Report No. NA-69-8
(DS-69-3)

FINAL REPORT

Project No. 510-003-07X

FRICTION EFFECTS OF RUNWAY GROOVES, RUNWAY 4R-22L JOHN F. KENNEDY INTERNATIONAL AIRPORT - PHASE II

AD 692075

JULY 1969

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

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for

AIRCRAFT DEVELOPMENT SERVICE

July 1969

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DEPARTMENT OF TRANSPORTATION
Federal Aviation Administration
National Aviation Facilities Experimental Center
Atlantic City, New Jersey 08405

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ABSTRACT

Wet and dry runway friction tests were conducted on concrete Runway 4R-22L at John F. Kennedy International Airport, New York City, using a Fixed Slip Runway Friction Tester. These tests were conducted to determine if significant friction increases or decreases were generated as a result of transversely grooving the runway surface with 3/8-inch-wide, 45°, V-shaped grooves, having a 1 3/8-inch pitch. Data analysis indicates that at the test speeds of 50 and especially 60 mi/h, an appreciable increase in overall wet runway friction values due to grooving was obtained for these series of tests. In addition, the treatment of the runway surface by the cutting of uniformly spaced grooves markedly smoothed the resultant wet runway friction values. The chemical removal of rubber from the touchdown area of the 22 end of the ungrooved runway substantially improved the friction values of this end compared to those of the untreated 4 end.

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INTRODUCTION

Purpose

The purpose of this phase of the project was to measure the brake slip friction value of Runway 4R-22L at John F. Kennedy (JFK) International Airport, New York City, before and after runway grooving. These tests were conducted using the Federal Aviation Administration (FAA) Fixed Slip Runway Friction Tester (FSRFT).

Background

Commercial jet transport aircraft have generally experienced more difficulty in stopping on wet runways than propeller-driven aircraft. This is due mainly to their higher landing speeds and lower aerodynamic drag.

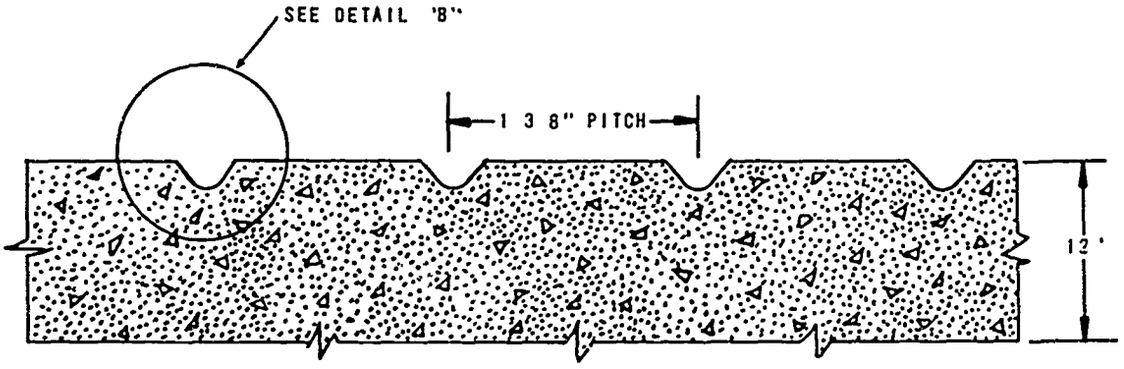
In the interest of safety, the Port of New York Authority (PNYA), in 1965 undertook a program for improving surface conditions of its runways. The initial PNYA approach was a rubber removal program for the runways at JFK International Airport. This approach developed into a periodic program of chemically cleaning the rubber-contaminated touchdown areas, using a blend of cresylic acid, benzene, and synthetic wetting detergents.[1] Because of the heavy volume of traffic, the rubber accumulations in the general touchdown area reappeared in very short order, necessitating frequent rubber removal treatment.

In the fall of 1966, the PNYA decided to groove JFK instrument Runway 4R-22L. This decision was influenced by the favorable report received from the FAA, the National Aeronautics and Space Administration (NASA), the United Kingdom, and the California Road Department. The PNYA engineers expressed concern over runway loading on this concrete runway. Subsequently, a rounded V-shaped groove pattern was specified (Figure 1). This groove configuration was chosen to minimize stress concentrations normally found in sharp-edged groove patterns. The entire runway length of 8400 feet and 140 feet of the 150-foot runway width was transversely grooved with this groove configuration, omitting only those concrete slabs containing the centerline and touchdown lighting systems. The contract effort to groove this runway began in May 1967 and was completed in August 1967.

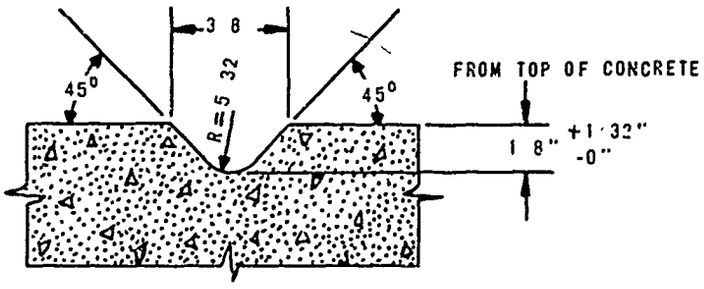
Description of Equipment:

Friction Tester - The equipment used to measure runway friction was the FAA's FSRFT (Figure 2) which is a modified Swedish Skiddometer, Model BV-6. The Skiddometer operates in a fixed slip

[1] Department of Transportation, Federal Aviation Administration Advisory Circular, AC No. AC150/5380-3 dated June 28, 1968



TYPICAL SURFACE SECTION A-A



DETAIL - "B"

FIG. 1 JFK RUNWAY 4R-22L GROOVE CONFIGURATION

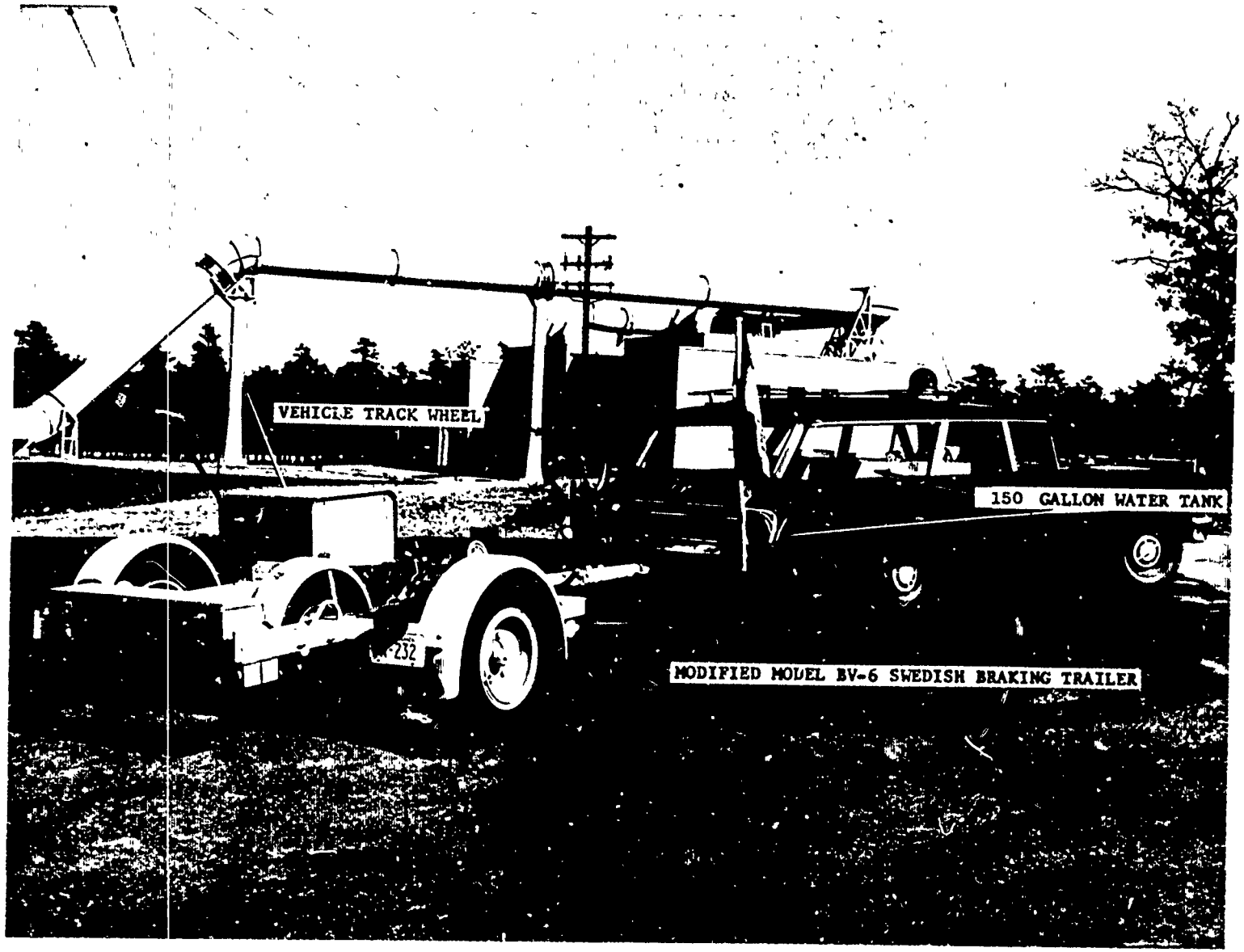


FIG. 2 FAA's FIXED SLIP RUNWAY FRICTION TESTER AND TOWING VEHICLE

mode and was originally conceived by the National Swedish Road Research Institute for the purpose of measuring the friction values of snow and ice-covered runways. This friction tester utilizes the standard automotive test tire and loading, as specified by the American Society of Testing Material (ASTM) for friction testing.

This tester was used in a different manner than that prescribed by the National Swedish Road Research Institute; namely, to measure friction of wet and dry runway surfaces. To accomplish this, the project engineering personnel of the National Aviation Facilities Experimental Center (NAFEC) designed and installed a special water dispensing system (Figure 3). This design incorporated a belt-driven constant displacement water pump coupled to the axle of the FSRFT. The output of the pump varies directly with speed thereby providing a constant water thickness independent of vehicle speed. A water thickness of approximately .020 inch was obtained, meeting the ASTM Specification E-274 which states that a water depth of .020 ±.005 inch be used when measuring wet pavement friction. The pump is operated by means of a magnetic clutch, powered and controlled from the tow vehicle. During friction measuring operations, the magnetic clutches of the three-wheel axle are engaged (locked) thus forcing the test wheel to rotate with the same angular speed as the two outer wheels. Since the diameter of the test tire is smaller than the diameter of the outer tires, the peripheral speed of the test tire becomes less than that of the outer tires. Thus, the design causes the test tire to be retarded, generating a tire/pavement slipping action. This action produces a constant slip ratio of approximately 13 percent. Slip ratio is defined as the ratio of the difference between the vehicle speed and the test tire speed divided by the vehicle speed times 100. The action of the friction forces between the test tire and runway surface produces a torque on the test wheel which is measured by the test wheel strain gage transducer.

The water dispensing system and friction recording system are separately and remotely controlled by the operator in the tow vehicle enabling, first, dry testing, followed by wet testing over the desired test path. When the water dispensing system is activated, a water film approximately .020-inch thick is deposited on the pavement surface 18 inches ahead of the test tire, thus providing conditions for wet testing.

