On strain of wooden houses measured by strain meter and criterion for earthquake-proof.

By

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Abstract.

This article is to descrive how and what sort of strain and vibration come to pass when static force be given to wooden house and also to survey the state of proper vibration in order to study on relation between them and to establish the criterion for earthquake-proof of wooden houses.

Principal results obtained are as follows:

(1) There exists relation between strain Δx and ratio of moment of force k as follows:

$$k = c(\Delta x)^a$$

(2) The close relation exists between c and criterion for earthquake-proof. That is, the bigger the value of c, the higher grade of criterion for earthquake-proof.
(3) The close relation exists between period T and grade of criterion. That is, the smaller the value of T, the higher grade of criterion.

(i) In A-grade of criterion the value of T is less than 0.3 sec.

(ii) In B-grade it is between 0.3 to 0.45 sec.

(iii) In C-grade it is more than 0.45 sec.

(4) The smaller the value of damping ratio v, the higher grade of criterion. And there exists between c, T and v as follows:

$$c = 77.0 \times 0.427^T$$

$$c^{1-0.957} \times v^{0.957} = 1.2$$

Value of a seems to have no directly relation to the criterion but the term of solid friction ρ. That is, the bigger the value of ρ, the bigger the value of a.

1. Introduction.

There are various number of damages caused by destructive earthquake.

Among them, the damage on wooden house is the greatest for human life in Japan. Therefor we must contribute and make our best effort to minimize this kind of damage by building the earthquake-proof houses. But under present ecconomical situation it is not easy task to realize. There is no other proper way, than giving the durable strength on present house. If we will try to give them durable strength, first of all, we must know how the present houses are durable, otherwise we can't plan the way of scientifical improvement.

At present, the criterion for earthquake-proof on wooden house is already published by Prof. *Y.* Yokoo of this reseach institute and put into effect in everyquarter. In Kyoto prefecture, the criterion has also been put into practise by the hand of protective disaster section of architectural depertment since 1949, and these houses are classifed into 4 grades A, B, C and D.

As a whole grade A is durable for priminary degree of seismicity but the rest of grades are less durable in due course.

We picked up several model houses from each grade, already designated by authority in this prefecture and surveyed the strain variation, which are accompanied with variation of horizontal force, state of vibration, vibrating period and damping ratio etc.

2. Measuring instruments and method.

Instrument used for measuring strain is changing flux type strain meter as shown in Fig. 1. It is attached to the edge of wire which is fixed obliquely on both beam and post, and the distance, between junction of beam and post and the points where wire is fixed, is 130 cm respectively as shown in Fig. 2. Electromotiv force accompanied with the variation of strain is to be recorded by the galvanometer on the revolving bromide.

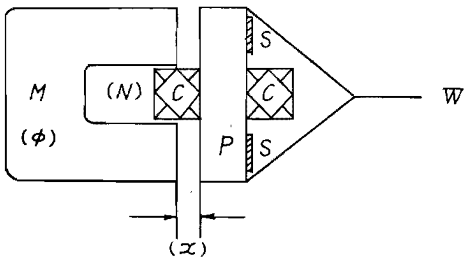

Fig. 1. Illustration of the Strain meter.
M Magnet, C : Coil, P : iron core
S : plate-spring, W : Wire

Incase

ϕ = total flux of magnet

N= turn number of coil loops

x = gap

electromotive force E induced in coil to be formed following formula:

$$E=\frac{\phi N}{x}\frac{dx}{dt}\times 10^{-8} \text{ volt}$$

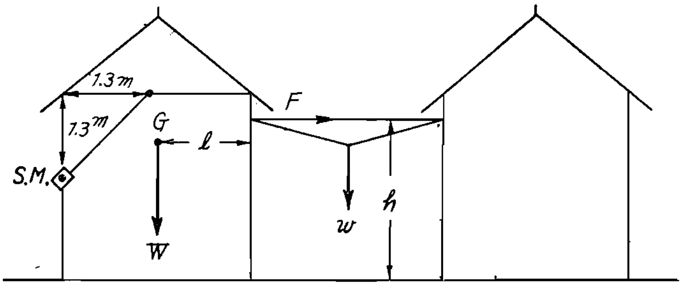

Fig. 2. Illustration of measuring method.

Therefore if all constants of ϕ, N, x and galvanometer are clearly known, the strain value Δx will come into being by amplitude and period on the recording paper.

