre-stress force, which in turn would purportedly reduce amplitude of vibration by a factor of two.

3.2.4 Effect of Strong-backs

Onysko [1988b], in a previously mentioned study, investigated the effect of placing one 38x140 mm (2 x 6 inch nominal) "strong-back" at midspan versus attaching two "strong-backs" at third points along the span, for floors subjected to static loading. An envelope of maximum deflections due to a point load over each joist was plotted, and it was stated that the effect of one strong-back placed along the centerline was "about" equivalent to placing strong-backs at third points of the span. It was also observed that the maximum deflection, due to a point load on the center joist, no longer occurred under the center joist, but under the third points of the span. Again, as stated earlier, this report was a summary, and therefore little numerical data was supplied.

3.3 Conclusions

While there has been a considerable amount of research done on wood floor systems, some of the bracing systems investigated in this thesis have not, to the best of the writer's knowledge, been thoroughly evaluated. It is the goal of this thesis to help to fill the gaps in the research in the area of wood floor bracing systems.

III

EQUIPMENT AND PROCEDURES

3.1 Introduction

This chapter will describe the materials, connection and construction methods, and procedures utilized in all stages of this research project. In all, seven different 4.9 by 4.9 m (16 x 16 ft.) square floor specimens were subjected to a wide variety of support, load, and bracing conditions. Four floor specimens were constructed using 38 by 286 mm (2 by 12 inch nominal) solid sawn joists, and three specimens were built with parallel chord trusses 305 mm (12 inches) deep. All seven of the floors were tested while supported on all four sides (hereafter to be denoted as S-S-S-S), then two of the side supports were lowered to give an end-supported only support condition (hereafter denoted as S-F-S-F). Additional imposed loads were applied to the floors at 960 and 1915 kN/m^2 (20 and 40 psf) levels. The three solid sawn floor bracing systems, and the five truss floor bracing systems were evaluated for all of the different support and end conditions for comparison purposes.

The objectives of the experimental phase were to quantify the effect of several lateral bracing systems on the static and dynamic response of two types of wood joist floor systems: solid sawn and parallel chord truss systems. Comparisons of the load sharing capability of braced versus unbraced floors was used to quantify the static response of the floor systems. Dynamic parameters were obtained from two different types of dynamic load: free-vibration, and forced vibration. The dynamic parameters used to evaluate the bracing systems were resonant frequencies, viscous modal damping ratios, and system logarithmic decrement damping ratios. This chapter is separated into seven sections: Description of test equipment, Description of floor specimens, Description of the various bracing systems, Description of test procedures, Methods of data analysis, and Conclusions.

3.2 Test Equipment

3.2.1 Test Frame

To allow access under the floor specimens, a steel test frame was constructed to support the wood floors off of the concrete laboratory floor. The test frame consisted of four rectangular tube steel beams supported at all four corners by W16x30 columns, 0.84 m (2.75 ft) tall. The test frame beams were built-up sections, fabricated from two, A-36 steel MC 10x28.5 sections welded flange tip to flange tip to form a tube. Once the test frame was erected, 9.5 mm (0.375 inch) diameter cable was, attached and tensioned diagonally in the vertical planes between columns (X-Bracing). The cable was also attached and tensioned in the horizontal plane between beams on opposite sides of the frame (see figure 3-1). The frame was braced with cables to raise it's resonant frequency higher than that of the wood floor specimens. Prior to testing any wood floor specimens, the steel frame's vibration response to impact was checked, after which the cables were tightened to raise the frame frequency as high as possible. Even though this precaution was taken some frequency interaction between the wood floor and the steel test frame was observed. Since the subject matter of this document relates to changes in dynamic properties due to joist bracing, and this interaction was present in both cases, the wood floor frequencies were not modified to remove the effects of the test frame. With this in mind, it must be brought to the readers attention that the system frequencies reported in this document are a combination of the wood floor frequencies as influenced by the frequency of the test frame. At the time of writing of this thesis, sufficient data was not available to supply the reader with a frequency adjustment factor, due to the complex vibrational characteristics of the test frame.

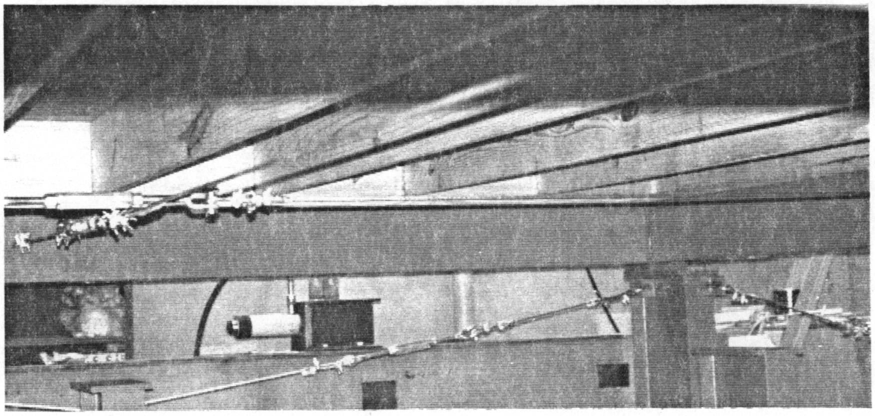

Figure 3-1: Steel Test Frame With Tensioned Cables

3.2.2 Accelerometers

The dynamic response of the floor specimens was monitored using four-piezoelectric accelerometers placed at various locations on the joists and sheathing of the floor systems. Endevco Model #7221 accelerometers placed on the bottom of the floor joists/trusses were used to record the data for this thesis. In particular, the acceleration data acquired for this thesis was ascertained from the accelerometer located at the centerpoint of the floor specimens.

3.2.3 Dial Gages

Static response of the floor systems was monitored using spring-loaded dial gages accurate to +\- 0.03 mm (+\- 0.001 inch). A total of nine dial gages were used, with one placed on the bottom of each joist in the floor, at midspan. The dial gages were placed on a solid support, thereby ensuring that any change in deflection recorded was deflection of the floor joist only.

3.2.4 Free-Vibration Apparatus

The second type of dynamic loading was a free-vibration test. The floor specimens were set into free-vibration through the sudden release of a 318 kg (700lb) weight from underneath the centerpoint of the floor. Two 12.7 mm (0.5 inch) holes were drilled in the sheathing on either side of the center joist at the centerpoint of the floor system. A bracket was hung from a plate on the top surface of the floor, from which the weight was attached and released. The release mechanism was simply a pair of common vise-grips attached to the mass by means of a leader cable. Figure 3-2 shows the mass suspended from the underside of a joist floor. The free-vibration test had the advantage that no additional mass was placed on the floor system when the dynamic response was measured.

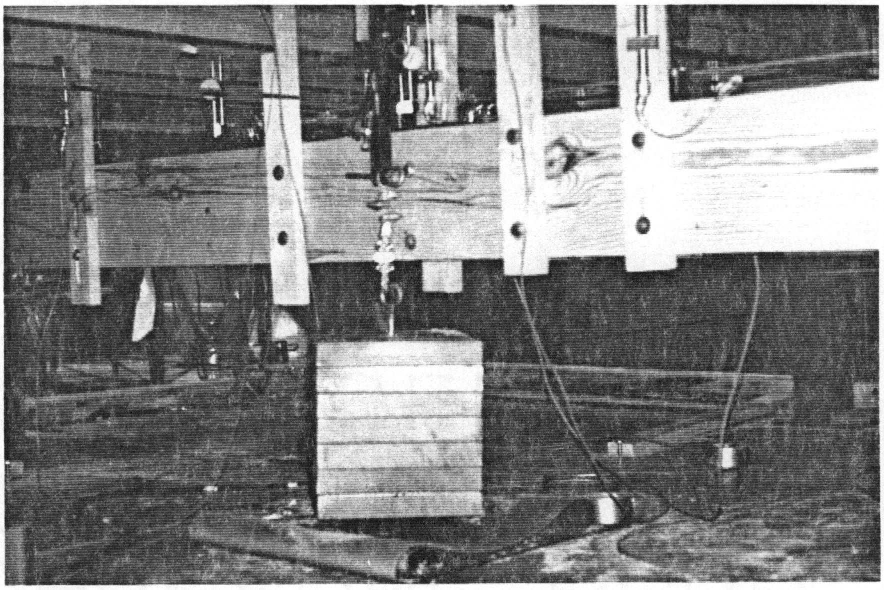

Figure 3-2: Free-Vibration Mass Suspended From Floor

3.2.5 Drop-Weight Apparatus

Forced vibration was induced using the drop-weight apparatus shown in Figure 3-3. The mechanical impactor consisted of an 11.8 kg (26 lb) weight dropped from a height of 533 mm (21 inches) onto a high tensile steel spring with a spring constant of 36 N/mm (205 lb/inch). This dynamic load was used to simulate a random impact load similar to that which could occur in residential or commercial structures during normal activities.

3.2.6 Data Acquisition

A commercial software package was used for data acquisition on this research project. The amplified accelerations were wired directly to the data acquisition board. The data was recorded at a rate of 1000 data points per second. Data was acquired for a total of three seconds, thereby giving an acceleration record 3000 data points long.

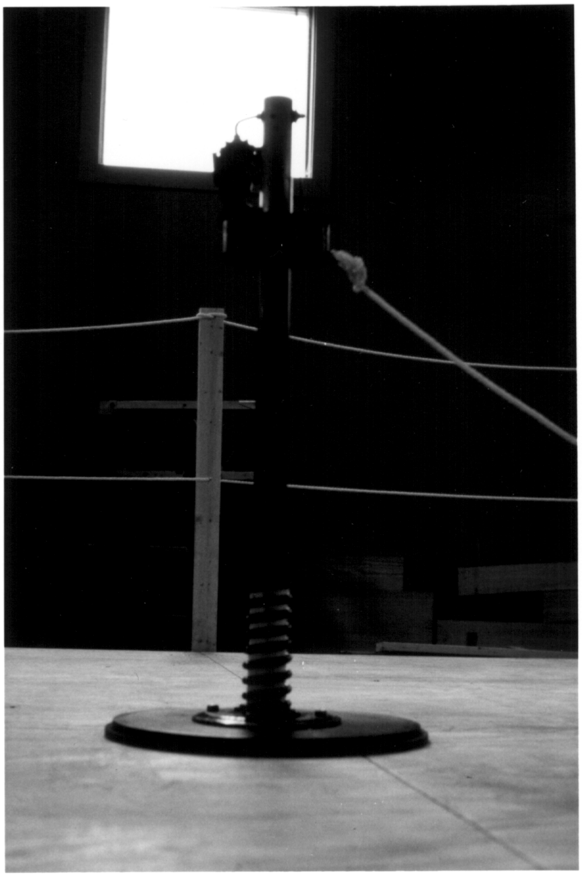

Figure 3-3: Drop-Weight Apparatus

3.3 Floor Specimen Descriptions

3.3.1 Solid Sawn Floor Systems

Four floors, constructed with 38 by 286 mm (2 x 12 inch nominal) floor joists were tested in this project. For the remainder of this document these solid-sawn floors will be referred to as SS-1, SS-2, SS-3, and SS-4 denoting solid-sawn floors number one through four. As previously mentioned, all four of these floor specimens had plan dimensions of 4.9 m by 4.9 m (16 x 16 ft.) (see Figure 3-4).

Each floor system had joist spacings of 610 mm (24 inches) on center, and was sheathed with 18.3 mm (23/32 inch) thick, tongue-in-groove, Exposure I rated Sturd-I-Floor plywood sheathing. The sheathing was glued and nailed to the joists, using an elastomeric adhesive, and 8d common nails, 3.3 mm (0.131 inch) in diameter by 63.5 mm (2.5 inches) in length. The nail spacing used on the perimeter of the sheathing was 152 mm (6 inch), while the interior nail spacing was 305 mm (12 inches). The sheathing was laid such that the strong (2.4 m (8 ft)) direction was perpendicular to the joist span. The joists were supported by a header with standard, light-gauge metal, 38 by 286 mm (2 x 12) joist hangers, attached to the side of the header. The header rested on a 38 by 184 mm (2 x 8 inch) sill plate, which was notched out for joist hanger clearance, and bolted to the steel support beams.

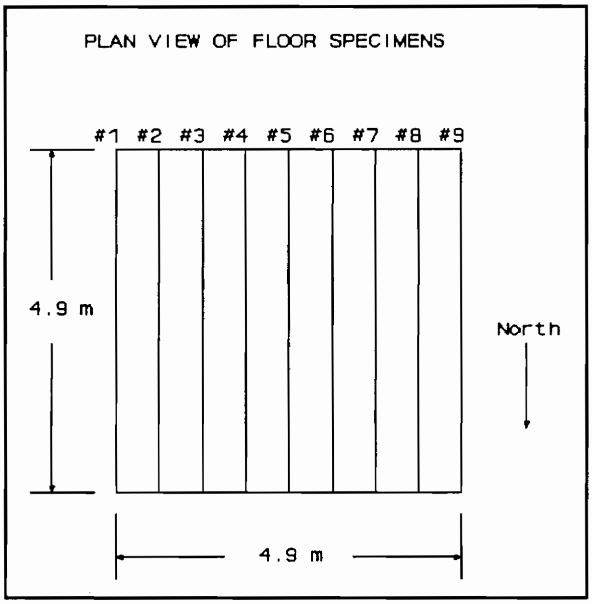

Figure 3-4: Plan View of Floor Specimens

Prior to construction, each joist's stiffness was calculated using a static load test. A 9.1 kg (20 lb) weight was placed at midspan of the simply supported joist laying flatwise, while the deflection due to the load was measured. From that deflection, the static stiffness (EI) was calculated from structural theory for deflection of a simply supported beam, point-loaded at midspan. These stiffnesses were utilized in the determination of load sharing capabilities of the solid sawn floors.

The floors were constructed and tested in a controlled environment in which the moisture content was held relatively constant, therefore, any change in material properties due to varying moisture levels was neglected.

3.3.2 Parallel Chord Truss Floors

Three parallel chord truss systems were constructed and tested. These floors will hereafter be referred to as TR-1, TR-2, and TR-3. Again, the plan dimensions of the truss floor systems was 4.9 by 4.9 m (16 by 16 ft) (see Figure 3-4). Bottom-chord bearing, metal-plate connected, trusses were used. The truss members were made of Number 2 and Better, Southern Pine, 38 by 89 mm (2 by 4 inch nominal) in cross-section. Truss depth was 305 mm (12 inches), and the trusses were designed for 1915 kN/m^2 live load. The trusses were spaced at 610 mm (24 inches) on center, and were also sheathed with the 18.3 mm (23/32 inch) thick, tongue-in-groove plywood sheathing. The sheathing was glued and nailed using the same methods as was used for the solid sawn floors, and was laid such that the strong direction of the plywood spanned perpendicular to the joist spans. No header was used, however, the trusses were linked together using a two, 4.9 m (16 ft) long, 38 by 89 mm (2 by 4 inch) stringers attached in the notch provided at both ends of the truss, over which, a plywood cap was nailed. In order to be consistent, the sill plate was notched underneath the bearing edge of the trusses, until there was only a 38 mm (1.5 inches) ledge of bearing to simulate the presence of a 38 by 89 mm (2 by 4 inch) sill plate. This size sill plate was called out in the engineering drawing provided by the truss manufacturer.

As with the solid-sawn joists, the static stiffness of the trusses was determined prior to their use in the floor system. The trusses were placed on simple supports, and a 23 kg (50 lb) mass was placed at midspan, and the change in deflection was recorded.

3.4 Lateral Bracing Systems

The different types of lateral bracing systems used for the floor systems will be described and discussed in this section. One row of each type of bracing system evaluated in this thesis was placed midspan of all the floor systems. Material and construction methods follow.

3.4.1 Solid-Sawn Floor Bracing Systems

Three types of lateral bracing systems were investigated for the solid-sawn floor systems: X-bridging, solid blocking, and finally, post-tensioning of the solid-blocking. For reference, these bracing systems will be abbreviated as BR, BL, and PT, respectively. The first two bracing types are sometimes used in traditional residential floor construction, while the third was tested as a preliminary investigation into the additional benefits, if any, of this type of bracing. Each bracing type was installed along a line perpendicular to each of the floor joists, at midspan of the joist length.

3.4.1.1 X-Bridging The X-bridging consists of two pieces of construction grade lumber, 19 mm (3/4 inch) thick by 30 mm (1-3/4 inch) wide, placed in an "X" formation between each joist in the floor system. One end of each piece of bridging was toe-nailed to the top side face of one joist, and toe-nailed at the other end to the bottom side face of the adjacent joist using 2-8d common nails, 3.3mm (0.131 inch) diameter by 63.5 mm in length (see Figure 3-5). The bridging was cut such that the face of the bridging member was flush with the side-face of the joist, for efficient connectivity and load transfer. Again, one line of X-bridging was used along mid-span of the floor system.

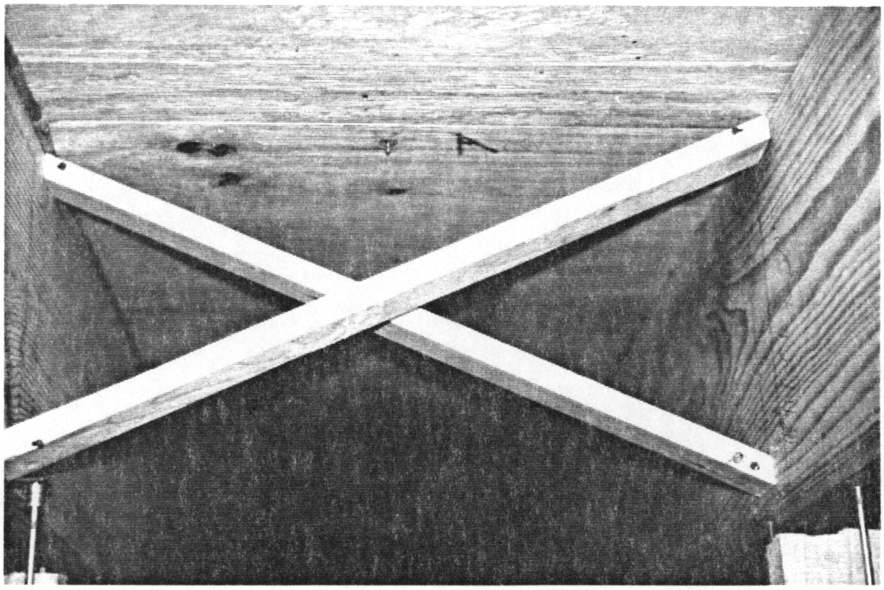

Figure 3-5: Bridging in Solid-Sawn Floor

3.4.1.2 Solid-Blocking Solid-blocking was made from pieces of the same lumber as was used for the floor joists, therefore this bracing system was the same width and depth as that of the solid-sawn joists used in the floor itself (38 x 286 mm or 2 x 12 inches nominal) (see Figure 3-6).

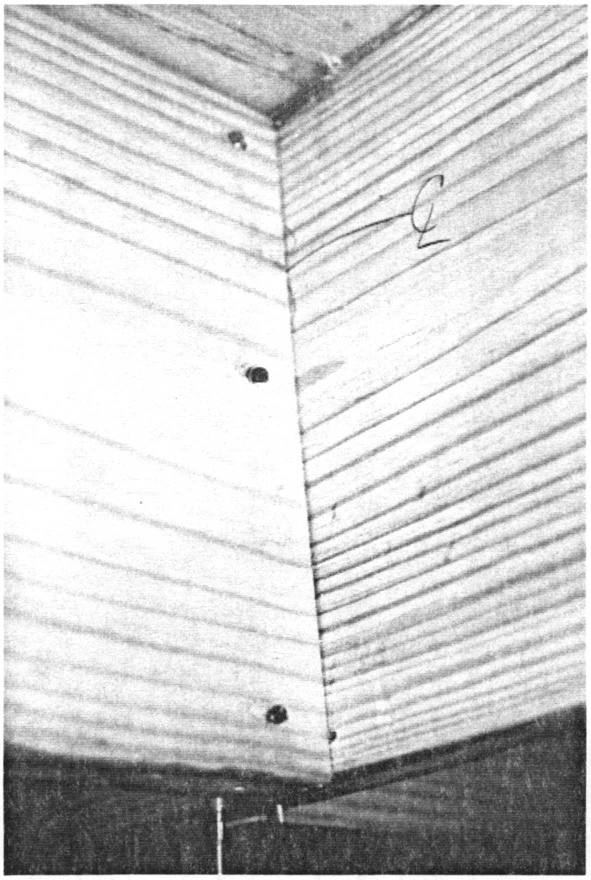

Figure 3-6: Blocking in Solid-Sawn Floor

Once the necessary length of each piece of blocking was determined and obtained, the blocking was toe-nailed to the side of the two adjacent joists. Each end of the blocking received 6 - 8d common nails, 3.3 mm (0.131 inches) in diameter by 29 mm (2-1/2 inches) in length, three on each side of the blocking at each end. The length of each piece of blocking was such that each piece of blocking fit snugly into each and every bay between floor joists. The row of blocking was staggered about the center line of the floor system to allow clearance for the post-tension apparatus which was to be installed after the blocked-only floor configuration had been tested.

3.4.1.3 Post-Tensioned Solid Blocking After the necessary data was acquired for the blocked-only bracing condition, a 38 mm (1-1/2 inch) diameter hole was drilled along the centerline of the floor span. The hole was drilled at mid-depth of each joist, and was located such that it ran in-between the staggered rows of blocking. Two pieces of 13 mm (1/2 inch) diameter steel "post-tension rod" were utilized, one piece of rod was run into the floor from each outside joist until they met in a bay under the floor. Both ends of both pieces of rod were threaded. The rod ends under the floor were screwed into opposing ends of a 45 KN (10 kip) load cell, while a plate was slipped over the rods on the outside edges of the outside joists, after which 14.3 mm (9/16 inch) nuts were screwed onto both ends (see Figure 3-7). Post-tension was applied by tightening the nut at one end of the rod, until the voltage reading from the calibrated load cell signified one of the two post-tension levels tested in the experiment: 13 kN (3 kips) or 22 kN (5 kips). The voltage was constantly monitored throughout the floor loading procedure so as to maintain the desired level of post-tension at all times.

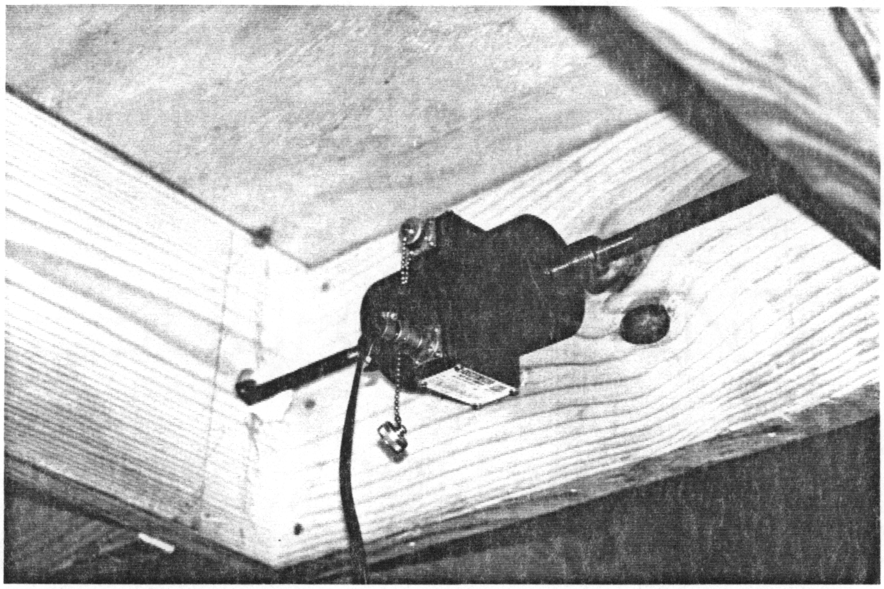

Figure 3-7: Post-Tension Rod and Load Cell Under Floor

3.4.2 Parallel Chord Truss Bracing Systems

In all, five different types of bracing systems were evaluated for the parallel chord truss bracing systems. The first three were individual components, while the last two were combinations of the first three components. The first type of bracing tested was a "bottom-chord brace". This bracing will be abbreviated and referred to as BCB. This brace was required by the manufacturer if dry-wall or "sheetrock" was <u>not</u> installed on the under side of the trusses. Their contribution to the static and dynamic response of the floor system was as yet unknown. The second type of bracing investigated was a steel strap bridging often used in truss floor applications. This type of bracing will be abbreviated and referred to as XB. The third type of bracing is known as a "strong-back", or SBB. This bracing is usually required in floor truss applications, however, it's necessity has been questioned by truss manufacturers. The last two bracing systems were combinations of the first three systems; steel strap X-bracing plus bottom-chord bracing (or XB+BB), and strong-back bracing plus bottom-chord bracing (or SB+BB). One line of each type of bracing was used, and as in the solid-sawn systems, the trusses were braced along the midspan of each joist such that the bracing divided the floor into two equal halves. A more specific description of each bracing system follows.

<u>3.4.2.1 Bottom Chord Bracing</u> The bottom-chord brace used in this investigation was a 4.9 m (16 ft) long, 38 by 89 mm (2 by 4 inch nominal) Number 2 and Better, spruce-pine-fir stud, attached to the bottom chord of each truss in the floor

system. It was attached to the bottom chords of the trusses with one-#8 drywall screw, 4.2 mm (0.164 inch) in diameter by 76 mm (3 inches) in length. The wide (89 mm (3.5 inch)) face of the bottom chord brace was attached to the bottom chord of the truss. See Figure 3-8 for an example of a bottom-chord brace.

3.4.2.2 X-Bracing The strap X-Bracing used on the truss floor systems was a prefabricated, cold-formed steel, Simpson Strong Tie #TB-30. As with the other systems, one line of the X-Bracing was placed at midspan of each truss, along the centerline of the floor. Two straps per bay were attached in a criss-cross fashion, with each strap nailed to the top of a truss between the sheathing and truss at one end, and to the bottom of the adjacent truss at the other end. Each end connection used three-3d galvanized nails, 3.2 mm in diameter by 31.8 mm (1.25 inches) in length.

3.4.2.3 Strong-Back Bracing The strong-back brace used in this investigation was a 4.9 m (16 feet) long, 38 x 140 mm (2 by 6 inch nominal), piece of Number 2 and Better, spruce-pine-fir lumber, nailed to a vertical web member located at midspan of the truss (see Figure 3-8). The strong-back was attached to the web member using three-10d nails, 3.8 mm (0.148 inches) in diameter by 76 mm (3 inches) in length. The strong-back was placed as close as possible to the top-chord of the truss for consistency.

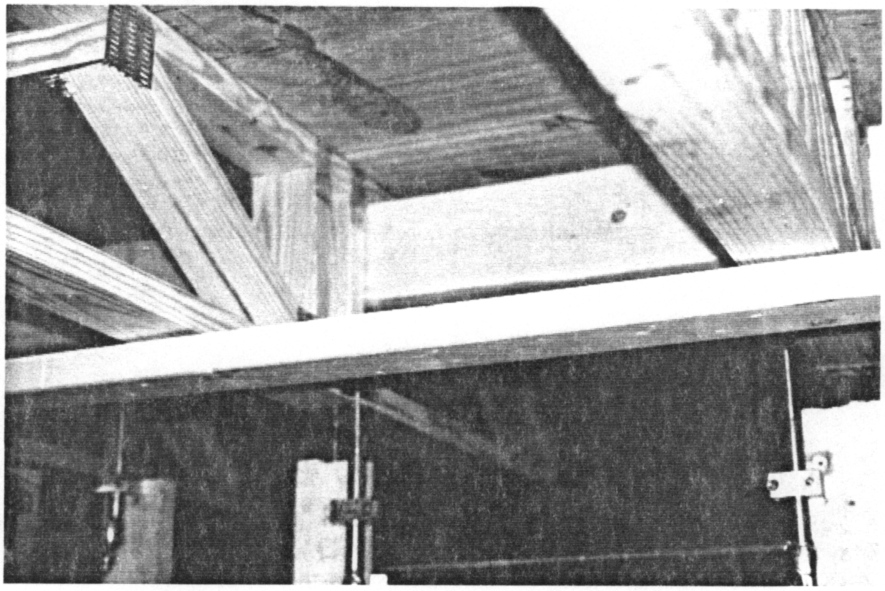

Figure 3-8: Example of Strong-Back and Bottom-Chord Brace Connections

3.4.2.4 X-Bracing plus Bottom Chord Brace This bracing system was merely a combination of the two aforementioned systems. The connections for each of the individual components was exactly the same as was previously described for that component.

3.4.2.5 Strong-Back plus Bottom Chord Brace This bracing system was also a combination of the two aforementioned systems. The connections for each of the individual components was exactly the same as was previously described for that component. Figure 3-8 shows this bracing combination installed on one of the test specimens.

3.5 Test Procedures

This section describes the steps used to acquire the data used to calculate the bracing evaluation parameters. In all, three types of tests were performed on each of the test specimens. The first test was a static, load-sharing evaluation of the braced floors versus the unbraced floors. The last two tests were dynamic tests performed to calculate frequency and damping characteristics of the braced versus unbraced systems. The first dynamic test was a free-vibration test from which data was gathered to calculate the frequency and damping characteristics of the braced versus unbraced systems. The second dynamic test was a forced vibration test using a drop weight apparatus which simulated a human step or "heel drop".

3.5.1 Static Load Sharing Tests

Twenty-133N (30 lb) steel-punchings filled sand bags were used for a total static load of 2.7 kN (600 lb.). A dial gage was placed under each of the nine joists/trusses in the floor system at midspan. All of the load sharing tests were performed with the S-F-S-F boundary condition (end-supported floor), with no other live load on the floor. To begin, each of the nine initial dial gage readings were recorded. Then, the sandbags were placed over joist #1 at midspan (see Figure 3-4 for joist numbering system), and all nine of the dial gages were recorded for the load at joist #1 load state. Next, the sandbags were moved from joist/truss #1 to joist/truss #2, after which all nine dial gage readings would again be recorded. This process was repeated until the load had been placed over each of the nine joists/trusses in the floor system. With both the initial and final dial gage readings, a change in deflection was calculated for each particular load placement, thereby giving the data for comparing braced versus unbraced deflection profiles.

3.5.2 Free-Vibration Tests

Free-vibration tests were conducted by releasing a weight suspended from the center of the floor as previously described. The 318 kg (700 lb) weight was hoisted onto the free-vibration bracket suspended from the centerpoint of the floor system. Once in place, the data acquisition system would be initialized. After all systems were checked, the operator would start the data acquisition system and release the weight by opening the locked vise-grips. After three seconds had elapsed, the recorded acceleration trace would be checked for abnormalities on the micro-computer. The floor conditions would be changed and the entire process would be repeated. This test essentially released the floor specimen from a deformed state to allow it to vibrate about it's unloaded deflected position.

3.5.3 Drop Weight Tests

These tests used the previously described drop-weight apparatus. Prior to testing the actual floor specimens, several drop weight traces were recorded and compared to ascertain the repeatability of the drop weight system. It was found that, with a modified release mechanism, the impact produced by the drop weight apparatus was repeatable, and therefore, only one drop weight per floor condition and instrument orientation was recorded.

