Introduction, measurements and their units

1. Introduction

- Instructors:
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  - Consultation/questions: in Teams or via email. More info at geod.bme.hu – staff.
- Topics covered in the course: basic mathematics and physics required to understand measurements and surveying calculations, basics of surveying calculations, usage of the engineer's level, measurements with the level, drafting of measurements, basics of mapping and map reading.
- Requirements to pass the course:
  - 2 control tests, 1 homework: each is 20 points, covers the topics previously examined in class.
  - 60 points can be achieved from the tests and homework, at least half of this (30 points) have to be achieved to pass the subject.
- Online study material: edu.epito.bme.hu – current semester – Department of Geodesy and Surveying – Basic Surveying

2. What is surveying? The role of surveying in civil engineering

- The difference between surveying and geodesy.
  - Surveying: the determination of position and orientation of objects (marker points) on, above or below the Earth's surface.
  - Geodesy: the science of determining the shape and characteristics of the Earth's gravity field (very closely tied to the actual shape of the Earth).
- The role of surveying in civil engineering projects:
  - Before construction begins: creation of a detailed survey of the area of interest (existing landmarks and objects, characteristics of the terrain, etc.)
  - During construction: the maintenance of geometric control, positioning and orienting structures and appliances, monitoring the construction site and the surroundings for deformation, constant supervision and verification of the geometry.
  - After construction: surveying the completed structure/building for registry and maintenance purposes. Monitoring of the structure for deformation.

3. Angles, distances and area

The two main measurement types in surveying: distance measurements and angle measurements. Distance measurements are carried out with EDM's (electro-optical distance meters), angle measurements are carried out with circle reading instruments (theodolites, total stations).

Area is computed using derived quantities (coordinates) or using the distances and angles.

The shape of every object on the surface can be determined by the coordinates of their markers (marker points, vertices). The coordinates are computed using distance and angle measurements.

Before going any further, the precision of the measurements (or any numerical value for that matter) has to be covered. When giving a numerical result or value, the precision of it means the number of decimals after the decimal point. For example, a distance of 15.341 m is given in the units of meter with millimeter precision, that is, three decimals (as the millimeter is the third decimal). As another example, let’s say we have to specify a length of 13.42 m in decimeter units with millimeter precision. This length in decimeter units would be 134.2 dm, however, this is only given with centimeter precision (as the first decimal denotes the centimeter value), so we have to add a trailing 0 to arrive at millimeter precision: 134.20 dm.

Precision is engineering calculations and metrology (the science of taking measurements) is not to be confused with accuracy. Precision describes the number of decimal places of a measured value while accuracy defines a range in which the value lies with some probability. For example, we can say that we measured a length to be 23.342 m and according to the manufacturer of our instrument, such a length can be measured with an accuracy of ± 4 mm (with 0.6 probability for example). We can write this as 23.342 m ± 4 mm, where the precision is 3 (or millimeter precision) and the accuracy is ± 4 mm. If we measure it again, we might get a different result, but the 0.6 probability tells us that if we carry out the measurement a large amount of times, approximately 60% of all the values will deviate from the correct value of our length by an amount that is less than or equal to 4 mm.

Let’s see another example to see the difference between precision and accuracy, according to measurements. Accuracy refers to the degree of perfection obtained in the measurement—in other words, how close the measurement is to the true value. When the accuracy of a survey is to be improved, greater precision must be used. Precision, refers to the degree of perfection used in the instruments, methods, observations, and care of the survey. In summary,

- Precision : Degree of perfection used in the survey (measurements are close to the average value)
- Accuracy : Degree of perfection obtained in the results (the average value is close to the true value)

Let’s consider the measurement of a distance between two points .Suppose we know that the actual distance is exactly 300.00 m and that three different survey crews are to make the measurement using different instruments and methods. Each crew measures the distance five times.

295.902	299.980	299.997
295.908	300.060	299.999
295.905	299.955	300.002
295.907	300.020	299.998
295.903	299.990	300.003
Average		
295.905	300.001	300.000

The first crew was precise but not accurate, the second crew was accurate but not precise, the third one was both accurate and precise.

