Designation: D3387 – 11

Standard Test Method for Compaction and Shear Properties of Bituminous Mixtures by Means of the U.S. Corps of Engineers Gyratory Testing Machine (GTM)[1]

This standard is issued under the fixed designation D3387; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This method employs a testing machine (Fig. 1) that generates a precisely controlled gyratory kneading process which is used to prepare and test specimens of bituminous paving mixtures. This method is intended for use in bituminous mixtures design and control testing as well as accelerated traffic simulation. The objective is to compact to the ultimate in place density under the anticipated vertical stress while monitoring the process in terms of unit mass, and shearing resistance including the plastic properties. Particular attention is given to the development of the plastic properties associated with the compaction phenomenon. The maximum permissible bitumen content is indicated directly by the first evidence of a progressive increase in shear strain (as indicated by a progressive increase in the gyratory angle) accompanied by a progressive reduction in shear strength (as indicated by a progressive reduction in roller pressure.) The procedures described here are for mix design and plant control as well as accelerated traffic simulation.

1.2 This test method covers two separate modes of operation of the Gyratory Testing Machine (GTM), namely: (1) GTM oil-filled roller mode; and (2) GTM air-filled roller mode. With the air filled roller, the GTM machine angle varies according to the resistance encountered during the gyratory kneading process. Thus the GTM using the air-filled roller is considered a better mechanical analog of the interaction between pneumatic tire and pavement structure.

1.3 This test method is for use with mixtures containing asphalt cement, asphalt binder cutback asphalt, asphalt emulsion. Test molds are available in 4- in. (101.6 mm), 6-in. (152.4 mm), and 8-in. (203.2 mm)diameters with corresponding height of 8-in (203.2 mm), 10-in.(254.0 mm), and 12-in. (304.8 mm) respectively. These molds can accommodate maximum particle sizes of 1 in. (25.4 mm) 1.5-in. (38.1 mm) and 2.0-in. (50.8 mm) respectively.

1.4 *Units*—The values stated in inch pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.5 The text of this standard references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables and figures) shall not be considered as requirements of the standard.

1.6 *This standard may involve hazardous materials, operations, and equipment. This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D3666 Specification for Minimum Requirements for Agencies Testing and Inspecting Road and Paving Materials

E1 Specification for ASTM Liquid-in-Glass Thermometers

3. Terminology

3.1 *Definitions:*

3.1.1 *Critical roller pressure, p'*—the roller pressure required for a Gyratory Shear Factor (GSF) equal to unity. That is, the roller pressure when SG = τmax. (See Annex A1.)

3.1.2 *Equilibrium density*—density when a rate of densification of 1 lb/ft^3 (16 kg/m^3) per 100 revolutions of the GTM roller carriage is reached. This rate of densification is intended to duplicate the ultimate in place density.

3.1.3 *Gyratory Angle*—measure of the magnitude of the gyratory strain θ. Four pertinent angles are defined as follows:

3.1.3.1 Machine angle (machine setting) θ_0.

[1] This test method is under the jurisdiction of ASTM Committee D04 on Road and Paving Materials and is the direct responsibility of Subcommittee D04.26 on Fundamental/Mechanistic Tests.

