Evaluation of a Failure Capacity of an Anchor Foundation in the Case of a Seismic Event by Shaking Table Test

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SUMMARY
In this study, a shaking table test was performed for the evaluation of a failure capacity of an anchor foundation system in the case of an aged condition. For the shaking table test, three kinds of specimens were manufactured as follows: 1) a non-damaged anchor; 2) a specimen with cracks running through the anchor; and 3) a specimen with cracks along the expected corn-shape fracture away from the anchor. In the case of the non-damaged anchor and with cracks running through the anchor, failure mode was determined as failure of anchor steel. In the case of the cracks occurring away from the anchor, the concrete was fractured along the destructive surface with a smaller load than in the first and second cases. As a result, it can be concluded that a degradation of concrete foundation can affect to the seismic safety of nuclear facility.
Keywords: anchor foundation, aged condition, shaking table test, seismic capacity

1. INTRODUCTION

In this study, shaking table tests were performed for investigation of ultimate seismic capacity of concrete anchor foundation in Nuclear Power Plants. The anchor foundation is designed that it has enough capacity against that the earthquake can occur in Korea. But an aging related degradation caused by external load, variation of temperature, vibration/impact and other external environment conditions can effect to an ultimate capacity of concrete anchor foundation (NUREG/CR-5434, NUREG/CR-5463). Therefore in this study, the effect of cracks on the concrete foundation was investigated by using a shaking table test.

2. DVELOPMENT OF TEST MODEL

2.1. Overview

A test model was designed not for some special structure and equipment and a typical structure that can simulate concrete crack caused by aging related degradation. A concrete block was modelled for concrete foundation and steel anchor bolt used for fastening a super structure. Three kinds of specimens were manufactured as follows: 1) a non-damaged anchor; 2) a specimen with cracks running through the anchor; and 3) a specimen with cracks along the expected corn-shape fracture away from the anchor. In the case of super structure, I-type steel member and steel block were used. The super structure was designed as rigid body condition for determining the behaviour of anchor foundation.

2.2. Design of Concrete Foundation

For the developing a concrete foundation, block type concrete specimens were designed. The dimension of concrete specimen was 900mm×600mm×200mm and design strength was 280kg/cm^2. In the case of anchor bolt, M8 × 120mm type bolt was used and a buried length was 60mm. For the developing an artificial crack, a stainless steel sheet was inserted to concrete specimen. The drawing of concrete block was shown in Fig 1. For the determining of concrete compressive strength, 3 standard specimens were manufactured and compressive strength tests were performed. The compressive strength test results are shown in Table 1. As shown in Table 1, the ultimate compressive strength determined as about 20% higher than that of design strength.

