DEVELOPMENT OF THE SPRING-PIN

This research contained within was conducted in conjunction with an industrial sponsor, Structurecraft Builders Inc of British Columbia. This company specializes in design-build contracts for architectural timber structures. In timber construction, much of the structural cost comes from the joinery of the timber members. There are many connection options available to the engineer in wood, but there are situations that arise in which research is necessary for the engineer to control escalating construction costs or even make the architectural system a possibility at all. This results in some exciting opportunities for research and development that is needed in the heavy timber construction industry.

My research is focused on the implementation of a heavy timber structural system for a proposed design-build project, but many general contributions to the body of timber engineering were made as a by-product of this process. This thesis refers to many different research issues in the timber engineering field, although not solving all of them rigorously, may provide some information to other research. Although some results may be inferred from the testing, further research is required to expand the findings in this research to become generally applicable.

1. DEVELOPMENT OF THE SPRING-PIN

The spring pin is an "off the shelf" fastener typically used in the automotive industry. The innovation of using this connector comes from the application in wood. The spring-pin is a hollow tube with a gap running longitudinally along its entire length allowing the diameter of the connector to be compressible (See Figure 1.1). The pin is installed by jamming it into a pre-drilled hole slightly smaller than its diameter. The pin will compress during the installation process and therefore be tight fitting and snug in its final position.

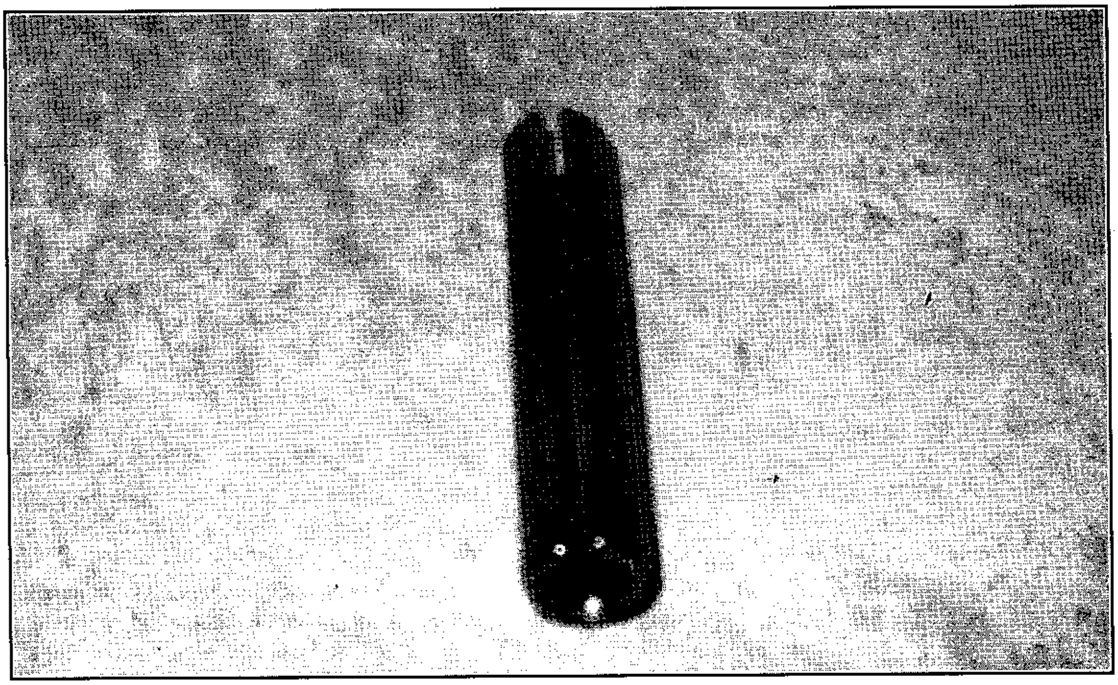

Figure 1 ½" diameter spring-pin

The spring pin timber connection was developed by Structurecraft to meet an architectural need for a high profile project involving a large glass timber façade at Surrey City Centre (See Figure 2). The spring pin connections were used to connect the bracing arms to the columns and the mullion beams. A low level of visibility was desired for the highly exposed connections between the refined timber mullion beams. The connection plates were mortised into the receiving wood member to reduce the visibility of the joinery by means of what is called a knife-plate connection (See Figure 2).

Page 13 – The author's details were omitted. The author was Mark Robertson, MASc of University of British Columbia. It should have been noted that this paper was first presented at the 9th World Conference on Timber Engineering in Portland, Oregon, USA in August 2006.

