301/3

CLOSE RANGE PHOTOGRAMMETRIC ANALYSIS OF EARTHEN BUILDINGS UNDER SEISMIC LOADING

Frederick C. Cuny and Clifford J. Mugnier
INTERTECT
P. O. Box 10502
Dallas, Texas 75207

ABSTRACT

This paper describes an INTERTECT project to demonstrate the feasibility of a new analytical technique for evaluating the performance of earthen buildings and other non-instrumentable structures subjected to earthquake-induced loads. Close range photogrammetric equipment will be linked to, and triggered by, seismographic instrumentation to observe and record the performance of buildings during actual loading. If successful, the technique will provide a tool for observing adobe and other earthen buildings during seismic events. Successful development of this technique will give researchers and scientists a new tool for earthquake engineering research and will open numerous types of buildings and other structures such as earthen dams to observation, which have not previously been subject to complete analytical examination under actual or simulated loading conditions.

BACKGROUND

Purpose of the Project

The purpose of this project is to develop a new analytical tool for examining earthen buildings and other structures which cannot be adequately instrumented. It is possible to instrument a number of buildings where certain properties of the materials used are known. However, for many types of structures, total instrumentation is not feasible, especially for those made of earthen materials (e.g., adobe and rammed earth buildings), and certain low quality masonry structures.*

Current earthquake engineering knowledge is based upon:

(1) Observation of damage to buildings

(2) Testing of scale models

(3) Calculation of component performance strength based upon known properties of the materials.

Much of this data is based on "before and after" comparisons, and there are few practical methods by which the actual deformation and collapse of buildings can be seen during an actual seismic event. Thus, a major gap exists in research methodology.

APPROACH

Photogrammetric engineering is the science of obtaining reliable information about physical objectives and the environment through the process of recording, measuring and interpreting photographic images and patterns. Close range photogrammetry is the application of principles of precision measurement to map (or measure) objects that are difficult to study in other ways. Data is derived from measurements and information obtained from photographs with optical analog instruments and/or analytic computations. Current applications include: observations of large-scale structures such as astronomic radio reflectors and bridges subject to environmental deformation; recording of measureable deformations in engineering models; and monitoring the manufacturing of other precision instruments.

Close range photogrammetry has many potential applications in earthquake engineering. Essentially, it is an analytical tool. Close range photogrammetry offers an analytical method for examining the response of non-instrumentable structures subjected to seismic loads.

(1) Close range permits observations of both full-scale buildings and model structures without direct contact.

---

*It has been estimated that as much as 60% of the world's man-made structures cannot be adequately instrumented and observed during earthquakes. This represents a sizeable portion of the buildings of concern in natural hazards reduction. Furthermore, the cost of fully instrumenting a large building can be enormous and, in poor quality buildings, such instrumentation is subject to damage in the collapse of the building.

(2) Close range can expand capabilities for observing structures and opens a new and wide range of structures to investigation.

An advantage of this project is that the proposed methodology makes practical use of existing technology. By doing so, a new tool can be added to the earthquake engineering field at minimal cost.

Methodology

This project proposes to develop a new technique for analysis of structures under seismic loading, by linking close range photogrammetric equipment directly to seismographic recording devices. The photogrammetric equipment will be placed in arrays surrounding the structure to be examined and linked directly to the recorders. When a seismic event occurs, a series of precision photographs will be triggered and, at the same time, localized ground motion will be recorded. The resulting data will record, in real time, the deformations of the building at specific loadings. This will enable researchers to conduct a precision analysis of the performance of buildings and specific components at various points in time during the seismic event.

RESEARCH ACTIVITIES

Major Elements of the Research Plan

Three activities will be initiated concurrently when the project begins. First, the photogrammetric array and mount will be designed. The mount will be built so that ground movement will not affect the position of the camera during a seismic event. It will be highly portable and able to be assembled rapidly on site.

Once the array has been built, the photogrammetric equipment will be linked to seismographic recording equipment via a triggering device activated by the seismograph. The equipment will then be ready for field use.

At the present time, it is proposed that the equipment be tested on site during a full-scale dynamic test. The University of New Mexico currently conducts periodic full-scale tests using explosive arrays to create ground motion similar to earthquake-induced ground motion. If such a test is conducted during the period of this project, the equipment will be placed on site to test this concept. If such a test is not conducted, the project will establish the photogrammetric methodology and the seismographic linkage independently, although a direct correlation will not be possible without an event where ground motion and structural motion both take place. A mount and frame will be tested under simulated ground motion conditions to establish the workability of the dampening system used for the mount. The actual selection of an alternative test facility will be made after it has been determined that a full-scale test is not possible. Research facilities utilizing shaker tables can also provide an opportunity for testing the photogrammetric methodology.

