The Project Management of Investigating Dowel Laminated Timber

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Architectural Engineering

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I. Nomenclature

- ANSI – American National Standards Institute
- ASCE – American Society of Civil Engineers
- ASTM – American Society for Testing Materials
- CLT – Cross Laminated Timber
- DLT – Dowel Laminated timber
- NDS – National Design Specification (for Wood Construction)

1.0 Introduction

During the Winter Quarter of 2020, three Architectural Engineering students investigated a new type of timber product, dowel laminated timber, for their senior project. Dowel laminated timber (DLT) is a specialty product typically associated with sustainable design and is a form of mass timber. The three students had little knowledge about mass timber outside of a timber design course; their knowledge was primarily in wood framing design. Therefore, the topic was chosen because dowel laminated timber is a topic that holds a large learning opportunity not only for the students but also for the profession. The purpose of the senior project was to investigate dowel laminated timber through fabricating specimens, analyze the performance of the specimens, and improve professional standards.

One goal of the project was to investigate dowel laminated timber by create a DLT panel while only using similar tools from a third world country. The restriction of only using third world country tools was to investigate if dowel laminated timber is a feasible building material for third world countries. To create a manufacturing restriction similar to a developing country's conditions, only the hand tool and wood saws provided by the CAED support shop were used.

The second goal was to test and analyze the DLT panel. Tests were conducted using CAED’s High Bay Laboratory and the Riehle universal testing machine. The universal testing machine allowed for the specimen’s strength and serviceability to be tested. The results from the testing were then compared to values that were calculated to predict the specimen’s strength and serviceability.

The last goal throughout the project was to practice and maintain a high level of professionalism to improve our professional skills. Throughout the project, a professional standard was followed in weekly meetings where an agenda was followed and updates on the project were presented. Every meeting produced detailed notes about the conversation and action items for the next meeting. The professionalism of the weekly meetings was also practiced when communicating with professionals outside of the senior project. Multiple professionals were respectfully contacted for support and followed up with face-face meetings.

2.0 Background

Mass timber encompasses buildings that use large solid wood panels as walls, floors, or roofs. These wood panels can be created by using dowel laminated timber (DLT), cross laminated timber (CLT), nail laminated timber (NLT), and glued laminated timber (glulam). CLT uses perpendicular layers of dimensional lumber and glue to form panels. The layers being perpendicular allows for the panel to have similar strength and stability in all directions. NLT consists of dimensional lumber stacked on edge and fastened using nails or bolts. The boards spanning in a single direction create a textured appearance that can be varied. Glulams are composed of select boards bonded together with an adhesive. Glulams are used for beams and columns because of their high strength and stiffness. Lastly, DLT consists of dimensional lumber stacked on edge with a dowel connecting all the boards. DLT is a significantly new product in North America; the first DLT project was completed in 2017.

These mass timber products have unique benefits over the other common building materials (concrete, steel, and masonry). Designers can leverage the design flexibility of mass timber to achieve larger heights and spans. Mass timber products have the benefit of using a renewable and sustainable resource that reduces the carbon footprint of a building. Mass timber construction is fast and easier than construction with other materials. The laminated timber is fabricated off site and only requires assembly when on site. Mass timber provides great fire protection due to the outer layer of wood charring during a fire and protecting the structural integrity of the inside layers. During an earthquake, mass timber building preforms well due to its light weight. Finally, numerous studies show an improvement in occupant health and well-being when a building uses exposed wood.

3.0 Fabrication Procedure

The two main criteria in fabricating the DLT panel were to follow the fabrication requirements in the ICC-ES ESSR 4069 Report (Appendix A1) and to use handheld tools that would be available in developing nations.

3.1 Prototype Construction

To aid in the alignment of the handheld tools, a jig was constructed that would allow the holes to be drilled accurately from board to board for the DLT panel. Accurate repeatability was especially important because the final design requires dowels to run through nearly one hundred snug fit holes which hold the whole specimen together. Two prototypes of the jig were made that tested different construction techniques prior to the fabrication of the final jig.

The first DLT panel prototype measured 12 in. wide and 24 in. long (Figure 1). This prototype was built using a jig made from scrap material as a constructability proof of concept. (Figure 2)

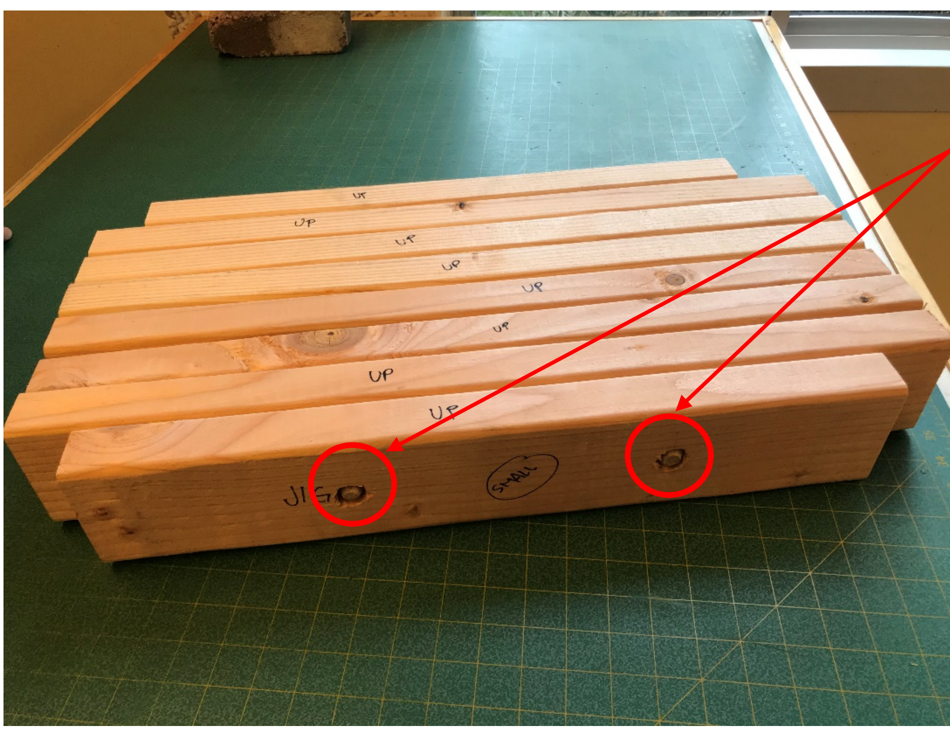


Figure 1: DLT Panel #1

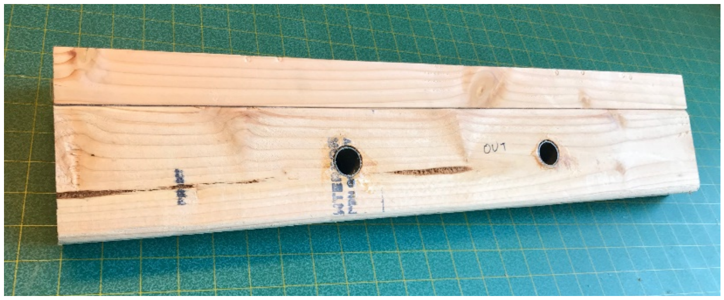


Figure 2: Construction Jig #1

The second prototype was built to test the constructability of a dowelled butt joint connection between two panels. The dowelled butt joints were integrated to create spans that were theoretically longer than the manufactured length of a typical board. The dowelled butt joints were placed in the worst possible locations along the span to consider improper design or construction that may arise in developing nations. The dowelled butt joints are placed in locations of high moment and shear demand, which under enough load, would result in an unstable pin connection due to row tear out failure mode. The only system resisting this pin behavior is the moment resistance of the stacked dowels. The second prototype consisted of two 12 in. x 24 in. panels which were butt jointed to each other using dowels to lock them in place (Figure 3). This prototype was built using a newly constructed jig which would accommodate the dowelled butt joints (Figure 4).

Figure 3: DLT Panel Prototype #2

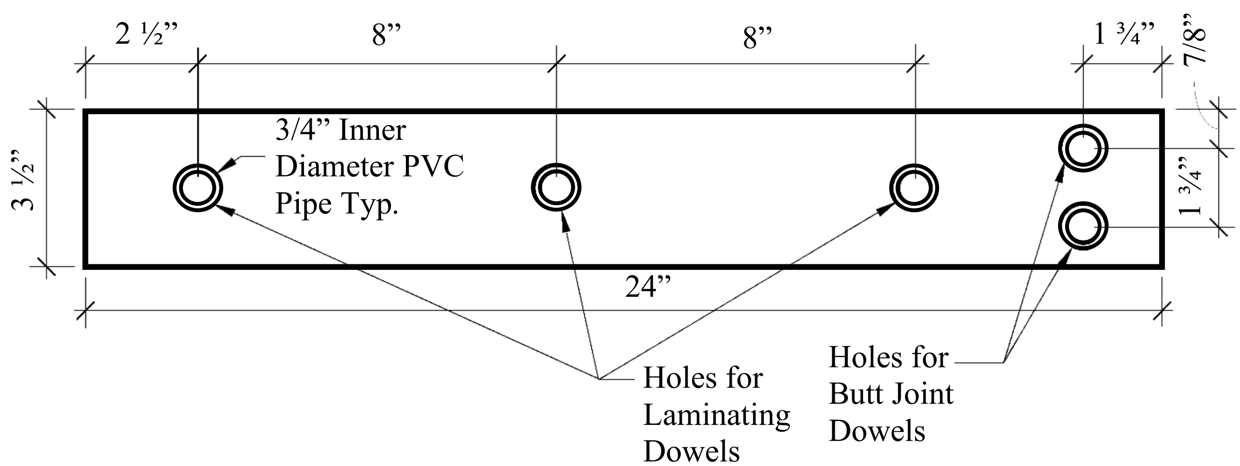
Figure 4: Construction Jig #2

Although both prototypes were generally successful, there were some opportunities for improvement in the construction of the final jig and DLT panel. The following are some conclusions taken away from the prototype jigs:

1) The dowelled butt joint holes did not align perfectly (Figure 3). Due to the nature of the jig, every error in the jig is increased by a factor of two
   a. Every connection in the jig should be glued and screwed to avoid damage and loss of precision of the jig over the course of construction.
   b. After drilling the dowelled butt joint holes with the jig, the holes should be slightly reamed to allow for extra room, as some dowels were very difficult to hammer all the way through the panels.
2) Oak hardwood dowels work well because they are a very hard wood but still have some flexibility when it comes to fitting through the holes.
3) PVC pipe works well as a bushing for hole guides in the drill because the smooth surface does not catch the drill bit and it is durable over time (Figure 6).
4) A backer board should be clamped behind each piece during the drilling process to avoid blowout from drilling the hole (Figure 6).
5) The overall concept of the jig works, but the final jig must be made with much more accuracy than the prototype jigs.

3.2 Final Construction

In order to build the final jig with more accuracy relative to the prototypes, the final jigs were built using tools in the CAED Support Shop, but the specimens were still built using only handheld tools. The final jig was built to the specifications of Schematic 1 with utmost accuracy.



Schematic 1: Final Jig Design

The following is the procedure followed to construct the final jig:

1) Glue (2) ¾” x 3 ½” x 24” pieces of hardwood together to double thickness to 1 ½” thick to act as the base of the jig.
2) Cut (5) ¾” inner diameter PVC pipe to 1 ½” lengths to act as bushings in the drill.
3) Use the drill press to drill holes in the base of the jig to match the outer diameter of the PVC pipe (Figure 6).
4) Sand outer surface of PVC pipes, and epoxy PVC pipes into the holes of the jig
5) Glue and screw ¾” x 3” x 24” hardwood board to the top edge of the jig to keep edge distance of holes consistent in boards (Figure 6).
6) Glue and screw a stop block to the end of the jig opposite of the butt joint holes.

Figure 5: Drilling Holes to Accept PVC Pipe Bushing

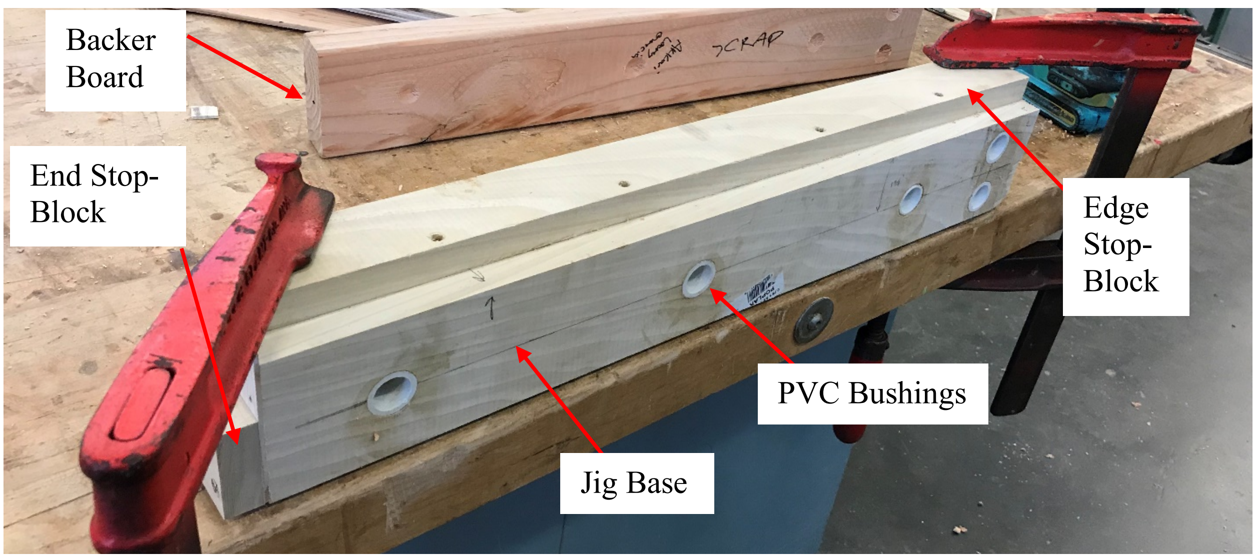
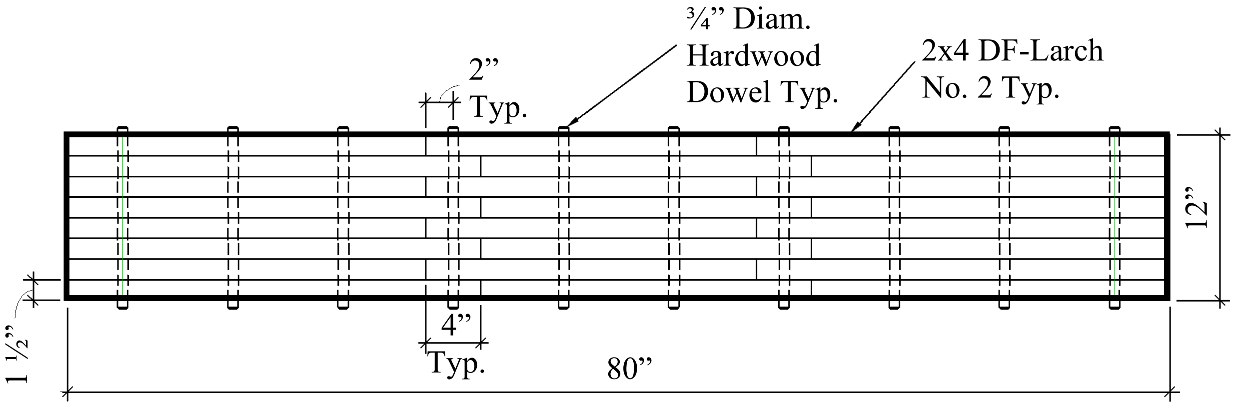
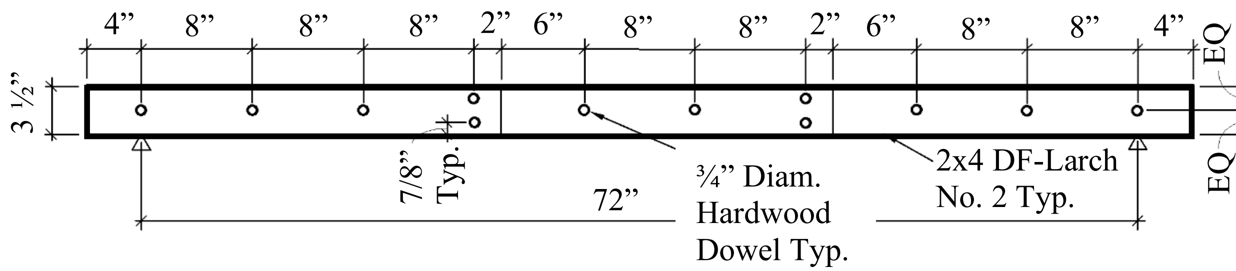


Figure 6: Assembling the Jig

Once the jig was constructed, the three trials of the DLT panel were built in accordance with Schematics 2-3 with procedures outlined below.



