-*Submitting*- - *Technical Paper* -

STATIC TEST ON FRICTION COEFFICIENT OF CONCRETE FOUNDATION

Quang Hieu BUI*1, Toshikazu KABEYASAWA*2, Toshimi KABEYASAWA*3, and Youji HOSOKAWA*4

ABSTRACT

The damages of reinforce concrete buildings on spread foundation could decrease with base slip behavior if the foundation base shear exceeds the friction strength at the base of the footings [1]. Therefore, in this paper the static loading on the slip behavior was carried out to investigate the friction coefficients with various surface conditions which could be used at the base foundations. The tests show the average friction coefficients of 0.145, 0.121 and 0.108 for friction between steel-oil layer-steel plates, plastic-oil layer-plastic plates, and steel-oil layer-plastic plates, respectively.

Keywords: friction coefficient, slip behavior, concrete foundation, static test

1. INTRODUCTION

During recent decades, in Japan some strong earthquake records have been observed such as Niigata-Chuetsu earthquake and Hyogo earthquake. However, the damages of existing reinforced concrete (RC) buildings estimated from the inelastic time-history analysis overestimate the observed damages, if these accelerograms are used as the input motions at the bases of the damaged buildings. One of the reasons could be estimated as the earthquake intensities input to the buildings were generally smaller than those recorded in the free-fields, due to the soil-structure interaction or input loss at the foundation. On the other hand, the sliding was observed in the full-scale shake table test of RC school buildings between the spread foundation and the concrete mat slab with concrete to concrete joint surface [1]. The maximum response inter-story drift and associated damages of the buildings with sliding foundation were apparently less than those in case with fixed foundation.

The sliding behavior at the bases during the earthquake response could be used positively in seismic design to control the damages of the superstructures with relatively higher strength. It has been found theoretically that the required level is closely related to the friction coefficient at the base foundation. Therefore, in this study the static loading on the slip behavior was planned and carried out in order to investigate the friction coefficients with various surface conditions, such as concrete to concrete, steel plate to concrete, plastic plate to concrete, between two steel/plastic plates, which could be used at the base foundations. The static friction coefficients were identified also under the different levels of the constant normal force.

2. TEST PROGRAMS

2.1 Test specimens

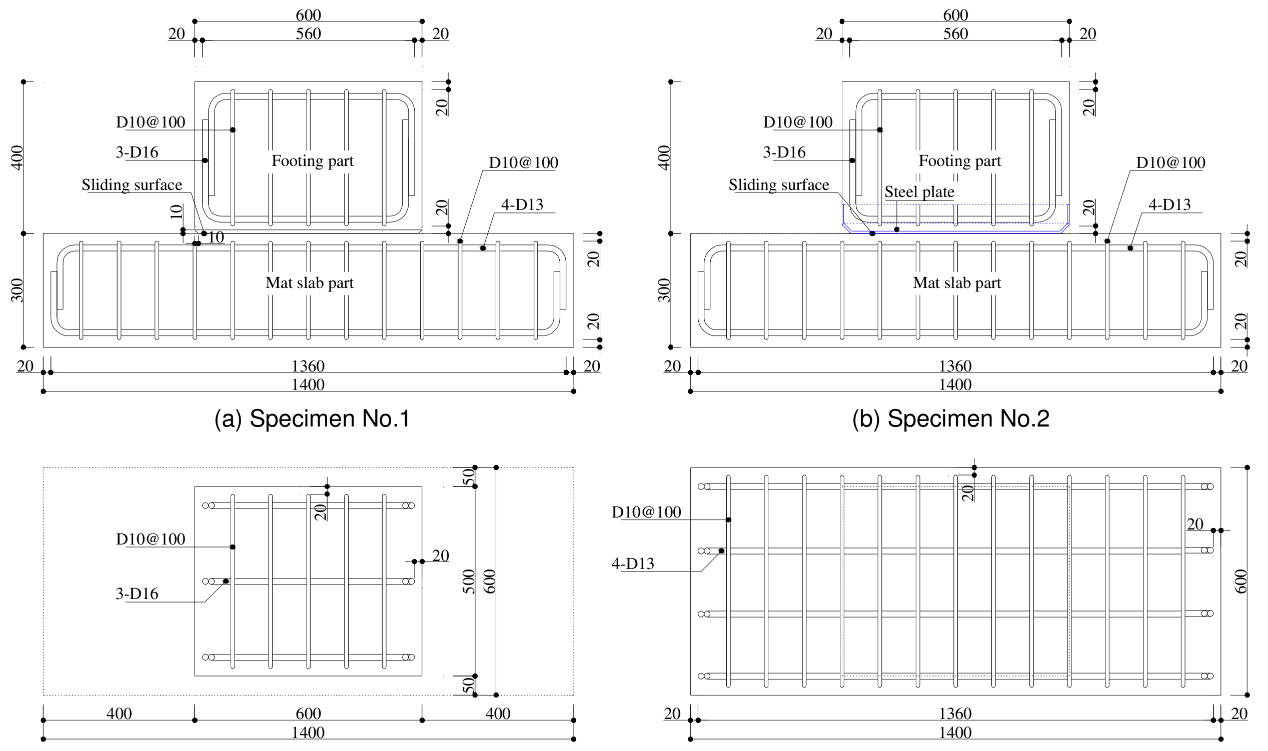
Two specimens constructed having different contact surface material (No.1 and No.2), both of which consisted of two parts, representing concrete footing and concrete mat slab. In order to survey the model of the construction process at the concrete surface between two concrete parts, the mat slab part was cast and then after one week, the footing part was placed continuously. The concrete to concrete surface connections were made in the specimen No.1. The process of making specimen No.2 is almost the same with specimen No.1, though in the base of the footing part steel plate of 6mm thickness was placed, as shown in Fig. 1. Both of the mats had a same rectangular cross section of 600x1400mm^2 with a height of 300mm, while the cross section of the footing parts was 500x600mm^2 with 400mm height.