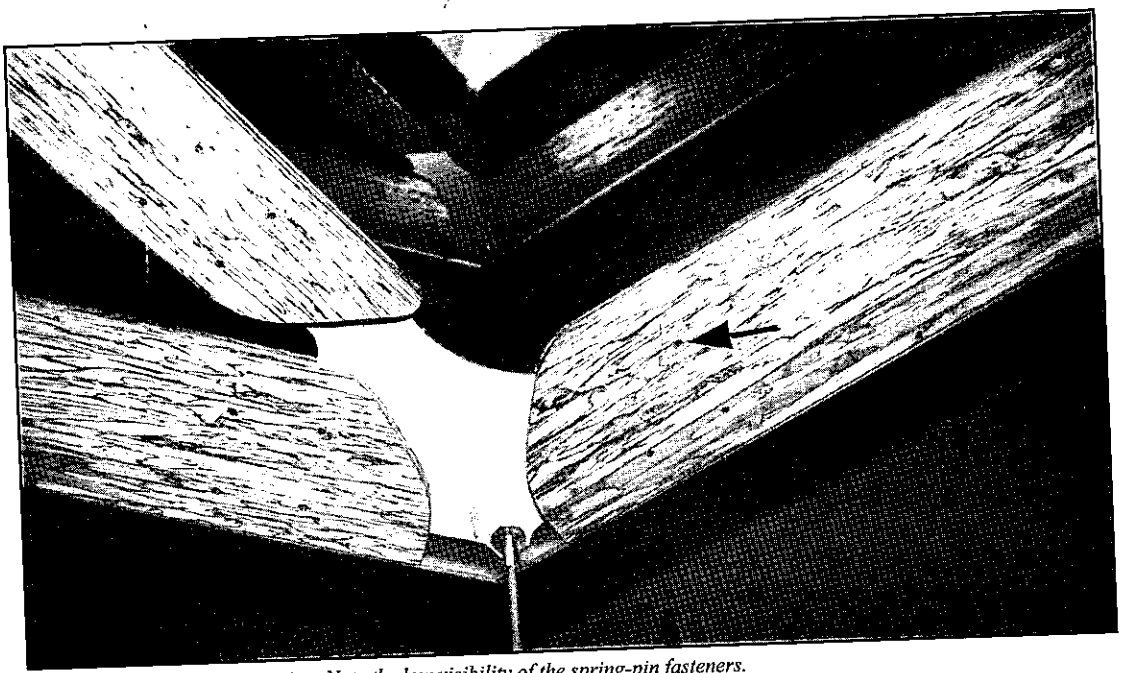

Figure 2 Spring-Pin Connection. Note the low visibility of the spring-pin fasteners.

Traditionally, bolts would be used for such connections; however these would have been unacceptable from a construction tolerance and visual standpoint. Since spring pins are compressible, they can be installed into the connection in a tight fitting manner negating the need for highly visible mechanical fasteners such as nuts & bolts. Furthermore, bolted connections are quite insufficient because of the required tolerances inherently involved with bolt installation and resulting loss of stiffness and quite possibly strength. Bolts have been observed to fail in a manner analogous to a zipper with one bolt reaching peak capacity at a time. The tight fit of the spring-pin would, in theory, encourage all fasteners to reach peak strength at the same time.

2. PRELIMINARY TESTING PROGRAM

To confirm that the spring-pins met or exceeded the CSA–086 design recommendations for bolted connections, a modest testing program was done to observe the strength of the spring-pin connections. The testing program consisted of testing 12 test specimens with a 4-pin configuration with the same curve shaped cross-section as the in-situ connections (See Figure 3).

2.1 Test Specimen Geometry

The original test specimens were made to model exactly what was used in the Surrey City Centre Project. The test specimens consisted of shaped PSL with dimensions 89x180. The embedded knife plate was tested with 3 sets of ¼" steel and 3 sets of 3/8" aluminium plate. The row and fastener spacing were twice what code recommends, but the loaded end distance was 1 diameter larger than the minimum required.

2.2 Evaluation of Tests

The results of the tests indicated an increase in strength for the spring-pin connections over the code for bolted connections.

