CALIFORNIA DIVISION OF SAFETY OF DAMS
FAULT ACTIVITY GUIDELINES

William A. Fraser
Chief, Geology Branch
Division of Safety of Dams
California Department of Water Resources
wfraser@water.ca.gov

January 26, 2001

ABSTRACT

This paper discusses the fault activity guidelines used by the Division of Safety of Dams to evaluate faults in California. In California, earthquakes represent the most severe loading that some dams will experience. To provide a high degree of protection from earthquake-related dam failure the seismic sources that could conceivably affect a dam must be identified. Clear and all-inclusive guidelines for assessing fault activity are needed by investigating geologists evaluating the seismic hazards. The California Department of Water Resources, Division of Safety of Dams, defines an *active* fault as having ruptured within the last 35,000 years. A *conditionally active* fault is defined as having ruptured in the Quaternary, but its displacement history during the last 35,000 years is unknown. Fault inactivity is demonstrated by a confidently located fault trace that is consistently overlain by unbroken geologic materials older than 35,000 years. Faults that have no indication of Quaternary activity are presumed to be *inactive,* except in regions of sparse Quaternary cover.

INTRODUCTION

In California, earthquakes represent the most severe loading some dams will experience. Strong ground shaking can result in instability of the dam itself, strength loss of the foundation, instability of the natural reservoir rim, and release of the reservoir by seiche. Active faults within the foundation of the dam have the potential to cause damaging displacement of the structure. To prevent catastrophic release of water from the reservoir, appropriate design measures must be employed to resist earthquake-imposed loads.

To provide a high degree of protection from earthquake-related dam failure, identification of the seismic sources that could conceivably affect a project is needed. Seismotectonic investigations, often involving detailed field studies to determine the recency of fault activity and magnitude of paleoseismic earthquakes, are an important part of a site investigation for dams.

This paper discusses the fault activity guidelines used by the Division of Safety of Dams to evaluate faults in California. In reviewing the safety of existing and proposed dams, the California Division of Safety of Dams (DSOD) uses a deterministic method to estimate ground motion parameters for design analyses. In a deterministic seismic hazard assessment the judgement as to which faults are active seismic sources is perhaps the most critical step. Clear guidelines as to which faults are considered active are of interest to project planners, investigating geologists, and design engineers.

In developing these guidelines, the criteria used by other agencies, particularly agencies involved in dam design, were reviewed. Slemmons and McKinney (1977) provide an historical summary of the various definitions of the term “active fault”, many of which are application specific.

DETERMINISTIC SEISMIC HAZARD ANALYSIS

In a deterministic seismic hazard assessment, faults within the proximity of the site are identified and assessed for activity. For each seismic source, an earthquake scenario consisting of the maximum magnitude a fault is capable of generating at the closest distance to the site under consideration is specified as the basis for the ground motion estimate. Statistically-based ground motion estimates for the several significant seismic sources are reported to engineering staff, who study the estimates and decide which to use in modeling the maximum loading for the structure.

A deterministic seismic hazard analysis is time-independent. The specified event is possible, but there is no consideration of the likelihood of occurrence within a given time frame, such as the life of the dam. This approach contrasts with the probabilistic seismic hazard analysis, which formally considers event likelihood and the uncertainty of the ground motion estimate.

The investigator compiles information on the known faults in the proximity of the site from previously published geologic maps and reports. Based on the results of this compilation, a detailed project-specific fault investigation may be required.

Such investigations begin with evaluation of aerial photographs and other forms of remote sensing, such as infra-red or radar imagery, to locate faults and assess their activity. Historic aerial photographs may be especially helpful in recognizing fault-produced landforms in areas where construction or agriculture have altered the topography. Ground-based geophysical surveys, such as gravity, magnetism, and reflection or refraction seismology, may help determine fault locations. Once located, trench exposures are used to assess fault activity and character of expected movements. Maximum magnitude is determined through an evaluation of fault segmentation and displacement history. A comprehensive summary of techniques of fault activity evaluation has been compiled by Slemmons and dePolo (1986).

Active faults and conditionally active faults are used to develop the design ground motion. The faults judged to be inactive are eliminated from further consideration.

