Center of Gravity Test Code—SAE J874a

SAE Standard
Editorial change June 1977

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Society of Automotive Engineers, Inc.
400 COMMONWEALTH DRIVE, WARRENDALE, PA. 15096

LAND SEA AIR SPACE

PREPRINT

CENTER OF GRAVITY TEST CODE—SAE J874a

SAE Standard

Report of Construction and Industrial Machinery Technical Committee approved December 1954 and last revised February 1968. Editorial change June 1977.

1. Objective—The objective of these tests is to determine the location of the center of gravity of construction and industrial machines or other machinery. It is reported by three dimensions in lengths from specified mutually perpendicular reference planes. For conventional machines, these will normally be as follows:

XY Plane—The horizontal plane on which the machine rests without penetration.
XZ Plane—A vertical plane through the tread centerline.
YZ Plane—A vertical plane through an axle centerline.
X—Longitudinal distance of center of gravity from YZ plane.
Y—Lateral distance of center of gravity from XZ plane.
Z—Height of center of gravity above XZ plane.

2. Scope—This code applies to all types of self-propelled machinery. It covers five methods of determination as follows:

Suspension Method
Null Point Method
Platform Support Reaction Method
Reaction Method
Balance Method

3. Suspension Method

3.1 Definition—The suspension method is a means of locating the center of gravity based on the principle that the center of gravity of any freely suspended body is in the vertical plane through the point of suspension. The body is successively suspended in three or more positions and the respective planes containing the center of gravity are established. Intersection of these planes locates the center of gravity.

3.2 Practical Considerations

3.2.1 This method inherently provides a cross check of results for accuracy.

3.2.2 The components of machines tested under this method must be secured against changes in position.

3.2.3 The lifting crane, hook block, slings, and other rigging must be carefully analyzed to insure safety and ascertain their effect on the balance of the suspended machine.

3.3 Facilities, Apparatus, and Materials

3.3.1 Means for lifting the required load.

3.3.2 Apparatus such as slings, hook blocks, and other rigging as required to suspend the machine and provide for adjustment to its different test positions, preferably while suspended.

3.3.3 Means to block, bolt, or chain movable components of the machine securely in the specified relation to each other.

3.3.4 Means to indicate level of coordinate axes, accuracy of ± 0.5%.

3.3.5 Plumb bob.

3.3.6 Surveyor's transit. (Desirable but not essential.)

3.3.7 Measurement of lengths – accuracy of ± 0.5% or ± 2 mm, whichever is greater.

3.3.8 Scribing board, made of plywood or other flat stock, large enough to cover the area of the estimated location of the center of gravity. Board should provide for facing with paper having edges with numbered graduations. A scribing area at least 0.7 metre square is desirable.

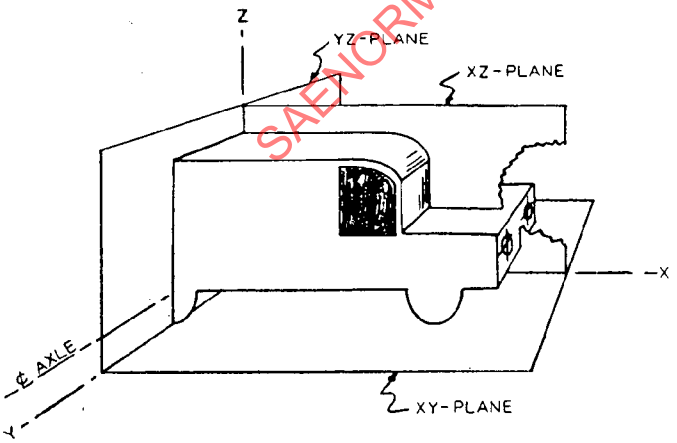


FIG. 1

3.4 Procedure

3.4.1 Clean machine and remove extraneous material.

3.4.2 Assure that machine conforms with specified conditions. This includes quantities of coolant, fuel and lubricant, tire inflation pressures, and so forth. Record this information on the test summary sheet.

