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LABORATORY EVALUATION OF POTENTIOMETER, LVDT, AND LOAD CELL SENSORS MOUNTED ON A BELFORT TRANSMITTING AND RECORDING PRECIPITATION GAGE

BY

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ACKNOWLEDGMENTS

The study described in this report was conducted by Steve Gray under the supervision of E. J. Carlson, Head, Hydraulics Research Section, Hydraulics Branch. The study was requested by the Division of Atmospheric Resources Research. Mr. Dean Newkirk, of that division, furnished the precipitation gages and some recorders that were used, and made valuable suggestions during the testing. Other personnel from the Division of Atmospheric Resources Research viewed results of some early tests and made several suggestions.

PURPOSE

A study of a Belfort transmitting and recording precipitation gage, requested by the Operational Support and Demonstration Branch, Division of Atmospheric Resources Research, was performed to evaluate various methods of recording precipitation data and comparing these methods with the recording precipitation gage record.

INTRODUCTION

The model, catalog No. 5915R Belfort transmitting and recording precipitation gage (fig. 1), converts the weight of collected precipitation into equivalent depths of accumulated water in conventional units of inches or millimeters. Two 8-inch precipitation gages were provided the Hydraulics Branch, and the mechanism on both gages included a dual traverse chart-recording system and a low-torque precision potentiometer with electrical output (figs. 2, 3, and 4).

The original study request made by Atmospheric Resources Research was to add an LVDT (linear variable differential transformer) to the gage (fig. 5) and to operate the precipitation gage at ambient temperature and at cold temperatures, each with various rates of precipitation being added. The data were to be automatically collected by an OmniData International datapod, DP 111 data acquisition system (fig. 6), for both the potentiometer already mounted on the gage, and the LVDT, with the chart recorder operating normally. After preliminary tests, it was determined that other devices currently available could also be used to measure precipitation. Discussions with personnel in the Atmospheric Resources Research Division and with manufacturers of data acquisition instruments led to the decision to test three load cells concurrently with the potentiometer and LVDT, all mounted on the precipitation gage.

RESULTS AND CONCLUSIONS

A Belfort transmitting and recording precipitation gage was used to evaluate a potentiometer, and LVDT sensors to record very low rates of precipitation. The potentiometer and LVDT were necessarily mounted below the gage platform; therefore, the characteristics of the spring, levers, gears, and bearings - including friction - were all reflected in the record for these

Figure 1. - Belfort transmitting and recording precipitation gage.

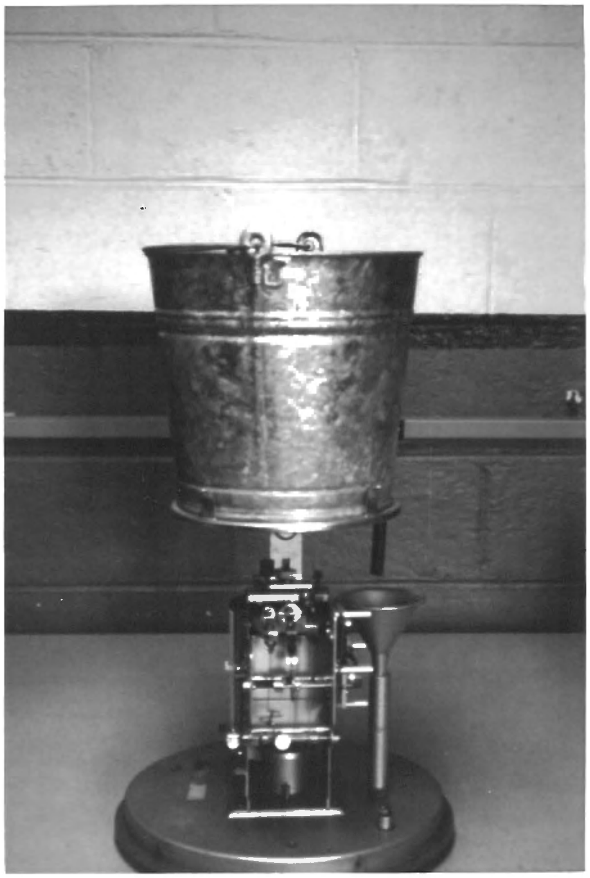

Figure 2. - Precipitation gage showing linkage and collecting bucket.

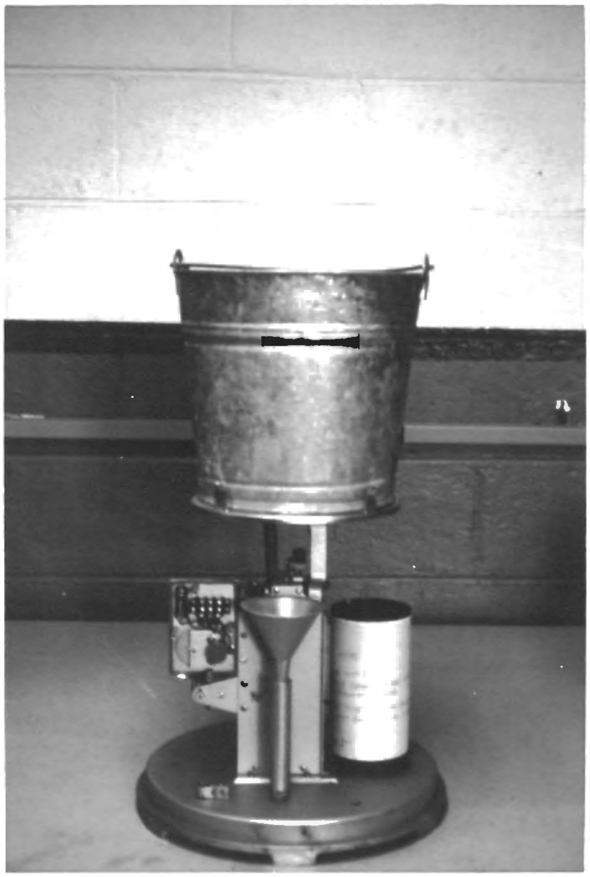

Figure 3. - Precipitation gage showing the potentiometer, overflow, and drum recorder.

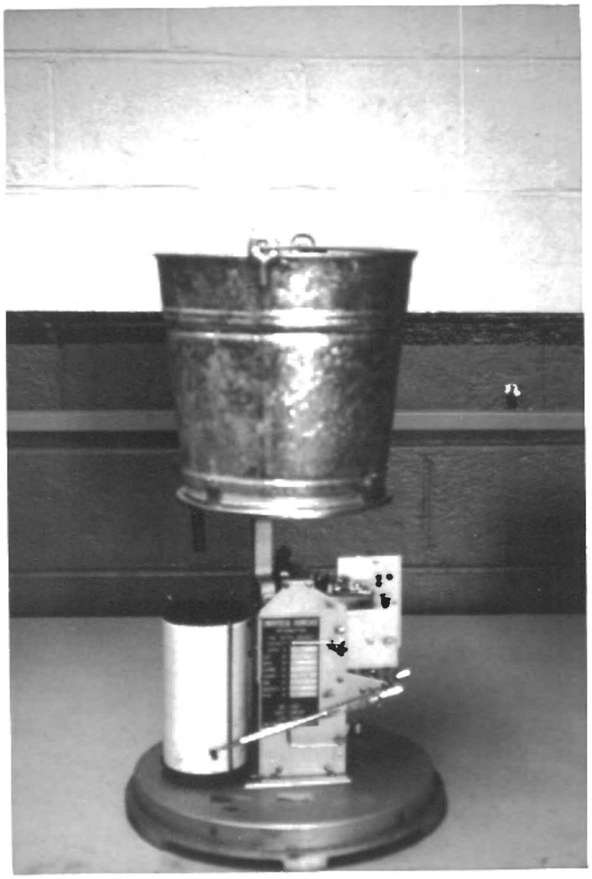

Figure 4. - Belfort transmitting and recording precipitation gage without cover showing chart recorder and pen arm.

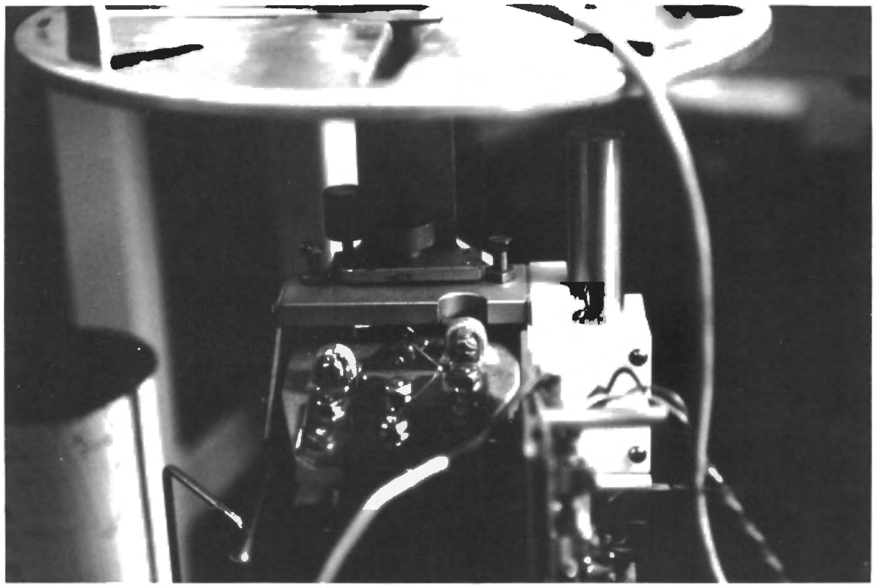

Figure 5. - LVDT (linear variable differential transformer) sensor mounted on gage for testing.

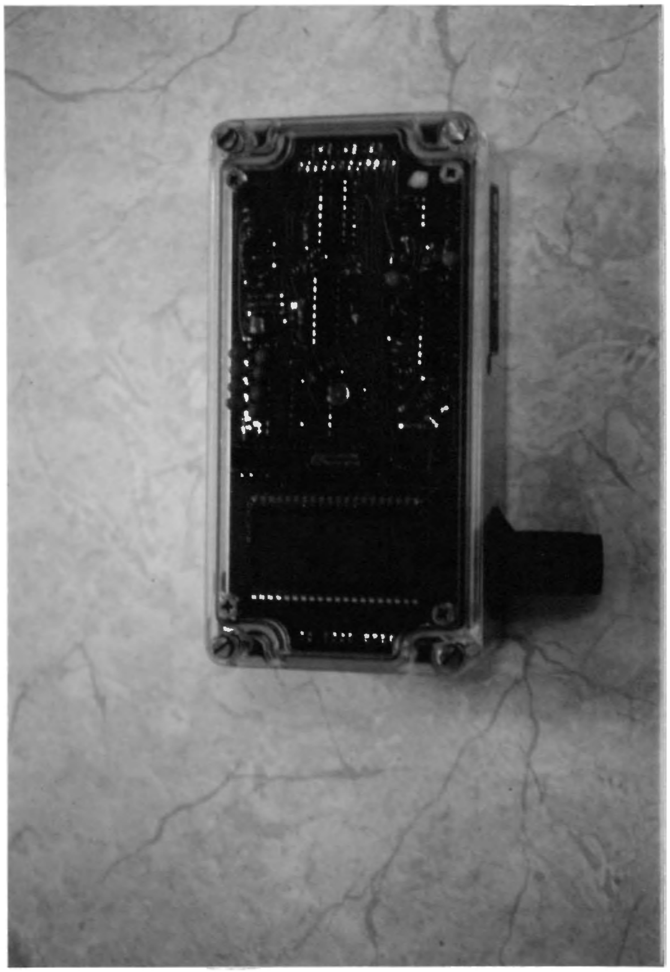

Figure 6. - OmniData International datapod DP-111 used for data acquisition and storage.

two sensors. During preliminary testing, three load cells made by Schaevitz, Tedea, and Revere Companies were obtained, and they were tested as sensors of precipitation. The load cells were mounted one above the other on the precipitation gage platform, thereby eliminating the influence of the gage spring, levers, gears, and bearings. Data from the potentiometer and LVDT were recorded on OmniData International Datapods. Data from the three load cell sensors were recorded on Moseley strip chart recorders.

