STRONG-MOTION INSTRUMENTATION OF EARTH DAMS

J. J. Fedock (I)

SUMMARY

Guidelines for locating strong-motion instrumentation at earth dam sites are presented. Information obtained from analytical methods, forced-vibration tests, and the interpretation of strong-motion records from earth dams provides the basis for the selection of instrumentation locations at idealized dam sites. Application of these guidelines are presented for two cases. One earth dam has existing instrumentation which is in basic agreement with the recommendations described herein, and the planned instrumentation scheme at another earth dam site is also presented.

INTRODUCTION

To obtain critical information regarding a dam's earthquake behavior, it is necessary to install seismic instrumentation in the region close to the dam and on the earth embankment. In particular, strong-motion accelerographs placed at the dam location will provide the most valuable information available for describing the seismic behavior of the structure. Various federal, state, and local agencies are currently operating strong-motion instrumentation programs with the general goal of obtaining information about earth dam response during earthquakes. This report is intended to assist in the development and implementation of those programs.

It is assumed that one of the primary goals of the strong-motion instrumentation program is the acquisition of data for use in improving the design process of future earth dams or for evaluation of the seismic hazard of present earth dams. Consequently, the strong-motion instrumentation schemes presented in this report are designed to meet these goals. This implies that the dams selected for instrumentation not only should be expected to yield strong-motion data during some time period, but the information obtained should also be the most appropriate for use in achieving the desired goals. In particular, it is assumed that strong-motion data regarding structural behavior during damaging-level earthquakes are the most desirable types of information (Ref. 1).

The strong-motion instrumentation networks described in this study are subdivided into the following categories: 1) Free-field motion instrumentation, 2) Input motion instrumentation, and 3) Response motion instrumentation. Schemes designed to record motions for each of these categories are discussed in the following sections. Specific recommendations are presented for instrumenting an "ideal" earth dam and the surrounding region. Examples of existing and planned instrumentation schemes for earth dams which are in basic agreement with these guidelines are shown.

(I) Research Civil Engineer, U.S. Geological Survey, Menlo Park, California, and Assistant Professor, University of Santa Clara, California, USA

FREE-FIELD MOTION INSTRUMENTATION

Instrumentation that is designed to measure free-field motions near a dam should be located at a distance from the structure such that any recorded motion would be essentially the same as that obtained if the dam were not present. It is highly desirable to place this instrumentation at nearby sites in which the foundation conditions are similar to those of the dam. However, it may be necessary to place this instrumentation relatively distant from the dam to avoid any influence from foundation-structure interaction. Unfortunately, there is little experimental data to help in estimating the required distances between the free-field sites and the dam itself.

Due to topographic considerations and the immense size of most earth dams, it is obvious that one free-field site is insufficient for adequately defining the free-field motion. The recommendations for free-field instrumentation locations near an "ideal" earth dam are: 1) In the region of both abutments, and 2) Downstream of the dam. Self-contained, triaxial accelerographs are suggested for each free-field site with the orientation of the components corresponding to the transverse, longitudinal, and vertical axes, respectively, of the dam (Fig. 1). This instrumentation should also have a radio WWVB receiver or an internal time-code generator for providing real time. The "ideal" earth dam referred to is one that meets the conditions outlined in Ref. 2.

The abutment sites should not be adjacent to the dam but rather at a distance away from the ends of the dam approximately equal to the shear wavespeed times the fundamental period of vibration (Ref. 2). It is anticipated that the influence of the dam's presence upon the recordings at these locations will be insignificant. At the downstream site the instrumentation should be placed on the same foundation material that underlies the dam. The distance between the downstream toe and the location site should be approximately the same as that specified for the instruments in the region of the abutments. This distance is in reasonable agreement with the criteria used by the U.S. Army Corps of Engineers (Ref. 3).

This proposed scheme for measuring free-field motions should provide information regarding phase lags and direction of the incoming seismic waves. It may also permit an evaluation of the influence of the local topography on the ground motion since the downstream and abutment instruments will have a substantial elevation difference.

