CHAPTER 1

INTRODUCTION

1-1. Purpose and Scope. This manual is issued as a guide for use by individuals and organizations in the Corps of Engineers engaged in the planning of instrumentation programs and in the preparation, installation, and collection of data from instruments and devices for measurement of structural behavior installed on or embedded within concrete gravity prototype structures for civil works projects. The manual describes new techniques which have evolved from recent technological advances in electronic instrumentation as well as methods which have been developed over a long period of time for the preparation, fabrication, protection, and installation of instruments and the collection of data therefrom. Efforts to improve the techniques will be continued, based on field experience and laboratory investigations, and the manual updated when appropriate. Instruments described include those installed for the measurement of strain, stress, joint movement, pore pressure, interior concrete temperature, uplift pressure, leakage, structural deflection, head loss, and distance measurement.

1-2. Applicability. The provisions of this manual are applicable to all field operating activities having Civil Works design responsibilities.

1-3. References.

a. Other Engineer Manuals. Portions of the following manuals relate to aspects of structural design and behavior to which the instruments and devices described herein relate.

EM 1110-2-1802	Subsurface Investigations - Geophysical Explorations
EM 1110-2-1908, parts 1 and 2	Instrumentation of Earth and Rock-Fill Dams
EM 1110-2-2000	Standard Practice for Concrete
EM 1110-2-2200	Gravity Dam Design
EM 1110-2-2300	Earth and Rock-Fill Dams General Design and Construction Considerations
EM 1110-2-2501	Wall Design (Floodwalls)
ER 1110-2-100	Periodic Inspection and Continuing Evaluation of Completed Civil Works Structures
ER 1110-2-103	Strong Motion Instruments for Recording Earthquake Motions on Dams
ER 1110-2-1802	Reporting Earthquake Effects
ER 1110-2-1150	Post Authorization Studies

b. Other Technical Publications. Appendix A consists of a selected bibliography of literature pertaining to instruments for and measurement of structural behavior of prototype concrete gravity structures.

1-4. Program Planning and Execution.

a. Responsibility. Structural behavior instrumentation programs may be proposed by a field agency when necessary to measure the structural integrity of a concrete structure or when an opportunity exists to obtain data which will add to basic knowledge, check design assumptions or aid in the solution of incompletely solved problems. When a program is considered desirable, a recommendation should be forwarded to the Chief of Engineers through channels indicating the scope and objective of the proposed program, estimated cost, and justification. The Chief of Engineers may also direct that such a program be initiated by a field agency when a need exists. Planning structural behavior investigation programs for concrete structures, development of guides for the installation and observation of instruments, and assembling, processing, and dissemination of collected data are responsibilities of the Engineering Divisions in the U.S. Army Engineer Districts. Installation of the instruments and collection of data during construction in accordance with prescribed procedures are the responsibilities of the Construction Divisions in the Districts. Collection of data from the instruments after construction is the responsibility of the Operations Divisions. Coordination, review, approval, and termination of such programs are functions of the Chief of Engineers.

b. Guide to Critical Readings. Threshold limits will be established for each safety-related instrument in the structural behavior program. These critical values (usually maxima) should directly reflect design criteria, be derived from design data, or represent engineering judgment and experience. Quantitative limit values will be developed prior to completion of construction, and may be subsequently modified as the performance history of the structure is established.

c. Disposition of Results. Preparation of graphical history plots, schematic diagrams, or tabulations based on the processed data is required for all approved Structural Behavior Instrumentation installations. Results shall be available for examination during the scheduled periodic inspections, and where appropriate, summaries included as a part of the formal periodic inspection reports.

1-5. Contract Work.

a. General. The general policy of the Chief of Engineers is to perform all civil works by contract unless it is in the best interest of the United States to accomplish the work by Government forces. However, the specialized nature of instrumentation facilities and the care required in the preparation, calibration, and placement of test apparatus demands that these features of work be retained under close operational control of the Corps of Engineers. In view of these conditions, direct procurement by the Government of embedded meters, cable, tubing, test sets, microscopes, slide micrometers, scales, indicating or recording equipment, and similar items not normally encountered in construction work, and the utilization of Government personnel to accomplish certain phases of the fabrication and installation work, such as embedment of instruments and splicing of cables, is recommended.

b. Work Performed by Contractor. Work which may be accomplished by the construction contractor should be limited to the following types:

(1) Furnish and install embedded conduit and supports for cable leads.

(2) Furnish and install the basic terminal reading station facilities, including cabinet, panel board, terminal strips, and power or lighting outlets therein.

(3) Make cable connections at reading stations.

(4) Furnish and install uplift cell collector boxes, piping, and all reading station facilities associated with uplift cells.

(5) Furnish and install pipe shafts for deflection plumb lines.

(6) Construct reference monuments in connection with precise alignment facilities.

