SECURITY CLASSIFICATION OF THIS PAGE

"DTIC FILE COPY"

(2)

UNCLASSIFIED

REPORT DOCUMENTATION PAGE

DTIC ELECTE OCT 1 3 1988 D

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY ...ULE	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release; Distribution is unlimited
AD-A200 397	5. MONITORING ORGANIZATION REPORT NUMBER(S) AFOSR-TR- 88-1116
University of Michigan Civil Engineering — 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION AFOSR/NA
6c. ADDRESS (City, State, and ZIP Code) Ann Arbor, MI 48109	7b. ADDRESS (City, State, and ZIP Code) Bolling Air Force Base Washington, DC 20332
8a. NAME OF FUNDING/SPONSORING ORGANIZATION AFOSR — 8b. OFFICE SYMBOL (If applicable) NA	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER AFOSR-86-0314
8c. ADDRESS (City, State, and ZIP Code) AFOSR/NA Bolling AFB, DC 20332 Bolling Air Force Base Washington, DC 20332	10. SOURCE OF FUNDING NUMBERS PROGRAM ELEMENT NO. 61102F; PROJECT NO. 2917; TASK NO. A1; WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)
Non Contacting Evaluation of Strains and Cracking Using Optical and Infrared Imaging Techniques

12. PERSONAL AUTHOR(S)
A. E. Naaman

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Final	FROM 9/1/86 TO 6/1/88	1988, 8, 22	16

16. SUPPLEMENTARY NOTATION
DOD - University Research Instrumentation Program

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Concrete cracking; motion-tracking measurement systems; non-contacting evaluations; thermovision; equipment

19. ABSTRACT (Continue on reverse if necessary and identify by block number)
This grant was issued under the DOD University Research Instrumentation Program. Two new test systems were purchased and set-up: a thermovision system and a non contacting three dimensional motion measuring system. The first system consists of an infrared scanner supported by a video recorder, a thermal image computer, corresponding software and other peripherals. It is being used as a non-contact non-destructive technique to analyse the mechanical response of and crack initiation in concrete under specified loading. The second system is a high accuracy three-dimensional motion tracking, digitizing and analysis system. It essentially consists of two high resolution infrared dual axis sensors (cameras), a camera controller unit, a microcomputer, a data acquisition unit, and related software. This system can track the coordinates of up to 64 individual marker points placed on a test specimen with a frequency of 5000 hertz at accuracies of a fraction of a millimeter.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL Dr. Spencer T. Wu	22b. TELEPHONE (Include Area Code) (202) 767-6962 — 22c. OFFICE SYMBOL AFOSR/NA

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

88 1011 156

FINAL REPORT **AFOSR-TR- 88-1116**

NON CONTACTING EVALUATION OF STRAINS AND CRACKING USING OPTICAL AND INFRARED IMAGING TECHNIQUES

1. INTRODUCTION

This grant was issued under the DOD University Research Instrumentation Program and was conducted under the direction of the Air Force Office of Scientific Research. Two new test systems were primarily purchased and set up: a thermovision system and a non-contacting three dimensional motion measuring system. The thermovision system is being used as a non-contacting non-destructive technique to analyse the mechanical response of, and crack initiation in concrete under specified loading. The non-contacting motion measuring system is being considered to replace displacement transducers in tests of concrete structural components subjected to cyclic fatigue and cyclic dynamic loads. A list of the main instrument components of each system is given in Appendix A. Following some background information, a description of projects and ideas planned for the use of these systems is given below.

2. BACKGROUND INFORMATION ON THERMOVISION

The electromagnetic spectrum is divided into different wave length regions called bands. Thermography makes use of infrared spectral bands. The boundary of the infrared spectrum spans from visual perception at the short wavelength to the microwave radio wavelength. The infrared band is also further subdivided into four lesser bands, namely: the near infrared (0.75-3 micrometers), the middle infrared (3-6 micrometers), the far infrared (6-15 micrometers), and the extreme infrared (15-100 micrometers). While infrared photography is sensitive to wavelengths smaller than about 1.2 micrometer, thermal infrared wavelengths lie beyond 2 micrometers.