<u>Code Capacity (CSA O86-01)</u>
SPECIFIED STRENGTH = 70 KN
FAILURE MODE: Embedding Failure without Plastic Hinging
RELEVANT GROUP FACTORS: JR = 0.8, JL = 0.83 => JF = 0.66

<u>Test Results:</u>
Number of Specimens = 12 (6 twin ended)
Mean Strength of Tests = 114 KN
Standard Deviation = 8 KN
5th Percentile of Tests = 102 KN
C.O.V. = 6.7%

The direct comparison of the Canadian Code to the test results shows that the code understates the capacity of the spring pin connection by 35%. This number is very similar to the group factor, JF = 0.66, calculated by the code. The hypothesis that the tight-fit of the spring-pins reduce the group effect seemed promising at this stage of the spring-pin development.

3. LITERATURE ON TIGHT-FITTING PINS

It remains to be known whether the equations developed are also applicable to tight-fitting dowels. There are 3 sources of literature that talk directly on the impact of tight-fit for timber connections with multiple fasteners.

3.1 Borg Madsen, Behavior of Timber Connections. Madsen discusses research conducted in the Netherlands in which 61 test specimens were used to study the effect of hole-clearances on multiple fastener capacity. The study involved fabricating one set of specimens with precision drilling in order to eliminate hole-clearances, and comparing the results to specimens fabricated according to "typical construction" practices. The results demonstrate that the connection capacity is unaffected by hole clearances unless connection slip was less than 3mm. It is interesting to note that the amount of bolt tolerance was carefully recorded in this study.

3.2 Borg Madsen, Behavior of Timber Connections. Research done at UBC compares bolted connections with and without glue injection in the holes. The test involved comparing 3 configurations of bolted connection... single bolt, 4 bolt group, and a 6 bolt group. The results show that reinforcing the holes with glue results in an increase in strength of 30-40% for the single fasteners, and 10-20% for the 4 and 6 bolt group connections. The connection slip for these tests was recorded as being about 5-8mm.

3.3 Research was conducted in Zurich Switzerland demonstrating that the precision of drilling has an effect on the strength of multiple fastener connections when a brittle failure mode occurs. This effect can be as much as a 40% reduction in strength when comparing a hole clearance of 2mm to 0.05mm. When the failure mode is ductile it is observed that the hole clearances no longer play a significant role in the connection due to re-distribution of forces.

3.4 Research at UBC by Mischler, A., Prion H., Lam F., concluding that tolerances only affect timber connections when a non-ductile failure occurs. This research controlled the hole tolerances in each direction. The tolerance in the direction perpendicular to grain was shown to have the most significant effect on the strength due to the introduction of tension perpendicular to grain stresses.

4. EXPANDED TEST PROGRAM

The literature search raised some questions about the potential of tight-fitting pins. An expanded testing program was launched to add to the reliability of the results and to study the effect of tight-fit on a timber connection. The first series of tests were single pin tests. These tests were conducted with a geometry as shown below.

