GPS & EDM Measurements – Why Don't They Match?

Have you ever measured the distance between 2 points that were established by GPS with your EDM? Have you been surprised or alarmed? If so, this workshop is for you.

This will be a "hands on" class to teach you why this happens and how to solve the problem, so bring your calculators. The theory and equations will be kept to a minimum, but the topics will include GPS vectors as measurements, State Plane verses "Ground" Coordinates and grid lengths verses ground surface distances.

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EDM & GPS Measurements – Why Don't They Agree? Part One.

A question put to me often by surveyors all over the country is "Why do my EDM measurements disagree with the State Plane Coordinates I was given by the GPS surveyor?" In the majority of cases, the source of this problem has very little to do with GPS. It has everything to do with how the surveyor is using the coordinates that were produced using GPS.

In the series of articles to follow, we will explore the proper use of the State Plane Coordinate System. The whole process will be covered step by step by the end of the series. The purpose of this first article will be to dispel a common myth. Have you ever heard someone say, "The traverse that we ran was close to the shore, so we didn't have to bother with any of that 'reduction stuff' since we were so close to sea level"? What do you think? Is that an accurate statement?

Ok, before we jump to any conclusions, it will be necessary for us to be acquainted with some of the basics. I learn best by working through a problem. For this demonstration, I have selected a pair of monuments located in Absecon, New Jersey. This location was chosen because it is situated only 25 seconds east of the Central Meridian and it is very close to sea level. It will serve as a perfect illustration of the problem that many surveyors are having across the country.

The State Plane Coordinate System in New Jersey is based on the Transverse Mercator Projection. Refer to **Table 1** in the appendix for the Mapping Projection Parameters and a map of New Jersey showing Absecon in relation the Central Meridian as **Exhibit 1**. The same example could be developed for other states that use the Lambert Projection. The NGS Data sheets for the two control points used in this example can be found in the appendix as **Exhibit 2** and **Exhibit 3**.

In this example, we want to set our Total Station on **STEELMAN 2 RM 4** to begin a traverse and we want to use **STEELMAN 2 AZ MK 2** as an azimuth mark for orientation on the NJPCS. The first thing you would probably do is measure the distance with your EDM. After reducing the slope distance to a horizontal distance, you might record something very close to 354.838 meters. I said, "very close" because we are not discussing measurement error theory or instrument calibration here. As it turns out, this distance actually is the ground distance between these two marks, so we will use it in this example.

Notice that we are given the distance between the two marks on the NGS data sheet as 354.840 meters. You say, "Not bad shooting." We appear to be within a couple of millimeters of the published distance. You might think that this confirms your assumption that no "State Plane Reduction Stuff" will be necessary and proceed to traverse happily off into the Pine Barrens. Everything will be fine until you close your traverse on another control point several kilometers away.

Some of you may have also noticed something else before you picked up the instrument. When you inverse the pair of State Plane Coordinates, you get a distance that is very different from the one you measured. The inversed grid length is 354.8048 meters, which is 33 millimeters shorter than what you measured. What is going on here?

Part of the answer is that the distance shown between the two marks on the NGS Data sheet is the Geodetic Distance, which means that it is measured along the curved surface of the ellipsoid. At this location, the ellipsoid would be around 25 meters over our heads. How do I know this you ask? We are given all the information that we need right on the NGS Data sheet to determine this interesting fact and also other useful things such as reducing our measurement to the grid surface. An examination of **Figure 1** and **Figure 2** will clarify this.

Ok, now it is time to reach some conclusions. Notice that the NGS Data sheet provides us with the Scale Factor for the control stations along with the coordinates. For both points the scale factor is 0.99990000. This scale factor is especially interesting to us because it is the exact same scale factor used to define the SPCS in New Jersey. Refer to **Table 1**. This makes perfect sense because these two stations are practically on top of the Central Meridian.

Those of you that compared your measured distance to the inversed grid length may have also been interested to know what the accuracy of your measurement was. If you divided the published distance by the perceived error of 33 millimeters, you may have concluded that you achieved a dismal accuracy of around 1 part in 10,000. What you were really looking at was the affect of the scale factor along the Central Meridian, which actually is 1 part in 10,000. What do you suppose would happen when this traverse closes on another control point several kilometers away and no account is taken for the scale factor? Even worse, what if only a loop traverse was run and closed back on itself at STEELMAN 2 RM 4? The problem would go undetected as it so often does. See **Figure 3** for an example of a connecting traverse and the misclosure that results when the distances are not reduced to the grid. **Table 2** presents the differences between coordinates computed on the grid and coordinates computed on the ground.

<u>Summary of Part One</u> – The whole purpose of this entire exercise was to demonstrate that the proper use of the State Plane Coordinate System requires our distances be reduced to the grid no matter what the elevation is. It is true that elevation can be an important element in the reduction computation. We purposely chose an example at sea level so that elevation would not be a factor in order to focus your attention on another very important aspect of the State Plane Coordinate System; the Scale Factor. It has been demonstrated that ignoring the grid scale factor will introduce as much as 1 part in 10,000 distortion into any final surveying work product.

Hopefully, the myth has been dispelled and I have captured your attention. The next article will cover each step of the computation to reduce an EDM measured distance to the corresponding grid length. You will see how the elevation and the scale factor are used in the computation. You will also be introduced to another aspect that must be considered called the Geoid Height.

EDM & GPS Measurements – Why Don't They Agree? – Part Two

This is the second in a series of three articles addressing the familiar "Grid versus Ground" issue. Included is a detailed look at the distance reduction computations for the Absecon, New Jersey example from the previous article. You will need to refer back to the first article for the data and other information used in the 4 steps below. The reduction computation can be found in the appendix as **Exhibit 4.**

Step 1. Reduce The Slope Distance To The Horizontal Distance.

