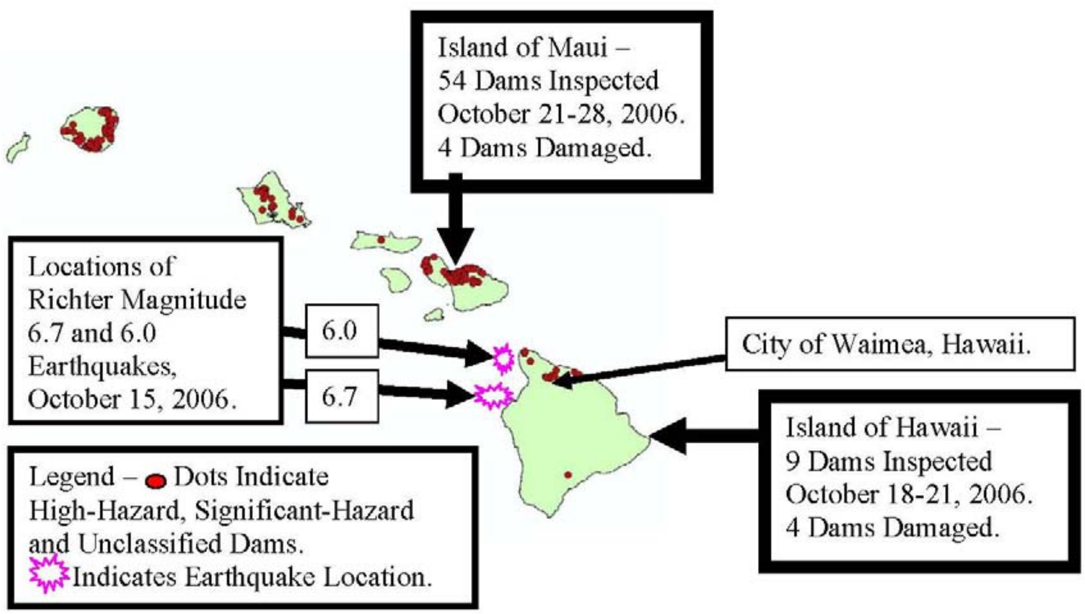
RECLAMATION
Managing Water in the West

Water Operation and Maintenance Bulletin

No. 220



In This Issue . . .

Post-Earthquake Dam Inspections in Hawaii, October 2006

U.S. Department of the Interior
Bureau of Reclamation

June 2007

This *Water Operation and Maintenance Bulletin* is published quarterly for the benefit of water supply system operators. Its principal purpose is to serve as a medium to exchange information for use by Bureau of Reclamation personnel and water user groups in operating and maintaining project facilities.

The *Water Operation and Maintenance Bulletin* and subject index may be accessed on the Internet at: <**http://www.usbr.gov/pmts/infrastructure/inspection/waterbulletin**>.

Although every attempt is made to ensure high quality and accurate information, the Bureau of Reclamation cannot warrant nor be responsible for the use or misuse of information that is furnished in this bulletin.

For further information about the
Water Operation and Maintenance Bulletin, contact:

Jerry Fischer, Managing Editor
Bureau of Reclamation
Technical Service Center (86-68360)
PO Box 25007, Denver, CO 80225-0007
Telephone: (303) 445-2748
FAX: (303) 445-6381
Email: jfischer@do.usbr.gov

Cover photograph *Map showing where the two earthquakes of Richter magnitudes 6.7 and 6.0 occurred on October 15, 2006, near the northwest coast of the Island of Hawaii. The map also shows the location of high-hazard, significant-hazard, and unclassified dams.*

Water Operation and Maintenance Bulletin

No. 220 – June 2007

CONTENTS

Page

Available on the Internet at:
http://www.usbr.gov/pmts/infrastructure/inspection/waterbulletin

Post-Earthquake Dam Inspections in Hawaii, October 2006[1]

by Bob Woodby, Civil Engineer, P.E., Dam Inspection Specialist, Instrumentation and Inspections Group, U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, Denver, Colorado

Summary

Two significant earthquakes, Richter magnitudes 6.7 and 6.0, occurred on Sunday, October 15, 2006, within a few minutes of each other beginning at 7:07 a.m. in the Pacific Ocean near the northwest coast of the Island of Hawaii (figures 1 through 4). By the evening of October 18, there had been 116 aftershocks. The strongest aftershock, a magnitude 4.4, occurred at 10:35 a.m. on October 15. The initial earthquake occurred about 24 miles beneath the ocean floor west of the Island of Hawaii on a previously unknown Pacific Plate fault. It is believed that the earthquakes were caused by surging lava and rock that built up massive weight over many years, and the increased weight pushed down on the ocean floor and the Earth's crust, causing movement below. The Modified Mercalli Intensity Scale (based on the description of the earthquake as felt at the sites) was as high as VII to VIII, depending on the location relative to the earthquakes. Residents on the Island of Hawaii reported feeling rocking for about 1 minute and then rocking for 40 seconds about 8 minutes later. On the Island of Hawaii, chimneys fell at numerous residences, some buildings and private residences were significantly damaged, masonry rock walls cracked and collapsed, and numerous roads were closed for repairs after significant rockfalls occurred. The land portions of an Ironman Triathlon continued along highways with only one lane open in some areas due to rockfalls. Numerous aftershocks also occurred during the next 2 weeks that were felt on the Islands of Hawaii. On Tuesday, October 17, a disaster was declared for the State of Hawaii, and on the same day, Reclamation was requested to assist the State of Hawaii Department of Land and Natural Resources (DLNR) by performing post-earthquake dam inspections of 63 high- and significant-hazard dams and some unclassified dams on the Island of Hawaii and the Island of Maui, as well as some unclassified dams (figures 1 through 5). Two Reclamation dam engineers arrived in Hawaii beginning on October 18, and in 12 days, they inspected 63 dams for earthquake-induced damage with assistance from the DLNR, the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS), the County of Hawaii, Hilo, Department of Water Supply (DWS), Maui County Department of Water Supply (MCDOWS) employees, and private dam owners. Special thanks are extended from this author to the DLNR, NRCS, DWS, MCDOWS, and dam owners and dam operators for their knowledge, experience, and assistance during the post-earthquake inspections and in the preparation of this paper.

[1] This paper will be presented at the 2007 Association of State Dam Safety Officials Annual Conference (ASDSO), Austin, Texas, September 9–13, 2007.

DLNR identified 136 dams (high- and significant-hazard dams and some unclassified dams) for inspection on the Hawaiian Islands. After Reclamation inspected the 63 dams, the U.S. Army Corps of Engineers (COE) Honolulu District inspected the remaining 73 dams beginning at the end of October 2006.

This dam inspector arrived at the Kona Airport on the Island of Hawaii at about noon on October 18, 2006, and began post-earthquake dam inspections that afternoon. Another Denver Reclamation dam engineer, Mr. Chris J. Veesaert, arrived in Maui 4 days later to perform post-earthquake dam inspections. The 63 post-earthquake dam inspections were completed in 12 days with a hit-the-ground-running approach, working 12 hours or more each day, in order to perform the inspections in a thorough and timely manner. Nine of the 63 dams inspected were on the Island of Hawaii, and 54 were on the Island of Maui (figures 1 through 5). Of the 63 dams inspected, 62 are embankment dams, and 1 is a concrete arch dam. Of the 63 dams, 8 embankment dams (4 on the Island of Hawaii and 4 on the Island of Maui) exhibited earthquake-induced damage ranging from minor to significant damage (figures 3, 4, and 5). Many of the dams inspected had significant amounts of tree and other vegetation growth that significantly restricted access and visual examination of the surfaces of the dams, especially the downstream faces. A machete was used to gain access to the surfaces of several of the dams that had significant tree and other vegetation growth. In the spring of 2006, DLNR requested dam owners to remove trees and other vegetation to facilitate satisfactory visual inspection of the dams. Tree removal was in progress at some of the dams during the October 2006 inspections. Prior to the October 2006 post-earthquake dam inspections, on March 14, 2006, the Kaloko Dam failed on the Island of Kauai, Hawaii, killing 7 people and releasing about 300 million gallons of water (figure 1). Shortly after the March 14 failure, all of the 176 high- and significant-hazard dams and some unclassified dams on the Hawaiian Islands were inspected by COE. The October 2006 post-earthquake dam inspections by Reclamation presented here were performed in response to the October 15 earthquakes, and these were a second round of inspections after the COE inspections.