Instrumentation - The friction forces exerted on the test wheel are registered by a pen recorder (Figure 4). The recorder and associated electrical equipments are located in an instrument cabinet mounted on the frame of the trailer. The readout on the chart paper is traced in analog format and the displacement of the pen provides a numerical value known as "Brake Friction Number" (BFN_{13}). This

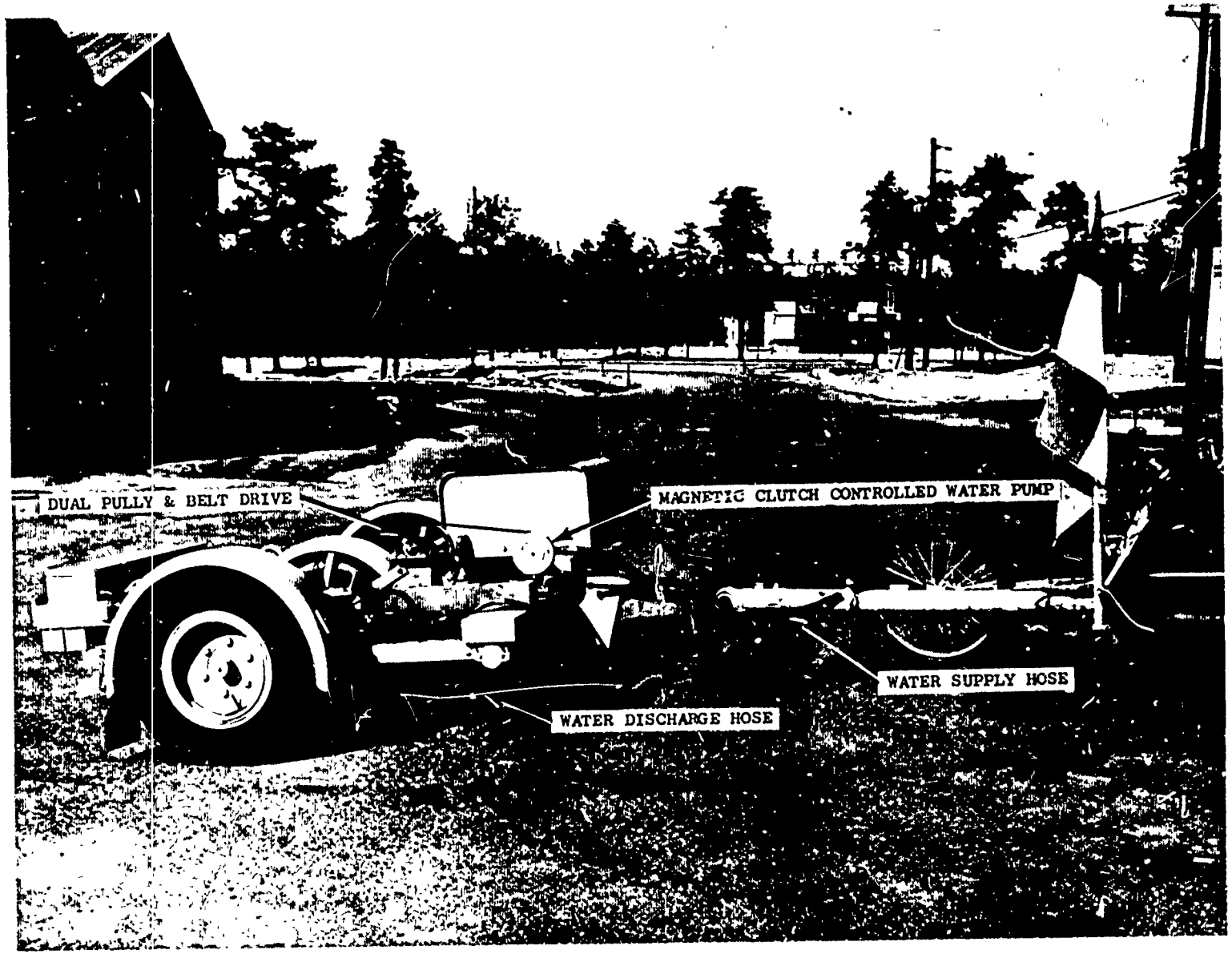


FIG. 3 WATER DISPENSING SYSTEM

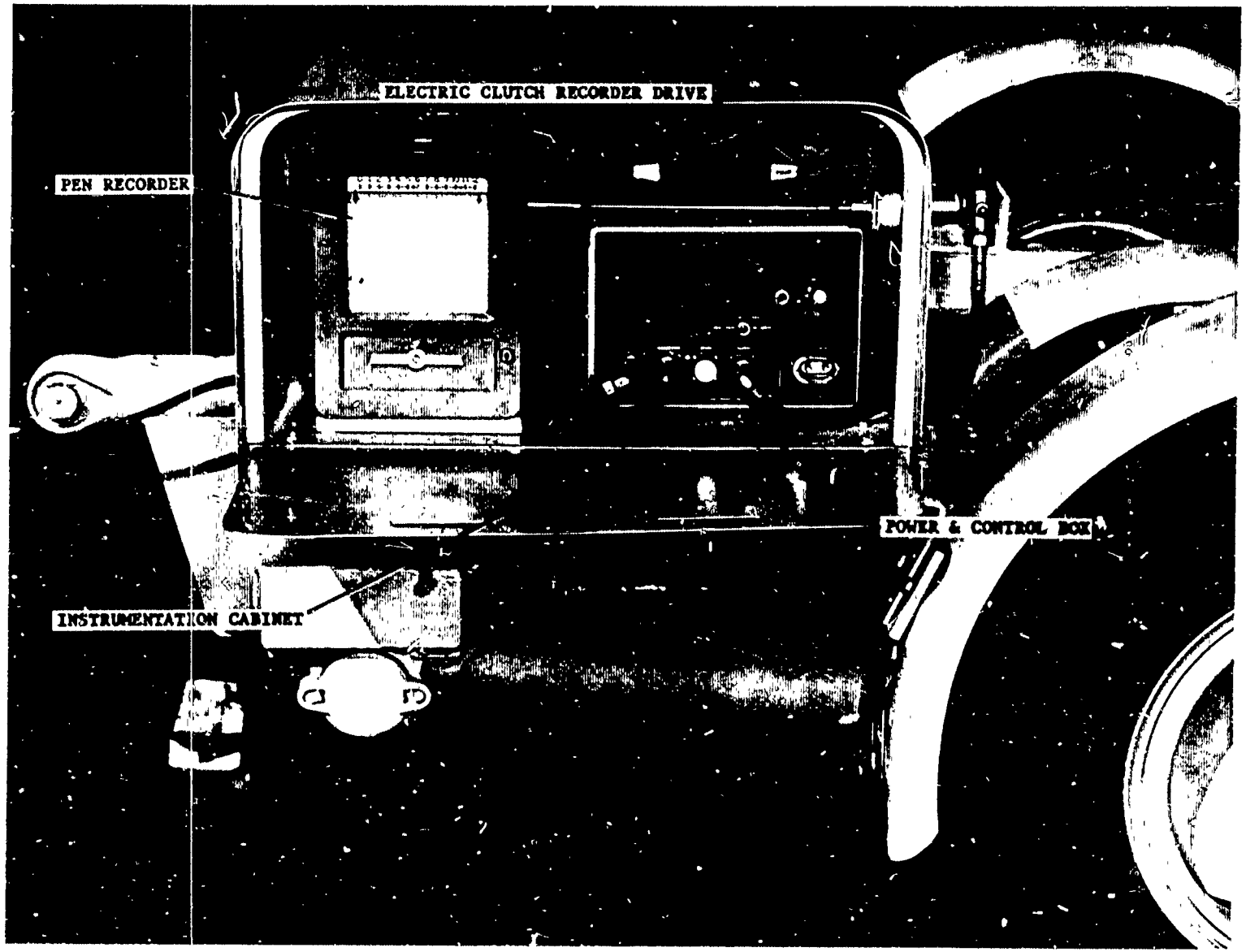


FIG. 4 INSTRUMENTATION CABINET AND RECORDER

value is the measured coefficient of friction times 100, obtained by testing in the brake slip mode at 13 percent slip. The recorder has a combination electric chart paper drive which is used during calibration, and a mechanical external chart paper drive for recording friction.

The mechanical drive consists of a flexible cable connected to the left outer trailer wheel. This arrangement produces chart paper lengths proportional to the distance tested - independent of test speed. Each vertical subdivision of chart paper length is equal to approximately 77 2/3 feet of runway distance and each horizontal line represents an uncorrected BFN_{13} value of 1, full scale represents a BFN_{13} value of 120. The recorder is also equipped with an electric timer which provides a pip at 1-second intervals. This pip is recorded by a pen on the margin of the chart paper. The distance between pips facilitates verifying the speed of the tester.

Test Tire - The friction measuring tire used in these tests was developed by the ASTM to provide a standard test tire which is manufactured to closely held specifications. The tire, designated by ASTM as E-249, was specifically designed for pavement friction measuring. This four-ply tire is a standard automotive size (7.50/14) which is inflated to a specified pressure of 24 psi and vertically loaded to 1085 pounds. A smooth tread configuration (no circumferential grooves) was used to eliminate variances in friction due to wearing tire tread and groove depth.

Towing Vehicle - The vehicle provided for towing the Skiddometer was a late model station wagon. This automobile is equipped with a constant speed device, a two-way radio (for airport communications) and a specially built 150-gallon capacity water tank. This amount of water is sufficient to wet 20,000 linear feet of pavement. The gross weight of the vehicle, with two operators and a full tank of water, totaled approximately 4500 pounds. When towing the 3400-pound FSRFT with the test wheel in the braking mode, the top speed of the system was limited to slightly over 60 mi/h. Acceleration was also affected, and 50 mi/h was the maximum speed within 1000 feet.

Test Methods and Procedures:

Calibration - Prior to each series of test runs, the FSRFT was calibrated (Figure 5). This calibration was accomplished by applying known horizontal loads to the platform of the calibration stand. The horizontal forces are transmitted to the contact area of the tire resting on the platform. The dynamometer reading was related to the displacement of the recorder pen which recorded the uncorrected

FIG. 5 CALIBRATION EQUIPMENT

coefficient of friction (BFN). Repeated calibrations provided information from which system accuracy and/or deterioration would be observed.

Runway Pattern and Nomenclature - The test pattern used on the 8400-foot runway consisted of four test tracks or paths (Figure 6). One thousand feet at each end of the runway were reserved for accelerating and stopping; the remaining 6400 feet were friction tested. Track No. 1 is located 3 feet southeast of the runway centerline, to clear centerline paint marks, and all runs on Track No. 1 were made in the 4 or northeasterly direction. Track No. 2 is located 7 feet from the southeast edge of the runway, and tests on this track were conducted in the 22 or southwesterly direction. Test runs on Track No. 3 were conducted in the 4 direction, 55 feet from the northwest edge of the runway (20 feet northwest of the centerline), while tests on Track No. 4 were made in the 22 direction and 55 feet from the southeast edge of the runway (20 feet southeast of centerline). Track Nos. 1, 3, and 4 provided data of the most contaminated portion of the runway, while Track No. 2 (runway edge) provided data on the least contaminated portion of the runway. This test design allows a comparison to be made between the rubber-contaminated (touchdown and rollout area) portions of the runway and the relatively uncontaminated portion along the runway edge.

Test Runs - Twenty-four standard test runs were made on each of the four tracks. Of these runs, 12 were made in a dry condition (without use of the water dispensing system) at 10, 30, and 50 mi/h, followed by 12 wet runs at the same speeds. At the completion of the 24th run, 6 additional higher speed wet test runs were made at 60 mi/h, 1 on each track, and 2 extra runs off the standard test track pattern. These high speed runs, however, required an additional 500 feet for acceleration, thereby reducing the test portion of the runway by an equal amount. Sixty miles per hour was the highest test speed obtainable with the limited horsepower available in the tow vehicle.

DISCUSSION

Friction Tests

Friction measurement tests were made on two occasions, one of which was conducted before the runway was grooved and one after. Before-grooving tests were compared directly with after-grooving tests as the environmental conditions were very similar. The ambient temperature during the pregrooving test was 47°F, and the temperatures during the postgrooving tests varied from 40° to 43°F. Visual inspection of the four test tracks disclosed heavy deposits of tire rubber predominately at the 1500-foot 4R end of Tracks 1, 3, and 4. Track 2, the runway

