Study on Earthquake Response of Refueling Machine

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Abstract

Most of the equipments in the nuclear power plants are rigidly fixed to the structures with the anchor bolts and so on. But the equipments having the wheels such as the refueling machine are supposed to show the different behavior of slipping response during the earthquakes.

In order to clarify this phenomenon, the vibration tests were carried out by using the scaled model of the refueling machine and the analytical methods which showed the good agreement with the test results were studied.

Based on this study, the analytical method which can evaluate the slipping behavior of the refueling machine during the earthquake was established.

1. Introduction

Fig.-1 shows the location of refueling machine in the reactor building.

The refueling machine is consisted of a bridge, a trolley, a fuel hoist, and so on. The bridge travels on the bridge rail from the above of the reactor core to above of the spent fuel storage pool. On the other hand the trolley travels on the trolley rail installed on the bridge in the rectangular direction of the bridge rail.

The bridge and the trolley have anti-overturning devices and guide rollers, in order not to fall down during earthquakes. The schematic view of the refueling machine is shown in Fig.-2. In this study, the element friction tests (wheels, rails and anti-overturning devices) and 1/4 scaled model test considering the mutual influence between the bridge and the trolley were carried out.

The simulation analyses based on these vibration test results are described in this paper.

2. The vibration tests

The vibration tests were carried out by using the element test model in order to get the friction coefficient between the wheels and the rails, and the 1/4 scaled test model in order to investigate the slipping response of the bridge and the trolley.

Fig.-3 shows the element test specimen and Fig.-4 shows the 1/4 scaled test specimen. The response accelerations and the relative

displacement between the wheels and the rails were measured. The friction coefficient was evaluated by judging the slipping from the response acceleration wave form.

The sinusoidal and the seismic waves were used as the input to be vibration table.

These vibration test results were used for the confirmation of the validity of the simulation analyses.

3. The equation of motion

1 degree of freedom model with a slipping friction system is shown in Fig.-5.

In case without slipping, the equation of motion can be written as Eq.(1).

$$m\ddot{x} + cx + k(x-xr) = -m\ddot{u} \qquad \cdots\cdots (1)$$

If the slip occures, the equation of motion can be written as Eq.(2).

$$m\ddot{x} = -m\ddot{u} + F \qquad \cdots\cdots (2)$$

where, m is mass of structure, c damping factor, k stiffness of spring, x response displacement, ü input acceleration, xr slipping displacement, F frictional force.

In the multi-degrees of freedom system, these equations of motion can be extended to Eq.(3).

$$\begin{bmatrix} Mm & \\ & Ms \end{bmatrix} \begin{Bmatrix} \ddot{X}m \\ \ddot{X}s \end{Bmatrix} + \begin{bmatrix} Cm & \\ & Cs \end{bmatrix} \begin{Bmatrix} \dot{X}m \\ \dot{X}s \end{Bmatrix} + \begin{bmatrix} Km & \\ & Ks \end{bmatrix} \begin{Bmatrix} Xm \\ Xs \end{Bmatrix} + \begin{bmatrix} & \\ & Kc \end{bmatrix} \begin{Bmatrix} Xm \\ Xs \end{Bmatrix} +$$

$$\begin{bmatrix} & \\ & \mu Kr \end{bmatrix} \begin{Bmatrix} Xm \\ Xr \end{Bmatrix} = - \begin{bmatrix} Mm & \\ & Ms \end{bmatrix} \begin{Bmatrix} \ddot{u} \\ \end{Bmatrix} \qquad \cdots\cdots (3)$$

where, M is mass of structure, C damping factor, K stiffness of linear type spring, Kc stiffness of non linear type spring, Kr stiffness of linear type spring for Xr, μ friction coefficient, suffix m slipping structural system, suffix s non slipping.

In Eq.(3), third to fifth term represent restoring force and such treatment of these restoring force is the feature of this analysis method.