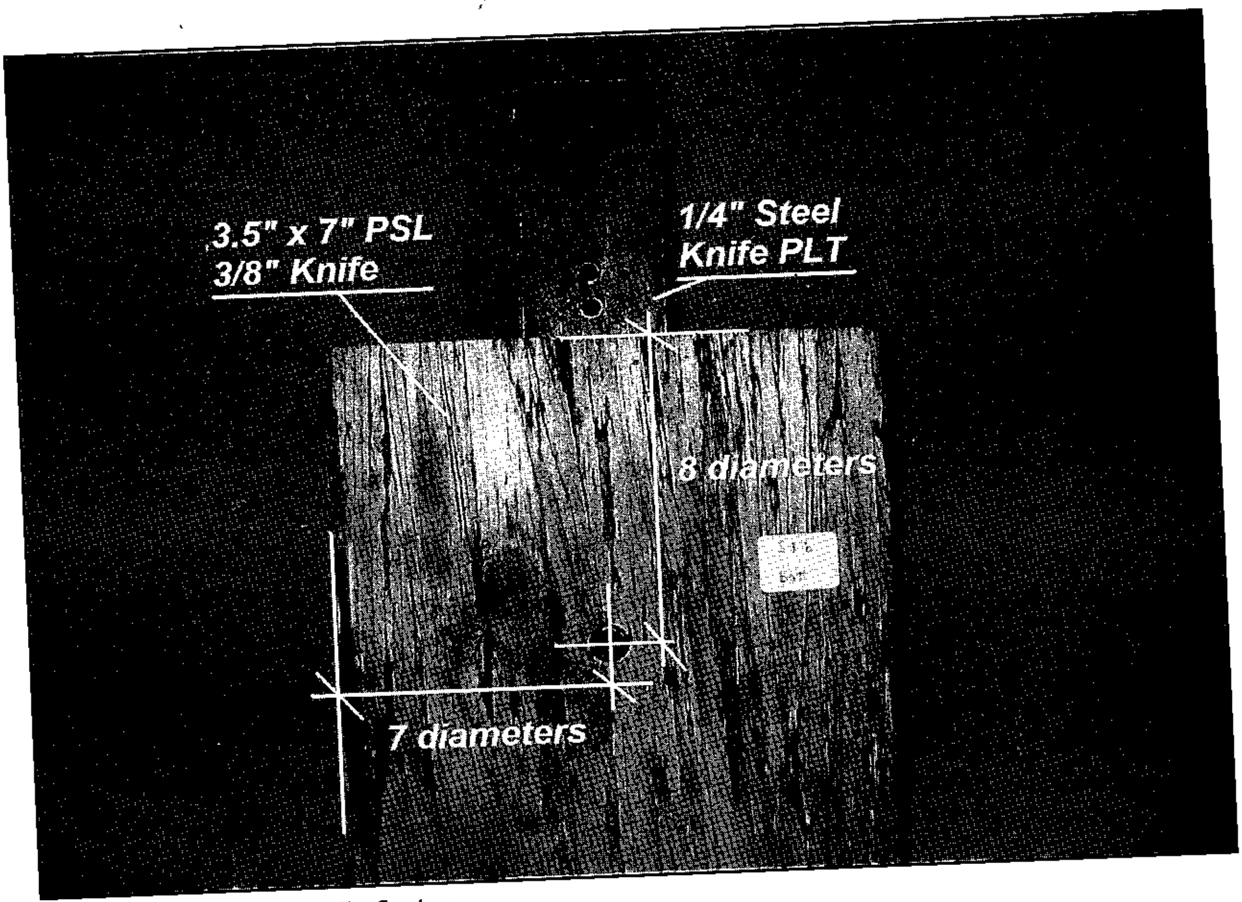

Figure 3 Typical Single Fastener Test Specimen

The strength of the single pin specimen was 30KN. After comparing these results to the 4 pin results it was observed that the group factor for four pins was 0.85, not 0.66 as the code would recommend.

As well as determining the strength of a single pin, the testing also found the stiffness parameters of the spring-pin in wood. The Foschi equation (1974), developed by Ricardo Foschi at the University of British Columbia, was used to predict the non-linear response of nails in wood. This equation is generally applicable and fits a curve to test data with three parameters, initial stiffness, an intercept vertical intercept of the tangent to the curve, and a secondary stiffness.

$$P(\square) = (K+ K2*\square)*(1-e^{(-K1*\square/K)}) \quad [1]$$

TABLE 1 The stiffness values found through testing

PARALLEL TO GRAIN COMPRESSION TEST

Parameter	Mean Value	C.O.V.	Std.Dev.	Units
K	50	12%	7.5	KN
K1	26	15%	14.7	KN/mm
K2	0	N/A	N/A	KN/mm

4.1 Monte Carlo Simulation

The values for displacement found in table 1 are statisitical variables. Using these variables a simple model was developed that could predict the average and deviation of the displacement curves for multiple pin connections. When statistical variables are used for the stiffness parameters, this model becomes a form of Monte Carlo Simulation. The calculation is performed many times with random stiffness variables until a solution converges. The converged solution gives information on the average load displacement curve and an estimation of the dispersion. This model was compared to the actual test results of a multiple pin connection and can be seen in Figure 4. The average curve, the 5th percentile, and the 95th percentile were plotted.

