Effectiveness of strong-back/wood I-blocking for improving vibration performance of engineered wood floors

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ABSTRACT

It is recognised that cross-bridging used in solid sawn lumber joist floors improves floor vibration performance. Little technical information is currently available on the effectiveness of strong-back/blocking/bridging for improving vibration performance of engineered wood floors. To bridge the information gap, experimental and subjective evaluations were conducted on a truss floor (L/360 floor) before and after the installation of strong-backs, and on a wood I-joist floor (L/450 floor) before and after the installation of wood I-blocking. The effects of strong-back spacing and stiffness on its effectiveness were further examined. It was found that the installation of strong-backs and wood I-blocking significantly reduced static deflections and reduced dynamic responses of the floors with moderate improvements in subjective evaluation ratings. No significant change was found in the fundamental natural frequencies and modal-damping ratios of the floors resulting from the installation of strong-backs/wood I-blocking. Reducing strong-back spacing from 3 m to 2 m improved its effectiveness. Doubling strong-back stiffness also slightly improved its effectiveness, but the improvement was too small to be perceptible by the evaluators. However, it was observed that the installation of one or two rows of strong-backs in the truss floor or one row of wood I-blocking in the wood I-joist floor did not improve vibration performance sufficiently to satisfy the evaluators. It is concluded that the installation of strong-backs and wood I-blocking improves vibration performance for engineered wood floors to some degree, depending on their spacing and stiffness as well as other factors that will be reported later. On the basis of these results, it appears that more technical information is required on the contribution of performance-enhancing elements such as strong-back/blocking/bridging towards increasing allowable span for engineered wood floors.

1. INTRODUCTION

It is recognized that cross-bridging used in solid sawn lumber joist floors improves floor vibration performance. The contribution of cross-bridging in solid sawn lumber joist floors was taken into account in the floor vibration-controlled design method in Part-9 of National Building Code of Canada (NBCC 1995). Little technical information is currently available on the effectiveness of strong-back/blocking/bridging for improving vibration performance of engineered wood floors. The wood industry in most countries has used a rule of thumb that calls for a maximum spacing of 2.1 m (7 feet) for bridging and strong-back. The rationale for this spacing does not appear to have any scientific basis.

To bridge the information gap, a series of laboratory studies on the effectiveness of strong-back/blocking/bridging for improving engineered wood floor performance was conducted at Forintek Canada Corp. and University of New Brunswick (UNB). It was found that the effectiveness of strong-back/blocking/bridging is affected by such floor construction parameters as joist depth, joist spacing, floor deck thickness, presence of floor ceilings, ceiling stiffness, strong-back stiffness, spacing of strong-back/solid blocking/cross-bridging, etc. Blocking type and the method of attachment also affect its effectiveness. As it is not possible to report all of our results in this paper, it focuses on two studies. One study concerns the effectiveness of strong-back spacing and stiffness for improving the vibration performance of a wood truss floor. The second study concerns the effectiveness of wood I-blocking instead of solid wood blocking for improving the vibration performance of a wood I-joist floor.

These two studies were conducted at Forintek's eastern laboratory. In the first study, four cases were examined. Case 1-A, the base floor, was a 5.9 m (about 20 feet) span wood truss floor with a plywood sub-floor. Case 1-B was the base floor with one row of strong-back at mid-span. Case 1-C was the base floor with two rows of strong-backs at mid-span. Case 1-D was the base floor with two rows of strong-backs spaced at about 2 m (7 feet). The base floor was designed to meet a

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deflection criterion of L/360 under a uniform live load of 1.9 kPa (40 psf). In the second study, two cases were examined. Case 2-A, the base floor, was a 4.9 m (16 feet) span wood I-joists floor with a plywood sub-floor. Case 2-B was the base floor with one row of wood I-blocking at mid-span. The base floor was under-designed since the recommended L/480 span is 4.6 m (15 feet 1 inch).

The vibration performance of all test floors was subjectively evaluated by 20 evaluators using a protocol evolved at Forintek which includes a questionnaire and rating score system. Performance tests were also conducted using protocols developed at Forintek (Hu 1998). The performance tests include a concentrated load test to determine static deflections under the action of a 1 kN concentrated load; a shaker excitation test to determine natural frequencies and modal-damping ratios; and a ball-drop impact test to determine real-time dynamic responses to an impulse. The 1 kN static load and ball-drop impact were applied at various locations along the centre joist while measurements were taken at the same locations to estimate the distance over which the strong-backs and the wood I-blocking might be considered effective.

