

Seismic estimation of a stone lantern using 3-D DEM analysis and shaking table test

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Introduction

A stone construction like a lantern and a gravestone is a simple unstable structure which stacked stones. So the damage of a stone lantern caused by the earthquake has occurred mostly. It is necessary to take the prevention from a fall of a lantern into consideration because the fall of a lantern is very dangerous.



Introduction

Seismic Estimation of the stone lantern is not evaluated in Japan.



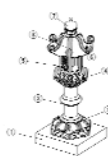
The effect of reinforcement will not be enough and a lantern will fall.

In this study, we estimate the seismic performance of a stone lantern using **3-D DEM analysis** and **real scale shaking table test**, and evaluate the seismic resistance of the reinforced lantern.

Shaking Table Test using Real Scale Lantern

Shaking Table Test

Type of Stone Lanterns
Slender Type (Kasuga Tourou)
Top-Heavy Type (Shinzen Tourou)



Kasuga Tourou



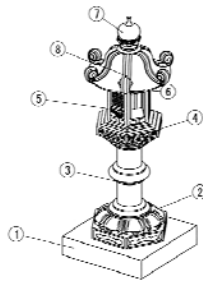
Shinzen Tourou

Shaking Table Test

Cases
Non-Reinforcement Lantern
Reinforcement Lantern
(Inner-Steel Pipe Penetrated)



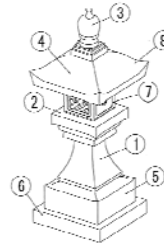
Parameter of Kasuga Tourou



Height (mm)	1,870
Weight (N)	5,723.2

	Size (mm)		
	Width	Length	Height
① Shiba-Dai	700	700	150
② Daiza	600	520	180
③ Hashira	300	300	580
④ Hibukuro-Uke	520	450	160
⑤ Hibukuro	340	294	320
⑥ Itaishi	320	277	180
⑦ Giboshi	180	180	250
⑧ Kasa	700	619	230

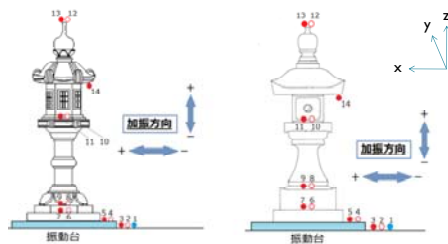
Parameter of Shinzen Tourou



Height (mm)	1,800
Weight (N)	6,752.2

	Size (mm)		
	Width	Length	Height
① Hashira	374	374	439
② Hibukuro-Uke	439	439	163
③ Giboshi	179	179	309
④ Itaishi	293	293	154
⑤ Naka-Dai	520	520	228
⑥ Shiba-Dai	660	660	205
⑦ Hibukuro	293	293	260
⑧ Kasa	683	683	325

Measurement of Specimen



○	x方向
●	y方向
●	z方向

Reinforcement Lantern



Kasuga Tourou



Shinzen Tourou

Strength of Stone and Reinforcement Equipments

	N/cm ²	
	圧縮	引張、曲げ
石材: 御影石	6000	640
ボルト: SUS304	23500	23500
鉄筋: SD295A	29500	29500

Shaking Table Test

Earthquake Motions

Sine Wave ▪ **Kasuga Tourou** : 1.5Hz and 9.0Hz(100~400gal)
Shinzen Tourou : 4.0Hz and 7.5Hz(100~400gal)

Type of Earthquake Motions

JMA-Kobe (NS and UD)

(1995 Hyogoken Nambu Earthquake)

K-NET Ichinoseki (NS and UD)

(2008 Iwate-Miyagi Internal Earthquake)

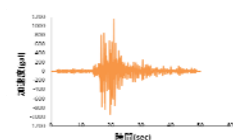
Shaking Table Test (Earthquake Motions)

1995 Hyogoken Nambu Earthquake

<NS Component>

Max Acc. : **1,152gal**

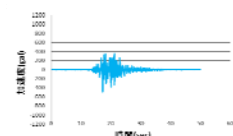
Mac Vel. : **102kine**



<UD Component>

Max Acc. : **357gal**

Mac Vel. : **36kine**



Shaking Table Test (Earthquake Motions)

2008 Iwate-Miyagi Internal Earthquake

<NS Component>

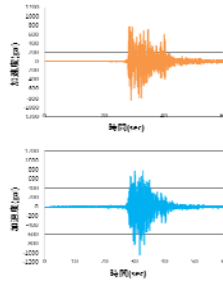
Max Acc. : 833gal

Mac Vel. : 54kine

<UD Component>

Max Acc. : 1,032gal

Mac Vel. : 38kine



Test Result(Kasuga: Non-reinforcement)

JMA-Kobe (50%) : Felt down with rocking, rotation and sliding



Before Test



Shaking



After Test

Test Result(shinzen: Non-reinforcement)

JMA-Kobe (50%) : Rocking and rotating occurred at column, but specimen did not fall down.



Before Test



Shaking



After Test

Test Result(shinzen: Non-reinforcement)

JMA-Kobe (70%) : Felt down with rocking and sliding except rotating.