3.4.3 Secure components in specified position and liquids against spillage. Select and arrange material for doing this job in such a manner that it will not appreciably affect test results.

3.4.4 Attach scribing board to side of the machine, parallel to the XZ plane and centered approximately over the transverse projection of the center of gravity.

3.4.5 Prepare for checking transverse level of suspended machine. This may be done with spirit level or manometer if reference line parallel to transverse axis has been established on machine prior to suspension.

3.4.6 Attach lifting apparatus and in successive operations suspend the vehicle with the transverse axis level and longitudinal axis:

(a) Approximately level.
(b) Up at least 15 deg toward front.
(c) Up at least 15 deg toward rear.

3.4.7 In each suspended position, using either the plumb bob or transit, locate and mark on the scribing board the vertical plane perpendicular to the XZ plane and passing through the point of suspension. See Fig. 3. Before scribing, be sure that:

(a) The transverse axis of the machine is level.
(b) The line of sight passes through the point of suspension AND IS PERPENDICULAR TO THE LONGITUDINAL AXIS OF THE MACHINE.

3.4.8 Measure and record the distances from the geometric center of the intersection points of the lines marked on the scribing board to the XY and YZ reference planes of the vehicle.

3.4.9 Measure and record the distance between each point of intersection of lines on the scribing board and the geometric center of all intersection points. These distances are an indication of inaccuracies in technique and should not exceed 2.5% of the distance from the geometric center to the XY reference plane of the vehicle.

3.4.10 Establish the y and z coordinates of the center of gravity using the same procedures outlined above.

(a) Keep the longitudinal axis of the machine level and tilt the transverse axis.

(b) Center the scribing board over the longitudinal projection of the center of gravity.

3.4.11 Record the average dimension of the z coordinates, for the two determinations, on the test summary sheet. (The difference of the two determinations should not exceed 2% of the average.)

3.4.12 Record description of machine and test results on summary sheet.

4. Null Point Method

4.1 Definition—The null point method is a means of locating the center of gravity based on the principle that the center of gravity of a balanced body is in the vertical plane through the line of support. The machine is successively balanced on three or more lines and the respective planes containing the center of gravity are established. Intersection of these planes locates the center of gravity.

4.2 Practical Considerations—The method affords a check on the accuracy of results by providing two independent determinations of the vertical location of the center of gravity. Rigidity of the system employed contributes to the accuracy of results.

4.3 Facilities, Apparatus, and Materials

4.3.1 A platform sufficiently large and rigid to support test machine and its mounted equipment. The platform shall include two knife edges firmly attached beneath it. The space between the knife edges should be approximately 0.2 times the estimated height of the center of gravity of the test machine above the plane of the knife edges. The knife edges shall be positioned one on each side of and approximately equidistant from the platform center of gravity. Either the platform should be of a size to permit the test machine to be placed on it both longitudinally and transversely, or the construction should be such as to permit the knife edges to be positioned both parallel to and perpendicular to the longitudinal axis of the platform.

4.3.2 A horizontally mounted, hardened steel plate of sufficient size and rigidity to simultaneously support both knife edges. Support for this steel plate shall be so constructed that it will permit tilting the platform, about either its

The φ symbol is for the convenience of the user in locating areas where technical revisions have been made to the previous issue of the report. If the symbol is next to the report title, it indicates a complete revision of the report.

