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14. ABSTRACT
Provides a method of evaluating vehicle test course surface roughness by committee assessment using accelerometers and by spectral analysis of course irregularities. Describes use of profilometer and conversion of profilometer data to power spectral density (wave number spectra) curves. Includes wave number spectra of vehicle endurance test courses at DTC Test Centers.

15. SUBJECT TERMS

Automotive test course	Roughness of roads	Wave number spectrum
Test course surface roughness	Profilometer	Vehicle test course

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US ARMY DEVELOPMENTAL TEST COMMAND
TEST OPERATIONS PROCEDURE

*Test Operations Procedure (TOP) 1-1-010 31 October 2006
DTIC AD No. *****

VEHICLE TEST COURSE SEVERITY (SURFACE ROUGHNESS)

1. SCOPE. Test course surface roughness is one of many attributes (e.g., longitudinal slope, side slope, mud/dust, soil strength, radius of curvature) used to define a test course. This TOP describes methods for evaluating vehicle test course surface roughness by committee assessment using accelerometers and by spectral analysis of course irregularities using a profilometer. Described are the use of the profilometer and conversions of profilometer data to power spectral density (PSD) curves known as wave number spectra. It includes wave number spectra of vehicle endurance test courses at the US Army Aberdeen Test Center (ATC) and the Yuma Test Center (YTC). Characteristic curves of endurance test courses, which were developed using the wave number spectrum method of analysis provide a quantitative measure of course conditions for assessing and comparing course surface roughness.

*This TOP supersedes TOP 1-1-010, 6 April 1987

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Consistent course roughness is essential to properly evaluate and compare reliability and durability data obtained years apart. Unless maintained, test course surface roughness may change depending on weather conditions and traffic density.

2. FACILITIES AND INSTRUMENTATION:

2.1 Facilities.

Item	Requirement
High-Speed Paved Road	See paragraph 5.1
Munson Gravel Road	See paragraph 5.1
Belgian Block Course	See paragraph 5.1
Perryman Test Area Courses	See paragraph 5.1
Churchville Area Courses	See paragraph 5.1
Yuma Test Center Courses	See paragraph 5.2

2.2 Instrumentation.

Device for Measuring:	Permissible Error of Measurement
Profile (profilometer system - see para 4.1)	$\pm$0.05 inches
Acceleration (inspection vehicle – para 3)	$\pm$0.1 g
Displacement (inspection vehicle – para 3)	$\pm$0.1 inches
Speed (inspection vehicle – para 3)	$\pm$0.5 mph

3. MONITORING TEST COURSE SURFACE ROUGHNESS BY COMMITTEE INSPECTION. Test course roughness is monitored by direct measurement with a purpose-built profilometer (paragraph 4) and by a special committee which measures roughness by riding over the courses in an instrumented M1025 High-Mobility Multipurpose Wheeled Vehicle (HMMWV) or similar appropriate vehicle at a pre-established speed for each course. The vehicle is instrumented to measure road speed (sample rate: 1 Hz), right rear upper control arm acceleration (50 Hz), and right rear upper control arm displacement (50 Hz). Road speed is held constant throughout each test course, and the difference between the 90- and 10-percent probability values for acceleration and displacement are compared to limits for each test course. For maintenance purposes, the data sets are compiled for approximately each mile of test course.

a. Test course inspections are conducted by the committee on a monthly basis. To obtain comparable data, the same committee inspects each course as in previous inspections using the same vehicle to minimize variables. The vehicle is maintained in the same condition as in previous inspections with particular attention given to its suspension system, shock absorbers, and tire inflation pressures. For a given course, the same driver is used for each inspection.

b. Vehicle speeds and acceleration and displacement control limits for each ATC course are shown in Table 1and 2 and in Figures 1 and 2. These results are used in conjunction with the committee's assessment of course conditions and the results of the corresponding profilometer measurement to bring the surface roughness level to within its control limits.

TABLE 1. ATC TEST COURSE INSPECTION LIMITS FROM INSTRUMENTED M1025 HMMWV

Course and Section	Allowable Range
ATC Munson Test Area (MTA)	
Gravel Road: Section I 90- and 10-percent displacement, in.	0.5 to 1.0 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.2 *g*'s
Section II 90- and 10-percent displacement, in.	0.5 to 1.0 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.2 *g*'s
Course Composite 90- and 10-percent displacement, in.	0.5 to 1.0 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.2 *g*'s
Belgian Block Course: Section I 90- and 10-percent displacement, in.	1.2 to 1.7 inches
90- and 10-percent acceleration, *g*'s	1.8 to 2.3 *g*'s

TABLE 1 (CONT'D)

Course and Section	Allowable Range
ATC Perryman Test Area (PTA)	
Perryman A Course:	
Section I	
90- and 10-percent displacement, in.	0.5 to 1.0 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.2 *g*'s
Section II	
90- and 10-percent displacement, in.	0.5 to 1.0 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.2 *g*'s
Course Composite	
90- and 10-percent displacement, in.	0.5 to 1.0 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.2 *g*'s
Perryman No. 1 Course:	
Section I	
90- and 10-percent displacement, in.	0.5 to 1.2 inches
90- and 10-percent acceleration, *g*'s	1.8 to 2.4 *g*'s
Section II	
90- and 10-percent displacement, in.	0.5 to 1.2 inches
90- and 10-percent acceleration, *g*'s	1.8 to 2.4 *g*'s
Section III	
90- and 10-percent displacement, in.	0.5 to 1.2 inches
90- and 10-percent acceleration, *g*'s	1.8 to 2.4 *g*'s
Section IV	
90- and 10-percent displacement, in.	0.5 to 1.2 inches
90- and 10-percent acceleration, *g*'s	1.8 to 2.4 *g*'s
Course Composite	
90- and 10-percent displacement, in.	0.5 to 1.2 inches
90- and 10-percent acceleration, *g*'s	1.8 to 2.4 *g*'s
Perryman No. 2 Course:	
Section I	
90- and 10-percent displacement, in.	1.2 to 1.7 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.5 *g*'s
Section II	
90- and 10-percent displacement, in.	1.2 to 1.7 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.5 *g*'s
Course Composite	
90- and 10-percent displacement, in.	1.2 to 1.7 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.5 *g*'s

TABLE 1 (CONT'D)

Course and Section	**Allowable Range**
Perryman No. 3 Course: Section I 90- and 10-percent displacement, in.	1.5 to 2.0 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.5 *g*'s
Section II 90- and 10-percent displacement, in.	1.5 to 2.0 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.5 *g*'s
Section III 90- and 10-percent displacement, in.	1.5 to 2.0 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.5 *g*'s
Section IV 90- and 10-percent displacement, in.	1.5 to 2.0 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.5 *g*'s
Course Composite 90- and 10-percent displacement, in.	1.5 to 2.0 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.5 *g*'s
ATC Churchville Test Area (CTA)	
Churchville B Course (Smooth Section): Section I 90- and 10-percent displacement, in.	0.7 to 1.4 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.2 *g*'s
Section II 90- and 10-percent displacement, in.	0.7 to 1.4 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.2 *g*'s
Churchville B Course (Rough Section): Section III 90- and 10-percent displacement, in.	0.7 to 1.4 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.2 *g*'s
Section IV 90- and 10-percent displacement, in.	0.7 to 1.4 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.2 *g*'s
Section V 90- and 10-percent displacement, in.	0.7 to 1.4 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.2 *g*'s

TABLE 1 (CONT'D)

Course and Section	Allowable Range
Course Composite 90- and 10-percent displacement, in.	0.7 to 1.4 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.2 *g*'s
Churchville C Course Course Composite 90- and 10-percent displacement, in.	0.5 to 1.0 inches
90- and 10-percent acceleration, *g*'s	0.5 to 1.2 *g*'s

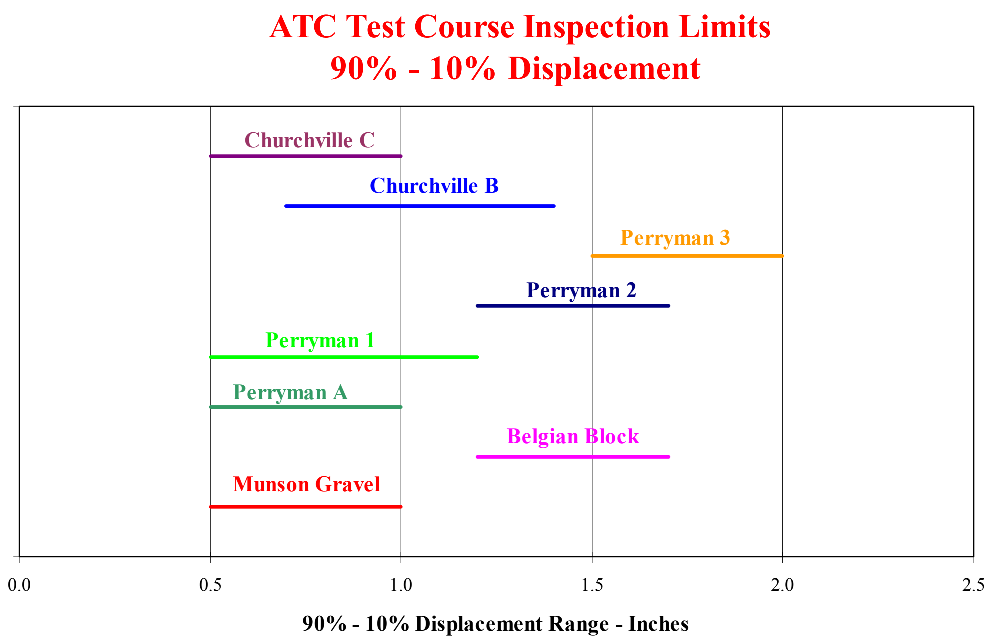

Figure 1. ATC Test Course displacement range limits.

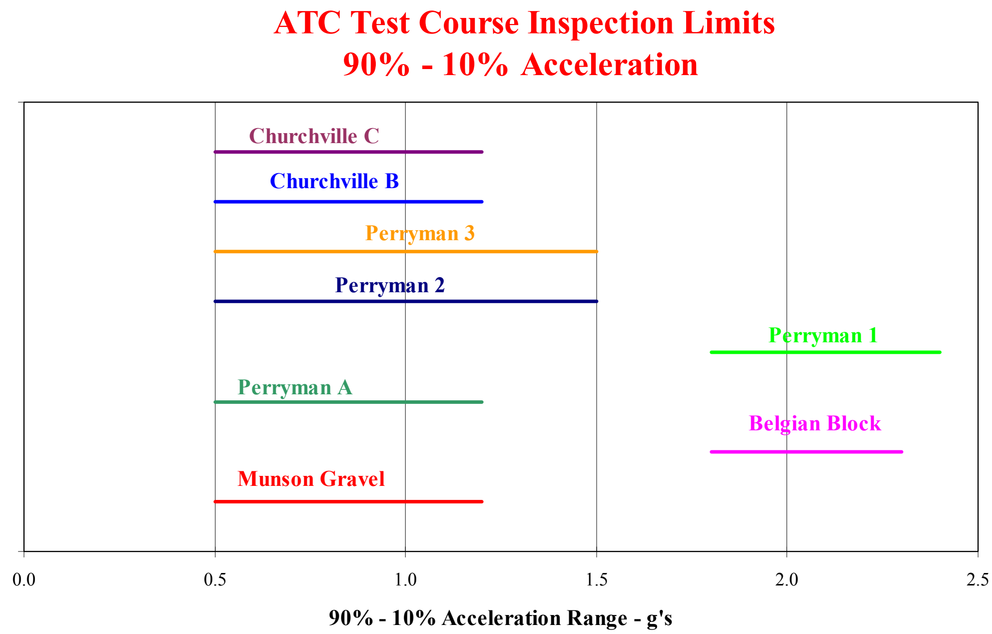

Figure 2. ATC Test Course acceleration range limits.

TABLE 2. ATC TEST COURSE INSPECTION SPEEDS

Test Course	Speed, mph	Speed, km/hr
Munson Gravel	35	56
Belgian Block	25 (20 mph in turns)	40 (32 km/hr in turns)
Perryman A	35	56
Perryman 1	35	56
Perryman 2	25	40
Perryman 3	15	24
Churchville B – Smooth	35	56
Churchville B – Rough	20	32
Churchville C	30	48

4. DETERMINING TEST COURSE SURFACE ROUGHNESS BY MEASURING COURSE PROFILE. The surface profiles of test courses at ATC are also measured on a monthly basis using a profilometer. This special purpose trailer makes a series of displacement and angular measurements that lead to computation of surface roughness as a function of distance traveled over the test course. Measurements are taken at 7.6 cm (3 in) increments over the length of the test course. These uniformly sampled, digitized values are analogous to the digitization of transducer signals in the time domain, and many of the standard analysis techniques that are applied in the time domain are applicable in the spatial domain. Test course profile data are used

in conjunction with the inspection committee data for course maintenance, are provided to customers for use with digital dynamic models and are retained for historical purposes.

One of the most common forms of presenting time series data is to transform it to the frequency domain using the Fast Fourier Transform (FFT) and compile the time record as a power spectral density (PSD) function. This same process is used with the spatial data (where the equal distance measurement intervals are equivalent to equal time intervals) and the resultant spectrum is called a wave number spectrum as shown in Figure 3. The X-axis or wave number, which has units of cycles per foot (or meter), is the inverse of the test course wavelength and is equivalent to frequency in the time domain. The Y-axis of the wave number spectrum has units of displacement (course roughness) squared divided by the analysis bandwidth (cycles per foot). This is usually expressed as ft^2/cycle/ft or, more commonly, ft^3. The test course rms roughness is the square root of the area under the wave number spectrum between any two wave numbers. The rms value is, therefore, dependent upon both the spectral shape and the integration limits, and the same rms value can be obtained from a large number of spectra. Although definition of the integration bandwidth is application specific, it is generally accepted for ride dynamics (TOP 1-1-014, Ride Dynamics) that rms determination will be made between wavelengths of approximately to 0.15 to 20 m (0.5 to 64 ft).

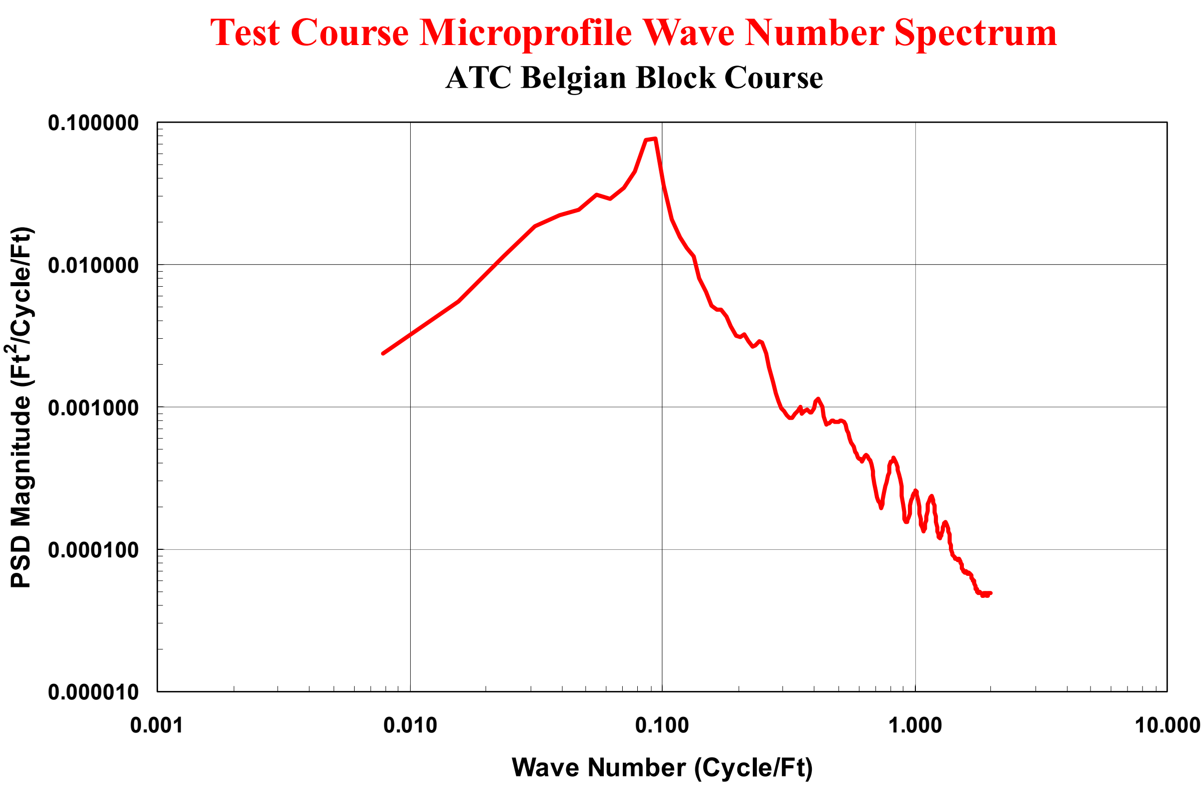

Figure 3. Typical Test Course Wave Number Spectrum.

4.1 Profile-Measuring Equipment. Test course profiles are measured with a profilometer system. The current system consists of a wagon type trailer (four wheels with two axles) drawn by a tow vehicle (fig. 4), a data acquisition subsystem, and a mobile PC-computer-based data analysis system. The profilometer front axle is free to rotate about the yaw axis, but is constrained from other motion relative to the frame. A linkage to the drawbar is employed to constrain the front axle and align the wheels parallel to the drawbar. The rear axle is free to rotate about the roll axis and is constrained from all other motion relative to the frame. This system provides a platform, which is articulate enough to conform to the anticipated terrain and to follow the tow vehicle. There are no compliant suspension components between the axles and the frame.

