

Seismic design of concrete gravity dams*

India has been witnessing a surge in the construction of concrete gravity dams as part of the increased number of hydel power projects. With most of the dams located in the Himalayan belt, the dams must adhere to state-of-the-art seismic design and construction guidelines. Over the years, Indian practices have not always kept pace with the worldwide developments. Hence, it is important to bridge the gap between the state-of-the-practice in India vs that in the developed countries. With this view, the National Information Centre for Earthquake Engineering (NICEE) at the Indian Institute of Technology Kanpur (IIT Kanpur) hosted two world renowned experts on seismic safety of concrete dams, namely Anil K. Chopra (University of California at Berkeley) and Larry Nuss (United States Bureau of Reclamation (USBR), Denver, Colorado) during February–March 2009.

As a first step towards capacity building in this area, a national seminar on ‘Seismic safety for concrete gravity dams’ was held on 27 February 2009 at the India Habitat Centre, New Delhi, with 120 participants distributed almost equally from industry and academia. The seminar was sponsored by Building Material and Technology Promotion Council (BMTPC), Council of Scientific and Industrial Research, CSI-India, Department of Science and Technology, Indian National Academy of Engineering, Ministry of Earth Sciences, NTPC Limited, Poonam and Prabhu Goel Foundation and IIT Kanpur.

In the first lecture, Anil K. Chopra discussed the seismic analysis, design and safety evaluation issues of concrete gravity dams. This was followed by the

talk on risk-based analysis and decision issues by Larry Nuss. Among the Indian experts, M. Gopalakrishnan (INCOLD Committee on Seismic Aspects of Dam Design, New Delhi) discussed the seismic risk criteria used in the seismic design of Indian dams. The influences of foundation and dam discontinuities on the response of concrete gravity dams were illustrated by D. K. Paul (Department of Earthquake Engineering, Indian Institute of Technology Roorkee) using distinct element method analysis of Koteshwar dam in Uttarakhand. I. D. Gupta (Central Water and Power Research Station, Pune) presented the seismic response of dams using the stochastic characteristics of earthquake excitations. Finally, Durgesh C. Rai (Department of Civil Engineering, IIT Kanpur) drew the attention of the audience to a few important issues of the Indian seismic design practice for dams.

The proceedings ended with a panel discussion involving the speakers and the participants. It was moderated by Sudhir K. Jain (Coordinator of NICEE). P. L. Narula (Geological Survey of India, Faridabad) also added valuable comments on pertinent issues. The following are the salient recommendations from the panel discussion:

- Disparity between Indian and international state-of-the-practice: The present Indian state-of-the-practice on seismic safety of concrete gravity dams is lagging behind the international state-of-the-art and practice. There is an urgent need of bridging this gap so that construction and operation of safer dams in the country can be ensured. This may involve significant changes in the existing dam design and construction guidelines which can only be possible through combined efforts of academicians and practising engineers.

- Rigorous site-specific studies: At present, site-specific studies being conducted in India for seismic hazard evaluation are primarily desktop studies based on available data in the literature. However, a state-of-the-art site-specific study for the concerned dam site must be complemented with vital inputs which are specific to actual field conditions,

such as seismological instrumentation of the area prior to construction, detailed investigation of local geotechnical conditions, geological investigations on the presence of active faults, ongoing tectonic activities in the neighbourhood, etc.

- Seismic evaluation of existing dams: Seismic safety of existing dams should be evaluated in the light of new knowledge about seismic behaviour of such structures as well as new insights available about seismicity of various regions in the country. A co-ordinated and systematic programme for evaluation of seismic safety of existing dams should be constituted involving various stakeholders, such as owners and operators of dams as well as agencies overseeing safety of dams. The safety of dams should be assessed by a multi-disciplinary review panel board consisting of experts from structural engineering, seismology, hydrology and geotechnical engineering.

- Instrumentation: There is an urgent need to frame a policy to install and maintain instruments in dam structures to monitor their health as well as response during extreme events, such as floods, earthquakes, etc. The maintenance and monitoring of instruments can be assigned to competent and professional agencies. Data recorded by the instruments should be easily available to the concerned monitoring organization and also for academic research.

- Mission-oriented research programme: A strong and focused nationwide research and development programme should be initiated to address various issues which are typical to Indian dams and conditions. It should address issues ranging from seismic hazard evaluation to analysis and design of dam structures. The objective of research efforts should be to develop knowledge and tools which can empower the dam building industry to improve their current practices and bring it to the international level. Universities and colleges should be encouraged to take up research projects in collaboration with the industry, which will also help in long-term goals of developing human resources in the area of design, construction and operation of dams.

