The movements of actual reinforced concrete buildings caused by the atmospheric temperature

The Movements of Actual Reinforced Concrete Buildings caused by the Atmospheric Temperature

Le mouvement des constructions en béton armé provoqué par la température atmosphérique

Die Bewegungen bestehender Stahlbetonbauten infolge athmosphärischer Temperatur

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The movements of the expansion joints in two kinds of reinforced concrete buildings were continuously measured for a period of more than one year. One building was a three-storied barrack with a wooden roof and the other was a one-storied ware-house with a flat roof. Both buildings are built in Shimamatsu Village of Hokkaido District in Japan, the latitude of which is about 43 degree in north.

Series-I The three-storied building

(1) Outline of the observation project

The building has a simple rectangular plan of 12.9 m (two spanned) in width and 85.5 m (4.5 m × 19 spans) in length as is shown in Fig.1, where the position of an expansion joint is indicated by an arrow. The detail of the expansion joint is also shown in Fig.1 ; the clearance of the columns was about 8 cm and each set of adjacent two columns was constructed on one common foundation ; it means that the building was separated in two blocks by the expansion joint, but they were connected each other under the ground. A wooden truss with a zinc roof was attached all over the top slab of reinforced concrete. This type of roof is not so common in Japan today, but the wooden roof would serve more or less as an aid for thermal insulation of the top of building.

The measuring apparatus were modified from the usual self-registering thermometers of 7-day cycle, by which the change of clearance of the expansion joint could be measured continuously instead of the thermal record. These apparatus were preliminarily calibrated by comparing with 1/100 mm dial gauge. The nine measuring points were set on the concrete floors near the columns, as are shown in Fig.1, to detect the movements of three frames in longitudinal direction of the building: two outside frames and one center frame.

The concrete skeleton of building was constructed in the season of August to October 1952 and the building was finished in April of the next year.

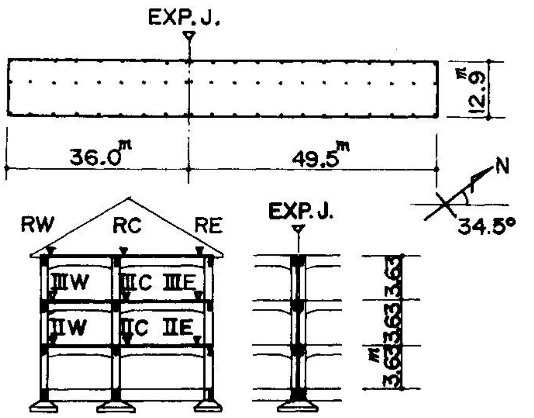

Fig.1

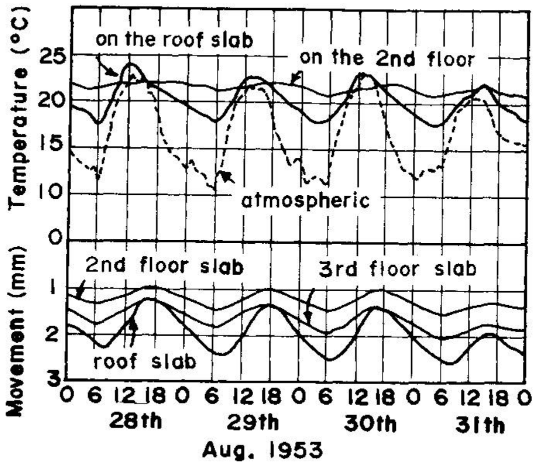

Fig.2

The observations on the movements of the expansion joint were started in August 1953 after a preliminary test for one month and were continued for about three years. The atmospheric temperature and the room temperature near the measuring apparatus were also recorded at the same time.

(2) The results of observations

a) A daily movement of building

An example of daily movements of the expansion joint, concerning to the center frame which would be less affected by the direct sunshine, is shown in Fig.2. It could roughly be assumed that the change of clearance indicates the expansion or contraction for a half length of building, because the blocks of building would move respectively by being fixed at the midpoint of each block.