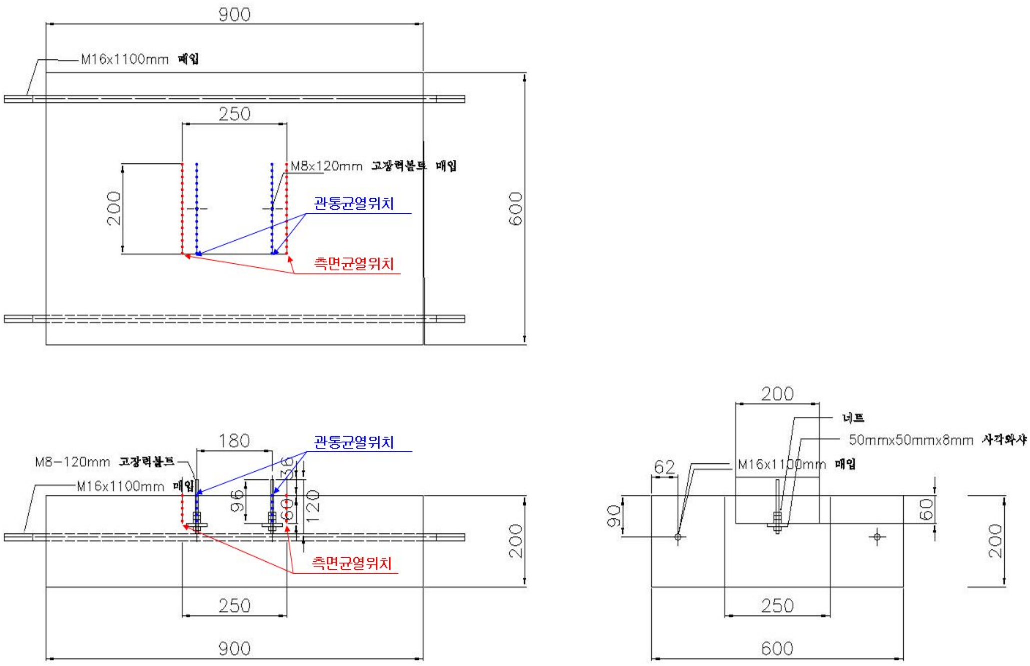


Figure 1. The drawing of Concrete Block

Table 1. The results of compressive strength test for standard concrete specimen

	Failure strength (MPa)	Dimension (mm×mm)	Nominal strength (MPa)
1	32.84	100x200	32.85 (335kg/cm^2)
2	32.35	100x200	32.36 (330 kg/cm^2)
3	34.31	100x200	34.32 (350 kg/cm^2)

For the determining expecting failure strength of concrete specimen, the methodology followed by ACI 349-01 was used as shown in Table 2. An artificial crack was only considered for calculation and a strength reduction factor was not considered for determine a real failure strength.

Table 2. Calculation of failure strength of anchor foundation (ACI 349-97, ACI 349-01)

Item		Equation	Results
Description of anchor bolt	specified tensile strength of anchor steel	$F_{uta} = 0.9 \cdot 100kgf / mm^2$	882.598 MPa
	effective cross-sectional area of anchor	$A_{se} = \frac{\pi \cdot (8mm)^2}{4}$	50.265mm2
	nominal strength in tension of a single anchor	$N_{sa} = A_{se} \cdot F_{uta}$	44.364 kN
specified compressive strength of concrete		$F_{ck} = 33MPa$	
effective anchor embedment depth		$h_{ef} = 60mm$	
coefficient for strength		$k_c = 10$	
projected concrete failure area of one anchor, for calculation of strength in tension		$A_{N_{co}} = 9 \cdot h_{ef}^2$	3.24x104 mm^2
concrete side-face blowout strength of anchor in tension		$A_{N_c} = 3 \cdot h_{ef}(1.5h_{ef} + 35mm)$	2.25x104 mm^2
modification factor, for strength in tension, to account for edge distances smaller than 1.5h_{ef}		$\psi_{edN} = 1$	
modification factor, for strength in tension, to account for cracking (no damage)		$\psi_{cN} = 1.25$	
modification factor, for strength in tension		$\psi_{edN} = 1$	
basic concrete breakout strength in tension of a single anchor in cracked concrete		$N_b = k_c \cdot \sqrt{f_{ck}} \cdot h_{ef}^{1.5}$	26.698 kN
nominal concrete breakout strength in tension of a single anchor (no damage)		$N_{cbn} = \frac{A_{N_c}}{A_{N_{co}}} \cdot \psi_{edn} \cdot \psi_{cn} \cdot \psi_{cpN} \cdot N_b$	33.373 kN
nominal concrete breakout strength in tension of a single anchor (side crack)		$N_{cbn} = \frac{A_{N_c}}{A_{N_{co}}} \cdot \psi_{edn} \cdot \psi_{cn} \cdot \psi_{cpN} \cdot N_b$	23.176 kN

2.3. Description of Test Mode

A super structure developed using 2 of 400kg steel block and I-type steel beam used as vertical column. The column was fastening to concrete foundation block by using an anchor bolt. The drawing of super structure and the shape of whole test model are shown in Fig 2 and 3. The dimension of each part of test model and the location of mass centre are summarized in table 3.

