

Digital Land Surveying And Mapping(DLS&M)
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Lecture – 16
Quality Assessment of GPS Surveying
(Position, Baseline and Network)

Welcome students, today is the 16th class on digital land surveying mapping. Today I will be talking on quality of GPS surveying; that means, whatever GPS data you have processed you need to evaluate whether the quality of the processed parameter like position, baseline and network is of the quality required for the project need or not.

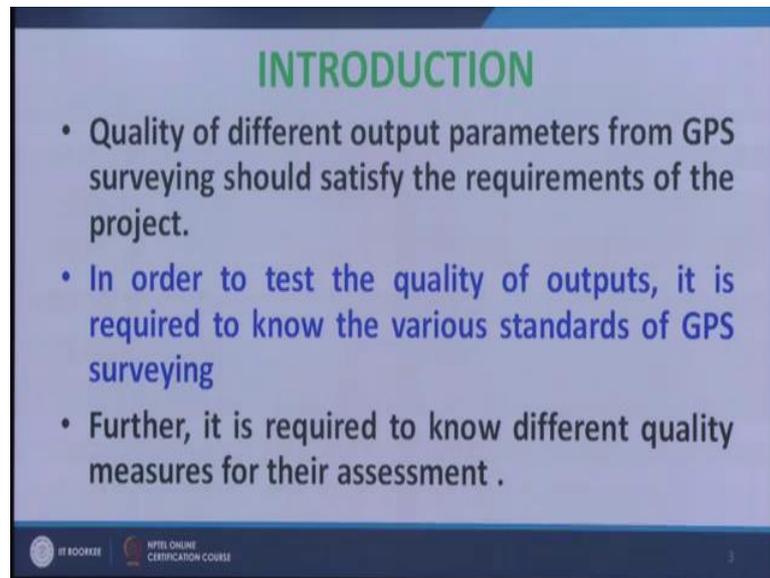
So, today I am going to talk on that respect quality assessment of GPS surveying or point or position baseline and network and the topic will be covered under this following head. Of this the most important is first to; that means, first we need to know really what may be the standard or what are the standards really field engineers decided for different parameters of GPS parameters to be achieved. So, the standards that has been declared or evolved out of time has to be discussed and there are 2 types one is that position standard another is the baseline standard, and the second one is that whatever we have processed or we derived from the GPS data that process parameters we need to test. So, to test we need to have some measures.

So, in the second hand quality measures, and define quality measures for point and baseline length and GPS network that will be discussed. So, GPS surveying generally we do want to get the position of a point, the length of a baseline and subsequently the GPS network we do go for. So, all those things should satisfy the requirement of the project. So, before we go for any surveying work we do first decide what should be the quality or what should did what are the specification that the land surveying work should achieve and that is what is the requirement of the, and that will depend on the requirement of the project.

So this is the thing which we decide before we start any surveying work. Now to after we decide the quality that the land surveying work has to satisfy. We need to test the quality of outputs now that requirements of the projects actually we define on the basis of the standards that has been predefined and available and that we will discuss as I told you

and then once we take the observations then we need to test the quality of the output whether it met the specification of the project and to compare the standards we need to have some measures.

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INTRODUCTION

- Quality of different output parameters from GPS surveying should satisfy the requirements of the project.
- In order to test the quality of outputs, it is required to know the various standards of GPS surveying
- Further, it is required to know different quality measures for their assessment .

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That means, we need to find out from the observe parameters, from the observe measurement we do compute the parameters and we will get the parameters from there we need to derive some other quality measures which will define about the quality of the parameters which we have processed and then those measures has to be checked with the standards. So, we need to know some measures. So, that is what it is told in this.

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QUALITY ASSESSMENT OF GPS SURVEYING

STANDARDS FOR GPS SURVEYING

- Designated in terms of root-mean-square error (RMSE) of the average of the set of squared differences between data set coordinate values and the true or theoretical location of the point obtained preferably from an independent source of higher accuracy.
- Expressed in metric (International System of Units, SI) units.
- Specifications published by the Federal Geodetic Control Subcommittee (FGCS) considered as standards for GPS surveying.
- These standards are independent of the method of GPS surveying
- Two types: position standards and baseline standards.

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Now, to start with that standards of for GPS surveying now I will explain about the root mean square error, root mean square error, root mean square error.