Very low rates of feed to the precipitation gage were required to simulate measurements of increased precipitation as it occurs in wintertime storms. Adding lead shot and ball bearings at specified intervals to the gage was tried, but this method was abandoned because of vibration of the gage due to impact of the falling balls. A Masterflex tube pump was used for all final tests, which provided a constant and steady rate of fluid feed. The rate of precipitation used for all tests was approximately 0.5 mm/h (0.02 in/h). Three tests were conducted at room temperature, approximately 25 °C (77 °F), and three tests were conducted in a cold room at approximately -21.7 °C (-7 °F). Each of the tests were conducted for a 24-hour period. The precipitation gage and load cells were tested with 0, 50, and about 80 percent preload for all tests; thereby, the sensors were tested over an approximate full-load range of precipitation gage in the two temperature environments used.

The data for each sensor were taken from each recording device used and recorded on a table by hand for each test. Results of each sensor for each test were then compared by plotting the results on a single graph for each test. The comparative results are given on figures 17, 19, 21, 23, 25, and 27. The graphs show variation between sensors along with a line giving the exact rate of liquid feed by the Masterflex pump. Data from the tests conducted in the electronics shop show the precipitation gage recorder, the potentiometer, and the LVDT have considerable deviations from a smooth curve. It is believed that friction in the gears, levers, and bearings is a cause for these jumps in the data recording. Smaller jumps are evident on the tests conducted in the cold room for the gage recorder, potentiometer, and the LVDT.

Data from the three load cells showed uniform traces very close to the line of actual feed rate for the tests in the electronic shop (warm temperature). In the cold room tests, the load cells showed more deviation. A large part of the deviations is due to reading the data from the primary recording strip charts with a comparator and transferring it to another graph. On the primary strip chart records, a 24-hour period only covered about one-tenth of the chart width, making the chart line very steep and difficult to read small increases. There was some waviness on the load cell chart records, particularly in the cold room tests. The Schaevitz load cell appeared to perform better in all tests than the Tedea or the Revere load cells.

We believe a load cell could be used as a precipitation gage sensor to give results as good and probably much better than the precipitation gage recorder, the potentiometer, and the LVDT for very low precipitation rates.

Additional tests should be made with one or more selected load cells using a more accurate recorder than the Moseley strip chart recorders. A microcomputer with very accurate analog and digital capabilities should be used. Tests should be made with load cells over a range of temperatures to test the load cells for safe temperature range and temperature effect.

All primary data records are available in the Hydraulics Branch.

PRECIPITATION GAGE

The Belfort gages tested had an 8-inch-diameter, knife-edge orifice to collect all forms of precipitation. The galvanized bucket which rests on a platform was mounted on the vertical link of a four-bar linkage. This vertical link or movement bracket is supported from below by a precision spring assembly. Extension of the spring by the weight of collected precipitation is multiplied and modified for recording by a horizontal lever. This lever is connected to the pen arm through another link and lever assembly. The pen is damped by a dashpot.

Accumulated precipitation is recorded on a rotating drum chart. A dual traverse recording system is used; that is, half of the capacity is recorded by the upward traverse of the pen and the other half by the downward traverse. The gage has a capacity of 12 inches of precipitation. Chart drum rotation is once in 24 hours and the clock is spring-driven. Manufacturers claim accuracy for the gage is better than 0.5 percent of full scale for ambient temperatures between -40 and 51.7 °C (-40 and 125 °F). Antifreeze and oil are added to the bucket to prevent freezing and evaporation of the precipitation.

Recording Equipment

A National Semiconductor microcomputer was available in the Hydraulics Branch for a short time for use temporarily in the precipitation gage tests for data acquisition. Initial effort was concentrated in programing that computer - which has an accuracy of 1 part in 16,000 - for data acquisition. After discussions with Atmospheric Resources Research personnel, it was decided that chart recorders should be used because of the time required to program and test the digital data acquisition system. Three Moseley model 7100B strip chart recorders made by Hewlett-Packard Company were provided by Atmospheric Resources Research Division, and two of them were used for recording data obtained with the three load cells tested (fig. 7). The Moseley strip chart recorders have a small zero offset, and for the small increase in load applied (very small precipitation rate), only about one-tenth or less of the chart width could be used in the 24-hour period. The accuracy of reading values of the chart recorders for comparative plotting was, therefore, limited.

For the potentiometer and LVDT data aquisition system, datapods supplied by OmniData International Company were used to record the data. This device records a mark each 5 minutes of added time if at least one increment of a set weight value is added. If more than one set weight increment is added in a 5-minute time interval, an additional mark is recorded for each weight

Figure 7. - Moseley strip chart recorders, Model 7100B, used for recording data from three load cells.

increment added. These marks are transposed to times using a model 217 datapod cassette recorder also furnished by OmniData International. The set weight increment can be varied. For the tests made on the precipitation gage, a set weight increment value equal to 0.05 inch of precipitation on the 8-inch gage was used. The datapods worked very well to record data from the potentiometer and the LVDT pickups. Recorders and datapod equipment were loaded on a cart so they could be moved with no disturbance to the cold room for tests. Temperature was measured with a FLUKE multimeter and recorded on a strip chart recorder. Temperature in the cold room was recorded on the continuous Bristol recorder provided by the Concrete and Structural Branch for the calorimeter rooms in the laboratories.

Load Cells

A model JP-50 Schaevitz load cell (fig. 8) was available and tested as one of the data acquisition instruments. Mr. Hugh Hilleary of Radco Electronics Company obtained a model 1010 load cell made by Tedea Company (fig. 9) and a model MCBU 025 load cell made by Revere Company (fig. 10). These two load cells were loaned for testing and evaluation at no cost to the Bureau. The three load cells were mounted - one above the other - on the bucket platform. All of the load cells were mounted above the precipitation gage gears and linkage; therefore, the gears and linkage friction had no effect on the operation of the load cells.

Potentiometer

Potentiometers have been used by Atmospheric Resources Research to acquire data from remote precipitation gages with the data being transmitted via satellite to a central station. The potentiometer is a continuous rotation type with a maximum resistance of 25 000 ohms ±0.5 percent spanning 354° ±2°. The maximum current capacity of the potentiometer is 0.006 A. The potentiometer data sensor comes mounted on the transmitting and recording precipitation gage (fig. 3).

PRELIMINARY TESTS

Using Steel Balls

Two methods were considered for adding weight to the precipitation gage to simulate precipitation. The first was use of small lead shot which varied considerably in weight from shot to shot, or ball bearings whose size and weight were uniform both in size and weight. Twenty-five pounds of 5/16-inch-diameter stainless steel ball bearings were purchased from Kaman Bearing Company. Each ball weighed 2.02 grams with practically no variation in weight from ball to ball.

An apparatus was designed and constructed to drop one steel ball at a time from a reservoir of steel balls. A sliding slotted plate was operated with a solenoid and a timing device (fig. 11). Time intervals for dropping single balls into a 4-inch-diameter by 15-inch-high aluminum tube mounted on the gage platform (fig. 12) could be varied widely to change the rate of adding weight to the precipitation gage. Several tests were made and the apparatus

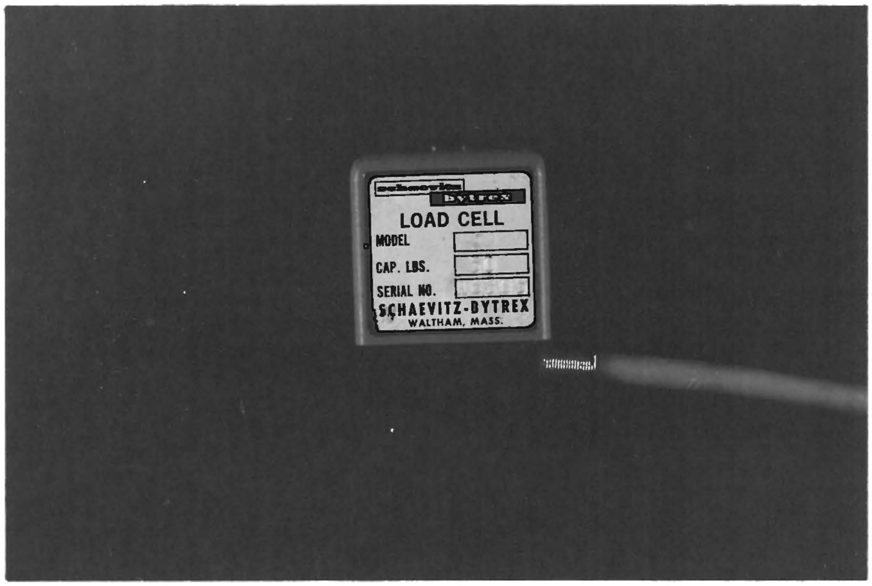

Figure 8. - Model JP-50 Schaevitz load cell used as a sensor mounted on the precipitation gage.

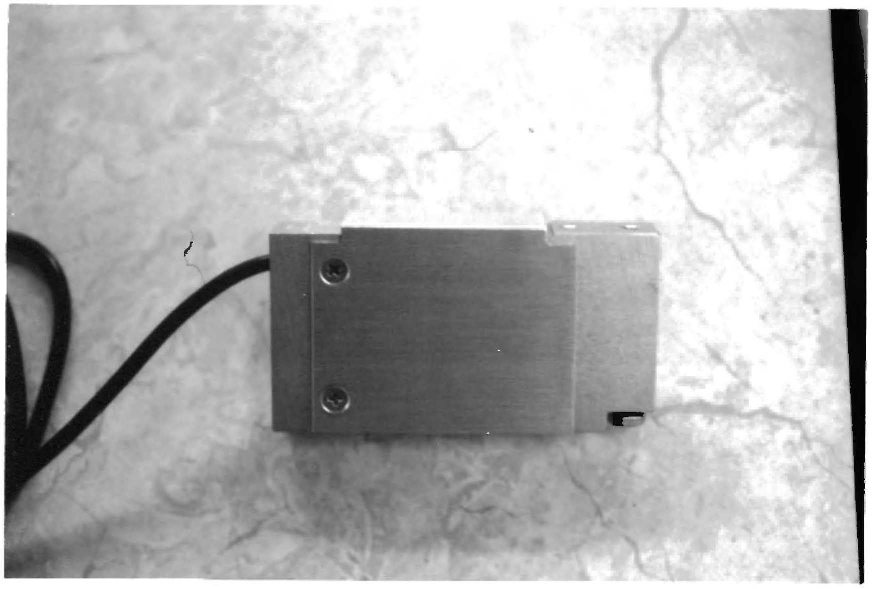

Figure 9. - Load cell made by Tedea Company, model 1010, used as a sensor mounted on the precipitation gage.

