목재공학20(1) : 72~78(原著)
Mokchae Konghak. 20(1) : 72~78. 1992

합판과 목재사이 못 접합에 있어서 하중 속도에 대한 Damping과 강성 (stiffness)*1

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Damping and Stiffness of Nailed Joints between Wood and Plywood : Response to Loading Rate*1

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요 약

지진과 관련있는 하중 속도에서 damping을 측정하기 위하여 합판과 목재 사이에 한개의 못을 사용한 접합에 대하여 조사 했다. 조사된 하중은 sine function의 15Hz와 ASTM하중 속도 사이에서 행했다. Damping 율은 4Hz까지의 하중 속도에서는 증가를 보였으며 그후 15Hz까지는 점진적으로 감소하였다. 강성은 높은 하중 범위에서 slip moduli가 지속적으로 증가 하였다. 낮은 하중 범위에서 2.5Hz까지 증가 하였으며 그후는 감소 하였다. Damping 율과 slip modulus는 하중 속도와 상관 관계가 낮은 반면 work capacity와 dissipated energy는 높은 상관 관계를 보았다.

1. INTRODUCTION

Damping and stiffness of nailed joints greatly affect the overall structural reliability of light-frame wood buildings. Damping is the result of energy dissipation during vibration caused by dynamic loads. Under cyclic loading, structural systems that dissipated energy displays the load-deformation traces as hysteresis loops. The energy dissipation is easily evaluated from these loops, which is in turn used to determine damping.

The main source of damping in build-up structures is interlayer friction in joints. Wood buildings belong to such structures. They are composed of components that are in close contact at joints which dissipated energy as the building deflects under loads. This energy dissipation or damping is especially important when the loads are caused by earthquakes and winds. The coefficient of damping in systems with nailed wood joint is about 10%[3, 8], while that of wood material is only about 0.35%[15]. The known damping properties are mostly associated with specific wood systems and not with joints where the damping takes place. Consequently, information is needed on damping in the most common wood joints, soch as nailed joints of light-frame

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wood buildings.

Several investigations[9, 11] show that the loading rate during testing affects damping. The damping ratio in nailed joints tested at 1.0 Hertz rate was observed to be about 22%. The effect of loading rate at frequencies above 1.0 Hertz has not been studied. Therefore, the main objective of this study to develop the relation between the loading rate and damping ratio. Another objective was to evaluate the effect of loading rate on slip modulus.

2. MATERIALS AND METHODS

A total eight samples were tested in single shear, each representing one-nail joint between typical framing and sheathing materials. Each sample was tested at different loading rate. The loading functions employed were ramp and sinusoidal functions with much larger rates of loading than those of the American Society for Testing and Materials(ASTM)[1]. To reduce the variability in specimen properties and to enhance the statistical reliability, the same section of sheathing materials and lumber were used for all samples. Each stud and plywood section was tested 8 times, once for each loading function. Because each sample consisted of 30 replications a total of 240 specimens was tested.

The selection of clearwood lumber section was mainly based on Specitic gravity(SG). After material selection, 13-inch sections were cut from individual pieces. Each section was weighed and measured for volume and moisture content. Moisture content was measured by a resistant type moisture meter. The volume was adjusted to ovendry base using tabulated shrinkage volume for clearwood[12]. Therefore, the SG is based on ovendry weight.

Three 4 by 8-feet sheets of 3/8″ thickness, three ply Douglas-fir plywood of sheathing grade, were obtained from a local supplier. Each sheet was first cut into 4-inch by 8-foot strips with face grain oriented parallel to the long axis of the strip. Next each strip was then cut into 16″ lengths. All pieces that contained defects, such as knots and gaps between lamination, were discarded. The 6d, galvanized, smooth, box nails were used for all specimen.

To achieve uniform nailing 5/64 inch holes were drilled in each wood and plywood sction preselected nail locations 2 inches from the end. The nail was positioned on the predrilled 5/64 inch hole and driven first into the plywood, and then into the wood until the head was 5/8 inch above the plywood surface. Next, the specimen was placed on the testing machine and the nail pushed in until the top of the head was