Inspection Checklists

The dam inspections were documented using post-earthquake dam inspection checklists developed by DLNR. The checklists were modeled after the United States Committee on Large Dams (USCOLD) publication “Guidelines for Inspections of Dams Following Earthquakes.” Checklists were filled out at each dam, and photographs with captions for each checklist were provided at a later date.

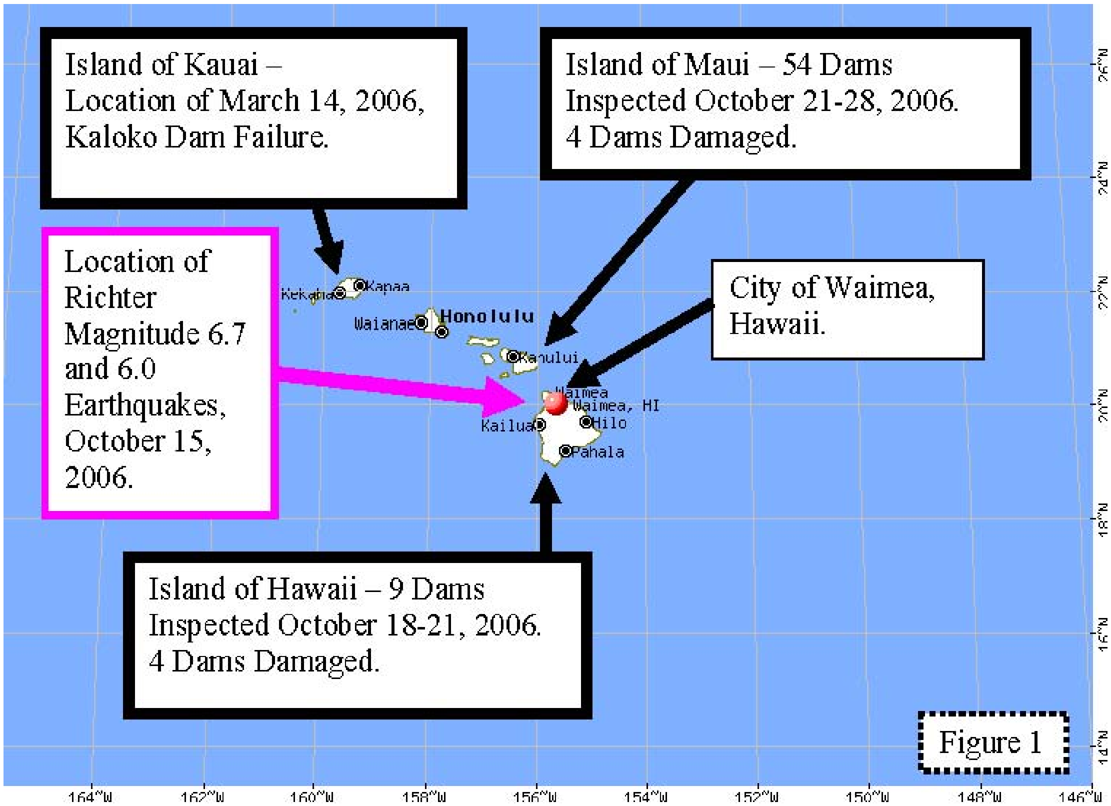


Figure 1

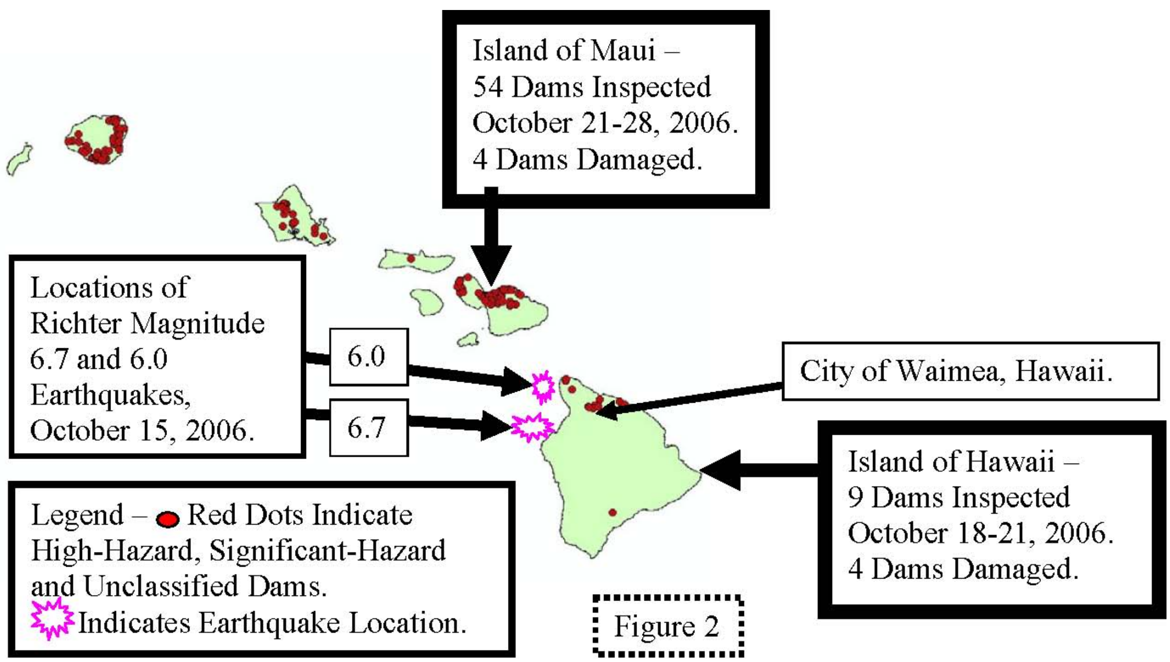


Figure 2

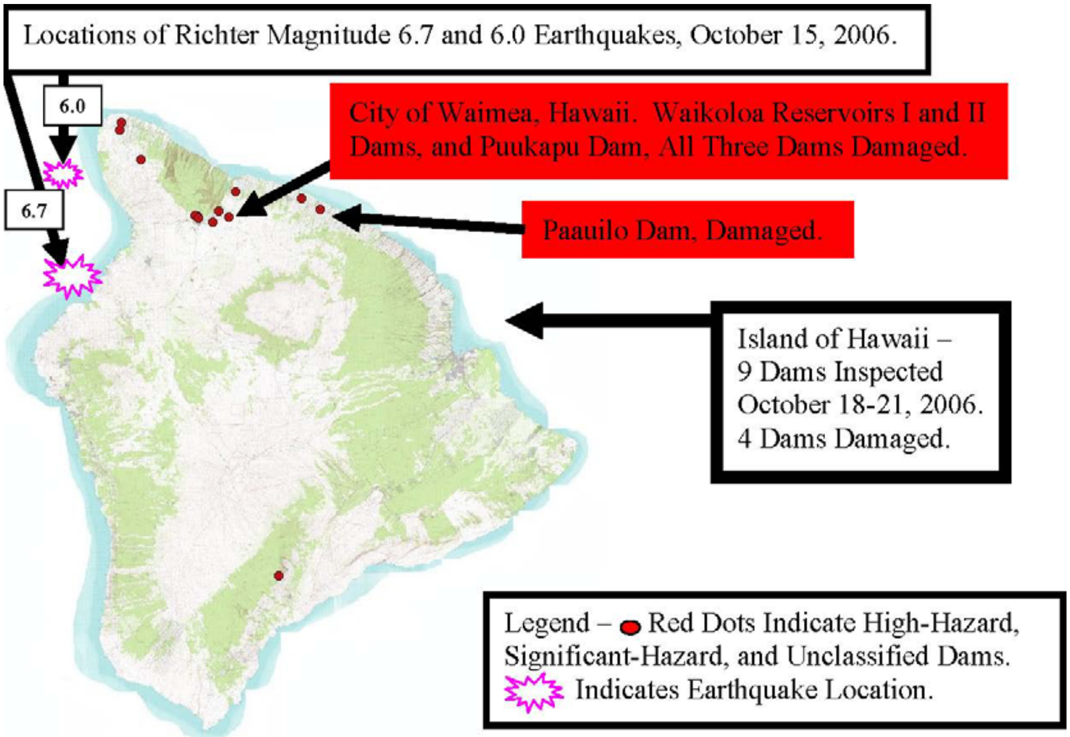


Figure 3

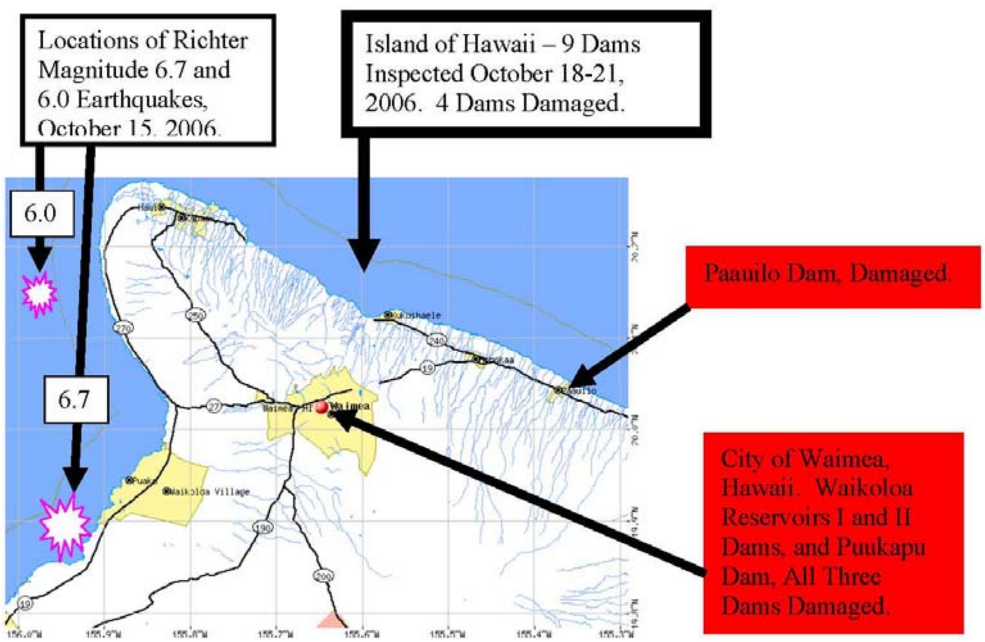


Figure 4

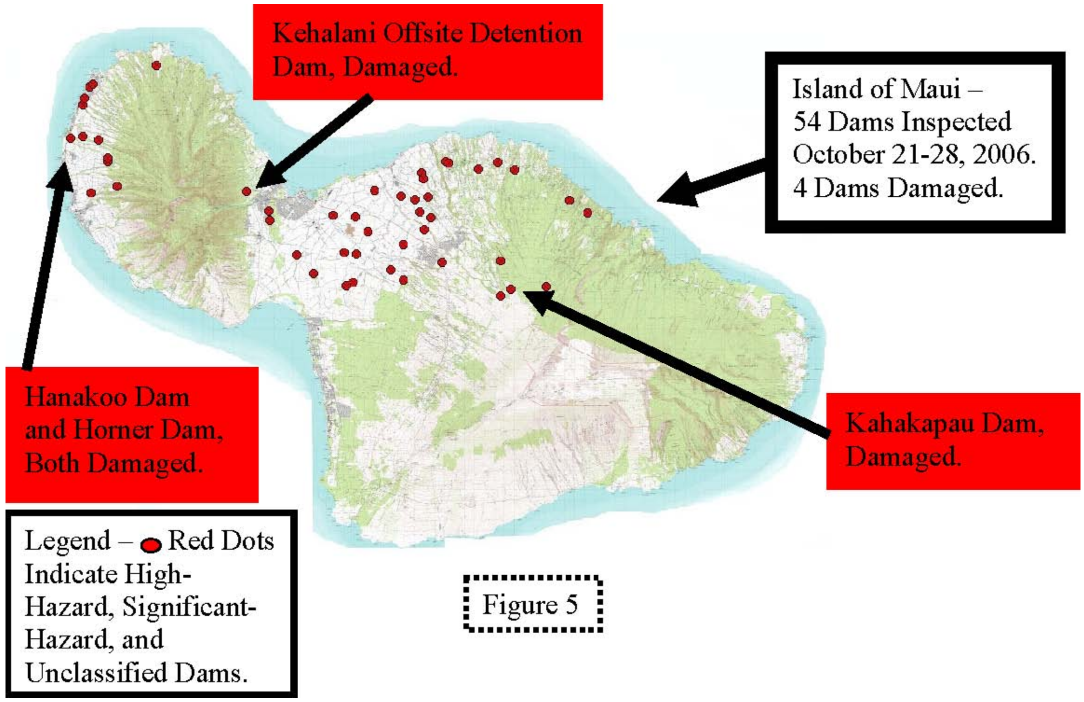


Figure 5

Waikoloa Reservoirs I, II, and III, Inspected October 20-21, 2006

The most significant earthquake-induced damage of all 63 dams inspected was at Waikoloa Reservoirs I and II on the Island of Hawaii (figures 1, 2, and 5, and photos 1 through 15). A third dam, Waikoloa Reservoir III, had no visible evidence of significant earthquake-induced damage. Reservoirs I, II, and III were constructed in 1970, 1975, and 1985, respectively, and their embankment heights are 38 feet, 35 feet, and 30 feet, respectively. These three circular to almost oval-shaped reservoirs are located in series to one another. Reservoir II, the north dam, has the highest crest elevation, and Reservoir III has the lowest. Reservoir I is located between Reservoir II and III. The reservoirs are used to store drinking water for the city of Waimea (population about 8,000) and surrounding communities. Waimea city limits begin about 1 mile south and downstream from the reservoirs. Water is supplied to the dam with pipelines from two other dams. A drinking water treatment plant is located about halfway downhill to Waimea.

Waikoloa Reservoirs I and II store up to about 60 and 50 million gallons, respectively. The dams exhibited cracking of their crests and concrete linings, open joints in the concrete liner panels, spalled concrete parapets, and significant new seepage and sandboil activity at the downstream toes (photos 1 through 15). At about 6:30 p.m. on October 20, drawdown of Reservoirs I and II was initiated after the inspections revealed significant earthquake damage. The reservoir drawdowns were initiated to stop the sandboils and seepage flow and to reduce the potential threat of dam failure and downstream inundation in Waimea. During this time, the third drinking water reservoir, Reservoir III, and several wells were used to supply drinking water for the city of Waimea. Designs for repair of Reservoir I and II dams are ongoing.