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$$RMSE_{\text{height}} = \frac{\sum_{i=1}^n (H - H_i)^2}{n}$$

$$RMSE = \frac{\sum_{i=1}^n [(X - x_i)^2 + (Y - y_i)^2]}{n}$$

(planimetric position)
 [local coordinate system, (N, E, H)]

(RMSE) Position
 Root Mean Square Error

$P(X, Y, Z) = 3D$
 (N, E, H)

$(X, Y, Z) \Rightarrow$ True coordinates
 $(N, E, H) \Rightarrow$ of P

$(x_1, y_1, z_1) \rightarrow 1st (n, e, h)$
 $(x_2, y_2, z_2) \rightarrow 2nd (n, e, h)$
 $(x_n, y_n, z_n) \rightarrow nth (n, e, h)$

So, suppose the for any parameter the true value is x and for that parameter we have taken observation n observations, suppose x 1, x 2, x n, n observations we have taken now for this observation, set of observation what is the root mean square error that is we can find by using a relation like this x minus x i. The difference or the observe value from the true value, squaring it then adding all the squares for all the n observations and

taking a mean and then square root of this that is the root mean square error of the observation of the observation. So, it is the difference of the observed values from the true value is squaring of that and then squaring for all the observations and taking a mean of that and then square root.

So this is the parameter we use for defining the standard or for GPS surveying, now let me take an example of the location of a position. Now we know the position of a point can be defined by Cartesian coordinate x y z are all when a metric coordinate north and east, and orthometric height. Now in case of the 3D position if we want to define. So, suppose x y z are the true coordinate of point p and for during some observation suppose x_1, y_1, z_1 is the first observed location then x_2, y_2, z_2 is the second observed like that if we take n observation then we will have n th observation. Now for this set of observation the root mean square error can be written like this through x minus x defines x_i whole square plus y defines y_i whole square, z defines z_i whole square and summation of these for i equal to 1 to n and then divided by n square root. So, this is the 3D root mean square error for the position.

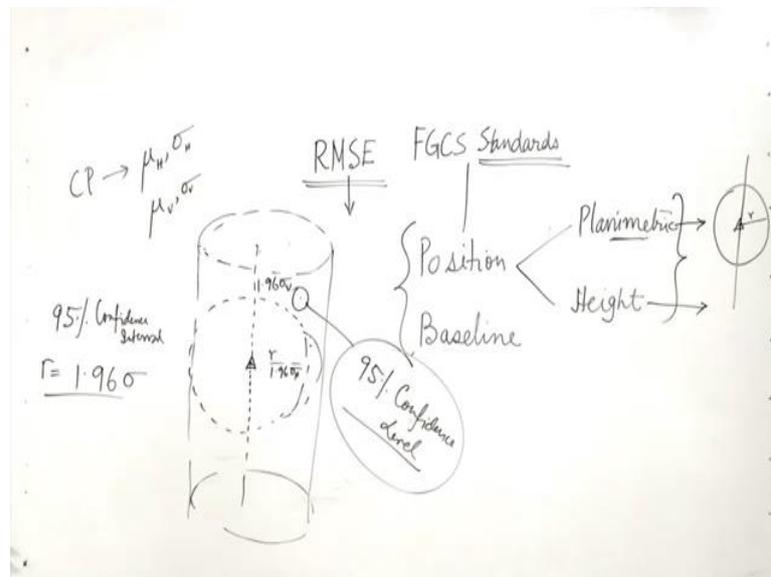
Now, suppose I want to find out the root mean square error with respect to planimetric position, root mean square error with respect to planimetric position. So, in that case is as far the Cartesian coordinate we simply take the summation of the x coordinate and y coordinate difference square and summation and divided by the number of observations taking square root this will be the root mean a square error in planimetric position of the point in Cartesian coordinates. Now if we want to know what is the root mean square error of the point in plainmetric position in local coordinate system local coordinate system that is north east, for that we need to have the north east and orthometric height actual to coordinate of the point and corresponding to these we need to have $n_1, e_1, h_1, n_2, e_2, h_2$ like this n_n, e_n, h_n ; that means, corresponding to each Cartesian coordinate observe coordinate we need to have the modified local coordinates and for the planimetric position local coordinate system mean square error we can do it get it by N minus n difference i whole square E difference e_i whole square, summation i equal to 1 to n divided by n is called like this.

