SAE International®

SURFACE VEHICLE RECOMMENDED PRACTICE

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# Tire Quasi-Static Envelopment of Triangular/Step Cleats Test



RATIONALE

This document was developed as part of a set of Recommended Practices intended to allow modelers to determine the parameters required by any of the common tire models for calculating spindle loads given the road surface profile from a single set of experimental results, thus eliminating duplicate testing. This version addresses minor editorial problems found in the previous version.

## 1. SCOPE

This SAE Recommended Practice describes a test method for determining properties of a non-rolling tire quasi-statically enveloping either a set of triangular cleats or a single step cleat. In the case of the triangular cleats the normal force and vertical deflection of the non-rolling tire are determined. In the case of the step cleats the normal force, longitudinal force, and vertical deflection of the non-rolling tire are determined. The method applies to any tire so long as the equipment is properly sized to correctly conduct the measurements for the intended test tire.[1] The data are intended for use in determining parameters for road load models and for comparative evaluations of the measured properties in research and development.

NOTE: Herein, road load models are models for predicting forces applied to the vehicle spindles during operation over irregular pavements. Within the context of this document, forces applied to the pavement are not considered.

### 1.1 Procedures

A single procedure is specified. The differences in the test from the standpoint of the two cleat designs are whether the wheel is free to rotate about the spindle and what data must be measured and reported. These are spelled out in the body of this document.

### 1.2 Test Machines

This document is test machine neutral. It may be applied using any type of test machine capable of fulfilling the requirements stated in this document. The test machine must be capable of accommodating the tire sizes to be tested, along with the required cleats.

NOTE: Test results are a function of the Tire/Wheel assembly, not just a function of the Tire alone.

## 2. REFERENCES

### 2.1 Applicable Documents

[1] Proper cleat height sizing requires that the test tire only contact the test cleat, and not the surface to which the cleat is fastened.



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The following publications form a part of this specification to the extent specified herein. Unless otherwise indicated, the latest issue of SAE publications shall apply.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

SAE J2047 Tire Performance Technology

SAE J2429 Free-Rolling Cornering Test for Truck and Bus Tires

SAE 770870 The Effect of Tire Break-In on Force and Moment Properties, K. D. Marshall, R. L. Phelps, M. G. Pottinger, and W. Pelz, 1977

SAE 810066 The Effect of Aging on Force and Moment Properties of Radial Tires, M. G. Pottinger and K. D. Marshall, 1981

2.1.2 Other Publications

Available in wall chart form as #TTMP-7/95 from the Rubber Manufacturers Association, 1400 K St., N.W., Washington, DC 20005.

OSHA Standard 1910.177 - Servicing Multi-Piece and Single Piece Rim Wheels

Available from American National Standards Institute, 25 West 43rd Street, New York, NY 10036-8002, Tel: 212-642-4900, www.ansi.org.

ISO/IEC 17025:2005 - General requirements for the competence of testing and calibration laboratories

## 3. DEFINITIONS

The definitions that follow are of special meaning in this document and are either not contained in other Recommended Practices or are worded somewhat differently in this practice.

### 3.1 CLEAT DIMENSIONS

3.1.1 Cleat Height (H)

Cleat Height is the vertical distance from the crest of the cleat to the supporting Simulated Roadway, see Figures 1 and 2.

3.1.2 Cleat Width (W)

Cleat Width is the physical left-to-right width of the crest of the cleat.

### 3.2 TEST

A test is the execution of the procedure described in this document one time on one tire at a single set of test conditions.

## 3.3 TEST PROGRAM

A Test Program is a designed experiment involving multiple tests of the type described in this practice.[2]

## 4. NOMENCLATURE

Table 1 lists the symbols used in this document. For definitions not in Section 3 of this practice please see SAE J2047.

