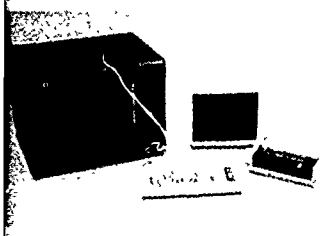
INSTRUCTION REPORT GL-91-1

US Army Corps of Engineers

USER'S MANUAL FOR COMPUTER-CONTROLLED MICROWAVE OVEN SYSTEM (CCMOS) FOR DRYING SOIL



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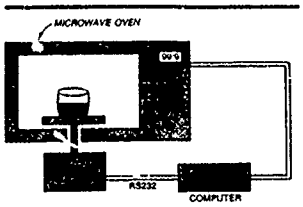

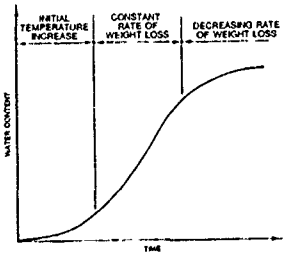

May 1991
Final Report

GEOTECHNICAL LABORATORY

Prepared for US Army Engineer Division, Ohio River
Cincinnati, Ohio 45201-1159

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Water content and soil compaction need to be continuously monitored during the compaction of soil structures. Equipment to monitor field compaction in real time is needed because of the high production rate of modern construction equipment. A microwave drying system based on computer control of microwave energy application was developed at the US Army Engineer Waterways Experiment Station for determining water content rapidly and accurately. This document is a user's manual for that microwave drying system and describes the equipment, its use, its requirements, and safety precautions that should be observed during operation.

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Microwave oven
Rapid water content measurement
User's manual
Water content

PREFACE

This instruction report was prepared by the Geotechnical Laboratory (GL), US Army Engineer Waterways Experiment Station (WES), and describes the use of equipment developed under the sponsorship of the US Army Engineer Division, Ohio River (ORD), to determine soil water content rapidly and accurately. A patent on the equipment is pending.

The report was prepared by Mr. Paul A. Gilbert of the Soils Research Facility (SRF), Soil and Rock Mechanics Division (SRMD), GL, under the direct supervision of Mr. Gene P. Hale, Chief, SRF, and Dr. D. C. Banks, Chief, SRMD. The study was conducted under the general supervision of Dr. William F. Marcuson III, Chief, GL, WES.

Commander and Director of WES during the publication of this report was COL Larry B. Fulton, EN. Dr. Robert W. Whalin was the Technical Director.

Contents

USER'S MANUAL FOR COMPUTER-CONTROLLED MICROWAVE OVEN SYSTEM (CCMOS) FOR DRYING SOIL

Introduction

1. The purpose of this manual is to provide instructions and pertinent information for the user of the Computer-Controlled Microwave Oven System (CCMOS). The following items are discussed herein:

   a. A brief description of the components, both individually and collectively.

   b. The requirements for system operation.

   c. Installation and maintenance instructions.

   d. Safety precautions.

   e. Operating instructions.

2. The CCMOS is a device that provides rapid and accurate determination of water content. Major components of the system consist of a microwave oven, an electronic balance, a small 64-Kilobit computer, a monitor, and a printer as well as a program cartridge (which can be detached from the computer) on which system-controlled software is stored. The system is designed to be rugged and easy to use; however, some precautions are necessary during installation and use. These are outlined in the following sections that are intended to allow trouble-free operation.

System Components

Microwave oven

3. The most visible item in CCMOS is the microwave oven; it is also the component that requires the greatest power input and the one that will require the most careful adjustment and handling. The dimensions of the oven are as follows:

   a. Exterior: 24 in.* wide by 15-3/4 in. high by 20-5/8 in. deep.

   b. Interior: 15 in. wide by 9-1/2 in. high by 16 in. deep.

   c. Oven cavity size: 1.4 cu ft.**

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* To convert inches to millimetres, multiply by 25.4.
** To convert cubic feet to cubic metres, multiply by 0.02831685.

Internal balance

4. An electronic balance is part of the internal structure of the greater oven body as can be seen from the schematic in Figure 1. The balance is fastened onto the bottom plate of the frame. A Teflon load button extends from the weighing mechanism of the scale through the liner and into the oven space. A Teflon platform sits on the load button inside the oven cavity; soil specimen and container are placed on the Teflon platform.

