A study on shear capacity of post-installed bonded anchors

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ABSTRACT: Direct shear tests were carried out on 60 specimens (single type: 51, group type: nine) of post-installed bonded anchors, mainly to determine the difference in shear capacity between anchors with and without added steel fiber and with or without undercut. The test results did not clearly show the effect of undercut, but the addition of steel fiber had an effect on the maximum load only when the embedment length was short. Further, it was found that the maximum load, which was most conspicuously influenced by the length of anchor embedment, was somewhat affected also by the loading method and the number of anchors loaded simultaneously. Based on the load-deformation curves obtained from these tests, load-deformation curves for difference of anchor embedment depth were idealized.

1 INTRODUCTION

In seismic strengthening and retrofitting and repair work of building structures, post-installed anchors (hereinafter referred to as anchors) are used in major joints. High shear resistance is the primary requirement, particularly in the case of seismic strengthening anchors. So far, expansion anchors have been widely used for seismic strengthening, but bonded ones are now increasing in use. In order to increase the anchoring force over conventional bonded anchors, anchors added with steel fiber to strengthen fixing force and/or with undercut to produce a wedge effect have recently been developed. In the following tests, our main object was to determine the difference in shear capacity between anchors with and without steel fiber, and with or without undercut, but we also aimed at identifying the effect of such factors as the length of anchor embedment, loading method, and the number of simultaneously loaded anchors.

2 TEST SPECIMENS

A total of 60 capsule-type bonded anchors were tested (Table 1). Among them nine single type specimens were anchors made of polyester resin(R-type), three group-type (three in a set) specimens and nine single-type specimens were bonded anchors added with steel fiber (RF-type), and six group-type specimens and 33 single-type specimens were RF-type anchors whose were undercuted(RFU-type). These anchor specimens were installed 150mm inside the edge of a concrete block made to simulate the

beam of an existing building (Fig.1). Fig.2 shows the manner that the bonded anchors were fixed to the concrete blocks. The tests were designed on the assumption of using anchors in the joint between the strengthening steel frame and the existing concrete frames. As shown in Fig.1, the anchor head (the part to be exposed) had a steel frame made of H-shape steel member in which spiral bars (D10-ø125-@50) were arranged, with non-shrink mortar injected with pressure in the surrounding area. The interface between the non-shrink mortar and the concrete·block, which would be

Table 1 A list of test anchors

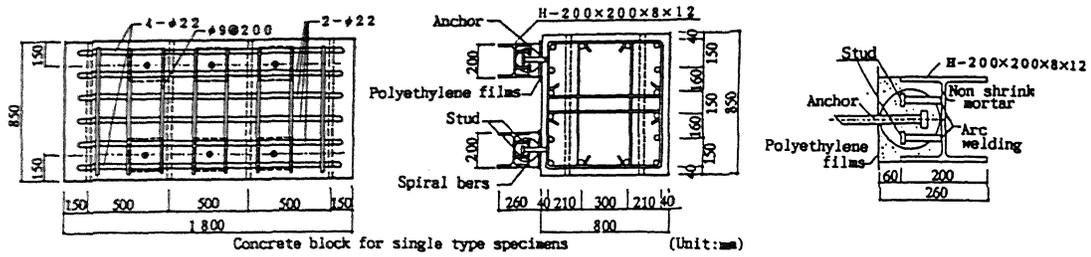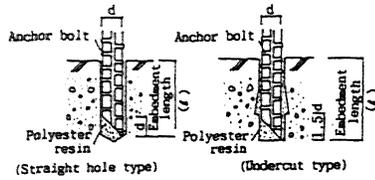| Number of anchor	Kind of anchor	Diameter da(mm)	Embedment depth	Loading method	Friction	Number of specimen
1	R	D22	5da	One way	Without	4
				Cyclic		2
			8da	One way		3
	RF		5da			4
				Cyclic		2
			8da			3
			4da	One way		4
	RFU		5da		With	3
				Cyclic		
			6.5da	One way	Without	2
				Cyclic		
			8da	One way		4
				Cyclic		
			12da			2
				One way	With	
	D13		5da	One way	Without	3
					With	4
3	RF	D22	8da	Cyclic	Without	3
	RFU		5da			