The characteristic curve of restoring force between wheels and rails is shown in Fig.-6. The slipping friction force can be written as Eq.(4).

$$Fs = \mu(W \pm \Delta W) \qquad \cdots\cdots (4)$$

where, Fs is the slipping friction force, μ friction coefficient, W weight of structure, ΔW increment of vertical force causing up-down motion. Thus the slipping friction force was changed attending on up-down force between wheels and rails.

A slipping friction system in the analysis model can be described by a pair of a horizontal and a vertical spring.

When a horizontal spring force becomes greater than a slipping friction force, the stiffness of a horizontal spring changes into very weak value.

4. Simulation analyses

4.1 Simulation analysis model

Simulation analyses were performed for the test results of the 1/4 scaled model shown in Fig.-4. The bridge and the trolley of the refueling machine were modeled by the lumped mass and the beam elements. The slipping condition was considered by the bi-linear type springs, and the friction coefficient 0.1 is used considering the tests results. Simulation analysis model is shown in Fig.-7.

4.2 The results of simulation analysis

The natural frequency of the simulation model is shown in Table-1.

Fig.-8 and Fig.-9 show the comparison between the results of simulation analysis and that of vibration tests. Where, Fig.-8 shows the response excited by sinusoidal wave, and Fig.-9 shows the response WAVE to the earthquake excitation.

The results of the simulation analyses were in good agreement with the vibration tests results. Through these study results, the validity of this simulation analysis method considering slipping friction systems was confirmed.

5. Conclusions

Based on the vibration tests and its simulation analysis for the 1/4 scaled model, the following results were obtained.

(1) The behavior of the structures in slipping response during the earthquake can be simulated by multi-degrees of freedom with the bi-linear type spring at the junction part of the wheels and the rails.

(2) In order to simulate the slipping behavior of the refueling machine during the earthquake, it is necessary to consider the changing of the slipping friction force caused by the vertical response motion.

(3) When the refueling machine will slip, the form of response acceleration wave become the trapezoid one including the high frequency component.

(4) It is confirmed that this analytical method give the good simulated results to vibration test.

Acknowledgements

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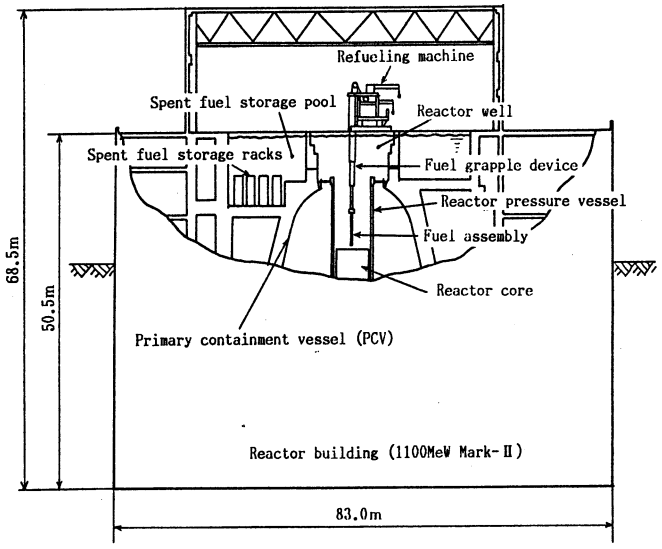