Everyone is familiar with this computation. The most common method used is to multiply the slope distance by the sine of the zenith angle. Another useful way employs the Pythagorean theorem to solve for the horizontal distance given the difference in height between the two marks and treating the slope distance as the hypotenuse of a right triangle. In our example, this computation was assumed to have already taken place. The reduced horizontal distance is 354.838 meters. This is labeled as the "Horizontal Distance in **Exhibit 4**.

Step 2. State Plane Coordinate Inverse Computation.

Using the Pythagorean theorem once again, compute the grid inverse of the two marks given their respective northing and easting coordinates. The grid inverse is equal to the square root of the sum of the squared delta northing and the squared delta easting coordinates. The inversed grid length is 354.8048 meters or 354.805 rounded to three decimal places. Refer to **Exhibit 4** to see the "SPCS Grid Inverse Computation".

Problem Presents Itself

Here is where the problem presents itself. Comparing the inversed grid length to our reduced horizontal measurement reveals a discrepancy of 33 millimeters. Faced with this situation, some surveyors begin to question the control rather than their procedures. For whatever the reason is many surveyors are not comfortable with the state plane coordinate system, which is evident, by how often this problem arises. Often times the choice is made to ignore the discrepancy hoping the problem will go away somehow. This course of action only makes the situation worse by allowing the problem to become more complex than it really is. Let's examine this in greater detail.

How Close Is Close Enough?

Dividing 354.805 meters by 0.033 meters indicates the accuracy of our work up to this point which equals 1 part in 10,752. Is that acceptable? How close is close enough and how is that decided? This decision will be made using objective error analysis.

Error Propagation

Making the following assumptions – that the control is accurate, that the EDM is working properly, that it is capable of measuring to precision of at least +/- 5mm + 5ppm, and that the EDM and target have been carefully centered over the marks to within 1 to 2 mm, we can also assume that 33 millimeters is too much discrepancy to be acceptable. Using well know error propagation methods, we find that over this length the difference should not exceed 12 millimeters 95 percent of the time.

The error propagation is computed as follows:

$(0.005^2 + ((5/1000000)*354.8)^2 + 0.002^2 + 0.002^2)^{1/2}$ = +/-0.006m one sigma (68% confidence)

+/-0.006m * 1.96 = +/-0.012m or +/-12mm 95% confidence

Clearly something else is involved here. The explanation is simple, but not well known or readily accepted by those having difficulty with this subject. The measurement made at the earth's surface cannot be compared directly to the corresponding length on the surface of the grid. These two surfaces are separated by hundreds of meters. See **Figure 2.**

Point Emphasized

To emphasize this point, consider a traverse located in an area where the difference in elevation ranged around 200 meters. Would you use only observed slope distances from this traverse in all the subsequent computations that you perform such as traverse closure, boundary line analysis, subdivision design, etc? You wouldn't waste your time with such nonsense, right? Every single slope measurement gets converted to a horizontal distance before the measurement is used in further computations.

Likewise, before a comparison can be made in this example, a transformation must take place, that is, the ground surface measurement must be reduced to the grid and then compared to the grid length obtained by inversing the pair of state plane coordinates. That brings us to step 3.

Step 3. Ground To Grid Reduction

There will be two parts in this reduction. The first part reduces the measurement to the surface of the ellipsoid to produce a *Geodetic Distance.* The second part reduces the geodetic distance to the surface of the state plane coordinate grid producing a grid distance. Later it will be shown how to combine these two parts into one reduction step, which will produce a grid distance directly from the ground surface horizontal measurement.

Step 3, Part 1. Horizontal Distance Reduced To The Ellipsoid

This step can be compared to the "sea-level" reduction used for NAD27. It is similar, but different in that rather than reducing the line length to sea level, the line is reduced to the surface of the ellipsoid.

The separation between the geoid *(sea level for our purposes here)* and the ellipsoid is called the *Geoid Height*, symbolized thus **"N"**. It is the distance measured from the surface of the ellipsoid to the surface of the geoid. In the contiguous USA, the geoid height ranges between minus 25 and minus 35 meters, except for places in the Rocky Mountains where the separation becomes as low as around minus 5 meters. In Alaska the Geoid Heights are positive.

The affect of ignoring this separation causes the length to be reduced to sea level rather than the surface of the ellipsoid. An error of up to 5-PPM can result because the NAD83 State Plane Grids are projected from the ellipsoid and not mean sea level. Try the following computations for yourself with and without the geoid height to see what the affect is. The error may seem small on this one line, but it will accumulate in the traverse as a systematic error.

To transform the distance to the ellipsoid, a "reduction" factor is needed. This factor is known as the *Elevation Factor* in the NOS NGS 5 manual to distinguish it from the *Grid Scale Factor*, which we will use in the step to follow. I prefer to use the term Ellipsoid Factor rather than Elevation Factor because it is more meaningful considering the surface that the measurement is actually transformed on to.

