Lecture T5 – Co-ordinate Calculations

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Application

The designer, in developing his design of an abstract ribbon in space, needs to define the shape he has created in some fashion or it otherwise remains nothing more than a pretty picture. The system of definition universally employed is to describe a series of points along the route.

Any point in space can be defined by the use of three numbers, referred to as the co-ordinates of the point, with each number representing a distance from a given datum point, two of which are in the horizontal plane and one in the vertical plane.

Application

The designer could simply scale these distances off his drawing in respect of each point. He would however have some difficulty in describing his datum point to the road builder.

A greater degree of precision than that provided by scaling is required. This is provided by co-ordinate calculation.

Ultimately, the picture that the designer has created has to be transferred from the drawing board into reality - the route must be set out in other words.

Application

This represents one of the restraints under which the designer works because, if it is not possible to set out the design, all his efforts have been a waste of time. Setting out comprises the process of relating the points on his route as defined by the designer to known points on the earth's surface.

These known points comprise a hierarchy of primary, secondary and tertiary trigonometrical survey beacons, located to high orders of accuracy.

Application

The surveyor is thus also concerned with co-ordinate calculation for the proper setting out of the road for construction.

With rapid advancements in the accuracy and availability of survey instruments that make use of satellite tracking and positioning, it is common practice today to use this form of surveying for most road design and construction projects. The fundamental differences of this form of survey to that previously adopted is covered in more detail hereafter.

The Grid System

Prior to the use of satellite positioning, each country or geographical area around the world established and used their own system of survey measurement. In South Africa, the datum point from which all measurements on the earth's surface are made is the intersection of Longitude 0, which passes through Greenwich, and the Equator.

The system used in the Northern Hemisphere is known as the Gauss System. True North is taken as the zero bearing and angles are measured in an anti-clockwise direction. Distances increase from South to North on the x-axis and from West to East on the y-axis.

The Grid System

In the Southern Hemisphere, the Gauss System is also used but the system is rotated twice. Rotation is about the Equator and then about Lo 0, and is known as the Gauss Conform System.

The zero bearing is thus true South. Distances increase from North to South on the x-axis and from East to West on the y-axis. Bearings increase in a clockwise direction.

Elevations are typically measured from a datum of mean sea level (MSL) or low water ordinary spring tide (LWOST).

The Grid System

The more commonly used system these days is the Universal Transverse Mercator projection and grid system which was adopted by the U.S. Army in 1947 for designating rectangular coordinates on large scale military maps. With the advent of inexpensive GPS receivers, many other map users are adopting the UTM grid system for coordinates that are simpler to use than latitude and longitude.

The UTM system divides the earth into 60 zones each 6 degrees of longitude wide. These zones define the reference point for UTM grid coordinates within the zone. UTM zones extend from a latitude of 80° S to 84° N.

The Grid System

UTM zones are numbered 1 through 60, starting at the international date line, longitude 180°, and proceeding east. Zone 1 extends from 180° W to 174° W and is centered on 177° W.

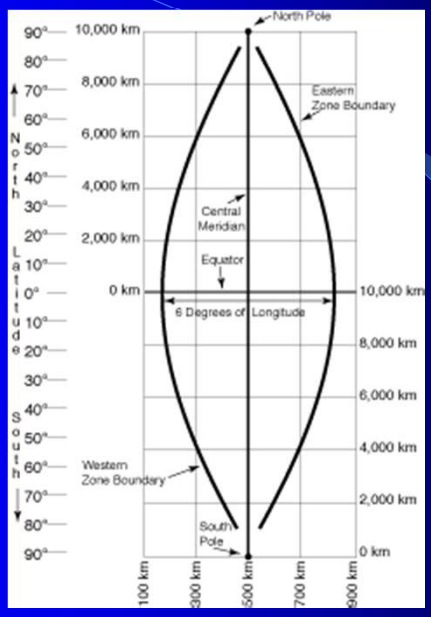
Each zone is divided into horizontal bands spanning 8 degrees of latitude. These bands are lettered, south to north, beginning at 80° S with the letter C and ending with the letter X at 84° N. The letters I and O are skipped to avoid confusion with the numbers one and zero.

The Grid System

A square grid is superimposed on each zone. It's aligned so that vertical grid lines are parallel to the centre of the zone, called the central meridian.

UTM grid coordinates are expressed as a distance in metres to the east, referred to as the "easting", and a distance in metres to the north, referred to as the "northing".

The Grid System



The Grid System

UTM easting coordinates are referenced to the centre line of the zone known as the central meridian. The central meridian is assigned an easting value of 500,000 metres East. Since this 500,000m value is arbitrarily assigned, eastings are sometimes referred to as "false eastings". An easting of zero will never occur, since a 6° wide zone is never more than 674,000 metres wide.

