Evaluation of duration of load factors for wooden structural materials

S. Nakajima¹, S. Matsuzato², N. Yamaguchi³ and T. Nakagawa⁴

¹ Building Research Institute, Tsukuba, Japan
² KEYTEC Co. Ltd., Kisarazu, Japan
³ Building Research Institute, Tsukuba, Japan
⁴ Building Research Institute, Tsukuba, Japan

ABSTRACT: The adequacy of the duration of load factor was discussed in terms of the accuracy of the stress level. The results are summarized as follows: (1) The duration of load factor will be not be conservatively evaluated when the samples being tested have a wide variety in their bending capacity. (2) When the distribution of the bending capacity of the samples has smaller coefficient of variation the load bearing capacity of the each samples can be more accurately estimated. And as a result the duration of load factor can be adequately evaluated. (3) An alternative testing and evaluation method to evaluate the duration of load factor of the structural wooden materials was proposed. The method was based on the idea that the test specimens that do not fail for a long time should have higher bending capacity than the test specimens that fail in a short period. And the stress ratio was adjusted on this idea. The duration of load factor was well evaluated by the proposed alternative testing and evaluation method.

1 INTRODUCTION

The duration of load factors for lumbers and wood based materials are generally determined using the formula proposed by Wood (1951). The formula proposed by Wood was derived from the results of a series of duration of load tests conducted for small clear specimens (Wood (1951) and Liska (1950)). Madsen (1992) conducted a series of duration of load test for full scale lumbers and collected technical information for the duration of load characteristics of full scale lumbers. The Building Standard Law in Japan (2000) requires full scale duration of load test for newly developed wooden structural materials to derive their duration of load factors and to determine the long term allowable strength of the materials. The evaluation method requires to test full scale materials at least at three or more stress levels and to clarify the relationship between the stress level and the time to failure.

It is quite important to accurately estimate the maximum strength of each test specimens to adequately evaluate the duration of load factors. Side matching is one solution to accurately estimate the maximum strength of the test specimens. But it is absolutely impossible to apply this method to wooden components such as I-joists or box-beams. The maximum strength of I-joists and box-beams can be estimated by calculating the average maximum strength of a certain number of test specimens. But in this case the accuracy of the estimation will depend on the variation of the maximum strength of the materials being tested.
When the maximum strength has a wide variation a certain difference may occur between the estimated maximum strength and the actual maximum strength. And this difference will lead inadequate evaluation of the duration of load factors. The effect of the variation of the maximum strength on the evaluated results of the duration of load factors is discussed in this paper.

2 EVALUATION OF THE DURATION OF LOAD FACTORS FOR I-JOISTS

2.1 Outline

The duration of load factor for I-joists was evaluated using the testing and evaluation methods stipulated in the Enforcement Order No.1446 (2000) of the Japanese Building Standard Law.

2.2 Test specimens

The height and width of the test specimens were 235mm and 58mm respectively. The materials used for the flanges and webs of the test specimens are as follows:

[Flange]
Material: Laminated veneer lumbers structurally graded according to the Japan Agriculture Standard (JAS).
Structural Grade: JAS 120E for MOE and JAS 50V-43H for horizontal shear capacity.
Size: Height 35mm, and Width 58mm.

[Web]
Material: Structural panels structurally graded according to the Japan Agriculture Standard (JAS).
Structural Grade: JAS Grade No.4.
Size: Thickness 9.5mm.

The flanges and the webs of the I-joists were jointed by the resorcinol resin adhesives.

2.3 Bending test

20 test specimens were tested for their bending properties. The average bending strength of the 20 test specimens was used to calculate the loads to apply at the duration of load test. The bending test was a third point bending test and the loading speed was set at 10mm/min. The span was set as to be 3810mm and was same as the span of the duration of load test.

