AN EVALUATION OF FRICTION COEFFICIENT OF JAPANESE TRADITIONAL WOODEN FOUNDATION

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Abstract

Foundations of traditional Japanese wooden structures consist of wood columns supported by stone footings. The connection between columns and stone foundation can be considered as pinned joints when wood columns are inserted into stone bases. In other case wood columns just rest on stone surface and therefore in case of lateral loads this load is supported by friction force developed by contact between wood and stone. In this research, equivalent friction coefficient of this Japanese traditional wooden foundation is investigated experimentally by means of shaking table tests on scale reduced test specimen. Test specimen is a framed structure with four columns resting on stone bases. Stone bases are fixed to the shaking table. Concrete mortar tiles and two types of stone finishing were used as bases. These types of finishing used for stone were 8 mai bishan (coarse bush hammer) and 10 mai bishan (fine bush hammer). Pulse waves were used as input motion for shaking table tests. Accelerometers were setup at specimen top and on shaking table. It is assumed that while specimen and table move together without sliding both accelerations are same. Then, when both signals start to differ it is considered that sliding started and that acceleration is used to calculate the static friction coefficient. The dynamic friction coefficient is obtained using the average acceleration during sliding. For concrete tile bases 3 runs of shaking table tests were performed and for stones bases five runs for each type were performed. This friction coefficients were used to perform the time history analysis. However, comparison with experiment shows that vibration during sliding are not well reproduced. Therefore, refining of modelling is required.

Keywords: shaking table test; friction coefficient; traditional Japanese wooden structure; time history analysis

1. Introduction

Japanese cultural timber buildings, mainly shrines and temples, use old traditional construction methods; resulting in a flexible structure that can absorb shaking. Elaborated or complex wooden connections permits energy dissipation due to friction behavior in joints. On the other hand, the conventional construction method of wooden structures which is currently the mainstream of detached houses in Japan, inherits some joining methods however, it uses many reinforcing elements such as bracing, bolts and plates, increasing the lateral stiffness of the entire structure to resist the lateral action of vibrations.

In the current Japanese Building Standard Law, the provisions related to wooden construction generally consist of conventional construction methods, and it is not applicable to evaluate the seismic performance of traditional constructions. The reason is that the complex traditional joints are difficult to modelled using conventional structural analysis. In addition, there are subtle differences in traditional construction methods between regions. However, in 2008, the Ministry of Land, Infrastructure, Transport and Tourism stablished a committee for “Design Method and Performance Verification Tests for Traditional Wooden Construction” and began conducting experiments and studies on traditional construction methods.