2. DESCRIPTION OF THE TEST FLOORS

2.1. Wood truss floor

The base floor 1-A, had a clear span of 5.9 m and a width of 4.9 m. It was constructed with 238 mm deep wood floor trusses spaced at 400 mm on centres and 15.5 mm T&G Canadian Softwood Plywood sub-floor. The sub-floor was attached to the trusses with No.8, 50 mm long flooring screws. Figure 1 shows the floor plan with the numbering and layout of the trusses. This floor was installed on a 1.6 m-high wood foundation that permitted access to the underside of the floor structure. In cases 1-B and 1-C the strong-backs of 38mm by 140 mm lumber were installed according to the guidelines provided in the CCMC concluding report (CWC et al.1997), three 76 mm nails were used per joist to attach the strong-backs to the vertical cords at mid-span. In case 1-D the strong-backs were nailed to two rows of 38 mm by 89mm wood blocks spaced at about 2 m. The wood blocks were connected to each truss at top and bottom flanges with two 76mm nails. In all cases ends of the strong-backs were attached to the edge joists resting on the wood foundation.

2.2. Wood I-joist floor

The base floor 2-A, had a clear span of 4.9 m and a width of 4.9 m. It was constructed with 243 mm deep wood I-joists spaced at 488 mm on centres and 15.5 mm T&G Canadian Softwood Plywood sub-floor. The joist ends were attached to the walls with face mount joist hangers. The two floor edges were not supported. The sub-floor was attached to the I-joists with No.8, 50 mm long flooring screws. The wood I-joist blocking was cut from the same floor joist material to a length tightly fitting the space between two joists. Each blocking was fastened with two 89 mm long toenails per flange.

In both studies the mechanical properties of the floor components were determined non-destructively. A free-free transverse vibration technique developed by Chui (1991) was used to determine the true bending and shear stiffness for the trusses and wood I-joists. Strong-back apparent bending stiffness was also determined on the basis of their fundamental frequencies of free-free beam vibration. The bending stiffness and planar shear stiffness of the plywood sub-floor panels were determined by a cantilever plate vibration technique developed by Lau and Tardif (1991). Table 1 summarises the mean values of the measured properties.

3. PERFORMANCE TEST METHODS

The methods used for performance testing were based on the floor test protocols developed at Forintek and reported by Hu (1998), which were presented to the October, 1997 meeting of ASTM D07 on Wood.

3.1. 1kN concentrated load test

This test was conducted to determine the static deflections of the floors under a 1 kN concentrated static load. The basic elements needed to measure static deflection under a concentrated load are: (a) a stable reference from which to measure floor movement, (b) accurate and sensitive deflection measuring devices, and (c) a loading system. A person (tester) having an approximate weight of 1 kN was used as the concentrated load. A 241 mm (9.5") wood I-joist supported on the edges of the test floors was used as the reference beam for deflection measurements. Seven electronic gauges with a resolution of 0.001 mm were mounted on the reference beam and used to simultaneously measure deflection over selected joist locations. To account for variation in weight of the tester over time the deflection data was normalised to concentrated load of 1 kN.

The tester applied the concentrated load while standing over the centre joist at each of the locations of interest. Three deflection measurements were recorded for each loading. The average of the three sets of deflection profiles was then used to represent the deflection profile of the test floor.

To estimate the distance over which the strong-backs and the wood I-blocking might be considered effective, deflection profiles in the across-joist direction were measured at an interval of span/6 for the truss floor, and at an interval of span/8 for the wood I-joist floor. For each deflection profile measurement, the concentrated load was applied on the centre joist at each of the locations, and the deflection measured under the centre joist and each of the three adjacent joists on either side of it. This resulted in five deflection profiles in the across-joist direction for the truss floor (seven for the wood I-joist floor), and in a profile of maximum static deflection along the centre joist under the 1 kN load at various locations on the centre joist. The maximum deflection profile along the centre joist provided an estimation of the distance over which any performance enhancement element in a floor might be considered effective.