Computer

5. The computer used is a 64-Kilobit unit equipped with a BASIC interpreter stored in read-only memory. The computer is equipped with software drivers to accommodate RS232C serial communication with the balance described above. Additionally, the computer is equipped with a user port through which the microwave oven is controlled.

Software cartridge

6. Software controlling the drying process is stored on EPROM modules mounted on a printed circuit board and contained in a cartridge that inserts into the communications port of the computer.

Printer

7. The printer used with the system is a small ASCII compatible unit that uses the thermal transfer process for printing. Thermal paper is stored on a reel that is mounted on the printer and unwinds on demand.

Monitor

8. A monochrome monitor is provided with the system. A screen-saving feature is available in the software (on request) which blanks the monitor screen when a period of 2 min passes with no key pressed on the computer keyboard. The screen-saving feature minimizes burnout of the phosphorescent backing on the monitor screen.

Surge protectors

9. Power surges and interruptions commonly occur at construction sites in remote locations. The computer and integrated circuit chips in the interface circuitry may be damaged or destroyed by electrical "spikes" of short duration but very high voltage which typically accompany power surges and emergency electrical backup equipment switching on. The surge protector, which is furnished with the system, captures and attenuates electrical spikes as they occur to prevent damage to sensitive electronic components. It must be understood that surge protectors cannot remedy problems associated with extended periods of low voltage (brownouts) or power outages (blackouts);

