A Study on Vibration Performances of Japanese Traditional Timber Buildings based on Microtremor Measurements

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ABSTRACT :

It aims at expressing the vibration performances of the Japanese traditional timber building based on the microtremor measurements.
There are many traditional timber dwelling houses in Japan. These houses has a frontage of about 3 - 5 m and with a length of about 15 m. Therefore, these houses are more soft stiffness than the common new houses of which the natural frequencies are about 6.0 Hz. These houses have lower seismic performances than new one. The residents and the local governments need to grasp the vibration performances of the Japanese traditional timber building and to retrofit these houses for leaving to posterity.
Our research group conducted the field survey with a microtremor measurement for Japanese traditional timber dwelling houses on a part of the Tokai district. The district is afraid of a damage by an expected the Tokai earthquake or the To-Nankai earthquake. We are selected some area which have cooperate with us to survey. These area have many traditional buildings built about a hundred years ago. A natural frequencies of these houses are about 3 - 4 Hz. And we recommend retrofitting these houses.
And our research group executed a microtremor measurement for a seismic retrofitting of the Japanese traditional timber dwelling houses. As a result of these investigation and it was grasped that the natural frequency after seismic retrofit construction was higher than before. For example and the natural frequency 3.22 Hz become 4.68 Hz after seismic retrofit construction. And we were able to propose effective seismic retrofit based on a microtremor measurement of the timber structure.

KEYWORDS: Vibration Performance, Microtremor Measurement, Traditional Timber Building

1. INTRODUCTION

The location of our research group is in Mino City, Gifu Prefecture, JAPAN. This city has many Japanese traditional timber dwelling houses. This city is on a part of Tokai district, which is afraid of damage by an expected Tokai earthquake or To-Nankai earthquake in recent years. In the Mino city, our research group conducted a field survey with a microtremor measurement for these houses, and evaluated its vibration characteristics. In Japan, House repair of seismic is watched by public with interest. To understand condition of structure make better for repair of seismic. So This study aims Vibration Performances of Japanese Traditional Timber Buildings based on Microtremor Measurements he one of early diagnosis.

In Japan, There are not seismic diagnosis and a legal system of the seismic retrofitting at the wooden building. Therefore, this purpose is to implementing seismic diagnosis and seismic retrofitting at the wooden houses which used microtremor measurement and confirming the effect of the microtremor measurement.

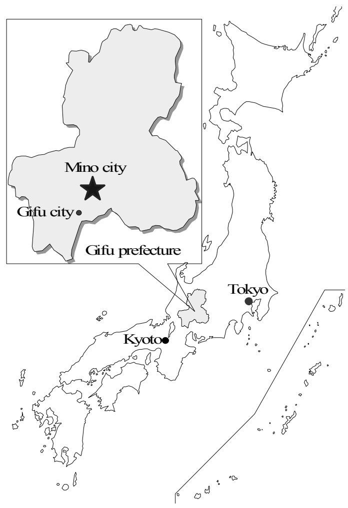


Figure 1
Location of Mino City

2. METHOD OF MEASURING MICROTREMOR

Our research group has measured timber structures by a portable vibration measurement machine of SPC-51 with the six velocity-meters of VSE-15D of the servo-mechanism. The portable vibration measurement machine of SPC-51, the six velocity-meters of VSE-15D and a measuring microtremor scene is shown figure 2. We set up the six sensors on the first and second floors at the north-south and east-west directions.
The full range of measuring is 100 [mm/sec], and the sampling frequency is a Rene 100 [Hz}. we compute the natural frequency and the damping ratio by calculation with a fast Fourier transform with the steady 1024 points data which we have got at measuring. The second floor spectrum was divided by the first floor spectrum to consider ground vibration. In the fast Fourier transform, we use ten times smoothing. We calculated damping ratio by a way of a root two.

Figure 2 Portable Vibration Measurement Machine, Velocity-meters and Measuring Microtremor Scene

3.OUTLINE OF RESERCH

We research two type Japanese timber houses, traditional timber houses and lately houses. The investigation as follows. Vibration characteristics on microtremor measurements and Quakeproof evaluation.
Evaluation by the effective wall length. The evaluation is most famous in Japan. The timber structures were checked by a plan refering to investigations of the structure's background.