Detailed Description of Photogrammetric Methodology

The building's deformation <u>in progress</u> will be recorded by a pair of calibrated photogrammetric cameras. This imagery will then be developed and an analysis will be performed to determine the three-dimensional coordinates (X-Y-Z) of specific points before, during, and after deformation. These

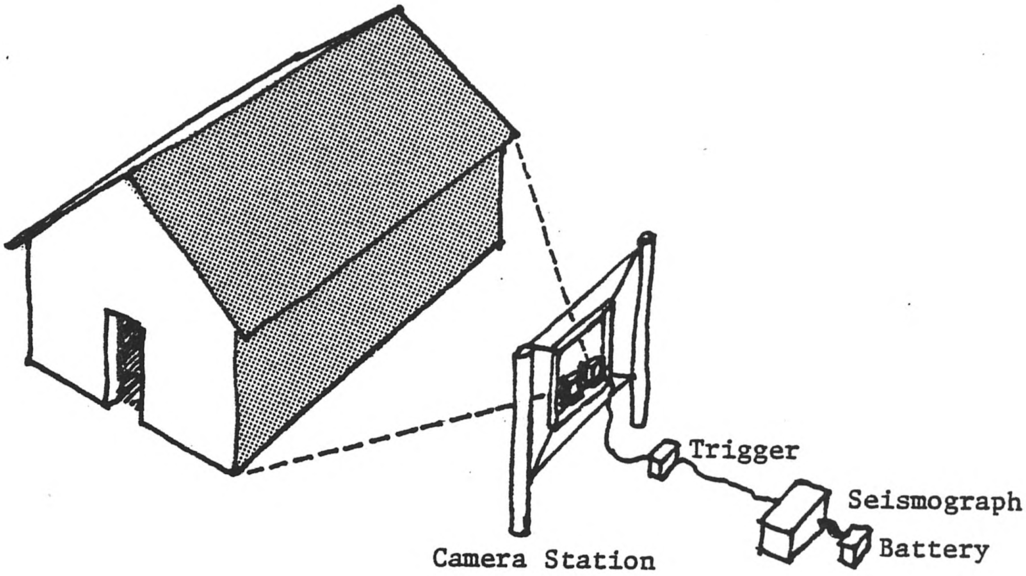

Figure 1
Basic Array

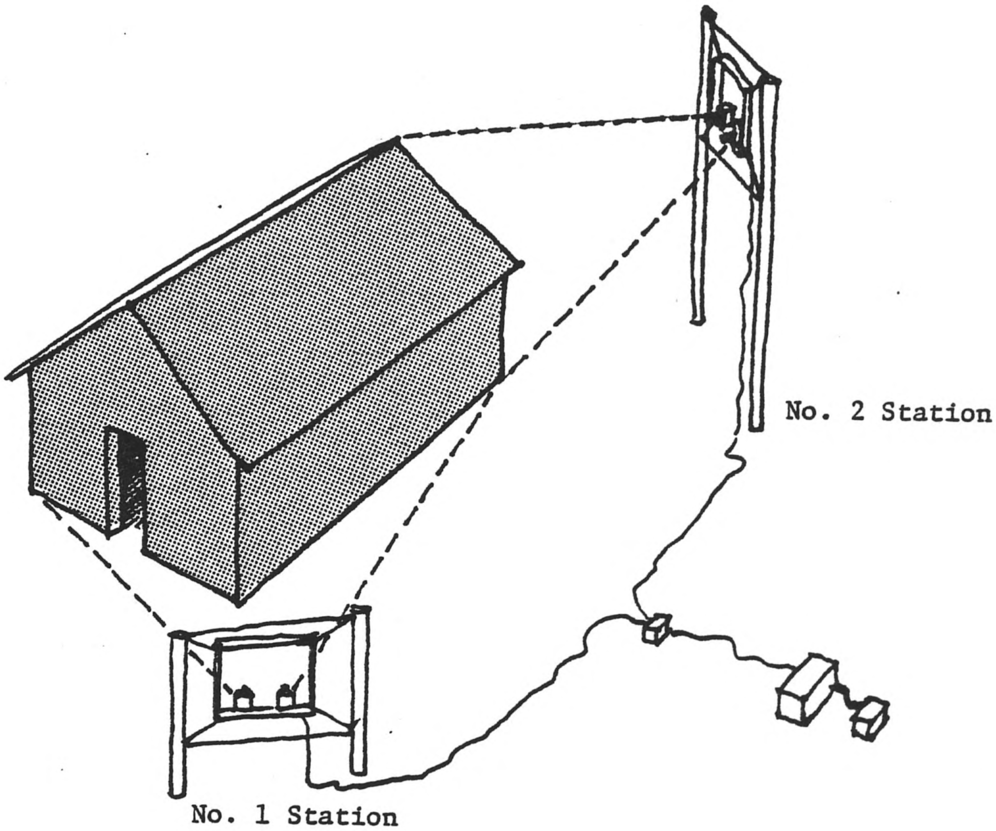

Figure 2
Comprehensive Array

precise coordinates will be used to compute the resultant vectors of deformation and will define the three-dimensional movement history of the seismic event.