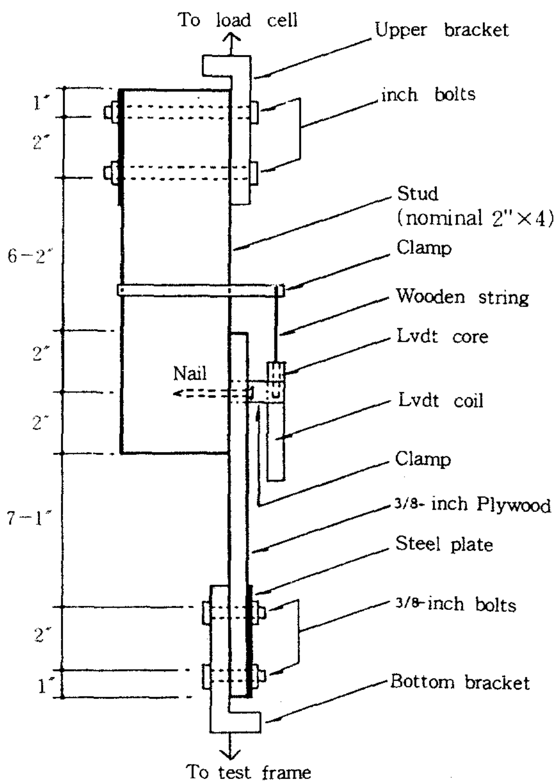

Fig. 1. Specimen construction and testing arrangement

in the plane of the plywood surface. The predrilling of naill holes and machine pushing of nails was carried out to reduce the variability associated with specimen construction.

After testing the specimens were dissembled and 1-inch strip cut off from each plywood section close to the used nail hole. A new specimen was constructed from these plywood and stud section but with a new nail. Then the testing was performed at a different loading rate. For each successive specimen construction, the nail sites were moved 1″ along the center lines of the wood and plywood sections, except when the stud section was attached to the opposite narrow face of the wood section, The interface length between lumber and sheathing of 4″ was kept constant for all the specimen.

The assembled specimens were mounted to the testing machine by brackets attached to the test frame as shown in Fugure 1. This arrangement minimized the bending effect, because the applied force acted through the plane that was parallel and very close to the joint interface. A linear variable differential transducer (LVDT)was used to monitor the slip between lumber and sheathing. The load cell was used to monitor the applied load. All samples were subjected to cyclic loading at four load levels each cycled three times.

The syncronous function modulation was designed to compliment the operation of sweep/modulation generator to control both amplitude and frequency changes in the generator to control both amplitude and frequency changes in the generator for input to testing machines. Two data acquisition systems were employed in PDP 11/10 microcomputer and an X-Y recorder were used to check the accuracy of the information on the microcomputer as well as the accuracy of the damping ratios and slip moduli, computed by the microcomputer. To eliminate the effect of moisture content changes, all tests were conducted in the conditioning room at about 12% equilibrium moisture content.

Figure 2 illustrate typical load-slip traces recorded directly during testing. These traces are non-linear, especially at higher load, and possesses a considerable damping as indicated by the large hysteresis loops. Some traces are non-symmetrical with respect to the load axis, possibly because the local material properties in lumber and plywood on one side of nail are different from those on the other side. The slip never returns to zero after complete unloading because of the permanent set gets progressively larger under increasing loads. Consequently, the behavior of nail joint depends on the previous loading.

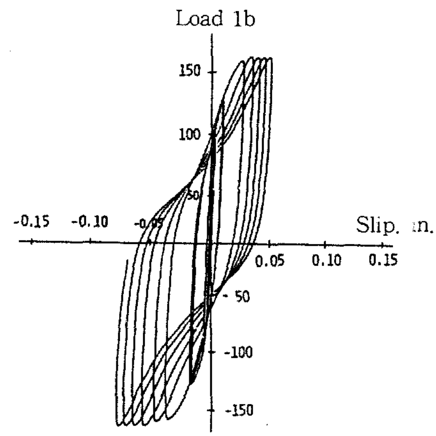

Fig.2. A typical load-slip trace

The hysteresis loops get wider under increased load level. At 70-1b, the loops are very narrow and loading and unloading traces almost coincide often. Therefore, especially several rough traces at high testing rates produced no meaningful energy areas and were eliminated from the data analysis. Trace roughness at high load levels and problems with specimen manufacture and testing further reduced the number traces used in data analysis.

3. RESULTS AND DISCUSSION

Among the three cycling loops at each load level, the second was not directly affected by the cycling at the lower and higher load. Therefore, the second loop(Figure 3) was used to evaluate the joint damping and stiffness. The damping variables analyzed by using Medearis[8] were total dissipated energy per cycle, total work capacity per cycle, and damping ratio. Other variables evaluated were characteristic point on each load versus slip traces, which were used to define the joint stiffness, K_{ij}, at each load level. (Figure 3). These points are G.B.D.and O'. They were selected at the intersection of the trace with both coordinate axis and at extreme loads for each cycle. Straight lines through these points linearly approximate the load versus slip relations for each load level.