Values of instrumental constant shown as in Table 1. As for the deformation

total flex of magnet	ϕ = 3.74×10^{1} maxwell
turn number of coil toops	N = 3×10^{3} turn
resistance of coil	R_c= 79.0Ω
gap	x = 1.0 cm
sensibility of galvanometer (current)	S_c = 1.49×10^{-7}amp/mm
〃 (voltage)	S_v = 1.19×10^{-5} volt/mm
resistance of galvanometer	γ_g = 80.0Ω
proper period of galvanometer	T_g= 2.5×10^{-1} sec
decrement of galvanometer	μ_1^2 = 0

Table 1.

on houses, it is provided wire streched between the house to be surveyed and another nearby house with the weight hanging down in the center of the wire and give the strain on both houses. And then suddenly weight is taken off when houses bigin to vibrate, gradually decreasing its vibrating amplitude and restored to the state of halt.

The way to know horizontal force is to know the tension of the wire by the weight and length of wire from the point of horizontal force applied to the point where the weight hung and height of wire from the ground and extent of weight droped.

3. Result of measurement.

The houses which were measured, are as follows.

(1)	#C class house of Kyoto public Suzaku high school before it's improving operation	1st floor
(2)	#D class house of the same as above	1st floor
(3)	the same as above	2nd floor
(1′)	#C class house of the same as above after the improvement	1st floor
(2′)	#D class house of the same as above	1st floor
(3′)	the same as above	2nd floor
(4)	Building of Kyoto prefectural depertment of Architecture	1st floor
(5)	Building of Kyoto prefectural depertment of Agriculture	1st floor
(6)	House of Kyoto public school for deaf and dumb	1st floor
(7)	the same as above	2nd floor

The relation between ratio of moment of force $k=\frac{F\cdot h}{W\cdot l}$ and strain Δx of these houses shown as in Table 2.

where F= horizontal force

h = hight from the point of horizontal force application to the ground

W= weight of house $\left(\text{assumed } \begin{matrix}\text{1st floor : 160 kg/m}^2 \\ \text{2nd floor : 210 kg/m}^2\end{matrix}\right)$

l = horizontal distance between the center of gravity and cuter side post which is located to the direction of horizontal force.

Fig. 3 is illustrated taking k on the ordinate and Δx on the abscissa of logarithmic paper. It is obivious to see that the value of Δx increases accompanied with the increase of k striat-linearly. This fact shows the relation between k and Δx shown as below

$$k=c(\Delta x)^a \quad (c \text{ and } a \text{ are const.})$$

Comparison between the values of c and a obtained from above mentioned Fig. 3 and the criterion decided at Kyoto prefectural depertment of Architecture is shown in Table 3. There acknowledges that the close relation exists between c and the criterion for earthquake-proof.

That is to say

(3′) #*D* class house of Suzaku high school (after improving operation), 2nd floor

W=220.5ton l=4.82m h=2.65m

F (kgr)	k ($\times10^{-4}$)	Δx ($\times10^{-5}$)
133.2	3.324	0.354
146.0	3.642	0.431
151.9	3.783	0.468
202.6	5.056	0.968
226.5	5.650	0.715

(1′) #*C* class house of Suzaku high school (after improving operation), 1st floor

W=220.5ton l=4.82m h=2.65m

F (kgr)	k ($\times10^{-4}$)	Δx ($\times10^{-5}$)
72.2	1.797	0.552
85.6	2.132	0.576
106.0	2.647	0.819
147.3	3.679	1.030
147.9	3.712	1.106

(4) Building of Kyoto prefectural depertment of Architecture, 1st floor

W=90.6ton l=4.55m h=4.80m

F (kgr)	k ($\times10^{-4}$)	Δx ($\times10^{-5}$)
56.7	6.610	1.637
83.8	9.752	4.470
90.1	10.489	5.187
91.1	10.603	5.323
114.2	13.298	14.389

(3) #*D* class house of Suzaku high school(before improving operation), 2nd floor

W=220.5ton l=4.82m h=2.45m

F (kgr)	k ($\times10^{-4}$)	Δx ($\times10^{-5}$)
43.7	1.009	0.798
74.1	1.708	0.891
102.7	2.368	3.194

(2′) #*D* class house of Suzaku high school (after improving operation), 1st floor

W=220.5ton l=4.82m h=2.65m

F (kgr)	k ($\times10^{-4}$)	Δx ($\times10^{-5}$)
117.2	2.920	0.531
128.8	3.204	0.915
139.1	3.475	0.804
139.8	3.480	0.726
143.0	3.563	0.847
164.9	4.116	1.000
165.8	4.132	1.241
183.1	4.567	1.793

(7) House of Kyoto public school for deaf and dumb, 2nd floor

W=146.2ton l=4.54m h=4.80m

F (kgr)	k ($\times10^{-4}$)	Δx ($\times10^{-5}$)
8.3	0.595	0.441
12.5	0.741	0.412
15.1	1.075	0.830
20.2	1.453	1.205
24.5	1.767	1.367
27.2	1.958	1.521
31.0	2.233	1.886
33.2	2.392	2.007
36.2	2.605	2.002