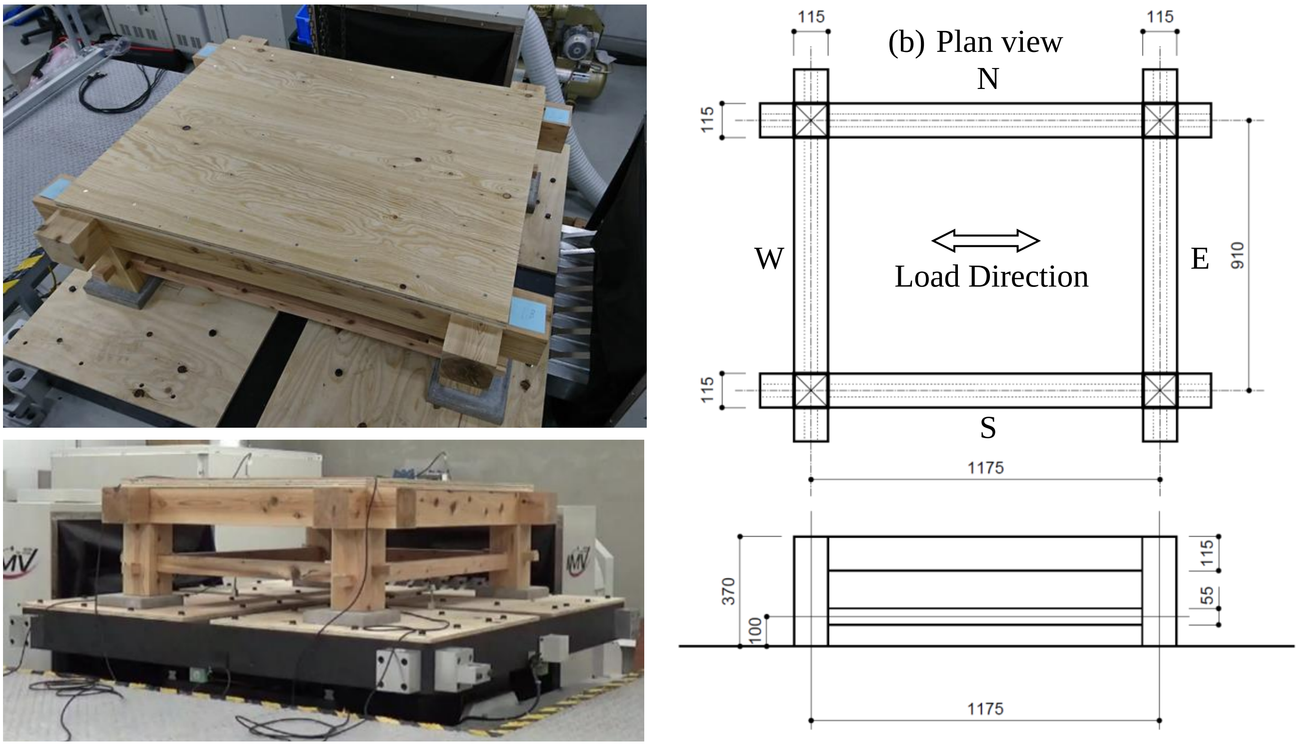
The foundations of many traditional constructions employ a non-tight construction with pillars erected directly on the foundation stone, which is called stone mosaic or cornerstone construction. If the foundation stone has irregularities, a process called lighting is performed to adjust the bottom of the pillar base to the shape of the foundation stone.

Compared to continuous foundations and footings, which are commonly used in conventional construction methods that can be considered as fixed foundations, foundations of traditional wooden construction that are not fixed in the base permits an easy inspection and maintenance of the bottom part of the building. Also, unlike continuous foundation, footing foundation, and pile foundation, there is no construction guidelines for traditional building foundation, and it is believed that it is required to establish a structural calculation procedure.

In this study, sliding behavior of column bases of traditional wooden construction is examined experimentally. Then, the objective of this study is to perform a vibration test using a shaking table. A simple model was built and put on a stone bases and subjected to a series of input motion. Based on test results to establish friction parameters, an analytical model is formulated using a finite element method software. Time history response analysis was performed using the model, and its applicability was verified by comparison with experimental results.

2. Test Specimen

For experimental tests, a simple model was used as the test specimen. Photographs and dimensions of the test specimen is shown in Fig. 1. Test specimen is a framed structure with four columns resting on stone bases. Stone bases are fixed to the shaking table. Concrete mortar tiles and two types of stone finishing were used as bases. These types of finishing used for stone were 8 mai bishan (coarse bush hammer) and 10 mai bishan (fine bush hammer). The typical joint of the test specimen has a structure in which a short tenon is inserted and joined to each frame element. To fix the accelerometer and other equipment on the upper part of the test specimen, a piece of plywood is fixed as a top plate. The direction of vibration is shown in the plan view and corresponds to EW direction.



(a) Photographs

(c) Elevation

Fig. 1 – Test specimen

2.1 Vibration characteristics of the test specimen

To estimate the period or frequency of vibration of the test specimen ambient vibration measurements were carried out. Servo velocity sensor were setup at top of the specimen and on shaking table test. Then, from these measurements the correspondent transfer function is obtained to identify the predominant frequency of vibration of the test specimen. Transfer functions between shaking table and points on top of test specimen are shown if Fig. 2. Then it can be concluded that the predominant frequency of the test specimen is 34 Hz.