Fig.-1 Location of resueling machine in reactor building

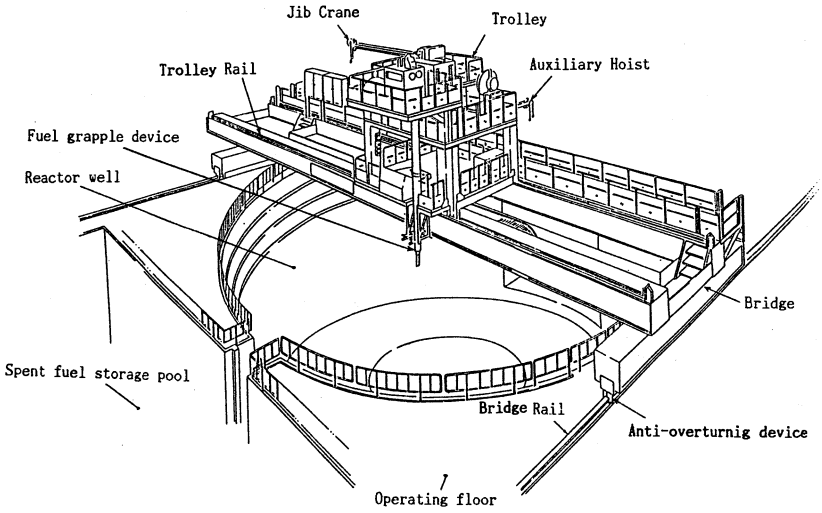

Fig.-2 Schematic view of a refueling machine

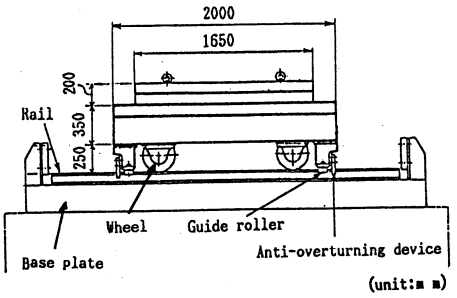

Fig.-3 The element test model

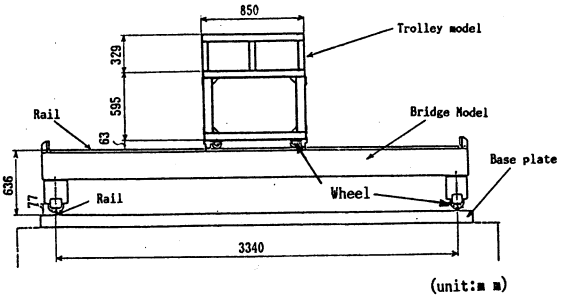

Fig.-4 The 1/4 scaled test model

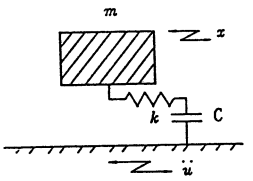

Fig.-5 1 degree of freedom model with a slipping friction element

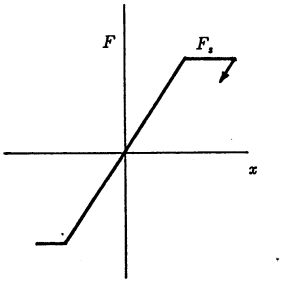

Fig.-6 Characteristic curve of retoring force

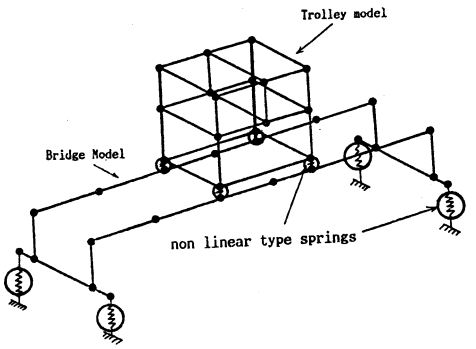

Fig.-7 The simulation analysis model

Table -1 Comparison of the natural frequency between Test and Analysis

	Natural frequency (Hz)	
	1/4 scaled test model	simulation analysis
1	3.6	3.8
2	5.5	5.5
3	.....	11.1
4	.....	19.8
5	19.8	22.2