Figure 4. ATC profilometer.

a. The profilometer contains an inertial gyroscope to measure pitch and roll angle and an ultrasonic distance-measuring device to measure the vertical distance between the frame and the terrain. The vertical gyro also provides a signal to a stabilized platform so that the ultrasonic subsystem always points along the vertical. A shaft encoder provides a pulse output every 0.1 inches of travel. A counter accumulates the pulses and an interrupt is issued to activate the data acquisition system at a programmable distance (currently 3 in.).

b. The profile of a road surface is calculated from the pitch and roll angles and the ultrasonic subsystem outputs. The pitch angle data are first used to determine the locus of the profilometer chassis midpoint's motion. A set of data are acquired at regular intervals of travel along the surface, from which the locus of travel can be calculated as:

$$y_{mp} = \Sigma \sin(\theta_i)\, dl$$

$$x_{mp} = \Sigma \cos(\theta_i)\, dl$$

where θ is the pitch angle and dl is the increment of travel along the surface.

The ultrasonic sensors are at a height:

$$y'_L = y_{mp} + w/2 \sin(\phi)$$
$$y'_R = y_{mp} - w/2 \sin(\phi)$$

where w/2 is the distance from the midpoint to each sensor and ϕ is the roll angle of the chassis.

Finally, the ultrasonic subsystem component is added to yield

$$y_L = \Sigma \sin(\theta_i)\, dl + w/2 \sin(\phi) + U_L$$
$$y_R = \Sigma \sin(\theta_i)\, dl - w/2 \sin(\phi) + U_R$$

where U_L and U_R are the distance measured by the left and right ultrasonic sensors, respectively.

c. The profiles obtained represent values obtained at a nonuniform sampling interval. Linear interpolation techniques are utilized to obtain samples at equal intervals of horizontal distance as required by the spectral transformation. A digital filtering technique is also employed to account for the non-unity transfer function induced by the profilometer geometry. A moving two-sided exponentially weighted average technique (detrending) is utilized to remove long wavelength (low spatial frequency) data created by the integration process used in the above equations. This is described in reference no. 7 and is shown mathematically as:

$$y_n(x) = \frac{\sum \{y(x + l\delta x) + y(x - l\delta x)\} e^{-l\delta x/\gamma}}{2\sum e^{-l\delta x/\gamma}} \qquad (sum\ from\ l = 0\ to\ E)$$

where:

y(x)	= elevation at point x.
$y_n(x)$	= correction factor.
l	= step number.
δx	= measurement interval (0.25 ft).
γ	= weighting constant.
E	= limit of summation.

$$y_d(x) = y(x) - y_n(x)$$

where:

$y_d(x)$ = Detrended elevation at point x.

d. This filtering process does not discriminate between low frequency data created as an artifact of the integration process (due to offsets in amplifiers and digitizers, etc.) and legitimate long wavelength data such as hills. Thus, the output of the profilometer is useful for describing surface roughness for wavelengths up to approximately 30 m (100 ft) (depending upon the detrending routine coefficients), and is inappropriate for measuring slopes. It is generally accepted among the terrain roughness community that wavelengths beyond 18 m (60 ft) have little effect on vehicle dynamics, and are ignored.

5. WAVE NUMBER SPECTRUM ANALYSIS OF DTC TEST COURSES. The various endurance test courses at APG are regularly measured for their surface roughness using the profilometer system. Before these measurements were made, the profilometer system was calibrated on a fixed course with known characteristics. A single pass of the vehicle along the center of each test course is made monthly to obtain a characteristic wave number spectrum. This single pass is considered sufficient since the wave number spectra curves of several passes across the width of a course have shown reproducibility to within 3 to 5 dB of each other (except for shoulder ruts). The courses measured and the resulting wave number spectra are described in the following paragraphs by test center. These curves are plotted in terms of power per unit spatial frequency versus spatial frequency. Hence, the units will be ft^2/cycle per ft = ft^3 for the ordinate and cycles per ft = ft^{-1} for the abscissa. These spectra are general characterizations of the surface roughness of each test course and should be considered typical for that course. Applications that require actual surface roughness at the time of a test (e.g., model validation, ride quality) should conduct a terrain measurement at the time of the test. The wave number spectra for each course are presented in the following paragraphs. Sufficient data exists for most ATC courses such that percentile spectra (10th and 90th) were computed in addition to the average spectrum. The $\pm$3 dB bands around the average spectrum are also shown for each course. These bands are significant because they correspond to spectral control tolerance bands for closed-loop laboratory vibration tests. Thus, control of test course surface roughness (with some exception on the smoother courses where the excursion above or below the tolerance bands represents a difference of a few hundredths of an inch) is maintained at a level similar to that of a laboratory vibration test. The data for the YTC courses is based on a single sample, and bounds cannot be determined.

The area under a wave number spectra curve is related to the overall surface roughness. A steep slope of these curves indicates more low frequency content, which should affect universal joints, transmissions, and other drive train components. A shallow slope, conversely, indicates more high frequency content, which should affect wheel bearings, shock absorbers, and other suspension and structural components.

5.1 ABERDEEN TEST CENTER COURSES

5.1.1 High-Speed Paved Road. This is a 5 km (3 mi) straightway with banked turnaround loops at each end for tests requiring uninterrupted operations such as cooling tests, operation at high speed, etc. The course has a speed limit of 80 km/hr (50 mph) on the straight section (which may be exceeded by written waiver) and 40 km/hr (25 mph) in the turnaround loops. The pavement is continuous asphalt and the course is in the PTA.

The wave number spectrum of this course (fig. 5) is the lowest obtained from the ATC test courses.

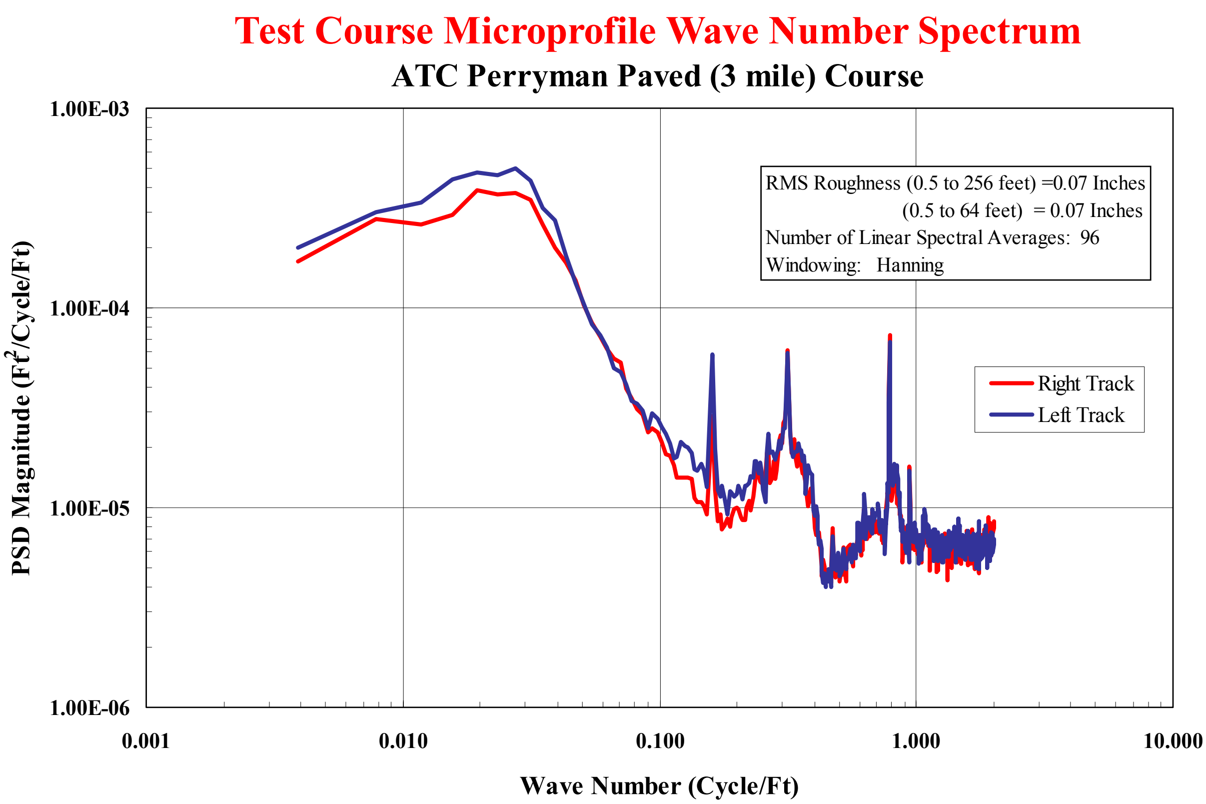

Figure 5. Wave Number Spectrum of Perryman Paved Course.

5.1.2 Munson Gravel Road. This road in the MTA (see TOP 1-1-011) is a loop of about 3 km (2 mi) with left and right curves. The surface is compacted gravel and dirt, maintained by grading.

The wave number spectrum of this course (fig. 6) is higher than that of the high-speed paved road, indicating higher overall roughness. The slope of the gravel road PSD is also more shallow, indicating proportionately more high frequency contact.

5.1.3 Perryman Test Area Course A. A 3.9-km (2.4-mi) secondary road in the PTA is used for tests of various types of vehicles. This road has sharp and sweeping turns typical of unimproved country roads. The course is maintained by grading and filling with native soil.

The wave number spectrum of this course (fig. 7) is slightly higher than that of the gravel road, indicating more overall roughness. The slopes of both curves are the same, indicating the same proportion of frequency content.

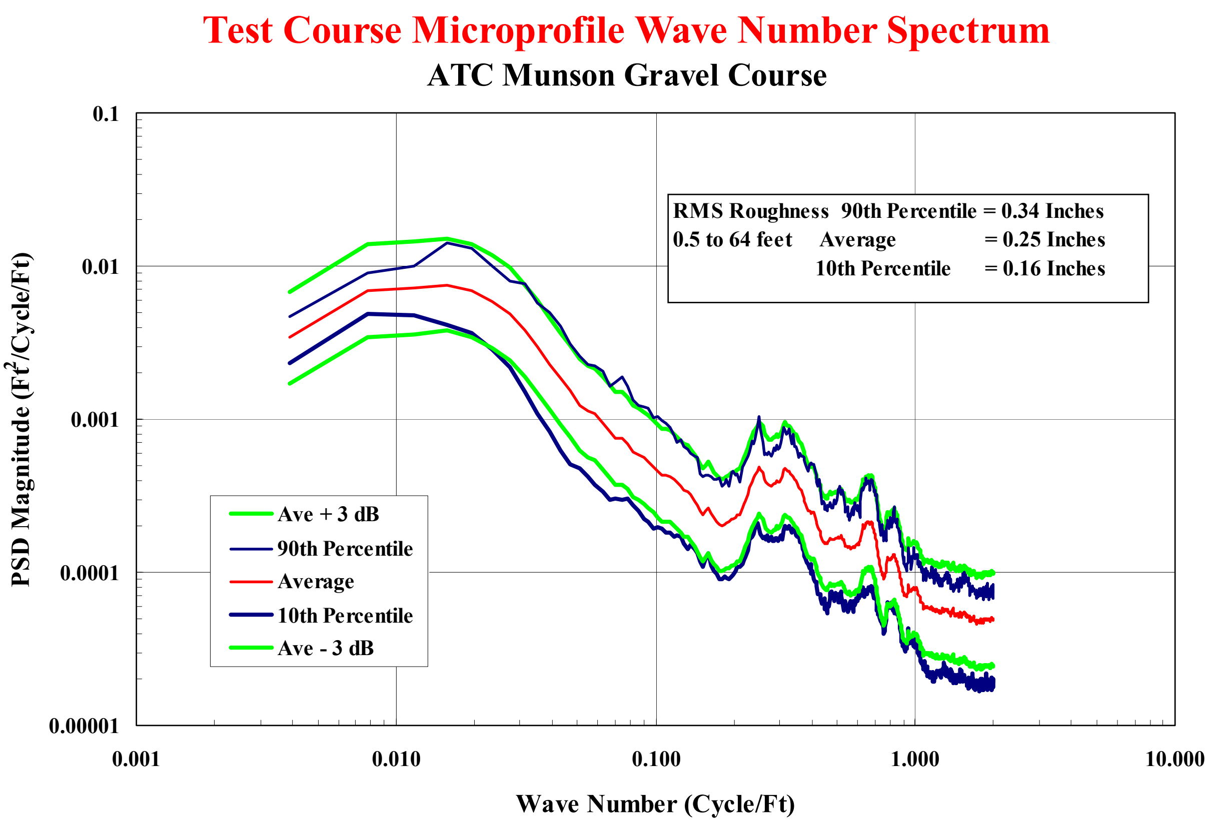

Figure 6. Munson Gravel Course master spectrum.

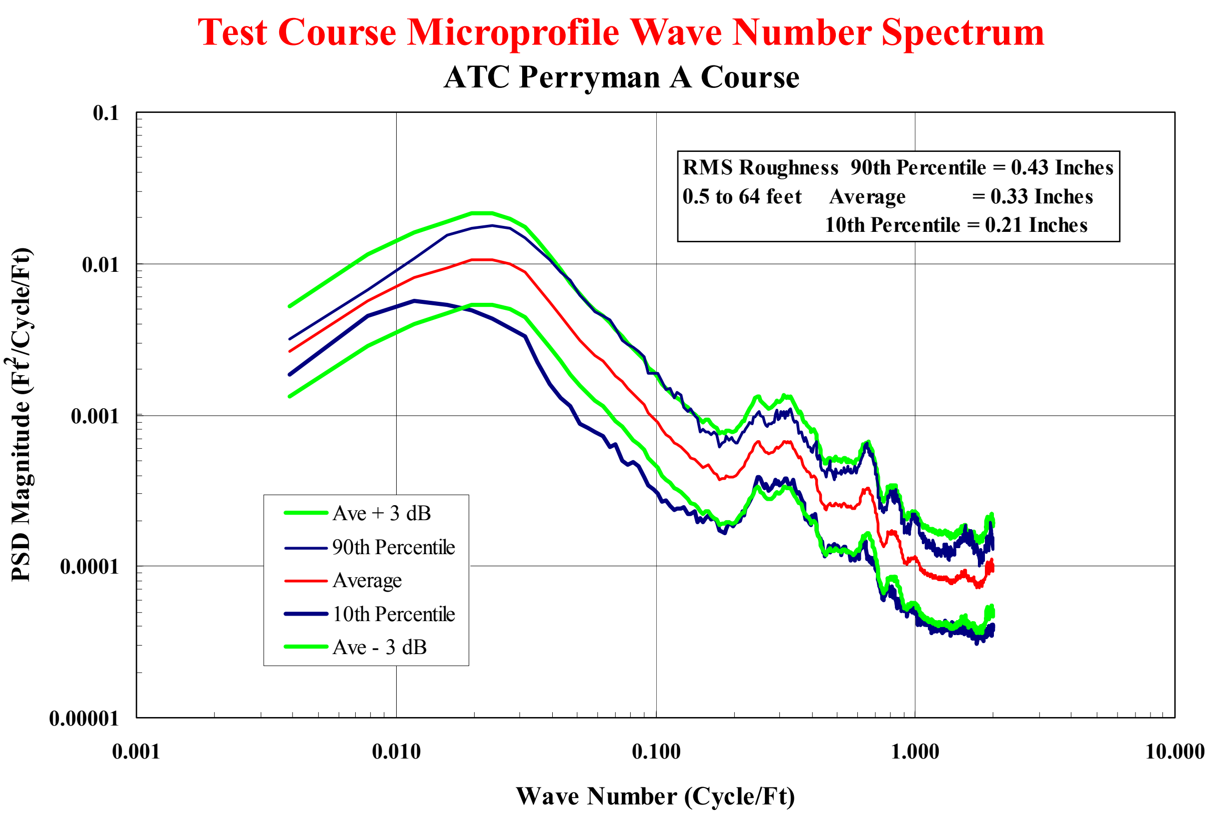

Figure 7. Perryman A Course master spectrum.

5.1.4 Perryman No. 1 Course. This is a moderate course with a substantial roadbed primarily of quarry spall and bank gravel. The loop indicates both sharp sweeping curves, and the surface ranges from smooth to rough; roughness is due to potholes, washboard, and rutting. Potholes and other sharp depressions are normally limited to 15-cm (6-in.) deep by filling with crushed stone.

The wave number spectrum of this course is shown in Figure 8. This curve has the same slope as Perryman A, but is slightly higher.