3.2 lately houses

We research lately houses which designed by same designing group. So method of construction resembles. The weight distinction heavy or light of roof and wall. Table 1 shows the things.

Table1 Self-weight

	roof	wall	Self-weight [kN/m2(floor area)]
light structure	light	light	3.2
	light	weighty	3.6
weighty structure	weighty	light	3.6
	weighty	weighty	4.6
very weighty structure	very weighty	very weighty	6.1

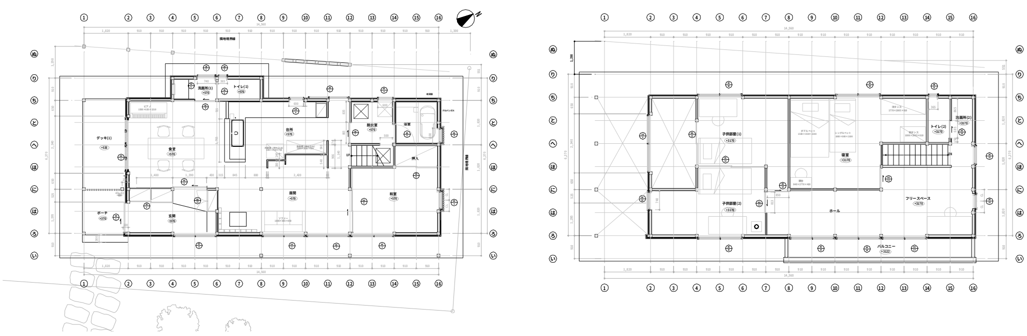


Figure 3 the Lately House (S-house) Plan

Figure 4 Lately House (S-house) Photo

Table 2 Outline of Lately Houses

		1st story height	1st floor area	dead load			natural frequency
		cm	m2	roof	walls	kg	Hz
Lately	S house	260.0	77.7	metal sheet roofing	siding	25.85	7.520
		260.0	77.7	metal sheet roofing	siding	25.85	10.245
	NM house	293.0	57.3	metal sheet roofing	mortar finish on metal lathing	21.44	11.230
		293.0	57.3	metal sheet roofing	mortar finish on metal lathing	21.44	10.050
	B house	258.2	55.8	metal sheet roofing	siding	18.58	6.684
		258.2	55.8	metal sheet roofing	siding	18.58	13.574
	C house	260.0	53.0	metal sheet roofing	siding	17.62	7.128
		260.0	53.0	metal sheet roofing	siding	17.62	10.546
	M house	240.0	84.9	metal sheet roofing	siding	28.24	8.780
		240.0	84.9	metal sheet roofing	siding	28.24	11.320
	NG house	234.6	90.2	metal sheet roofing	siding	30.01	9.960
		234.6	90.2	metal sheet roofing	siding	30.01	7.617

3.1 Traditional timber houses (In The investigation that appointed an area.)

We research in conservation district of traditional timber houses. So method of construction resembles; tiled roof and mud wall. Story height is about 270cm. It supposes that the structures are 362kN/m2. This is standard weight as Japanese Traditional timber houses.

Figure 5 Japanese Traditional Timber Buildings

Table 3 Outline of Traditional Houses

		1st story height	1st floor area	dead load			natural frequency
		cm	m2	roof	walls	kg	Hz
Traditional	S-house	270.0	241.0	tiled roof (Kawara)	mud wall	51.46	3.223
		270.0	241.0	tiled roof (Kawara)	mud wall	51.46	3.906
	F-house	270.0	132.1	tiled roof (Kawara)	mud wall	43.67	4.492
		270.0	132.1	tiled roof (Kawara)	mud wall	43.67	3.222
	O-house	254.9	297.6	tiled roof (Kawara)	mud wall	72.62	2.246
		254.9	297.6	tiled roof (Kawara)	mud wall	72.62	4.102
	KK house	243.0	137.8	tiled roof (Kawara)	mud wall	42.47	2.539
		243.0	137.8	tiled roof (Kawara)	mud wall	42.47	4.883
	N house	268.0	115.7	tiled roof (Kawara)	mud wall	22.71	2.246
		268.0	115.7	tiled roof (Kawara)	mud wall	22.71	4.980
	M house	340.0	400.9	tiled roof (Kawara)	mud wall	95.23	2.243
		340.0	400.9	tiled roof (Kawara)	mud wall	95.23	4.101
	KT house	221.0	282.2	tiled roof (Kawara)	mud wall	116.68	2.832
		221.0	282.2	tiled roof (Kawara)	mud wall	116.68	4.199
	I house	221.5	209.9	tiled roof (Kawara)	mud wall	45.75	3.506
		221.5	209.9	tiled roof (Kawara)	mud wall	45.75	5.503