The concept of black body is essential in dealing with thermal radiation and Thermography. A black body is defined as any object which absorbs all radiation that is incident upon it at any wavelength. Kirchoff's law states that a black body is equally capable in emitting radiation. If the temperature of the black body radiation increases over 525 ^{o}C it becomes visible and no longer appears black. Three physical laws describe the radiation emitted from a black body: Planck's Law, Wien's Displacement Law, and Boltzman's Law. These laws combined with the quantum theory of Max Planck form the basis of spectral radiation and thermography.

Modern instruments such as the Thermovision 870 purchased for this project can detect small temperature differences associated with the infrared thermal radiation from objects. This equipment primarily comprises an infrared scanner, a display unit with accessories, and a thermal image computer system. The scanner detects the infrared radiation from the surface of objects under study and converts the electromagnetic thermal energy radiated into electronic video signals. These signals are amplified and transmitted to a display monitor to form a thermal image of the object. A computerized image analysis system is used to simplify the image and to quantify the information allowing for efficient presentation, storage and retrieval. Many external parameters can be included in the analysis such as emissivity, ambient temperature, and distance.

3. CONCRETE CRACKING AND THERMOVISION

The only significant work undertaken in the use of thermovision to study cracking in concrete and known to the PI is that of M.P. Luong from France (Refs. 1-3). Luong used infrared thermography as a non-destructive and non-contact technique to examine the mechanical response of concrete, rock, and rock salt specimens subjected to a given static unconfined compression to which a vibratory excitation is superimposed. He investigated in particular the heat generation due to energy dissipation by the material which has been excited beyond its stable reversible limit. Luong's main aim of study was to illustrate the onset of crack propagation and/or flaw coalescence caused by the thermo-mechanical coupling, when increasing micro-cracking is generated by vibratory excitation.

In previous investigations, Luong had successfully used Infrared Thermography as an experimental method for detection of plastic deformation during crack propagation in a steel plate under monotonic loading, and for investigating damage, fatigue and creep occurring in such materials.

On the basis of experimental evidence, Luong was able to evaluate information about the location and significance of structural defects needed as a basis for maintenance decisions. He concluded that Thermography allows a measure of the material damage and permits the detection of the limit of a progressing damaging process under load beyond which failure is imminent.

The experimental setup used by Luong was a high frequency (100 Hertz) special servo-hydraulic testing machine which provided a means of vibration and dynamic testing of engineering materials. Control of the machine was provided by a sophisticated closed-loop electronic central system.

The thermography system purchased at the University of Michigan under this contract, consists of an infrared scanner supported by a video recorder, a thermal image computer with high resolution color monitor, corresponding software and other peripherals (Fig. 1). Since a high frequency actuator that can generate vibratory energy and consequently radiation in a loaded specimen was not available to the PI, a different idea was followed to use the equipment in detecting cracking in concrete and fiber reinforced concrete specimens subjected to monotonic compressive loading. In this still preliminary and exploratory experiment, specimens were preheated uniformly to about 150 ^{o}F prior to testing. When cracking occurs during testing, the cracked regions tend to have higher temperature due to the release of energy. Thus a cluster of cracks may be seen by the thermal camera. Fig. 2 to 4 show examples of crack clusters. Such images are still too rough to determine with accuracy cracking profiles and other details. However,

Fig. 1 Thermovision System Used to Spot Cracking in Concrete Cylinders Subjected to Compressive Loading

