

A Brief Introduction to Significant Figures for Civil Engineers

As an engineer, one of your ongoing responsibilities will be to accurately and clearly convey the results of experimental or analytical work. Data used for calculations will always include some degree of uncertainty based on the measurements made as described above. The way that you represent numerical quantities must be carefully considered to include accurate information, which implicitly means some information about the accuracy of the numerical values. In practice, the number of significant figures shown for a numerical quantity can provide useful information about the accuracy of the corresponding measurement or the result of computations based on measurements. However, if not chosen correctly, the number of significant figures can serve to misrepresent the implied accuracy as well.

To determine the number of significant figures to show in a result we must use a common set of rules. The CE department recommends the following rules for taking measurements and using them in computations. Please note that to avoid duplications these rules may refer to other references.

Measurements

1. Use a measurement instrument that has been calibrated to work in the anticipated measurement range.
2. Avoid using an instrument for measurements that will likely always be in a very narrow range (less than 10 percent) of the instrument's full range.
3. Use the same instrument for all measurements of a given parameter that need to be compared, i.e., use the same load cell for all force measurements acting on a beam, or the same pH meter for pH measurements.
4. Determine the instrument's accuracy and record it with your data.
5. Make a note if the readings are not stable and some effort must be taken to "eyeball" an average or representative value.

Computations

1. Use the full number of significant figures obtained in the original measurements or given values in all calculations.
2. In general do not round intermediate results. Exception: for convenience when writing computations, rounding may be done but intermediate results should retain at least as many significant figures as for the quantity with the least significant figures plus 1 more.
3. Refer to ASTM Standard D 6026 for more discussion of significant figures. Note that although D 6026 makes specific reference to geotechnical data, the principles are applicable to most other civil engineering work as well.
4. When unit conversions or other factors are used care must be taken when determining the appropriate number of significant figures. For example, to convert 2.31 feet to inches you would multiply by 12 inches/foot. A calculator would produce a result of 27.72 inches, which would be the correct value to carry through for intermediate results. Because the factor of 12 for converting a measurement in feet to inches is a precise value, you would not need to limit your answer to the two significant figures implied. To do otherwise would improperly mask the precision in the original measurement. The correct final answer would be 27.7 inches which would keep the three significant figures obtained in the original measurement of 2.31 feet.

Final Results

1. In general the final results obtained through computations on measurement data should be limited to the number of significant figures obtained in the least precise measured or given value.
2. For more information about rounding and reporting final results refer to ASTM Standard D 6026.

Example 1 – Strain Gage lab experiment

Following the calibration steps given in the procedure, strain data was collected for a range of beam end deflections. Table E1.1 below show the data as it was recorded. Table E1.2 shows how the data should be formatted to show the appropriate number of significant figures.

Table E1.1 – Data entered as read from the instruments. Note that the multimeter automatically changed the measurement range at some point between the 323.8 and 371 readings which in effect reduced the resolution of the readings.

Micrometer Spindle Position (inch)	Beam end deflection,y (inch)	Strain (μϵ)
1.003	0	0.0
0.978	0.025	45.0
0.953	0.05	91.2
0.928	0.075	137.3
0.903	0.1	183.9
0.878	0.125	230.1
0.853	0.15	276.8
0.828	0.175	323.8
0.803	0.2	371
0.778	0.225	418
0.753	0.25	465

Table E1.2 – When reporting the results select the appropriate number of significant figures for each column of data. Show 3 sig figs to the right of the decimal point for deflection since the micrometer could be read to that precision. Round the strain reading to the nearest whole number since the multimeter shifted to a lower sensitivity setting.

Micrometer Spindle Position (inch)	Beam end deflection,y (inch)	Strain (μϵ)
1.003	0.000	0
0.978	0.025	45
0.953	0.050	91
0.928	0.075	137
0.903	0.100	184
0.878	0.125	230
0.853	0.150	277
0.828	0.175	324
0.803	0.200	371
0.778	0.225	418
0.753	0.250	465

When the strain was plotted vs. deflection, the trendline equation reported by Excel was $\text{strain } (\mu\epsilon) = 1865 * \text{deflection (inch)} - 1.924$. This means that the slope was found to be 1865 $\mu\epsilon/\text{inch}$ and the offset was -1.924 inch. These values could be considered intermediate computation values and it would be acceptable to keep the number of digits shown.