FAULT ACTIVITY GUIDELINES

Numerous definitions for active faulting have been proposed, but no one definition has been universally accepted (Slemmons and McKinney, 1977). In 1995, Division of Safety of Dams geology staff substantially revised their active fault guidelines. This process included detailed review by the Division of Safety of Dams Consulting Board for Earthquake Analysis (Housner et al., 1989, 1994), - a panel consisting of eminent experts in the fields of geology, seismology, and earthquake engineering. The goal of this revision was to develop clear guidelines for assessing fault activity, as well as precise categories of activity to provide a basis for design decisions. The guidelines also provide direction to geologists in planning fault investigations on behalf of dam owners.

A text of the guidelines is included as Appendix 1 and is discussed in some detail below. Three general categories of faults are defined: *active, inactive, and conditionally active*.

Active seismic sources

An *active* seismic source is defined as a fault that has ruptured within the last 35,000 years. The 35,000-year value was selected based on the belief that Holocene activity (the last 10,000 years) is not a sufficiently conservative criterion for elimination of a fault when estimating ground motion for dam design. The 35,000-year criterion essentially defines a level of risk. Faults exhibit a wide range of average recurrence intervals, from a few tens of years to over several hundred thousand years, and a fault that has not moved in the last 35,000 years is assumed to have a ground-rupturing earthquake recurrence interval of more than 35,000 years. This low level of activity makes the likelihood of future events sufficiently improbable that the fault may be disregarded for design purposes.

This or any fault activity criterion is somewhat arbitrary by its very nature. There is no physical reason why a fault that has not moved during the last 35,000 years cannot move again. This point is illustrated by the October 16, 1999 Magnitude 7.1 Hector Mine Earthquake. Much of the fault zone that produced this earthquake had not ruptured previously during the Holocene, clearly illustrating the need to design dams for a criterion more conservative than Holocene activity. The 35,000-year criterion was selected because it provides this conservatism, while retaining the practicality of having several age-dating techniques available to investigating geologists.

Two sub-categories of active faulting are defined: *Holocene active* and *Latest Pleistocene* active. At the present time the distinction between these sub-categories is descriptive only, and both categories are treated as active seismic sources for the purposes of design. These sub-categories conceivably could define separate criteria applicable to dams of different type, risk category, or location within California.

The guidelines provide examples of the lines of evidence that are used to classify a fault as Holocene active. Stratigraphic displacement of Holocene age materials is a primary way to identify a Holocene active fault. Other criteria used to demonstrate Holocene activity include geomorphic, geologic, geodetic, and seismologic evidence. Holocene active faults are usually well-documented in the geologic literature. An example of a Holocene active fault is shown in Figure 1, in which a trench exposure at Leyden Creek reveals that the Calaveras fault has repeatedly offset Holocene colluvium (Kelson et al., 1996).