UTM northing coordinates are measured relative to the equator. For locations north of the equator the equator is assigned the northing value of 0 metres North. To avoid negative numbers, locations south of the equator are made with the equator assigned a value of 10,000,000 metres North.

The Grid System

Some UTM northing values are valid both north and south of the equator. In order to avoid confusion, the full coordinate needs to specify if the location is north or south of the equator. Usually this is done by either including the letter for the latitude band or the UTM zone number.

If this is your first exposure to the UTM coordinate system you may find the layout of zones to be confusing. In most land navigation situations, the area of interest is much smaller than a zone. The notion of a zone falls away and we are left with a simple rectangular coordinate system to use with our large-scale maps.

The Grid System

ALL UTM zones cover six-degree latitude swaths. In South Africa, where we use Transverse Mercator as well as Universal Transverse Mercator (UTM), each of our Lo systems covers only two-degree latitude swaths. As a result of this difference, in SA we have a scale enlargement correction of 1.0, in other words there is no scale enlargement. In any other area of South Africa where UTM is utilised there is a scale enlargement correction of 0.9996. This is a mean scale enlargement correction over a six-degree swath.

The Grid System

There will be discrepancies in scale enlargement over the six-degree swath, but this is the mean and is applied throughout the zone. A more precise correction for a specific area can be achieved by measuring with a total station between any 2 points that have been fixed with the GPS equipment and divide the total station distance by the GPS UTM obtained distance and this will give you a factor to apply to any further measurements in that specific area.

The Grid System

With the grid properly defined, any point on the Earth's surface can thus be completely described by a distance from each of the datum planes and is thus quoted as (y, x, z) with x being measured from the Equator, y from Lo 0 and z from MSL or LWOST.

It should be self-evident that, whatever datum is selected, it must be common to all the points for which co-ordinate calculations are required. Trying to calculate a distance between two points when one is quoted on the basis of Lo 21 and the other on Lo 23 is downright inconvenient.

The Grid System

It does not automatically follow that this system is always employed. A survey of limited extent may perhaps be based on a purely arbitrary local grid. In some cases it is a requirement that a local grid be used due to the high accuracy needed without the use of scale enlargement factors.

Such an example could be a large industrial complex like an oil refinery with significant pipework that is manufactured to precise tolerances off site and then assembled on site at precise locations.

Basic Calculations

All the designer requires is a reasonable knowledge of geometry and trigonometry and the ability to solve a single equation of the form:-

$$x_2 = x_1 + \delta x$$

Solution can be either to find δx with known values of x_1 and x_2, or to find x_2 from known values of x_1 and δx. Almost all forms of co-ordinate calculation are merely various combinations of the two presentations of this equation known respectively as the Join and the Polar.

Basic Calculations

The Join

The outcome from the calculation of the Join is to obtain the distance and the bearing between the x and y co-ordinates of two known points.

The major application of the Join is in the setting out of works with conventional survey equipment where the surveyor will require the distance and the bearing of defined design points to be set out from fixed survey control points.

Basic Calculations

The Polar

The outcome from the calculation of the Polar is to obtain the x and y co-ordinates of a point defined by a distance and a bearing from a point of known x and y co-ordinates .

The Polar is the calculation used during traverses, hence its alternative name. The fieldwork involved in a traverse includes setting up at a point and reading the bearing and distance to the next point after having taken a back sight to the previous point for orientation purposes. In order to check the accuracy of the work, the traverse proceeds from a known point and closes on another known point.

Setting out of Works

As covered under the section on the Grid System earlier in this lecture, the designer has undertaken a detailed design of the proposed road and has produced numerous plans with details pertaining to what must be built where.

Of critical importance in the production of these plans is the inclusion of the survey system being used, details of all known survey control points and sufficient coordinated design points that will allow the surveyor to accurately set out the works in the field.

Setting out of Works

The notes in the SARF Geometric Design Manual refer to various setting out calculations and techniques that relate to first principles and the use of survey equipment that makes use of conventional distance and bearing measurements. With the advent and rapid improvement of GPS equipment, the modern surveyor is fast moving to this type of equipment for setting out most aspects of the road design for construction, thus making the long-winded laborious calculations obsolete.

Triangulation

Triangulation is the name given to the process whereby the properties of the triangle are used to calculate the co-ordinates of an unknown point. Triangulation is brought into play when the available data is not so conveniently arranged that either a simple Polar or Join will suffice.

For example, the bearing to the unknown point from one known point and the distance from another may be known. The trick is to reorder this information so that the unknown co-ordinates can be calculated.

Resection

Resection is the process of deriving the coordinates of the set up point from observations to known points. A case in point is creating a survey beacon close to the route from observations to remote trigonometrical survey beacons.

A minimum of three known stations is required to derive a unique answer so that resection is also known as the three-point problem.