2.4 Duration of load test

The test specimens were loaded at three different stress ratios. The load that corresponds to each stress ratio was calculated by equation 1.

\[
\text{Dead load to apply at the duration of load test} = \frac{\text{Average bending capacity} \times \text{Stress Ratio}}{100}
\]

(1)

The dead load was loaded by the third point loading. The span was 3810mm. 10 test specimens were tested for one stress level. The test specimens were tested at three stress levels 90%, 80% and 70%. The test was conducted in a climate chamber that was controlled to 20 ºC, and 65% R.H.

2.5 Results of the bending test

The bending capacity of the test specimens was 19.9kN in average. The standard deviation and the coefficient of variation were 2.8kN and 13.9% respectively.
2.6 Results of the duration of load test

The test specimens were loaded for 180 days. Test specimens loaded at the stress level of 90% and 80% failed within 180 days. Only one of the test specimens tested at the stress level of 70% failed within 180 days. Figure 1 gives the relationship between the stress level and time to failure.

Test specimens loaded at the same stress level showed different time to failure. For example the time to failure of the test specimens loaded at the stress level of 80% ranged from 7.8min to 37524.5min. The duration of load factor was evaluated from the test data shown in figure 1. The duration of load factor was evaluated as to be 0.66.

![Figure 1. Relationship between the stress level and time to failure.](image)

Note: $t$ is duration of time to failure in minutes.

3 THE EFFECT OF THE UNCERTAINTY IN ESTIMATING THE BENDING CAPACITY ON THE EVALUATED RESULTS OF THE DURATION OF LOAD FACTOR

3.1 Outline

When test specimens have wide variation in their bending capacities the bending capacity of some of the test specimens will quite differ from the average bending capacity. And the difference between the bending capacity of the individual test specimens and the average bending capacity will cause inaccurate estimation of the bending capacity of individual test specimens. And this inaccuracy will be significant when the bending capacities of the test specimens have wider variation. Uncertainty in estimating the bending capacity of the test specimens will cause inadequate loading level for the duration of load test. And as a result the time to failure will differ among test specimens even they are loaded at the same load. Uncertainty in estimating the bending capacity of the individual test specimens and the inadequacy in choosing the load for the duration of load test are discussed in this session. The effect of the uncertainty in estimating the bending capacity on the evaluated results of the duration of load factor was clarified by some numerical calculation.

3.2 Calculation method to estimate the duration of load factor

The calculation methods used to estimate the duration of load factors were as follows:

(1) The bending capacities of the test specimens were assumed to have normal distribution and the bending capacities of 30 samples were calculated by generating random numbers. In this case the mean value of the samples was regarded as to be the average bending capacity of the samples.
(2) The first 10 samples were assumed to be loaded at the 90% stress level and the second 10 samples were assumed to be loaded at the 80% stress level and the last 10 samples were assumed to be loaded at the 70% stress level.

(3) Time to failure for each sample was calculated by using equation 2. Equation 2 represents a linear line that takes the two points, (Stress Level, Time to Failure) = (1.0, 10min) and (Stress Level, Time to Failure) = (0.55, 50years). And equation 2 is commonly known as to represents the relationship between the stress level and the time to failure of solid lumbers.

\[
\log(t) = \frac{7.41}{100} \left( SL - 0.55 \right) \text{ (2)}
\]

Where, \( t \) is time to failure in minutes and \( SL \) is the actual stress level

(4) The actual stress level and the apparent stress level can be calculated by equation 3 and 4. As the load loaded to each sample is known and the actual bending capacity of the each sample is known the actual stress level can be calculated. The actual stress level was installed to equation 2 and the time to failure for each sample was calculated.

\[
\text{Apparent stress level} = \frac{\text{Load applied}}{\text{Average Bending Capacity}} \quad (3)
\]

\[
\text{Actual stress level} = \frac{\text{Load applied}}{\text{Actual Bending Capacity}} \quad (4)
\]

The calculated results were plotted on the graph that had apparent stress level for its vertical axis and logarithm of the time to failure for its horizontal axis. And the duration of load factor was evaluated.

The steps (1) to (5) were repeated for hundred times and the duration of load factor was calculated for hundred times.