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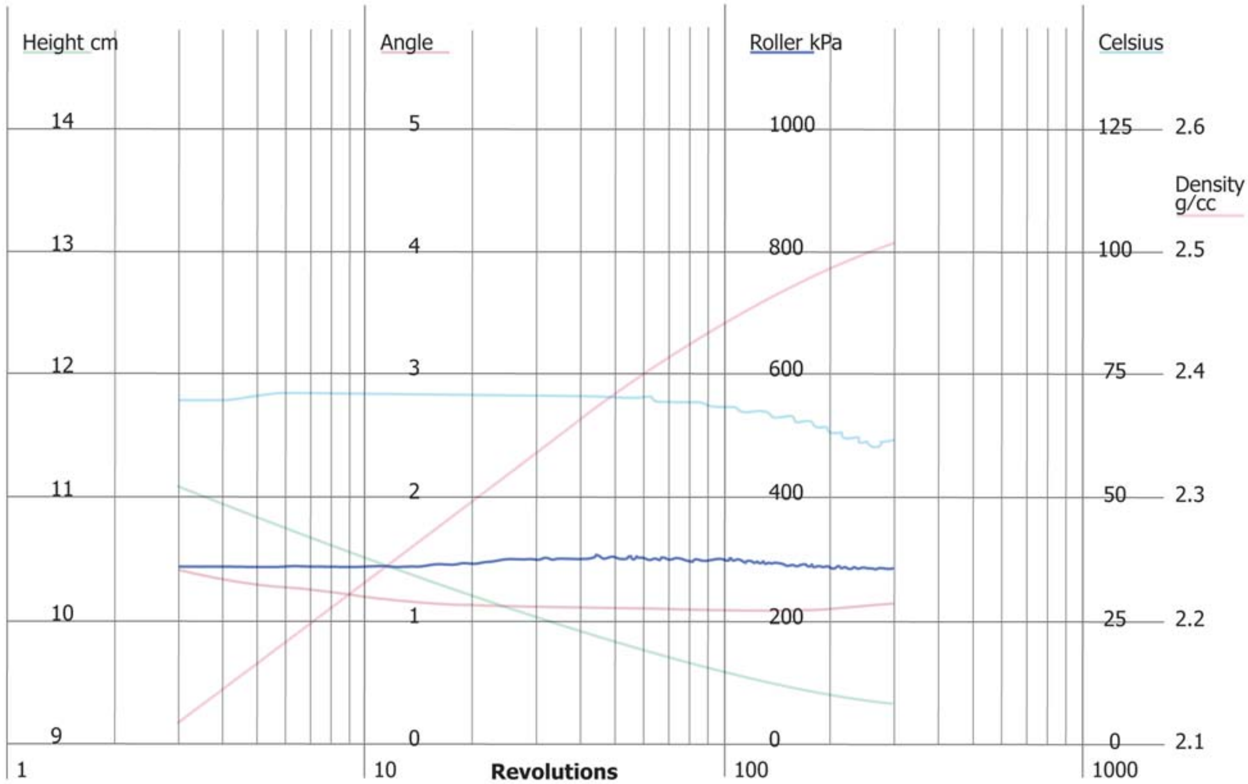
[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.



GTM Compaction and Shear Test

Date - 7/19/2006 Time - 17:39:06 TestNumber - 389 (Re-Print from data file)
KETI AC-13 4.4-2
2006-7-19 qouya xiao
Mold Diameter = 10 cm
Total Specimen Weight in grams = 1900.0 Percent Bitumen (Total Wt) = 4.4

Compaction Stress in kPa = 800 Revolutions at end of Compaction = 300
Compaction terminated at equilibrium
Specimen Height in cm at end of Compaction = 9.344
Unit Weight Total Mix in g/cu cm = 2.5082
Unit Weight Aggregate Only in g/cu cm = 2.3978 O-rings not used in mold
Gyratory Compatibility Index D30/D60 = 0.97
Total Work Done in NM = 14226

Oil Cell Machine Angle in degrees = 0.85
Intermediate Gyratory Angle in degrees = 1.10
Gyratory Angle at end of Compaction in degrees = 1.15
Gyratory Stability Index GSI = 1.05

Average Roller Pressure in kPa at end of compaction = 288
Static Shear Strength in kPa = 313 Taumax in kPa = 255
Gyratory Shear Factor GSF = 1.23
Static Shear Modulus in kPa = 21077
Static Compression Modulus in kPa = 63232 Mu = .5

FIG. 1 Largest Model of Gyratory Testing Machine

3.1.3.2 Minimum gyratory angle or shear strain θ_{min}.

3.1.3.3 Maximum gyratory angle or shear strain θ_{max}.

3.1.3.4 Final gyratory angle θ_f. This is the angle at the conclusion of test.

3.1.4 *Gyratory Compactibility Index* (GCI)—the ratio of the unit mass (total mix) at 30 revolutions of the GTM to the unit mass (total mix) at 60 revolutions of the GTM.

3.1.5 *Gyratory Compression Modulus (Eg)*—a calculated value based upon the gyratory shear modulus Gg and a measured or assumed value of Poissonś ratio μ. Eg = 2 Gg (1 + μ).

3.1.6 *Gyratory Shear Factor* (GSF)—the ratio of the measured gyratory shear strength to the theoretical maximum induced pavement shear stress; SG / τmax. This is a factor of safety type index with regard to failure in simple shear for the defined loading conditions. The GSF value is not applicable when GSI > 1.0.

3.1.7 *Gyratory Shear Modulus* (G_g)—The gyratory shear SG divided by the gyratory shear strain tanθ, ($G_g = S_G / \tan \theta_0$).