5. QUAKEPROOF EVALUATION BY VIBRATION PERFORMANCE

By vibration performances, quakeproof evaluation is estimate. In this session, the quakeproof evaluation is rate of bearing wall. Figure0 shows the relation between rare of bearing wall and the natural frequencies. Rate of bearing wall are estimated by this approximate equation as follow

The whole; R^2=0.8917
Rare of bearing wall by vibration performance=3.4685 x natural frequencies + 2.5734

The traditional timber houses; R^2=0.5755
Rare of bearing wall by vibration performance=2.4066 x natural frequencies + 2.7426

The lately houses; R^2=0.6016
Rare of bearing wall by vibration performance=2.5591 x natural frequencies + 4.6262

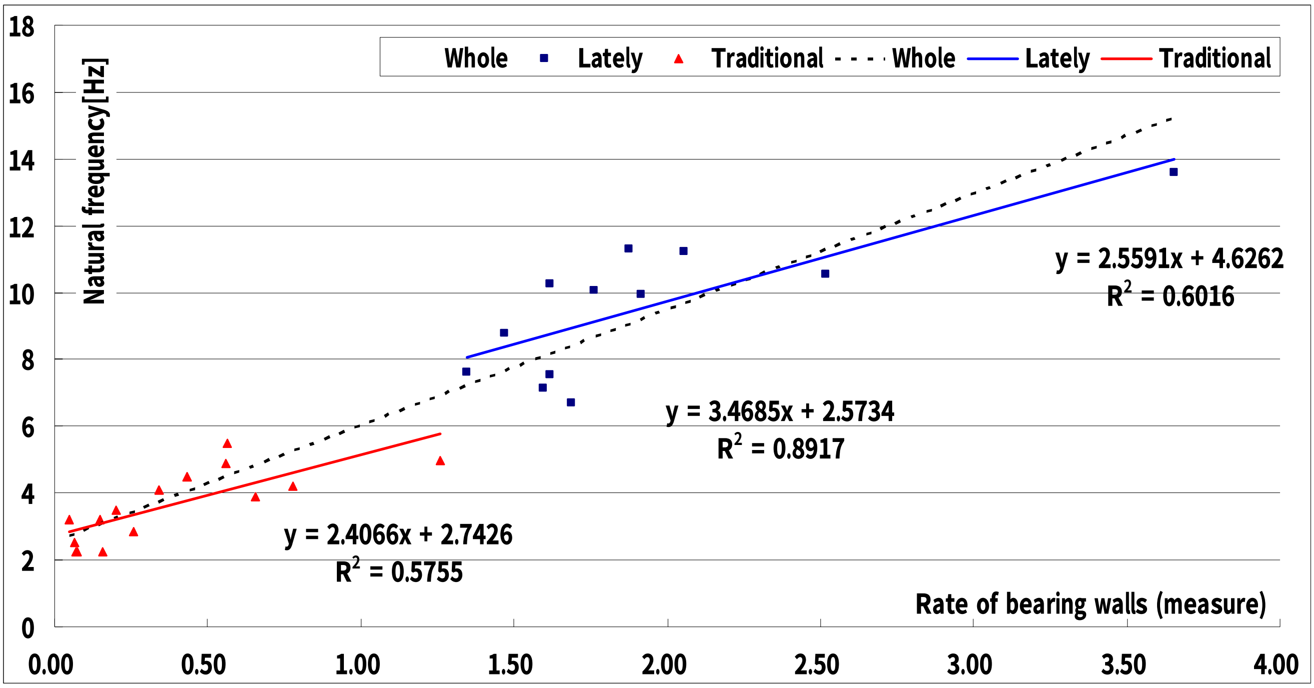


Figure6 Relation Between Rare of Bearing Wall and the Natural Frequencies.