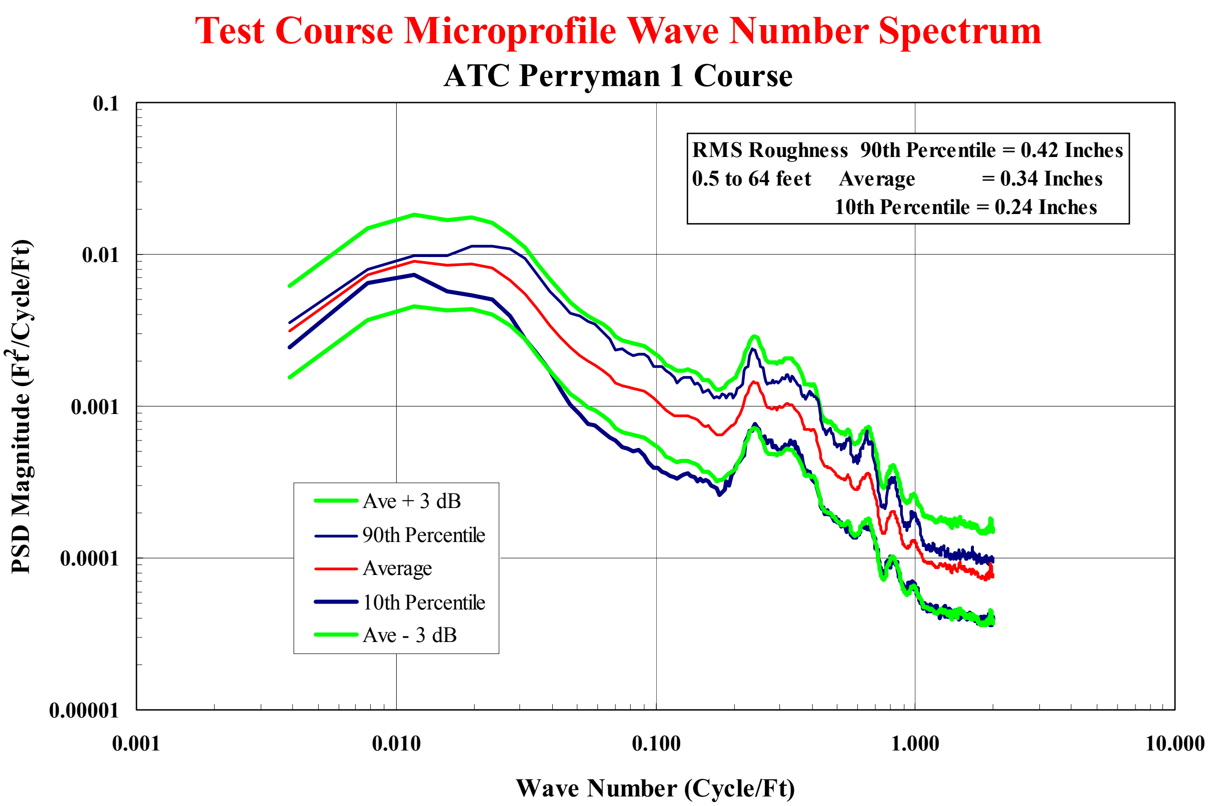

Figure 8. Perryman No. 1 Course master spectrum.

5.1.5 Perryman No. 2 Course. This course is laid out in a loop of moderately irregular terrain. The native soil includes sassafras loam, a silty loam with 17.3-percent clay content, and sassafras silt loam with less than 15-percent clay. Surfaces range from smooth to rough, and there are sweeping turns. Under wet conditions, severe mud is present; when dry, the course is extremely dusty. Potholes and depressions are limited to 46-cm (18-in.) deep.

The wave number spectrum of this course (fig. 9) is higher than that of Perryman No. 1 Course, and the slope is steeper than that of Perryman No. 1 Course.

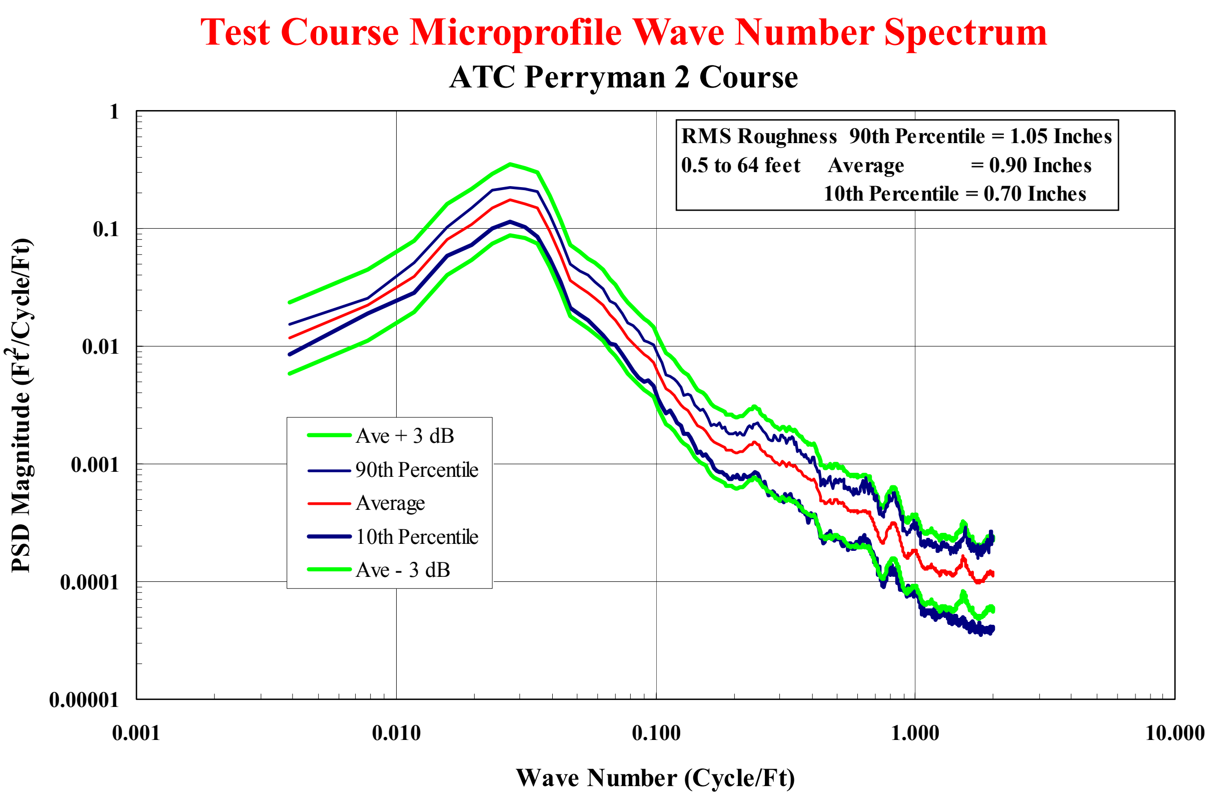

Figure 9. Perryman No. 2 Course master spectrum.

5.1.6 Perryman No. 3 Course. This is a rough course of native soil similar to the soil of Perryman No. 2 Course. Mud ranges from light (with free water) to cohesive. Although dust is severe when the course is dry, there is always mud in some areas. The profile is a series of repetitive humps spaced approximately 45 meters (148 feet) to 60 meters (197 feet) apart. Potholes and depressions are limited to 90-cm (36-in.) deep.

The wave number spectrum of Perryman No. 3 Course, shown in Figure 10, is higher than any other and has the steepest slope encountered.

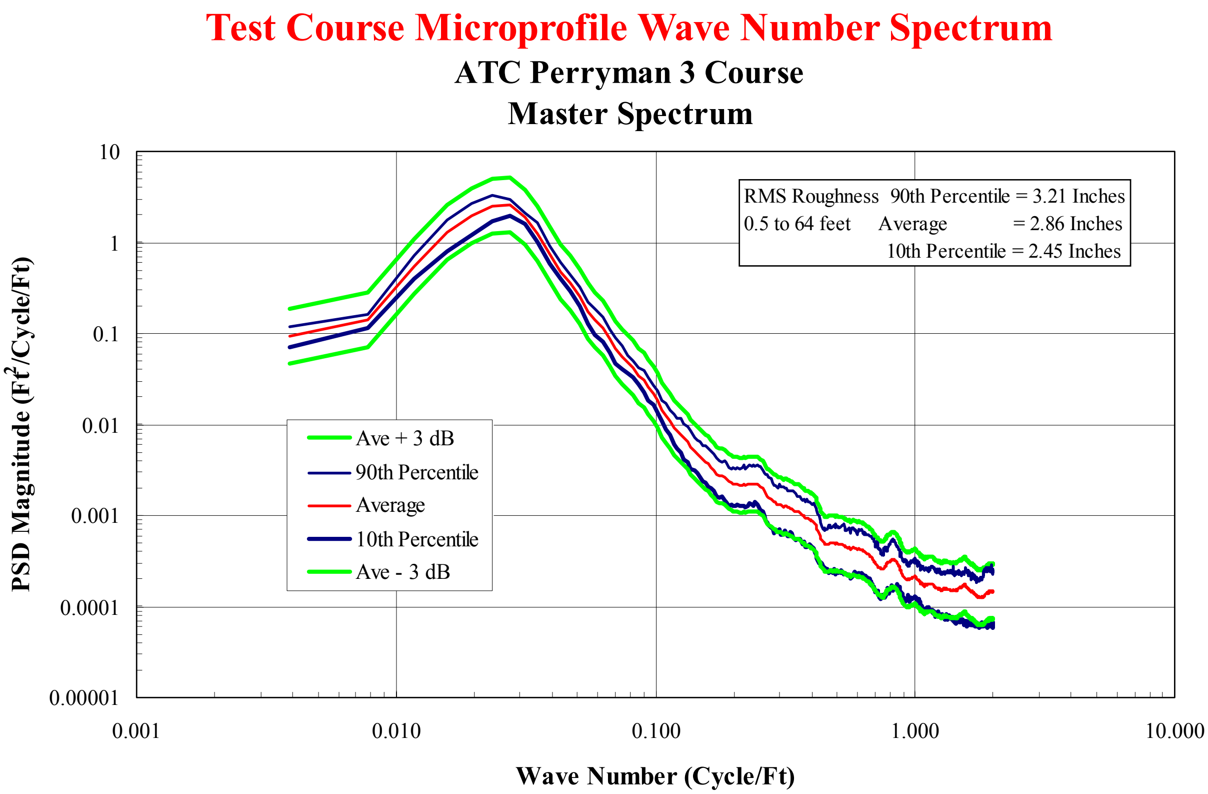

Figure 10. Perryman No. 3 Wave Number Spectrum.

5.1.7 Perryman No. 4 Course. This is a tract of extremely rough terrain including marshy areas with swamp-type vegetation. The profile is a series of main repetitive humps spaced in a pattern, the horizontal distance from high to low averaging about 4 m (13.8 ft) and the vertical distance from low to high averaging about 3.7 m (12.5 ft). The soil of the course is native soil as described for the Perryman 2 course. A wave number spectrum is not available.

5.1.8 Churchville Area Courses. These courses are characterized by a series of steep hills with slopes up to 29 percent.

a. Figures 11 and 12 are wave number spectrum plots of Churchville B Course, which consists of grades up to 29 percent. The terrain is moderate to rough native soil and stone ranging from muddy-to-dusty, depending on the weather. The rough portion of Churchville B Course is significantly more severe than the remainder of the course.

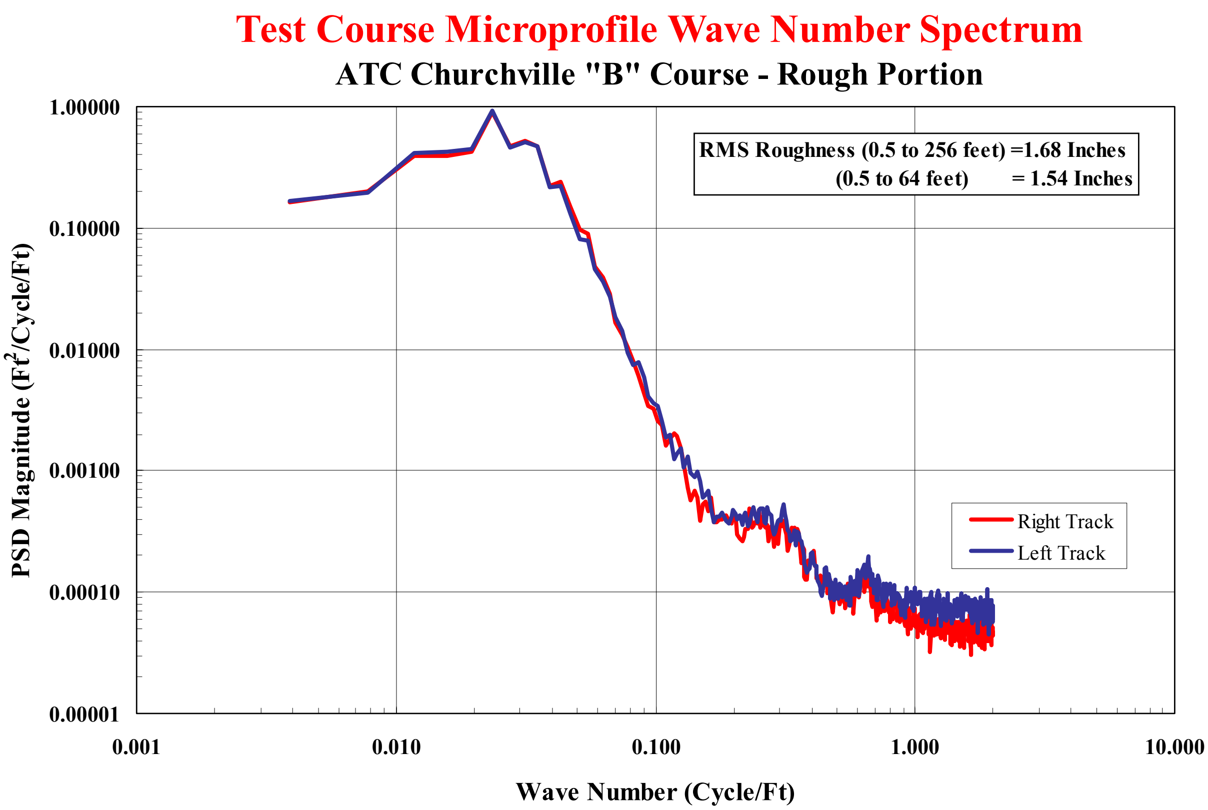

Figure 11. Churchville B Course, “rough” portion spectrum.

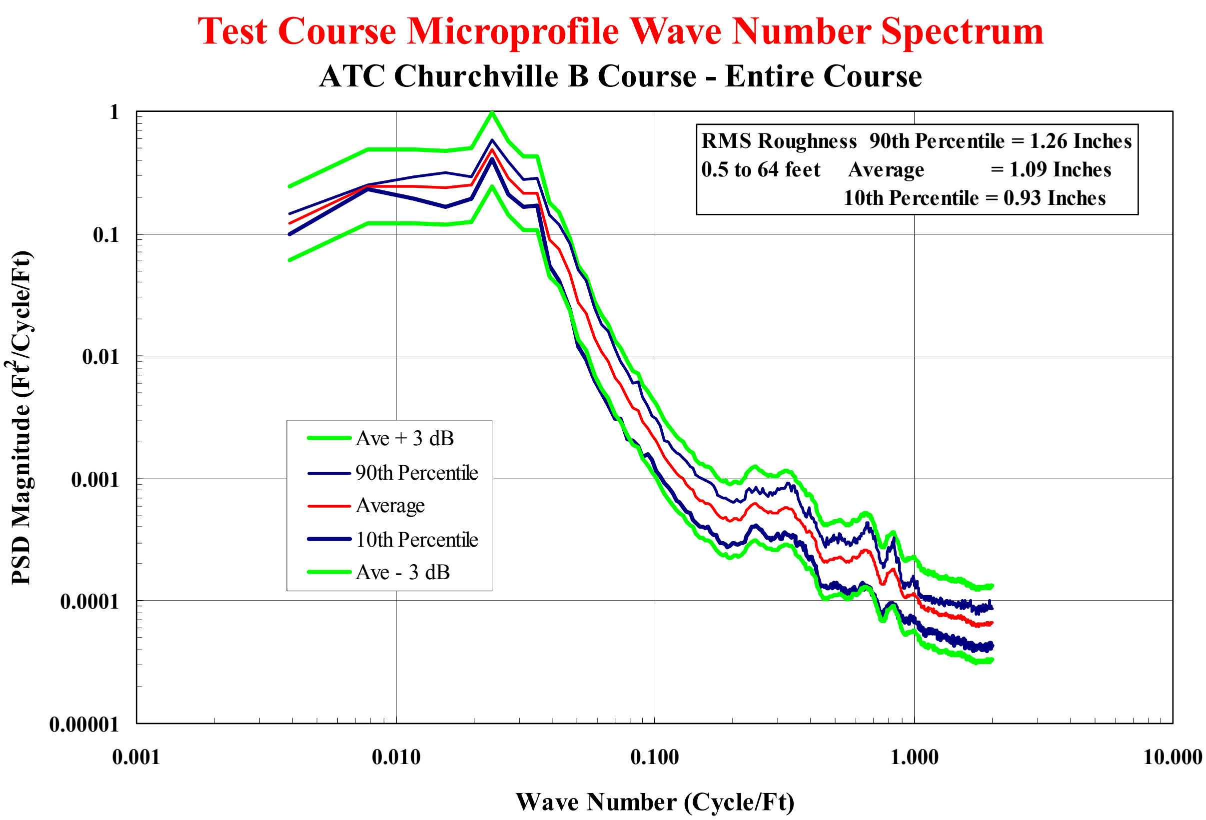

Figure 12. Churchville B Course, entire course spectrum.

b. Figure 13 is a wave number spectrum plot of Churchville C Course, which is a 2.4-km (1-1/2-mi) secondary road test course with controlling grades of 10 percent and turnarounds at each end. This wave number spectrum is about the same as that of the Munson gravel road.