INPUT MOTION INSTRUMENTATION

Because of the unique geometry and foundation conditions of most earth dams, there are inherent inadequacies in any generalized instrumentation scheme for measuring input motions. Despite these limitations, the following instrumentation locations should provide the best information for describing the motions immediately adjacent to the dam: 1) On one or both abutments adjacent to the embankment at, or slightly below, the crest level, 2) A few meters beyond the base of the downstream toe on a cross-section through the maximum height of the embankment, 3) Directly beneath the dam crest within the upper few meters of the foundation soil or within the underlying rock on the same cross-section as that in 2. It is recommended that self-contained, three-component accelerographs, similar to that described previously, be placed at each of these locations with the components oriented in the same directions as those of the free-field instrumentation (Fig. 2).

By locating instruments on both abutments at the crest level, it would be possible to evaluate the phase lags of the input motions at this elevation. This information would be helpful in estimating the rocking responses of the dam as well as the in-phase translational motions. Abutment recordings would also provide valuable data regarding abutment-dam interaction effects. Measurements from the foundation level instruments would be important in analyzing differential ground motions along the maximum section of the dam.

RESPONSE MOTION INSTRUMENTATION

The instrumentation proposed in this section is intended to provide information that will identify the fundamental mode of predominant response in the directions corresponding to the transverse, longitudinal, and vertical axes of the dam. Additional modes that are expected to significantly contribute to the overall response of the dam will also be identified by the proposed scheme. The recommended instrumentation should also provide critical information regarding the actual mode shapes.

The recommendations for locations of instruments which are intended to measure the response motions of an "ideal" earth dam are: 1) On the crest on a cross-section through the maximum height of the dam and preferably at the midpoint along the crest, 2) On the crest at a distance from either abutment equal to approximately 1/4 to 1/3 of the crest length of the dam, 3) On the downstream slope at approximately 4/10 of the the maximum dam height on the same cross-section as that in 1, 4) On the upstream slope at approximately 4/10 of the maximum dam height on the same cross-section as that in 1, 5) On the downstream slope on the same cross-section as that in 2, and on the same horizontal plane as that in 3, 6) Directly beneath the crest at approximately 4/10 of the maximum dam height on the same cross-section as that in 1, and, 7) Directly beneath the crest at approximately 7/10 of the maximum dam height on the same cross-section as that in 1. The number and orientation of accelerometers at each of these locations will be discussed in terms of the expected predominant modes of response. Location numbers refer to the specific positions on the dam just described (Fig. 3).

Accelerometers oriented in the transverse direction should be placed at locations 1, 3, 4, 6, and 7 to provide information regarding the fundamental mode of response in the transverse direction. Note that all of these accelerometers are on the vertical plane through the maximum height of the dam and this plane is expected to experience the largest deformations in the transverse direction. Comparisons of the responses at the crest and at the 4/10 and 7/10 height locations may help in determining the nature of the mode shape along a vertical axis through the center of the dam and over the height of the dam along the upstream and downstream slopes. Data which will be obtained from these accelerometers will help to establish if the dam is deforming primarily in a shearing mode or if other types of deformation are significant.

Analysis of the three transverse motions at the 4/10 height locations may establish the existence of significant compressional or tensile zones over a horizontal plane. This information would be quite valuable in assessing the liquefaction potential of the embankment material. Since additional transversely-oriented accelerometers are recommended at the foundation level on the same vertical plane that contains the response-measuring instruments, comparisons of the input motions to the responses on this plane may be made.

To provide data for identifying the first mode in the longitudinal direction of the dam, accelerometers oriented in this direction should be positioned at locations 1, 2, and 3. A vertically-oriented accelerometer at location 2 should also help in supplying information about this mode since analytical and experimental evidence (Ref. 4,5) indicate that this longitudinal mode is significantly coupled with anti-symmetric vertical motion along the crest.

The fundamental vertical mode will be recorded by vertically-oriented accelerometers at location 1, 2, 3 and 6. Not only will the accelerometers at locations 1 and 6 be used to help identify this particular mode but their measurements can be compared to each other to evaluate the compressional and tensile strains in the vertical direction. Vertically-oriented accelerometers at locations 2 and 3 should supply data regarding this mode shape along the dam's length and over its height.