The figure suggests that the length of reinforced concrete building varies all the time, following the change of atmospheric temperature, and that the maximum and minimum values appear about three hours later than those of daily temperature change. The magnitude of daily change of the length was the largest for the roof slab, showing less values in order of the third floor and the second floor (see Fig.3). And the value for the roof slab nearly corresponds to one-third or a half of the free length change for half length of the building estimated by the daily fluctuation of

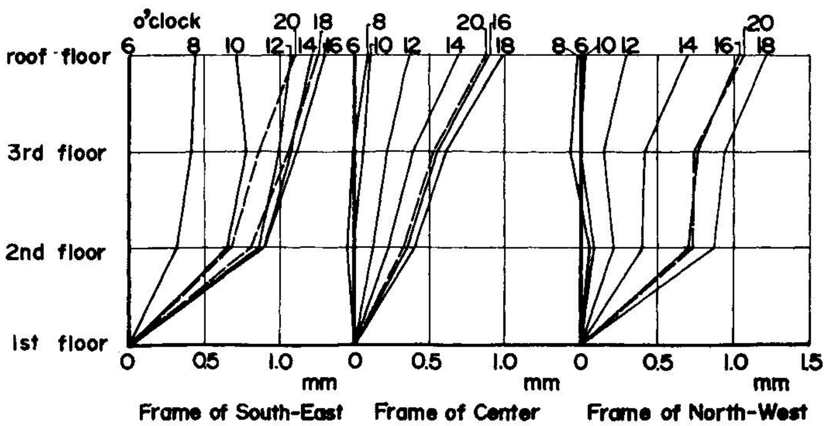

Fig.3

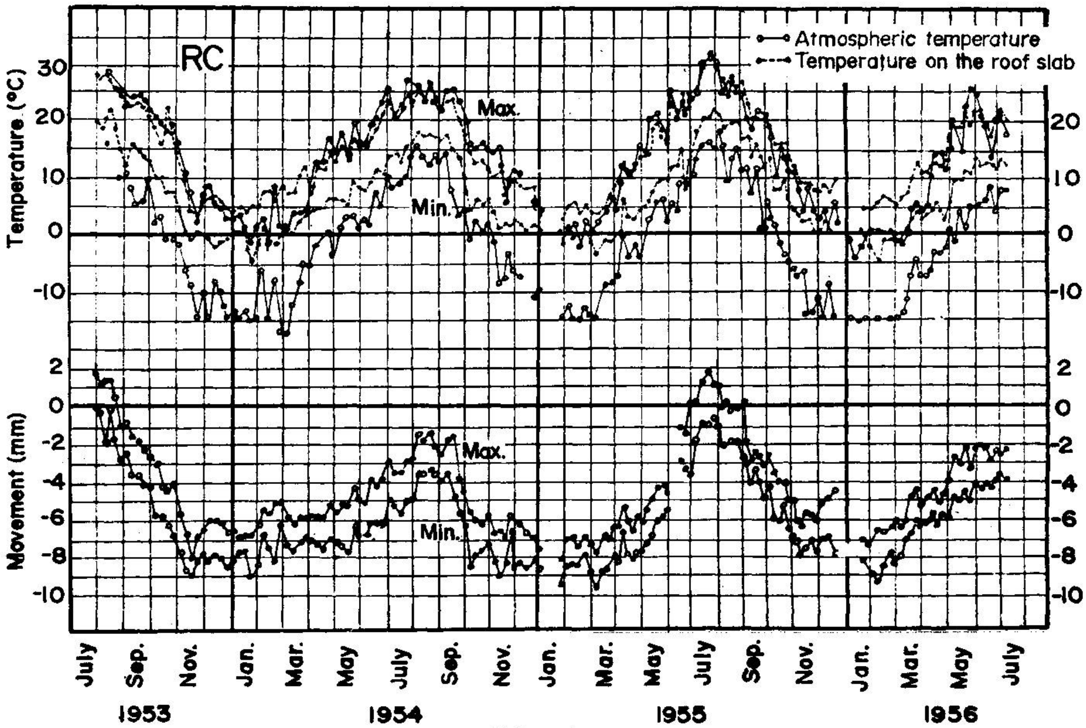

Fig.4

indoor temperature with the thermal expansion coefficient of concrete (0.000012).