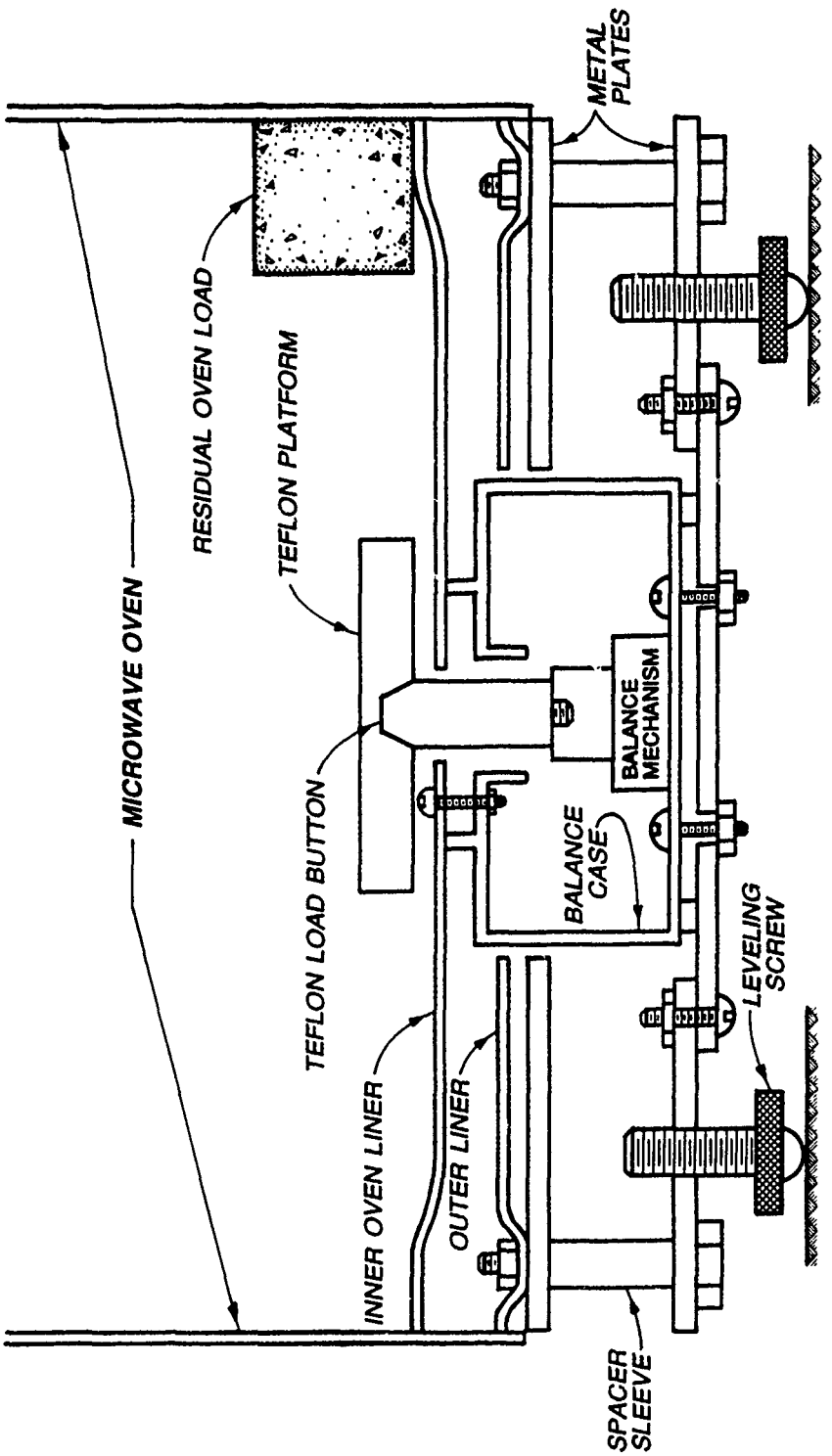

Figure 1. Section of oven-body system

such situations can be corrected only by an uninterruptable power supply with battery backup.

Connection of components

10. A wiring diagram of CCMOS is shown schematically in Figure 2. Connectors for the microwave oven, program cartridge, and 5-V power connector are flat-edge connectors. The serial port and video port connectors for the printer and monitor, respectively, are circular slotted male pin connectors. The computer power supply (not shown) is also a circular male pin connector.

System Requirements

Microwave oven

11. A stable AC electrical power source is required for CCMOS. Microwave oven input requirements and expected electronic outputs are listed below:

a. Power source: 120-V AC single phase, 14.5 amps, 60 Hz.

b. Input power: 1,400 W (±10 percent).

c. Maximum output power: 700 W (±13 percent, -8 percent).

d. Output frequency: 2,450 MHz (2,450,000,000 Hz).

The oven circuitry is protected by a 15-amp fuse and typically draws 12 amps during operation. Therefore, the electrical service breaker box supplying power to the oven should provide a minimum of 15 amps.

12. Air inside the microwave oven is circulated to remove steam and vapor and to keep certain of the system electronic components cool. Certain soils, such as dredged materials, generate large amounts of vapor and odor during microwave drying. Because of the possible presence of toxic chemicals in the vapor discharged by the microwave oven, it should be vented to outside air.

Electronic balance

13. The balance used in CCMOS requires a stable AC power source without electrical spikes. Therefore, the balance should be connected into the surge protector described in the previous section. The balance must be level for proper operation; since it is internal to the larger microwave oven structure, leveling screws are provided for leveling the entire structure.

14. The oven system should be placed on a sturdy surface that does not rock or tilt. Additionally, the operating environment should be free from mechanical vibrations; therefore the equipment should not be put on the same

