PSEUDO-DYNAMIC TEST AND EVALUATION OF THE MAXIMUM RESPONSE OF A GLULAM FRAME UNDER BIG EARTHQUAKE ATTACK

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SUMMARY

This study presents the results of pseudo-dynamic tests and evaluation of seismic response by assuming restoring force characteristics under intense earthquake motions. The objective of the resistance frame is the three hinge arch in span. At the first the cyclic loading test was carried out for assuming restoring force characteristic. Next, pseudo-dynamic tests were carried out. Several techniques were used to estimate the maximum response of the frame. The techniques were equivalent linear analysis, property of energy conservation and the method using energy input ratio. The results calculated by these techniques and time history response analysis using assumed restoring force characteristic model were compared with pseudo-dynamic tests. The effectiveness of the equivalent linear analysis is demonstrated using calculations from a single damping ratio.

INTRODUCTION

The seismic behavior of wood structures is not as well understood as the seismic behavior of steel or reinforced concrete structures. One reason for this discrepancy is that wooden structures are typically small-scale structures such as houses. Another reason is that in wood framed structures the resisting element is not as clearly defined as in steel or concrete structures. However glued laminated timber (glulam) frames have a clearly defined shear wall and relatively large-scale.

In Japan, there are many glulam buildings that consist of arch frames. Due to traffic conditions the length of member is limited. Therefore moment resisting connections between members is often necessary for large span buildings such as a gymnasiums or factories. The primary energy absorption in these frames occurs in the joints, typically it is important for evaluating the seismic performance to know the frame's energy absorption during an earthquake. It is reported that even structures with a moment resisting joint in shoulder part have from four to ten percent equivalent damping factors.[Yasumura1992]

Objective in this paper is to accumulate the following data and to determine the behavior for evaluation of seismic performance for the arched structure that is popular in Japan.

1. To make the restoring force characteristic model by carrying out cyclic loading test.

2. To verify the model through comparison of results between pseudo-dynamic tests and time history analysis for some recorded waves.

3. To estimate the maximum response using the equivalent linearization technique.

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EXPERIMENTAL PROCEDURE

Test Specimen

The test specimen is typical for a building consisting of arched frames for the transverse direction and braced frames in the longitudinal direction. The transverse span length is 10m. The bay length in the longitudinal direction is 4m. The shape of arch is shown in figure-1 and the connection detail in the shoulder is shown in figure-2. The lateral force is applied through the pin connection at the top of frame. Vertical load is ignored. This investigation used two loading regimes. One was a cyclic test, its loading schedule is given in figure 3. The other was a pseudo-dynamic test. In the cyclic test one specimen was prepared. This test was used to determine the load-displacement relationship, equivalent damping factor and so on. In pseudo-dynamic test three specimens were prepared and seven cases were tested as shown in table1. The fraction of critical damping factor is 2% in proportion to initial stiffness in cyclic loading test. The loading parameters of pseudo-dynamic test were an input-wave and an assumed mass loading. Input-waves were the north-south component of 1995 Kobe earthquake recorded in Kobe Marine Meteorological Observatory and the north-south component of El-Centro 1940. Assumed mass is explained in detail in the next section.