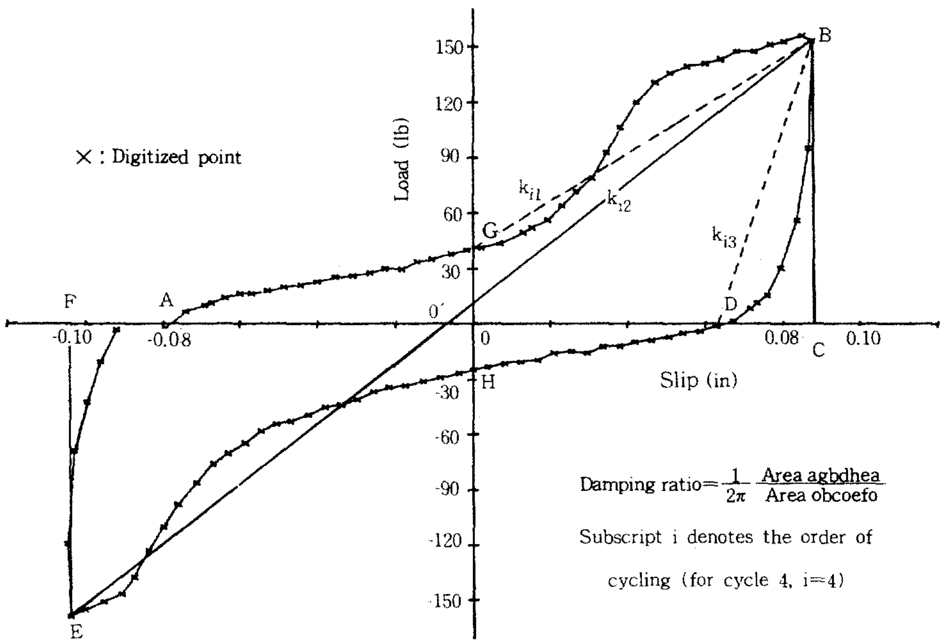

Fig.3. A typical digitized load-slip trace

3.1 Relation between damping ratio and loading rate

Individual effect of load level and loading rate were found to be significant in all case for damping variables on the 5% significant level. In addition to individual effects, the interaction between the load level and loading rate was examined at $\alpha=0.05$. The result shows that a significant two-way interaction exists between load level and loading rate for all three dependent variable : dissipated energy, work capacity, and damping ratio. Because the interaction between the two effects was significant for all the load levels, the analysis was conducted separately at each load level. Thus the analysis of load-level effects on three dependent variables individually for each loading. Dissipated energy and work capacity were found to be vary with changes in loading rate(Figures 4 & 5). This variation is interrelated, so that the amount of changes from one level to next is not same. Consequently, the loading rate also influence the damping ratio. Damping ratios are significantly differ-nt between the adjacent low rates, but not so at high rates.(Figure 6)

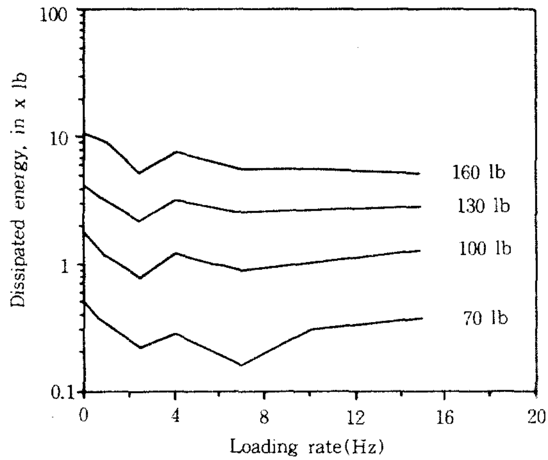

Fig. 4. Relationship between loading rate and dissipated energy per load cycle for different load levels.

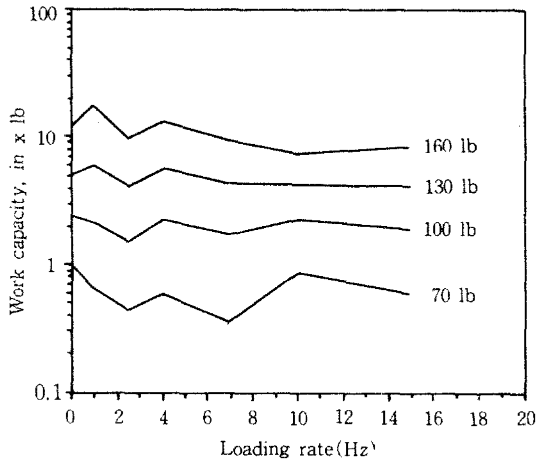

Fig. 5. Relationship between loading rate and work capacity per load cycle for different load levels.