An example for the movements of all measuring points in daytime are shown in Fig.3, which shows the effect of direct sunshine. In the morning, the frame of south-east side would expand comparatively quickly compared with the other frames. On the contrary, the frame of north-west side would further expand in the afternoon, while the south-east frame would already have started to contract. It means that the reinforced concrete building would have the three-dimensional deformations every day.

b) An annual movement of building

The daily maximum and minimum values of length change for the roof slab in the center frame throughout three years are plotted in Fig.4. Those of the atmospheric temperature and the indoor temperature on the roof slab are also plotted in the same figure. It must be noted that the data obtained in every winter season from the middle of November to the middle of April would be considerably affected by the room heating.

Table 1 Movement of the roof slab in the center frame

expansion				contraction				total change	atmos. temp.		
date	length	indoor max.	indoor min.	date	length	indoor min.	atmos. min.		max.	min.	total
	mm	°C	°C		mm	°C	°C	mm	°C	°C	°C
29 July '53	+1.71	28.8	23.8	29 Jan. '54	-9.15	-4.8	-26	10.86	29 July 12 Aug. 28.6	24 Jan. -26	54.6
								7.86			53.0
18 Aug. '54	-1.29	26.2		(6 Mar. '55)	-9.69	-2.8	-13	8.40	18 Aug. 27.0	18 Jan. -23	50.0
								11.46			54.0
20 July '55	+1.77	32.4	23.8	(2 Feb. '56)	-9.36	-3.8	-20	11.13	20 July 31.0	24 Jan. -21	52.0
31 July '56	+0.66	26.6	(21.6)					10.02	31 July 28.0		48.0

Fig. 4 indicates that the length of building gradually changes by the change of the atmospheric temperature in every season. The movements and conditions of the roof slab in the center frame are summarized in Table 1.

An approximately linear relation can be found between the daily minimum length of the center frame and the daily minimum indoor temperature, as is shown in Figs.5(a) and 5(b).

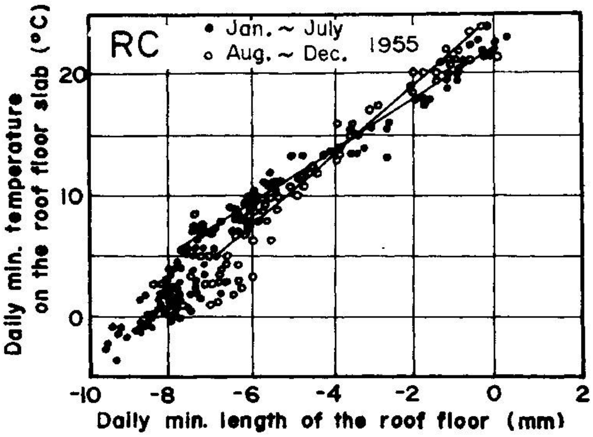

Fig.5 (a)

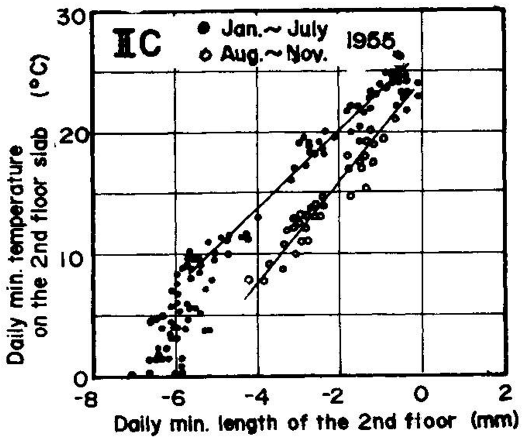

Fig.5 (b)

These figures show that there are some difference of proportionality between the data in the period from summer to winter and the data from winter to summer, and the measured data tend to distribute on a loop line. The inclination of these lines show the rate of the length change corresponding to the temperature gradient, and the rate becomes somewhat smaller when the ordinates of the graph are scaled by the daily minimum values of the atmospheric temperature.