Schematic 2: DLT Panel Plan View



Schematic 3: DLT Panel Elevation View

1) Using Douglass Fir-Larch No. 2, cut 2x4 boards to the length
2) Cut ¾” diameter oak dowels to 15” lengths
3) Carve or sand the ends of the dowels to create a chamfer, making initial insertion into holes easier (Figure 7)
4) Clamp 2x4 board into jig (pushed against both stops) along with a backer board to avoid drill blowout, and clamp the jig to workbench (Figure 8)
5) Drill ¾” holes with a handheld electric drill using the jig as a drill bit guide (Figure 9)
6) Ream butt joint holes slightly
7) Assemble panels, each being 8 boards wide, alternating board orientation to fit butt joints together, and hammering each board through the dowels (Figure 10)
8) Line up butt joints and hammer two butt joint dowels through all the boards (Figure 11)
9) Clamp the panels with pony clamps and leave clamped overnight to allow moisture in boards and dowels to equalize (Figure 12)

Figure 7: Chamfered End of Dowel

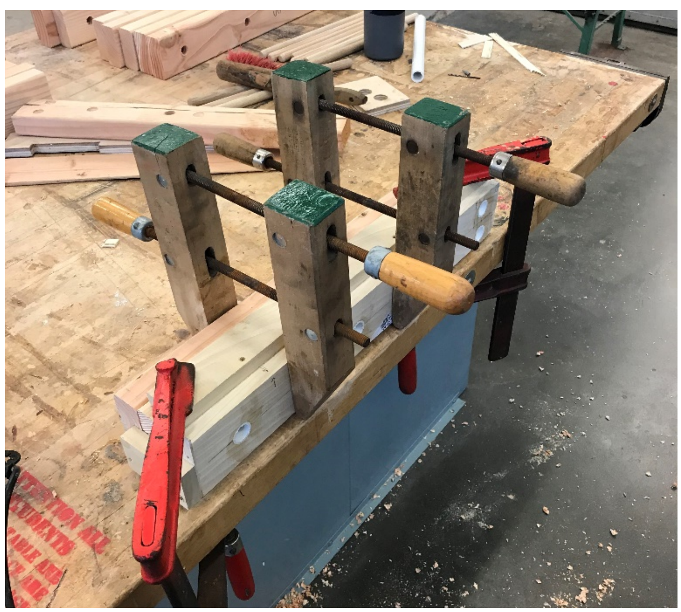


Figure 8: Board Clamped to Jig and Workbench

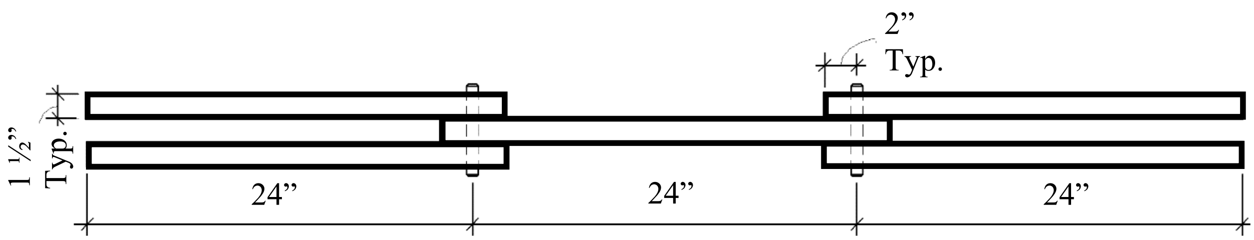
Figure 9: Drilling Holes in Boards Using the Jig as a Guide

Figure 10: Assembling Individual DLT Panels

Figure 11: Joining DLT Panels by Inserting Butt Joint Dowels

Figure 12: Clamping DLT Panel Overnight to Equalize Wood Moisture

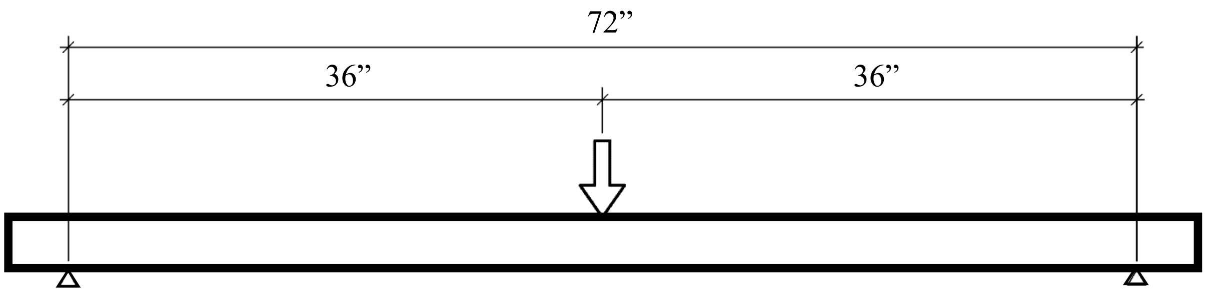
In order to better understand failure mechanisms of the DLT panel, two baseline specimens were prepared as well. Baseline 1 is a single 2x4 spanning 6 ft. which gauges the strength of the boards, and Baseline 2 is a model of the dowelled butt joint connection used in the DLT panel which gauges the strength of the dowelled butt joints (Schematic 4). The baseline specimens would provide a qualitative understanding of failure modes, as well as quantitative estimations of failure loads for the DLT panel.



Schematic 4: Baseline 2 Plan View

4.0 Test Description / Set-up

All specimens were tested using a three-point test with a 6 ft. span (Schematic 5). A three-point test was used to allow for higher moments and deflections for a given load. High moments were necessary to observe the moment connection splice and a large variation in deflection was necessary to compare the test to theory. The theoretical values of each specimen were calculated prior to testing to estimate elastic loads and corresponding deflection values as well as help determine the expected failure modes (Appendix A2).

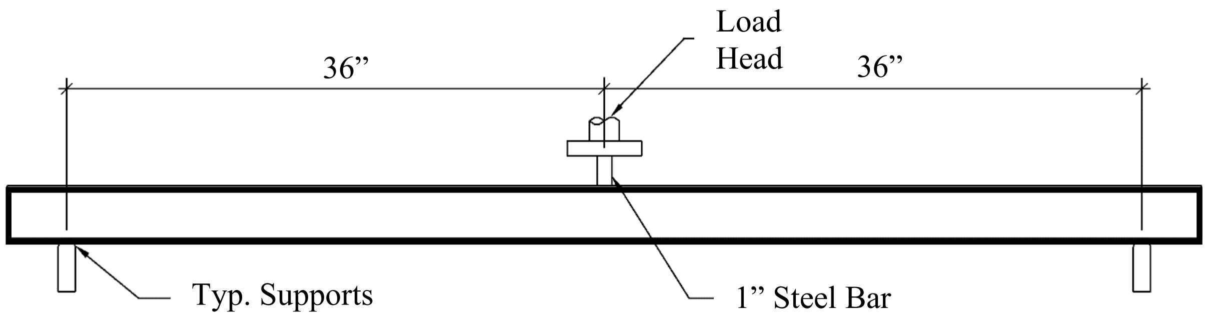


Schematic 5: Loading Diagram

There were three types of specimens tested: A DLT panel and two baseline specimens. Each specimen had three trials of testing. Due to time constraints and testing machine availability, the trials were conducted over a span of two weeks.

The equipment used for this experiment was the Riehle universal testing machine (300,000 lb. capacity) located in the High Bay Laboratory at California Polytechnic State University, San Luis Obispo. The students were taught how to operate the machine by the High Bay Laboratory Technician.

For the baseline tests, the typical Riehle steel supports were used as supports and a 1 in. thick steel bar was placed under the load head to act as a point load (Schematic 6). The final test set-up for baseline 1 can be seen in Figure 13, and the final test set-up for baseline 2 can be seen in Figure 14.



Schematic 6: Baseline Specimens Test Elevation View

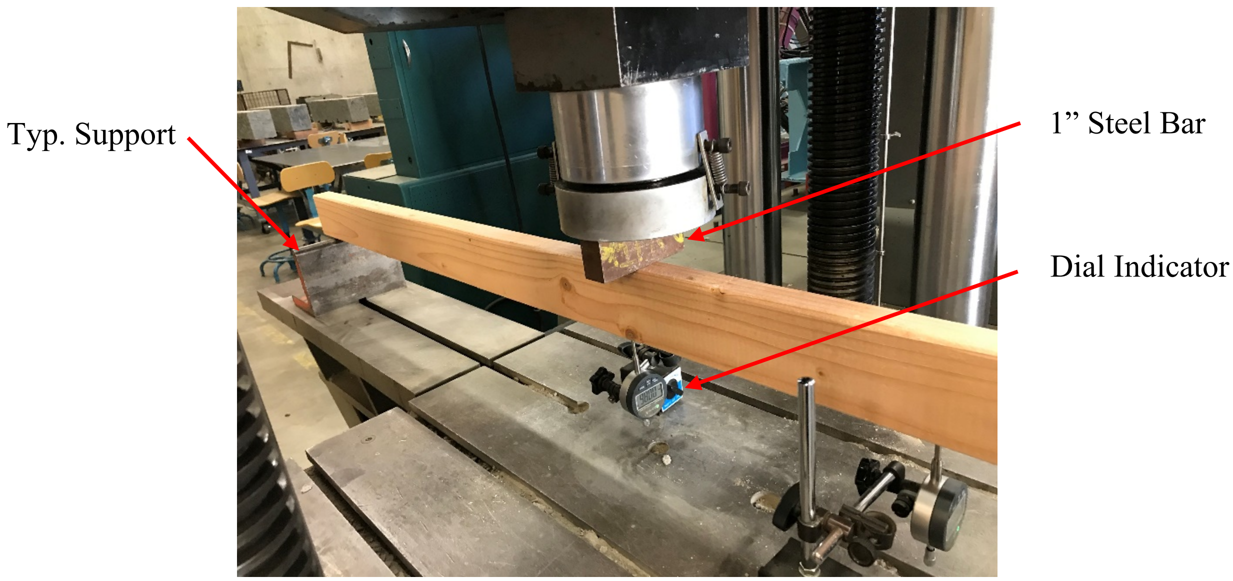


Figure 13: Baseline 1 Specimen Test Set-Up

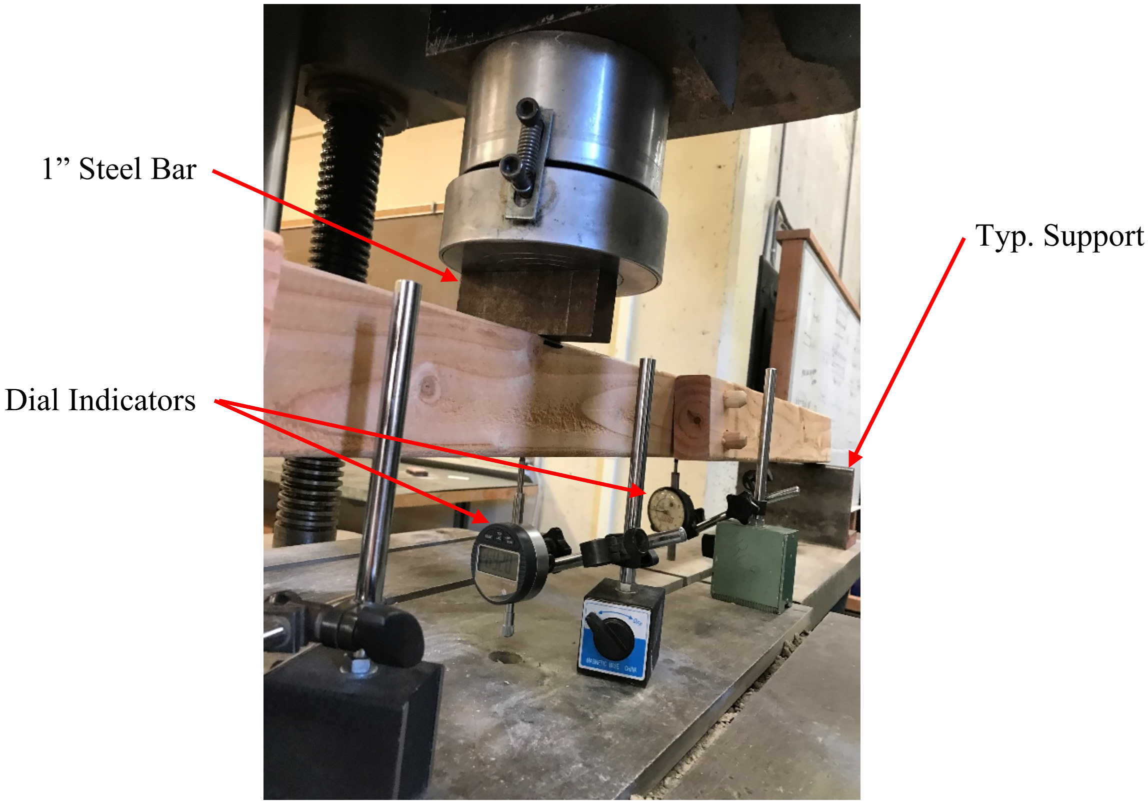
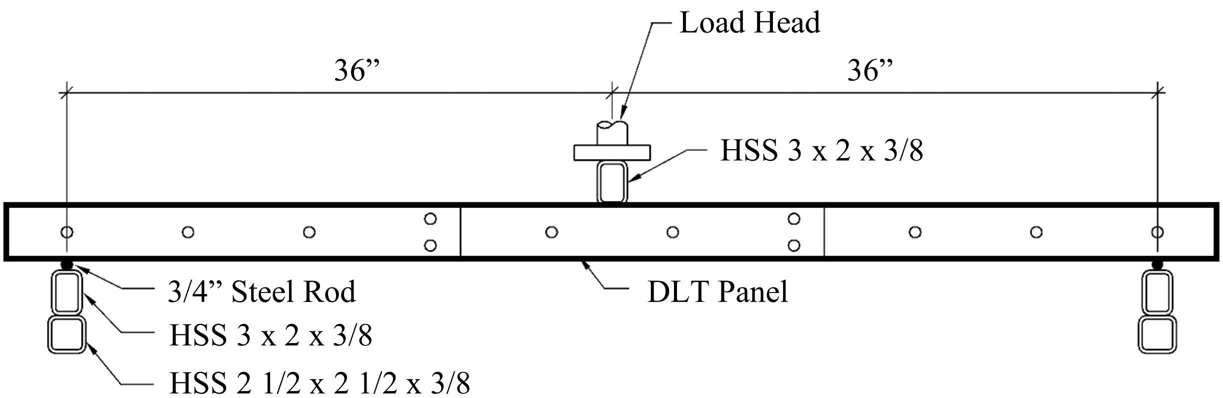


Figure 14: Baseline 2 Specimen Test Set-Up

For the DLT panel tests, the supports were built up of two HSS tubes stacked and clamped to the table of the machine, along with a steel rod resting atop the HSS tubes. One HSS tube was placed under the load head to act as a point load (Schematic 7). This customized set-up was required in order to distribute the load across the entire width of the panel. The final test set-up for the DLT panel can be seen in Figure 15.