*A report on one-day National Seminar on ‘Seismic Safety for Concrete Gravity Dams’, organized by National Information Centre for Earthquake Engineering (NICEE) and Building Material and Technology Promotion Council, New Delhi in collaboration with Central Board of Irrigation Power, at India Habitat Centre, New Delhi on 27 February 2009; and a four-day short course on ‘Seismic Design of Concrete Gravity Dams’, organized by NICEE during 3–6 March 2009 at Indian Institute of Technology, Kanpur.

• Training and exposure to young professionals: The country needs to invest more on training of young engineers (both professionals and academicians) within the country and in the international environment. Systematic effort is needed to depute them to international agencies for medium term training. More Indian engineers need to be sponsored to attend international conferences.

The seminar at New Delhi was followed by a four-day short course on 'Seismic design of concrete gravity dams'. It was attended by 150 participants including practising engineers, students and faculty members.

The course was conducted by Anil K. Chopra and Larry Nuss. The first day of the course involved two absorbing lectures by Chopra on earthquake analyses of simple and complex systems. Starting with the basic principles of structural dynamics for single degree of freedom systems, he lucidly explained the transition to multi-degree-of-freedom systems and finally the dynamics of dam model discretized into finite elements. Nuss introduced the participants to the geological and seismological investigations required for estimation of potential seismic hazard level at a dam site by both deterministic and probabilistic methods.

On Day 2, Nuss introduced the traditional methods of seismic analysis and design of gravity dams. The evolution of procedures with growing complexities in the structural modelling was well appreciated by the audience. The limitations of traditional static structural analysis methods and the need for dynamic analysis were well presented by Chopra. The computer programs EAGD-84 and EAGD-Slide (Earthquake Analysis of Gravity Dams), which were developed at the University of California at Berkeley for preliminary seismic analysis of gravity dams and extensively used by design firms in USA, were explained in detail by Nuss. The limitations of the programs and the need to analyse the actual dam-water-foundation interaction under earthquake shaking was well appreciated by the participants.

On the third day, Chopra presented a simplified method of seismic analysis of dams. The parametric dependence of dam-water-foundation interaction on seismic response of the overall system was explained through appropriate case studies of various dams. Nuss discussed the current seismic design, analysis and stability evaluation criteria of concrete dams which are followed by the US Bureau of Reclamation. The probabilistic safety evaluation method for dams, 'potential failure mode analysis', was explained and illustrated with examples. This highlighted the state-of-the-art earthquake-resistant design procedures of the dams in USA.

On the last day, Nuss concluded the technical sessions with a presentation on seismic remediation of Stewart Mountain dam in Arizona, USA. The dynamic stability of the concrete arch dam was improved significantly by installing prestressed anchors along the full height of the dam, and also new spillways were added. The accomplishment of the challenging task highlighted the state-of-the-art construction methods practised in USA. It was a great learning experience for all the participants.

The participants also had the opportunity to visit the Structural Engineering, Geotechnical Engineering and the Water Resources Engineering laboratories of IIT Kanpur, and get a feel of the ongoing research activities. A trip to the Ganga barrage at Kanpur was also organized for the participants.

Sudhir K. Jain (NICEE) summed up the success of the short course based on the brainstorming interactions among the experts and the participants. The short course saw free and vibrant technical interactions among the participants and the experts. Over the years, Indian concrete dams have faced serious issues of concern during operational stage, namely (a) accumulation of silt behind the dam, (b) configuration of overflow gates, etc. These and several other problems unique to the Indian dam industry were discussed in detail and the urgent need for further research was emphasized.

The two events were successful, as this was the first time that representatives from major Indian firms involved in the design and construction of concrete dams gathered under the same roof with academicians. It was heartening to see the keenness of the young professional engineers to learn the state-of-the-art techniques through relevant questions and intense technical interactions. The participants were eager to have more such opportunities to discuss and deliberate on design and construction issues of earth and rockfill dams. Possibility of organizing earthquake-resistant dam design competitions among practising engineers was also discussed.

As a follow-up of the events, a discussion forum has been initiated for practising engineers and academicians in the area of seismic analysis and design of concrete gravity dams. Interested persons can get registered at the following website for participating in the forum: <http://www.sefindia.org/forum/ahlists/?p=subscribe>.

Also, the computer programs EAGD-84 and EAGD-Slide are available for free download (<http://www.nicee.org/EAGD>).

Apart from these, compact discs containing powerpoint presentations and a large number of valuable documents of USBR were also released by NICEE for both the events, and these can be procured from NICEE (www.nicee.org).

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