So, this is the root mean square error of the position with reference to planimetric position and in local coordinate system. Similarly for the height we can get out root mean square error with respect to height equal to H minus H_i whole square, i equal to 1

to n divided by n is square. So, now, these values have to be compared with the standard define and as per the value we can say the quality or standard of the point, either 3D quality or 2D quality or height quality we can find out by using this relations.

There are so many standards available widely available all over the world each and every (Refer Time: 12:02) they have their own standards. Now in this course I have taken the specification published by federal geodetic control subcommittee of US as the standard for GPS surveying because that has been adopted widely FG standards for position and baseline.

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Now, these defined by root mean square error and the position actually there are 2 types of position one is called planimetric position, so planimetric and another is height. So, actually GPS generally we get less accuracy in height then planimetric, so planimetric position so the planimetric and height standards are to be defined differently; however, for both these actually, the actual standard definition is same, but the amount may be varying depending upon your project requirements. Now the planimetric position standard is defined by a circle of radius r and height is defined by a line about the center at this, so if this is the true location or we do define a circle having radius r generally we take r is equal to 99 percent confidence. So, 99 percent confidence interval; that means that means 1.96 sigma.

So, if you have a point whose position is known control point, so already a defined control point. So, when among we define a control point we define by its mean and standard deviation. So, if we take the position of the control point is this one and the 1.96 sigma radius a circle, so I can say this is the error circle with the which I will get if I get my position than that position I can say that had the 95 percent confidence. Now corresponding to this location again we can take a vertical line which is again for control point this is the for horizontal, for horizontal position and for vertical position mu and sigma. So, again 1.96 percent we can take and if we, if we draw this like this, we will say we will get a cylinder, we will get a cylinder having 1.96, this is 1.96 sigma v and 1.96 sigma h and if the position 3D position lies within this cylinder then we can say that this position is having 95 percent confidence level, that it will be within (Refer Time: 16:26) So, this is the way how would you define the standard.

So now this is the way how we do define, now the value of sigma these values may be of defined amount and depending upon the amount of this value sorry not (Refer Time: 16:52), but sigma depending upon this value this is the root mean square error. So, this depending upon this value we can divide the different standard into four classes millimeter, centimeter, decimeter, meter.

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STANDARDS FOR GPS SURVEYING : POSITION STANDARDS

Table Accuracy Standards (Horizontal, Ellipsoid/ Orthometric Height)

Classes	Categories	Accuracy (95% Confidence) in meters
Millimeter	1-Millimeter	0.001
	2-Millimeter	0.002
	5-Millimeter	0.005
Centimeter	1-Centimeter	0.010
	2-Centimeter	0.020
	5-Centimeter	0.050
Decimeter	1-Decimeter	0.100
	2-Decimeter	0.200
	5-Decimeter	0.500
Meter	1-Meter	1.000
	2-Meter	2.000
	5-Meter	5.000
	10-Meter	10.000

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Now within the millimeter we can have two 1 millimeter or 2 millimeters standard or 5 millimeter standard, centimeter 1 2 5 centimeter, decimeter 1 2 5 decimeter, meter 1 2 5 meter and finally, 10 meter.

So, these are the four classes millimeter, centimeter, decimeter, meter and among each class there may be again 3 subtypes 1 2 3, that be 1 2 3 millimeter, 1 2 3 centimeter, 1 2 3 decimeter sorry 1 2 5 decimeter and 1 2 5 10 meter so that means, these values depending upon these values we can help our cylinder 95 percent cylinder bigger or a smaller. So, depending upon how big or how small this confidence cylinder with which this position unknown position lies we will say that this is the level of accuracy that is a level of standard.

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STANDARDS FOR GPS SURVEYING : BASELINE STANDARDS

- Defined in terms of ratio of permissible error over length of baseline
- Expressed in terms of parts per million (ppm).
- Baseline standards are being categorized in seven orders and thus, seven standards are available for baseline.
- Baseline belonging to an order satisfies particular accuracy standard.