(5) Building of Kyoto prefectural depertment of Agriculture, 1st floor

W=46.9ton l=5.40m h=2.86m

F (kgr)	k $(\times 10^{-4})$	Δx $(\times 10^{-5})$
14.4	1.585	11.541
17.6	1.948	18.032
19.4	2.143	38.704
24.4	2.701	40.719
27.4	3.013	48.197
29.5	3.225	59.943
34.4	3.808	57.732
34.9	3.860	79.010
44.4	4.910	89.164
52.6	5.820	94.715
59.3	6.560	107.66
68.5	7.590	146.05
76.4	8.470	160.82
83.5	9.240	173.73
99.5	11.000	257.94

(6) House of kyoto public school for deaf and dumb, 1st floor

W=146.2ton l=4.54m h=4.80m

F (kgr)	k $(\times 10^{-4})$	Δx $(\times 10^{-5})$
6.5	0.469	1.173
9.4	0.681	1.407
12.7	0.856	2.497
15.0	1.080	3.050
20.1	1.448	4.478
31.6	2.281	7.137
35.7	2.568	8.487
42.0	3.022	9.878

(2) #D class house of Suzaku high school (before improving operation), 1st floor

W=220.5ton l=4.82m h=2.45m

F (kgr)	k $(\times 10^{-4})$	Δx $(\times 10^{-5})$
37.3	0.859	2.226
43.7	1.009	2.986
49.7	1.147	3.100
55.8	1.286	3.810
62.0	1.428	2.524
68.1	1.569	4.197
74.1	1.708	3.983
80.0	1.845	4.847
85.7	1.976	4.147
91.4	2.101	4.935
97.1	2.238	4.716
102.7	2.368	4.708

(1) #C class house of Suzaku high school (before improving operation), 1st floor

W=220.5ton l=4.82m h=2.45m

F (kgr)	k $(\times 10^{-4})$	Δx $(\times 10^{-5})$
30.8	0.710	2.571
37.3	0.859	2.789
43.7	1.009	3.714
74.1	1.708	4.802
85.7	1.976	7.548
91.4	2.101	6.196
97.1	2.238	5.996
102.7	2.368	8.049

Table 2.

(i) In A-grade value of c is more than 3.0 and over in A-grade the higher the grade, the bigger the value of c.

(ii) In B-grade it is between 0.8 and 3.0 and it differ according to the grade same as above.

(iii) In C-grade it is less than 0.8 the bigger as well.

Secondary we investigated the proper vibration on each building. The data of this measurement such as recorded amplitude ($\bar{y}_n$), period (T_n), double am-

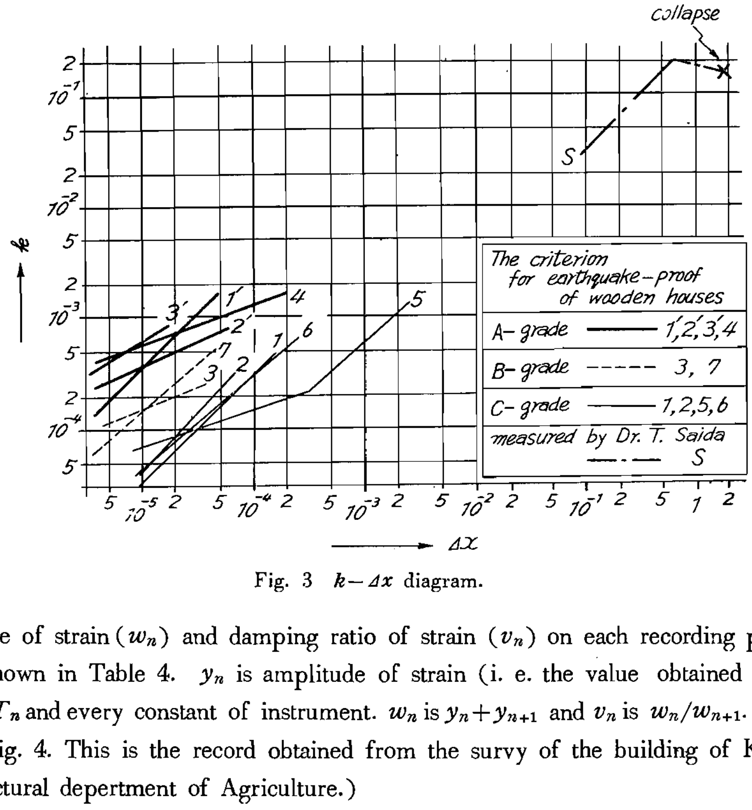

Fig. 3 $k-\Delta x$ diagram.

plitude of strain (w_n) and damping ratio of strain (v_n) on each recording paper are shown in Table 4. y_n is amplitude of strain (i. e. the value obtained from $\bar{y}_n$), T_n and every constant of instrument. w_n is y_n+y_{n+1} and v_n is w_n/w_{n+1}. (See the Fig. 4. This is the record obtained from the survy of the building of Kyoto prefectural depertment of Agriculture.)