Fig.1 Test specimen details

Fig.2 Fixing method of bonded anchor

Table 2 The properties of Material of concrete

Unit weight $\tau(t/m^3)$	Compressive strength $\sigma(kgf/cm^2)$	Young's modulus $E(\times10^5/cm^2)$
2.25	210	2.18

(Mix proportion of specified design strength Fc-180kgf/cm²)

Table 3 The properties of material of anchor re-bars

da (mm)	Sectional area As(cm²)	Yield strength $\sigma y(kgf/cm^2)$	Tensile strength σmax (kgf/cm²)
D22	3.87	4167	6133
D13	1.27	3780	4961

Table 4 The properties of material of mortar

	Unit weight $\tau(t/m^3)$	Compressive strength $\sigma(kgf/cm^2)$	Yong's modlus $E(\times10^5kgf/cm^2)$
Before test	2.18	479	2.15
After test	2.13	529	2.20

the shear surface of the anchor specimen, was applied with polyethylene film in two layers to avoid friction in the case of the non-friction specimens so that shear force could
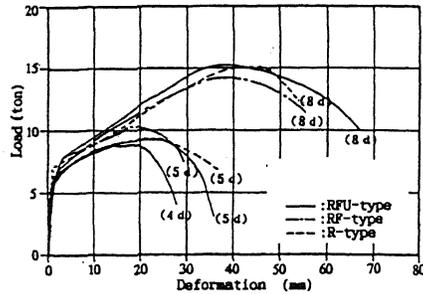

Fig.4 Typical load-deformation curves

be transmitted only to the anchor. On the other hand, for the specimens with friction, the surface of the concrete block was roughened so that shear force could be transmitted to not only the anchor but also the bonding between the non-shrink mortar and the concrete. The properties of the materials used in these specimens are shown in Tables 2 to 4.

3 TEST PROCEDURE

Loads were applied to the anchor specimens through a steel loading beam, using an oil jack with a capacity of 70 tons attached to a reaction steel frame (Fig.3). In order to transmit only the shear force to the anchor specimen in the loading process, a load was applied so that the axis of the oil jack could pass the shear plane of the anchor specimen in contact with the concrete surface. Loads were applied in two types, one-way loading and alternate cyclic loading. The
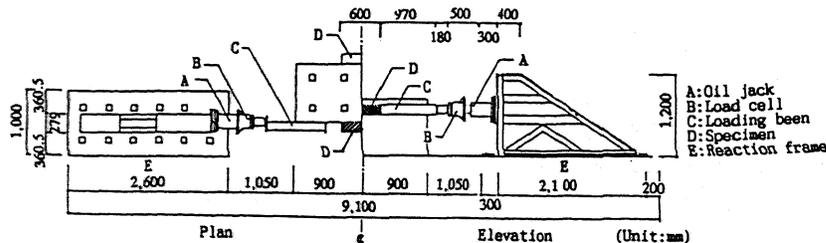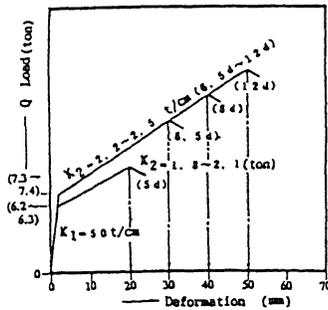

Fig:3 Loading apparatus

Fig.5 Idealized load–deformation curves

Fig.6 Relationship between the maximum load and the deformation at the maximum load

Fig.7 Load–deformation curves (with or without cyclic loading)

loading history adopted for the alternate cyclic loading was: after repeating the loading to cause 0.75cm horizontal deformation five times, the specimen was pushed out toward the positive side. Loads were measured by means of a load cell inserted between the jack and the loading beam. The displacement transducers were used to measure horizontal and vertical deformations. The horizontal deformation was measured about 2cm above the shear plane of each anchor specimen.