These rates are shown in Table 2, where the estimated rate of free length change for half length of the building is 0.51 mm/°C. It can be supposed that the data would become somewhat larger when the temperature of concrete body was taken as the standard, because the data for the indoor temperature is generally somewhat larger than those for the atmospheric temperature. The figures in Table 2 show that the length change of the floor in the second story is largely constrained by the foundation which would not have any displacement. It is difficult to compare these data with the result of stress analysis of the frame, because the temperature distribution in real concrete body was not measured in

Table 2 The rate of length change for the center frame mm/°C

position	daily min. atmospheric temp.		daily min. indoor temp.		rate of free movement
	spring	autumn	spring	autumn	
roof slab	0.42	0.36	0.45	0.34	0.51
3rd floor	0.33	0.33	0.37	0.38	
2nd floor	0.31	0.19	0.31	0.25	
footing	0	0	0	0	

this observation and also because there is some question in the assumption that the frames would change their length by being fixed at the midspan of each frame. In the trial calculation, the rate of length change for the second floor should be about 90 % of its free rate of length change.

Series-II The one-storied ware-house with a flat roof

(1) Outline of the house

The ware-house has the width of 19.92 m (3 spanned) and the length of 220.77 m (35 spanned) and the house was completely separated in three blocks by two expansion joints, as is shown in Fig. 6. In this case, the joints were prepared at the middle of longitudinal beams and the footing tie-beams were also separated at the joints.

The same measuring apparatus as were used in Series-I were set on ten points: four roof beams and two footing tie-beams for one expansion joint, two outside roof beams and two footing tie-beams for the other joint.

The concrete skeleton was constructed in August to September 1953. The observations on the movements of the expansion joints were started in March 1955 and were continued for fifteen months.

Most part of the house has no room heating even in winter.

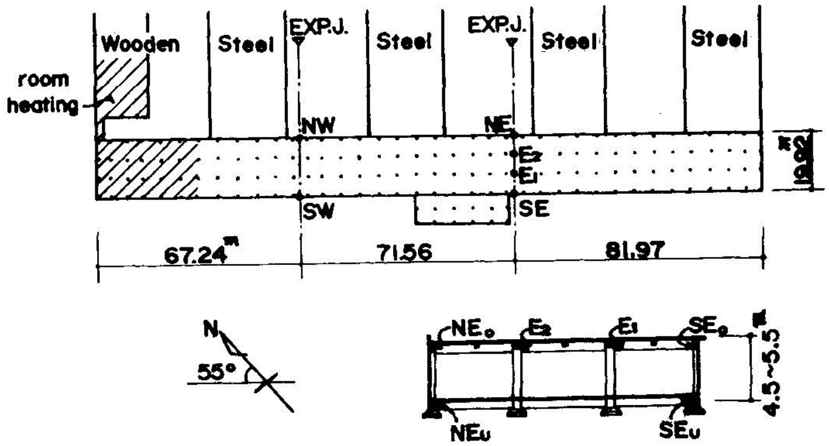

Fig.6

(2) The results of observation

Fig. 7 shows an abstract of data obtained by this observation. Similar tendencies of the daily and annual movements of the expansion joints as were described in Series I, were also observed in this house. The daily maximum expansion appeared about two hours later than the maximum atmospheric temperature and the magnitudes of daily change of length were about two-thirds of the values of free length change estimated by the daily atmospheric temperature difference. These phenomena mean that this house is more sensible for the temperature change than the above-mentioned three-storied building. The reason is supposed to be in the bare flat roof of comparatively wide area instead of a wooden roof in this case.

There are five ridges of the other ware-houses of steel construction connected to the north-east side of this house. So, the direct sunshine would be remarkably shielded by these attached houses. The effect of the sunshine is shown in Fig. 8, in which a