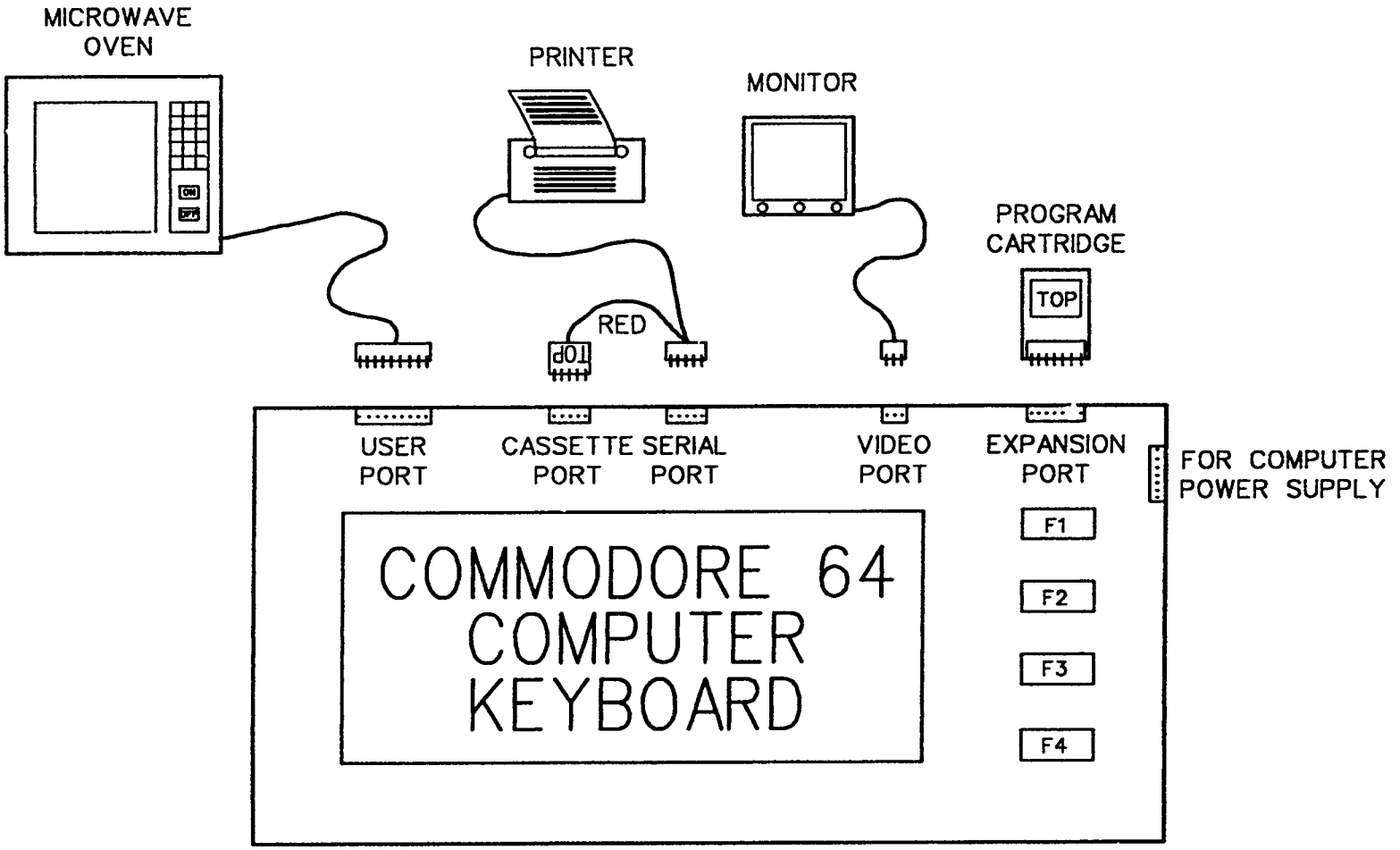

Figure 2. Schematic wiring diagram of CCMOS

table as a vacuum pump, a sieve shaker, a compressor, or any equipment that vibrates. Also, it is important that the equipment be kept as clean and dust-free as possible It is especially important that the Teflon components in the interior of the oven be kept free of dust and grit. A procedure recommended for cleaning the oven interior will be subsequently outlined.

Computer

15. The computer should be furnished power through the surge protector. For protection against dust contamination, a rubber keypad seal is provided. Additional seals (for a Commodore 64 computer) are available from VIZIFLEX SEELS, Inc., of Hackensack, NJ.

Installation and Maintenance

16. During installation, electronic components are connected as shown on Figure 1. The computer, balance, printer, and monitor should be connected to electrical power through the surge protector. The microwave oven may be connected to an unprotected wall socket because the oven circuit contains its own surge protection electronics.

17. The oven system must be level on its supporting surface as was stated earlier. Three leveling screws are furnished for leveling, two in the front of the machine and one in the rear. A small spirit level may be set on the bottom metal plate parallel to the front of the device and the two front leveling screws used to level the device in that direction. The level may be then set perpendicular to the front edge of the device and the rear screw used to level in that direction. Two levelings, one in each direction, are generally sufficient.

18. It is extremely important to keep the oven interior as free from dust and grit as possible. Periodically, preferably at the end of each day of use, the Teflon platform that sits on the Teflon load button (see Figure 1) should be removed, and the button of the oven cleaned with a small vacuum cleaner and wiped out with a clean damp cloth. The oven cavity should not be swept out with a brush or broom because this might cause particles of soil to fall and wedge between the oven liner and Teflon load button, causing the system to malfunction. Additionally, before the Teflon platform is replaced, the load button should be snugged very gently with the fingers with a clockwise rotation to ensure that it does not "back out" as the result of normal use and vibration and come into contact with the inner oven liner.

19. The Teflon platform should then be restored to the button. If unusual wear is observed between the button and platform, the entire assembly should be replaced (available from the US Army Engineer Waterways Experiment station (WES)) as the fit between button and platform is critical to the proper operation of the device.