2.2 Test process

The test was carried out in two phases. In the first phase, two specimens were tested with the original types of the contact surfaces: concrete to concrete for specimen No.1 and concrete to imbedded steel plate for specimen No.2.

In case of specimen No.2, additional tests were conducted in the second phase, so that here we call the first phase as CASE1, while the second phase as CASE2 to CASE11. In the second phase, various types of joint surface were tested by placing a plate or two plates between the footing and the mat slab of the original specimen No.2, where the details of the joint layers and the used plates at the joint surface are shown in Table 1.

*1 Graduate Student, Earthquake Research Institute, The University of Tokyo, JCI Student Member
*2 Researcher, Building Dept., National Institute for Land and Infrastructure Management, JCI Member
*3 Professor, Earthquake Research Institute, The University of Tokyo, JCI Member
*4 Project Researcher, Earthquake Research Institute, The University of Tokyo, JCI Member



(a) Specimen No.1 (b) Specimen No.2

(c) Horizontal section of footing part (d) Horizontal section of mat slab part

Fig.1 Details of test specimens (all dimension in mm)

2.3 Materials

The mechanical characteristics of concrete and steel bars of footing and mat slab parts are listed in Table 2, while the properties of the steel plate and plastic plates used in second phase are shown in Table 3.

Table 1 Detail of joint surfaces and test process

	Test process		Input materials which are arranged in the order from footing part to mat slab part.	Dimension
No.1	Phase 1	-	Original contact surface	-
No.2	Phase 1	CASE1	Original contact surface	-
	Phase 2	CASE2	1) Galvanized steel plate	2x600x800mm^3
		CASE3	1) Steel plate 2) Steel plate	1x600x700mm^3 1x600x800mm^3
		CASE4	1) Steel plate 2) Sand layer(*) 3) Steel plate	1x600x700mm^3 1mm thickness 1x600x800mm^3
		CASE5	1) Steel plate 2) Steel plate	3x600x700mm^3 3x600x800mm^3
		CASE6	1) Steel plate 2) Oil layer 3) Steel plate	3x600x700mm^3 - 3x600x800mm^3
		CASE7	1) Plastic plate 2) Plastic plate	2x600x700mm^3 2x600x800mm^3
		CASE8	1) Plastic plate 2) Steel plate	2x600x700mm^3 1x600x800mm^3
		CASE9	1) Plastic plate 2) Oil layer 3) Steel plate	2x600x700mm^3 - 3x600x800mm^3
		CASE10	1) Plastic plate 2) Oil layer 3) Plastic plate	2x600x700mm^3 - 2x600x800mm^3
		CASE11	1) Steel plate 2) Oil and sand layers 3) Steel plate	3x600x700mm^3 - 3x600x800mm^3

(*) Sand, was used in this test, was standard sand which have the maximum particle size of around 0.2mm.