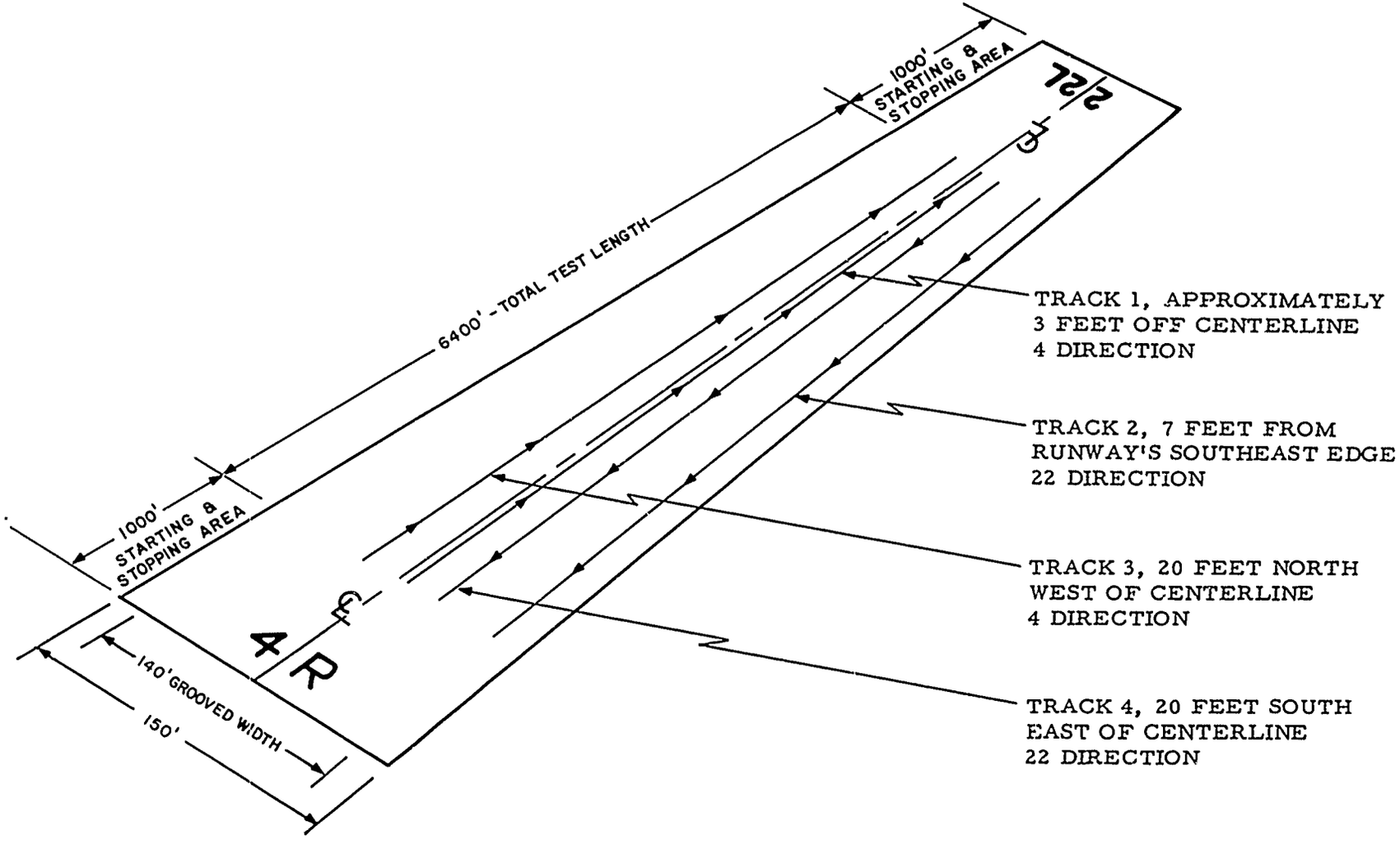


FIG. 6 RUNWAY 4R-22L TEST TRACK CONFIGURATION

southeast edge, was found to be relatively uncontaminated by rubber deposits as well as the 22L end which was treated for rubber removal 5 days prior to the before-grooving tests conducted on April 26, 1967.

Dry Runway Surface Friction Tests: By comparing the before-grooving tests conducted on April 26, 1967, with the after-grooving tests conducted on December 5, 1967, the following results are noted by the test data shown in the Appendix:

Track 1 (centerline) - The BFN_{13} values for the postgrooving dry tests indicate a slight increase in friction values over the pregrooving values, pages 1-2 and 1-3. The values for the wet tests, pages 1-4 and 1-5, indicate a substantial increase in friction values at the higher test speeds of 50 and 60 mi/h. It is noted that the postgrooving analog friction traces are markedly smoother than the pregrooving traces.

Track 2 (southeast runway edge) - Since this track is near the edge of the runway and relatively free of rubber deposits and the polishing action of traffic, it would be expected that any friction value changes would be caused mainly by the grooves and that this portion of the runway would represent the original surface conditions exposed to the environment. As noted in the previous track, a slight increase in friction due to grooving is noted for the dry tests, pages 1-6 and 1-7; whereas a substantial increase is again noted especially for the higher 50- and 60-mi/h test speeds, pages 1-8 and 1-9. The slightly lower friction values for the 30-mi/h wet test are unexplainable except possibly due to seasonal friction effects, the thermodynamics of friction testing and/or the cooling effects of the test water on the tire. A definite smoothing of the postgrooving traces is noted.

Track 3 (20 feet northwest of centerline) - The test data for this track, pages 1-10 through 1-13, show a slight decrease in postgrooving friction values except for the high speed 60-mi/h tests. Again, the before-grooving analog friction traces are not as smooth as the after-grooving traces.

Track 4 (20 feet southeast of centerline) - Track 4 is the counterpart of Track 3 and produces friction data somewhat similar. This is borne out by an analysis of the data, pages 1-14 through 1-17, except that the 30- and 50-mi/h after-grooving friction values offer a substantial increase over the before-grooving values in addition to the 60-mi/h increase.

Miscellaneous Test Runs - These extra 60-mi/h wet tests were conducted to provide additional data outside the test track area.

Analysis of the ungrooved runway data for the test paths 30 feet each side of the centerline, shown in the Appendix, pages 1-18, indicates that they are very similar to the data produced at the runway edge, shown in page 1-8. This indicates that the heavily rubber-contaminated areas do not extend as far as 30 feet from the runway centerline.

The data for the postgrooving test runs, 5 feet each side of the centerline, shown in the Appendix, page 1-19, indicate a marked similarity to the adjacent 60-mi/h data for Test Tracks 1, 3, and 4, shown in page 1-5, 1-13, and 1-17, respectively.

Calibration

The analysis of the calibration records made prior to each series of tests and past records indicates that this tester produces calibration results of less than ±3 percent deviation.

SUMMARY OF RESULTS

In summary, these friction tests indicate that at test speeds from 50 to 60 mi/h, and with the test tire loading and pressure inherent in this friction measuring system, a significant increase in wet runway friction values, due to these grooves, was observed. Markedly smoother wet runway friction traces were obtained after grooving as compared to the pregrooved data. It is evident from the data that uniform spacing of grooves has created an equalizing effect which, in turn, produced a more uniform friction surface. By grooving a runway and reducing the magnitude and the amount of the fluctuations in friction coefficient, it is hypothesized that more effective aircraft braking is produced. The smaller and fewer changes in friction should generate smaller fluctuations in braking forces, and the higher friction values indicated by test results at 50 and 60 mi/h will result in shorter stopping distances. Most aircraft antiskid systems operate on the principle of modulating the brake pressure upon sensing incipient skid conditions. Constant aircraft braking torque as opposed to intermittent braking torque should stop an aircraft in shorter distances on wet runways.

The most significant results are the overall increased wet friction values in the 50- and 60-mi/h speed ranges. It is noted that, in some cases, wet friction values are higher than dry friction values and at a few of the lower test speeds some of the measured friction values

indicate a decrease of friction due to grooving while all the higher test speeds indicate friction increases. These variances may be attributed to the thermodynamics of the testing components and surfaces. Other investigators have subsequently concurred that as temperatures increase, the resultant friction values decrease. Due to these temperature effects, the characteristics of the test parameters are altered thus affecting the friction values obtained. These thermal variances are dependent upon many variables among which the most important are: (1) heat input due to friction; (2) varying textures and surface materials; (3) cooling due to tire rotational speed; (4) cooling due to ambient wind; (5) ambient temperature; (6) tire/surface interface temperature; (7) test water temperature; (8) runway surface temperature; and (9) hysteresis.

A comparison of the data for the same track for wet and dry, and for before- and after-grooving contained in the Appendix, revealed a striking similarity in the analog trace shape and, to a lesser degree, magnitude. Variance in magnitude can be attributed to the friction effects of grooving, deviation from the test path, tire and pavement temperatures, environmental effects, and other variables.

The use of cresylic acid formula to remove rubber deposits from the 22L end of the ungrooved runway has produced notably improved wet friction values when compared to the untreated 4R end as shown in the Appendix, pages 1-4, 1-12, and 1-16, thus indicating the degree of effectiveness of this rubber removal process.

CONCLUSIONS

Based upon analysis of the results of these tests, it is concluded that:

1. There is an appreciable increase in the overall wet friction values at the higher test speeds of 50 and 60 mi/h attributed to the transverse groove pattern of Runway 4R-22L at JFK International Airport.

2. A more equalized friction surface due to the grooves is indicated by the wet postgrooved analog friction traces being smoother than the pregrooved values; i.e., fewer oscillations and of lesser amplitude.

3. The braking effectiveness of aircraft on grooved Runway 4R-22L at JFK is likely to be improved due to the higher indicated friction as well as the more equalized friction surface created by the grooves.

4. Chemical removal of rubber from the touchdown area of an ungrooved runway using the cresylic acid method is very effective in restoring higher friction values.

RECOMMENDATIONS

It is recommended that:

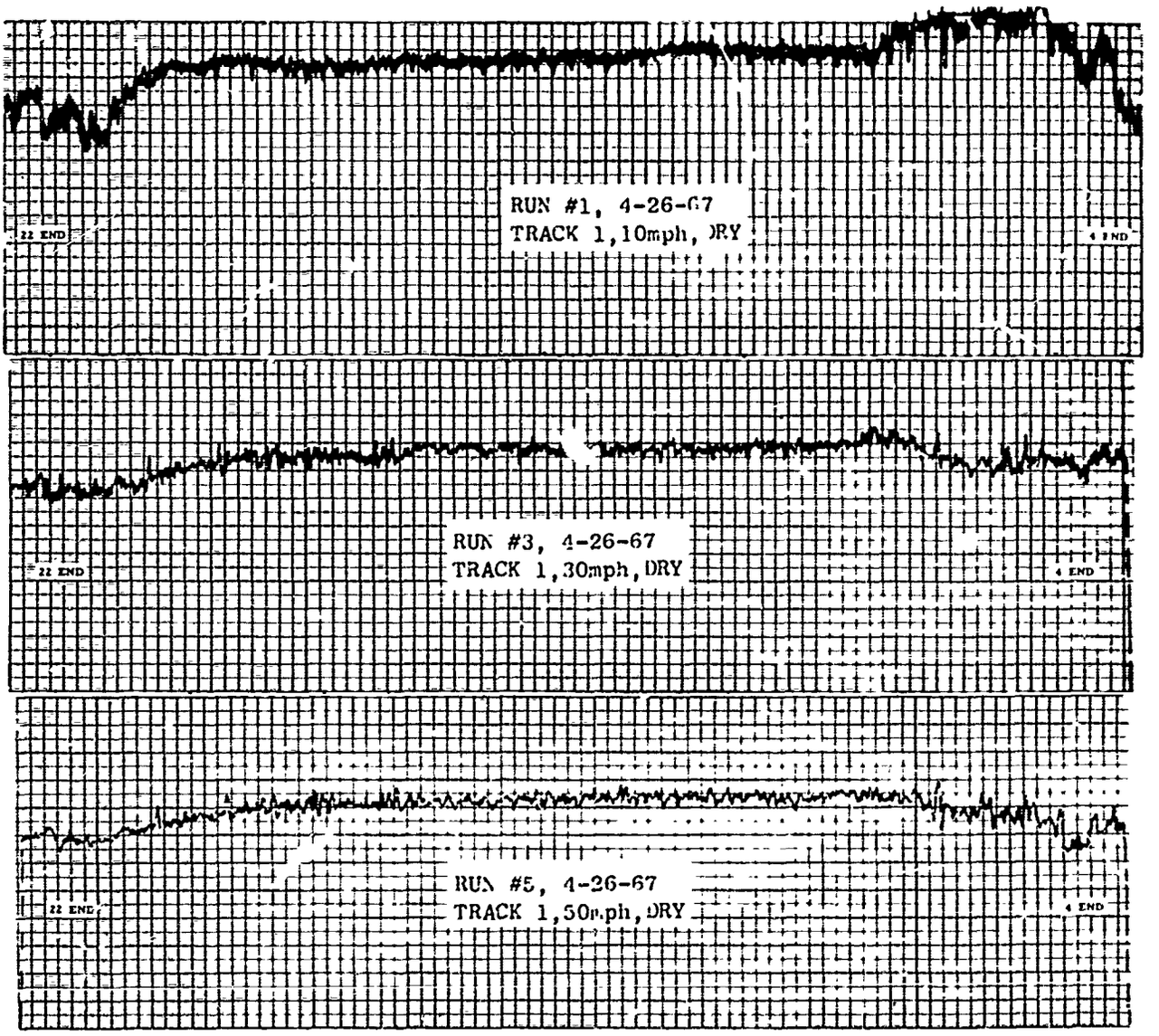
1. Friction tests be conducted on all grooved civil airport runways at speeds up to 80 mi/h and higher, if safely obtainable.

2. Aircraft braking tests be conducted to determine the effectiveness of various transverse groove patterns in reducing stopping distances.