Angles

Most common units of angles are decimal degrees (15.122°), sexagesimal units (DMS, 12° 22’ 30” or in geodetic format 12-22-30), radians (2.5) and gradians (centesimal units, gon, 12.234^{g}). The most common system of angular measurement is the sexagesimal system, in which a complete rotation of a line (or a circle) is divided into 360 degrees of arc. In this system, 1 degree is divided into 60 minutes, and 1 minute is further divided into 60 seconds of arc. DMS values: 1 deg = 60 min, 1 min = 60 sec. (1 deg = 3600 sec). DMS values in surveying are written as DDD–MM–SS, where D means the degree part, M means the minute part and S means the second part. For example: 25–02–06 (25 degrees, 2 minutes and 6 seconds). It is not correct to write it like so: 25–2–6 (the leading zeros for the minute and the second part always have to be included). In engineering surveying, the typical precision is 1 arc second, that is, the fractional part of the arc second is rounded up or down.

Conversion from decimal degree to DMS:

1. Take the integer part of the value in decimal degrees. This is the degree value.

2. Take the fractional part of the value in decimal degrees and multiply it by 60. The integer part of the result is the minute value.
3. Take the fractional part resulting from the multiplication in step 2 and multiply it by 60. This is the second value.

Examples:

$$32.456° = 32 - 27 - 22$$

$(0.456 \cdot 60 = 27.36) \rightarrow 27$ is the minute value

$(0.36 \cdot 60 = 21.6) \rightarrow 22$ is the second value

$$12.5° = 12 - 30 - 00$$

Conversion from DMS to decimal degree:

1. Take the degree part of the DMS value. This is the integer part of the decimal degree value.
2. Take the minute part of the DMS value and divide it by 60. Add this to the results from step 1.
3. Take the second part of the DMS value and divide it by 3600. Add this to the results from step 2.

Examples:

$$52 - 30 - 41 = 52 + 30/60 + 41/3600 = 52.51138°$$

$$210 - 47 - 20 = 210 + 47/60 + 20/3600 = 210.78°$$

If we use gradians (grad) as our units, we divide the circle into 400 parts instead of 360 (as with the degree units). This means that a right angle of 90° is equal to 100^g. One gradient can be divided into centigrads and one centigrad can be further divided into centicentigrads. Gradians uses the decimal system (as opposed to the sexagesimal), which means that 1 grad = 100 c (centigrad) and 1 c = 100 cc (centi-centigrad) which also means that 1 grad = 10000 cc.

Conversion between degrees and gradians:

$$1° = \frac{360}{400} \cdot 1^g \qquad 1^g = \frac{400}{360} \cdot 1°$$

$$21.856° = \frac{400}{360} \cdot 21.856° = 24.284^g$$

$$64.381^g = \frac{360}{400} \cdot 64.381^g = 57.9429°$$

1 radian denotes a central angle of a circle for which the length of the curve opposite the central angle equals the radius of the circle.

Conversion between radians and degrees:

$$\pi \text{ rad} = 180°$$

$$127.634° = \frac{\pi}{180} \cdot 127.634° = 2.2276 \text{ rad}$$

$$4.57 \text{ rad} = \frac{180}{\pi} \cdot 4.57 \text{ rad} = 261.8417°$$

4. Addition and subtraction using DMS values

Addition and subtraction is carried out similarly to addition and subtraction with regular numbers by hand. For example:

$$\begin{array}{r} 32 - 45 - 51 \\ \underline{+142 - 36 - 25} \end{array}$$

$$= 175 - 22 - 16$$

We first add the second values together: $51 + 25 = 76$. As one minute equals only 60 seconds, we carry one minute and have a remainder of 16. If we add the minute part we receive $45 + 36 + 1 = 82$. One degree contains only 60 minutes, so we carry one degree and have a remainder of 22 minutes. Adding the degrees we get $32 + 142 + 1 = 175$.

Other examples:

$(359 - 59 - 59) + (0 - 00 - 10) = 360 - 00 - 09 = 0 - 00 - 09$ (We can subtract $360°$, as the angle remains the same).

$(240 - 52 - 10) + (17 - 25 - 30) = (258 - 17 - 40)$

Subtracting DMS values:

$$\begin{array}{r} 57 - 40 - 24 \\ \underline{-187 - 11 - 46} \\ = -129 - 31 - 22 \end{array}$$

We take the angle which has the smaller absolute value $(57 - 40 - 24)$ and calculate how much we have to add to each of the digits to get the digits of the other angle. In case of the seconds, we have to add 22 to the 24 to receive 46. For the minutes, we have to first add 20 minutes to the 40 minutes to receive 60 minutes (which equals 1 degree and 0 seconds, the one degree will be carried over to the degree part), and then add 11 more minutes to get to 11 in the second angle. Which means that altogether we added 31 minutes to the minute part of the first angle. As for the degree part, we have $57 + 1 = 58$ in the first angle (the 1 degree was carried over from the minute part), so we have to add 129 degrees to it. The sign of the results is the sign of the angle with the bigger absolute value.