3.1.8 *Gyratory Shear Strength* (S_G)—the shear resistance of the specimen which is, among other things, a function of the imposed vertical pressure and degree of strain. The S_G value is influenced by the characteristics of the aggregate, binder and level of densification achieved.

3.1.9 *Gyratory Stability Index* (GSI)—the ratio of the maximum gyratory angle to the minimum gyratory angle $\theta_{max}/\theta_{min}$.

4. Significance and Use

4.1 The GTM test method described here is intended to be used to determine the maximum allowable bitumen content, establish unit mass requirements, and arrive at a rational shear strength. The GTM is also used to conduct accelerated traffic simulation. It is essential that the vertical pressure corresponds to the maximum anticipated vertical contact pressure between tire and pavement, since the theoretical stress for compaction and maximum induced shear is based on the concept of employing maximum anticipated loads.

4.2 The use of this method fin the selection of the optimum bitumen content is limited to mixtures that are susceptible to the development of excess pore pressure when the voids become overfilled with bitumen. This applies to dense graded HMA but does not apply to SMA mixes or to open graded friction courses. (This restriction does not apply to the gyratory strength factor, GSF.) A gyratory stability index (GSI) in excess of unity, overfilled voids and therefore serves to establish the maximum permissible bitumen content. The optimum bitumen content should be selected at a value of GSI equals one. This is established by interpolation of a graph of GSI vs. bitumen content. An increase in this index indicates an excessive bitumen content for the compaction pressure employed and foretells instability of the bituminous mixture for the loading employed. A reduction in roller pressure during the compaction process likewise indicates loss of stability because of overfilled voids; this phenomenon also serves as an indicator of maximum allowable bitumen content as does the increase of gyratory angle which gives a stability index in excess of unity.

4.3 It must be pointed out that the gyratory angle, being a measure of shear strain, is highly sensitive to temperature, especially on the rich side of optimum where the voids are overfilled and the shear stress is being transferred to the bituminous phase. Also, once the voids become over-filled, the bituminous mixture is subject to the phenomenon that may be best described as "stress-softening", that is flattening of the stress-strain curve (reduction in stability) with continued kneading. Attempts to relate GSI values to performance is not recommended other than to identify the maximum permissible bitumen content as that at which the GSI value starts to exceed one.

NOTE 1—The quality of the results produced by this standard are dependent on the competence of the personnel performing the procedure and the capability, calibration, and maintenance of the equipment used. Agencies that meet the criteria of Standard Practice D3666 are generally considered capable of competent and objective testing/sampling/inspection/etc. Users of this standard are cautioned that compliance with D3666 alone does not completely assure reliable results. Reliable results depend on many factors; following the suggestions of D3666 or some similar acceptable guideline provides a mean of evaluating and controlling some of those factors.

5. Apparatus

5.1 *Gyratory Testing Machine (GTM) and Appurtenances*—The primary equipment for this test is the Gyratory Testing Machine (GTM) and appurtenances. Fig. 1 is a photograph of the largest model GTM which is equipped to test 4-in. (101.6 mm), 6-in. (152.4 mm), or 8-in. (203.2 mm) specimens. Refer to manufacturer's manual for more information.

5.2 Supplementary Equipment – the following conventional materials testing laboratory equipment will be required:

5.2.1 *Ovens*—Ventilated ovens shall be provided for heating aggregates, bituminous material, and specimen molds and for curing cut-back mixes and emulsion mixes. It is recommended that the heating units be thermostatically controlled so as to maintain the required temperature within 5°F (2.8°C).

5.2.2 *Balances,* one having a capacity of 5 kg or more, sensitive to 1.0 g and one having a capacity of 2 kg, sensitive to 0.1 g.

5.2.3 *Thermometers*—Armored glass or dial-type thermometers with metal stems are recommended. A range from 50 to 400°F (9.9 to 20.4°C) with sensitivity of 5°F (2.8°C) is required.

5.2.4 *Miscellaneous Apparatus*—Trowels, spatulas, scoops, spoons, gloves, rubber gloves, metal pans.

6. Test Specimens

6.1 Refer to manufacturer's manual for detail information.

6.2 Prepare at least three specimens for each combination of aggregate and bitumen. Include a range of bitumen contents so as to fully develop the compaction curve, develop a smooth curve of GSI vs. bitumen content and have at least three bitumen contents in which the gyratory angle shows progressive increase with continued compaction. Conduct check tests on outliers as necessary to insure smooth curves of density, GSI and gyratory shear vs. bitumen content.