TABLE 1 - SYMBOLS DEFINED

| Symbol | Defined Term |
|---|---|
| $\delta_Z$ | Vertical Deflection |
| $F_X$ | Longitudinal Force |
| $F_Z$ | Normal Force |
| H | Cleat Height |
| $\theta$ | Triangular Cleat Apex Half Angle |
| p | Inflation Pressure |
| $R_l$ | Loaded Radius |
| $\sigma$ | Standard Deviation (Note Subscripts) |
| W | Cleat Width |



## 5. LABORATORY QUALITY SYSTEM REQUIREMENT

The laboratory performing the procedure specified in this document shall have a quality system either conforming to ISO/IEC 17025 or which can be shown to be functionally equivalent to ISO/IEC 17025. The elements of such a system are assumed below and are not, therefore, specifically called out within this practice.

## 6. APPARATUS

The required apparatus consists of a loading machine, a set of cleats, and test rims.

### 6.1 Loading Machine

The loading machine consists of a tire loading and positioning system, a measuring system, a flat surface simulated roadway, and the space housing the machine, which shall be maintained at 22 °C ± 2 °C.

#### 6.1.1 Loading and Positioning System

The system shall maintain the tire with the tire/wheel plane within ±0.05° of perpendicular to the simulated roadway during all loading. Loading shall produce normal forces accurate to within ±1.0% of the test machine's full-scale normal force range. The machine's full-scale normal force range shall allow imposition of loads equivalent to at least 400% of the test requester specified 100% load. The machine's hub must be fixed with respect to rotation about the wheel spindle when testing with the triangular cleats, as described in 6.2.1, and free to rotate around the spindle when testing with the step cleat that is described in 6.2.2.

[2] There are many experimental possibilities: repeated test of the same tire, tests of the same tire under multiple test conditions, tests of tires with different specifications (design details), application of this test as part of a series of different tests, etc.

6.1.2 Measuring System

This system shall measure normal force ($F_Z$) to within ±0.5% of the test machine's full-scale normal force range, longitudinal force ($F_X$) to within ±0.5% of the test machine's full scale longitudinal force range, and loaded radius ($R_l$) to within ±0.5 mm.[3] The system shall have a normal force range that allows measurement of forces equivalent to those existing at 400% of the test requester specified 100% load.

6.1.3 Simulated Roadway

The simulated roadway shall be a smooth flat surface, free of loose materials and deposits adapted for mounting the cleats used in this test. The material of which the roadway is made is unimportant so long as the roadway satisfies the following criteria.

6.1.3.1 The roadway shall be large enough to fully support each of the cleats used in this test.

6.1.3.2 The roadway and its supporting structure shall be sufficiently rigid so as to not change appreciably in either transverse or longitudinal orientation or in curvature under the machine's maximum applied normal force.

6.1.3.3 If the roadway can be translated in the longitudinal direction, it shall be provided with a lock or locks that prevent translation during this test.

6.2 Cleats

Detailed cleat design except for the contour of the surface interacting with the tire is the responsibility of the testing facility and may be done, as necessary, to allow adaptation and securing of the cleat to the simulated roadway. The design shall ensure that no point on the cleat deflects by more than 0.5% of the tire deflection during testing. The cleats shall have a smoothly machined surface.

6.2.1 Triangular Cleats

The cleat cross sections shall be isosceles triangles as indicated in Figure 1. There shall be a set of five cleats with apex half angles of θ = 45, 60, 75, 80, and 85°. As noted in 10.1, the 75° and 85° cleats are optional in the standard test. The cleat height (H) shall be large enough such that at no time within the test does the tire come in contact with the simulated roadway, which supports the cleat. The cleat width (W) shall be sufficient to fully support the tire width in contact. The cleat crown radius shall be between 1.5 and 3.0 mm. The apex of the cleat shall lie on the vertical line from the spindle axis to the simulated roadway.

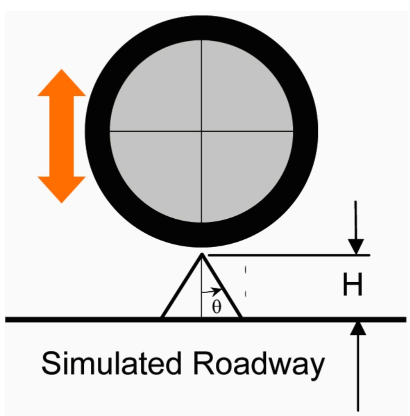


FIGURE 1 - TRIANGULAR CLEAT



[3] Should the measuring system sense multiple forces and moments, the output shall be corrected for load cell interaction by a matrix method conceptually equivalent to that discussed in SAE J2429.