4 TEST RESULTS AND DISCUSSION

4.1 Load–deformation characteristics

Fig.4 shows typical load–deformation curves obtained from one-way loading on the various types of anchor specimens. Each of them shows elastic behavior up to about 7 tons, but subsequently the load increases gradually following growing horizontal deformation reaching the maximum load with about 20mm deformation for the 5da-embedded specimen and about 40mm for the one with 8da embedment. These load–deformation curves do not vary much between types of anchors. The load–deformation curves of a single-type specimen subjected to one-way loading, idealized based on the load–deformation curves obtained from this tests, is shown in Fig.5. While the elastic stiffness (K1) stays at about 50 t/cm regardless of the type of anchor and embedment length (1), the shear yield load (Qy), and subsequent stiffness (K2) are affected by the length of anchor embedment. The anchor re-bar (D22) used has a allowable shear strength for sustained loading (As $\sigma y/$ $1.5/\sqrt{3}$)of 6.21 tons, which closely corresponds to the Qy at 1=5da.

4.2 Maximum load and deformation at the time

Fig.6 shows the relationship between the maximum load per anchor and the deformation at the time. In 5da-embedded specimens with friction, all the deformation at the maximum
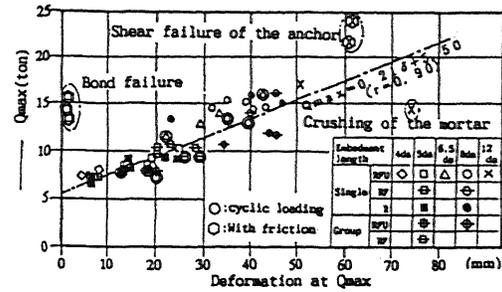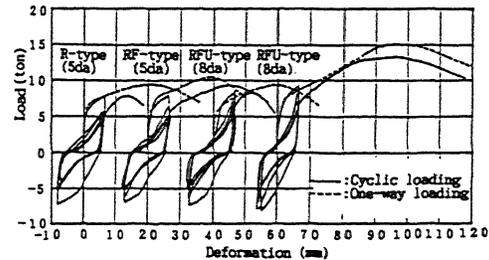
load are as slight as 2mm but in the other specimens, as the maximum loads rise, the deformations at the time tend to increase. The maximum loads of many of these specimens were determined by shear failure of the concrete block. Then, on the specimens the maximum loads of which were determined by shear failure of the concrete block, the correlation between the maximum load (Qmax) and the deformation (δ) at the maximum load were studied. The results showed that a relatively high correlation (correlation coefficient r =0.90) existed between Qmax and

4.3 Factors influencing maximum load

A comparison of the load–deformation curves of specimens with and without cyclic loading is shown in Fig.7. The curves of all the specimens show a decrease in shear strength caused by repeat of loading. Fig.8 compares the typical load–deformation curves of specimens with friction and non-friction ones, by using 5da and 12da embedded specimens. In the 5da-embedded specimen without friction, deformation increases at about 6 tons of loading. The maximum load is reached with a deformation of about 20-25mm. In the case of the specimen with friction, after the maximum load is reached when deformation is about 2mm, the bond of concrete and mortar is broken to decrease the load rapidly. Parallel with this, the deformation increases toward the point

