Effects of Wood Decay on Deformation Mechanism and Shear Performance of Screwed and Nailed Joints

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Introduction

Wood decay is an important cause of degradation of wooden construction for the severity of its damage to the structure. Common countermeasure is to reinforce the degraded wood members with reinforcing equipment using nails and screws. However, only a limited number of studies have focused on the difference between the performances of screwed and nailed joints with sound wood and those with decayed wood and hence the accumulated knowledge is insufficient.
This study was aimed at investigating the performance of screwed and nailed joints with decayed wood.

Materials & Methods

Specimens

Solid lumber of **Sakhalin fir** (*Abies sachalinensis*)
Average wood dencity = 406 kg/m^3, average moisture content = 9.0%

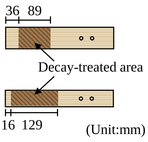


Fig. 1. Decayed specimens.

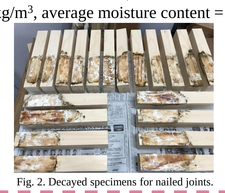
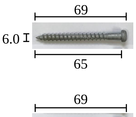


Fig. 2. Decayed specimens for nailed joints.

Screws & Nails



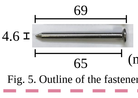


Fig. 5. Outline of the fasteners.

Screws : “ TBA-65D ”
(Effective length = 65mm, Effective diameter = 4.5mm)
Originally designed to be used with hold-down hardware and made by Tanaka Co., Ltd., Ibaraki, Japan.

Nails : “ N125 ” (Shortened)
(Effective length = 65 mm, Diameter = 4.6 mm)
N125 Nails (Standardized in Japanese Industrial Standard) were cut into 69 mm in full length so that it has the same effective length as the screws “ TBA-65D ”.

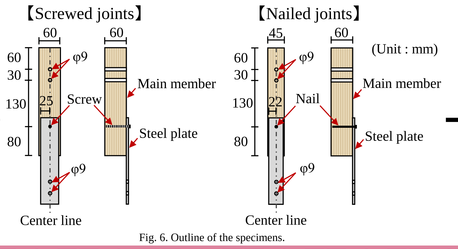


Fig. 6. Outline of the specimens.

Decay treatment

with brown-rot fungus, *Fomitopsis palustris* using
“**rot fungus feeder unit**”

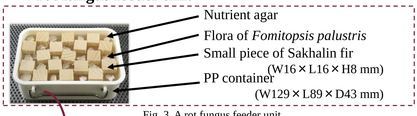


Fig. 3. A rot fungus feeder unit.

Placed on specimens & fastened with stretch wrap

Placed in a closed environment at 28 ℃ and 75% RH for 20 weeks or more

Fig. 4. Attachment of rot fungus feeder unit.

Single shear test

The load was applied parallel to the grain of the main member. The relative slip was measured by 2 displacement transducers located on the two sides of the specimen.

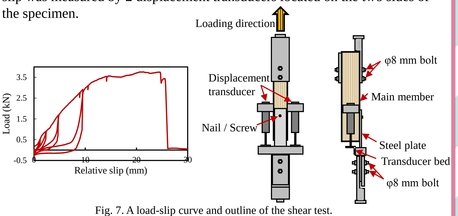


Fig. 7. A load-slip curve and outline of the shear test.

The load was applied to produce a relative slip of a certain slip level and subsequently reduced to 0 mm. This loading procedure was repeated to produce 2, 4, and 8 times of the slip level and subsequently, the load was kept monotonically applied until the tests were terminated when the relative slip reached at 30 mm or fastener breakages occurred.
The slip levels were determined from ½ times of the yield displacement obtained from the preliminary monotonic loading tests conducted respectively on the screwed and nailed joints with un-decayed member. (0.5 mm for the nailed joints and 1.2 mm for the screwed joints.)

Results & Discussion

Specimen failure

Screwed joints
8 out of 10 controls and 10 out of 12 decayed specimens failed. Specimen failure due to main-member splitting was observed only in 1 control and the others were all due to fastener breakage.

Nailed joints
3 out of 5 controls and 4 out of 20 decayed specimens failed and they were all due to splitting of the main member. Deformation of the joints was accompanied by withdrawal of the nail in 3 out of 5 controls and 8 out of 20 decayed specimens.

	Mode III		Mode IV
【Screw】			
Control (n=10)	**2**	:	**8**
Decayed (n=12)	**9**	:	**3**
【Nail】			
Control (n=5)	**0**	:	**5**
Decayed (n=20)	**0**	:	**20**

Fig. 8. Observed failure modes of the joints.

Failure modes

Following EYM (European Yield Model), failure modes of the screwed and nailed joints could be classified into 2 types with one plastic hinge formed in the fastener (Mode III) and two hinges (Mode IV) by observing the deformed fastener (Architectural Institute of Japan 2006).

Screwed joints: The dominant failure modes of the joints were clearly different between the control and decayed specimens; 2 out of 10 controls and 9 out of 12 decayed specimens showed the failure of Mode III, whereas the others showed the failure of Mode IV. This result could be attributed to the degradation of the bearing strength of the decayed main members. Therefore, it is inferred that the deformation mechanism of the joints were affected by decay.

Nailed joints: Only Mode IV was observed and the effect of decay on the deformation mechanism of the joints was not confirmed.

Evaluation of the shear performance

To evaluate the shear performance of the joints, the initial stiffness (K_s), maximum shear resistance (P_{max}), yield shear resistance (P_y), and ultimate shear resistance (P_u) were determined from the envelop load-slip curves as follows (Japan Housing and Wood Technology Center, 2017).

