Practical Seismic Safety Estimation Method of Reinforced Concrete Underground Structures Subjected to Strong Earthquake Motion

Background

In consideration of severe damages of reinforced concrete (RC) structures caused by the Hyogoken Nanbu Earthquake in 1995, the electric power industry adopts the structural design concept that allows the structures to undertake a certain amount of damage under strong motion, and investigates the application of its method to RC underground structures. The design concept is that of allowable deformation, that is, allowing certain damage of a structure to absorb earthquake energy and thus escape from collapse. In order to spread the method to practical use, the verification method of the structural safety as well as the numerical method for estimating the soil-structure interaction behavior with high accuracy should be established.

Objectives

To suggest the seismic performance verification method for assuring the safety of RC underground structures in nuclear power stations subjected to the assured largest earthquake and to enhance the seismic safety of the structures.

Principal Results

1. Applicability of total stress model to earthquake response analysis of the ground

Based on the results obtained from the1/30scale model tests using a centrifuge and the numerical simulations for those tests using the total stress model and effective stress model, it is concluded that the total stress model can be applied to the earthquake response analysis of the ground, the strain of which develops in the range from 1.0 through 2.0 % (Fig.1).

2. How to deal with the vertical motion in earthquake response analysis and its effects on the response of underground structures

The vertical motion was dealt as a static load in earthquake response analysis up to now. The cases when both horizontal and vertical motions are dealt as time historical waves was investigated with numerical simulations and the results showed that response behaviors of the structure with and without considering a coincidence of the occurrence time of maximum acceleration of both motions had little difference. This means that given time historical wave of both motions might be input at the same time in numerical simulations. It was also confirmed that the numerical results considering both horizontal and vertical motions showed little influence on the seismic safety of the structures as compared with those considering only the horizontal motion as long as the magnitude of vertical motion stayed in the current design level (Fig.2).

3. Structural safety verification procedure for shear failure of RC underground structures

The safety factor for shear failure in the current design code was rationalized by considering an excellent seismic performance of underground structures (Fig.3) and two estimation methods for shear failure, one method used the linearly damaged rule and another method used FEM considering materials' nonlinearity, were newly suggested based on the highly-developed numerical simulation techniques, which are practically applied to the structural design.

4. Probabilistic safety estimation procedure for RC underground structures

A probabilistic safety estimation procedure for RC underground structures, which included a simplified earthquake response analysis of ground and a load deformation analysis of the structure using the Monte Carlo simulation, was suggested, in which the physical properties of soil and structure were considered as probabilistic variables (Fig.4). It was concluded that the procedure could be adopted to practical use with some restricted conditions of used models for soil and structure.

Future Development

The research results will be reflected in the revised version of "Guideline for Seismic Performance Verification Procedure of RC Underground Structures in Nuclear Power Stations" and it will be published in May 2005 from the JSCE. The results will also be spread to practical use through technical courses and so on.

Main Researchers

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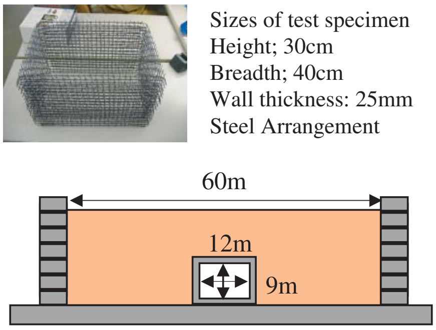
References

(1) Effects of Vertical Ground Motion on Seismic Performance Verification System of RC Underground Structures, CRIEPI Report, No. U04003, August 2004

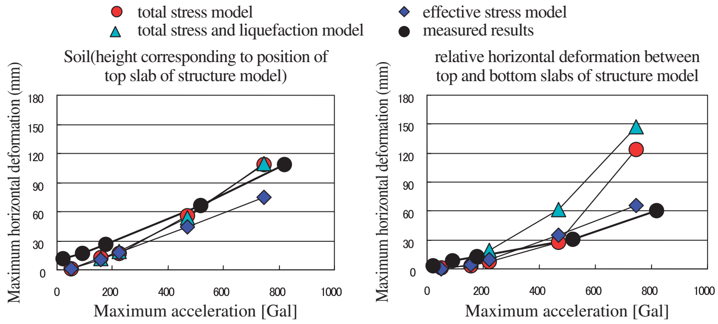
(2) Experimental Study on Shear Capacity Evaluation of Reinforced Concrete Members Subjected to Distributed Load, CRIEPI Report, No. U02052, April 2003