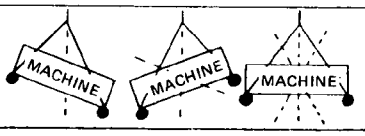
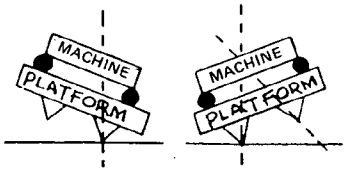
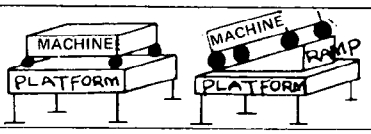
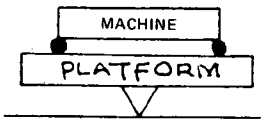
Method	Results	Illustration	Major Equipment	Comments
Suspension method Machine suspended by cable and slings	Longitudinal, lateral, and vertical location		Crane or method of lifting Slings of different lengths	Has graphical analysis accuracy.
Null point method Machine on platform supported by 2 knife edges	Longitudinal, lateral, and vertical location		Platform mounted on two knife edges	Very accurate method if balance point is accurately located, angle is carefully determined, and relative vehicle movement is measured. Location is found by computation.
Platform support reaction method Platform on 3 or 4 load cells	Longitudinal, lateral, and vertical location		Platform mounted on 3 or 4 load cells with accessories	Lateral and longitudinal location obtained quickly. A somewhat elaborate set up. Location found by computation.
Reaction method A scale under each wheel or end	Longitudinal and lateral location		Scales	Accuracy depends on accuracy of scales and accuracy of measurements. Not recommended for finding vertical location. Location found by computation.
Balance method Platform with one long knife edge under C of G of platform	Longitudinal and lateral location		Platform mounted on knife edge under C of G of platform	Accuracy depends on care taken in balancing. Normally will give a fairly accurate location.

FIG. 2—SUMMARY OF CENTER OF GRAVITY

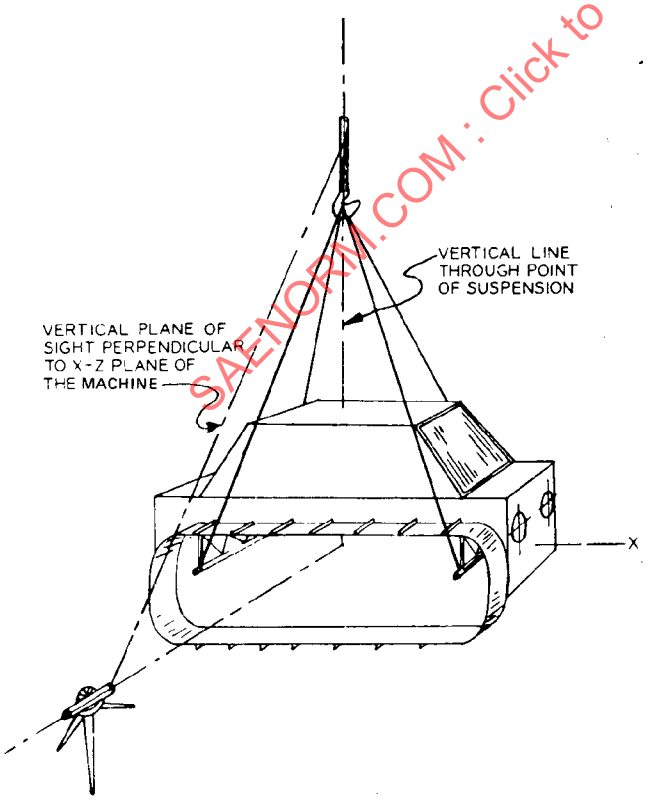


FIG. 3

transverse or longitudinal axis, at least 5 deg from the horizontal in either direction.

4.3.3 Means to block, bolt, or chain movable components of machine securely in the specified relation to each other.

4.3.4 Means to secure the machine to the platform so as to minimize its movement when the system is tilted.

4.3.5 Means to tilt and control either end or side of the test system to angles up to 10 deg.

4.3.6 Means to establish the angle of tilt, either directly or through the use of trigonometric functions. Accuracy 3 min.

4.3.7 Means to measure the amount of longitudinal or lateral movement of test machine relative to the platform when the system is tilted. Accuracy: ± 2 mm.

4.3.8 Measurement of lengths—accuracy of ± 0.5% or ± 2 mm, whichever is greater.

4.3.9 Means to indicate the null or balance point of the tilted system. (This may be a sensitive weight indicating device built into the tilting equipment.)

4.3.10 Means to establish required weights. Accuracy 0.5% of measured mass.

4.4 Procedure

4.4.1 Clean machine and remove extraneous material.

4.4.2 Assure that machine conforms with specified conditions. This includes quantities of coolant, fuel and lubricant, tire inflation pressures, and so forth. Record this information on the test summary sheet.