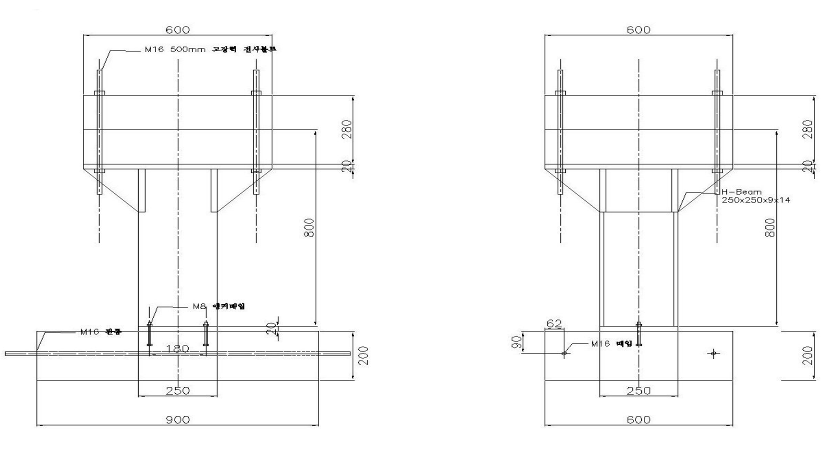


Figure 1. The drawing of test model

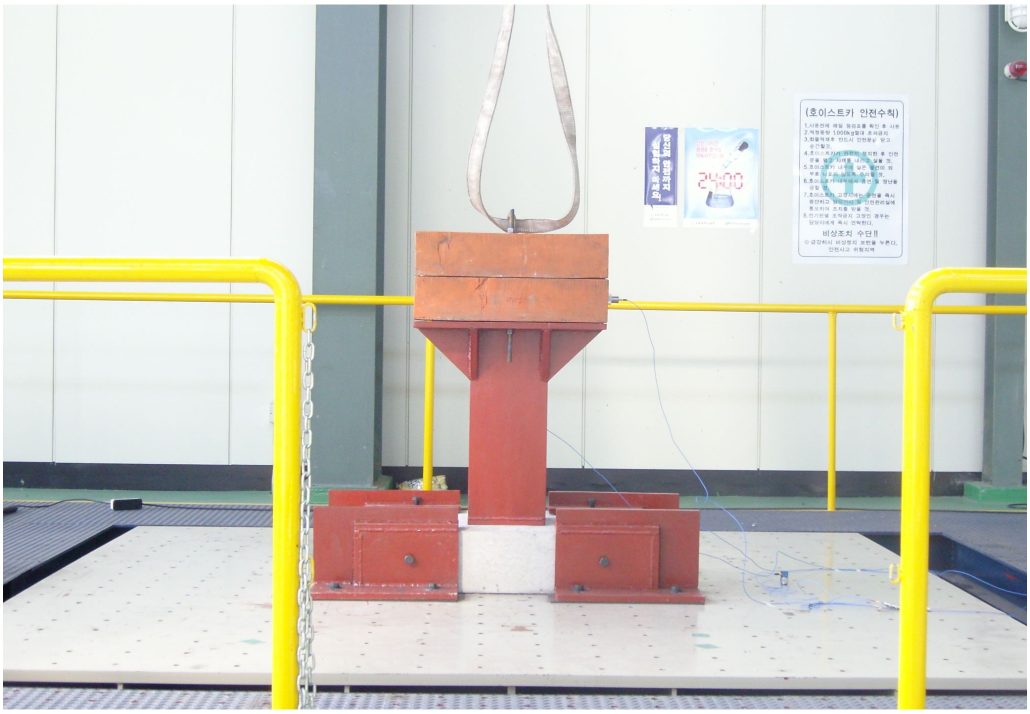


Figure 1. The shape of test model

Table 3. Dimension of test model and mass centre

	Mass (kg)	Centroid from the floor (m)
Steel block	800.00	0.80
Supporter	56.52	0.65
Vertical member	19.23	0.58
Horizontal member	8.40	0.48
I-beam	46.34	0.32
Anchor bolt connecter	8.40	0.01
Total	938.89	0.753

3. SHAKING TABLE TEST

3.1. Measurement System

The overview of measurement system is shown in Fig. 4. Accelerometers are connected to data acquisition system. As shown in Fig. 4, there are 4 accelerometer used for acceleration measurement at the position of P1 ~P4. The position of P1, P2, P3 and P4 are a mass centre, centre of column, centre of concrete block and floor of asking table, respectively. The dimensions of 1 dimensional shaking table are summarized in Table 4.
For the evaluation of the dynamic characteristic of target experimental model, an impact hammer test was performed. Through the impact hammer test, a frequency response function was measured and a transfer function was determined.