Table 2 Characteristics of concrete and reinforcement

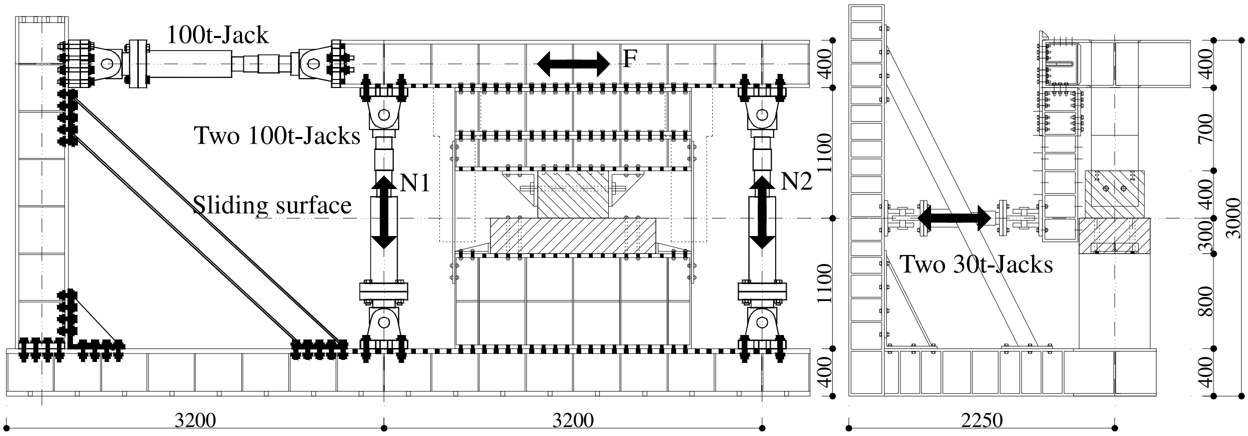
Concrete			
Specimen part	Mat slab		Footing
Concrete Strength (N/mm^2)	31.0		31.9
Reinforcement			
Type	D10	D13	D16
Yield Stress (N/mm^2)	381	366	365
Young Modulus (x10^{4}N/mm^2)	19	18.6	18.7
Tensile Strength (N/mm^2)	534	506	535

Table 3 Characteristics of plates

Type	Galvanized steel plate	Steel plate	Steel plate	Plastic plate
Thickness (mm)	2.05	1.05	2.86	1.9
Yield Stress (N/mm^2)	199.2	230.3	184.4	5.2
Young Modulus (x10^{4}N/mm^2)	17.77	17.91	18.40	0.6
Tensile Strength (N/mm^2)	261.2	275.7	325.8	60.75

2.4 Loading method

The loading frame at ERI, University of Tokyo, as shown in Figure 2, was used for the test, by which the lateral forces could be applied in two directions with the normal force. In the first phase test, for No.1 and CASE1 of No.2, the lateral shear force was applied in the in-plane loading direction as shown in Fig.2(a), by changing the normal forces of the two jacks with the



(a) In-plane loading direction (first phase)   (b) Out-of-plane loading direction (second phase)

Fig.2 The loading method (all dimension in mm)

following relations, so that the moment at the joint phase would be zero:

$$\Delta N=0.40625F$$
$$N_1=0.5(N_0+\Delta N) \quad (1)$$
$$N_2=0.5(N_0-\Delta N)$$

where, F: the measured lateral force at each loading step; N_0: the total target normal force, which was varied with the loading cycle to be described with the test results, while N_1 and N_2: the normal forces to be applied by the left and right oil jacks, respectively.