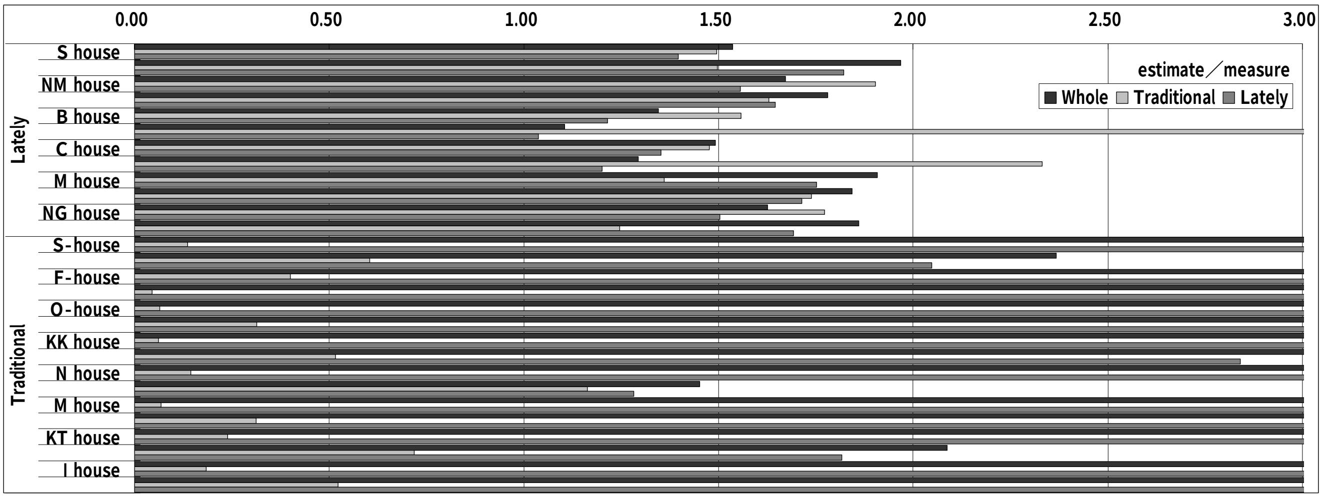


Figure 7 Relation Between Rare of Bearing Wall and the Natural Frequencies.

Table 4 Compare the Estimated Value with Measuring Value.