Other examples:

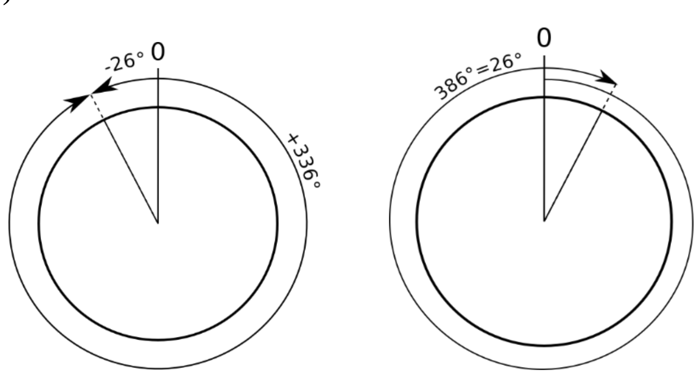
$(57 - 12 - 47) - (36 - 58 - 25) = 20 - 14 - 22$

$(0 - 00 - 01) - (359 - 59 - 50) = -359 - 59 - 49$

Dealing with negative angles and angles greater than 360°

A negative value for the angle means that the angle is measured in the opposite direction. For example, if we choose the clockwise direction for the direction of the positive angles, then a negative angle means that it is measured in the counterclockwise direction.

The value of any angle can be increased or decreased by any multiple of 360° without changing the direction denoted by the angle. This means that a negative angle can be substituted by a positive one by adding $n \cdot 360°$ to its value (where n is an integer). An angle which is greater than 360° can be smaller angle by subtracting 360° from the original value (see on the figure below).



A negative angle can be substituted with a positive one by adding 360° to its value (figure on the left). An angle which is bigger than 360° can be substituted with angle less than 360° (figure on the right).

Distances

The metric system is used:

$1\ \text{km} = 1000\ \text{m}$

$1\ \text{m} = 10\ \text{dm}$

$1\ \text{dm} = 10\ \text{cm}$

$1\ \text{cm} = 10\ \text{mm}$

$1\ \text{mm} = 1000\ \mu m$ (micrometers)

Area

The metric system is used.

$1\ \text{km}^2 = 1000\ \text{m} \cdot 1000\ \text{m} = 1{,}000{,}000\ \text{m}^2$

$1\ \text{m}^2 = 10\ \text{dm} \cdot 10\ \text{dm} = 100\ \text{dm}^2$

$1\ \text{dm}^2 = 100\ \text{cm}^2$

$1\ \text{cm}^2 = 100\ \text{mm}^2$

5. Rounding in surveying

When doing computation with a calculator, the answer is displayed with many digits after the decimal. To report all the significant digits displayed by the calculator can be incorrect because such an answer may imply more exactness than is warranted or is even possible to be measured. Use of too many significant figures is usually a sign that the surveyor or technician is inexperienced and does not fully understand the nature of the measurement or of the computation being performed.

In surveying calculations, the so called banker's rounding is used. This means that whenever 0.5 is encountered as the fractional part of a number, the number is rounded to the nearest even integer.

This approach to rounding can be considered more unbiased than the rounding used in mathematics. While calculating, even and odd numbers are encountered with the same probability, so using the banker's rounding, we theoretically round down as many times as we round up.

For example: $2.5 \approx 2$, $3.5 \approx 4$, $4.5 \approx 4$, $5.5 \approx 6$ and so on.

To round off 0.1836028 m to the nearest centimeter, means two significant figures (first is decimeter, second centimeter, third millimeter). In this case we simply drop the extra digits after the 0.18 m in the original solution. In general, if the first extra digit is less than 5, we drop it along with any additional digits to the right. But, if the first extra digit is more than 5, after we drop it we must add 1 to the last digit of our rounded solution and if the extra digit is exactly 5, then we round to the even number. For example, 0.1836028 rounded off to the nearest millimeter (three significant figures) would be 0.184 because the first extra digit after the third is greater than 5. Some additional examples are as follows:

- 3456 m becomes 3500 m rounded off to the nearest hundred meter.
- 0.123 m becomes 0.12 m rounded off to the nearest centimeter.
- 4565 m becomes 4560 m rounded off to the nearest ten meter.
- 987.432 m becomes 987 m rounded off to nearest meter.
- 234.55 m becomes 234.6 m rounded off to the nearest decimeter.