Balance calibration

20. Occasionally it may be necessary to calibrate the balance internal to the oven cavity. This operation is not recommended routinely unless irregular system operation is observed (such as negative water content indication). The relationship between the balance and oven is shown in Figure 1. The procedure to remove the balance from the oven and to calibrate it is as follows:

a. Remove the brick and Teflon platform from the oven cavity.

b. Remove the hold-down screw that secures the inner oven liner to the balance case.

c. Turn the oven upside down on a smooth clean surface.

d. Remove the 12 screws that secure the 1/8-in. plate onto which the balance is fastened to the thick, 1/4-in. bottom plate.

e. Disconnect the power cord from the rear of the balance.

f. Lift the plate and balance vertically without scraping the Teflon load button against the inner oven liner.

g. Set the plate and balance (right side up) on the bottom plate of the oven and set the Teflon platform onto the button.

h. Reattach the power cord to the balance and allow the balance to warm up at least 30 min (if it has not been plugged in).

i. Slide the rear calibration switch up (with the display on).

j. "CAL 0" will be displayed; press RE-ZERO.

k. After a short pause "CAL F" will be displayed.

l. Put a 2,000-g mass on the Teflon platform.

m. Press RE-ZERO, and after a pause "CAL END" will be displayed.

n. Slide the rear calibration switch down.

o. Unplug the power cord from the rear of the balance.

p. Turn the balance oven and align the holes in the thin plate with the holes in the thick plate.

q. Replace the screws.

r. Using "needle-nose pliers," plug the power cord into the back of the balance.

s. Turn the unit over onto the leveling screws.

t. Replace the hold-down screw and Teflon platform.

Precautions

General

21. The microwave system is electronic in nature; therefore the same safety precautions should be observed in the use of this device as would be with any electrical appliance. All electrical plugs should be maintained in good condition with no frayed insulation or exposed wires. The electronic components should always be kept dry and stored in a clean environment between 32 °F and 100 °F (the equipment should be used in an environment between 60 °F and 100 °F with less than 100-percent relative humidity). If the components are taken suddenly from a cold to a warm, moist environment, the equipment should be allowed to sit in the warm environment at least 6 hr before use to allow thermal equilibrium to be reached and any water that has accumulated as the result of the condensation to evaporate.

22. The equipment should always be supplied with a stable 120-V AC power source, and all components should remain connected to power at all times; however, the computer, printer, and monitor should be switched off when the unit is not to be used for extended periods.

23. It is important that the oven door seal properly to prevent microwave radiation leakage. The door of the oven is designed with interlocks (reed switches and door strike switches) to prevent open-door use. No attempt should ever be made to defeat these interlocks. The microwave system should never be operated if the door has been damaged or warped. Additionally, it is advisable to check the system periodically for leakage with a microwave leakage detector. An allowable emission of microwave radiation is 5 mW/cm^2 measured at 5 cm from the surface of the oven. If leakage intensity is higher than this level, the door should be serviced by a qualified technician.

Equipment precautions

24. The software cartridge should be plugged into the expansion port at all times. "TOP" should always face up on this cartridge. NEVER plug this cartridge into the computer with the top facing down; otherwise SERIOUS internal damage will result to the computer and its power supply. This cartridge must always be correctly inserted when the computer is turned on. NEVER plug this cartridge into or unplug it from the computer while power is applied.

25. Electrical arcing inside the microwave oven will VERY QUICKLY AND SERIOUSLY damage the magnetron tube internal to the oven body. For this reason, any time electrical arcing is observed in the oven, the "STOP" button on

the membrane keypad should be pressed, or the oven door should be opened immediately to stop magnetron operation.

26. Arcing is generally caused by either metal in the oven or empty oven operation. Therefore, NEVER put any METAL article inside the oven while it is operating, and NEVER operate the oven without the unglazed brick which provides an empty oven load.

27. Food or water associated with food should NEVER be placed inside the microwave drying system. Water should NEVER be spilled inside the oven space because it will run into the balance housed below the oven space and destroy the electronics of the balance.

Operating precautions

28. Objects should never be dropped onto the balance platform; if an object is inadvertently dropped onto the platform, the balance should be calibrated as previously described.