The drop weight apparatus was placed on top of the centerpoint of the floor system, and bolted in place. The weight was lifted and locked in position by the release mechanism. After the data acquisition system was initialized, the weight was released, which instantaneously started the data acquisition software. After three seconds had elapsed, the recorded acceleration trace was observed and checked for any abnormalities. The floor condition would then be changed, and the test procedure was repeated.

3.6 Data Analysis

This section will describe the steps used in processing the raw data to determine the final results presented in this document. Since the same parameters were desired for both types of floor systems, the analysis methods were the same for both. This section is divided into three sections: Static data analysis, Dynamic data analysis, and Statistical analysis.

3.6.1 Static Data Analysis

For each load, boundary, and bracing condition, joist/truss deflection profiles were recorded from the load-sharing test. From these deflections an equivalent "load carried" was calculated for each joist.

Using the EI values calculated for each joist, and the subsequent deflection of that member, the load carried by that member was derived from the deflection equation for a simply-supported beam with a concentrated load at midspan, derived from structural theory. No composite action between the sheathing and joist was assumed, the moment of inertia used was for that of the joist only.

$$\Delta=\frac{PL^3}{48EI} \tag{3-1}$$

from which:

$$P=\frac{48\times\Delta\times E\times I}{L^3} \tag{3-2}$$

where:

P = load carried by the joist
Δ = deflection of joist
EI = stiffness of joist
L = clear span of floor joist

Using equation (3-2), the load carried by the member in question was calculated, from which the comparison of braced versus unbraced floor systems was made.

From the result of equation (3-2), the percent change in load carried parameter was calculated for the braced versus unbraced deflection for all bracing systems as follows:

$$\% \ Change = \frac{P_{braced} - P_{unbraced}}{P_{unbraced}} \times 100 \tag{3-3}$$

where:

P_{braced} = load carried by the braced joist
$P_{unbraced}$ = load carried by the unbraced joist

The results of the above calculations are presented in the RESULTS chapter.

3.6.2 Dynamic Data Analysis

Three operations were performed on the acceleration traces acquired with the data acquisition software: calibration, filtering, and calculation of power spectral density. All of the calculations were performed using a commercial mathematical software package called DADiSP [1991].

The data was calibrated to convert the units from voltage to meters/second/second. The calibration coefficient was given on the accelerator amplifier box as 1g=100mV.

The data was filtered by first transforming the data from the time domain to the frequency domain, by the use of the Fast Fourier Transform command in the software package. Once in the frequency domain, a band pass filter from five (5) to forty-five (45) hertz was used to eliminate all of the low and high frequency noise in the signal. An Inverse Fast Fourier Transform was then performed on the data to transform the data back to the time domain, resulting in a calibrated and filtered acceleration trace.

After calibration, and filtering, the power spectral density of the trace was calculated using the PSD command in the software package. The power spectral density of the trace showed all of the frequencies present in the filtered acceleration record, along with the relative unit of power present at each frequency. The necessary information to obtain the three dynamic parameters used to evaluate each of the bracing systems was derived in this manner. The next three sections describe the methods used to calculate the necessary parameters from the filtered acceleration traces, and the power spectral density curves.

3.6.2.1 Modal Frequency and Separation These frequency parameters were taken from the power spectral density curve. The frequency for vibration mode #1 was taken as the first significant peak on the curve, and modal frequencies #2 through #4 were taken subsequently. Modal separation is simply the algebraic difference between adjacent modal frequencies, in Hertz. Figure 3-9 shows a typical power spectral density curve with the chosen modal frequencies and the separation between each mode indicated.

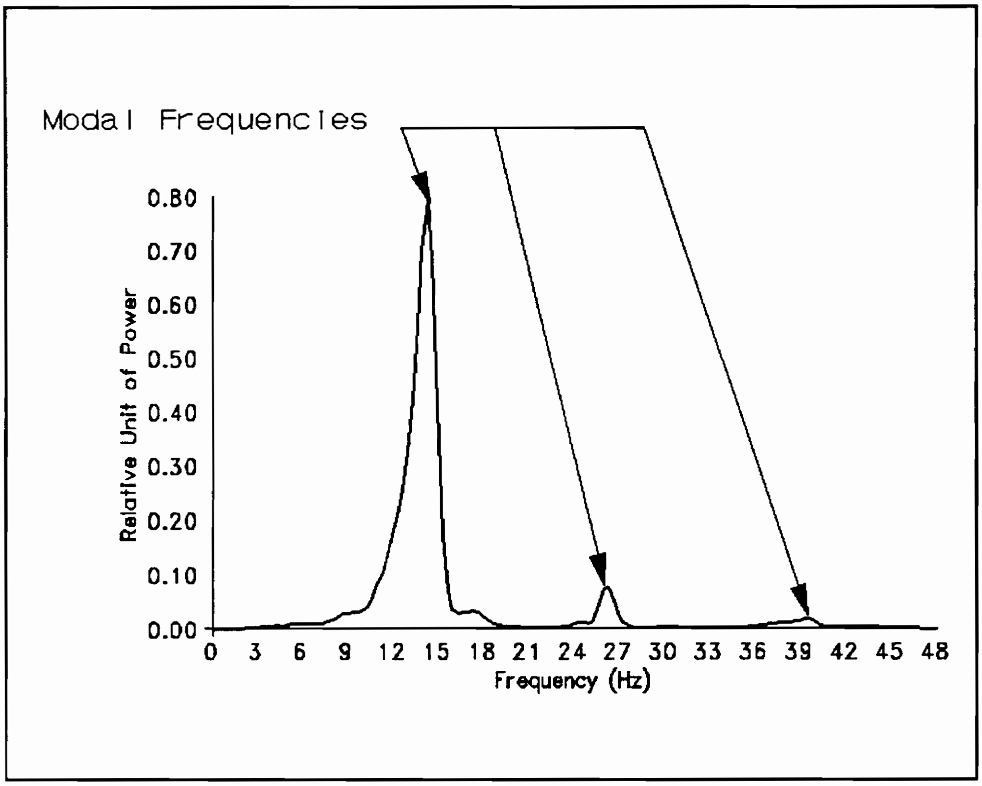

Figure 3-9: Typical Power Spectrum, Showing Selected Frequencies

3.6.2.2 Modal Damping This parameter was also taken from the power spectral density curve. It represents the amount of energy dissipation associated with each mode of vibration, and is calculated using the equation:

$$\xi = \frac{f_2 - f_1}{f_1 + f_2} \times 100 \qquad (3\text{-}4)$$

where:

ξ = percent critical damping
f_1 = frequency at p/√2, to the left of the peak
f_2 = frequency at p/√2, to the right of the peak
p = peak amplitude of power spectrum at the mode in question

This method for calculating the modal damping ratio is referred to as the "Half-Power Method" [Clough and Penzien, 1975]. Figure 3-10 illustrates the variables used to calculate modal damping.

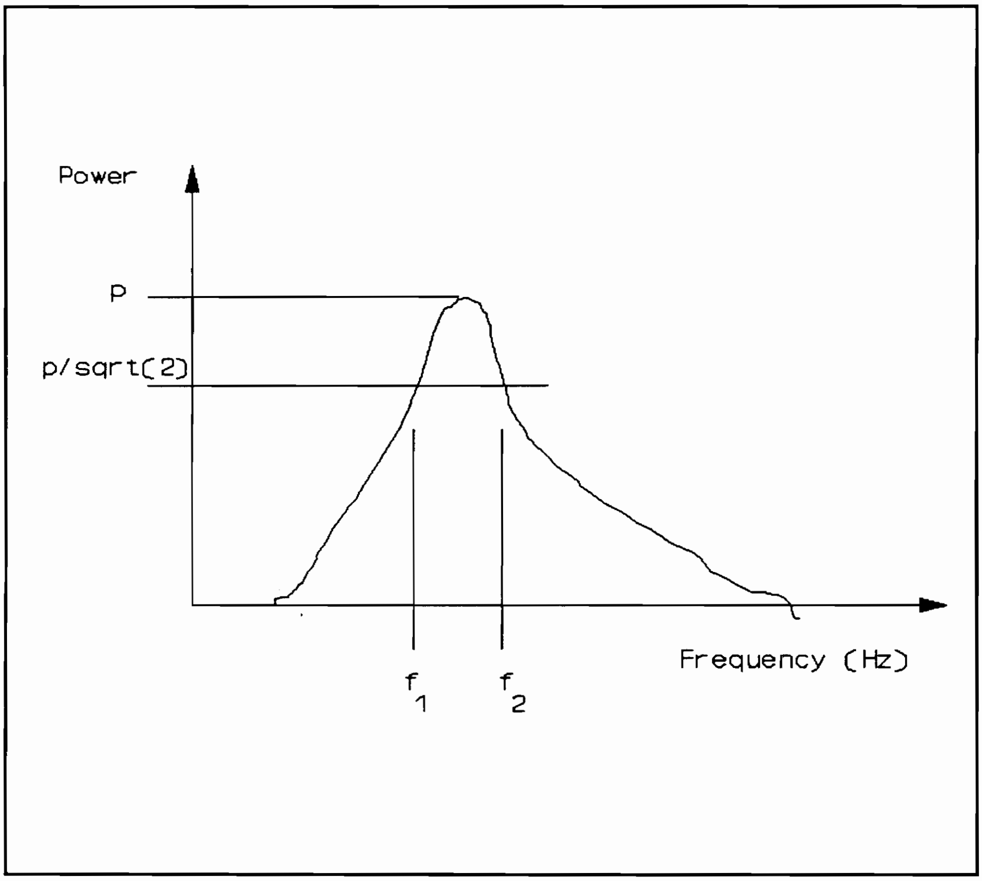

Figure 3-10: Modal Damping by Half-Power Method

3.6.2.3 Logarithmic Damping While the modal damping ratio represents the amount of energy dissipation associated with each individual mode, logarithmic damping represents the amount of damping present in the whole system. Logarithmic damping is based on the rate of decay of oscillation, and can be defined as the natural logarithm of two amplitudes, successive or otherwise. It is calculated in two steps as follows [Berg 1989]:

$$\delta = \left(\frac{1}{n}\right) \times \ln\left(\frac{a_1}{a_2}\right) \tag{3-5}$$

then:

$$\xi = \frac{\frac{\delta}{2\pi}}{\sqrt{1 + \left(\frac{\delta}{2\pi}\right)^2}} \approx \frac{\delta}{2\pi} \tag{3-6}$$

where:

δ = logarithmic decrement
a_1 = amplitude of the first chosen peak
a_2 = amplitude of the second chosen peak
n = number of peaks between a_1 and a_2
ξ = damping ratio

The above equations were taken from a structural dynamics text [Berg, 1989]. Logarithmic damping was calculated from the filtered acceleration trace for each boundary, load, and bracing condition.

3.6.3 Statistical Analysis

In order to account for the inherent variance of the parameters calculated, and to provide the reader with a better understanding of the limitations of the results, a statistical analysis was performed. First, the results of the load sharing test for both the four solid-sawn joist systems, and three truss floor systems were averaged. Next the coefficient of variation of the deflections from each floor were computed to provide a measure of the reliability of the results.

For the dynamic results, the sample means and coefficients of variation, were calculated for the modal frequencies, modal separations, and modal and logarithmic damping ratios. To determine if there was a significant change in the braced versus unbraced parameters, a t-Test at the 95% confidence level was performed on the means using the statistical software package Minitab [1991]. The mean values tested were the modal frequencies, separation between the frequencies, modal damping ratios, and logarithmic damping ratios. The null hypothesis was that the means of the braced systems were equal to the means of the unbraced systems, and rejection of the null would show that there was a significant change between the braced and unbraced systems.

3.7 Conclusions

This chapter detailed all the material and methods which were used in this research. Sufficient detail was presented to allow the results presented in this research to be reproduced by others.

IV

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will present the results of the static and dynamic tests described in the previous chapter. There are four different parameters used to evaluate the performance of the lateral bracing systems in this thesis: one static and three dynamic. The static results focus on the change in concentrated load distribution of the braced versus the unbraced systems. These results are from the load sharing tests described in Chapter 3, in which it was explained that a concentrated load of 2669 N (600 lb) was applied at one floor joist/truss at a time, while the deflections of all nine floor joists/trusses were monitored for each load position. Then, based on the recorded deflection, an equivalent load carried was calculated from structural theory for a simply supported beam loaded at midspan. The calculated unbraced "load carried" was then compared to the braced load carried. The percent change in load carried by the braced versus unbraced floor members was computed.

The three dynamic criteria used to compare the braced and unbraced systems are based on two floor response characteristics: resonant frequencies, and percent critical damping. First, the frequencies of the first three modes of vibration of the braced and unbraced systems were compared. Next, the change in the separation between the first three modal frequencies for the braced and unbraced systems were compared. The third comparison criteria is the change in percent critical damping of the braced versus the unbraced systems. Typical results from one of each type of floor system will be presented, followed by a summary of all floors of that type. Discussion of the results will follow the presentation of each set of results. This chapter is made up of the two sections; Static Test Results, and Dynamic Test Results. The complete data obtained during the tests is presented in Stark and Dolan [1993a and b]

4.2 Static Test Results

This section presents the results of the load sharing tests for both solid-sawn, and parallel chord truss floor systems. As previously discussed, both the "load carried", and the percent change in load carried are presented here. The percent change in load carried is presented for each of the bracing systems. This percentage is the change in the amount of load carried by braced versus the unbraced floor member. Due to the variance in the deflections away from the loaded floor member, only the change in the load carried by the loaded floor member will be included for comparison of braced versus unbraced systems in the discussion section.

4.2.1 Static Test Results-Solid Sawn Bracing Systems

Table 4-1 below shows the load carried by seven of the nine joists with the concentrated load on joist #4. The table also shows the percent change in load carried for the braced versus the unbraced floors. Recall that the load was placed at each of the nine joists in the floor, and that for each load position, the deflection of all nine joists was recorded. Recall also that BR, BL, and PT stand for the bridging, blocking, and post-tensioned bracing systems respectively, as described in Chapter 3. Only the maximum (22.2 kN (5 kip)) post-tensioned blocking level was investigated in the static tests, since the primary goal of this thesis was to investigate the effect of the post-tensioned blocking on the dynamic response of solid-sawn floors.

As already stated, these loads were calculated from the individual joist deflections for each bracing condition, and also from the static stiffness (EI) for each individual joist. Since the stiffness (EI) values for the joists were not constant for each floor system, the variance of the joist stiffnesses introduced additional variance in the data. Therefore, in two cases, the calculated load carried, exceeds the amount of load applied. This is in part due to the non-constant joist stiffnesses, in addition to human error in reading the dial gages. Creep of the floor systems also contributed to these excesses. Though the concentrated load was applied only long enough to read the dial gages, the weight of the person moving on and off the floor, and moving the load from joist to joist could amplify the creep problem.

Tables 4-1, 2 and 3 and Figures 4-1,2, and 3 represent a "typical" solid-sawn floor load distribution profile of floor SS-4. The tables show the load carried by the loaded joist, and that carried by the three joists on either side of the loaded joist. It was decided to show only three joists on either side of the load since it was observed that this was the extent to which even the most effective bracing systems were able to distribute the load. Also, only the profiles for the inner seven joists were presented since the edge effects of the floor affected the two side joists on either side of the floor. Table 4-1 shows the load distribution of joists #1 - #7, with the load applied at joist #4. The percent change in the load carried by the braced versus the unbraced joist is also presented. This was calculated by comparing the braced load carried with that carried by the unbraced joist. Accompanying each table is a figure showing the same deflections used to calculate the load carried in the table (see Figure 4-1). The percent change is thus presented graphically to give one a visual presentation of the effect of each bracing system. Table 4-2 and Figure 4-2 show the load distribution for the same floor specimen, but with the load at joist #5. Table 4-3 and Figure 4-3 again show the same typical floor specimen except that the load is applied at joist #6.

Table 4-1:
Typical Load Distribution with the Concentrated Load at Joist #4
Solid-Sawn Floor SS-4
Force (Newtons) Carried By Each Joist Based on Deflection From Load Sharing tests.

LOAD DISTRIBUTION - 2669 N LOAD - Floor SS-4							
	LOAD AT JOIST #4						
BRACING CONDITION	Load in Joist #1	Load in Joist #2	Load in Joist #3	Loaded Joist #4	Load in Joist #5	Load in Joist #6	Load in Joist #7
UB LOAD (N)	-27	58	465	1120	455	177	83
BR LOAD (N) (% CHANGE)	224 (+933.3)	214 (+271.4)	535 (+15.1)	1023 (-8.7)	390 (-14.3)	204 (+15.0)	46 (-44.4)
BL LOAD (N) (% CHANGE)	188 (+800.0)	214 (+271.4)	526 (+13.2)	979 (-12.6)	476 (+4.8)	257 (+45)	73 (-11.1)
PT LOAD (N) (% CHANGE)	152 (+666.7)	255 (+342.9)	526 (+13.2)	909 (-18.9)	440 (-3.2)	221 (+25.0)	73 (-11.1)

UB = Unbraced

BR = Bridging

BL = Blocking

PT = Post-Tensioned Blocking

(% CHANGE) = percent change in load carried, braced versus unbraced

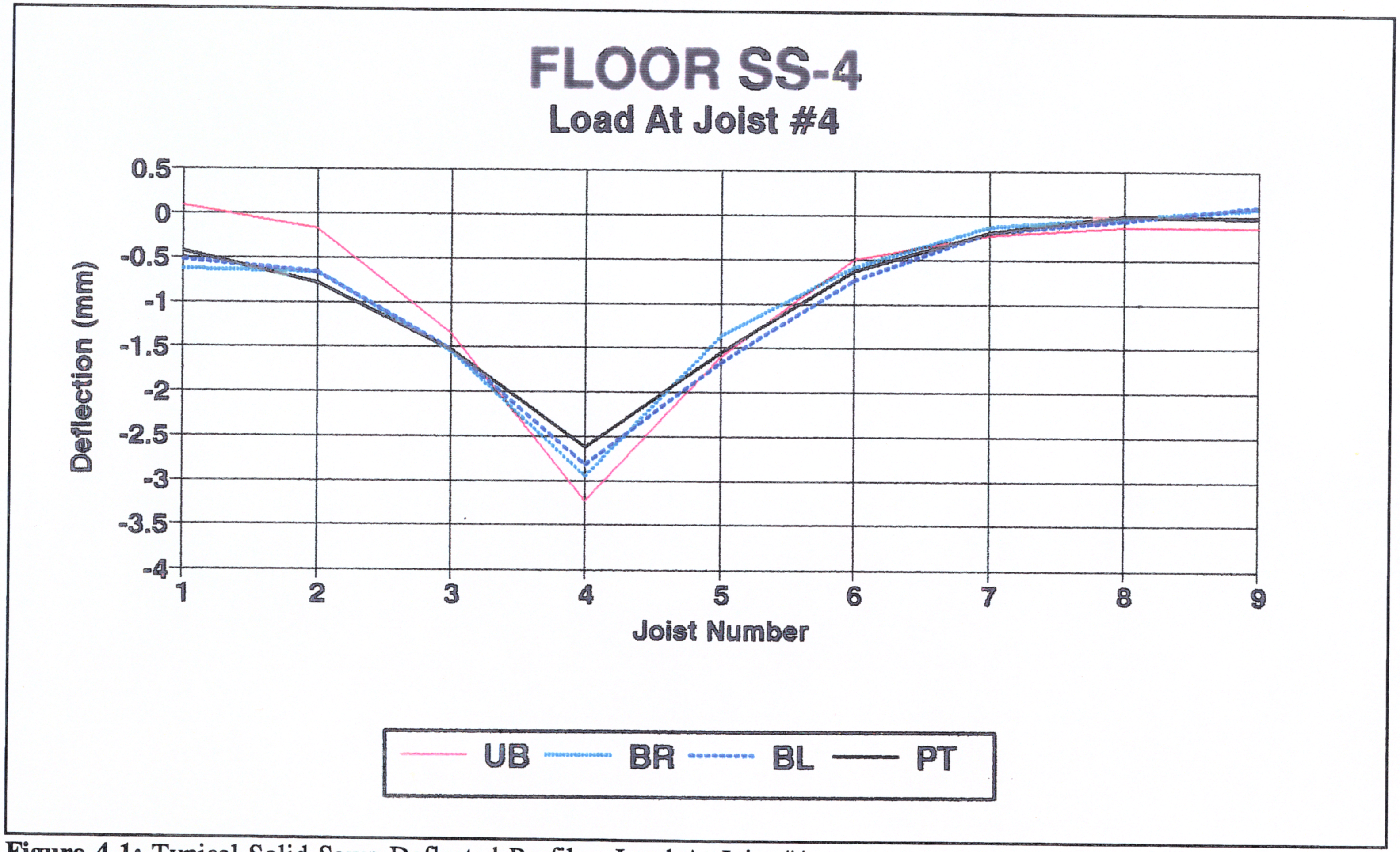

Figure 4-1: Typical Solid-Sawn Deflected Profile - Load At Joist #4

Table 4-2:
Typical Load Distribution with the Concentrated Load at Joist #5
Solid-Sawn Floor SS-4
Force Carried By Each Joist Based on Deflection From Load Sharing Tests.

LOAD DISTRIBUTION - 2669 N LOAD - Floor SS-4							
	LOAD AT JOIST #5						
BRACING CONDITION	Load in Joist #2	Load in Joist #3	Load in Joist #4	Loaded Joist #5	Load in Joist #6	Load in Joist #7	Load in Joist #8
UB LOAD (N)	-8	97	485	1089	514	156	64
BR LOAD (N) (% CHANGE)	82 (+1100.0)	167 (+72.7)	591 (+21.8)	960 (-11.9)	540 (+5.2)	119 (-23.5)	21 (-66.7)
BL LOAD (N) (% CHANGE)	90 (+1200.0)	237 (+145.5)	573 (+18.2)	909 (-16.6)	585 (+13.8)	211 (+35.3)	57 (-11.1)
PT LOAD (N) (% CHANGE)	90 (+1200.0)	202 (+109.1)	538 (+10.9)	844 (-22.5)	531 (+3.4)	220 (+41.2)	50 (-22.2)

UB = Unbraced

BR = Bridging

BL = Blocking

PT = Post-Tensioned Blocking

(% CHANGE) = percent change in load carried, braced versus unbraced

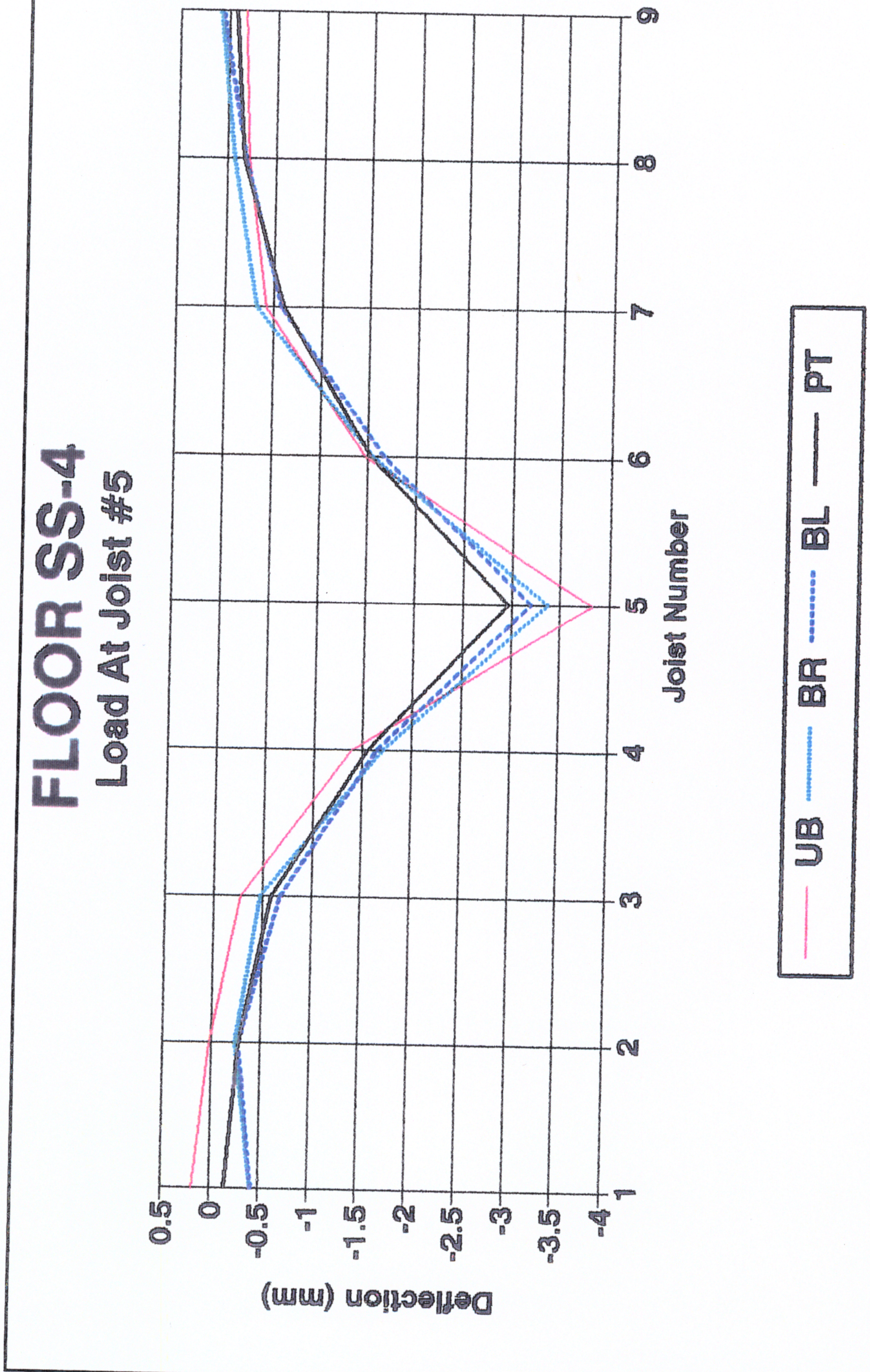

Figure 4-2: Typical Solid-Sawn Deflected Profile - Load At Joist #5

Table 4-3:
Typical Load Distribution with the Concentrated Load at Joist #6
Solid-Sawn Floor SS-4
Force Carried By Each Joist Based on Deflection From Load Sharing Tests.

LOAD DISTRIBUTION - 2669 N LOAD - Floor SS-4							
	LOAD AT JOIST #6						
BRACING CONDITION	**Load in Joist #3**	**Load in Joist #4**	**Load in Joist #5**	**Loaded Joist #6**	**Load in Joist #7**	**Load in Joist #8**	**Load in Joist #9**
UB LOAD (N)	**35**	**115**	**375**	**1213**	**532**	**128**	**58**
BR LOAD (N) **(% CHANGE)**	**53** (+50.0)	**221** (+92.3)	**455** (+21.2)	**1116** (-8.0)	**551** (+3.4)	**157** (+22.2)	**36** (-37.5)
BL LOAD (N) **(% CHANGE)**	**123** (+250.0)	**273** (+138.5)	**808** (+115.4)	**948** (-21.9)	**560** (+5.2)	**157** (+22.2)	**58** (0.0)
PT LOAD (N) **(% CHANGE)**	**105** (+200.0)	**291** (+153.8)	**476** (+26.9)	**824** (-32.1)	**523** (-1.7)	**185** (+44.4)	**123** (+112.5)

UB = Unbraced

BR = Bridging

BL = Blocking

PT = Post-Tensioned Blocking

(% CHANGE) = percent change in load carried, braced versus unbraced

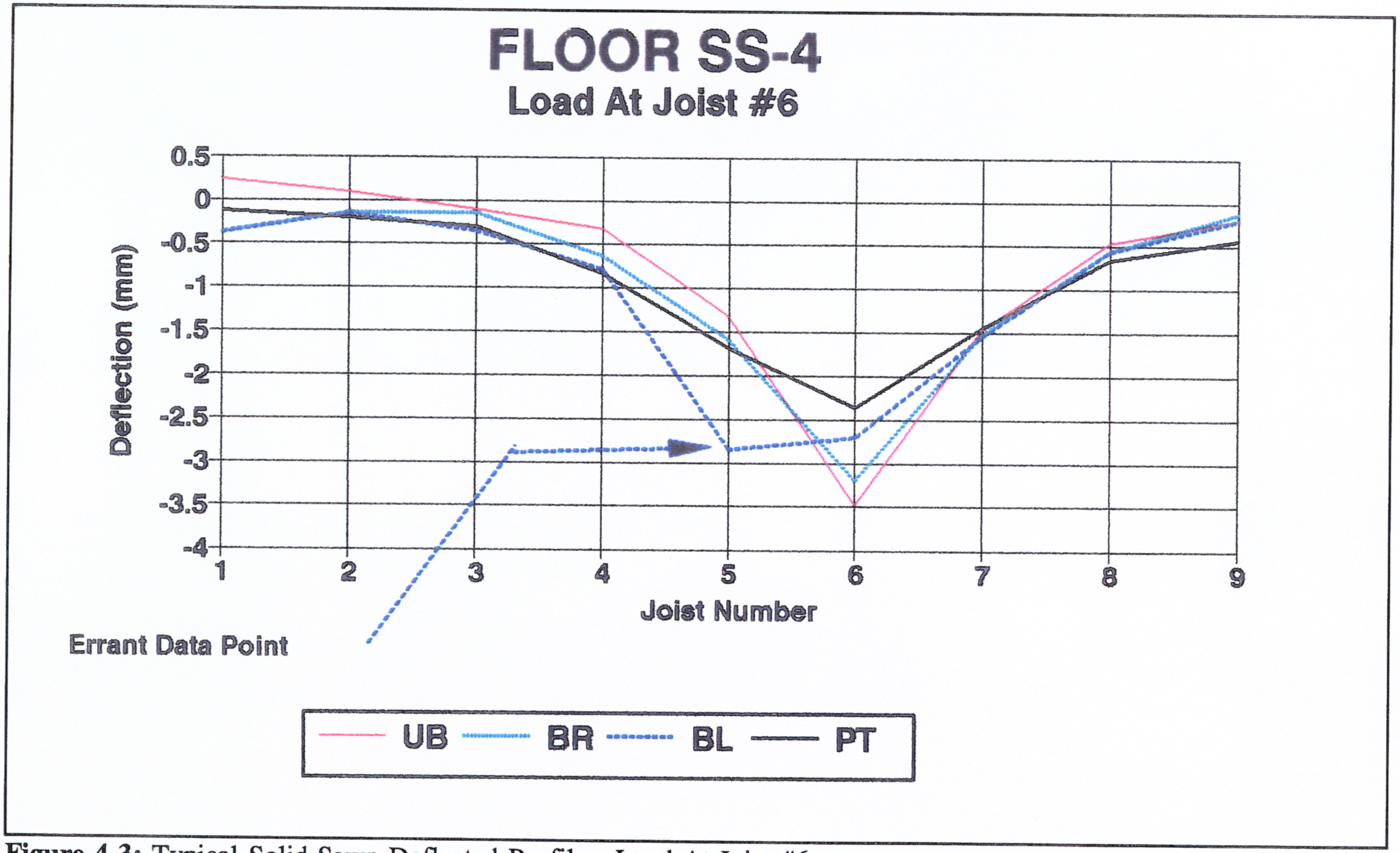

Figure 4-3: Typical Solid-Sawn Deflected Profile - Load At Joist #6

Notice from Tables 4-1, 2, and 3, and Figures 4-1, 2, and 3 that while the bracing systems tend to reduce the deflection, and thus the load carried, under the load, they tend to increase the deflection, and load carried, of adjacent joists, thereby improving the load distribution ability of the test floors. With this improvement in load distribution, the floor itself responds more as a system or ribbed plate, than as merely nine individual joists. The bracing improves the floor's ability to resist applied loads.