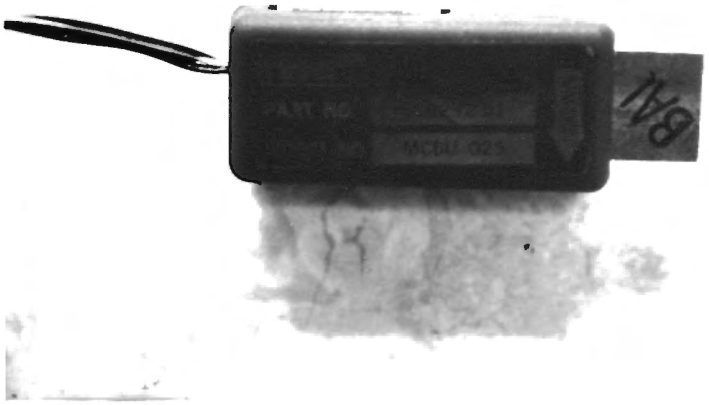

Figure 10. - Model MCBU 025 load cell made by Revere Company used as a sensor on the gage.

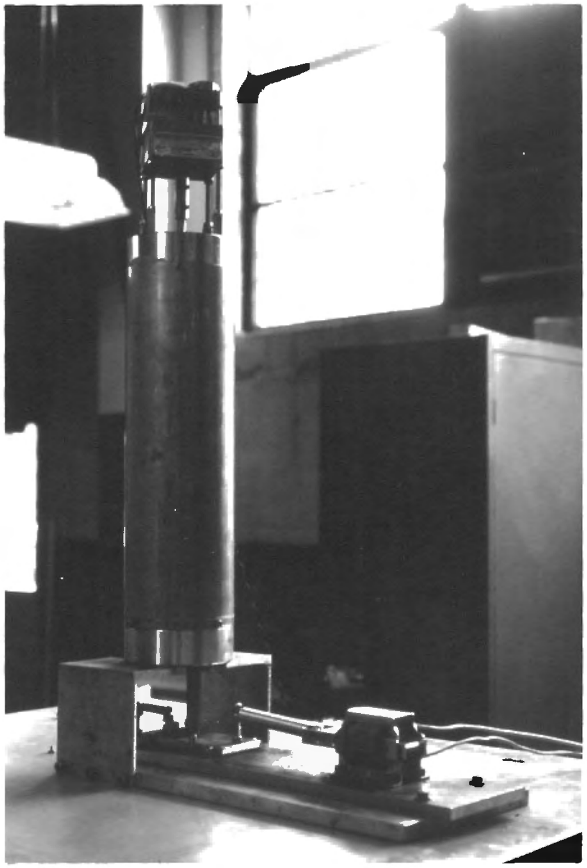

Figure 11. - Apparatus with sliding slotted plate with a timer and solenoid for dropping steel balls into precipitation gage. This system was used in preliminary tests.

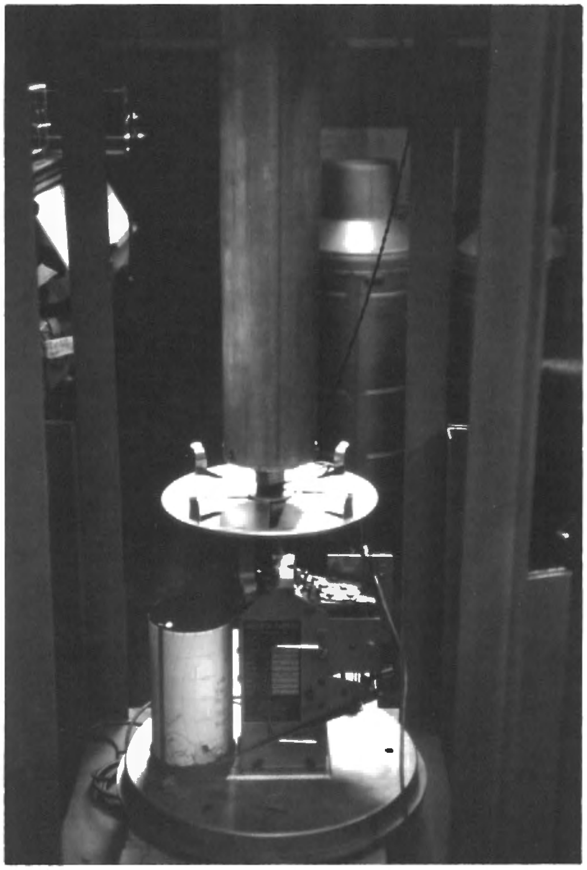

Figure 12. - Aluminum tube, used for receiving steel balls, mounted on precipitation gage platform.

worked very well. The Moseley chart recorders - used to record the increase of weight added with time - showed that each time a ball was dropped a small vibration occurred to the gage mass which was picked up by the potentiometer and LVDT analog instruments. This vibration was transmitted to the recorders. The rate of feed recorded was very steady; however, the impact of the balls overcame the friction in the precipitation gage gears and linkage. The friction problem, if there was one, therefore, could not be observed from the chart. Discussions with Atmospheric Resources Research engineers resulted in abandoning the steel ball method of feeding very low rates of weight addition during the tests. The friction problem in the gears and linkage could not be identified when the steel balls were used.

Adding Fluid Using a Pressure Tank

The second method tried was adding a steady stream of fluid to the precipitation gage which would not influence the friction problem, because there would be no impact on the gage. A nitrogen pressure bottle provided the pressure to force a steady stream of fluid from a pressure container through a small plastic tube into the gage (fig. 13). Clamps on the tubing and a valve on the nitrogen bottle were used to control the rate of flow. Small pressure variations in the system, which could not be completely stabilized with the clamps and nitrogen bottle valve, made it impossible to maintain a steady low rate of feed. Use of an expensive pressure regulator - not available in the laboratory - would be required to maintain a steady rate of feed for this system. Therefore, the pressure feed system was abandoned and a Masterflex tubing pump system was obtained.

Model 7553-10 Masterflex Pump

A Masterflex pump, model 7553-10, with a multichannel head was purchased from Cole Parmer Company (fig. 14). The combination pump head and speed control provided a precipitation feed range of 0.03 to 3.0 mL/min. The rate used for the six evaluation tests conducted was approximately 0.27 mL/min which was equal to approximately 0.5 mm/hr of water added to the precipitation gages with an 8-inch-diameter orifice. The pump was bench-tested and the set feed rate was maintained constant with practically no deviation. The pump worked well for all tests.

CALIBRATION OF PRECIPITATION GAGE

Before any tests were made, the precipitation gage was calibrated and checked to make sure the linkage and weighing system was operating properly. Weights equivalent to approximately 800 grams (822.7 g = 1 in of precipitation at 60 °F) were successively added to the platform of the gage, and the indicator on the gage chart recorder was checked. The linkage and arm holding the pen were adjusted until the pen on the chart would indicate equivalent precipitation to the weight added. The two precipitation gages used during the study were calibrated with standard weights before any tests were made with the particular gage being used.

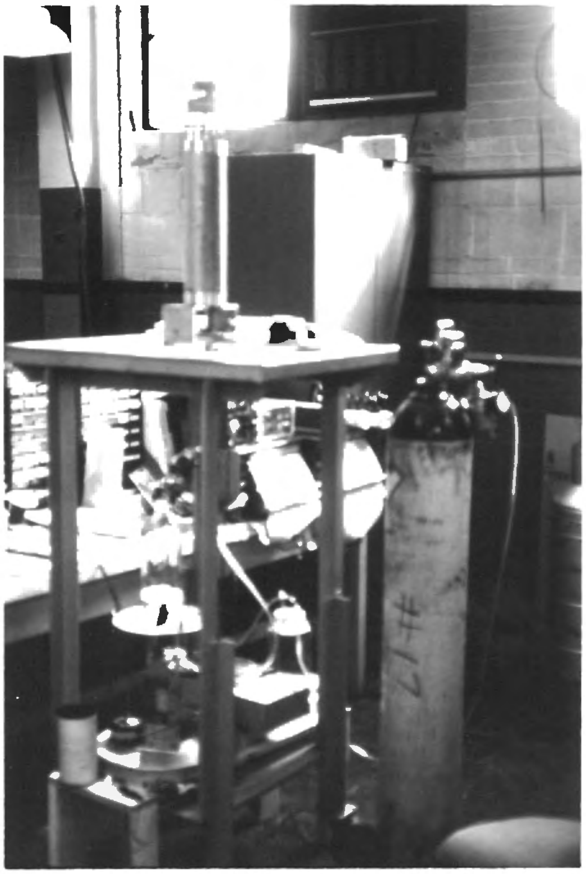

Figure 13. - Pressure system using nitrogen bottle for adding fluid to the precipitation gage. This system was not used for final tests.

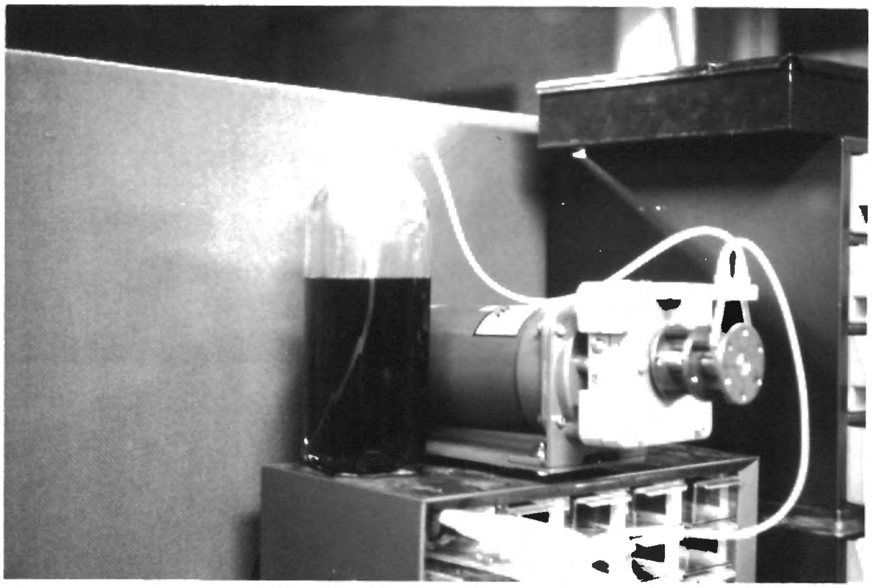

Figure 14. - Masterflex pump model 7553-10 made by Cole-Parmer Company used to feed fluid to the precipitation gage for the six evaluation tests.

PRECIPITATION GAGE TESTS

Precipitation Simulation

To be able to evaluate the increased precipitation for winter storms, it is necessary to measure small amounts of precipitation very accurately. Data show that for the Colorado Weather Modification Project, 40 percent of the average precipitation occurs at a rate equal to or less than 0.02 inch or 0.5 mm/h and 67 percent of the precipitation occurs at a rate equal to or less than 0.04 inch or 1.0 mm/h. It was desirable, therefore, to test the data acquisition systems at very low feed rates.

The following memorandums and personal records were prepared during the course of the study to specify limits of the study at various times during its progress:

Memorandum to Chief, Operational Support and Demonstration Branch, from Head, Hydraulic Research Section, through Chief, Hydraulics Branch, dated March 11, 1982, Subject: Laboratory Evaluation of LVDT with OmniData International Datapod Rain Gage Recorder.

