Development of Rigging System for Prefabricated Wood I-joist Floor Panels

Sigong Zhang[1], Ying Hei Chui[2*], David Joo[3], Jean-Philippe Letarte[4], and Luca Dalcastagne[5]

[1] *Postdoctoral Fellow, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB, Canada*
[2] *Professor, Department of Civil and Environmental Engineering, University of Alberta, Edmonton, AB, Canada*
[3] *Principal, HausTec Ltd., Calgary, AB, Canada*
[4] *Technical Engineer, MyTiCon Timber Connectors, Surrey, BC, Canada*
[5] *Project Manager, Giusti Group of Companies - Wall Tech, Calgary, AB, Canada*
[*] *Corresponding author's e-mail: yhc@ualberta.ca*

ABSTRACT
Panelized building construction are highly mechanized. Material handling and lifting equipment dominate construction sites and constitute the critical element in achieving productivity. In recent construction practice, panelized wood I-joist floor panels are normally lifted into place by mobile crane using flexible slings inserted through the predrilled holes on the I-joist web and sheathing panels above the I-joist top flange and then wrapped around the I-joists at the four corners. However, the pre-drilled holes on the web and sheathing may weaken the floor panels. Moreover, a range of techniques for lifting and handling mass timber panels have been developed. A typical rigging technique consists of a lifting ring and a steel plate with pre-drilled holes. By using several self-tapping screws, the panel was connected with the rigging device for lifting. However, since prefabricated I-joist floor panels are much lighter than mass timber panels and the I-joist flange is relatively narrow and thin, the rigging device for mass timber panels cannot be applied directly to I-joist floor panels, but a modified design can be developed for prefabricated I-joist floor panels. In the present study, a new rigging device was designed for prefabricated wood I-joist panels and their load capacity was evaluated by withdrawal tests. Several factors influencing the withdrawal capacity were investigated including screw types and quantities, flange width and materials, and OSB thickness.

KEYWORDS
Rigging system; Prefabricated floor panels; Wood I-joists

INTRODUCTION
Over the past decade, several jurisdictions in Canada have erased restrictions that limited the construction of wood-frame buildings to four-storeys. The push to amend legislation to allow the 5- or 6-storey wood-frame buildings reflects huge market potential of mid-rise wood construction in commercial and multi-family residential housing to embrace the increasing urban density. In parallel, prefabrication of building elements has been growing rapidly in wood construction. This trend is simply a natural evolution towards the use of modern methods of construction, which brings many benefits for both productivity and quality in the construction process (Ni and

Popovski, 2015). Example of these include prefabricated wall, roof and floor systems. Once all of the prefabricated panels and building components are completed, they are shipped to construction site and assembled together. Such construction technique called panelization. In anticipation of these market opportunities, more and more companies are interested in developing a production line for prefabricated engineered wood panels.

Panelized building construction are highly mechanized. Material handling and lifting equipment dominate construction sites and constitute the critical element in achieving productivity. In recent construction practice, panelized wood I-joist floor panels are normally lifted into place by mobile crane using flexible slings (e.g., polypropylene straps) inserted through the predrilled holes on the I-joist web and sheathing panels above the I-joist top flange and then wrapped around the I-joists at the four corners as shown in Figure 1. Such rigging assembly has been commonly used for years in the construction of panelized wood buildings. However, the pre-drilled holes on the web and sheathing may weaken the floor panels. On the other hand, as an emerging building solution, cross-laminated timber (CLT) floors have been increasingly used in construction. A range of techniques for lifting and handling CLT panels have been developed. As shown in Figure 2, a typical rigging technique consists of a lifting ring and a steel plate with pre-drilled holes. By using several self-tapping screws, the CLT panel was connected with the rigging device for lifting. However, since prefabricated I-joist floor panels are much lighter than CLT panels and the I-joist flange is relatively narrow and thin, the rigging device for CLT panels cannot be applied directly to I-joist floor panels, but a modified design can be developed for prefabricated I-joist floor panels.