Structure		Rate of bearing walls (measure)	the whole		Traditional		Lately	
			estimate	estimate／measure	estimate	estimate／measure	estimate	estimate／measure
Lately	S house	1.62	2.482492	1.54	2.295732	1.49	2.088052	1.40
		1.62	3.1830895	1.97	2.9472795	1.50	2.7286995	1.82
	NM house	2.05	3.436333	1.67	3.182793	1.90	2.960273	1.56
		1.76	3.132955	1.78	2.900655	1.63	2.682855	1.65
	B house	1.69	2.2675564	1.35	2.0958444	1.56	1.8915084	1.21
		3.65	4.0389754	1.11	3.7432434	3.39	3.5113474	1.04
	C house	1.60	2.3817088	1.49	2.2020048	1.48	1.9958928	1.35
		2.52	3.2604766	1.29	3.0192486	2.33	2.7994646	1.20
	M house	1.47	2.806438	1.91	2.596998	1.36	2.384278	1.75
		1.88	3.459472	1.84	3.204312	1.74	2.981432	1.71
	NG house	1.91	3.109816	1.63	2.879136	1.77	2.661696	1.50
		1.35	2.5074307	1.86	2.3189247	1.25	2.1108567	1.69
Traditional	S-house	0.15	1.3777333	9.37	1.2683193	0.14	1.0778273	7.97
		0.66	1.5533326	2.37	1.4316246	0.60	1.2384006	2.05
	F-house	0.43	1.7039932	3.93	1.5717372	0.40	1.3761692	3.44
		0.05	1.3774762	28.59	1.2680802	0.04	1.0775922	24.29
	O-house	0.07	1.1265466	16.09	1.0347186	0.06	0.8481346	13.19
		0.34	1.6037242	4.72	1.4784882	0.31	1.2844802	4.10
	KK house	0.07	1.2018769	17.94	1.1047749	0.06	0.9170189	14.89
		0.56	1.8045193	3.22	1.6652253	0.52	1.4680933	2.84
	N house	0.16	1.1265466	7.13	1.0347186	0.15	0.8481346	5.84
		1.26	1.829458	1.45	1.688418	1.16	1.490898	1.28
	M house	0.07	1.1257753	15.21	1.0340013	0.07	0.8474293	12.47
		0.34	1.6034671	4.73	1.4782491	0.31	1.2842451	4.11
	KT house	0.26	1.2772072	4.91	1.1748312	0.24	0.9859032	4.12
		0.78	1.6286629	2.09	1.5016809	0.72	1.3072849	1.82
	I house	0.20	1.4504926	7.25	1.3359846	0.18	1.1443606	6.21
		0.57	1.9639213	3.47	1.8134673	0.52	1.6138553	3.09
AVERAGE		1.04	2.14	5.43	1.97	0.96	1.77	4.63
STDEVA		0.91	0.86	6.52	0.80	0.85	0.79	5.42
MAX		3.65	4.04	28.59	3.74	3.39	3.51	24.29
MIN		0.05	1.13	1.11	1.03	0.04	0.85	1.04
AVERAGE					1.37	0.34	2.57	1.49
STDEVA					0.25	0.30	0.48	0.25
MAX					1.81	1.16	3.51	1.82
MIN					1.03	0.04	1.89	1.04

In the whole, the difference between the estimated value with the measuring value are 1.11~28.59. The average is 5.43. The standard deviation is 6.52

In the traditional houses, the difference between the estimated value with the measuring value are 0.04~1.16. The average is 0.34. The standard deviation is 0.3.

In the lately houses, the difference between the estimated value with the measuring value are 1.04~1.82. The average is 1.49. The standard deviation is 0.25.

4. COMPARING STIFFNESS BY VIBRATION PERFIRMANCE OR QUAKEPROOF EVALUATION

Stiffness is computed by vibration performance or quakeproof evaluation. Kmt is stiffness by vibration performance. Kwall is stiffness by quakeproof evaluation.

$$Kmt[kgf/cm] = 4\pi^2 \cdot m[kg] \cdot fm^2[Hz] \tag{4.1}$$

$$K_{wall}[kgf/cm] = \frac{\text{length of bearing walls}[cm] \times 200[kgf]/100[cm]}{\text{story height }[cm]/150[rad.]} \tag{4.2}$$