Memorandum to Chief, Hydraulics Branch, from Chief, Division of Atmospheric Resources Research, dated April 21, 1982, Subject: Laboratory Evaluation of Precipitation Recording Using LVDT and OmniData International Datapod Rain Gage Recorder.

Personal record of Chief, Hydraulics Branch, dated August 19, 1982, Subject: Rain Gage Testing.

Memorandum to Chief, Operational Support and Demonstration Branch, through Chief, Hydraulics Branch, from Head, Hydraulics Research Section, dated September 2, 1982, Subject: Laboratory Evaluation of Various Data-Sensing Devices with Belfort Weighing Bucket Precipitation Gage.

Personal record of Donald Rottner (approximately October 15, 1982), Subject: Precipitation Gage Study ("Currently conducting study of temperature dependency of mechanical and electronic data from weighing precipitation gages").

Memorandum to Chief, Hydraulics Branch, Attention D-1532, from Chief, Division of Atmospheric Resources Research, dated October 21, 1982, Subject: Rain Gage Tests.

During the period of the above communications, many preliminary tests were conducted and discussions held to show how various weight adding and data acquisition systems would operate to determine a final procedure for evaluation tests. The final schedule of tests as shown below was established to be conducted after the equipment was checked out in the Electronics Shop:

Temperature	Rates/each temperature
-20 °C (-4 °F)	0.5 mm/h (0.02 inch) - 600 h
-10 °C (14 °F)	1.0 mm/h (0.04 inch) - 300 h
0 °C (32 °F)	5.0 mm/h (0.2 inch) - 60 h
+10 °C (50 °F)	

This was three rates of feed for temperatures making it a total of 12 tests, requiring a testing time of forty 24-hour days.

Because of fund limitations, only two series of full tests were conducted as shown below:

Approximate temperature	Test No.	Precipitation rates
+25 °C (+77 °F) room temperature in Electronics Shop	1	0.5 mm/h (0.02 inch/h) - zero preload on precipitation gage - 24 h
-	2	0.5 mm/h (0.02 inch/h) - approximately 6 inches rain preloaded on precipitation gage - 24 h
-	3	0.5 mm/h (0.02 inch/h) - approximately 10 inches rain preloaded on rain gage - 24 h
-21.7 °C (-7 °F)	4	0.5 mm/h (0.02 inch/h) - zero preload on precipitation gage - 24 h
-	5	0.5 mm/h (0.02 inch/h) - approximately 6 inches of rain preloaded on precipitation gage - 24 h
-	6	0.5 mm/h (0.02 inch/h) - approximately 10.7 inches of rain preloaded on precipitation gage - 24 h

TESTS AT ROOM TEMPERATURE

Test No. 1

A few preliminary tests were made to be sure the precipitation gage and cylinder chart recorder, datapods, three load cells, potentiometer, LVDT, and the Moseley chart recorders were all working properly and recording the data according to the calibrations made. A calibration check was made with the antifreeze fluid feed system by weighing the fluid in the beaker container set on the gage platform (fig. 15) at the beginning of each test and at the end of each test. Time was recorded at beginning and end of the test and, with exact weight added, an actual rate of fluid calibration was made.

Test 1 was conducted in the Electronics Shop at room temperature. The temperature was 21.7 °C (71 °F) at the beginning of the test and varied less than ±3.9 °C (±7 °F) during the entire 24-hour test. The temperature was measured with a FLUKE multimeter and recorded on a Honeywell strip chart recorder. Data from the potentiometer and LVDT sensors were recorded on two individual OmniData International datapods. The data from the datapods were transposed from solid-state chips, recorded in digital form, to a computer printout using a StarplexModel 217 datapod/cassette reader loaned by OmniData International (figs. 16a and 16b). Data from the Schaevitz, Revere, and Tedea load cells were transmitted to two Moseley chart recorders giving a continuous record. The weighing precipitation gage pen recorded a continuous record of the added weight on the dual-traverse chart mounted on a rotating cylinder. Data from each of the charts were read using a magnifying comparator and recorded by hand on the table showing readings of each sensing instrument with time. To compare all of the methods, data from each record were plotted using the Hewlett-Packard 9825 computer-plotter (fig. 17).

Test 1 was started with a load on the precipitation gage equal to the weight of an empty bucket. This included three load cells and a near empty beaker to hold the antifreeze liquid. Figure 17 shows that the LVDT did not pick up any added weight until 425 minutes after the beginning of adding fluid, and the potentiometer did not start picking up weight until 615 minutes after the beginning of adding liquid or after about 3.5 mm and 5 mm of precipitation had been added, respectively. The precipitation gage record (fig. 17) showed a loss of weight between the 60- and 90-minute time periods and then held steady with practically no change in indicated weight until 240 minutes after the start of the test. After about 240 minutes, it showed a gradual increase.

The record shows a sudden increase in weight as indicated by the potentiometer and LVDT with no increase in time at several points along the record chart. The sudden increases are very likely due to the increasing weight overcoming friction and making a jump in the system. The general slope of the recorded points for the precipitation gage, potentiometer, and LVDT records was about the same slope as the line showing actual added fluid.

The record of the three load cells followed the line of actual added fluid very closely. This test - for no initial load on the precipitation gage and tested at room temperature - showed the three load cells gave a much closer record to the actual rate of weight added than did the gage recorder, potentiometer, and the LVDT.

Test 2

Test 2 was similar to test 1, except the precipitation gage was loaded to about one-half capacity before starting the test. Test 2 was conducted in the Electronics Shop. The temperature was 25.6 °C (78 °F) at the beginning with a variation between 25.0 and 26.1 °C (77 and 79 °F) throughout the test. The same sensors - precipitation gage weight recorder, potentiometer, LVDT,

Figure 15. - A large beaker placed on the gage platform to receive fluid from the Masterflex tube pump.

```
MO-DA-YR-HR:MN?11-17-82-13:15

11  17  2245 .25
11  17  2300 .5
11  17  2345 .75
11  18  0030 1.0
11  18  0100 1.25
11  18  0125 1.5
11  18  0150 1.75
11  18  0245 2.0
11  18  0245 2.75
11  18  0320 2.5
11  18  0345 2.75
11  18  0415 3.0
11  18  0445 3.25
11  18  0505 3.5
11  18  0540 3.75
11  18  0615 4
11  18  0615 4.25
11  18  0615 4.5
11  18  0645 4.75
11  18  0645 5
11  18  0645 5.25
11  18  0645 5.5
11  18  0645 5.75
11  18  0645 6
11  18  0730 6.0
11  18  0935 6.25
11  18  1015 6.5
11  18  1015 6.75
11  18  1015 7
11  18  1020 7.25
11  18  1110 7.5
11  18  1230 7.75
11  18  1300 8
11  18  1300 8.25
11  18  1305 8.5
EOF
```

Pot Test

11/17/82
11/18/82

Figure 16a. - Test 1 - potentiometer readings on OmniData datapod and printed from OmniData reader. Zero preload on precipitation gage.

```
11 17 1950 .25
11 17 2025 .5
11 17 2100 .75
11 17 2155 1
11 17 2205 1.25
11 17 2300 1.5
11 17 2345 1.75
11 17 2350 2
11 18 0055 2.25
11 18 0120 2.5
11 18 0200 2.75
11 18 0235 3
11 18 0305 3.25
11 18 0335 3.5
11 18 0350 3.75
11 18 0425 4
11 18 0505 4.25
11 18 0540 4.5
11 18 0605 4.75
11 18 0615 5
11 18 0630 5.25
11 18 0645 5.5
11 18 0645 5.75
11 18 0645 6
11 18 0645 6.25
11 18 0645 6.5
11 18 0645 6.75
11 18 0915 7
11 18 1005 7.25
11 18 1015 7.5
11 18 1015 7.75
11 18 1015 8
11 18 1110 8.25
11 18 1255 8.5
11 18 1300 8.75
EOF
```

disp

LVDT TEST 1

11/17/82 — 11/18

Figure 16b. - Test 1 - LVDT readings on OmniData datapod and printed from OmniData reader. Zero preload on precipitation gage.

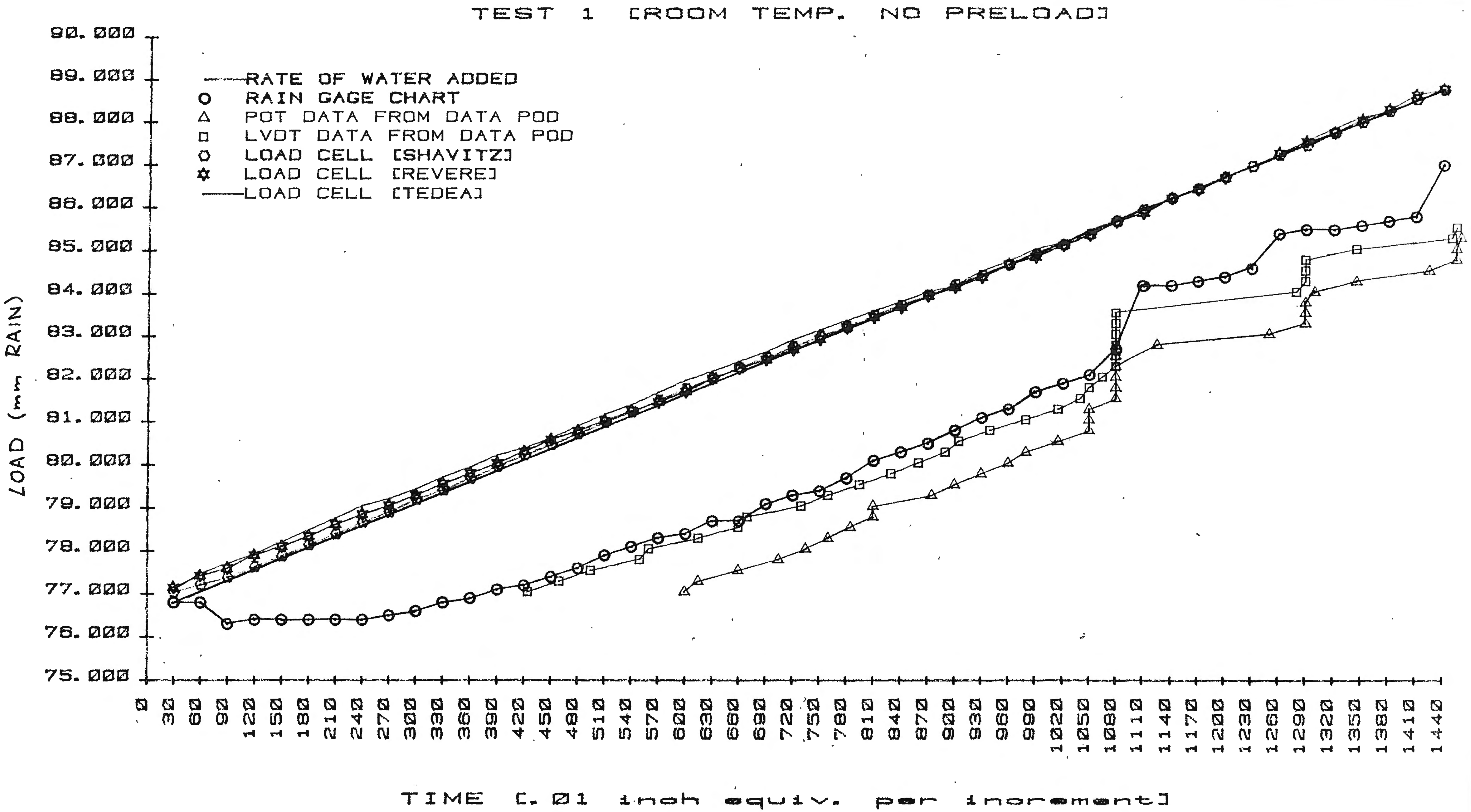
TEST 1 [ROOM TEMP. NO PRELOAD]
——RATE OF WATER ADDED
O RAIN GAGE CHART
△ POT DATA FROM DATA POD
□ LVDT DATA FROM DATA POD
○ LOAD CELL [SHAVITZ]
✡ LOAD CELL [REVERE]
——LOAD CELL [TEDEA]
LOAD (mm RAIN)
90.000
89.000
88.000
87.000
86.000
85.000
84.000
83.000
82.000
81.000
80.000
79.000
78.000
77.000
76.000
75.000
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
600
630
660
690
720
750
780
810
840
870
900
930
960
990
1020
1050
1080
1110
1140
1170
1200
1230
1260
1290
1320
1350
1380
1410
1440
TIME [.01 inch equiv. per increment]

Figure 17

and three load cells - were all mounted on the gage as in test 1. The test was made to see what response each of the sensors would produce with the precipitation gage loaded to one-half capacity. It was conducted for a 24-hour period.