On the basis of these values, we brough out the values of proper vibration period (T), damping ratio without solid friction ($\bar{v}$), term of solid friction (ρ) and damping ratio with solid friction (v). It is considered that T and v are not the values obtained from exact free vibration at the biginning of vibrating motion, so be took the mean value excluded the 1st vibration.

There exists the following relation between $\bar{v}$ and ρ

$$w_n = \bar{v}\cdot w_{n+1} + 2\rho(1+\bar{v})$$

Taking w_n as the ordinate and w_{n+1} as the abscissa, a straight line is supposed

No.	Measured Houses: Name	Measured Houses: Floor	Criterion for earthquake-proof	c ($\times 10^{-4}$)	a	Proper Vibration: T sec.	Proper Vibration: $\bar{v}$	Proper Vibration: ρ ($\times 10^{-7}$ cm)	Proper Vibration: v
3′	#D class house of Suza-ku high school (after improving operation)	2nd	A(middle)	6.00	0.55	0.257	1.010	6.720	1.042
4	Building of Kyoto prefectural depertment of Architecture	1 st	A(middle)	5.38	0.39	—	—	—	—
2′	#D class house of Suza-ku high school (after improving operation)	1 st	A(lower)	3.80	0.44	0.278	1.014	5.180	1.045
1′	#C class house of Suza-ku high school (after improving operation)	1 st	A(lower)	3.40	0.98	—	—	—	—
3	#D class house of Suza-ku high school (before improving operation)	2nd	B(middle)	1.48	0.39	0.366	1.053	4.879	1.061
7	House of Kyoto public school for deaf and dumb	2nd	B(lower)	1.32	0.61	0.415	1.089	6.710	1.159
5	Building of Kyoto prefectural depertment of Agriculture	1 st	C(higher)	0.70 0.11	0.33 0.86	0.580 0.627	1.270 1.052	3.920 185.000	1.285 1.135
2	#D class house of Suza-ku high school (before improving operation)	1 st	C(middle)	0.40	1.06	0.511	1.082	9.600	1.161
1	#C class house of Suza-ku high school (before improving operation)	1 st	C(middle)	0.32	0.97	0.516	1.170	8.032	1.181
6	House of Kyoto public school for deaf and dumb	1 st	C(lower)	0.42	0.90	—	—	—	—
add	Official residence of practise forest, faculty of Agriculture, Tokyo Imp. Univ.	1 st		0.40	1.00	(measured by Dr. T. Saida)			

Table 3.

to be formed on the section paper. The value of $\bar{v}$ is obtained from the gradient of the straight line and ρ from the value of $2\rho(1+\bar{v})$ where the straight line intersect with the abscissa.

By such way, the obtained values of proper vibration period (T), damping ratio without solid friction ($\bar{v}$), the term of solid friction (ρ) and damping ratio with solid friction (v) are appended in the previous mentioned Table 3.

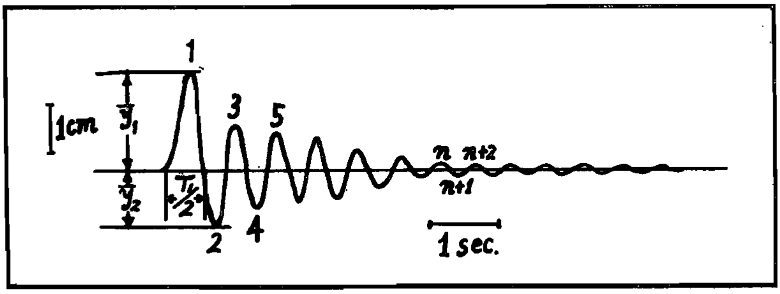

Fig. 4. Record of damping vibration obtained from the measurment of the bulding of Kyoto prefectural depertment of Agriculture.

(3′) *D class house of Suzaku high school (after improving operation) 2nd floor

	$\bar{y}_n$ (mm)	T_n (sec.)	y_n ($\times 10^{-5}$)	w_n ($\times 10^{-5}$)	v_n
1	1.391	.24	3.43	6.81	
2	1.135	.29	3.38	6.57	1.035
3	1.194	.26	3.19	6.30	1.041
4	1.163	.26	3.11	5.38	1.170
5	.818	.27	2.27	4.51	1.191
6	.841	.26	2.24	4.06	1.111
7	.737	.24	1.82	3.91	1.039
8	.848	.24	2.09	3.88	1.001
9	.726	.24	1.79	3.87	1.008
10	.845	.24	2.08	4.12	.940
11	.704	.28	2.03	4.19	.981
12	.753	.28	2.16	4.08	1.028
13	.719	.26	1.92	3.79	1.074
14	.759	.24	1.87	3.76	1.009
15	.707	.26	1.89	4.16	.905
16	.818	.27	2.27	3.91	1.062
17	.640	.25	1.64	3.67	1.065
18	.732	.27	2.03	3.39	1.080
19	.509	.26	1.36	3.08	1.100
20	.697	.24	1.72	3.06	1.005
21	.546	.24	1.34	3.04	1.005
22	.690	.24	1.70		