(7) Furnish unskilled labor required during the embedment of instruments and cable leads.

c. Plans and Specifications. Project plans should show the complete instrument layout, supplemented by detail drawings covering the size and location of cable conduit, terminal reading stations, panel boards, terminal strips, uplift cell collector boxes, uplift piping, deflection plumb line shafts, and reference monuments.

The project specifications should include a separate technical section setting forth workmanship, materials,, codes, and standard practices, and similar installation requirements pertaining to items of work for which the contractor will be responsible in connection with the instrumentation facilities. Government-furnished equipment should also be listed.

d. Measurement and Payment. Establishment of units of measurement for instrumentation facilities is generally not feasible, and payment should be made by lump sum. A single lump sum payment item covering all features of the structural instrumentation installation is recommended for facilities of normal size and scope. For minor programs the work performed by the contractor frequently may be included under one of the larger concrete items, and no separate payment made.

1-6. Types of Instruments.

a. Relationship to Measurement of Safety Conditions. The instruments described herein can be grouped into two main categories; those that directly measure conditions that relate to safety and those that indirectly measure conditions related to the safety of the structure. A further category describes instruments that could be grouped into either one of the two main categories.

b. Safety Related Instruments. Instruments that measure overall movement, or phenomena that cause overall movement of the structure can be grouped into the category of direct measurement of safety conditions. Plumbing, alignment, and uplift pressure measuring instruments are in this category. Seismic instruments measure the intensity and characteristics of an earthquake as it is happening and therefore do not warn of unsafe conditions before the fact. They can, however, tell the conditions and forces experienced by the structure during the earthquake which may be of importance in determining whether the structure is unsafe after the shock.

c. Instruments Indirectly Related to Safety. Instruments that measure quantities such as stress and strain, length change, pore pressure, leakage, and temperature change are not directly related to safety determination. They generally measure standard conditions of the structure which if they become extreme or unusual will indicate conditions related to structure safety. Certain types of these instruments fall in a category between the above mentioned two, that is they sometimes measure structural safety conditions directly and at other times indirectly. For example, crack and joint measuring instrumentation normally measure expansion and contraction of joints which are an expected movement, however, if these instruments are installed over a crack that has developed unexpectedly, then they are primarily being used to monitor structural movement related to safety.

1-7. Instrument Uses. The instruments described in this manual serve a variety of jobs, and for that reason, grouping them as to the jobs they perform is also a helpful categorization. Table l-l is intended to be used as a quick reference to indicate what instruments perform what functions.

1-8. Collection of Complementary Data.

a. Related Data. The collection of related and supporting data pertaining to structural behavior is an integral part of the instrumentation program, and should proceed concurrently with the readings of the embedded instruments. Types of information required to support or clarify the instrument observation results include:

(1) Construction Progress. Schematic concrete placing diagram showing lift placement dates, concrete placing temperatures, and lift thicknesses.

(2) Concrete Mixes. Cement contents, water-cement ratios, and typical combined aggregate gradings for interior and exterior mixes, typical fine aggregate gradings, before and after mixing, and amount of entrained air, admixtures used, and how introduced.

(3) Cement. Type, source, or sources, physical and chemical properties, including heat of hydration.

(4) Aggregates. Types, geologic classification, petrographic description, source or sources, and chemical and physical properties.

(5) Curing and Insulation. Type and method of curing; type, location, and duration of insulating protection.

(6) Temperatures. Daily maximum and minimum air temperatures.

(7) Pool Elevations. Daily reservoir and tailwater elevations.

(8) Concrete Properties. Specific heat, conductivity, diffusivity, thermal coefficient of expansion, dynamic and static modulus of elasticity, creep, compressive, flexural, and tensile strength.

(9) Temperature Control Procedures. Location, size, and arrangement of embedded cooling pipes, cooling water temperatures, pumping rates, and sequence or history of cooling operations; extent and method of precooling concrete mixes.

(10) Foundation Conditions. Final rock elevations, unusual geologic features.

TABLE 1-1

INSTRUMENT USE INDEX
(Prepared by CE)