Printouts from the OmniData International datapods (figs. 18a and 18b) showed erratic periodic pickup on data increases of weight from both the potentiometer and the LVDT. The datapods pick up an increased weight indication at 5-minute intervals. The minimum weight that the datapods were programed to indicate an increase was for 0.25 mm of precipitation. The rate of fluid feed was approximately 0.5 mm of precipitation/h or 0.25 mm each one-half hour, so the datapods should pick up a recording each 30 minutes for steady feed rate. The records on both the potentiometer and LVDT were erratic in showing periods between time readings. They varied between 0 and 90 minutes for the potentiometer and between 0 and 80 minutes for the LVDT. The variation in time periods reflects the variation of recording constant increments of weight. Friction in the linkage and gear systems on the precipitation gage prevented complete freedom of movement for very long steady and low rates of weight increase. Occasionally, as shown on figure 19, a large jump in weight occurred with no increase in time, similar to test 1.

The records for the three load cells again showed a uniform rate of weight pickup and were very close to the line indicating actual rate of adding fluid. The precipitation gage chart recorder was somewhat erratic and showed jumps in weight addition similar to the potentiometer and the LVDT, again indicating friction problems on the precipitation gage recording mechanism.

Test 3

Test 3 was conducted with the precipitation gage preloaded to about 83 percent of its designated capacity. Tests 1, 2, and 3 evaluated the gage over approximately the full precipitation range of the gage.

Test 3 was made in the electronics shop and the ambient temperature varied from 25.6 °C (78 °F) at the beginning of the test to 21.7 °C (71 °F) at the end of the 24-hour test. The same sensors - precipitation gage weight recorder, potentiometer, LVDT, and three load cells - were all mounted the same as for tests 1 and 2. The test was performed with the Masterflex tube pump feeding a constant steady rate of antifreeze fluid at approximately one-half mm of precipitation/h. Again, as in tests 1 and 2, the printout from the OmniData International datapods showed the data pickup from the potentiometer and the LVDT were erratic with time intervals varying between 0 and 110 minutes for the LVDT and between 0 and 150 minutes for the potentiometer (figs. 20a and 20b). Time intervals should all be very close to 30 minutes, as is shown for the three load cells, for a continuous record of weight added. The data for the load cells were recorded on two Moseley chart recorders, and the data were read with a magnifying comparator and then transferred to a table and plotted with the HP-9825 computer-plotter (fig. 21). Friction in the precipitation gage linkage and gears apparently is great enough to cause the potentiometer and LVDT to give erratic readings for low rates of feed. The recorder pen on the precipitation gage is also erratic for the low rate of feed. The record from the three load cells followed the line of the exact addition of the fluid with slight deviation.

```
MO-DA-YR-HR:MN?11-18-82-13:41
Time-icr
Min.
50  11  18  2151 .25
20  11  18  2241 .5
25  11  18  2301 .75
50  11  18  2326 1
25  11  19  0016 1.25
40  11  19  0041 1.5
5   11  19  0126 1.75
5   11  19  0131 2
10  11  19  0236 2.25
50  11  19  0246 2.5
0   11  19  0336 2.75
50  11  19  0336 3
60  11  19  0426 3.25
10  11  19  0526 3.5
25  11  19  0536 3.75
5   11  19  0611 4
0   11  19  0616 4.25
15  11  19  0616 4.5
25  11  19  0631 4.75
75  11  19  0706 5
20  11  19  0821 5.25
10  11  19  0841 5.5
5   11  19  0851 5.75
0   11  19  0856 6
0   11  19  0856 6.25
0   11  19  0856 6.5
0   11  19  0856 6.75
15  11  19  0856 7
65  11  19  0911 7.25
5   11  19  1016 7.5
90  11  19  1021 7.75
65  11  19  1151 8
0   11  19  1256 8.25
5   11  19  1256 8.5
35  11  19  1301 8.75
    11  19  1336 9
EOF
```

Test 2

DOT

11/18/82 – 11/19/82

Figure 18a. - Test 2 - potentiometer readings on OmniData datapod and printed from OmniData reader. Approximately 6 inches of precipitation preload on the gage.

```
MO-DA-YR-HR:MN?11-18-82-13:41
Time for
[illegible]
    11  18  1721.25
5   11  18  1726.50
70  11  18  1836.75
45  11  18  19211.
30  11  18  19511.25
50  11  18  20411.5
65  11  18  21461.75
30  11  18  22162
30  11  18  22462.25
40  11  18  23262.5
35  11  19  00062.75
35  11  19  00413
10  11  19  00513.25
40  11  19  01313.5
65  11  19  02363.75
30  11  19  03064
30  11  19  03364.25
35  11  19  04114.5
15  11  19  04264.75
35  11  19  05015
35  11  19  05365.25
40  11  19  06165.5
0   11  19  06165.75
15  11  19  06316
55  11  19  07266.25
15  11  19  08416.5
15  11  19  08566.75
0   11  19  08567
0   11  19  08567.25
0   11  19  08567.5
0   11  19  08567.75
0   11  19  08568
80  11  19  10168.25
65  11  19  11218.5
30  11  19  11518.75
5   11  19  12569
0   11  19  12569.25
40  11  19  13369.5
0   11  19  13369.75
    EOF
```

Test 2

LVDT

11/18/82 - 11/19/82

13:3

Figure 18b. - Test 2 - LVDT readings on OmniData datapod and printed from OmniData reader. Approximately 6 inches of precipitation preload on the gage.

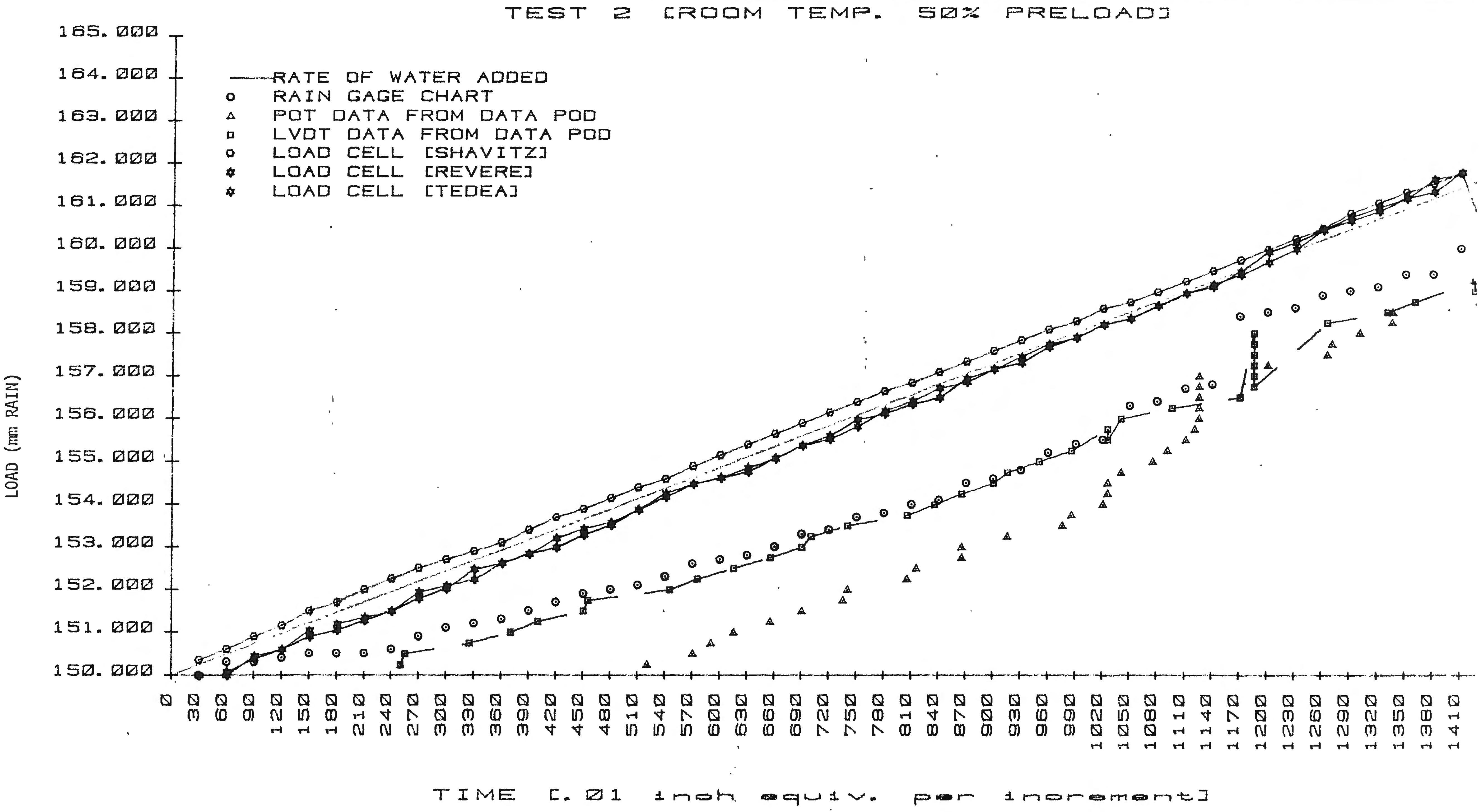
TEST 2 [ROOM TEMP. 50% PRELOAD]
RATE OF WATER ADDED
RAIN GAGE CHART
POT DATA FROM DATA POD
LVDT DATA FROM DATA POD
LOAD CELL [SHAVITZ]
LOAD CELL [REVERE]
LOAD CELL [TEDEA]
LOAD (mm RAIN)
165.000
164.000
163.000
162.000
161.000
160.000
159.000
158.000
157.000
156.000
155.000
154.000
153.000
152.000
151.000
150.000
0 30 60 90 120 150 180 210 240 270 300 330 360 390 420 450 480 510 540 570 600 630 660 690 720 750 780 810 840 870 900 930 960 990 1020 1050 1080 1110 1140 1170 1200 1230 1260 1290 1320 1350 1380 1410
TIME [.01 inch equiv. per increment]