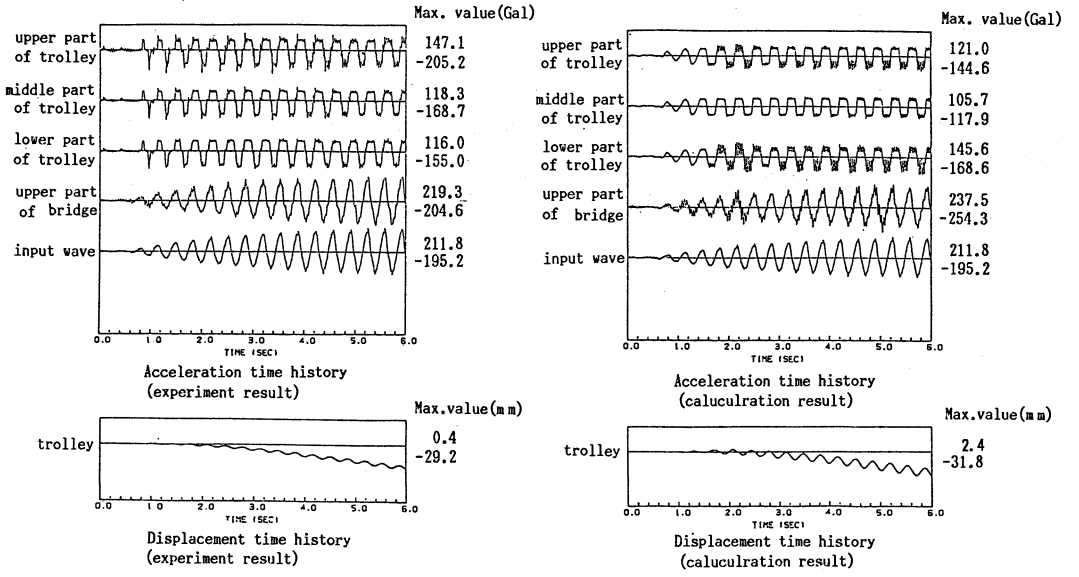

Fig.-8 Comparison of response results between Test and Analysis
(by sinusoidal wave excitation)

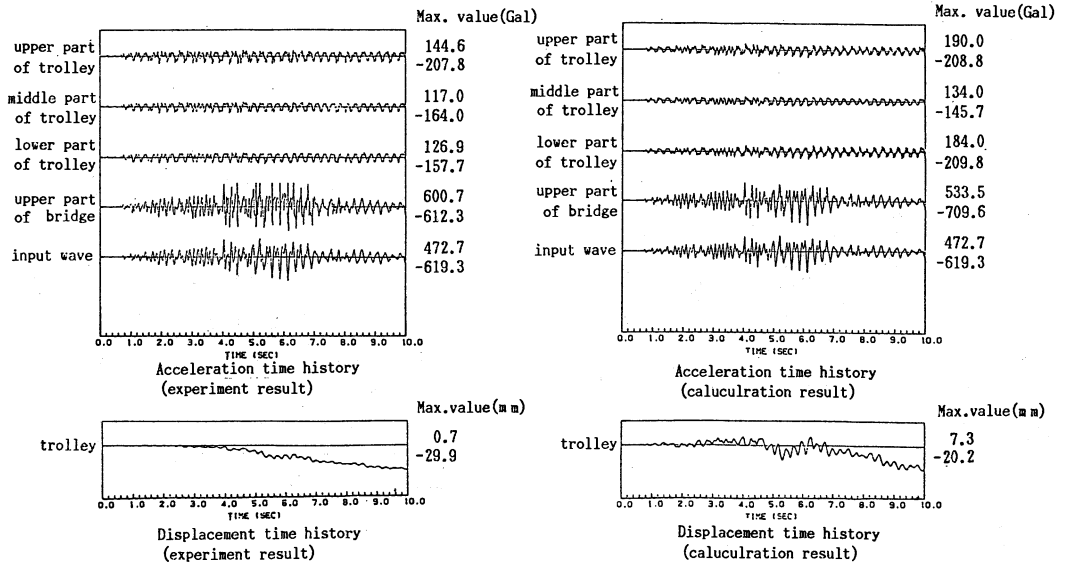

Fig.-9 Comparison of response results between Test and Analysis
(by seismic wave excitation)