The ellipsoid factor is simply a ratio between the geodetic distance and the horizontal ground distance. Dividing the mean radius of the earth by the average ellipsoid height of the line added to the earth's mean radius will yield this ratio I call the ellipsoid factor. Multiplying the horizontal ground distance by the ellipsoid factor produces the geodetic length. Take note that the use of the terms "reduce" or "reduction" does not imply that the magnitude of the distance decreases. In the example before us, the geodetic distance is actually longer than the ground distance by a very small amount. **Figure 2** provides a visual clue why this is true at the location in our example. For any location where the terrain elevation is near sea level, the ellipsoid will be overhead. The result of this computation is labeled as the "Geodetic Distance" under the "Ground to Grid Computation" heading in **Exhibit 4.**

<u>Step 3, Part 2. Geodetic Distance Reduced To The SPCS Grid</u>

To make this part of the reduction, the scale factor for each of the points will be needed. Fortunately, we rarely, if ever, will be required to compute the scale factor. It will always be available to us on the NGS data sheet along with the coordinates and convergence. Most software programs that make SPCS computations also output the scale factor. If you are interested in how to actually compute the scale factor, you may refer to the NOS NGS 5 manual for the equations.

For our purposes, it is more important to know what the scale factor is and what it does. Recall from the previous step the way in which the ellipsoid factor was computed. That ratio represents the difference between the geodetic distance and the ground distance. Likewise, the scale factor is the ratio between the grid distance and the geodetic distance. To obtain the grid distance, we simply multiply the geodetic distance by the average scale factor for the line. The result of this computation is labeled as the "SPCS Grid Distance" under the "Ground to Grid Computation" heading in **Exhibit 4.** That ends the reduction computation. In Step 4, we make a comparison to check our work.

Combined Factor

As stated above, the two parts of Step 3 can be combined into one step. To do this, simply multiply the ellipsoid factor by the grid factor to produce a single factor called the *Combined Factor*. The same grid distance will result when the ground distance is multiplied by the combined factor. A single combined factor can be computed for many surveying projects and used to reduce all the distances measured in that area.

Step 4. Comparison Between Published and Measured

Now you can compare the grid distance computed from your measurement to what we may regard as the published value, that is, the inversed grid distance from the published coordinates. This step is labeled, "Comparison" in **Exhibit 4**.

Relieved or alarmed? If the discrepancy exceeds what you would expect from your EDM now, then there is cause to question the control. If the marks were established using static or fast static GPS surveying techniques, the difference should be very small. The stipulation of course is that the base line between the marks was observed in the GPS survey. In other words, if the two marks were surveyed with GPS using a radial method and the base line between them was not observed, then the discrepancy could be larger than desired since the two marks would be "side shots".

Try This Experiment

If you still aren't convinced that extreme accuracy can be obtained from GPS, try this experiment some time. Take your GPS receivers to an EDM calibration base line. Be sure to use care in setting over the marks just as you would if you were calibrating your EDM. You will find that the GPS base lines you process will match the published "mark-to-mark" distances on the NGS data sheet extremely well.

Here are the results of some comparisons made on the Burlington County EDM Calibration Base Line located near Lumberton, New Jersey.

The published Mark-to-Mark distance on this line between the 0 meter mark and the 1000 meter mark is 1000.0414m +/-0.6mm. These marks were occupied during a static GPS survey for around 50 minutes on two separate occasions. The results obtained by post processing the GPS data collected during these two occupations yielded the following base line lengths:

Results on 12/5/95 = 1000.041m +/- 0.0003
Results on 12/6/95 = 1000.043m +/- 0.0003

The length on the first day is within 0.001m agreement with the published distance at the millimeter level. Luck perhaps? The results on the second day differ from the published distance by 2 millimeters rounding up. Two millimeters in one thousand meters equates to an accuracy of 1 part in 500,000. You can see similar results using RTK with careful centering of the antenna pole.

<u>Summary of Part Two</u> - The above exercise provides evidence to support the opening statement in the first article. The grid versus ground issue has very little to do with GPS. It has everything to do with the way the surveyor is using the coordinates that were produced from GPS measurements. If you take the time to do the test on an EDM base line, the grid versus ground issue will begin to vanish before your eyes.

The EDM and GPS are capable of producing comparable measurements. This article dealt entirely with the transformation of distances from one surface to another. In the next and final article of this series, we will examine how to transform the coordinates from one surface to another. These "localized" coordinate systems can be useful in certain applications. The disadvantages of local coordinates will also be presented.

<u>EDM & GPS Measurements – Why Don't They Agree? – Part Three</u>

This is the final part in this three part series of articles on the subject of "Grid vs. Ground" coordinates or measurements – whichever way you see it. This article will begin with an explanation why the title, "EDM & GPS – Why Don't They Agree?" was chosen to present this topic.

<u>Problem Discovered</u>

Think for a moment how this grid vs. ground problem is first discovered. It isn't discovered during the GPS survey. After careful survey planning, data collection, and data processing the usual finished product is a file of coordinate values. Confidence in these values comes from the QA/QC phases of the data processing and relying on good surveying procedures during the data collection. Any problems discovered during the QA/QC, like high RMS, misnamed stations, incorrect antenna height measurements, obstructions, etc. must be remedied before producing the final coordinates. Those problems are unrelated to the "grid vs. ground" issue.

This issue only gets discovered when someone physically occupies a pair of these points to measure between them with an EDM. Without fail, this one act will always prompt the question, "Why don't they agree?" by surveyors not familiar with State Plane Coordinates. As it turns out, this problem has existed for a long time, but it took the wide spread use of GPS to force surveyors into learning how to use the SPCS properly. Prior to GPS, many surveyors would occupy geodetic control monuments to tie their traverses to the SPCS, but the coordinates that they produced were a kind of 'pseudo-state plane coordinate' because they did not make the necessary reductions to their EDM measurements. In essence, they were traversing along the surface of the ground and not on the surface of the grid. Refer to **Figure 3** and **Table 2** for a comparison of coordinates computed on the grid with coordinates computed at ground.