If you were asked to predict the strain for a given beam end deflection, you would compute the strain using the trendline equation then round to the appropriate number of significant figures. For example, if the beam end deflection is given as 0.160 inch, then the strain would be computed as

$$\text{strain} = 1865 \mu\epsilon/\text{inch} * 0.160 \text{ inch} - 1.924 \text{ inch} = 296.5 \mu\epsilon \rightarrow \boxed{297 \mu\epsilon}$$

If the beam end deflection is given as 0.16 inch, then the strain would be computed as

$$\text{strain} = 1865 \mu\epsilon/\text{inch} * 0.16 \text{ inch} - 1.924 \text{ inch} = 296.5 \mu\epsilon \rightarrow \boxed{300 \mu\epsilon}$$

Example 2 – Pressure measurements lab experiment

In Part A of this experiment, you measure the height of the water column using a scale marked in sixteenths of an inch increments and the corresponding transducer output signal, V , in mV. Then you compute the theoretical pressure at the base of the water column using Eq.1, $P = \gamma H$ where

- P = static fluid pressure (pounds per square inch)
- γ = unit weight of water ≈ 0.0361 pounds per cubic inch
- H = height of the water column (inch) relative to the datum

While this computation is straightforward, selecting the appropriate sig figs is not so simple when one or more of the quantities involves fractions. *For the purposes of this and other CE lab courses, and unless noted otherwise, when a measurement is based upon a fractional-inch scale the number of sig figs should be equal to the number of sig figs to the left of the decimal point plus 1. When reporting fractional-inch measurements, round the exact decimal equivalent of the fraction to the nearest one-tenth (0.1).*

Typical data collected for Part A of this experiment is shown in Table E2.1. The height data, H , are recorded to the nearest 1/16 inch as they are read from the scale. The transducer signal voltage data, V , that correspond to the pressure at the base of the water column are also shown in the table. Table E2.2 represents the version of the data as it is entered into an Excel worksheet. (The author prefers to use red color font for manually entered data and blue color font for computed results.)

Table E2.1 – Data collected in Part A.

A	B
H (inch)	V (mV)
0	-0.99
8 3/16	-0.72
11 7/8	-0.63
15 3/8	-0.52
18 1/8	-0.41

Table E2.2 – Data entered into the worksheet with computed pressure.

A	B	C	D
H (inch)	P (psi)		V (mV)
	computed	reported	
0	0.0	0.000	-0.99
8.2	0.29602	0.296	-0.72
11.1	0.40071	0.401	-0.63
15.4	0.556	0.556	-0.52
18.1	0.653	0.653	-0.41

Please note that column B is only shown here to help illustrate what is actually going on behind the scenes in the worksheet and it should not normally appear in your worksheet.

As the Excel worksheet is built, keep in mind that computed results and displayed results are not always the same. In first case where there was not water in the system, for a water column height of 0 inches, the value of 0 used to compute the pressure using Eq. 1 are identical. However, once the water column height is measured in the second row, we now encountered a different condition. Since 8 3/16 inch could be represented as 8.1875, we know that that answer has 5 significant figures. But we also know that we could not have discerned that kind of implied precision because

- the scale divisions of 1/16 inch are far larger than 0.0005 inch;
- the scale could not be held directly against the water column due to the physical arrangement of the equipment;
- the orientation of the scale was probably not perfectly vertical, and
- most people cannot visually see that degree of detail even if the scale divisions were 0.0005 inch.

Table E2.2 shows how the data would be entered into Excel. Referring to fractional scale rule above, the height value could be entered as “=8+3/16” and the number formatting would be used showing one figure

A Brief Introduction to Significant Figures for Civil Engineers

to the right of the decimal point. Keep in mind though that the following calculation will be using the actual computed value in column A (8.1875, 5 sig figs) for subsequent calculations.

The computed pressure, P, would be computed as 8.1875 inch x 0.0361 psi/inch= 0.29602 psi, and is shown in column B of Table E2.2. Since the constant provided for use in Eq. 1 was 0.0361 psi/inch has 3 sig figs, this would limit our displayed result to 3 sig figs as shown in column C to be 0.296 psi.

The next step is to enter the transducer signal voltage, then plot P (on the y axis) vs. V(on the x axis). When you plot the data you should choose to also plot the trendline and its equation. In this case the trendline equation shown in Excel is $y = 1.147x + 1.136$, which can be edited to use our variable names:

$P = 1.147V + 1.136$ **This equation is the calibration equation for our pressure transducer.**

where

P is the pressure in pounds per square inch (psi)

V is the transducer signal voltage in millivolts (mV)

For Parts B and C of the experiment, we will use the pressure transducer's calibration equation to determine the water column pressure. For example, assuming the measured water column height is 13 7/16 inch, and the transducer signal was -0.56 mV, the transducer signal would be substituted for V in the calibration equations as $P = 1.147(-0.56) + 1.136$ with the result shown in column C in Table E2.3. Since the measured transducer voltage has 2 sig figs, our reported result will also need to be limited to 2 sig figs as shown in column D.

Table E2.3 – Data entered into the worksheet with pressure computed using the calibration equation.

A	B	C	D
H (inch)	V (mV)	P (psi)	
		computed	reported
=13+7/16	-0.56	0.49354	0.49

Please note that column C is only shown here to help illustrate what is actually going on behind the scenes in the worksheet and it should not normally appear in your worksheet.