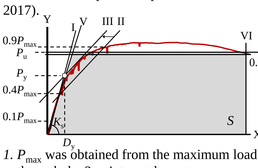


Fig. 9. Method of evaluating shear performance of the joints. Ks, initial stiffness; Pmax, maximum shear resistance; Py, yield shear resistance; Dy, yield displacement; Pu, ultimate shear resistance..

1. P_{max} was obtained from the maximum load. A straight line (line I) was drawn as it passes through the 2 points on the curve corresponding to 10 and 40 % of P_{max}.
2. A straight line (line II) was drawn as it passes through the 2 points corresponding to 40 and 90 % of P_{max}.
3. A straight line (line III) was drawn as it has the same slope as line II and it is tangent to the curve.
4. The load and slip corresponding to the intersection of line I and III were obtained and defined as P_y and the yield slip, D_y, respectively.
5. A straight line (line V) was drawn as it passes through the origin and the coordinate D_y and P_y. The slope of lineV was obtained and defined as K_s.
6. A straight line (line VI) was drawn vertical to the horizontal axis from the point corresponding to 80 % of P_{max} after the maximum load.
7. The area of the shape surrounded by the curve, horizontal axis, and line VI was calculated and defined as S.
8. A straight line (line VII) was drawn parallel to the horizontal axis as the area of the shape surrounded by line V, line VI, line VII, and the horizontal axis is equal to S.
9. The load corresponding to the intersection of line V and VII was obtained and defined as P_u.

Two control and one decayed specimens of screwed joints showed low rising of the load and could not be evaluated appropriately by this method, therefore they were excluded from succeeding evaluation.

Shear performance of the joints - Decayed vs. Sound

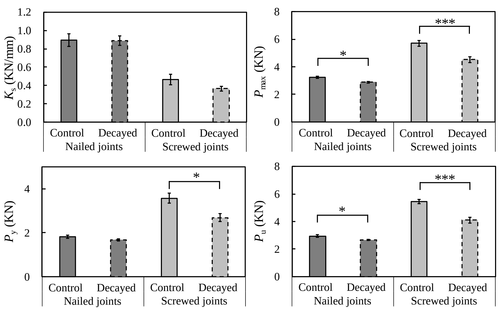


Fig. 10. Values of Ks, Pmax, Py, and Pu
(* = significant at the 5% level, *** = significant at the 0.5% level).

Screwed joints
The difference between decayed and control specimens in P_{max}, P_y, and P_u were significant at the 5% level whereas that in K_s was not. Therefore, it is considered that the maximum, yield, and ultimate shear resistance of the screwed joints were significantly degraded by decay.

Nailed joints
The difference between decayed and control specimens in P_{max} and P_u were significant at the 5% level whereas those in K_s and P_y were not. Therefore, it is considered that the maximum and ultimate shear resistance of the nailed joints were significantly degraded by decay.
In this study, the decayed specimens for nailed joints were considered to be in the stages of incipient decay as the decayed area were limited to the surface layer part. Therefore it is inferred that most part of the decayed specimens were almost sound, though, the effect of decay was reflected as degradation of P_{max} and P_u. This result implies that a slight decay on joints can cause statistically significant degradation on its performance.

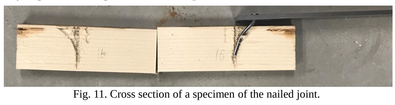


Fig. 11. Cross section of a specimen of the nailed joint.

Comparison of screwed and nailed joints
By comparing the results, it is inferred that in the case of screwed joints, the effect of decay that appeared as the change in the deformation mechanism as was on the performance, reflected to P_y and therefore the difference in P_y was significant in contrast to the result of nailed joints.

No significant degradation in K_s
In this study, the effect of decay on the initial stiffness was not confirmed in either of the screwed or nailed joints and this result is coinciding with preceding studies for screwed joints (Takanashi et al. 2018) and nailed joints (Toda et al. 2010). It is inferred that the change in the deformation mechanism of joints caused by decay such that observed in the case of screwed joints appears after the yield point and therefore it was not reflected to K_s.

References
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Japan Housing and Wood Technology Center (2017) Mokuzou jikugumikouhou jyutaku no kyoyou ouryokudo sekkei 1: 300-301. (in Japanese).
Takanashi R, Toda M, Miyauchi T, Mori M, Mori T (2018) Shear Strength of Multi-screw Joints Connected to Decayed Lumber. Mokuzai Gakkaishi 64(3): 122-129. (in Japanese with English summary).
Toda M, Mori M, Ohashi Y, Hirai T (2010) Effects of Wood Decay on the Shear Performance of Nailed Timber Joint. Mokuzai Gakkaishi 56(1): 41-47. (in Japanese with English summary).

Conclusion

Screwed joints: The failure modes of both Mode III and IV were observed and the dominant failure modes of the screwed joints were clearly different between the control (Mode IV) and decayed specimens (Mode III). Degradation of shear performance of the screwed joints was confirmed in P_{max}, P_y, and P_u and degradation in P_y was considered to reflect the change in the dominant failure modes caused by decay.
Nailed joints: Only the failure mode of Mode IV was observed and the effect of decay on the deformation mechanism was not confirmed. Degradation of shear performance of the nailed joints was confirmed in P_{max} and P_u.
Degradation in K_s was not confirmed in either of screwed or nailed joints.