Seismic Performance Evaluation of Dam Gates in Large-Scale Earthquake

Background

Seismic structural design of dams and associated appurtenant structures in hydraulic power plants has been conducted using seismic coefficient method in which seismic load is treated as equivalent static load. In recent years, infrastructures have suffered enormous damages from large-scale earthquakes in Japan. It is necessary to evaluate seismic performance of the dam structures subjected to large-scale earthquakes which may exceed the design seismic condition. Although dam gates are vital appurtenances in dams, there are few experimental data regarding the seismic behavior and failure mode of the gates in large-scale earthquakes. Therefore, it is required for the gates to experimentally investigate ultimate limit state and establish analytical evaluation methodology.

Objectives

The purpose of this study is to evaluate seismic performance of a radial gate, as a typical type of dam gate, in large-scale earthquake by model loading tests and numerical simulations.

Principle Results

1. Model Loading Tests

Monotonically static loading tests of one-fourth scale radial gate models (Fig.1) were carried out under hydrostatic and earthquake loads (Fig.2). We obtained the following results about seismic behavior and failure mode.

(1) Axial load-displacement relationships of strut arms indicated that inelastic behavior commenced prior to reaching maximum strength mainly due to the yielding of the arms (see Fig.3). After passing maximum strength, the strength of the arms moderately reduced.

(2) The failure modes of the models were the buckling of the strut arms in the vertical plane. Only one span of each strut arm became deformed due to buckling (Fig.5). Buckling deformations of upper strut arms appeared in advance of those of lower ones because the upper strut arms had smaller sized cross section than lower ones.

(3) The maximum strength of the models was over 1.1 times the axial compressive buckling strength P_{cr} which was calculated based on a design standard for gates [*1]. Thus it is conformed that P_{cr} is available for safety strength evaluation of radial gates

2. Numerical Simulations

Elasto-plastic finite deformation analysis was carried out by applying the model loading test condition using the finite element model illustrated in Fig.4 which consisted of mainly shell and beam elements. Fig.3 shows that the load-displacement relationships of analysis results agreed well with the test results up to maximum strength. The analysis results also well approximated the experimental failure modes as illustrated in Fig.5. We can conclude that finite element elasto-plastic analysis makes it possible to evaluate seismic behavior and failure modes of radial gates.

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Future Developments

Ultimate limit states of various types of gates will be experimentally investigated for establishing methodology of seismic performance assessment.

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Reference

NISA and CRIEPI, 2008, “Research Report on Seismic Performance of Electric Power Facilities (Model Tests) in FY 2007” (in Japanese)

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*1：The Hydraulic Gate and Penstock Association, “Technical Standard for Gates and Penstocks (fifth revised edition)”, 2007 (in Japanese)

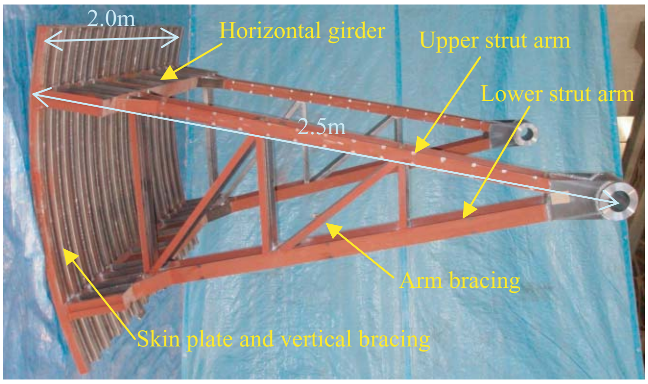


Fig.1 Dam gate model

Dam gate models were manufactured by welding thin plate members based on the geometry of an actual radial gate. Models with different shaped arm bracings were also manufactured.

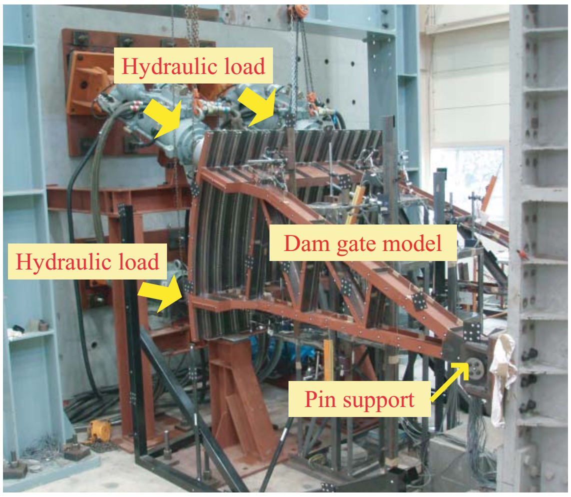


Fig.2 Static loading test

Dam gate model was so mounted upside down on loading apparatus that stable loading was possible using hydraulic actuators.