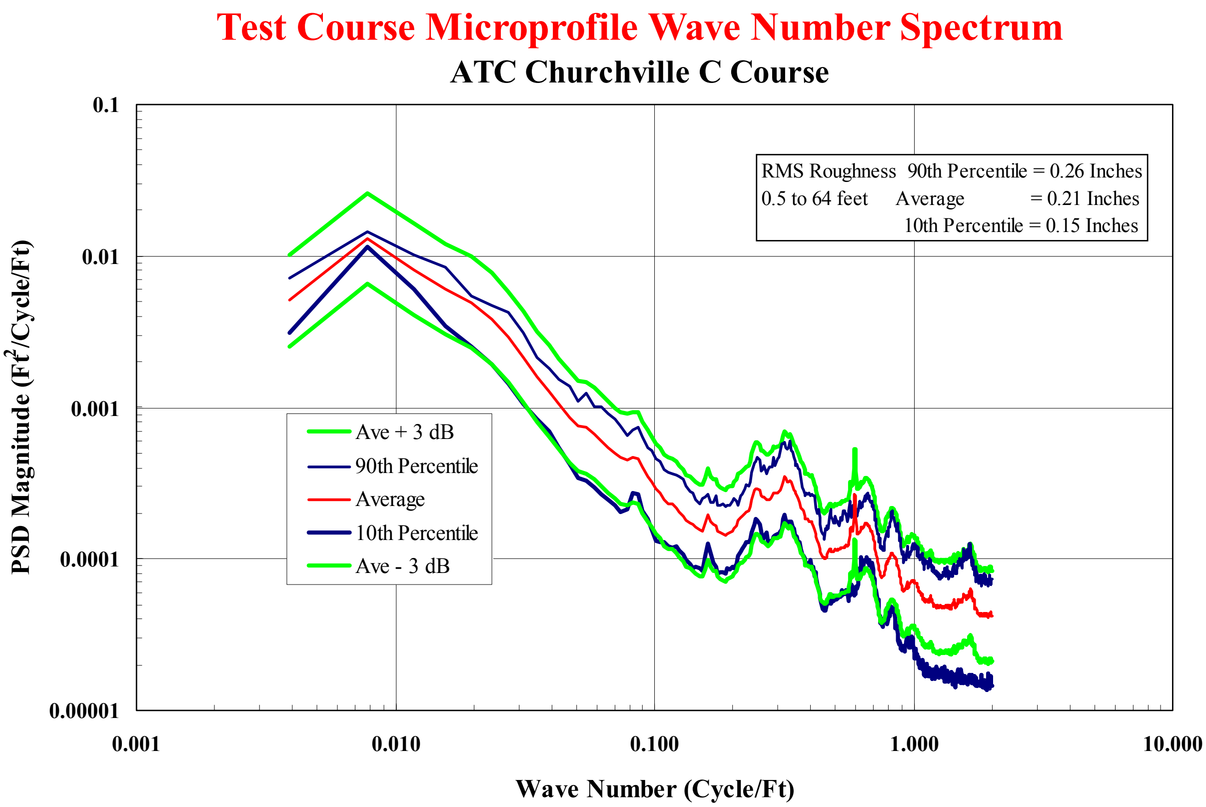

Figure 13. Churchville C Course spectrum.

5.1.9 Belgian Block Course. This is a paved course with unevenly laid granite blocks forming an undulating surface. It duplicates a rough cobblestone road such as is found in many parts of the world. About 1.2 km (3/4 mi) long, the course is useful as a standard rough road for accelerated tests of wheeled vehicles. It is generally included in cycles of courses used for vibration studies. The motion imparted to a vehicle is a random combination of roll and pitch and high frequency vibrations.

The wave number spectrum of the Belgian Block Course is shown in Figure 14. The peak at 0.295 cycle/m (0.0899 cycle/ft), a wavelength of 3.4 m (11.1 ft), indicates periodic undulation at this frequency.

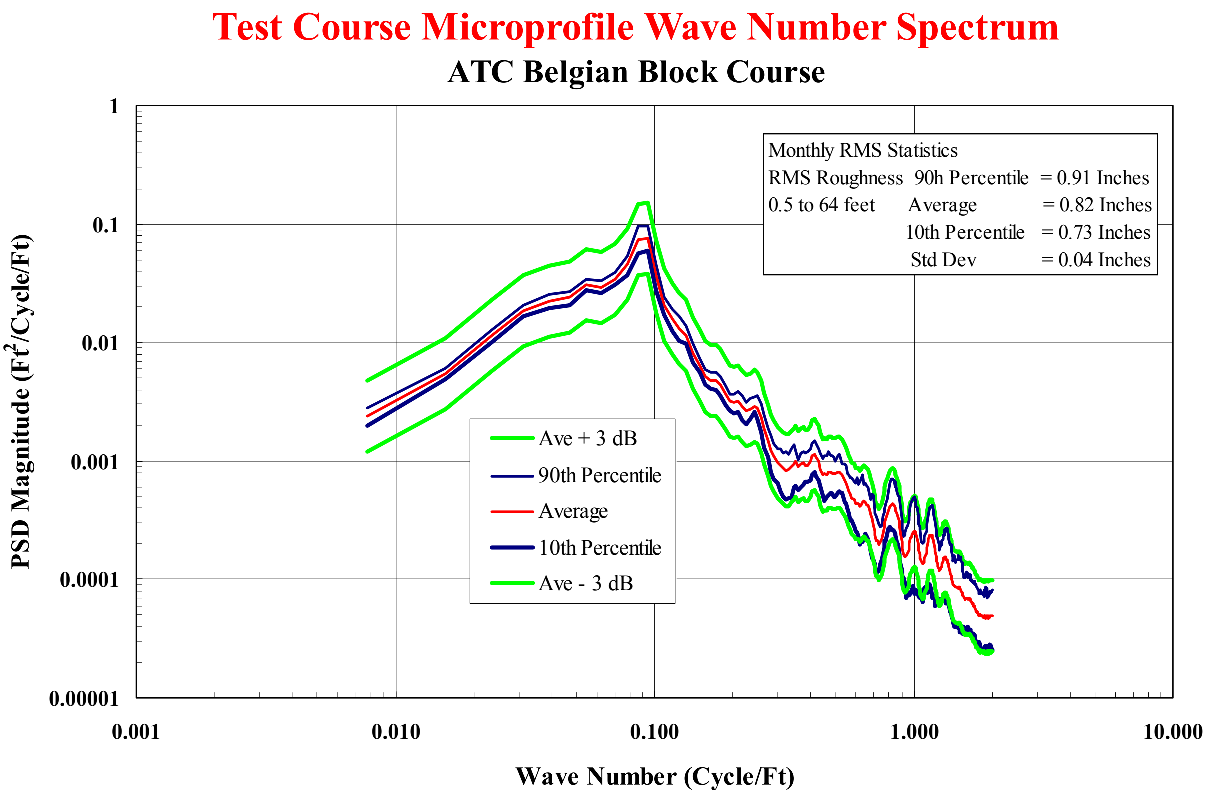

Figure 14. Belgian Block Course spectrum.

5.1.10 Overlay of ATC Test Courses

The average wave number spectra for the ATC courses described above are combined in figure 15 and are shown with the rms roughness integration band limits.

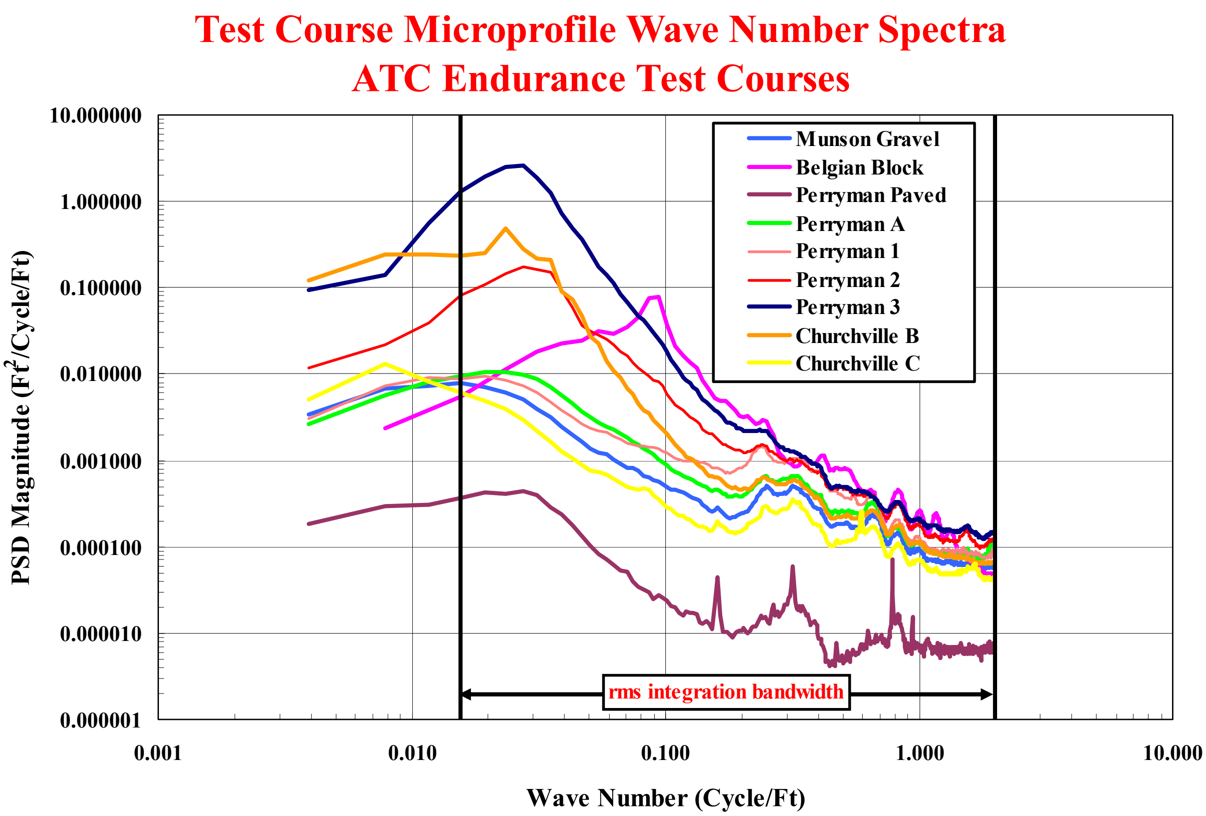

Figure 15. Overlay of ATC Endurance Test Courses

5.2 YUMA TEST CENTER COURSES

5.2.1 Laguna Paved (formerly Paved Dynamometer)

The Laguna Paved Course is a 3.6 km (2.25-mile), smooth, near-level (0.8-percent grade), 9-meter (30-ft) wide roadway with 152-meter (500-ft) radius turnarounds at each end, surfaced with high-strength asphalt. Performance and durability tests of vehicles are performed on this course. The wave number spectrum is presented in Figure 16.

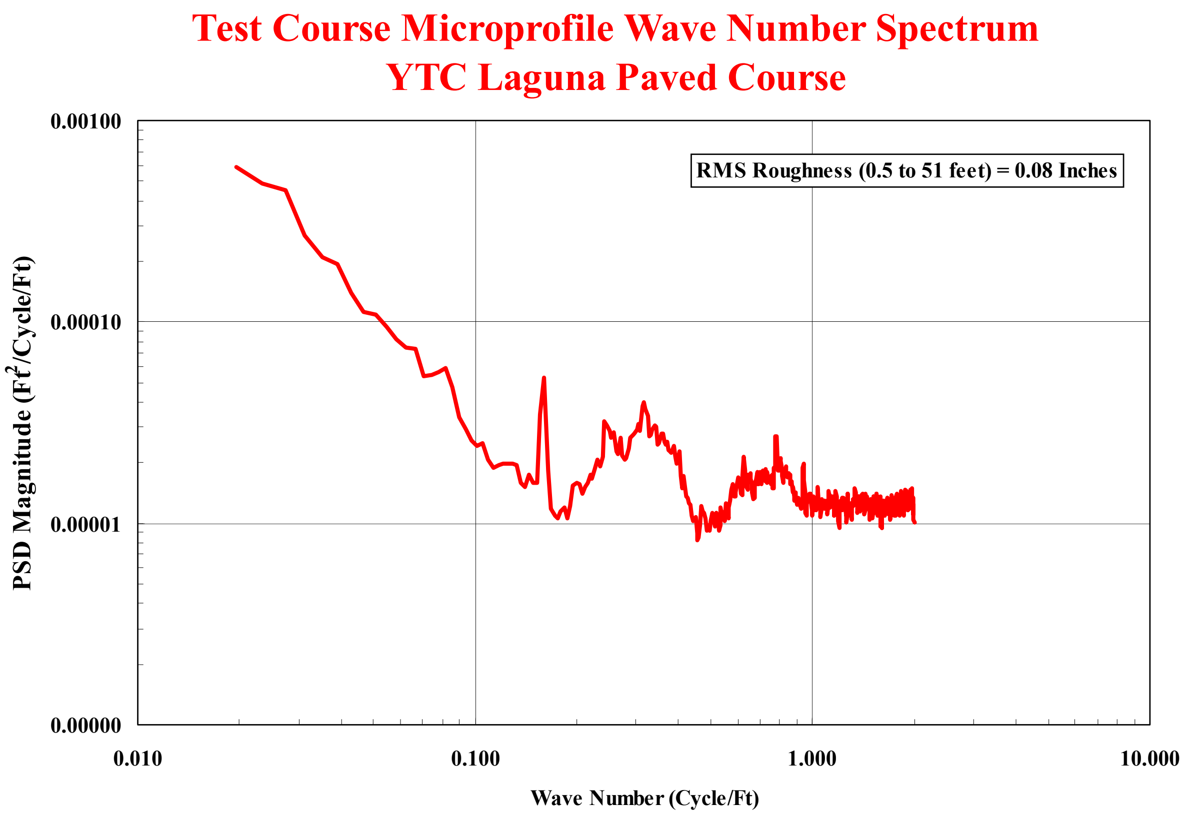

Figure 16. YTC Laguna Paved Course wave number spectrum.

5.2.2 KOFA Level Gravel (previously Truck Gravel Loop)

This course is designed to represent an improved secondary gravel road. The course is a nearly level oval loop 5 km (3.1 mi) long and 12 meters (40 ft) wide. The course is composed of quarried road construction grade gravel that has been compacted and graded. The wave number spectrum is presented in Figure 17.

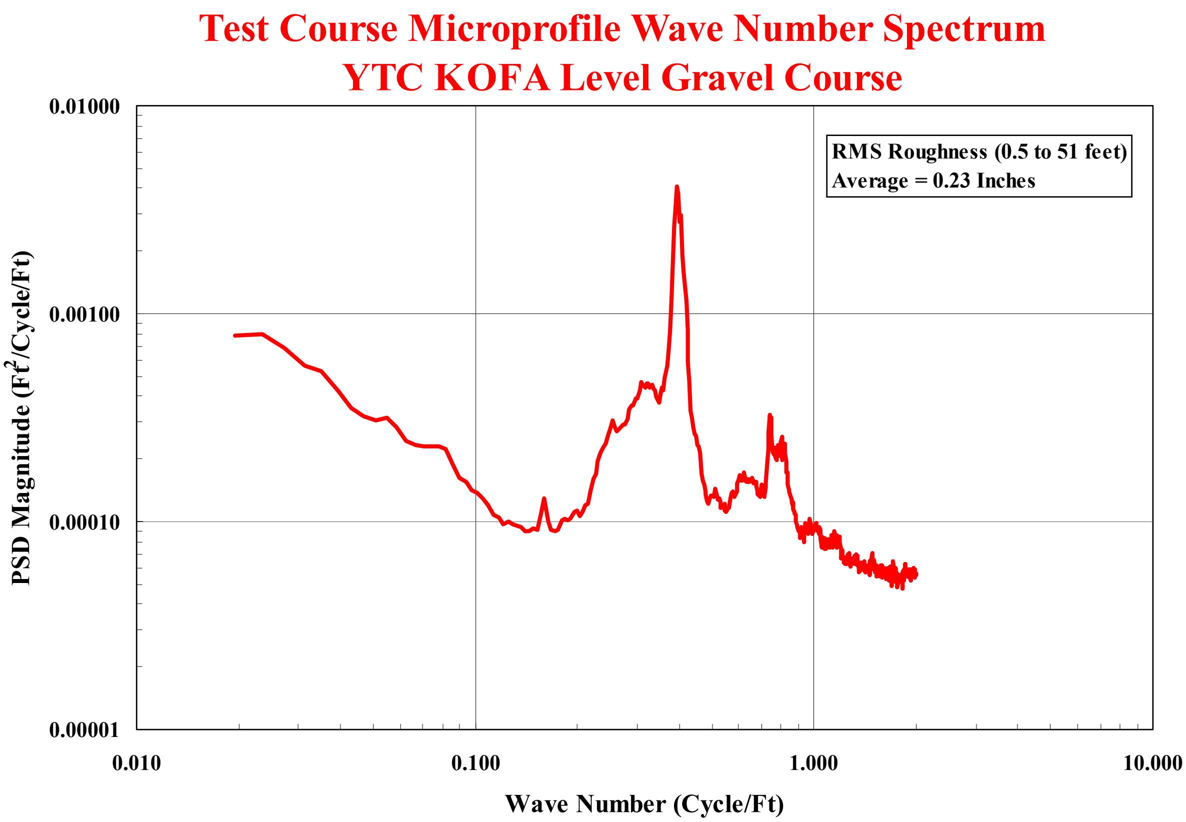

Figure 17. KOFA Level Gravel Course wave number spectrum.

5.2.3 Laguna Level Gravel (formerly Old U.S. Highway 95)

Laguna Level Gravel is an abandoned portion of state route 95 that runs through Yuma Proving Ground. The abandoned highway is a compacted graded gravel road bed. The course is used primarily for RAM and performance testing of both wheeled and tracked vehicles. The road bed is composed of Riverbend Family-Carrizo Family Complex soils which are very gravelly. The course is 12.2 km (7.6 mi) in length with a loop at either end of the course. The overall length of the course is 13.5 km (8.4 mi). The wave number spectrum is presented in Figure 18.

