Session:

Hydropower safety
What is good practice?

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Seismic Safety of Large Dam in China

In China large dams are playing very important role in water resources management, for flood mitigation and clean energy supply, thereby promoting the sustainable development of society and economy. Most high dams in China are concrete dams.

China is a country of high seismicity.

A series of critical hydropower projects with arch dam of about 300m high are constructed in the severe seismic regions of China.

Considering the uncertainties of seismic input and the structural complexities of high dams as well as the catastrophic aftermath of their secondary disaster, it is of extremely importance to prevent any collapse of high dam under the largest reasonable potential earthquake defined as Maximum Credible Earthquake (MCE).

The major obstacles to assess the seismic catastrophe of high concrete dams are:

1. Clearly defining MCE and reasonably selecting its site-specific seismic input parameters;
2. Quantitatively evaluating the criterion of the limit state of dam-breach for designer.
So far, the most reasonable and feasible approach is to use the “stochastic finite fault method”. It is an areal seismic source model to directly synthesize the accelerograms of MCE for the near-fault strong earthquake instead of the traditional point seismic source model.

The major active fault of the critical potential seismic source is divided into a series of sub-faults as point sources with provided mode, rate, and time sequence of the rupture. By accumulating the effects of each point source on the dam site in sequence, the strong ground motion can be directly generated.

MCE is often characterized as near-field strong earthquake. The special features of near fault strong earthquakes include the effects of rupture directivity and the hanging wall on ground motion at dam site etc..
All the fault parameters, e. g., strike, dip directivity, dip angle, rupture area and its length, width, as well as the average slip over the fault should be estimated theoretically or semi-empirically.
During the Wenchuan earthquake the energy was unequally released over 100s along the fault plane of 300km long and 30km deep. Its areal source model and parameters were identified by the accelerograms recorded at 7 stations near the fault.

As the ground motion at Shapai RCC arch dam site during the earthquake was not recorded it was reestablished by using the “stochastic finite fault method”.

Reestablished artificial accelerograms at Shapai dam site

Reestablished PGA of 0.262g with long duration of more than 40 minutes

The original design PGA at Shapai dam site is 0.138g.
For quantitatively evaluating the criterion of dam-breach a more realistic model for seismic response analysis of dam-foundation-reservoir system, considering all critical factors close to the realities as possible simultaneously is developed.

Dynamic interaction of dam-foundation-reservoir system;

Opening of dam contraction joints during earthquake;

Topography features and geological disturbances near dam including critical potential sliding blocks with contact surfaces;

Radiation damping of far-field foundation;

Spatial variation of seismic input along dam foundation.

The whole system is meshed in space by finite elements and in time by central finite-differences is solved as a wave propagation problem by explicit integration in time domain.
Moreover, the modeling of crack initiation and propagation in concrete and foundation materials must be involved by using the damage theory with damage variable and smeared-crack model to simulate the damage-rupture process of the dam system based on the experimental damage evolution rules.

A new approach is proposed to consider the strength and stiffness degradation of material caused by damage as well as the irreversible deformation revealed under unloading but without damage-plastic coupling.
The proposed approach seems more suited to analyze the damage-rupture process of both arch and gravity concrete dams during strong earthquake.

Number of nodes: 425,568
Number of elements: 404,090
Number of D.O.F: 1,276,704

The tensile strength and its evolution curves were tested with specimens drilled from dam body after the earthquake by using 15000KN dynamic test machine in IWHR.

A 3-D FEM parallel program of proposed approach was developed and remote-operated on the supercomputer TH-1A, which was once the world's fastest computer.

Time consuming of traditional serial computation: 949.4h
Time consuming of parallel computation on TH-1A: 18.9h

The efficiency of parallel computation is remarkable:

Damage on foundation rock masses

Dam is basically not damaged even near the bottom pedestal, its behavior during earthquake is verified
Verifying the behavior of Koyna gravity dam during Dec.11, 1967 Earthquake

Impenetrable cracks were discovered both in downstream and upstream at the level near the abrupt change of downstream slope. After earthquake the uplift pressure has no change and the bore core indicated that the dam-foundation interface was good connected. Obviously, the grout curtain was not damaged.
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