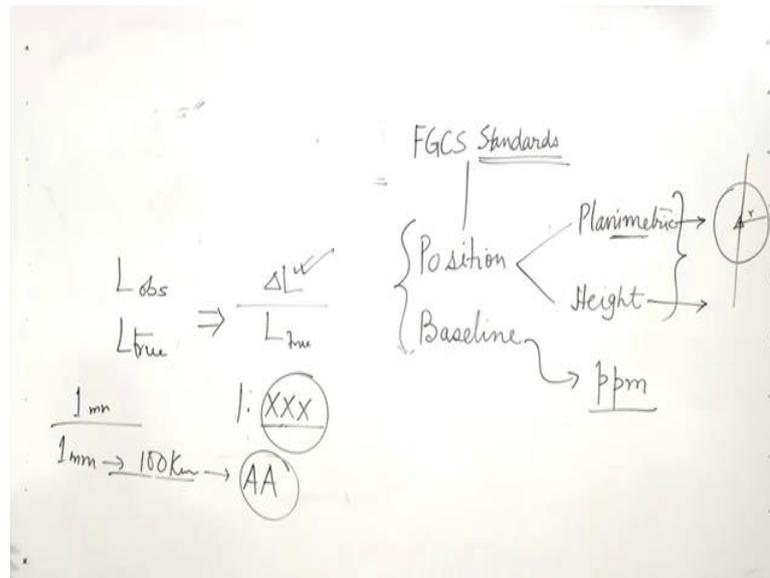
Table GPS Baseline Accuracy Standards as defined by FGCS

Order	Allowable Error ratio	ppm
AA	1:100,000,000	0.01
A	1:10,000,000	0.1
B	1:1,000,000	1.0
C1	1:100,000	10
C2I	1:50,000	20
C2II	1:20,000	50
C3	1:10,000	100

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In case of baseline what we do? We do measure in some standard is defined in some other way that is called using parts per million.

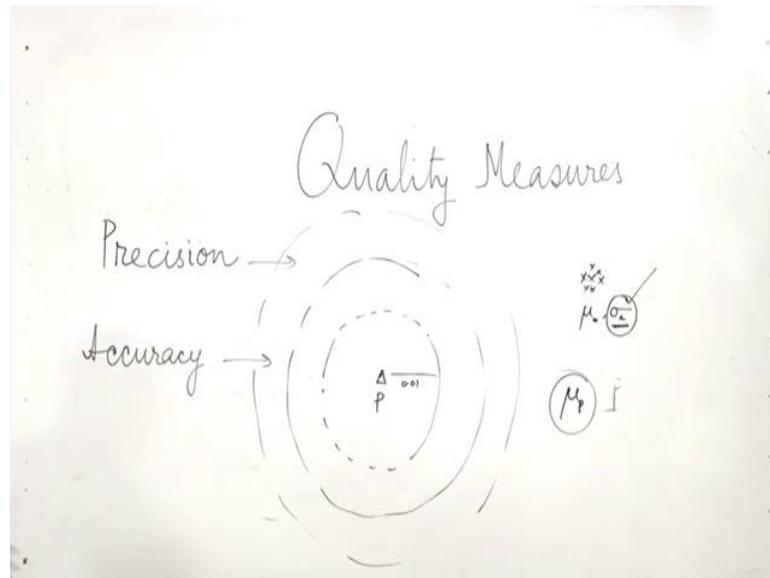
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So, if we have a true length of a baseline true length and that is the observed length. So, from there we can divide the change in the error in length divided by true length. Now this can be 1 is to some value. So, depending upon this 1 is to this value our standard will be defined, so lesser the error higher will be this ratio and better will be our order.

So in that way you can see here that there are 7 orders in which the baseline can be defined; that means, a a, a order b, c 1, c 2, c 3 and even 2 also 2 1, 2 2. So, and the parts per million is this; that means, 1 millimeter will be error in 1000; that means, 1 millimeter is to and if I say if I convert it to meter than 100 kilometers; that means, 1 millimeter error in measurement of 100 kilometer if we can observe, we can achieve this error in 1 millimeter error in 100 kilometer measurement of distance of baseline then we can say that the order achieved is a. In that way define that has been (Refer Time: 20:29) and accordingly we can say it.