(2′) *D class house of Suzaku high school (after improving operation) 1st floor

	$\bar{y}_n$ (mm)	T'_n (sec.)	y_n ($\times 10^{-5}$)	w_n ($\times 10^{-5}$)	v_n
1	2.606	.37	9.92	1.298	
2	.901	.33	3.06	5.04	2.577
3	.741	.26	1.98	4.17	1.210
4	.852	.25	2.19	4.47	.934
5	.740	.30	2.28	4.57	.978
6	.744	.30	2.29	4.33	1.053
7	.734	.27	2.04	3.96	1.091
8	.669	.28	1.92	3.39	1.168
9	.550	.26	1.47	3.24	1.046
10	.574	.30	1.77	3.64	.890
11	.550	.33	1.87	3.78	.962
12	.715	.26	1.91	3.69	1.023
13	.720	.24	1.78	3.50	1.053
14	.620	.27	1.72	3.41	1.025
15	.589	.28	1.69	3.24	1.050
16	.537	.28	1.55	2.77	1.170
17	.440	.27	1.22	2.65	1.045
18	.536	.26	1.43	2.60	1.020
19	.423	.27	1.17		

(3) #D class house of Suzaku high school (before improving operation) 2nd floor

	$\bar{y}_n$ (mm)	T_n (sec.)	y_n $(\times 10^{-5})$	w_n $(\times 10^{-5})$	v_n
1	2.469	.35	7.620	12.970	
2	1.444	.42	5.350	10.570	1.229
3	1.557	.38	5.220	10.370	1.020
4	1.624	.36	5.160	9.685	1.070
5	1.350	.38	4.525	8.735	1.109
6	1.225	.39	4.210	8.020	1.089
7	1.200	.36	3.810	6.910	1.160
8	1.033	.34	3.100	6.232	1.109
9	.987	.36	3.132	6.362	.980
10	1.018	.36	3.230	6.540	.974
11	1.015	.37	3.310	6.620	.987
12	1.012	.37	3.310	6.770	.977
13	.958	.41	3.460	6.068	1.112
14	.870	.34	2.608	5.060	1.198
15	.870	.32	2.452	4.791	1.054
16	.780	.34	2.333	4.749	1.009
17	.760	.33	2.410		

(7) House of kyoto public school for deaf and dumb 2nd floor

	$\bar{y}_n$ (mm)	T_n (sec.)	y_n $(\times 10^{-5})$	w_n $(\times 10^{-5})$	v_n
1	20.890	.43	9.240	12.841	
2	8.360	.42	3.601	5.469	2.348
3	4.227	.43	1.868	3.620	1.510
4	4.269	.40	1.752	3.482	1.040
5	4.009	.42	1.730	2.753	1.265
6	2.374	.43	1.023	2.112	1.300
7	1.998	.53	1.089	1.769	1.193
8	1.248	.53	.680	1.209	1.463
9	1.353	.38	.529	1.109	1.090
10	1.446	.39	.580	1.209	.919
11	1.527	.40	.629	1.229	.985
12	1.492	.39	.600	1.198	1.027
13	1.453	.40	.598	1.198	1.000
14	1.460	.40	.600	1.112	1.073
15	1.385	.36	.512	.928	1.200
16	1.156	.35	.416		

(5) Building of Kyoto prefectural depertment of Agriculture 1st floor

	$\bar{y}_n$ (mm)	T (sec.)	y_n $(\times 10^{-5})$	w_n $(\times 10^{-5})$	v_n
1	19.200	.82	161.50	244.20	
2	13.000	.62	82.70	141.60	1.725
3	9.100	.63	58.90	124.00	1.148
4	9.900	.64	65.10	116.60	1.068
5	7.950	.63	51.50	102.50	1.131
6	8.000	.62	51.00	89.50	1.146
7	6.050	.62	38.50	76.70	1.166
8	5.900	.63	38.20	66.68	1.150
9	4.400	.63	28.48	49.16	1.340
10	3.400	.61	21.28	38.85	1.279
11	2.800	.61	17.57	29.07	1.370
12	2.000	.56	11.50	21.40	1.360
13	1.750	.55	9.90	17.65	1.210
14	1.300	.58	7.75	15.35	1.150
15	1.300	.57	7.60		