4.4.3 Secure components in specified position and liquids against spillage. Select and arrange material for doing this job in such a manner that it will not appreciably affect test results.

4.4.4 Record mass W_p of platform with knife edges and fastening equipment. See Fig. 4.

4.4.5 Record mass W_v of test machine.

4.4.6 Record dimensions x_p and z_p, locating the center of gravity of the platform with knife edges and fastening equipment[1] in positions in which they are to be used during final determination.

4.4.7 Record distances a, a′, and c. See Fig. 4.

4.4.8 Position the machine on the platform with the machine center of gravity approximately midway between the platform knife edges, with the longitudinal axis of the machine perpendicular to the knife edges for the determination of the center of gravity location in the XZ plane, or parallel to the knife edges for the determination of the center of gravity location in the YZ plane.

[1] Required only when mass of fastenings is more than 1% of the mass of the vehicle.

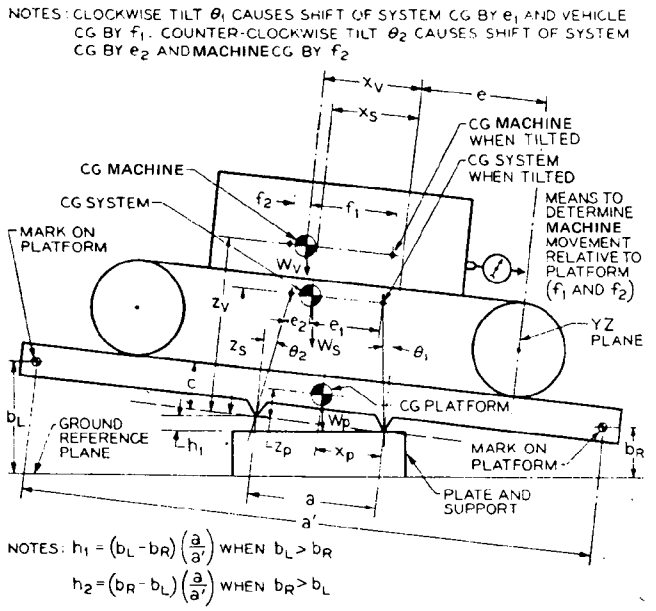


FIG. 4

4.4.9 Block the machine suspension and fasten the machine securely to the platform by either chaining or bolting. Record distance e. See Fig. 4.

4.4.10 Set up equipment for determining amount of longitudinal or lateral movement of the machine relative to the platform.

4.4.11 Tilt the system with the Y-axis down until it is in balance.

4.4.12 Measure b_L and b_R, calculate and record the height h_1, or the angle of tilt θ_1, and the movement f_1 of the test vehicle relative to the platform.

4.4.13 Tilt the system with the Y-axis up until it is in balance.

4.4.14 Record the height h_2, or the angle of tilt θ_2, and the movement f_2 of the test vehicle relative to the platform.

4.4.15 Reposition test vehicle or knife edges 90 deg from previous position on platform and repeat to establish y and check z.

4.5 Symbols and Computations

4.5.1 Symbols. See Fig. 4.

4.5.2 Computations when tilt is determined by linear measurement:

$$z = \frac{a(W_p + W_v) - W_v(f_1 + f_2)}{\left(\frac{h_1}{\sqrt{a^2 - h_1^2}} + \frac{h_2}{\sqrt{a^2 - h_2^2}}\right)W_v} - \frac{W_p z_p}{W_v} - c$$

$$x = e + \frac{W_s z_s h_1 - W_p x_p \sqrt{a^2 - h_1^2}}{W_v \sqrt{a^2 - h_1^2}} + f_1$$

$$\text{where } z_s = \frac{a - (f_1 + f_2)\left(\frac{W_v}{W_v + W_p}\right)}{\frac{h_1}{\sqrt{a^2 - h_1^2}} + \frac{h_2}{\sqrt{a^2 - h_2^2}}}$$

y ..... use analogous formula.