If the second transverse mode (anti-symmetric along the longitudinal axis) is excited, accelerometers oriented in the transverse direction at locations 2 and 5 should be used to provide data for identifying it. Data from these accelerometers, in addition to the transversely-oriented ones at locations 1 and 3, can be used to distinguish the first two transverse modes from each other.

Rocking behavior about a longitudinal axis through the dam would be recorded by the vertically-oriented accelerometer at location 3 and the majority of the transversely-oriented accelerometers. Previous studies (Ref. 4,6) indicate that the lowest rocking mode would contain large transverse components at locations 1 and 6, and data from the accelerometers at these locations would be helpful in identifying this mode. Because of the coupled nature of this mode, the phase relationships of the recorded motions may provide additional information regarding the existence of rocking response.

A total of 14 accelerometers placed at seven separate locations on and within the dam have been recommended for measuring the response motions of the dam. A central-recording system with remote accelerometers is well-suited for the instrumentation just proposed. If it is assumed that the behavior of the dam can be represented in terms of the modal responses described previously without introducing significant errors, then the data obtained from this instrumentation scheme should provide sufficient information to adequately describe the seismic response of the dam. However, in the event of a large earthquake in which damaging levels of motion may exist, additional instrumentation would be desirable to provide information regarding non-linear behavior and possible failure mechanisms.

EXAMPLE INSTRUMENTATION SCHEMES

Fig. 4 depicts the strong-motion instrumentation scheme at Long Valley Dam which is located approximately 40 km NW of Bishop, California. This earth dam has been instrumented by the Office of Strong-Motion Studies of the California Division of Mines and Geology with 22 accelerometers positioned on the embankment and in the immediate vicinity. All of the recording instruments are interconnected for common triggering and real time is provided by WWVB receiver. The number and positions of the accelerometers at Long Valley Dam are in basic agreement with the guidelines presented herein. However, no downhole instrumentation exists at the dam site. Several important sets of strong-motion data have already been obtained from these instruments (Ref. 7).

The planned strong-motion instrumentation scheme at Anderson Dam is shown in Fig. 5. Located approximately 2 km from the Calaveras fault and 20 km from the San Andreas fault in Santa Clara County, California, this structure is being instrumented by the Branch of Engineering Seismology and Geology of the U.S. Geological Survey. Free-field instrumentation, consisting of self-contained, three-component accelerographs, is planned for the dam abutment and downstream of the embankment. A 13-channel central recording unit with remote accelerometers will measure the earthquake responses on the embankment and at the downstream toe.

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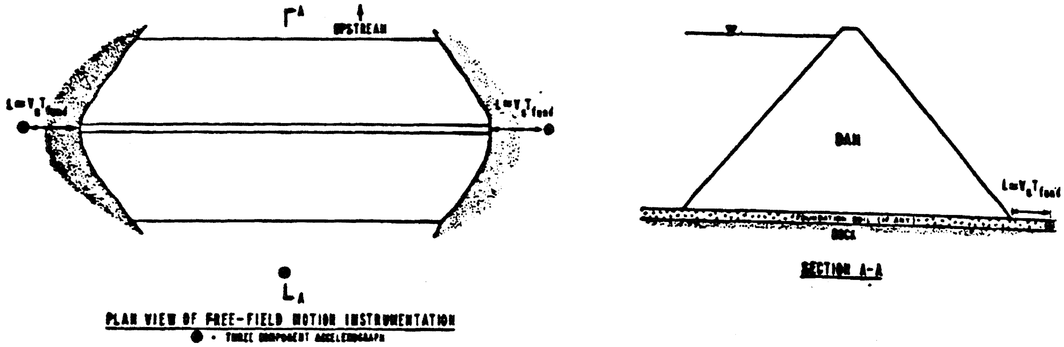

Fig. 1. Recommended Instrumentation for Recording Free-Field Motions Near "Ideal" Earth Dam

