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CREEP DEFORMATION OF POST-INSTALLED BONDED ANCHORS

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Abstract

This study conducted creep tests for inorganic and organic types of post-installed anchors. The slope of the load displacement curve at the time of the bond strength test and the beginning of the creep test was equivalent to approximately 1/3 of the ultimate load. The slope of the inorganic-type anchor was more than 1.5 times that of the organic type.
The displacement at creep failure during the creep test was approximately two times that at the ultimate load regardless of the anchor type. The times to reach the displacement at the ultimate load were estimated at the free and load ends. The estimated value from the result of the free end was smaller than that from the load end. Accordingly, a remarkable difference between the estimated values from the load and free ends was observed in the specimen with a small amount of creep deformation.
The displacement variation of 1 to 90 days was examined to estimate the creep limit of the post-installed anchors. The displacement variation in the organic-type anchor became quite larger at a stress level of approximately more than 0.50. In comparison, the variation of the inorganic-type anchor increased at a stress level of ~0.6–0.7. Assuming that the creep limits of the post-installed anchors were represented by the inflection points of the variation–stress level curves, the creep limits of the inorganic and organic types are ~0.6–0.7 and ~0.50, respectively.

Keywords: Post-installed anchor, Inorganic-type anchor, Creep deformation, Creep limit

1. Introduction

The ceiling of the Ted Williams Tunnel in South Boston, Massachusetts, USA collapsed on July 10, 2006. The National Transportation Safety Board subsequently released a report about the accident mainly attributing the collapse to “epoxy creep” [1]. Meanwhile, the concrete ceiling panels inside the Sasago Tunnel in Japan collapsed on December 2, 2012. It has been a topic of concern that the used post-installed anchors of the ceiling panels may have deteriorated from long-term use. Post-installed anchors are essential for successful construction when equipment is attached to a concrete structure. These post-installed anchors can be exactly and easily positioned. More than 500 million post-installed anchors are used in Japan annually, which makes their safety an important topic. However, only a few studies have been conducted on the tensile creep behavior of the post-installed bonded anchors in Japan. Accordingly, Yano et al. studied the creep behavior of the post-installed anchors of polyester resin [2], while Nakano et al. studied the anchors of epoxy ester [3]. The creep behavior of the organic-type bonded anchors is summarized in the book entitled Anchorage in Concrete Construction [4].

Nevertheless, few studies have focused on the creep behavior of the inorganic-type post-installed bonded anchors. This study is conducted to investigate deformation and compare the inorganic and organic types of post-installed bonded anchors.

2. Experimental materials and methods

2.1 Anchor materials

Table 1 presents the three types of post-installed bonded anchors used in the tests. The inorganic-type anchor contained ultra-rapid hardening cement, sand, and other materials in a cartridge. Water was poured into the top of the cartridge for the inorganic type. The materials were mixed using a special mixer in the cartridge. They were then injected into a drilled hole with a caulk gun.

Two types of organic-type adhesive were used, namely, epoxy resin and epoxy acrylate resin. The organic-type anchor was formed by mixing a base agent and a hardening agent in a mixing nozzle.

Table 1 – Properties of the anchor materials

Symbol	Type of anchor	Adhesive			
		Base agent	Hardening agent	Compressive strength (N/mm^2)	Static modulus of elasticity (kN/mm^2)
In	Inorganic	Ultra-rapid hardening cement, quartz sand	Water	62.4	25.0
Ep	Organic (epoxy)	Bisphenol A-type epoxy resin, bisphenol F-type epoxy resin, quartz sand	m-Xylene diamine, aliphatic polyamine, quartz sand	109.0	2.73
Ea	Organic (epoxy acrylate)	Bisphenol A-type epoxy acrylate, reactive monomer	Benzoyl peroxide	198.6	2.23

2.2 Bond strength

Table 2 lists the concrete properties and material specifications of the deformed bars used in the bond strength and creep tests. The compressive strength and static modulus of elasticity of the concrete were measured using 100 × 200 mm cylinder specimens. Fig. 1 shows the specimen shape. The concrete was placed in steel pipes to prevent splitting failure. The steel pipes had an outer diameter of 216 mm and a thickness of 4.5 mm. D13 were used for the anchors. The embedment length was seven times the nominal diameter of the deformed bar. The bond strength tests were performed in more than one month since the anchor was fixed.