Next, the load sharing results will be presented for all of the solid-sawn floor systems tested. The change in the load carried by the loaded joist only will be focused upon, with the assumption that a reduction under the load results in an increase in the load sharing ability of the floor system. Table 4-4 shows the percent changes in load carried by the loaded joist for each of the solid-sawn floors. Remember that each bracing system's percent change is derived from comparison with the unbraced load carried. As with the typical results, only the inner five joists were presented since they had at least two joists on either side of the loaded joist. For each floor, Table 4-4 also presents the mean and coefficient of variation of the percent changes in load carried for each joist in that floor. All of the reductions in load carried for each bracing system were averaged, resulting in an overall average performance for each type of bracing. The overall COV is presented to give the reader a "feel" for the consistency of the reductions for each bracing system, and was calculated using the individual values, not the average values of the reduction in load carried.

Table 4-4:
Percent Change in the Concentrated Load Carried by the Loaded Joist
Braced -vs- Unbraced
All Solid-Sawn Floor Specimens.

PERCENT REDUCTION IN LOAD CARRIED BY THE LOADED JOIST: SOLID-SAWN FLOORS
BRACED -vs- UNBRACED

UB versus	FLOOR	LOAD AT #3	#4	#5	#6	#7	FLOOR AVERAGE	%COV FOR FLOOR
BR	**SS-2 (%)**	-12.3	-13.7	-13.0	-12.7	-15.4	**-13.42**	**9.1**
	SS-3 (%)	-13.8	-13.3	-22.4	-10.0	-13.8	**-14.7**	**31.4**
	SS-4 (%)	-4.5	-8.7	-11.9	-8.0	-6.6	**-7.9**	**34.4**
		BR: OVERALL AVERAGE AND %COV—>					**-12.0**	**35.1**
BL	**SS-2 (%)**	-6.6	-12.1	-26.0	-24.7	-19.6	**-17.8**	**46.7**
	SS-3 (%)	-13.8	-14.0	-16.8	-13.1	-13.0	**-14.1**	**11.0**
	SS-4 (%)	-15.2	-12.6	-16.6	-21.9	-5.8	**-14.4**	**40.9**
		BL: OVERALL AVERAGE AND %COV —>					**-15.5**	**37.3**
PT	**SS-2 (%)**	-13.2	-17.7	-29.5	-29.1	-32.2	**-24.3**	**34.3**
	SS-3 (%)	-10.3	-7.0	-11.2	-11.5	-16.3	**-11.3**	**29.6**
	SS-4 (%)	-26.5	-18.9	-22.5	-32.1	-20.4	**-24.1**	**22.1**
		PT: OVERALL AVERAGE AND %COV —>					**-19.9**	**42.4**

UB = Unbraced
BR = Bridging
BL = Blocking
PT = Post-Tensioned Blocking
SS-2 = solid-sawn floor #2
SS-3 = solid-sawn floor #3
SS-4 = solid-sawn floor #4
FLOOR AVERAGE = average percent change in load carried by loaded joist, each floor
%COV FOR FLOOR = coefficient of variation of average reductions for each floor
OVERALL AVERAGE AND %COV = mean and %COV for all reductions for each type of bracing

4.2.2 Discussion of Results-Solid Sawn Bracing Systems

The solid sawn static results are discussed in this section. The results presented above are based on the static deflection of both the braced and unbraced joists for the four solid sawn floor systems tested. When the first floor (SS-1) was tested, the exact testing methods had not been finalized, and the load sharing test was conducted on the unbraced floor condition only. Therefore, the braced means and coefficients of variation are based on the results of floors SS-2, SS-3, SS-4.

In order to calculate the load carried by each joist, each joist was assumed to be a simply supported beam with no contribution from the sheathing. This is a conservative assumption, and since only changes in deflection are being considered, the effect of this assumption will be neglected.

In evaluating the results, it is important to recall the testing conditions and procedure. The load sharing tests were done on an end supported floor only. Also recall that the floor was loaded starting at joist #1 and progressing to joist #9, therefore, a higher variance in the data for the joists on the east side of the load (the lower numbered joists), than for the load on the west side of the joists (the higher numbered joists) was observed. The traffic of the researchers over the lower numbered joists, and the fact that after a joist was loaded, the dial gage reading often did not return to it's exact initial reading, indicated that creep affected the results.

With these facts in mind, the results of the static tests will be discussed. Each type of bracing will be discussed individually, starting with bridging first, followed by blocking, and then, post-tensioned blocking.

4.2.2.1 Bridging: From Table 4-4 it can be seen that bridging reduced the load carried by the loaded joist an average of 12.0%, with a minimum of a 4.5% reduction for floor SS-4 loaded at joist #3, and a maximum of a 22.4% reduction for floor SS-3 loaded at the middle joist, joist #5. Though this is a wide variation, the trend shows that there was an effect on the static response of the floor systems tested. These results are greater than the 8.2% reduction observed in the National Home Builders Association report [NAHB, 1961]. This is due to the fact that the specimens tested in this research were different than those in the NAHB study. In the NAHB study, the floor joists were spaced at 406 mm (16 inches) on center, and joists depths were varied from 197 to 292 mm (7.75 to 11.5 inches). Also, the NAHB report used a 113 and 159 kg (250 and 350 lb) concentrated loads for the static tests, while this research utilized a 272 kg (600 lb) concentrated load. The variance in the bridging results is in part due to the effect of construction and installation methods on the adequacy of the bridging. Some of the pieces of bridging would split when toe-nailed, and though they were renailed in a different area, the performance of the bridging was inconsistent. The contact area between each piece of bridging and joist was small, and careful attention had to be paid to the joist-to-bridging connection for "best" possible performance.

4.2.2.2 Blocking: The blocking reduced the load carried by the loaded joist an average of 15.5% . These reductions ranged from a 5.8% reduction for floor SS-4, loaded at joist # 7, to a 26.0% reduction in floor SS-2, loaded at joist #5. Again these results differ from the NAHB results for blocking of an 8.9% reduction in deflection, due to the same reasons presented in the preceding section. The variance in the results, is again, partially due to the blocking to joist connection performance. Due to the twist of each of the joists, the blocking would often fit snugly at the top, while there would be a small gap at the bottom. When one considers the deflected shape of the floor with the concentrated load, the bottom of the blocking-to-joist connection would be in tension. The resulting variations may be due to the nails not providing optimum pull-out resistance to this tension.

4.2.2.3 Post-Tensioned Blocking: Post-tensioning the blocking improved the performance over the blocking alone. The average reduction in load carried was 19.9%, with results ranging from a minimum of 7.0% to a maximum of 32.2% . The blocking was post-tensioned to a 22.2 kN (5 kip) load level in all load sharing tests. The results do not meet the 50% reduction predicted by Arapetyan et.al. [Arapetyan et.el. 1990]. This could be due to the different test procedures. In the Arapetyan study, the 50% reduction was observed by first loading a floor, then incrementing the post-tension load up to 8.9 kN (2 kip), while the results presented here were observed by first tensioning the blocking, then applying the load. As with the blocking, the variance could be due to the performance of the blocking to joist connection.

4.2.3 Static Results - Truss Floor Bracing Systems

Five types of bracing were investigated for the parallel chord truss floor systems: bottom-chord bracing, steel X-bracing, strong-back bracing, and the combination systems of steel X-bracing plus bottom-chord bracing, and strong-back plus bottom-chord bracing (BCB, XB, SBB, XB+BB, and SB+BB respectively). The same parameters were used for comparing the truss floor bracing systems. Also, the same test-procedures, and data analysis methods as those used in the solid-sawn tests were followed. The variance of the stiffness values (EI) of the trusses in certain floors caused the sums of the loads carried by the trusses in those floors to exceed the amount of load applied to the floor for several of the bracing conditions. The stiffness variance, along with the variance present in the deflections themselves, is the cause for this error. Tables 4-5, 4-6, and 4-7 present the load carried by each of the trusses in a typical truss floor, TR-2. Table 4-5 shows the results with the load applied at truss #4, while Tables 4-6, and 4-7, show similar results for the load applied over trusses #5, and #6 respectively. Following Table 4-5, Figure 4-4 shows the tabular results graphically (as was presented for the solid-sawn floor results). Similarly, Figure 4-6 shows the results of Table 4-5, and Figure 4-7 shows the results of Table 4-6. These tables and figures are in the same format as those shown for the solid-sawn systems.

Table 4-5:
Load and Percent Change in Load Carried: Load At Truss #4
Truss Floor TR-2.
Braced versus Unbraced.

LOAD DISTRIBUTION 2669 N LOAD- FLOOR TR-2								
	LOAD AT TRUSS #4							
Type of Brace		**Load in Truss #1**	**Load in Truss #2**	**Load in Truss #3**	**Loaded Truss #4**	**Load in Truss #5**	**Load in Truss #6**	**Load in Truss #7**
UB	**LOAD (N)**	**-80**	**19**	**457**	**1339**	**625**	**167**	**58**
BCB	**LOAD (N)**	**195**	**154**	**648**	**1330**	**482**	**121**	**42**
	(%CHANGE)	(+342.9)	(+733.3)	(+41.8)	(-0.7)	(-22.9)	(-27.8)	(-28.6)
XB	**LOAD (N)**	**184**	**136**	**648**	**1356**	**687**	**121**	**25**
	(%CHANGE)	(+328.6)	(+633.3)	(+41.8)	(+1.3)	(+10)	(-27.8)	(-57.1)
SBB	**LOAD (N)**	**218**	**210**	**590**	**1008**	**509**	**250**	**67**
	(%CHANGE)	(+371.4)	(+1033.3)	(+29.1)	(-24.7)	(-18.6)	(+50.0)	(+14.3)
XB+BB	**LOAD (N)**	**-126**	**25**	**440**	**1196**	**750**	**287**	**175**
	(%CHANGE)	(-57.1)	(+33.3)	(-3.6)	(-10.7)	(+20.0)	(+72.2)	(+200.0)
SB+BB	**LOAD (N)**	**-92**	**105**	**474**	**955**	**589**	**343**	**141**
	(%CHANGE)	(-14.3)	(+466.7)	(+3.6)	(-28.7)	(-5.7)	(+105.6)	(+142.9)

UB = unbraced floor condition

BCB = bottom chord braced floor condition

XB = X-braced floor condition

SBB = strong-back braced floor condition

XB+BB = X plus bottom chord braced floor condition

SB+BB = strong-back plus bottom chord braced floor condition

(%CHANGE) = the percent change in load carried, braced versus unbraced floor

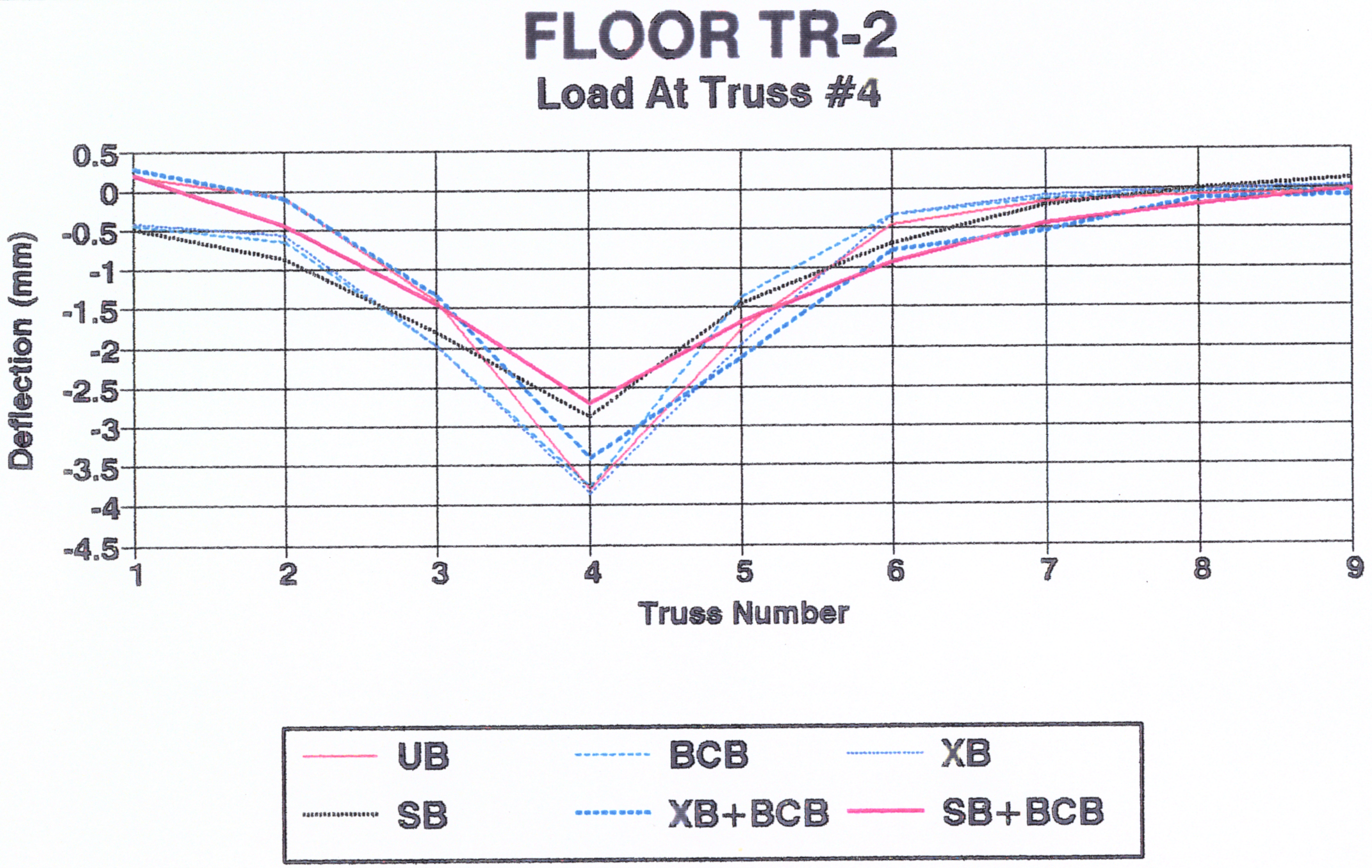

Figure 4-4: Typical Truss Deflection Profile - Load At Truss #4

Table 4-6:
Load and Percent Change in Load Carried: Load At Truss #5
Truss Floor TR-2
Braced versus Unbraced.

LOAD DISTRIBUTION 2669 N LOAD- FLOOR TR-2								
	LOAD AT TRUSS #5							
Type of Brace		**Load in Truss #2**	**Load in Truss #3**	**Load in Truss #4**	**Loaded Truss #5**	**Load in Truss #6**	**Load in Truss #7**	**Load in Truss #8**
UB	**LOAD (N)**	**-25**	**42**	**491**	**1446**	**547**	**116**	**52**
BCB	**LOAD (N)**	**62**	**208**	**687**	**1392**	**482**	**108**	**26**
	(%CHANGE)	(+350)	(400)	(+40.0)	(-3.7)	(-11.9)	(-7.1)	(-50.0)
XB	**LOAD (N)**	**68**	**299**	**741**	**1160**	**602**	**133**	**26**
	(%CHANGE)	(+375)	(+620)	(+50.9)	(-19.8)	(+10.2)	(+14.3)	(-50.0)
SBB	**LOAD (N)**	**87**	**316**	**660**	**1080**	**612**	**224**	**77**
	(%CHANGE)	(+450)	(+660)	(34.5)	(-25.3)	(+11.9)	(+92.9)	(+50.0)
XB+BB	**LOAD (N)**	**-31**	**125**	**491**	**1035**	**732**	**241**	**112**
	(%CHANGE)	(-25.0)	(+200)	(0.0)	(-28.4)	(+33.9)	(+107.1)	(+116.7)
SB+BB	**LOAD (N)**	**6**	**208**	**518**	**991**	**602**	**274**	**121**
	(%CHANGE)	(+125)	(+400)	(+5.5)	(-31.5)	(+10.2)	(+135.7)	(+133.3)

UB = unbraced floor condition

BCB = bottom chord braced floor condition

XB = X-braced floor condition

SBB = strong-back braced floor condition

XB+BB = X plus bottom chord braced floor condition

SB+BB = strong-back plus bottom chord braced floor condition

(%CHANGE) = the percent change in load carried, braced versus unbraced floor

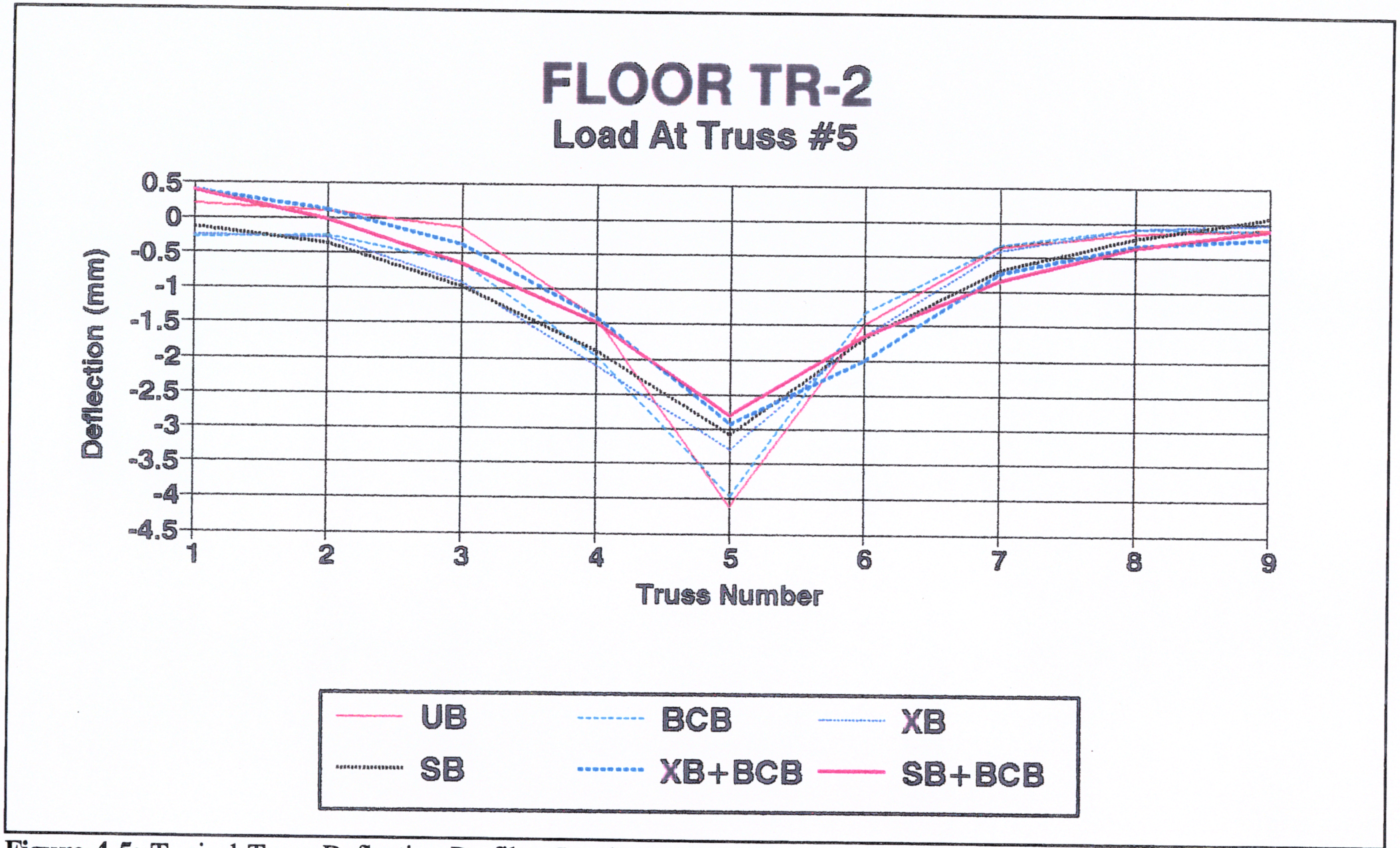

Figure 4-5: Typical Truss Deflection Profile - Load At Truss #5

Table 4-7:
Load and Percent Change in Load Carried: Load At Truss #6
Truss Floor TR-2
Braced versus Unbraced.

LOAD DISTRIBUTION 2669 N LOAD- FLOOR TR-2								
	LOAD AT TRUSS #6							
Type of Brace		**Load in Truss #3**	**Load in Truss #4**	**Load in Truss #5**	**Loaded Truss #6**	**Load in Truss #7**	**Load in Truss #8**	**Load in Truss #9**
UB	**LOAD (N)**	**7.5**	**45**	**419**	**1325**	**515**	**164**	**89**
BCB	**LOAD (N)**	**100**	**268**	**750**	**1307**	**407**	**86**	**134**
	(%CHANGE)	(+1233)	(+500)	(+78.7)	(-1.4)	(-21.0)	(-47.4)	(+50.0)
XB	**LOAD (N)**	**125**	**223**	**750**	**1316**	**523**	**112**	**36**
	(%CHANGE)	(+1567)	(+400)	(+78.7)	(-0.7)	(+1.6)	(-31.6)	(-60.0)
SBB	**LOAD (N)**	**158**	**357**	**643**	**1029**	**515**	**250**	**54**
	(%CHANGE)	(+2011)	(+700)	(+53.2)	(-22.4)	(0.0)	(+52.6)	(-40.0)
XB+BB	**LOAD (N)**	**8.3**	**143**	**518**	**1112**	**573**	**258**	**152**
	(%CHANGE)	(+11.1)	(+220)	(+23.4)	(-16.1)	(+11.3)	(+57.9)	(+70.0)
SB+BB	**LOAD (N)**	**50**	**196**	**482**	**936**	**540**	**327**	**134**
	(%CHANGE)	(+567)	(+340)	(+14.9)	(-29.4)	(+4.8)	(+100)	(+50.0)

UB = unbraced floor condition

BCB = bottom chord braced floor condition

XB = X-braced floor condition

SBB = strong-back braced floor condition

XB+BB = X plus bottom chord braced floor condition

SB+BB = strong-back plus bottom chord braced floor condition

(%CHANGE) = the percent change in load carried, braced versus unbraced floor

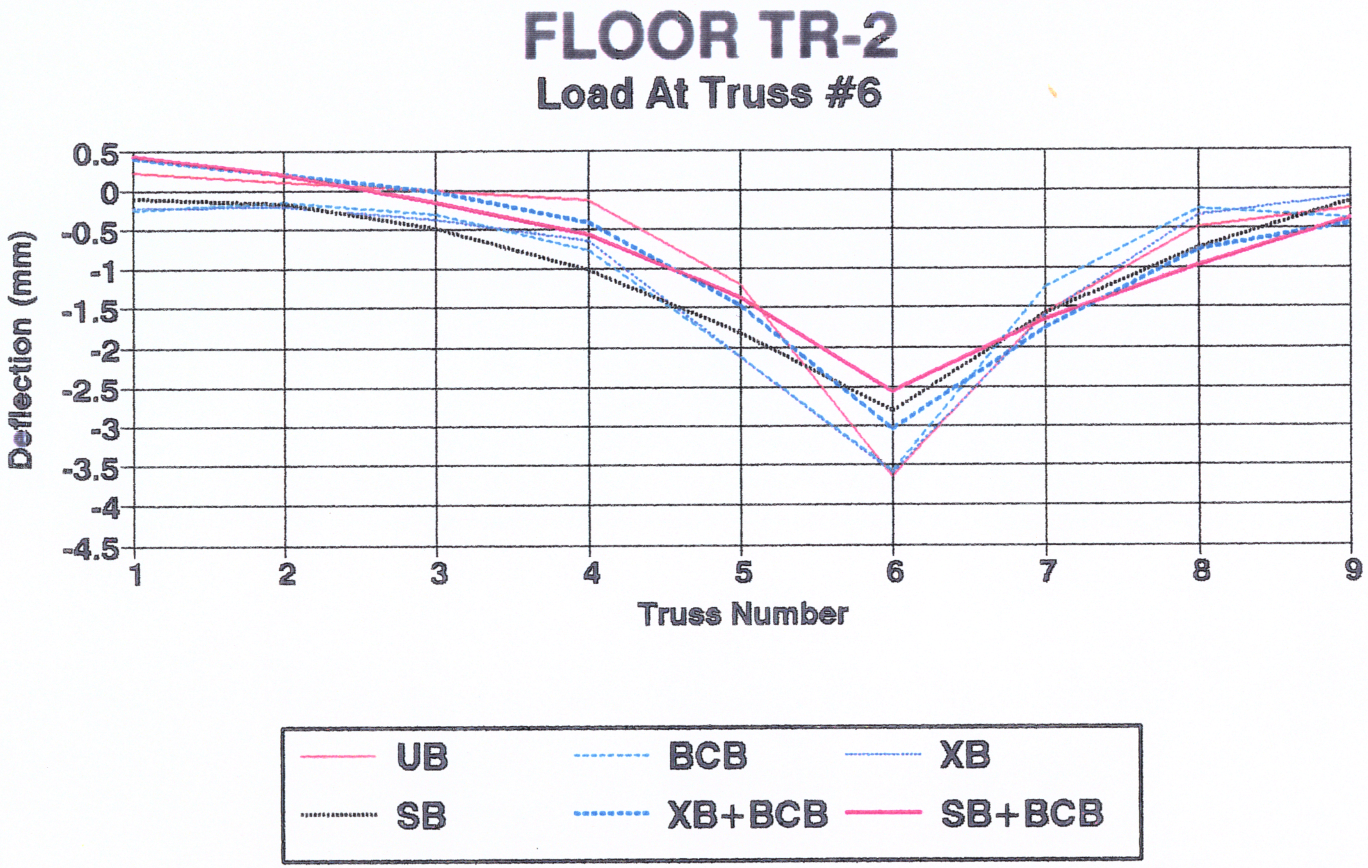

Figure 4-6: Typical Truss Deflection Profile - Load At Truss #6

The load sharing results for all the truss floors tested are presented next. As with the solid-sawn systems, the percent change in load carried of the loaded joist only will be presented, under the assumption that a reduction in load carried by the truss under the load, results in an increase in the load sharing ability of the floor system. Table 4-8 shows the percent change in load carried for each of the truss floors along with the average change and coefficient of variation of the information.

4.2.4 Discussion of Results - Truss Floor Bracing Systems

The results in Table 4-8 are based upon the truss deflections of floor specimens TR-1, TR-2, and TR-3. The same assumptions and calculation procedures as used with the solid sawn systems were followed. Also, the same S-F-S-F boundary conditions were used. The results for each type of bracing system are discussed individually.

4.2.4.1 Bottom-Chord Bracing: Table 4-8 shows that the change in the load carried by the loaded truss was negligible for the bottom-chord braced truss floors. This type of bracing gave an overall average reduction of 2.9%, with values ranging from a 4.8% increase to a 9.2% decrease. One possible explanation for the increase in deflection is that the X-bracing had to be installed when the floor was constructed. Therefore, the bracing systems were tested in this order: X-bracing, X- plus bottom-chord bracing, bottom-chord braced only, unbraced, strong-back braced and strong-back plus bottom chord braced.

Table 4-8:
Percent Change in the Concentrated Load Carried by the Loaded Truss
All Truss Floor Systems: Braced -vs- Unbraced.

PERCENT CHANGE IN LOAD CARRIED BY THE LOADED TRUSS:
TRUSS FLOORS
BRACED -vs- UNBRACED

UB versus	FLOOR	LOAD AT					FLOOR AVERAGE	%COV FOR FLOOR
		#3	#4	#5	#6	#7		
BCB	TR-1 (%)	-0.7	-2.1	-5.1	-5.6	-9.2	**-4.5**	**72.9**
	TR-2 (%)	-4.7	-0.7	-3.7	-1.4	-5.8	**-3.3**	**66.4**
	TR-3 (%)	+4.8	+2.0	+1.3	-7.9	-3.9	**-0.7**	**687.8**
		BCB: OVERALL AVERAGE AND %COV—>					**-2.9**	**134.0**
XB	TR-1 (%)	-11.5	-2.1	-14.0	-8.3	-7.1	**-8.6**	**52.7**
	TR-2 (%)	-17.4	+1.3	-19.8	-0.7	-5.8	**-8.5**	**113.6**
	TR-3 (%)	-0.7	-9.4	-3.3	+3.3	-15.1	**-5.0**	**144.3**
		XB: OVERALL AVERAGE AND %COV —>					**-7.4**	**96.3**
SBB	TR-1 (%)	-25.2	-24.3	-27.4	-18.8	-22.0	**-23.5**	**13.9**
	TR-2 (%)	-26.8	-24.7	-25.3	-22.4	-23.0	**-24.4**	**7.3**
	TR-3 (%)	-41.4	-37.6	-39.7	-40.4	-28.9	**-37.6**	**13.4**
		SBB: OVERALL AVERAGE AND %COV —>					**-28.5**	**26.1**
XB+BB	TR-1 (%)	-23.7	-16.7	-25.5	-18.7	-18.4	**-20.6**	**18.4**
	TR-2 (%)	-28.9	-10.7	-28.4	-16.1	-21.6	**-21.1**	**37.2**
	TR-3 (%)	-17.9	-24.2	-13.9	-15.2	-27.6	**-19.8**	**29.9**
		XB+BB: OVERALL AVERAGE AND %COV —>					**-20.5**	**27.6**
SB+BB	TR-1 (%)	-26.6	-28.5	-31.8	-27.1	-31.9	**-29.2**	**8.7**
	TR-2 (%)	-31.5	-28.7	-31.5	-29.4	-23.7	**-29.0**	**11.0**
	TR-3 (%)	-46.2	-45.6	-42.4	-42.4	-32.9	**-41.9**	**12.7**
		SB+BB: OVERALL AVERAGE AND %COV —>					**-33.4**	**21.6**

UB = unbraced floor condition
BCB = bottom chord braced floor condition
XB = X-braced floor condition
SBB = strong-back braced floor condition
XB+BB = X plus bottom chord braced floor condition
SB+BB = strong-back plus bottom chord braced floor condition
TR-_ = truss floor number _
FLOOR AVERAGE = average change in load carried by loaded truss, each floor
%COV FOR FLOOR = coefficient of variation of reductions for each floor
OVERALL AVERAGE AND %COV = mean and coefficient of variation for all values of each type of bracing

It is possible that the metal plate connectors used on the truss members had seated between the time that the bottom-chord braced and unbraced floors were tested. Increases were observed for both the bottom-chord braced and X-braced systems, however, none were observed for the combination X-plus bottom-chord braced systems which were tested prior to the unbraced condition. Why no increase was observed for the X-plus bottom chord braced system could be testimony to the effectiveness of this bracing combination, for unlike the X-brace and bottom-chord braced conditions alone, the combination produced more significant reductions in load carried. However, it cannot be stated that the bottom-chord brace alone had any significant effect on reducing the load carried by the loaded truss, due to the small magnitude of the overall average and high variance in the results shown.