(2) #D class house of Suzaku high school (before improving operation) 1st floor

	$\bar{y}_n$ (mm)	T_n (sec)	y_n $(\times 10^{-5})$	w_n $(\times 10^{-5})$	v_n
1	3.275	.82	19.999	34.189	
2	2.765	.69	14.190	22.630	1.510
3	2.750	.52	8.440	16.560	1.369
4	2.182	.50	8.120	16.010	1.031
5	1.965	.54	7.890	14.180	1.130
6	1.688	.50	6.290	12.570	1.129
7	1.656	.51	6.280	11.460	1.096
8	1.339	.52	5.180	10.225	1.120
9	1.210	.56	5.045	8.807	1.160
10	.994	.51	3.762	7.350	1.199
11	.984	.49	3.588	7.049	1.041
12	.945	.49	3.461	6.669	1.041
13	.880	.49	3.208	5.768	1.154
14	.690	.50	2.560	4.645	1.240
15	.610	.46	2.085	3.797	1.222
16	.501	.46	1.712	3.013	1.260
17	.398	.44	1.301		

(1) *C class house of Suzaku high school (before improving operation) 1st floor					
	$\overline{y_n}$ (mm)	T_n (sec)	y_n $(\times 10^{-5})$	w_n $(\times 10^{-5})$	v_n
1	2.097	72	16.010	30.410	
2	2.610	.52	14.400	29.970	1.016
3	2.763	.53	15.570	27.260	1.098
4	1.862	.59	11.690	19.890	1.370
5	1.545	.50	8.200	15.580	1.278
6	1.268	.57	7.380	14.830	1.050
7	1.350	.52	7.450	13.180	1.128
8	1.100	.49	5.730	11.950	1.101
9	1.010	.58	6.220	9.920	1.203
10	.570	.61	3.700	7.257	1.365
11	.598	.56	3.557	5.949	1.220
12	.433	.52	2.392	4.853	1.225
13	.515	.45	2.461	4.422	1.097
14	.420	.44	1.961	4.262	1.036
15	.493	.44	2.301		

Table 4.

As is clearly understood from this Table that the worse the grade of criterion for earthquake-proof, the bigger the period (T) and damping ratio (v). Especially this relation is seen more obvious between the criterion and the period.

That is to say

(i) In A-grade the value of period is less than 0.3 sec.

(ii) In B-grade it is between 0.3 to 0.45 sec.

(iii) In C-grade, more than 0.45 sec.

According to this result it will be concluded that we can decide the criterion for earthquake-proof on wooden houses and buildings by measuring the value of c, v and T.

4. Examination and Consideration.

As we descrived above, there seems to be supposed that a certain relation between strain Δx and ratio of moment of force k is in existence as shown hereunder.

$$k = c(\Delta x)^a$$

But as a whole, such a relation is to be thinkable to exist on any wooden house. The relation between k and Δx obtained from Dr. T. Saida's test at the offical residence of seminary forest, the faculty of Tokyo Imperial University in spring 1939, is shown in Table 5. As was strain and force which used by him are different from thoses of used by this writer, so converted to here in k and Δx.

In his test, they wer far wide vibration than the one writer did and values obtained in his test form a straight line as in Fig. 3 previously mentioned and it proves that the relation still exists.

In case of the house being in perfect elastic body, the following relation comes into being that ratio of moment of force should be in propotion to strain by Hooke's law

$$\Delta x = c'\cdot k \quad (c' \text{ is constant})$$

But in fact, this is merely the hypothesis on house, and the following relation is formed as

$$k = c(\Delta x)^a \text{ i.e. } (\Delta x)^a = \frac{1}{c}k$$

Official residence of practise forest, facutly of Agriculture, Tokyo Imp. Univ. 1st floor			
W=25.0 ton l=3.4 m h=3.3 m			
F (ton)	k ($\times 10^{-2}$)	Δx ($\times 10^{-1}$)	Remark
1.0	3.474	1.2	
2.0	6.942	2.5	
3.0	10.413	3.0	
4.0	13.884	3.7	
5.0	17.355	4.8	
6.0	20.826	6.7	
4.75	16.500	18.3	collapse

Table 5.

In comparison of both, it shows that a times multiplication of strain of house Δx is proportionated the ratio of moment of force k and that in case $a=1$, strain increases in accordance with the increase of k by Hooke's law. In this case c is equal to reciprocal of Hooke's proportion constant, the bigger the value of c and a, the smaller the strain it becomes.

The relation between c and the criterion is clearly appeared on the survey before and after the improving operation for earthquake-proof of Suzaku high school houses as follows.

Value was 0.32 at #C class house (1st floor) turn out to 3.40 so the #D class house (1st floor) from 0.40 to 3.80 and the #D class house (2nd floor) from 1.48 to 6.00 respectively. In another words, #C and #D class houses (1st floor) which were in C (middle)-grade on criterion changed into A (lower)-grade so the #D class house from B (middle)-grade to A (middle)-grade. Thus they increased their durability after the improving operation.