3.2. Dynamic tests

The tests were conducted to determine the dynamic characteristics of the floors such as natural frequencies, viscous modal-damping ratios, and Root-Mean-Square (RMS) acceleration or initial velocity response to a 1 N-Second (N-s) impulse. The test procedure was carried out in two parts: (a) modal testing to determine the natural frequencies and viscous modal-damping ratios, (b) forced vibration testing to determine the acceleration/velocity responses to a dynamic impact load.

A typical dynamic test system consists of three major items: (a) an exciter for inducing floor vibrations, (b) a transduction system for acquiring the excitation force and the floor vibration signals, (c) a signal analyzer for extracting the desired information from the acquired signals. Several devices can be used as the exciter. In this study, a 45 kN shaker was used as the exciter for modal testing, while a 5 kg medicine-ball was used as the exciter in forced vibration testing. The medicine-ball measuring approximately 310 mm in diameter was soft bodied. A force transducer having a sensitivity of 0.23 mv/N was used to acquire the excitation forces. Six accelerometers having sensitivity of about 500 mv/g were used to acquire the floor vibration responses. The accelerometers were attached to the plywood sub-floor with beeswax. A multi-channel analyzer was used to record and post-process the signals.

Modal testing followed a standard procedure generally described in ISO 7626-2 (1990) and specified in Forintek's protocols (Hu 1998). Random excitation was selected because of its many advantages as discussed in ISO 7626-2 (1990). The shaker was located on a joist adjacent to the centre joist and offset from the mid-span of the test floor areas. At such a location, it was unlikely that a nodal point of the first five modes would exist. The floor vibration was measured at mid-span of each joist. Figure 1 shows a typical modal test set-up and the locations for the shaker and accelerometers. The force and acceleration signals were recorded by the multi-channel analyzer and were post-processed to determine the natural frequencies and viscous modal damping ratios.

Forced vibration testing followed a procedure also described in the Forintek floor test protocols (Hu 1998). The excitation was generated by dropping the 5 kg medicine-ball onto a test floor through a force plate instrumented with the force transducer. A tester performed the ball-drop while sitting on a stool located on the floor. The ball was caught when it rebounded to avoid multiple impacts. An accelerometer was always located at the impact location to measure the response of the floor. Ball-drop impact tests were conduced at several locations along the centre joists to further estimate the distance over which the strong-backs and the wood I-blocking might be considered effective. Five measurements at an interval of span/6 along the centre joist were taken on the truss floor, and seven measurements at an interval of span/8 along the centre joist in the wood I-joist floor. Again the impact force and acceleration signals were recorded by the multi-channel analyzer. Subsequently the acceleration signals were integrated to obtain velocity responses. The impact force signals were analysed and used to normalise the velocity responses to a 1 N-s impulse.

4. SUBJECTIVE EVALUATION PROTOCOL

Floor vibration performance was appraised subjectively using a method evolved by Forintek to assess performance improvements in the test floors resulting from the addition of strong-backs or wood I-blocking.

To more closely approximate normal living conditions during subjective performance evaluations, the floor under evaluation was carpeted and furnished. Twenty evaluators selected from Forintek staff were asked to evaluate the performance of the floor before and after installation of strong-backs or wood I-blocking. Only one evaluator was allowed

on the floor at a time. He or she first walked freely on the floor while observing clues related to floor performance. The evaluator was then seated on a chair located at the centre of the floor, while another person walked on the floor according to a designated pattern. Again the evaluator was observing clues related to floor performance. Immediately after, the evaluator was asked to fill out a questionnaire that provided an overall performance rating for the floor as well as a score for performance-related clues such as feeling, seeing and hearing.

The order followed for subjective evaluations is given in table 2. It has been recognised that during subjective evaluation, people tend to compare the performance of the current floor with that of the floor he or she previously evaluated. Therefore, the order in which the floors are evaluated will influence rating results. The ideal subjective evaluation should be conducted side by side on two floors, one being used as a reference floor through the evaluation, and the other being the test floor. Because of physical limitations, it was not possible to build two floors side by side. It was expected that the subjective evaluation procedure used would result in more liberal ratings of performance.

5. RESULTS AND DISCUSSION

The measured performance attributes of the base floors and the floors with strong-backs/wood I-blocking are shown in Table 2. These included the static deflection under a 1 kN concentrated load at the floor centre, the natural frequencies of the floor and their associated viscous damping ratios, the RMS-acceleration and the initial velocity responses to a 1 N-s impulse at the floor centre. The average rating score of the 20 evaluators was also included in the table.