This went undetected for a long time, but now because so many points are being established with GPS, the reduction computations can no longer be ignored. The reason for this is that the measurements made with GPS are extremely good when made properly and with the mere push of a button, the processing software will produce real SPC values on the grid, not the ground. The surveyors that have ignored this up to now will have to catch up to learn what actually happens when that button gets pushed. It is hoped that this series of articles has been helpful in this regard.

Some Review

Before we get started with the subject of Part 3, let's look back at what has been covered so far in the first two parts.

In the first article, it was demonstrated that the distortion that is built into the projection cannot be ignored no matter what the elevation is. The example being used is at sea level and the distortion is 1 part in 10,000 – that is just over a foot in only two miles!

The second article explained how to reduce a distance measurement to the grid surface step by step. A single combined factor can be computed for the whole project area and used to reduce all the distances without the loss of accuracy required for the application.

It should also be mentioned that the subject of this series of articles has been restricted to the treatment of lengths and coordinates. It was felt that the arc to cord correction for angular measurements was small enough in most applications that it could be ignored.

Now, we will examine how to apply this knowledge to the coordinates themselves rather than the distances.

Coordinates Can Be Scaled Too

By now you are familiar with how to apply the combined scale factor to a distance to reduce it to the grid. A distance of 1000.000 meters between to points on the ground is 999.900 meters on the SPCS grid surface where the combined factor equals 0.99990000.

This same principle can be applied directly to the coordinates themselves to increase or decrease their magnitude, that is, raise them from the grid to a surface near the ground or visa versa. This method of manipulating the SPCS can give rise to heated debates between the advocates of this method and those that are opposed to this method. Obviously, there are positive and negative aspects to everything, including how coordinates are produced and what they are used for.

A Continuing Debate

This article will not promote either side of this debate, but will only describe how this is already being done and how these so called, "localized ground" coordinates are being used. Some of the issues raised by both sides will be mentioned. Various organizations, agencies, counties, and DOTs around the country have adopted methods and procedures for dealing with the grid versus ground fact. These methods can be separated basically into two categories – 1) Use the SPCS as it was designed to be used as published by NGS, and 2) Create hybrid coordinate systems that are related to SPCS in some way.

Number two can be further broken down into two additional categories – 2a) The hybrid coordinate systems are designed to best fit the average elevation for an entire county. Each county has its own system, and 2b) Use the SPCS as in number one above for the entire state, but create localized coordinate systems for various projects, like highway construction for example.

As has been already stated, this topic can be debated and good arguments presented by the parties on all sides. My personal view is that each method can be used to great advantage in those applications that are well suited for them. Each surveyor needs to be well acquainted with the SPCS to be able to recognize when to apply one of these methods. The biggest point in this regard relates to the ability to follow the footsteps of the previous surveyor. Often times, the way in which a system of localized coordinates was produced does not get passed on with the northing and easting values. That is the number one reason given to discourage this practice. Nevertheless, a surveyor faced with this problem needs to know how to unravel a tangled situation like this. Knowing how to create a localized coordinate system is the very same knowledge required to return a hybrid coordinate system back into something that begins to resemble State Plane Coordinates.

Absecon Example Revisited

Recall that the scale factor used to reduce the line to the grid was computed by averaging the scale factors for the end points of the line. The elevations of the end points were also averaged to find the average elevation of the line in order to reduce it to the ellipsoid.

What would happen to the coordinates of the end points if they were divided by the combined factor? The answer is that they would increase in magnitude in proportion to one another. In the table below, the grid coordinates of the control have been divided by a ***Combined Factor of 0.99990382*** to produce 'ground coordinates'.

Point Name	Grid North	Grid East	Ground N	Ground E	Delta N	Delta E
STEELMAN 2 AZ MK	64612.500	150488.828	64618.715	150503.304	-6.215	-14.476
STEELMAN 2 RM 4	64948.826	150601.837	64955.074	150616.324	-6.248	-14.487

Scaling the grid coordinates in this way has the desired affect of producing new coordinates that are situated "near the ground" surface. This means that when an inverse is computed, the resulting length will match the horizontal distance measured with an EDM - in this case 354.839 meters.

Something else becomes immediately apparent. The ground coordinates are shifted northward by around 6 meters and eastward by around 14.5 meters. For some surveyors, this shift isn't quite enough. They would recommend applying a greater shift by either adding or subtracting a large constant so that these scaled ground coordinates are not mistaken for State Plane Coordinates. Adding 300,000 to the northings and subtracting 100,000 from the eastings would result in the following:

Point Name	Project Datum N	Project Datum E
STEELMAN 2 AZ MK	364618.715	50503.304
STEELMAN 2 RM 4	364955.074	50616.324

The reader will discover that the inverse of the so-called "Project Coordinates" will still produce the same ground distance.

Some situations and applications require that the shift between the grid coordinates and the scaled ground coordinates be kept as small as possible. This requirement may also come from the desire on the part of some surveyors to have it "both ways" – State Plane Coordinates that are at ground and match their EDM measurements. Having reached this point in this article, it is hoped that the reader will be comfortable with the fact that it is impossible to have it both ways. The SPCS is not at ground and coordinates at ground are not State Plane Coordinates. With that said, we will now examine how to produce a set of ground coordinates that are "localized" to keep the shift from the corresponding grid coordinates as small as possible.

We will use the connecting traverse depicted in **Figure 3** as an example. The following table contains the ***Localized Ground Coordinates*** for the starting and ending control points.