6. Practice examples with angle conversions

1. Convert the following angles to decimal degree form:
    a. 35° 20’ (use two decimal places)
    b. 129° 35’ 15” (use four decimal places)
2. Convert the following angles to decimal degree form:
    a. 00° 45’ (use two decimal places)
    b. 77° 23’ 49.5” (use five decimal places)
3. Convert the following angles to degrees, minutes, and seconds:
    a. 45.75° (to the nearest minute)
    b. 123.1234° (to the nearest second)
4. Convert the following angles to degrees, minutes, and seconds:
    a. 86.65° (to the nearest minute)
    b. 27.54329° (to the nearest tenth of a second)
5. What is the sum of 25° 35’ and 45° 40’? Subtract 85° 56’ from 137° 32’.
6. What is the sum of 45° 35’ 45” and 65° 50’ 22”? Subtract 45° 52’ 35” from 107 °32’ 00”.
7. Convert the angles in Problem 1 and Problem 3 to centesimal units.
8. Convert the following angles to the sexagesimal system:
    a. 75^g
    b. 125.75^g
    c. 200.4575^g

7. Practice of addition, subtraction and average of angles using DMS values

Additon of angles: γ = α + β If γ > 360° then subtract 360°

incorrect		correct	
α =	86-59-42.1	α =	86-59-42.1
+β =	33-45-37.3	+β =	33-45-37.3
γ =	**119-104-79.4**	γ =	**120-45-19.4**

incorrect		correct	
α =	217-34-19	α =	217-34-19
+β =	186-29-57	+β =	186-29-57
γ =	**403-63-76**	γ =	**44-04-16**

Practice:

α = 214-21-54
+β = 135-44-12
γ = 350-06-06

α = 314-24-41
+β = 222-11-42
γ = **536-36-23 (-360°) = 176-36-23**

α = 180-00-01

$+\beta = 180\text{-}00\text{-}00$

$\gamma = \mathbf{360\text{-}00\text{-}01\ (-360°) = 0\text{-}00\text{-}01}$

$\alpha = 145\text{-}25\text{-}45$

$+\beta = 122\text{-}57\text{-}54$

$\gamma = \mathbf{268\text{-}23\text{-}39}$

Calculate the angle between two directions (subtraction of angles)

$\beta = l_R - l_L$ (right side - left side) If $\beta<0°$ (negative) then add 360°

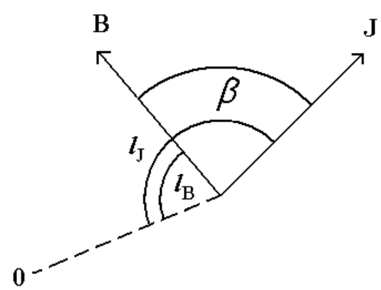
			341-76-79
l_R =	342-17-19	l_R =	342-17-19
$-l_L$ =	141-27-41	$-l_L$ =	141-27-41
β =	**200-49-38**	β =	**200-49-38**

Practice:

$l_R = 214\text{-}21\text{-}54$

$-l_L = 135\text{-}44\text{-}12$

$\beta = \mathbf{78\text{-}37\text{-}42}$



$l_R = 0\text{-}00\text{-}00$ **(+360°)**

$-l_L = 184\text{-}54\text{-}11$

$\beta = \mathbf{175\text{-}05\text{-}49}$

$l_R = 331\text{-}43\text{-}18$ **(+360°)**

$-l_L = 331\text{-}43\text{-}19$

$\beta = \mathbf{359\text{-}59\text{-}59}$

$l_R = 98\text{-}22\text{-}32$

$-l_L = 211\text{-}55\text{-}49$

$\beta = \mathbf{-(113\text{-}33\text{-}17)+360°=246\text{-}26\text{-}43}$

Calculate the average (arithmetic mean) of 2 angles (using banker's rounding)

$\alpha_1 = 352\text{-}51\text{-}27$

$\alpha_2 = 352\text{-}51\text{-}21$

$\alpha = \mathbf{352\text{-}51\text{-}24}$

$\alpha_1 = 78\text{-}17\text{-}49$

$\alpha_2 = 78\text{-}17\text{-}32$

$\alpha = \mathbf{78\text{-}17\text{-}40}$

$\alpha_1 = 3\text{-}19\text{-}58$

$\alpha_2 = 3\text{-}20\text{-}04$

$\alpha = \mathbf{3\text{-}20\text{-}01}$

$\alpha_1 = 246\text{-}59\text{-}54$

$\alpha_2 = 247\text{-}00\text{-}06$

$\alpha = \mathbf{247\text{-}00\text{-}00}$