In general, the installation of strong-backs and wood I-blocking improved the subjective rating scores of the floors, and reduced significantly the static deflections and reduced the dynamic responses such as the RMS-accelerations and the initial velocities at the floor centre. The significant reduction in static deflection at the floor centre after the installation of strong-backs and wood I-blocking indicates a re-distribution of the concentrated load to adjacent joists. No significant change in fundamental natural frequency resulted from the installation of strong-backs or wood I-blocking. Since it is known that the fundamental natural frequency is predominately controlled by the floor stiffness along the joist direction, this implies that the installation of strong-backs or wood I-blocking did not significantly increase the floor stiffness along the joist direction. A significant increase in the natural frequencies of the higher modes was observed for the truss floor. This means that the installation of strong-backs significantly increased the floor stiffness in the across-joist direction. However, such is not the case for the wood I-joist floor where no increase in frequencies was observed for the higher modes. In all cases 1% or 2% change in modal-damping ratios was observed after the installation of strong-backs or wood I-blocking. But, the change is too small to confidently conclude that the modal-damping ratios were significantly affected by the addition of strong-backs or blocking. As pointed by Ole Døssing (1988) that modal-damping ratios are not so simple to determine, and are often the modal parameters measured with the greatest degree of uncertainty.

To assess through some codified criterion the effect on floor serviceability of installing strong-backs or blocking, the static deflections measured at the floor centre were compared with the serviceability criterion for engineered wood floors (CWC et al.1997). The performance of a floor is defined as acceptable if the plot for a floor is above the boundary shown in Figure 2. It can be observed that for the truss floor, which was designed to meet a deflection of L/360 under uniform load, the installation of one or two rows of strong-backs did not reduce the static deflection of the floor sufficiently to meet the criterion. This agrees with the subjective rating results of Table 2, where the ratings ranged from not acceptable to marginal. In the case of the wood I-joist floor (Figure 2), it was interesting to note that the static deflection of the floor with wood I-blocking met the criterion, but the performance of the floor was still not acceptable to the evaluators (Table 2).

Figures 3 and 4 illustrate the maximum static deflection and the initial velocity profiles along the centre joists of the truss floors and the wood I-joist floors, respectively. Figure 3 reveals that the centre of the floor was no longer the weakest area once the strong-backs were installed at mid-span instead the largest deflections and initial velocities were measured at about 1 m on either side of mid-span. This phenomenon was not observed for the wood I-joist floor (Figure 4) with one row of wood I-blocking at mid-span (i.e. about 2.5 m blocking spacing) nor for the truss floor (Figure 3) with two rows of strong-backs spaced at about 2 m (7 feet). By comparison with the truss floor having one row of strong-back at mid-span (i.e. about 3 m strong-back spacing), the floor having the two rows of strong-backs spaced at about 2 m demonstrated better performance. Spacing the two rows of strong-backs 2 m apart resulted in a reduction of maximum deflection and of the initial velocity (Figure 3), in addition to slightly increasing the fundamental frequency and improving the subjective rating (Table 2). By comparison, the maximum deflection and initial velocity profiles of the floors without strong-backs/wood I-blocking, the floors with strong-backs/wood I-blocking significantly reduced static deflections and initial

velocities within a 2 m vicinity of the strong-backs/blocking. All above observations suggest that the effective spacing of strong-backs/wood I-blocking over which they effectively improved the static and dynamic performance of the floors is about 2 m (7 feet).

By comparison with the truss floor having one row of strong-back at mid-span, the floor with two rows of strong-backs at mid-span had a slightly better vibration performance indicated by the smaller static deflection and initial velocity (Figure 3), and the higher natural frequencies of the higher modes (Table 2). However, the subjective rating did not show the same trend. A possible explanation for this is that the improvement in the vibration performance of the floor due to doubling strong-back stiffness was too small to be perceptible by people.

6. CONCLUSIONS AND RECOMMENDATIONS

It is concluded that the installation of strong-backs and wood I-blocking improves the floor load-sharing capacity for engineered wood floors. The installation of strong-backs also increases floor stiffness in the across-joist direction. The installation of strong-backs/wood I-blocking does not significantly increase floor stiffness along the joist direction. No any conclusion can be drawn regarding the increase in modal-damping ratios resulting from the installation of strong-backs/wood I-blocking. However, they do improve floor vibration performance to some degree. The degree of improvement depends on their spacing and stiffness as well as other factors, which will be reported later. On the basis of these results, it appears that more technical information is required on the contribution of performance-enhancing elements such as strong-back/blocking/bridging towards increasing allowable span for engineered wood floors.