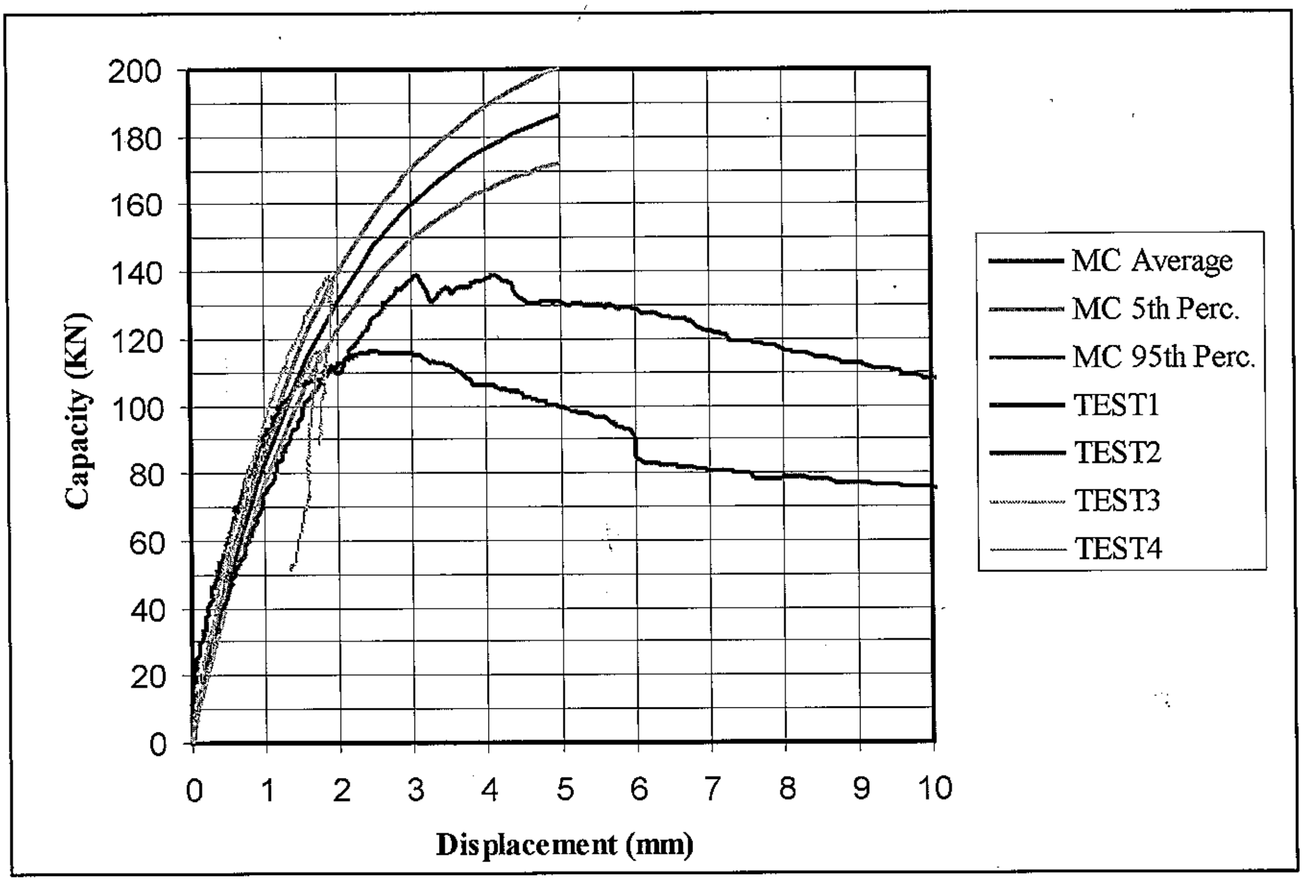

Figure 4 The comparison of the load-displacement curves of the 4-pin specimens to the analytical model.

The test results seem to fit reasonably well within the 95th and 5th percentile boundaries until fracture of the timber occurs. The curves deviate from the predicted curve once splitting of the wood occurs.

Once the model was established and appeared to predict the behaviour of multiple pin connections to a reasonable degree, another random variable was introduced to represent the tolerance of the bolthole. According to the Canadian Code on Timber Connection, CSA-086, the bolthole can be as up to 2mm larger in diameter than the bolt. The model assumed two statistical distributions for bolthole tolerance and randomly applied them to every fastener in the Monte Carlo Simulation. The two different distributions are as follows:

- Uniform Distribution, the bolt hole tolerance can be between 0 and 2mm and equally likely to occur over the entire range.
- Geometric Distribution, this reflects the reality the bolt is more likely to be placed in the centre of the hole than the left or right edge. This distribution has the shape of a half circle with the highest probability in the center.

Using 4 bolts in the schematic model, the Monte Carlo simulation was run with the added random variable and a comparison can be seen in Figure 5.

