Project on 3-D Full-Scale Earthquake Testing Facility
(The Fifth Report)

By

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ABSTRACT

The construction of "E-Defense" planed by NIED completed on March end 2005.
This paper presents the outline result of performance test of the earthquake testing facility carried out from April 2004 to March 2005.
The performance test was carried out about the performance determined by the structural factors and the performance determined mainly by the method of control, and a control parameter.
The performance test result has fully satisfied plan specification, and can expect that a useful result will be obtained also in the full-scale experiment started from June, 2005.

KEYWORDS:

E-Defense
Control performance
Sine wave reappearance
Seismic wave reappearance

1. INTRODUCTION

Many human lives were taken by collapse of a building in the Hyogo southern earthquake (Kobe earthquake disaster) which occurred on January 17, 1995. Needing the design of the building which can protect only a human life at the time of occurrence of a big earthquake, even if it allows damage of the building of a certain quantity has newly been recognized. Based on this recognition, E-Defense was planed and completed on March, 2005.E-defense can shake the actually near size structure by various seismic waves, and can analyze, record and analyze process of the structure collapses process scientifically. And the experiment result becomes possible to the effective reinforcement method of the existing structure, and the design method to the structure built newly. This paper has described the outline of the performance test result performed for April, 2004 to about one year.

2. OUTLINE OF E-DEFENSE

Photo 1 shows the complete view of E-DEFENSE, and Photo 2 shows the section view of it.

Photo 1

Photo 2

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1) Executive Director, NIED
2) Director, E-Defense
3) Chief, E-Defense
4) Deputy Manager, E-Defense

Table 1 shows main specification of E-DEFENSE.

Table 1

Item	Specification	
Loading Capacity	1,200ton	
Table Size	20m×15m	
Driving Type	Accumulator Charged Electo-Hydrolic Servo Control	
Shaking Direction	Horizontal	Vertical
Max. Acceleration (At Max. Loading)	More than 900cm/s^2	More than 1,500 cm/s^2
Max. Velocity	200cm/s	70cm/s
Max. Displacement	±100cm	±50cm
Max. Allowable Moment	Overturning	Yawing
	More than 150MN・m (At Vertical 980cm/s^2 Shaking)	More than 40MN・m (At Vertical 980cm/s^2 Shaking)

3. OUTLINE OF THE PERFORMANCE TEST RESULT

The performance test carried out the "fundamentality ability test" and the "control performance test."

3.1. Fundamentality ability test

In the fundamentality ability test, the performance was checked about the following 11 items determined by structural specification.

(1) Maximum loading capacity
(2) Maximum displacement
(3) Maximum velocity
(4) Maximum velocity continuation time
(5) Maximum velocity at continuous shaking
(6) Maximum acceleration
(7) Rotating shaking
(8) Allowable overturning moment
(9) Allowable yawing moment
(10) Shaking limitation
(11) Allowable input frequency

Here, performance test result of (10) Shaking limitation is introduced among the above-mentioned examinations.

3.1.1. Test result of X axis shaking limitation

Figure 1 shows X axis shaking limitation.
Figure 2 and 3 show the test result of the maximum velocity at Point 1, of the maximum acceleration at Point 2 in Figure 1.

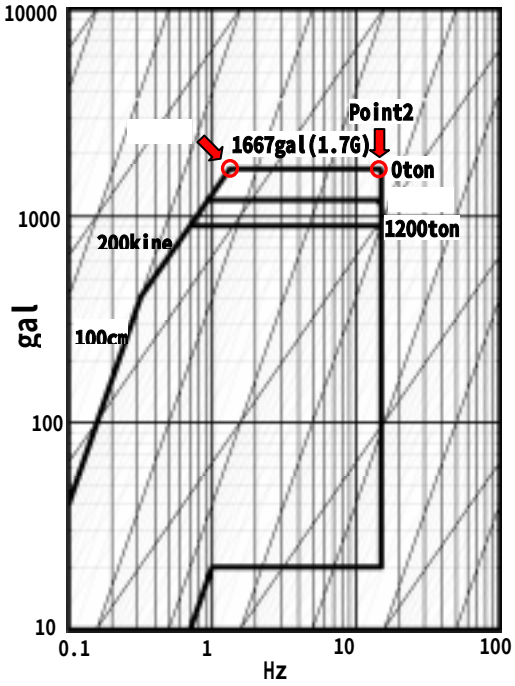
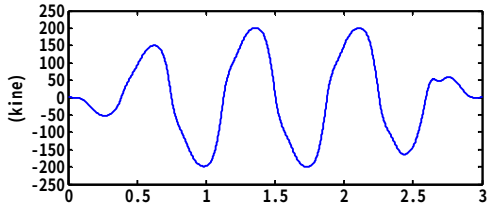
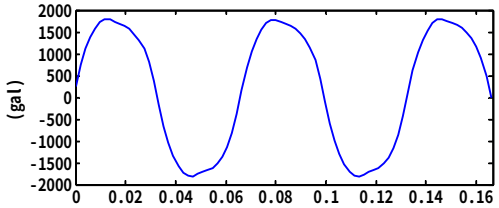