4.2.4.2 Steel X-Bracing: The X-bracing showed an overall average reduction in load carried of 7.4% . The reductions of the loaded trusses ranged from an increase of 3.3% for floor TR-3, loaded at truss #6, to a maximum reduction of 19.8% for floor TR-2, loaded at truss #5. This bracing system also gave results which had a high coefficient of variation. This is in part due to the two increases in load carried over the unbraced systems of 1.3 and 3.3% .

4.2.4.3 Strong-Back Bracing: The strong-back bracing gave an overall average reduction of 28.5% . The reductions ranged from 18.8% for floor TR-1, loaded at truss #6, to a 41.4% reduction for floor TR-3, loaded at truss #3. The strong-back braced floors showed much more consistent values of reduction than did the two previous systems as seen by the reduction in the coefficients of variation. The additional transverse bending stiffness provided by the strong-back bending about it's strong axis contributed to this effect.

4.2.4.4 X- plus Bottom-Chord Bracing: The bracing combination of X- and bottom-chord bracing performed better than that of each component individually. This bracing system showed an average overall reduction of 20.5%, with a minimum value of 10.7% reduction, to a maximum reduction of 28.9% . Again, there was significantly less variance than was observed for each of the individual components for this bracing combination.

4.2.4.5 Strong-Back plus Bottom-Chord Bracing: An average reduction in load carried of 33.4% was observed for the strong-back plus bottom-chord brace combination. The reductions ranged from a maximum 46.2% reduction, to a minimum of 23.7% reduction. This bracing combination showed the best results of any of the bracing systems evaluated for truss-floor systems. The average overall reduction in load carried was the highest, and the variance of the parameter was the lowest of all the bracing systems.

4.3 Dynamic Test Results

This section presents the results of the dynamic tests for the solid-sawn and parallel-chord truss floor systems. As in the static test results, first a typical representation of the results is presented, followed by a summary of all the results for both floor types. Three dynamic parameters are presented and discussed: resonant frequencies, the separation of those resonant frequencies, and finally, damping ratios for the braced and unbraced floors. The resonant frequencies will be presented for both the free-vibration, and drop-weight loadings at the different live load conditions. The effect of the bracing systems on the resonant frequencies, and the separation of the resonant frequencies will then be discussed. Finally, the modal and logarithmic damping ratios will be presented and discussed.

4.3.1 Solid-Sawn Floor Dynamic Results

This section gives the results and discussion for the dynamic testing of the four solid-sawn floor systems. Both the resonant frequency and damping results will be presented and discussed. The results of both the free-vibration and drop-weight loadings, for all boundary and live load conditions will be presented and discussed. Both the S-S-S-S and S-F-S-F floor boundary conditions were utilized, along with two live load levels: 0 and 960 KN/m^2 (0 and 20 psf). It was decided not to use the 1915 KN/m^2 (40 psf) live load level on the solid sawn floors since most solid-sawn floors would never be loaded to that level for any significant amount of time. Five bracing conditions were evaluated: UB, BR, BL, and two levels of post-tensioned blocking: 13 KN and 22 KN (3 and 5 kips). The two levels of post-tensioning will be abbreviated as PT3 and PT5, respectively.

4.3.1.1 Resonant Frequency Results

Tables 4-9 and 4-10 show a typical frequency response spectrum from the free-vibration and drop weight tests, for both boundary conditions and live load levels, for a typical floor, SS-2. Note that for all conditions the first fundamental frequency remains relatively unchanged. These tables show that, for some of the bracing systems, the frequencies of higher modes of vibration are raised.

Figure 4-7 shows a typical power spectrum for floor SS-2, from which one group of values in Table 4-10 were taken. This figure shows the changes in the higher frequencies in a graphical format.

Tables 4-11, and 4-12 present the statistical means and coefficients of variation for the four solid-sawn floor systems. These tables are based on data acquired from the four solid-sawn floors for both types of dynamic tests, and all boundary and live load conditions.

Table 4-9:
Typical Solid-Sawn Floor Resonant Frequencies
Free-Vibration Test
Floor SS-2.

TYPICAL RESONANT FREQUENCY RESPONSE -						
Type of Brace	FREE-VIBRATION TEST					
	Mode #1 (Hz)	Mode #2 (Hz)	Mode #3 (Hz)	Mode #1 (Hz)	Mode #2 (Hz)	Mode #3 (Hz)
	S-S-S-S No Live Load			S-S-S-S 960 KN/m²		
UB	15.7	24.7	34.3	8.7	12	16.3
BR	16.3	27.7	40.7	8.7	14	20.3
BL	16	27.3	40.7	9	15.3	22
PT3	16	27.7	40.3	9.3	15.3	N/A
PT5	16	28	38	9	15.3	18.7
	S-F-S-F No Live Load			S-F-S-F 960 KN/m²		
UB	16	22.7	27	8.3	10.7	14
BR	15.7	22.3	28	8.3	10.7	16.3
BL	15.7	22	28	8.7	11.7	18.3
PT3	15.7	23.7	27	9	13.7	20
PT5	15.7	24.7	28.7	9	17.3	21

UB = unbraced floor condition

BR = bridging braced floor condition

BL = blocking braced floor condition

PT3 = post-tensioned blocking, 13.3 kN (3 kip) post-tension force

PT5 = post-tensioned blocking, 22.2 kN (5 kip) post-tension force

N/A = no significant mode present

Table 4-10:
Typical Solid-Sawn Resonant Floor Frequencies
Drop-Weight Test
Floor SS-2.

TYPICAL RESONANT FREQUENCY RESPONSE -						
	DROP WEIGHT TEST					
Type of Brace	**Mode #1 (Hz)**	**Mode #2 (Hz)**	**Mode #3 (Hz)**	**Mode #1 (Hz)**	**Mode #2 (Hz)**	**Mode #3 (Hz)**
	S-S-S-S No Live Load			**S-S-S-S 960 KN/m^2**		
UB	13.3	21	32.3	8.3	11.3	16
BR	13.7	25.3	39	8.7	13.7	20.3
BL	14.3	26.3	39.7	9	15.3	N/A
PT3	13.7	26.3	40	9	15.3	N/A
PT5	14.7	26.3	37.7	9	15.3	N/A
	S-F-S-F No Live Load			**S-F-S-F 960 KN/m^2**		
UB	13.3	20	34.7	8	10	14.3
BR	14	21.3	34.3	8.3	12.7	17.3
BL	14.3	21	34	8.7	11.7	17.7
PT3	14.3	22.7	36	8.7	12	N/A
PT5	14.3	23	36	8.7	14.7	17.7

UB = unbraced floor condition

BR = bridging braced floor condition

BL = blocking braced floor condition

PT3 = post-tensioned blocking, 13.3 kN (3 kip) post-tension force

PT5 = post-tensioned blocking, 22.2 kN (5 kip) post-tension force

N/A = no significant mode present

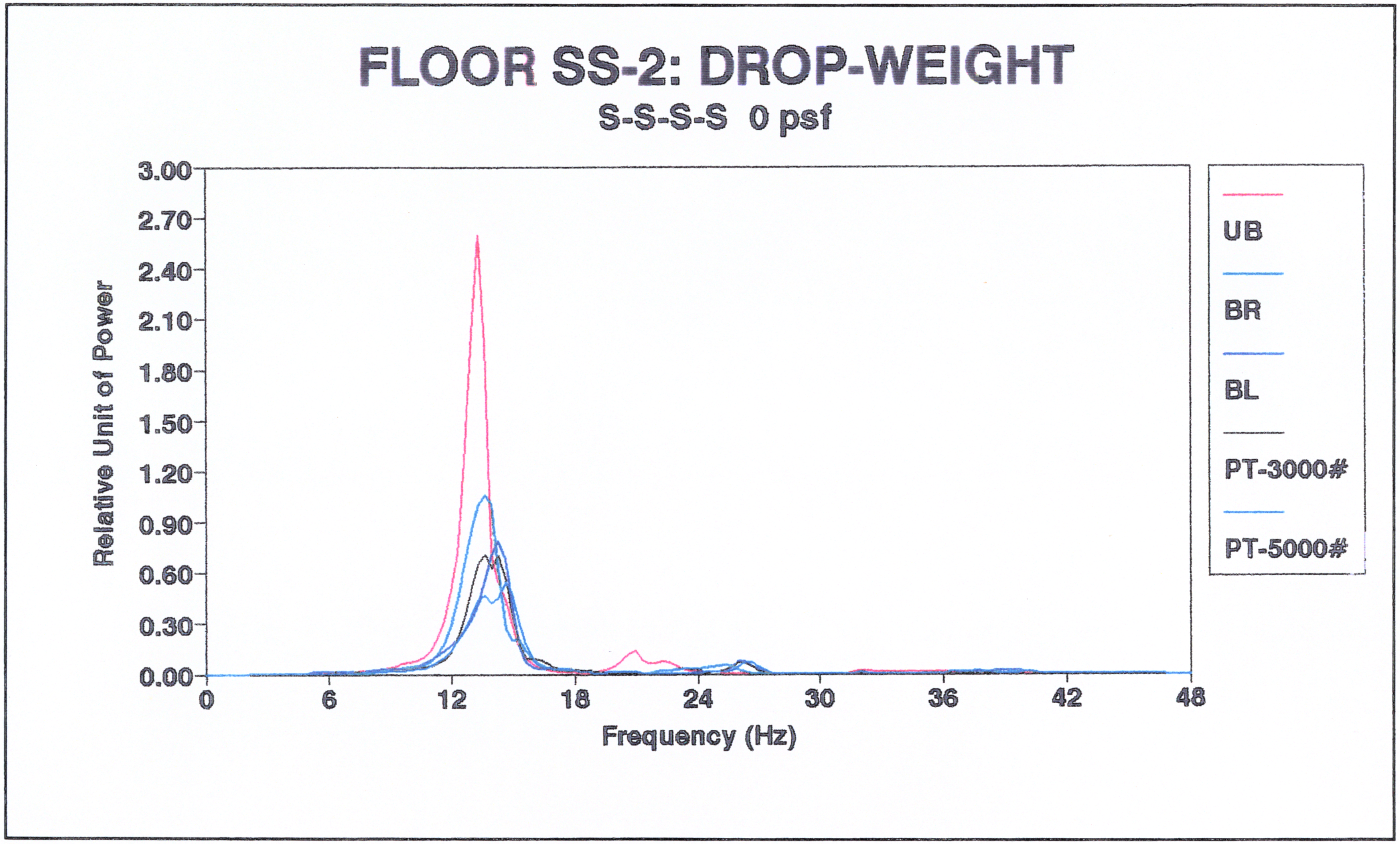

Figure 4-7: Typical Power Spectrum - Floor SS-2: All Bracing Conditions

Table 4-11:
Average Resonant Frequency Response
All Solid-Sawn Floors
Free-Vibration Tests.

AVERAGE RESONANT FREQUENCY RESPONSE SOLID SAWN FLOORS						
	FREE-VIBRATION TEST					
Type of Brace	**Mode #1 (Hz)**	**Mode #2 (Hz)**	**Mode #3 (Hz)**	**Mode #1 (Hz)**	**Mode #2 (Hz)**	**Mode #3 (Hz)**
	S-S-S-S No Live Load			S-S-S-S 960 KN/m^2		
UB (%COV)	**15.8** (3.6)	**24.2** (1.8)	**32.3** (5.4)	**8.6** (2.2)	**11.9** (4.3)	**15.9** (6.7)
BR (%COV)	**16.1** (1.2)	**27.3** (1.2)	**38.1** (10.9)	**8.6** (4.9)	**13.3** (5.1)	**20.1** (3.8)
BL (%COV)	**15.9** (4.0)	**27.1** (0.6)	**36.9** (12.3)	**9.2** (14.1)	**14.5** (4.7)	**20.0** (9.4)
PT3 (%COV)	**16** (0.0)	**27.2** (1.4)	**38.8** (6.2)	**8.7** (5.0)	**14.7** (3.0)	**20.3** (4.3)
PT5 (%COV)	**15.9** (1.2)	**27.3** (2.4)	**35.2** (11.4)	**9.2** (7.5)	**14.7** (3.9)	**20.3** (7.5)
	S-F-S-F No Live Load			S-F-S-F 960 KN/m^2		
UB (%COV)	**15.8** (4.4)	**21.5** (3.6)	**27.2** (2.6)	**8.3** (3.3)	**10.4** (2.7)	**13.8** (3.3)
BR (%COV)	**15.5** (2.8)	**22.7** (5.0)	**28.5** (9.2)	**8.3** (3.3)	**11.1** (3.8)	**15.3** (10.1)
BL (%COV)	**15.5** (2.8)	**22.0** (4.1)	**30.3** (11.3)	**8.3** (4.6)	**11.8** (7.2)	**17.8** (14.4)
PT3 (%COV)	**15.4** (3.8)	**23** (3.1)	**30.3** (15.9)	**8.3** (5.7)	**13.1** (13.7)	**17.5** (13.2)
PT5 (%COV)	**15.2** (3.3)	**23.8** (3.5)	**32.2** (15.7)	**8.3** (8.0)	**14.8** (19.4)	**19.3** (7.9)

UB = unbraced floor condition
BR = bridging braced floor condition
BL = blocking braced floor condition
PT3 = post-tensioned blocking, 13.3 kN (3 kip) post-tension force
PT5 = post-tensioned blocking, 22.2 kN (5 kip) post-tension force
S-S-S-S = four-side supported floor boundary condition
S-F-S-F = two-side supported floor boundary condition
(%COV) = coefficient of variation for mode of frequency for all four joist floors
N/A = insufficient data

Table 4-12:
Average Resonant Frequency Response
All Solid-Sawn Floors
Drop-Weight Tests.

AVERAGE FREQUENCY RESPONSE SPECTRUM SOLID SAWN FLOORS						
	DROP WEIGHT TEST					
Type of Brace	**Mode #1 (Hz)**	**Mode #2 (Hz)**	**Mode #3 (Hz)**	**Mode #1 (Hz)**	**Mode #2 (Hz)**	**Mode #3 (Hz)**
	S-S-S-S No Live Load			S-S-S-S 960 KN/m^2		
UB (%COV)	**13.5** (3.2)	**20.7** (2.9)	**31.7** (1.9)	**8.2** (2.3)	**11.3** (5.9)	**15.6** (6.9)
BR (%COV)	**14.1** (2.3)	**24.1** (4.6)	**37.1** (8.6)	**8.4** (3.8)	**12.8** (7.5)	**19** (9.6)
BL (%COV)	**14.2** (1.4)	**25.1** (3.9)	**36.7** (12.8)	**8.7** (2.4)	**14.3** (5.9)	**19.9** (7.0)
PT3 (%COV)	**13.9** (2.7)	**24.9** (5.1)	**37.4** (8.3)	**8.6** (3.3)	**14.2** (5.9)	**19.9** (7.0)
PT5 (%COV)	**14.1** (3.6)	**24.9** (5.4)	**36.2** (6.9)	**8.4** (6.0)	**14.4** (5.3)	**20.8** (3.4)
	S-F-S-F No Live Load			S-F-S-F 960 KN/m^2		
UB (%COV)	**13.2** (3.8)	**19.3** (2.4)	**29.6** (20.5)	**8.0** (6.0)	**10.2** (2.5)	**14.0** (4.8)
BR (%COV)	**14.0** (2.5)	**20.5** (5.4)	**30.0** (16.3)	**8.1** (5.1)	**11.5** (6.9)	**15.7** (11.4)
BL (%COV)	**13.9** (4.5)	**20.7** (1.7)	**31.4** (11.6)	**8.3** (3.3)	**11.4** (2.5)	**16.9** (4.9)
PT3 (%COV)	**13.8** (4.1)	**21.6** (4.6)	**31.5** (17.3)	**8.4** (3.8)	**11.5** (2.7)	**15.9** (9.7)
PT5 (%COV)	**13.9** (3.9)	**22.4** (2.7)	**34.6** (15.8)	**8.6** (2.3)	**12.4** (15.5)	**16.8** (9.2)

UB = unbraced floor condition
BR = bridging braced floor condition
BL = blocking braced floor condition
PT3 = post-tensioned blocking, 13.3 kN (3 kip) post-tension force
PT5 = post-tensioned blocking, 22.2 kN (5 kip) post-tension force
S-S-S-S = four-side supported floor boundary condition
S-F-S-F = two-side supported floor boundary condition
(%COV) = coefficient of variation for mode of frequency for all four joist floors
N/A = insufficient data

4.3.1.2 Discussion of Resonant Frequency Results

First, the differences between the free-vibration and drop-weight frequencies will be discussed. Recall the difference in excitation between the free-vibration and drop-weight tests. Free-vibration was induced by the sudden release of a 318 kg (700 lb.) mass from the underside of the floor, while the drop-weight apparatus impacted the floor with only an 11.8 kg (26 lb.) mass. The free-vibration tests set the floors into a more vigorous state of vibration than that present in the drop-weight tests. This difference in vibrational states caused the steel test frame to have a greater effect on the frequencies of the free-vibration tests than those of the drop-weight tests. This difference can be seen when comparing either the typical dynamic results shown in Tables 4-9 and 4-10, or in the average dynamic results shown in Tables 4-11 and 4-12. Notice that the difference between the free-vibration and drop-weight frequencies is more pronounced with no imposed load present. The increase in floor mass due to the imposed load reduced the frequencies of the floors enough to decrease the floor-test frame interaction. The dynamic results from the floors with some amount of imposed load present represent a more realistic loading condition since a floor in a residential or commercial structure will have some amount of imposed load present.

The effect of each type of bracing system on the resonant frequencies and separations are discussed individually next. For ease of comparison, tables are presented which compare each braced and unbraced floor condition utilizing the results from the average values presented in Tables 4-11 and 4-12. These tables present, along with the frequencies, the results of the statistical comparison of the braced versus unbraced floors. As discussed in Chapter 3, a statistical analysis was performed on the braced versus unbraced floor frequencies and separation of frequencies. A t-Test was utilized, in which each braced versus unbraced frequency and separation were compared, with the null hypothesis that the means were equal. When this hypothesis is rejected, it signifies that there was a significant change between the braced versus unbraced means being compared at the 95% level of confidence. Therefore, a "Y" in the t-Test Result column of the following comparison tables means that there is a 95% probability that type of bracing produced a change in that particular frequency or modal separation for those test conditions. A "N" in the t-Test Result column subsequently means that there was no significant change when comparing the braced to the unbraced frequency or separation. The amount of variance in a particular frequency or modal separation value has an effect on the outcome of the t-Test. For instance, if there is a large amount of variance, as shown by a high coefficient of variation in Tables 4-11 and 4-12, then the t-Test will fail to reject the hypothesis that the means are equal. In other words, the data used to calculate the average values has too much "spread" between values, and the t-Test does not show that there is a difference between the braced and unbraced averages. This can lead the reader to wonder why for one mode, a two or three Hz difference between the braced versus unbraced values has a "Y" in the t-Test result column, while for another mode the same difference between the braced and unbraced values has a "N" in the t-Test result column. The results and comparison tables are presented in this order: bridging, blocking, and post-tensioned blocking.

Bridging

The comparison of the bridged and unbraced results are presented in Tables 4-13 and 4-14. These tables show the first three resonant frequencies from the free-vibration and drop-weight tests, respectively. Also, the t-Test results of the bridged versus unbraced frequencies and separations are given in these tables.

Tables 4-13 and 4-14 show that the bridging had no significant effect on the first fundamental frequency for any of the floor or test conditions. The bridging mainly affected the magnitude of the second and third modes of vibration, as well as the separation between modes #1 and #2. Notice that bridging significantly affected the frequency and separation primarily for the S-S-S-S boundary condition. This is due to the support of the side joists in the S-S-S-S boundary condition allowing the additional stiffness due to the "truss" action of the bridging and plywood to have a more significant effect than that provided by the end-supported floors only.

Table 4-13:
Change in Magnitude and Separation of Average Resonant Frequencies
with Results of t-Tests
All Solid-Sawn Floors
Free-Vibration Tests
Bridging -vs- Unbraced.

CHANGE IN MAGNITUDE AND SEPARATION OF AVERAGE RESONANT FREQUENCIES - SOLID-SAWN FLOORS: BRIDGING -vs- UNBRACED

	FREE-VIBRATION TEST					
	S-S-S-S No Live Load			**S-S-S-S 960 kN/m^2**		
	UB (Hz)	**BR (Hz)**	**t-Test Result**	**UB (Hz)**	**BR (Hz)**	**t-Test Result**
MODE #1	15.8	16.1	N	8.6	8.6	N
		Separation—>	Y		**Separation—>**	Y
MODE #2	24.2	27.3	Y	11.9	13.3	Y
		Separation—>	N		**Separation—>**	Y
MODE #3	32.3	38.1	N	15.9	20.1	Y
	S-F-S-F No Live Load			**S-F-S-F 960 kN/m^2**		
	UB (Hz)	**BR (HZ)**	**t-Test Result**	**UB (Hz)**	**BR (Hz)**	**t-Test Result**
MODE #1	15.8	15.5	N	8.3	8.3	N
		Separation—>	N		**Separation—>**	N
MODE #2	21.5	22.7	N	10.4	11.1	N
		Separation—>	N		**Separation—>**	N
MODE #3	27.2	28.5	N	13.8	15.3	N

UB = unbraced floor condition
BR = bridged floor condition
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

Table 4-14:
Change in Magnitude and Separation of Average Resonant Frequencies
with Results of t-Tests
All Solid-Sawn Floors
Drop-Weight Tests
Bridging -vs- Unbraced.

CHANGE IN MAGNITUDE AND SEPARATION OF AVERAGE RESONANT FREQUENCIES-SOLID-SAWN FLOORS: BRIDGING -vs- UNBRACED

	DROP-WEIGHT TEST					
	S-S-S-S No Live Load			**S-S-S-S 960 kN/m^2**		
	UB (Hz)	**BR (Hz)**	**t-Test Result**	**UB (Hz)**	**BR (Hz)**	**t-Test Result**
Mode #1	13.5	14.1	N	8.2	8.4	N
		Separation—>	Y		**Separation—>**	Y
Mode #2	20.7	24.1	Y	11.3	12.8	N
		Separation—>	N		**Separation—>**	N
Mode #3	31.7	37.1	Y	15.6	19.0	Y
	S-F-S-F No Live Load			**S-F-S-F 960 kN/m^2**		
	UB (Hz)	**BR (Hz)**	**t-Test Result**	**UB (Hz)**	**BR (Hz)**	**t-Test Result**
Mode #1	13.2	14.0	N	8.0	8.1	N
		Separation—>	N		**Separation—>**	Y
Mode #2	19.3	20.5	N	10.2	11.5	Y
		Separation—>	N		**Separation—>**	N
Mode #3	29.6	30.0	N	14.0	15.7	N

UB = unbraced floor condition
BR = bridged floor condition
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

Blocking

The comparison of the blocked and unbraced results are presented in Tables 4-15 and 4-16. These tables show the first three resonant frequencies from the free-vibration and drop-weight tests, respectively. Also, the t-Test results of the blocked versus unbraced frequencies and separations are given in these tables.

The blocking did significantly raise the first fundamental frequency for the S-S-S-S boundary condition drop-weight tests, at both of the imposed load levels. The average increase was less than one Hertz for both floor conditions. Since this change was seen only in the drop-weight tests, it cannot be stated that blocking will consistently have this effect. It should also be noted that the coefficient of variation of the first fundamental frequency was also the lowest of any of the bracing systems. Therefore, the t-Test gave a significant difference for this mode of vibration.

As with the bridging, the blocking had a consistent effect on the modal separations and magnitudes of the higher modes of vibration. The blocking was, however, effective for both the S-S-S-S and S-F-S-F boundary conditions. This attests to the effectiveness of this type of bracing system.

Table 4-15:
Change in Magnitude and Separation of Average Resonant Frequencies
with Results of t-Tests
All Solid-Sawn Floors
Free-Vibration Tests
Blocking -vs- Unbraced.

CHANGE IN MAGNITUDE AND SEPARATION OF AVERAGE RESONANT FREQUENCIES - SOLID-SAWN FLOORS: BLOCKING -vs- UNBRACED

	FREE-VIBRATION TEST					
	S-S-S-S No Live Load			**S-S-S-S 960 kN/m^3**		
	UB (Hz)	**BL (Hz)**	**t-Test Result**	**UB (Hz)**	**BL (Hz)**	**t-Test Result**
MODE #1	15.8	15.9	N	8.6	9.2	N
		Separation--->	Y		**Separation--->**	N
MODE #2	24.2	27.1	Y	11.9	14.5	Y
		Separation--->	N		**Separation--->**	N
MODE #3	32.3	36.9	N	15.9	20.0	Y
	S-F-S-F No Live Load			**S-F-S-F 960 kN/m^3**		
	UB (Hz)	**BL (HZ)**	**t-Test Result**	**UB (Hz)**	**BL (Hz)**	**t-Test Result**
MODE #1	15.8	15.5	N	8.3	8.3	N
		Separation--->	N		**Separation--->**	Y
MODE #2	21.5	22.0	N	10.4	11.8	N
		Separation--->	N		**Separation--->**	N
MODE #3	27.2	30.3	N	13.8	17.8	N

UB = unbraced floor condition
BL = blocked floor condition
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

Table 4-16:
Change in Magnitude and Separation of Average Resonant Frequencies
with Results of t-Tests
All Solid-Sawn Floors
Drop-Weight Tests
Blocking -vs- Unbraced.

CHANGE IN MAGNITUDE AND SEPARATION OF AVERAGE RESONANT FREQUENCIES: SOLID-SAWN FLOORS: BLOCKING -vs- UNBRACED

	DROP-WEIGHT TEST					
	S-S-S-S No Live Load			**S-S-S-S 960 kN/m^2**		
	UB (Hz)	**BL (Hz)**	**t-Test Result**	**UB (Hz)**	**BL (Hz)**	**t-Test Result**
Mode #1	13.5	14.2	Y	8.2	8.7	Y
		Separation—>	Y		**Separation—>**	Y
Mode #2	20.7	25.1	Y	11.3	14.3	Y
		Separation—>	N		**Separation—>**	N
Mode #3	31.7	36.7	N	15.6	19.9	Y
	S-F-S-F No Live Load			**S-F-S-F 960 kN/m^2**		
	UB (Hz)	**BL (Hz)**	**t-Test Result**	**UB (Hz)**	**BL (Hz)**	**t-Test Result**
Mode #1	13.2	13.9	N	8.0	8.3	N
		Separation—>	N		**Separation—>**	N
Mode #2	19.3	20.7	Y	10.2	11.4	Y
		Separation—>	N		**Separation—>**	Y
Mode #3	29.6	31.4	N	14.0	16.9	Y

UB = unbraced floor condition
BL = blocked floor condition
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

Post-Tensioned Blocking

The comparison of the post-tensioned blocking and unbraced results are presented in Tables 4-17, and 4-18. Recall that two levels of post-tensioning were used: 13.3 and 22.2 kN (3 and 5 kips). These tables show the first three resonant frequencies from the free-vibration and drop-weight tests, respectively. Also, the t-Test results of the post-tensioned blocking versus unbraced frequencies and separations are given in these tables.

The post-tensioned blocking had no significant effect on the first fundamental frequency for either post-tension level. This is, in part, due to the higher variances, as shown by the higher coefficient of variation, for some of the tests. Had a greater number of test specimens been built, the effect of this bracing system on the first fundamental frequency would be able to be quantified better.

The post-tensioned blocking consistently effected the separation and magnitudes of the higher modes of vibration. As with the blocking, the post-tensioned blocking was effective for both S-S-S-S, and S-F-S-F boundary conditions.

Table 4-17:
Change in Magnitude and Separation of Average Resonant Frequencies with Results of t-Tests: Solid-Sawn Floors: Free-Vibration Tests Post-Tensioned Blocking -vs- Unbraced.

	13.3 kN POST-TENSIONED BLOCKING -vs- UNBRACED FLOOR					
	S-S-S-S No Live Load			**S-S-S-S 960 kN/m²**		
	UB (Hz)	**PT3 (Hz)**	**t-Test Result**	**UB (Hz)**	**PT3 (Hz)**	**t-Test Result**
MODE #1	15.8	16.0	N	8.6	8.7	N
	Separation—>		Y	**Separation—>**		Y
MODE #2	24.2	27.2	Y	11.9	14.7	Y
	Separation—>		N	**Separation—>**		Y
MODE #3	32.3	38.8	Y	15.9	20.3	Y
	S-F-S-F No Live Load			**S-F-S-F 960 kN/m²**		
	UB (Hz)	**PT3 (HZ)**	**t-Test Result**	**UB (Hz)**	**PT3 (Hz)**	**t-Test Result**
MODE #1	15.8	15.4	N	8.3	8.3	N
	Separation—>		Y	**Separation—>**		N
MODE #2	21.5	23.0	Y	10.4	13.1	N
	Separation—>		N	**Separation—>**		N
MODE #3	27.2	30.3	N	13.8	17.5	N
	22.2 kN POST-TENSIONED BLOCKING -vs- UNBRACED FLOOR					
	S-S-S-S No Live Load			**S-S-S-S 960 kN/m²**		
	UB (Hz)	**PT5 (HZ)**	**t-Test Result**	**UB (Hz)**	**PT5 (Hz)**	**t-Test Result**
MODE #1	15.8	15.9	N	8.6	9.2	N
	Separation—>		Y	**Separation—>**		N
MODE #2	24.2	27.3	Y	11.9	14.7	Y
	Separation—>		N	**Separation—>**		N
MODE #3	32.3	35.2	N	15.9	20.3	Y
	UB (Hz)	**PT5 (HZ)**	**t-Test Result**	**UB (Hz)**	**PT5 (Hz)**	**t-Test Result**
MODE #1	15.8	15.2	N	8.3	8.3	N
	Separation—>		Y	**Separation—>**		Y
MODE #2	21.5	23.8	Y	10.4	14.8	N
	Separation—>		N	**Separation—>**		N
MODE #3	27.2	32.2	N	13.8	19.3	N

UB = unbraced floor condition
PT3 = post-tensioned blocking, 13.3 kN (3 kip) post-tension force
PT5 = post-tensioned blocking, 22.2 kN (5 kip) post-tension force
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

Table 4-18:
Change in Magnitude and Separation of Average Resonant Frequencies with Results of t-Tests: Solid-Sawn Floors: Drop-Weight Tests Post-Tensioned Blocking -vs- Unbraced.