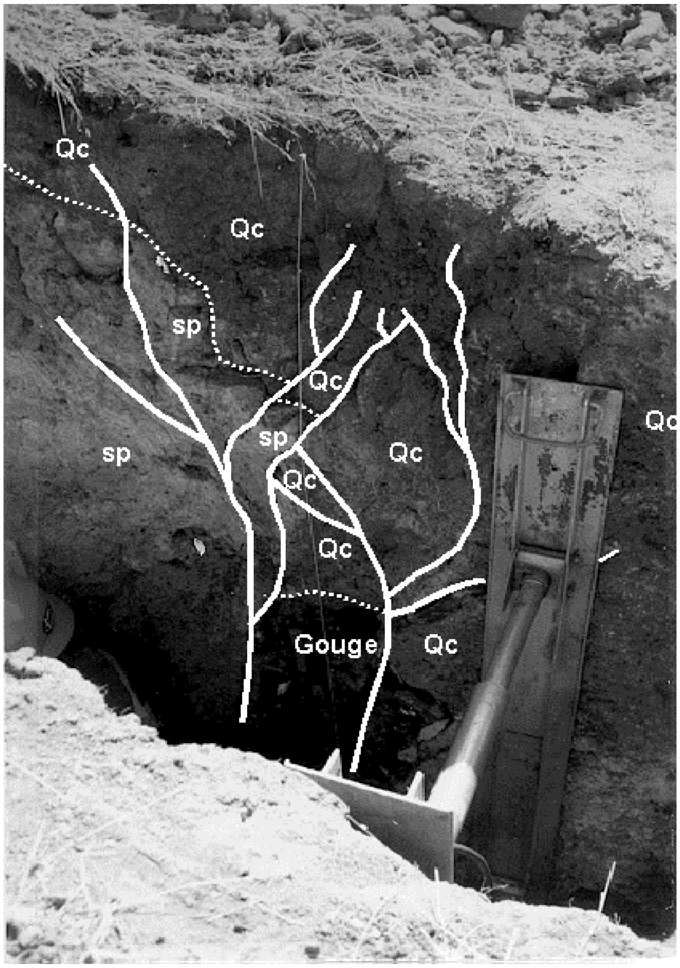

Figure 1. Holocene active fault. A recent investigation at Leyden Creek revealed evidence for as many as six surface ruptures along the Northern Calaveras fault during the last 2,500 years. The fault juxtaposes serpentinite (sp) and Holocene colluvium (Qc). Soil fissures within Holocene colluvium extend to within six inches of the surface. [Modified after Kelson et al., (1996); file photo by M.K. Merriam, Division of Safety of Dams]

Faults of Latest Pleistocene age are usually not as well documented in the literature and may be more difficult to recognize. Age dating of geologic materials within this time frame is possible using radiocarbon and soil stratigraphic techniques. An example of a Latest Pleistocene active fault is shown in Figure 2, in which the Franklin fault offsets 31,000-year-old alluvium near Walnut Creek, California.

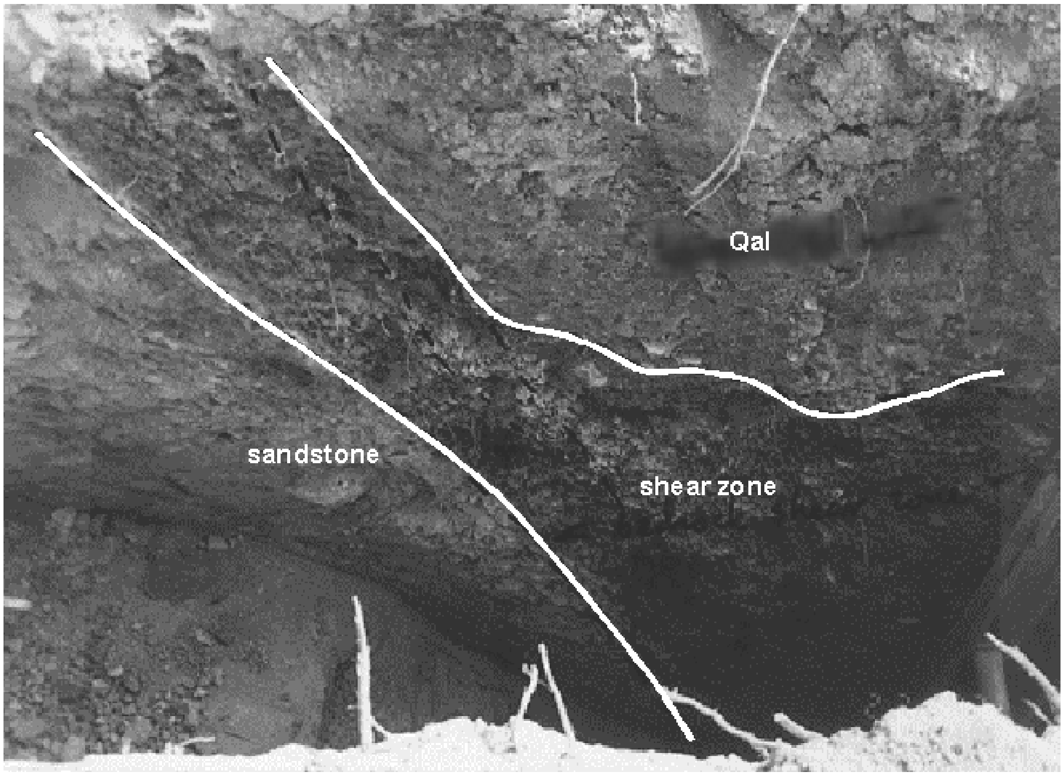

Figure 2. Latest Pleistocene active fault. A 1997 investigation of the Franklin fault near Walnut Creek has identified offset of 31,000 year old alluvium (Qal). [File photo by J.K. Howard, Division of Safety of Dams]