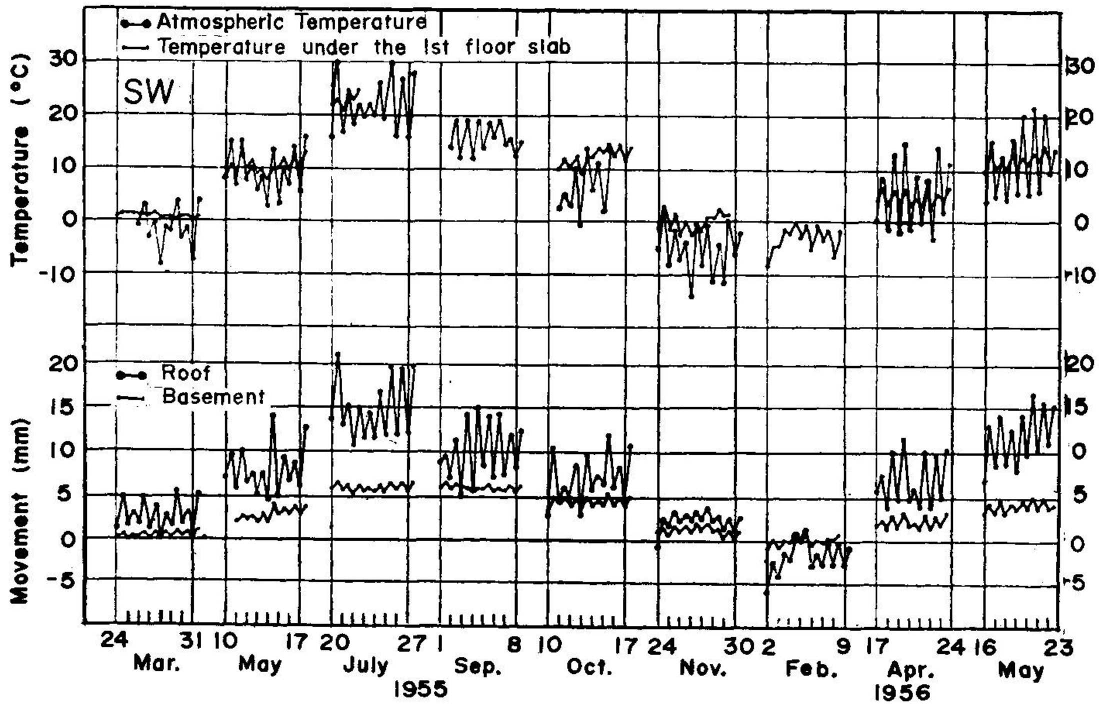

Fig.7

remarkable difference can be seen between the expansion in the south-west side frame and that of the north-east side frame. In this case, the north-east side frame showed the maximum expansion at 2 o'clock in the afternoon and then tended to contract, but the south-west side frame showed the maximum value about two hours later and the magnitude of expansion became more than twice of the former.

An approximately linear relation can be seen in Fig. 9, between the daily minimum atmospheric temperature and the daily minimum length of the house. In this case, it is difficult to separate the data by the season as was done in Series-I. The rates of length change are culculated in Table 3, in which the rate of free length change is estimated to be 0.92 mm/°C for the one expansion joint and 0.83 mm/°C for the other joint. The measured data correspond to about two-thirds of the estimated value at the respective joints. It is not sure whether the difference of the rate would be originated by the thermal stresses of the reinforced concrete frames or by the too large assumption of the length of building which is taken into account here.

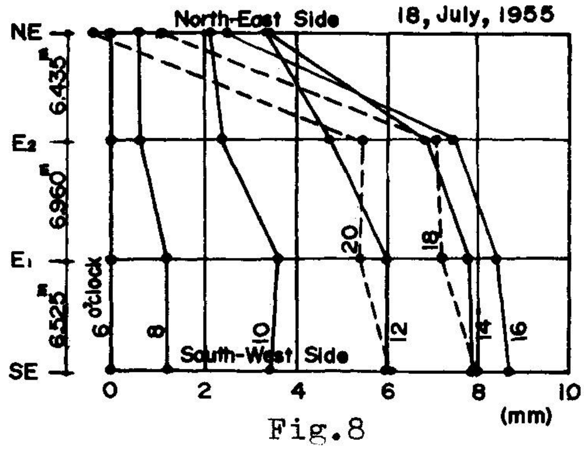

Fig.8

Table 3 The rate of length change in the roof mm/°C

position	daily min. atmospheric temp.	daily min. indoor temp.$^{+}$	rate of free movement
S E	0.52	0.52	0.92
N E	0.49	0.55	
S W	0.48	0.52	0.83
N W	0.49	0.52	