Duration of load factor was calculated for the samples with coefficient of variations 1%, 5% and 10% respectively. For each case the duration of load factor was calculated for 100 times. The average of the 100 calculated results was calculated and regarded as to be the duration of load factor.

3.3 Estimated duration of load factor

The bending capacities were calculated by generating random numbers for the distribution that has the mean value of 19.9kN and the coefficient of variation of 10%. The calculated bending capacities and the actual stress levels of the 30 samples are shown in table 1. The actual stress levels were calculated by equation 3. The actual stress level ranged from 0.75 to 1.14 for the group whose targeted stress level was 0.9. And the actual stress level ranged from 0.73 to 0.99 for the group whose targeted stress level was 0.8. And the actual stress level ranged from 0.59 to 0.92 for the group whose targeted stress level was 0.7.

The relationships between the apparent stress ratio and the time to failure are shown in figure 2. Figure 2(a) gives the results for the samples whose coefficient of variation (COV) was 10%, figure 2(b) gives the results for the samples whose coefficient of variation (COV) was 5% and figure 2(c) gives the results for the samples whose coefficient of variation (COV) was 1%. The time to failure ranged wider for the group that had higher coefficient of variation (COV) for their bending capacity.

The duration of load factors were calculated higher for the group that had higher coefficient of variation for their bending capacities. The duration of load factor for the samples that had 1% COV for their bending capacity was calculated as to be 0.55. And the duration of load factors for the samples that had 5% COV and 10% COV for their bending capacity were calculated as to be 0.59 and 0.67 respectively.
Table 1. Calculated bending capacities and the actual stress levels of the 30 samples.

<table>
<thead>
<tr>
<th>Target Stress Level = 0.9</th>
<th>Target Stress Level = 0.8</th>
<th>Target Stress Level = 0.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bending Capacity (kN)</td>
<td>Bending Capacity (kN)</td>
<td>Bending Capacity (kN)</td>
</tr>
<tr>
<td>Actual Stress Level</td>
<td>Actual Stress Level</td>
<td>Actual Stress Level</td>
</tr>
<tr>
<td>22.3</td>
<td>16.7</td>
<td>19.0</td>
</tr>
<tr>
<td>0.80</td>
<td>0.95</td>
<td>0.73</td>
</tr>
<tr>
<td>18.4</td>
<td>19.7</td>
<td>23.0</td>
</tr>
<tr>
<td>0.97</td>
<td>0.81</td>
<td>0.60</td>
</tr>
<tr>
<td>21.0</td>
<td>20.9</td>
<td>16.3</td>
</tr>
<tr>
<td>0.75</td>
<td>0.76</td>
<td>0.85</td>
</tr>
<tr>
<td>19.4</td>
<td>21.9</td>
<td>18.5</td>
</tr>
<tr>
<td>0.92</td>
<td>0.73</td>
<td>0.75</td>
</tr>
<tr>
<td>21.8</td>
<td>18.2</td>
<td>15.1</td>
</tr>
<tr>
<td>0.82</td>
<td>0.87</td>
<td>0.92</td>
</tr>
<tr>
<td>18.7</td>
<td>23.6</td>
<td>18.8</td>
</tr>
<tr>
<td>0.96</td>
<td>0.67</td>
<td>0.74</td>
</tr>
<tr>
<td>15.7</td>
<td>16.1</td>
<td>22.4</td>
</tr>
<tr>
<td>1.14</td>
<td>0.99</td>
<td>0.62</td>
</tr>
<tr>
<td>23.2</td>
<td>21.0</td>
<td>20.3</td>
</tr>
<tr>
<td>0.77</td>
<td>0.76</td>
<td>0.69</td>
</tr>
<tr>
<td>21.5</td>
<td>21.0</td>
<td>17.2</td>
</tr>
<tr>
<td>0.83</td>
<td>0.76</td>
<td>0.81</td>
</tr>
<tr>
<td>20.5</td>
<td>20.8</td>
<td>23.6</td>
</tr>
<tr>
<td>0.88</td>
<td>0.77</td>
<td>0.59</td>
</tr>
<tr>
<td>20.5</td>
<td>20.0</td>
<td>19.4</td>
</tr>
<tr>
<td>0.89</td>
<td>0.81</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Figure 2. Relationship between the apparent stress ratio and the time to failure.