Figure 1



(Max. 200.6cm/s Min. -200.5cm/s at 1.33Hz)

Figure 2



(Max. 1797.7gal Min. -1808.5gal at 15Hz)

Figure 3

3.1.2. Test result of Y axis shaking limitation

Figure 4 shows Y axis shaking limitation.
Figure 5 and 6 show the test result of the maximum velocity at Point 1, of the maximum acceleration at Point 2 in Figure 4.

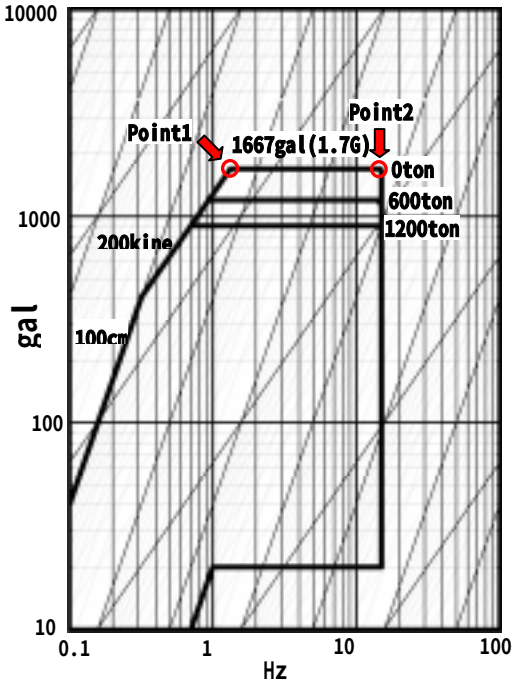
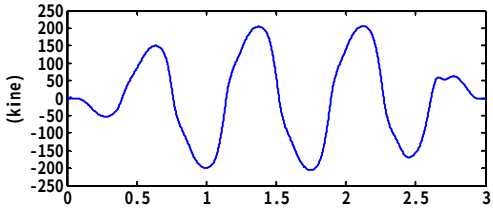
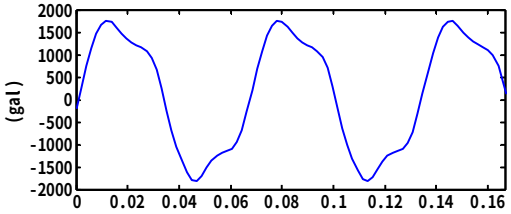


Figure 4



(Max. 205.3cm/s Min. -205.7cm/s at 1.33Hz)

Figure 5



(Max.1750.2gal Min. -1823.2gal at 15Hz)

Figure 6

3.2. Control performance test.

In the control performance test, the performance was checked about the following eight items determined by the method of control, and adjustment of a control parameter.

(1) Static displacement error
(2) Cross talk of static displacement
(3) Dynamic stability
(4) Dynamic response
(5) Reappearance of sine wave
(6) Reappearance of sweep wave
(7) Reappearance of seismic wave
(8) Reappearance of random wave

Here, performance test result of (4) Dynamic response, (5) Reappearance of sine wave and (7) Reappearance of seismic wave is introduced among the above-mentioned examinations.

3.2.1. Test result of dynamic response

Figure 7 and 8 show the test result of X and Z axis compensated dynamic response.