Figure 1. Typical rigging assemblies for wood I-joist floor panels (Source: H+ME Technology)

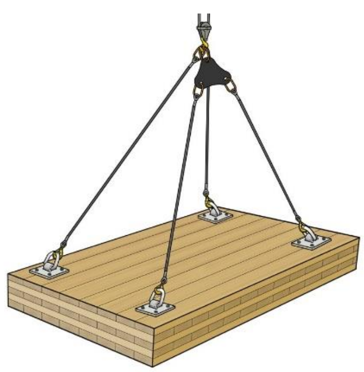

Figure 2. A typical rigging assembly for CLT panels (MyTiCon, 2018)

In the present study, a new rigging device was developed for wood I-joist panels and their load capacities with different joists and screws are evaluated by withdrawal tests. In order to determine the allowable loads for lifting usage and installation specifications, withdrawal tests for the rigging device were conducted and presented in this section. Several factors influencing the lifting capacity were also investigated including anchor placements, flange materials and width, screw numbers and OSB thickness.

DESIGN OF RIGGING DEVICE

A new rigging device has been developed for wood I-joist floor panels. The proposed rigging device consists of an anchor plate (a custom-made steel plate) and a lifting ring welded to the plate. There are eight pre-drilled holes on the plate to accommodate several self-tapping screws. The screw pattern was designed to fit the flange of I-joist and maximize the bite of the screws if the plate is wrongly installed on the job site. The dimension details of the anchor plate can be found in Figure 4.

The rigging device offers a good amount of flexibility in terms of allowable capacity, which can be expanded by increasing the number of screws. For the sake of simplicity, two screw arrangements are recommended: four screws in the middle and eight screws. The rigging device is designed to be compatible with 6 mm diameter ASSY self-tapping screws which are approved by CCMC and ICC-ES. Two types of the ASSY screws can be used: ASSY®SK 6×50 (fully thread) and ASSY®SK 6×60 (partial thread). Their basic dimensions are tabulated in Table 1. Other dimensions and material details can be found in the Structural Screw Design Guide by MyTiCon (2018). The ASSY®SK screws have large washer head with the highest head pull-through resistance of all ASSY® screws.

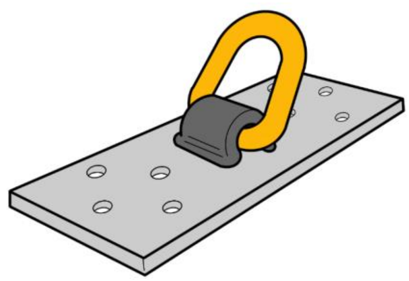

Figure 3. Proposed rigging plate

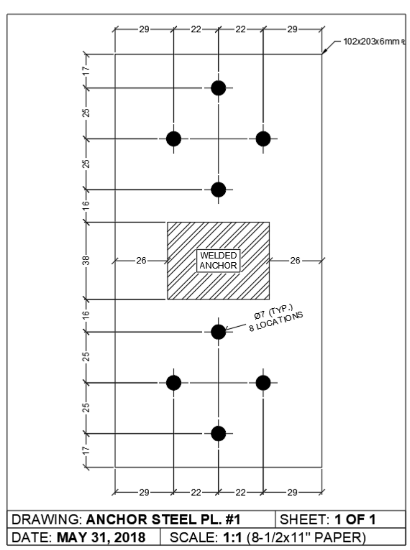

Figure 4. Dimensions of the anchor plate

Table 1. ASSY®SK screws for tests

Screws	Diameter (mm)	Length (mm)	Thread length (mm)
ASSY®SK 6×50	6	50	45
ASSY®SK 6×60	6	60	37