Inspection of Reservoir II

The inspection began with Reservoir II, with assistance from dam operators, DLNR, NRCS, and DWS. The weather was warm, with a few scattered clouds and a forecast of afternoon rainshowers. It should be noted that the dam operators provided valuable information during the inspection regarding the changed conditions that occurred at the dam since the earthquakes, and they also visually monitored the reservoirs, seepage, and sandboil activity during lowering of the reservoirs throughout the night of October 20-21. The reservoir was holding about 50 million gallons with a water depth of about 28 feet. The reservoir water surface elevation was about 5 feet 5 inches below the top of the concrete parapet wall. The crest of the dam is about 20 feet wide with a thin layer of asphaltic material on top. The concrete liner of the reservoir has a concrete curb or parapet wall about 1 foot high. The dam has a small free-overflow concrete spillway crest and inlet/outlet works pipes.

The inspection of Reservoir II began on the dam crest. Significant earthquake damage was immediately evident. Numerous new longitudinal and transverse cracks were evident on the crest of the dam, measuring up to about 2 inches wide, 40 feet long, and up to 3 feet deep (photos 1 and 2). The cracks are likely deeper and could have opened and then closed up during the earthquakes. In order to determine the depth of the open portion of the cracks, they were probed with a steel tape measure. Bulging of the crest asphaltic material up to a few inches high was evident between the parapet wall and many of the longitudinal cracks (photos 1 and 2). Earthquake shaking caused areas of separation, or openings, between the parapet wall and adjacent crest material that measured up to 1 inch wide, 20 feet long, and 1 foot deep at about 6 locations (photos 2 and 3). The bulges and areas of separation were caused by the earthquake-induced movement of the dam embankment and concrete liner. Several new cracks were evident on the asphalt-paved access road where the road connects to the dam crest.