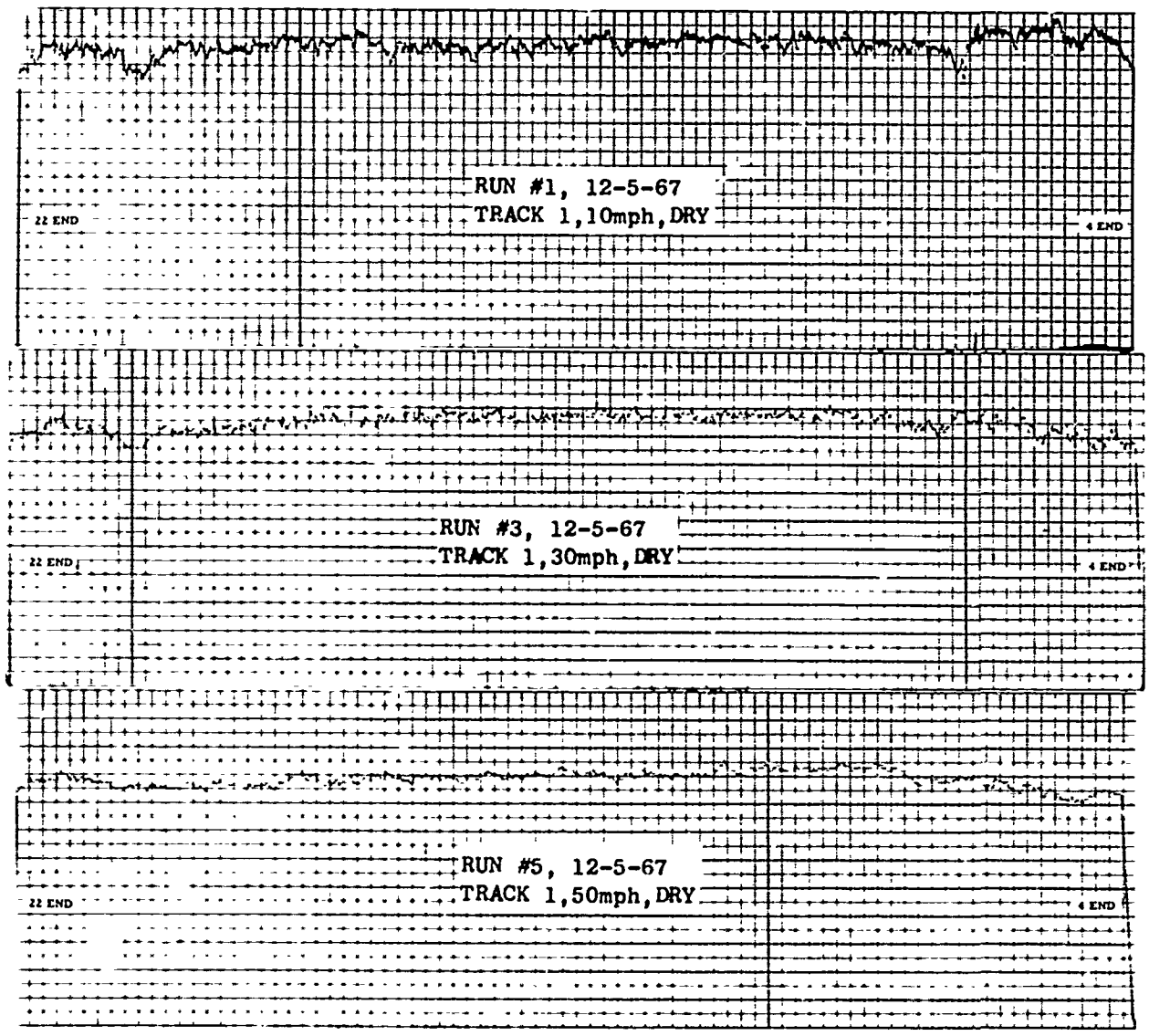
APPENDIX

WET AND DRY FRICTION DATA
DRY RUNWAY SURFACE CONDITIONS

April 26, 1967, and December 5, 1967 Friction Tests



BEFORE GROOVING - TRACK 1, CENTERLINE



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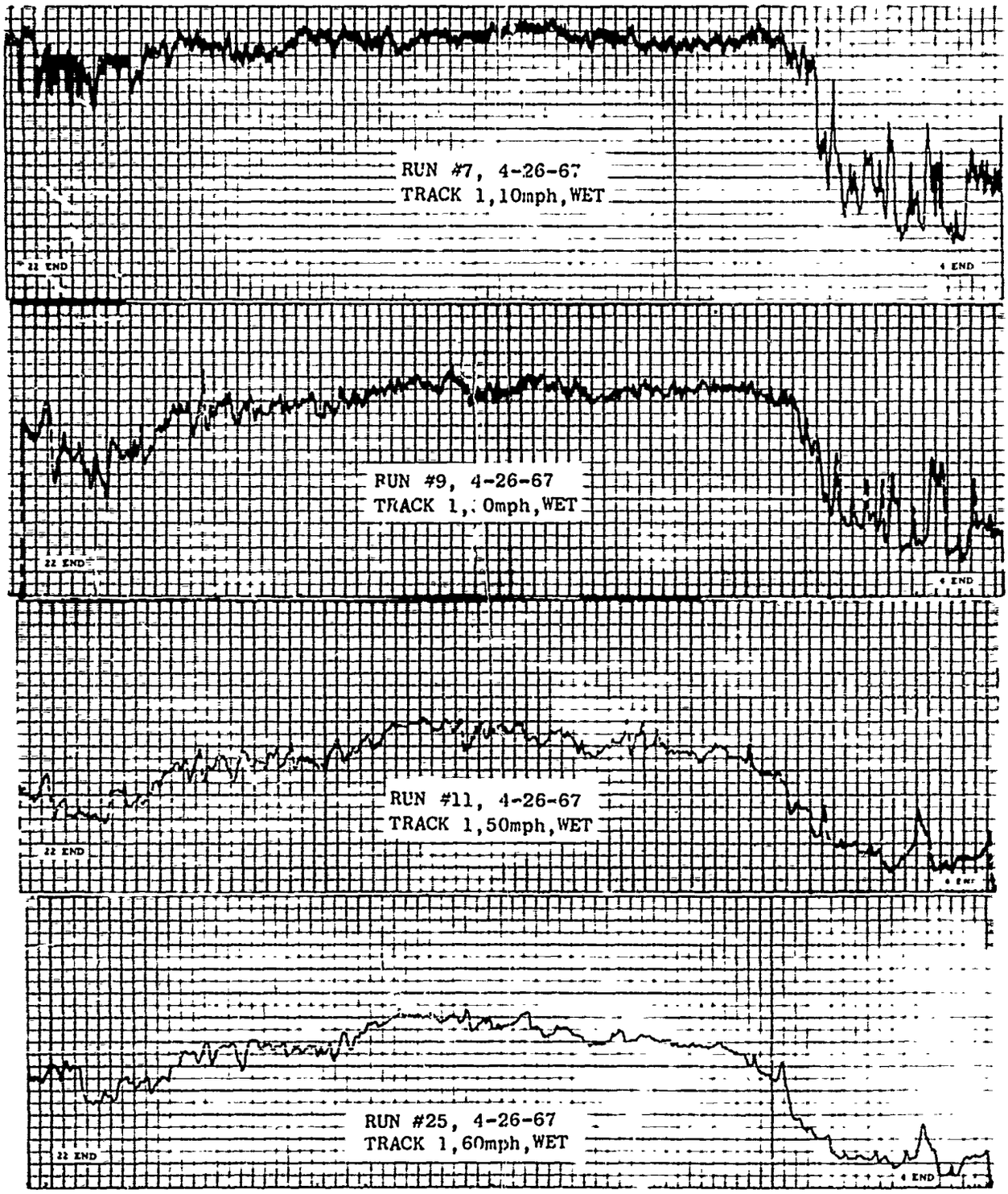

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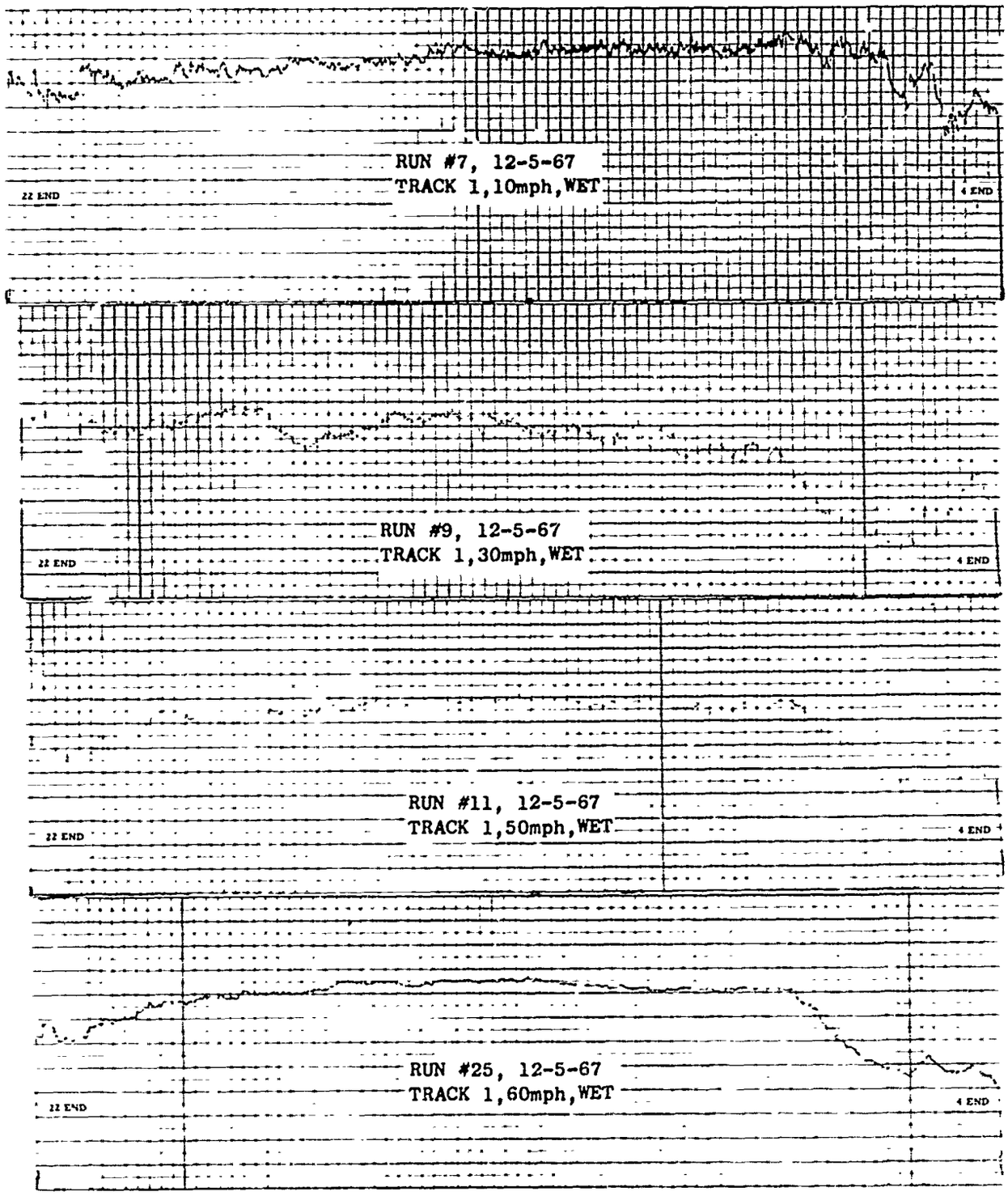
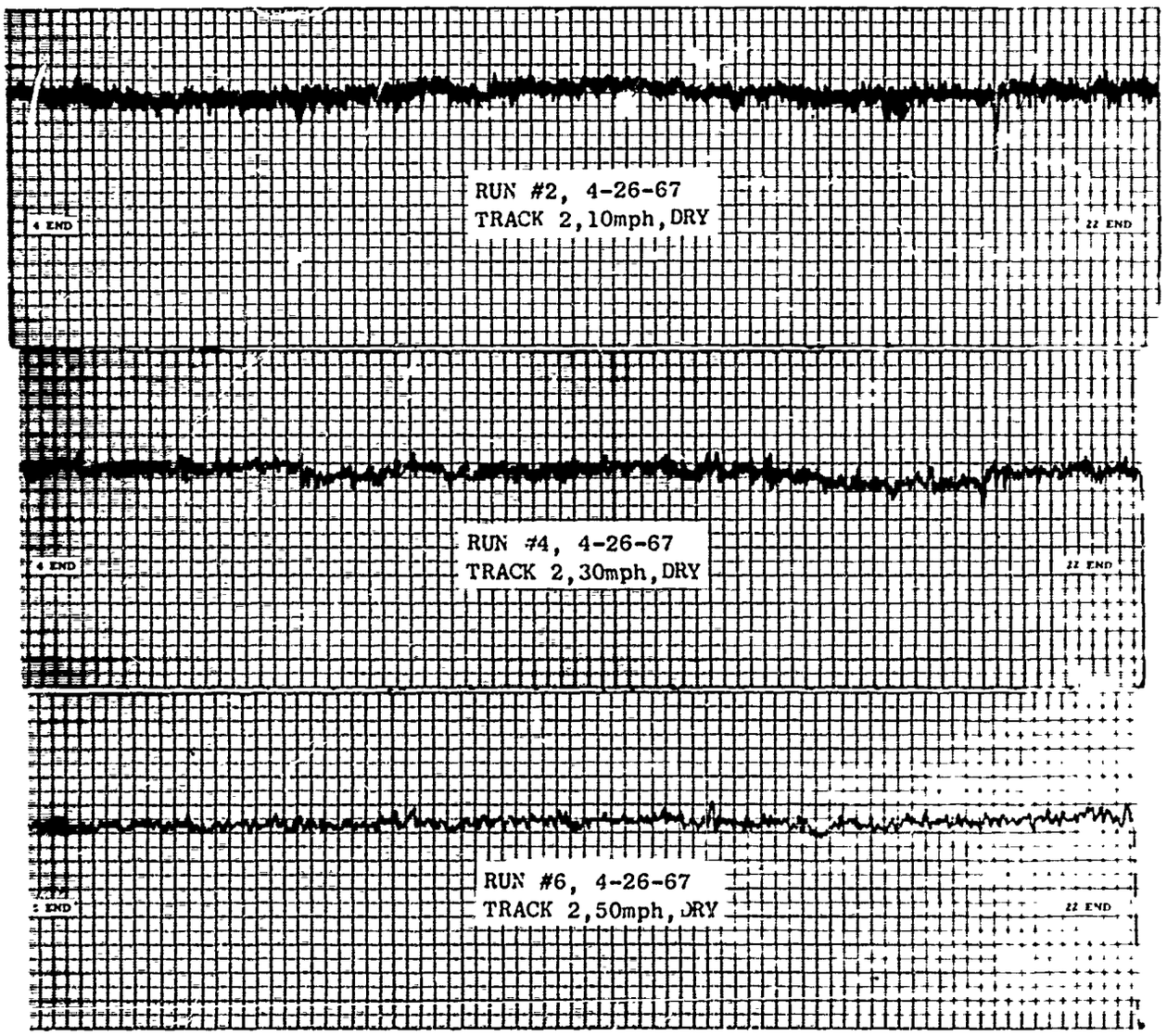
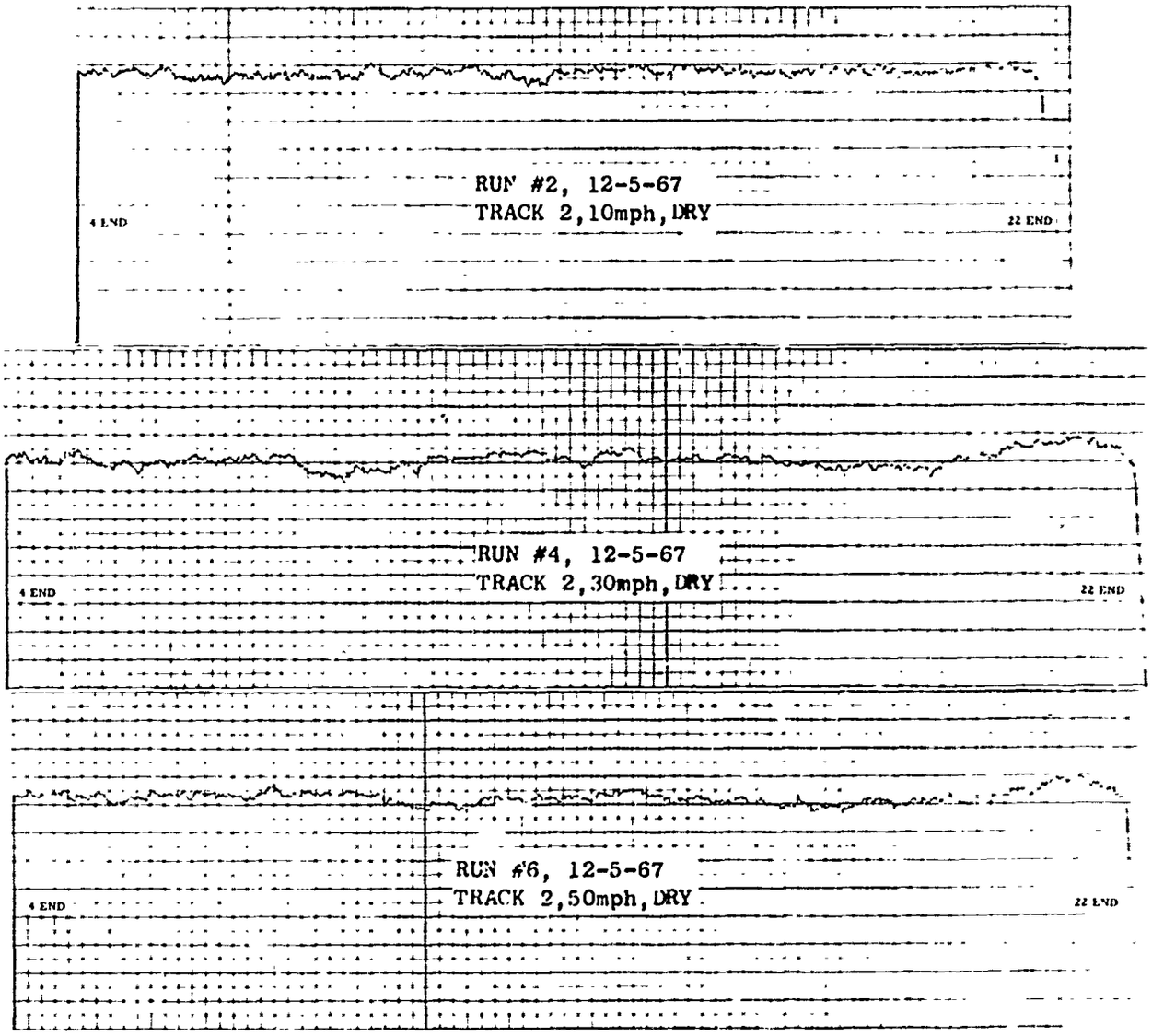