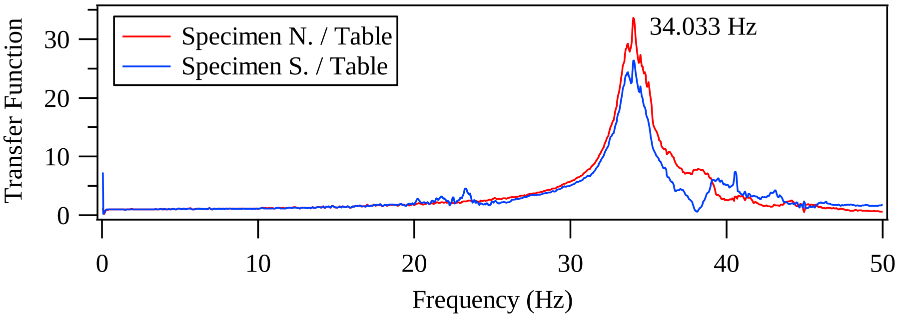


Fig. 2 – Predominant frequency of test specimen

3. Shaking Table Test

To estimate the friction coefficients for the different type of base foundations pulse wave was employed as input motion. A typical result of the shaking table test for pulse wave is shown in Fig. 3. Accelerations of shaking table measured by accelerometers located at north side (Table N) and south side (Table S) are plotted in yellow and green lines respectively. Accelerations of the specimen corresponds to the top part and were measured by accelerometers located at north side (Specimen N) and south side (Specimen S) that are plotted in red and blue lines respectively. When specimen and shaking table move together without sliding all signals follow same path. When sliding starts the signals from specimen start to follow different path. Then the acceleration that corresponds to the initial sliding is employed to estimate the equivalent static or low velocity friction coefficient. It can be also observed that sliding occurs in a lapse from the initial sliding until acceleration falls. Then the average acceleration during this lapse of sliding is used to estimate the high velocity friction coefficient.

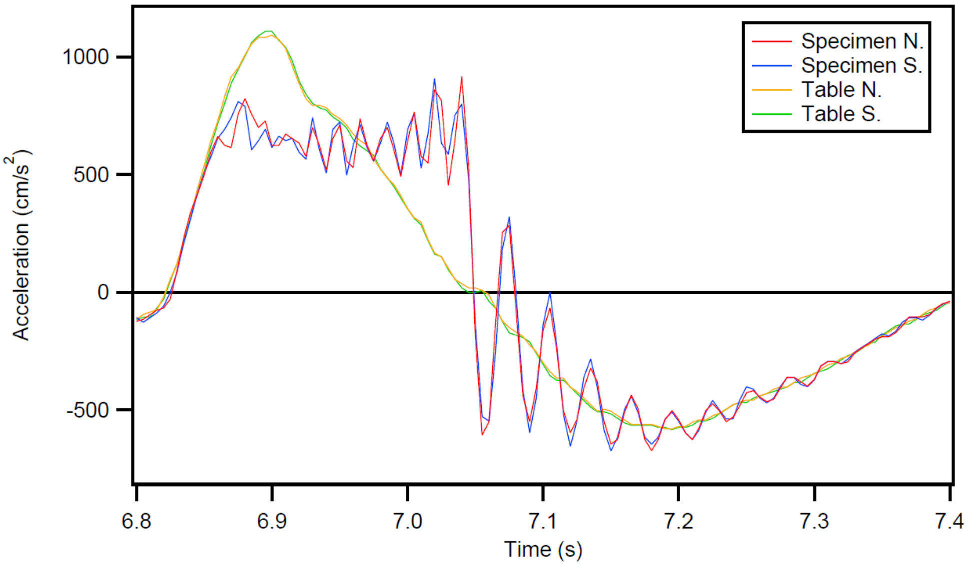


Fig. 3 – Typical results for shaking table test using pulse wave as input

Acceleration results for concrete tile bases are summarized in Table 1. In this case 3 runs of the shaking table test were performed.