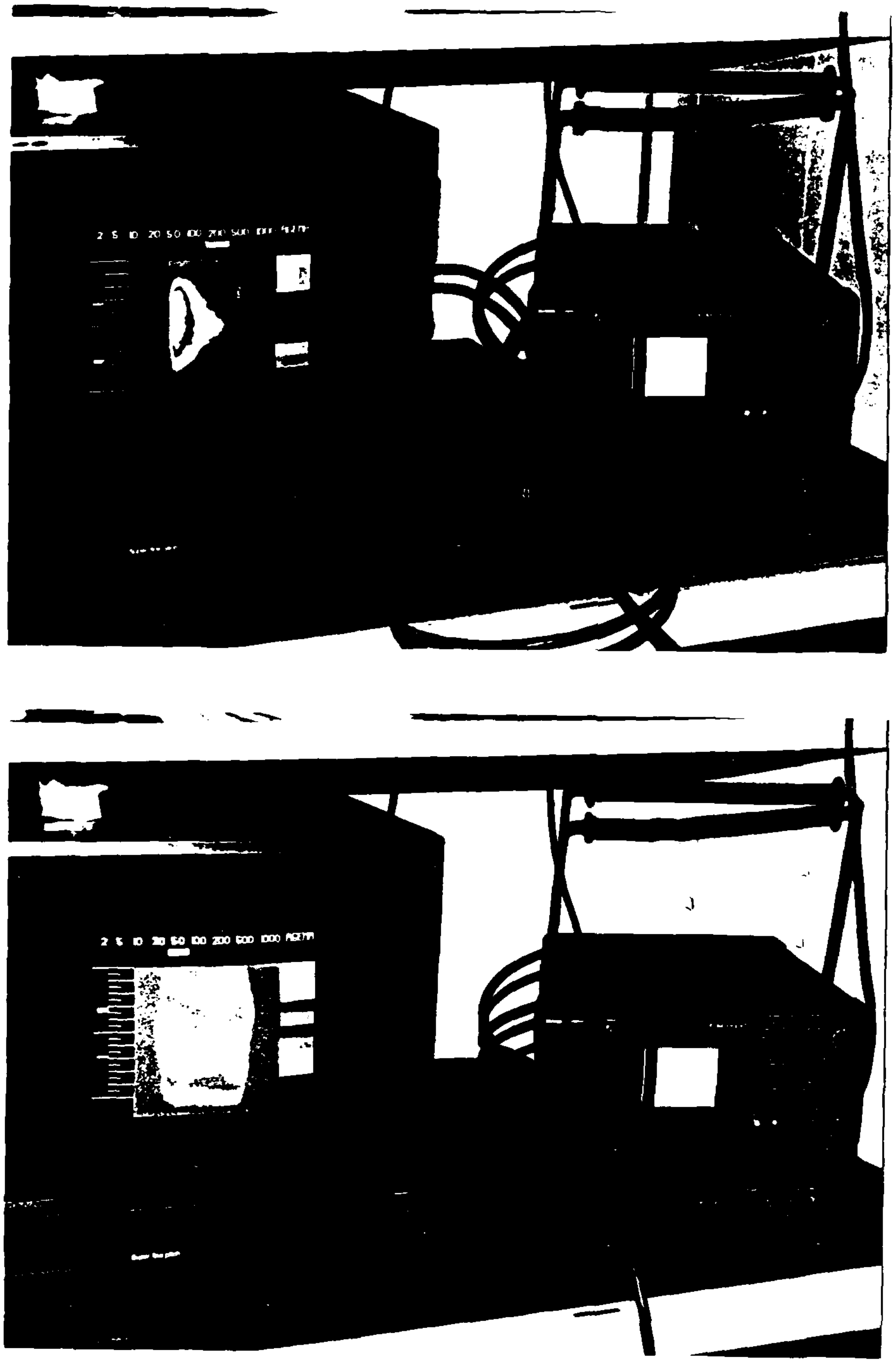

Fig. 2 Color Contours on Thermovision Monitor Follow Cracking Activities in Concrete Cylinders Under Test