Because it was difficult to control the three jacks with the in-plane loading for CASE1, the out-of-plane lateral force was applied the second phase, CASE2 to CASE11 of specimen No.2, as shown in Fig.2(b), where the lateral shear force was applied at the joint level by the two horizontal jacks, so that the normal load was kept to be constant at the target levels with the two vertical jacks basically.

After the target constant normal load was applied, the lateral force was increased so that the specimen started to slip, and then the lateral force was reversed at the maximum peak displacement of ±10mm. The target normal force in case of specimen No.1 was 180kN, corresponding to the normal stress of around 650kN/m^2, for the sectional area of the sliding surface with 480x580mm^2. In CASE1 of the specimen No.2, the target normal force was varied as the eight levels of 180kN, 90kN, 67.5kN, 45kN, 22.5kN, 135kN, 270kN and 360kN, corresponding to the normal stresses of 745kN/m^2, 373kN/m^2, 279kN/m^2, 186kN/m^2, 93kN/m^2, 559kN/m^2, 1118kN/m^2 and 1490kN/m^2 respectively, for the sliding surface area of 444x544mm^2. From CASE2 to CASE11, the target normal forces were varied as 180kN, 90kN and 270kN in each case.

The horizontal displacement meters were set up in order to measure the total slip displacement between the two concrete footing and mat slab. In addition, the sliding displacements were also measured between the concrete and the insert plates, as well as between the two insert plates, to identify the joint surface where the sliding would occur.

3. TEST RESULTS AND DISCUSSION

3.1 Specimen No.1 (first phase test)

The horizontal force was increased gradually by which the joint would slide or slip. However in this case, the adhesion force between two concrete surfaces might have been too large to slip so that the footing part was damaged before sliding occurs. Figure 3 shows the damage state of specimen No.1 after the horizontal loading was attained up to about 600kN.

The mat slab part of specimen No.1 was cast in January, 27th 2012 and only one week later the footing part was cast monolithically on this part. Because of the cold weather and short time period when two parts were cast continuously, in some place of surface contact two parts might have been stuck completely together. This might be the reason why the adhesion force between two concrete surfaces had become too large so that the base slip behavior could not occur and the friction coefficient could not be identified by the loading test.