FIG. 2 GTM Compaction and Shear Test

6.3 *Preparation of Aggregates*—Separate the aggregate into the various size fractions necessary for accurately recombining into test mixtures conforming to specified grading requirements.

6.4 *Preparation of Mixtures*—Combine the freeoven-dried aggregates into appropriate size batches. See 6.6 for size of compacted specimens. Heat the aggregate to the desired temperature, into the aggregate mixture. Mixing of the aggregate and bitumen shallshould be as thorough and rapid as possible; mechanical mixing is recommended.

NOTE 2—For estimating purposes use 156.0 pounds/cubic foot (2.5 Mg/m^3) as the unit weight of compacted specimen.

6.5 For mixes employing penetration/viscosity/PG grades of asphalt, the temperature of the aggregate and asphalt at the time of mixing should correspond to the temperatures anticipated to be used at the plant during manufacture of the paving mix. These temperatures will generally be somewhere in the range of 250 to 325°F (121 to 163°C).

6.6 For mixtures employing liquid bitumen (cutbacks or emulsions), the asphalt need not be heated but the aggregate should be dried to constant weight at 221 to 230° F (105 to 110°C). Cool the aggregate to room temperature and then mix with liquid bitumen. Following mixing, cure the loose mixture in a ventilated oven maintained at 221 to 230 ° F (105 to 110°C) for at least 12 hours prior to compaction at this temperature. The mix may be stirred occasionally during curing to accelerate loss of volatiles.

6.7 *Size of Specimens*—The GTM can prepare a wide range of specimen lengths in the different diameter molds, including duplications of actual pavement thickness. It is recommended that for most purposes, a ratio of 1 to 1 of diameter to height be used so as to obtain the most favorable ratio of particle size to mold size for height as well as diameter. Recommended sizes are:

Mold Diameter	Specimen Height
4 to 4.01 inches (101.6 to 101.9 mm)	3.5 to 4 inches (88.9 to 101.6 mm)
6 to 6.01 inches (152.4 to 152.7 mm)	5.5 to 6 inches (139.7 to 152.4 mm)
8 to 8.01 inches (203.2 to 203.5 mm)	7.5 to 8 inches (190.5 to 203.2 mm)

NOTE 3—Trial batches might be needed to verify the batch weights to obtain desired specimen heights.

7. Calibration and Standardization

7.1 Refer to manufacturer's manual for detail information.

8. Test Procedure

8.1 *Compaction and Shear Test*

8.1.1 Set the GTM heater control to the maximum anticipated pavement temperature. Install the mold chuck front clamp piece and turn the heater on. Allow sufficient time for the heater indicator light to show that the temperature has been attained by lighting up intermittently (approximately 1 hour is required).

8.1.2 Prepare three initial batches of mix at each of the following suggested bitumen contents: (1) At the estimated optimum bitumen content (2) 0.5 % less than estimated optimum (3) 0.5 % greater than estimated optimum. Conduct additional tests and check tests for outliers as required ensuring fully developed smooth curves of density, GSI and gyratory shear vs. bitumen content. Include at least three specimens for which GSI exceeds one.

8.1.3 Test parameters to be checked, input, or recorded include the following:

8.1.3.1 Material Type – bituminous mix.

8.1.3.2 Location where test material will be in pavement structure – surface/subsurface including thickness of cover layers.

8.1.3.3 Contact Pressure – to be estimated from anticipated maximum tire pavement contact pressure as pavement design criteria.

8.1.3.4 Vertical Pressure – the program calculates and displays the needed vertical pressure based on the design contact pressure, thickness of cover layers and type of materials input by the operator.

8.1.3.5 Quantity of Materia.l

8.1.3.6 Percent bitumen.

8.1.3.7 Specimen Description.

8.1.3.8 Test Termination Condition (Equilibrium Density, Specimen Height, Density or Number of Revolutions).

NOTE 4—New GTM program allows the user four different options for controlling the end-point of the compaction process. Refer to manufacturer's manual for more information.

8.1.4 Set Vertical Pressure which the specimen will be subjected to under design contact pressure during use. Subsurface material will obviously experience lower stress than surface material.