7. REFERENCES

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8. ACKNOWLEDGEMENTS

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Table 1: Measured Mechanical Properties of the Test Floor Components

Floor Component	Density	Bending Stiffness	Shear Stiffness
Truss	4.43 kg/m	838 kN m^2	2.29 MN
I-Joist	3.67 kg/m	521 kN m^2	4.12 MN
Sub-floor	6.9 kg/m^2	2.314 kN m^2/m	35.09 MN/m (planar)
Strongback-1/-2	2.39 /2.19 kg/m	88.7/ 88.9 kN m^2	

Table 2: Floor Performance Attributes and Subjective Rating Results

Floor Type	Truss Joist Floor				Wood I-Joist Floor	
Order of Subjective Evaluation	Floor 1-A	Floor 1-B	Floor 1-C	Floor 1-D	Floor 2-A	Floor 2-B
Installation of Strong-Backs/ Wood I-Blocking	Base Floor with no strong-back	Base Floor with one row of strong-back at mid-span	Base Floor with two rows of strong-backs at mid-span	Base Floor with two rows of strong-backs spaced at 2 m	Base Floor with no blocking	Base Floor with one row of wood I-blocking at mid-span
1 kN Static Deflection (mm)	2.08	1.12	0.97	1.27	1.59	0.87
Dynamic Responses to an 1 N-s impulse at floor centre:						
RMS-Acceleration (mg)	12.7	7.6	6.1	8.8	12.5	7.5
Initial Velocity (mm/s)	7.3	4.1	3.2	4.9	6.3	4.3
Mode-1:						
Frequency (Hz)	11.2	11.5	11.5	11.6	12.1	12.5
Damping (%)	4	6	6	5	10	12
Mode-2:						
Frequency (Hz)	15.2	18.5	20.8	19.5	18.8	18.9
Damping (%)	2	5	3	3	5	*10
Mode-3:						
Frequency (Hz)	18.9	20.6	31.2	27.8	24.3	24.4
Damping (%)	4	3	3	2	3	5
Mode-4:						
Frequency (Hz)	22.7	25.0			27.6	27.4
Damping (%)	2	3			3	3
Mode-5:						
Frequency (Hz)	24.8				33.9	34.8
Damping (%)	1				3	3
Subjective rating score	3.6	3.0	3.4	2.5	3.8	3.4

Note:
* The damping value is not reliable due to the noise in the signal
The rating score <=1, the floor is definitely acceptable
The rating score <=2, the floor is acceptable
The rating score <=3, the floor is marginal
The rating score <=4, the floor is not acceptable
The rating score <=5, the floor is definitely not acceptable