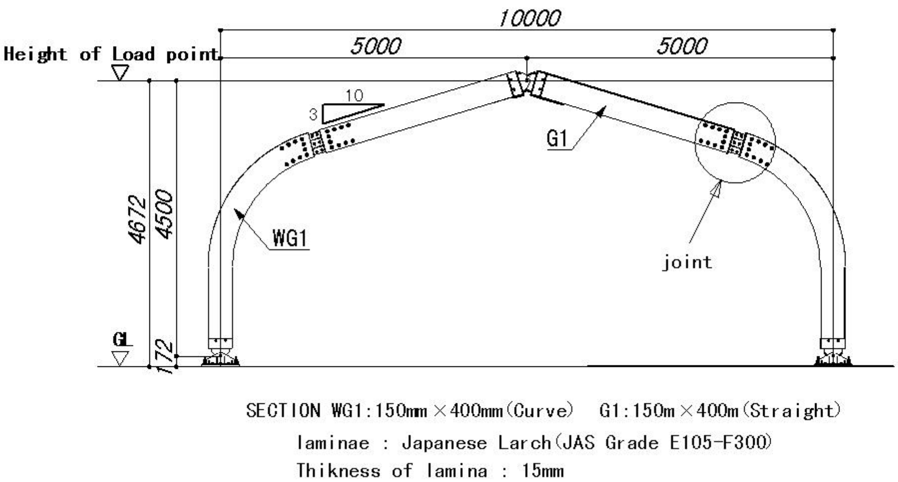

Figure 1 Outline of specimen

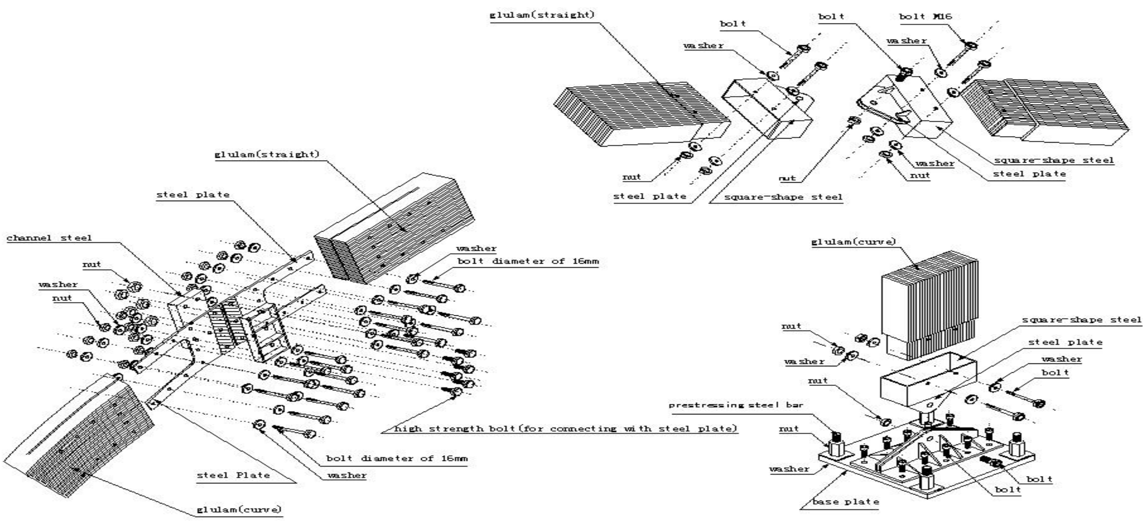

Figure 2 Detail of joint

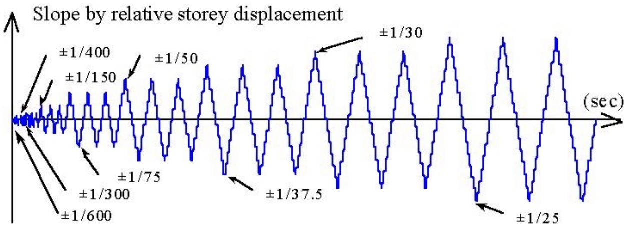

Figure 3 Schedule of cyclic loading test

Note: 3cycles at the same displacement except 1/600

Table1 Parameters of pseudo-dynamic test

Name of Specimen	*, ç"*	*Ao*	*Input wave*	*Mass (t)*	*Initial stiffness (tf/cm)*	*Natural frequency (sec j*	*Rupture*	*Maximum response (cm)*
K-11	0.80			0.0029		0.591	-	13.85
K-12	0.50	2.0G	*Kobe*	0.0047		0.752	›	24.81
K-21	0.50		*El-centro*	0.0047		0.752	-	20.06
K-22				0.0056	0.33	0.823	›	27.04
E-31		1.0G	*El-centro*	0.0059		0.839	-	5.71
E-32	0.80			0.0088		1.028	-	7.11
E-33		2.0G	*Kobe*	0.0059		0.839	›	20.24

Assumed mass

The target mass is expressed by equation-1.

$$m = P_{\max} / (D_S \times A_0) \qquad 1$$

where m is mass, $P_{\max}$ is the maximum force in cyclic loading test D_S is the deformability and damping factor of structure and A_0 is five percent acceleration response applied for input-wave in equivalent frequency. D_S is defined by equation-2 after changing the skeleton curve into bi-linear.