Before Test



Shaking



After Test

Test Result (Kasuga: Reinforcement)

JMA-Kobe : Rocking and rotating occurred a little at Hibukuro-uke, but specimen did not fall down.

Ichinoseki : Severe rocking occurred at Hibukuro-uke. Specimen did not fall down but minor damaged and cracked at a column.



Test Result (Shinzen: Reinforcement)

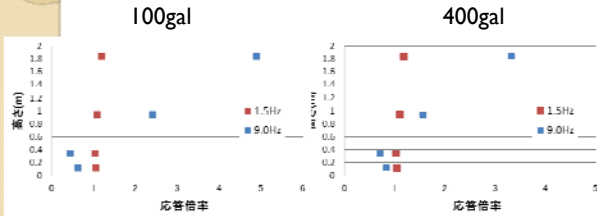
神戸波 : Rocking and rotating occurred a little at Hibukuro-uke, but specimen did not fall down.

一関波 : Severe rocking occurred at Hibukuro-uke. Specimen did not fall down.



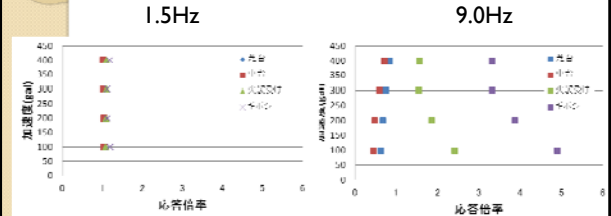
Test Result (Kasuga: Reinforcement)

Sine Wave NS Component



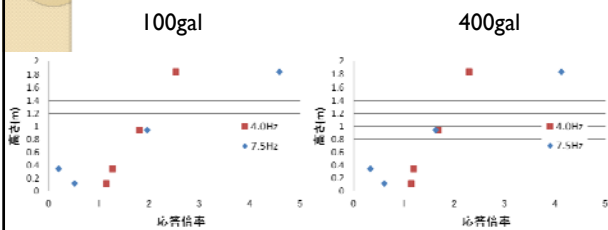
Test Result (Kasuga: Reinforcement)

Sine Wave NS Component



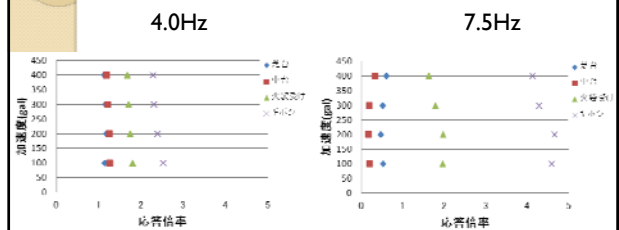
Test Result (Shinzen: Reinforcement)

Sine Wave NS Component

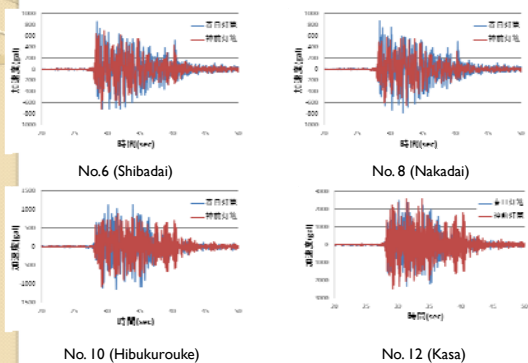


Test Result (Shinzen: Reinforcement)

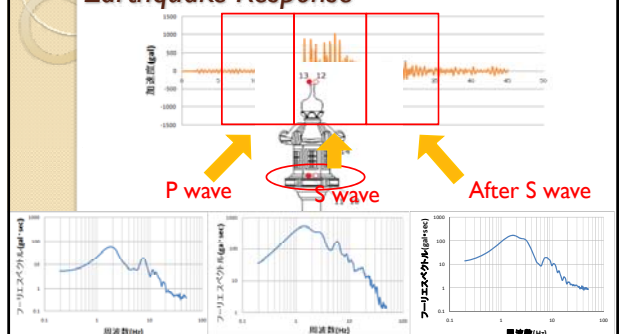
Sine Wave NS Component



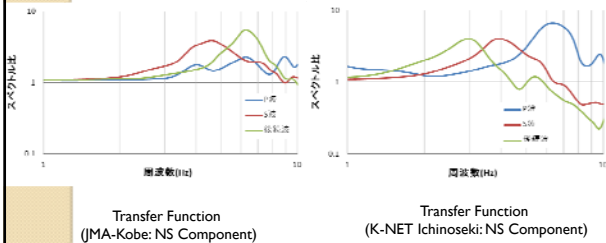
Test Result (Earthquake Motions)



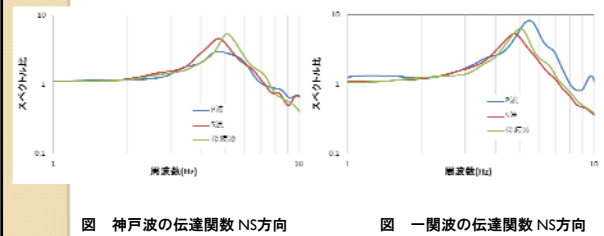
Spectral Characteristics of Earthquake Response



