

Understanding & Calculating Local Gravity Corrections

Although pressure gauges themselves are not affected by gravity, pressures measured using a piston gauge loaded with a set of dead weights are affected by the local value of gravity due to the mass of the weights. Weight sets have mass and mass varies with gravity. This would not be a concern except that gravity varies from place to place. And, while gravity variations are not significant globally, they can have a relatively significant affect on piston gauge readings using deadweight testers (DWTs). Because DWTs use physical weights with mass, the variations in gravity must be corrected for in order to accurately determine the pressures being measured.

Causes of gravity variations

Gravitation is a natural phenomenon where all objects with mass attract one another, which we commonly refer to as objects having “weight.” The Earth’s gravity is the attractive force that the Earth exerts on objects on or near its surface. The precise strength of the Earth’s gravity varies depending on location. The “average” value at the Earth’s surface, known as standard gravity, is 9.80665 m/s^2 (32.1740 ft/s^2). That is, if the Earth were a perfect sphere without any topographic relief or density variations, the force of gravity would be 9.80665 m/s^2 at every point on the surface.

An object on the surface is attracted to every other particle in or about the earth, as well as the universe for that matter. Those particles that are closest to one another exert the strongest influence.

Because the Earth is not a perfect sphere, the strength of the Earth’s gravity varies with latitude, altitude, local topography and geology, and other factors. These variations in the acceleration of gravity result in a change in the weight of an object of about 0.8% over the surface of the earth, and about 0.2% over the contiguous United States.

The factors that most influence local gravity are as follows.

- **Latitude**

The most significant influence on the local acceleration of gravity is latitude. Gravity is weaker at lower latitudes (nearer the equator) because the Earth’s rotation causes it to bulge at the equator and flatten at the poles. Due to its rotation, the radius of the Earth is 42.72 km (26.5 miles) larger at the equator than when measured at the poles. Because of the greater distance to the center of the Earth at the equator, the force of gravity at the equator is about 9.780 m/s^2 whereas the force of gravity at the poles is about 9.832 m/s^2 . An object will weigh about 0.53% more at the poles than at the equator.

- **Altitude or Elevation**

Gravity decreases with altitude, since greater altitude means greater distance above sea level. All other things being equal, an increase in altitude from sea

level to the top of Mount Everest (29,029 feet) causes a weight decrease of about 0.28%.

- **Other variables**

Local variations in topography (such as the presence of mountains) and geology (such as the varying density of rocks in the vicinity) also cause fluctuations in the Earth's gravitational field. These are referred to as gravitational anomalies. If an object being tested is located in a valley, there will be an attraction upward toward any nearby mountains. If there is a large (less or more dense) geologic feature buried between the center of the Earth and the measuring point on the surface, the gravity at the surface will be affected. Geologists often use local gravity measurements to locate anomalies which assist them in discovering oil and mineral deposits.

There are other variables that affect the value of local gravity such as the tidal effects caused by the moon and sun, air buoyancy, moisture condensation, electrostatic attraction, magnetic attraction, and air currents caused by temperature variations. However, the effects of these other variables are negligible for our purposes.

Correcting for gravity

The procedure for determining and correcting for the affects of gravity is to compute the weight of the DWT weight sets based on standard gravity (9.80665 m/s² or 32.1740 ft/s²), and then correct the value for the variations caused gravity. Lucky for us, others have already worked out the mathematics.

If the latitude (*f*) and the elevation (*h*) in feet above sea level are known, the gravity correction (*Cg*) will be given approximately by:

$$Cg = -R (0.00261 \cos 2f + 0.000000095 h + 0.00006)$$

where R is the reading of the piston gauge.

This correction will usually compensate for gravitational variation with an error of less than 0.005 percent in any part of the United States.

Examples

Following are some examples for calculating gravity corrections at various locations.