Schematic 7: DLT Panel Test Elevation View

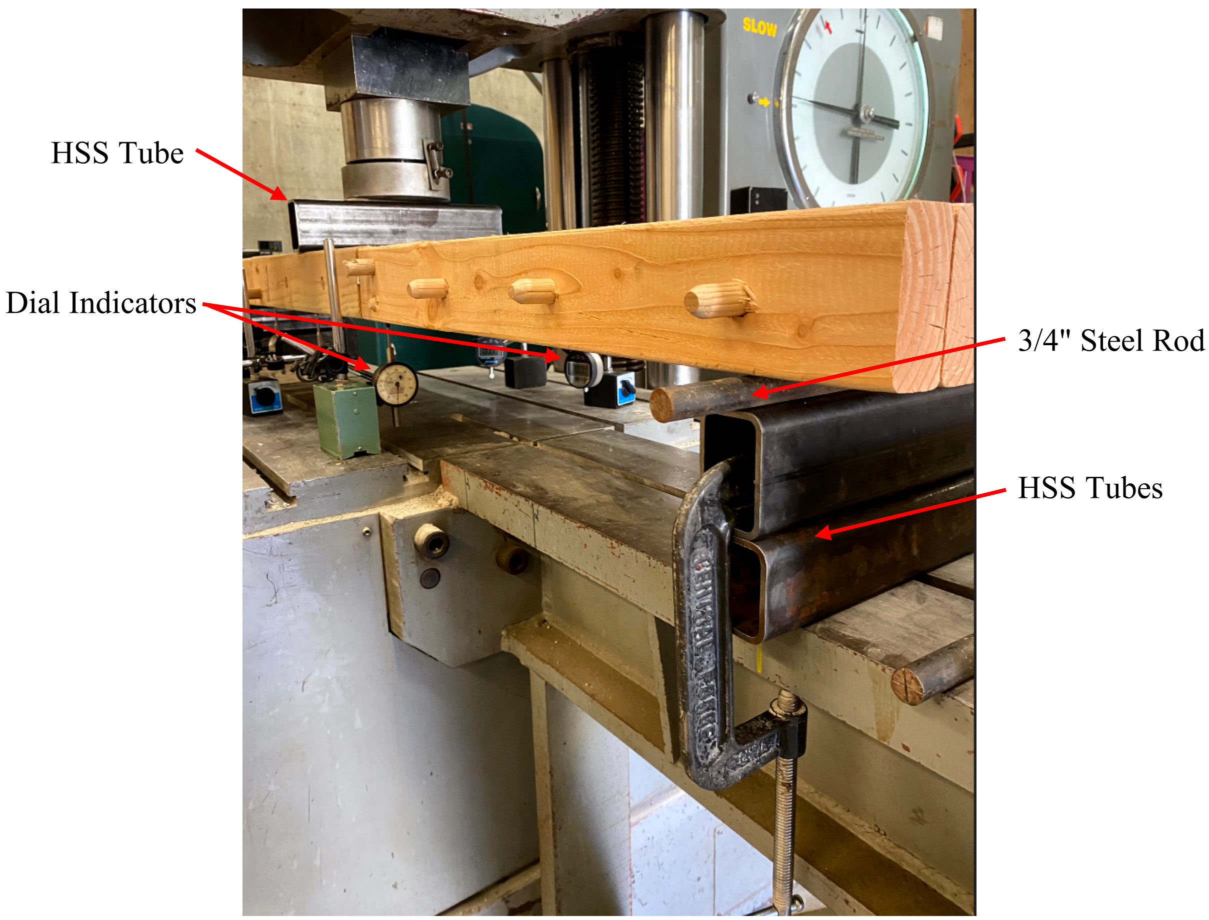
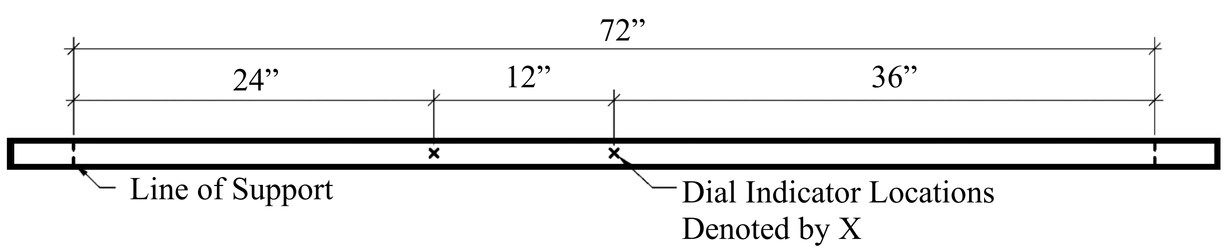


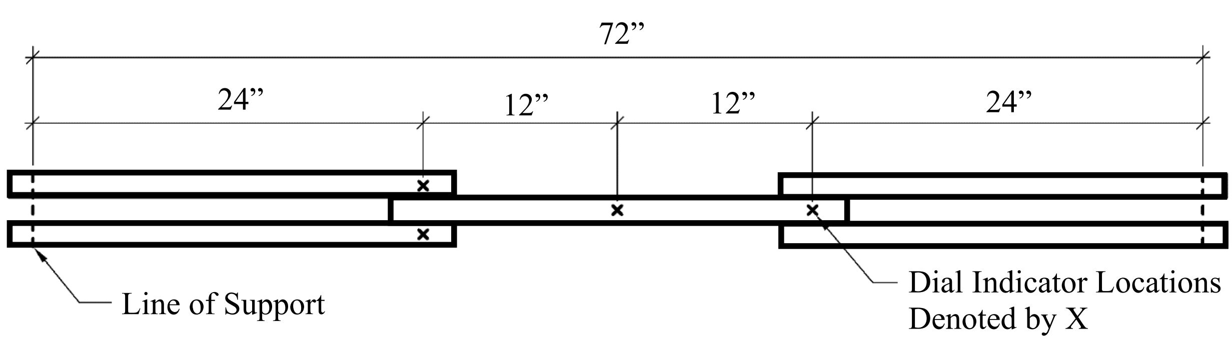
Figure 15: DLT Panel Test Set-Up

Testing Procedure:

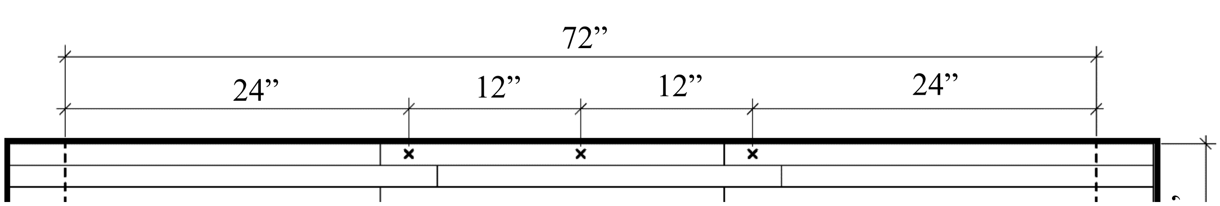
1) Dial indicators were zeroed and placed in locations denoted by an X in plan views as shown in Schematics 8-10.
2) Shims were placed at supports where the specimen did not sit flat (Figure 16).
3) All specimens were loaded to the expected elastic loads and then unloaded to zero three times to observe elastic behavior. Dial indicator measurements were recorded at the expected elastic loads as well as with no load in between loading iterations.
4) After elastic loads were measured, dial indicators were removed, and the specimens were loaded until the maximum load was reached.
5) Qualitative observations and failure modes were recorded throughout the testing process.



Schematic 8: Baseline 1 Specimen Plan View of Dial Indicator Locations



Schematic 9: Baseline 2 Specimen Plan View of Dial Indicator Locations



Schematic 10: DLT Panel Plan View of Dial Indicator Locations

Figure 16: Example of a Shim Used for a Baseline 2 Specimen Test

5.0 Results

The results presented are the expected elastic loads and deflections based on preliminary calculations, and compared with the loads and deflections recorded for each of the two baseline tests and DLT panels. Each specimen was tested three times.

5.1 Preliminary Calculated Results

The pre-calculations gave guidelines to an expected range of loading, and to provided expected outcomes to determine the loads applied to the specimens. The calculations were done by LRFD method of analysis. LRFD was used to determine the strength of our specimens without any design factors. The LRFD calculations were calculated using baseline and the DLT panel characteristics found under the DF-Larch, No. 2 category in the NDS (National Design Specifications® for Wood Construction, 2018), and were analyzed as simply supported beam with a center point load. A maximum point load was determined for each failure mode (bending, shear, deflection) and the governing load was used in the test.

The particular values that were essential for the pre-calculations are seen below:

- bending stress
- shear stress
- modulus of elasticity
- maximum moment
- maximum shear

It is important to note that in the Baseline 2 prototype, which detailed the connections of the DLT panel, and the DLT panel itself tested the dowel strengths. The Baseline 2 prototype explicitly tested the connections by isolating any other contributing factors to the failure. The DLT panel was the combination of both baseline prototypes. The T-C couple within the Baseline 2 prototype and the DLT panel was calculated to check the typical strength of row tear out from the dowels, and the shear strength of the dowels. The ¾" diameter dowels and the respective shear and axial moments were calculated as well.

The DLT panel's dowels created continuity since there is no pin connection, which created a T-C couple, due to the two dowels holding the boards together. Therefore, the T-C couple was used to find the maximum expected shear and moment. The panels were 10.5" long, 6 holes each 1.75".

The moment was solved by the given equation:

$$T = \frac{M}{b}$$

where M= PL (moment)
b= width of panel, 10.5 (6 holes x 1.75")

Both baseline preliminary calculations yielded strikingly similar results for all stresses, moments, and shears. The lowest value for each test were used for all the specimens. The DLT panel preliminary calculations were also close in comparison to each baseline test, and therefore were included as well. Below are the values important to the investigation of Baseline 1 and 2, and for the DLT panel.

	Baseline 1	**Baseline 2**	**DLT Panel**
F'b (psi)	3292	3371	3942
F'v (psi)	518	518	-
E' (psi)	1,600,000	1,600,000	-
F'c⊥ (psi)	-	1370	-
M_{max} (lb)	10,073	10,315	-
V_{max} (lb)	18183	454	-
P_{Mmax} (lb)	560	573	5367
P_{Vmax} (lb)	3626	3626	14504
$P_{M\ RO}$ (lb)	-	-	465
$P_{Vmax\ RO}$ (lb)	-	-	7264

Table 1: NDS Pre-Calculations for Each Test

For each of the prototypes and DLT panel, the deflection limits were also calculated and recorded. Below are the deflections for each per the IBC requirements.

	Baseline 1	Baseline 2	DLT Panel
P L/240 (lb)	331	132	2647
P L/360 (lb)	221	1816	1765

Table 2: Deflections and Maximum Axial Loads for Each Test

The results above provided crucial guidelines for us as we proceeded with the testing of each prototype and the DLT panel. These results were a practical way to employ the knowledge learned in our curriculum classes and enhance our understanding of why pre-calculations matter in research.

5.2 Results from Testing

Three trials were performed for each specimen, nine trials in total. Each trail was averaged. The results for the baseline 1 trial are below:

		middle	***off center (2')***
	P (lb)	**Δ (in)**	**Δ (in)**
Trial 1	267.5	0.25	0.21
Trial 2	217	0.33	0.21
Trial 3	247	0.15	0.13

Table 3: Result Averages of Baseline 1 2x4 Test

During the first trial of the Baseline 1 testing, when the loading of the specimen reached about 75 lb., there was a loud popping sound. A hairline split occurred at a knot near the center, and was the reason for tension failure due to the knot being present. During the second trial, the gage near the end of the specimen tilted and contacted the bottom of the Riehle universal testing machine; therefore, the deflections off center after 570 lb. will not be used in the analysis of the results as the validity of those deflections are questionable.

The averages for the three trials for the Baseline 2 test are shown below. The loading at the center of the specimen was recorded, as well as deflections of the dowels on the left, right side and the centers (near and far from the front of the Riehle universal testing machine, respectively).

		L dowel	*R dowel*	*middle*	*center B*
	P (lb)	**Δ (in)**	**Δ (in)**	**Δ (in)**	**Δ (in)**
Trial 1	41.2	0.19	0.45	0.39	0.36
Trial 2	29.3	0.64	0.69	0.61	0.52
Trial 3	49.3	0.62	0.6	0.61	0.6

Table 4: Result Averages of Baseline 2 Connections Test

The second trial displayed slow creeping after unloading each time. The baseline was slow to return to its original shape. The photo below shows the bending that gradually increased during the Baseline 2 testing.

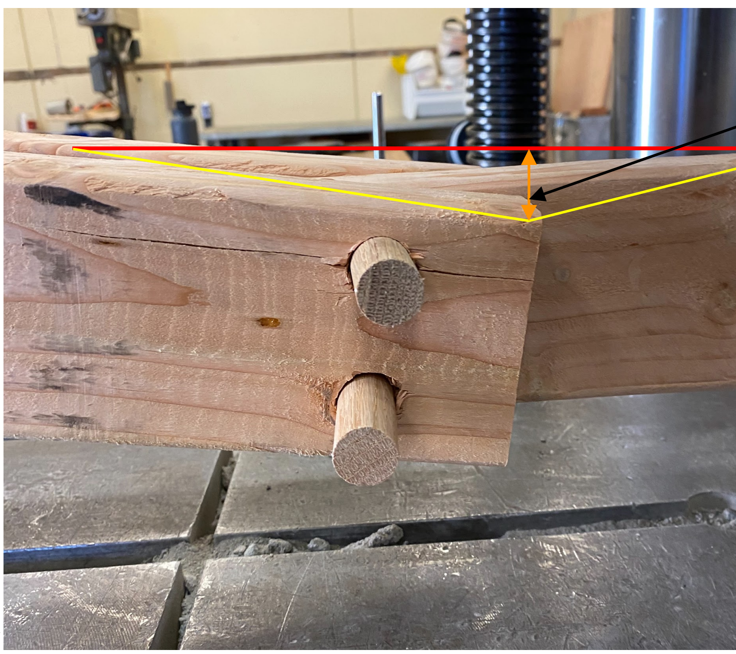


Figure 17: Bending of Baseline 2 During Testing

The final three trials tested the DLT panel. The greatest amount of loading was applied to the three panels, which increased the number of loading and unloading cycles.

		front left	*front right*	*middle left*	*middle right*	*back*
	P (lb)	**Δ (in)**	**Δ (in)**	**Δ (in)**	**Δ (in)**	**Δ (in)**
Trial 1	188.4	0.43	0.4	0.43	0.44	0.46
Trial 2	195	0.24	0.24	0.25	0.24	0.24
	P elastic	**Δ elastic**	**Δ elastic**	**Δ elastic**	**Δ elastic**	**Δ elastic**
Trial 3	201	0.16	0.13	0.23	0.22	0.21

Table 4: Result Averages of DLT Panel Test

No significant observations were made during these trials. The deflection recorded in red signifies that the deflection gage got stuck during that one loading cycle, yielding an outlier deflection, and will be omitted from results.

6.0 Discussion

The preliminary calculations provided quantitative and qualitative behavioral expectations for the three experimental tests conducted. The figures provided in the discussion section of this report are post-experimental images of the testing specimens to show qualitative failure behavior. The different configurations of the baseline specimens can be seen in Figures 18-19.