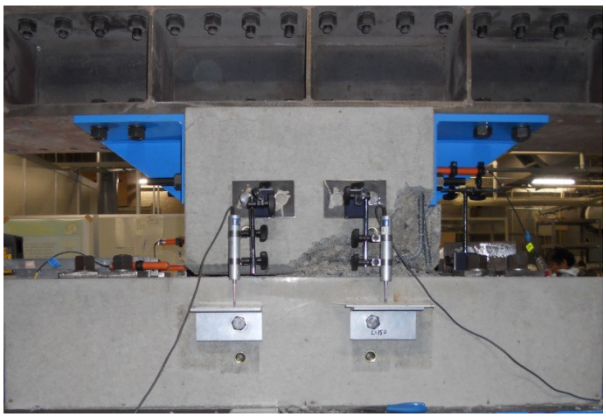


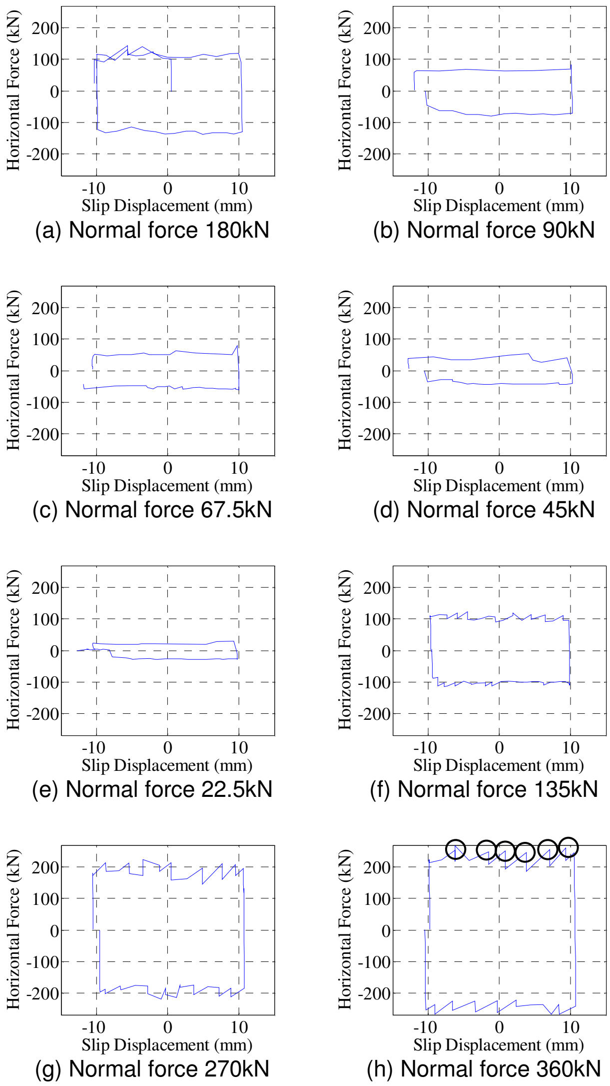
Fig.3 Damage of specimen No.1

3.2 Specimen No.2, CASE1 (first phase test)

In the first loading case for the second specimen, the lateral loading was applied in-plane direction. The surface joint was imbedded steel plate to concrete. The observed relations between the horizontal force and the slip displacement of two parts in each case of target input normal force are shown in Fig.4(a) to Fig.4(h). In each level of the constant normal force, when the horizontal force reaches to the static friction force, the sliding occurred and at that time the horizontal force decreased. As a result, the relations between the horizontal force and the slip displacement had the saw-tooth shape, which was the more obvious when the normal force was larger. The reason may be explained by the stick-slip phenomenon, which occurred because the static friction was larger than the dynamic friction. However, this experiment did not consider this phenomenon, so the friction in here is the static friction. And the static friction coefficient was calculated by the following equation (2):

$$\mu=F/N \qquad (2)$$

where, F: the peak of horizontal force in the interval of loading, for example the points which chose in Fig.4h; and N: the normal force.



(a) Normal force 180kN (b) Normal force 90kN

(c) Normal force 67.5kN (d) Normal force 45kN

(e) Normal force 22.5kN (f) Normal force 135kN

(g) Normal force 270kN (h) Normal force 360kN

Fig.4 Horizontal forces and slip displacements in CASE1, specimen No.2

The maximum and the average of the static friction coefficients between the imbedded steel plate and concrete, which are calculated as above calculation method, are listed in Table 4.

The average of the average values and maximum values of static friction coefficients between steel and concrete in all cases of the normal forces were 0.784 and 0.853 respectively. In each level of the constant normal force, the differences between the maximum values and the average values were not too large, almost around 1.1 times. The observed static friction coefficients are plotted in relations with the normal stress levels as shown in Figure 5.

Table 4 Observed friction coefficients in CASE1

Normal Force (kN)	Normal Stress (kN/m^2)	Average value	Maximum value
180	745	0.690	0.753
90	373	0.747	0.790
67.5	279	0.811	0.873
45	186	0.875	0.931
22.5	93	0.972	1.115
135	538	0.766	0.819
270	1118	0.720	0.794
360	1490	0.687	0.747

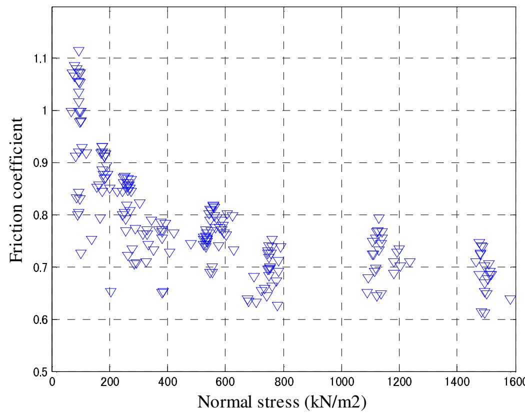


Fig.5 Friction coefficients and normal stresses in CASE1, specimen No.2

In this figure, the corresponding friction coefficient is shown with relation to the normal stress, which is measured when the horizontal force reached the peaks of loading. When the normal stress increases from around $90kN/m^2$ to $540kN/m^2$, the friction coefficient goes down from 0.972 to 0.766 in average value. On the other hand, when the normal stress changes in range of $745kN/m^2$ and $1490kN/m^2$, the coefficient almost remains in constant value of 0.699. As a result, it was found that the static friction coefficient depended not only on the contact material at the joint but also on the normal stress level: the static friction coefficient decreased as the normal stress increased.