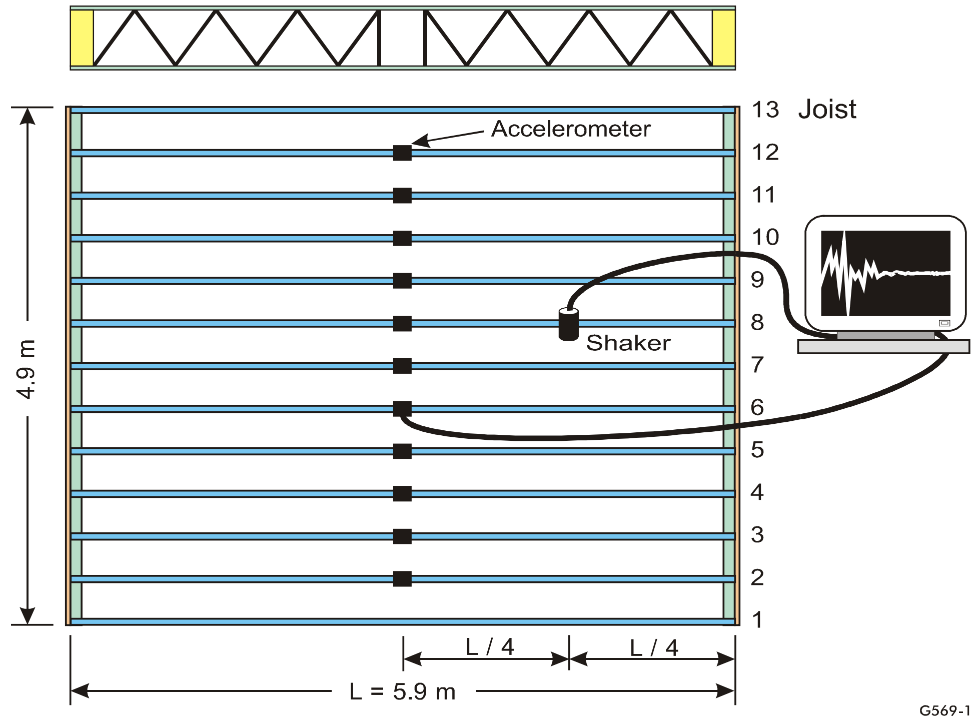
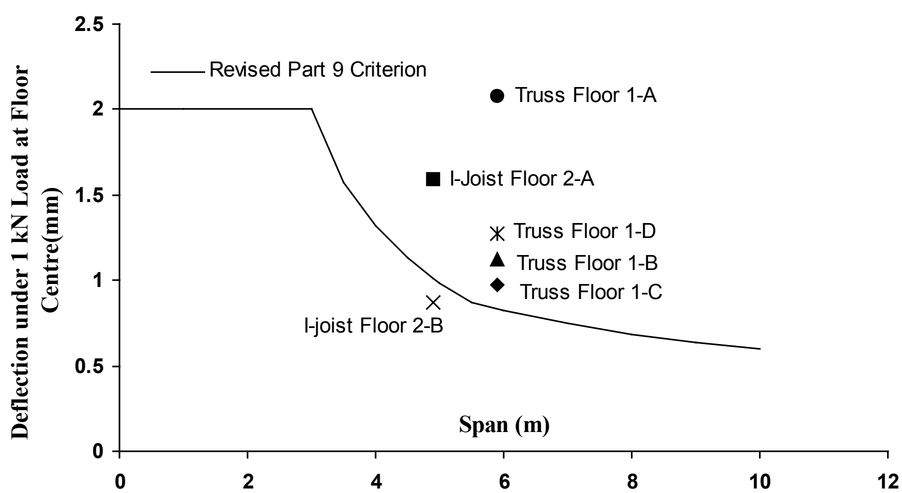


Figure 1: Base truss floor plan and a typical modal test set-up



Truss Floor 1-A: Truss floor with no strong-back
Truss Floor 1-B: Truss floor with one row of strong-back at mid-span
Truss Floor 1-C: Truss floor with two rows of strong-backs at mid-span
Truss Floor 1-D: Truss floor with two rows of strong-backs spaced at about 2m
I-Joist Floor 2-A: Wood I-joist floor with no blocking
I-Joist Floor 2-B: Wood I-joist floor with one row of blocking at mid-span

Figure 2: Performance of test floors vs. revised Part 9 criterion for engineered wood floors