DROP-WEIGHT TEST						
	13.3 kN POST-TENSIONED BLOCKING -vs- UNBRACED					
	S-S-S-S No Live Load			**S-S-S-S 960 kN/m^2**		
	UB (Hz)	**PT3 (Hz)**	**t-Test Result**	**UB (Hz)**	**PT3 (Hz)**	**t-Test Result**
Mode #1	13.5	13.9	N	8.2	8.6	N
		Separation—>	Y		Separation—>	Y
Mode #2	20.7	24.9	Y	11.3	14.2	Y
		Separation—>	N		Separation—>	N
Mode #3	31.7	37.4	Y	15.6	19.9	Y
	S-F-S-F No Live Load			**S-F-S-F 960 kN/m^2**		
	UB (Hz)	**PT3 (Hz)**	**t-Test Result**	**UB (Hz)**	**PT3 (Hz)**	**t-Test Result**
Mode #1	13.2	13.8	N	8.0	8.4	N
		Separation—>	Y		Separation—>	Y
Mode #2	19.3	21.6	Y	10.2	11.5	Y
		Separation—>	N		Separation—>	N
Mode #3	29.6	31.5	N	14.0	15.9	N
	22.2 kN POST-TENSIONED BLOCKING -vs- UNBRACED					
	S-S-S-S No Live Load			**S-S-S-S 960 kN/m^2**		
	UB (Hz)	**PT5 (Hz)**	**t-Test Result**	**UB (Hz)**	**PT5 (Hz)**	**t-Test Result**
Mode #1	13.5	14.1	N	8.2	8.4	N
		Separation—>	Y		Separation—>	Y
Mode #2	20.7	24.9	Y	11.3	14.4	Y
		Separation—>	N		Separation—>	N
Mode #3	31.7	36.2	N	15.6	20.8	Y
	S-F-S-F No Live Load			**S-F-S-F 960 kN/m^2**		
	UB (Hz)	**PT5 (Hz)**	**t-Test Result**	**UB (Hz)**	**PT5 (Hz)**	**t-Test Result**
Mode #1	13.2	13.9	N	8.0	8.6	N
		Separation—>	Y		Separation—>	N
Mode #2	19.3	22.4	Y	10.2	12.4	N
		Separation—>	N		Separation—>	N
Mode #3	29.6	34.6	N	14.0	16.8	N

UB = unbraced floor condition
PT3 = post-tensioned blocking, 13.3 kN (3 kip) post-tension force
PT5 = post-tensioned blocking, 22.2 kN (5 kip) post-tension force
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

4.3.1.3 Modal and Logarithmic Damping Ratio Results

Tables 4-19 and 4-20 give an example of typical results for the modal and logarithmic damping ratios for solid-sawn floor SS-2. As explained in Chapter 3, the modal damping ratios are calculated from the power spectrum peaks, while the log decrement values are calculated from the filtered and calibrated acceleration traces. The damping values are given as percent of critical damping. Where "N/A" is shown in the table, the parameter in question was negligible and therefore was not calculated.

The mean values for modal and logarithmic damping ratios of the solid-sawn floors are presented. Tables 4-21 and 4-22 present these results for all boundary, load, and bracing conditions. Note that the coefficients of variation are, on average, higher than those seen for the modal frequencies. The large variance in the logarithmic decrement damping ratios is partially due to the non-logarithmic shape of some of the time-acceleration traces, and partially due to the subjective nature of the peak amplitude selections from the traces. Also, the data is in a discrete form and not a continuous function, therefore some of the true peak values fall between data points. In these cases, one or the other adjacent data points was chosen as the peak amplitude.

The variation in the modal damping ratios is partly due to the assumptions made when using this type of damping calculation. It is also due to the subjective nature of the selection of discrete data points for the calculation of this type of damping ratio.

Table 4-19:
Typical Modal and Logarithmic Damping Ratios
Floor SS-2
Free-Vibration Tests.

TYPICAL MODAL AND LOG DECREMENT DAMPING RATIOS -								
	FREE-VIBRATION TEST							
TYPE OF BRACE	MODE 1 (% Crit.)	MODE 2 (% Crit.)	MODE 3 (% Crit.)	LOG DEC (% Crit.)	MODE 1 (% Crit.)	MODE 2 (% Crit.)	MODE 3 (% Crit.)	LOG DEC (% Crit.)
	S-S-S-S No Live Load				S-S-S-S 960 KN/m^2			
UB	4.1	1.9	3.0	4.2	3.5	1.6	1.4	4.5
BR	3.9	1.7	1.2	4.3	4.1	4.3	2.9	3.8
BL	4.6	2.3	0.8	3.1	2.6	1.5	N/A	4.7
PT3	4.9	1.5	1.2	4.2	2.8	3.9	N/A	3.6
PT5	5.8	2.1	N/A	4.5	3.1	2.6	4.1	4.8
	S-F-S-F No Live Load				S-F-S-F 960 KN/m^2			
UB	3.5	1.9	1.7	5.0	3.1	4.6	1.3	3.7
BR	3.1	1.8	2.8	3.6	3.1	3.9	5.7	3.9
BL	3.8	2.2	2.6	3.1	3.3	4.8	2.2	3.3
PT3	3.8	2.2	N/A	3.7	3.6	1.3	N/A	4.3
PT5	6.3	4.5	2.8	4.3	2.9	3.2	N/A	3.5

UB = unbraced floor condition
BR = bridged floor condition
BL = solid-blocked floor condition
PT3 = post-tensioned blocking, 13.3 kN (3 kip) post-tension force
PT5 = post-tensioned blocking, 22.2 kN (5 kip) post-tension force
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = modal damping ratio (in percent critical damping)
LOG DEC = percent critical logarithmic damping ratio
N/A = no significant mode present

Table 4-20:
Typical Modal and Logarithmic Damping
Floor SS-2
Drop-Weight Tests.

TYPICAL MODAL AND LOG DECREMENT DAMPING RATIOS -								
	DROP-WEIGHT TEST							
Type of Brace	**MODE 1 (% Crit.)**	**MODE 2 (% Crit.)**	**MODE 3 (% Crit.)**	**LOG DEC (% Crit.)**	**MODE 1 (% Crit.)**	**MODE 2 (% Crit.)**	**MODE 3 (% Crit.)**	**LOG DEC (% Crit.)**
	S-S-S-S No Live Load				S-S-S-S 960 KN/m^2			
UB	2.4	1.7	1.3	3.4	3.0	2.3	1.4	3.5
BR	5.7	2.3	2.4	4.2	3.5	2.7	N/A	3.9
BL	3.8	1.4	1.5	4.3	2.6	1.6	N/A	4.1
PT3	4.8	1.4	0.7	4.4	2.7	2.3	N/A	3.4
PT5	6.4	1.3	0.8	4.2	2.7	1.8	N/A	4.4
	S-F-S-F No Live Load				S-F-S-F 960 KN/m^2			
UB	2.0	2.0	3.0	3.3	3.6	2.2	1.7	4.1
BR	3.7	2.1	2.0	4.8	3.1	2.1	3.2	3.6
BL	2.6	2.5	1.3	3.2	2.6	6.7	3.6	4.4
PT3	2.3	2.2	3.1	4.2	2.7	5.6	N/A	3.3
PT5	2.6	1.7	1.2	3.5	3.3	4.3	3.4	4.5

UB = unbraced floor condition
BR = bridged floor condition
BL = solid-blocked floor condition
PT3 = post-tensioned blocking, 13.3 kN (3 kip) post-tension force
PT5 = post-tensioned blocking, 22.2 kN (5 kip) post-tension force
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = modal damping ratio (in percent critical damping)
LOG DEC = percent critical logarithmic damping ratio
N/A = no significant mode present

Table 4-21:
Average Damping Ratios For All Solid-Sawn Floors
Free-Vibration Tests.

	FREE-VIBRATION TEST							
Type of Brace	**MODE 1 (% Crit.)**	**MODE 2 (% Crit.)**	**MODE 3 (% Crit.)**	**LOG DEC (%Crit.)**	**MODE 1 (% Crit.)**	**MODE 2 (% Crit.)**	**MODE 3 (% Crit.)**	**LOG DEC (% Crit.)**
	S-S-S-S No Live Load				**S-S-S-S 960 KN/m²**			
UB	**3.5**	**2.0**	**2.3**	**4.4**	**3.4**	**1.8**	**1.4**	**4.6**
(%COV)	(12.6)	(14.0)	(37.6)	(18.3)	(10.7)	(14.3)	(9.5)	(21.8)
BR	**4.5**	**3.3**	**1.2**	**4.4**	**3.5**	**4.6**	**6.5**	**4.4**
(%COV)	(32.2)	(45.5)	(N/A)	(2.1)	(15.0)	(10.3)	(48.1)	(18.9)
BL	**4.3**	**2.1**	**1.5**	**4.6**	**5.3**	**2.9**	**5.7**	**4.3**
(%COV)	(5.6)	(24.2)	(41.2)	(32.3)	(50.7)	(50.8)	(67.8)	(14.7)
PT3	**4.1**	**1.8**	**1.5**	**4.5**	**4.3**	**3.8**	**4.4**	**4.3**
(%COV)	(15.8)	(24.1)	(24.9)	(13.2)	(29.4)	(21.9)	(76.6)	(14.3)
PT5	**3.6**	**1.7**	**0.6**	**4.9**	**5.0**	**2.8**	**2.9**	**4.1**
(%COV)	(53.9)	(26.6)	(70.7)	(8.8)	(35.1)	(29.8)	(47.4)	(16.1)
	S-F-S-F No Live Load				**S-F-S-F 960 KN/m²**			
UB	**3.6**	**2.1**	**1.4**	**3.8**	**3.2**	**4.2**	**2.1**	**3.9**
(%COV)	(10.8)	(19.4)	(18.7)	(21.0)	(14.1)	(34.5)	(46.7)	(32.7)
BR	**4.0**	**3.3**	**2.7**	**4.2**	**3.2**	**4.4**	**4.7**	**3.8**
(%COV)	(18.1)	(31.9)	(18.2)	(17.8)	(46.3)	(40.6)	(22.1)	(52.0)
BL	**4.5**	**3.0**	**2.8**	**4.2**	**6.2**	**6.4**	**3.7**	**4.9**
(%COV)	(36.3)	(34.3)	(24.3)	(21.3)	(51.0)	(61.0)	(37.1)	(32.1)
PT3	**4.4**	**2.5**	**2.9**	**4.5**	**4.8**	**2.1**	**1.8**	**5.2**
(%COV)	(12.0)	(13.0)	(34.4)	(24.0)	(29.5)	(41.5)	(51.3)	(34.5)
PT5	**5.2**	**4.6**	**4.3**	**4.3**	**8.7**	**2.4**	**1.6**	**3.9**
(%COV)	(20.6)	(17.6)	(82.6)	(0.94)	(104.8)	(39.5)	(11.4)	(30.1)

UB = unbraced floor condition
BR = bridged floor condition
BL = solid-blocked floor condition
PT3 = post-tensioned blocking, 13.3 kN (3 kip) post-tension force
PT5 = post-tensioned blocking, 22.2 kN (5 kip) post-tension force
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
MODE _ = average modal damping ratio (percent critical damping)
LOG DEC = percent critical logarithmic decrement damping ratio
(% COV) = coefficient of variation for all four solid sawn floors
N/A = insufficient data for calculation of coefficient of variation

Table 4-22:
Average Damping Ratios For All Solid-Sawn Floors
Drop-Weight Tests.

	DROP-WEIGHT TEST							
Type of Brace	**MODE 1**	**MODE 2**	**MODE 3**	**LOG DEC.**	**MODE 1**	**MODE 2**	**MODE 3**	**LOG DEC.**
	S-S-S-S No Live Load				**S-S-S-S 960 KN/m^2**			
UB	**3.4**	**1.7**	**1.5**	**4.3**	**2.9**	**2.5**	**1.5**	**4.9**
(%COV)	(23.5)	(18.1)	(21.4)	(26.8)	(22.6)	(21.1)	(5.1)	(47.7)
BR	**4.1**	**4.2**	**1.8**	**4.5**	**2.8**	**4.1**	**4.6**	**3.9**
(%COV)	(31.3)	(43.6)	(70.2)	(13.9)	(15.0)	(30.6)	(32.2)	(10.9)
BL	**3.5**	**2.0**	**1.2**	**4.4**	**3.0**	**2.5**	**2.1**	**4.5**
(%COV)	(17.9)	(24.8)	(72.3)	(13.9)	(11.2)	(48.2)	(35.7)	(17.8)
PT3	**3.6**	**2.2**	**0.93**	**4.1**	**3.5**	**3.1**	**2.2**	**3.6**
(%COV)	(27.2)	(37.8)	(80.2)	(16.8)	(34.0)	(38.7)	(35.6)	(11.1)
PT5	**4.2**	**1.8**	**1.7**	**4.1**	**5.3**	**2.4**	**1.4**	**4.9**
(%COV)	(45.7)	(23.5)	(47.5)	(5.7)	(57.2)	(33.0)	(12.0)	(16.7)
	S-F-S-F No Live Load				**S-F-S-F 960 KN/m^2**			
UB	**2.5**	**2.0**	**2.6**	**3.9**	**3.3**	**2.8**	**2.3**	**4.6**
(%COV)	(17.7)	(29.6)	(16.0)	(19.3)	(24.4)	(34.1)	(61.2)	(20.8)
BR	**3.2**	**3.1**	**1.4**	**5.2**	**3.3**	**3.0**	**2.9**	**4.0**
(%COV)	(15.6)	(29.5)	(67.8)	(26.0)	(33.2)	(20.7)	(17.5)	(11.0)
BL	**3.5**	**3.4**	**1.7**	**4.6**	**2.8**	**3.5**	**2.9**	**4.7**
(%COV)	(25.7)	(47.2)	(45.5)	(45.8)	(17.8)	(61.7)	(26.9)	(32.7)
PT3	**3.0**	**2.4**	**1.5**	**3.8**	**3.4**	**3.2**	**2.0**	**4.2**
(%COV)	(25.6)	(21.3)	(88.3)	(8.6)	(27.2)	(52.8)	(17.3)	(26.1)
PT5	**3.1**	**2.2**	**1.4**	**3.7**	**3.3**	**2.8**	**2.2**	**3.5**
(%COV)	(30.2)	(32.6)	(51.8)	(5.6)	(26.2)	(50.2)	(43.9)	(24.6)

UB = unbraced floor condition
BR = bridged floor condition
BL = solid-blocked floor condition
PT3 = post-tensioned blocking, 13.3 kN (3 kip) post-tension force
PT5 = post-tensioned blocking, 22.2 kN (5 kip) post-tension force
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
MODE _ = average modal damping ratio (percent critical damping)
LOG DEC = percent critical logarithmic decrement damping ratio
(% COV) = coefficient of variation for all four solid sawn floors
N/A = insufficient data for calculation of coefficient of variation

4.3.1.4 Discussion of Modal and Logarithmic Damping Ratio Results

As with the modal frequency results, a comparison table using the average damping ratio results is used for comparing each type of bracing versus unbraced floors. It must be stressed that the variance of the data used to calculate the means affects the outcome of the t-Test results. Though there appears to be a sizeable change between a braced and an unbraced damping ratio, if one or both of the damping ratios has a large coefficient of variation, the t-Test does not show a significant difference. Comparison tables and discussion are presented separately for each type of bracing system.

Bridging

Tables 4-23 and 4-24 present comparisons of the bridged versus unbraced free-vibration and drop-weight average damping ratios respectively. The t-Test results show that the bridging significantly raised the damping ratios on four occasions, all for the free-vibration tests. This is in part due to the difference between the magnitudes of vibration between the free-vibration and drop-weight tests. When free-vibration was induced in the floor systems, the resulting vibration was more violent than in the drop-weight tests.

The modal damping ratio of the second and third modes of vibration were significantly raised for the S-S-S-S boundary condition at the 960 kN/m^2 (20 psf) imposed load level. The modal damping for the third mode of vibration was significantly raised for the S-F-S-F boundary condition at both imposed load levels. Since the second and

Table 4-23:
Comparison of Bridged -vs- Unbraced Average Damping Ratios
Solid-Sawn Floors
Free-Vibration Tests.

COMPARISON OF AVERAGE DAMPING RATIOS SOLID SAWN FLOOR BRIDGING -vs- UNBRACED						
	FREE-VIBRATION TEST					
	S-S-S-S No Live Load			S-S-S-S 960 kN/m^2		
	UB (% Crit.)	BR (% Crit.)	t-Test Result	UB (% Crit.)	BR (% Crit.)	t-Test Result
Mode #1	3.5	4.5	N	3.4	3.5	N
Mode #2	2.0	3.3	N	1.8	4.6	Y
Mode #3	2.3	1.2	N/A	1.4	6.5	Y
Log. Dec.	4.4	4.4	N	4.6	4.4	N
	S-F-S-F No Live Load			S-F-S-F 960 kN/m^2		
	UB (% Crit.)	BR (% Crit.)	t-Test Result	UB (% Crit.)	BR (% Crit.)	t-Test Result
Mode #1	3.6	4.0	N	3.2	3.2	N
Mode #2	2.1	3.3	N	4.2	4.4	N
Mode #3	1.4	2.7	Y	2.1	4.7	Y
Log. Dec.	3.8	4.2	N	3.9	3.8	N

UB = unbraced floor condition

BR = bridged floor condition

t-Test Result = test for significant difference at 95% confidence level

S-S-S-S = four-sided floor support

S-F-S-F = end supported only floor support

Mode #_ = modal damping ratio from average value table (percent critical)

Log. Dec. = average percent critical logarithmic decrement damping ratio

N/A = insufficient number of data points for comparison

Table 4-24:
Comparison of Bridged -vs- Unbraced Average Damping Ratios
Solid-Sawn Floors
Drop-Weight Tests.

COMPARISON OF AVERAGE DAMPING RATIOS SOLID SAWN FLOOR BRIDGING -vs- UNBRACED

	DROP-WEIGHT TEST					
	S-S-S-S No Live Load			**S-S-S-S 960 kN/m²**		
	UB (% Crit.)	**BR (% Crit.)**	**t-Test Result**	**UB (% Crit.)**	**BR (% Crit.)**	**t-Test Result**
Mode #1	3.4	4.1	N	2.9	2.8	N
Mode #2	1.7	4.2	N	2.5	4.1	N
Mode #3	1.5	1.8	N	1.5	4.6	N
Log. Dec.	4.3	4.5	N	4.9	3.9	N
	S-F-S-F No Live Load			**S-F-S-F 960 kN/m²**		
	UB (% Crit.)	**BR (% Crit.)**	**t-Test Result**	**UB (% Crit.)**	**BR (% Crit.)**	**t-Test Result**
Mode #1	2.5	3.2	N	3.3	3.3	N
Mode #2	2.0	3.1	N	2.8	3.0	N
Mode #3	2.6	1.4	N	2.3	2.9	N
Log. Dec.	3.9	5.2	N	4.6	4.0	N

UB = unbraced floor condition

BR = bridged floor condition

t-Test Result = test for significant difference at 95% confidence level

S-S-S-S = four-sided floor support

S-F-S-F = end supported only floor support

Mode #_ = modal damping ratio from average value table (percent critical)

Log. Dec. = average percent critical logarithmic decrement damping ratio

N/A = insufficient number of data points for comparison

third modes of vibration do not effect the perception of the floor vibration as much as the fundamental mode, a change in these modes of vibration would not be as beneficial for the floor performance as a change in the first mode of vibration would be. Bridging provided the largest number of significant changes in the damping ratios out of all the bracing systems, in part due to the type of connection used to install the bridging.

Blocking

Tables 4-25 and 4-26 show the comparison of the average blocking versus unbraced damping ratios. Table 4-25 shows that the blocking significantly raised the damping ratio of mode #1 for the S-S-S-S boundary condition with no imposed load. This value of modal damping had a very low coefficient of variation and therefore could be said to be significantly different from the unbraced value. However, this was the only occurrence of a significant change for this bracing system. It therefore cannot be said that blocking will significantly effect the damping characteristics of any of the floor systems.

Table 4-25:
Comparison of Blocked -vs- Unbraced Average Damping Ratios
Solid-Sawn Floors
Free-Vibration Tests

COMPARISON OF AVERAGE DAMPING RATIOS SOLID SAWN FLOOR BLOCKING -vs- UNBRACED						
	FREE-VIBRATION TEST					
	S-S-S-S No Live Load			S-S-S-S 960 kN/m^2		
	UB (% Crit.)	BL (% Crit.)	t-Test Result	UB (% Crit.)	BL (% Crit.)	t-Test Result
Mode #1	3.5	4.3	Y	3.4	5.3	N
Mode #2	2.0	2.1	N	1.8	2.9	N
Mode #3	2.3	1.5	N	1.4	5.7	N
Log. Dec.	4.4	4.6	N	4.6	4.3	N
	S-F-S-F No Live Load			S-F-S-F 960 kN/m^2		
	UB (% Crit.)	BL (% Crit.)	t-Test Result	UB (% Crit.)	BL (% Crit.)	t-Test Result
Mode #1	3.6	4.5	N	3.2	6.2	N
Mode #2	2.1	3.0	N	4.2	6.4	N
Mode #3	1.4	2.8	N	2.1	3.7	N
Log. Dec.	3.8	4.2	N	3.9	4.9	N

UB = unbraced floor condition

BL = blocked floor condition

t-Test Result = test for significant difference at 95% confidence level

S-S-S-S = four-sided floor support

S-F-S-F = end supported only floor support

Mode #_ = modal damping ratio from average value table (percent critical)

Log. Dec. = average percent critical logarithmic decrement damping ratio

Table 4-26:
Comparison of Blocked -vs- Unbraced Average Damping Ratios
Solid-Sawn Floors
Drop-Weight Tests.

COMPARISON OF AVERAGE DAMPING RATIOS SOLID SAWN FLOOR BLOCKING -vs- UNBRACED						
	DROP-WEIGHT TEST					
	S-S-S-S No Live Load			**S-S-S-S 960 kN/m^2**		
	UB (% Crit.)	**BL (% Crit.)**	**t-Test Result**	**UB (% Crit.)**	**BL (% Crit.)**	**t-Test Result**
Mode #1	3.4	3.5	N	2.9	3.0	N
Mode #2	1.7	2.0	N	2.5	2.5	N
Mode #3	1.5	1.2	N	1.5	2.1	N
Log. Dec.	4.3	4.4	N	4.9	4.5	N
	S-F-S-F No Live Load			**S-F-S-F 960 kN/m^2**		
	UB (% Crit.)	**BL (% Crit.)**	**t-Test Result**	**UB (% Crit.)**	**BL (% Crit.)**	**t-Test Result**
Mode #1	2.5	3.5	N	3.3	2.8	N
Mode #2	2.0	3.4	N	2.8	3.5	N
Mode #3	2.6	1.7	N	2.3	2.9	N
Log. Dec.	3.9	4.6	N	4.6	4.7	N

UB = unbraced floor condition

BL = blocked floor condition

t-Test Result = test for significant difference at 95% confidence level

S-S-S-S = four-sided floor support

S-F-S-F = end supported only floor support

Mode #_ = modal damping ratio from average value table (percent critical)

Log. Dec. = average percent critical logarithmic decrement damping ratio

Post-Tensioned Blocking

Tables 4-27 and 4-28 show the comparison of average damping ratio results from both levels of post-tensioned blocking versus the average unbraced damping ratios. These tables show that the post-tensioned blocking had no consistent effect on any of the damping ratios. There were only three significant changes in average damping due to post-tensioned blocking. Two of these significant changes occurred in the free-vibration testing, and one occurred in the drop-weight tests. Due to the inconsistency of the results it cannot be said that post-tensioning of the blocking had any effect on the modal or logarithmic damping ratios.

Table 4-27:
Comparison of Post-Tensioned Blocking -vs- Unbraced Average Damping Ratios At 13.3 kN and 22.2 kN Post-Tension Levels Solid-Sawn Floors: Free-Vibration Tests.

	13.3 kN POST-TENSIONED BLOCKING -vs- UNBRACED					
	S-S-S-S No Live Load			**S-S-S-S 960 kN/m^2**		
	UB (% Crit.)	**PT3 (% Crit.)**	**t-Test Result**	**UB (% Crit.)**	**PT3 (% Crit.)**	**t-Test Result**
Mode #1	3.5	4.1	N	3.4	4.3	N
Mode #2	2.0	1.8	N	1.8	3.8	Y
Mode #3	2.3	1.5	N	1.4	4.4	N
Log. Dec.	4.4	4.5	N	4.6	4.3	N
	S-F-S-F No Live Load			**S-F-S-F 960 kN/m^2**		
	UB (% Crit.)	**PT3 (% Crit.)**	**t-Test Result**	**UB (% Crit.)**	**PT3 (% Crit.)**	**t-Test Result**
Mode #1	3.6	4.4	N	3.2	4.8	N
Mode #2	2.1	2.5	N	4.2	2.1	N
Mode #3	1.4	2.9	N	2.1	1.8	N/A
Log. Dec.	3.8	4.5	N	3.9	5.2	N
	22.2 kN POST-TENSIONED BLOCKING -vs- UNBRACED					
	S-S-S-S No Live Load			**S-S-S-S 960 kN/m^2**		
	UB (% Crit.)	**PT5 (% Crit.)**	**t-Test Result**	**UB (% Crit.)**	**PT5 (% Crit.)**	**t-Test Result**
Mode #1	3.5	3.6	N	3.4	5.0	N
Mode #2	2.0	1.7	N	1.8	2.8	N
Mode #3	2.3	0.6	N/A	1.4	2.9	N
Log. Dec.	4.4	4.9	N	4.6	4.1	N
	S-F-S-F No Live Load			**S-F-S-F 960 kN/m^2**		
	UB (% Crit.)	**PT5 (% Crit.)**	**t-Test Result**	**UB (% Crit.)**	**PT5 (% Crit.)**	**t-Test Result**
Mode #1	3.6	5.2	N	3.2	8.7	N
Mode #2	2.1	4.6	Y	4.2	2.4	N
Mode #3	1.4	4.3	N	2.1	1.6	N/A
Log. Dec.	3.8	4.3	N	3.9	3.9	N

UB = unbraced floor condition
PT3 = 13.3 kN Post-Tensioned Blocking condition
PT5 = 22.2 kN Post-Tensioned Blocking condition
t-Test Result = test for significant difference at 95% confidence level
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = modal damping ratio from average value table (percent critical)
LOG DEC = average percent critical logarithmic decrement damping ratio
N/A = insufficient number of data points for comparison

Table 4-28:
Comparison of Post-Tensioned Blocking -vs- Unbraced Average Damping Ratios
At 13.3 kN and 22.2 kN Post-Tension Levels
Solid-Sawn Floors: Drop-Weight Tests.

	13.3 kN POST-TENSIONED BLOCKING -vs- UNBRACED					
	S-S-S-S No Live Load			**S-S-S-S 960 kN/m^2**		
	UB (% Crit.)	**PT3 (% Crit.)**	**t-Test Result**	**UB (% Crit.)**	**PT3 (% Crit.)**	**t-Test Result**
Mode #1	3.4	3.6	N	2.9	3.5	N
Mode #2	1.7	2.2	N	2.5	3.1	N
Mode #3	1.5	0.93	N	1.5	2.2	N
Log. Dec.	4.3	4.1	N	4.9	3.6	N
	S-F-S-F No Live Load			**S-F-S-F 960 kN/m^2**		
	UB (% Crit.)	**PT3 (% Crit.)**	**t-Test Result**	**UB (% Crit.)**	**PT3 (% Crit.)**	**t-Test Result**
Mode #1	2.5	3.0	N	3.3	3.4	N
Mode #2	2.0	2.4	N	2.8	3.2	N
Mode #3	2.6	1.5	N	2.3	2.0	N
Log. Dec.	3.9	3.8	N	4.6	4.2	N
	22.2 kN POST-TENSIONED BLOCKING -vs- UNBRACED					
	S-S-S-S No Live Load			**S-S-S-S 960 kN/m^2**		
	UB (% Crit.)	**PT5 (% Crit.)**	**t-Test Result**	**UB (% Crit.)**	**PT5 (% Crit.)**	**t-Test Result**
Mode #1	3.4	4.2	N	2.9	5.3	N
Mode #2	1.7	1.8	N	2.5	2.4	N
Mode #3	1.5	1.7	N	1.5	1.4	N
Log. Dec.	4.3	4.1	N	4.9	4.9	N
	S-F-S-F No Live Load			**S-F-S-F 960 kN/m^2**		
	UB (% Crit.)	**PT5 (% Crit.)**	**t-Test Result**	**UB (% Crit.)**	**PT5 (% Crit.)**	**t-Test Result**
Mode #1	2.5	3.1	N	3.3	3.3	N
Mode #2	2.0	2.2	N	2.8	2.8	N
Mode #3	2.6	1.4	Y	2.3	2.2	N
Log. Dec.	3.9	3.7	N	4.6	3.5	N

UB = unbraced floor condition
PT3 = 13.3 kN Post-Tensioned Blocking condition
PT5 = 22.2 kN Post-Tensioned Blocking condition
t-Test Result = test for significant difference at 95% confidence level
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = modal damping ratio from average value table (percent critical)
LOG DEC = average percent critical logarithmic decrement damping ratio
N/A = insufficient number of data points for comparison

4.3.2 Truss Floor Dynamic Results

Dynamic tests were performed on the same bracing systems that were used in the static truss floor tests: UB, BCB, XB, SBB, XB+BCB, and SBB+BCB. Note that the combinations of XB+BCB and SBB+BCB were further abbreviated to XB+BB and SB+BB in the tables in this section to conserve column space. The same two floor boundary conditions and dynamic floor loadings were used as in the solid-sawn floor tests, however, three, instead of two, imposed load levels were used: 0, 960, and 1915 KN/m^2 (0, 20, and 40 psf). The truss floors were tested at the additional imposed level of 1915 KN/m^2 (40 psf) since the trusses were specifically designed for this live load.

4.3.2.1 Resonant Frequency Results

Results from a typical truss floor, TR-1, are presented in Tables 4-33 and 4-34. As for the solid-sawn floor results, the differences between free-vibration and drop-weight frequencies for the same boundary and load conditions can be seen. As stated earlier, this difference is in part due to the higher excitation in the free-vibration test, causing a greater influence from the steel test frame. This difference between frequency decreases, as the imposed load level increases. This is partially due to the effect of the added mass, which lowers the floor frequencies below that of the resonant frequency of the steel test-frame.

Table 4-29:
Typical Truss Floor Resonant Frequencies
Free-Vibration Tests
Floor TR-1.

TYPICAL RESONANT FREQUENCY RESPONSE - FLOOR TR-1												
	FREE-VIBRATION TEST											
Type of Brace	**Mode #1 (Hz)**	**Mode #2 (Hz)**	**Mode #3 (Hz)**	**Mode #4 (Hz)**	**Mode #1 (Hz)**	**Mode #2 (Hz)**	**Mode #3 (Hz)**	**Mode #4 (Hz)**	**Mode #1 (Hz)**	**Mode #2 (Hz)**	**Mode #3 (Hz)**	**Mode #4 (Hz)**
	S-S-S-S No Live Load				**S-S-S-S 960 KN/m^2**				**S-S-S-S 1915 KN/m^2**			
UB	17	24.7	33.3	36.3	9	12.3	14.7	21.3	6.3	9.3	12.7	18.3
BCB	17.3	27	38	42.3	9	13	13.3	25.3	6	10	14.3	19.3
XB	17.3	25.7	33.7	37.7	9	13	18.3	24.3	6.3	9.3	13.7	19
SBB	17.3	31	38.7	N/A	9	15.3	22	N/A	6.3	8.7	11.7	16
XB+BB	17.3	28	38.7	44.7	9.3	14.3	20.3	26	7	9.3	14	20
SB+BB	17.3	28.7	31.3	39	9.3	16	22.3	28.3	6.7	12	15.3	19.7
	S-F-S-F No Live Load				**S-F-S-F 960 KN/m^2**				**S-F-S-F 1915 KN/m^2**			
UB	17	23	28	35	8.7	11.3	13.7	15.7	6.3	8.7	10.7	14.3
BCB	17	24.3	32.3	37.7	9	12	15.7	21.3	6.7	7.7	10.7	12
XB	17	24.3	30	38.7	8.7	11.7	14.7	20.3	6.3	8.7	11.3	14.7
SBB	17	25.3	29.3	37.7	9	13	18.3	N/A	6.7	9.7	18.7	N/A
XB+BB	17	25	34.3	37.7	9.3	12	16.7	26	6.7	9	12.3	17
SB+BB	17	25.7	28.7	39.3	10	12.7	14.7	17.7	6.3	10	14.3	19

See Note on page 113.