Figure 19

```
MO-DA-YR-HR:MN?11-19-82-14:05

 11  19  1410.25
 11  19  1410.5
 11  19  1640.75
 11  19  16501
 11  19  17251.25
 11  19  18151.5
 11  19  19301.75
 11  19  19402
 11  19  20152.25
 11  19  21002.5
 11  19  21302.75
 11  19  21553
 11  19  22253.25
 11  19  22553.5
 11  19  23353.75
 11  19  23454
 11  20  00204.25
 11  20  00554.5
 11  20  01454.75
 11  20  01455
 11  20  02305.25
 11  20  03005.5
 11  20  03455.75
 11  20  04306
 11  20  04406.25
 11  20  05106.5
 11  20  06156.75
 11  20  06157
 11  20  06457.25
 11  20  07207.5
 11  20  07507.75
 11  20  08308
 11  20  08408.25
 11  20  09008.5
 11  20  10108.75
 11  20  10109
 11  20  11009.25
 11  20  11459.5
 11  20  12409.75
 11  20  125510
 11  20  133510.25
 11  20  140510.5
EOF
```

TEST 3

POT.
11/19 - 11/20/82

11/19/82 - 11/2

Figure 20a. - Test 3 - potentiomenter readings on OmniData datapod and printed from OmniData reader. Approximately 10 inches of precipitation preload on the gage.

```
MO-DA-YR-HR:MN?11-19-82-14:05

  11 19 1410 .25
  11 19 1410 .5
10 11 19 1600 .75
45 11 19 1645 1
50 11 19 1735 1.25
40 11 19 1815 1.5
30 11 19 1845 1.75
35 11 19 1920 2
40 11 19 2000 2.25
50 11 19 2050 2.5
30 11 19 2120 2.75
30 11 19 2150 3
10 11 19 2200 3.25
5 11 19 2250 3.5
55 11 19 2345 3.75
35 11 20 0020 4
5 11 20 0035 4.25
70 11 20 0115 4.5
35 11 20 0150 4.75
56 11 20 0245 5
55 11 20 0320 5.25
25 11 20 0345 5.5
55 11 20 0440 5.75
20 11 20 0500 6
55 11 20 0555 6.25
45 11 20 0640 6.5
5 11 20 0645 6.75
40 11 20 0725 7
20 11 20 0805 7.25
45 11 20 0850 7.5
40 11 20 0930 7.75
35 11 20 1005 8
35 11 20 1040 8.25
50 11 20 1130 8.5
25 11 20 1205 8.75
50 11 20 1255 9
35 11 20 1330 9.25
30 11 20 1400 9.5
EOF
```

Test 3

LVDT

11/19/82 – 11/2

Figure 20b. - Test 3 - LVDT readings on OmniData datapod and printed from OmniData reader. Approximately 10 inches of precipitation preload on the gage.

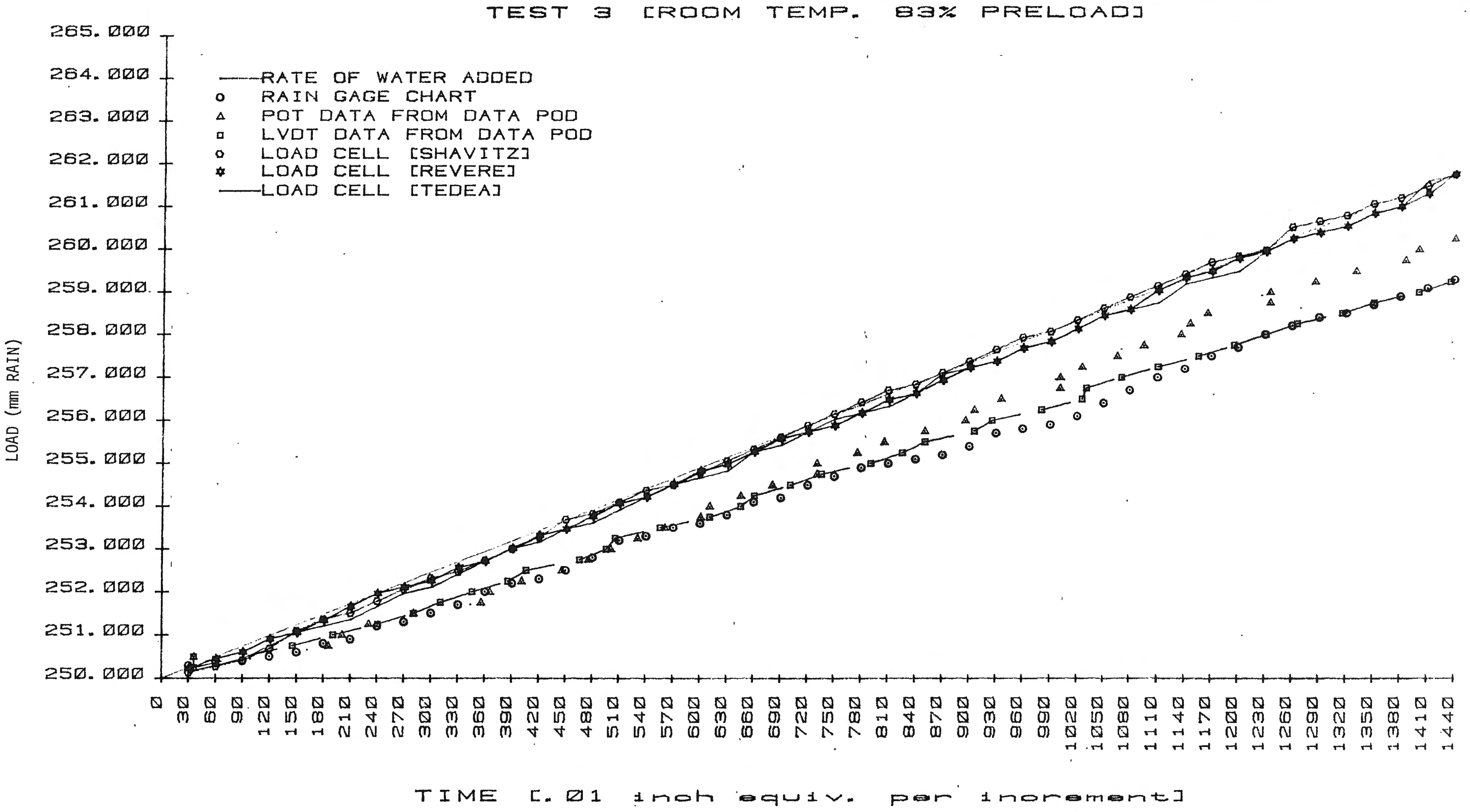
TEST 3 [ROOM TEMP. 83% PRELOAD]
RATE OF WATER ADDED
RAIN GAGE CHART
POT DATA FROM DATA POD
LVDT DATA FROM DATA POD
LOAD CELL [SHAVITZ]
LOAD CELL [REVERE]
LOAD CELL [TEDEA]
LOAD (mm RAIN)
265.000
264.000
263.000
262.000
261.000
260.000
259.000
258.000
257.000
256.000
255.000
254.000
253.000
252.000
251.000
250.000
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
600
630
660
690
720
750
780
810
840
870
900
930
960
990
1020
1050
1080
1110
1140
1170
1200
1230
1260
1290
1320
1350
1380
1410
1440
TIME [.01 inch equiv. per increment]

Figure 21

TESTS IN COLD ROOM

Test 4

Test 4 was the first test conducted with the equipment in the cold room. The test was started with no load on the precipitation gage. The precipitation gage with the same sensors mounted on it, as for tests 1, 2, and 3, was moved on a cart to the cold room in the laboratories. The temperature had been monitored and controls adjusted to hold a temperature nearly constant, near -20 °C (-4 °F). The actual temperature during the 24-hour test period varied between -20.6 °C (-5 °F) and -24.4 °C (-12 °F). The same sensors - precipitation gage, weight recorder, potentiometer, LVDT, and three load cells - were all mounted the same as in tests 1, 2, and 3. Test 4 was run for approximately 24 hours. Data from the potentiometer and LVDT were recorded on the OmniData International datapods and transposed to a printout using the Omnidata International datapod/cassette reader (figs. 22a and 22b). Data from the three load cells were recorded on Moseley chart recorders and then read using a magnifying comparator and recorded on a table. Data from all five sensors were plotted on a single sheet using the HP-9825 computer-plotter (fig. 23) to compare the response of each of the sensors.

The chart shows the precipitation gage recorder does not start to indicate adding weight until about 300 minutes after the start of the test. Adding fluid with the Masterflex pump at the rate of 1/2 mm/h would be 2.5 mm of precipitation before the gage started to indicate adding of precipitation. The LVDT sensor did not start to pick up weight for about 300 minutes, and the potentiometer did not start to indicate weight increase for about 600 minutes after the beginning of the test. The Schaevitz load cell followed the rate of adding fluid exactly. The Revere and Tedea load cell graphs showed high increases for about 300 minutes and then leveled off, arriving at the actual rate line after 24 hours of testing. The method of calibrating the load cells - measuring the load on the precipitation gage at the beginning and at the end of the test and comparing the total weight added with a total indication on each load cell - gave a calibration for each load cell. The records on the Moseley recorder charts for the load cells were generally very linear with small deviations. The small amount of total deviation in 24 hours for all of the three load cell records on the Moseley chart combined with reading individual points by eye with a comparator appears to be the reason for deviations shown on the comparative graphs. A digital readout using a computer averaging system as suggested early in the program could have given a better indication of the actual readout from the load cells. Using only a nearly constant temperature in the cold room did not allow the determination directly on load cell variation of temperature. Comparing the load cell records of test 1, 21.1 °C (70 °F) with test 4 -21.7 °C (-7 °F) showed the Revere and Tedea cells in the cold temperature had a higher rate of increase at the beginning of the cold room test than for the warm temperature test. The Revere and Tedea cells are off center load-type cells. The Schaevitz is a center load cell. The Schaevitz record followed the actual loading line very closely.

```
MO-DA-YR-HR:MN?11-23-8207:20
MO-DA-YR-HR:MN?11-23-82-07:20


11  23  0725 .25
11  23  0725 .5
11  23  0725 .75
11  23  0725 1
11  23  0725 1.25
11  23  0725 1.5
11  23  0725 1.75
11  23  0725 2
11  23  1720 2.25
11  23  1830 2.5
11  23  1840 2.75
11  23  1925 3
11  23  2000 3.25
11  23  2040 3.5
11  23  2125 3.75
11  23  2155 4
11  23  2240 4.25
11  23  2320 4.5
11  24  0000 4.75
11  24  0045 5
11  24  0045 5.25
11  24  0205 5.5
11  24  0210 5.75
11  24  0240 6
11  24  0315 6.25
11  24  0400 6.5
11  24  0425 6.75
11  24  0455 7
11  24  0525 7.25
11  24  0600 7.5
11  24  0625 7.75
11  24  0635 8
11  24  0705 8.25
~~11  24  0750~~
~~11  24  0805~~
~~11  24  0845~~
EOF
```

POT TEST

Empty
COLD Rm
11/23 - 11/24/82

EMP

7:20 - 11/

7:20 - 11/

Figure 22a. - Test 4 - potentiometer readings from OmniData datapod and printed by OmniData reader. Zero preload on precipitation gage.

```
FMT  03.
PRO   13.   11 .   12.    05.    14.    02.    03.
EOL  OD.    8A.    FF.    FF.    FF.    FF.    FF.
EOF  45.    4F.    46.    OD.    8A.    FF.    FF.
BYT  01.
NCH  01.

MO-DA-YR-HR:MN?11-23-82-07:20


11  23  0725 .25
11  23  0725 .5
11  23  1220 .75
11  23  1255 1
11  23  1340 1.25
11  23  1430 1.5
11  23  1505 1.75
11  23  1550 2
11  23  1630 2.25
11  23  1715 2.5
11  23  1750 2.75
11  23  1825 3
11  23  1905 3.25
11  23  1940 3.5
11  23  2025 3.75
11  23  2100 4
11  23  2140 4.25
11  23  2215 4.5
11  23  2305 4.75
11  23  2350 5
11  24  0015 5.25
11  24  0050 5.5
11  24  0125 5.75
11  24  0210 6
11  24  0245 6.25
11  24  0325 6.5
11  24  0355 6.75
11  24  0435 7
11  24  0505 7.25
11  24  0545 7.5
11  24  0610 7.75
11  24  0620 8
11  24  0655 8.25
11  24  0735 8.5
~~11  24  0800~~
~~11  24  0845~~
EOF
```

LVDT TES
Emp

Figure 22b. - Test 4 - LVDT readings from OmniData datapod and printed by OmniData reader. Zero preload on precipitation gage.