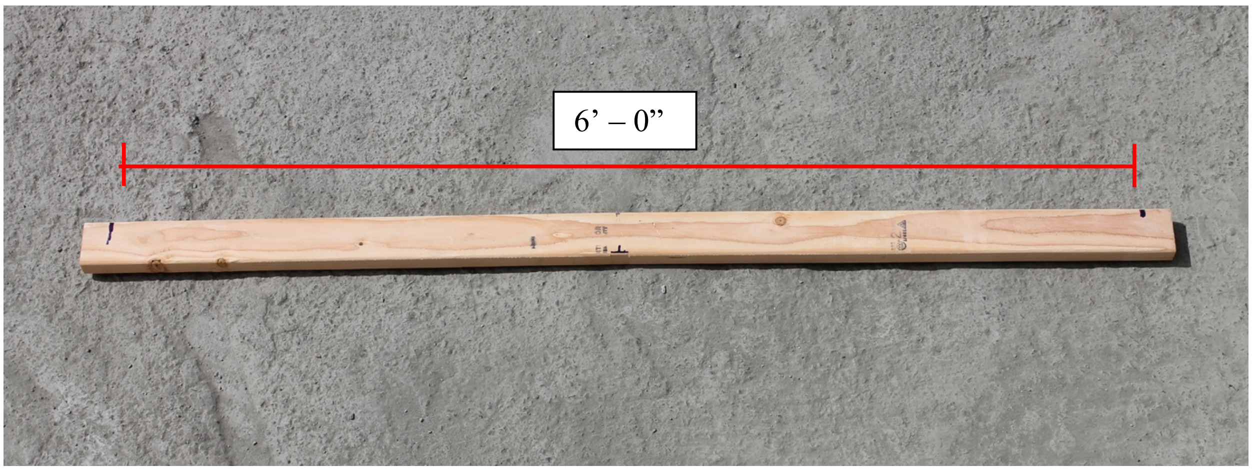


Figure 18: Baseline 1

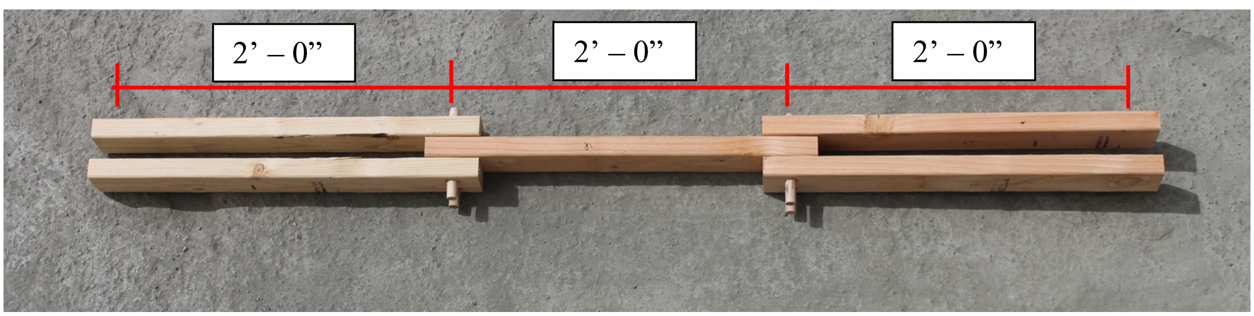


Figure 19: Baseline 2

Baseline 1 was expected to be governed by industry standard deflection limits for beams, calculated as L/240. When loaded to the estimated deflection limits, Baseline 1 remained in the elastic region because after unloading, the specimen returned to approximately 0 in. deflection. The next expected elastic load was governed by the bending capacity of Baseline 1. Once Baseline 1 was loaded to the expected bending elastic load, the specimen had entered the plastic region as the deflection of the specimen did not return to 0 in. once unloaded. Once Baseline 1 had entered the plastic region, the specimen was loaded to a maximum load to observe the failure mode. The failure of mode of Baseline 1 was due to bending, resulting in splintering on the underside of the beam due to tension stresses (Figure 20).

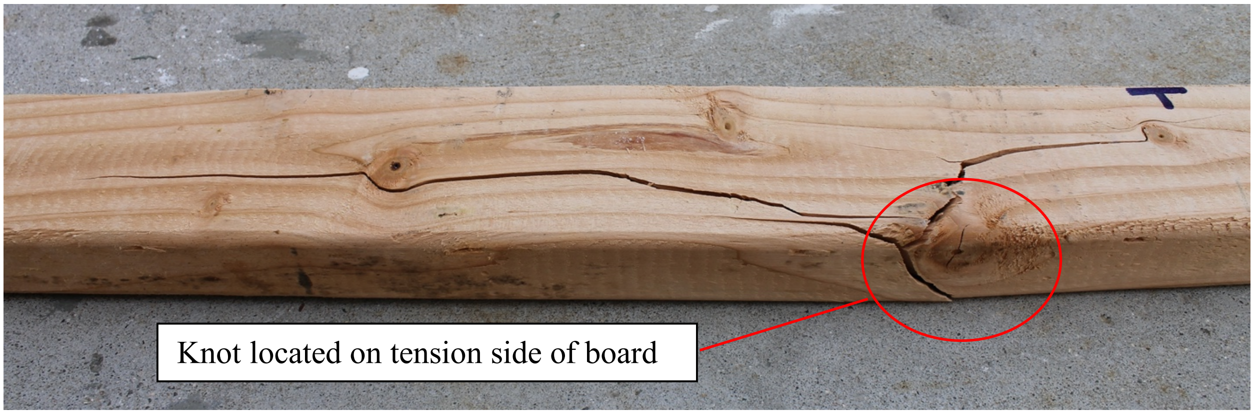


Figure 20: Baseline 1 bending failure

Although the theoretical behavior closely aligned with the experimental behavior for Baseline 1, the experimental deflection values were generally higher than the theoretical values. This variance in experimental results can be due to the variability of timber as a material because design values for the modulus of elasticity are generally conservative compared to actual material properties.

Baseline 2 was expected to be elastically governed by connection failure of row tear out failure mode of the Douglas Fir boards. The T-C couple created at each dowelled butt joint would produce a shear stress parallel to grain near the end of the boards which is a weak point in timber as a material. The dowels are located too close to the end of the board per NDS code requirements and would not typically be allowed in construction. However, the dowels were placed there to produce a worst possible case of construction. For in undeveloped nations, experience and oversight are not common and mistakes such as improper edge distance can occur.

When loaded to the estimated row tear out elastic limit, Baseline 2 already experience permanent deflection after being unloaded. This observation emphasizes the variability in timber as well as the incredibly resistance of shear parallel to grain. Although row tear out was not experienced under these theoretically elastic loads, the permanent deflection implied that the timber fibers were being compressed parallel to grain. After the theoretically elastic loads were applied, Baseline 2 was loaded to a maximum load and observed to have a row tear out failure mode as expected. Once row tear out occurred in Baseline 2, the joints began to behave as pins and the structure was no longer stable.

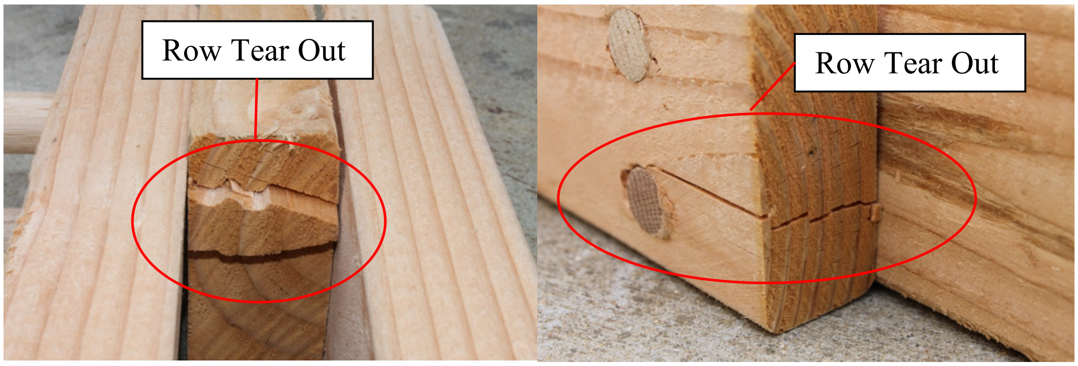


Figure 21: Baseline 2 row tear out failure

The DLT panel was expected to behave similarly to Baseline 2 because both were built with the same dowelled butt joint connection. When loaded to the estimated row tear out elastic limit, the panel also experienced permanent deflection after being unloaded similar to Baseline 2. There was a variability of up to 0.5 in. in the deflection response of each trial of the DLT panel which demonstrates the inconsistency of these dowelled butt joints. After theoretical elastic loading, the panel was loaded to a maximum load that resulted in a row tear out failure mode as expected. The maximum load of the panel was approximately seven times the maximum load of Baseline 2. This factor of seven was theorized because there are seven more joint connections in the panel than there are in Baseline 2. The elastic loads for Baseline 1 were approximately 100 lbs. greater than the expected elastic loads of the panel, showing that the weakness in the panel comes from the joints as opposed to the strength of the boards.

7.0 Industry Interaction

The importance of this project not only gave us the experience to conduct research through testing, but also allowed for the practice of interacting with those in the industry. The two aspects of industry interaction are in the organization of our trip to the Pacific Northwest (see Section 9.0 Travel to Pacific Northwest) and fundraising. The need for fundraising for our expenses of our travels predominantly, and also the purchasing of the lumber used to build each specimen tested.

The interaction with the industry was a key part in the completion of this project. The reason for our research and goal was to advance our education in the timber industry, with an emphasis in mass timber. We recognized the fast-growing industry of mass timber, and since we all had a demonstrated interest in the material, we chose to utilize our Senior Project as an opportunity to learn more. To learn more about mass timber and specifically how DLT is being used within the field, we actively reached out to industry professionals to discover more about the material[1].

In the organization of our trip and fundraising, it was apparent that communication would be the majority of our efforts. The majority of the communication with the professionals in the industry was within the realms of email communication, so it was important to rely on the skills that are typically taught outside of the classroom, otherwise known as "soft skills". These "soft skills" include how to eloquently and respectfully communicate with senior professionals in the industry, and how to properly write requests to potential supporters. The email formats were created from the past experiences of emailing professors for help in our studies; for example, the emails we sent years ago to Professor Baltimore while we all were enrolled in ARCE 224 served as wonderful templates to model our communications after. Another example of inspiration for email communication came from scheduling speakers for SEAOC meetings, and thanking professionals who attended and interacted with us at SEAOC's Structural Forum (See examples of email formatting in Appendix). Even though email served as the main form of communication, all the professionals that were contacted were eventually met in person. Our correspondent from StructureCraft served as our tour guide, and those who we communicated with for monetary support were met in person at the SEAOSC Scholarship Dinner on February 5th, 2020.

[1] The companies and non-profit organizations we reached out to were the American Wood Council and Simpson StrongTie.

7.1 Fundraising

Each weekly meeting brought new ideas and critiques to the project. During one of the weekly meetings, we strategized how to best fundraise and decided to target industry friends of the ARCE Department, who has supported student leaning in past. Initially, we reached out to a Senior Director of the American Wood Council (AWC) asking for support, either monetarily or through further connections. After a few emails exchanged, it was obvious that it would unsuccessful to receive any forms of funding from the AWC directly as it is a non-profit organization with set and rigorous protocol. Our last minute request did not meet their requirements. But it was made known that with more lead time and adhering to deadlines, AWC had opportunities for funding. Most of the additional support outside of the AWC that was provided from this communication did not fit well with our project description, (one funding opportunity was for protecting California National Parks, which was irrelevant to our research) nor could we meet the deadline for these opportunities because deadlines were too soon for us to prepare any sort of application for funding. It was not a futile effort because we established great connections with whom we spoke with at this organization, and learned the value of planning ahead in order to have appropriate information and applications for fundraising opportunities. The fundraising for the project was the most difficult aspect of the project due to the uncertainty of the outcomes. Because of the short timeline that a quarter system offers, it is difficult to quickly fundraise.

Our first attempt at fundraising gave us the motivation to continue trying. We moved towards our second industry plus potential scholarships. We reached out to local representatives at Simpson StrongTie for possible opportunities. They were gracious in their offerings to help, as they agreed to aid to the best of their abilities. In our communication exchange with Simpson StrongTie, representatives gave us examples of typical fundraising brochures used to inform the finance department of the company about opportunities to help students. In that case, we decided to also create a brochure of our project. One member of the group created a brochure of our senior project on the request of the representatives of Simpson StrongTie to give to the financial sector of the organization (see Appendix __). The discussion of funds has been still active, and will be complete by the end of the school year.

In regards to the scholarship opportunities, our group also took initiative to meet with Al Estes, Head of the Architectural Engineering Department at California Polytechnic State University. We discussed the possibility of earning some sponsorship from the Department's Learn By Doing Fund. Again, we learned the value of being prepared prior to a meeting for we gained great insight in organization and negotiation. The initial meeting was futile, as we were taken aback by the lack of preparedness we demonstrated due to the questions by the Department Head. For example, there was no itinerary concretely planned for the excursion, and no photos were brought to better describe the experiment. With only one group member present, it was difficult for the complete picture of the project to be explained since each group member had various involvement in each part of the project. Taking the lessons learned, the next meetings were more successful because we learned from our mistakes from the first meeting: we had a specific itinerary outlined, including flight information and places of interest we needed to visit to conduct further research. The most important part of our preparation for the next meeting was having an outlined budget. By having specifics about where our expenses were from, Al was able to better understand our purpose of the project and feel more comfortable about where the department funding would go. Due to our painstakingly accurate information presented, we were promised to receive a third of the amount of funding we earn through industry sponsorship.

The latest effort for funding is through the Senior Project Scholarships the Architectural Engineering Department is offering. This opportunity allows us to reflect on all that we have achieved in our project, if we have in fact met our goals, and what our results will be useful for. One group member applied for this (as this is specified in the requirements of the scholarships). We applied to the Cole E. Eugene Scholarship and the KNA Senior Project Scholarship. The scholarship committee decided the winners of the scholarships at the end of the school year in June and we were awarded the CYS Eugene Senior Project Scholarship.

8.0 Travel to Pacific Northwest

During the 2020 Winter Quarter, we had the opportunity to travel to the Pacific Northwest for further investigation of DLT. The purpose of traveling on behalf of our project was to learn firsthand about the process of DLT manufacturing to industry standards, and to see various types of ways mass timber in general is being used in structures. As previously mentioned in Section 7.0 Industry Interaction, the organization for the trip and meeting engineers in the mass timber industry expanded our practice in industry interaction. The organization was integral to the success of the trip, and therefore took months to plan. It was decided among the group that one member specifically would take responsibility to communicate with specific persons of the companies and locations we wanted to visit. We decided to focus on how DLT was fabricated in industry and then how it was commonly used in the Pacific Northwest. Therefore, the organization of the trip included contacting StructureCraft to schedule a tour, to travel to various CLT-framed buildings in the Pacific Northwest, and to visit the Bullitt Center in Seattle, Washington. The specific persons we needed to be in contact with a representative from the Business Development Office of StructureCraft, and the tour guides for the Bullitt Center. Being in contact with these representatives allowed us to coordinate the travel and events during our time in the Pacific Northwest. The reason we assigned this to one group member was to concentrate the communication within one representative and have less confusion in coordination amongst multiple people within our team. From our initial research, we narrowed down the various options we had to enhance our research.

The main part of the trip was the tour at StructureCraft because of the valuable information they could provide us about DLT production, and it would serve as a direct comparison to our research and findings. In order to schedule a visit, the initial planning of the trip consisted of contacting a representative from StructureCraft, the leading manufacturer of DLT in North America. An estimator from the business development team was in contact with us in a matter of days after sending an initial email to the given contact on StructureCraft's website. Once communication was initially established between our group and the representative at StructureCraft, we were respectful of the time of those at StructureCraft and our own schedules during the quarter. We decided to go at the end of Week 7 of Winter Quarter, in order to have our specimen of our panels of DLT already made and in the beginning stages of being tested in order to have tangible knowledge to use in conversing with the engineers at StructureCraft, and that our original process of fabrication was not subconsciously influenced by knowledge gained from our visit. After a couple weeks of communication between the company and our group, we heard back from StructureCraft about our request to visit and it was granted.

Once it was established that we indeed were able to visit StructureCraft, we then had to work to get the logistics of the trip finalized. Airfare tickets were purchased for the entire weekend to Seattle, Washington. We arrived in Seattle on Thursday, February 20th. Lodging was also planning prior to going, and we stayed in the Ballard neighborhood.

We visited StructureCraft on February 21st, 2020. We traveled to the facility in the morning, and had our tour in the afternoon. During our hour and a half visit, our person of contact gave us a detailed tour of the entire facility and manufacturing plant. The amount of information and knowledge we gained during our tour was priceless, and we reflected that what we learned could not have been extracted from a pamphlet; it was very beneficial that we toured the facility.