Fig. 2 shows the bond strength test apparatus. A steel plate was set on the specimen to cause bond failure. The steel plate for the tests had outer and inner diameters of 180 mm and 30 mm, respectively. Each specimen was loaded using the center hall jack. The load and displacement were measured at the free and load ends. The displacement measurement at the load end was 130 mm from the concrete surface.

Table 2 – Properties of the concrete and deformed bar

Symbol	Concrete		Deformed bar			
	Compressive strength (N/mm^2)	Static modulus of elasticity (kN/mm^2)	Type		Yield strength (N/mm^2)	Elastic modulus (kN/mm^2)
In-30N	30.4	27.8	D13	MK785	791	190
Ep-30N						
In-24N	24.6	29.8				
Ea-24N						

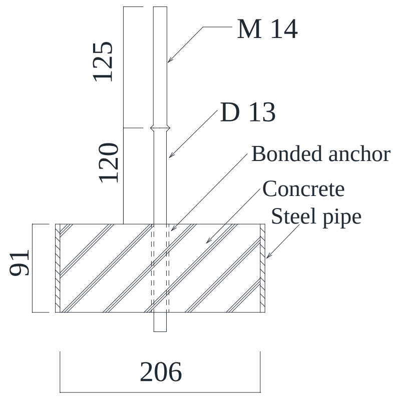


Fig. 1 – Specimen

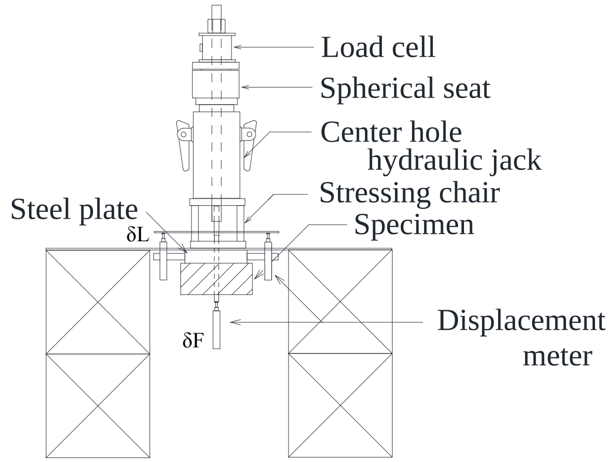


Fig. 2 – Bond strength test apparatus

2.3 Creep test

Fig. 3 shows the creep test apparatus. A specimen was placed in the upper part of the apparatus, and a sustained load was applied with a spring. The bolt in the lower part of the apparatus was tightened after the spring was compressed with the hydraulic jack. The specimen was then subjected to sustained loading when the load applied by the hydraulic jack was removed. The tests were conducted at 20 °C and 60% relative humidity. The displacements were measured every 5 kN to reach the sustained load. The steel plate was positioned similar to the bond strength test. One-third of the ultimate load was first applied and removed. The procedure was repeated thrice after that. The sustained load was applied at the target load level. Table 3 presents the creep test conditions. The sustained loads, which were 0.30–0.72 times of the ultimate load, were applied in over three months to evaluate the influence of the sustained load.