- ❖ At Atlanta, Georgia, the reading on a piston gauge before gravity correction was 93,500 PSI. The latitude is 33.65° (cos 67.30° = 0.3859), and the elevation is 1007 ft.

$$\begin{aligned} Cg &= -93,500 ((0.00261 \times 0.3859) + (0.000000095 \times 1007) + 0.00006)) \\ &= -93,500 (0.00101 + 0.000095 + 0.00006) \\ &= -93,500 (0.00117) \\ &= -109 \end{aligned}$$

Thus, the corrected pressure = 93,500 – 109 = 93,391 PSI (0.12% less than indicated by the gauge)

- ❖ At Anchorage, Alaska, the reading on a separate piston gauge before gravity correction was also 93,500 PSI. The latitude is 61°13' ($\cos 122.43^\circ = -0.5363$), and the elevation is 104 ft.

$$\begin{aligned} C_g &= -93,500 ((0.00261 \times -0.5363) + (0.000000095 \times 104) + 0.00006) \\ &= -93,500 (-0.0014 + 0.00001 + 0.00006) \\ &= -93,500 (-0.00133) \\ &= +124 \end{aligned}$$

Thus, the corrected pressure = 93,500 + 124 = 93,624 PSI (0.13% more than indicated by the gauge)

- ❖ At Honolulu, Hawaii, the reading on a separate piston gauge before gravity correction was also 93,500 PSI. The latitude is 21°18' ($\cos 42.6 = 0.7361$), and the elevation is 670 ft.

$$\begin{aligned} C_g &= -93,500 ((0.00261 \times 0.7361) + (0.000000095 \times 670) + 0.00006) \\ &= -93,500 (0.0019 + 0.00006 + 0.00006) \\ &= -93,500 (0.00202) \\ &= -189 \end{aligned}$$

Thus, the corrected pressure = 93,500 – 189 = 93,311 PSI (0.20% less than indicated by the gauge)

Unit conversions

- ❖ **Standard gravity.** Often, the acceleration of gravity will be expressed in different units.

$$\begin{aligned} \text{Standard gravity} &= 9.80665 \text{ m/sec}^2 \\ &= 980.665 \text{ cm/sec}^2 \\ &= 980.665 \text{ galileo (gals) [1 gal = 1 cm/ sec}^2] \\ &= 0.980665 \text{ milligals} \\ &= 32.1740 \text{ ft/s}^2 \end{aligned}$$

- ❖ **Degrees-minutes-seconds to a decimal equivalent.** In order to apply the trigonometric functions to the latitudes, it is necessary to convert the latitude to its decimal equivalent.

Using an example of 37 deg, 18 min, 41 sec (37° 18' 41'"):

- Divide the 41 seconds by 60 sec/min and add this to the specified minutes, or 18.6833'.
- Divide the 18.6833 minutes by 60 min/deg and add this to the specified degrees, or 37.3114°.
- Correct for significant figures, our initial 37°18' 41" is equal to 37.31°.

Determining local gravity information

The easiest ways of determining the local information that will go into your gravity calculations is to search for the information on the Internet. For example, by searching for “Anchorage” and “latitude” will provide various sites that often

display both the latitude and longitude. Another source is to use Google Maps (<http://maps.google.com/>).

Locating your facility's elevation is nearly as easy. The pad or ground elevations are usually shown on construction and other local plans, if you have these available. You can also search for **topographic maps** and the **name** of your city on the Internet, locate the exact place of your facility, and then interpolate between the topographic lines to determine your elevation. If these methods fail, you can visit the local building department who should be able to assist you.

Using the NGS database

Local gravity information can also be obtained from the "Surface Gravity Prediction" Web site of the National Geodetic Survey, formerly the National Oceanic and Atmospheric Administration (NOAA).

Go to: http://www.ngs.noaa.gov/cgi-bin/grav_pdx.prl, and enter the latitude, longitude, and elevation (sea level height) for your testing facility. (Note: pay careful attention to the conventions required for entering the data in each field.)

If the data was entered correctly, the online calculator will provide the local gravity in milligals.

Note: The method used to calculate the gravity at the NOAA Web site is not based on the formulae provided herein, but rather on interpolation from known gravity measurements at specific locations within their database. As such, the resulting gravity includes an estimated uncertainty based on the distance to the data locations.

To determine the gravity correction, divide the NOAA gravity value by the standard gravity value (0.980665 milligals). This correction factor is then multiplied by the deadweight pressure to obtain the corrected applied pressure.