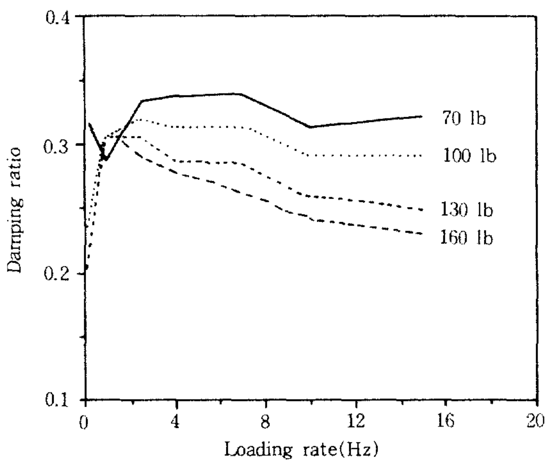

Fig. 6. Relationship between loading rate and damping ratio per load cycle for different load levels.

The relation between the load and damping variables were also investigated. The ramp loading rates were converted into frequencies to have them expressed by the same variable for all samples. The converted frequencies somewhat varied from specimen to specimen and from load level to load level, because the frequency of the load ramp rate changed with specimen stiffness and nonlinearity. Linear regression analysis for all eight rates and load levels, which quantified the relationships among Figure 4 to 6, revealed several significant effects. Table 1 lists the regression constants and correlation coefficients, R. The values of R for work capacity and dissipated energy are above 0.74. There is the value associated with acceptable correlation between MOE and MOR for lumber. However, the values of R in predicting damping ratio are smaller, which means that the testing in this study has not revealed a strong correlation between damping ratio and load level and loading rate.

Table 1. Regression equations relating joint properties and the effect of load level and loading rate

Dependant variables Y*	Regression equation: Y=A+B(LL)+C(LR)−D A	B	C	D	R
DR	0.386	-0.583E-3	-0.048	0.25	0.517
TOWC	-5.216	0.070	0.003	2.00	0.781
TODC	-7.938	0.109	0.463E-5	3.50	0.745

* DR : Damping ratio
TOWC : Total work capacity/loop (in.-lb)
TODC : Total dissipated energy/loop (in.-lb)
LL : Load level
LR : Loading rate (Hz)

3.2 Relation between stiffness and loading rate

The analysis of variance at $\alpha=0.05$ was also performed to determine if joint stiffness is affected by loading rate and load level. The results show that these moduli depend on both, load level and loading rate. Furthermore, the effect of level and rate is interdependent. As expected, loading rate and load level are strongly correlated to slip moduli, but the effect of loading rate is much weaker. Thus, slip moduli change mostly with load level and somewhat loading rate. However, effects of load level and loading rate are not additive. For all loading functions investigated, the loading rate has negligible effect on slip moduli k_{i1} and k_{i3}. For this reason, no regression equations were developed to correct the joint stiffness for k_{i1} and k_{i3} to account for the variation in the load function. The investigation was concerned with the relation between load functions, total slip and slip modulus, k_{i2}.

Table 2 shows resulting regression constants and correlation coefficient for regression analysis. The total slip is highly correlated to the loading rate and load level. An exception is slip modulus, K_{i2}, which shows a weak correlation. Therefore, testing in this study has revealed a strong correlation between load functions and all the slip moduli except modulus k_{i2}

Table 2. Regression equations relating joint-slip properties to load level and loading rate.

Dependant variables Y*	Regression equation: Y=A+B(LL)+C(LR)−D A	B	C	D	R
TOS	-0.051	0.401E-4	0.008E-1	2.0	0.764
K_{i2}	0.328E5	-0.138E3	-0.775E4	0.1	0.594

* TOS : Total slip (in.)
K_{i2} : Slip modulus (lb/in.)
subscript i denotes the order of load level(i=1,2,3,4 for 70-1b, 100-1b, 130-1b, and 160-1b level, respectively)

4. CONCLUSIONS

The results of this study show that dissipated energy and work capacity increase with increasing load for joints that are constructed and tested in the same condition. The work capacity decreased with increasing loading rate up to about 7.0 Hz. Between 7.0 and 15.0 Hz, it increases somewhat at the 70 load level, but it keeps on decreasing at other load levels. The damping ratio generally decreases with increasing load except at the 1.0 Hz sinusoidal loading rate. The damping ratio moderately increases with loading rate between ASTM static and 4 Hz rate. Then it slowly decreases between 4 Hz and 15 Hz.

The results also show that slip moduli increase with loading rate between ASTM and 2.5 Hz loading rate, then they decrease at all the higher rates tested. An exception is a 160 lb load level which is associated with an increase of moduli with increasing loading rate. Sudden impact loading after changing the load direction may affect the hysteresis loop at fast loading rates of 10 and 15 Hz. Additional testing is recommended to define these effects.

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