Table 3 – Experimental conditions

Symbol	Type of anchor	Sustained load (kN)	Stress level
In-30N-0.30	Inorganic	32.8	0.30
In-30N-0.45		49.1	0.45
In-30N-0.59		64.7	0.59
Ep-30N-0.48	Organic (epoxy)	59.1	0.48
Ep-30N-0.54		65.9	0.54
Ep-30N-0.59		72.7	0.59
In-24N-0.34	Inorganic	30.6	0.34
In-24N-0.50		45.4	0.50
In-24N-0.68		61.6	0.68
In-24N-0.72		65.8	0.72
Ea-24N-0.33	Organic (epoxy acrylate)	26.7	0.33
Ea-24N-0.50		40.8	0.50
Ea-24N-0.57		46.8	0.57
Ea-24N-0.65		53.5	0.65
Ea-24N-0.72		59.2	0.72

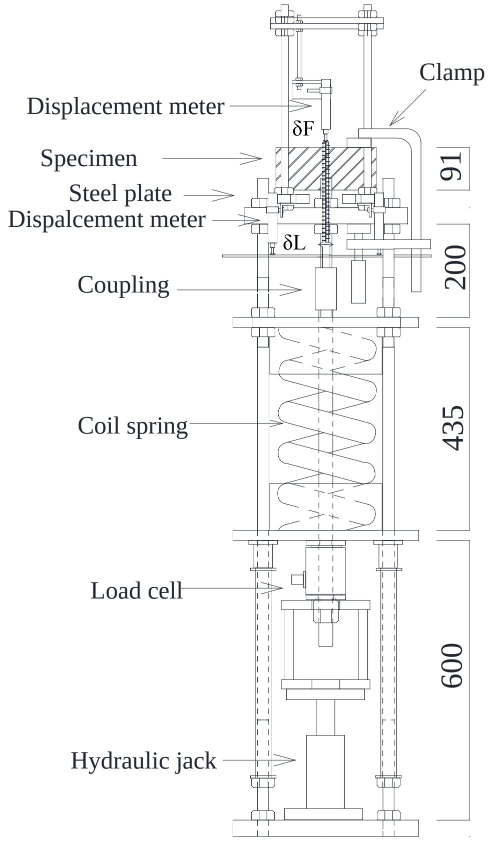


Fig. 3 – Creep test apparatus

3. Results

3.1 Bond strength

Table 4 shows the results of the bond strength test. The bond strengths (τb1) were calculated using the following equation:

$$\tau b1 = Pmax/\pi \cdot da1 \cdot l_b \quad (1)$$

where τb1 = bond strength, Pmax = ultimate load, da1 = nominal diameter of the deformed bar, and l_b = embedment length.

The average ultimate loads of the In-30N and Ep-30N anchors were 110.2 kN and 122.7 kN, respectively. As for the failure mode, bond failure occurred after rebar yielding at all the specimens with a concrete strength of 30 N/mm^2. The bond strengths of the In-24N and Ea-24N anchors were 25.1 N/mm^2 and 22.6 N/mm^2, respectively. The data were not used for the average because the hardening failure only occurred in one specimen even if three specimens were tested in the Ea-24N anchors. As regards the displacement of the free end at the time of ultimate load, the displacement of the Ea-24N anchors was about two times that of the In-24N anchors. Similarly, the displacement of the Ep-30N anchors was larger than that of the In-30N anchors. As a result, the displacement of the organic type was larger than that of the inorganic type. The difference in the material characteristics has appeared.