Figure left, clockwise order: Inside the manufacturing facility, our first view of StructureCraft, us after the tour

Our person of contact was incredibly knowledgeable about DLT, and was our source of information. We learned that various types of lumber are used in the fabrication of DLT. For example, European wood is used for façade lumber. More specifically, Douglas Fir produces more grey wood while Alaskan Cedar gives a brownish-hue to its wood produced. Beech wood serves as the lumber of choice for the ridged dowels in DLT. StructureCraft specifically uses Spruce Pine Fir, Douglas Fir, and Hem Fir in special circumstances. DLT is finger-jointed to get longer spans, and to have it appear seamless to the naked eye. We were very impressed that the facility was designed by StructureCraft engineers; they spoke about how the flow of the manufacturing facility is intentional in order to produce DLT in the most efficient way for maximum efficiency and minimal waste. StructureCraft specially sources their lumber from Canada in order to minimize their carbon footprint; most lumber in the Pacific Northwest is from Canada, and is mechanically graded. The wood that is chosen to be used, including those that have had imperfections cut off from boards, is kiln-dried to about 12% MC. The boards are then finger-jointed to desired lengths, which could range from 8 feet to 20 feet. After being finger-jointed, the boards are fed through the planer in order to achieve uniform thickness. The boards are then stacked horizontally and to achieve desired width of the panel. In the design of the facility, crane lifts were included and installed in order to lift the panels around the facility. A hydraulic press clamps boards on tops and on the sides when the dowels are being installed; the press drills holes into the panels and presses the dowels into the panels. Dowels have longitudinal grooves to assist in better insertion into panels. Typical spacing for dowel placement is 16 in. o.c.

In order to actually have the dowels stay in the panels without any other form of adhesive, the dowels are intentionally drier than the panels itself; the dowels are at about a 5% MC. Therefore, since the panels have a higher MC than the dowels, the dowels will absorb some of the moisture, expanding and swelling within the panel and locking into place. The dowels and boards meet moisture equilibrium eventually, within a matter of days or weeks, depending on weather and season circumstances.

Structurally, the dowels hold some shear resistance, but otherwise are not as structural as the plywood applied to the back of the DLT panel. A plywood sheet is installed on the non-façade side of the panel, which allows for concrete to be poured on top of the DLT panel. A common layering sequence in a building, from top to bottom, is concrete, an acoustic layer, plywood, and then the DLT panel. This installation of plywood makes the panels themselves one-way panels.

From an architectural standpoint, DLT is gaining popularity, especially within the technology industry. The desired aesthetic of wood aligns well with the goal of providing those working in the technology industry to achieve a sense of natural balance within the workplace. Mass timber is usually used in structures 7 stories tall or less, but much more development in future codes will hopefully allow for 12 story mass timber buildings. The reason DLT is becoming more popular today is because of the overall advantages DLT can provide. DLT has more structural efficiency. It is thinner than other types of mass timber; therefore using less timber overall. StructureCraft has done research in the development of DLT as well, with the help of other companies in the industry. It has been tested and proven by their research that a DLT at 6 in. has a 2 hour fire rating. StructureCraft has also finessed the “sweet spot” of the length of a panel for maximum efficiency of a panel, which ranges between 8 feet and 16 feet. Also, connections of the panels themselves can be customized for the specified project, upon request of the architects and structural engineers, expanding the aesthetic variety that DLT can display. Since DLT uses the strength of interlocking without adhesives and minimal number of nails, no formaldehyde is used in the construction of DLT, making it eligible for recycling (unlike CLT). DLT is only made from certified sustainable mills found in North America, adding to the positive effects it has on the environment. At the end of our tour, StructureCraft graciously gifted us with a sample panel of their manufactured DLT. All of this information was given to us during the tour; one group member took careful notes while the other group members were more engaged with the tour, asking questions and continuing a dialogue throughout the tour.

After our time at StructureCraft, we had the opportunity to visit BrockCommons, the tallest timber building in North America. It is located on the campus of the University of British Columbia. We were able to see firsthand how the designers used timber in all facets of a structure, from the actual structural frame of the building to the architectural details of the rooms and hallways.

The following day, our group visited the Bullitt Center in the Capitol Hill neighborhood of Seattle, Washington. The tour was conducted by a representative of the Architecture Department at the University of Washington. The building’s structure is CLT, which was why we wanted to visit the building: not only is it an example of another building built predominantly out of CLT, but it also served as an example of eco-friendly structures, which connects to the sustainability aspect of CLT that we wanted to learn more about. The building itself is a zero-energy building, built by LEED Gold. It participates in the Living Breathing Challenge, where no toxic materials can be used in the design and building of the structure. Therefore, it was not surprising to find that the floors of the structure were built with NLT (Nail Laminated Timber), a “cousin” of DLT. NLT is usually butt jointed in order to achieve longer spans, which was understandable in the fabrication of the Bullitt Center’s long but narrow floors.

Figure Above: Our visit to BrockCommons

Figure Below: Our tour of the Bullitt Center

9.0 Global Impact

Our senior project was designed to be a multi-layered endeavor to reflect the various subjects of education we receive through our curriculum. To better understand how we could impact our global world through our work, we planned our project to capture the majority of the particularly *globalization, constructability, cultural, environmental, and economic* considerations.

9.1 Globalization

The globalization aspect of our project was integral in the conception of our building process for the DLT Panels, as well as the presentation of our findings.

Our preliminary research and discussions with select ARCE faculty demonstrated that in developing nations, the cost of equipment and machinery is higher than labor costs. Hence, it would be custom for these nations to employ a great amount of people to help build rather than to purchase a machine to do the job. Therefore, we designed the construction process for our panels to mirror the practices in these nations. Since we only used hand tools and physical labor to build the panels, this gave a “trial-and-error” opportunity to discover unforeseen problems and nuisances that would be present in this sort of fabrication method. This way, our unique process of fabricating the panels, after crucial revisions, could be delivered to builders in developing nations.

To make this applicable to a multitude of nations, we worked to keep the fabrication process as clear and specific as possible to minimize any confusion in translation. The importance of applicability to a range of developing nations was important to us throughout the project to ensure our research and work could be shared globally.

The delivery of the knowledge of this project, especially the fabrication process, also emulates globalization. Our research and labor methods may be given to others globally and transfer it to their construction practices with minimal translation. Since we originally considered practices common in these areas of the world, we transfer typical knowledge of our country into means of understanding that best fits their learning methods. As we were surrounded by ARCE faculty that had experience in the global exchange of information, we recognized that our work could come to fruition in years to come.

9.2 Constructability

The construction of the DLT Panel Specimen was the main aspect of constructability, because it was a significant portion of the project. In designing our process of fabrication, it was essential to only use hand tools and our own physical strength to build the specimens, as it is typical in developing nations. The only tools used were hand drills and hammers. We had to lift, hammer, and drill each specimen and prototype, which turned out to be more labor-intensive than we imagined. It taught us the importance of clear instructions and physical strength. Furthermore, our first fabrication instructions would be edited to stagger the points and connections of the DLT Panel Specimen, which we would not have learned were ineffective if we did not actually build and test it.

9.3 Cultural

The cultural aspect of our project is connected to our DLT panel construction as well. It was vital to not veer from common practices of developing nations to ensure that the methods of fabrication and research was not futile. All of the prototypes and specimens were manufactured by hand, emulating common building practices found in these nations. Labor is cheaper than equipment, and therefore to conform to these construction ideas, we imitated these practices in our own construction.

9.4 Environmental

The greatest impact of our project can be connected to the environmental aspect. DLT as a material will be effective in saving threatened environments around the world because of the absence of toxic adhesives, as compared to other mass timber products. The inspiration for our project was due to environmental concerns; the infected oceans of Vietnam shed light on the dangers of negligent recycling processes, and DLT would be an impeccable substitute to avoid horrible accidents in the future. Timber itself is a renewable resource, and when no added toxins are introduced to the material (in the form of adhesives or epoxies) it can be recycled to use again. The recycling of DLT is an advantage to this material, as it can minimize deforestation in countries and waste produced globally.

Paddock, R. (2016). Toxic Fish in Vietnam Idle a Local Industry and Challenge the State, https://www.nytimes.com/2016/06/09/world/asia/vietnam-fish-kill.html (October 11, 2019).

Figure 22: Dead Fish along a Popular Fishing Beach in Vietnam

9.5 Economic

The economic aspect of our project was evident in or acquiring of the materials to build our prototypes and specimen. We had to greatly consider any differences in purchasing lumber for our specimens; the question of lumber availability due to costs was greatly well-thought-out. Since a variety of countries have different reasons for material preferences, it was imperative to use lumber that would be both easily accessible but also adequate for building the prototype. Furthermore, the economic realm of construction of counties is influential because, as previously mentioned, the fact that labor is cheaper than equipment heavily influenced our construction process. It was uplifting to know that the construction process of these panels could involve various groups connected to the building of panels, which would directly contribute to any existing micro-economies present in these nations. For example, the persons responsible for acquiring the lumber, the persons to plane and trim the lumber, and the laborers would all be involved. Since economics include both money and people, this aspect had to be considered and effectively represented in our construction process.

10.0 Conclusion

DLT products can be manufactured in the conditions of third world countries. In developing nations, labor is relatively inexpensive and machinery is expensive. DLT is a feasible product since it is labor intensive and only uses hand tools. In addition to the tools, DLT requires large amount of dimensional lumber for assembly. A wood economy is already established in many third world countries and with the addition of mills and planners, dimensional lumber is obtainable. Dimensional lumber will be the greatest expense when producing DLT. Third world countries have the lumber, labor, and hand tools to manufacture DLT products, however the transfer of knowledge can become challenging. The challenge in transferring knowledge comes from teaching using different methods depending on the country.

The location of the butt joints should not match the DLT panel that was tested. The DLT panel tested the worst-case assembly of the butt joints by align them across the panel. Aligning the joints created a weak and inefficient DLT panel for our testing. To create an efficient DLT product, the butt joints should be staggered and longer splice lengths should be used. The goal of these changes are to avoid row tear out from the dowels being close to the edge of the boards. Row tear out is the biggest issue that needs to be avoided and it can be prevented with proper assembly. Apart from issues of aligning the joints, the DLT panel was manufactured with good quality.

The purpose of this experiment was to test the feasibility and strength of DLT panel that was produced using resources available in a developing nation. In terms of feasibility, the construction techniques used to build the DLT could be easily translated to a developing nation where labor and timber are readily available. In terms of strength, this method of building DLT would not be a reasonable construction method in a developing nation due to the large amount of material required and the weakness of the dowelled butt joints. The dowelled butt joints could be improved by staggering the joints to avoid row tear out.

Finally, a high level of professionalism that was maintained throughout the investigation provided valuable experience for the young professionals. The interactions with industry professionals and the weekly meeting sharpened the communication skills of the students. Clear and eloquent communication was practiced throughout the investigation and was especially important when fundraising and receiving permission to travel. These skills are important as the students transition from an academic environment to industry.

11.0 References

- rethink Wood. 2019. *Mass Timber in North America*. American Wood Council.
- International Code Council-Evaluation Service. 2019. *ESR-4069*
- StructureCraft. 2019. *Dowel Laminated Timber, The All Wood Mass Timber Panel.* Ver. 4

12.0 Appendix

ICC EVALUATION SERVICE

ICC-ES Evaluation Report

ESR-4069

Issued November 2019

Revised November 8, 2019

This report is subject to renewal November 2020.

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DIVISION: 06 00 00 —WOOD, PLASTICS AND COMPOSITES
Section: 06 17 21—Dowel-Laminated Timber

REPORT HOLDER:

STRUCTURECRAFT BUILDERS INC.

EVALUATION SUBJECT:

DOWEL-LAMINATED TIMBER (DLT)

1.0 EVALUATION SCOPE

Compliance with the following codes:

- 2018, 2015, 2012 and 2009 *International Building Code®* (IBC)
- 2018, 2015, 2012 and 2009 *International Residential Code®* (IRC)

For evaluation for compliance with codes adopted by the Los Angeles Department of Building Safety (LADBS) see ESR-4069 LABC and LARC Supplement.

Property evaluated:

- Structural
- Fire Resistance

2.0 USES

StructureCraft DowelLam™ Dowel-Laminated Timber (DLT) is a mechanically laminated timber panel, pegged together by hardwood dowels, for use as floor and roof deck panels in Types III, IV (Heavy Timber) and V Construction, and in Types I and II Construction where permitted by IBC Section 603 and elsewhere in the code. StructureCraft DowelLam™ Dowel-Laminated Timber may also be used in structures regulated under the IRC when an engineered design is submitted in accordance with IRC Section R301.1.3.

3.0 DESCRIPTION

3.1 General:

StructureCraft Dowel-Laminated Timber panels described in this evaluation report consist of planed and finger-jointed sawn lumber laminations, set on edge and mechanically fastened together by inserting $^3/_4$-inch diameter profiled hardwood dowels running perpendicular to the wide faces of the laminations. The dowels are inserted into predrilled holes $^1/_{32}$ inch less than the $^3/_4$-inch dowel diameter to secure a tight fit. The moisture content of the lumber at the time of manufacture does not exceed 19 percent, and the dowels are dried to 5 to 8 percent moisture content prior to insertion. Once inserted, the dowels swell as they come into equilibrium with the higher moisture content of the surrounding lumber, providing additional friction for a tight fit of the dowel in the laminations.

The StructureCraft Dowel-Laminated Timber panels are available in thicknesses of 4 inches nominal (89 mm) to 12 inches nominal (286 mm), widths of 12 inches (305 mm) to 14 feet (4.3 m) and lengths up to 60.7 feet (18.5 m).

3.2 Material:

3.2.1 Wood Laminations: Wood laminations used in manufacturing StructureCraft Dowel-Laminated Timber are produced from either visually graded or mechanically stress rated lumber as required in the approved StructureCraft quality documentation. The moisture content of the laminations is 19 percent or less, prior to insertion of the wood dowels. Finger joints in the laminations, where used, meet the requirements for Certified End Joints according to the West Coast Lumber Inspection Bureau (WCLIB). The adhesive used for the finger joints is a non-formaldehyde-based, one-component polyurethane, also conforming to the approved StructureCraft quality documentation.

3.2.2 Dowels: The $^3/_4$-inch diameter wood dowels used in StructureCraft DLT are hardwood dowels manufactured in accordance with the standards contained in the approved StructureCraft quality documentation. A profile of the dowel is shown in Figure 1. Dowel patterns for the different DLT panel thicknesses, including dowel spacing and positioning within the panel, are shown in Figure 2.

4.0 DESIGN AND INSTALLATION

4.1 General:

Design and installation of StructureCraft Dowel-Laminated Timber panels described in this evaluation report must be in accordance with this evaluation report, the applicable code provisions, and the StructureCraft published design and/or installation instructions. Sections 2304, 2305, 2306, and 2307 of the IBC are applicable to StructureCraft Dowel-Laminated Timber.

4.2 Reference Design Values:

Reference design values for Allowable Stress Design (ASD) of StructureCraft Dowel-Laminated Timber panels resisting out-of-plane loading are shown in Table 1. These values are for loads applied parallel to the wide face of the panel laminations (normal to the wide faces of the panels) where the panels are continuously supported at bearing lines which cross the laminations at panel ends or intermediate locations.

Use of StructureCraft DLT panels spanning to bearing lines which are exactly parallel with the laminations is outside the scope of this report.

4.3 Adjustment Factors:

The reference design values of Table 1 must be adjusted by the load duration factor C_D and temperature factor C_t (or C_t, K_F, ϕ, and λ for Load and Resistance Factor Design) in accordance with Section 4.3 of the *National Design Specification® for Wood Construction* (NDS) and Tables 4A and 4C of the NDS *Supplement – Design Values for Wood Construction* (Supplement). The size factor C_F is already considered, where applicable, in the design values of Table 1 and may not be additionally applied. The beam stability factor, C_L, of Section 3.3.3 of the NDS shall be taken to be 1.0 for the StructureCraft DLT Panels of Table 1. The bending design values in Table 1 include the repetitive member factor, C_r = 1.15, and must not be further increased for repetitive use.

4.4 Fire Resistance:

Where fire performance is required, the fire resistance rating (FRR) of exposed StructureCraft Dowel-Laminated Timber may be determined in accordance with Chapter 16 of the NDS. Additionally, the Heavy Timber construction provisions of Section 602.4 of the IBC for lumber decking are applicable to the StructureCraft Dowel-Laminated Timber described in this evaluation report.

4.5 Use of Dowel Laminated Timber in Diaphragm Construction:

For the purposes of diaphragm construction, StructureCraft DLT panels are considered laminated decking and must be sheathed with wood structural panel sheathing in accordance with the requirements of Section 4.2 of the *Special Design Provisions for Wind and Seismic* (SDPWS) and subject to the additional requirements of SDPWS Section 4.2.7.1.