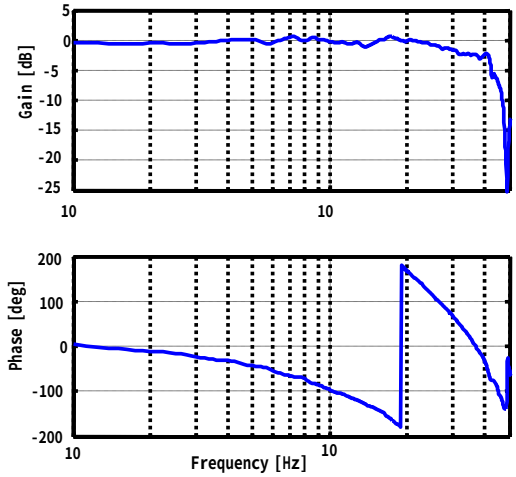


Figure 7

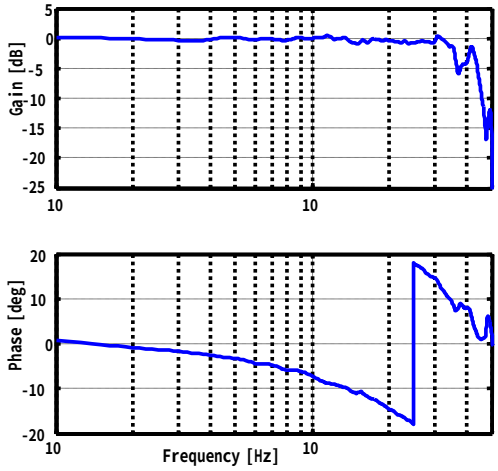


Figure 8

All of the amplitude characteristics are under ±2dB bellow 20Hz, and having the good frequency characteristic was confirmed.

3.2.2. Test result of reappearance of sine wave

In the reappearance examination of sine wave, evaluation of the reappearance was performed by harmonic distortions of acceleration waveform and the dynamic cross-talk ratio.

(1) Evaluation formula of harmonic distortions of acceleration waveform

$=((Arsp\_a_2^2+Arsp\_a_3^2+\cdots.+Arsp\_a_{10}^2)^{1/2}\div Arsp\_a_1)\times 100\%$

Where,

$Arsp\_a_1(cm/s^2)$: amplitude of primary acceleration wave

Arsp_a2~ Arsp_a10(cm/s2) :amplitude of from secondary to tenth acceleration wave (under 100Hz)

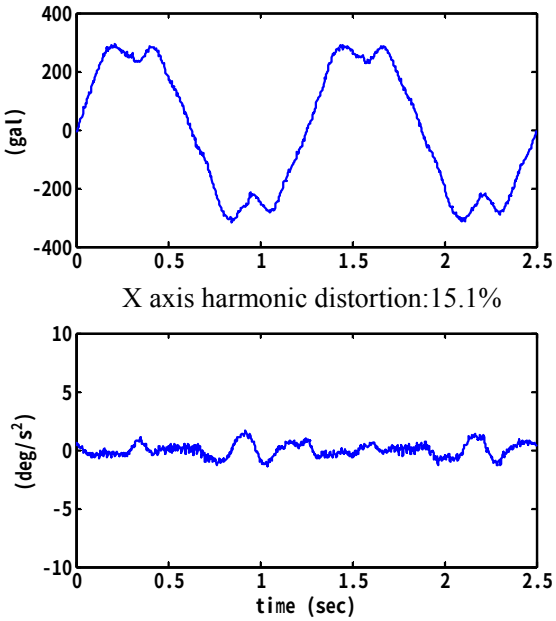
(2) Evaluation formula of dynamic cross-talk ratio.

$=(Arsp\_b_1\div Atgt\_a_1)\times 100\%$

$Arsp\_b_1$ (cm/s^2) : amplitude of cross-talk primary acceleration wave

$Atgt\_a_1(cm/s^2)$: amplitude of primary acceleration wave

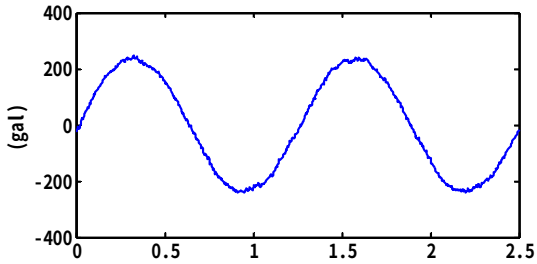
Figure 9~12 show the examples of the reappearance sine wave test results



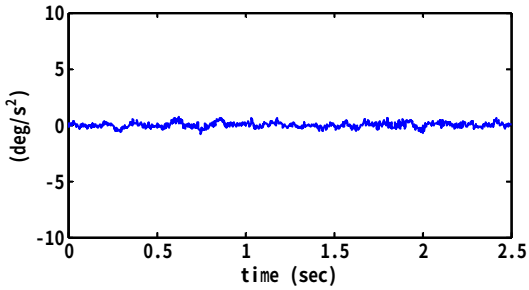
X axis harmonic distortion:15.1%

Yaw axis dynamic cross-talk ratio:0.39%

Figure 9
(X axis 0.8Hz 300gal under the basic control)