Table 4 – Results of the bond strength test

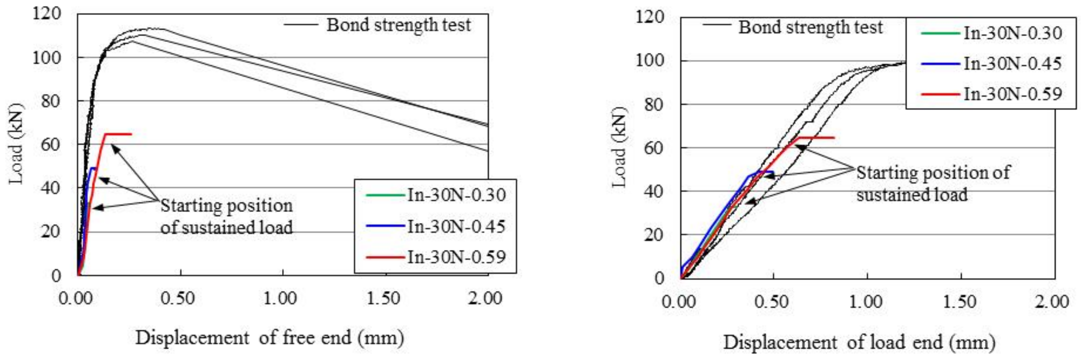
Symbol	Diameter		Embedment length (mm)	Ultimate load (kN)		Bond strength (N/mm^2)		Displacement at ultimate load			
	da1*1 (mm)	da2*2 (mm)						Free end (mm)		Load end (mm)	
			L_b	Pmax	Average	τb1	Average	δF	Average	δL	Average
In-30N	12.7	18	91	113.3	110.2	31.2	30.4	0.12	0.24	4.90	4.10
				107.2		29.5		0.27		3.36	
				110.1		30.3		0.33		4.04	
Ep-30N	12.7	16	91	121.7	122.7	33.5	33.8	1.29	1.40	7.69	7.02
				126.4		34.8		1.15		7.14	
				119.9		33.0		1.77		6.24	
In-24N	12.7	18	91	90.3	91.0	24.9	25.1	0.39	0.43	1.00	1.08
				92.9		25.6		0.47		1.17	
				89.7		24.7		0.43		1.07	
Ea-24N	12.7	16	91	81.9	82.0	22.6	22.6	0.94	0.96	1.45	1.45
				-		-		-		-	
				82.1		22.6		0.98		1.46	