Table 1 – Test results for concrete tile base

Run	**Sliding Acc. (cm/s^2)**			**Average Acc. (cm/s^2)**		
	N	S	Av.	N	S	Av.
Run 1	662.55	654.26	658.41	686.22	703.09	694.65
Run 2	709.88	722.61	716.25	700.41	678.67	689.54
Run 3	785.59	722.61	754.10	643.62	649.38	646.50
Average			709.58			676.90

Acceleration results for stone bases are summarized in Table 2 and Table 3. In this case 5 runs of the shaking table test were performed for each type of finishing. In these results the initial sliding acceleration and the time when this sliding occurs are presented.

Table 2 – Test results for stone base 8 mai bishan

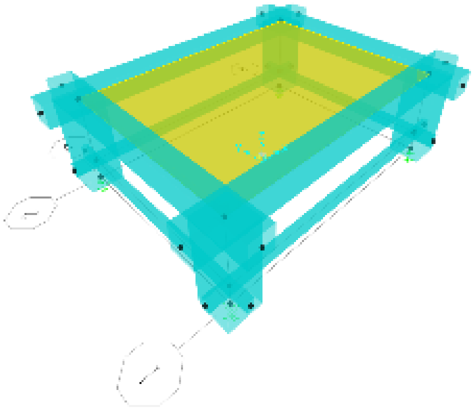
Run	**Accelerometer N**		**Accelerometer S**	
	Time (s)	Acc. (cm/s^2)	Time (s)	Acc. (cm/s^2)
Run 1	2.7890	804.76	2.7935	851.14
Run 2	2.5180	882.85	2.5155	836.25
Run 3	2.8005	886.99	2.8030	916.32
Run 4	2.8375	557.02	2.8470	631.67
Run 5	2.5260	856.35	2.5280	864.45

Table 3 – Test results for stone base 10 mai bishan

Run	**Accelerometer N**		**Accelerometer S**	
	Time (s)	Acc. (cm/s^2)	Time (s)	Acc. (cm/s^2)
Run 1	2.5490	660.54	2.5445	665.73
Run 2	2.9065	605.64	2.9060	617.27
Run 3	3.2765	571.92	3.2765	571.37
Run 4	3.1950	565.53	3.1960	609.58
Run 5	3.7895	536.78	3.7880	557.46

4. Friction support modelling

Analytical model was constructed using the software SAP2000. The upper structure is a wood frame structure with a wooden roof. The wood material properties correspond to Akita cedar. The friction support is modelled by adapting a link element that represent a friction isolator. Characteristic of the model and support properties are shown in Fig. 4. The friction coefficients correspond to those obtained from shaking table tests. These coefficients are summarized in Table 4. The net pendulum radius is set up as infinite in such a way that the friction surface results in a plane surface.



Friction Isolator Property

Stiffness: 4.8 kN/cm

Friction Coefficient:

μ_slow

μ_fast

Rate Parameter: r = 0.5

Net Pendulum Radius: ∞

Fig. 4 – Bar macro-element

Table 4 – Friction coefficients

Type of friction	**Concrete tile base**	**8-mai Bishan**	**10-mai Bishan**
μ_{slow}	0.690	0.869	0.608
μ_{fast}	0.552	0.798	0.565

Fig. 5 shows the analysis results compared with the experimental results in the case of concrete tile base when pulse input is used. The general response is reasonably acceptable however, during sliding no vibration is observed in analysis results. Also, the lapse of sliding is shorter for analysis results.