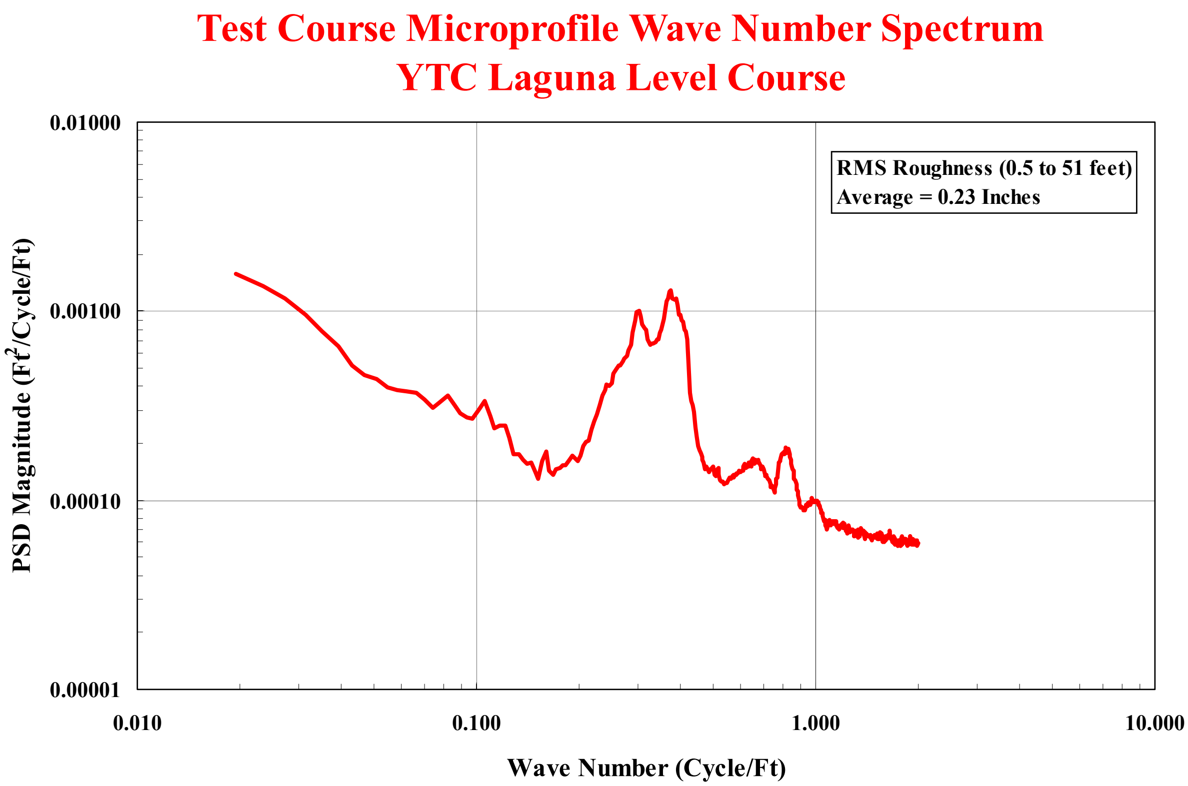

Figure 18. Laguna Level Course wave number spectrum.

5.2.4 Patton Level Gravel (formerly Tank Gravel)

The Patton Level Gravel is a 5.8 km (3.6 mi) loop and with a surface of quarried road construction grade gravel that has been compacted and graded. The four landforms that the Patton Level Gravel course crosses are dissected fan, alluvial fan and terrace, and sand dune. The course is used for testing track-laying vehicles and heavy trucks under conditions similar to a secondary graveled road. The course consists of short, straight sections and curves of varying radii, which provide a test of steering mechanisms at medium vehicle speeds. The wave number spectrum is presented in Figure 19.

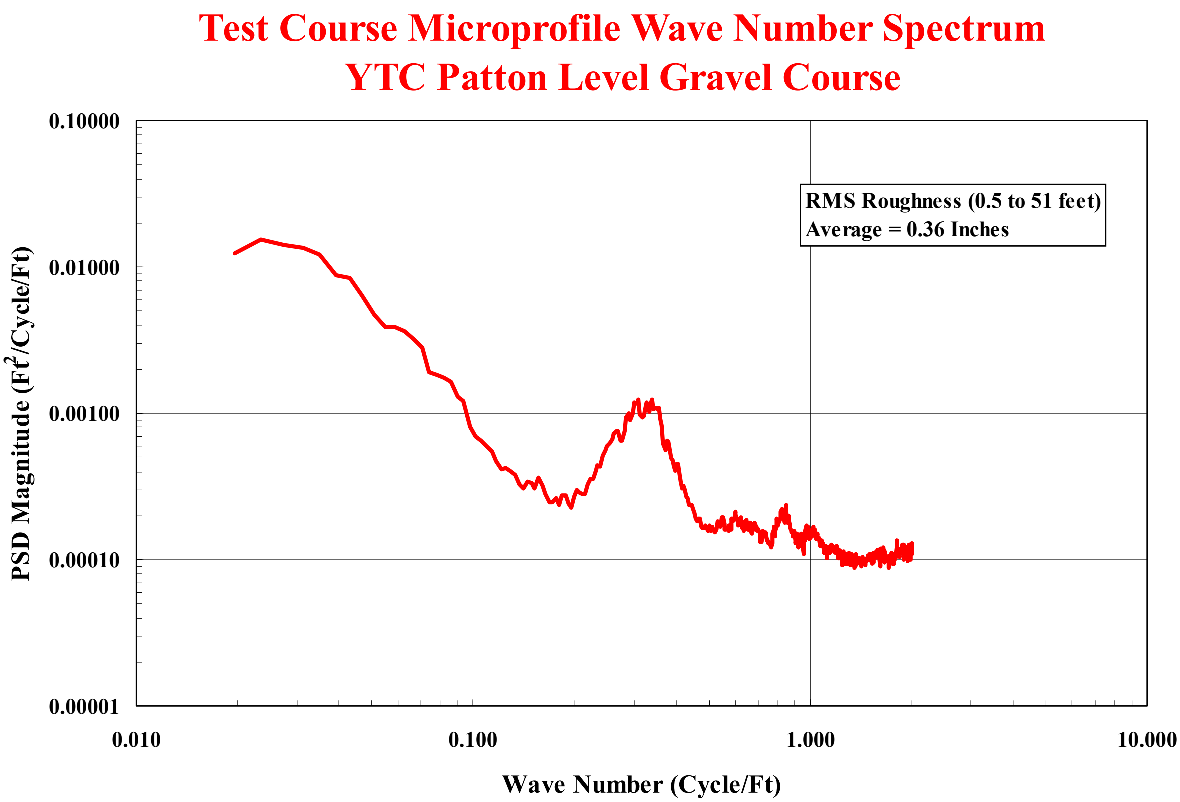

Figure 19. Patton Level Gravel Course wave number spectrum.

5.2.5 Patton Hilly Trails (formerly Tank Hills)

Patton Hilly Trails is a 4.0 km (2.5 mi) loop course that crosses surfaces composed of sand, gravel, and exposed rock. This course contains many steep slopes with grades up to 40% and lengths up to 61 meters (200 ft). The three prominent landforms that the Patton Hilly Trails course crosses are bedrock, dissected fan, and alluvial fan. The surface cover of the upper 5 cm (2 in) of these landforms are mostly subrounded to angular gravel that range from poorly-graded gravel with either silt, sand or clay to well-graded gravel with silt [Unified Soil Classification System (USCS): GP, GP-GM, GC to GW-GM]. These landforms also exhibit three different soil types, which include Lithic Torriorthents developed on bedrock, Gunsight-Chuckawalla developed on dissected fan surfaces, and Cristobol-Gunsight found on the alluvial fan surface. The wave number spectrum is presented in Figure 20.

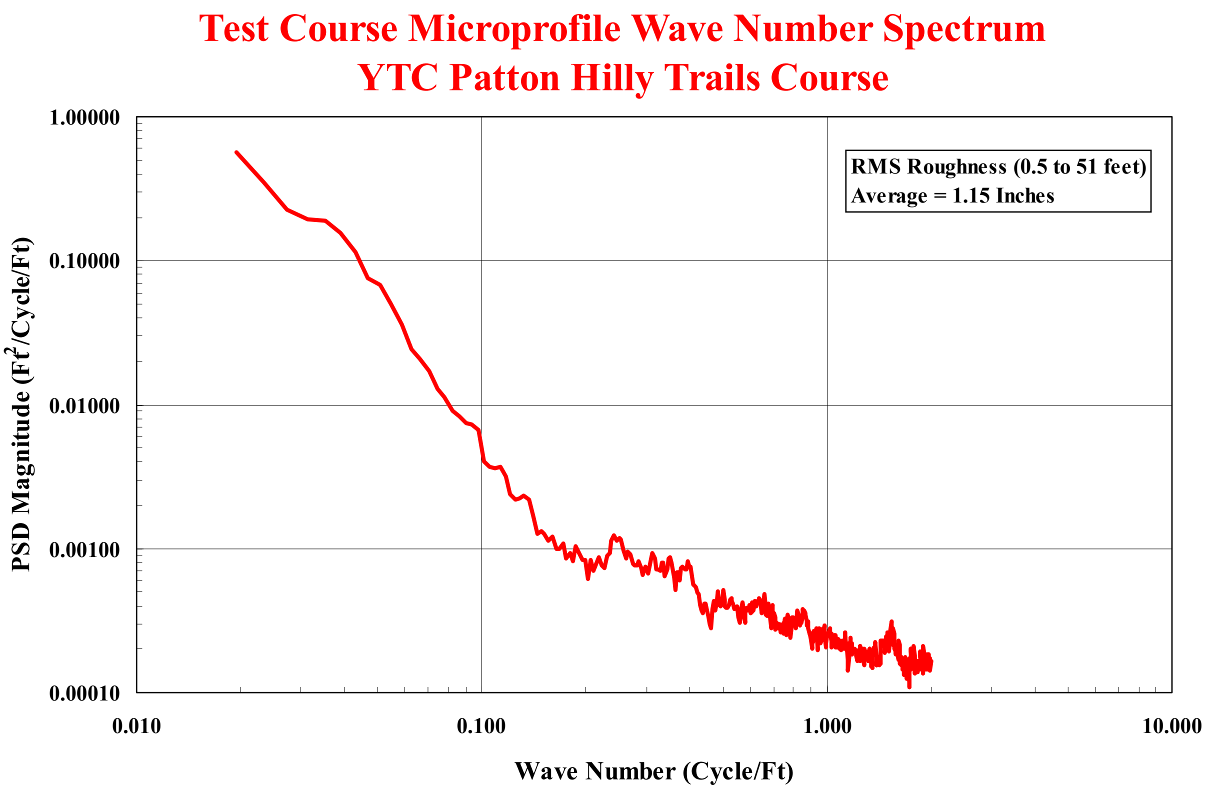

Figure 20. Patton Hilly Trails Course wave number spectrum.

5.2.6 Patton Level Trails (formerly Tank Level Cross Country)

The Patton Level Trails is a 10.9 km (6.8 mi) loop and traverses level sandy terrain with many bumps to provide a severe test of vehicle suspensions with moderate loads on the drive train. The three prominent landforms that the Patton Level Trails course crosses are alluvial fans, alluvial plains, and washes. The surface cover of the upper 5 cm (2 in) of these landforms are mostly subrounded to angular gravel that range from poorly-graded gravel with either silt, sand or clay to well-graded gravel with silt [USCS: GP, GP-GM, GC to SM, SP-SM, SP]. These landforms exhibit three different soil types, which include Cristobol-Gunsight found on the alluvial fan surface, Superstition-Rositas developed on alluvial plains, and Riverbend developed on alluvial terraces and washes. The wave number spectrum is presented in Figure 21.

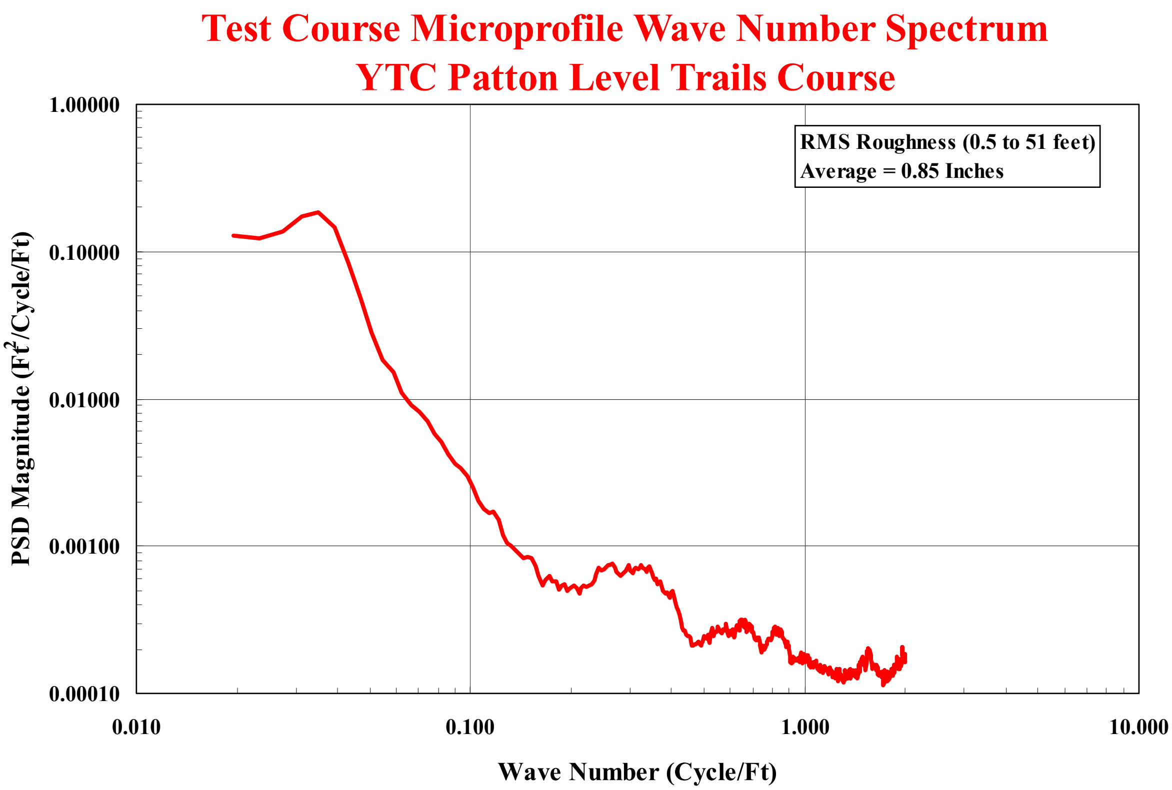

Figure 21. Patton Level Trails Course wave number spectrum.

5.2.7 Patton Hilly Gravel (formerly Truck High Hills)

The Patton Hilly Gravel course is a 4.3 km (2.7 mi) course containing many steep slopes with grades up to 30% and segments up to 122 meters (400 ft). Course surfaces vary from sand and gravel to exposed bedrock. The two prominent landforms that the Patton Hilly Gravel course crosses are alluvial wash and fan, and other less common landforms consisting of bedrock, dissected fan, and alluvial terrace. The surface cover of the upper 5 cm (2 in) of all these landforms are mostly subrounded to angular gravel that range from poorly-graded gravel with either silt, sand or clay to well-graded gravel with sand [USCS: GP, GP-GM, GC to GW]. The two dominant landforms exhibit Cristobol-Gunsight soil found on the Qf2 alluvial fan surface and Carrizo soil developed in alluvial washes. The wave number spectrum is presented in Figure 22.

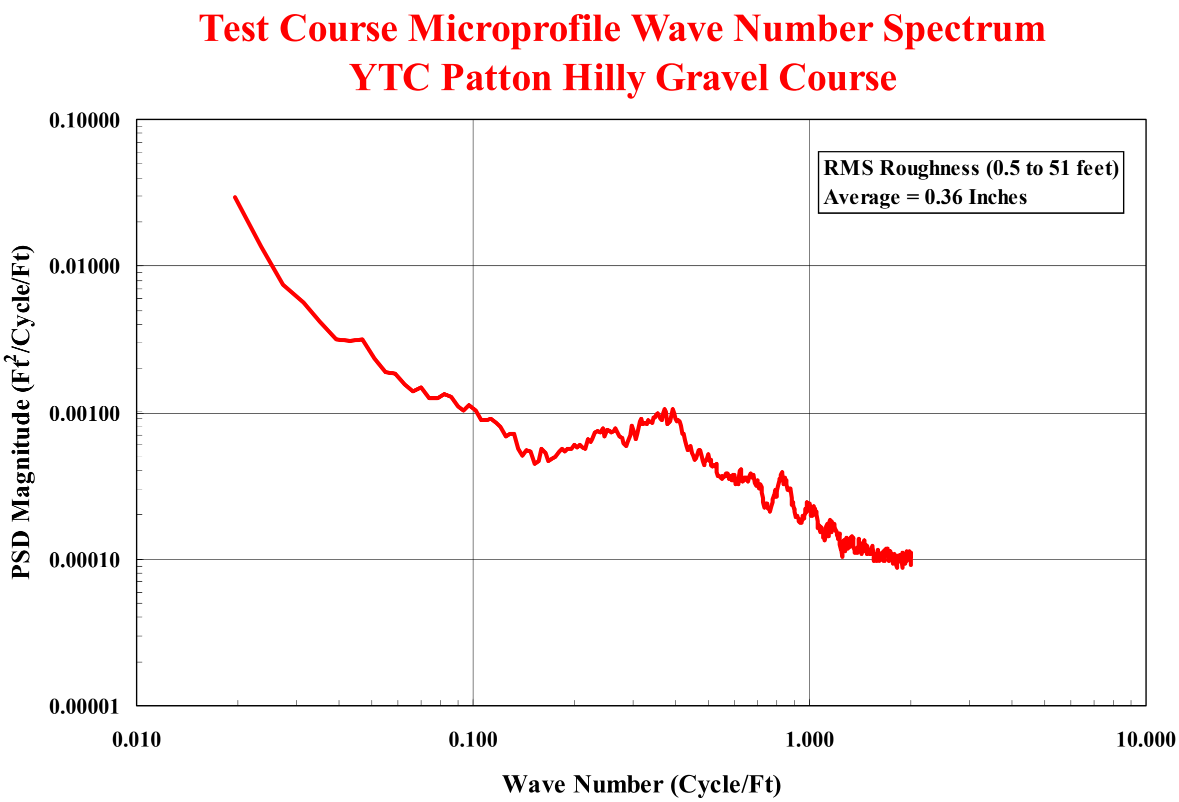

Figure 22. Patton Hilly Gravel Course wave number spectrum.