Table 4-30:
Typical Truss Floor Resonant Frequencies
Drop-Weight Test
Floor TR-1.

TYPICAL RESONANT FREQUENCY RESPONSE - FLOOR TR-1												
	DROP WEIGHT TEST											
Type of Brace	Mode #1 (Hz)	Mode #2 (Hz)	Mode #3 (Hz)	Mode #4 (Hz)	Mode #1 (Hz)	Mode #2 (Hz)	Mode #3 (Hz)	Mode #4 (Hz)	Mode #1 (Hz)	Mode #2 (Hz)	Mode #3 (Hz)	Mode #4 (Hz)
	S-S-S-S No Live Load				S-S-S-S 960 KN/m^2				S-S-S-S 1915 kN/m^2			
UB	14	21.7	23	26.3	8.7	12	16.3	22.3	6.3	9.0	12.3	18.0
BCB	14.7	24	27	36.3	8.7	13	18.7	25	6.7	10.0	14.0	19.7
XB	14.3	22.7	25.7	36.3	8.7	12.7	18	24.7	6.3	9.3	13.7	19.0
SBB	15	22	26.3	37.7	9	14.7	21.3	N/A	6.3	11.3	16.0	20.3
XB+BB	14.7	24.7	27	37.7	9	14	20.7	24	6.7	10.7	15.0	20.3
SB+BB	15	25	27	38	9	15.7	19	22.7	6.7	11.7	17.3	20.7
	S-F-S-F No Live Load				S-F-S-F 960 KN/m^2				S-F-S-F 1915 KN/m^2			
UB	14	21	23.3	34.7	8.3	11.3	14	18.3	6.3	8.7	10.7	14.7
BCB	14.3	22.3	25	34	8.7	11.7	15.3	21	6.3	9	12.3	16.7
XB	14.7	21.7	26	37	8.3	11	14.7	20	6.3	8.7	11.3	15.3
SBB	15	23.7	26	34.7	8.7	12.3	17.7	24.3	6.3	9.7	13.7	N/A
XB+BB	14.7	23	25.7	33	8.7	12	16.7	22.7	6.3	9.3	12.7	17.3
SB+BB	15	24.3	27.3	36.3	8.3	12.3	18	25	6.7	10	14.7	17.7

See Note on page 113.

Note: The following abbreviations are used in Tables 4-29 and 4-30.

UB = unbraced floor condition

BCB = bottom chord braced floor condition

XB = X-braced floor condition

SBB = strong-back braced floor condition

XB+BB = X plus bottom chord braced floor condition

SB+BB = strong-back plus bottom chord braced floor condition

Figure 4-8 shows graphically the power spectrum used to complete part of the above tables. Notice the decrease in the power of the braced versus unbraced frequency spectrum for all modes of vibration.

The mean frequencies, and coefficients of variation of the frequencies, for all three of the truss floors are then presented in tables 4-31 and 4-32.

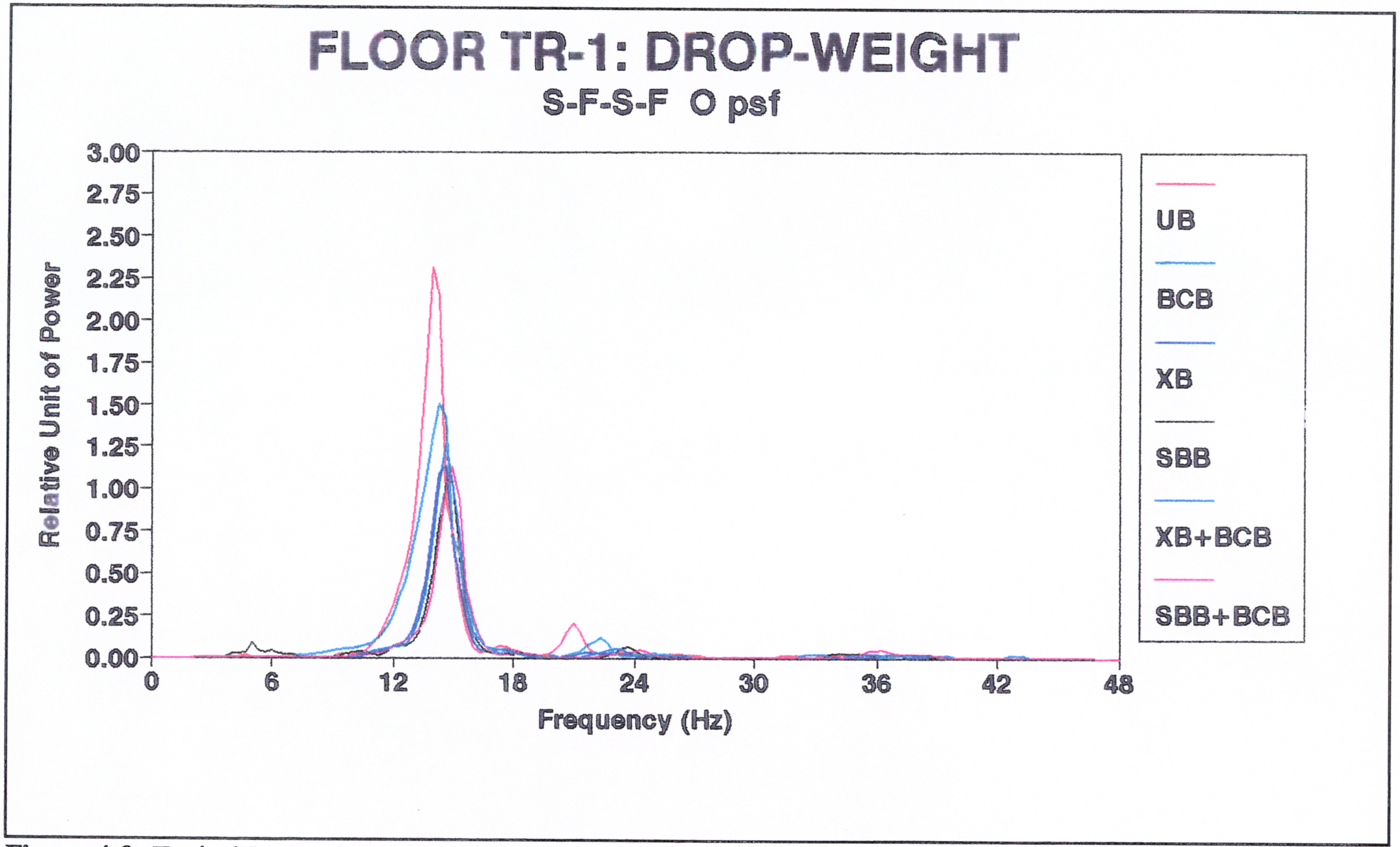

Figure 4-8: Typical Power Spectrum - Floor TR-1: All Bracing Conditions

Table 4-31: Average Resonant Frequency Response - Truss Floors - Free-Vibration Tests.

Type of Brace	FREE-VIBRATION TEST								
	Mode #1 (Hz)	Mode #2 (Hz)	Mode #3 (Hz)	Mode #1 (Hz)	Mode #2 (Hz)	Mode #3 (Hz)	Mode #1 (Hz)	Mode #2 (Hz)	Mode #3 (Hz)
	S-S-S-S No Live Load			S-S-S-S 960 KN/m^2			S-S-S-S 1915 KN/m^2		
UB (%COV)	17.2 (1.1)	25 (2.3)	33.3 (1.0)	9 (0.0)	12.4 (1.6)	14.5 (1.6)	6.4 (3.0)	9.2 (2.1)	12.7 (5.3)
BCB (%COV)	17.2 (1.1)	27.2 (1.4)	35.4 (7.5)	9 (0.0)	13.2 (2.9)	17.2 (9.5)	6.4 (6.0)	10.1 (1.9)	14.2 (1.7)
XB (%COV)	17.3 (0.0)	26.1 (2.0)	36.3 (6.4)	8.8 (2.2)	12.7 (2.6)	16.7 (17.3)	6.6 (2.9)	9 (9.8)	12.9 (12.8)
SBB (%COV)	17.4 (1.1)	30.1 (5.1)	36.6 (10.8)	9.0 (0.0)	15.2 (1.3)	27.1 (22.9)	6.6 (2.9)	10.2 (13.2)	13.8 (13.8)
XB+BB (%COV)	17.6 (2.2)	28.2 (1.4)	38.7 (0.9)	9.2 (2.1)	14.1 (2.7)	18.2 (18.5)	6.9 (2.8)	10.1 (6.9)	14.9 (5.2)
SB+BB (%COV)	17.4 (1.1)	27.7 (5.3)	35.2 (15.4)	9.1 (2.1)	14.4 (14.8)	19.1 (15.8)	6.7 (0.0)	11.7 (4.0)	15.5 (1.5)
	S-F-S-F No Live Load			S-F-S-F 960 KN/m^2			S-F-S-F 1915 KN/m^2		
UB (%COV)	16.7 (2.0)	22.8 (0.8)	27.8 (1.4)	8.4 (2.3)	11.1 (1.7)	13.4 (5.2)	6.3 (5.3)	8.4 (4.6)	10.2 (7.5)
BCB (%COV)	16.8 (2.3)	23.9 (4.5)	30.1 (10.9)	8.3 (6.9)	12.2 (1.9)	15 (6.3)	6.7 (0.0)	8.7 (10.2)	11.7 (7.6)
XB (%COV)	16.9 (1.4)	23.7 (2.8)	29.3 (2.3)	8.8 (2.2)	11.7 (0.0)	15.1 (2.5)	6.4 (3.0)	8.7 (3.8)	11.7 (2.9)
SBB (%COV)	17 (0.0)	25 (1.3)	34.7 (13.4)	8.9 (2.2)	12.6 (3.1)	18.3 (1.8)	6.7 (0.0)	9.6 (2.0)	15 (34.6)
XB+BB (%COV)	17.1 (1.1)	25 (2.7)	31.2 (9.2)	9.1 (2.1)	11.7 (7.6)	14.2 (16.5)	6.7 (0.0)	8.8 (7.9)	11.9 (14.4)
SB+BB (%COV)	16.9 (1.1)	25.1 (2.0)	31.7 (16.4)	9.2 (7.5)	12.4 (1.6)	17.2 (12.9)	6.6 (2.9)	9.9 (2.0)	12.8 (16.5)

see Note on page 117.

Table 4-32: Average Resonant Frequency Response - Truss Floors - Drop-Weight Tests.

Type of Brace	DROP-WEIGHT TEST								
	Mode #1 (Hz)	Mode #2 (Hz)	Mode #3 (Hz)	Mode #1 (Hz)	Mode #2 (Hz)	Mode #3 (Hz)	Mode #1 (Hz)	Mode #2 (Hz)	Mode #3 (Hz)
▨	S-S-S-S No Live Load			S-S-S-S 960 KN/m²			S-S-S-S 1915 KN/m²		
UB (%COV)	14.1 (1.4)	18.1 (17.0)	21.2 (11.9)	8.6 (2.3)	11.9 (1.6)	16.2 (1.2)	5.8 (12.0)	9.1 (2.1)	12.3 (2.7)
BCB (%COV)	14.8 (3.4)	22 (18.4)	25.2 (10.3)	8.7 (0.0)	13 (2.6)	18.5 (1.3)	6.7 (0.0)	9.9 (2.0)	14.1 (1.4)
XB (%COV)	14.7 (2.3)	21.1 (15.6)	25.7 (N/A)	8.7 (0.0)	12.3 (4.7)	18 (0.0)	6.3 (0.0)	9.7 (3.5)	13.9 (1.4)
SBB (%COV)	15.2 (1.3)	19.3 (11.9)	26.3 (0.0)	8.8 (2.2)	14.8 (1.3)	21.2 (1.1)	6.4 (3.0)	11.2 (1.7)	16 (N/A)
XB+BB (%COV)	14.6 (5.8)	19.3 (24.9)	22.3 (29.6)	8.9 (2.2)	13.8 (2.8)	18.4 (19.3)	6.8 (2.8)	10.8 (1.8)	15.3 (3.1)
SB+BB (%COV)	15 (2.2)	21.3 (24.3)	26.7 (1.8)	8.8 (2.2)	15.6 (3.3)	19 (N/A)	6.7 (0.0)	11.7 (2.9)	16.5 (7.1)
▨	S-F-S-F No Live Load			S-F-S-F 960 KN/m²			S-F-S-F 1915 KN/m²		
UB (%COV)	14.2 (1.4)	18 (14.5)	22 (8.6)	8.3 (0.0)	11.1 (1.7)	14 (0.0)	6.3 (5.3)	8.6 (2.3)	10.8 (1.8)
BCB (%COV)	14.1 (4.9)	18 (21.4)	21.2 (25.6)	8.4 (2.3)	11.3 (5.1)	15.4 (1.2)	6.3 (0.0)	9 (0.0)	11.9 (3.2)
XB (%COV)	14.4 (1.3)	18.8 (13.5)	23.8 (12.9)	8.3 (0.0)	11.2 (3.4)	15.0 (2.2)	6.3 (0.0)	9.2 (10.4)	11.4 (1.7)
SBB (%COV)	14.7 (2.3)	18.2 (25.9)	20.6 (23.0)	8.6 (2.3)	12.1 (1.6)	17.7 (0.0)	6.3 (0.0)	9.4 (2.0)	13.7 (2.4)
XB+BB (%COV)	15 (2.2)	19.3 (16.4)	23.2 (15.3)	8.6 (2.3)	12 (0.0)	15.8 (8.0)	6.4 (3.0)	9.6 (4.0)	13.2 (3.9)
SB+BB (%COV)	14.9 (1.3)	20.7 (25.1)	23.3 (24.2)	8.4 (2.3)	12.2 (1.6)	18.2 (2.1)	6.6 (2.9)	9.9 (2.0)	14.2 (3.6)

see Note on page 117.

Note: The following abbreviations are used in Tables 4-31 and 4-32.

UB = unbraced floor condition

BCB = bottom chord braced floor condition

XB = X-braced floor condition

SBB = strong-back braced floor condition

XB+BB = X plus bottom chord braced floor condition

SB+BB = strong-back plus bottom chord braced floor condition

S-S-S-S = four-sided floor support

S-F-S-F = end supported only floor support

MODE # _ = average modal frequency, Hz

(% COV) = coefficient of variation for all three truss floors

N/A = insufficient data for calculation of coefficient of variation

4.3.2.2 Discussion of Resonant Frequency Results

Each type of truss floor bracing system will be discussed individually. As in the solid-sawn floor results, comparison tables are presented which show the braced versus unbraced average frequencies and the results of the t-Tests. The five bracing systems are discussed in the following order: bottom-chord bracing, steel X-bracing, strong-back bracing, X- plus bottom-chord bracing, and finally strong-back plus bottom-chord bracing (BCB, XB, SBB, XB+BB, and SB+BB respectively).

As discussed in Chapter 3, a statistical analysis was performed on the braced versus unbraced floor frequencies and separation of frequencies. These results are shown in the following comparison tables. A t-Test was utilized, in which, each braced versus unbraced frequency, and separation between adjacent frequencies, were compared, with the null hypothesis that the means were equal. When this hypothesis was rejected, it signified that there was a significant change between the braced and unbraced mean values at the 95% level of confidence. Therefore, a "Y" in the t-Test Result column in the following comparison tables means that there is a 95% probability that the particular type of bracing being compared produced a change in the particular frequency or mode separation. A "N" in the t-Test Result column means that there was no significant change in the mean values, when comparing the braced to the unbraced frequency or mode separation. The amount of variance in a particular frequency or mode separation has an effect on the outcome of the t-Test. For instance, if there is a large amount of variance, as shown by a high coefficient of variation in Tables 4-35 and 4-36, then the t-Test will fail to reject the hypothesis that the means are equal. In other words, the data used to calculate the average values has too much "spread", and the t-Test does not show that there is a difference between the braced and unbraced averages. This phenomenon can lead one to wonder why for one mode, a two or three Hz difference between the braced versus unbraced values has a "Y" in the t-Test result column, while for another mode the same difference between the braced and unbraced values has a "N" in the t-

Test Result column.

Bottom-Chord Bracing

As seen in Tables 3-33, and 4-34, the bottom-chord bracing system had no significant effect on the first fundamental frequency for any of the floor conditions. This bracing system affected only the modal separation and higher modes of vibration, in all but one test, with the S-S-S-S floor boundary condition only. Therefore, it can be stated that this type of bracing could only effect a truss floor system with support under each end of the bottom-chord brace. This is due to the floor acting as a two-way plate in bending when the S-S-S-S boundary conditions are imposed, while for the S-F-S-F boundary condition, the floor acts as a one-way plate in bending. The S-S-S-S boundary condition causes both bending and tension forces in the bracing member.

Since the bottom-chord brace affected only the higher modes, this type of bracing alone would not significantly improve the perceptibility of a truss floor system which has annoying vibrational response.

Table 4-33:
Change in Magnitude and Separation of Average Resonant Frequencies
with Results of t-Tests: Truss Floors
Free-Vibration Tests
Bottom-Chord Bracing -vs- Unbraced.

	FREE-VIBRATION TEST					
	S-S-S-S No Live Load			**S-F-S-F No Live Load**		
	UB (Hz)	**BCB (Hz)**	**t-Test Result**	**UB (Hz)**	**BCB (Hz)**	**t-Test Result**
MODE #1	17.2	17.2	N	16.7	16.8	N
	Separation— >		Y	**Separation— >**		N
MODE #2	25.0	27.2	Y	22.8	23.9	N
	Separation— >		N	**Separation— >**		N
MODE #3	33.3	35.4	N	27.8	30.1	N
	S-S-S-S 960 kN/m^2			**S-F-S-F 960 kN/m^2**		
	UB (Hz)	**BCB (HZ)**	**t-Test Result**	**UB (Hz)**	**BCB (Hz)**	**t-Test Result**
MODE #1	9.0	9.0	N	8.4	8.3	N
	Separation— >		N	**Separation— >**		N
MODE #2	12.4	13.2	N	11.1	12.2	N
	Separation— >		N	**Separation— >**		N
MODE #3	14.5	17.2	N	13.4	15.0	N
	S-S-S-S 1915 kN/m^2			**S-F-S-F 1915 kN/m^2**		
	UB (Hz)	**BCB (HZ)**	**t-Test Result**	**UB (Hz)**	**BCB (Hz)**	**t-Test Result**
MODE #1	6.4	6.4	N	6.3	6.7	N
	Separation— >		Y	**Separation— >**		N
MODE #2	9.2	10.1	Y	8.4	8.7	N
	Separation— >		N	**Separation— >**		N
MODE #3	12.7	14.2	N	10.2	11.7	N

UB = unbraced floor results
BCB = bottom-chord braced results
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

Table 4-34:
Change in Magnitude and Separation of Average Resonant Frequencies
with Results of t-Tests: Truss Floors
Drop-Weight Tests
Bottom-Chord Bracing -vs- Unbraced.

	DROP-WEIGHT TEST					
	S-S-S-S No Live Load			**S-F-S-F No Live Load**		
	UB (Hz)	**BCB (Hz)**	**t-Test Result**	**UB (Hz)**	**BCB (Hz)**	**t-Test Result**
MODE #1	14.1	14.8	N	14.2	14.1	N
	Separation—>		N	**Separation—>**		N
MODE #2	18.1	22.0	N	18.0	18.0	N
	Separation—>		N	**Separation—>**		N
MODE #3	21.2	25.2	N	22.0	21.2	N
	S-S-S-S 960 kN/m^2			**S-F-S-F 960 kN/m^2**		
	UB (Hz)	**BCB (HZ)**	**t-Test Result**	**UB (Hz)**	**BCB (Hz)**	**t-Test Result**
MODE #1	8.6	8.7	N	8.3	8.4	N
	Separation—>		Y	**Separation—>**		N
MODE #2	11.9	13.0	Y	11.1	11.3	N
	Separation—>		N	**Separation—>**		N
MODE #3	16.2	18.5	N	14.0	15.4	N
	S-S-S-S 1915 kN/m^2			**S-F-S-F 1915 kN/m^2**		
	UB (Hz)	**BCB (HZ)**	**t-Test Result**	**UB (Hz)**	**BCB (Hz)**	**t-Test Result**
MODE #1	5.8	6.7	N	6.3	6.3	N
	Separation—>		N	**Separation—>**		N
MODE #2	9.1	9.9	Y	8.6	9.0	N
	Separation—>		Y	**Separation—>**		N
MODE #3	12.3	14.1	Y	10.8	11.9	Y

UB = unbraced floor results
BCB = bottom-chord braced results
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

Steel X-Bracing

Comparison of the x-bracing results is presented in Tables 4-35 and 4-36. This bracing system also had no significant effect on the first fundamental frequency for any of the floor conditions. The x-bracing appears to have affected primarily the second and third modes of vibration, and the separation between them. This bracing system was, however, effective for both S-S-S-S, and S-F-S-F boundary conditions. Also, this bracing system seemed to produce significant changes mainly at the 960 and 1915 kN/m^2 (20 and 40 psf) live load levels. This could be attributed to the fact that the x-bracing needs to be put under more than the dead load of the floor, to produce any change in dynamic response of a floor.

Strong-Back Bracing

Comparisons of the strong-back bracing results are presented in Tables 4-37 and 4-38. As can be seen in these tables, this bracing system more frequently affected the frequencies and separations than the two previously presented systems. The strong-back significantly increased the first fundamental frequency for two floor conditions, once for S-F-S-F, 960 kN/m^2 (20 psf), in free-vibration, and once for the S-S-S-S, no live load, drop-weight test. This bracing system also increased the separation and magnitudes of the second and third modes of vibration more than any of the other truss floor bracing systems.

Table 4-35:
Change in Magnitude and Separation of Average Resonant Frequencies with Results of t-Tests: Truss Floors
Free-Vibration Tests
Steel X-Bracing -vs- Unbraced.

▨	FREE-VIBRATION TEST					
	S-S-S-S No Live Load			S-F-S-F No Live Load		
	UB (Hz)	XB (Hz)	t-Test Result	UB (Hz)	XB (Hz)	t-Test Result
MODE #1	17.2	17.3	N	16.7	16.9	N
	Separation—>		N	Separation—>		N
MODE #2	25.0	26.1	N	22.8	23.7	N
	Separation—>		N	Separation—>		N
MODE #3	33.3	36.3	N	27.8	29.3	Y
	S-S-S-S 960 kN/m^2			S-F-S-F 960 kN/m^2		
	UB (Hz)	XB (HZ)	t-Test Result	UB (Hz)	XB (Hz)	t-Test Result
MODE #1	9.0	8.8	N	8.4	8.8	N
	Separation—>		Y	Separation—>		N
MODE #2	12.4	12.7	N	11.1	11.7	N
	Separation—>		N	Separation—>		N
MODE #3	14.5	16.7	N	13.4	15.1	Y
	S-S-S-S 1915 kN/m^2			S-F-S-F 1915 kN/m^2		
	UB (Hz)	XB (HZ)	t-Test Result	UB (Hz)	XB (Hz)	t-Test Result
MODE #1	6.4	6.6	N	6.3	6.4	N
	Separation—>		N	Separation—>		N
MODE #2	9.2	9.0	N	8.4	8.7	N
	Separation—>		N	Separation—>		Y
MODE #3	12.7	12.9	N	10.2	11.7	N

UB = unbraced floor results
XB = X-braced results
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

Table 4-36:
Change in Magnitude and Separation of Average Resonant Frequencies
with Results of t-Tests: Truss Floors
Drop-Weight Tests
Steel X-Bracing -vs- Unbraced.

▨	**DROP-WEIGHT TEST**					
	S-S-S-S No Live Load			**S-F-S-F No Live Load**		
	UB (Hz)	**XB (Hz)**	**t-Test Result**	**UB (Hz)**	**XB (Hz)**	**t-Test Result**
MODE #1	14.1	14.7	N	14.2	14.4	N
	Separation—>		N	**Separation—>**		N
MODE #2	18.1	21.1	N	18.0	18.8	N
	Separation—>		N/A	**Separation—>**		N
MODE #3	21.2	25.7	N/A	22.0	23.8	N
	S-S-S-S 960 kN/m^2			**S-F-S-F 960 kN/m^2**		
	UB (Hz)	**XB (HZ)**	**t-Test Result**	**UB (Hz)**	**XB (Hz)**	**t-Test Result**
MODE #1	8.6	8.7	N	8.3	8.3	N
	Separation—>		N	**Separation—>**		N
MODE #2	11.9	12.3	N	11.1	11.2	N
	Separation—>		N	**Separation—>**		Y
MODE #3	16.2	18.0	Y	14.0	15.0	N
	S-S-S-S 1915 kN/m^2			**S-F-S-F 1915 kN/m^2**		
	UB (Hz)	**XB (HZ)**	**t-Test Result**	**UB (Hz)**	**XB (Hz)**	**t-Test Result**
MODE #1	5.8	6.3	N	6.3	6.3	N
	Separation—>		N	**Separation—>**		N
MODE #2	9.1	9.7	N	8.6	9.2	N
	Separation—>		Y	**Separation—>**		N
MODE #3	12.3	13.9	Y	10.8	11.4	Y

UB = unbraced floor results
XB = X-braced results
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

The improved performance can be attributed to the bending stiffness of the strong-back itself. The strong-back improved the transverse stiffness of the floor, and thereby improved the load sharing between trusses, which increased the higher mode, resonant frequencies of the floor.

X- plus Bottom-Chord Bracing

The comparison results of the bracing combination of X- plus bottom-chord bracing are presented in Tables 4-39 and 4-40. This bracing combination increased the first fundamental frequency in four out of a possible twelve tests, twice in the free-vibration test, and twice in the drop-weight tests. In the free-vibration tests, the fundamental frequency was increased for the S-S-S-S boundary condition with 1915 kN/m^2 (40 psf) imposed load, and also for the S-F-S-F boundary condition with 960 kN/m^2 (20 psf) imposed load level. In the drop-weight tests, both increases occurred with no imposed load, for the S-S-S-S, and S-F-S-F boundary conditions. Due to the fact that these increases occurred for both the free-vibration and drop-weight tests, at a wide variety of boundary and load conditions, it implies that this bracing combination is good. This bracing combination also frequently increased the resonant frequencies, and the separation between frequencies, in both the free-vibration and drop-weight tests. Which again attests to the effectiveness of this bracing combination.

Table 4-37:
Change in Magnitude and Separation of Average Resonant Frequencies with Results of t-Tests: Truss Floors
Free-Vibration Tests
Strong-Back Bracing -vs- Unbraced.

	FREE-VIBRATION TEST					
	S-S-S-S No Live Load			**S-F-S-F No Live Load**		
	UB (Hz)	**SBB (Hz)**	**t-Test Result**	**UB (Hz)**	**SBB (Hz)**	**t-Test Result**
MODE #1	17.2	17.4	N	16.7	17.0	N
	Separation—>		Y	**Separation—>**		Y
MODE #2	25.0	30.1	Y	22.8	25.0	Y
	Separation—>		N	**Separation—>**		N
MODE #3	33.3	36.6	N	27.8	34.7	N
	S-S-S-S 960 kN/m^2			**S-F-S-F 960 kN/m^2**		
	UB (Hz)	**SBB (HZ)**	**t-Test Result**	**UB (Hz)**	**SBB (Hz)**	**t-Test Result**
MODE #1	9.0	9.0	N	8.4	8.9	Y
	Separation—>		Y	**Separation—>**		N
MODE #2	12.4	15.2	Y	11.1	12.6	Y
	Separation—>		N	**Separation—>**		Y
MODE #3	14.5	27.1	N	13.4	18.3	Y
	S-S-S-S 1915 kN/m^2			**S-F-S-F 1915 kN/m^2**		
	UB (Hz)	**SBB (HZ)**	**t-Test Result**	**UB (Hz)**	**SBB (Hz)**	**t-Test Result**
MODE #1	6.4	6.6	N	6.3	6.7	N
	Separation—>		N	**Separation—>**		N
MODE #2	9.2	10.2	N	8.4	9.6	Y
	Separation—>		N	**Separation—>**		N
MODE #3	12.7	13.8	N	10.2	15.0	N

UB = unbraced floor results
SBB = strong-back braced results
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

Table 4-38:
Change in Magnitude and Separation of Average Resonant Frequencies with Results of t-Tests: Truss Floors
Drop-Weight Tests
Strong-Back Bracing -vs- Unbraced.

▨	**DROP-WEIGHT TEST**					
	S-S-S-S No Live Load			**S-F-S-F No Live Load**		
	UB (Hz)	**SBB (Hz)**	**t-Test Result**	**UB (Hz)**	**SBB (Hz)**	**t-Test Result**
MODE #1	14.1	15.2	Y	14.2	14.7	N
	Separation—>		N	**Separation—>**		N
MODE #2	18.1	19.3	N	18.0	18.2	N
	Separation—>		N	**Separation—>**		N
MODE #3	21.2	26.3	N	22.0	20.6	N
	S-S-S-S 960 kN/m^2			**S-F-S-F 960 kN/m^2**		
	UB (Hz)	**SBB (HZ)**	**t-Test Result**	**UB (Hz)**	**SBB (Hz)**	**t-Test Result**
MODE #1	8.6	8.8	N	8.3	8.6	N
	Separation—>		Y	**Separation—>**		Y
MODE #2	11.9	14.8	Y	11.1	12.1	Y
	Separation—>		N	**Separation—>**		Y
MODE #3	16.2	21.2	Y	14.0	17.7	Y
	S-S-S-S 1915 kN/m^2			**S-F-S-F 1915 kN/m^2**		
	UB (Hz)	**SBB (HZ)**	**t-Test Result**	**UB (Hz)**	**SBB (Hz)**	**t-Test Result**
MODE #1	5.8	6.4	N	6.3	6.3	N
	Separation—>		N	**Separation—>**		Y
MODE #2	9.1	11.2	Y	8.6	9.4	Y
	Separation—>		N/A	**Separation—>**		Y
MODE #3	12.3	16.0	N/A	10.8	13.7	Y

UB = unbraced floor results
SBB = strong-back braced results
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

Table 4-39:
Change in Magnitude and Separation of Average Resonant Frequencies with Results of t-Tests: Truss Floors
Free-Vibration Tests
X- plus Bottom-Chord Bracing -vs- Unbraced.

