

DAM BREACH ANALYSES FOR FLOOD CONTROL DAMS

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INTRODUCTION

Flood control detention and debris basins can be found wherever you travel in Southern California. They play an important role here, especially in areas where, in the past, development preceded floodplain mapping and alluvial floodplains were encroached upon. These basins provide an increased level of protection to downstream residents and businesses against potentially devastating flood and debris flows. Many of these basins have been built in response to chronic flooding problems in downstream urbanizing areas. Ironically, these same basins hold the possibility of causing even worse flooding in those downstream areas if their dam embankments are breached.

The larger flood control dams, those under the jurisdiction of the state Division of Safety of Dams, are required to have up-to-date dam breach analyses and downstream inundation maps prepared. These maps must be filed with the California Office of Emergency Services (OES), which makes them available to local emergency personnel. The fact that these flood control dams impound water infrequently and only for a relatively short duration does not exempt them from this requirement. Maps should also be revised when changing conditions downstream warrant. Guidelines for preparing dam breach analyses and inundation mapping have been prepared by the OES.

BACKGROUND

In 1998, GEI Consultants, Inc. (GEI) prepared dam breach analyses for four flood control dams in Ventura County, California. The Ventura County Flood Control District owns and operates other flood control dams and wanted to have a reasonable and systematic method for estimating dam breach parameters. The district also retained GEI to prepare downstream inundation mapping for two of the dams. One of these, the Stewart Canyon Debris Basin Dam, provides a good case study, because it illustrates some typical situations in Southern California.

Stewart Canyon Debris Basin is located in the city of Ojai, north of Ventura (see Figure 1). The purpose of the basin is to intercept and store debris flows from the two-square-mile tributary drainage area. The watershed tributary to the debris basin is a steep natural canyon within the Santa Ynez Mountain range. The dam was constructed in 1963 and is about 34 feet high. The dam crest is about 1,300 feet long and 20 feet wide. The dam embankment is composed of a mixture of silty sand, gravel, and cobble, with riprap slope protection.

The spillway crest is 80 feet wide and has a capacity of 11,200 cfs at the crest. By comparison, the 100-year combined outlet and spillway discharge is 2,642 cfs. The concrete chute of the spillway gradually transitions to a 10-foot-wide by 10.5-foot-deep rectangular concrete channel. The channel transitions to a box culvert further downstream. The estimated maximum debris storage capacity is 328,000 cubic yards, while the expected 100-year debris production with a 100 percent burn is 300,000 cubic yards.

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OES GUIDELINES

The California Emergency Services Act establishes the authority, the process, and the criteria under which inundation mapping should be prepared. As previously stated, the OES administers the inundation mapping program and has established guidelines and performance criteria to this end (OES, 1991). Key performance criteria include:

- Estimate and describe the mode of dam failure.
- Calculate the outflow hydrograph at the dam, indicating the peak outflow and reservoir emptying time.
- Route the hydrograph downstream until the flows are either absorbed by a large body of water or contained to main channel.
- Determine downstream water surface elevations at peak flood.
- Plot calculated peak flood elevations at downstream cross sections and mark the inundation area.
- Mark key downstream cross sections with the flood wave travel time, time of flood peak, peak flood elevation, deflooding time, flow at flood peak, and floodplain width.

Under certain conditions, such as where the effects of potential inundation can be ascertained without an inundation map, or where adequate evacuation procedures can be developed without benefit of an inundation map, the OES may waive the requirement for an inundation map. Flood control dams are not exempt unless they meet these special conditions.

BREACH PARAMETERS

In general, it is not possible to estimate embankment dam breach parameters with a high degree of certainty because of the many variables that can contribute to a dam failure. Some of the key variables that influence embankment dam breach parameters include: reservoir volume, dam height, crest width, embankment slopes, material used to construct the dam, inflow hydrology prior to the breach, the topography immediately downstream of the dam, and the initial reservoir elevation. There is limited data available from past dam failures. Much of the available data was estimated after the failure from field measurements, eyewitness accounts, and photographs. As a result, experience and engineering judgement become important factors in these evaluations.