8.1.5 When using an oil- filled roller set a machine angle of 0.8°.

8.1.6 When using an air filled roller set an initial machine angle of 2° with a high pressure (> 1.5 x p') in the roller cylinder to preclude compression of the roller during the angle setting procedure. After the initial machine angle is set at 2° reduce the air pressure in the roller cylinder to the critical pressure p' corresponding to the size specimen. (See Annex A and definition for p').

8.1.7 Prepare a mold filled with the test mix and heated within 2.8°C of the anticipated plant mix temperature. Install the mold in the GTM. Start compaction test andof the shear mix.

8.1.8 During compaction the computer will record all measured parameters as follows in each revolution:

8.1.8.1 Revolution number.

8.1.8.2 Specimen height.

8.1.8.3 Specimen density.

8.1.8.4 Gyratory angle.

8.1.8.5 Work done (energy provided).

Program then make those calculations necessary to determine if the selected termination condition has been met. The GTM will compact the mix until the selected termination condition is reached, at which point the computer will stop the roller carriage. There is no need to stop the carriage during the test at any point.

NOTE 5—This applies to computerized models only. For non-computerized models, refer to manufacturer's manual.

8.1.9 Upon completion of compaction, allow the mold chuck temperature to stabilize at the maximum anticipated pavement temperature before taking the final readings.

8.2 *Cyclic Loading Test*

8.2.1 When the compaction test has been completed the GTM software includes an optional test that can be run on the new computerized GTM. This is the cyclic loading test which measures the dynamic compression and rebound moduli of the test specimen. This test is conducted on a specimen immediately after a compaction test has been run. The cyclic loading test option can be selected at the end of a compaction and shear test. Clicking on the cyclic loading option button will start the cyclic loading program The cyclic loading program sequences the vertical pressure applied to the specimen while the specimen is also undergoing gyratory kneading.

8.2.2 The cyclic loading program will set up a screen graph to give an analog display of the applied pressure cycle and the resulting specimen deflection. This graphical display is linear in both the vertical axis and the horizontal axis. The horizontal axis for this graph is time, not revolutions as was the case for the compaction test.

8.2.3 The program will store measurements of specimen deflection and cyclic pressure change for 11 revolutions, then stop the roller carriage, compute all dynamic parameters and print out the result.

8.3 *Wall Friction Test*

8.3.1 When the GTM compaction and shear test have been completed there is an optional test that can be performed to give an improved accuracy to the test results; this is the wall friction test. This test must be performed immediately after the compaction and shear test have been completed. If a wall friction test is planned, click on the wall friction test option on the computerized GTM or follow the manufacturer's directions for the noncomputerized model to obtain the wall friction data. Enter the measured wall friction data into the computer or on the data sheet. This correction for wall friction is then used in subsequent calculations.

8.3.2 Click on the text box associated with the wall friction option and enter the wall friction pressure reading noted above. Then click the next button. The computer will then print the test results using the wall friction data entry.

8.3.3 When a wall friction entry is made the computer printout for the compaction test will include a section for results that include corrections for wall friction in the computations as well as the standard computations.

9. Calculation or Interpretation of Results

9.1 After specimen compaction is terminated the computer will use the measurements collected to calculate results and print a report (no manual calculation is needed). The following are the main calculated results:

9.1.1 Unit Weight at the end of compaction

9.1.2 Gyratory Compatibility Index (GCI).

NOTE 6—With newer models of GTM, recommending using Total Work Done (Total Energy Provided) instead of GCI.