+ measured near the joint

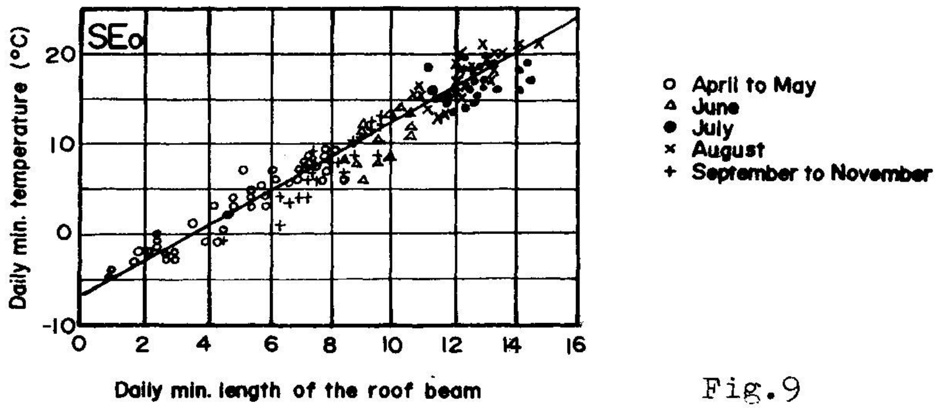

Fig.9

It is notable that the footing tie-beams also have small movements all the time following the movements of roof beams (Fig. 7). The wall in the frame would give a large effect to this movement of footing. Fig. 10 shows the relation of daily minimum length of the roof beam and that of the footing tie-beam.

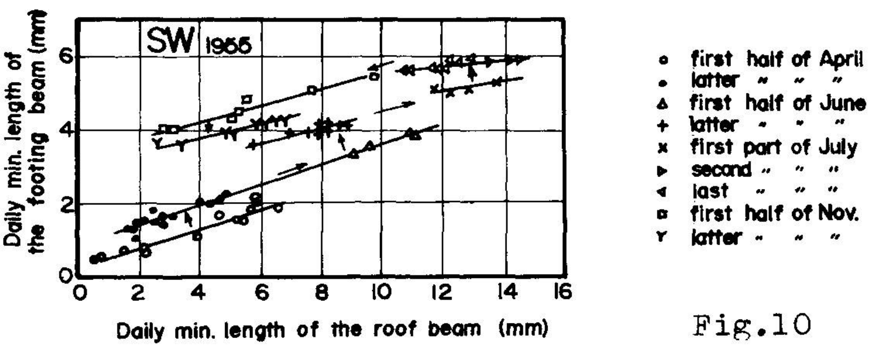

Fig.10

The figure clearly shows that there exists a linear relation between the two quantities for a period of one or two months and tnen suddenly another linear relationship appears. It would mean that some number of footings had a slip in the horizontal direction because of a too large change in length of the frame.

Summary

The movements of the expansion joints in two kinds of reinforced concrete buildings were continuously measured for a period of more than one year. The results of observations showed that the length of reinforced concrete buildings changed all the time following the change of atmospheric temperature, and that an approximately linear relation was found through a year between the daily minimum length and the daily minimum temperature. Some other analyses were developed on the observed data.

Résumé

Les mouvements des joints de dilatation dans deux sortes de construction en béton armé furent continuellement mesurés pendant la période de plus d'une année. Le résultat des observations montra que la longueur des constructions en béton armé variait constamment par suite du changement de la température atmosphérique et qu'une relation approximativement linéaire entre la longueur minimale journalière et la température minimale journalière pouvait être formulée tout au long d'une année. Quelques autres analyses furent développées au moment de l'observation.

Zusammenfassung

Die Bewegungen der Dilatationsfugen in zwei Stahlbetonbauten sind während mehr als eines Jahres gemessen worden. Die Beobachtungen zeigten, dass die Bautenlänge dauernd gemäss der atmosphärischen Temperaturschwankung änderten, und dass für ein Jahr eine annähernd lineare Beziehung zwischen der Tagesmindestlänge und der -temperatur gefunden wurde. Weitere Theorien sind aufgrund der beobachteten Daten entwickelt worden.