GEI developed a step-by-step parametric approach to estimate dam breach parameters. In this approach, we limited the range of judgement to a reasonable universe based on empirical equations developed from past embankment dam failures. Key steps in the analysis are summarized below.

Step 1 - Empirical equations were used to estimate the possible and reasonable range of key breach parameters such as average breach width, breach development time, and peak breach discharge. Other breach parameters such as the breach bottom elevation are generally established by the geometry of the embankment dam.

Step 2 - The erosion rate and volume of material removed from the breach were estimated based on empirical relationships (Von Thun and Gillette, 1990; and MacDonald and Langridge-Monopolis, 1984).

Step 3 - A sensitivity analysis was performed using the DAMBRK model. HEC-1 could also be used for this purpose. The analysis was performed by varying the breach bottom width and breach development time to determine the sensitivity of the peak breach discharge to these variables. Other input breach parameters to DAMBRK, such as breach side slope, breach bottom elevation, bottom of dam elevation, and the elevation that initiates the breach were held constant during the sensitivity analysis.

Step 4 - This is the judgement step of the analysis, where the results of Step 3 were compared with the results of Steps 1 and 2. The construction materials used in the dam, along with dam height, crest width, side slopes, and other factors were considered and compared with the results of Steps 1 through 3 to estimate a realistic erosion rate and volume of material expected to be removed from the breach. Based on the erosion rate and volume of material removed calculated in Step 3 of the analysis, reasonable breach parameters were selected for analysis purposes.

Step 5 - An optional fifth step involves repeating Steps 1 through 4 for different initial reservoir elevations. This step can be used to test the sensitivity of the results to the timing of the inflow hydrograph to the reservoir. Step 5 was not needed in the analysis of the Stewart Canyon Debris Basin Dam. During a field visit, GEI and the district agreed to use an initial reservoir water surface at the spillway crest and a 10-year inflow to the reservoir to initiate the breach of the dam, consistent with OES guidelines.

A piping failure mechanism was used in the analysis because the inflow of a 10-year storm event would not overtop the dam. A 10-year storm event was routed through the basin to initiate piping, in accordance with OES guidelines. Results of the dam breach parametric analysis indicate that, with a breach side slope of 1H:1V, the final breach base width would be about 41 feet. Breach development time was estimated to be about one-half hour. The resulting peak breach discharge from the DAMBRK model was about 2,700 cfs.

INUNDATION MAPPING

The area expected to be inundated in the event of a dam failure was mapped based on the above breach parameters. The area is primarily residential. Peak breach discharges are expected to be attenuated and energy to be dissipated in the upper residential areas, since the flow will tend to spread out and encounter resistance from the houses and established vegetation. By the time flows from a dam break reach Ojai Avenue, less than a mile downstream of the dam, the depth of flow would be less than one foot and the velocity would be about three feet per second. This is primarily due to the fact that the path of inundation is characterized by a developed alluvial fan. Flood flows will therefore tend to spread out. A key assumption in mapping the inundation area is that the box culvert approximately 1300 feet downstream of the dam would become clogged with debris from the breach.

CONCLUSION

As urbanization continues to place pressure on resources and infrastructure, we can expect detention basins and debris basins to continue to play an important role in providing flood protection. While most developed areas will therefore be protected from up to 100-year-frequency storm events, there will also continue to be a risk associated with the failure of the dams that are intended to protect those downstream areas. Developing dam failure inundation mapping downstream of detention dams provides a valuable tool for emergency managers to help them manage this risk.

GEI's parametric approach has been used to estimate dam breach parameters for numerous dams nationwide. The application of the parametric approach to Stewart Canyon Debris Basin illustrates how this iterative, efficient procedure can be used on typical flood control dams in Southern California. The analysis first limits the range of judgement to a reasonable universe based on empirical equations developed from past embankment dam failures. A sensitivity analysis of those parameters then assists the engineer in selecting reasonable breach parameters. The process of estimating realistic dam breach parameters is thus made easier, while still being based ultimately on sound engineering judgement and experience.

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