Effects of re-entrant corner on seismic performance of high concrete gravity dams

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Abstract

The seismic vulnerability assessment of any important infrastructure like concrete gravity dam is an integral part for the seismic risk evaluation. Vulnerability of the concrete gravity dam depends on many factors including its geometric configuration, since the geometric shape of a concrete gravity dam assures its stability during static and dynamic loading conditions. In case of high concrete gravity dams, sometimes it becomes necessary to provide slope at its upstream face and in the consequence re-entrant corner appears in the geometry. Stress concentration in the re-entrant corner region causes initiation of crack in the dam body, which is an alarming issue among engineering community. Therefore in the present work, effects of re-entrant corner on seismic performance of concrete gravity dams are investigated using incremental dynamic analysis method on typical high concrete gravity dams. A possible solution to the problem is also proposed in the study.

Keywords: High concrete gravity dam; Seismic vulnerability assessment; Re-entrant corner; Damage states.

1. Introduction

Concrete gravity dams are considered as mega-structures because of its existence for multiple purposes including hydro power generation, flood control, irrigation, water resource conservation, etc. This civil engineering structure is known for its uniqueness in geometric shape and design, proportioned in such a way that its own weight is enough for its stability against all the forces acting on it [1]. It is the necessity of the time to build new dams or to increase the capacity of existing dams because with the population inversion worldwide, the existing natural resources are seems to be insufficient to meet the demand in coming future. This is why there is an increasing trend of constructing new dams worldwide.
In India alone there are 5171 dams, out of which 4858 are completed and 333 are under construction [2]. But, at the same time the fact cannot be ignored, that there is also a huge risk associated with the failure of such a massive structures. The amount of risk in terms of human/inhabitant lives and properties magnifies up to many fold when the talk of failure comes for the relatively higher concrete gravity dams. Therefore, the seismic vulnerability evaluation of existing and proposed concrete gravity dams has become virtually relevant in the recent times in order to quantify the associated risk [3].

The most crucial section in terms of loading condition in the dam is the maximum non-overflow section of dam, the shape of which is depending upon its height along with the loading conditions and the shear resistance of the underlying rock. Usually the upstream face of the dam is kept vertical to shift concentration of vertical weight of the dam closer to upstream side in order to overcome the reservoir load. In some cases, when height of the dam is more, a slope on the lower part of the upstream face is provided to improve the sliding safety of the base and thus a re-entrant corner is created. The shape of concrete gravity dam not only decides its static and dynamic stability but also the cracking patterns likely to occur during any extreme loading event like earthquake. Especially, the shapes of high concrete gravity dams with incorporated re-entrant corner are prone to severe cracks during earthquake in the nearby region due to sudden change in the stiffness along dam height. Though, there are numerous studies present in the available literature supporting the role of geometric configuration in crack formation during earthquake excitations [e.g. 4, 5, 6, 7, 8 and 9]. But, the exact level of impact due to presence of re-entrant corner in the geometrical configuration, on cracking behaviour of high concrete gravity dams is unknown due to lack of studies on the topic in available database. Therefore in this study, the effects of re-entrant corner on the linear and non-linear behaviour of the high concrete gravity dams under seismic loadings are considered as prime objectives. Two typical geometric configurations of high concrete gravity dams are analysed for different earthquakes under incremental dynamic analysis (IDA). Fragility curves and damage probability matrix (DPM) are plotted on the basis of observed damages in the dams and thereby possible solutions are proposed.

2. Numerical Modeling

In this study high concrete gravity dams with two different typical geometric configurations are considered for non-linear modeling and simulations. The considered geometries are presented in fig. 1.

![Image](image.png)

**Fig. 1.** Geometric configurations considered in the study (a) Dam1; (b) Dam2

The main features of the geometry of dam1 model are two slopes at upstream face and one slope on the downstream face. The height and the base width of the dam are 197m and 215m respectively. The two slopes on upstream face are separated with a vertical wall in between. The bottom slope (nearly 1:0.3) goes up to 93m on upstream face of the dam. A slope of nearly 1:0.9 is provided on the downstream side of the dam. The dam configuration is provided with base width to height ratio nearly equals to 1.09. A re-entrant corner is provided in the dam at a height of 93m. In dam2 model, height is 235m and base width is 262.5m. A slope of 1:0.625 is provided at the upstream face till the height of 80m in the model. Due to this slope a re-entrant corner is created in the geometry.

In finite element models, dam-foundation interactions are assured assuming foundation blocks having widths nearly equal to 4 times the base of the dams and heights nearly equal to the height of the dams. Bottoms of the foundation blocks are assumed fixed while Rollers are attached along the vertical sides of each of the foundation block. The nodes along the bases of the dams and the corresponding nodes along the foundation blocks are tied in order to have no sliding condition at the dam-foundation interfaces in all the FE models. In FE modeling all the
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