5.0 CONDITIONS OF USE

The StructureCraft Dowel-Laminated Timber described in this report complies with, or is a suitable alternative to what is specified in, those codes listed in Section 1.0 of this report, subject to the following conditions:

5.1 Use of StructureCraft DowelLam™ DLT panels must be limited to dry service conditions where the moisture content in lumber in service is less than 19 percent, as in most covered structures.

5.2 The StructureCraft Dowel Laminated Timber panels recognized in this evaluation report used in floor and roof deck construction are intended to span the direction of the laminations and be supported along lines crossing the laminations at panel ends and/or intermediate locations.

5.3 The use of StructureCraft Dowel-Laminated Timber in diaphragm construction must be in accordance with SPDWS Section 4.2, subject to the additional requirements of SPDWS Section 4.2.7.1 for laminated decking.

5.4 Loading and support conditions, other than those described in Section 4.2, are outside the scope of this evaluation report.

5.5 Dowel-laminated decking panels must be anchored to supports in accordance with the applicable code.

5.6 Notching and drilling StructureCraft Dowel-Laminated Timber panels have not been evaluated and are outside the scope of this evaluation report. The reference design values recognized in Table 1 of this report are for flat-faced rectangular-section panels.

5.7 StructureCraft Dowel-Laminated Panels are manufactured in Abbotsford, Canada under a quality control program with inspections by ICC-ES.

6.0 EVIDENCE SUBMITTED

6.1 Quality Documentation in accordance with the ICC-ES Acceptance Criteria for Quality Documentation, AC10, dated June 2014.

6.2 Results of structural testing of StructureCraft Dowel-Laminated Timber panels.

6.3 Structural calculations, drawings, and details.

6.4 Results of fire testing conducted in accordance with ASTM E119.

7.0 IDENTIFICATION

7.1 Every StructureCraft Dowel-Laminated Timber panel is identified with a stamp containing the following information: manufacturer's name (StructureCraft Builders Inc.) or logo, manufacturing address (1929 Foy Street, Abbotsford V2T 6B1, BC, Canada), manufacturing date and shift, product name, panel species and grade/model designation, and the evaluation report number (ESR-4069).

7.2 The report holder's contact information is the following:

STRUCTURECRAFT BUILDERS INC.
1929 FOY STREET
ABBOTSFORD, BRITISH COLUMBIA V2T 6B1
CANADA
(604) 940 8889
www.structurecraft.com
mail@structurecraft.com

TABLE 1—REFERENCE DESIGN VALUES (ASD) FOR STRUCURECRAFT DOWEL-LAMINATED TIMBER DECKING [4,5,6]

SPRUCE-PINE-FIR DLT					
Grade	**Nominal Size [1] (Panel Thickness) (in.)**	**$F_b(S_{eff})C_r$ or [2,7] $F_b(S_{eff})C_FC_r$ (lbf-ft/ft)**	**EI (x10^6 lbf-in.^{2}/ft)**	**V [3] (lbf/ft)**	**R [8] (lbf/ft-in.)**
2100f-1.8E	2x4 (3.5)	4,880	77	2,970	5,100
	2x6 (5.5)	12,145	299	5,130	5,100
1950f-1.7E	2x8 (7.25)	18,315	648	7,020	5,100
Select Structural	2x4 (3.5)	4,360	64	2,970	5,100
	2x6 (5.5)	9,400	250	5,130	5,100
	2x8 (7.25)	14,085	572	7,020	5,100
	2x10 (9.25)	20,450	1,187	9,180	5,100
	2x12 (11.25)	27,965	2,136	11,340	5,100
No.1/No.2	2x4 (3.5)	3,050	60	2,970	5,100
	2x6 (5.5)	6,580	233	5,130	5,100
	2x8 (7.25)	9,860	534	7,020	5,100
	2x10 (9.25)	14,315	1,108	9,180	5,100
	2x12 (11.25)	19,575	1,993	11,340	5,100
No.3	2x4 (3.5)	1,745	51	2,970	5,100
	2x6 (5.5)	3,760	200	5,130	5,100
	2x8 (7.25)	5,635	457	7,020	5,100
	2x10 (9.25)	8,180	950	9,180	5,100
	2x12 (11.25)	11,185	1,709	11,340	5,100
DOUGLAS FIR LARCH (NORTH) DLT					
Grade	**Nominal Size [1] (Panel Thickness) (in.)**	**$F_b(S_{eff})C_r$ or [2,7] $Fb(S_{eff})C_FC_r$ (lbf-ft/ft)**	**EI (x10^6 lbf-in.^{2}/ft)**	**V [3] (lbf/ft)**	**R [8] (lbf/ft-in.)**
2400f-2.0E	2x4 (3.5)	5,580	86	3,960	7,500
	2x6 (5.5)	13,880	333	6,840	7,500
Select Structural	2x4 (3.5)	4,710	81	3,960	7,500
	2x6 (5.5)	10,150	316	6,840	7,500
	2x8 (7.25)	15,215	724	9,360	7,500
	2x10 (9.25)	22,085	1,504	12,240	7,500
	2x12 (11.25)	30,205	2,705	15,120	7,500
No.1 & btr.	2x4 (3.5)	4,010	77	3,960	7,500
	2x6 (5.5)	8,645	299	6,840	7,500
	2x8 (7.25)	12,960	686	9,360	7,500
	2x10 (9.25)	18,810	1,425	12,240	7,500
	2x12 (11.25)	25,730	2,563	15,120	7,500
No.1/No.2	2x4 (3.5)	2,965	69	3,960	7,500
	2x6 (5.5)	6,390	266	6,840	7,500
	2x8 (7.25)	9,580	610	9,360	7,500
	2x10 (9.25)	13,905	1,266	12,240	7,500
	2x12 (11.25)	19,015	2,278	15,120	7,500
No.3	2x4 (3.5)	1,655	60	3,960	7,500
	2x6 (5.5)	3,570	233	6,840	7,500
	2x8 (7.25)	5,355	534	9,360	7,500
	2x10 (9.25)	7,770	1,108	12,240	7,500
	2x12 (11.25)	10,625	1,993	15,120	7,500

See page 5 for footnotes.

TABLE 1—REFERENCE DESIGN VALUES (ASD) FOR STRUCURECRAFT DOWEL-LAMINATED TIMBER DECKING [4,5,6] (Continued)

Grade	Nominal Size [1] (Panel Thickness) (in.)	$F_b(S_{eff})C_FC_r$ [2,7] (lbf-ft/ft)	EI (x10[6] lbf-in.[2]/ft)	V [3] (lbf/ft)	R [8] (lbf/ft-in.)
COAST SITKA SPRUCE DLT					
Select Structural	2x4 (3.5)	4,535	73	2,750	5,460
	2x6 (5.5)	9,775	283	4,750	5,460
	2x8 (7.25)	14,650	648	6,500	5,460
	2x10 (9.25)	21,265	1,345	8,500	5,460
	2x12 (11.25)	29,085	2,421	10,500	5,460
No.1/No.2	2x4 (3.5)	3,225	64	2,750	5,460
	2x6 (5.5)	6,955	250	4,750	5,460
	2x8 (7.25)	10,425	572	6,500	5,460
	2x10 (9.25)	15,130	1,187	8,500	5,460
	2x12 (11.25)	20,695	2,136	10,500	5,460
No.3	2x4 (3.5)	1,830	60	2,750	5,460
	2x6 (5.5)	3,945	233	4,750	5,460
	2x8 (7.25)	5,915	534	6,500	5,460
	2x10 (9.25)	8,590	1,108	8,500	5,460
	2x12 (11.25)	11,745	1,993	10,500	5,460
HEM-FIR (NORTH) DLT					
Grade	**Nominal Size [1] (Panel Thickness) (in.)**	**$F_b(S_{eff})C_FC_r$ [2,7] (lbf-ft/ft)**	**EI (x10[6] lbf-in.[2]/ft)**	**V [3] (lbf/ft)**	**R [8] (lbf/ft-in.)**
Select Structural	2x4 (3.5)	4,535	73	3,190	4,860
	2x6 (5.5)	9,775	283	5,510	4,860
	2x8 (7.25)	14,650	648	7,540	4,860
	2x10 (9.25)	21,265	1,345	9,860	4,860
	2x12 (11.25)	29,085	2,421	12,180	4,860
No.1 & btr.	2x4 (3.5)	4,185	73	3,190	4,860
	2x6 (5.5)	9,020	283	5,510	4,860
	2x8 (7.25)	13,525	648	7,540	4,860
	2x10 (9.25)	19,630	1,345	9,860	4,860
	2x12 (11.25)	26,845	2,421	12,180	4,860
No.1/No.2	2x4 (3.5)	3,485	69	3,190	4,860
	2x6 (5.5)	7,520	266	5,510	4,860
	2x8 (7.25)	11,270	610	7,540	4,860
	2x10 (9.25)	16,360	1,266	9,860	4,860
	2x12 (11.25)	22,375	2,278	12,180	4,860
No.3	2x4 (3.5)	2,005	60	3,190	4,860
	2x6 (5.5)	4,325	233	5,510	4,860
	2x8 (7.25)	6,480	534	7,540	4,860
	2x10 (9.25)	9,405	1,108	9,860	4,860
	2x12 (11.25)	12,865	1,993	12,180	4,860

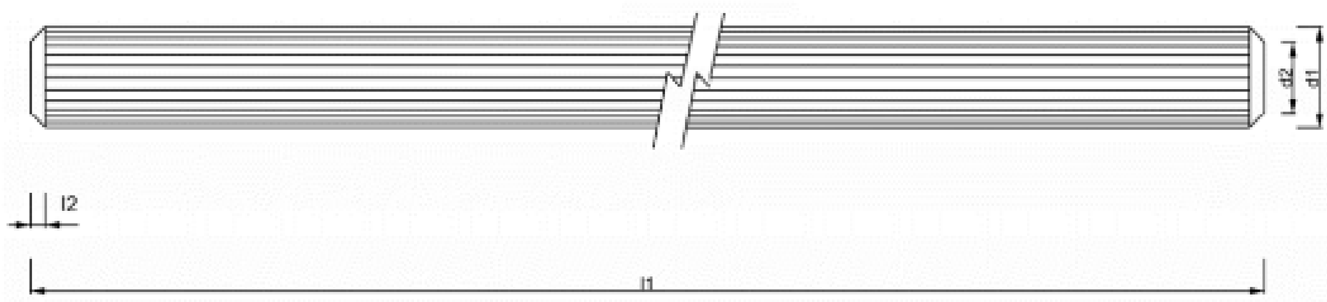
See page 5 for footnotes.

TABLE 1—REFERENCE DESIGN VALUES (ASD) FOR STRUCURECRAFT DOWEL-LAMINATED TIMBER DECKING [4,5,6] (Continued)

Grade	Nominal Size [1] (Panel Thickness) (in.)	$F_b(S_{eff})C_FC_r$ [2,7] (lbf-ft/ft)	EI (x10[6] lbf-in.[2]/ft)	V [3] (lbf/ft)	R [8] (lbf/ft-in.)
YELLOW CEDAR DLT					
Select Structural	2x4 (3.5)	4,185	69	3,850	6,480
	2x6 (5.5)	9,020	266	6,650	6,480
	2x8 (7.25)	13,525	610	9,100	6,480
	2x10 (9.25)	19,630	1,266	11,900	6,480
	2x12 (11.25)	26,845	2,278	14,700	6,480
No.1/No.2	2x4 (3.5)	2,790	60	3,850	6,480
	2x6 (5.5)	6,015	233	6,650	6,480
	2x8 (7.25)	9,015	534	9,100	6,480
	2x10 (9.25)	13,085	1,108	11,900	6,480
	2x12 (11.25)	17,900	1,993	14,700	6,480
No.3	2x4 (3.5)	1,655	51	3,850	6,480
	2x6 (5.5)	3,570	200	6,650	6,480
	2x8 (7.25)	5,355	457	9,100	6,480
	2x10 (9.25)	7,770	950	11,900	6,480
	2x12 (11.25)	10,625	1,709	14,700	6,480
NORTHERN SPECIES DLT					
Grade	**Nominal Size [1] (Panel Thickness) (in.)**	**$F_b(S_{eff})C_FC_r$ [2,7] (lbf-ft/ft)**	**EI (x10[6] lbf-in.[2]/ft)**	**V [3] (lbf/ft)**	**R [8] (lbf/ft-in.)**
Select Structural	2x4 (3.5)	3,400	47	2,420	4,200
	2x6 (5.5)	7,330	183	4,180	4,200
	2x8 (7.25)	10,990	419	5,720	4,200
	2x10 (9.25)	15,950	871	7,480	4,200
	2x12 (11.25)	21,815	1,566	9,240	4,200
No.1/No.2	2x4 (3.5)	2,180	47	2,420	4,200
	2x6 (5.5)	4,700	183	4,180	4,200
	2x8 (7.25)	7,045	419	5,720	4,200
	2x10 (9.25)	10,225	871	7,480	4,200
	2x12 (11.25)	13,985	1,566	9,240	4,200
No.3	2x4 (3.5)	1,220	43	2,420	4,200
	2x6 (5.5)	2,630	166	4,180	4,200
	2x8 (7.25)	3,945	381	5,720	4,200
	2x10 (9.25)	5,725	791	7,480	4,200
	2x12 (11.25)	7,830	1,424	9,240	4,200

For **SI**: 1 inch = 25.4 mm; 1 lb = 4.45 N

1. Nominal size of panel laminations. Actual thickness is the actual width (depth) of the panel laminations.
2. S_{eff} is the effective section modulus of the DLT panel.
3. V is the reference shear resistance of the panel at the dowel locations.
4. Design values are for panels spanning the direction of the lamination axes and supported at bearing lines crossing the lamination axes at ends and/or intermediate locations.
5. Design values are given per foot panel width.
6. Design values are for flat-face rectangular section panels.
7. Design values are subject to the adjustment requirements of Section 4.3, noting C_F (where applicable) and C_r = 1.15 are already considered in the table values.
8. Reaction values are based on the NDS values for bearing-perpendicular-to-grain per foot of panel width and inch of bearing length.



d1 = 0.78 in., l1 < 30 in., d2 >0.5 in., l2 < 0.25 in.

FIGURE 1—HARDWOOD DOWEL USED IN STRUCTURECRAFT DOWEL-LAMINATED TIMBER

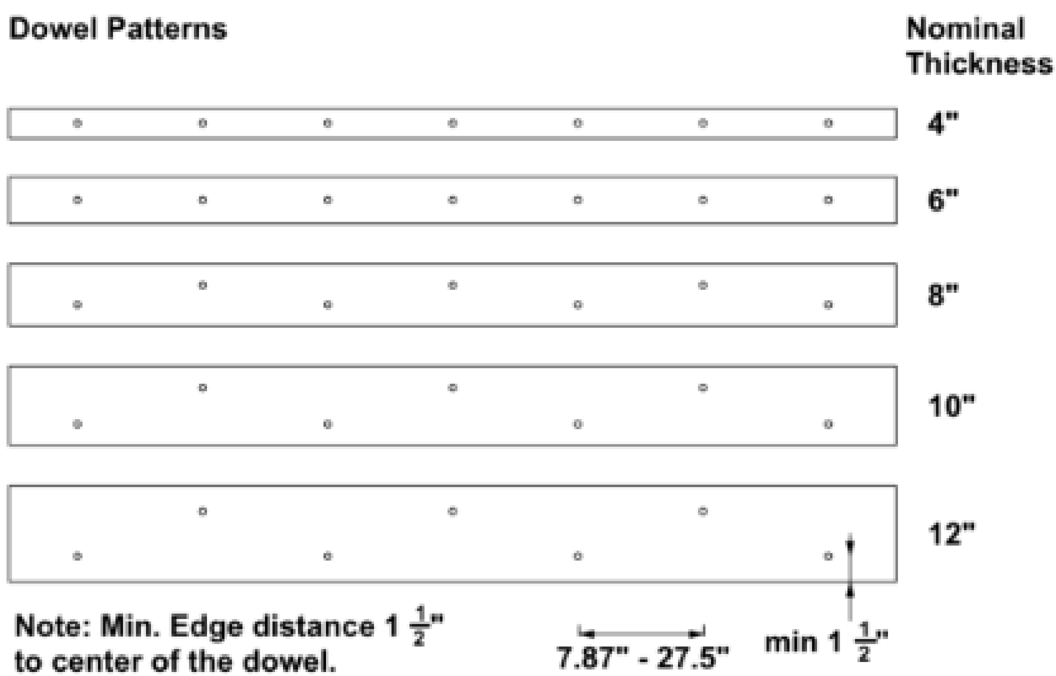


FIGURE 2—DOWEL PATTERNS OF STRUCTURECRAFT DOWEL-LAMINATED TIMBER DECKING

ICC-ES Evaluation Report

ESR-4069 LABC and LARC Supplement

Issued November 2019

Revised November 8, 2019

This report is subject to renewal November 2020.