WITHDRAWAL TESTS

Test materials and parameters

As shown in Figure 5, a pair of rigging devices were used repeatedly in the withdrawal tests. In order to simulate the realistic construction scenarios, the screws were reused multiple times until they have notable damages. In general, the flange material of I-joists is typically laminated veneer lumber (LVL) or solid sawn lumber (SSL). Thus, two types of I-joists were tested: TJI® Joists with LVL flange by Weyerhaeuser and PKI joists having SSL flange by Pinkwood Ltd in Calgary. In order to cover various construction scenarios in lifting process, three anchor placements were considered: a) anchor center on the flange of the I-joist; b) anchor with 30^{o} rotation and only half of the screws into the flange; and c) anchor with screws into the OSB only. These three placements are illustrated in Figure 6. Note that most test specimens were built for the first placements and the second and third placements were designed to give some indications of wrong installation on-site. Other parameters include two thicknesses of OSB panels (19/32" (15 mm) and 23/32" (18 mm)), and two screw numbers (4 and 8). In summary, all test parameters are tabulated in Table 2.

Figure 5. Rigging devices for tests

(a) center (b) rotated (c) on OSB

Figure 6. Three anchor placements

Table 2. Test parameters

Parameters	Details
Sling angle	60^o
Screw type	ASSY®SK 6x50 ASSY®SK 6x60
Wood I-joist	TJI210, TJI560, PKI10 and PKI40
Flange width	53 mm, 64 mm and 89 mm
OSB	19/32" (15 mm) and 23/32"(18 mm)
Screw number	4 and 8
Anchor placements	anchor center on the flange of the I-joist; anchor with 30^o rotation and only half of the screws into the flange; anchor with screws into the OSB only

Test matrix and specimens

By incorporating all test parameters in Table 2, a test matrix was made and shown in Table 3. In total, there are 19 specimen configurations and each of them has six repetitions. As shown in Figure 7a, the specimens were built by combining two OSB strips on the top and bottom flanges, respectively. Four different sizes of OSB strips/panels were used: 24”×3”, 24”×4”, 24”×6”, and 24”×12”. In addition, the last size of the OSB panel was developed for specimens with anchor only screwed into the OSB as shown in Figure 7b. In particular, two wood wedges were attached on the OSB strips to create a 60^o sling angle in the withdrawal tests. Six replicates were tested for each configuration.

Table 3. Test matrix for rigging plate withdrawal tests

No.	Label	Position	OSB		Screws		I-joist		
			t (mm)	Size (in×in)	L_s (mm)	N_s	type	flange width (mm)	L_i (in)
1	FC-15-60-4-53-TJI	center	15	24×3	60	4	TJI210	53	24
2	FC-15-60-4-64	center	15	24×3	60	4	PKI10	64	24
3	FC-15-60-8-64	center	15	24×4	60	8	PKI10	64	24
4	FC-15-60-8-89	center	15	24×4	60	8	PKI40	89	24
5	FC-15-60-8-89-TJI	center	15	24×4	60	8	TJI560	89	24
6	FC-18-60-4-64	center	18	24×3	60	4	PKI10	64	24
7	FC-18-60-8-64	center	18	24×4	60	8	PKI10	64	24
8	FC-18-60-8-89	center	18	24×4	60	8	PKI40	89	24
9	FC-15-50-4-53-TJI	center	15	24×3	50	4	TJI210	53	24
10	FC-15-50-4-64	center	15	24×3	50	4	PKI10	64	24
11	FC-15-50-8-64	center	15	24×4	50	8	PKI10	64	24
12	FC-15-50-8-89	center	15	24×4	50	8	PKI40	89	24
13	FC-15-50-8-89-TJI	center	15	24×4	50	8	TJI560	89	24
14	FC-18-50-4-64	center	18	24×3	50	4	PKI10	64	24
15	FC-18-50-8-64	center	18	24×4	50	8	PKI10	64	24

16	FC-18-50-8-89	center	18	24×4	50	8	PKI40	89	24
17	FO-15-60-8-64	offset	15	24×6	60	8	PKI10	64	24
18	FO-15-50-8-64	offset	15	24×6	50	8	PKI10	64	24
19	OSB-18-50-8	center	18	24×12	50	8	PKI10	N.A.	24

Note: t is the thickness of OSB panels;
L_s is the screw length and N_s is screw number;
L_i is the length of I-joists.