The concrete liner had numerous old vertical and angled cracks that had been patched with white silicone-type sealant material placed in and/or across the cracks, and there were old joint openings with silicone sealant material in them and/or joint filler packing material that had been placed in the joints. However, the inspection revealed new vertical and angled cracks in several liner panels (photo 5). The cracks measured up to about 0.1 inch wide, extending up to the top of the parapet wall from an undeterminable depth down the panels (limited by visibility into the reservoir). Additionally, several of the joints between concrete liner panels had separated due to the earthquake and were opened less than about 1 inch, and at two joints the most significant new joint openings were 2 inches wide (photo 4). The 2-inch joint openings exhibited old 1-inch-wide white silicone-type joint filler material that had been pulled apart where the joints had opened up to 2 inches wide during the earthquakes (photo 4). Operating personnel reported that the repairs were completed about 20 years ago because of leakage concerns, and the joints were open about 1 inch prior to the earthquakes. The concrete parapet wall at one of these new 2-inch-wide joint openings exhibited new cracking and spalling with exposed reinforcing steel (photo 4). Numerous other joints in the parapet wall exhibited new cracking and spalling with exposed rebar.

During the examination of the dam crest, operating personnel and individuals visiting the damaged areas and walking on the crest were requested to not walk on the damaged areas or disturb them so that the damage conditions could be preserved and visually examined for changing conditions in the near future. After examining the dam crest and visible portions of the concrete liner, the visible portions of the spillway and inlet/outlet works were examined, and there was no observed evidence of earthquake damage.

The downstream face of the dam, abutments, and visible portions of the foundation were then examined. No cracks, sloughs, bulges, or depressions were observed. Operating personnel reported that the northeast portion of the dam foundation area of Reservoir II was normally moist, but after the earthquakes, the inspection revealed that this area of the foundation had ponded water up to about 3 inches deep in the 6-inch-high grass covering the area. However, of particular concern, operating personnel also reported a significant increase in ponded water between Reservoir I and Reservoir II since the earthquakes (photo 6). Reservoir II is about 30 feet above and about 100 feet northwest of Reservoir I (photo 6). Small amounts of ponded water had been observed for many years prior to the earthquakes, but after the earthquakes, the pond had approximately tripled in size to about 50 feet long and about 6 inches deep and had partially inundated an asphalt-paved access road between the dams (photo 6). The old pond conditions with smaller amounts of water could have been a result of rainfall runoff and/or seepage from Reservoir II, although this has not verified.

The increased ponded water inundating the access road was discharging a visually estimated 1 gallon per minute flow toward the downstream toe of Reservoir I. However, during the inspection of the downstream toe and foundation of Reservoir II, more flowing water from the pond was located in a small drainage area on the foundation just downstream from the middle of the southwest portion of the dam toe. The flow was visually estimated to be about 10 gallons per minute, flowing to the southwest and away from the pond between Reservoirs I and II.

The dam operators reported that this was the first time these flows and the increased pond size had been observed, and that no flow had been observed in this area when examined by them a week prior to the earthquakes. In this area, the downstream toe of the dam embankment was observed to be moist for a distance of about 8 feet above the foundation/dam toe contact (photo 6). The moist toe area was about 70 feet long, and there was standing water about 2 inches deep on the foundation near the toe. These conditions were also reported by dam operators to be new since the earthquakes. These new moist and standing water conditions "raised a red flag" of concern for this inspector because of previous experiences with dams exhibiting similar seepage conditions. The inspection team immediately directed their efforts to a close examination of the moist toe area. This inspector and one other team member began walking the toe of the dam in two lines, and in less than 1 minute after the "red flag" alert, two new active sandboils were located at the maximum section of the dam on the southwest side of the downstream toe about 1.5 feet above the foundation contact with the toe (photos 6 through 8).

The two new sandboils were each about 2 to 3 inches in diameter and were located about 18 inches apart (photos 6 through 8). The sandboils had a combined seepage flow of about 10 gallons per minute, and the flows were transporting small amounts of fine-grained material (photos 7 and 8). About 10 percent of the seepage was flowing into the ponded water, inundating the access road between Reservoirs I and II, and the rest of the seepage flowed to the southwest drainage area (discussed above) and away from the pond between Reservoirs I and II (photos 6 through 9). Dam operators had not seen these sandboils previously and confirmed that the sandboils were new since the earthquakes because the operators examined the dam a week before the earthquakes and there were no sandboils in this area at that time. The sandboils were located on the dam toe at 29.5 feet below the top of the crest of dam parapet wall, or about 1.5 feet above the foundation at the maximum section (photos 6 through 8). The sandboils were not clearly visible, being hidden by 6-inch-tall grass covering the downstream face of the embankment. The sandboils were then marked with flagging for future monitoring and inspection.

Inspection of Reservoir I

After inspecting Reservoir II, the inspection of the adjacent Reservoir I was performed. The concrete liner of the reservoir has a concrete curb or parapet wall about 1 foot high. The dam has a small free overflow spillway and an outlet works and inlet pipe. The water in the reservoir was 30 feet deep. Operating personnel reported that, prior to the earthquakes, ponded water and small flows from the pond were typically evident on the foundation just downstream from the north portion of the downstream toe of the dam. However, they expressed concern that after the earthquakes, significantly larger flows were evident, the ponded water near the toe of the dam was significantly deeper, and they could not locate the source of any new water flow into this area. Operating personnel also reported that during rainfall events, significant amounts of surface runoff from the hillside north of the dam flow along the north toe of the dam into the area where the ponded water is located. This side of the dam embankment is about 17.5 feet high (photos 9 through 11). The reservoir water surface elevation was about 5 feet below the top of the liner parapet wall (photo 9).

Photo 1.—Waikoloa Reservoir II Dam – Earthquake-induced new longitudinal crack in the dam crest (arrows denote alignment). Note new bulging of the crest in the area of the crack caused by earthquake shaking of the dam. Numerous other new longitudinal cracks and bulged areas are evident on the dam crest.
10/20/2006

Photo 2.—Waikoloa Reservoir II Dam – Earthquake-induced new longitudinal crack in the dam crest (short arrows denote alignment). Note new bulging (area between long arrows and short arrows) of the crest paving caused by earthquake shaking of the dam and the 1-inch wide separation (long arrows) between the reservoir concrete lining parapet wall and the crest embankment material. Numerous other new longitudinal cracks, bulged areas, and areas of separation are evident on the dam crest. New transverse cracks are evident at several other locations on the dam crest.
10/20/2006

Photo 3.—Waikoloa Reservoir II Dam – Closeup view of the new typical earthquake-induced 1-inch wide, 20-foot-long separation between the reservoir concrete lining and the crest embankment material (arrow), shown in the previous photograph, evident at numerous locations and of various lengths on the crest.

10/20/2006

Photo 4.—Waikoloa Reservoir II Dam – New opening at joint (upper arrow) about 2 inches wide (evident at this and one other joint, note old white joint filler material where joint used to be open about 1 inch), and typical new concrete damage with exposed reinforcing steel bar (lower arrow) at the concrete reservoir liner panels caused by earthquake motion. New concrete spalling damage (lower arrow) such as this is evident at numerous joints in the concrete liner panels.