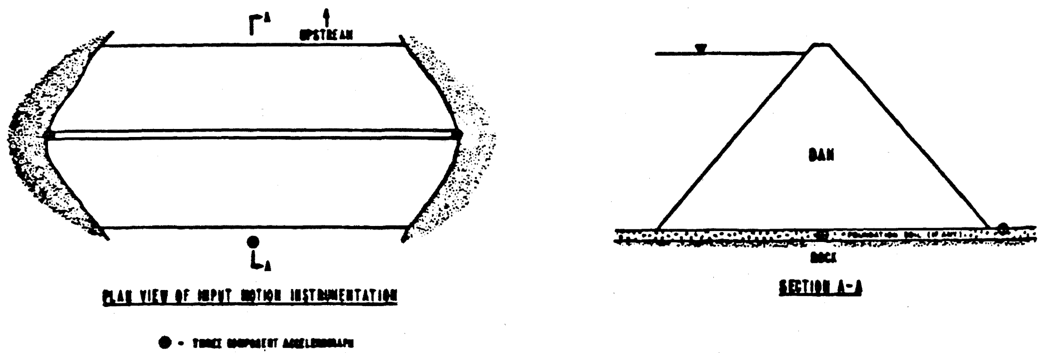

Fig. 2. Recommended Instrumentation for Recording Input Motions to "Ideal" Earth Dam

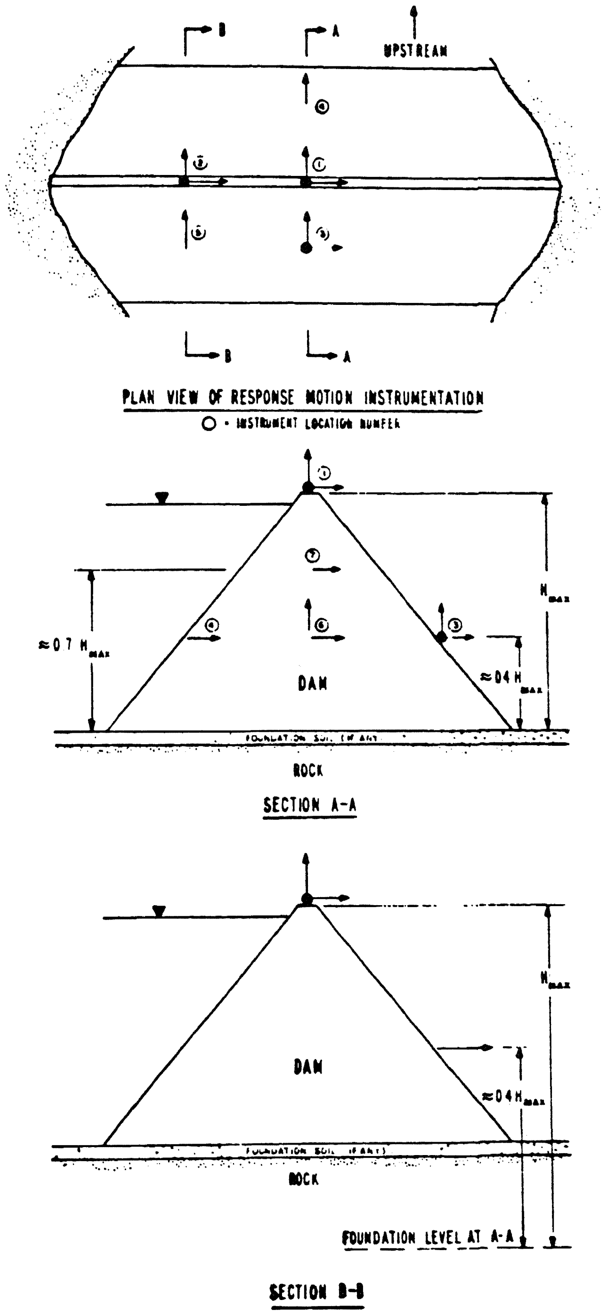

Figure 3. Proposed Instrumentation for Recording Response Motions of "Ideal" Earth Dam