5.2.8 Laguna Level Trails East/Laguna Level Trails West (formerly Truck Level Cross Country East Loop/Truck Level Cross Country West Loop)

The Laguna Level Trails East endurance course consists of a 5.1 km (3.2 mi) loop course, whereas the Laguna Level Trails West is 9.8 km (6.1 mi) in length. Both loops cross surfaces composed mostly of sand and gravel. The Laguna Level Trails East has a slightly rough, relatively hard sand and gravel surface, and is suitable for tractor-trailer combinations and commercial trucks. The Laguna Level Trails West has more gravel and sand washes than the East Loop, and is suitable for commercial trucks. Both courses are nearly level except for gentle embankments where alluvial washes are crossed. The four landforms that the Laguna Level Trails East/West courses cross are dissected fan, alluvial fan and terrace, and wash. The surface cover of the upper 5 cm (2 in) of these landforms are mostly subrounded to angular gravel that range from poorly-graded gravel with either silt, sand or clay to well-graded gravel with sand [USCS: GP, GP-GM, GC to GW]. These landforms also exhibit four different soil types, which include Carsitas-Chuckawalla developed on dissected fan surfaces, Gunsight-Chuckawalla found on alluvial fan/terrace surfaces, Riverbend developed on terraces, and Carrizo formed within alluvial washes. The wave number spectra are presented in Figures 23 and 24.

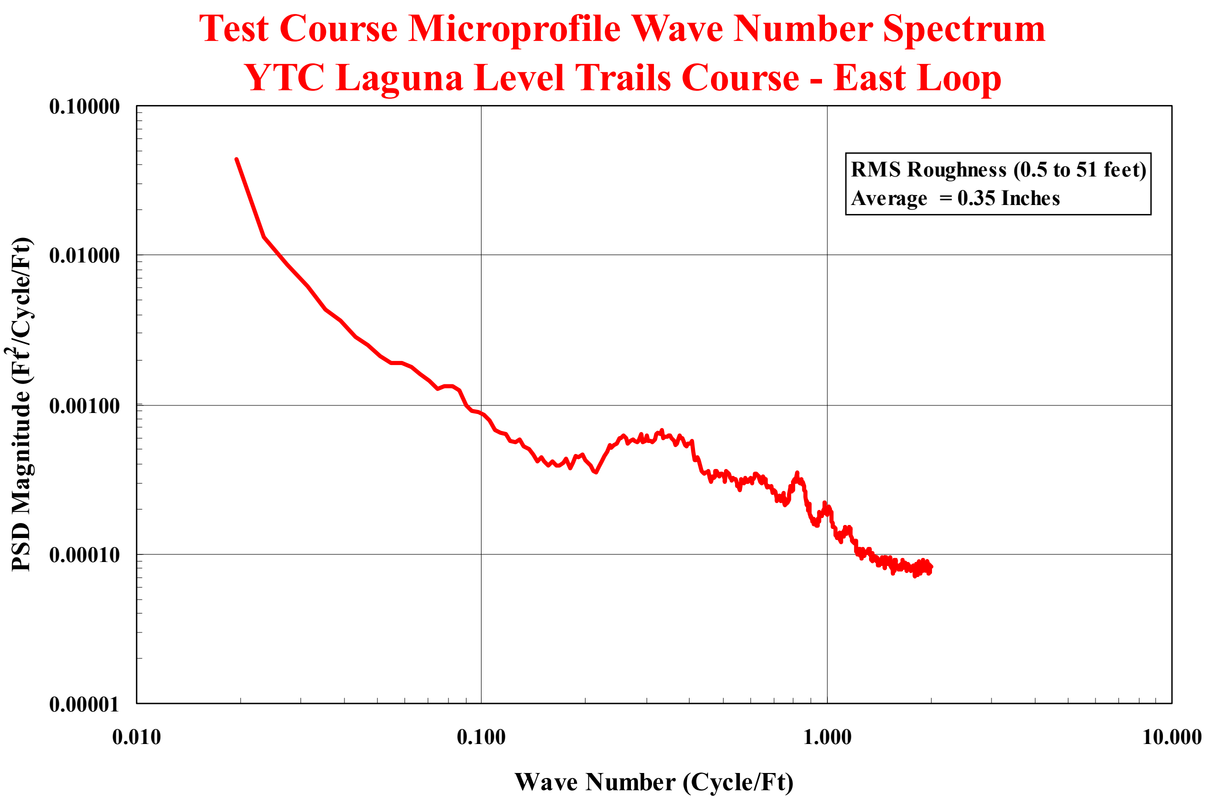

Figure 23. Laguna Level Trails Course – East Loop wave number spectrum.

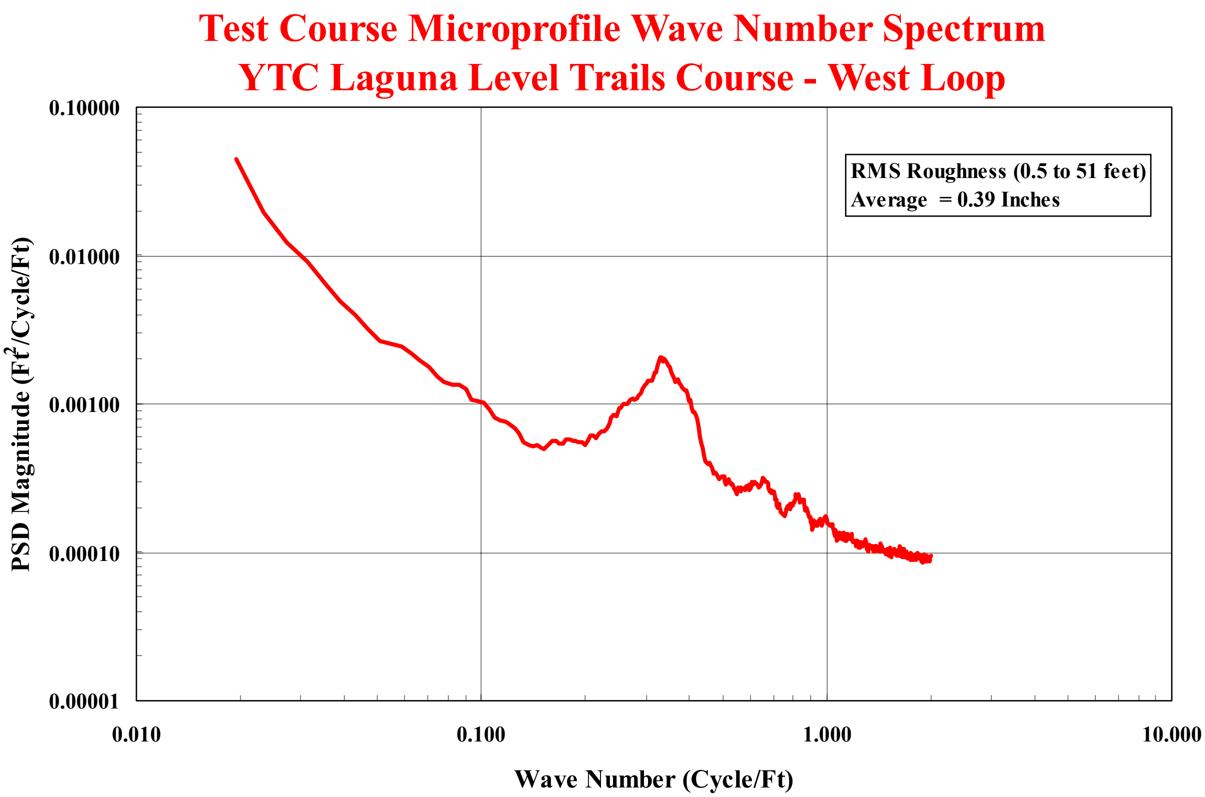

Figure 24. Laguna Level Trails Course – West Loop wave number spectrum.

5.2.9 Laguna Hilly Trails (formerly Truck Rolling Hills)

The Laguna Hilly Trails is a 3.2 km (2.0 mi) loop course that traverses hilly terrain composed of loose rock, gravel, and sand with grades up to 30% with a length of 30 meters (100 ft). The four landforms that the Laguna Hilly Trails course crosses are bedrock, dissected fan, alluvial terrace, and alluvial wash. The surface cover of the upper 5 cm (2 in) of these landforms are mostly subrounded to angular gravel that range from poorly-graded gravel with either silt, sand or clay to well-graded gravel with sand [USCS: GP, GP-GM, GC to GW]. These landforms also exhibit four different soil types, which include Lithic Torriorthents found on bedrock, Gunsight-Chuckawalla developed on dissected fan surfaces, Cristobol-Gunsight on alluvial terraces, and Carrizo found within washes. The wave number spectrum is presented in Figure 25.

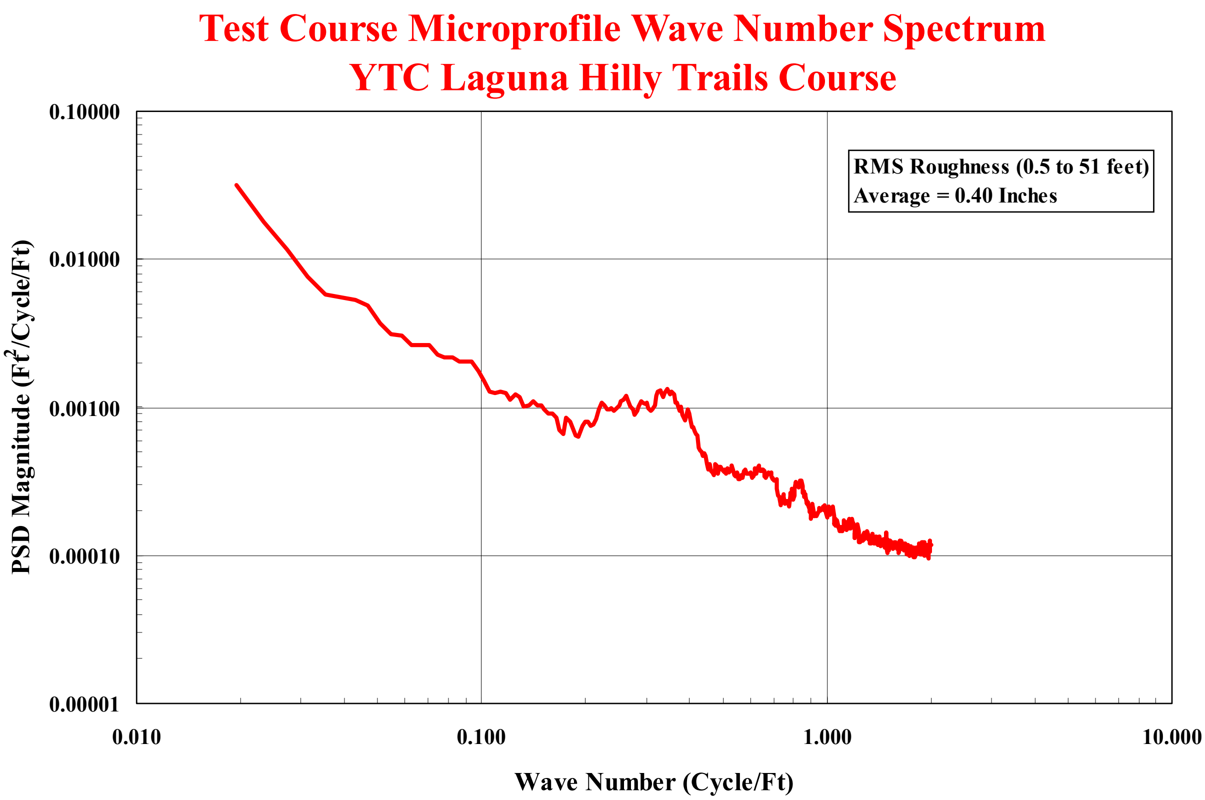

Figure 25. Laguna Hilly Trails wave number spectrum.

5.2.10 Middle East

This composite course is 33.1 km (20.6 mi) in length and replicates the terrain of a Middle Eastern country**.** The most common soil complex is the Riverbend Family-Carrizo Family Complex composed of cobbly coarse loamy sands found in the wash bottoms. The second most common soil complex is the Gunfight Family-Chuckawalla Family Complex soils composed of gravely-loamy soils found on the terrace side slopes. The third most common soil complex is the Chuckawalla Family Gunfight Family Complex composed of fine very gravely loamy sands found on the top of terraces. The last soil complex encountered is the Gilman Family-Harqua Family -Glenbar Family Complex composed of very fine loamy silty soils found on the basin floors of the course. Only certain portions of this course were measured due to the severity of the terrain (profilometer mobility). The start section is 3.2 km (2 mi) long and has hilly washes that lie perpendicular to the course. Section A is 3.5 km (2.2 mi) long traveling counter clockwise from the West Access Road off Old Pole Line Road. Section B is 2.3 km (1.4 mi) long traveling counter clockwise from the East Access Road off Old Pole Line Road (near Contraves Station). The Wash/End section is 3.5 km (2.2 mi) long and goes through a wash to the start/finish of the course. The wave number spectra are presented in Figures 26 through 29.

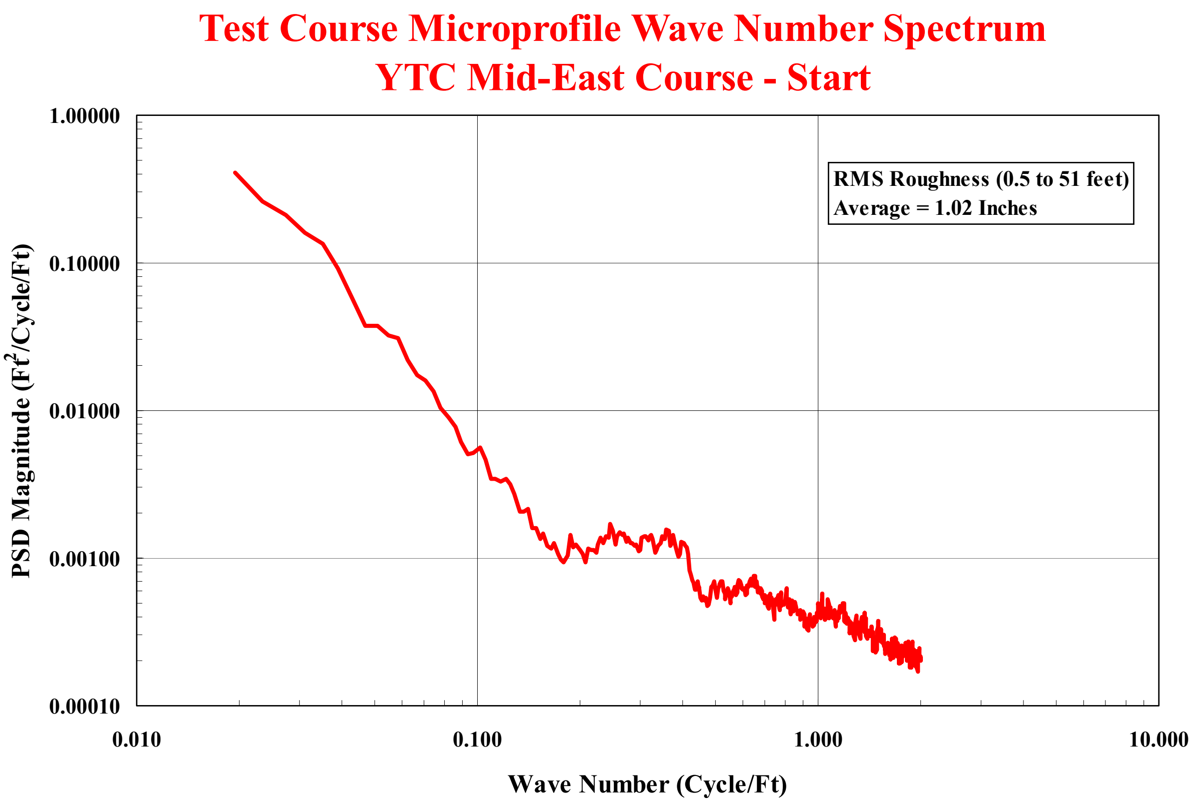

Figure 26. Mid-East Course – Start wave number spectrum.