CHANGE IN MAGNITUDE AND SEPARATION OF AVERAGE RESONANT FREQUENCIES - TRUSS FLOORS:
X- plus BOTTOM CHORD BRACED -vs- UNBRACED

	FREE-VIBRATION TEST					
	S-S-S-S No Live Load			**S-F-S-F No Live Load**		
	UB (Hz)	**XB+BB (Hz)**	**t-Test Result**	**UB (Hz)**	**XB+BB (Hz)**	**t-Test Result**
MODE #1	17.2	17.6	N	16.7	17.1	N
		Separation—>	N		**Separation—>**	Y
MODE #2	25.0	28.2	Y	22.8	25.0	Y
		Separation—>	Y		**Separation—>**	N
MODE #3	33.3	38.7	Y	27.8	31.2	N
	S-S-S-S 960 kN/m^2			**S-F-S-F 960 kN/m^2**		
	UB (Hz)	**XB+BB (HZ)**	**t-Test Result**	**UB (Hz)**	**XB+BB (Hz)**	**t-Test Result**
MODE #1	9.0	9.2	N	8.4	9.1	Y
		Separation—>	Y		**Separation—>**	N
MODE #2	12.4	14.1	Y	11.1	11.7	N
		Separation—>	N		**Separation—>**	N
MODE #3	14.5	18.2	N	13.4	14.2	N
	S-S-S-S 1915 kN/m^2			**S-F-S-F 1915 kN/m^2**		
	UB (Hz)	**XB+BB (HZ)**	**t-Test Result**	**UB (Hz)**	**XB+BB (Hz)**	**t-Test Result**
MODE #1	6.4	6.9	Y	6.3	6.7	N
		Separation—>	N		**Separation—>**	N
MODE #2	9.2	10.1	N	8.4	8.8	N
		Separation—>	N		**Separation—>**	N
MODE #3	12.7	14.9	Y	10.2	11.9	N

UB = unbraced floor results
XB+BB = X- plus bottom chord braced results
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

Table 4-40:
Change in Magnitude and Separation of Average Resonant Frequencies
with Results of t-Tests: Truss Floors
Drop-Weight Tests
X- plus Bottom Chord Bracing -vs- Unbraced.

CHANGE IN MAGNITUDE AND SEPARATION OF AVERAGE RESONANT FREQUENCIES - TRUSS FLOORS: X- plus BOTTOM CHORD BRACED -vs- UNBRACED

	DROP-WEIGHT TEST					
	S-S-S-S No Live Load			**S-F-S-F No Live Load**		
	UB (Hz)	**XB+BB (Hz)**	**t-Test Result**	**UB (Hz)**	**XB+BB (Hz)**	**t-Test Result**
MODE #1	14.1	14.6	N	14.2	15.0	Y
		Separation—>	N		**Separation—>**	N
MODE #2	18.1	19.3	N	18.0	19.3	N
		Separation—>	N		**Separation—>**	N
MODE #3	21.2	22.3	N	22.0	23.2	N
	S-S-S-S 960 kN/m²			**S-F-S-F 960 kN/m²**		
	UB (Hz)	**XB+BB (HZ)**	**t-Test Result**	**UB (Hz)**	**XB+BB (Hz)**	**t-Test Result**
MODE #1	8.6	8.9	N	8.3	8.6	N
		Separation—>	Y		**Separation—>**	N
MODE #2	11.9	13.8	Y	11.1	12.0	N
		Separation—>	N		**Separation—>**	N
MODE #3	16.2	18.4	N	14.0	15.8	N
	S-S-S-S 1915 kN/m²			**S-F-S-F 1915 kN/m²**		
	UB (Hz)	**XB+BB (HZ)**	**t-Test Result**	**UB (Hz)**	**XB+BB (Hz)**	**t-Test Result**
MODE #1	5.8	6.8	N	6.3	6.4	N
		Separation—>	N		**Separation—>**	Y
MODE #2	9.1	10.8	Y	8.6	9.6	N
		Separation—>	N		**Separation—>**	Y
MODE #3	12.3	15.3	N	10.8	13.2	Y

UB = unbraced floor results
XB+BB = X- plus bottom chord braced results
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

Strong-Back plus Bottom-Chord Bracing

Comparisons are presented for the strong-back plus bottom-chord bracing systems in Tables 4-41 and 4-42. This bracing combination raised the first fundamental frequency for two floor conditions: the drop-weight tests with S-S-S-S and S-F-S-F boundary conditions with zero imposed load. This bracing combination also frequently increased the resonant frequencies, and the separation between adjacent resonant frequencies. This improvement occurred for both S-S-S-S, and S-F-S-F boundary conditions which implies that this bracing combination is effective. The improvement in performance is due to the increased transverse stiffness of the floors attributed to the bracing.

Table 4-41:
Change in Magnitude and Separation of Average Resonant Frequencies
with Results of t-Tests: Truss Floors
Free-Vibration Tests
Strong-Back plus Bottom-Chord Bracing -vs- Unbraced.

CHANGE IN MAGNITUDE AND SEPARATION OF AVERAGE RESONANT FREQUENCIES - TRUSS FLOORS:
STRONG-BACK plus BOTTOM CHORD BRACED -vs- UNBRACED

	FREE-VIBRATION TEST					
	S-S-S-S No Live Load			S-F-S-F No Live Load		
	UB (Hz)	SB+BB (Hz)	t-Test Result	UB (Hz)	SB+BB (Hz)	t-Test Result
MODE #1	17.2	17.4	N	16.7	16.9	N
	Separation—>		N	Separation—>		Y
MODE #2	25.0	27.7	N	22.8	25.1	Y
	Separation—>		N	Separation—>		N
MODE #3	33.3	35.2	N	27.8	31.7	N
	S-S-S-S 960 kN/m^2			S-F-S-F 960 kN/m^2		
	UB (Hz)	SB+BB (HZ)	t-Test Result	UB (Hz)	SB+BB (Hz)	t-Test Result
MODE #1	9.0	9.1	N	8.4	9.2	N
	Separation—>		Y	Separation—>		N
MODE #2	12.4	14.4	N	11.1	12.4	Y
	Separation—>		N	Separation—>		N
MODE #3	14.5	19.1	N	13.4	17.2	N
	S-S-S-S 1915 kN/m^2			S-F-S-F 1915 kN/m^2		
	UB (Hz)	SB+BB (HZ)	t-Test Result	UB (Hz)	SB+BB (Hz)	t-Test Result
MODE #1	6.4	6.7	N	6.3	6.6	N
	Separation—>		N	Separation—>		N
MODE #2	9.2	11.7	N	8.4	9.9	Y
	Separation—>		N	Separation—>		N
MODE #3	12.7	15.5	Y	10.2	12.8	N

UB = unbraced floor results
SB+BB = strong-back plus bottom chord braced results
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

Table 4-42:
Change in Magnitude and Separation of Average Resonant Frequencies
with Results of t-Tests: Truss Floors
Drop-Weight Tests
Strong-Back plus Bottom Chord Bracing -vs- Unbraced.

CHANGE IN MAGNITUDE AND SEPARATION OF AVERAGE RESONANT FREQUENCIES - TRUSS FLOORS:
STRONG-BACK plus BOTTOM CHORD BRACED -vs- UNBRACED

▒	DROP-WEIGHT TEST					
	S-S-S-S No Live Load			S-F-S-F No Live Load		
	UB (Hz)	SB+BB (Hz)	t-Test Result	UB (Hz)	SB+BB (Hz)	t-Test Result
MODE #1	14.1	15.0	Y	14.2	14.9	Y
		Separation—>	N		Separation—>	N
MODE #2	18.1	21.3	N	18.0	20.7	N
		Separation—>	N		Separation—>	N
MODE #3	21.2	26.7	N	22.0	23.3	N
	S-S-S-S 960 kN/m²			S-F-S-F 960 kN/m²		
	UB (Hz)	SB+BB (HZ)	t-Test Result	UB (Hz)	SB+BB (Hz)	t-Test Result
MODE #1	8.6	8.8	N	8.3	8.4	N
		Separation—>	Y		Separation—>	Y
MODE #2	11.9	15.6	Y	11.1	12.2	Y
		Separation—>	N/A		Separation—>	Y
MODE #3	16.2	19.0	N/A	14.0	18.2	Y
	S-S-S-S 1915 kN/m²			S-F-S-F 1915 kN/m²		
	UB (Hz)	SB+BB (HZ)	t-Test Result	UB (Hz)	SB+BB (Hz)	t-Test Result
MODE #1	5.8	6.7	N	6.3	6.6	N
		Separation—>	N		Separation—>	N
MODE #2	9.1	11.7	Y	8.6	9.9	Y
		Separation—>	N		Separation—>	Y
MODE #3	12.3	16.5	N	10.8	14.2	Y

UB = unbraced floor results
SB+BB = strong-back plus bottom chord braced results
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
Mode #_ = frequency for mode of vibration, in hertz, from power spectrum
Separation = result of t-Test comparing braced -vs- unbraced modal separation
Y = significant difference at 95% confidence interval from t-Test
N = no significant difference at 95% confidence interval from t-Test

4.3.2.3 Modal and Logarithmic Damping Ratio Results

Tables 4-43 and 4-44 give examples of typical truss floor modal and logarithmic damping ratios. As explained in Chapter 3, the modal damping ratios are calculated from the power spectrum peaks, while the log decrement values are calculated from the filtered and calibrated acceleration traces. The damping values are shown as percent critical damping. When "N/A" is shown in the table, it means that the parameter in question was negligible, and therefore was not calculated.

The mean values for modal and logarithmic damping ratios of all the truss floors are presented in Tables 4-45 and 46. These tables present the results for both free-vibration and drop-weight tests, with the various boundary and live load combinations. Note that the coefficients of variation are on average higher than those seen for the resonant frequencies. The variance in the logarithmic decrement damping ratios is due to the non-logarithmic shape of some of the time-acceleration traces. Also, the subjective nature of the peak amplitude selections used in the calculation of the logarithmic decrement caused some additional variation. The variation in the modal damping ratios is in part due to the assumptions made when using this type of damping calculation, such as the assumption that the system is a series of independent single degree-of-freedom oscillators.

Table 4-43:
Typical Modal and Logarithmic Damping Ratios
Floor TR-1: Free-Vibration Tests.

	FREE-VIBRATION TEST											
Type of Brace	MODE 1 (%Crit.)	MODE 2 (%Crit.)	MODE 3 (%Crit.)	LOG DEC. (%Crit.)	MODE 1 (%Crit.)	MODE 2 (%Crit.)	MODE 3 (%Crit.)	LOG DEC (%Crit.)	MODE 1 (%Crit.)	MODE 2 (%Crit.)	MODE 3 (%Crit.)	LOG DEC (%Crit.)
	S-S-S-S No Live Load				S-S-S-S 960 KN/m^2				S-S-S-S 1915 KN/m^2			
UB	2.7	2.1	2.5	4.3	2.4	2.4	3.5	2.9	4.4	2.3	1.7	4.6
BCB	2.7	2.4	1.8	3.6	4.0	3.0	2.9	5.2	5.5	1.6	4.3	3.9
XB	2.8	1.5	3.2	3.8	3.1	2.0	1.6	2.9	2.2	2.1	1.8	3.4
SBB	2.3	1.7	0.46	4.4	3.2	1.8	6.9	5.3	11.1	4.8	3.7	3.8
XB+BB	2.7	2.2	0.94	4.5	2.6	1.8	1.3	4.2	2.4	3.2	2.6	4.2
SB+BB	2.8	1.5	2.3	5.0	2.3	2.7	4.2	4.6	2.7	1.5	3.8	5.6
	S-F-S-F No Live Load				S-F-S-F 960 KN/m^2				S-F-S-F 1915 KN/m^2			
UB	2.9	2.9	1.9	3.5	2.8	2.1	1.9	4.7	9.4	22.6	7.9	5.0
BCB	3.3	2.3	2.2	3.7	2.8	2.1	2.6	3.1	2.7	1.9	3.2	3.2
XB	2.6	2.0	1.8	4.7	1.8	1.7	1.6	3.7	2.6	1.9	2.0	4.4
SBB	2.3	4.4	1.5	3.8	1.7	1.6	0.87	1.79	2.4	2.5	2.3	4.9
XB+BB	2.4	2.5	2.0	3.9	2.6	5.0	3.1	5.3	5.0	3.8	3.6	6.5
SB+BB	3.4	3.1	2.7	3.4	5.9	4.2	11.7	7.85	2.9	1.9	2.3	3.2

UB = unbraced floor condition
BCB = bottom chord braced floor condition
XB = X-braced floor condition
SBB = strong-back braced floor condition
XB+BB = X plus bottom chord braced floor condition
SB+BB = strong-back plus bottom chord braced floor conditon
S-S-S-S = four-sided floor support
S-F-S-F = two-sided floor support

Table 4-44:
Typical Modal and Logarithmic Damping Ratios
Floor TR-1: Drop-Weight Tests

	DROP-WEIGHT TESTS											
Type of Brace	**MODE 1 (%Crit.)**	**MODE 2 (%Crit.)**	**MODE 3 (%Crit.)**	**LOG DEC (%Crit.)**	**MODE 1 (%Crit.)**	**MODE 2 (%Crit.)**	**MODE 3 (%Crit.)**	**LOG DEC (%Crit.)**	**MODE 1 (%Crit.)**	**MODE 2 (%Crit.)**	**MODE 3 (%Crit.)**	**LOG DEC (%Crit.)**
	S-S-S-S No Live Load				**S-S-S-S 960 KN/m^2**				**S-S-S-S 1915 KN/m^2**			
UB	2.3	1.6	1.9	1.1	2.2	1.7	1.3	3.6	2.5	2.1	1.4	3.0
BCB	2.5	1.8	2.4	3.7	2.4	2.1	1.4	4.2	2.3	2.3	1.3	4.6
XB	2.3	1.3	3.5	4.2	3.3	2.7	1.5	5.7	1.9	1.6	1.2	2.5
SBB	2.6	1.8	1.2	4.3	2.4	1.8	1.5	3.5	2.8	1.6	1.7	3.9
XB+BB	3.4	1.4	1.5	5.3	2.3	1.8	1.7	4.1	2.4	2.0	2.5	3.5
SB+BB	2.5	2.7	1.1	3.8	2.3	1.8	0.55	3.7	2.2	2.5	2.0	2.7
	S-F-S-F No Live Load				**S-F-S-F 960 KN/m^2**				**S-F-S-F 1915 KN/m^2**			
UB	2.5	1.5	3.1	4.2	2.3	1.8	2.0	3.8	2.6	1.9	1.9	2.4
BCB	3.6	1.7	3.3	4.3	2.2	2.1	2.8	3.7	4.9	3.3	1.5	3.0
XB	3.0	3.9	3.4	4.2	2.6	1.4	1.4	3.6	3.0	2.6	2.6	2.7
SBB	2.7	1.2	0.98	3.5	2.4	1.7	1.4	4.3	3.4	2.0	1.8	2.8
XB+BB	3.0	1.8	2.9	4.7	2.0	2.2	1.5	2.5	3.0	2.0	1.8	2.5
SB+BB	2.7	1.5	1.4	4.9	2.4	1.7	1.7	3.0	2.6	1.8	1.7	2.3

UB = unbraced floor condition
BCB = bottom chord braced floor condition
XB = X-braced floor condition
SBB = strong-back braced floor condition
XB+BB = X plus bottom chord braced floor condition
SB+BB = strong-back plus bottom chord braced floor conditon
S-S-S-S = four-sided floor support
S-F-S-F = two-sided floor support

Table 4-45: Average Damping Ratios For Truss Floors: Free-Vibration Tests.

	FREE-VIBRATION											
Type of Brace	**MODE 1 (%Crit.)**	**MODE 2 (%Crit.)**	**MODE 3 (%Crit.)**	**LOG DEC (%Crit.)**	**MODE 1 (%Crit.)**	**MODE 2 (%Crit.)**	**MODE 3 (%Crit.)**	**LOG DEC (%Crit.)**	**MODE 1 (%Crit.)**	**MODE 2 (%Crit.)**	**MODE 3 (%Crit.)**	**LOG DEC (%Crit.)**
	S-S-S-S No Live Load				**S-S-S-S 960 KN/m^2**				**S-S-S-S 1915 KN/m^2**			
UB	**3.0**	**1.7**	**1.9**	**4.0**	**2.3**	**2.0**	**2.9**	**3.6**	**6.3**	**3.1**	**2.6**	**3.5**
(%COV)	(23.6)	(43.3)	(26.3)	(24.5)	(23.1)	(21.7)	(34.5)	(17.7)	(67.0)	(48.2)	(41.0)	(37.6)
BCB	**2.9**	**2.2**	**3.2**	**4.5**	**3.2**	**2.6**	**3.4**	**5.2**	**3.2**	**2.0**	**3.4**	**3.8**
(%COV)	(11.4)	(11.9)	(62.2)	(17.7)	(21.1)	(14.4)	(32.8)	(8.9)	(60.0)	(51.5)	(35.9)	(11.0)
XB	**2.7**	**1.9**	**2.2**	**3.5**	**4.5**	**2.3**	**3.7**	**3.9**	**2.6**	**2.1**	**2.4**	**4.0**
(%COV)	(8.6)	(24.9)	(40.2)	(19.6)	(60.2)	(13.4)	(81.2)	(23.0)	(17.1)	(25.6)	(52.3)	(34.4)
SBB	**2.8**	**2.0**	**1.2**	**3.6**	**3.1**	**1.9**	**6.9**	**4.8**	**3.7**	**4.6**	**5.6**	**4.0**
(%COV)	(30.9)	(26.8)	(54.1)	(18.9)	(7.1)	(28.8)	(7.0)	(12.5)	(37.1)	(67.3)	(63.1)	(17.2)
XB+BB	**2.6**	**2.1**	**1.1**	**4.1**	**2.6**	**2.1**	**1.9**	**4.5**	**3.2**	**6.7**	**4.4**	**4.4**
(%COV)	(14.3)	(10.5)	(25.8)	(10.4)	(12.5)	(48.2)	(31.6)	(9.3)	(53.2)	(58.9)	(53.6)	(4.4)
SB+BB	**2.9**	**3.6**	**2.5**	**4.2**	**2.7**	**3.5**	**3.2**	**4.8**	**2.3**	**1.7**	**2.4**	**3.7**
(%COV)	(9.3)	(80.7)	(8.6)	(18.6)	(15.0)	(43.2)	(46.4)	(17.9)	(14.0)	(20.7)	(56.8)	(4.0)
	S-F-S-F No Live Load				**S-F-S-F 960 KN/m^2**				**S-F-S-F 1915 KN/m^2**			
UB	**3.5**	**3.3**	**1.9**	**4.1**	**4.0**	**2.9**	**5.0**	**4.5**	**4.9**	**9.1**	**4.0**	**3.9**
(%COV)	(31.6)	(28.4)	(16.2)	(14.3)	(32.4)	(25.9)	(85.7)	(25.6)	(79.6)	(129.0)	(85.0)	(48.7)
BCB	**4.9**	**3.0**	**2.4**	**4.6**	**9.6**	**2.0**	**3.1**	**4.3**	**3.5**	**3.0**	**2.8**	**4.3**
(%COV)	(29.3)	(20.3)	(18.7)	(26.9)	(61.2)	(11.4)	(21.0)	(24.7)	(38.7)	(33.0)	(34.9)	(43.1)
XB	**2.9**	**2.4**	**2.8**	**5.4**	**2.8**	**1.9**	**2.1**	**4.6**	**2.4**	**1.9**	**2.1**	**3.7**
(%COV)	(10.3)	(25.1)	(47.9)	(12.0)	(32.0)	(35.1)	(19.2)	(20.3)	(29.9)	(5.6)	(8.7)	(17.6)
SBB	**2.7**	**3.1**	**1.5**	**3.8**	**2.2**	**2.1**	**1.4**	**3.7**	**2.9**	**5.7**	**7.5**	**4.4**
(%COV)	(13.2)	(40.1)	(16.5)	(1.6)	(60.9)	(28.4)	(39.0)	(51.6)	(14.5)	(115.1)	(56.3)	(66.0)
XB+BB	**3.6**	**2.8**	**2.5**	**4.4**	**3.2**	**4.5**	**4.9**	**4.9**	**2.5**	**11.9**	**2.4**	**4.0**
(%COV)	(28.8)	(17.2)	(17.5)	(13.3)	(38.0)	(43.7)	(61.5)	(6.7)	(17.4)	(131.3)	(18.3)	(45.7)
SB+BB	**3.5**	**2.7**	**2.0**	**3.7**	**3.3**	**2.8**	**6.2**	**5.7**	**3.1**	**1.9**	**8.0**	**3.5**
(%COV)	(4.0)	(12.6)	(30.2)	(8.1)	(76.1)	(44.9)	(79.2)	(33.8)	(37.7)	(30.8)	(108.2)	(31.5)

see Note on page 138.

Table 4-46: Average Damping Ratios For Truss Floors: Drop-Weight Tests.

	DROP-WEIGHT TEST											
Type of Brace	MODE 1 (%Crit.)	MODE 2 (%Crit.)	MODE 3 (%Crit.)	LOG DEC (%Crit.)	MODE 1 (%Crit.)	MODE 2 (%Crit.)	MODE 3 (%Crit.)	LOG DEC (%Crit.)	MODE 1 (%Crit.)	MODE 2 (%Crit.)	MODE 3 (%Crit.)	LOG DEC (%Crit)
	S-S-S-S No Live Load				S-S-S-S 960 KN/m^2				S-S-S-S 1915 KN/m^2			
UB	2.9	1.9	2.1	3.8	2.3	2.0	1.9	3.8	6.2	2.3	1.8	4.2
(%COV)	(18.4)	(10.7)	(17.0)	(61.8)	(5.2)	(13.2)	(30.4)	(5.9)	(98.3)	(9.2)	(22.6)	(33.1)
BCB	3.6	1.8	1.8	4.2	1.8	2.1	1.4	3.7	2.9	2.3	1.7	3.7
(%COV)	(31.2)	(5.9)	(47.7)	(10.3)	(50.8)	(3.9)	(9.4)	(14.0)	(21.0)	(8.0)	(20.9)	(21.9)
XB	2.9	1.7	3.5	4.7	2.9	2.4	2.0	4.4	2.7	2.2	1.5	3.6
(%COV)	(22.1)	(23.7)	(N/A)	(15.5)	(14.5)	(15.5)	(37.7)	(28.5)	(36.6)	(27.3)	(19.3)	(43.2)
SBB	2.4	2.0	1.1	4.4	3.2	1.6	1.5	4.3	2.9	1.6	1.7	3.4
(%COV)	(30.0)	(9.8)	(18.9)	(11.8)	(43.5)	(39.5)	(70.7)	(28.7)	(17.5)	(12.2)	(N/A)	(11.8)
XB+BB	5.0	2.5	1.6	5.0	3.4	2.0	1.4	4.2	2.8	2.0	1.8	3.9
(%COV)	(42.2)	(49.2)	(12.4)	(21.2)	(38.1)	(8.0)	(23.2)	(1.3)	(11.8)	(11.9)	(51.9)	(20.5)
SB+BB	3.3	2.2	1.2	4.8	2.7	2.2	0.55	4.3	2.5	2.1	1.0	3.4
(%COV)	(25.0)	(29.0)	(4.9)	(31.9)	(18.6)	(19.1)	(N/A)	(19.0)	(31.6)	(23.7)	(141.4)	(20.9)
	S-F-S-F No Live Load				S-F-S-F 960 KN/m^2				S-F-S-F 1915 KN/m^2			
UB	3.0	1.6	2.7	4.4	2.5	2.2	2.1	4.2	2.7	2.1	2.0	3.1
(%COV)	(19.2)	(11.9)	(19.5)	(26.2)	(7.7)	(19.0)	(19.9)	(9.2)	(24.3)	(34.5)	(36.6)	(34.6)
BCB	4.3	2.4	2.4	4.5	3.1	2.0	2.3	3.8	3.4	2.7	2.1	4.1
(%COV)	(31.4)	(52.7)	(47.0)	(6.7)	(28.0)	(9.6)	(20.6)	(13.8)	(38.2)	(23.4)	(26.0)	(32.4)
XB	3.5	2.8	3.0	5.0	3.6	2.0	2.8	4.4	3.1	4.1	2.7	3.9
(%COV)	(17.3)	(37.2)	(23.5)	(16.1)	(38.8)	(24.3)	(56.6)	(20.0)	(28.3)	(74.1)	(35.3)	(39.3)
SBB	3.3	2.3	1.5	4.7	3.0	2.0	1.6	3.8	3.2	2.2	1.5	3.1
(%COV)	(24.7)	(48.5)	(32.5)	(49.9)	(22.6)	(15.3)	(24.5)	(10.9)	(11.2)	(11.8)	(20.3)	(17.5)
XB+BB	3.1	1.9	3.9	4.4	3.0	2.1	1.9	4.5	2.8	2.0	1.9	3.4
(%COV)	(4.9)	(6.0)	(36.8)	(18.9)	(31.2)	(13.1)	(26.5)	(40.4)	(9.5)	(19.2)	(7.6)	(24.3)
SB+BB	3.6	1.7	1.3	6.0	2.7	1.9	1.8	3.3	2.9	1.8	1.7	3.0
(%COV)	(21.9)	(15.6)	(11.7)	(25.0)	(10.6)	(29.0)	(8.2)	(9.5)	(7.9)	(4.4)	(1.7)	(27.6)

see Note at top of page 138.

Note: The following abbreviations are used in Tables 4-45 and 4-46.

UB = unbraced floor condition

BCB = bottom chord braced floor condition

XB = X-braced floor condition

SBB = strong-back braced floor condition

XB+BB = X plus bottom chord braced floor condition

SB+BB = strong-back plus bottom chord braced floor condition

S-S-S-S = four-sided floor support

S-F-S-F = two-sided floor support

MODE _ = average modal damping ratio (percent critical)

LOG DEC = percent critical logarithmic decrement damping ratio

(%COV) = coefficient of variation of truss floor damping ratios

N/A = insufficient data for calculation of coefficient of variation

4.3.2.4 Discussion of Modal and Logarithmic Damping Ratio Results

As with the solid-sawn floor systems, no consistent patterns were observed for any of the bracing systems. As a matter of fact, only 4 out of 240 t-Tests run showed any significant changes in damping, one was an increase in the log decrement value for a bottom-chord braced condition, one was a decrease in a strong-back braced modal ratio, and two were decreases in the strong-back plus bottom-chord braced modal ratios. Three of the four significant changes were decreases in damping while the fourth was an increase. This indicates that the bracing did not significantly affect the damping.

As with the resonant frequency results, a comparison table showing the average damping ratio results is used for comparison of each type of braced versus unbraced floors. Again, it must be stressed that the variance of the data used to calculate the means affects the outcome of the t-Test results. Though there appears to be a sizeable change between a braced and an unbraced damping ratio, if one or both of the damping ratios has a large coefficient of variation, the t-Test will not indicate that there was a significant difference. Comparison tables and discussion are presented separately for each type of bracing system.

Bottom-Chord Bracing

The bottom-chord braced versus unbraced average damping ratio comparisons are shown in Tables 4-47 and 4-48. These tables show that the bottom-chord bracing had no detectable effect on the damping ratios. Only one significant increase occurred for the logarithmic damping ratio for the free-vibration test with a S-S-S-S boundary condition and 960 kN/m^2 (20 psf) of imposed load. No other significant change was observed.

Table 4-47:
Comparison of Bottom-Chord Braced -vs- Unbraced Average Damping Ratios
Truss Floors: Free-Vibration Tests.

CHANGE IN AVERAGE MODAL AND LOGARITHMIC DAMPING RATIOS - TRUSS FLOORS: BOTTOM CHORD BRACED -vs- UNBRACED						
	FREE-VIBRATION TEST					
	S-S-S-S No Live Load			**S-F-S-F No Live Load**		
	UB (%Crit.)	**BCB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**BCB (%Crit.)**	**t-Test Result**
MODE #1	3.0	2.9	N	3.5	4.9	N
MODE #2	1.7	2.2	N	3.3	3.0	N
MODE #3	1.9	3.2	N	1.9	2.4	N
Log Dec.	4.0	4.5	N	4.1	4.6	N
	S-S-S-S 960 kN/m^2			**S-F-S-F 960 kN/m^2**		
	UB (%Crit.)	**BCB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**BCB (%Crit.)**	**t-Test Result**
MODE #1	2.3	3.2	N	4.0	9.6	N
MODE #2	2.0	2.6	N	2.9	2.0	N
MODE #3	2.9	3.4	N	5.0	3.1	N
Log Dec.	3.6	5.2	Y	4.5	4.3	N
	S-S-S-S 1915 kN/m^2			**S-F-S-F 1915 kN/m^2**		
	UB (%Crit.)	**BCB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**BCB (%Crit.)**	**t-Test Result**
MODE #1	6.3	3.2	N	4.9	3.5	N
MODE #2	3.1	2.0	N	9.1	3.0	N
MODE #3	2.6	3.4	N	4.0	2.8	N
Log Dec.	3.5	3.8	N	3.9	4.3	N

UB = unbraced floor condition
BCB = bottom chord braced floor condition
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
MODE #_ = modal damping ratio from average value table, (percent critical)
Log. Dec. = average percent critical logarithmic decrement damping ratio
Y = significant change at 95% confidence level, from t-Test
N = no significant change at 95% confidence level, from t-Test

Table 4-48:
Comparison of Bottom-Chord Braced -vs- Unbraced Average Damping Ratios
Truss Floors: Drop-Weight Tests.

CHANGE IN AVERAGE MODAL AND LOGARITHMIC DAMPING RATIOS - TRUSS FLOORS:
BOTTOM CHORD BRACED -vs- UNBRACED

	DROP-WEIGHT TEST					
	S-S-S-S No Live Load			**S-F-S-F No Live Load**		
	UB (%Crit.)	**BCB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**BCB (%Crit.)**	**t-Test Result**
MODE #1	2.9	3.6	N	3.0	4.3	N
MODE #2	1.9	1.8	N	1.6	2.4	N
MODE #3	2.1	1.8	N	2.7	2.4	N
Log Dec.	3.8	4.2	N	4.4	4.5	N
	S-S-S-S 960 kN/m^2			**S-F-S-F 960 kN/m^2**		
	UB (%Crit.)	**BCB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**BCB (%Crit.)**	**t-Test Result**
MODE #1	2.3	1.8	N	2.5	3.1	N
MODE #2	2.0	2.1	N	2.2	2.0	N
MODE #3	1.9	1.4	N	2.1	2.3	N
Log Dec.	3.8	3.7	N	4.2	3.8	N
	S-S-S-S 1915 kN/m^2			**S-F-S-F 1915 kN/m^2**		
	UB (%Crit.)	**BCB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**BCB (%Crit.)**	**t-Test Result**
MODE #1	6.2	2.9	N	2.7	3.4	N
MODE #2	2.3	2.3	N	2.1	2.7	N
MODE #3	1.8	1.7	N	2.0	2.1	N
Log Dec.	4.2	3.7	N	3.1	4.1	N

UB = unbraced floor condition
BCB = bottom chord braced floor condition
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
MODE #_ = modal damping ratio from average value table, (percent critical)
Log. Dec. = average percent critical logarithmic decrement damping ratio
Y = significant change at 95% confidence level, from t-Test
N = no significant change at 95% confidence level, from t-Test

Steel X-Bracing

The X-braced versus unbraced average damping ratio comparisons are shown in Tables 4-49 and 4-50. Based on the t-Test results, this bracing system had no significant effect on any of the damping ratios. The damping ratios calculated for the three truss floors varied too much from floor to floor, hence, based on the results of this research, it cannot be stated that there was a change in damping due to this type of bracing.

Strong-Back Bracing

The strong-back versus unbraced average damping ratios are compared in Tables 4-51 and 4-52. Again, due to variance and low sample size, no consistent effect was observed in the damping ratio data. However for the drop-weight test with a S-S-S-S boundary condition and 1915 kN/m^2 (40 psf) imposed load, the average damping ratio for mode #2 decreased due to the strong-back bracing. Since this was observed only once for this type of bracing, it cannot be concluded whether or not this is a viable result or a data abnormality.