Therefore the durability of the house for earthquake is obtainable by measuring the value of c.

Thus the proper values of house c and a are considered that they do not keep on the same values until the time of house-collapse but altered their values when strain gets bigger to some extent. On the record of (5) the house of Kyoto prefectural depertment of Agriculture, when strain Δx is near around 30×10^{-5}, a turn out from 0.33 to 0.86 and c from 0.70 to 0.11. This shows that the house proceed one process to collapse and the durability of the house for earthquake decreased when the horizontal force get bigger to certain value than in the case of hroizontal force is small. So the same on the proper vibration period it changes from 0.580 sec. to 0.627 sec. at around the same value of strain ($\Delta x = 30\times10^{-5}$) and this fact shows also the decrease of durability of the house. On the other hand ρ increases suddenly to 185.000×10^{-7} cm from 3.920×10^{-7} cm. At the same time, $\bar{v}$ changes from 1.270 to 1.052 and v from 1.285 to 1.135.

Thus houses seems to be thought gradually approaching to the process of collopse decreasing it's durability with several processes in accordance with the increase of horizontal force.

Value of c, which obtained from writer's measurement, is the value of proportion constant. The reason why writer took the value of 10^{-5} is because of the experimental result of measuring strain on certain B-grade wooden house (which is standing 100 m away at right angle to the street car rail-road) by wind pressure and earthquake vibration, strain given by passing the street car over was 10^{-6}, strain by wind blow with the velocity of 5~6 m/sec. was 10^{-5} and strain when house had begun to sound ominous cracking sound by ground vibrations was 10^{-4} And the k–Δx straight line above the value of strain 3×10^{-4} obtained from the survey of Kyoto prefectural depertment of Agriculture building and the straight line obtained from the house tumble experiment by Dr. T. Saida are concorded eachother. At any of houses they are thought to be in the last process before the tumble, when they are given the strain about 10^{-4} and thus it is considered to be proper that the criterion for earthquake-proof before the last process to tumble of all houses.

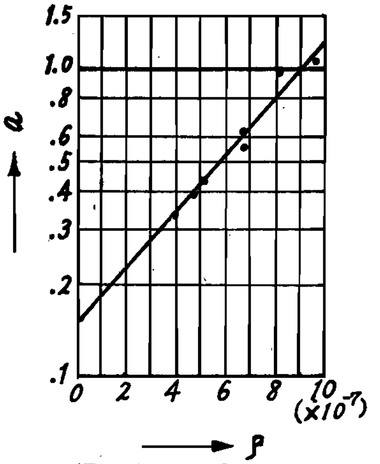

Fig. 5. a—ρ diagram.

As stated above, a is signifying the extent of elastic character and this value is related to the term of solid friction ρ obtained from proper vibration. Taking the value of a on the ordinate and $\rho\times10^{-7}$ cm. on the abscissa, a graph is made on the semilogarithmic paper as shown Fig. 5 and every dots line up on a straight line. This fact shown that exist the relation on both as shown below.

$$a = p \cdot q^{\rho} \quad (p \text{ and } q \text{ are const.})$$

and now p and q obtained as

$$p = 0.145$$
$$q = 1.23$$

and following relation comes into being as

$$a = 0.145 \times 1.23^{\rho}$$

That is to say a is exponential function of ρ and the bigger the value of a, the bigger the value of ρ, straining harder by solid friction.

And the higher grade of criterion for earthquake-proof, the shorter proper vibration period of house. This is proved by the fact that the period is short on that ferroconcrete building which belongs to higher grade of criterion for earthquake-proof and it is short on the house of Suzaku - high school after imploving operation than before. In order to obtain the relation between c and T, a graph is made on the semilogarithmic paper taking $c \times 10^{-1}$ on the ordinate (logarithmic scale) and $T \times 10^{-1}$ sec. on the abscissa each value of c on each value of T is form a straight line as shown in Fig. 6, and shows that c is exponential function of T. From the Fig. 6, the relation between c and T is obtained.

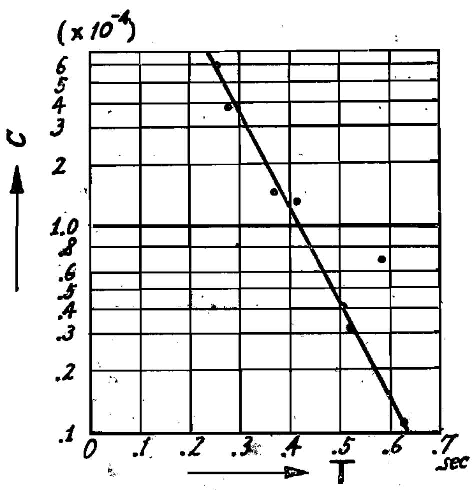

Fig. 6. $c-T$ diagram.

$$c = 77.0 \times 0.427^{T}$$

Here it can be concluded that the smaller the value of T, the bigger the value of c and c is also obtainable from the value of T. In another words the simple way to obtain the criterion for earthquake-proof on house is measuring the proper vibrating period.