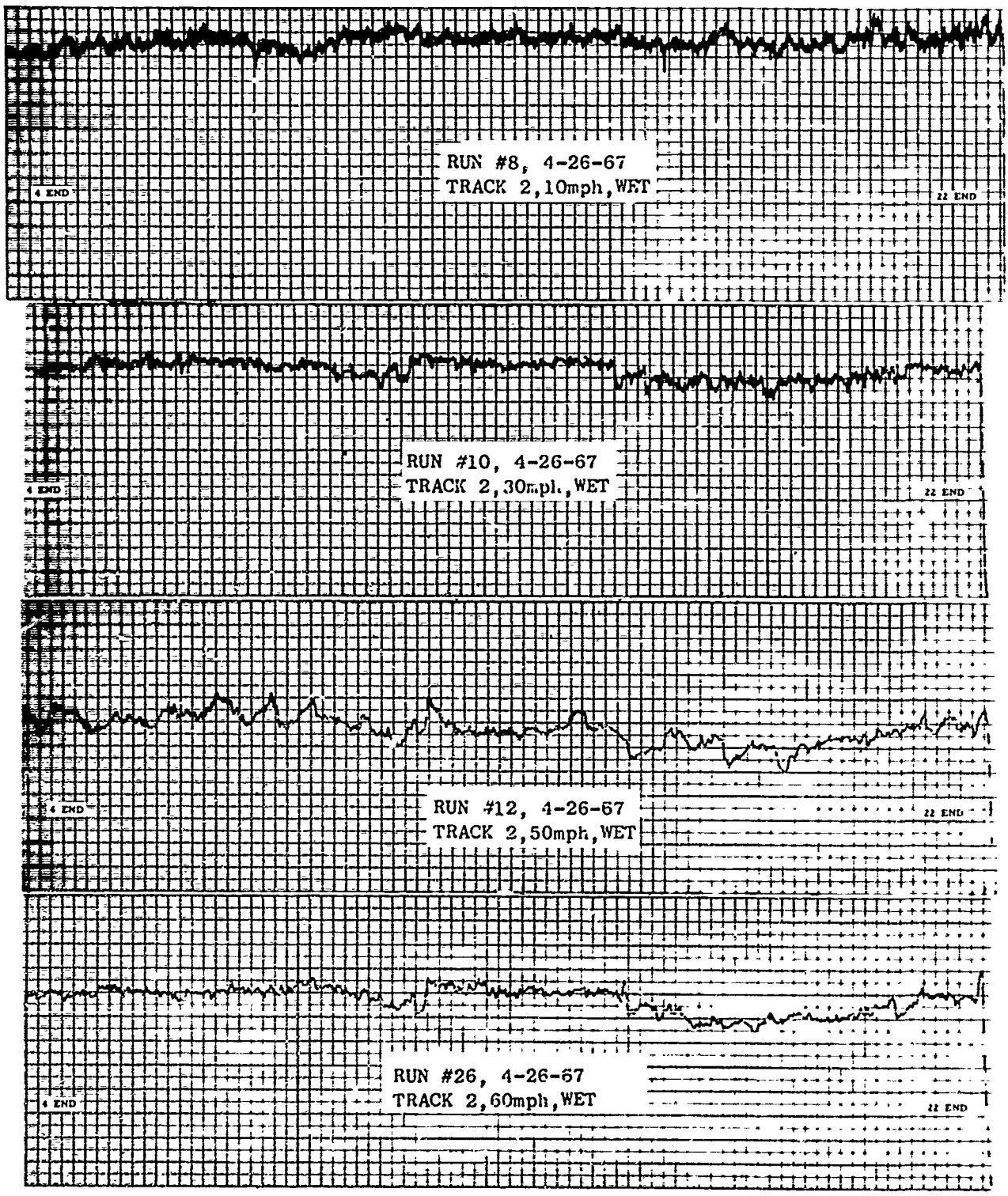
AFTER GROOVING - TRACK 1, CENTERLINE



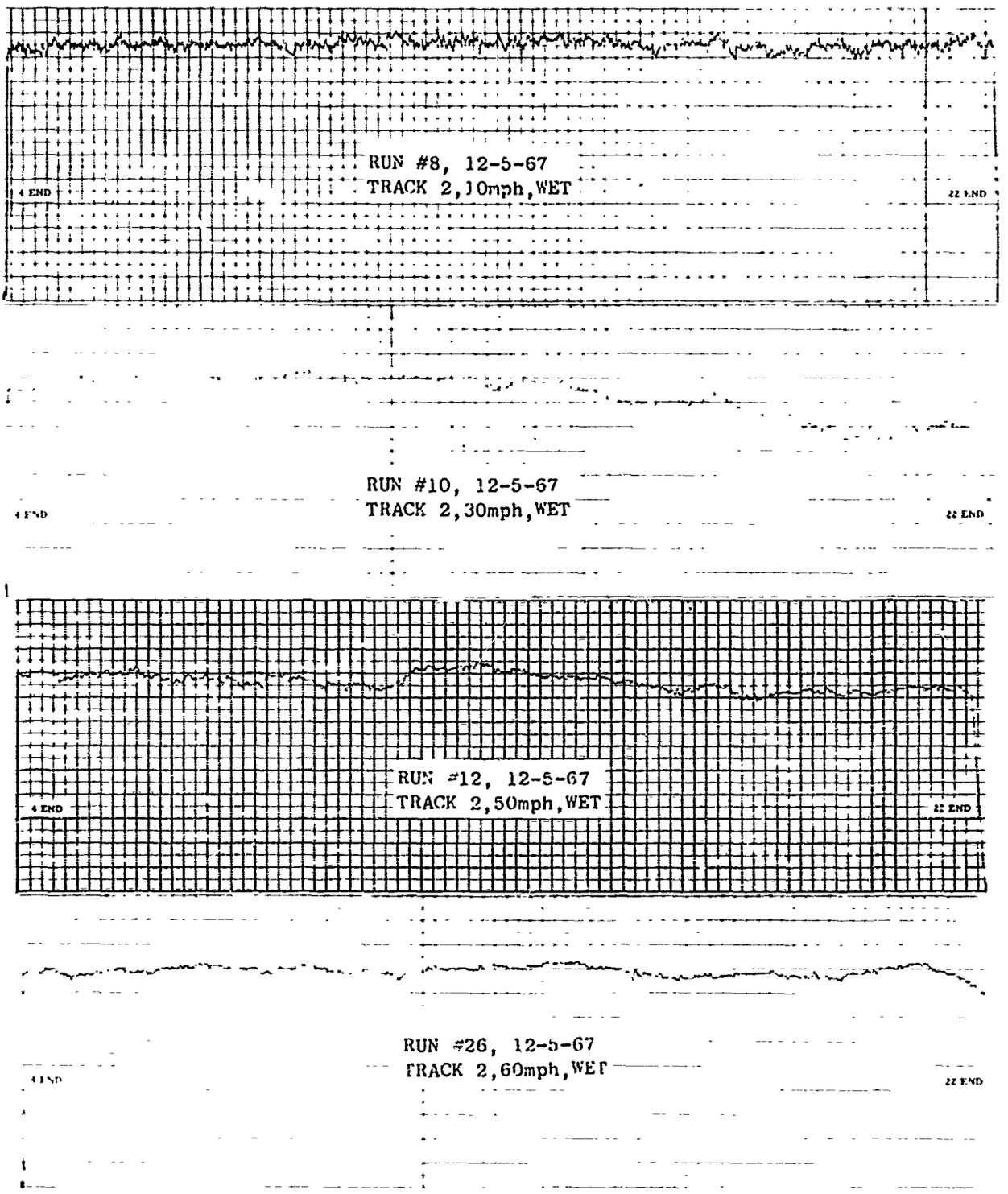
BEFORE GROOVING - TRACK 2, SOUTHEAST RUNWAY EDGE