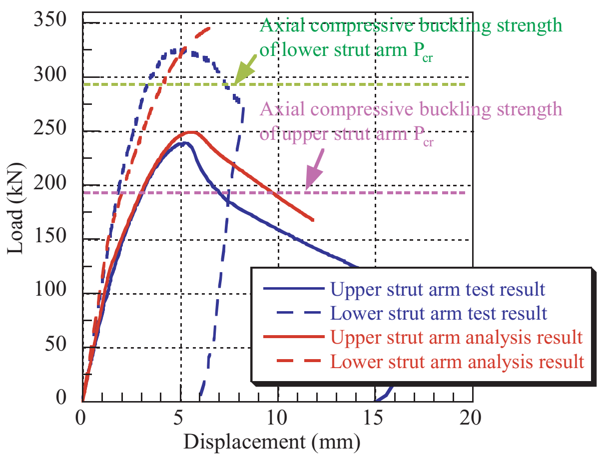


Fig.3 Axial load-displacement relationship of strut arms

Test result indicated that strength of strut arms moderately reduced after passing maximum load. The load-displacement relationship of analysis results agreed well with the test results up to maximum load.

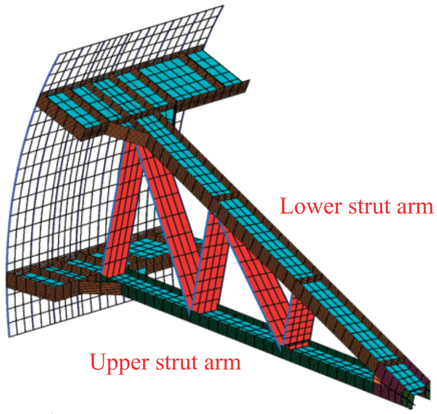
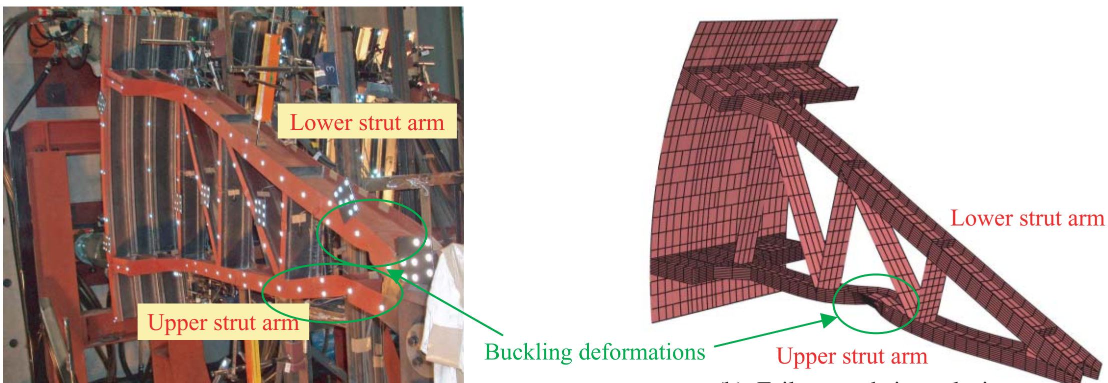


Fig.4 Finite element model

This is a symmetrical 1/2 analysis model matched with the model position shown in Fig. 2. Horizontal girders and strut arms consisted of shell elements which had measured thickness properties. The modeling of other members was simplified to the extent of not affecting analysis results.



(a) Failure mode at the final stage of loading test

(b) Failure mode in analysis
(Deformations at 11 mm axial displacement of lower strut arm are multiplied three times)

Fig.5 Typical failure modes in loading test and finite element analysis

Failure modes in loading tests were the buckling of strut arms in vertical plane and analysis results well approximated the experimental failure modes. The buckling of upper strut arms appeared before those of lower ones because of smaller sized cross section.

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