10/20/2006

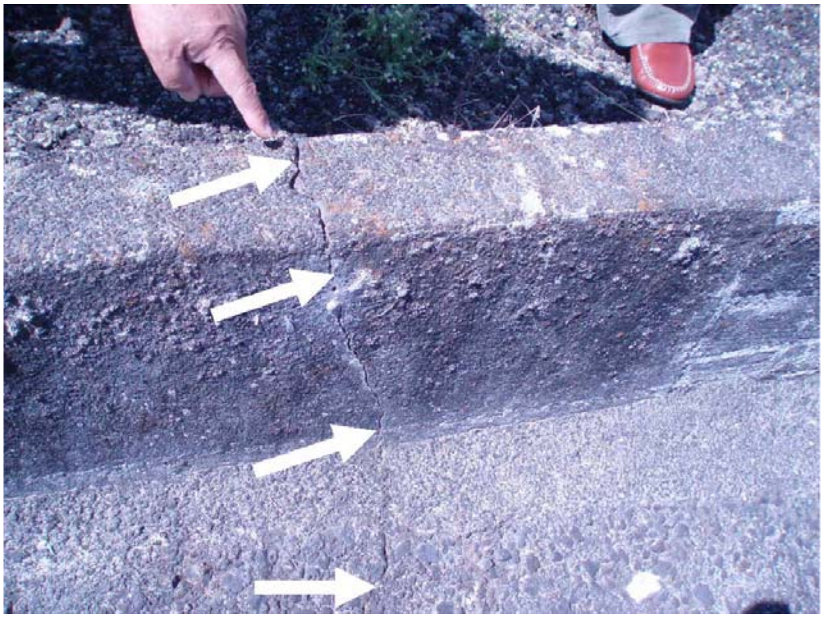


Photo 5.—Waikoloa Reservoir II Dam – Typical earthquake-induced new crack (arrows) in the reservoir concrete liner and parapet wall.
10/20/2006

Photo 6.—Waikoloa Reservoir II Dam – Two earthquake-induced new sandboils (right arrow) at downstream toe of Reservoir II Dam. Note ponded water inundating the paved access road (left arrow) between Reservoirs I and II. About 10 percent (1 gallon per minute) of sandboil seepage was flowing into the ponded water, and 90 percent was flowing into southwest drainage area in background of photo located between right and middle arrows. Note Reservoir I Dam (middle arrow).
10/20/2006

Photo 7.—Waikoloa Reservoir II Dam – Two earthquake-induced new sandboils (lower arrows) at the downstream toe of the dam shown in the previous photograph, facing upstream. Upper arrow denotes crest of Reservoir II Dam.

10/21/2006

Photo 8.—Waikoloa Reservoir II Dam – Closeup view of the two earthquake-induced new sandboils (arrows) at the downstream toe of Reservoir II Dam flowing at a total visually estimated rate of about 10 gallons per minute, shown in the previous photograph.

10/20/2006

Upon inspection of the downstream toe of the dam in this area, a significant amount of lush old aquatic vegetation was evident in 12 inch-deep ponded water (photos 9 and 10). After a few minutes of inspecting the toe area in hip waders, this inspector found moving water that was barely noticeable as it was surfacing, flowing to the right and to the left as it reached the surface. The aquatic vegetation covering the pond partially obscured the seepage flow from view. Upon clearing the vegetation in about a 6-foot-diameter area, flow from three sandboils was visible breaking the surface of the pond at a visually estimated combined flow rate of about 30 to 40 gallons per minute (photos 9 through 14). The sandboils were transporting and depositing sediment materials in classic sandboil fashion (photo 14). The sandboils were each about 4 to 6 inches in diameter and were located within a 3-foot-diameter area (photos 11 through 14). The sandboil flow was breaking the pond surface and rising to about 1 inch above the surface of the pond (photos 11 through 14).

The sandboils were probed by hand, and it was possible to insert an arm into them up to the shoulder with no resistance except for flowing seepage. The eroded paths of the seepage curved upstream toward the dam embankment. The sandboils were then probed with the total length of a 5-foot-long stick with little or no resistance. At this time, it was decided to probe the sandboils no further because the sandboils were new, and it was not known if further probing would cause a significant increase in seepage flow and sediment transport. The story about the Dutch boy with his thumb stuck into the leaking dike came to mind. The 5-foot stick with flagging material attached was inserted into the ground in the ponded water, a few feet to the left of the sandboils, to mark the location for future inspection and seepage monitoring.

About 30 minutes after locating the sandboils, heavy rainfall began and continued for several hours. It should be noted that after the rainfall began, it would have been extremely difficult to locate moving water from the sandboils in the ponded water due to the rainfall landing on and disturbing the ponded water surface and because the depth and flow in the ponded water area increased significantly along the dam toe and downstream foundation due to the rainfall runoff. At this point, luck was apparently on our side.

The dam crest, visible portion of the reservoir concrete liner, downstream face, abutments, and foundation were examined next. On the crest, much less damage was evident at Reservoir I than at Reservoir II. The crest has a grass cover. A few areas of separation measuring about 0.5 inch wide, 50 feet long, and a probed depth of about 1 foot, were evident between the concrete liner parapet wall and the dam crest (photo 15). There were a few longitudinal cracks in the dam crest measuring about 0.25 inch wide and 10 feet long, with a probed depth of about 1 foot. No new cracks were evident on the visible portion of the concrete liner. The downstream face and visible portions of the abutments and foundation exhibited no significant cracking, sloughing, bulges, or depressions (photos 9 through 11).

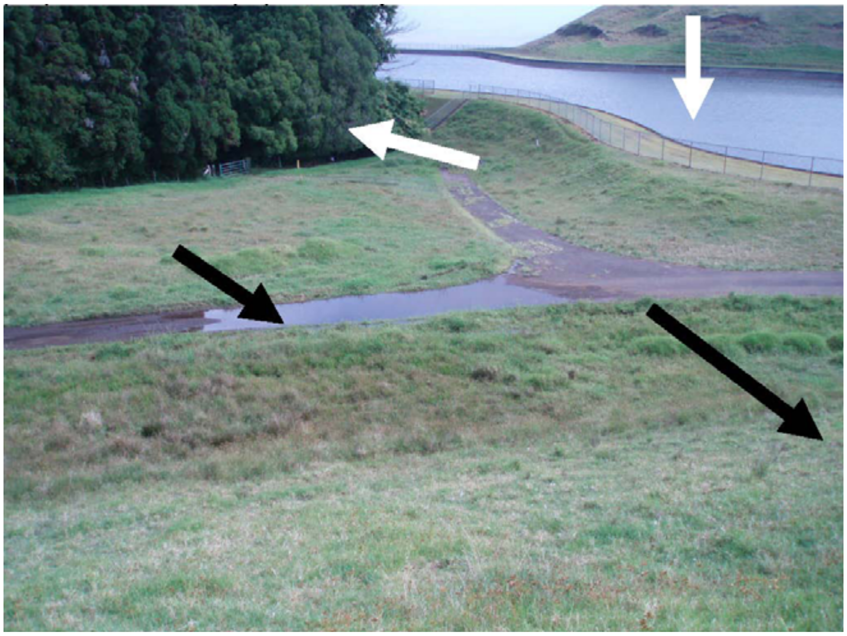


Photo 9.—Waikoloa Reservoir I Dam – Reservoir I (right short arrow) viewed from the crest of Waikoloa Reservoir II Dam. Left short arrow denotes water inundating the access road between the dams. Middle short arrow denotes sandboils location hidden behind trees in photograph. Long arrow denotes Waikoloa Reservoir II sandboils location.
10/20/2006

Photo 10.—Waikoloa Reservoir I Dam – Earthquake-induced sandboil area (left arrow) at the downstream toe of the dam. Right arrow denotes the downstream face of the dam. Dam is 17.5 feet high at this location. Photograph is blurry due to low light conditions and rainfall.
10/20/2006

Photo 11.—Waikoloa Reservoir I Dam – Earthquake-induced sandboil area (lower arrow) at the downstream toe of the dam with three sandboils. Middle arrow denotes the downstream face of the dam, upper arrow denotes downstream face of Reservoir II Dam.

10/20/2006

Photo 12.—Waikoloa Reservoir I Dam – Sandboil area (arrows denote three sandboils) at the downstream toe of the dam, facing downstream. Three sandboils are flowing at total visually estimated rate of about 30 to 40 gallons per minute, with soil particles suspended and accumulated around the sandboils.

10/20/2006

Photo 13.—Waikoloa Reservoir I Dam – Closeup view of the three sandboils (arrows) shown in the previous photograph. Note soil materials in suspension (arrows) in the rising flow from the sandboils breaking about 1 inch above the pond surface.