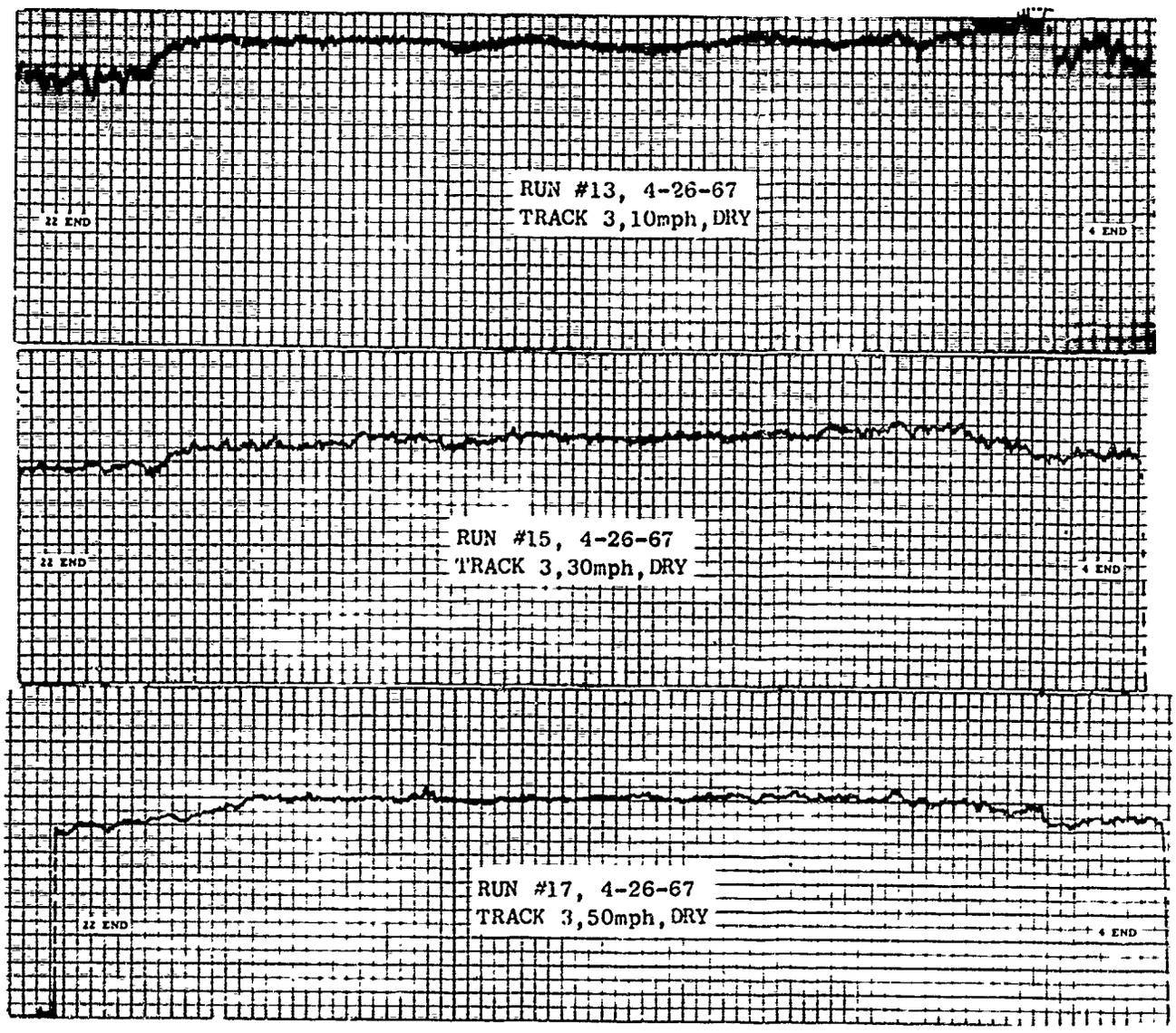
AFTER GROOVING - TRACK 2, SOUTHEAST RUNWAY EDGE



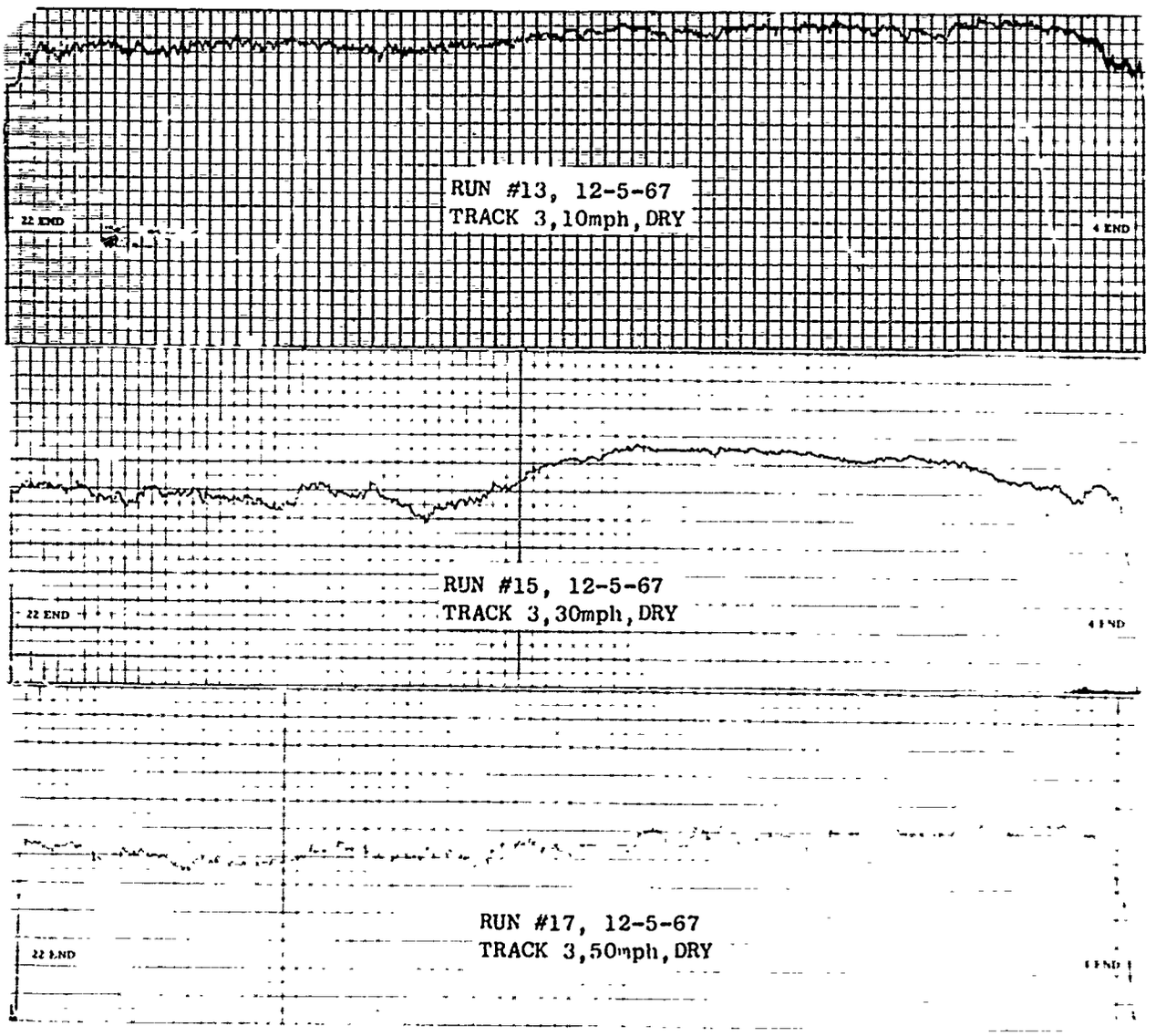
BEFORE GROOVING - TRACK 2, SOUTHEAST RUNWAY EDGE



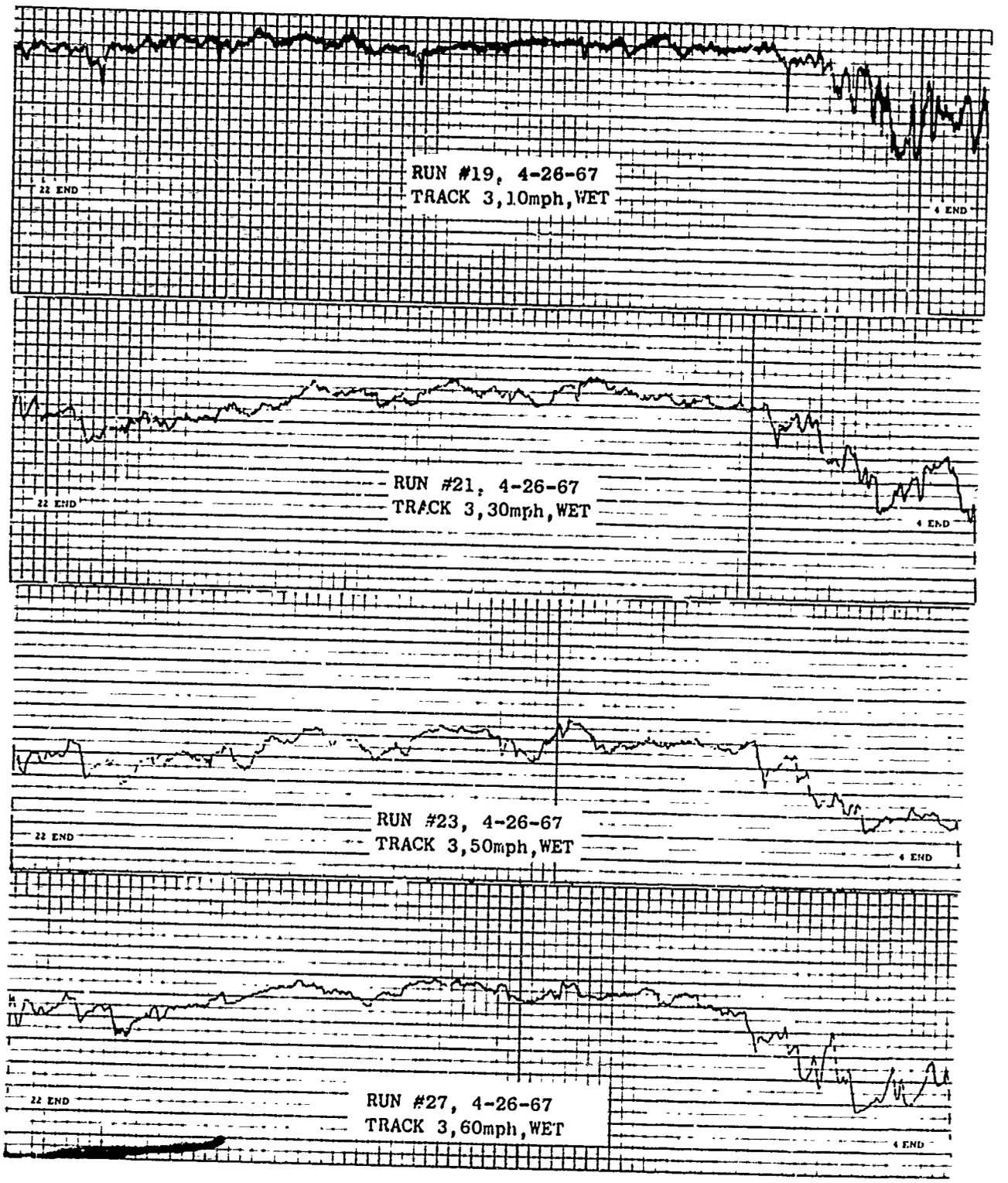
AFTER GROOVING - TRACK 2, SOUTHEAST RUNWAY EDGE