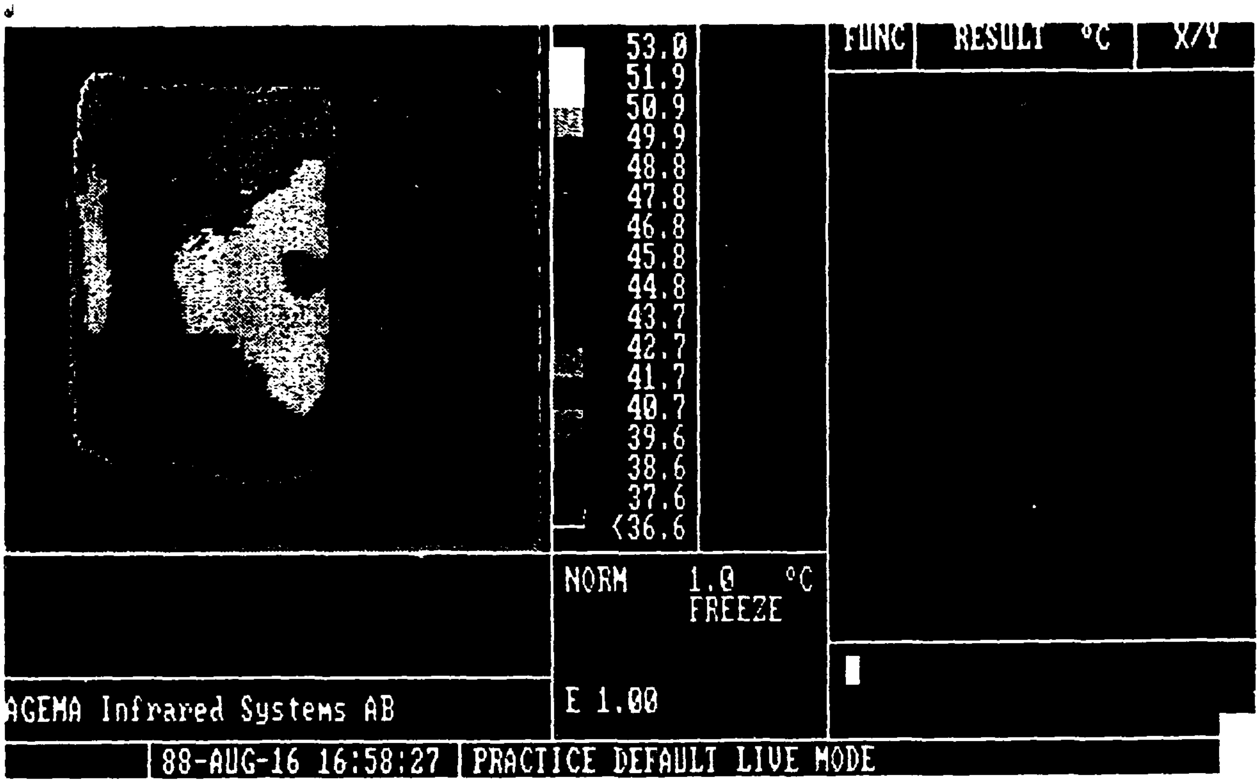

Fig. 3 This picture shows the thermal image of a concrete specimen tested under compression. The different colors indicate different temperatures. The light shaded areas represent the areas where cracking occurred first.