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So, this is what is the standard whenever we will go for any GPS away we have to make use of this standard for our comparison purpose. So, now, the quality measures, so quality measures now it is the precision and accuracy these are the 2 measures used as the quality they are used to measure the quality of position or baseline. Now what is precision how do you relate this position measurement with this standards. Now as you know the position means having the measurements close to each other and if I have a set of measurement like this I will have a mean and standard deviation of the measurement. Now if I see this sigma, now I will compare this sigma n with the standards we have third position with this value.

So wherever this value we will be within this then I will say, I will able to tell that by precision standard my precision has been achieved centimeter or decimeter or millimeter or 5 millimeters like that. So, and similarly for accuracy if we know the exact location of any parent, now I may derive this error ellipse as I told you 1.96; that means, 0.1, 0.01 millimeter or I can get numbers of circles around this point taking these as a radius. Now suppose my, now suppose this is the position I got for a location and if it falls within these suppose (Refer Time: 23:12) it appears. So, now, suppose the radius of the circle is suppose 0.05 0.05. So, I can say that the accuracy of the position is 5 centimeter.

So, in that way we can define the quality of our position. Now, further we should see that the GPS position should satisfy this criteria.

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ASSESSMENT OF GPS SURVEYING: QUALITY MEASURES

- Accuracy of GPS Surveying is being defined in terms of distances at the 95% confidence level i.e., 95% of the dataset may have an error with respect to true ground position/ height (in reference datum) equal to or smaller than the desired standard.
- Different measures may be used to evaluate accuracy in GPS surveying parameters.

POINT POSITION

- Precision of a parameter is being defined by its standard deviation.
- Precision of the estimated parameters for GPS positioning evaluated by its standard deviation.
- GPS positioning considered as acceptable if it lie within 95% confidence interval (as per GPS surveying standard).

In GPS surveying, the precision for planimetric position should satisfy

$$\frac{-3.091}{\sqrt{n}} \leq \frac{\Delta X}{\sigma_x} \leq \frac{3.091}{\sqrt{n}}, \text{ for } n < 30$$

$$\frac{-1.96}{\sqrt{n}} \leq \frac{\Delta X}{\sigma_x} \leq \frac{1.96}{\sqrt{n}}, \text{ for } n \geq 30$$

Further, the precision for GPS position should satisfy

$$\frac{-3.091}{\sqrt{n}} \leq \frac{\Delta X}{\sigma_x} \leq \frac{3.091}{\sqrt{n}}, \text{ for } n < 30$$

$$\frac{-1.96}{\sqrt{n}} \leq \frac{\Delta X}{\sigma_x} \leq \frac{1.96}{\sqrt{n}}, \text{ for } n \geq 30$$

where, σ_x , σ_y and σ_z are the standard deviations of the observed position.

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For this is another point; that means, this is the precision criteria. Now for baseline, now this is for planimetric position for vertical height also similar think, I can, we can think of line, depending upon at what height beyond this point our point reaches that according to that we can say. Now in case of baseline for precision we do measure the, as I am only discussed during the baseline position that in case of baseline we do point out the different component of the baseline and along with this component we will get the standard deviation of the baseline.

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Quality Measures

✓ Precision →

✓ Accuracy →

$$\sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2} \cdot 2$$

$$\frac{\Delta L}{L_{true}}$$

$$\sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2}$$

in ppm

Accuracy

$\Delta X \rightarrow \sigma_x$

$\Delta Y \rightarrow \sigma_y$

$\Delta Z \rightarrow \sigma_z$

So, now if we this square plus sigma y dashed square plus sigma z dashed square, square root divided by del x square del y square plus del z square these are the components of the true length of the baseline. Now I will get a ratio in parts per million, now these value I will compare if we compare with this standards, whatever is the ratio from that I will be able to say what is the position standard of the measured baseline. And for accuracy what we need to do, already I told you it is the error in length divided by true length. So, this is also we will be able to get in parts per million and this value we will compare with this to find out to say that what is the accuracy of the accuracy standard we have achieved.

So, in that way we can compare we can knowing the basic standard and then computing the values from the process data we can know what is the accuracy standard or precision standard we could achieve and subsequently we can say whether this accuracy standard or precision standard is satisfying our project need or not, if it does not meet the need of the project then we have to re do whole of a work or we have to found out what is the source of error, how we can improve the quality; that means, the standard deviation can be reduced and mean can be put towards (Refer Time: 27:14).