9.1.3 Total Work Done (Total Energy Provided).

9.1.4 Gyratory Stability Index (GSI).

9.1.5 Gyratory Shear Factor (GSF)

9.1.6 Static Shear Modulus.

9.1.7 Static Compression Modulus.

9.1.8 Dynamic Shear Modulus (if cyclic loading test is chosen at the end of compaction test).

9.1.9 Dynamic Compression Modulus (if cyclic loading test is chosen at the end of compaction test).

9.2 All of the information collected during each test is stored in a file on the computer disk drive.

9.3 Test results can be retrieved at a later date and a report duplicating the end-of-test report can be printed.

9.4 The test-results-file can also be retrieved into an Excel spreadsheet for other study if desired.

10. Report

10.1 The following are various items to be reported along with the test report:

10.1.1 Date and time.

10.1.2 Test Number.

10.1.3 Name of operator.

10.1.4 Total Specimen Weight.

10.1.5 Percent of Bitumen.

10.1.6 Compaction Stress.

10.1.7 Number of Revolution at the end of compaction.

10.1.8 Compaction Terminated Condition.

10.1.9 Specimen Height at End of Compaction.

10.1.10 Unit Weight of Total Mix.

10.1.11 Unit Weight of Aggregate only.

10.1.12 Used of O-rings or not.

10.1.13 Gyratory Compatibility Index.

10.1.14 Total Work Done.

10.1.15 Machine Angle.

10.1.16 Intermediate Gyratory Angle.

10.1.17 Gyratory Angle at the end of Compaction.

10.1.18 Gyratory Stability Index.

10.1.19 Average Roller Pressure.

10.1.20 Static Shear Strength.

10.1.21 Gyratory Shear Factor.

10.1.22 Static Shear Modulus.

10.1.23 Static Compression Modulus.

10.1.24 Dynamic Shear Modulus (if cyclic loading test is chosen at the end of compaction test).

10.1.25 Dynamic Compression Modulus (if cyclic loading test is chosen at the end of compaction test).

10.2 In addition to the parameters in 10.1, the report shall include the following parameters for each specimen tested using the oilfilled roller mode of operation:

10.2.1 Gyratory shear strength (S_G), and

10.2.2 Gyratory strength factor (GSF).

10.3 An example of a test report (retrieved from test file) is provided in the 11.1. The test report includes specimen identification, setup parameters and calculated results. The test report also includes a graph of the measurements recorded each revolution.

11. Precision and Bias

11.1 *The within-laboratory repeatability standard deviation for gyratory stability index (GSI) has been determined to be 0.007, based on one lab, 4 test replicates, and 16 different samples. The within-laboratory repeatability standard deviation for Density has been determined to be 0.044 gm/cc, based on one lab, 4 test replicates, and 16 different samples The betweenlaboratory reproducibility of this test method is being determined and will be available on or before June 2016. Therefore, this Standard should not be used for acceptance or rejection of a material for purchasing purposes.*

11.2 *Bias*—since there is no accepted reference material suitable for determining the bias for the procedure in these test methods for measuring the GSI and density, no statement on bias is being made.

12. Keywords

12.1 asphalt; compaction; density; energy; equilibrium; GTM; gyratory; mix design ; rut ; shear; stability

ANNEX

(Mandatory Information)

A1. DEVELOPMENT OF THE FORMULA FOR GYRATORY SHEAR, S_G

A1.1 Referring to the schematic in Fig. A1.1 and taking moments about 0, the equation for gyratory shear, S_G, is developed as follows:

$$2 \cdot P \cdot L = S_G \cdot A \cdot h + 2 \cdot F \cdot a - N \cdot b \quad \text{(A1.1)}$$

$$S_G = \frac{2(P \cdot L - F \cdot a) + N \cdot b}{A \cdot h}$$

A1.2 The equation in A1.1 is for the θ_o position; since the shear at the θ_{max} position is desired, it is approximated by assuming a linear stress-strain relationship and multiplying the previously calculated value by the ratio θ_{max}/θ_o so that the equation is then expressed as follows:

$$S_G = \frac{2(P \cdot L - F \cdot a) + N \cdot b}{A \cdot h}\left(\frac{\theta_{max}}{\theta_o}\right) \quad \text{(A1.2)}$$

where:

P = load on upper roller,
L = distance from center of path of upper roller to vertical axis through center of sample,
N = normal vertical load on specimen and is equal to the total load on ram,
A = end area of specimen,
h = height of specimen,
θ_o = initial gyratory shear angle,
θ_{max} = maximum gyratory shear angle,
a = 0.637 × radius of mold (distance to the center of gravity for a circular arc equal to one half of the periphery),
B = arm of vertical force couple = $h \cdot \tan\theta_o$, and
F = Force caused by wall friction.

NOTE A1.1—When $S_G = \tau_{max}$, P = P'

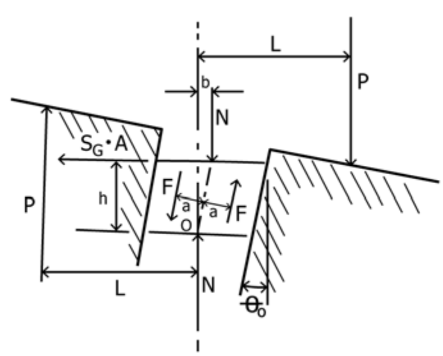


FIG. A1.1 Development of Formula for Gyratory Shear