Table 4-49:
Comparison of X-Braced -vs- Unbraced Average Damping Ratios
Truss Floors: Free-Vibration Tests.

CHANGE IN AVERAGE MODAL AND LOGARITHMIC DAMPING RATIOS - TRUSS FLOORS: X-BRACED -vs- UNBRACED						
▨	FREE-VIBRATION TEST					
	S-S-S-S No Live Load			S-F-S-F No Live Load		
	UB (%Crit.)	XB (%Crit.)	t-Test Result	UB (%Crit.)	XB (%Crit.)	t-Test Result
MODE #1	3.0	2.7	N	3.5	2.9	N
MODE #2	1.7	1.9	N	3.3	2.4	N
MODE #3	1.9	2.2	N	1.9	2.8	N
Log Dec.	4.0	3.5	N	4.1	5.4	N
	S-S-S-S 960 kN/m^2			S-F-S-F 960 kN/m^2		
	UB (%Crit.)	XB (%Crit.)	t-Test Result	UB (%Crit.)	XB (%Crit.)	t-Test Result
MODE #1	2.3	4.5	N	4.0	2.8	N
MODE #2	2.0	2.3	N	2.9	1.9	N
MODE #3	2.9	3.7	N	5.0	2.1	N
Log Dec.	3.6	3.9	N	4.5	4.6	N
	S-S-S-S 1915 kN/m^2			S-F-S-F 1915 kN/m^2		
	UB (%Crit.)	XB (%Crit.)	t-Test Result	UB (%Crit.)	XB (%Crit.)	t-Test Result
MODE #1	6.3	2.6	N	4.9	2.4	N
MODE #2	3.1	2.1	N	9.1	1.9	N
MODE #3	2.6	2.4	N	4.0	2.1	N
Log Dec.	3.5	4.0	N	3.9	3.7	N

UB = unbraced floor condition
XB = X-braced floor condition
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
MODE #_ = modal damping ratio from average value table, (percent critical)
Log. Dec. = average percent critical logarithmic decrement damping ratio
Y = significant change at 95% confidence level, from t-Test
N = no significant change at 95% confidence level, from t-Test

Table 4-50:
Comparison of X-Braced -vs- Unbraced Average Damping Ratios
Truss Floors: Drop-Weight Tests

CHANGE IN AVERAGE MODAL AND LOGARITHMIC DAMPING RATIOS - TRUSS FLOORS:
X-BRACED -vs- UNBRACED

	DROP-WEIGHT TEST					
	S-S-S-S No Live Load			**S-F-S-F No Live Load**		
	UB (%Crit.)	**XB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**XB (%Crit.)**	**t-Test Result**
MODE #1	2.9	2.9	N	3.0	3.5	N
MODE #2	1.9	1.7	N	1.6	2.8	N
MODE #3	2.1	3.5	N/A	2.7	3.0	N
Log Dec.	3.8	4.7	N	4.4	5.0	N
	S-S-S-S 960 kN/m^2			**S-F-S-F 960 kN/m^2**		
	UB (%Crit.)	**XB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**XB (%Crit.)**	**t-Test Result**
MODE #1	2.3	2.9	N	2.5	3.6	N
MODE #2	2.0	2.4	N	2.2	2.0	N
MODE #3	1.9	2.0	N	2.1	2.8	N
Log Dec.	3.8	4.4	N	4.2	4.4	N
	S-S-S-S 1915 kN/m^2			**S-F-S-F 1915 kN/m^2**		
	UB (%Crit.)	**XB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**XB (%Crit.)**	**t-Test Result**
MODE #1	6.2	2.7	N	2.7	3.1	N
MODE #2	2.3	2.2	N	2.1	4.1	N
MODE #3	1.8	1.5	N	2.0	2.7	N
Log Dec.	4.2	3.6	N	3.1	3.9	N

UB = unbraced floor condition
XB = x-braced floor condition
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
MODE #_ = modal damping ratio from average value table, (percent critical)
Log. Dec. = average percent critical logarithmic decrement damping ratio
Y = significant change at 95% confidence level, from t-Test
N = no significant change at 95% confidence level, from t-Test
N/A = insufficient number of data points for comparison

Table 4-51:
Comparison of Strong-Back Braced -vs- Unbraced Average Damping Ratios
Truss Floors: Free-Vibration Tests

CHANGE IN AVERAGE MODAL AND LOGARITHMIC DAMPING RATIOS - TRUSS FLOORS: STRONG-BACK BRACED -vs- UNBRACED

	FREE-VIBRATION TEST					
	S-S-S-S No Live Load			**S-F-S-F No Live Load**		
	UB (%Crit.)	**SBB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**SBB (%Crit.)**	**t-Test Result**
MODE #1	3.0	2.8	N	3.5	2.7	N
MODE #2	1.7	2.0	N	3.3	3.1	N
MODE #3	1.9	1.2	N	1.9	1.5	N
Log Dec.	4.0	3.6	N	4.1	3.8	N
	S-S-S-S 960 kN/m^2			**S-F-S-F 960 kN/m^2**		
	UB (%Crit.)	**SBB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**SBB (%Crit.)**	**t-Test Result**
MODE #1	2.3	3.1	N	4.0	2.2	N
MODE #2	2.0	1.9	N	2.9	2.1	N
MODE #3	2.9	6.9	N	5.0	1.4	N
Log Dec.	3.6	4.8	N	4.5	3.7	N
	S-S-S-S 1915 kN/m^2			**S-F-S-F 1915 kN/m^2**		
	UB (%Crit.)	**SBB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**SBB (%Crit.)**	**t-Test Result**
MODE #1	6.3	3.7	N	4.9	2.9	N
MODE #2	3.1	4.6	N	9.1	5.7	N
MODE #3	2.6	5.6	N	4.0	7.5	N
Log Dec.	3.5	4.0	N	3.9	4.4	N

UB = unbraced floor condition
SBB = strong-back braced floor condition
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
MODE #_ = modal damping ratio from average value table, (percent critical)
Log. Dec. = average percent critical logarithmic decrement damping ratio
Y = significant change at 95% confidence level, from t-Test
N = no significant change at 95% confidence level, from t-Test

Table 4-52:
Comparison of Strong-Back Braced -vs- Unbraced Average Damping Ratios
Truss Floors: Drop-Weight Tests

CHANGE IN AVERAGE MODAL AND LOGARITHMIC DAMPING RATIOS - TRUSS FLOORS: STRONG-BACK BRACED -vs- UNBRACED

	DROP-WEIGHT TEST					
	S-S-S-S No Live Load			**S-F-S-F No Live Load**		
	UB (%Crit.)	**SBB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**SBB (%Crit.)**	**t-Test Result**
MODE #1	2.9	2.4	N	3.0	3.3	N
MODE #2	1.9	2.0	N	1.6	2.3	N
MODE #3	2.1	1.1	N	2.7	1.5	N
Log Dec.	3.8	4.4	N	4.4	4.7	N
	S-S-S-S 960 kN/m²			**S-F-S-F 960 kN/m²**		
	UB (%Crit.)	**SBB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**SBB (%Crit.)**	**t-Test Result**
MODE #1	2.3	3.2	N	2.5	3.0	N
MODE #2	2.0	1.6	N	2.2	2.0	N
MODE #3	1.9	1.5	N	2.1	1.6	N
Log Dec.	3.8	4.3	N	4.2	3.8	N
	S-S-S-S 1915 kN/m²			**S-F-S-F 1915 kN/m²**		
	UB (%Crit.)	**SBB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**SBB (%Crit.)**	**t-Test Result**
MODE #1	6.2	2.9	N	2.7	3.2	N
MODE #2	2.3	1.6	Y	2.1	2.2	N
MODE #3	1.8	1.7	N/A	2.0	1.5	N
Log Dec.	4.2	3.4	N	3.1	3.1	N

UB = unbraced floor condition
SBB = strong-back braced floor condition
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
MODE #_ = modal damping ratio from average value table, (percent critical)
Log. Dec. = average percent critical logarithmic decrement damping ratio
Y = significant change at 95% confidence level, from t-Test
N = no significant change at 95% confidence level, from t-Test
N/A = insufficient number of data points for comparison

X- plus Bottom-Chord Bracing

The X- plus bottom-chord bracing versus unbraced average damping ratios are compared in Tables 4-53 and 4-54. Based on the t-Test results, this bracing combination had no significant effect on any of the braced versus unbraced damping ratios. Due to this fact, any trends seen in the data are speculation, not based on statistical information. For instance, consider the mode #1 damping ratio for the free-vibration tests, braced versus unbraced values shown in Table 4-53. The average damping ratios appear to increase in five of six cases, however, when the coefficient of variation of these averages is considered, this observation loses validity.

Table 4-53:
Comparison of X plus Bottom- Chord Braced -vs- Unbraced Average Damping Ratios
Truss Floors: Free-Vibration Tests

CHANGE IN AVERAGE MODAL AND LOGARITHMIC DAMPING RATIOS - TRUSS FLOORS:
X- plus BOTTOM CHORD BRACED -vs- UNBRACED

	FREE-VIBRATION TEST					
	S-S-S-S No Live Load			S-F-S-F No Live Load		
	UB (%Crit.)	XB+BB (%Crit.)	t-Test Result	UB (%Crit.)	XB+BB (%Crit.)	t-Test Result
MODE #1	3.0	2.6	N	3.5	3.6	N
MODE #2	1.7	2.1	N	3.3	2.8	N
MODE #3	1.9	1.1	N	1.9	2.5	N
Log Dec.	4.0	4.1	N	4.1	4.4	N
	S-S-S-S 960 kN/m^2			S-F-S-F 960 kN/m^2		
	UB (%Crit.)	XB+BB (%Crit.)	t-Test Result	UB (%Crit.)	XB+BB (%Crit.)	t-Test Result
MODE #1	2.3	2.6	N	4.0	3.2	N
MODE #2	2.0	2.1	N	2.9	4.5	N
MODE #3	2.9	1.9	N	5.0	4.9	N
Log Dec.	3.6	4.5	N	4.5	4.9	N
	S-S-S-S 1915 kN/m^2			S-F-S-F 1915 kN/m^2		
	UB (%Crit.)	XB+BB (%Crit.)	t-Test Result	UB (%Crit.)	XB+BB (%Crit.)	t-Test Result
MODE #1	6.3	3.2	N	4.9	2.5	N
MODE #2	3.1	6.7	N	9.1	11.9	N
MODE #3	2.6	4.4	N	4.0	2.4	N
Log Dec.	3.5	4.4	N	3.9	4.0	N

UB = unbraced floor condition
XB+BB = X- plus bottom-chord braced floor condition
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
MODE #_ = modal damping ratio from average value table, (percent critical)
Log. Dec. = average percent critical logarithmic decrement damping ratio
Y = significant change at 95% confidence level, from t-Test
N = no significant change at 95% confidence level, from t-Test

Table 4-54:
Comparison of X plus Bottom-Chord Braced -vs- Unbraced Average Damping Ratios
Truss Floors: Drop-Weight Tests

CHANGE IN AVERAGE MODAL AND LOGARITHMIC DAMPING RATIOS - TRUSS FLOORS:
X- plus BOTTOM CHORD BRACED -vs- UNBRACED

DROP-WEIGHT TEST

	S-S-S-S No Live Load			S-F-S-F No Live Load		
	UB (%Crit.)	XB+BB (%Crit.)	t-Test Result	UB (%Crit.)	XB+BB (%Crit.)	t-Test Result
MODE #1	2.9	5.0	N	3.0	3.1	N
MODE #2	1.9	2.5	N	1.6	1.9	N
MODE #3	2.1	1.6	N	2.7	3.9	N
Log Dec.	3.8	5.0	N	4.4	4.4	N

	S-S-S-S 960 kN/m^2			S-F-S-F 960 kN/m^2		
	UB (%Crit.)	XB+BB (%Crit.)	t-Test Result	UB (%Crit.)	XB+BB (%Crit.)	t-Test Result
MODE #1	2.3	3.4	N	2.5	3.0	N
MODE #2	2.0	2.0	N	2.2	2.1	N
MODE #3	1.9	1.4	N	2.1	1.9	N
Log Dec.	3.8	4.2	N	4.2	4.5	N

	S-S-S-S 1915 kN/m^2			S-F-S-F 1915 kN/m^2		
	UB (%Crit.)	XB+BB (%Crit.)	t-Test Result	UB (%Crit.)	XB+BB (%Crit.)	t-Test Result
MODE #1	6.2	2.8	N	2.7	2.8	N
MODE #2	2.3	2.0	N	2.1	2.0	N
MODE #3	1.8	1.8	N	2.0	1.9	N
Log Dec.	4.2	3.9	N	3.1	3.4	N

UB = unbraced floor condition
XB+BB = X- plus bottom-chord braced floor condition
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
MODE #_ = modal damping ratio from average value table, (percent critical)
Log. Dec. = average percent critical logarithmic decrement damping ratio
Y = significant change at 95% confidence level, from t-Test
N = no significant change at 95% confidence level, from t-Test

Strong-Back plus Bottom-Chord Bracing

The strong-back plus bottom-chord bracing versus unbraced average damping ratios are compared in Tables 4-55 and 4-56. There were two significant changes in average damping ratios for this bracing condition. Both occurred in the drop-weight tests, and both were significant decreases. One decrease occurred in the average modal damping ratio for mode #3, for a floor with zero imposed load and the S-S-S-S boundary condition. The second decrease occurred in the average logarithmic damping ratio for a floor with the S-F-S-F boundary condition and 960 kN/m^2 (20 psf) imposed load. Since the changes were observed only twice for this type of bracing, it cannot be deduced whether this is a viable result or a data abnormality. Since the damping ratio is a measure of energy dissipation, the result would signify that by adding bracing, and thus adding additional stiffness to the floor system, the damping ratio is decreased. By increasing the floor stiffness, the frequency of the floor should also increase. When this increase in frequency is accompanied by an increase in damping, the overall result would be a reduction in the duration of oscillation. However, no significant reduction in duration of oscillation was observed for this bracing condition.

Table 4-55:
Comparison of Strong-Back plus Bottom- Chord Braced -vs- Unbraced
Average Damping Ratios
Truss Floors: Free-Vibration Tests

CHANGE IN AVERAGE MODAL AND LOGARITHMIC DAMPING RATIOS - TRUSS FLOORS:
STRONG-BACK plus BOTTOM CHORD BRACED -vs- UNBRACED

	FREE-VIBRATION TEST					
	S-S-S-S No Live Load			**S-F-S-F No Live Load**		
	UB (%Crit.)	**SB+BB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**SB+BB (%Crit.)**	**t-Test Result**
MODE #1	3.0	2.9	N	3.5	3.5	N
MODE #2	1.7	3.6	N	3.3	2.7	N
MODE #3	1.9	2.5	N	1.9	2.0	N
Log Dec.	4.0	4.2	N	4.1	3.7	N
	S-S-S-S 960 kN/m^2			**S-F-S-F 960 kN/m^2**		
	UB (%Crit.)	**SB+BB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**SB+BB (%Crit.)**	**t-Test Result**
MODE #1	2.3	2.7	N	4.0	3.3	N
MODE #2	2.0	3.5	N	2.9	2.8	N
MODE #3	2.9	3.2	N	5.0	6.2	N
Log Dec.	3.6	4.8	N	4.5	5.7	N
	S-S-S-S 1915 kN/m^2			**S-F-S-F 1915 kN/m^2**		
	UB (%Crit.)	**SB+BB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**SB+BB (%Crit.)**	**t-Test Result**
MODE #1	6.3	2.3	N	4.9	3.1	N
MODE #2	3.1	1.7	N	9.1	1.9	N
MODE #3	2.6	2.4	N	4.0	8.0	N
Log Dec.	3.5	3.7	N	3.9	3.5	N

UB = unbraced floor condition
XB+BB = X- plus bottom-chord braced floor condition
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
MODE #_ = modal damping ratio from average value table, (percent critical)
Log. Dec. = average percent critical logarithmic decrement damping ratio
Y = significant change at 95% confidence level, from t-Test
N = no significant change at 95% confidence level, from t-Test

Table 4-56:
Comparison of Strong-Back plus Bottom-Chord Braced -vs- Unbraced
Average Damping Ratios
Truss Floors: Drop-Weight Tests.

CHANGE IN AVERAGE MODAL AND LOGARITHMIC DAMPING RATIOS - TRUSS FLOORS:
STRONG-BACK plus BOTTOM CHORD BRACED -vs- UNBRACED

▨	**DROP-WEIGHT TEST**					
	S-S-S-S No Live Load			**S-F-S-F No Live Load**		
	UB (%Crit.)	**SB+BB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**SB+BB (%Crit.)**	**t-Test Result**
MODE #1	2.9	3.3	N	3.0	3.6	N
MODE #2	1.9	2.2	N	1.6	1.7	N
MODE #3	2.1	1.2	Y	2.7	1.3	N
Log Dec.	3.8	4.8	N	4.4	6.0	N
	S-S-S-S 960 kN/m^2			**S-F-S-F 960 kN/m^2**		
	UB (%Crit.)	**SB+BB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**SB+BB (%Crit.)**	**t-Test Result**
MODE #1	2.3	2.7	N	2.5	2.7	N
MODE #2	2.0	2.2	N	2.2	1.9	N
MODE #3	1.9	0.55	N	2.1	1.8	N
Log Dec.	3.8	4.3	N	4.2	3.3	Y
	S-S-S-S 1915 kN/m^2			**S-F-S-F 1915 kN/m^2**		
	UB (%Crit.)	**SB+BB (%Crit.)**	**t-Test Result**	**UB (%Crit.)**	**SB+BB (%Crit.)**	**t-Test Result**
MODE #1	6.2	2.5	N	2.7	2.9	N
MODE #2	2.3	2.1	N	2.1	1.8	N
MODE #3	1.8	1.0	N/A	2.0	1.7	N
Log Dec.	4.2	3.4	N	3.1	3.0	N

UB = unbraced floor condition
SB+BB = strong-back plus bottom-chord braced floor condition
S-S-S-S = four-sided floor support
S-F-S-F = end supported only floor support
MODE #_ = modal damping ratio from average value table, (percent critical)
Log. Dec. = average percent critical logarithmic decrement damping ratio
Y = significant change at 95% confidence level, from t-Test
N = no significant change at 95% confidence level, from t-Test
N/A = insufficient number of data points for comparison

4.4 Conclusion

This chapter presented the static and dynamic results for both types of floor systems. Three parameters were presented: load and percent total load carried for the unbraced and braced floors, resonant frequencies of the unbraced and braced floors, and modal and logarithmic damping ratios for unbraced and braced floors. The reader must bear in mind that these results are based on a small number of test specimens, and therefore must not be considered as deterministic. The results of the statistical comparison tests performed on the data may therefore show no effect due to a bracing type when actually there was. While this is almost always the case with scientific research, it is more probable when a small number of specimens are used.

Also, one must remember that the effects of time and moisture changes are not present in these results. The performance of these bracing systems could be affected due to shrinking and swelling of the floors due to variation in moisture and cycles of heating and cooling. The connections used for the various bracing systems could loosen over time as the floor is loaded and unloaded.

V

CONCLUSIONS

5.1 Introduction

This chapter will summarize the results and discussions for the solid-sawn and parallel chord truss floor systems. Included in this summary will be a discussion of each type of bracing system studied in the thesis. Research and design recommendations will then be presented to close-out this chapter.

5.2 Solid-Sawn Bracing Systems

The results for the three types of solid sawn bracing system will be summarized here. Both the static and dynamic results will be summarized for each type of bracing in order to give the reader an overall impression of the performance of each system. The performance of each bracing system is based on each system's effects on three parameters: percent reduction in load carried by the loaded joist/truss (reduction in deflection), change in, and separation of resonant frequencies, and finally, change in damping ratios. What does a change in each of these parameters mean to someone building a floor in the field? A reduction in the amount of load carried by the loaded joist/truss results in an improvement in a floor's ability to act as a system rather than as a series of individual joists/trusses. An improvement in load sharing, improves the floor's ability to transfer the loads applied to it. This affects an occupant's perception of impact loads and often makes the floor system more acceptable to occupants.

A change in the magnitude and separation of resonant frequencies is a relative matter. If a bracing system is found to raise either the first fundamental frequency, or one or more of the higher frequencies, this could be beneficial depending on the type of loads the floor is subjected to. For instance, if a piece of rotating machinery is placed on a floor, and the frequency of rotation of the machine is close to one or more of the floor's frequencies, then the floor's response will be unacceptable. A bracing system which is known to raise the floor's frequency could be installed as a remedial measure. Conversely, if an existing floor with this bracing system is found to have an undesirable response to some dynamic load, the bracing could be removed, with the possibility that the resonant frequencies of the floor system would be changed enough to remedy the problem. For a type of bracing which increases the separation between modes of vibration, the bracing system could be installed in a floor to decrease the interaction between adjacent modes of vibration (modes #1 and #2, for instance). Reducing interaction between adjacent frequencies, can improve a floor's response to random dynamic loading.

An increase in the damping ratio for a floor, improves it's ability to dissipate energy. If a bracing system increases the damping characteristics of a floor, the floor's ability to absorb impact, and other random dynamic loadings, is improved. With these ideas in mind, the results for each bracing system will be summarized and discussed.

5.2.1 Bridging

In the static load test, bridging reduced the load carried by the loaded joist by an average of 12% . Dynamically, bridging had no significant effect on the first fundamental frequencies for the floor conditions tested. However, it did effect the magnitude and separation between the resonant frequencies of the higher modes of vibration in 13 out of a possible 32 tests. The X-bridging significantly changed the damping of the solid-sawn floors in more tests than the other solid-sawn bracing systems investigated. X-bracing significantly raised the modal damping for four of the 32 modal damping ratios calculated. Due to the non-deterministic characteristic of damping ratios, it cannot be stated that bridging will or will not change a floor's damping characteristics. Bridging improved the floor performance by increasing the transverse stiffness of the floor system, improving the load sharing, and also by increasing the number of connections in the system in which to dissipate energy.

5.2.2 Blocking

Blocking reduced the load carried by the loaded joist by an average of 15.5% . The blocking raised the value of the first resonant frequency two out of twelve times, an average of 0.6 Hz. It also increased the magnitude and separation between the higher modes of vibration in 14 out of 32 tests. The blocking significantly raised the modal damping ratio once.

5.2.3 Post-Tensioned Blocking

From the static load tests, the post-tensioned blocking reduced the load carried by the loaded joist by an average of 19.9% . This bracing system did not significantly effect the first fundamental frequency for any of the floor conditions tested. This is in part due to the variance of the results for each floor causing the t-Test to fail to indicate the occurrence of a significant change. The post-tensioned blocking affected the magnitude and separation between the higher modes of vibration in 19 out of 32 tests. This bracing system showed changes in the higher modes more often than any of the other bracing systems investigated. Post-tensioning significantly raised the modal damping ratio for two floor conditions, and lowered it once.

Overall, the bracing systems investigated for the solid-sawn floors improved the static response of the floors, but had no significant effect in the dynamic characteristics of the floors.

5.3 Parallel Chord Truss Bracing Systems

The conclusions drawn from the static and dynamic tests for each of the five bracing systems investigated in this thesis will be presented next.

5.3.1 Bottom-Chord Bracing

This bracing system had reduced the load carried by the loaded truss by an average of 2.9%, however, the variance in the data was so great that it cannot be stated that this bracing system would be effective in increasing the load sharing capabilities of a truss floor.

Bottom-chord bracing did not significantly change the first fundamental frequency for any of the test or floor conditions used in this research. The bottom-chord bracing did effect the higher frequencies and the separation between them in 10 of 48 tests. However, this bracing was effective mainly for the S-S-S-S boundary condition. It significantly changed a mode of vibration for the S-F-S-F boundary condition only once. Bottom-chord bracing changed only one damping ratio out of 48 possible, and therefore, it cannot be said that this system will effect the damping characteristics of a truss floor system.

5.3.2 X-Bracing

X-bracing reduced the load carried by the loaded truss by an average of 7.4 %. Again, the variance for this bracing system was high and it's improvement in the load sharing ability at the load level used is questionable. This bracing system did not significantly change any of the first fundamental frequencies for the test conditions used in this experiment. It affected the magnitude and separation between the adjacent resonant frequencies of the higher modes of vibration in 9 of 48 tests. It also had no discernable effect on the damping of any of the floors.

5.3.3 Strong-Back Bracing

The strong-back reduced the load carried by the loaded truss by an overall average of 28.5 %. The variance of these reductions was also less than that of the two previous bracing systems. The strong-back raised the first fundamental frequency in two out of a possible twelve tests. It affected the magnitude and separation between the higher modes of vibration in 22 out of 48 tests. The strong-back changed the damping one time, in which it significantly reduced the damping of mode #2, for the floor with 1915 kN/m^2 (40 psf) imposed load, and S-S-S-S boundary condition.

5.3.3 X plus Bottom Chord Bracing

This bracing combination reduced the load carried by the loaded truss by an overall average of 20.5 %. The variation in these reductions was on the order of that of the strong-back bracing. This bracing combination raised the first fundamental frequency in four out of 12 tests. The magnitude and separation between the higher modes of vibration was increased in 14 out of 48 tests. This bracing system had no effect on any of the modal or log damping ratios.

5.3.4 Strong-Back plus Bottom Chord Bracing

This bracing combination significantly reduced the load carried by the loaded truss by an overall average of 33.4 %. It significantly raised the first fundamental frequency in two of 12 tests. The higher frequencies and separation between those frequencies was significantly raised in fifteen of 48 tests, five times for the S-S-S-S boundary condition, and ten times with the S-F-S-F boundary condition. The bracing combination affected the modal and logarithmic damping for two floor conditions: once it significantly reduced the damping of mode #3 for the S-S-S-S boundary condition with no imposed load in the drop weight test, and once it reduced the logarithmic decrement damping for the S-F-S-F boundary condition with 960 kN/m^2 (20 psf) imposed load also in a drop weight test.

5.4 Conclusion - Future Research and Design Recommendations

The solid-sawn bracing system of post-tensioned blocking showed potential for improving the static and dynamic response of wood floor systems. This system could be used to retrofit existing floors with good results. The writer recommends that when investigating or installing the post-tension apparatus, the hole for the post-tension rod be drilled slightly lower than the mid-depth line on the floor joist, for optimum benefit from the post-tension rod. It is also recommended that any future research use a larger number of floor specimens for a more deterministic idea of the benefits of this bracing system.

Should one decide to use one of these bracing systems in practice, the writer proposes that at least two lines of bracing, preferably at third points along the joist or truss span, be used in floor systems. It is also recommended that either the steel X-bracing or strong-back bracing be installed in truss floors. The strong-back alone, and both of the combination truss bracing systems, showed significant improvements in the static and dynamic response of truss floors. If the steel X- or strong-back bracing is attached during installation of the trusses, and if drywall is then attached to the underside of the trusses, a combination bracing system would exist. The combination of the strong-back and bottom-chord bracing was found to be the most effective bracing system for the parallel chord truss floors. The strong-back alone, and the steel X-bracing plus bottom-chord bracing also were effective retrofits for truss floors. Steel X-bracing or bottom-chord bracing alone were ineffective as retrofits for improving floor performance.

LITERATURE CITED:

[1] Arapetyan, R., G. Schierle. 1990. *Vibration Reduction Using Prestress In Wood Floor Framing*. Proceedings of the Forth Rail Bridge Centenary Conference. Edinburgh, Scotland. 2:1196-1201.

[2] Atherton, G.H., S.E. Corder, J.L. Jenkins, A. Polensek. 1972. *Response of Nailed Wood-Joist Floors to Static Loads*. Forest Products Journal. 22(9):52-61.

[3] Berg, Glen V. 1989. *Elements of Structural Dynamics*. New Jersey. Prentice-Hall. pp. 36,37.

[4] Chui, Y.H. 1986a. *Vibrational Performance Of Timber Floors And The Related Human Discomfort*. Journal of the Institute of Wood Science. 10(5): 183-186.

[5] Chui, Y.H. 1990. *A Dynamic Approach For Timber Floor Design*. The New Zealand Journal of Timber Construction. 6(1): 9-10.

[6] Clough, Ray W., and Joseph Penzien. 1975. *Dynamics of Structures*. New York. McGraw-Hill. pp. 70-73.

[7] Corder, S., D. Jordan. 1975. *Some Performance Characteristics Of Wood Joist Floor Panels*. Forest Products Journal. 25(2):38-44.

[8] DADiSP. 1991. *Data Analysis and Display Software*. DSP Development Corporation. Cambridge, MA. November 1991.

[9] Minitab. 1991. *Minitab Statistical Software*. Version 8.2. Minitab Inc. State College, PA. 1991.

[10] National Association of Home Builders. 1961. *Bridging In Residential Floor Construction*. Research Institute Lab. LR-6. :26-37, 48-80.

[11] Ohlsson, S. 1986. *A Note On Floor Vibration and Serviceability*. Summary of a presentation at CIB-W56 meeting, Stockholm Sweden. pp. 1,2.

[12] Ohlsson, S. 1988a. *Ten Years Of Floor Vibration Research-A Review Of Aspects And Some Results*. Presented at the Symposium on Serviceability of Buildings held at the University of Ottawa. pp. 2.

[13] Ohlsson, S. 1988b. *Springiness and Human-Induced Floor Vibrations; A Design Guide*. Document D12-1988. Swedish Building Council for Building Research, Stockholm Sweden. pp. 14,44,52.

[14] Ohlsson, S. 1988c. *Stiffness Characteristics Of Wood Joist Floors*. Proceedings of the International Timber Engineering Conference, Seattle Washington. pp. 1-3.

[15] Onysko, D. 1970. *Performance Of Wood-Joist Floors I; A Questionnaire Survey*. Eastern Forest Products Laboratory. Report No. OPX 120E. Ottawa. 1975. pp. 18,19.

[16] Onysko, D. 1988. *Deflection Serviceability Criteria For Residential Floors*. Report for Forintek Canada Corp. Project No. 43-10C-024. Ottawa, Canada. pp. 2-4.

[17] Onysko, D. 1988b. *Performance And Acceptability Of Wood Floors-Forintek Studies*. Proceedings of a Symposium/Workshop on Serviceability of Buildings held at the University of Ottawa May 16-18, 1988. National Research Council of Canada, Ottawa. pp. 1-4.

[18] Polensek, A. 1970. *Human Response to Vibration of Wood-Joist Floor Systems*. Wood Science. 3(2):111-119.

[19] Polensek, A.1971. *Static And Dynamic Properties Of Glued Wood-Joist Floors*. Forest Products Journal. 21(12):31-39.

[20] Polensek, A. 1975. *Damping Capacity of Nailed Wood-Joist Floors*. Wood Science. 8(2):141-151.

[21] Stark, J., and J.D. Dolan. 1993a. *Detailed Data for Lateral Bracing Vibration Tests of Solid-Sawn Floors*. Department of Wood Science. Virginia Polytechnic Institute and State University, Blacksburg, VA.

[22] Stark, J., and J.D. Dolan. 1993b. *Detailed Data for Lateral Bracing Vibration Tests of Parallel-Chord Truss Floors.* Department of Wood Science. Virginia Polytechnic Institute and State University, Blacksburg, VA.

[23] Yeh, C.T., B.J. Hartz, C.B. Brown. 1971. *Damping Sources In Wood Structures*. Journal of Sound and Vibration. 19(4):411-419.

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May 1993