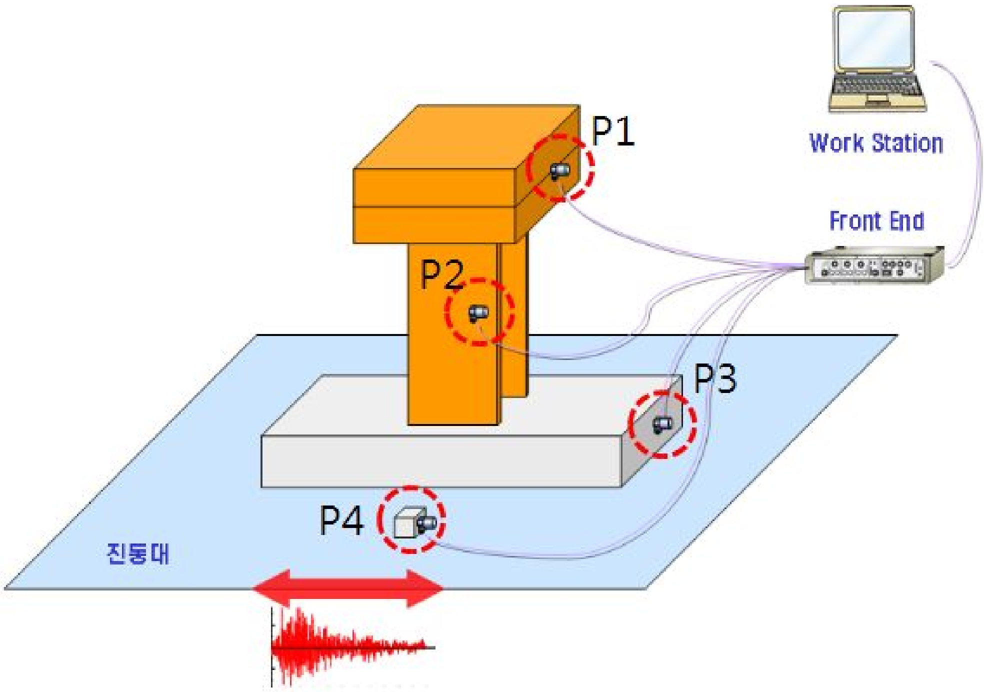


Figure 1. Measurement system of test model

Table 4. Specification of shaking table

Structure of shaking table	Actuator	40 tonf
	Seismic Mass	60 tonf
	Air Spring	12 tonf x 6ea
	System Frequency	2.0 Hz
Capacity of shaking table	Size	3.0 m x 3.0 m
	Maximum test capacity	10 tonf
	Maximum acceleration	1 g
	Maximum displacement	300 mm

3.2. Shaking Table Test

A shaking table test was performed by using an artificial seismic motion developed based on US NRC Reg. Guide 1.60 design spectrum (1973). The seismic input motion for shaking table test was gradually increased till a test model was failed. When the test model was failed according to gradually increased shaking table test, one more shaking table test was performed of new test model for failure acceleration level because of the investigation of fatigue or damage effect during shaking table test. The shaking table test was started as 0.1g PGA level of artificial acceleration time history. In the case of 0.1g PGA level shaking table test defined as loading condition 1. Therefore a PGA level 0.4g shaking table test is defined as loading condition 4.