29. Specimen containers should be placed on the balance platform as centrically as possible. A tare placed too far center will bend the Teflon pad button and possibly cause the unit to malfunction. Additionally, containers should be placed on the platform gently, and the door closed gently. The door should never be slammed or closed forcefully.

30. Total weight on the platform should not exceed 600 g, and minimum soil weight should not be less than 80 g. Specimen containers should be borosilicate glass beakers or ceramic crucibles and should be filled at least half full of soil. If stone fragments greater than 1/2 in. in diameter are used, then containers with lids and Styrofoam jackets* should be used in the event of an explosion. Untempered glass should never be put inside the microwave oven.

Exploding particles

31. Gravel and shale particles have been observed to explode in the microwave oven system; such explosions are undesirable because, as a result, materials will likely be ejected from the soil container and the test ruined

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* Paul A. Gilbert, 1988, "Computer-Controlled Microwave Oven System for Rapid Water Content Determination," Technical Report GL-88-21, US Army Engineer Waterways Experiment Station, Vicksburg, MS.
_____, 1990, "Computer-Controlled Microwave Drying Potentially Difficult Organic and Inorganic Soils," Technical Report GL-90-26, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

or the explosion could occur with enough force to break the specimen container. To minimize the danger of exploding particles:

a. Do not dry stone and shale particles bigger than 1 in. in the oven (preferably a maximum particle size of 1/2 in.).

b. If large particles must be dried, special "shale cycle" software may be requested that will dry such particles at reduced power to avoid explosion.

c. Use special Styrofoam jackets around the containers to absorb the energy of an explosion.

32. If an explosion should occur causing ejection of material from the container, the ejected material may be restored to the container and the test continued. This technique may be used to recover a specific test but should not be used routinely.

Operating Instructions

33. The user is prompted by CCMOS after the system is energized and the software executed. It is important that the user always exercise reasonable care and good technique when operating the equipment. To avoid electrical surges that may damage internal computer parts, the computer should always be switched on last, after the printer and monitor when energizing the system, and should be switched off first when shutting the system off.

34. The electronic balance must be allowed to "warm up" at least 30 min from the time the unit is first connected to electrical power to when the CCMOS is used. As long as the balance is connected to power after the initial 30-min warm-up period, it is on stand-by status, and CCMOS is ready for immediate use.

35. When the system is first activated, initialization requires about a second, after which the first screen prompt will appear: "PLEASE INPUT DATE OF TEST." In response, the user can input a date in any format (e.g., 1/2/90, 2 Jan 90, etc.); commas should not be used in the date. The user may opt not to input a date by simply pressing the "RETURN" key. Whatever the user enters here will appear on the hard copy from the printer.

36. The second prompt will be: "WHAT IS THE PROJECT NUMBER?" In response, the user may type in any combination of numbers and alpha characters (but not commas). The RETURN key is pressed after the project number.

37. The third prompt is: "WHAT IS THE JOB NUMBER?" Response will be the same as for the project number.

38. The fourth prompt is: "IS THIS A CLEAN SAND?" This prompt is answered with a capital "Y" (if the material is classified as predominately granular) or a capital "N" (if the material is classified as predominately silt or clay) followed by RETURN. If a correct and proper response is not provided, the prompt "IS THIS A CLEAN SAND?" will return to the display screen after each carriage return.

39. The fifth prompt is: "ARE YOU USING A PRINTER?" In a manner similar to the fourth prompt, this prompt must be given a capital "Y" or "N" to designate a "yes" or "no" response followed by a carriage return.

40. At this point, the screen will clear, and a period of as much as 15 sec may elapse before the sixth prompt appears: "PLACE TARE ON SCALE THEN PRESS ANY KEY." In response, the user gently places a clean dry container centrically on the Teflon platform to be used as a specimen container for the water content test. With the specimen container in place and the oven door open but still (not moving), an alpha character key is pressed, followed by RETURN.

41. The screen will clear, and the following prompt will appear: "FILL TARE WITH 100-200 GRAMS OF MOIST SOIL, PLACE ON PAN, PRESS ANY KEY." The command of this prompt is obvious and clear. The key referred to must be an alpha character key, followed by RETURN.

42. At this time, the tare and wet weights will be printed on the monitor screen followed by the final prompt: "CLOSE DOOR, PRESS ANY KEY." The user must close the door gently and press an alpha key and RETURN. The system now takes control through software and dries the soil specimen to the extent achieved in the conventional oven (maintained at 110 ±5 -C), prints the final water content, and sounds an alarm when completed.