6.2.2 Step Cleat

The cleat shall be a step as indicated in Figure 2. The cleat height (H) shall be large enough that at no time within the test does the tire come in contact with the simulated roadway, which supports the cleat. The cleat width (W) shall be sufficient so as to fully support the tire width. The cleat corner radius shall be between 1.5 and 3.0 mm. The step cleat and/or cleats shall permit testing at longitudinal offsets of 0% of the tire's unloaded radius, -10% of the tire's unloaded radius, and +10% of the tire's unloaded radius.

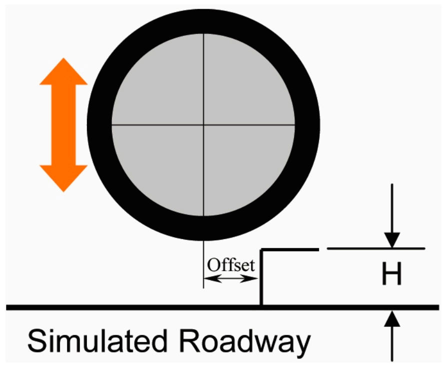


FIGURE 2 - STEP CLEAT



6.3 Test Wheels

Test wheels shall meet the dimensional tolerances of original equipment wheels supplied on new vehicles and shall match the rim profile for the applicable tire as specified by the appropriate tire and rim standards association, for example, the Tire and Rim Association, Inc.

NOTE: Wheel stiffness may have a discernable influence on the results. At this time, the presence of this effect has not been established. Further, there is not now a recognized way to appropriately characterize wheel stiffness for use in this document. It is planned to address this question by research carried out prior to the five-year review of this practice.

## 7. CALIBRATION[4]

Calibrate all measuring system components in accordance with the mandates of the written plan required by the laboratory quality system referenced in Section 5. Calibration must exercise all measuring system components over substantially their full range of application and must be performed at least once each year. The reference standards and instruments used in measuring system calibration shall be traceable to the National Institute of Standards and Technology or the appropriate national standards organization with currently valid calibration certificates on file in the testing laboratory's files when the system's calibration is performed. Gains, offsets, and other pertinent performance measures and comments on system behavior during calibration shall be kept permanently on file within the testing laboratory's archives and be available to customers on request.

## 8. PREPARATION OF APPARATUS[5]

Preparation of the apparatus shall ensure that the test equipment meets its calibration at the outset of each test program. The precise process control method used to verify readiness of the apparatus is likely to be unique to an individual test site, but must be specified in writing within the quality system of the laboratory. The results of process control experiments shall be available to customers upon request.

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[4] If required, Section 7 of SAE J2429 provides an expanded discussion of the question of calibration in the case of more complex but conceptually parallel measuring system.

[5] If required, Section 7 of J2429 provides example possibilities for a more complex, but related measuring system.

## 9. SELECTION AND PREPARATION OF TEST TIRES

### 9.1 Selecting the Tires for Good Comparability

The purpose of the test must be carefully borne in mind when selecting test tires since tire properties depend on numerous factors besides the tire design and materials. It is especially important to properly account for storage history (SAE 810066) and previous work history (SAE 770870). Due to the many complex questions that the test defined in this document may be used to address, specific tire selection recommendations can only be made for the case in which different tires are to be compared for design or materials effects. In that case, all test tires should be of approximately the same age, have been stored under essentially identical conditions, have experienced approximately the same exercise history, and have been sampled from production lots with similar statistical characteristics.

### 9.2 Inflation Pressure

The inflation pressure will significantly affect the deflection of a tire under load. Therefore the appropriate test inflation pressure must be specified by the requester and set to within ±5 kPa by the testing laboratory. Because tires typically operate at a temperature higher than that of the ambient air, operating inflation pressure is usually higher than cold inflation pressure. If the purpose of testing is to simulate the running state, then the inflation pressure used in the test must be equivalent to the on-road operating inflation pressure.