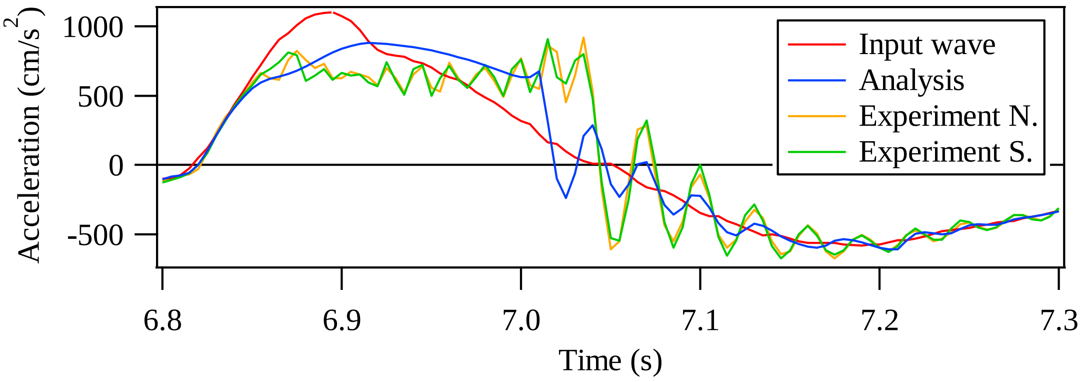


Fig. 5 – Acceleration response (concrete base, pulse input)

Results for 8-mai Bishan stone base are shown in Fig. 6 and for 10-mai Bishan are shown in Figure 7. In these both cases can be also observed that the sliding lapse is shorter for analysis results in comparison with experimental results. Also, no vibration during sliding is observed in analysis results.

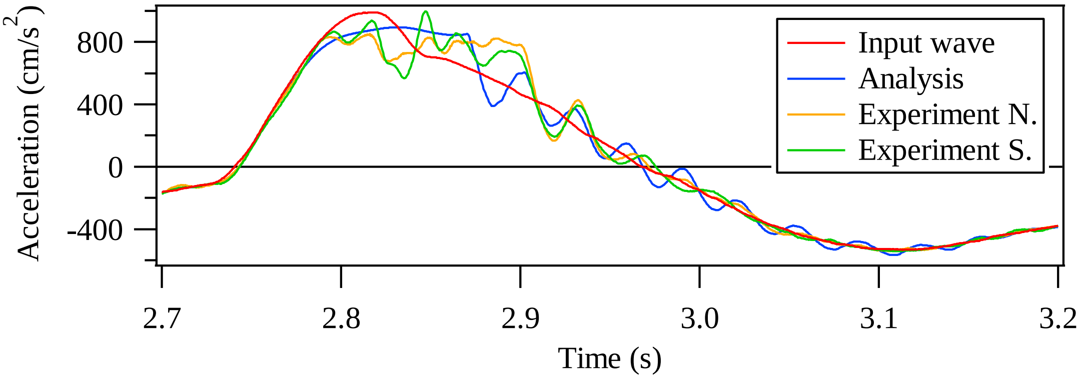


Fig. 6 – Acceleration response (8-mai Bishan stone base, pulse input)

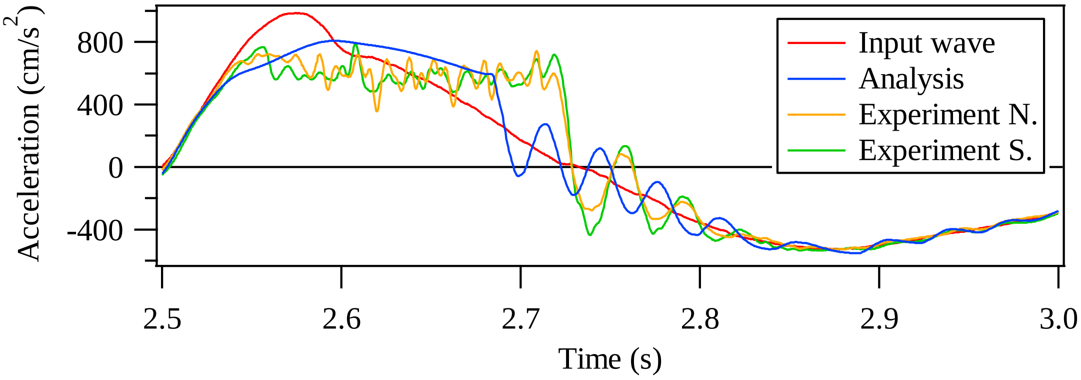


Fig. 7 – Acceleration response (10-mai Bishan stone base, pulse input)