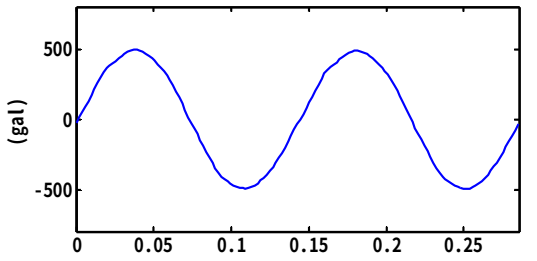


X axis harmonic distortion:5.2%

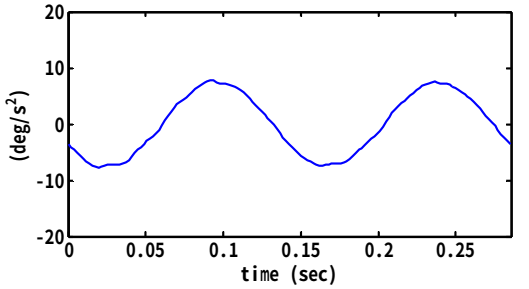


Yaw axis dynamic cross-talk ratio:0.19%

Figure 10
(X axis 0.8Hz 300gal under the wave compensation control)

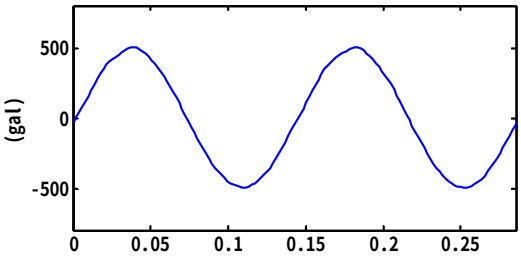


X axis harmonic distortion:2.7%

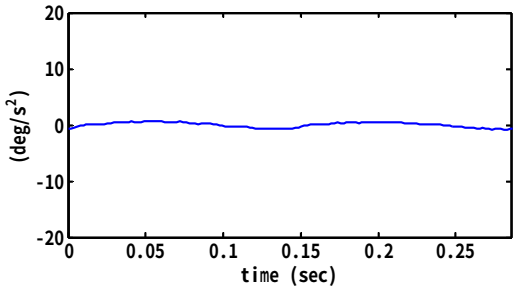


Yaw axis dynamic cross-talk ratio:46.38%

Figure 11
(X axis 7Hz 500gal under the basic control)
X axis harmonic distortion:2.7%



X axis harmonic distortion:1.0%



Yaw axis dynamic cross-talk ratio:2.25%

Figure 12
(X axis 7Hz 500gal under the wave compensation control)

The total test results are showed in Table 2.
Where,
CASE1:under the basic control
CASE2:under the wave compensation control

Table 2

	X axis 0.8Hz 300gal		X axis 7Hz 500gal	
	CASE1	CASE2	CASE1	CASE2
Acc. Harmonic Distortion (%)	15.14	5.23	2.67	1.04
Y axis Dynamic Cross-talk Ratio(%)	1.38	0.17	4.71	0.52
Z axis Dynamic Cross-talk Ratio(%)	0.23	0.02	0.71	0.03
Rolling axis Dynamic Cross-talk Ratio(%)	0.33	0.08	1.55	0.06
Pitching axis Dynamic Cross-talk Ratio(%)	2.34	0.05	11.29	0.49
Yawing axis Dynamic Cross-talk Ratio(%)	0.39	0.19	46.38	2.25

3.2.3. Test result of reappearance of seismic wave

In the reappearance examination of seismic wave, evaluation of the reappearance was performed by the bellow items.