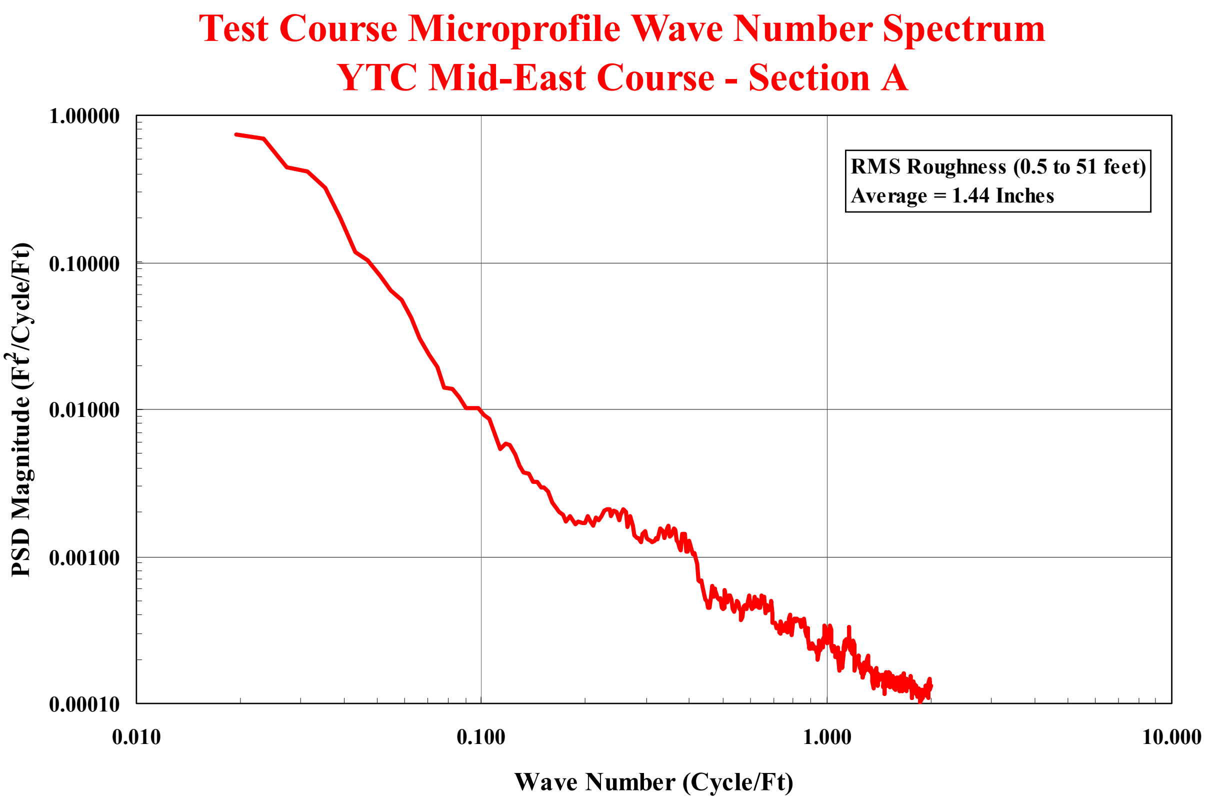

Figure 27. Mid-East Course – Section A wave number spectrum.

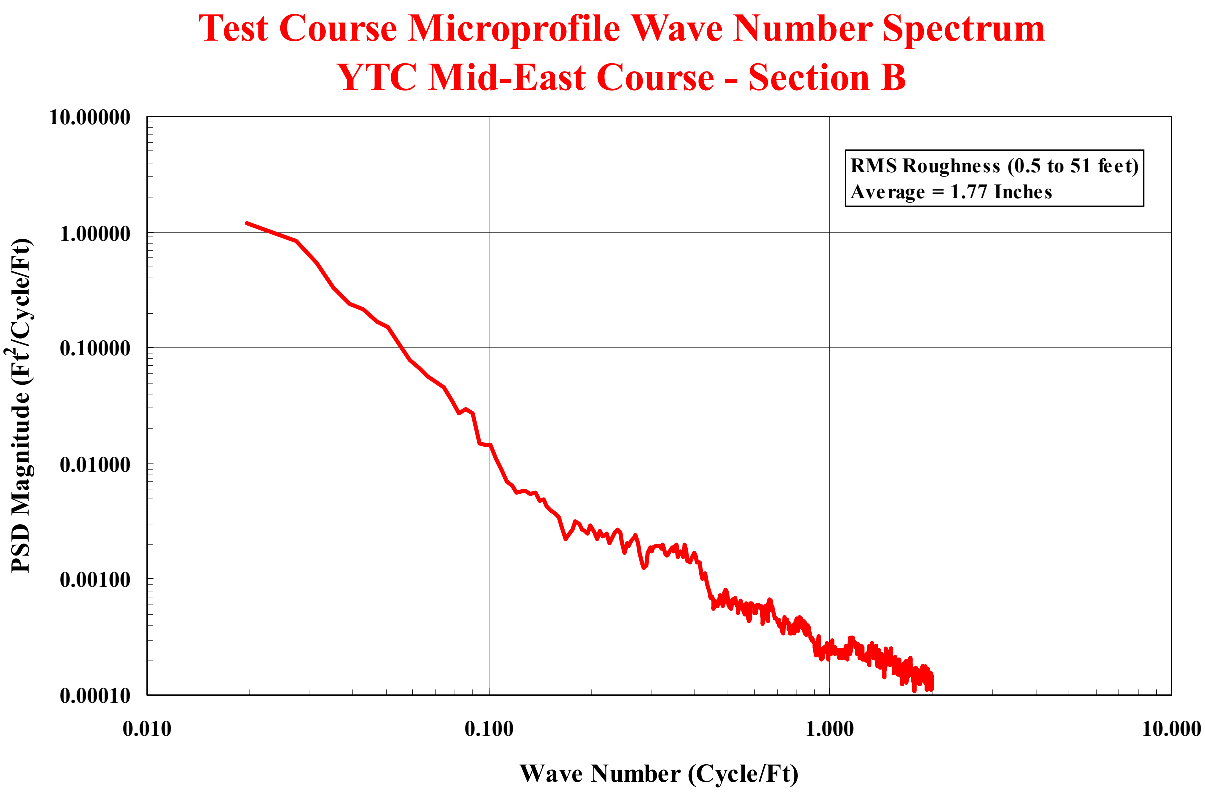

Figure 28. Mid-East Course – Section B wave number spectrum.

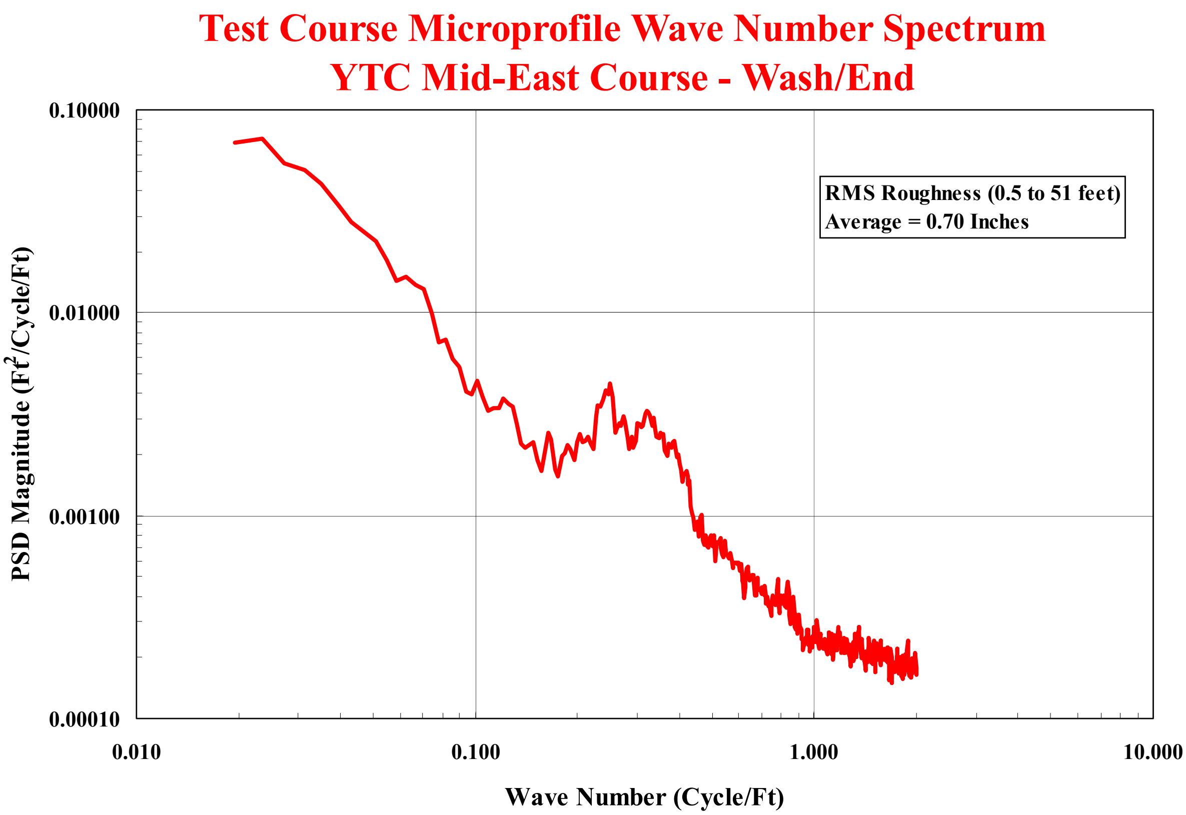

Figure 29. Mid-East Course – Wash/End wave number spectrum.

5.2.11 Desert March (formerly Rock Ledge Access Trail)

The Desert March course is a 43.4 km (27.0 mi) course through a variety of desert terrain features including limey fans, limey fan sandy, sandy uplands, sandy bottoms, and gravely hills. The route exposes a test vehicle to a rigorous test condition which exercises the suspension system, braking systems and the transmission with repeated shifting due to the torque requirements needed to traverse the varied terrain. The wave number spectrum is presented in Figure 30.

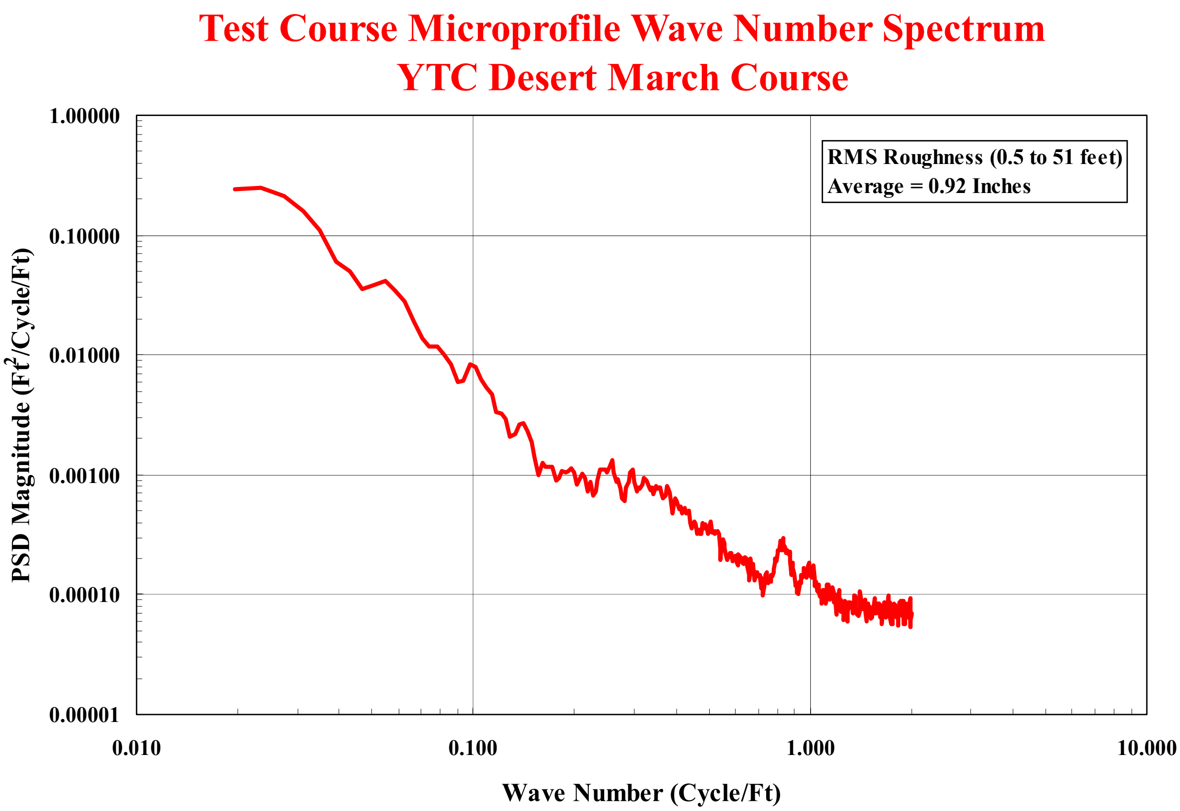

Figure 30. Desert March Course wave number spectrum.

5.2.12 Rock Ledge

This course is 6.0 km (3.7 mi) long, is located between two vertical rock outcroppings and is traversed with several exposed rock ledges. The course follows a natural water course through the mini canyon. The terrain is classified as basalt hills, and volcanic hills. The surface of the trail is primarily composed of Riverbend Family-Carrizo Family Complex soils which are very coarse sands which are very heavily cobbled. The second soil class is the Lithic Torriorthents and Typic Torriorthents complex. These soils are composed of fragmented bedrock, vertical rock outcrops and very thin soil layers. They are usually strewn with large stones up to 76 cm (30 in) in diameter that have spalled off the vertical ledges. In many cases there are no soils, just rocks of various sizes. The wave number spectrum of this course has not been computed.

5.2.13 Overlay of YTC Test Courses

The wave number spectra for the YTC courses described above are combined in figure 31.

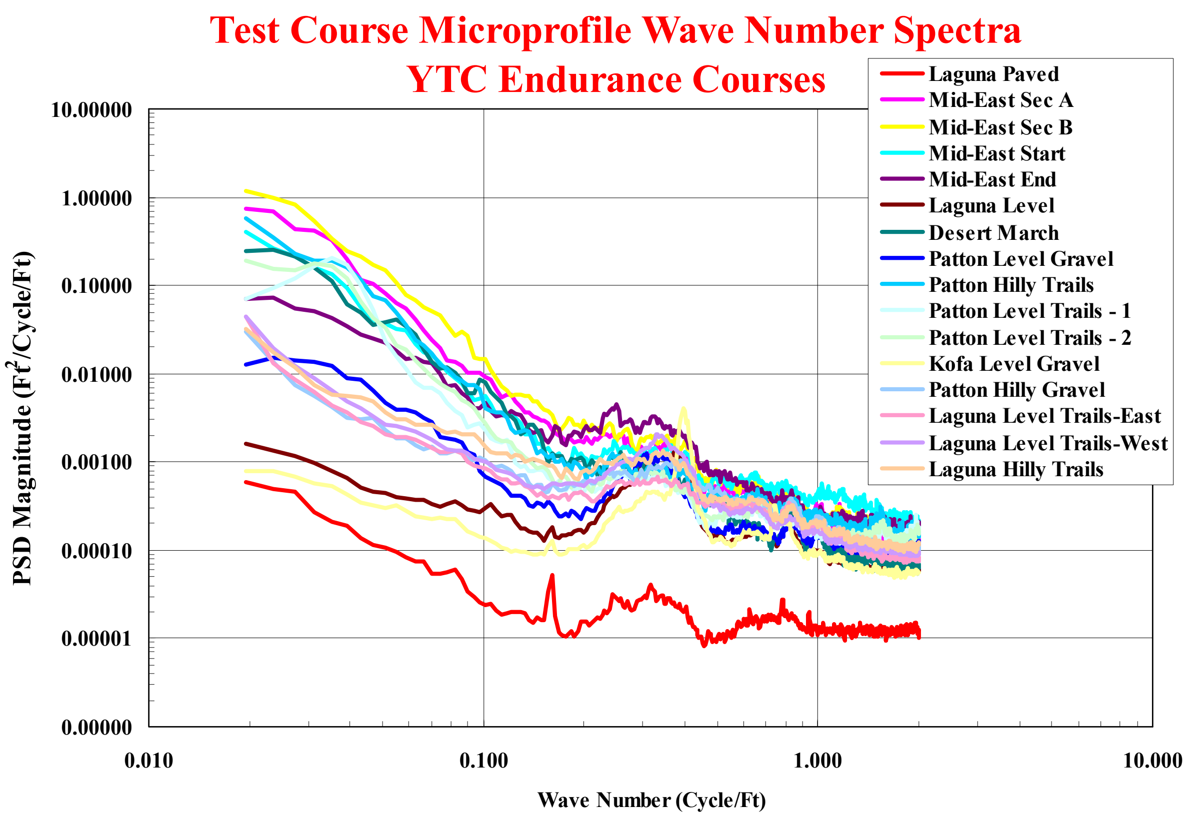

Figure 31. Overlay of YTC Endurance Test Courses

6. SOIL CLASSIFICATION

Numeric, symbolic and verbal soil classification descriptions are provided in tables 3 through 5.

Table 3. Particle Size Classes	
Class	**Size**
Cobble and Gravel	>4.75 mm particle diameter (No. 4 sieve)
Sand (sand-sized)	<4.75 mm to >75 um particle diameters (NOs. 3 to 200 sieves)
Silt and Clay (silt and clay-sized)	<75 um particle diameters (No. 200 sieve)

Table 4. USCS Classification	
USCS Symbol	**Description**
SW-SM	Well-graded sand with silt
SM-SP-SM, SP	Poorly-graded sand silt to poorly-graded sand to well-graded sand to well-graded sand
GW	Well-graded gravel with sand
GW-GM, GP-GM	Well-graded gravel with silt to poorly-graded gravel with silt
GC-GM, CL GP-GM	Silty, clayed gravel with sand to sandy clay to poorly-graded gravel with silt
GP-GM, GC	Poorly-graded gravel with silt to poorly-graded gravel with silt to clayey gravel
GM	Silty gravel with sand
GP, GP-GM, GC	Poorly-graded gravel with sand to poorly-graded gravel with silt to clayey gravel

Table 5. USDA Soil Classification	
USDA Soil Classification	**Description**
Superstition-Rositas	Sand
Carrizo	Extremely gravelly loamy coarse sand
Riverbend	Extremely cobbly sand loam
Cristobol-Gunsight	Silty, clayey gravel with sand to sandy day to poorly-graded gravel with silt
Gunsight-Chuckawalla	Extremely gravelly sandy loam to extremely gravelly loamy fine sand to very gravelly silt
Carsitas-Chuckawalla	Extremely gravelly sand to extremely gravelly loamy fine sand to very gravelly silt loam
Lithic Torriorthents	Extremely gravelly sandy loam

7. ROAD SURFACE CLASSIFICATION

Vehicle specifications generally divide descriptions of road surfaces into four categories: primary roads, secondary roads, trails and cross country. The specifications consist of description of the particular surface and a range of rms roughness values associated with that surface. The descriptions are consistent throughout the wide spectrum of vehicles, but the rms roughness values vary somewhat from vehicle to vehicle. The descriptions and suggested rms roughness values are presented below. DTC test courses grouped by terrain type are shown in Table 6.