4. TEST RESULTS AND INVESTIGATION

4.1. Test Results

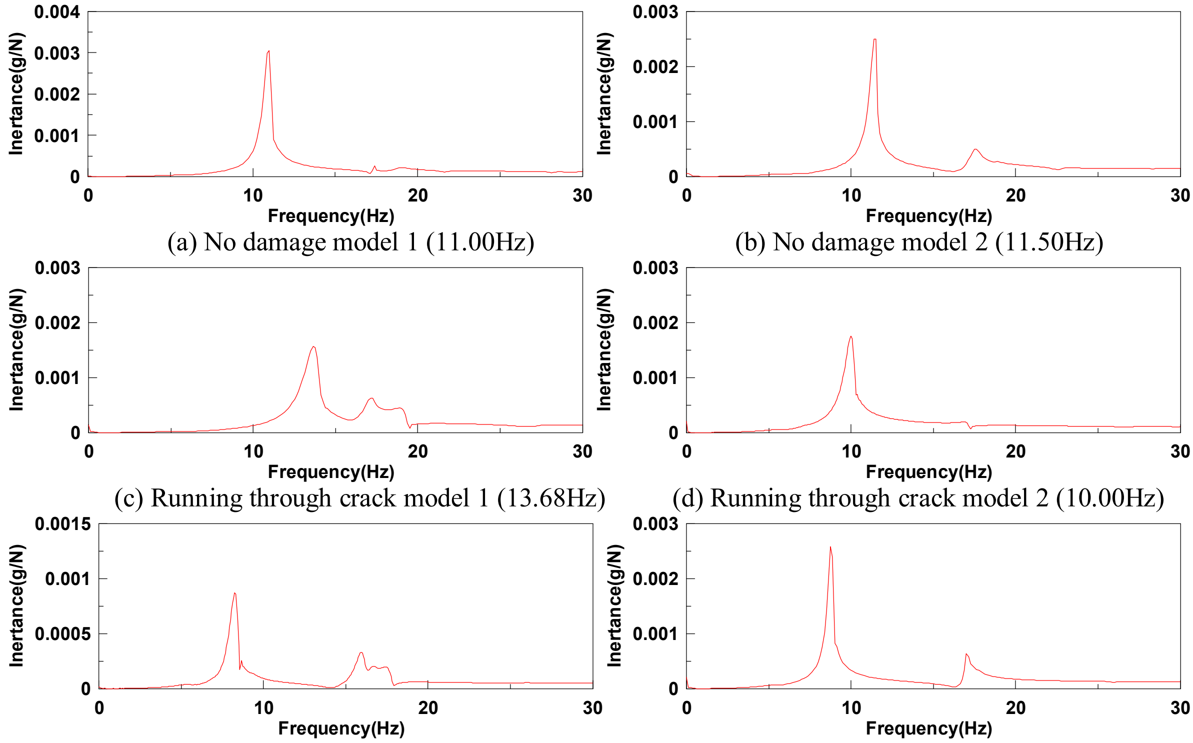
The results of impact hammer tests and shaking table tests are summarized in Table 5. A first mode frequency of the Table 5 represents that a results of an impact hammer test. This impact hammer test was performed after installed a test model and before a shaking table test. As shown in Table 5, in the case of no damage model, anchor bolt tensional failure occurred at loading case 7 when gradually increased loading condition and peak loading condition. Also, in the case of running through crack condition, same anchor bolt tensional failure occurred at the same loading condition. It can be noticed that the running through crack not much affect to the capacity of anchor foundation. Otherwise, in the case of side crack model, concrete breakout failure occurred at the loading condition 4. The 1st mode frequency was little lower than that of no damage model and running through cracked model. The capacity of anchor foundation was decreased because the side crack. The anchor bolt tensional failure and concrete breakout failure shape are shown in Fig. 5.

Table 5. The results of impact hammer test and shaking table test

Test Model	Test condition	Loading condition	PGA (P4, g)	Failure acceleration (P1, g)	Failure mode	1st mode frequency
No damage	Gradually increased loading condition	4	0.49			11.00
		5	0.54			
		6	0.67			
		7	0.82	1.28	Bolt tensional failure	
	Peak loading condition	7	0.79	1.47	Bolt tensional failure	11.50
Running through crack	Gradually increased loading condition	4	0.46			13.63
		5	0.52			
		6	0.67			
		7	0.80	1.42	Bolt tensional failure	
	Peak loading condition	7	0.82	1.39	Bolt tensional failure	10.00
Side crack	Gradually increased loading condition	3	0.38			8.25
		4	0.46	0.95	Concrete breakout	
	Peak loading condition	4	0.45	1.06	Concrete breakout	8.75