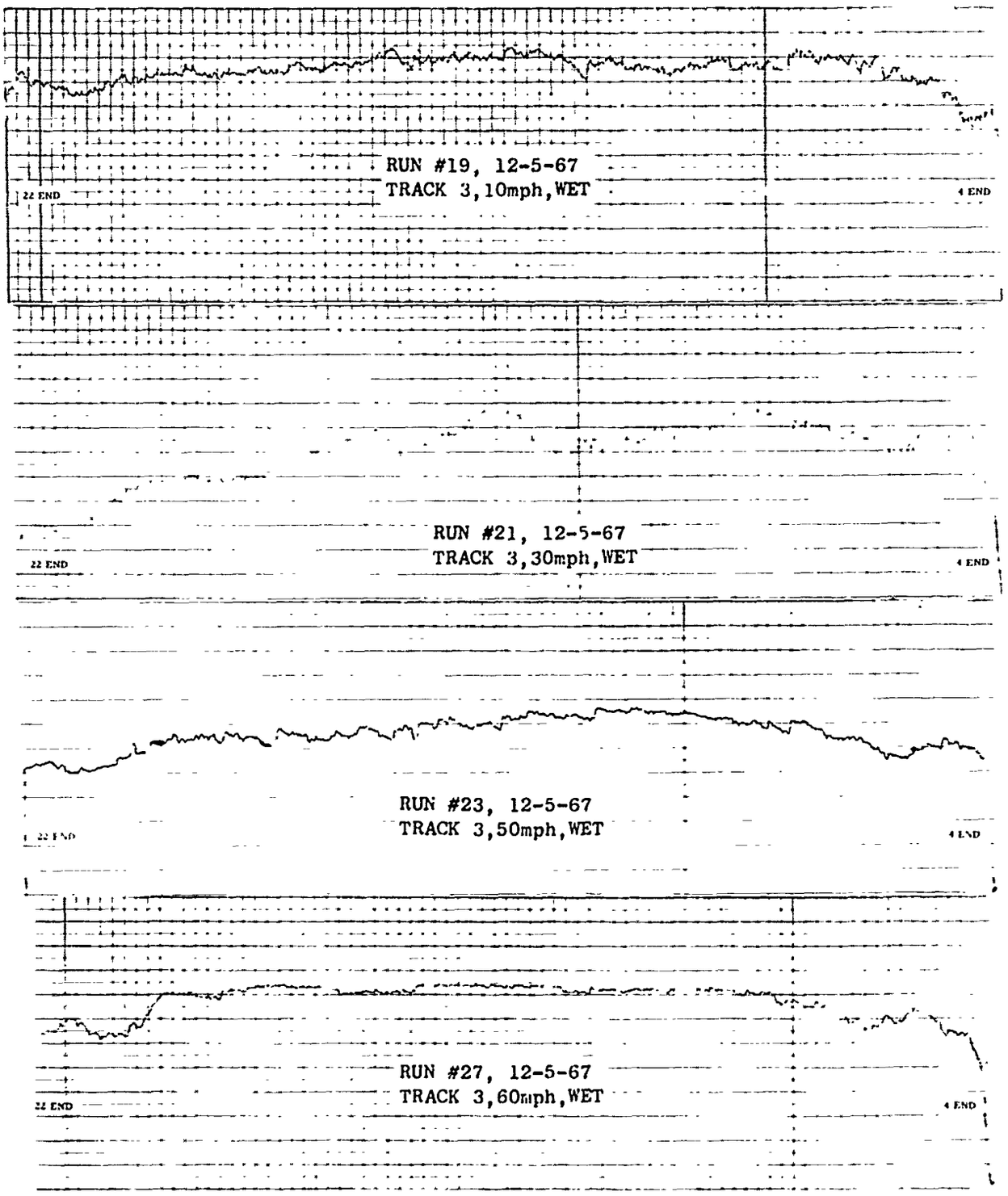
BEFORE GROOVING - TRACK 3, 20 FT. NORTHWEST OF CENTERLINE



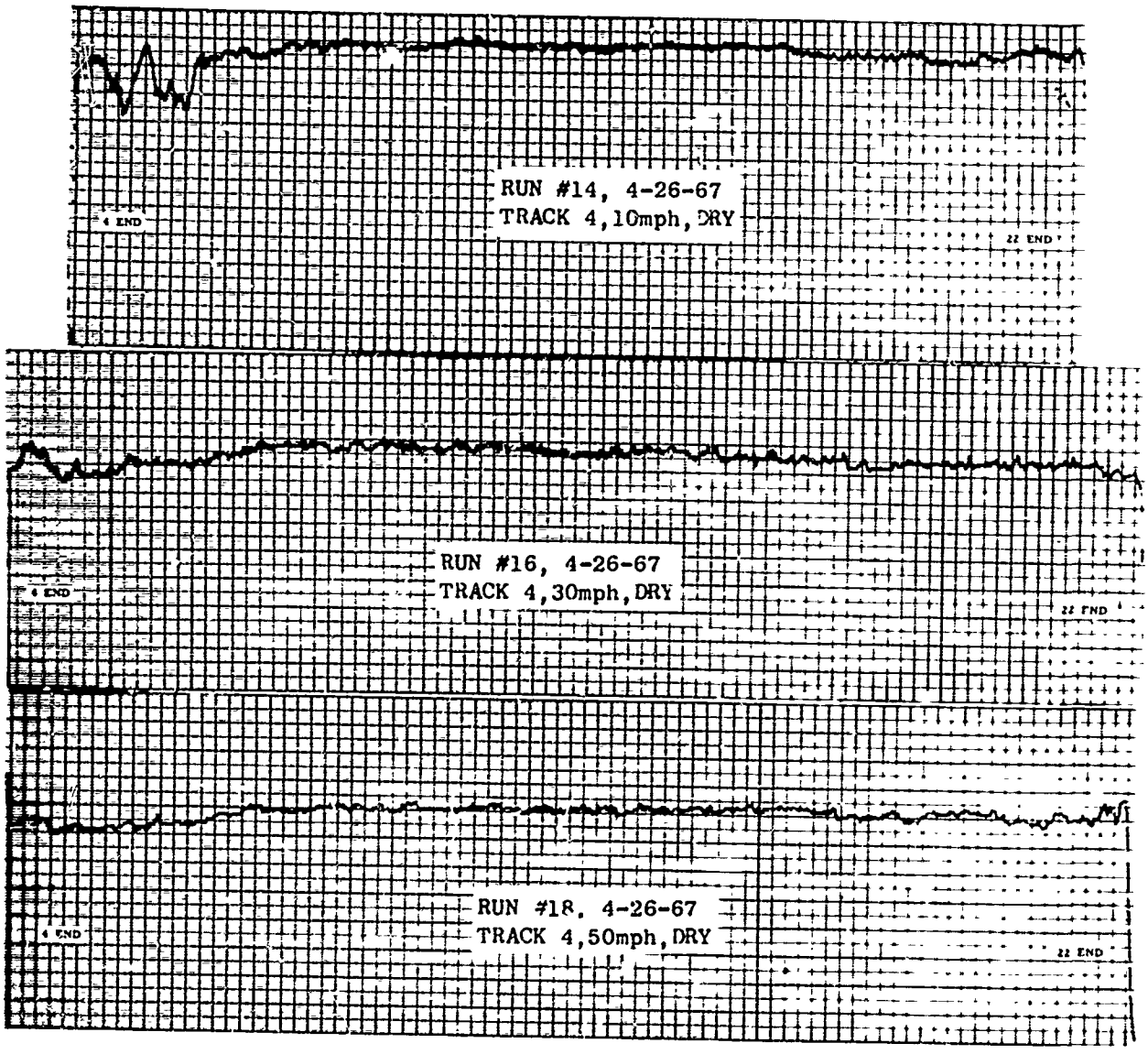
AFTER GROOVING - TRACK 3, 20 FT. NORTHWEST OF CENTERLINE



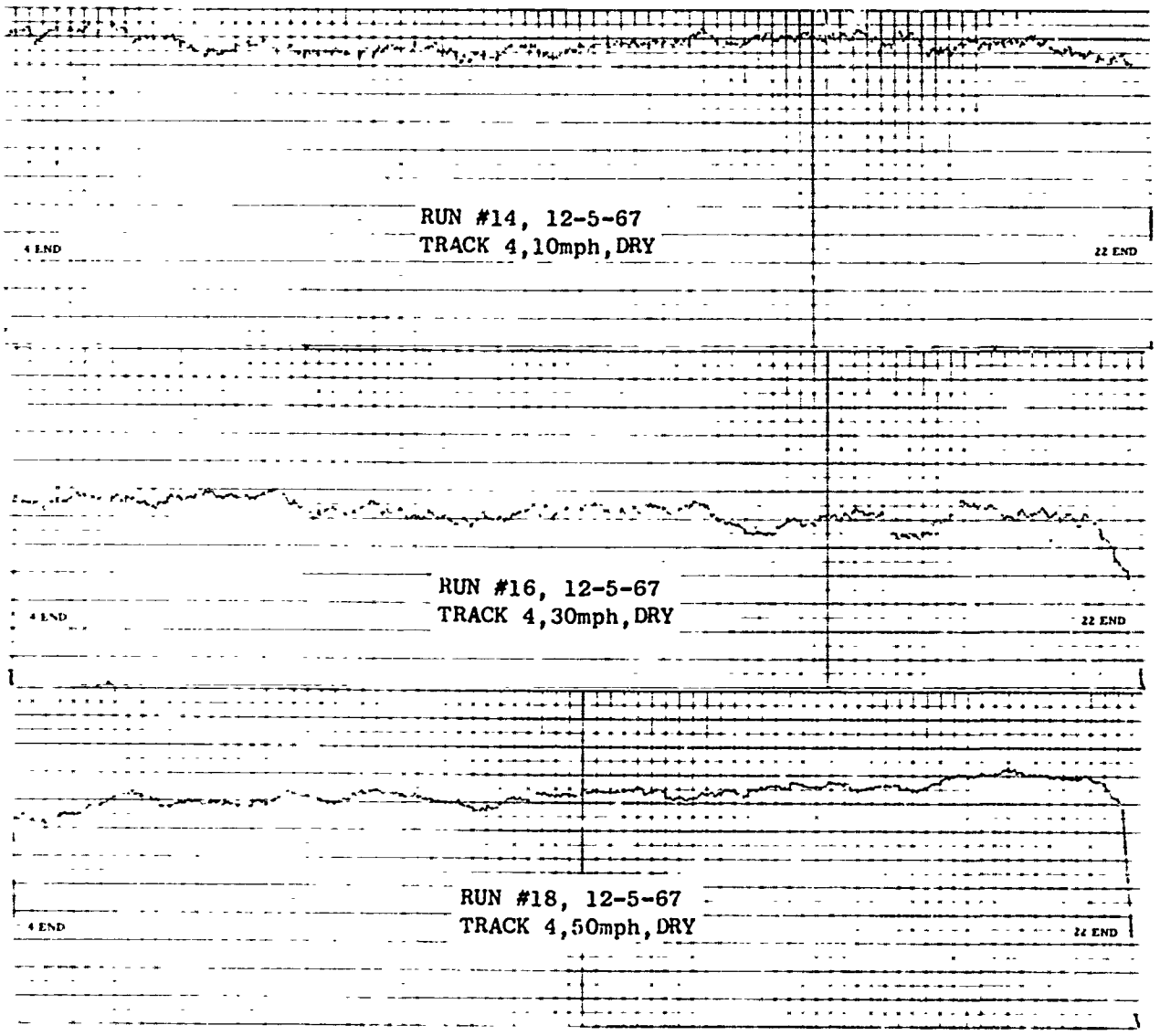
BEFORE GROOVING - TRACK 3, 20 FT. NORTHWEST OF CENTERLINE



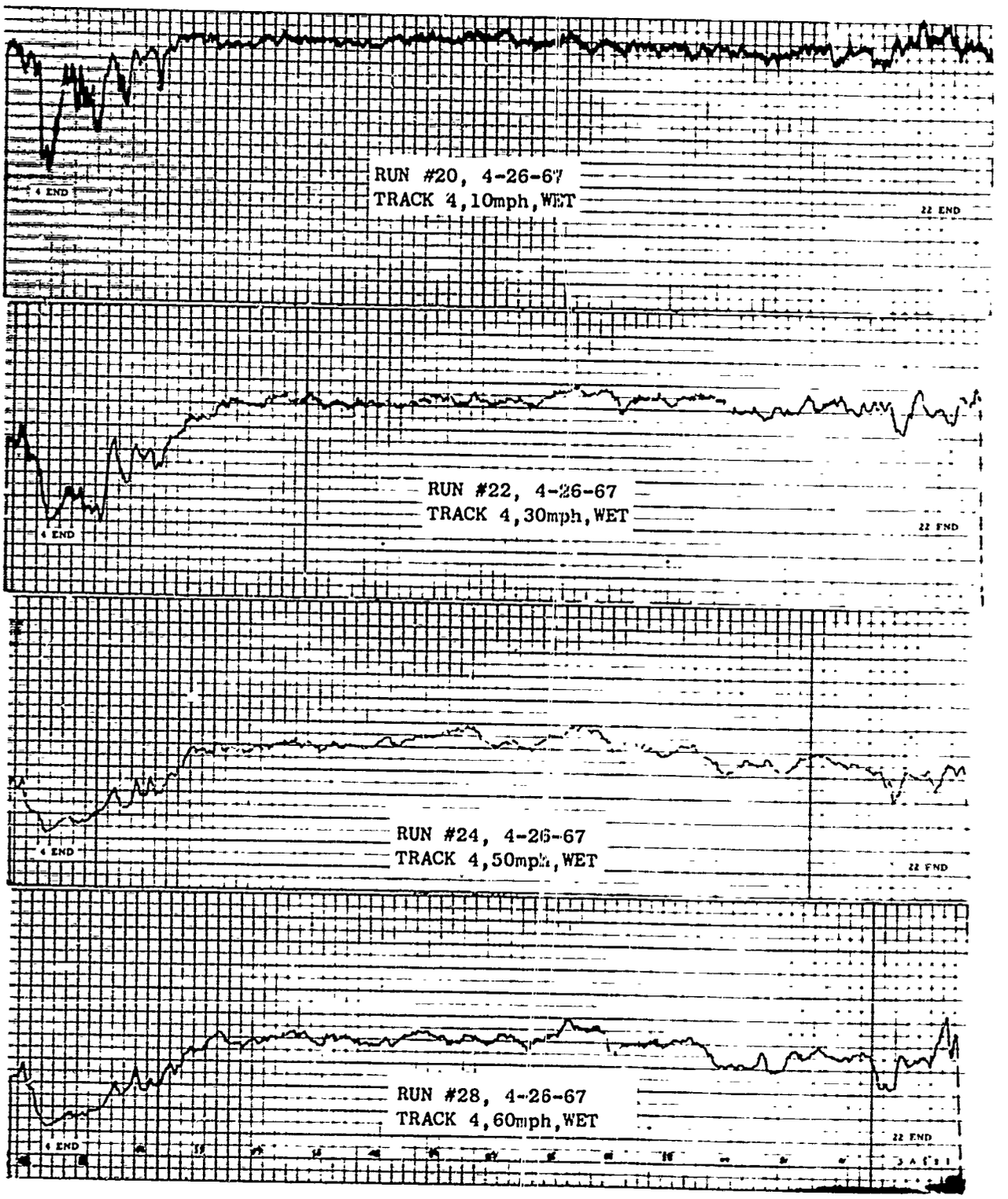
AFTER GROOVING - TRACK 3, 20 FT. NORTHWEST OF CENTERLINE



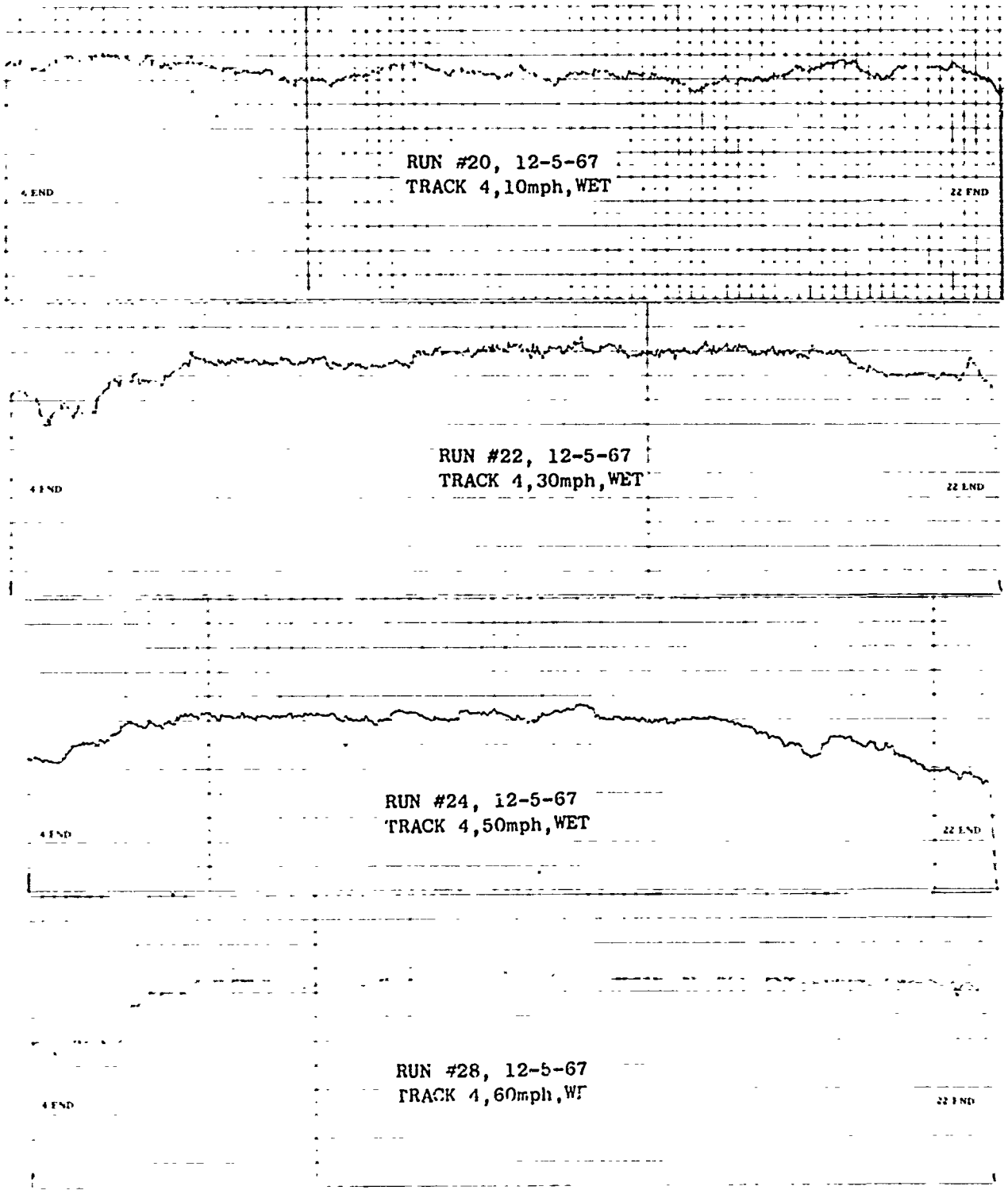