*1: nominal diameter of the deformed bar

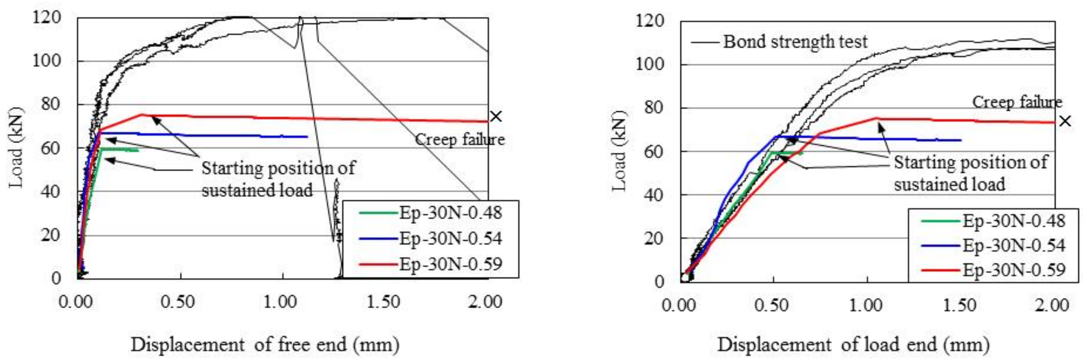
*2: drilled hole

3.2 Relationships between load and displacement

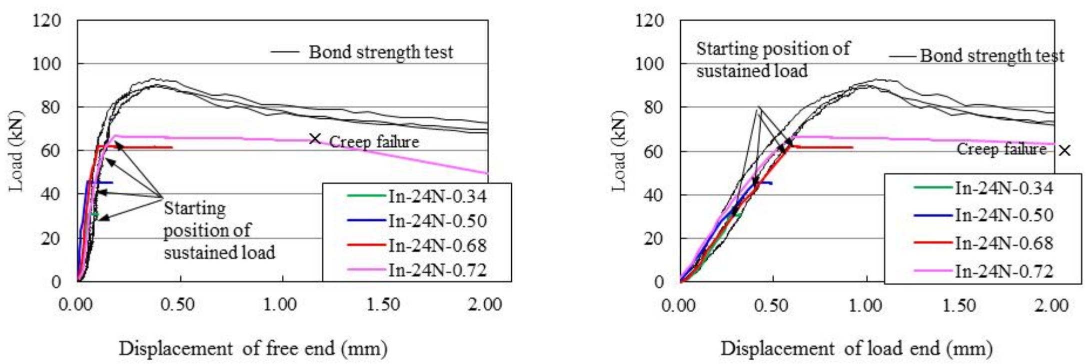
Fig. 4 shows the relationships between the load and the displacement. The slope of the load displacement curve at the time of the bond strength test and the beginning of the creep test was equivalent to about 1/3 of the ultimate load. The slopes at the free end up to 30 kN of the In-30N-0.45 anchors were 1072 kN/mm, whereas those of the Ep-30N-0.48, In-24N-0.68, and Ea-24N-0.72 anchors were 651 kN/mm, 994 kN/mm, and 558 kN/mm, respectively. The slope of the inorganic-type anchor was more than 1.5 times that of the organic type. The displacement at the creep test of the Ep-30N-0.59, Ea-24N-0.65, and Ea-24N-0.72 anchors with creep failure was much larger than that at the bond strength test when the sustained load reached the target load. Meanwhile, the displacement of the In-24N-0.72 anchor with creep failure was almost equivalent to that at the bond strength test. The deformation by load became larger in several seconds at the creep test of the organic-type anchor under high stress level. Accordingly, the time until the start of loading should be noted when conducting the creep test under high load.



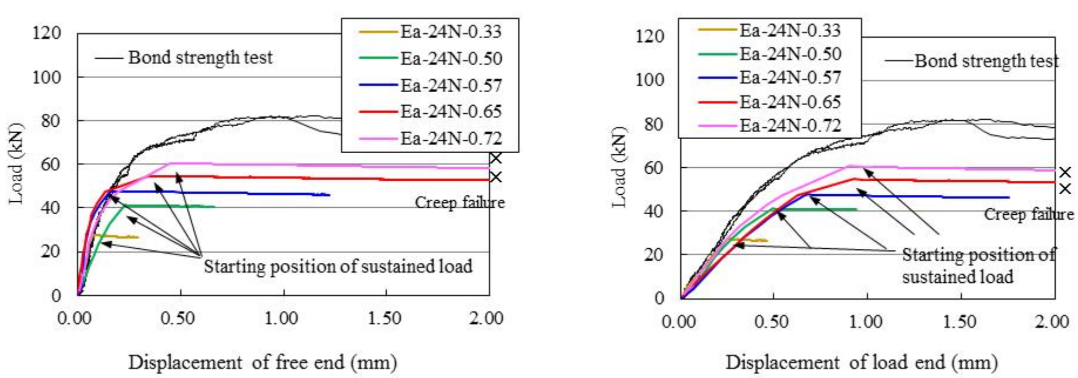
a) Inorganic-type load–displacement curve of 30 N/mm^2 concrete