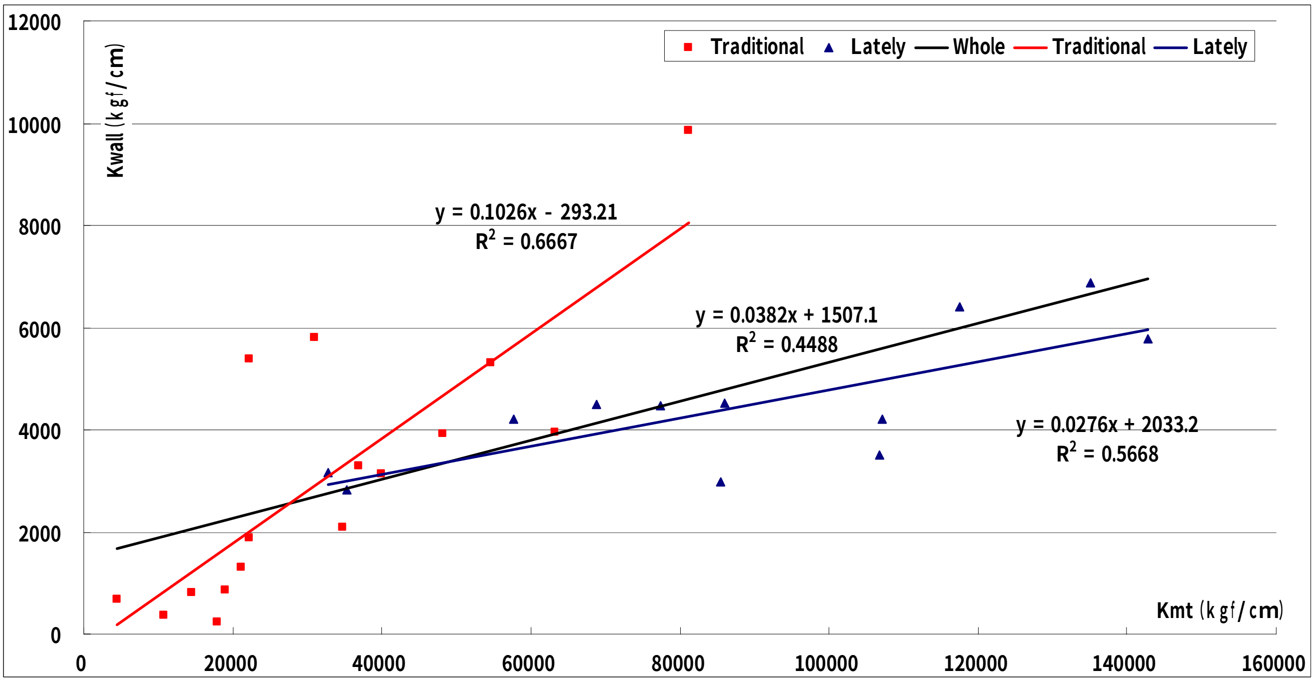


Figure 8 Comparing Stiffness

5.QUAKEPROOF EVALUATION BY VIBRATION PERFIRMANCE 2

By vibration performances, quakeproof evaluation is estimate. In this session, the quakeproof evaluation is length of bearing wall. Based 4, quakeproof evaluation is estimate.

$$K_{wall} = 0.0382 \times K_{MT} + 1507.1 \tag{5.1}$$

Substitute 4.1 and 4.2 for 5.1.

In the whole

$$\text{length of bearing walls}_{mt}[cm] = \frac{(0.0382 \times 4\pi^2 \times m[kg] \times fm^2[Hz] - 1507.1)(\text{story height }[cm])}{150[rad] \times 200[kg]/100[cm]} \tag{5.2}$$

Substitute approximate equation for 5.1.

In the Lately houses

$$\text{length of bearing walls}_{mt}[cm] = \frac{(0.0276 \times 4\pi^2 \times m[kg] \times fm^2[Hz] - 2033.2)(\text{story height}[cm])}{150[rad] \times 200[kg]/100[cm]} \tag{5.3}$$

In the traditional houses

$$\text{length of bearing walls}_{mt}[cm] = \frac{(0.1026 \times 4\pi^2 \times m[kg] \times fm^2[Hz] + 293.21)(\text{story height}[cm])}{150[rad] \times 200[kg]/100[cm]} \tag{5.4}$$