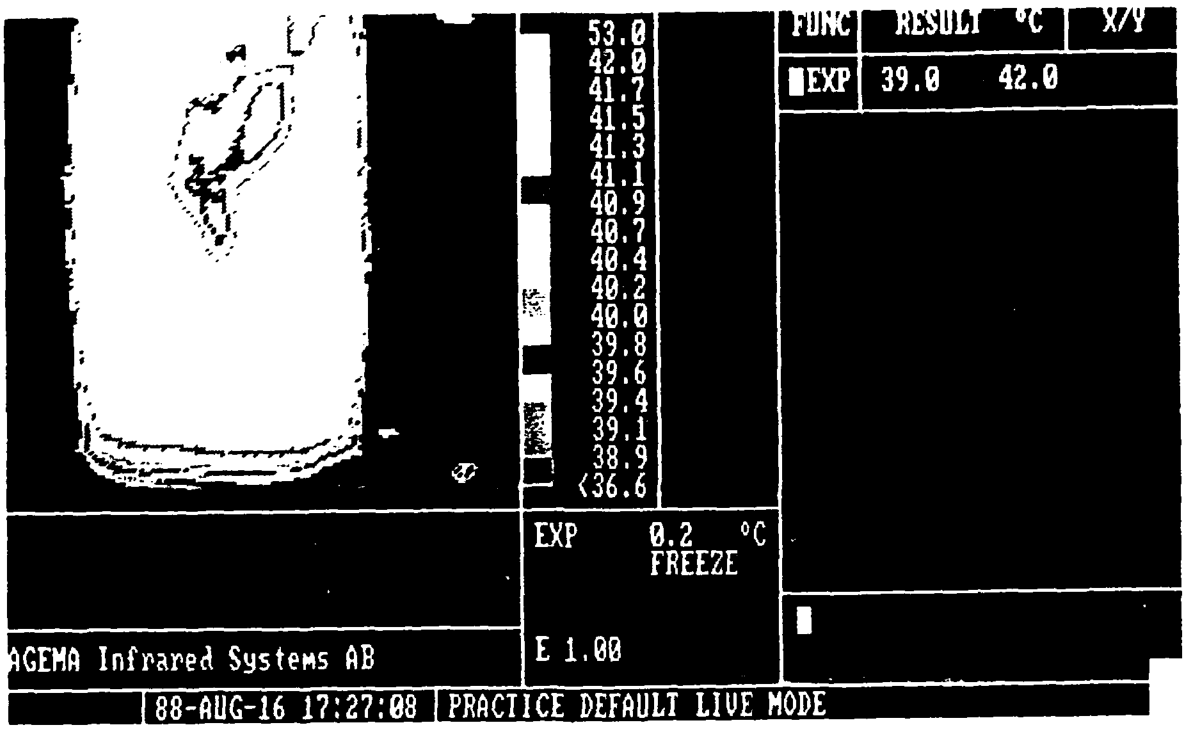

Fig. 4 This picture illustrates the scaling function of the software. It is used to highlight the area within a particular range of temperatures. Temperatures higher than the range specified appear white while lower temperatures appear black.

it is hoped that with time and experience, more detailed information will be extracted from such images. Another idea is being also considered in which a fan is directed at the specimen during testing, so that any crack that forms is cooled by the blown air (at room temperature) thus providing a difference in temperature between the faces of the crack and its air filled (voided) body. Such a difference in temperature is detectable by the Thermovision scanner and a thermal image modeling the cracking pattern at the surface of the specimen can be generated and analysed.

The above idea is being currently tested and analyzed at the University of Michigan. Once sufficient confidence in the results obtained is achieved, the same technique could be tried to detect cumulative damage through increased cracking under cyclic and dynamic loads.

4. NON-CONTACTING MOTION MEASURING SYSTEM

The second system purchased under this grant is a high accuracy three dimensional motion tracking, digitizing and analysis system. It essentially consists of two high resolution infrared dual axis sensors (cameras), a camera controller unit, a microcomputer, a data acquisition unit, and related software. This system can track the coordinates of up to 64 individual marker points placed on a test specimen with a frequency of 5000 hertz and accuracies of a fraction of a millimeter. Sixteen additional external channels can be handled simultaneously by the corresponding software and hardware. This system is being currently tuned and tried to measure strains and deformations in concrete specimens and in structural components subjected to various loading regimes (Fig. 5).

In particular two projects are being considered where the system will be used simultaneously with other standard instrumentation until we develop complete confidence in the results generated. In one program, partially prestressed concrete beams are being tested under random amplitude cyclic fatigue loading simulating truck loads on bridges. In addition to the standard electronic transducers (LVDT's) used to measure deflections, several markers will be placed at key points of the beams to allow measurements of deflections and rotations using the motion measuring system. A similar approach will be followed in analyzing the response of precast concrete frames subjected to cyclic loads simulating seismic excitations. Once confidence is established in the new system, the measurements of deflections, deformations and rotations can be undertaken with much more efficiency that with standard transducers.

5. ADDITIONAL INFORMATION AND FUTURE WORK

In addition to the two main systems described above, several instruments were also purchased to improve data acquisition, verification, and calibration. They include two signal conditioning units, one for eight channels of strain gages and the other for eight channels of LVDT's (see list section III in Appendix A).