b) Epoxy-type load–displacement curve of 30 N/mm^2 concrete



c) Inorganic-type load–displacement curve of 24 N/mm^2 concrete



d) Epoxy acrylate-type load–displacement curve of 24 N/mm^2 concrete

Fig. 4 – Relationship between load and displacement

3.3 Influence of the sustained load

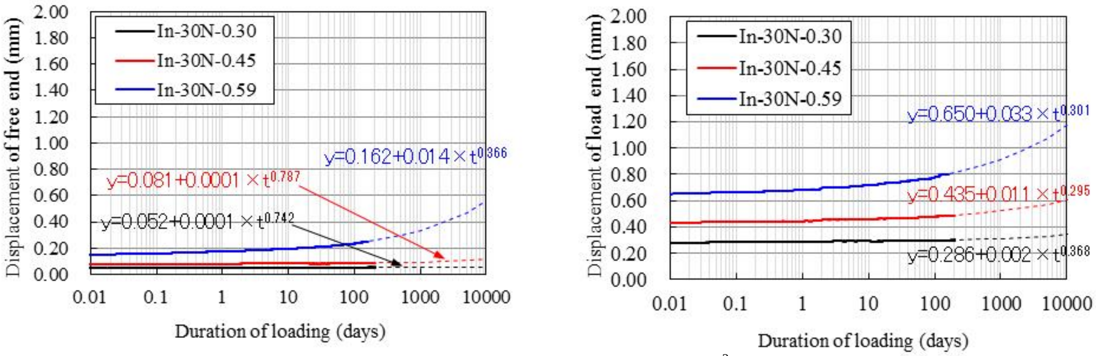
Fig. 5 shows the creep test results. The higher the sustained load, the larger the displacements. The creep failure occurred at the Ep-30N-0.59, In-24N-0.72, Ea-24N-0.65, and Ea-24N-0.72 anchors. The place of failure was between the surface of the rebar and the adhesives. The time to creep failure at the Ep-30N-0.59 anchor was 1.15 days, whereas that at the In-24N-0.74 anchor was 39 days. The time to creep failure at the Ea-24N-0.65 anchor was 15 h, whereas that at the Ea-24N-0.72 anchor was 5 h. The displacement of the inorganic type at the free end at the creep failure was 1.13 mm, whereas that of the organic type was about 3.5 mm. The displacements at the creep failure were about two times as large as that at the ultimate load regardless of the anchor type. The creep failure did not occur at the Ea-24N-0.57 anchor in 90 days, but occurred at the Ea-24N-0.65 anchor in 15 h. A stress level of more than 0.60 increased the creep deformation rate.

The displacements measured in these tests were extrapolated using Eq. (2) to estimate the long-term creep deformations [5]:

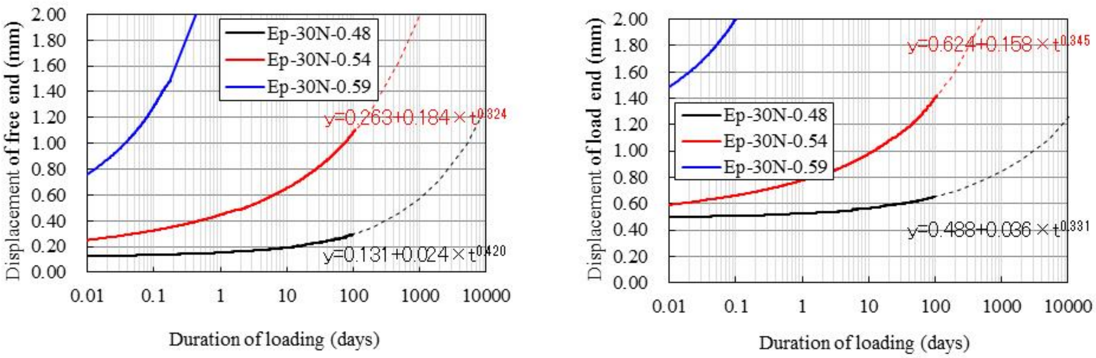
$$S(t) = So + a \cdot t^{b} \tag{2}$$

where So = initial displacement under the sustained load at t = 0, and a and b are constants (tuning factors). The time to reach the displacement at the ultimate load of the In-24N and Ea-24N anchors was estimated at the free and load ends. The time to reach the displacement at the ultimate load of the In-24N-0.34 and In-24N-0.50 anchors was estimated to be 64 years and 15 years at the free end, respectively. Meanwhile, the time of the In-24N-0.34 and In-24N-0.54 anchors was estimated to be more than 10,000 years at the load end. Consequently, a remarkable difference was observed between the estimated values from the load and free ends. The time of the Ea-24N-0.33 anchor was estimated to be 2400 years and 7300 years at the free and load ends, respectively. The time of the Ea-24N-0.50 anchor was also estimated to be 5.7 years and 20 years at the free and load ends, respectively. The estimated value from the free end was smaller than that from the load end. A remarkable difference between the estimated values from the load and free ends was observed in the specimen with a small amount of creep deformation. Two reasons were provided for this finding. The displacement of the load end contained both creep deformation and rebar extension. The first reason was the difference in the amount of the rebar extension between the ultimate and creep test loads. The second reason was the function of the estimate formula used, which was an exponential function. Applying the exponential function for the inorganic-type anchor with a small amount of creep deformation was thought to increase the error.