The test site will consist of an example building constructed over a disposal emplacement of unexploded ordinance. At some distance (20-40 meters) a suspension system will be constructed to support a pair of photogrammetric cameras. Photographs will be exposed by both cameras before detonation to provide a priori control; photographs will be exposed during detonation to monitor deformation in progress (at three-second intervals, the cyclic rate of the cameras); and photographs will be exposed after the conclusion of the initial seismic shock and aftershocks to provide a posteriori control.

The suspension system will consist of a series of cables connected to poles in a line parallel to the front face of the building. Platforms for each of the two cameras will be suspended by wires attached to springs to minimize gross swaying and vibrations. Cameras with automatic winders will be synchronized with stroboscopic lights to freeze action, and will be triggered by a seismograph. Detonation of the explosives will have to take place after dark to allow the stroboscopic lights to provide all illumination without experiencing image smear due to other light.

The major concern of the orientation of the cameras during the event is to maintain the building within the field of view. This will be achieved by the suspension system. The differential movement of the cameras with respect to the building and to each other is immaterial because of the analysis technique.

There are basically two methods of performing an analysis by photogrammetry. The traditional method is to reconstruct the perspective bundles of light rays by analog equipment by replacing the light rays of conjugate imagery with mechanical rods. This presents difficulties for the proposed application because virtually everything in the field of view will be in motion and no stable reference points can be used to adjust and orient the instrument. The maximum accuracy attainable by the analog method is about 1/10,000th of the maximum dimension of the building face being imaged.

The other method of photogrammetric analysis is to reconstruct the perspective bundles of light rays by differential analytical geometry. Analytical photogrammetry is not constrained by variations in the orientation of cameras with respect to the building or to each other, because the computations include a provision to resect the perspective centers of the cameras based on conjugate imagery wherever it may appear in the photographs. After the initial estimate of the resection is performed, the computations intersect conjugate imagery to redetermine object space coordinates (the building), and the process iterates. When the differential change in the orientation of the cameras and the computed coordinates of the cameras and the building converge to some pre-specified criterion, a final intersection of the object space coordinates is performed and the results are output by the software. The mathematical model is based on rigorous least-squares, and the capability is present to include an error propagation analysis of the geometric dilution of precision for an accuracy determination of each and every coordinate computed in three-dimensional space. Under ideal conditions, analytical photogrammetry has attained accuracies better than 1/100,000th the maximum dimension of the object being measured. This test is not likely to provide ideal conditions, but the accuracy attained is expected to be a substantial improvement over the analog potential.

The analytical approach has the ability to successfully perform the project, and can provide the insight for the best equipment to utilize in a subsequent phase of the research. The methodology employed will be commensurate with the standard photogrammetric state-of-the-art, and will be feasible for utilization by other researchers that have access to a photogrammetrist. The physical facility for such a test is available at Sandia Research Laboratory, New Mexico, and the seismograph will be off-the-shelf equipment obtained from several commercial and academic sources.

The photogrammetric equipment, the cameras, are available from a number of commercial sources. Aerometric Engineering Inc. can provide the cameras and technicians for the photography.

In this project, only one face of a building will be studied. The accuracies attained will serve as a basis for determining necessary configurations of camera arrays for more extensive applications involving more than one face at a time.

Current technology in structural analysis involves finite-element techniques that define structures in a three-dimensional coordinate system. The photogrammetric approach to deformation monitoring and measurement presents data in a form completely compatible with the finite element approach to structural analysis. As the level of sophistication in finite-element techniques increases to include statistical analyses of the accuracies of the input data, the accuracy determinations of analytical photogrammetry solutions will be available for integration in the form of variance-covariance matrices solvable for eigenvector/eigenvalue parameters to define ellipsoids of error for X-Y-Z coordinate determinations and resultant space vectors of displacement due to deformation.

IMPLICATIONS FOR FUTURE RESEARCH

There are five significant aspects of this project:

(1) Buildings and other structures, which are not now instrumentable, can be evaluated;

(2) Full-scale buildings can be examined and evaluated without actual contact;

(3) The actual deformation and movement of the buildings can be recorded and linked directly to localized seismographic data during both real and simulated seismic events;

(4) There is no risk to the equipment due to failure of a particular structure;

(5) The method proposed utilizes existing off-the-shelf equipment currently available and in widespread use in other engineering disciplines. Successful development of the concept will add a significant new tool for researchers at relatively low cost.

Successful development of this technique will provide a tool that can be used for examining buildings under real earthquake conditions. As earthquake prediction becomes a reality, photogrammetric arrays can be placed on site prior to onset of a seismic event to record the performance of structures under actual loading conditions. Thus the project not only will provide a precision tool useful for current research activities, but also, perhaps more importantly, it will provide an important tool for use when earthquake prediction techniques become more precise.

Substantial opportunities exist for linkages to existing earthquake research once the procedures have been developed and verified. There are a number of ongoing research programs funded by the National Science Foundation as well as by independent non-governmental foundations, research institutes, and private and state-supported universities that could benefit from these techniques.