It should be pointed out that the initial budget of this

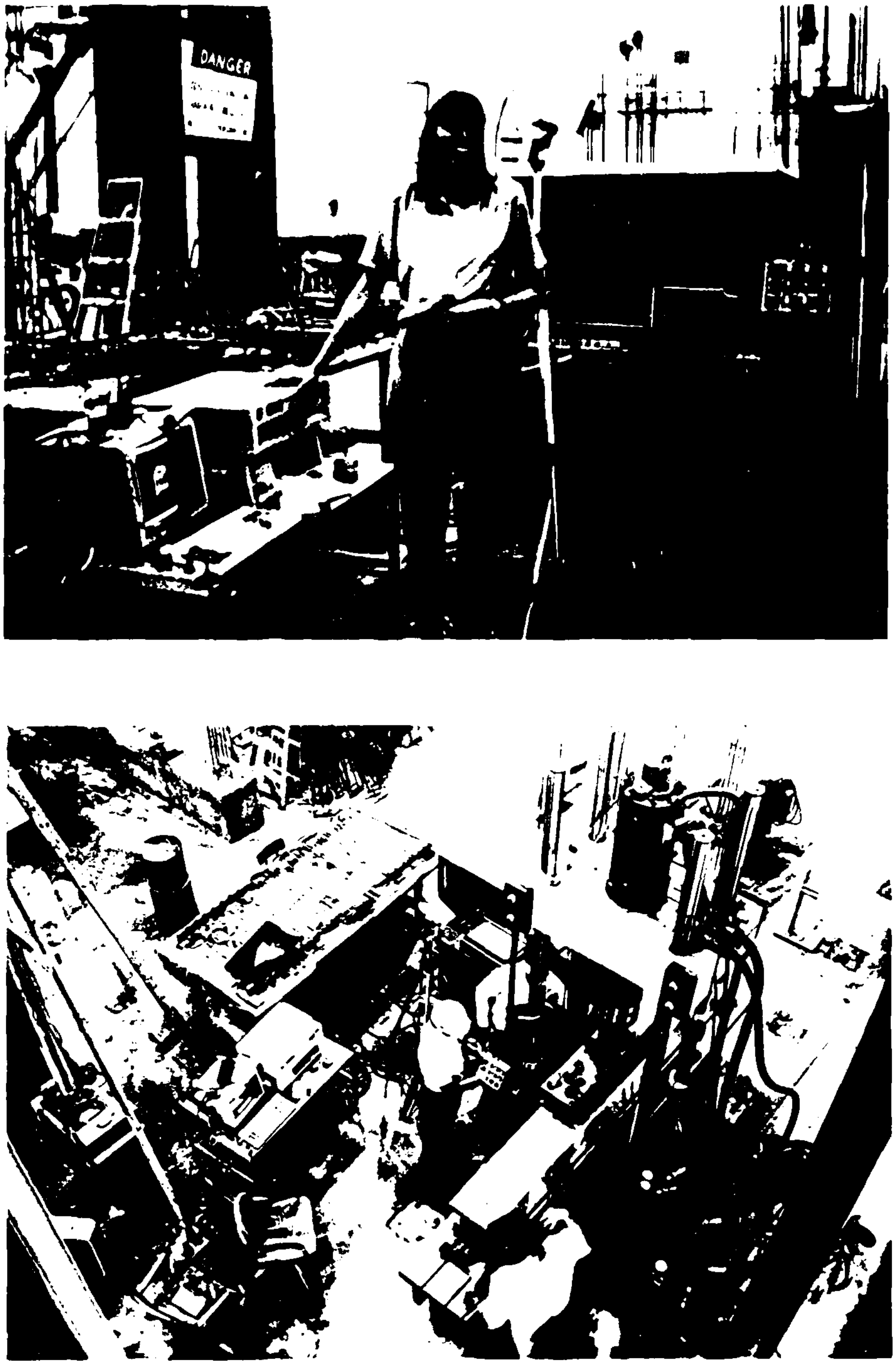

Fig. 5 Non Contacting Motion Measuring Instrument During Set-up and Calibration For Recording Deflections in Prestressed Concrete Beams

project was $ 151,760 of which $ 116,000 were granted by DOD and $ 35,760 by the University of Michigan. However the University of Michigan granted the principal investigator an additional $ 10,000 to allow the purchase of the complete systems needed thus bringing up the total budget to $ 161,760.

It is expected that in the next few years, these instruments will be sufficiently tuned and calibrated to be reliably used in standard testing applications of concrete and concrete structures in the Civil Engineering Department at the University of Michigan. Other applications of thermography to civil engineering problems will also be made possible such as in locating delamination and distress in bridges and buildings by spotting differences of temperature during exposure to the sun or cooling thereafter. Such information may be vital to allow rational decisions in setting of maintenance actions and policies.