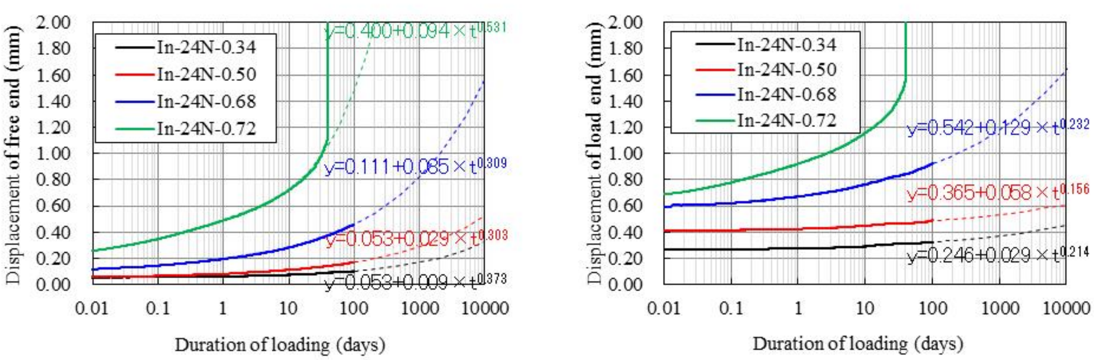
Table 5 and Fig. 6 present the relationships between the stress level and the difference of the displacement from 1 to 90 days. The variation in the displacement for the organic-type anchors became quite larger at a stress level of approximately more than 0.50. The displacement of the inorganic-type anchor became larger at a stress level of ~0.6–0.7. Assuming that the creep limits of the post-installed anchors were represented by the inflection points of the displacement curves in Fig. 6, the creep limit of the inorganic type was ~0.6–0.7, whereas that of the organic type was ~0.50. The compressive concrete creep failure was known to occur at a stress level larger than 0.70, which was consistent with these results. The creep limit of the inorganic-type anchor was likely higher than that of the organic type.



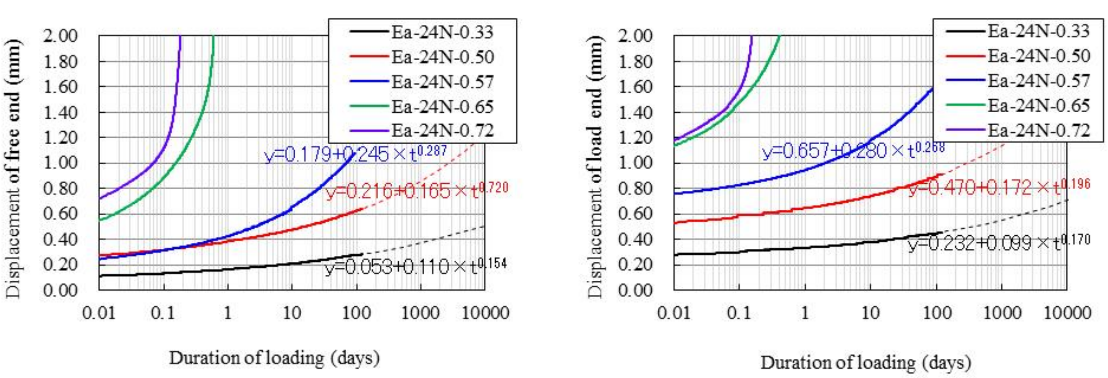
a) Inorganic-type creep deformation of 30 N/mm^2 concrete



b) Epoxy-type creep deformation of 30 N/mm^2 concrete



c) Inorganic-type creep deformation of 24 N/mm^2 concrete



d) Epoxy acrylate-type creep deformation of 24 N/mm^2 concrete

Fig. 5 – Relationships between the duration of loading and displacement

Table 5 – Relationships between the stress level and the variation in displacement