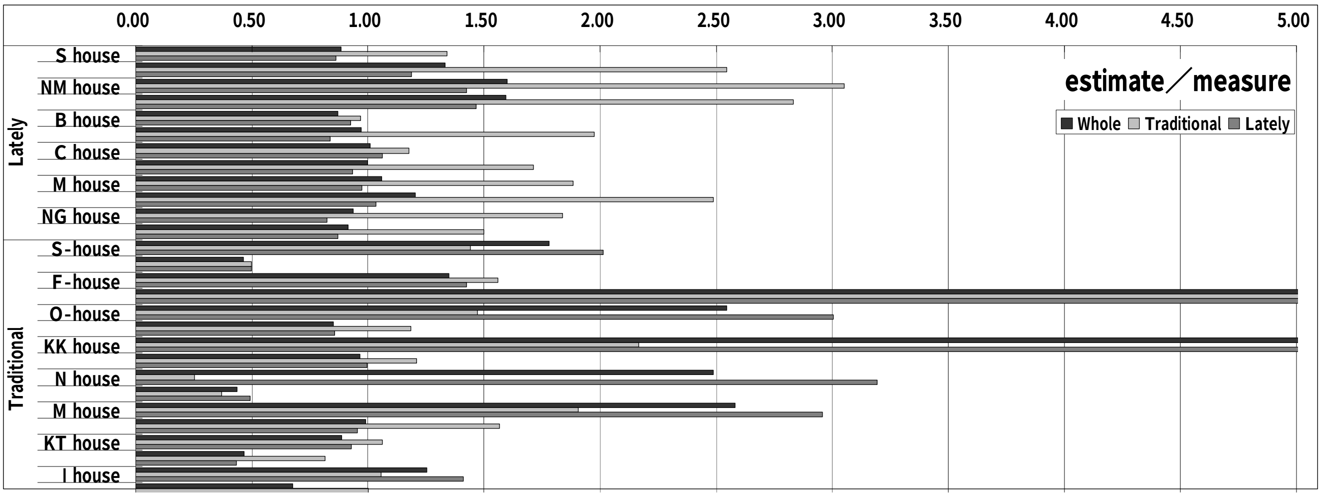


Figure9 Estimate / Measure

In the whole, the difference between the estimated value with the measuring value are 0.44~9.39. The average is 1.63. The standard deviation is 1.78.

In the traditional houses, the difference between the estimated value with the measuring value are 0.25~6.11. The average is 1.51. The standard deviation is 1.46.

In the lately houses, the difference between the estimated value with the measuring value are 0.82~1.47. The average is 1.03. The standard deviation is 0.22.

Table 5 Compare the Estimated Value with Measuring Value.

Structure		Length of bearing walls (measure)	All		Traditional/Historic		newly-built	
			estimate	estimate／measure	estimate	estimate／measure	estimate	estimate／measure
Lately	S house	3640.00	3216.57	0.88	4877.01	1.34	3142.41	0.86
		3642.50	4851.98	1.33	9269.48	2.54	4324.01	1.19
	NM house	3411.00	5453.82	1.60	10408.45	3.05	4862.73	1.43
		2923.00	4660.99	1.59	8279.00	2.83	4289.89	1.47
	B house	2730.00	2374.53	0.87	2641.45	0.97	2528.36	0.93
		5915.00	5740.64	0.97	11682.35	1.98	4960.41	0.84
	C house	2452.20	2476.37	1.01	2888.93	1.18	2607.61	1.06
		3867.50	3867.73	1.00	6625.93	1.71	3612.88	0.93
	M house	3619.00	3831.80	1.06	6818.82	1.88	3523.96	0.97
		4620.00	5571.02	1.21	11490.13	2.49	4780.57	1.03
	NG house	5005.00	4689.79	0.94	9201.41	1.84	4126.88	0.82
		3526.25	3232.12	0.92	5286.31	1.50	3073.69	0.87
Traditional	S-house	1168.80	2081.93	1.78	1684.82	1.44	2354.09	2.01
		5218.70	2422.02	0.46	2598.25	0.50	2599.81	0.50
	F-house	1890.00	2552.45	1.35	2948.57	1.56	2694.05	1.43
		210.00	1971.74	9.39	1388.87	6.61	2274.48	10.83
	O-house	687.48	1749.94	2.55	1011.64	1.47	2066.70	3.01
		3339.18	2846.29	0.85	3956.29	1.18	2858.82	0.86
	KK house	304.76	1555.17	5.10	660.70	2.17	1888.51	6.20
		2547.28	2457.66	0.96	3084.66	1.21	2540.57	1.00
	N house	603.31	1500.69	2.49	152.62	0.25	1927.84	3.20
		4811.22	2105.16	0.44	1776.16	0.37	2364.58	0.49
	M house	978.88	2526.89	2.58	1867.01	1.91	2895.92	2.96
		4484.31	4445.35	0.99	7019.73	1.57	4282.03	0.95
	KT house	2421.10	2149.82	0.89	2576.19	1.06	2248.91	0.93
		7263.31	3395.65	0.47	5922.33	0.82	3149.04	0.43
	I house	1385.08	1738.88	1.26	1465.23	1.06	1953.57	1.41
		3919.77	2655.31	0.68	3926.64	1.00	2615.70	0.67
AVERAGE		3092.31	3147.23	1.63	4696.75	1.70	3091.00	1.76
STDEVA		1776.26	1293.05	1.78	3430.86	1.19	953.78	2.13
MAX		7263.31	5740.64	9.39	11682.35	6.61	4960.41	10.83
MIN		210.00	1500.69	0.44	152.62	0.25	1888.51	0.43
AVERAGE					2627.48	1.51	3819.45	1.03
STDEVA					1854.68	1.46	861.52	0.22
MAX					7019.73	6.61	4960.41	1.47
MIN					152.62	0.25	2528.36	0.82