Inactive seismic sources

In planning and interpreting subsurface investigations, the investigating geologist needs to know the criteria by which a fault can be shown to be *inactive*. Inactivity is demonstrated by a confidently located fault trace that is consistently overlain by unbroken geologic materials 35,000 years or older, or other characteristics indicating lack of displacement within the last 35,000 years. Figure 3 shows a fault demonstrated to be inactive: The Water Peak fault, near New Hogan Reservoir, is overlain by geologic materials greater than 35,000 years old (USACE, 1995).

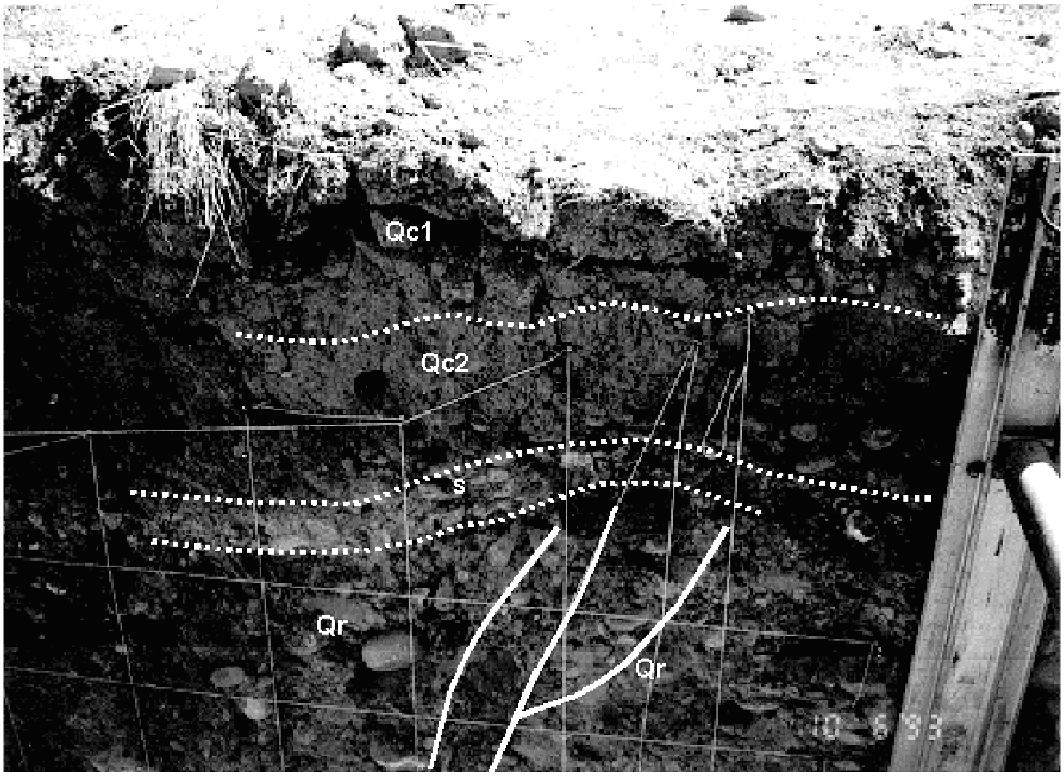

Figure 3. Inactive fault. A 1993 investigation by the U.S. Army Corps of Engineers demonstrated inactivity on the Waters Peak fault near Valley Springs, California. The down-to-the-east normal fault displaces Pleistocene Riverbank Formation (Qr). An unfaulted pedogenic silica horizon (s) developed on the alluvium dated at greater than 35,000 years old, and two younger unfaulted colluvium units (Qc1 and Qc2) overlie the fault. [File photo by author]

Faults that have no suggestion of Quaternary activity are generally presumed to be *inactive*. However, in regions of sparse Quaternary cover, a fault lacking evidence for Quaternary activity can not be assumed to be inactive. The presumption of inactivity requires a finding that there is no potential or expectation for activity. This may be demonstrated by fault characteristics inconsistent with the current tectonic regime.