Point Name	Grid N	Grid E	Elev	Comb Fact	Local N	Local E	GN - LN	GE - LE
STEELMAN 2 RM 4	64948.826	150601.837	9.317	0.999903880	64948.647	150601.938	0.179	-0.101
STEELMAN 2 AZ MK	64612.500	150488.828	2.301	0.999904980	64612.289	150488.919	0.211	-0.091
PINE 2	68739.917	148331.659	12.590	0.999903380	68740.103	148331.542	-0.186	0.117
PINE 1	68936.075	148765.899	14.730	0.999903020	68936.280	148765.824	-0.205	0.075
Centroid	66809.330	149547.056	9.735	0.999903815	66809.330	149547.056	0.000	0.000

The SPCS coordinates for the point named "Centroid" are computed by finding the average of all the Northing and Easting values in a project. This would comply with the definition for "centroid" as taken from the *Geodetic Glossary* (NGS, Sept.1986), *"The point whose coordinates are the average values of the coordinates of all the points of the figure."*

In this case, the centroid is the average of the starting and ending control points in the traverse. The centroid then becomes a "hinge" point or a "peg" to keep the shift as small as possible. Note the last two columns in the table listing the shifts. The shifts for the centroid are zero because the local ground coordinate is identical to the grid value for the centroid. The local ground coordinates are computed as follows:

Ground N = Centroid N - [(Centroid N - Grid N) / Combined Factor]
Ground E = Centroid E - [(Centroid E - Grid E) / Combined Factor]

These equations find the latitude and departure between the centroid and any other point in a project. Just as a grid length can be "raised" to the ground by dividing it by the combined factor, the latitudes and departures can also be transformed to produce "ground" latitudes and departures. Algebraically summing these "increased" latitudes and departures with the Northing and Easting values of the centroid will yield the local ground values for the point. One variation for computing local ground coordinates includes the option to "localize" on an existing control monument rather than computing a centroid. All other computations remain the same.

It is a very simple procedure and used very conveniently to deal with the grid vs. ground issue in certain applications, like construction layout for instance. Keep in mind that the very same attribute of these local coordinates considered to be wonderful and desirable by some surveyors is exactly the same attribute considered to be unacceptable by other surveyors. These local coordinates look just like State Plane Coordinates, but are not – by a very small amount, which makes them dangerous. In one respect these coordinates make certain tasks easier, while in other respects, the work load is increased because much more book keeping is required to document how the coordinates where produced. Here is an example of some notes that should accompany a set of local ground coordinates –

Project Name: Absecon Traverse
Date: 01/26/00
Reference Information: NJSPLS Example
Units: Meters
Vertical Datum: NAVD88
Horizontal Datum: Local Ground System

The horizontal coordinates are local ground coordinates that are based on the State Plane Coordinate System of ***New Jersey*** NAD83 ***(1986).***
The relationship between this local ground system and the grid system is as follows.
1) Both systems share a common centroid point with identical coordinates of
North 66809.330 **East** 149547.056
2) The projection surface used for the local ground system is based on the following:
Average Elevation = 9.735m
Combined Factor = 0.999903815
3) State Plane Coordinates can be computed from the local ground coordinates by:

$$N_G = N_C - [(N_C - N_L) \times CF] \qquad E_G = E_C - [(E_C - E_L) \times CF]$$

Where :
N_G, E_G = Grid North , Grid East
N_C, E_C = Centroid North, Centroid East
N_L, E_L = Local North, Local East
CF = Combined Factor

<u>Summary of Part Three</u> – The final part of this series described how surveyors in various counties, state DOTs, and other agencies or organizations are modifying the SPCS to produce 'near ground' coordinate systems. Advocates of this procedure want to use a system of coordinates that easily relates to the measurements made with their EDMs without applying scale factors. They also want the hybrid system of coordinates to have the appearance of State Plane Coordinates. Surveyors that are opposed to creating modified projections raise concerns about the confusion that results when these coordinates are mistaken for State Plane Coordinates. The additional 'bookkeeping' in the form of extra metadata about the source of these coordinates can also become a disadvantage when data is shared or exchanged in a GIS application for example.

<u>Conclusion</u> –

The State Plane Coordinate System was created to enable surveyors to traverse great extents across a curved earth, yet treat it as though it were a flat surface. The SPCS was designed so that "ordinary" surveying mathematics, like trigonometry would still be applicable eliminating the need for complex geodetic computations on an ellipsoidal surface. The most complex aspect of the SPCS is the need to account for the distortion caused by projecting a curved surface onto a developable "flat" surface. Since the SPCS was designed to be conformal, that is, retain the shape of areas, the distortion is forced into the lengths between points. The computations to account for the length distortion are simply applied through the use of scale factors.

Even with all of its simplicity and utility, the SPCS has never really been fully accepted by the majority of surveyors. Even where the SPCS is being used, it is being modified in various ways to accommodate the user's requirements. The time has come to accept the fact that the SPCS does not fulfill all the needs of surveyors and other mapping professionals. One of the biggest disadvantages of the SPCS is that it is only 2 dimensional. The technology existing today and that will be used by surveyors in the future will allow for 3 dimensional positioning with great ease.