$$D_S = 1/\sqrt{2\mu - 1} \qquad 2)$$

where μ is defined as the maximum response divided by yield displacement. As a result of a calculation using the cyclic loading test, D_S equaled 0.80. In addition to this value, a D_S structural design value of 0.50 is added as a parameter. Equivalent frequency at the maximum response is calculated using the cyclic loading test. So A_0 is about 2,000gal(cm/s/s) at the Kobe-wave and about 1,000gal at the El-Centro. The combination of parameter is given in table 1. The first letter in specimen name indicates the input-wave. “K” means Kobe-wave, and “E” means El-Centro. The first number indicates the specimen number, the next number indicates test repetition number in the same specimen. As an example “K-22” specimen means second Kobe-wave test conducted after “K-21”. On and after second test, assumed mass is increased or input-wave is changed

RESULT AND DISCUSSION OF TEST

The load displacement relationship from the cyclic loading test is shown in figure4. After the load increased to 0.5tf linear slip appeared due to the gap between the bolt and the bolt hole. Also it is thought that the gap between bolt and bolt hole opened at the base pin connection. The frictional resistance between the steel plate and glulam accounts for the linear increase in load. The frame was able to resist a maximum of approximately 4.8tf at a rotation of 1/25 radian (180cm displacement for a frame height of 4.5m). The crack appeared in the shoulder part at this time. The crack occurred at the lower bolt line on the curved glulam. Figure.5 depicts the relationship between maximum displacement and equivalent damping ratio. Equivalent damping ratio is defined by the next equation.

$$h_{eq} = \frac{1}{4\pi}\left(\frac{\Delta W}{W}\right) \qquad 3)$$

Where, ΔW is Dissipation energy of SDOF system, and W is Potential energy in SDOF system $(= Q_{B\cdot 1}\Delta / 2)$
Equivalent damping ratio of 13% decreases with increasing displacement. Finally at the maximum displacement, ratio of 6% without destroying in plus cycle shows. Photo1 and 2 shows the fracture in case of pseudo dynamic test. The rupture in bending appeared beside the crack in the shoulder. The combinations of parameter in excess of maximum load are for *Ds*=0.5 against Kobe and *Ds*=0.8 against Kobe. Therefore existing structure built similar to the test specimen may not survive when subjected to the Kobe earthquake.