10/20/2006

Photo 14.—Waikoloa Reservoir I Dam – Sandboil area shown in previous photographs, prior to lowering the reservoir. Inspector is collecting and examining soil materials from the earthquake-induced sandboils. The three sandboils are flowing at a total combined visually estimated rate of about 30 to 40 gallons per minute, with transported soil particles in suspension and accumulated around the sandboils.

10/20/2006

Photo 15.—Waikoloa Reservoir I Dam – Crest of Reservoir I Dam with cracking (middle arrow). Right arrow denotes Reservoir II Dam crest. Note the reservoir concrete lining parapet (left arrow). The Reservoir I sandboils are located at the downstream toe about 20 feet to right of photograph.

10/20/2006

Inspecting Reservoir III

Reservoir III was inspected next, and no significant earthquake damage was evident. No seepage was evident at the dam, abutments, or foundation. No new cracks were evident on the visible portion of the concrete liner. One 12-inch piece of spalled concrete was evident at the inlet pipe outfall structure on the crest of the dam. The downstream face and visible portions of the abutments and foundation exhibited no cracking, sloughing, bulges, or depressions. It was determined that Reservoir III could be used for the drinking water supply for Waimea and surrounding communities, while Reservoirs I and II would be lowered in an attempt to stop the sandboil seepage flows and reduce the potential for dam failure.

Lowering the Reservoir Water Surface Elevations in Reservoirs I and II

At 6:30 p.m., near sunset on October 20, 2006, the Mayor of Hawaii County (Hawaii County comprises the whole Island of Hawaii) was contacted by the inspection team via cellular telephone on speakerphone from the crest of Reservoir I to notify him of the inspection findings. The Mayor was informed of the earthquake damage at Reservoirs I and II, the observed new sandboil seepage flows and materials transport in the seepage flows, the unknown potential for dam failure associated with the new sandboil and seepage conditions, the potential for loss of life and property in Waimea if the dams failed, and the satisfactory visible condition of Reservoir III. Several concerns were discussed, including the possibility that there could be more cracking of the reservoir liner and separation of the reservoir concrete liner panel joints below the reservoir water surface elevation, cracking of the dams and/or foundations that is not visible, and the potential for changing seepage, internal erosion, and piping conditions in the dam and/or foundation that could either slowly or quickly develop into a potential dam failure. Based on the information he received, the Mayor's decision was to drain the reservoirs low enough to stop the sandboil seepage and to use Reservoir III for a drinking water supply for the city of Waimea and surrounding communities. The outlet works of Reservoirs I and II were immediately used to begin making releases into the normally dry Waiaka and Waimea streams, respectively.

After the telephone conversation with the Mayor, I provided a handwritten spreadsheet to two dam operators who had volunteered to spend the night at the dams. The spreadsheet was used throughout the night to record hourly the reservoir water surface elevations and sandboil activity and any comments regarding changing dam conditions. The dam operators visually examined Reservoirs I, II, and III with the aid of flashlights every 2 or 3 hours throughout the night. At that time, there were no Emergency Action Plans (EAPs) for Reservoirs I, II, and III. However, during the night of October 20, about 50 local policemen were stationed on the streets of Waimea in case of the need for evacuation of residents. This inspector spent the night at a residence in Waimea immediately downstream from the dams.

On the morning of October 21, the dam was visited again by most of the inspection team for a followup inspection. The dam operators that stayed at the dam overnight reported that the sandboil seepage flows were decreasing as the reservoirs were drawn down, as expected, and that no new damage or new sandboils were evident. By 8:00 a.m. on October 21, each reservoir had been drawn down about 6 feet, and the sandboil seepage flow rate had reduced by about half. Federal Emergency Management Agency (FEMA) representatives arrived at the site that morning and were taken on a tour of the damaged dams and the sandboil areas. A cursory inspection of the water treatment plant revealed minor to significant new earthquake-induced concrete cracking, spalling, and displacement. COE and FEMA inspectors performed a thorough inspection of the plant within the next few days.

On October 22, the sandboil seepage stopped at both dams when they were drawn down to about half of the reservoir depth, or about 15 feet. Reservoir II was then drained to about 1 foot of water depth, and Reservoir I was maintained at about 15 feet of water depth. Several lower cracks and open joints were visible in the lower portion of the Reservoir II liner. A few weeks later, Reservoir I was refilled to a depth of 23 feet, at which point the sandboil seepage started flowing again, so the reservoir was drained to several feet below that depth.

On Saturday, October 21, a local newspaper reported that the Hawaii County Assistant Civil Defense Administrator stated, “We will never know how close we came to a major disaster. This is the force of Mother Nature.”

Periodic visual inspections of Waikoloa Reservoirs I, II, and III are continuing as part of the ongoing operation and maintenance program at the dams. Designs for modification of Waikoloa Reservoirs I and II are in progress, and EAPs are being worked on at the time of the preparation of this paper in May 2007.

Paauilo Dam, Inspected October 18-19, 2006

Paauilo Dam is an embankment dam located near the city of Paauilo on the north coast of the Island of Hawaii (figures 1 through 4 and photos 16 through 20). The dam has an oval-shaped reservoir about 20 feet high with about a 900-foot-long crest, and stores water for irrigation (photos 16 and 18). A rubber reservoir liner was installed in 2002 (photos 16 and 18). The crest is covered with a thin layer of asphaltic surfacing material (photos 16 through 18). During the inspection, the water in the reservoir was 15 feet deep (photos 16 and 18). The dam has a free-overflow spillway, an outlet works, and an inlet ditch that discharges into an inlet pipe (photos 18 through 20). Spillway flow from a concrete-lined free-overflow inlet channel (photo 18) pass into a concrete energy dissipation structure with dentates, and flow then passes into an unlined discharge channel (photo 20), through a highway culvert, and into an unlined drainage channel that discharges into the Pacific Ocean. The dam crest was clear of vegetation, but the downstream face was covered with dense vegetation (Guinnka Grass) up to about 8 feet high that did not allow physical access to the downstream face for visual inspection (photo 19).

The dam was inspected on October 18, 2006, on the afternoon of arrival on the Island of Hawaii, and again the next morning, with assistance from one DLNR and one NRCS employee who provided valuable information regarding the changed condition of the dam due to earthquake-induced damage.

The crest of the dam exhibited several significant new earthquake-induced longitudinal cracks (photos 16 through 18). The largest crack was 460 feet long, up to 4 inches wide at the dam crest, and was probed to a depth of 12 inches (photos 16 and 17). This crack began at 135 feet to the right of the spillway and extended around the corner of the oval-shaped reservoir (photos 16 and 17). A second crack located on the opposite side of the dam crest from the spillway was about 100 feet long, a maximum of about 1 inch wide, and a few inches deep. This crack ran along the location where the reservoir liner material was keyed into

Photo 16.—Paauilo Dam – Lower arrow denotes the left end of the new 460-foot-long earthquake-induced crack (bottom arrow) located 135 feet to the right (facing downstream) of the spillway. Arrows denote the alignment of crack around the corner of the reservoir.

10/18-19/2006

Photo 17.—Paauilo Dam – Closeup view of the new crack shown in previous photograph, with a maximum surface width of about 4 inches.

10/18-19/2006

Photo 18.—Paauilo Dam – Short arrows denote the alignment of the new 25-foot-long earthquake-induced crack located 220 feet to the left (facing downstream) of the spillway. The long arrow denotes the spillway.
10/18-19/2006

Photo 19.—Paauilo Dam – Outlet works discharge structure with no earthquake damage. Arrow denotes downstream face of the dam. Note significant amount of tall vegetation on the face.

10/18-19/2006

Photo 20.—Paauilo Dam – Typical earthquake-induced new rock and soil slide area (arrows) on the open cut side slopes of the spillway discharge channel. 10/18-19/2006

the dam crest. A third crack located 220 feet to the left of the spillway was 25 feet long, 0.1 inch wide, and a few inches deep (photo 18). The cracks are likely deeper than probed because they could have opened and closed during the earthquakes.

New earthquake-induced cracking and minor sloughing was evident in a 5-foot-high, 100-foot-long embankment berm located between the right side of the dam and the access road. The cracks were about 30 feet long, about 1 to 2 inches wide, and a few feet deep.