3.3 Specimen No.2, CASE2 to CASE11 (second phase test)

In the second through tenth case of loading for the second specimen, the lateral loading was applied in the out-of-plane direction. The observed relations between the horizontal force and the relative slip

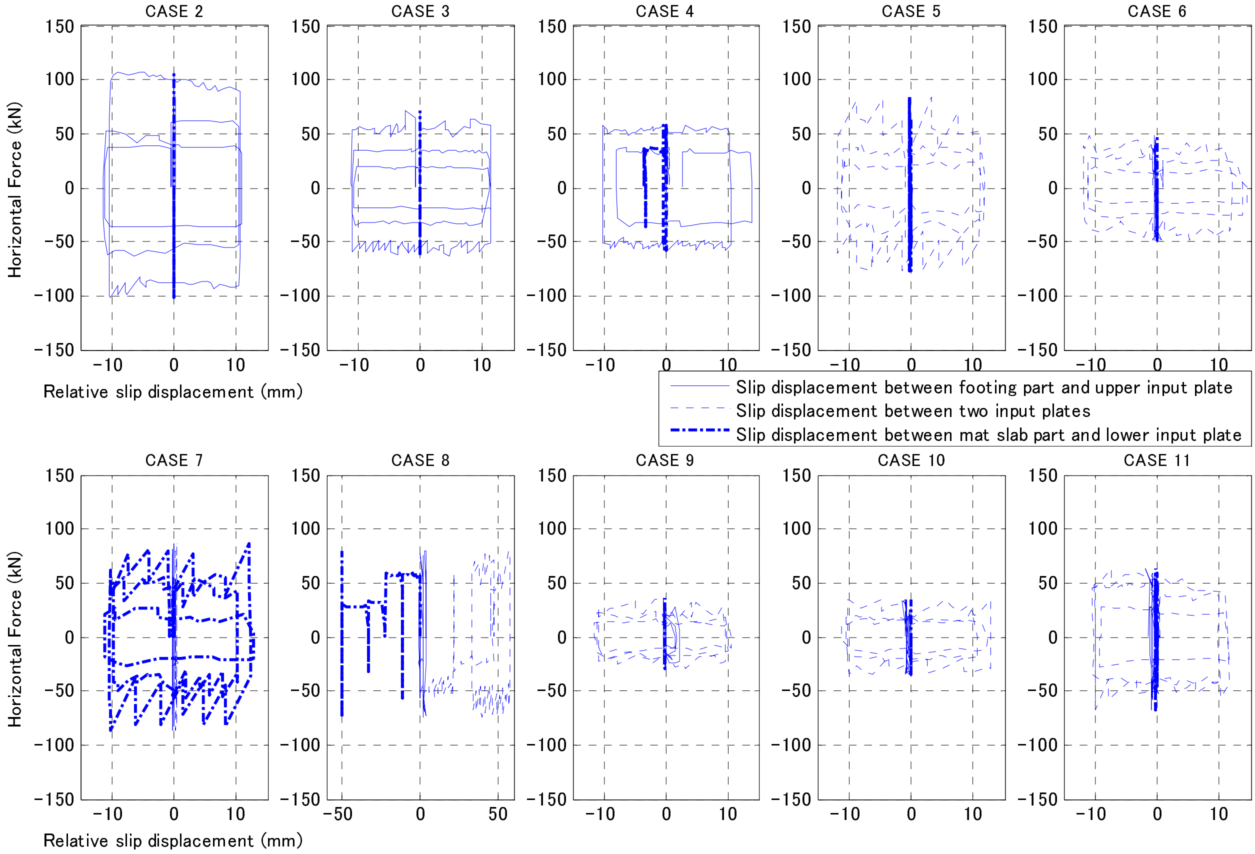


Fig.6 Horizontal forces and slip displacements in CASE2 to CASE11, specimen No.2

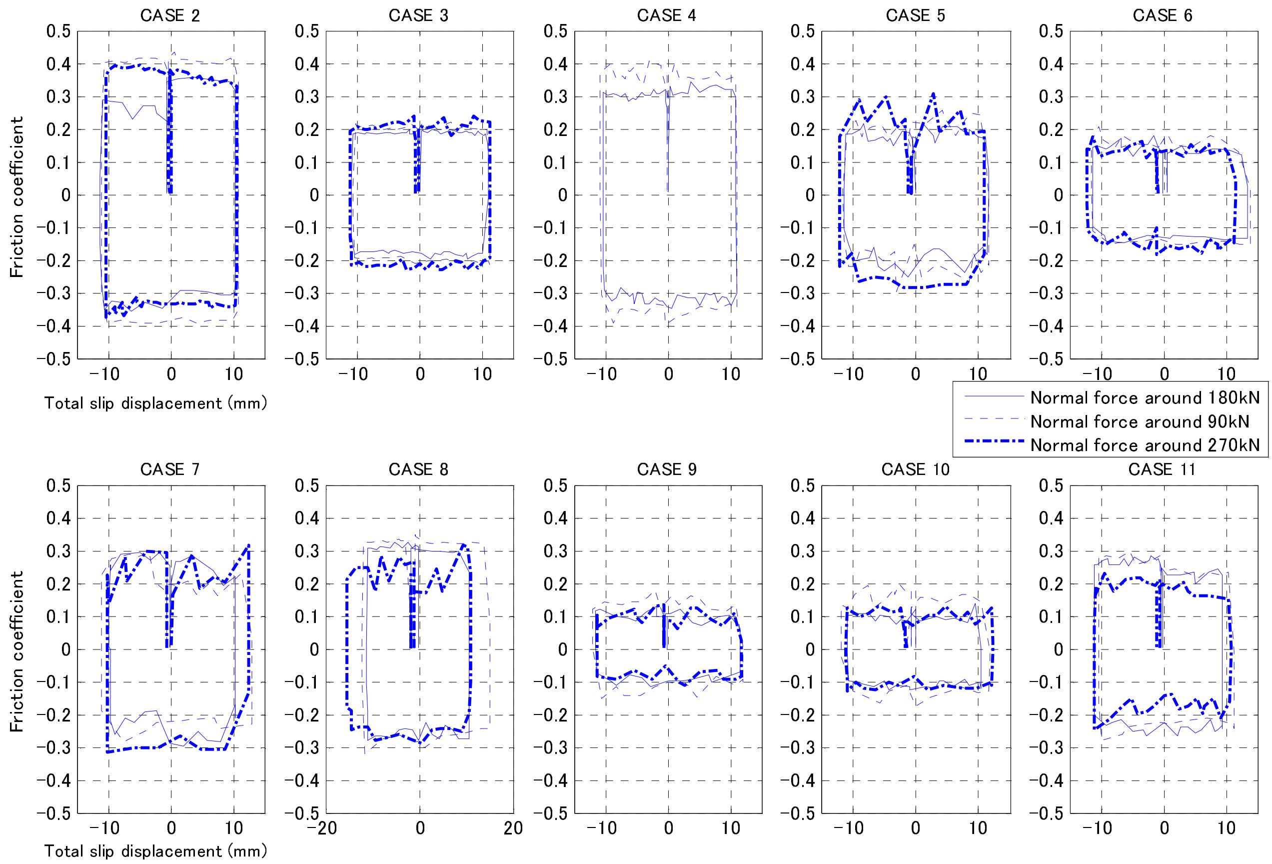


Fig.7 Friction coefficients and total slip displacements in CASE2 to CASE11, specimen No.2