Once upon a time, it was thought that the sun orbited a flat earth. Forward looking surveyors will be open to the idea that there must be a better way to position points and describe those positions. True 3-D COGO is possible today. The coordinate system already exists in the form of Earth Centered, Earth Fixed (ECEF) coordinates. Using ECEF coordinates eliminates the grid/ground distance dilemma. There are no zones or projection constants to apply using ECEF coordinates. One set of solid geometry equations is equally applicable around the world. This subject will be detailed in a future article. In the mean time, readers are encouraged to explore this issue for themselves. Additional information on 3-D COGO can be obtained on the web at http://www.zianet.com/globalcogo/index.html

Appendix - Tables, Figures & Exhibits

Table 1 - Mapping Projection Parameters for the New Jersey SPCS (NAD83)

Central Meridian	W 74î30'00.000000"
Latitude of Origin	N 38î50'00.000000"
Origin Northing	0.0000 m
Origin Easting	150000.0000 m
Scale along Central Meridian	0.999900000000

Exhibit 1 – Map of New Jersey Showing Central Meridian and SPCS Origin

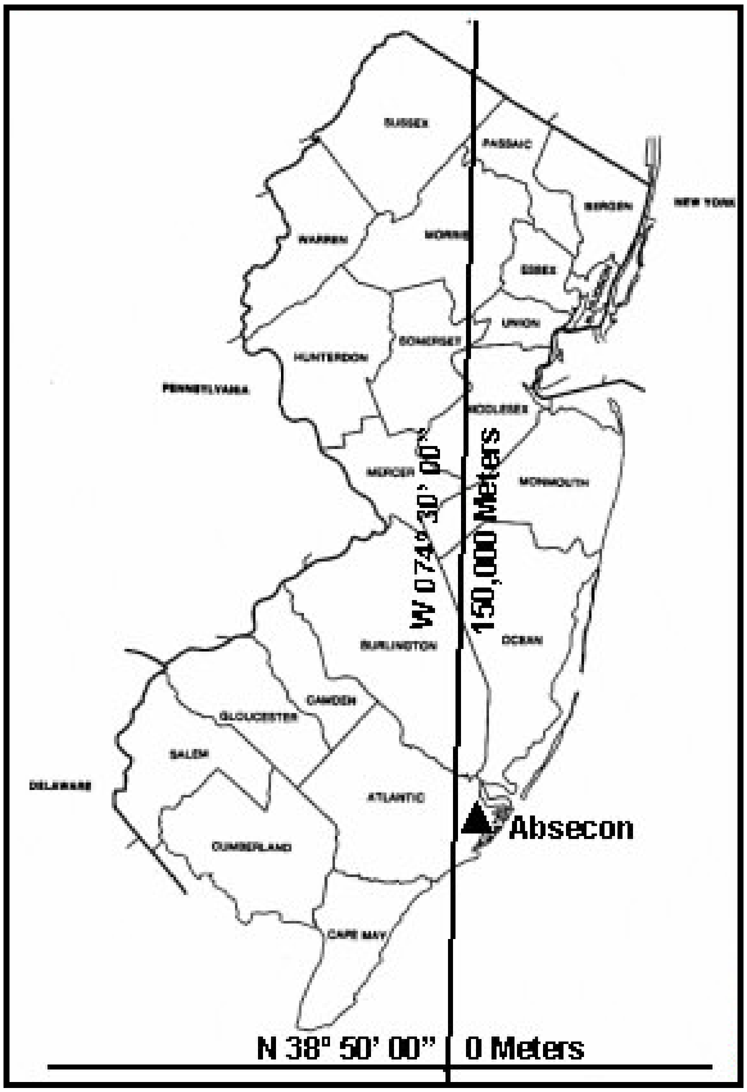

Exhibit 2 – NGS Data Sheet for STEELMAN 2 RM 4

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JU4104 ***********************************************************************
JU4104  DESIGNATION -  STEELMAN 2 RM 4
JU4104  PID         -  JU4104
JU4104  STATE/COUNTY-  NJ/ATLANTIC
JU4104  USGS QUAD   -  OCEANVILLE (1989)
JU4104
JU4104                         *CURRENT SURVEY CONTROL
JU4104  ___________________________________________________________________
JU4104* NAD 83(1986)-  39 25 06.31893(N)    074 29 34.83764(W)     ADJUSTED
JU4104* NAVD 88     -         9.4    (meters)      31.     (feet)  GPS OBS
JU4104  ___________________________________________________________________
JU4104  X           -   1,319,118.861 (meters)                     COMP
JU4104  Y           -  -4,754,336.670 (meters)                     COMP
JU4104  Z           -   4,028,294.964 (meters)                     COMP
JU4104  LAPLACE CORR-          -1.57  (seconds)                    DEFLEC96
JU4104  ELLIP HEIGHT-         -24.79  (meters)                     GPS OBS
JU4104  GEOID HEIGHT-         -34.11  (meters)                     GEOID96
JU4104
JU4104  HORZ ORDER  -  FIRST
JU4104  ELLP ORDER  -  THIRD     CLASS II
JU4104
JU4104.The horizontal coordinates were established by GPS observations
JU4104.and adjusted by the National Geodetic Survey in March 1993.
JU4104
JU4104.The orthometric height was determined by GPS observations.
JU4104
JU4104.The X, Y, and Z were computed from the position and the ellipsoidal ht.
JU4104
JU4104.The Laplace correction was computed from DEFLEC96 derived deflections.
JU4104
JU4104.The ellipsoidal height was determined by GPS observations
JU4104.and is referenced to NAD 83.
JU4104
JU4104.The geoid height was determined by GEOID96.
JU4104
JU4104;                    North         East     Units   Scale      Converg.
JU4104;SPC NJ       -    64,948.827   150,601.837   MT  0.99990000 +0 00 16.0
JU4104;UTM  18      - 4,363,333.591   543,641.486   MT  0.99962345 +0 19 19.0
JU4104
JU4104|---------------------------------------------------------------------|
JU4104| PID    Reference Object                     Distance      Geod. Az  |
JU4104|                                                           dddmmss.s |
JU4104| JU0332 STEELMAN 2                            43.496 METERS 03132     |
JU4104| JU4103 STEELMAN 2 AZ MK 2                   354.840 METERS 19835     |
JU4104|---------------------------------------------------------------------|
```

Exhibit 3 – NGS Data Sheet for STEELMAN 2 AZ MK 2