43. Appendix A shows the prompts that appear on the monitor and the forms of responses (in bold underlined type) as well as the table of values that are determined and reported during specimen drying.

44. Even though CCMOS has been thoroughly demonstrated to work safely and effectively on a variety of materials, it is recommended that when each new material is dried for the first time, material response and equipment be monitored closely and that results be confirmed in a constant temperature oven. The reason for this close monitoring is that a new untested material may contain minerals which produce an unexpected reaction upon microwave heating (such as exploding particles or oxidation) or minerals which dehydrate undesirably to yield erroneous water content information. This equipment like

all other laboratory equipment should be used with judgment and common sense. If, during use, an unexpected or seemingly dangerous phenomenon is observed, then use should be discontinued until the phenomenon can be explained and/or determined to be safe.

45. For additional and more detailed information on the CCMOS System, the reader is referred to Gilbert (1988, 1990).*

* Gilbert, op. cit.

APPENDIX A

MICROWAVE OVEN PROGRAM
INITIALIZING: STANDBY
WHAT IS THE DISTRICT: ? **HUNTINGTON**
WHAT IS THE DATE: ? **11/23/90**
WHAT IS THE PROJECT: ? **YATESVILLE DAM**
WHAT IS THE CONTRACT: ? **CQGQY383**
WHAT IS THE LOCATION: ? **YATESVILLE WV**
WHAT IS THE TIME: ? **1605**
WHAT IS THE SAMPLE NO.: ? **34-C**
WHAT IS THE CLASSIFICATION: ? **CL**
TECHNICIAN: ? **PAG**
IS THIS A CLEAN SAND?? **N**
ARE YOU USING A PRINTER?? **Y**
WANT TO COMPUTE DRY DENSITY?? **Y**
ENTER DENSITY SPECIMEN VOLUME IN CUBIC FEET: **9.29478723E-4**
ENTER DENSITY SPECIMEN WET WEIGHT IN GRAMS: **50.44**

(SCREEN WILL CLEAR, THE FOLLOWING INSTRUCTION WILL BE PRINTED)

PLACE TARE ON SCALE
PRESS ANY KEY AND RETURN? **G**

(SCREEN WILL CLEAR, THE FOLLOWING INSTRUCTION WILL BE PRINTED)

FILL TARE WITH 100-200
GRAMS OF MOIST SOIL, PLACE
ON PAN, PRESS ANY KEY AND RETURN? **R**

(THE FOLLOWING DATA WILL BE PRINTED FOR REVIEW AND VERIFICATION)

MICROWAVE OVEN
WATER CONTENT DETERMINATION
DATE: 11/23/90
PROJECT NO: YATESVILLE DAM
JOB NUMBER: CQGQY383
TARE WEIGHT: 97.69
WET WEIGHT: 148.1
DENSITY SPECIMEN VOLUME IN CUBIC FEET = 9.294787E-04
DENSITY SPECIMEN WET WEIGHT IN GRAMS = 50.44
CLOSE DOOR, PRESS ANY KEY AND RETURN? **H**

MICROWAVE OVEN

WATER CONTENT DETERMINATION

District: HUNTINGTON Project: YATESVILLE DAM Contract: CQGQY383

Location: YATESVILLE WV Date: 11/23/90 Time: 1605 Technician: PAG

Sample No.: 34-C Classification: CL Tare Weight (g): 97.69
Wet Weight + Tare (g): 148.10

DENSITY SPECIMEN VOLUME IN CUBIC FEET = 9.294787E-04
DENSITY SPECIMEN WET WEIGHT IN GRAMS = 50.44

ELAPSED TIME (SEC)	DRYING TIME (SEC)	WEIGHT (G)	WATER CONTENT (%)
0	0	148.1	0.00
30	30	147.8	0.06
60	60	145.9	4.56
90	90	144.1	8.62
120	120	142.7	12.00
150	150	141.7	14.55
180	180	141.1	16.13
240	210	140.6	17.48
300	240	140.4	18.03
361	270	140.2	18.59
421	300	140.0	19.15
481	330	139.9	19.43
541	361	139.8	19.71
601	391	139.7	20.00
661	421	139.7	20.00
841	421	139.7	20.00

WATER CONTENT = 20 %
FINAL WEIGHT = 139.7 G
DRY DENSITY = 99.70 PCF