Primary Roads: Two or more lanes, all weather, maintained, hard surface (paved) roads with good driving visibility used for heavy and high density traffic. These roads have lanes with a minimum width of 2.7 meters (9 ft), and the legal maximum GVW/GCW for the country or state is assured for all bridges. These roads are surfaces having an rms roughness value of less than 0.5 cm (0.2 in).

Secondary Roads: Two lanes, all weather, occasionally maintained, hard or loose surface (e.g., large rock, paved crushed rock, gravel) intended for medium-weight, low-density traffic. These roads have lanes with a minimum width of 2.4 meters (8 ft) and no guarantee that the legal maximum GVW/GCW for the country or state is assured for all bridges. These roads are surfaces having an rms roughness value varying between 0.5 and 1.5 cm (0.2 and 0.6 in).

Trails: One lane, dry weather, unimproved, seldom maintained loose surface roads, intended for low density traffic. Trails have a minimum width of 2.4 meters (8 ft), no large obstacles (boulders, logs, stumps) and no bridging. These are surfaces having an rms roughness value varying between 1.5 and 3.8 cm (0.6 and 1.5 in).

Cross-Country: Vehicle operations over terrain not subject to repeated traffic and where no roads, routes, well-worn trails or man-made improvements exist. (This definition does not apply to vehicle test courses which are used to simulate cross-country terrain). These are surfaces having an rms roughness value greater than 3.8 cm (1.5 in).

TABLE 6. TEST COURSES BY TERRAIN TYPE
(BASED ON RMS ROUGHNESS ONLY WHICH DOES
NOT IMPLY EQUIVALENT TEST RESULTS)[1]

Terrain Type	**rms roughness, in**	**ATC Courses**	**Nominal roughness, in**	**YTC Courses**	**Nominal roughness, in**
Primary	<0.2	Perryman Paved	0.07	Laguna Paved	0.08
Secondary	≥0.2 - ≤0.6	Munson Gravel Perryman A Perryman 1 Churchville C	0.25 0.33 0.34 0.21	KOFA Level Gravel Laguna Level Patton Level Gravel Patton Hilly Gravel Laguna Level Trails – East Laguna Level Trails – West Laguna Hilly Trails	0.23 0.23 0.36 0.36 0.35 0.39 0.40
Trails	>0.6 - ≤1.5	Belgian Block Perryman 2 Churchville B	0.82 0.90 1.09	Patton Hilly Trails Patton Level Trails Mid-East – start Mid-East Section A Mid-East Wash/End Desert March	1.15 0.85 1.02 1.44 0.70 0.92
Cross Country	>1.5	Perryman 3 Perryman 4	2.86 NA	Mid-East Section B	1.77

[1] Test results are a function of many test course attributes such as longitudinal slope, side slope, mud/dust, soil strength, radius of curvature and surface roughness. The response of a vehicle to surface roughness is dependent upon the shape of the wave number spectrum and the vehicle speed. Therefore, having equivalent rms roughness values does not imply that two test courses will produce equivalent test results.

The courses from each test center are shown by terrain type (based on rms roughness) in figures 32 through 35.

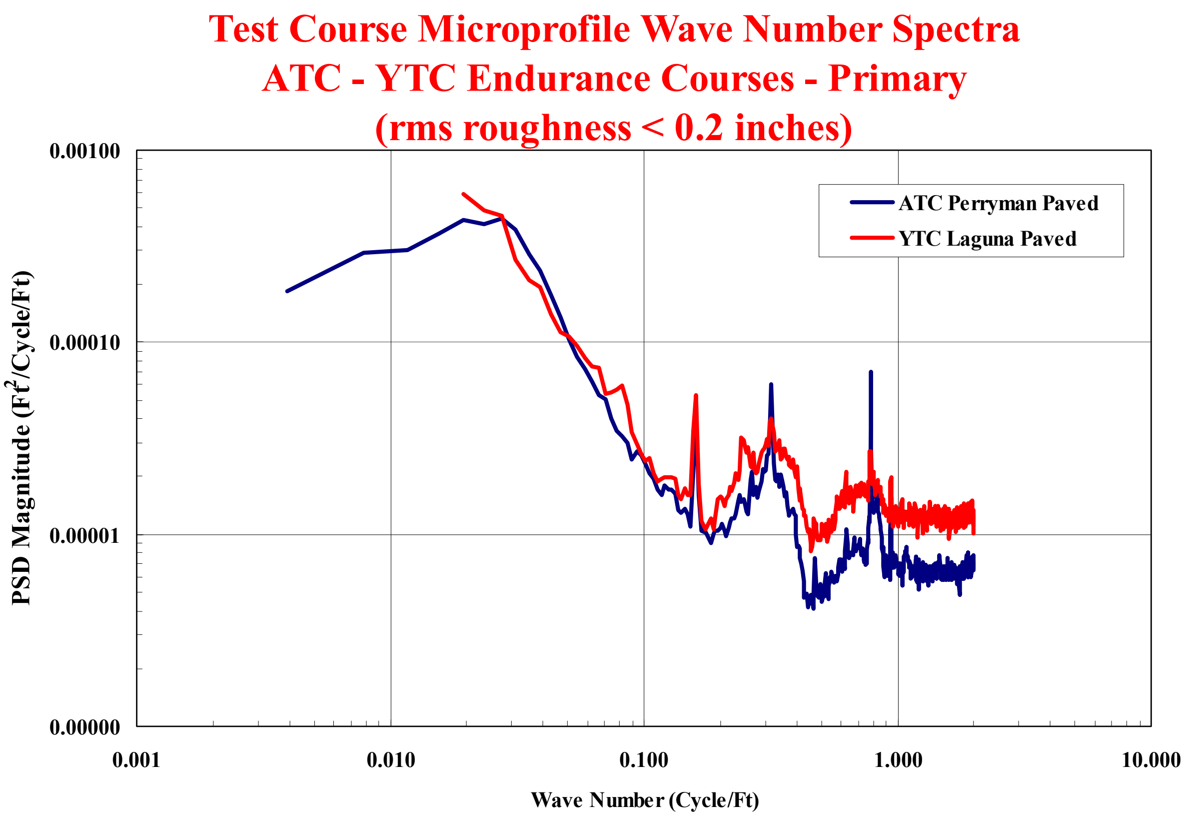

Figure 32. Primary Road Courses

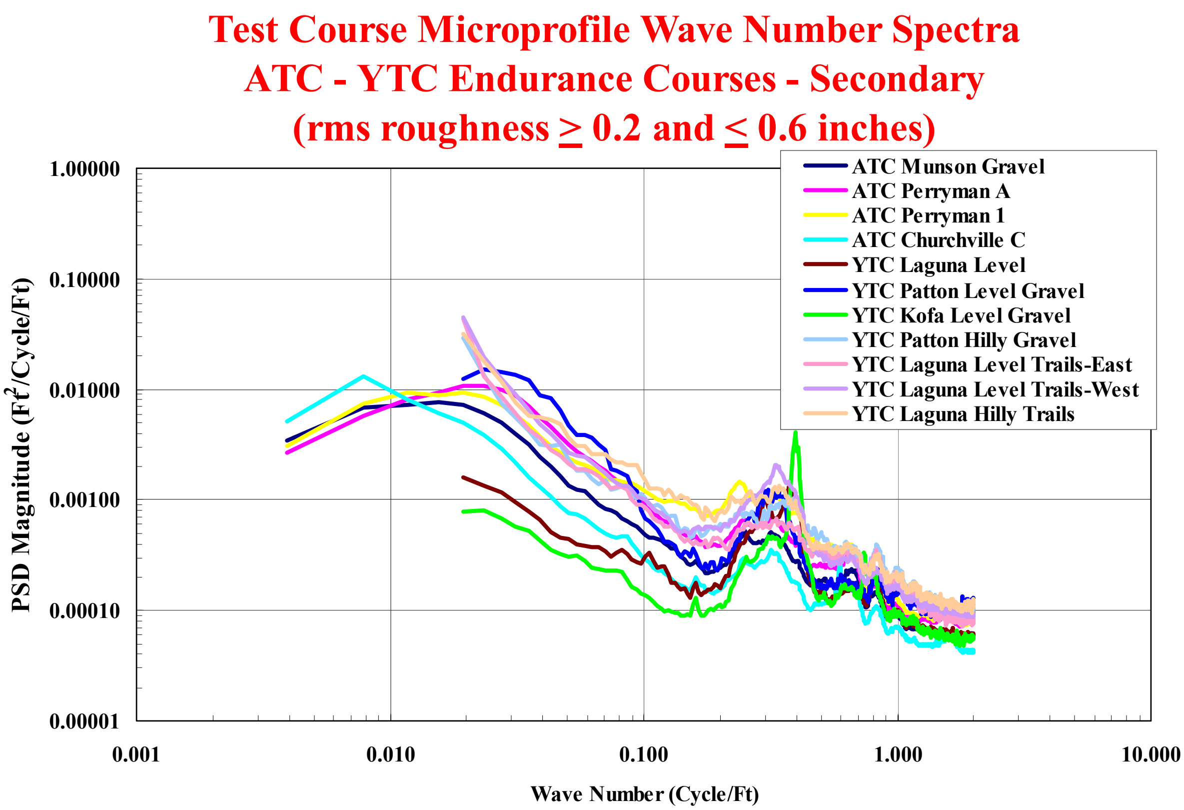

Figure 33. Secondary Road Courses

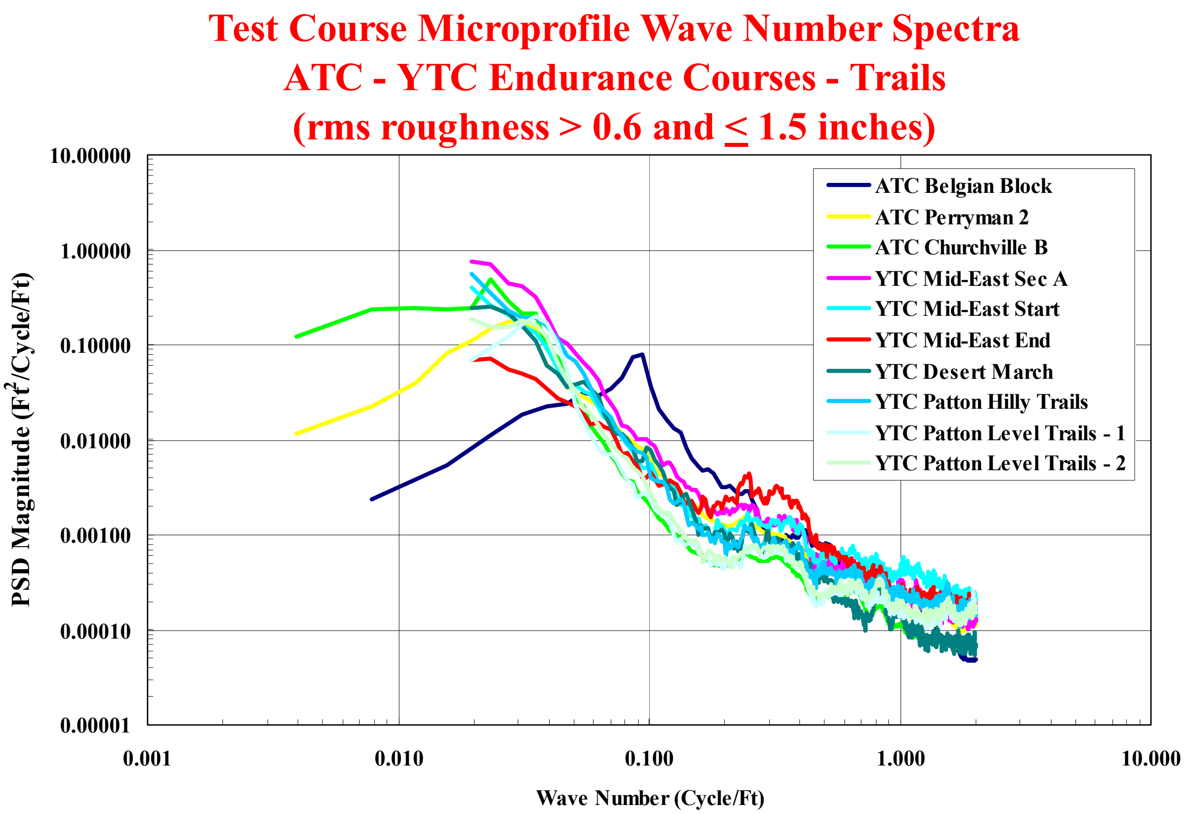

Figure 34. Trail Courses

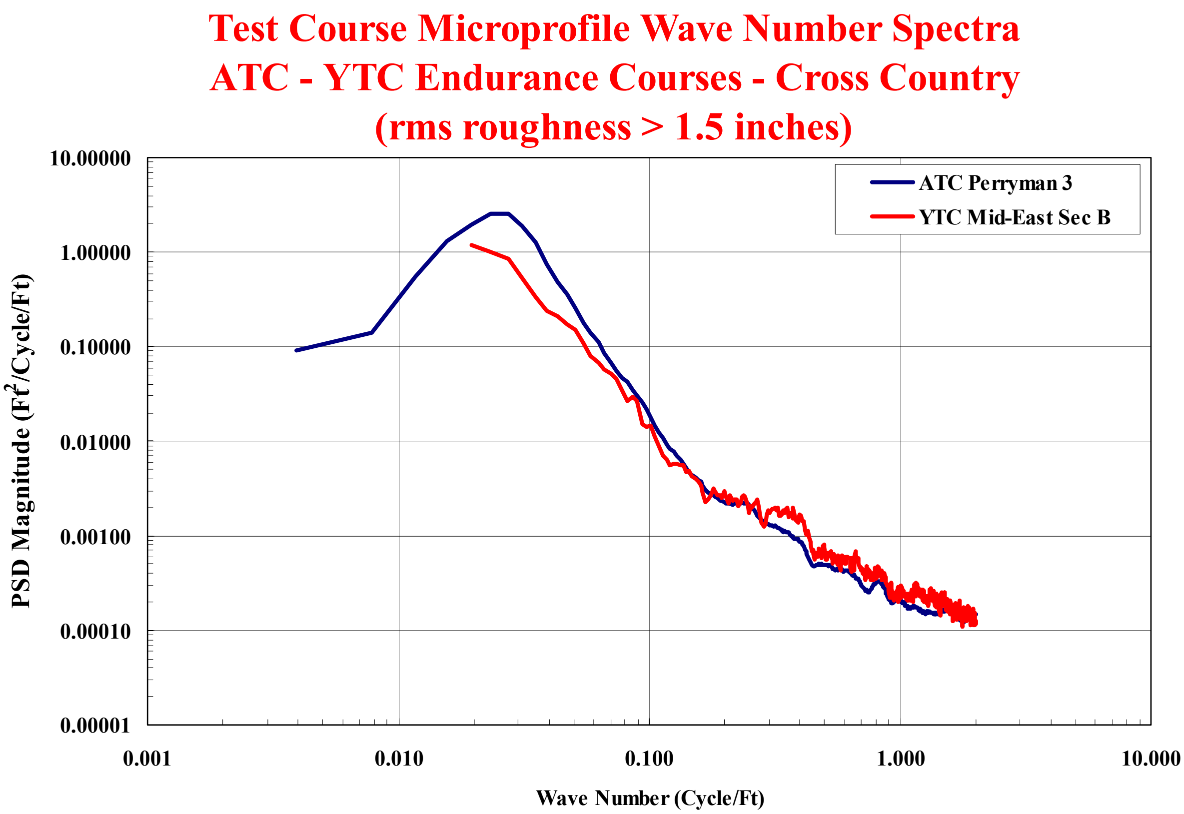

Figure 35. Cross Country Courses

APPENDIX A. REFERENCES

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2. APG Report No. APG-MT-3635, Special Study of Technique and Study of Automotive Test Course Index, Phase I and II, TECOM Project No. 9-CO-011-000-019, P. Paules and S. Harley, August 1970.

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7. Fix, G.A., TARADCOM Signal Analysis Program, September 1978.

8. FM5-410, Military Soils Engineering, 23 December 1992.

Forward comments, recommended changes, or any pertinent data which may be of use in improving this publication to the following address: Test Business Management Division (CSTE-DTC-TM-B), US Army Developmental Test Command, 314 Longs Corner Road Aberdeen Proving Ground, MD 21005-5055. Technical information may be obtained from the preparing activity: Automotive Directorate (CSTE-DTC-AT-AD), US Army Aberdeen Test Center, 400 Colleran Road, Aberdeen Proving Ground, MD 21005-5059. Additional copies are available from the Defense Technical Information Center, 8725 John J. Kingman Rd., STE 0944, Fort Belvoir, VA 22060-6218. This document is identified by the accession number (AD No.) printed on the first page.