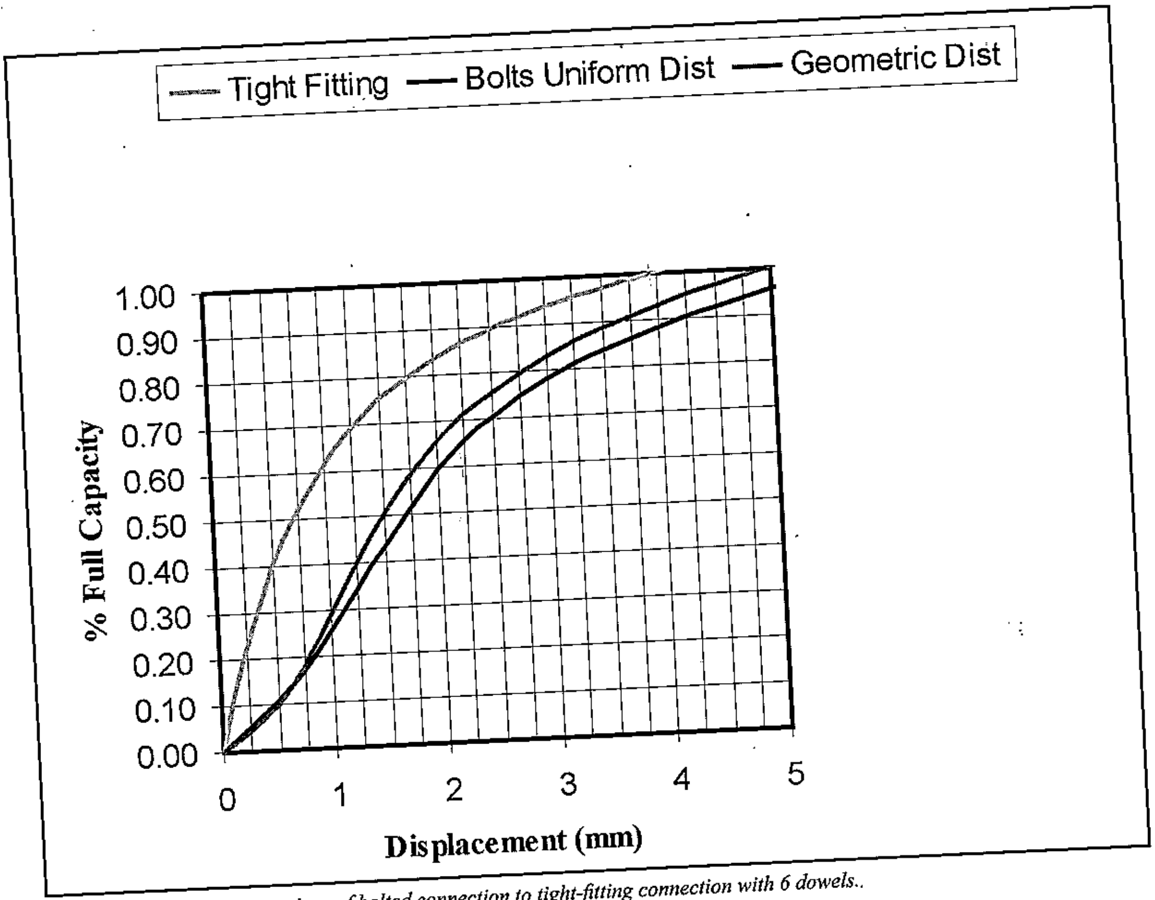

Figure 5 Analytical comparison of bolted connection to tight-fitting connection with 6 dowels..

This curve basically shows what percentage of full capacity the connection has reached for a given ultimate displacement. Most of the spring-pin connections failed after approximately 2-4mm. At this level of displacement the difference in total load present between the tight-fitting dowel and the loose dowel is roughly 10-15% at the most. Although this graph doesn't say anything about the difference in strength between the fasteners, it does say that bolts will be at least 10-15% of the capacity of their tight-fitting counterpart.

There is a significant difference in the behaviour of tight-fitting pins to that of loose bolts with a 2mm hole tolerance. The difference between the uniform probability distribution and the geometric probability distribution is not significant leading me to believe that the solution is not sensitive to the weighted distribution of the bolt hole tolerance.

5. CONCLUSION

The theoretical difference between the tight-fitting pins and the loose fitting bolts was quite small and supported the background research in section 3.0. Most literature states that timber connections are only effected by the hole tolerance if the observed ultimate displacement is less than 3mm. Beyond that, the connection capacity of a timber connection is unaffected by hole tolerance. However, it is reassuring to know that if a mistake is made and the designer is unaware that the connection is brittle, the tight-fitting connection will retain its strength better than loose bolts at low ultimate displacements.

Although it seems unlikely that there are no dramatic improvements in the strength of tight-fitting pins over bolts, the tight-fitting pins are significantly stiffer. For applications such as the Surrey City Center glass façade, where stiffness is critical, the performance of tight-fitting connections is desirable.