4.5.3 Computations when tilt is determined by angular measurement:

$$z = \frac{a(W_p + W_v)}{(\tan\theta_1 + \tan\theta_2)W_v} - \frac{f_1 + f_2}{(\tan\theta_1 + \tan\theta_2)} - \frac{W_p z_p}{W_v} - c$$

$$x = \frac{W_s z_s \tan\theta_1 - W_p x_p}{W_v} + f_1$$

$$\text{where } z_s = \frac{a - (f_1 + f_2)\left(\frac{W_v}{W_v + W_p}\right)}{(\tan\theta_1 + \tan\theta_2)}$$

y ..... use analogous formula.

5. Platform Support Reaction Method

5.1 **Definition**—The platform support reaction method is a means of locating the center of gravity based on the principle that the resultant of the platform support reactions caused by the mass of a body passes through the center of gravity of the body. The location of the machine with respect to the platform and the support reactions caused by the machine are measured and the center of gravity of the body is located by calculation.

5.2 Practical Considerations—Convenience and speed in taking the necessary readings are obtained at the expense of a somewhat elaborate installation. The calculations for locating the center of gravity in longitudinal and transverse directions are satisfactorily short. Overall accuracy depends primarily on the measuring means for the support reactions. With good measuring devices, the method can be extended to locating the center of gravity in vertical direction.

5.3 Facilities, Apparatus, and Materials

5.3.1 A platform scale with level platform of sufficient size and strength to accommodate the vehicle and with individual measuring means for the vertical platform support reactions at a minimum of three, but preferably four points. Accurately ±½% of observed load.

5.3.2 Horizontal stabilizing means for the platform that transmit only horizontal reactions and means of freeing vertical support reactions from any horizontal components. This may be achieved by three long horizontal stabilizing bars for the platform and fairly long vertical supports with spherical ends. The horizontal stabilizing bars and the upper spherical ends of the vertical supports should be in or very near the neutral plane (for bending) of the scale platform in order to prevent horizontal motion being caused by platform deflections. See Fig. 5.

5.3.3 Marks on the scale platform for locating the axes of the vertical support reactions and for establishing the platform reference axes M an N. See Fig. 5.

5.3.4 Steel tape longer than the greatest dimensions of the scale platform.

5.3.5 Plumb bob.

5.3.6 Additional facilities required for establishing the center of gravity in vertical direction (Z-coordinate, paragraph 1):

(a) Means to tilt machine on scale platform, minimum range 20 deg. This may be a tiltable cradle or a ramp or similar device. Cradle or ramp should be definitely located on the scale platform in a position that causes the tilted plane to be parallel to the M-axis of the platform.

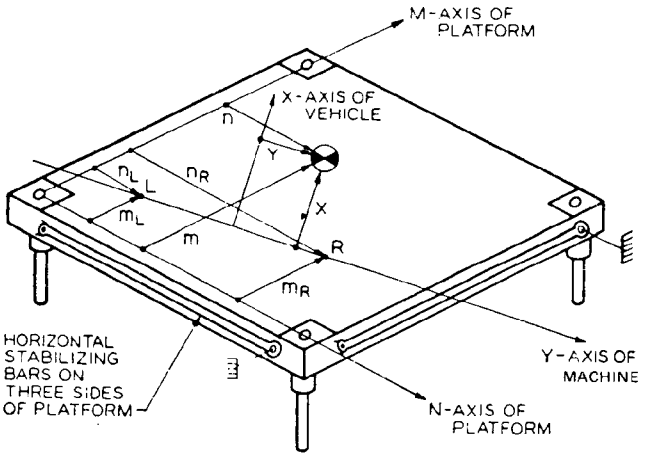
(b) Means to keep the Y-axis of the vehicle parallel to the M-axis of the platform.

(c) Means to establish the angle of tilt of vehicle. Accuracy ±10 min.

(d) Means to block, bolt, or chain movable components of vehicle securely in the specified relation to each other.