Note: t is duration of time to failure in minutes.

Calculation was conducted on the assumption that the duration of load factor of the sample should be 0.55. For this the results of the calculation indicate that the duration of load factor can be better estimated when the coefficient of variation of the bending capacities is small.

In general the coefficient of variation of the wooden structural material ranges from 10% to 15%. This means that the duration of load factor will not be conservatively evaluated when the load for the duration of load test is determined from the apparent stress ratio.

4 ALTERNATIVE TESTING AND EVALUATION METHOD TO EVALUATE THE DURATION OF LOAD FACTOR

4.1 Evaluation method

As mentioned above the duration of load factor has a possibility not to be conservatively evaluated because of the inaccurate estimation of the bending capacity of each test specimens. Testing and evaluation method that can adjust the stress level and conservatively evaluate the duration of load factor was proposed. The proposed method is as follows:

1) The time to failure of each test specimens loaded at certain apparent stress level depends on the actual bending capacity of the test specimens. It was assumed that the test specimens that did not failed for a long time should have higher bending capacities and the test specimens that failed soon should have lower bending capacities.
(2) For example when ten test specimens are loaded with the dead load that is equivalent to the 80% apparent stress level the test specimen that fails first should have the lowest bending capacity among the ten test specimens. On this idea the bending capacity of the test specimen that fails first was regarded as to be the 5th percentile of the bending capacity derived from the bending test. In the same way the bending capacity of the test specimen that fails secondly was regarded as to be the 15th percentile of the bending capacity. And the bending capacity of the test specimen that failed at last was regarded as to be 95th percentile of the bending strength.

(3) The true stress ratio for each test specimens can be calculated by dividing the applied load by the bending capacity estimated by the methods shown in (1) and (2).

(4) For example the true stress level for the test specimens that fails first can be calculated as follows:

\[ SL_{\text{true}} = \frac{(0.8 \times P_{0.05})}{(0.8 \times P_{\text{ave}})} \]  \hspace{1cm} (5)

Where, \( SL_{\text{true}} \) is the true stress level
\( P_{0.05} \) is the 5th percentile of the bending capacity
\( P_{\text{ave}} \) is the average of the bending capacity

(5) The duration of load factor was re-evaluated by the true stress level and the calculated or measured time to failure results.

4.2 Results

Figure 3 gives the results for the data obtained by the simulation. The coefficient of variation of the samples was set as to be 10%. The correlation coefficient of the liner regression can be improved to 0.91 by adjusting the stress level. And the duration of load factor derived from the true stress ratio was evaluated as to be 0.56 and this value was almost equivalent to 0.55 the duration of load factor assigned for the solid lumber.

Figure 4 shows the re-evaluated results for the test data that the test specimens were loaded at the apparent stress level of 80%. The duration of load factor was re-evaluated as to be 0.56 and was almost equivalent with the duration of load factor assigned for lumbers.

Figure 3. Relationship between the true stress ratio and the time to failure (Simulated results).

Note: \( t \) is duration of time to failure in minutes.
Note: $t$ is duration of time to failure in minutes.

5 CONCLUSION

The adequacy of the duration of load factor was discussed in terms of the accuracy of the stress level. The results are summarized as follows:

1. The duration of load factor will be not be conservatively evaluated when the samples being tested have a wide variety in their bending capacity.

2. When the distribution of the bending capacity of the samples has smaller coefficient of variation the load bearing capacity of the each samples can be more accurately estimated. And as a result the duration of load factor can be adequately evaluated.

3. An alternative testing and evaluation method to evaluate the duration of load factor of the structural wooden materials was proposed. The method was based on the idea that the test specimens that do not fail for a long time should have higher bending capacity than the test specimens that fail in a short period. And the stress ratio was adjusted on this idea. The duration of load factor was well evaluated by the proposed alternative testing and evaluation method.