where the maximum load of this non-friction specimen is reached. As for the 12da-embedded specimen without friction, the load increases gradually when it exceeds 7 tons. To keep pace with this, deformation begins to increase and the maximum load is determined, by shear failure of the concrete block, with a deformation of about 50mm. In the specimen with friction, after the shear strength records 19 tons with a deformation of about 1mm, the bond between the concrete and mortar is failure and the load decreases to about 15.5 tons. Then, the anchor re-bar fully supports the shear load and finally breaks with a deformation of some 60mm to reach the maximum load. From these test results, the bond strength between the concrete and the mortar is estimated at about 3.0-3.5 tons ($\tau = $ 7.5-8.76kg/cm^2). Fig.9 shows the relationship between maximum load and type of anchor. Among the 5da-embedded single-type specimens, the maximum loads of the RF-type specimens are about 10% higher regardless of one-way or cyclic loading, than those of the R and RFU types. And also, it finds that the maximum loads of the RF-type are slightly higher than those of the RFU-type, to the group-type specimens. Thus, when the embedment length was relatively short, the addition of steel fiber was found to have an effect on maximum load but the effect of undercut was not clearly found. It would be influence that the undercut was provided 1.5da above the bottom of embedment. The relationship between the maximum load (Qmax) and the length of anchor embedment (l) is shown in Fig.10. The maximum load grows as l increases,to amount to about 1.8 times as large in 6.5da and 8da embedment as in 5da embedment of the D22 specimens and almost twice as large in 12da from the latter. A formula deduced from regression analysis of Qmax and l is shown in Fig.10. As the formula gives the correlation coefficient r=0.90, it is found that Qmax and l have a considerably high correlation.

5 SUMMARY

Shear tests were carried out mainly on steel fiber-added and undercuted bonded anchors. Following were the findings:

1. In the case of one-way loading to single type anchors, the load-deformation characteristics show that the embedment length causes a difference in yield load, subsequent stiffness and deformation at the maximum load, but the elastic stiffness usually stays at K1=50t/cm. The yield load of 5da embedment closely corresponds to allowable shear force for sustained loading. Little difference is made to load-deformation curves by the type of anchor.

2. The failure mode of almost specimens without friction is characterized by shear failure of the concrete block. A relatively high correlation was observed between the maximum load and the deformation at the
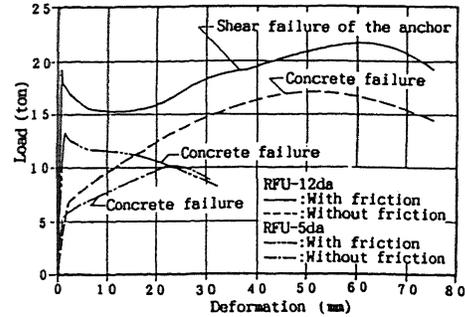

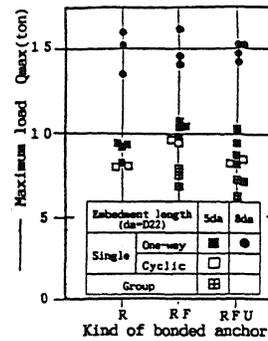Fig.8 Load-deformation curves of D22 specimens

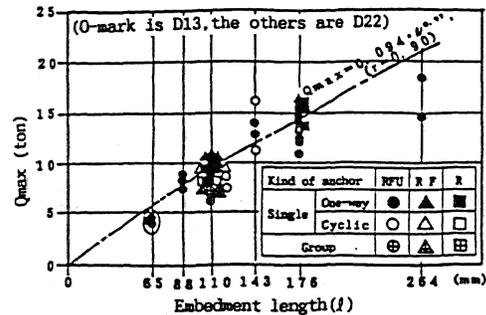Fig.9 Relationship between the maximum load (Qmax) and the kind of bonded anchors

Fig.10 Relationship between the maximum load (Qmax) and Embedment length(l)

maximum load.

3. The following factors have an effect on the maximum load:

a) The bond between the concrete and mortar on the shear surface has a relatively high effect. The bond strength is estimated to be τ=7.5-8.75kg/cm^2.

b) The embedment length has the most remarkable effect on maximum load, but the loading method and number of simultaneously tested anchors also have an effect on it.

c) With a short length of embedment (5da), the addition of steel fiber was found to have an effect on maximum load.