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ASSESSMENT OF GPS SURVEYING: QUALITY MEASURES

GPS NETWORK

- The outputs of any network adjustment get accepted once it satisfies the quality criteria.
- **Precision**
- Uncertainties associated with the adjusted coordinates of stations as determined by least-squares adjustment is represented by error ellipse. Maximum standard deviation (σ_U) along semi major axis, minimum (σ_V) along semi minor axis and clockwise rotation angle (t) from the Y axis to the semi-major axis of the ellipse compute at each station.
- Semimajor axis:
 - $$\sigma_U = \sigma_0 \sqrt{q_{xx} \sin^2(t) + 2q_{xy} \cos(t) \sin(t) + q_{yy} \cos^2(t)}$$
- Semiminor axis:
 - $$\sigma_V = \sigma_0 \sqrt{q_{xx} \cos^2(t) - 2q_{xy} \cos(t) \sin(t) + q_{yy} \sin^2(t)}$$
- Rotation angle, t :
 - $$\tan(2t) = \frac{2q_{xy}}{q_{xx} - q_{yy}}$$
- **Accuracy**
- The output coordinates of the network adjustment along with uncertainty must satisfy the accuracy considerations for Geodetic control points.

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Now finally, it is the network. So, already we have discussed about the GPS network position where we do redefine the location of the control point and when we are redefining the control point we do get the position along with the standard deviation and already I had discuss the GPS networking is done through (Refer Time: 27:53) analysis.

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The image shows a handwritten slide titled "Quality Measures". It contains the following mathematical expressions and a diagram:

$$\hat{X} = (A^T A)^{-1} A^T O$$
$$\hat{X} = \left[(A^T A)^{-1} \right] A^T W O$$

Below the equations, there is a diagram of a 2D coordinate system with axes x and y . A point is marked with a circled 'X'. A vector α is drawn from the origin to this point. A vertical line is drawn through the point, and a horizontal line is drawn from the point to the vertical line. The label Q_{xx} is written to the left of the vertical line, with an arrow pointing to it.

And during our point position we have seen that the position is defined by $A^T A$ inverse $A^T O$ or in baseline also we have the shown you if we in this case (Refer Time: 28:16) matrix we have taken as a unity and in case of another we have that unknown parameter is different like this, in these case this part is known biometrics called Q_{XX} .

Now, when this, this is a matrix we will get some parameters like that and this is our q_{xx} this is our q_{yy} , this is our q_{xy} . So, these values provides us the, now you can see here in case of GPS network the maximum standard deviation along the major axis a minimum standard division, along the minor axis is defined by these values and where and the rotation angle is this. So, this parameters we can get form this matrix, from this matrix these are the parameters from which we can find out the value of the angle t . Now we can substitute the angle t and to get and substitute these values from that matrix then we can find out the maximum error along major axis. So, this we will define the error ellipse and within that error ellipse actually we must have our control point position.

So already I had defined while we have deduct, we have deduced the GPS network analysis we had discussed where I have discussed about the error ellipse that error ellipse is defined by making use of this and our point should be within that error ellipse, if it is not done we have to re do the network analysis already I have discussed. Although if we satisfied then we should go for accuracy and for also accuracy measure again we have to do because it is the point positioning. So, whatever I had discussed about the quality

measures for positioning that is what is to be also for GPS network control points. So, those has to be followed and accordingly we should proceed forward.

So, with these I can conclude about the GPS surveying. So, summarizing we consider the to assess the quality of GPS surveying outputs; that means, position baseline or network where we are standard of GPS surveying parameters and different standards various standards for there are four basic standards for point measuring and seven standards or orders for baseline has been defined and different measures; that means, precision and accuracy has been defined. Standards are designated in terms of root mean square error of the average set of square different between data set coordinate values and the true or theoretical location. Planimetric positions standard expressed in terms of radius of the circle of uncertainty on a datum surface and vertical height with a linear uncertainty value. Baseline standards are defining are ppm parts per million, quality of GPS any parameters are being tested using corresponding position or accuracy measures.

So, with these I will have to conclude today's class and of course, this is the fundamentals and basics of GPS surveying has been discussed so far, from next class we will be going to the another domain of digital land surveying that is the total station. We will be, I will be discussing on the instrument as well as how that instrument can be used for carrying out the surveying (Refer Time: 32:43). With this I want to conclude today's class.

Thank you.