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DIVISION: 06 00 00 —WOOD, PLASTICS AND COMPOSITES
Section: 06 17 21—Dowel-Laminated Timber

REPORT HOLDER:

STRUCTURECRAFT BUILDERS INC.

EVALUATION SUBJECT:

DOWEL LAMINATED TIMBER (DLT)

1.0 REPORT PURPOSE AND SCOPE

Purpose:

The purpose of this evaluation report supplement is to indicate that Dowel Laminated Timber, described in ICC-ES master evaluation report ESR-4069, has also been evaluated for compliance with the codes noted below as adopted by the Los Angeles Department of Building and Safety (LADBS).

Applicable code editions:

- 2017 *City of Los Angeles Building Code* (LABC)
- 2017 *City of Los Angeles Residential Code* (LARC)

2.0 CONCLUSIONS

The Dowel Laminated Timber, described in Sections 2.0 through 7.0 of the master evaluation report ESR-4069, complies with the LABC Chapters 16 and 23, and the LARC, and is subjected to the conditions of use described in this supplement.

3.0 CONDITIONS OF USE

The Dowel Laminated Timber described in this evaluation report must comply with all of the following conditions:

- All applicable sections in the master evaluation report ESR-4069.
- The design, installation, conditions of use and identification of the Dowel Laminated Timber are in accordance with the 2015 *International Building Code®* (2015 IBC) provisions noted in the master evaluation report ESR-4069.
- The design, installation and inspection are in accordance with additional requirements of LABC Chapters 16, 17 and 23, as applicable.
- Under the LARC, an engineered design in accordance with LARC Section R301.1.3 must be submitted.

This supplement expires concurrently with the evaluation report, issued November 2019, revised November 8, 2019.

ICC-ES Evaluation Report

ESR-4069 CBC and CRC Supplement

Issued November 2019

Revised November 8, 2019

This report is subject to renewal November 2020.

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DIVISION: 06 00 00—WOOD, PLASTICS AND COMPOSITES
Section: 06 17 21—Dowel-Laminated Timber

REPORT HOLDER:

STRUCTURECRAFT BUILDERS INC.

EVALUATION SUBJECT:

DOWEL LAMINATED TIMBER (DLT)

1.0 REPORT PURPOSE AND SCOPE

Purpose:

The purpose of this evaluation report supplement is to indicate that Dowel Laminated Timber, described in ICC-ES master evaluation report ESR-4069, has also been evaluated for compliance with the codes noted below.

Applicable code editions:

- 2016 California Building Code (CBC)

For evaluation of applicable chapters adopted by the California Office of Statewide Health Planning and Development (OSHPD) and Division of State Architect (DSA), see Sections 2.1.1 and 2.1.2 below.

- 2016 California Residential Code (CRC)

2.0 CONCLUSIONS

2.1 CBC:

The Dowel Laminated Timber, described in Sections 2.0 through 7.0 of the master evaluation report ESR-4069, complies with CBC Chapters 16 and 23, provided the design and installation are in accordance with the 2015 *International Building Code®* (IBC) provisions noted in the master report and the additional requirements of the CBC Chapters 16, 17 and 23, as applicable.

The product has not been evaluated under Chapter 7A for use in the exterior design and construction of new buildings located in a Fire Hazard Severity Zone within State Responsibility Areas or any Wildland–Urban Interface Fire Area.

2.1.1 OSHPD: The applicable OSHPD Sections of the CBC are beyond the scope of this supplement.

2.1.2 DSA: The applicable DSA Sections of the CBC are beyond the scope of this supplement.

2.2 CRC:

The Dowel Laminated Timber, described in Sections 2.0 through 7.0 of the master evaluation report ESR-4069, complies with CRC Chapter 3, provided the design and installation are in accordance with the 2015 *International Residential Code®* (IRC) provisions noted in the master report.

The product has not been evaluated under CRC Section R337 for use in the exterior design and construction of new buildings located in a Fire Hazard Severity Zone within State Responsibility Areas or any Wildland–Urban Interface Fire Area.

The products recognized in this supplement have not been evaluated for compliance with the *International Wildland–Urban Interface Code®*.

This supplement expires concurrently with the evaluation report, issued November 2019, revised November 8, 2019.

ICC-ES Evaluation Report

ESR-4069 FBC Supplement

Issued November 2019
Revised November 8, 2019
This report is subject to renewal November 2020.

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DIVISION: 06 00 00—WOOD, PLASTICS AND COMPOSITES
Section: 06 17 21—Dowel-Laminated Timber

REPORT HOLDER:

STRUCTURECRAFT BUILDERS INC.

EVALUATION SUBJECT:

DOWEL LAMINATED TIMBER (DLT)

1.0 REPORT PURPOSE AND SCOPE

Purpose:

The purpose of this evaluation report supplement is to indicate that Dowel Laminated Timber, recognized in ICC-ES master evaluation report ESR-4069, has also been evaluated for compliance with the codes noted below.

Applicable code editions:

- 2017 *Florida Building Code—Building*

2.0 CONCLUSIONS

The Dowel Laminated Timber, described in Sections 2.0 through 7.0 of the master evaluation report ESR-4069, complies with the *Florida Building Code—Building*, provided the design and installation are in accordance with the 2015 *International Building Code®* (IBC) provisions noted in the master report.

Use of the Dowel Laminated Timber for compliance with the High-Velocity Hurricane Zone provisions of the FBC has not been evaluated, and is outside the scope of this supplemental report.

For products falling under Florida Rule 9N-3, verification that the report holder's quality assurance program is audited by a quality assurance entity approved by the Florida Building Commission for the type of inspections being conducted is the responsibility of an approved validation entity (or the code official when the report holder does not possess an approval by the Commission).

This supplement expires concurrently with the evaluation report, issued November 2019 and revised November 8, 2019.

REF

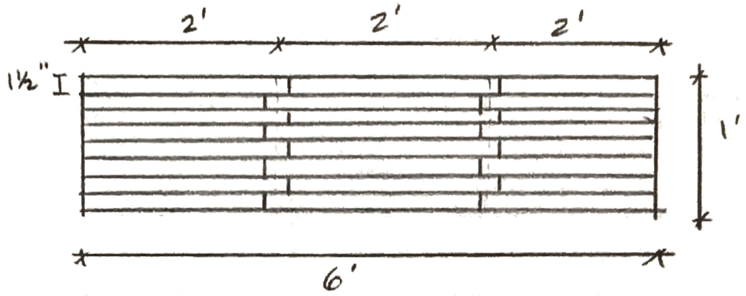
DLT LOAD TESTING ESTIMATIONS

ANS

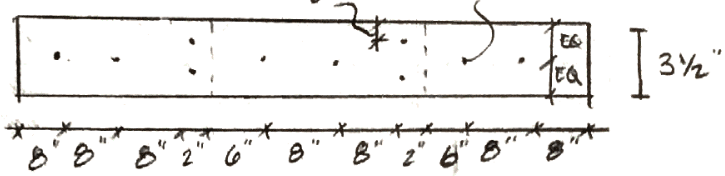
* ALL WOOD DF-LARCH NO.2, RED OAK DOWELS

SPECIMEN TEST:

SEE EXPERIMENT MEMO FOR DETAILED DIAGRAMS

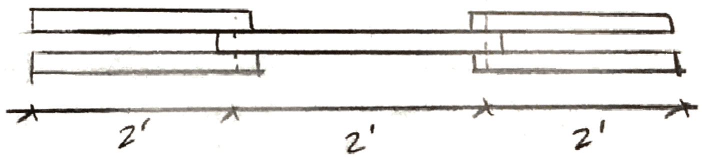


PLAN VIEW



BASELINE TEST 1: (1) 6' 2x4

BASELINE TEST 2:



FIND:

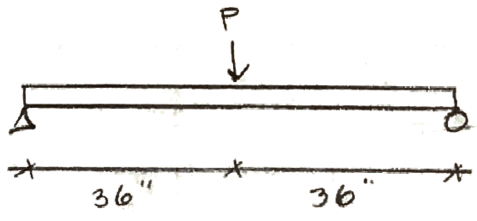
DEFLECTION IN ELASTIC RANGE

ALLOWABLE LOAD FOR ELASTIC RANGE

CAPACITY LOAD

USING: LRFD ANALYSIS METHOD

SINGLE POINT LOAD AT MIDSPAN



REF	BASELINE TEST 1	ANS
2018 NDS SUPP. TBL 1B	SINGLE 2x4, 6' LONG: DF-LARCH No. 2 $A = 5.250\ in^2$ $I_x = 5.359\ in^4$ $S_x = 3.06\ in^3$	
2018 NDS TBL 4.3.1	$F_b' = F_b C_M C_t C_L C_F C_{fu} C_i C_r K_f$ *NOTE: DUE TO FINDING CAPACITY, ϕ AND λ ASSUMED TO BE = 1.0	
NDS SUP. TBL 4A	$F_b = 900\ psi$	
NDS 4.3.3	$C_M = 1.0$ (ASSUMED MC < 19%)	
NDS 4.3.4	$C_t = 1.0$	
NDS 3.3-6	$C_L = \frac{1 + (F_{bE}/F_b^*)}{1.9} - \sqrt{\left[\frac{1+(F_{bE}/F_b^*)}{1.9}\right]^2 - \frac{F_{bE}/F_b^*}{0.95}}$	
	$F_{bE} = \frac{1.20\ E'_{min}}{R_B^2}$	
NDS 3.3-5	$R_B = \sqrt{\frac{l_e d}{b^2}}$	
NDS TBL 3.3.3	$l_e = 1.37 l_u + 3d$ $= 1.37(72'') + 3(3.5'')$ $l_e = 109.14''$	
	$R_B = \sqrt{\frac{(109.14'')(3.5'')}{(1.5'')^2}} = 13.03$	
NDS TBL 4.3.1	$E'_{min} = E_{min} C_M C_t C_i C_T K_f$ *NOTE: ϕ NOT INCLUDED → CAPACITY → $\phi = 1.0$ $E_{min} = 580{,}000\ psi$ $E'_{min} = 580{,}000(1.0)(1.0)(1.0)(1.0)(1.76)$ $E'_{min} = 1{,}020{,}800\ psi$	E'_{min}
	$F_{bE} = \frac{1.20\,(1{,}020{,}800\ psi)}{(13.03)^2} = 7215\ psi$	
NDS 3.3.3.8	$F_b^* = F_b C_M C_t C_F C_i C_r K_f$	
NDS SUP. TBL 4A	$C_F = 1.5$ $F_b^* = 900\ psi(1.0)(1.0)(1.5)(1.0)(1.0)(2.54)$ $F_b^* = 3429\ psi$	
	$F_{bE}/F_b^* = \frac{7215\ psi}{3429\ psi} = 2.104$	

REF		ANS
	$C_L = \frac{1+(2.104)}{1.9} - \sqrt{\left[\frac{1+(2.104)}{1.9}\right]^2 - \frac{(2.104)}{0.95}}$	
	$C_L = 0.960$	
NDS SUPP TBL 4A	$C_F = 1.5$	
NDS 4.3.7	$C_{fu} = 1.0$	
NDS 4.3.8	$C_i = 1.0$	
NDS 4.3.9	$C_r = 1.0$	
NDS TBL 4.3.1	$K_f = 2.54$	
	$F_b' = 900\ psi(1.0)(1.0)(0.960)(1.5)(1.0)(1.0)(1.0)(2.54)$	
	$F_b' = 3292\ psi$	F_b'
NDS TB 4.3.1	$F_v' = F_v\, C_M\, C_t\, C_i\, K_f$	
NDS SUP. TBL 4A	$F_v = 180\ psi$	
	$F_v' = 180\ psi(1.0)(1.0)(1.0)(2.88)$	
	$F_v' = 518\ psi$	F_v'
NDS TBL 4.3.1	$E' = E\, C_M\, C_t\, C_i$	
NDS SUP. TBL 4A	$E = 1,600,000$	
	$E' = 1,600,000\ (1.0)(1.0)(1.0)$	
	$E' = 1,600,000$	E'
	$F_b' = \frac{M_{max}}{S_x} \Rightarrow M_{max} = F_b' S_x$	
	$M_{max} = 3292\ psi(3.06\ in^3)$	
	$\boxed{M_{max} = 10,073\ lb \cdot in}$	M_{max}
	$F_v' = \frac{3V_{max}}{2A} \Rightarrow V_{max} = \frac{2AF_v'}{3}$	
	$V_{max} = \frac{2(5.25\ in^2)(518\ psi)}{3}$	
	$\boxed{V_{max} = 1813\ \#}$	V_{max}

REF		ANS	

DEFLECTION FOR ONE POINT LOAD AT MIDSPAN

$$\Delta_{max} = \frac{PL^3}{48EI}$$

$$\Delta_{L/240} = \frac{72''}{240} = 0.3''$$

$$\Delta_{L/360} = \frac{72''}{360} = 0.2''$$

$$P = \frac{48E'I\,\Delta_{max}}{L^3}$$

$$P_{L/240} = \frac{48(1,600,000)(5.359\text{ in}^4)(0.3'')}{(72'')^3}$$

$$\boxed{P_{L/240} = 331\#}$$

$$P_{L/360} = \frac{48(1,600,000)(5.359\text{ in}^4)(0.2'')}{(72'')^3}$$

$$\boxed{P_{L/360} = 221\#}$$

$$M_{max} = \frac{PL}{4} \Rightarrow \frac{4M_{max}}{L} = P$$

$$P_{M\,max} = \frac{4(10,073\ \#\cdot\text{in})}{72''}$$

$$\boxed{P_{M\,max} = 560\#}$$

$$V_{max} = \frac{P}{2} \Rightarrow P_{V\,max} = 2V_{max} = 2(1813\#)$$

$$\boxed{P_{V\,max} = 3626\#}$$

ANS:

$P_{L/240}$

$P_{L/360}$ (GOVERNS)

$P_{M\,max}$

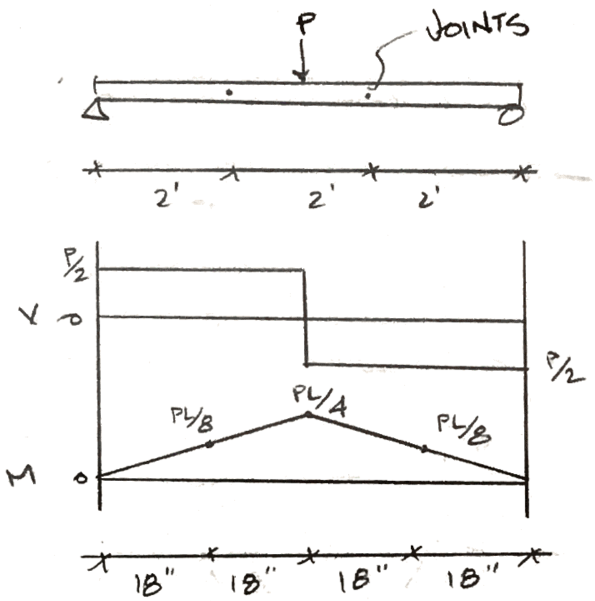
$P_{V\,max}$

REF

BASELINE TEST 2

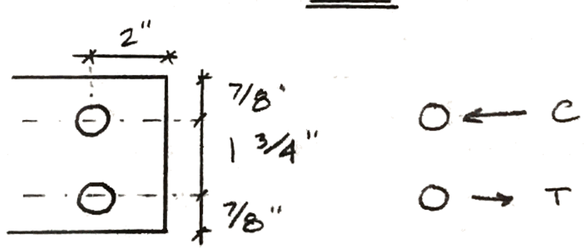
ANS

DOWEL CONNECTION TEST
AT DOWEL CONNECTION
CHECK TYP. STRENGTH
ROW TEAR OUT FROM DOWELS
SHEAR STRENGTH OF DOWELS



MOMENT AT JOINTS : $\frac{2}{3}\frac{PL}{4} = \underline{\underline{\frac{PL}{6}}}$