(1) Acceleration error in time history
Evaluation was performed by bellow formula.
$TWerr = (\Sigma(TWrsp-TWtgt)^2/\Sigma TWtgt^2)\times 100\%$
Where,
TWerr :error of acceleration(%)
TWrsp :response acceleration(cm/s^2)
TWtgt :target acceleration(cm/s^2)

(2) Acceleration energy spectrum density error
Evaluation was performed by bellow formula.
$ESerr = (\Sigma(ESrsp-EStgt)^2/\Sigma EStgt^2)\times 100\%$
Where,
ESerr :acceleration energy spectrum density error
ESrsp :response acceleration energy spectrum density ($((cm/s^2)^2/Hz^2)$)
EStgt :target acceleration energy spectrum density ($((cm/s^2)^2/Hz^2)$)

(3) Acceleration response spectrum error
Evaluation was performed by bellow formula.
$RSerr = (\Sigma(RSrsp-RStgt)^2/\Sigma RStgt^2)\times 100\%$
Where,
RSerr : acceleration response spectrum error
RSrsp :response acceleration spectrum (cm/s^2)
RStgt :target acceleration spectrum(cm/s^2)

(4) Dynamic cross-talk
Evaluation was performed by bellow formula.
- Rolling ratio : $\varphi r=L\times\varphi acc/Yaccp$
- Pitching ratio : $\theta r=L\times\theta acc/Xaccp$
- Yawing ratio : $\psi r=L\times\psi acc/XYaccp$

Where,
L : distance from the center to the edge of shaking table(cm)
Φacc :response angle acceleration of rolling axis(rad2/s2)
Θacc :response angle acceleration of pitching axis(rad2/s2)
Ψacc :response angle acceleration of yawing axis (rad2/s2)
Xaccp:peak value of X axis response acceleration in time history(cm/s2)
Yaccp:peak value of Y axis response acceleration in time history(cm/s2)

XYaccp:peak value of composite acceleration between X axis and Y axis in time history(cm/s2)

(5) Error of phase between shaking axis

By Fourier transform of the waveform, the phase was computed, and then it asked for the phase difference of a target wave and a response wave.
And the phase difference between axes was evaluated by the obtained phase difference.
Figure 13 and 14 show the test result of reappearance of seismic wave observed Kobe Marine Observatories.

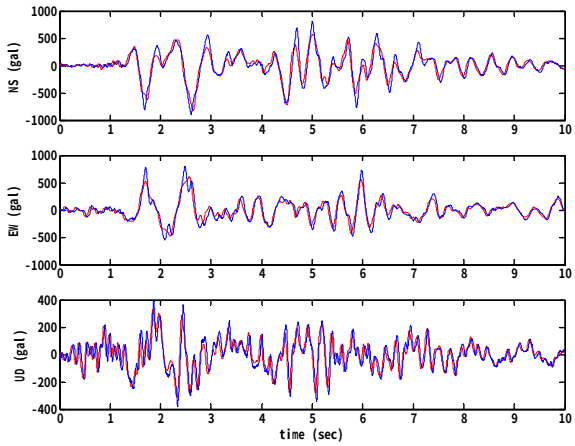


Figure 13 (under basic control)
Red line: target wave
Blue line: response wane

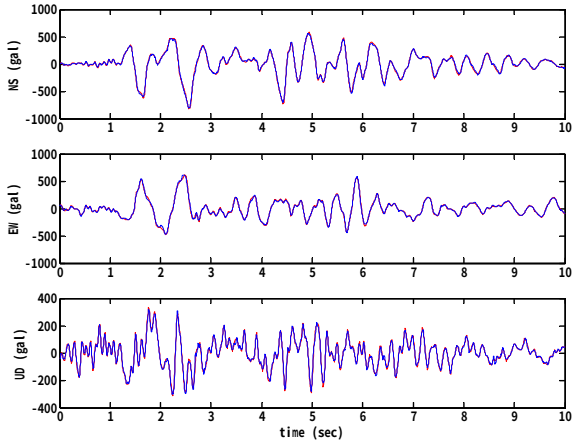


Figure 14
(under the wave compensation control)

The total test results are showed in Table 3.
Where,
CASE1:under the basic control
CASE2:under the wave compensation control

Table 3

		CASE1	CASE2
Acc. error in time history(%)	X axis	12.48	0.68
	Y axis	10.88	0.68
	Z axis	6.17	1.13
Acc. energy spectrum density error (%)	X axis	7.78	0.33
	Y axis	4.85	0.43
	Z axis	1.40	0.44
Acc. response spectrum error (%)	X axis	3.05	0.07
	Y axis	3.27	0.07
	Z axis	0.87	0.09
Dynamic cross-talk (%)	Roll	6.94	14.07
	Pitch	7.86	8.71
	Yaw	20.18	4.07
Error of phase between axis (sec)		0.002	0.0

4. CONCLUSION

By the above examination result, it has checked satisfying the required specification of this equipment. Moreover, it has also checked satisfying wave-shape reappearance of a target performance.
In a load loading examination, the further performance check is due to be performed from now on.