REFERENCES

1. Luong, Minh Phong, "Infrared Vibrothermography of Damaged Concrete", in French, Compte Rendus Academie des Sciences Paris, t. 301, Serie II, No. 7, 1985, pp. 459-464.

2. Luong, Minh Phong, "Characteristic Threshold and Infrared Vibrothermography of Sand", Geotechnical Testing Journal, ASTM, Junr 1986, pp. 80-86

3. Luong, Minh Phong, "Infrared Theromography of Fracture of Concrete and Rock", in SEM/RILEM International Conference

on the Fracture of Concrete and Rock, S.P. Shah and S.E. Swartz, Editors, pp. 561-571.

APPENDIX A

List of Main Instruments Purchased

I. Thermovision System

1. Thermovision 870 SWB Package VIII consisting of:
   - Scanner 870 SWB
   - Portable Monitor 870
   - Power Supply Charger
   - Lens SWB 20x20
   - Tool Kit
   - Operating Manual
   - Carrying Case No. 1

2. Thermal Image Computer TIC 8000 Interface and Software Package Without CPU IBM PC-AT consisting of:
   - TIC Interface
   - Set of Cables (3 each)
   - CATS (Computer Aided Thermography Software)
   - Operating Manual
   - Graphics Board
   - Multifunction Board

3. RGB Monitor Hitachi CM 1216 E

4. Lens SWB 7x7

5. Video Tape Recorder modified for THV:
   Including:
   - Power Supply
   - Interconnection Cable to Monitor 870
   - Battery Pack, 2Ah

6. RGB Monitor Sony PVM
   Interconnection Cables (2x32 = 64)

7. DISCON (Digital Infrared System for Coloration)
   Including composite color encoder:
   - DISCON Basic Unit
   - Power Supply Cable
   - Cable DISCON to Monitor 870
   - Mounting Kit 870 Monitor
   - Interconnection Cable with BNC connectors

8. Color Printer: Canon Model
   Printer Cable

9. AT-Compatible Zenith Z-386 microcomputer with plotter

II. 3-D Motion Measuring System

1. Complete OPTOTRAK three dimensional digitizing system.
   System includes:
   - 2 Northern Digital dual axis CCD cameras
     1:10,000 resolution, 0.05% max. inaccuracy
     w/custom 30 degree dual lenses
   - Camera controller and power unit
   - Three miniature IRED strober units
   - Infrared market kit, with 32 markers

- Appropriate cabling (10m)
- Data collection and 3D reconstruction software for IBM PC included (Direct Linear Transform method)
- 0.6 meter cube alignment frame with 40 calibrated control points.

2. WATSCOPE data acquisition unit
   - 16 single ended analog input channels

3. Data Analysis Package software (KINEPLOT)

4. Extra OPTOTRAK Camera (max 224 per system
   - Includes 40 Mipxel 2d correction CPU board

5. Bentley-286 Microcomputer (IBM PC-AT compatible)

III. <u>Other Instruments Related to Data Acquisition</u>

1. Schaevitz Instrumentation System consisting of the following components:

   1. PCB-502P Card Cage & Power Supply Rack Adaptor. Wired for 16-channels of LVDT inputs/outputs.

      1 - PCB-214A, Oscillator, Excitation
      1 - PCB-316A, Buffer Excitation
      4 - PCB-441, 2 Channel, Amp./Demod.
      1 - PCB-424, $\frac{A\&B}{2}$, Ave Amplifier
      1 - PCB-424 A-B, Difference Amplifier
      1 - lot - DRO-450 Digital Readout & Channel Selector Switch on a PCB-508 Hinged Front Panel
      1 - lot-System Integration & Test

PCB-441	1-2
PCB-441	3-5

2. Measurements Group, signal conditioning unit 2100

   1. Model 2100 Power Supply

   2. Model 2131 Digital Readout with Peak Hold/Retention Capability

   3. Model 2120K Strain Gage Conditioner/Amplifier

   4. Model 2150 Rack Adapter

   5. Model 2155 Portable Ten-Channel Enclosure

   6. Interconnecting Cable for Model 2130/2131