(3) An Investigation on Reaction Forces working on a Duct Type Structure Buried in Saturated Soil Foundation, Proceedings of the 27-th JSCE Earthquake Engineering Symposium, December 2003



(a) Laminated steel box and 1/30 scale model

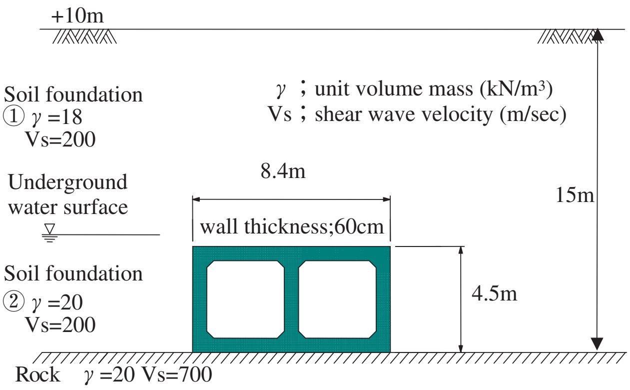
30G acceleration was applied by centrifuge and a test model of 12m in breadth and 9m in height was realized.



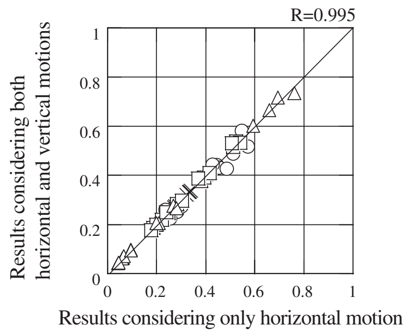
(b) Comparisons between measured and numerical results for deformation of soil and structure model

Based on the numerical results using a total stress model, effective stress model, etc., a total stress model can be applied to the strain range from 1.0% to 2.0% (corresponding to 100mm deformation in above figures).

Fig.1 Shaking table tests using centrifuge and investigated results



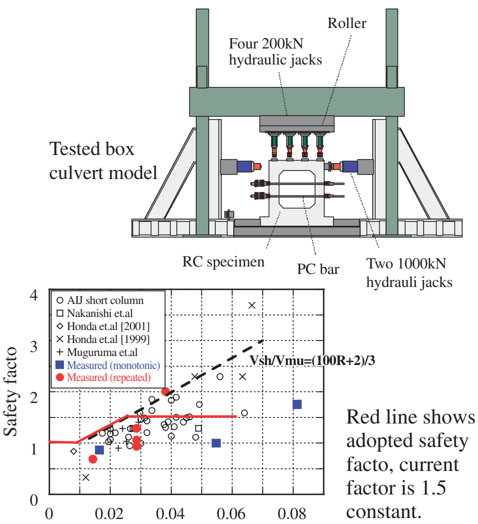
(a) Investigated RC culvert model (one layer and two boxes type) -Rock fixed condition-



(b) Vertical motion's effect by shear capacity ratios

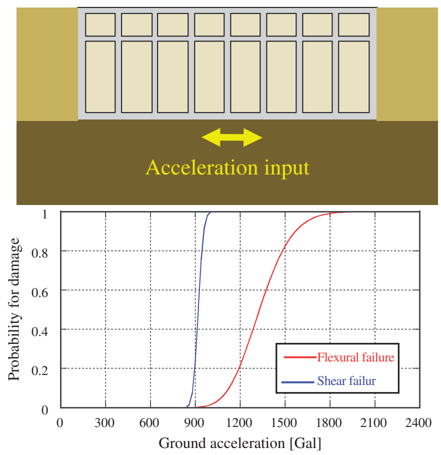
Shear capacity ratios of structural members(ratio of shear force to shear capacity) obtained from earthquake response analysis considering both horizontal and vertical motions are almost consistent with those considering only horizontal motion.

Fig.2 Foundation and structure model for investigating influence of vertical motion and calculated results of shear capacity ratios



The safety factor for shear failure of vertical members, which changes corresponding to shear deformation angle, is suggested.

Fig.3 Rationalization of shear capacity verification procedure



It takes about 10 minutes to calculate damage probability of a structure for one acceleration case and to draw a figure; that is, above figure for some underground structure.

Fig.4 An example of probabilistic safety analysis for an underground structure (two layers and eight boxes type water intake pit)