

17. *Relation between the Earthquake Damage of Non-wooden Buildings and the Nature of the Ground.*

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Most of building in Japan being constructed out of wood, many data as to the earthquake damage of wooden buildings were obtained in all destructive earthquakes since 1868, and investigations based upon the data have been done from various points of view.

On the contrary, as non-wooden buildings were relatively small in number and were only in restricted localities, damaged non-wooden buildings were relatively small in number. Accordingly, owing to the shortage of data many aspects are left for investigators to study statistically. There are few data upon the damage of non-wooden buildings that are servicable to statistical study except that of the Kwantô earthquake of 1923.

In the present paper the relation between the damage of buildings and the nature of the ground is described based upon the data¹⁾ regarding the damage of ferro-concrete and brick buildings in the former Tokyo city at the time of the great earthquake mentioned above.

At first the former Tokyo city was classified into the following three sections: (I) Honjo and Fukagawa where the alluvium is very thick, (II) the southern part of Kôjimachi, Shiba, Kyôbashi, Nihonbashi, Kanda, Shitaya and Asakusa where the alluvium is relatively thin, (III) the north-western part of Kôjimachi, Azabu, Yotsuya, Ushigome, the greater part of Koishikawa Akasaka and Hongô where the ground consists of the diluvium or the tertiary. Next, the percentage between the total number of damaged ferro-concrete buildings and the total number of investigated buildings is called the damage ratio. And the relation between the damage ratio and the nature of the ground is shown in Table I.

The above figures show that the harder the ground, the severer the damage of ferro-concrete buildings.

Next, the writer examined the relation between the nature of the

1) *The Report of the Imperial Earthquake Investigation Committee*, No. 100, C b, p.p. 211-332, ditto, No. 100, C a, p.p. 55-178.

ground and the number of story as well as the story that was most severely destroyed. The result is shown in Table II.

Table I. Relation between the nature of the ground and the damage ratio of ferro-concrete buildings.

	Soft Ground			Firm Ground		
	Number of Damage Buildings (A)	Number of Safe Buildings (B)	Damage Ratio $\frac{(A) \times 100}{(A)+(B)}$	Number of Damage Buildings (A)	Number of Safe Buildings (B)	Damage Ratio $\frac{(A) \times 100}{(A)+(B)}$
Fukagawa (District)	7	43	11	—	—	
Honjo	2	29		—	—	
Kyôbashi	13	52	25	7	10	34
Nihonbashi	28	64		—	—	
Kanda	10	35		6	23	
Shitaya	—	10		5	2	44
Asakusa	6	27		—	—	
Shiba	8	13		3	4	
Kôjimachi	15	39		11	13	
Hongô	—	3		2	16	
Koishikawa	2	10		9	10	
Ushigome	—	—		8	3	
Yotsuya	—	—		7	5	
Akasaka	—	2		4	6	
Azabu	—	—		2	2	
Total	91	327		64	94	41

Table II. Relation between the nature of the ground and the number of story as well as the story that was most severely destroyed.

Ground	The story that was most severely destroyed	The number of story						
		II	III	IV	V	VI	VII	VIII
Soft (Mainly the Down-town)	1	1	10	3	1	1	—	—
	2	2	7	5	4	1	3	—
	3	—	2	1	—	—	3	3
Firm (Up-town)	1	5	19	5	1	—	1	—
	2	1	—	1	—	—	—	—
	3	—	—	—	1	—	—	—

The figures in Table II are to be read as below; the number of three-storied building the first floor of which was most severely destroyed is 10 in the soft ground and 19 in the firm ground respectively, and so on. It is shown in the above table that the first floor was most severely destroyed in the firm ground, while in the soft ground the first floor was most severely destroyed when the number of story was small and the second as well as the third floors were most severely destroyed when the number of story was large.

The facts shown in Table I and Table II correspond with the results of theoretical study²⁾ based upon the idea that at the time of earthquake the vibration energy of buildings dissipates to the ground again as the elastic wave that starts from the foundation. According to the results obtained by theoretical study, the smaller the rigidity of buildings compared with the rigidity (or elasticity) of the ground is, the more is the dissipation of vibration energy and accordingly the smaller the vibration amplitude of buildings. The nature corresponds with the damage shown in Table I. And, according to the results of theoretical study, as the dissipation of vibration energy increases, the higher part undergoes the maximum stress (or the maximum bending moment). The fact shown in Table II are fairly explained by this nature.

Table III shows the relation between the nature of the ground and the damage ratio of brick buildings in the former Tokyo city at the time of the great Kwantô earthquake of 1923.

Table III. Relation between the nature of the ground and the damage ratio of brick buildings.

The Number of story	Soft Ground			Firm Ground		
	Number of Damage Buildings (A)	Number of Safe Buildings (B)	Damage Ratio $(A) \times 100$ $(A)+(B)$	Number of Damage Buildings (A)	Number of Safe Buildings (B)	Damage Ratio $(A) \times 100$ $(A)+(B)$
1	85	106	45	30	13	70
2	131	183	42	96	31	76
3	24	53	31	17	5	77
Total	240	342	41	143	49	74

The above table shows that brick buildings in the soft ground were destroyed much more than those in the firm ground without any relation

2) K. SEZAWA and K. KANAI, *Bull. Earthq. Res. Inst.*, **14** (1936), 164, 377, 514.
K. KANAI, *Bull. Earthq. Res. Inst.*, **17** (1939), 37.

to number of story.

By the above investigation it has been clasified that the softer the ground, the less the damage of ferro-concrete and brick buildings in the former Tokyo city at the time of the great Kwantô earthquake of 1923. The results obtained can be explained by the results of theoretical study upon the dissipation of vibration energy of buildings to the ground.

It has been said that the damage was always large in the soft ground at the time of destructive earthquakes that occurred in Japan. It seems to be quite contradictory to the results obtained at the present investigation.

The author explains the apparent contradiction as follows. Most of buildings shown in the statistics of earthquake damage are Japanese wooden houses, and in those houses the pillars and beams are connected with tenons. Those buildings are liable to be destroyed by the secondary action such as the unequal sinking of the foundation at the time of earthquake.³⁾ Accordingly, if the relation between the nature of the ground and the damage to buildings is clarified with respect to wooden buildings which are constructed by adopting honestly earthquake-proof technique, the results obtained may be much different from the statistics based upon non-earthquake-proof wooden houses.

In conclusion, I with to express my thanks to the Ministry of Education, for financial aid (Funds for Scientific Research) granted me for a series of investigations, of which this study is a part.

3) K. KANAI, *Bull. Earthq. Res. Inst.*, **25** (1947), 61.