```
JU4103 *********************************************************************
JU4103  DESIGNATION -  STEELMAN 2 AZ MK 2
JU4103  PID         -  JU4103
JU4103  STATE/COUNTY-  NJ/ATLANTIC
JU4103  USGS QUAD   -  OCEANVILLE (1989)
JU4103
JU4103                        *CURRENT SURVEY CONTROL
JU4103  ___________________________________________________________________
JU4103* NAD 83(1986)-  39 24 55.41251(N)    074 29 39.56332(W)     ADJUSTED
JU4103* NAVD 88     -        2.3    (meters)       8.     (feet)  VERTCON
JU4103  ___________________________________________________________________
JU4103  LAPLACE CORR-         -1.60  (seconds)                     DEFLEC96
JU4103  GEOID HEIGHT-        -34.12  (meters)                      GEOID96
JU4103
JU4103  HORZ ORDER  -  THIRD
JU4103
JU4103.The horizontal coordinates were established by classical geodetic methods
JU4103.and adjusted by the National Geodetic Survey in June 1990.
JU4103.No horizontal observational check was made to the station.
JU4103
JU4103.The NAVD 88 height was computed by applying the VERTCON shift value to
JU4103.the NGVD 29 height (displayed under SUPERSEDED SURVEY CONTROL.)
JU4103
JU4103.The Laplace correction was computed from DEFLEC96 derived deflections.
JU4103
JU4103.The geoid height was determined by GEOID96.
JU4103
JU4103;                   North         East     Units   Scale      Converg.
JU4103;SPC NJ       -    64,612.500   150,488.828   MT  0.99990000 +0 00 13.0
JU4103;UTM  18      - 4,362,996.737   543,530.373   MT  0.99962333 +0 19 15.9
JU4103
JU4103|---------------------------------------------------------------------|
JU4103| PID    Reference Object                     Distance      Geod. Az  |
JU4103|                                                           dddmmss.s |
JU4103| JU4104 STEELMAN 2 RM 4                     354.840 METERS 01835     |
JU4103| JU0332 STEELMAN 2                          397.348 METERS 01959     |
JU4103|---------------------------------------------------------------------|
```

Exhibit 4 - Distance Reduction Computations - Absecon, New Jersey Example

Solution to Absecon Example - Ground To Grid

Point Name	North	East	Elev	Geoid Ht.	Scale Factor
STEELMAN 2 RM 4	64948.827	150601.837	9.4	-34.11	0.999900000
STEELMAN 2 AZ MK 2	64612.500	150488.828	2.3	-34.12	0.999900000

SPCS Grid Inverse Computation

Delta N, Delta E	=	-336.327	-113.009
Delta N^2, Delta E^2	=	113115.8509	12771.0341
Delta N^2 + Delta E^2	=	125886.8850	