BEFORE GROOVING - TRACK 4, 20 FT. SOUTHEAST OF CENTERLINE



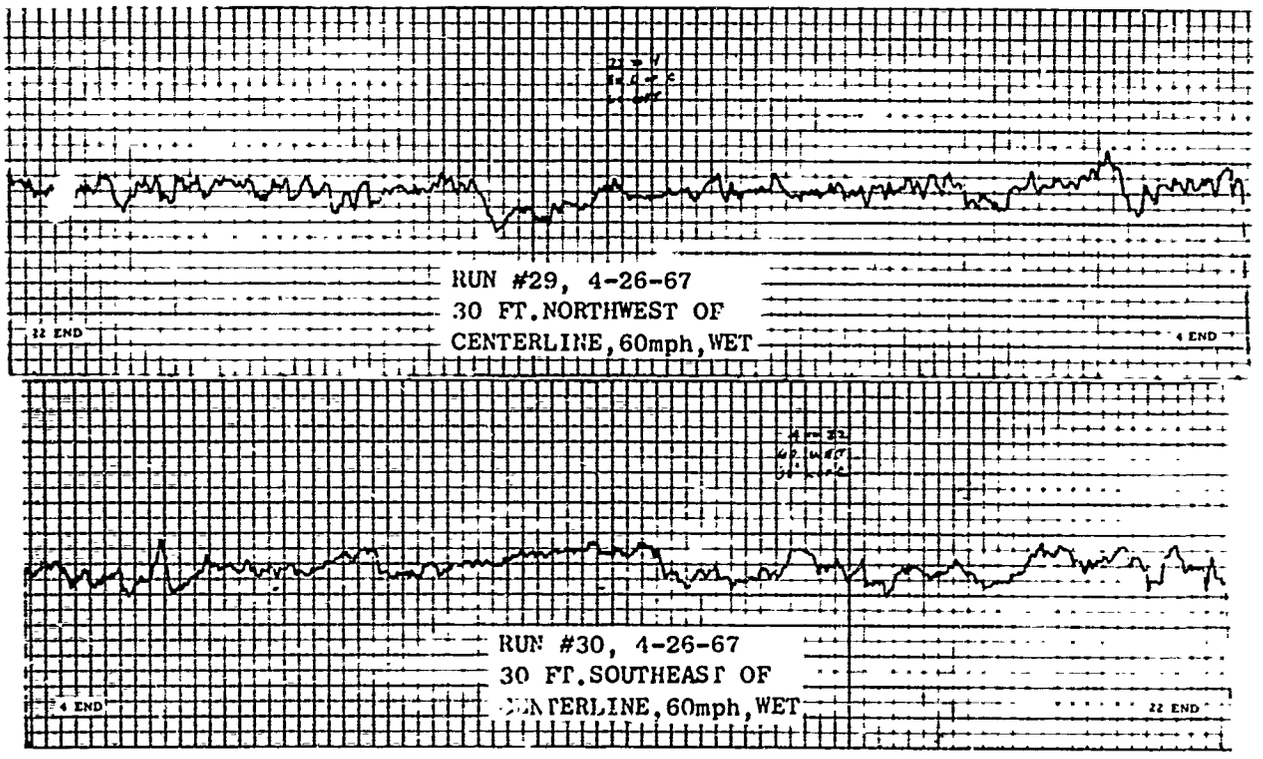
AFTER GROOVING - TRACK 4, 20 FT. SOUTHEAST OF CENTERLINE



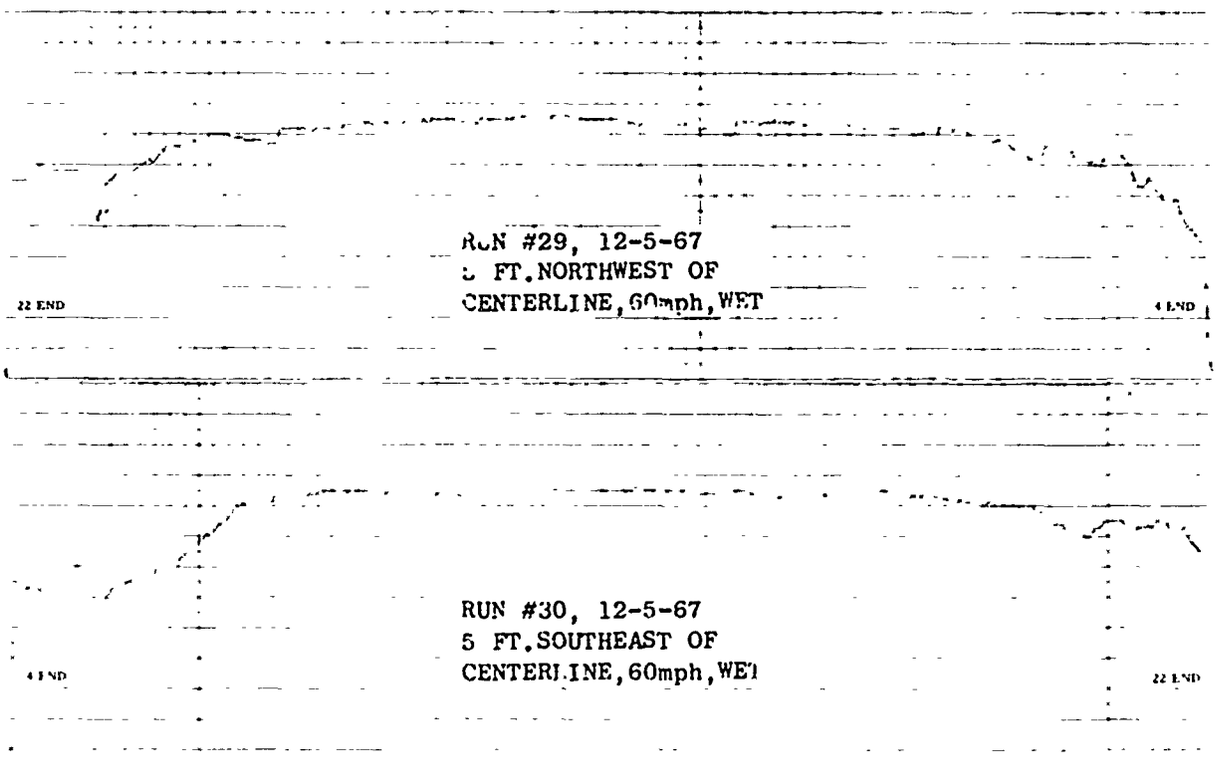
BEFORE GROOVING - TRACK 4, 20 FT. SOUTHEAST OF CENTERLINE



AFTER GROOVING - TRACK 4, 20 FT. SOUTHEAST OF CENTERLINE



MISCELLANEOUS BEFORE GROOVING 60 mph WET TESTS



MISCELLANEOUS AFTER GROOVING 60 mph WET TESTS

END

DATE

FILMED

9-25-69