Symbol	Type of anchor	Displacement of the free end (mm)		
		1 day	90 days	Dif.*1
In-30N-0.30	Inorganic	0.052	0.052	0.000
In-30N-0.45		0.080	0.084	0.004
In-30N-0.59		0.174	0.232	0.058
Ep-30N-0.48	Epoxy	0.154	0.290	0.136
Ep-30N-0.54		0.446	1.058	0.612
Ep-30N-0.59		3.034	-	-
In-24N-0.34	Inorganic	0.062	0.100	0.038
In-24N-0.50		0.082	0.166	0.084
In-24N-0.68		0.196	0.450	0.254
In-24N-0.72		0.490	(1.793)*2	(1.303)*2
Ea-24N-0.33	Epoxy acrylate	0.164	0.272	0.108
Ea-24N-0.50		0.382	0.618	0.236
Ea-24N-0.57		0.426	1.066	0.640
Ea-24N-0.65		-	-	-
Ea-24N-0.72		-	-	-

*1: difference of the displacement between 1 and 90 days
*2: estimated value from Eq. (2)

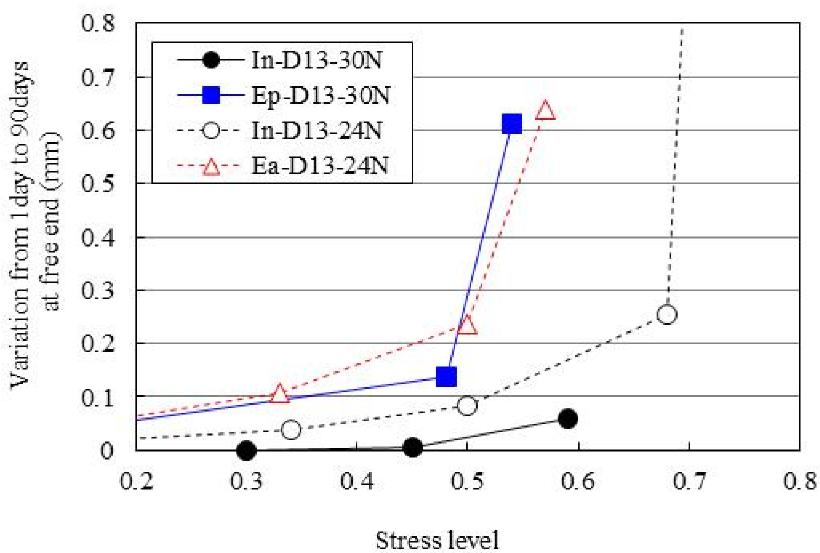


Fig. 6 – Relationships between the stress level and variation

4. Conclusions

The creep deformation of the inorganic- and organic-type post-installed bonded anchors was examined. The influences of the sustained load were also evaluated for the embedment length that was seven times the nominal diameter.

The slope of the load displacement curve at the time of the bond strength test and the beginning of the creep test was equivalent to about 1/3 of the ultimate load. The slope of the inorganic-type anchor was more than 1.5

times that of the organic type. The deformation by the load increased in several seconds for the creep test of the organic type at high-stress level tests.

The displacement of the inorganic type at the free end at the creep failure was 1.13 mm, whereas that of the organic type was about 3.5 mm. The displacements at the creep failure were about two times as large as that at the ultimate load regardless of the anchor type.

The displacement variations from 1 to 90 days were examined to estimate the creep limits. The variation in the displacement increased at a stress level of approximately more than 0.50. The displacement of the inorganic-type anchor increased at a stress level of ~0.6–0.7. Assuming that the creep limits of the post-installed anchors were represented by the inflection points of the displacement curves, the creep limit of the inorganic-type (In-24N) was ~0.6–0.7, whereas that of the organic type (Ea-24N) was ~0.50.

5. References

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