The only visible new earthquake-induced damage at the spillway was several areas of minor rock and soil slides, each less than 3 cubic yards, on the unlined open cut side slopes of the spillway discharge channel between the dam and the highway culvert (photo 20).

No seepage was observed at the dam, abutments, or foundation, and none has been previously reported.

Puukapu Dam, Inspected October 20, 2006

Puukapu Dam is a sediment retention embankment dam near the city of Waimea on the Island of Hawaii (figures 1 through 4 and photos 21 through 23). The dam

Photo 21.—Puukapu Dam – Minor earthquake-induced separation (arrow) between the backfill and right concrete wall of the Puukapu Watershed Canal facing upstream. The separation is earthquake-induced damage 15 feet long, 0.25 inch wide, and of unknown depth. This is the only location where separation is evident at the canal. The damage is about 300 feet upstream from the dam.
10/20/06

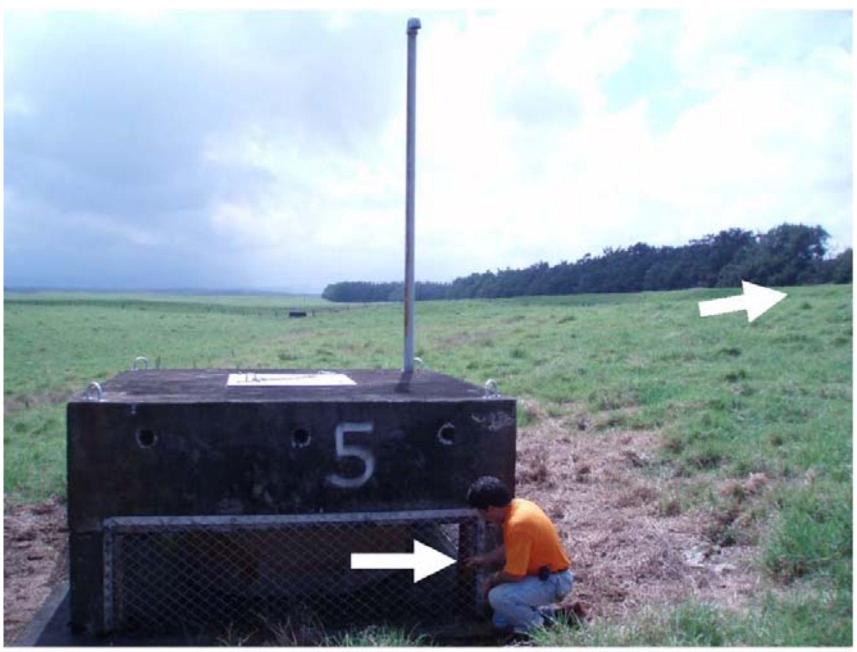


Photo 22.—Puukapu Dam – Spalled concrete and exposed reinforcing steel (left arrow) at the right downstream support column of dry well No. 5. Right arrow denotes the upstream face of the dam embankment.
10/20/06

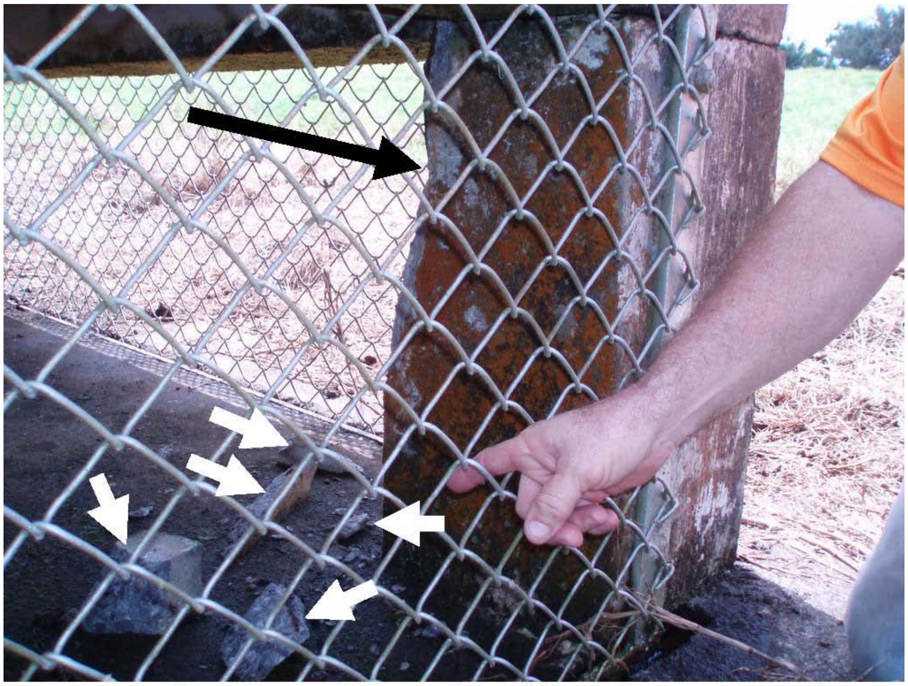


Photo 23.—Puukapu Dam – Closeup view of the spalled concrete and exposed reinforcing steel (long arrow) near top of the right downstream support column of dry well No. 5 shown in previous photograph. Note spalled concrete pieces (short arrows) on floor where man is pointing.

10/20/2006

is about 1,000 feet long and about 10 feet high. The dam surfaces have a grass cover (photo 22). The dam has a free-overflow spillway through the dam embankment. The ungated embankment spillway crest is lined with riprap. The outlets consist of six dry wells within the reservoir that are over 100 feet deep. Inflow is provided by the concrete-lined Puukapu Watershed Canal (photo 21). The inspection was performed with the assistance of DLNR and NRCS personnel, immediately prior to the inspections of Waikoloa Reservoirs I, II, and III, discussed above.

During the inspection, the reservoir was dry. Minor, new earthquake-induced damage was evident at the Puukapu Watershed Canal. The damage was minor separation between the right concrete canal wall and the adjacent backfill material (photo 21). The separation measured 0.25 inch wide, 15 feet long, and of unknown depth. The minor damage was about 300 yards upstream from the dam.

The only other new earthquake-induced damage was evident at a few minor cracked and spalled concrete areas on concrete columns of the drop inlet structures at dry wells No. 1 and No. 5 (photos 22 and 23). The spalled concrete pieces were between about 8 to 12 inches long (photos 22 and 23). The spalled areas had exposed reinforcing steel bars (photos 22 and 23). It was not possible to enter the dry wells because there were no provisions for confined space entry.

Kahakapau Dam, Inspected October 24, 2006

Kahakapau Dam on the Island of Maui has twin adjacent reservoirs (Reservoirs No. 1 and No. 2) that each hold 50 million gallons of water (figures 1, 2, and 5 and photo 24). The embankment dam is located in north central east Maui, near the northwestern portion of Haleakala National Park. The dam is about 30 feet high, and each reservoir had 26.5-foot-deep water during the inspection. The reservoirs have membrane liners covered with shotcrete, approximately 30-inch-high concrete parapet walls. Each reservoir has inlet/outlet works and small drop inlet spillways with buried discharge pipes and concrete discharge structures. The dam crests are asphalt paved. The downstream face and downstream foundation area of the dam have a grass cover that is mowed regularly to allow for visual inspection.

Photo 24.—Kahakapau Dam – New earthquake-included crack (short arrows) in the concrete lining of Reservoir No. 2 facing downstream. The crack is located 55 feet upstream from the reservoir water surface elevation staff gage (long arrow).

10/24/06

The dam was inspected with assistance from one DLNR and two MCDOWS employees. The MCDOWS personnel provided valuable information regarding the post-earthquake conditions observed. New earthquake-induced damage consisted of a few new transverse cracks in each reservoir's liner shotcrete coating and several cracks in the parapet wall at the same location as the cracks in the shotcrete (photo 24). The cracks in the shotcrete were about 0.1 to 0.2 inch wide and extended from the top of the shotcrete down as far as could be seen into the reservoir water (photo 24). It is unknown if the cracks extend into the dam embankment. The cracks in the parapet wall are in line with the transverse cracks in the shotcrete. No seepage was observed at the dam, abutments, or foundation, and none has been previously reported.