### 9.3 Tire Preparation

Clean the tire surface of dirt, loose material, or other contaminants. Mount the test tire on the tire and rim standards organization specified rim.[6] For rim wheels used on large vehicles such as trucks, tractors, buses, and off-road machines, mounting and demounting shall be done in accordance with the practices specified in OSHA 1910.177. OSHA 1910.177 does not apply to the servicing of rim wheels used on automobiles or on pickup trucks or vans utilizing automobile tires or truck tires designated “LT”. The rim used shall meet the specifications noted in 6.3.

### 9.4 Sample Size

Typically, a single tire selected at random from among the group of tires in each specification is an adequate sample if the goal is parametric data for producing a tire model. However, should the desire be to determine differences between tire specifications at a stated level of accuracy it will be necessary to use statistically valid sample sizes and to employ appropriate statistical analyses of the results to define the differences among specifications.

## 10. TEST PROCEDURE

### 10.1 Cleat Choice

The test requester must specify which cleats to use. There are two standard choices: 1) triangular cleats with apex half angles of 45°, 60° and 80°, and 2) the step cleat with a zero offset. There are two options: 1a) Triangular cleats with apex half angles of 75° and 85° may be added to the standard triangular cleat set and 2a) Step cleats offset by plus and minus 10% of the tire’s unloaded radius may be added to the standard zero-offset cleat.



[6] The Tire and Rim Association, Inc. is an example of a tire and rim standards organization.

10.2 Test Procedure

There are two basic methods for executing this test and are described in 10.2.2 and 10.2.3. For either method the test tire shall be positioned within ±5° of the test requester chosen circumferential position at the start of each loading. During data acquisition, appropriate low pass analog filtering shall be applied to prevent aliasing due to high frequencies from contaminating the acquired data. Low frequency oscillations are to be dealt with either through curve fitting or averaging, whichever is more appropriate for the test method chosen within the context of the laboratory performing the test.

In the case of the triangular cleats, lock the wheel spindle, thus eliminating the tire rotational degree of freedom. In the case of the step cleats, leave the wheel spindle free to rotate. For reasons of both equipment and personnel safety the roadway must be locked so as to eliminate longitudinal roadway motion during the tests described in this document.

This is the sequence for testing a single tire. Mount the first cleat on the test machine. Apply the method in 10.2.1 to determine the maximum allowable load usable with the first cleat. Test the tire by either the incremental or ramping method, 10.2.2 or 10.2.3. Mount the second cleat on the test machine. Determine the maximum allowable load usable with the second cleat. Conduct the test by either the incremental or ramping method. Follow this procedure sequentially until test data are determined for all applicable cleats.

10.2.1 Determining the Maximum Allowable Load to use with a cleat

Mount the test tire and rim assembly on the test machine. Ensure proper inflation. Carefully load the tire to a normal force equivalent to the lesser of 400% of the test requester's specified 100% load or the load at which the rim flange is within 25 mm of the cleat. The lesser of these two loads is the maximum load to be used in this test on the cleat currently in use.[7] This determination must be made for each different cleat employed in the test. It is specific to the tire specification and depends on the tire inflation pressure.

10.2.2 Incremental Loading Method

Divide the maximum allowable load, determined in 10.2.1, into 10 equal increments. Tare the measuring system. Determine and record the loaded radius at which skim contact exists between the tire and the roadway. In practice, this is the smallest loaded radius that can be achieved before normal force is exerted on the tire by the road.[8] Tare the measuring system. Load the tire to the lowest of the 10 normal force increments. Allow the load to stabilize. For a triangular cleat, over a one second period acquire 10 or more samples of normal force and loaded radius data at the stabilized load. For the step cleat, over a one second period acquire 10 or more samples of longitudinal force, normal force and loaded radius data at the stabilized load. Retract the tire to zero normal force. Tare the measuring system. Load the tire to the second lowest of the 10 normal force increments and allow the load to stabilize. Acquire 10 or more data samples over a one second period. Retract the tire to zero normal force. Repeat the tare/load/acquire data/unload sequence sequentially until data has been acquired at all 10 normal force increments. The normal force and loaded radius data including the skim data shall be preserved in a computer file ready for data processing.