displacements are shown in Figure 6, where the slip displacements were measured and shown independently between the joint surfaces of the plates and slab concrete. In the figure, the solid lines indicate the relative slip displacements between the footing part and the upper plate, while the dashed lines represent the relative slip displacement between the two plates and the dashed-dot lines shows the relative slip displacement between the mat slab part and the lower plate. The sliding would occur at the joint surface which had the smallest static friction coefficient. For example, in CASE2, the sliding was observed at the surface between the galvanized steel plate and the imbedded (mold) steel plate of the footing part. This was also the case in CASE3 and CASE4. In CASE5, CASE6, CASE9, CASE10 and CASE11, where the sliding surfaces were as listed in Table 5. However in CASE7, when the two plastic plates were placed between the footing and the mat slab in the original specimen, the sliding surface was the lower plastic plate to concrete surface of the mat slab part. In CASE8, the sliding surface changed, for a period at the plastic plate and the input steel plate, and for another period at the steel plate to mat slab's concrete, and so on.

The static friction coefficients of various contact surfaces are calculated from the equation (2) as in CASE1. The relations between the friction coefficient and the total displacement are shown in Fig.7, where the solid line, the dashed line and dashed-dot line show the friction coefficient in cases when the normal force was 180kN, 90kN and 270kN, respectively. The averaged values of the static friction coefficients in each case are shown in Table 5.

Table 5 Observed friction coefficients in CASE2 to CASE11, specimen No.2

Case	Sliding surface	Average friction coefficient		
		Normal force (kN)		
		180	90	270
CASE2	Galvanized steel plate to steel plate of footing part	0.314	0.339	0.353
CASE3	Steel plate to steel plate of footing part	0.185	0.204	0.213
CASE4	Steel plate to steel plate of footing part	0.313	0.364	-
CASE5	Steel plate to steel plate	0.186	0.213	0.242
CASE6	Steel plate-oil layer-steel plate	0.137	0.155	0.142
CASE7	Plastic plate to concrete surface of mat slab part	0.252	0.232	0.278
CASE8	Plastic plate to steel plate	0.286	0.311	0.249
CASE9	Plastic plate-oil layer-steel plate	0.098	0.133	0.094
CASE10	Plastic plate-oil layer-plastic plate	0.104	0.151	0.109
CASE11	Steel plate-oil and sand layers- steel plate	0.247	0.250	0.186

The averaged values of the static friction coefficients between two steel plates changed from 0.201 in CASE3 to 0.335 in CASE2, which may be because of the difference of the steel surfaces, where the joint surface was between the steel plate of the footing part and the galvanized steel plate in CASE2, while in CASE3 and CASE4 it was between the steel plate of footing part and the steel plate with 1mm thickness. On the other hand, in CASE5 the joint surface was between two 3mm thickness steel plates, and the averaged static friction coefficient was 0.272. The averaged static friction coefficient between concrete to plastic plate in CASE7 was 0.254 while the value between the steel plates and plastic plate was 0.282 in CASE8.

From Fig.7 and Table 5, when the oil layer was placed between the two plates, the friction coefficient could attain the smaller values than in the cases without oil. The averaged value of the static friction coefficient in CASE6 was 0.145, where the joint layer was steel plate-oil layer-steel plate, while the coefficient was 0.108 in case of plastic plate-oil layer-steel plate and 0.121 in case of plastic plate-oil layer-plastic plate. The friction coefficient between the plates could be reduced generally by the oil layer in all cases of the materials.

4. CONCLUSIONS

(1) When the footing part had been cast on the mat slab part monolithically after one week, namely in case of concrete to concrete joint, the footing part was damaged before sliding, due to the adhesion force, so that the friction coefficient could not be identified. On the other hand, the average static friction coefficient between concrete to steel plate was identified as 0.784.

(2) The average static friction coefficient of steel to steel plates was 0.272; the plastic plate to concrete was 0.254; the plastic to steel plate was 0.282.

(3) When the oil layer was spread between two plates, the average static friction coefficient of steel-oil-steel was 0.145; steel-oil-plastic was 0.108 and plastic-oil-plastic was 0.121.

(4) The static friction coefficient depends not only on contact material but on normal stress. The higher normal stress is the smaller static friction coefficient.

ACKNOWLEDGEMENT

This test was conducted at Structure Laboratory of Earthquake Research Institute, The University of Tokyo and was supported by JSPS Grants-in-Aid for Scientific Research (B).

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