SHEAR AT JOINTS : $\underline{\underline{\frac{P}{2}}}$



$$C = T = \frac{M}{1.75''} = \frac{PL}{6(1.75'')} = \underline{\underline{\frac{PL}{10.5}}}$$

BOARD : DF-LARCH NO.2
$A = 5.250\ in^2$
$I_x = 5.359\ in^4$
$S_x = 3.06\ in^3$

REF

ANS

$F_b' = F_b C_M C_t C_L C_F C_{fu} C_i C_r K_f$

*NOTE: ALL FACTORS THE SAME AS SINGLE 2x4 EXCEPT C_L

$$F_{bE} = \frac{1.20 E'_{min}}{R_B^2}$$

$$R_B = \sqrt{\frac{l_e d}{b^2}}$$

$l_e = 1.37 l_u + 3d = 1.37(36") + 3(3.5")$

$l_e = 59.82"$

$$R_B = \sqrt{\frac{59.82(3.5")}{(1.5)^2}} = 9.65$$

$E'_{min} = 1,020,800$ psi

$$F_{bE} = \frac{1.20(1020,800)}{9.65^2} = 13154 \text{ psi}$$

$F_b^* = 3429$ psi

$$F_{bE}/F_b^* = \frac{13154}{3429} = 3.836$$

$$C_L = \frac{1 + (F_{bE}/F_b^*)}{1.9} - \sqrt{\left[\frac{1 + (F_{bE}/F_b^*)}{1.9}\right]^2 - \frac{F_{bE}/F_b^*}{0.95}}$$

$$C_L = \frac{1 + 3.836}{1.9} - \sqrt{\left[\frac{1 + 3.836}{1.9}\right]^2 - \left[\frac{3.836}{0.95}\right]}$$

$C_L = 0.983$

$F_b' = 900 \text{ psi}(1.0)(1.0)(0.983)(1.5)(1.0)(1.0)(1.0)(2.54)$

$F_b' = 3371$ psi — F_b'

F_v' AND E' SAME FROM BASELINE 1

$F_v' = 518$ psi, $E' = 1,600,000$ psi — F_v', E'

$M_{max} = F_b' S_x = 3371 \text{ psi} (3.06 \text{ in}^3)$

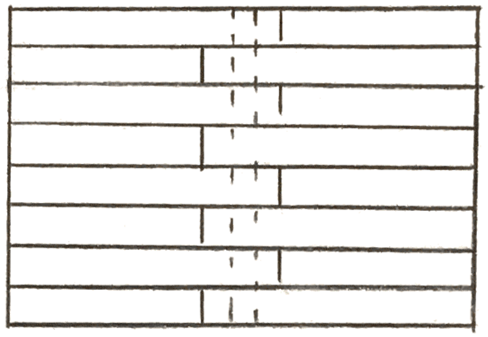
$\boxed{M_{max} = 10,315 \text{ \#}\cdot\text{in}}$ — M_{max} (DF)

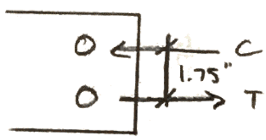
$$V_{max} = \frac{2A F_v'}{3} = \frac{2(5.25 \text{ in}^2)(518 \text{ psi})}{3}$$

$\boxed{V_{max} = 1813 \text{ \#}}$ — V_{max} (DF)

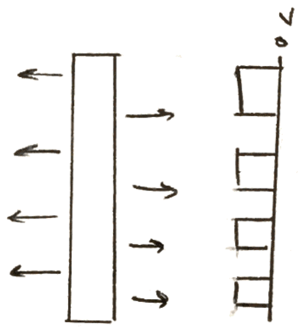
REF		ANS	
	DOWELS: 3/4" Φ RED OAK DOWELS, S.S. SELECT STRUCT.		
	$A = 0.442 \text{ in}^2$		
NDS SUP. TBL 4A	$F_{c\perp} = 820$ psi, $E = 1{,}400{,}000$ psi		
	$F_{c\perp}' = F_{c\perp} C_M C_t C_i K_f$		
	$= 820 \text{ psi} (1.0)(1.0)(1.0)(1.67)$		
	$F_{c\perp}' = 1370$ psi	$F_{c\perp}'$ RO	
	$F_{c\perp}' = \frac{4 V_{max}}{3A} \Rightarrow V_{max} = \frac{3 F_{c\perp}' A}{4}$		
	$V_{max} = \frac{3(1370 \text{ psi})(0.442 \text{ in}^2)}{4} \Rightarrow \boxed{V_{max} = 454\#}$		
	DIRECT SHEAR: 2 DOWELS → $V_{max} = 908\#$		
	MOMENT COUPLE SHEAR: 1 DOWEL → $V_{max} = 454\#$		
	DF FAILURE:		
	$P_{M\,max} = \frac{4 M_{max}}{L} = \frac{4(10315 \#\cdot in)}{72''}$		
	$\boxed{P_{M\,max} = 573\#}$	$P_{M\,max}$ (DF)	
	$P_{V\,max} = 2 V_{max} = 2(1813\#) \Rightarrow \boxed{P_{V\,max} = 3626\#}$	$P_{V\,max}$ (DF)	
	RED OAK DOWEL FAILURE		
PG. 5 OF CALCS	$V_{max} = \frac{PL}{10.5} \Rightarrow 2\left(\frac{10.5\, V_{max}}{L}\right) = P_{M\,max}$		
	$P_{M\,max} = \frac{10.5(454\#)2}{72''} \Rightarrow \boxed{P_{M\,max} = 132\#}$	$P_{M\,max}$ (RO)	(GOVERNS)
	$V_{max} = \frac{P}{2} \Rightarrow 2 V_{max} = P_{V\,max}$		
	$2(2 \cdot 454\#) = P_{V\,max} \Rightarrow \boxed{P_{V\,max} = 1816\#}$	$P_{V\,max}$ (RO)	
NDS TBL 12.5.1	ROW TEAR OUT:		
	$1.5D = 1.5(0.75) = 1.125'' < 1.75'' \Rightarrow$ OK ROW SPACING		
	PARALLEL TO GRAIN LOADING - 1.5D EDGE SPACING		
	$\frac{7}{8}''$ SPACING $> 1.125'' \Rightarrow$ NO GOOD EDGE SPACING	☆	
	MIN END DISTANCE → $3.5D = 3.5(0.75) = 2.6''$		
	$2.6'' > 2.0'' \Rightarrow C_\Delta = 0.5$		

REF | SPECIMEN | ANS





DOWEL SHEAR DIAGRAM



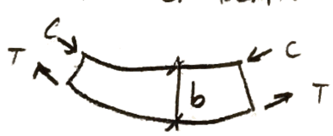
SEE PG. 5 OF CALCS

$V_{DOWELS} = \frac{PL}{10.5}$

SEE PG. 7 OF CALCS

$V_{max\ Dowels} = 454\ \#$

MOMENT OF BEAM



$T = \frac{M}{b} = \frac{PL}{10.5}$ (TOTAL FOR BEAM)

$\frac{PL}{10.5}$

BECAUSE THERE ARE 7 FACES OF CONTACT w/ DOWEL, $T = \frac{PL}{10.5}\left(\frac{1}{7}\right)$

$V_{Dowel} = \frac{PL}{73.5} \Rightarrow \frac{73.5 V_{Dowel}}{L} = P$

$P = \frac{73.5(454\#)}{72"} \Rightarrow \boxed{P_{M\ RO} = 465\#}$

$P_{M\ max}$ (RO)

REF		ANS
SEE PG. 7 CALCS	$P_{Vmax} = 4 \cdot 2V_{max} = 4 \cdot 2(908\ \#) \Rightarrow$ $\boxed{P_{Vmax\ RO} = 7264\ \#}$	P_{Vmax} (RO)
	DOUG-FIR ANALYSIS	
	$A = 12''(3.5'') = 42\ in^2$	
	$I_x = \frac{bh^3}{12} = \frac{12''(3.5)^3}{12} = 42.88\ in^4$	
	$S_x = \frac{I_x}{y} = \frac{42.88\ in^4}{1.75''} = 24.50\ in^3$	
SEE CALC PG. 2	$F_b' =$ SAME AS SINGLE 2x4 EXCEPT $C_L = 1.0$, $C_r = 1.15$	
	$F_b' = 900\,psi\,(1.0)(1.0)(1.0)(1.5)\,(1.0)(1.0)(1.15)(2.54)$	
	$F_b' = 3943\ psi$	
SEE CALCS PG. 3	$F_v' = 518\ Psi$, $E' = 1,600,000\ psi$ } SAME AS SINGLE 2x4	
	$M_{max} = F_b' S_x = 3943\ psi(24.50\ in^3)$	
	$M_{max} = 96,603\ lb \cdot in$	
	$P_{Mmax} = \frac{4\ M_{max}}{L} = \frac{4(96,603)}{72}$	
	$\boxed{P_{Mmax} = 5,367\ \#}$	P_{Mmax} (DF)
	$V_{max} = \frac{2AF_v'}{3} = \frac{2(42)(518)}{3} =$	
	$\boxed{P_{V\ max} = 14,504\ \#}$	P_{Vmax} (DF)
	$P_\Delta = \frac{48EI\Delta_{max}}{L^3}$	
see calcs pg. 4	$P_{L/240} = \frac{48(1,600,000)(42.88)(0.3'')}{72^3}$	
	$\boxed{P_{L/240} = 2647\ \#}$	$P_{L/240}$
	$P_{L/360} = \frac{48(1,600,000)(42.88)(0.2'')}{72''^3}$	
	$\boxed{P_{L/360} = 1765\ \#}$	$P_{L/360}$

RE: Cal Poly Senior Project - We would love your support!

KM

Kam-Biron, Michelle[redacted]
Tuesday, January 21, 2020 at 9:21 AM
To: Sophia Demetra Looney

From: Sophia Demetra Looney <slooney@calpoly.edu>
Sent: Monday, January 20, 2020 12:59 PM
To: Kam-Biron, Michelle <[redacted]>
Subject: Cal Poly Senior Project - We would love your support!

Hello Ms. Kam-Biron,

I hope this note finds you well.

My name is Sophia Looney and I am currently a fourth year student at Cal Poly SLO studying Architectural Engineering. I received your contact information from my senior project Advisor, Dr. Craig Baltimore. He spoke to us about your work at WoodWorks and how you could possibly be a wonderful resource to us. We understand that you have a breadth of knowledge of mass timber, ranging from fire-resistance design for wood construction to expertise on codes associated with timber construction. Being inspired by people like yourself, my fellow group mates and I decided to deepen our knowledge of mass timber through our senior project. Our senior project focuses on Dowel-Laminated Timber; we wanted to explore more about this fairly new mass timber product. We are planning to build our own sample of DLT and how ours can compare to industry standard. Specifically, we are making our own DLT using tools that we could presumably find in a developing nation, and how it compares to industry-fabrication and industry standards. In order to test the quality of our sample in comparison to industry manufactured produce, we will be using water to test the water retention of DLT, and the absorption patterns and volume of the water for each sample.

On behalf of our senior project group, I would love to ask for your support for our endeavors. We would be incredible appreciative of any knowledge or monetary donation on behalf of WoodWorks. Your support will help us accomplish our goal and allow us to complete our senior project successfully and in a timely manner. We are grateful of your consideration and hope you find our project to be of interest. Dr. Baltimore shared with us that you attend Cal Poly as an ARCE, and our group is very impressed by your accomplishments especially with WoodWorks; it is transparent that your Cal Poly education was a catalyst in your success. Therefore, each of us understand greatly the extraordinary education we are receiving at Cal Poly, and want to further take advantage of all opportunities to grow our knowledge through our senior project with the support from you and Woodworks.

Thank you in advance for your consideration; we appreciate the time taken to acknowledge our endeavors.

I look forward to speaking with you soon.

Kindly,

RE: Potential Student Visit to StructureCraft

Paolo Balce <[redacted]>
Friday, January 24, 2020 at 12:33 PM
To: Sophia Demetra Looney
Cc: Bryan Ulises Garcia; Reiley A. Akkari

Hi Sophia,

Thanks for contacting us. My name is Paolo and I'm an estimator for the business development team at StructureCraft. I'll be your main contact from here.

Good to hear there's interest in DLT. I'd be happy to give you all a tour of our facility and answer any questions you may have regarding DLT or our company in general. When do you plan to travel up here?

Best regards,

Paolo Balce
Business Development Estimator
[redacted]

StructureCraft Builders Inc.
D 778 820 0240
www.structurecraft.com

From: Sophia Demetra Looney <slooney@calpoly.edu>
Sent: January 22, 2020 10:43 PM
To: Gerald Epp Jr. <[redacted]
Cc: Bryan Ulises Garcia <bugarcia@calpoly.edu>; Reiley A. Akkari <rakkari@calpoly.edu>
Subject: Potential Student Visit to StructureCraft

Hello Gerald,

My name is Sophia Looney and I am a senior at California Polytechnic State University in San Luis Obispo, California. We are majoring in Architectural (Structural) Engineering, and at our university, we have the opportunity to explore and research any topic

A4.1

CAL POLY
SAN LUIS OBISPO

DLT

DOWEL LAMINATED TIMBER

ARCE SENIOR PROJECT
WINTER 2020

Who are we?
We are three Cal Poly ARCE Seniors who greatly enjoy mass timber, and decided to learn more about DLT through our Senior Project!

The group includes Reiley Akkari, Sophia Looney and Bryan Garcia. Our faculty advisor is Craig Baltimore, PhD, SE.

What is the purpose?
The purpose for our project is to explore DLT and its advantages and disadvantages as a new building material. We chose to focus on how DLT can be used as an option in developing nations, as toxins in glue-laminated timber can be harmful to the environment if not treated properly.

Inside the manufacturing facility at StructureCraft

What did we learn?

We can confirm that no toxic glue is used in the manufacturing which in turn makes safer environments for those fabricating the panels. Mass timber is also gaining popularity for its natural aesthetic. The placement of joints in DLT panels is an important aspect to consider when building DLT panels. Commercially, finger joints are used by standard DLT manufacturers, which is more effective and strong, but unfortunately uses glue. In our experiment, we applied the moment dowel connections in the worst way - in a line. The dowel joint location weakened the performance our panels by an order of magnitude of 8 in comparision to the first baseline test, due to it being the worst configuration.

How can you help?

All that we have accomplished has come with a cost; both our materials and our visit to StructureCraft cost in total $2500.

If you would like to support our project, please contact Sophia Looney at *slooney@calpoly.edu*

OUR EXPERIMENT

For our project, we conducted three tests; two baseline tests and one design test to investigate the strength in relation to dowel moment connections. To further investigate the construction practices of developing nations, specimens for each baseline test were constructed with only handheld tools such as hammers and drills.

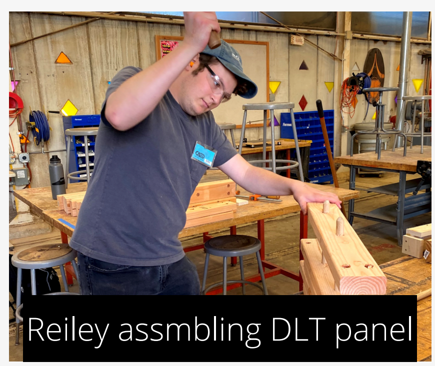
The first baseline test was testing the strength of the lumber itself by loading a single 2x4 board.

The second baseline test conducted was to test the strength of the dowel connections for a single connection. We built a prototype of just the connections and observed the failure mode.

The third test was the panel of DLT that we fabricated. The specimen was 6ft x1ft, loaded and analyzed as a one-way slab.

In addition, we traveled to the Pacific Northwest to visit the closest manufacturer of DLT, StructureCraft. The purpose of our travel was to learn more about DLT and how it is manufactured with industry practices and machinery.

DLT panel in construction



Reiley assmbling DLT panel

Example of Simpson StrongTie Connection

Single dowel connection