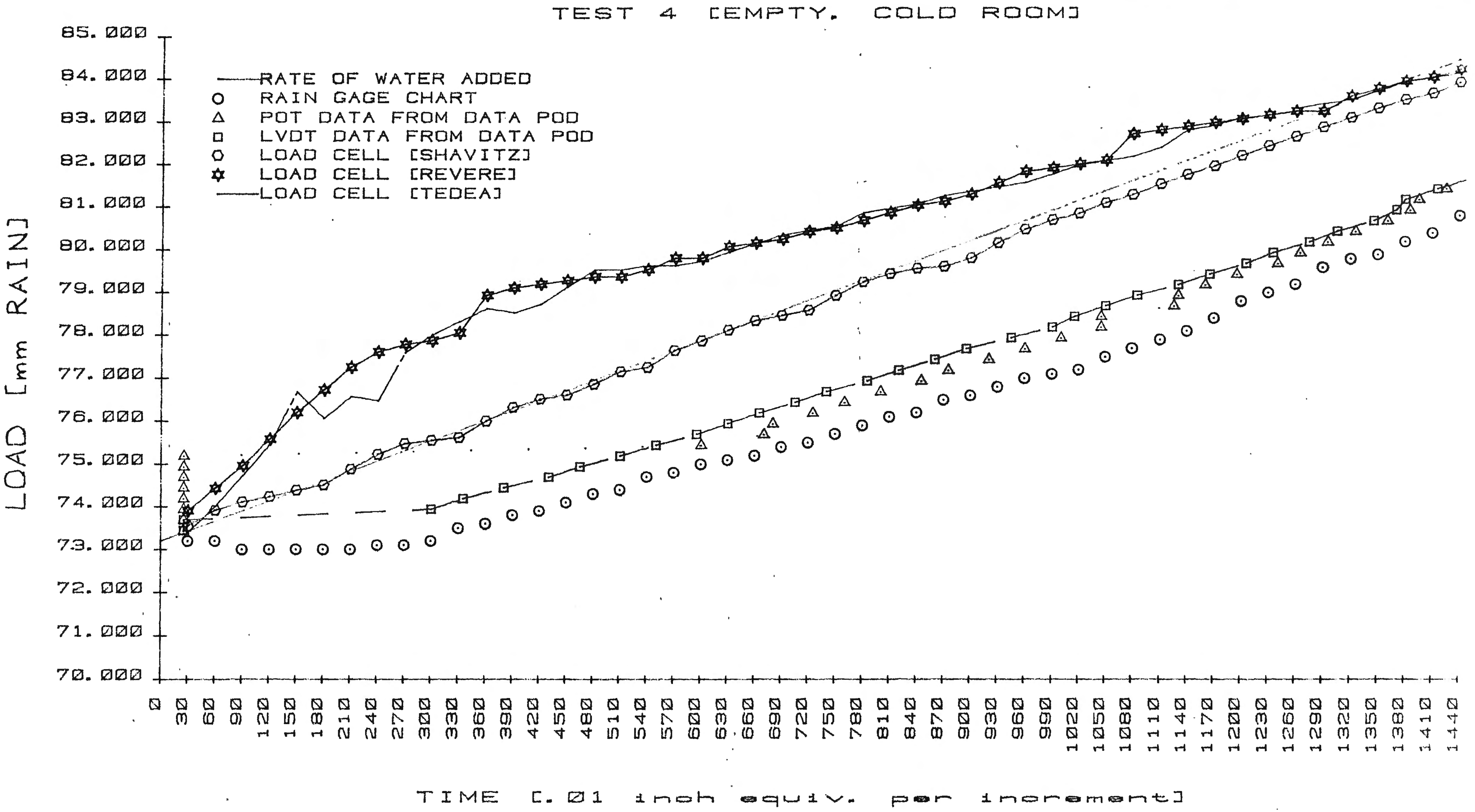
TEST 4 [EMPTY, COLD ROOM]
LOAD [mm RAIN]
85.000
84.000
83.000
82.000
81.000
80.000
79.000
78.000
77.000
76.000
75.000
74.000
73.000
72.000
71.000
70.000
RATE OF WATER ADDED
○ RAIN GAGE CHART
△ POT DATA FROM DATA POD
□ LVDT DATA FROM DATA POD
○ LOAD CELL [SHAVITZ]
✡ LOAD CELL [REVERE]
LOAD CELL [TEDEA]
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
600
630
660
690
720
750
780
810
840
870
900
930
960
990
1020
1050
1080
1110
1140
1170
1200
1230
1260
1290
1320
1350
1380
1410
1440
TIME [.01 inch equiv. per increment]

Figure 23

Test 5

Test 5 was conducted in the cold room, the same as test 4, except the precipitation gage platform was preloaded to about 50 percent of its rated capacity. The same sensors: precipitation gage weight recorder, potentiomenter, LVDT, and three load cells were all mounted the same as for test 4. During the 24-hour test, the temperature varied between -20.0 and -23.9 °C (-4 and -11 °F). Data from the potentiometer and LVDT were recorded on two OmniData International datapods and transposed to a printout using the OmniData International datapod/cassette reader (figs. 24a and 24b). Data from the three load cells - Tedea, Revere, and Schaevitz - were recorded on the Moseley chart recorders. Individual points were read from individual graphs using a magnifying comparator and recorded by hand on a table. The precipitation gage chart recorder was operated as in all previous tests with the lever arm pen recording on the drum chart.

Data from all six sensors were plotted on a single sheet using the HP-9825 computer-plotter (fig. 25). The precipitation gage recorder, potentiometer, and LVDT did not start recording weight increase until considerable time had elapsed after the beginning of the test - 125 minutes for the LVDT, 150 minutes for the precipitation gage, and 220 minutes for the potentiometer. The Schaevitz load cell recorder followed the exact graph of antifreeze fluid addition very closely with only small deviations. The plotted record for the Revere and Tedea load cells showed a more erratic record compared to the exact rate feedline than for the tests conducted at room temperature. This error could be due to the very small part of the chart used and because of the sensitivity and zero adjustments possible on the Moseley chart recorders. A more accurate pickup with digital readout using an averaging system would have given a more accurate record. Fluid addition in the 24-hour period was equivalent to 12.06 mm of precipitation.

Test 6

Test 6 was conducted in the cold room, the same as tests 4 and 5, except test 6 was started with the precipitation gage platform preloaded to about 89 percent of the gage capacity. Tests 4, 5, and 6 thereby covered approximately the full-load range of the gage. The same sensors: precipitation gage recorder, potentiometer, LVDT, and three load cells were mounted the same as for tests 1 through 5. Data from the potentiometer and LVDT were recorded on datapods and transposed to a printout using the OmniData International reader (figs. 26a and 26b). During the 24-hour test period, the temperature varied between -21.1 and -23.3 °C (-6 and -10 °F) with the temperature at one brief period going to a -25.3 °C (-13.5 °F). Data for all six sensors were recorded the same as in test 5 and plotted using the HP-9825 computer-plotter (fig. 27). The precipitation gage weight recorder started 30 minutes after the start of the test. The LVDT started recording only after 265 minutes had elapsed, and the potentiometer started recording only after 755 minutes had elapsed. There were jumps in the records of both the potentiometer and LVDT data. The graph of the precipitation gage recorder was steady with small deviations, but the slope of the record was somewhat flatter than the slope of the exact feed rate. The Schaevitz load cell followed the feed rate closer than the Revere and Tedea load cells. The Moseley recorder charts showed that some step deviations for the Tedea and

```
                 11-
MO-DA-YR-HR:MN?11-24-82-09:23


11  24  1303 .25
11  24  1348 .5
11  24  1428 .75
11  24  1453 1
11  24  1513 1.25
11  24  1558 1.5
11  24  1628 1.75
11  24  1653 2
11  24  1743 2.25
11  24  1828 2.5
11  24 .1828 2.75
11  24  1928 3
11  24  2043 3.25
-11  24  2113 3.5
11  24  2228 3.75
11  24  2248 4
11  24  2328 4.25
11  24  2353 4.5
11  25  0033 4.75
11  25  0058 5
11  25  0153 5.25
11  25  0223 5.5
11  25  0253 5.75
11  25  0303 6
11  25  0338 6.25
11  25  0423 6.5
11  25  0448 6.75
11  25. 0503 7
11  25  0553 7.25
11  25  0628 7.5
11  25  0658 7.75
11  25  0728 8
11  25  0813 8.25
11  25  0853 8.5
EOF
```

TEST 5

P07

11/24 - 11/25/82

Figure 24a. - Test 5 - potentiometer readings on OmniData datapod and printed from OmniData reader. Approximately 6 inches of precipitation preload on the gage.

```
MO-DA-YR-HR:MN?11-24-82-09:23

11 24 1128.25
11 24 1208.5
11 24 1258.75
11 24 1343 1
11 24 1443 1.25
11 24 1503 1.5
11 24 1533 1.75
11 24 1558 2
11 24 1653 2.25
11 24 1733 2.5
11 24 1803 2.75
11 24 1828 3
11 24 1913 3.25
11 24 2013 3.5
11 24 2038 3.75
11 24 2228 4
11 24 2248 4.25
11 24 2323 4.5
11 25 0008 4.75
11 25 0043 5
11 25 0108 5.25
11 25 0148 5.5
11 25 0223 5.75
11 25 0253 6
11 25 0323 6.25
11 25 0403 6.5
11 25 0443 6.75
11 25 0503 7
11 25 0543 7.25
11 25 0623 7.5
11 25 0653 7.75
11 25 0728 8
11 25 0743 8.25
11 25 0833 8.5
11 25 0908 8.75
EOF
MO-DA-YR-HR:MN?
```

TEST 5

LVDT

11/24 – 11/25/82

Figure 24b. - Test 5 - LVDT readings on OmniData datapod and printed from OmniData reader. Approximately 6 inches of precipitation preload on the gage.