Conditionally active seismic sources

The guidelines establish specific criteria for determining faults that require detailed investigation. In most areas of the State, demonstrated Quaternary activity is considered a reasonable and practical threshold for assuming that a fault may be associated with the current tectonic regime. A *conditionally active* fault is Quaternary active, but its displacement history during the last 35,000 years is not known well enough to determine activity or inactivity. The often misused and misunderstood term “potentially active fault” has been dropped from use. In regions of sparse Quaternary cover, such as the Sierra Nevada, pre-Quaternary faults that can be reasonably shown by Division staff to have attributes consistent with the current tectonic regime are also classified as conditionally active.

The Division of Safety of Dams treats *conditionally active* faults as seismic sources, with the understanding that additional investigation or analysis could change that designation. Figure 4 shows a conditionally active fault exposed in the foundation excavation for Shiloh Ranch Dam near Santa Rosa, California.

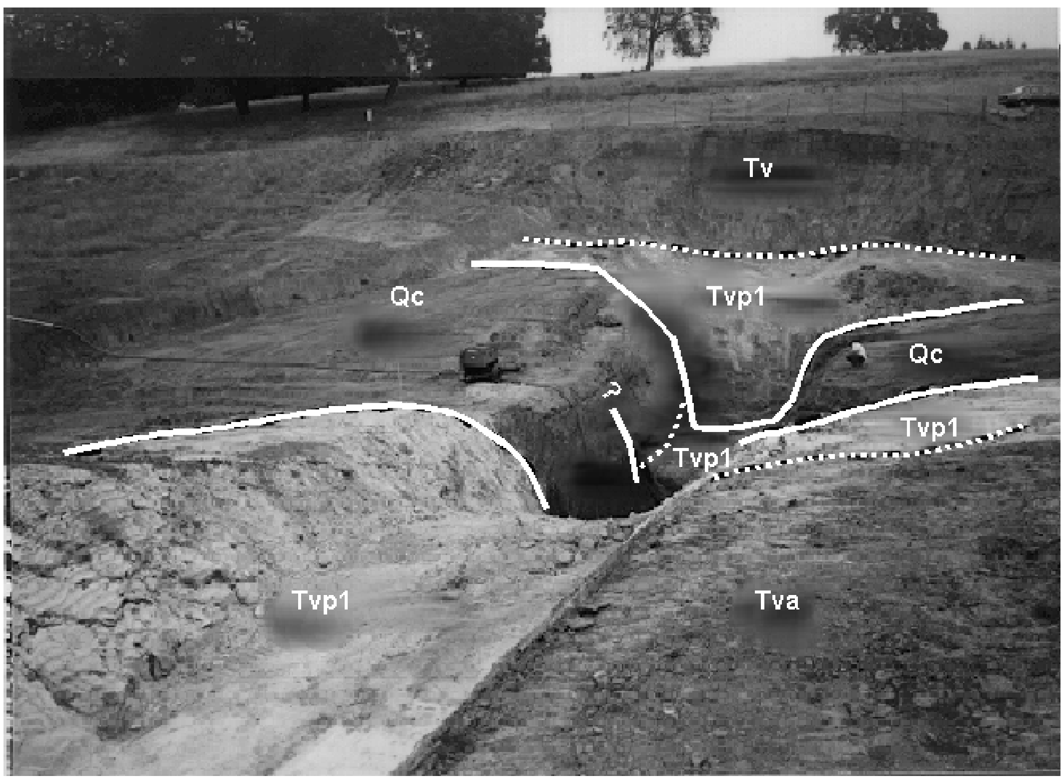

Figure 4. A conditionally active fault (shown by the white thick solid lines) is exposed in the foundation excavation for Shiloh Ranch Dam #2 near Santa Rosa. Tertiary white tuff (Tvp1) is in fault contact with Quaternary colluvium (Qc). The owner of the dam elected to design for fault offset rather than investigate the fault's displacement history during the last 35,000 years. Depositional contacts between the colluvium, white tuff, Tertiary andesite (Tva), and the undifferentiated volcanic unit (Tv) are shown by the dotted lines. [File photo by author]