		Location
STRAIN AND DEFLECTION MEASUREMENT		
Strain Measurement - Internal Gages		
Strain Meter	(Linear Measurement)	Chapter 2
Miniature Strain Meter	(Linear Measurement)	Chapter 2
Embedable Strain Gage	(Linear Measurement)	Chapter 2
Vibrating Wire Strain Gage	(Linear Measurement)	Chapter 2
Electrical Resistance Strain Gage	(Linear Measurement)	Chapter 2
Reinforced Concrete Meter	(Linear Measurement)	Chapter 2
Strain Measurement - External Gages		
Whittemore Mechanical Strain Gage	(1 or 2 Dimensional)	Chapter 2
Mechanical Scratch Gage	(Linear Measurement)	Chapter 2
Vibrating Wire Strain Gage	(Linear Measurement)	Chapter 2
Monfore Standardizing Strain Gage	(Linear Measurement)	Chapter 2
Linear Variable Differential Transducer	(Linear Measurement)	Chapter 2
Electrical Resistance Strain Gage	(Linear Measurement)	Chapter 2
EXPANSION AND CONTRACTION MEASUREMENT		
Crack or Joint Movement - Internal Gages		
Joint Meter	(Linear Measurement)	Chapters 2 and 5
Multiple Position Borehole Extensometer	(Linear Measurement)	Chapter 5
Crack or Joint Movement - External Gages		
Relative Movement Indicator	(3 Dimensional Measurement)	Chapter 5
Monolith Joint Displacement Indicator	(3 Dimensional Measurement)	Chapter 5
Ball-N-Box Gage	(3 Dimensional Measurement)	Chapter 5
Multiposition Strain Gage	(2 Dimensional Measurement)	Chapter 5
"L" Shaped Gage	(2 Dimensional + Rotation)	Chapter 5
Dial Gage	(Linear Measurement)	Chapter 5
Mechanical Scratch Gage	(Linear Measurement)	Chapters 2 and 5
Portable Crack Measuring Microscope	(Linear Measurement)	Chapter 5

TABLE 1-1 (Continued)

		Location
STRESS AND PRESSURE MEASUREMENT		
Stress Measurement		
Stress Meter	(Concrete Stress Measurement)	Chapter 2
Vibrating Wire Stress Meter	(Concrete Stress Measurement)	Chapter 2
Pressure Measurement		
WES Pressure Gage	(Hydrostatic Pressure Measurement)	Chapter 2
Gloetzel Pressure Cell	(Hydrostatic Pressure Measurement)	Chapter 2
WES Pressure Measuring Telemetry System	(Hydrostatic Pressure Measurement)	Chapter 3
WES Hydrostatic Pressure Cell	(Hydrostatic Pressure Measurement)	Chapter 3
Vibrating Wire Piezometer	(Hydrostatic Pressure Measurement)	Chapter 3
Hydrostatic Pore Water Pressure Cell	(Hydrostatic Pressure Measurement)	Chapter 3
Hydrodynamic Pressure Gage	(Hydrodynamic Pressure Measurement)	Chapter 8
Uplift Pressure Measurement		
Standpipe Uplift Cell	(Hydraulic Pressure Head Measurement)	Chapter 3
Diaphragm Uplift Cell	(Hydraulic Pressure Head Measurement)	Chapter 3
Water Level Indicator	(Used in Conjunction with Standpipe Uplift Cell)	Chapter 3
HYDRAULIC LEAKAGE MEASUREMENT		
Vee-Notch Weir	(Flow Measurement)	Chapter 3
Critical Depth Meter	(Flow Measurement)	Chapter 3
BENDING, TILTING, AND DEFLECTION MEASUREMENT		
Plumbness Measurement		
Plumb Lines		Chapter 4
Inverted Plumb Lines		Chapter 4
Optical Plummets	(Optical Measurement)	Chapter 4
Levelness Measurement		
Electrolevel	(Spint Level Measurement)	Chapter 4
Terzaghi Water Level Meter	(Water Level Measurement)	Chapter 4
Precise Leveling	(Settlement Measurement)	Chapter 6

TABLE 1-1 (Concluded)

		Location
PRECISE ALIGNMENT MEASUREMENT		
Alignment		
Laser Alignment Measurement		Chapter 6
Theodolite Alignment Measurement		Chapter 6
Triangulation		Chapter 6
Trilateration		Chapter 6
Settlement		
Precise Leveling		Chapter 6
Distance Measuring		
Electronic Distance Measurement		Chapter 6
SEISMIC MEASUREMENT		
Time History Measurement		
Strong Motion Accelerometers		Chapter 8
Peak Reading Accelerometers		Chapter 8
Hydrodynamic Pressure Gages		Chapter 8
Magnitude Measuring Device		
Seismoscope	(No time History)	Chapter 8
TEMPERATURE MEASUREMENT		
Resistance Thermometer		Chapters 2 and 7
Thermocouple		Chapter 7

b. Time of Collection. Much of the preceding listed information will usually be available from investigations carried out prior to and during the project design stage or will be obtained under usual construction control operations. A special supporting laboratory program for the determination of those concrete properties required in the analysis of results may be necessary for the larger or more important instrumentation installations.

c. Periodic Observation. Observers should be alert to detect cracks or similar evidences of structural distress which may develop, and record time of occurrence, initial size and extent, subsequent changes in size and extent, and any corrective action taken.

1-9. Comments. It is requested that comments concerning the instruments contained in this manual, or ones that should be included in the next change, be furnished to the Department of the Army, Waterways Experiment Station, Corps of Engineers, P. O. Box 631, Vicksburg, Mississippi, 39180, ATTN: WESSC, and a copy furnished to HQDA (DAEN-CWE-DC), WASH DC 20314. Two types of comments should be made: (a) Recommendations concerning the format of the manual, and (b) Recommendations for additional information on instruments proposed to be included in the manual.