7. ACHIEVEMENT

The approximate equations are shown as flow.

The whole;
Rare of bearing wall by vibration performance=3.4685 x natural frequencies + 2.5734 (R^2=0.8917)

$$\text{length of bearing walls}_{mt}[\text{cm}] = \frac{(0.0382\times 4\pi^2\times m[\text{kg}]\times fm^2[\text{Hz}]-1507.1)(\text{story height}[\text{cm}])}{150[\text{rad}]\times 200[\text{kg}]/100[\text{cm}]}$$

The traditional timber houses;
Rare of bearing wall by vibration performance=2.4066 x natural frequencies + 2.7426 (R^2=0.5755)

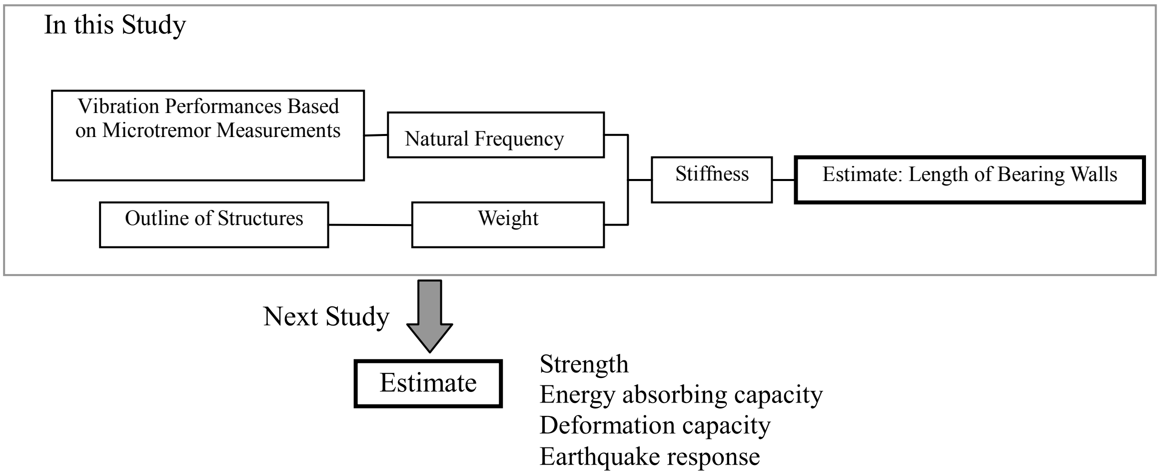
$$\text{length of bearing walls}_{mt}[\text{cm}] = \frac{(0.0276\times 4\pi^2\times m[\text{kg}]\times fm^2[\text{Hz}]-2033.2)(\text{story height}[\text{cm}])}{150[\text{rad}]\times 200[\text{kg}]/100[\text{cm}]}$$

The lately houses;
Rare of bearing wall by vibration performance=2.5591 x natural frequencies + 4.6262 (R^2=0.6016)

$$\text{length of bearing walls}_{mt}[\text{cm}] = \frac{(0.1026\times 4\pi^2\times m[\text{kg}]\times fm^2[\text{Hz}]+293.21)(\text{story height}[\text{cm}])}{150[\text{rad}]\times 200[\text{kg}]/100[\text{cm}]}$$

8. CONCLUSION

By vibration performance, quakeproof evaluation is estimate. There are 2ways. From now on, with this way quakeproof evaluation will be more accurate.
In addition to that vibration performance tried compare other quakeproof evaluation.



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