SUMMARY

To provide a high degree of protection from earthquake-related dam failure, the seismic sources that could conceivably affect a dam must be identified. However, there is no universally accepted definition for an active fault. The active fault criterion selected essentially defines an acceptable level of risk for the specific application. The Division of Safety of Dams has recently adopted a 35,000-year standard for determining fault activity for dam design and analysis. Clear and all-inclusive guidelines have been developed, which should assist geologists in California with planning fault investigations, as well as provide design engineers with an understanding of the implications of each fault activity class.

REFERENCES

Housner, G.W., Agbabian, M.S., Allen, C.R., Bolt, B.A., and Seed, H.B., 1989, Final Report: Consulting Board for Earthquake Analysis Meeting of June 1 and 2, 1988: California Division of Safety of Dams, Sacramento, California, 13 p.

Housner, G.W., Allen, C.R., Bolt, B.A., and Idriss, I.M., 1994, Final Report: Consulting Board for Earthquake Analysis Meeting of June 23 and 24, 1994: California Division of Safety of Dams, Sacramento, California, 17 p.

Kelson, K.I., Simpson, G.D., Lettis, W.R., and Harden, C.C., 1996, Holocene slip rate and earthquake recurrence of the northern Calaveras fault at Leyden Creek, Northern California: Journal of Geophysical Research, v. 101, n. B3, p. 5961-5975.

Slemmons, D.B., and McKinney, R., 1977, Definition of “active fault”: U.S. Army Engineer Waterways Experiment Station, Miscellaneous Paper S-77-8.

Slemmons, D.B., and dePolo, C.M., 1986, Evaluation of active faulting and associated hazards: *in* Wallace, R.E. (ed.), Studies in Geophysics, Active Tectonics, National Academy Press, 266 p.

U.S. Army Corps of Engineers, 1995, Geologic and seismologic investigation, New Hogan dam and reservoir: U.S. Army Corps of Engineers Sacramento District [Sacramento, California], 50 p.

DSOD Fault Activity Guidelines

for use in deterministic fault activity assessments

Active Seismic Sources (considered seismic sources for dam design or reevaluation)

Holocene Active Fault: is a fault on which surface or subsurface displacement has occurred within the Holocene epoch. Holocene activity is demonstrated by one or more lines of evidence including the following:

- Holocene (last 10,000 years) stratigraphic displacement
- geomorphic evidence of Holocene displacement or tectonism[1]
- geodetically measured tectonism or observations of fault creep
- well-located zones of seismicity

Latest Pleistocene Active Fault: is a fault on which no evidence of Holocene displacement is known, but which has experienced surface or subsurface displacement within the last 35,000 years. Latest Pleistocene activity is demonstrated by one or more of the following lines of evidence:

- stratigraphic displacement to units 11,000 to 35,000 years
- geomorphic evidence of Latest Pleistocene displacement or tectonism[1]

[1]tectonism refers to crustal deformations which are indicative of faulting

Conditionally Active Seismic Sources (treated as a seismic source for dam design or reevaluation because of incomplete or inconclusive evidence, with the understanding that additional investigation or analysis could change the designation)

Conditionally Active Fault: a fault which meets one of the following criteria.

- a Quaternary active fault (one that has experienced surface or subsurface displacement within the last 1.6 million years) with a displacement history during the last 35,000 years that is not known with sufficient certainty to consider the fault an active or inactive seismic source

- a pre-Quaternary fault which can be reasonably shown to have attributes consistent with the current tectonic regime. *Example...* In the foothills of the Sierra Nevada geomorphic province Mesozoic faults are considered Conditionally Active Seismic Sources unless proven otherwise

Inactive Seismic Sources (not considered for dam design or reevaluation)

Inactive Fault: a fault which has had no surface or subsurface displacement within the last 35,000 years. Inactivity is demonstrated by a confidently-located fault trace which is consistently overlain by unbroken geologic materials 35,000 years or older, or other observation indicating lack of displacement. Faults that have no suggestion of Quaternary activity are presumed to be inactive.