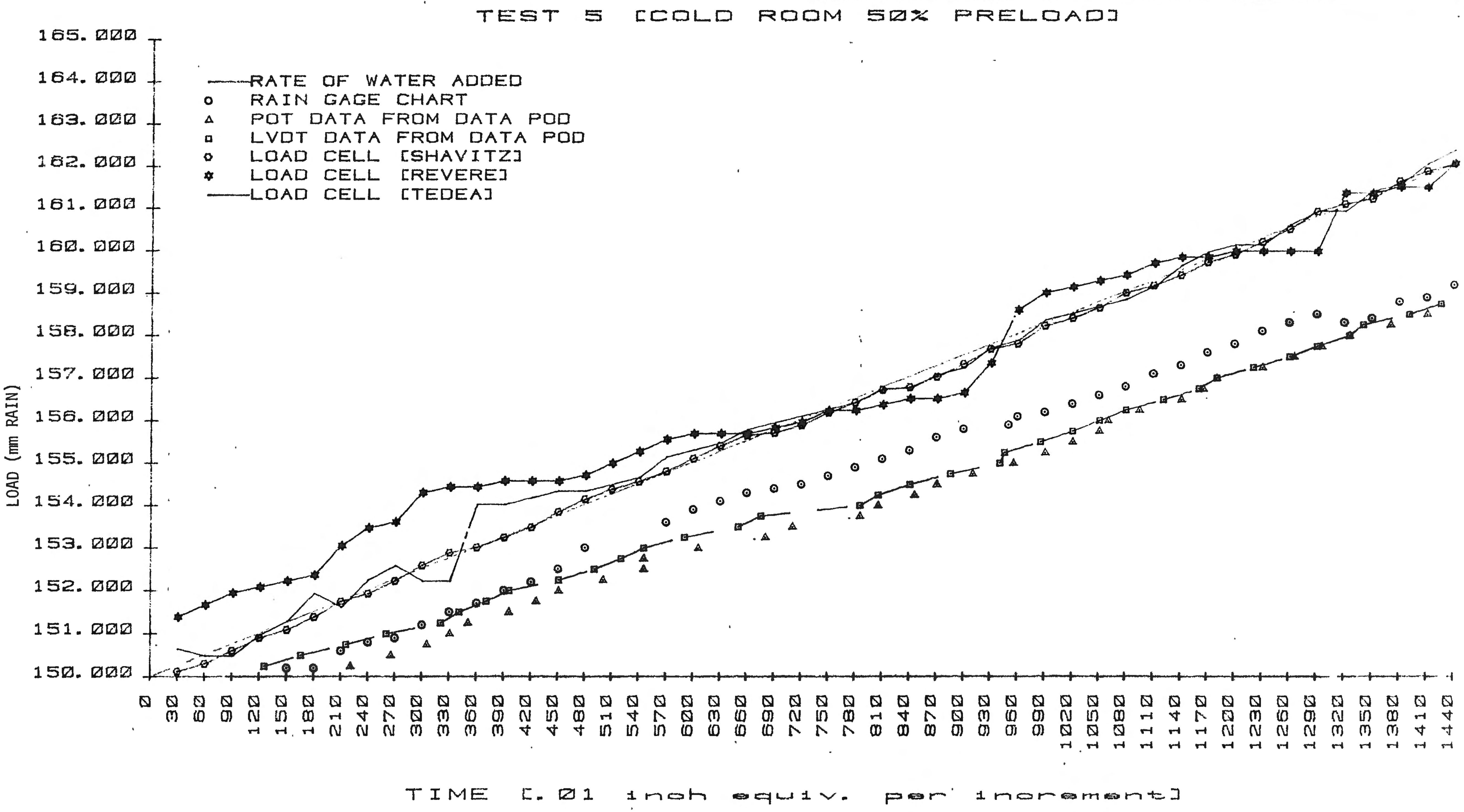
TEST 5 [COLD ROOM 50% PRELOAD]
RATE OF WATER ADDED
RAIN GAGE CHART
POT DATA FROM DATA POD
LVDT DATA FROM DATA POD
LOAD CELL [SHAVITZ]
LOAD CELL [REVERE]
LOAD CELL [TEDEA]
LOAD (mm RAIN)
165.000
164.000
163.000
162.000
161.000
160.000
159.000
158.000
157.000
156.000
155.000
154.000
153.000
152.000
151.000
150.000
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
600
630
660
690
720
750
780
810
840
870
900
930
960
990
1020
1050
1080
1110
1140
1170
1200
1230
1260
1290
1320
1350
1380
1410
1440
TIME [.01 inch equiv. per increment]

Figure 25

```
MO-DA-YR-HR:MN?11-25-82-10:16


11  25  2251 .25
11  25  2316 .5
11  26  0001 .75
11  26  0046 1
11  26  0106 1.25
11  26  0136 1.5
11  26  0141 1.75
11  26  0306 2
11  26  0311 2.25
11  26  0356 2.5
11  26  0421 2.75
11  26  0536 3
11  26  0541 3.25
11  26  0606 3.5
11  26  0641 3.75
11  26  0716 4
11  26  0746 4.25
11  26  0816 4.5
11  26  0836 4.75
11  26  0926 5
11  26  0936 5,25
11  26  1016 5.5
EOF
```

Test 6
DOT
11/25 - 11/26/82

Figure 26a. - Test 6 - potentiometer readings on OmniData datapod and printed from OmniData reader. Approximately 10.7 inches of precipitation preload on the gage.

```
MO-DA-YR-HR:MN?11-25-82-10:16


11  25  1441 .25
11  25  1516 .5
11  25  1556 .75
11  25  1646 1
11  25  1741 1.25
11  25  1811 1.5
11  25  1841 1.75
11  25  1906 2
11  25  2046 2.25
11  25  2121 2.5
11  25  2141 2.75
11  25  2231 3
11  25  2321 3.25
11  26  0006 3.5
11  26  0101 3.75
11  26  0126 4
11  26  0206 4.25
11  26  0306 4.5
11  26  0326 4.75
11  26  0421 5
11  26  0526 5.25
11  26  0606 5.5
11  26  0626 5.75
11  26  0716 6
11  26  0751 6.25
11  26  0821 6.5
11  26  0901 6.75
11  26  0921 7
EOF
```

Test 6

LVDT

11/25/82 - 11/26/82

Figure 26b. - Test 6 - LVDT readings on OmniData datapod and printed from OmniData reader. Approximately 10.7 inches of precipitation preload on the gage.

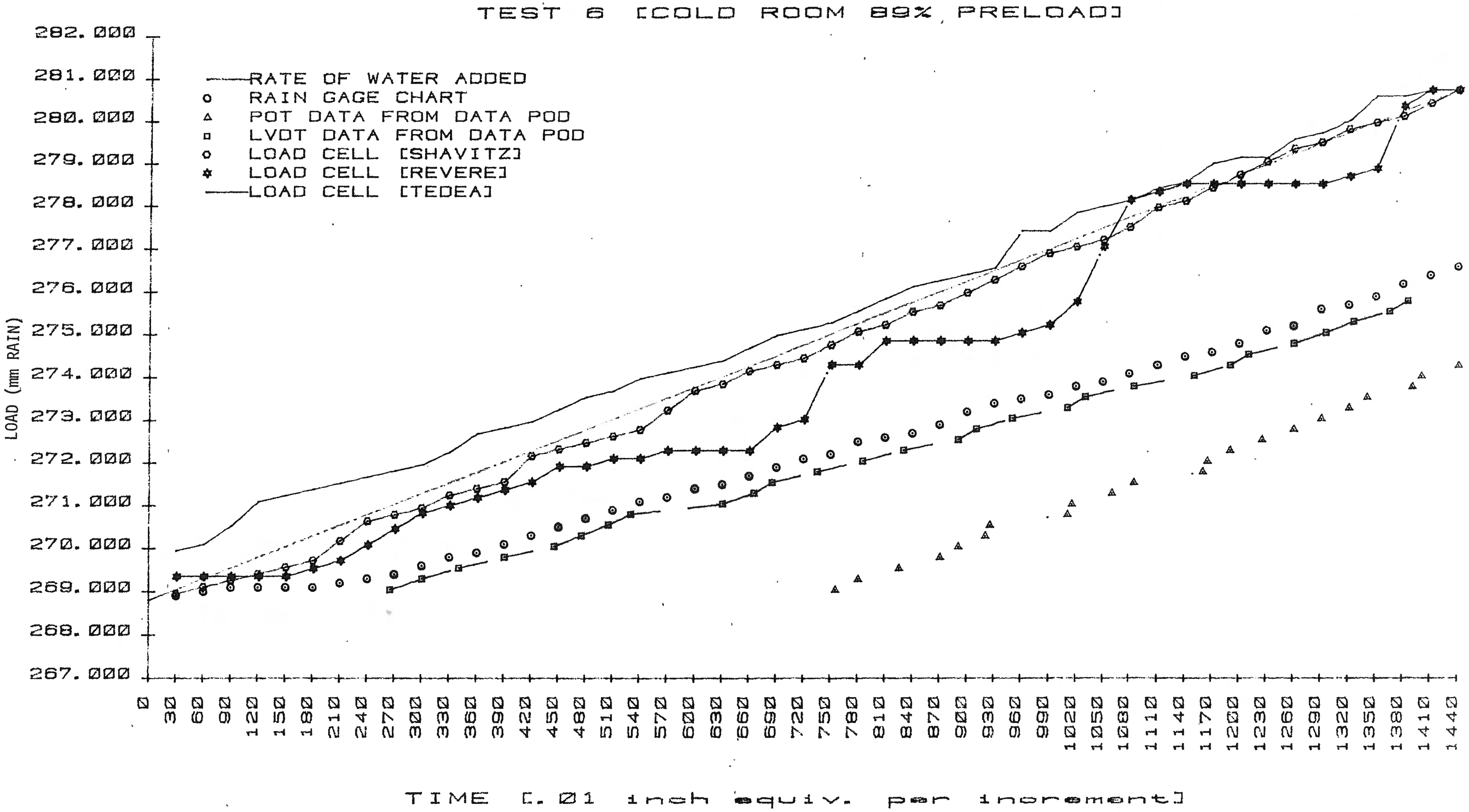
TEST 6 [COLD ROOM 89% PRELOAD]
RATE OF WATER ADDED
RAIN GAGE CHART
POT DATA FROM DATA POD
LVDT DATA FROM DATA POD
LOAD CELL [SHAVITZ]
LOAD CELL [REVERE]
LOAD CELL [TEDEA]
LOAD (mm RAIN)
282.000
281.000
280.000
279.000
278.000
277.000
276.000
275.000
274.000
273.000
272.000
271.000
270.000
269.000
268.000
267.000
0
30
60
90
120
150
180
210
240
270
300
330
360
390
420
450
480
510
540
570
600
630
660
690
720
750
780
810
840
870
900
930
960
990
1020
1050
1080
1110
1140
1170
1200
1230
1260
1290
1320
1350
1380
1410
1440
TIME [.01 inch equiv. per increment]

Figure 27

Revere load cells occurred and the record of the Schaevitz load cell was fairly smooth. Whether the deviations were due entirely to the load cells or due to the Moseley recorder is difficult to determine. The recorder charts would give a much better record if they could cover a wider part of the chart, but this was impossible with the very low rate of feed and the sensitivity and zero adjustment of the recorders. The total weight of fluid (antifreeze) added in the 24-hour period of the test was equivalent to approximately 12 mm of precipitation.