Hanakoo Dam, Inspected October 26, 2006

Hanakoo Dam is an embankment dam owned and operated by Kaanapali Farm Services (aka Pioneer Mill Company) and is a few miles from the Pacific Ocean on the west side of the Island of Maui (figures 1, 2, and 5 and photo 25 and 26). The reservoir provides irrigation water. The dam is about 20 feet high and about 600 feet long, with an ungravelled 15-foot-wide crest and hand-placed masonry rock slope protection on the upstream face. The dam has an 8-inch-diameter inlet pipe, a 2-foot-diameter horizontal spillway pipe at the right end of the dam, and an outlet works. The downstream face has no slope protection. The downstream face is covered with a significant amount of trees and bushy vegetation growth, which extremely limited the visual inspection of the face. The upstream face has a significant amount of vegetation at the left and right portions of the face, outside of the masonry covered center section of the face. The dam was inspected with the assistance of one DLNR and one Kaanapali Farm Services employee. During the inspection, the reservoir water was about 6 feet deep.

The only new earthquake-induced damage evident was a crack on the dam crest located about 50 feet from the right abutment (photos 25 and 26). The 60-foot-long, 2-inch-wide, 4-foot-deep crack was located in the middle of the crest (photos 25 and 26). It should be noted that the downstream face could not be completely inspected due to the significant tree and bushy vegetation growth.

Photo 25.—Hanakoo Dam – Right end (short arrows) of a 60-foot-long, 4-foot-deep earthquake-induced crack (probed 4 feet with coffee tree stick, crack could be deeper) on the crest of the dam facing the right abutment. Coffee tree stick is slender and stiff, good for probing. Right end of crack starts 50 feet to the left of the spillway (long arrow denotes spillway pipe). 10/26/06

Photo 26.—Hanakoo Dam – Closeup view of the right end of the 60-foot-long crack (arrows) shown in previous photograph. Note the machete inserted into the crack at lower arrow.

10/26/06

Horner Dam, Inspected October 26, 2006

Horner Dam is an embankment dam owned and operated by Kaanapali Farm Services (aka Pioneer Mill Company) and is located near Hanakoo Dam (discussed above) several miles from the Pacific Ocean on the west side of the Island of Maui (figures 1, 2, and 5 and photo 27). The reservoir provides irrigation water. The dam is about 25 feet high and about 800 feet long, with an ungravelled 15-foot-wide crest. There is no slope protection except for vegetation growth on the upstream face. The dam has an inlet pipe, a free overflow unlined spillway channel near the right end of the dam crest, and a siphon outlet works system. The downstream face has no slope protection. The downstream face is covered with a significant amount of trees and bushy vegetation growth, which significantly limited the access to the face for visual inspection. The upstream face has a significant amount of vegetation at the left and right portions of the face, outside of the masonry covered center section of the face. The dam was inspected with the assistance of one DLNR and one Kaanapali Farm Services employee. During the inspection, the reservoir water was about 20 feet deep.

In 1992, the dam embankment breached and failed near the middle of the dam crest where an approximately 2-foot-diameter steel pipe passed through the dam embankment. After the failure, the steel pipe was removed, and a divider berm was installed near the middle of the reservoir to the right of the failure location creating two adjacent reservoir basins separated by the berm. The right basin of

Photo 27.—Horner Dam – 2-foot-long, 1-foot-wide, 2-foot-deep sinkhole (arrow) on crest of dam of the left basin (dry reservoir) facing the left abutment. Sinkhole is 108 feet to the left of the berm dividing the left and right basins of the reservoir. 10/26/06

the reservoir holds irrigation water and has a siphon outlet works pipe that was installed in 1992 after the dam failure. The left basin of the reservoir is dry and is not used.

The only new earthquake-induced damage evident was a minor sinkhole on the crest of the left (dry) basin (photo 27). The sinkhole was 2 feet long, 1 foot wide, and 2 feet deep, and was located 108 feet to the left of the berm dividing the left and right basins (photo 27). A 12-inch-diameter eroded hole on the downstream face of the basin was located 5 feet below the dam crest and was connected to the sinkhole. The hole was caused by water entering the sinkhole and exiting at the downstream face. The hole on the downstream face was located by this inspector by crawling on hands and knees through wild pig “tunnels” in the dense vegetation on the downstream face. The face was otherwise inaccessible due to the vegetation. The Kaanapali Farm Services employee noted that the sinkhole was located at the same location where the dam breach failure occurred and that the failed area was repaired in 1992 with embankment material that might not have been adequately compacted in place.

Kehalani Offsite Retention Dam, Inspected October 27, 2006

Kehalani Offsite Retention Dam (aka Stanford Carr Development Retention Dam) was recently completed, except for final excavation of the reservoir floor that was ongoing during the inspection (figures 1, 2, and 5 and photos 28 and 29). Assistance was provided during the inspection by one DLNR and one Stanford Carr Development Company employee. The reservoir had 10-foot-deep water during the inspection. The dam is about 40 feet high and about 1,500 feet long with an ungravelled 20-foot-wide crest, an unlined inlet channel (to be lined with concrete), and a 48-inch-diameter storm drain corrugated metal pipe (CMP) inlet to the reservoir. The free overflow spillway has a concrete-lined discharge channel that passes under a roadway bridge to a concrete stilling basin. The dam provides storm water retention for a housing development. The only new earthquake-induced damage evident was several cracks on the left end of the dam crest (photos 28 and 29). The largest crack was a 150-foot long longitudinal crack on the crest that started at 40 feet to the right of the left end of the dam crest (photos 28 and 29). The crack was located between 3 and 8 feet downstream from the upstream shoulder of the crest. The crack was up to 12 inches wide at 12-inch-diameter vertical holes in the crack and was probed to 10 inches deep. Three other longitudinal cracks were evident on the upstream face of the dam just upstream from the 150-foot-long crack on the crest (photo 29). The cracks were parallel to each other and separated by 2 to 3 feet in the upstream direction, and minor sloughing about 6 inches deep was evident between the three cracks. No seepage was observed at the dam, abutments, or foundation, and none had been previously reported.

Photo 28.—Kehalani Offsite Retention Dam – Crest of the dam facing the right abutment from 40 feet right of the left end of the dam. Arrows denote a 150-foot-long, 10-inch-deep earthquake-induced longitudinal crack on the crest that starts at 40 feet to the right of the left end of the crest. Note the 12-inch-diameter, 10-inch-deep holes along the crack.
10/27/06

Photo 29.—Kehalani Offsite Retention Dam – Earthquake-induced cracking and sloughing (short arrows) on the upstream shoulder of the dam located about 20 feet left of the cracking shown in the previous photograph, facing the right abutment from about 20 feet to the right of the left end of the crest. Long arrows denote the 150-foot-long crack on crest shown in previous photograph. 10/27/06

Mission

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

The purpose of this bulletin is to serve as a medium of exchanging operation and maintenance information. Its success depends upon your help in obtaining and submitting new and useful operation and maintenance ideas.

Advertise your district's or project's resourcefulness by having an article published in the bulletin—let us hear from you soon!

Prospective articles should be submitted to one of the Bureau of Reclamation contacts listed below:

Jerry Fischer, Bureau of Reclamation, ATTN: 86-68360, PO Box 25007, Denver, CO 80225-0007; (303) 445-2748, FAX (303) 445-6381; email: jfischer@do.usbr.gov

Vicki Hoffman, Pacific Northwest Region, ATTN: PN-3234, 1150 North Curtis Road, Boise, ID 83706-1234; (208) 378-5335, FAX (208) 378-5305

Steve Herbst, Mid-Pacific Region, ATTN: MP-430, 2800 Cottage Way, Sacramento, CA 95825-1898; (916) 978-5228, FAX (916) 978-5290

Albert Graves, Lower Colorado Region, ATTN: BCOO-4846, PO Box 61470, Boulder City, NV 89006-1470; (702) 293-8163, FAX (702) 293-8042

Don Wintch, Upper Colorado Region, ATTN: UC-258, PO Box 11568, Salt Lake City, UT 84147-0568; (801) 524-3307, FAX (801) 524-5499

Dave Nelson, Great Plains Region, ATTN: GP-2400, PO Box 36900, Billings, MT 59107-6900; (406) 247-7630, FAX (406) 247-7898