(a) (b)

Figure 7. Specimen construction

Test setup and method

Figure 8 shows the details of the setup. Typical test setup for three anchor placements is illustrated in Figure 9. The loading rate was 1 mm/min. Each test was stopped after reaching the peak load.

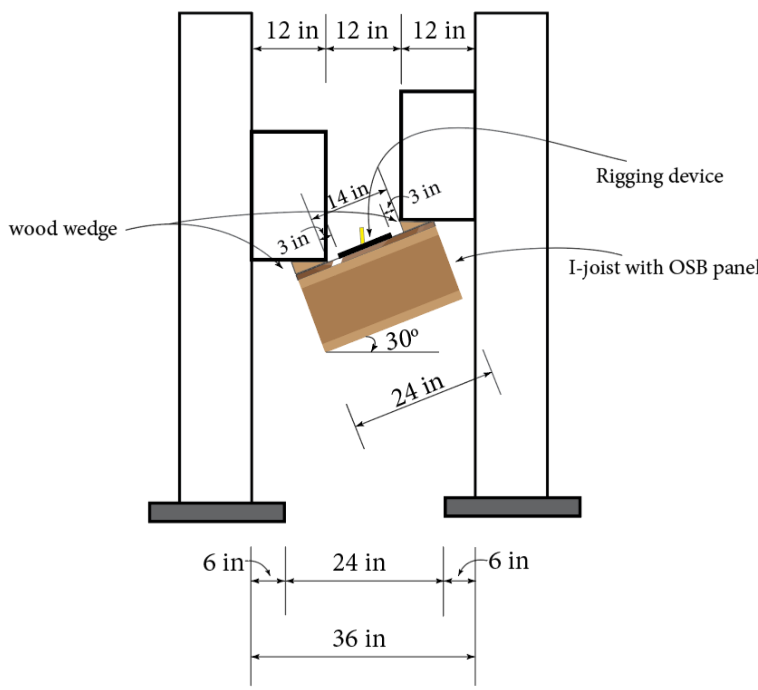

Figure 8. Test setup

(a) Center anchor (b) Rotated anchor (No.17-2) (c) Anchor on OSB (No.19-1)

Figure 9. Typical test setup for three different anchor placements

Test results

The peak loads of specimens from No.1 to No.18 are tabulated in Table 4, as well as their failure modes. There are two main failure modes for these specimens: one is screw withdrawal and the other is flange splitting. The former failure mode is the primary one and the latter mode was marked by bold font in Table 4. In most cases, there is no recognizable failure part can be found for the withdrawal failure mode because the failures may happen the screw part inside the wood. Some withdrawal failure has notable lifting up of the anchor plate as shown in Figure 10. The flange splitting may happen on the side or at the bottom and these two typical splitting failures are shown in Figure 11. It should be noted that there was an unexpected failure happened for the specimen of No. 8#5 (marked in red color in Table 4). In this test, the I-joist flange was pulled out as shown in Figure 12. This failure may be caused by the specimen touching the test frame during the test.

Form the test results in Table 4, it can be found from the peak loads that the joist flange and the screw penetration length significantly affect the withdrawal capacity. Wood I-joists with solid lumber flange allow more lifting loads than joists with LVL flange. The wider flange (89 mm) provides better withdrawal capacity in comparison with those of 64 mm flange specimens