5.4 Procedure

5.4.1 Clean the machine and remove extraneous material.



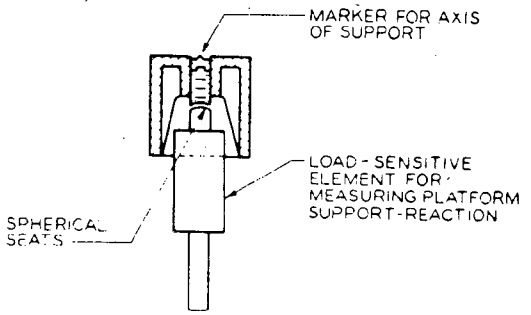


FIG. 5

5.4.2 Assure that machine conforms with specified conditions. This includes quantities of coolant, fuel and lubricant, tire inflation pressures, and so forth. Record this information on the test summary sheet.

5.4.3 Secure components in specified position and liquids against spillage. Select and arrange material for doing this job in such a manner that it will not appreciably affect test results.

5.4.4 Check functioning of the scale support reaction measuring devices, set for zero or take the no-load readings. If load readings are to be taken with machine in tilted position in order to establish the Z-coordinate of the center of gravity, set for zero or take no-load readings with cradle in horizontal position (or, no ramp on the platform) and then take no-load readings with cradle in tilted position (or, ramp on the platform).

5.4.5 Position the machine on the platform, preferably so as to cause fairly uniform support reactions. If cradle is used, take readings with cradle in horizontal and in tilted position. Record the platform support reactions under load and the location of the vehicle with respect to the M- and N-axes of the scale platform. See Fig. 5.

Note: It is sometimes more convenient to drop a plumb bob from the end points R and L of the reference axis, mark the points on the platform and locate them after the vehicle has been removed.

5.4.6 Remove the machine from the platform and take the final no-load readings.

5.4.7 Average the initial and the final no-load readings and subtract the averages from the respective load readings in order to establish corresponding support reactions.

5.4.8 The center of gravity of the machine is located with respect to the M- and N-axes of the scale platform by (see Fig. 5):

$$m = \frac{\Sigma \text{ Support-reaction moments about N-axis}}{\Sigma \text{ Support reactions}}$$

$$n = \frac{\Sigma \text{ Support-reaction moments about M-axis}}{\Sigma \text{ Support reactions}}$$

5.4.9 For machine in horizontal position, the center of gravity of the machine with respect to the reference points R and L is located as follows (see Fig. 5):

(a) Establish X-axis as the middle perpendicular of distance R-L.

(b) Establish Y-axis as line passing through R and L.

(c) Designate the coordinates of R and L with respect to the scale platform as m_R, n_R, m_L, and n_L respectively.

(d) Establish the quantities d, s_1^2, and s_2^2 from the formulas:

$$d^2 = (m_R - m_L)^2 + (n_R - n_L)^2$$
$$s_1^2 = (m_R - m)^2 + (n_R - n)^2$$
$$s_2^2 = (m - m_L)^2 + (n - n_L)^2$$

(e) Establish the coordinates of the center of gravity as:

$$y = \frac{s_2^2 - s_1^2}{2d} \quad \text{and} \quad x = \sqrt{s_1^2 - \left(y - \frac{d}{2}\right)^2}$$

(f) Check:

$$x = \sqrt{s_2^2 - \left(y + \frac{d}{2}\right)^2}$$

5.4.10 For machine in tilted position, intersect the resultant of the platform support reactions (located by m' and n') with the XY-plane of the vehicle (paragraph 1) by the formula (see Fig. 6):

$$x' = \frac{m' - m'_L}{\cos\theta} - r\tan\theta = \frac{m' - m'_L - r\sin\theta}{\cos\theta}$$

This formula assumes that the N-axis of the scale, the axis of tilt and the Y-axis of the vehicle are parallel ($m'_L = m'_R$). If there is a small difference between m'_L and m'_R, the average may be used instead of m'_L in the above formula. If the difference is greater than 5% of the vehicle width, however, the value of x' has to be found by the methods of three dimensional analytic or descriptive geometry.