Test Result (Kasuga: Reinforcement)



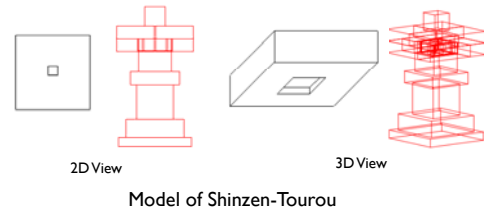
Test Result (Shinzen: Reinforcement)



Earthquake Response Analysis Using 3-D DEM

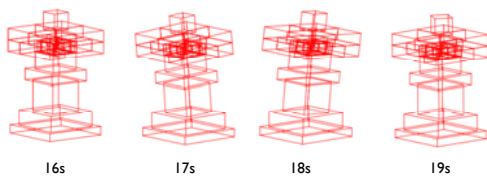
Analytical Model

In order to create a simple model, a component is expressed in a rectangular parallelepiped. The part which is carrying out form with the complicated hole which inserts an axis is expressed by combination of two or more rectangular parallelepipeds.



Analytical Results

Non-Reinforcement : JMA-Kobe(50%)

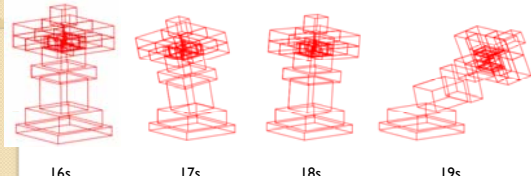


Experiment : Rocking and rotating occurred at column, but specimen did not fall down.

Analysis : Rocking occurred at column, but specimen did not fall down.

Analytical Results

Non-Reinforcement : JMA-Kobe(70%)

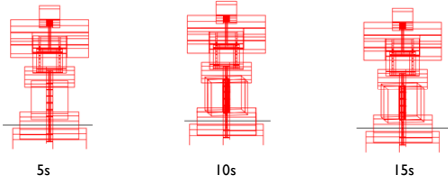


Experiment : Felt down with rocking and sliding except rotating.

Analysis : Same result as a experiment and direction of falling down is also same.

Analytical Results

Reinforcement : K-NET Ichinoseki

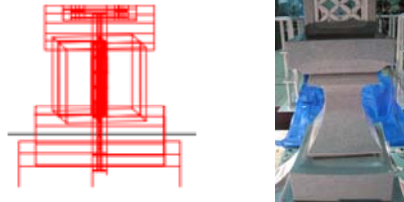


Experiment : Minor rocking and rotating occurred at column, but specimen did not fall down.

Analysis : Same result as a experiment and direction of rotation is also same.

Analytical Results

Reinforcement : K-NET Ichinoseki

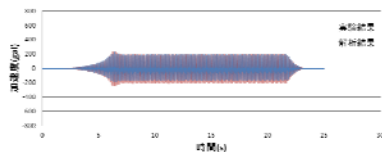


Experiment : Minor rocking and rotating occurred at column, but specimen did not fall down.

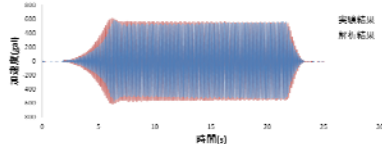
Analysis : Same result as a experiment and direction of rotation is also same.

Analytical Results

Sine Wave 7.5Hz NS Component



Response Acceleration at Shiba-dai

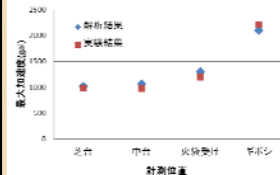


Response Acceleration at Hibukuro-Uke

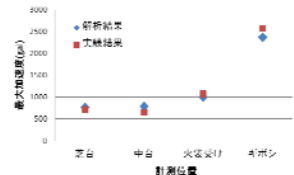
Analytical Results

	Response Acceleration(gal)	
	Experiment	Analysis
Shiba-Dai	1,014	975
Naka-Dai	1,064	970
Hibukuro-Uke	1,300	1,195
Giboshi	2,102	2,205

	Response Acceleration(gal)	
	Experiment	Analysis
Shiba-Dai	762	721
Naka-Dai	788	648
Hibukuro-Uke	998	1,075
Giboshi	2,373	2,574



Maximum Acceleration of JMA-Kobe



Maximum Acceleration of K-NET Ichinoseki

Remarks

1. Non-reinforce lanterns cannot prevent falling down even in 50% revel JMA-Kobe Earthquake. It is required to reinforce a lantern.
2. This reinforce method which let axis pass in a specimen have effect sufficiently. But some cracks and breaks is verified at Kasuga-Tourou.
3. This reinforce method cannot effect prevention of rocking sufficiently.
4. Natural frequency of lanterns are about 5Hz.
5. Natural frequency of lanterns become fall because of rocking.
6. The frequency characteristic changes with a kind of earthquake motion in Kasuga-Tourou.

Thank you!
謝謝!