Table 4. Peak loads of rigging plate withdrawal tests

No.	Label	Peak loads (kN)							COV (%)
		#1	#2	#3	#4	#5	#6	Mean	
1	FC-15-60-4-53-TJI	13.6	10.6	**10.3**	11.2	12.1	11.8	11.6	10.2
2	FC-15-60-4-64	14.2	13.9	11.3	**15.4**	15.4	17.6	14.6	14.3
3	FC-15-60-8-64	15.6	14.7	14.8	**14.0**	18.2	17.6	15.8	10.7
4	FC-15-60-8-89	17.1	13.9	**17.5**	17.5	20.6	18.7	17.5	12.5
5	FC-15-60-8-89-TJI	18.0	19.1	18.4	15.6	18.6	16.0	17.6	8.3
6	FC-18-60-4-64	10.5	11.7	**12.8**	12.9	13.6	**13.6**	12.5	9.7
7	FC-18-60-8-64	**11.1**	14.2	14.9	**16.0**	13.8	17.4	14.6	14.8
8	FC-18-60-8-89	14.5	17.3	14.7	16.2	16.8	13.0	15.4	10.7
9	FC-15-50-4-53-TJI	7.7	8.4	7.8	7.6	**8.0**	**7.8**	7.9	3.6
10	FC-15-50-4-64	11.0	12.4	10.4	10.1	11.1	14.1	11.5	13.0
11	FC-15-50-8-64	13.4	11.5	**15.7**	11.2	**15.1**	12.3	13.2	14.1
12	FC-15-50-8-89	**15.5**	**11.6**	**14.0**	**14.9**	**14.2**	**14.7**	14.2	9.6
13	FC-15-50-8-89-TJI	**12.8**	**12.1**	**12.0**	13.3	**10.5**	**14.4**	12.5	10.5
14	FC-18-50-4-64	12.8	12.4	10.4	12.3	12.2	7.3	11.2	18.7
15	FC-18-50-8-64	**10.7**	**10.8**	13.4	**10.8**	**14.3**	**17.2**	12.9	20.4
16	FC-18-50-8-89	**15.2**	**15.5**	**14.5**	12.7	16.5	17.2	15.3	10.2

17	FO-15-60-8-64	10.9	11.1	13.8	10.5	17.3	12.6	12.7	20.2
18	FO-15-50-8-64	**10.6**	**8.6**	**10.7**	**12.1**	**9.8**	**6.7**	9.8	19.3

Note: Peak load values in bold font indicate flange splitting failure; peak load marked by red color is used for specimen with flange pull-out failure; and the rest is of screw withdrawal failure.

Figure 10. Withdrawal failure of specimen No.9#2

(a) Flange splitting on the side (No.6 #3) (b) Flange splitting at the bottom (No. 12 #1)

Figure 11. Typical flange splitting failures

Figure 12. Flange pull-out of No.8 #5

Test results of No. 19 specimens with anchor plates only screwed to OSB are shown in Table 5. Two failure modes are illustrated in Figure 13: one is screw withdrawal and plate lifting, and the other is OSB panel failure. It can also be found that although the anchor plate was only screwed into OSB panel, their withdrawal capacities do not present significant reduction. Half withdrawal capacities or even two third of them are possessed by these No. 19 specimens comparing with No. 15 and 16 specimens whose eight screws are all threaded into the I-joist flange.

Table 5. Peak loads of rigging plate withdrawal tests for anchor plates only screwed to the OSB

Specimen	Peak load (kN)	Failure mode
No.19 #1	8.4	Screw withdrawal and plate lifting
No.19 #2	7.7	OSB failure
No.19 #3	8.0	OSB failure
No.19 #4	8.0	Screw withdrawal and plate lifting
No.19 #5	8.6	Screw withdrawal and plate lifting
No.19 #6	7.2	OSB failure
Mean: 8.0 kN	COV: 6.1%	

(a) Screw withdrawal and plate lifting

(b) OSB failure

Figure 13 Failure modes of rigging plate withdrawal tests for anchor plates only screwed to OSB

CONCLUSIONS

A new rigging device has been designed for prefabricated wood I-joist panels. By using self-tapping screws, the rigging device can be installed on the panel surface through connecting with the sheathing and I-joist flange. In order to determine the rigging capacity and installation specifications, withdrawal tests were carried out for the rigging device. The influence of anchor placements, flange materials and width, screw numbers and OSB thickness was investigated. In summary, for the allowable load limits of the new rigging device, the joist flange and the screw penetration length significantly affect the withdrawal capacity. Wood I-joists with solid lumber flange allow more lifting loads than joists with LVL flange. The wider flange (89 mm) provides better withdrawal capacity in comparison with those of 64 mm flange specimens.

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