5.4.11 The vertical coordinate of the center of gravity is

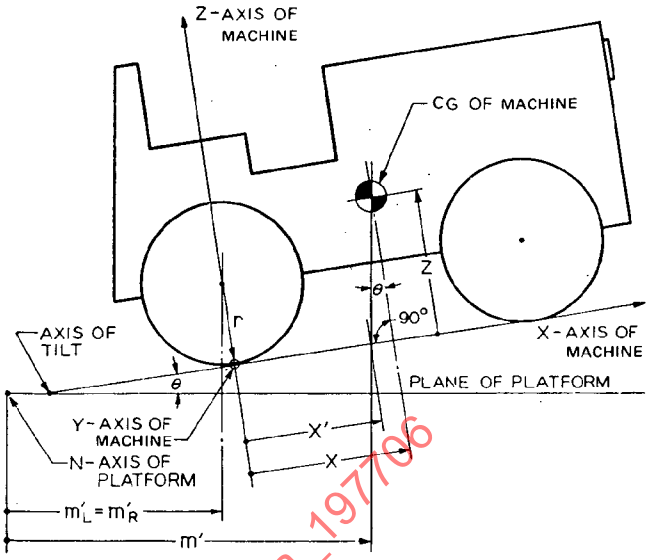
$$z = \frac{x - x'}{\tan\theta}$$

6. Reaction Method

6.1 Definition—The reaction method is a means of locating the center of gravity based on the principle that in the absence of horizontal reactions, the resultant of the external vertical reactions on any stationary body passes through its center of gravity. Location and magnitude of the external vertical reactions are measured and the resultant is located by calculation.

6.2 Practical Considerations

6.2.1 Because of limited accuracy of conventional weighing equipment, the weight reaction method is arbitrarily limited to the determination of the longitudinal and transverse location of the center of gravity. With highly accurate equipment and specialized technique, the method outlined could be extended to include determination of the vertical location of the center of gravity by measuring the reactions and angles with the vehicle in tilted position.



NOTE: ARRANGEMENT SHOULD BE MADE SO AS TO INSURE PARALLELISM BETWEEN N-AXIS OF PLATFORM, AXIS OF TILT AND Y-AXIS OF MACHINE

FIG. 6

6.2.2 If only two scales are available, the machine must be placed on the scales twice in order to locate the center of gravity in longitudinal and transverse direction. If three or more scales are available, all measurements can be taken with a single positioning of the machine on the scales. (Single scale determination of the reactions under several points of the machine taken successively would locate the center of gravity; this method is not recommended because of poor accuracy.)

6.3 Facilities, Apparatus, and Materials

6.3.1 Load scales (preferably mounted flush with the surrounding floor). Accuracy ±1% of observed load.

6.3.2 Means to block, bolt, or chain movable components of machine securely in the specified relation to each other.

6.3.3 Steel tape, graduated in inches, longer than the test machine under consideration.

6.3.4 Plumb bob.

6.3.5 Angle iron knife edges (where required to establish line supports).

6.4 Procedure

6.4.1 Clean the machine and remove extraneous material.

6.4.2 Assure that machine conforms with specified conditions. This includes quantities of coolant, fuel and lubricant, tire inflation pressures, and so forth. Record this information on the test summary sheet.

6.4.3 Secure components in specified position and liquids against spillage. Select and arrange material for doing this job in such a manner that it will not appreciably affect test results.

6.4.4 Position scale platforms in a common horizontal plane. If the vehicle is only partly supported by scales, position the remaining support points in the horizontal plane of the scale platforms. For best accuracy, make the distances between the lines or points of support as small as possible.

6.4.5 Check functioning of the scales, set for zero or determine the tare weight of blocks, knife edges, and so forth.

6.4.6 Position the machine on the scales, using knife edges where required to obtain definite and measurable lines or points of support.

6.4.7 Record scale reactions, distances between the support points, and location of the support points in XY-plane (paragraph 1).

6.4.8 Establish the coordinates of the center of gravity as:

$$x = \frac{\Sigma \text{ Weight-reaction moments about Y-axis}}{\text{Machine mass}}$$

$$\text{and } y = \frac{\Sigma \text{ Weight-reaction moments about X-axis}}{\text{Machine mass}}.$$