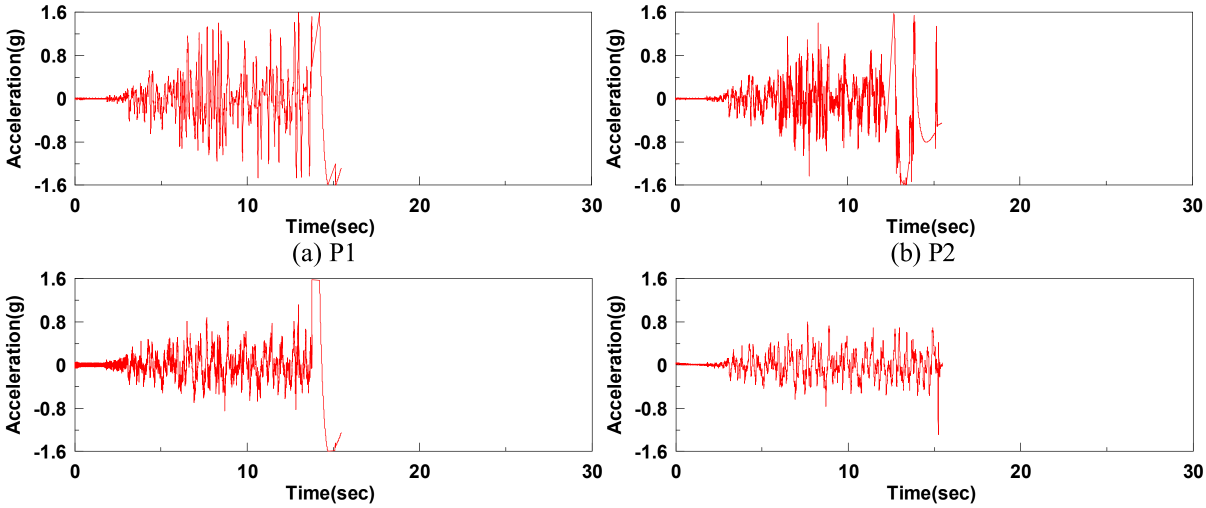
Figure 5. The failure shape of anchor bolt tensional and concrete breakout

The results of impact hammer test for evaluation of 1st mode frequency are shown in Fig. 6. The acceleration time history results of shaking table tests are shown in Fig. 7 to Fig. 9. As shown in Fig. 7 ~ Fig 9, in the case of anchor bolt tensional failure, it can be clearly noticed that the breaking point but in the case of concrete breakout failure, it is very difficult to find a breaking time. But the frequency of acceleration response clearly reduced after concrete break failure.



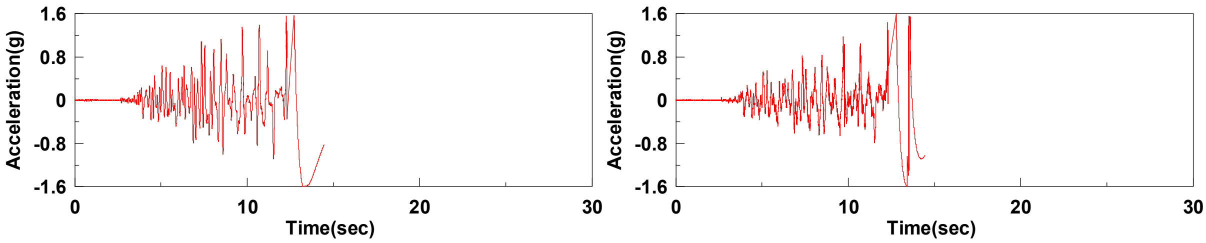
(a) No damage model 1 (11.00Hz)
(b) No damage model 2 (11.50Hz)
(c) Running through crack model 1 (13.68Hz)
(d) Running through crack model 2 (10.00Hz)
(e) Side crack model 1 (1st mode: 8.25Hz)
(f) Side crack model 1 (1st mode: 8.75Hz)