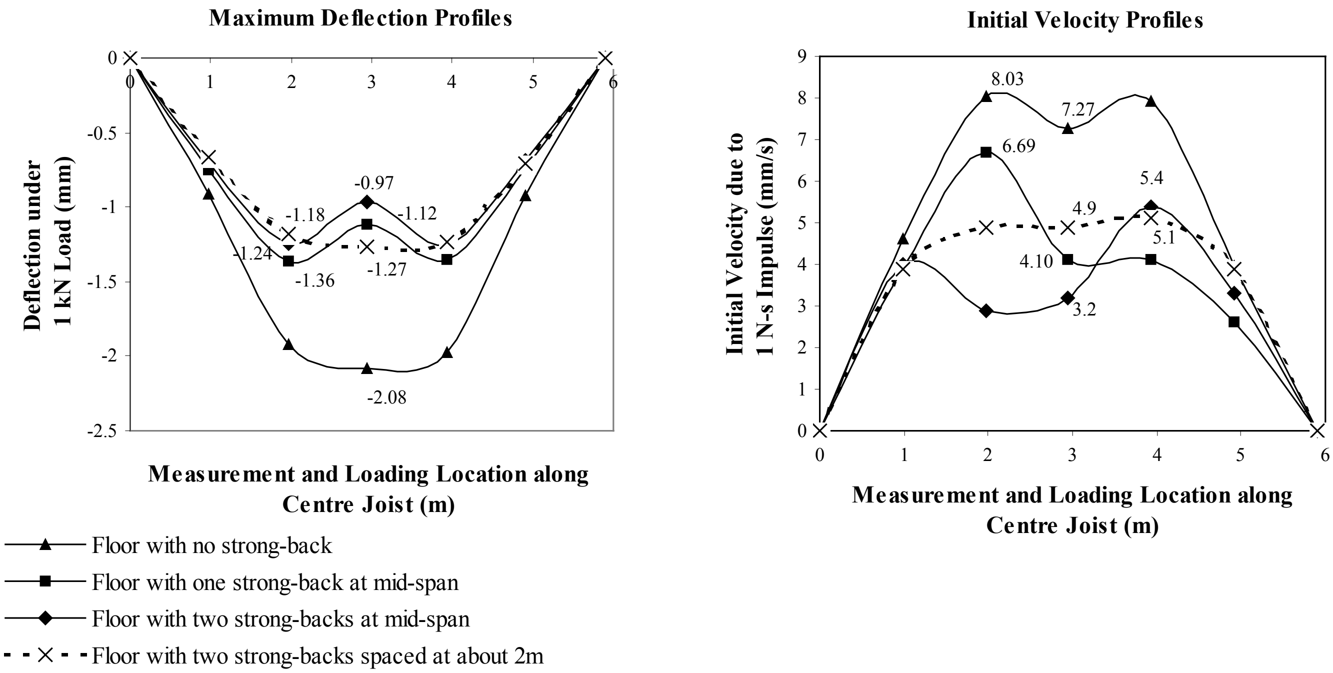


Figure 3: Maximum deflection and initial velocity profiles along the centre joist of the truss floor

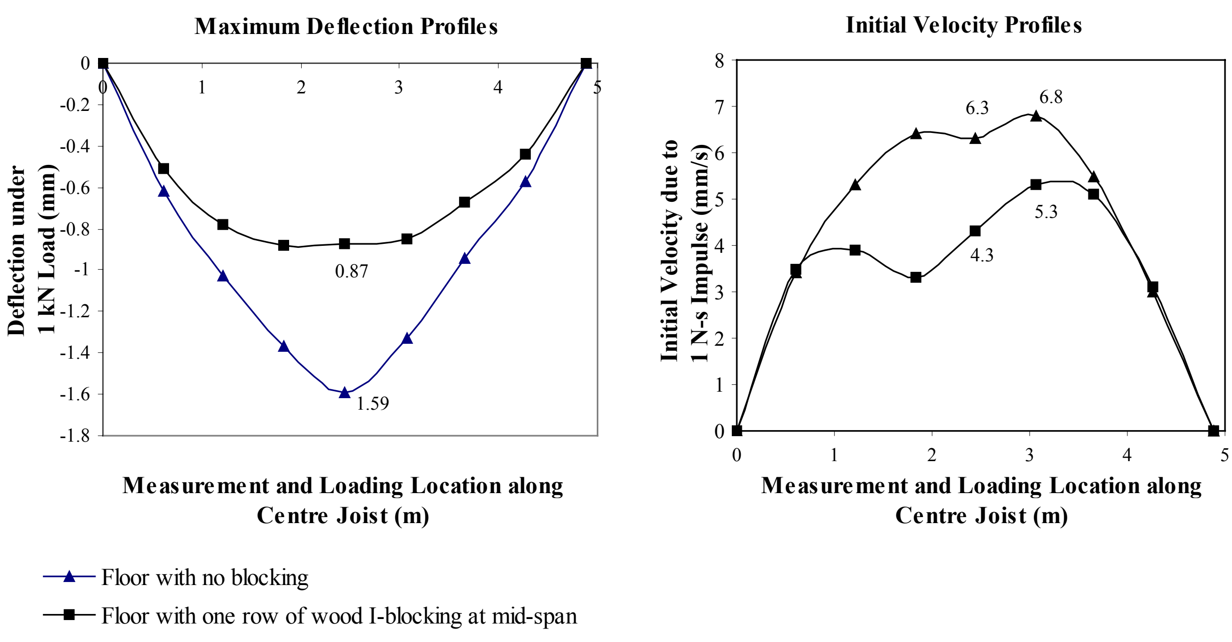


Figure 4: Maximum deflection and initial velocity profiles along the centre joist of the wood I-joist floor