(Delta N^2+Delta $E^2)^{1/2}$	=	354.805	

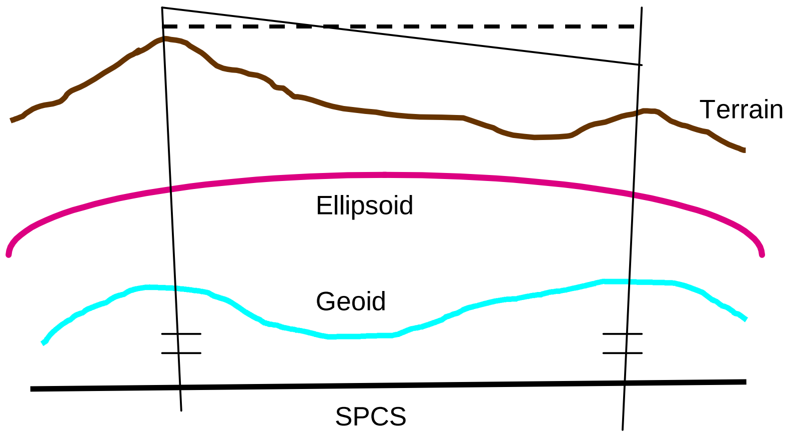
Ground To Grid Computation

Horizontal Distance	=	354.838 = (EDM Slope Measurement Reduced to Horizontal)
Ave Elev of Line	=	5.850 = (9.4 + 2.3) / 2
Ellipsoid Factor	=	1.000004436 = (R / (R + N + H)) = (6,372000 / (6,372000 + (- 34.1) + 5.850))
Geodetic Distance	=	354.840 = Horizontal Distance x Ellipsoid Factor
Average Scale Factor	=	0.999900000 = Sum of Scale Factors / 2
SPCS Grid Distance	=	354.804 = Geodetic Distance x Average Scale Factor

Comparison

Published Grid Dist	=	354.805	
Reduced EDM Dist	=	354.804	
Difference	=	0.001	Difference = 1 part in 354,800

Figure 1 - Reference Surfaces



In New Jersey, the surface of the State Plane Coordinate System is approximately 640 meters below the surface of the ellipsoid along the central meridian.

Figure 2 - Reference Surfaces in Absecon, NJ

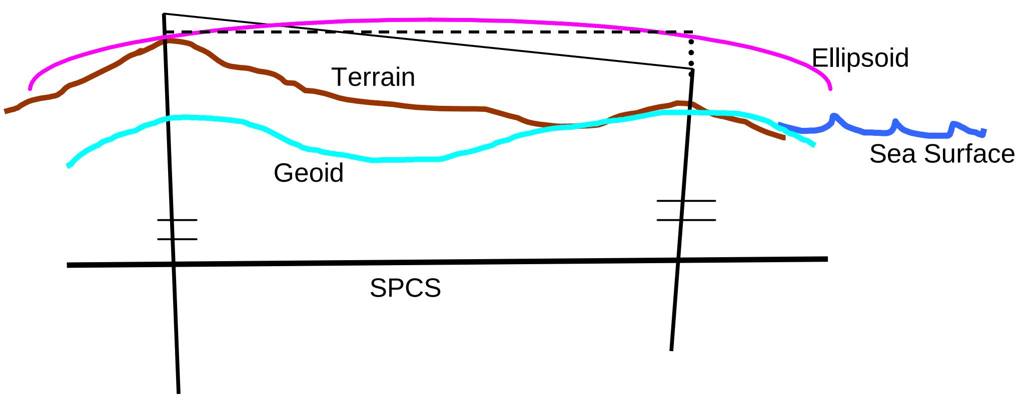
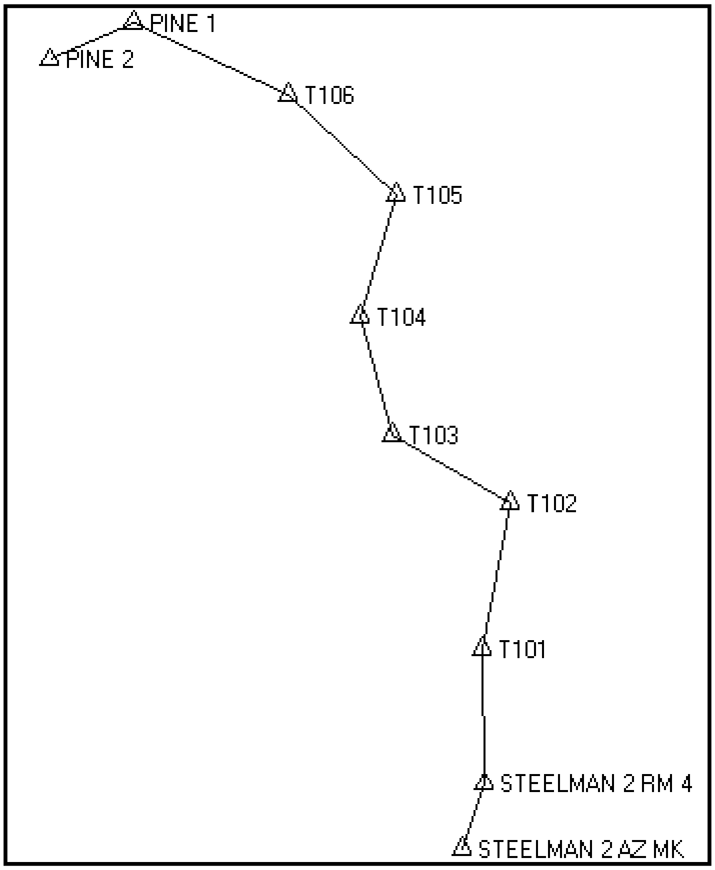
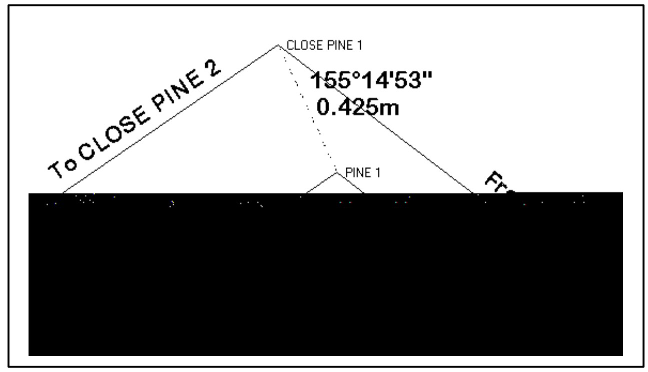


Figure 3 – Traverse Example Showing Closure





Traversing along the ground without reducing the distances to the grid causes a misclosure at PINE 1 of 0.425m. The total distance traversed was 5170.34 meters. This equates to an accuracy ratio of 1 part in 12,000 which is the direct result of not applying the grid scale factor of 1 part in 10,000.

Table 2 – SPCS Compared To 'Pseudo SPCS'

		SPCS		Pseudo SPCS			SPCS minus Pseudo			Grid-Grnd
Point Name	Grid Dist	N	E	N	E	Grnd Dist	Delta N	Delta E	Radial	Delta Dist
STEELMAN 2 AZ MK		64612.500	150488.828							
	354.805					354.839				-0.034
STEELMAN 2 RM 4		64948.826	150601.837							
	708.965					709.034				-0.069
T101		65657.760	150595.104	65657.829	150595.103		-0.069	0.001	0.069	
	773.436					773.511				-0.075
T102		66417.949	150737.639	66418.091	150737.652		-0.142	-0.013	0.143	
	713.073					713.142				-0.069
T103		66774.287	150119.985	66774.463	150119.938		-0.176	0.047	0.182	
	639.648					639.709				-0.061
T104		67391.941	149953.694	67392.177	149953.632		-0.236	0.062	0.244	
	668.972					669.037				-0.065
T105		68033.350	150143.741	68033.648	150143.697		-0.298	0.044	0.301	
	773.436					773.511				-0.075
T106		68555.980	149573.600	68556.329	149573.501		-0.349	0.099	0.363	
	892.666					892.753				-0.087
PINE 1		68936.075	148765.899	68936.461	148765.721		-0.386	0.178	0.425	
	476.49					476.536				-0.046
PINE 2		68739.917	148331.659	68740.284	148331.439		-0.367	0.220	0.428	