In order to find out the relation between c and $\bar{v}$, c and v, values of c, $\bar{v}$, $\bar{v}/c$, v and v/c are shown in Table 6 and Fig. 7 shows the graph made taking $c \times 10^{-4}$ on the ordinate and $(\bar{v}/c) \times 10^{-4}$ and $(v/c) \times 10^{-4}$ on the abscissa. The relation between c and $\bar{v}$, c and v obtained from Fig. 7 are following formla.

No.	Measured Houses Name	Floor	c ($\times 10^{-4}$)	$\bar{v}$	$\bar{v}/c$ ($\times 10^{4}$)	v	v/c ($\times 10^{4}$)
3′	#*D* class house of Suzaku high school (after improving operation)	2nd	6.00	1.010	0.168	1.042	0.174
2′	#*D* class house of the same as above	1st	3.80	1.014	0.266	1.045	0.275
3	#*D* class house of Suzaku high school (before improving operation)	2nd	1.48	1.053	0.710	1.061	0.717
7	House of Kyoto public school for deaf and dumb	2nd	1.32	1.089	0.820	1.159	0.878
5	Building of Kyoto prefectural depertment of Agriculture	1st	0.70 0.11	1.270 1.052	1.810 9.560	1.285 1.135	1.837 10.310
2	#*D* class house of Suzaku high school (before improving operation)	1st	0.40	1.082	2.770	1.161	2.905
1	#*C* class house of Suzaku high school (befor improving operation)	1st	0.32	1.170	3.630	1.181	3.695

Table 6.

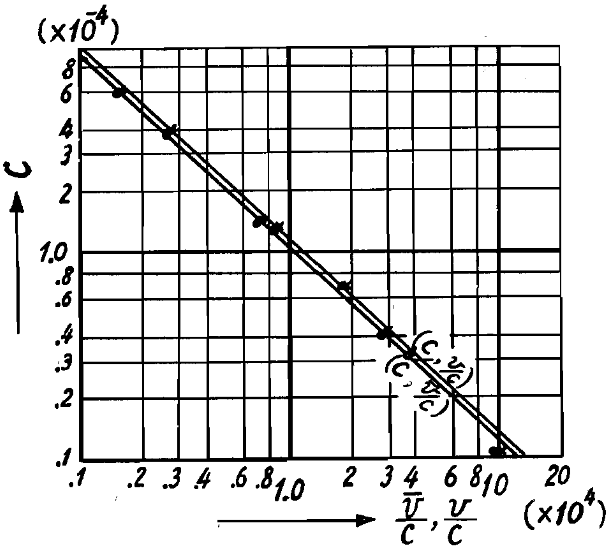

Fig. 7. $c-v/c$, $\bar{v}/c$ diagram.

$$c^{1-0.957} \times \bar{v}^{0.957} = 1.1$$
$$c^{1-0.957} \times v^{0.957} = 1.2$$

The bigger the value of $\bar{v}$ and v, the smaller the value of c, that is to say, the criterion for earthquake-proof is getting worse. Therefore to gain the damping ratio is also to obtain the criterion.

These result shows that there is close relation between the value of c and the criterion for the earthquake-proof of wooden houses which is now put into effect in every quarter. The bigger the value of c, the better the grade of criterion. But the value of c is related to proper vibrating period T and damping ratio $\bar{v}$ and v. The samaller the value of T and the values of $\bar{v}$ and v, thus the bigger the value of c. That is to say, the smaller the values of T, $\bar{v}$ and v, the better the grade of criterion for the earthquake-proof of wooden house.

On the other hand value of a does not seems to be directly related to the criterion at present but the term of solid friction ρ. The bigger the value of ρ, the bigger the value of a it becomes.

5. Conclusion.

The writer studied how did the houses strained when the static force was given then and surveyed the state of strain and proper vibration of houses and obtained the criterion for earthquake-proof of wooden houses, which had been one of subjects on modern earthquake-proof architecture, by measuring strain, proper vibration period, damping ratio and friction.

In conclusion of this report, writer wishes to express his cordial thanks to prof. K. Sassa for his kind guidance and instruction all the time through out this study and also to Mr. Matsui head of the depertment of Kyoto prefectural Architecture, Mr. Yamauchi chief of protective disaster section, technical expert Mr. Arahori and all personnels of protective disaster section and also to school masters of Suzaku high school and Kyoto public school for deaf and dumb for their co-operation on his survey.

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