Input motion recorded at Tsukidate during the 2011 East Japan great earthquake was used to investigate the seismic response of the test specimen. Portion of the analytical and experimental results are shown in Fig. 8 and Fig. 9 for 8-mai Bishan and 10-mai Bishan respectively. Similarly that in case of pulse input no vibration is observed during sliding in analysis case.

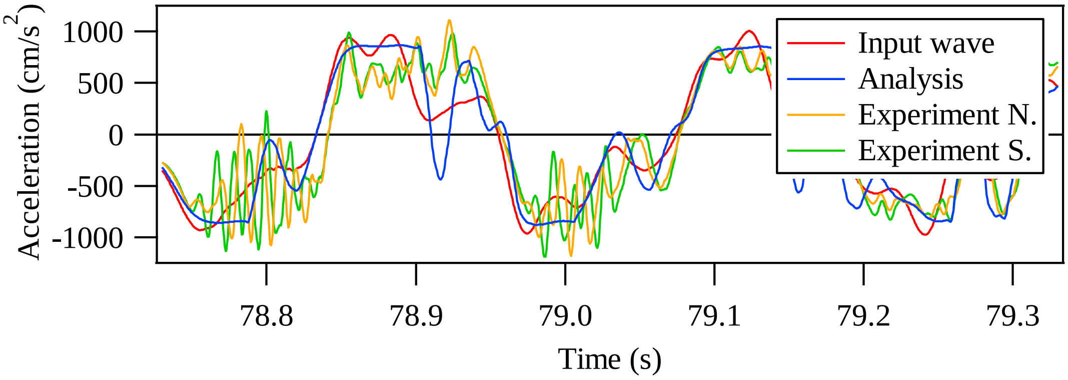


Fig. 8 – Acceleration response (8-mai Bishan stone base, earthquake input)

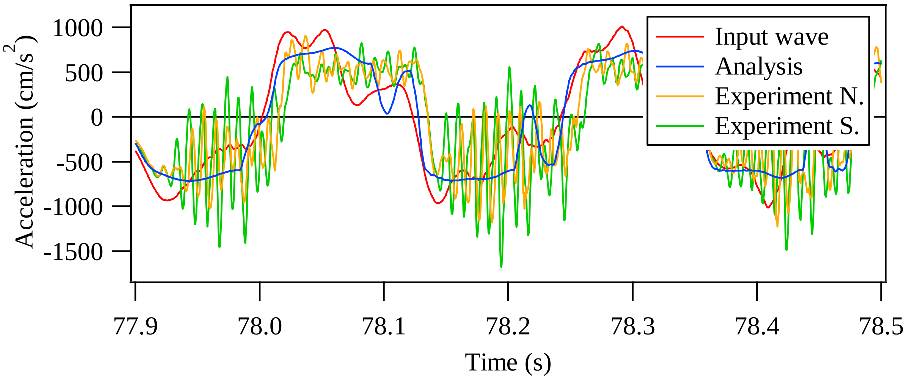


Fig. 9 – Acceleration response (10-mai Bishan stone base, earthquake input)

5. Conclusion

Friction behaviour of stone foundation in traditional Japanese wooden structure was study by means of a series of a shaking table tests. From these tests, friction coefficients for low velocity (static friction coefficient) and for high velocity (dynamic friction coefficient) were obtained.

Based on shaking table test results, analytical model was constructed using link elements of SAP2000 software to simulate the friction support behaviour. Time history response analysis was performed and its applicability to simulate the general response was verified. However, vibration during sliding is not well reproduced and therefore, future adjustment of the model is required.

6. References

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