Figure 6. The results of impact hammer test



(a) P1
(b) P2
(c) P3
(d) P4

Figure 7. The acceleration time history response of no damage model



(a) P1
(b) P2

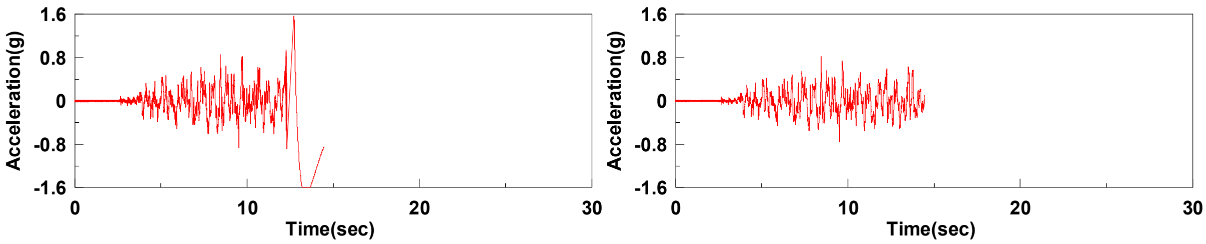


Figure 8. The acceleration time history response of running through crack model

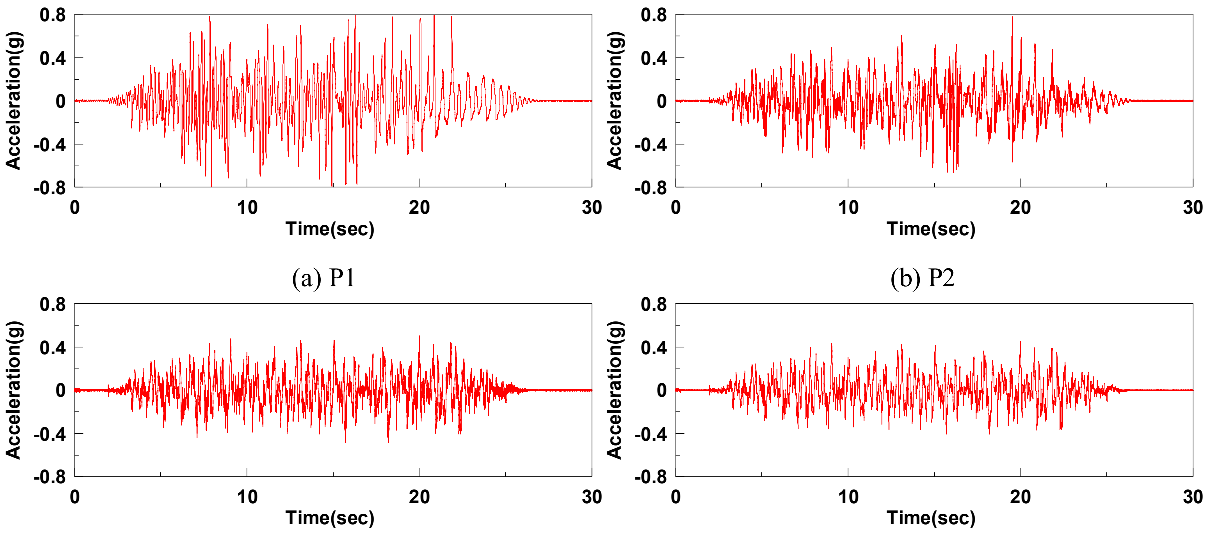


Figure 9. The acceleration time history response of side crack model

4.2. Investigation of Test Results

The compare of the shaking test results and design expectation are summarized in Table 6. As shown in Table 6, in the case of anchor bolt tensional failure, the expect failure loading are similar to experimental results. But in the case of concrete breakout failure, a failure loading of experiments are almost 1.5 times greater than that of expect. That because the material uncertainties of concrete are much higher than that of steel. And the strain rate effect can increase the failure loading of concrete foundation (Malvar and Allen, 1998).

Table 6. The comparison of shaking table test and design expect

	No damage model	Running through crack model	Side crack model
Failure mode (experiment)	Anchor bolt tensional failure	Anchor bolt tensional failure	Concrete breakout failure
Failure mode (expect)	Concrete breakout failure	Concrete breakout failure	Concrete breakout failure
Failure loading of shaking table test (kN)	47.408	44.828	34.186
Failure loading of design expect (kN)	44.364	44.364	23.176
experiment/design	1.067	1.010	1.475

5. RESULTS

In this study, a shaking table test was performed for the evaluation of the failure capacity of an anchor foundation system in the case of an aged condition. For the shaking table test, three kinds of specimens were manufactured as follows: 1) a non-damaged anchor; 2) a specimen with cracks running through the anchor; and 3) a specimen with cracks along the expected corn-shape fracture away from the anchor. In the case of the non-damaged anchor and with cracks running through the anchor, failure mode was determined as failure of anchor steel. In the case of the cracks occurring away from the anchor, the concrete was fractured along the destructive surface with a smaller load than in the first and second cases.
Through this study, it can be concluded that a running through crack not affect to the ultimate capacity of concrete anchor foundation, but a side crack along the destructive surface make the ultimate capacity of concrete anchor foundation. Also, the concrete anchor foundation has enough safety margins for sustaining a seismic loading.

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