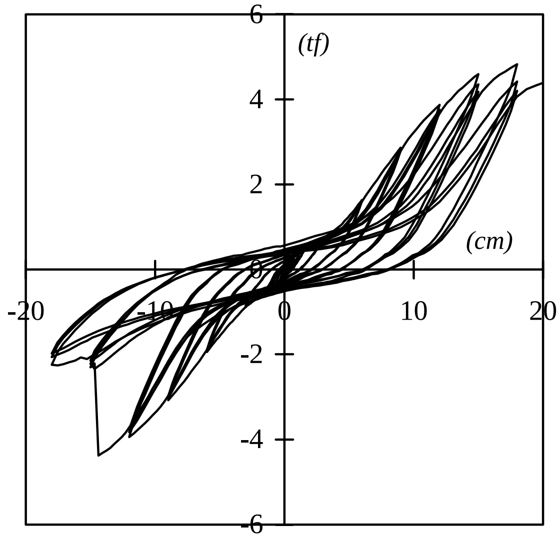

Figure4 Load displacement relationship

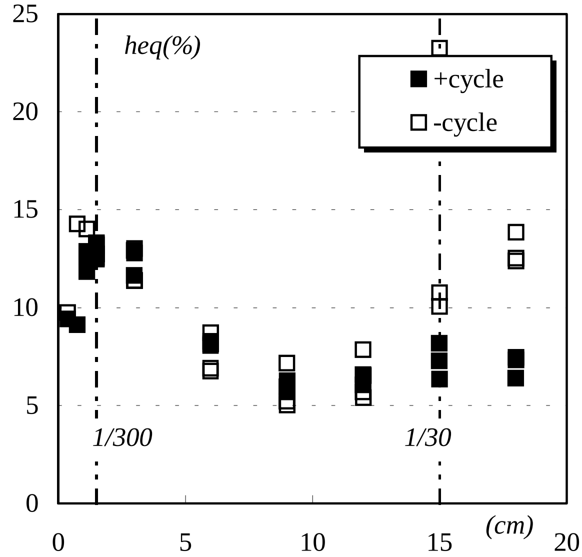

Figure5 Equivalent viscous damping ratio

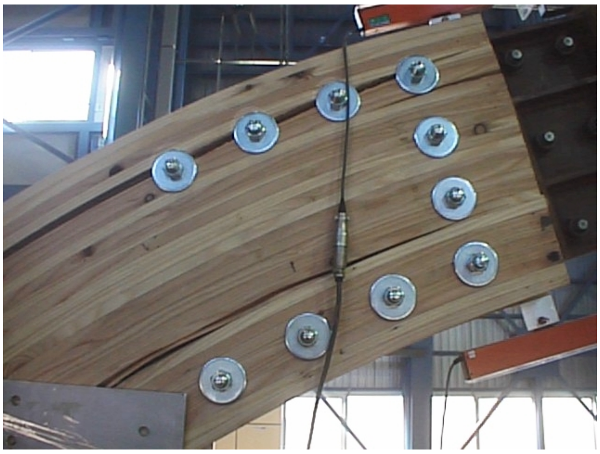

Photo1 Shear failure of column **Photo2 Splitting from bolt joint**

SINGLE DEGREE OF FREDOM MODEL (SDOF MODEL)

Elasto-plastic force-displacement relation is modeled based on cyclic loading test. The model of combination of bi-linear and slip fits in the test result of wooden structures shown in figure6. The better fitting parameters decided by trial shown in table2.

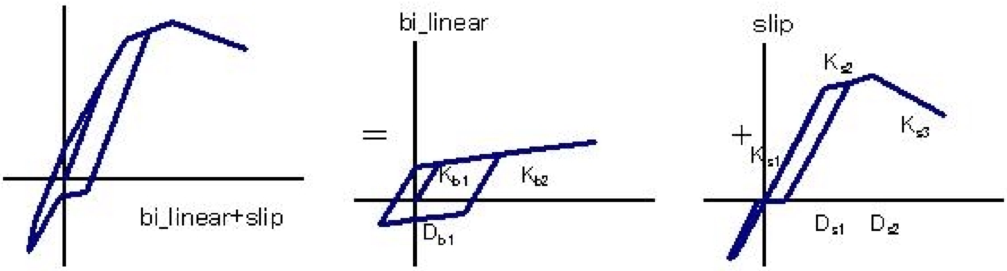

Figure 7 Model of restoring force characteristic

Table2 Parameters of model

K_{b1}	K_{b2}	K_{s1}	K_{s2}	K_{s3}	D_{b1}	D_{s1}	D_{s2}
0.45*tf/mm*	0.13 *tf/mm*	0.18 *tf/mm*	0.11 *tf/mm*	-0.02 *tf/mm*	3*mm*	7*mm*	18*mm*

TIME HISTORY ANALYSIS

Using model defined in SDOF model, time history analysis were executed, and the comparison of result between analysis and pseudo-dynamic test is shown in figure7. Time history and maximum response can be estimated by easy model such as combination of bi-linear and slip.