10.2.3 Ramped Loading Method

Tare the measuring system. Beginning with the tire slightly out of contact, ramp the loaded radius downward until the maximum allowable load defined in 10.2.1 is reached then retract the tire to the original loaded radius. The ramp shall be completed in between one and three minutes. During ramping, data shall be acquired at a rate of at least 25 samples per second. For a triangular cleat, acquire the normal force and loaded radius data. For the step cleat, acquire the normal force, longitudinal force, and loaded radius data. The data acquired during the loading cycle shall be preserved in a computer file ready for data processing.



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[7] This procedure prevents damage to the test machine, tire cutting by the rim flange, and destruction of the test wheel.
[8] After setting skim, a very small force may exist or the tire may actually clear the surface by a tenth of a millimeter or slightly more.

## 11. DATA PROCESSING AND PREPARATION

The testing laboratory will provide the data in a standardized format agreeable to the test requester. The header information originally required from the requester in order to perform the test shall be provided in the files of reported data along with data identifying the test machine, cleat, operator, and date plus time of the test. The header data information drawn from the test request shall include tire identification information, tire sizing, test rim sizing and any special requirements, the test inflation pressure, and the 100% load. The actual data (normal force and loaded radius) shall be in column format as specified in 11.1 and 11.2.

### 11.1 Incremental Loading Force/Deflection Data[9]

Average the 10 data samples acquired for each channel at a given target normal force. For a triangular cleat, the result will be averaged normal force and loaded radius data at each target normal force. For the step cleat, the result will be averaged longitudinal force, normal force and loaded radius data at each target normal force. The result will be 11 rows of data: the skim data and 10 sets of loaded data.

### 11.2 Ramped Loading Force/Deflection Data[9]

Provide the data points acquired during ramping. For a triangular cleat, the result will be a table of normal force and loaded radius data. For the step cleat, the result will be a table of longitudinal force, normal force, and loaded radius data.

## 12. DATA REPEATABILITY AND REPRODUCIBILITY

The focus at this time is on variation of a single test machine for single samples. Expectations of performance are expressed as result standard deviations. The stated expectations are derived from experience with typical loading machines governed by the requirements of a quality system developed in accordance with ISO/IEC 17025 (see Section 5) when using the incremental test method.

The variability among test tires is presently unknown and depends on tire specification, tire lot, and manufacturer. It is not considered below. It is expected that as a database develops over the next few years information on tire-to-tire test variability will become available.

For reasons of making the discussion somewhat more concrete, a hypothetical or example machine capable of exerting and measuring normal force magnitudes of 44 kN is introduced. <u>This is not a required capacity for any machine used to perform the tests listed in this practice</u>.

### 12.1 Load, Normal Force, Control

As noted in 6.1.1 a load control system based on current load control technology should be expected to be accurate to within ±1% of the maximum calibrated machine range. Fundamentally, ±1% is a band about $\pm 2.5\sigma$ wide or ±440 N wide for the 44 kN example. This implies that $\sigma_{Fzcontrol} \cong 0.4\%$ of the calibrated range or about 180 N for the 44 kN example.

### 12.2 Normal Force Measurement

As noted in 6.1.2 individual samples are within ±0.5% of the calibrated range for the measuring system. For the example machine with an $F_Z$ range of 0 to 44 kN, individual samples would be expected to lie within a band ±220 N wide. This represents about $\pm 2.5\sigma_{Fz}$. This implies that $\sigma_{Fz} \cong 0.2\%$ of the calibrated range or about 90 N for the example 44 kN system.

The relevant $F_Z$ statistic is the standard error of the mean for ten samples in the incremental case.

$\sigma_{Fzmean} \cong (\sigma_{Fz})/(10)^{0.5}$ or about 28.5 N for the example 44 kN system.



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[9] The loaded radius associated with the skim load must be subtracted from the loaded radius at each normal force to provide the deflection associated with each normal force.