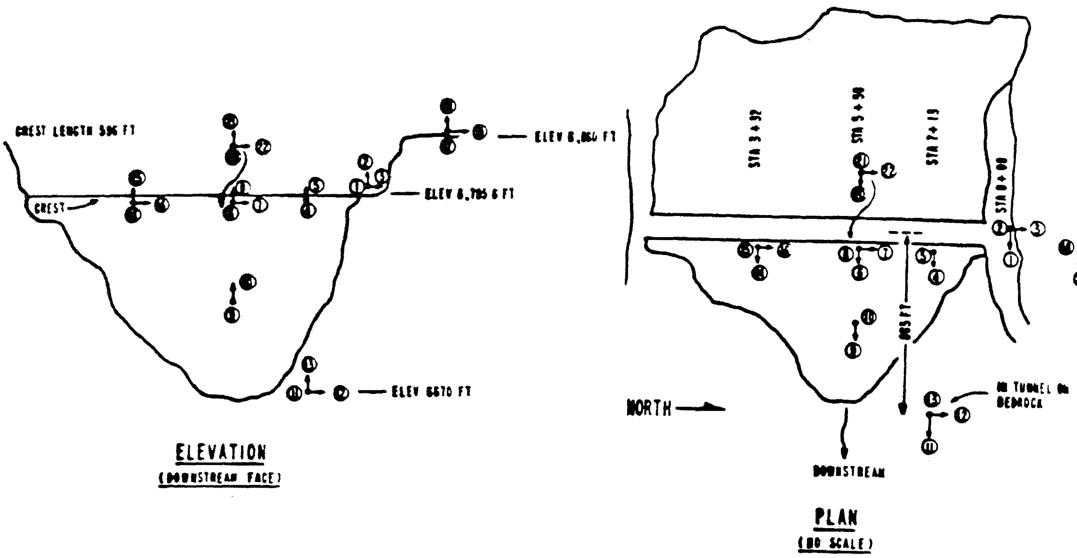

Fig. 4. Strong-Motion Instrumentation Scheme at Long Valley Dam (Ref. 7) (Accelerometer Locations Selected by J. Ragsdale of CDMG)

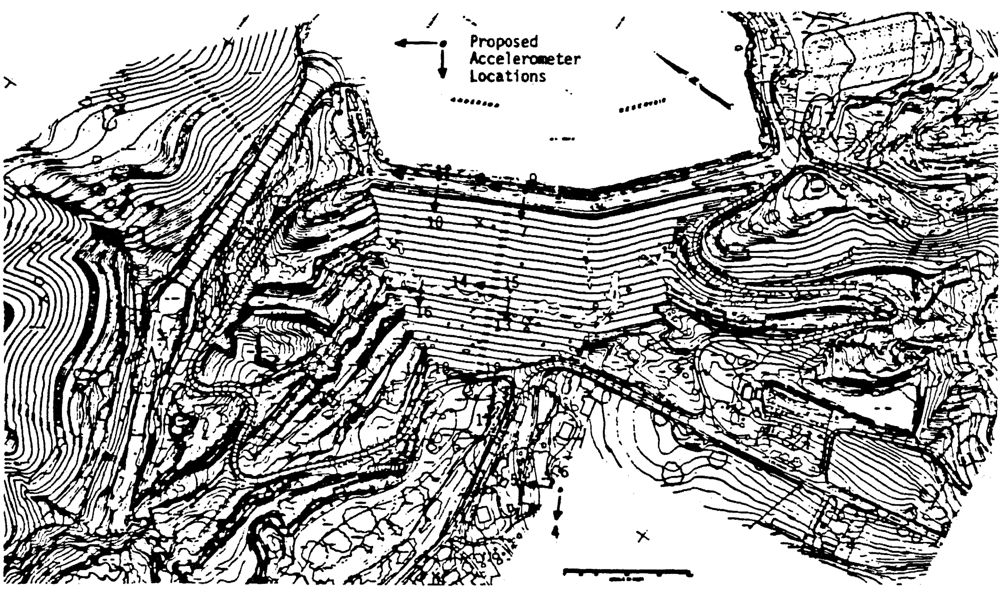

Fig. 5. Proposed Strong-Motion Instrumentation Scheme at Anderson Dam