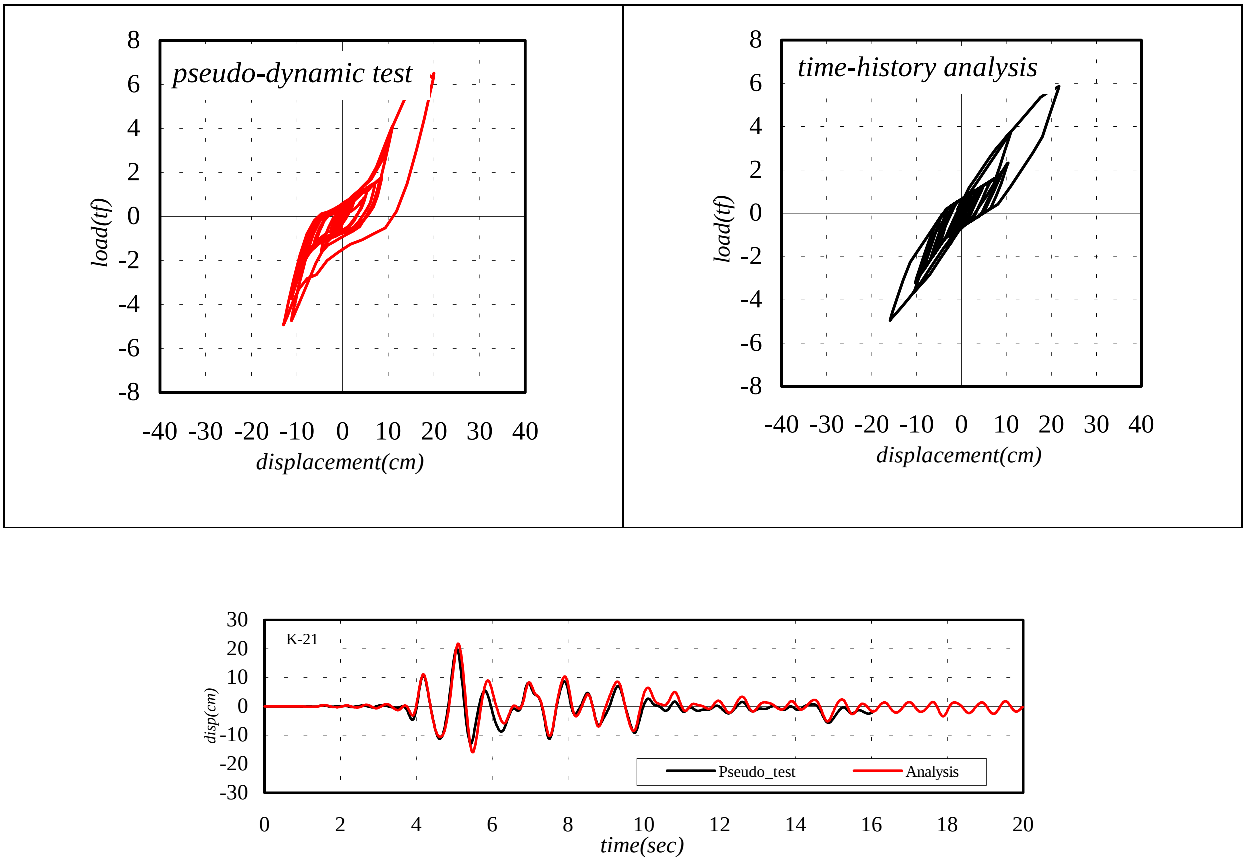

Figure7 Comparison between pseudo-dynamic test and analysis

ESTIMATION OF MAXIMUM RESPONSE USING THE EQUIVALENT LINEARIZATION TECHNIQUE

The estimated valves of maximum response using the equivalent linearization technique are shown in table 3. As the result of cyclic loading test, for equivalent damping factor has gotten constant with increasing displacement, constant valve, 6%, is always applied. In addition to this damping, 2% is added as fraction of critical damping. The calculation of equivalent linearization technique is suitable for structural design for obtaining a good agreement with test result. In this table, the maximum response using property of energy conservation is printed for information. This response is so big compared with test results

Table 3 Comparison of maximum response

	Pseudo-dynamic	*Equivalent*	*Energy conservation*	*Time history*
K-11	13.85	12.25	20.24	12.51
K-21	20.06	-	-	21.73
E-31	5.71	6.76	14.99	6.97
E-32	7.11	9.11	15.74	6.54

CONCLUSIONS

In this paper, presented are the seismic behavior on glulam structure that consists of arched frame through tests and analysis. Conclusions obtained are:

1) Maximum response against earthquake can be predicted by time history analysis using the combination of bilinear and slip model as elasto-plastic force-displacement relationship.

2) Equivalent damping ratio of arched frame with being treated connection type in shoulder part approach constant value, 6%, with increasing displacement.

3) The effectiveness of the equivalent linear analysis was demonstrated using calculations from a single damping ratio.

REFERENCES

Yasumura,M. Suzuki, H(1992): Lateral Loading test on Glued-laminated Arched Frames, Summaries of technical Papers of Annual Meeting Architectural Institute of Japan