North Carolina Department Of Transportation Coordinate Systems
A reference system for the Registered Surveyor and the GIS professional

Abstract

Driven by the transition to digital mapping, the Location and Surveys Unit of the North Carolina Department of Transportation developed procedures to establish project specific, localized coordinate networks. The designed procedures meet accuracy requirements for integrating highway project plans into statewide, or local government, Geographic Information Systems. It also establishes a reference base for registered surveyors to assign NC State Plane Grid coordinate values for right-of-way boundaries and any boundary feature related to the project alignments by station and projected or offset distance. The localized network is referenced to NC Grid by selecting an existing geodetic station or using GPS to establish a geodetic control station to be used at the Network Reference Station, (NRS).

Introduction

Coordinate utilization prior to digital mapping, 1986, was limited to controlling terrestrial targets, or identifiable features, for photo rectification and limited use as a tool for locating designed alignments on cross country surveys. Photogrammetric survey teams would perform project traverses to aid in obtaining X, Y, and Z values for placed targets or identifiable features. These traverses were tied to NC Grid and all control for terrestrial targets were reduced to state plane; therefore, base mapping was produced on the state plane.

In July 1991 the Location and Surveys Unit adopted a policy that all projects would be tied to the North Carolina Grid System. Prior to that policy implementation, major projects were tied to available grid marks to minimize traversing while setting up project alignments. No consideration was given to establishing usable coordinate values for retracement. Small projects were developed using assumed coordinates and magnetic bearings.

The need for a coordinate network that would allow project development by merging digital data from private engineering firms, local governments, Photogrammetry, and Location field survey crews became very apparent.

As a part of designing the procedures required to establish a local coordinate network, the following objectives were identified as key components to be satisfied by the localized coordinate network concept.

Key Components:

- the ability to integrate multi-source digital data
- retracement of project alignment and right-of-way boundary
- matching adjacent projects
- sharing digital data with local government GIS and Planning Departments
- retracement of mapped boundary features by registered surveyors

North Carolina Geodetic Survey

The NC Geodetic Survey (NCGS) had its inception in 1932 when O. B. Bester and George F. Syme, two North Carolina Highway Engineers, initiated the idea of a state grid system. These engineers hoped to reduce the large amount of computations needed to make accurate surveys of large areas. They presented their idea to Dr. O. S. Adams of the U.S. Coast and Geodetic Survey. Dr. Adams undertook a feasibility study for a state plane coordinate system utilizing the geodetic data derived from the National Network. As a result of his studies, the Lambert conformal conic projection was developed for those states with greatest extent in the East-West direction. The NCGS and NCDOT continue to be close partners in providing geodetic data to users.

The North Carolina State Plane is referenced to the Geodetic Reference System (GRS 80) ellipsoid with a mean radius of the earth of 6,370,944 meters. Published coordinates are based on the 1983 North American Datum. North Carolina uses the US Survey foot with a conversion factor of 3.280833333. The state plane network has a Central Meridian of 79 degrees 00 minutes West Longitude and North Latitude of Origin of 33 degrees 45 minutes. The state projection was made using the one-sixth rule with the southern standard parallel at 34 degrees 20 minutes and northern standard parallel at 36 degrees 10 minutes. This distribution of the scale factor provides for most areas of the state to exceed a ratio of 1:10,000 precision. Figure 1 is a graphic representation of the state plane.

NCDOT Coordinate Utilization

Preliminary Mapping for Planning and Functional Design

Location and Surveys is teamed with Photogrammetry to provide base mapping for corridor selection, preliminary design, and providing geographic addresses for environmental and cultural resources. This data is used to prepare exhibits conveying project concepts to citizens along the project. These exhibits aid in soliciting public input into project planning.

In order to merge local government casdastral and GIS data this preliminary mapping must be on state plane. As a public service, Photogrammetry offers for sale, aerial and topographic mapping to private citizens and engineering firms necessitating the mapping be on state plane. This mapping is generated from high altitude flights and generally covers large areas. The positional tolerance for topographic features on preliminary mapping does not meet the accuracy standards for plan sheet development; however, it is more than adequate for GIS applications.

Location and Surveys provide terrestrial targets with N and E values, on state plane (NAD 83), for Planning and Functional Design Mapping. The Z value for these targets is currently based on NGVD 1929.

Plan Sheet mapping for Right of Way delineation and Final Design

Base mapping provided to designers in developing plan sheets for right-of-way acquisition and project construction requires ground measurements. Property is purchased for right-of-way using areas computed from ground distances. Construction estimates are compiled and materials fabricated using dimensions from plan sheets. The demands for using ground distances dictates a coordinate network that allows project development utilizing ground measurements.

Base maps for plan sheets are compiled from low level aerial photography, using terrestrial targets tied to the project localized network. The difference in accuracy between planning and functional design mapping and plan sheet mapping will not allow for file merger. Therefore, having the planning and functional design mapping and plan sheets on slightly different datums does not generate problems.

Providing Ready Access to Private Users

The North Carolina Legislature passed legislation in 1974 requiring that highway plans be recorded in local Register of Deeds Office's to provide access to local users. Highway plans did not include references to the North Carolina Grid; therefore, use of the data was limited to the ability to re-establish alignments from existing pavement or right-of-way monuments set during construction. The management of the Location and Surveys Unit was committed to providing local engineers and surveyors with a sound reference datum to effectively utilize the recorded plans. This commitment was reinforced by the State Board of Registration for Professional Engineers and Land Surveyors' ready acceptance of this method of reference.

Each project is tied to NC Grid and a Datum Description, Figure 2, is included on the recorded plans. The Datum Description provides the private users with all pertinent data needed to calculate a NC Grid value for alignments, right-of-ways, and boundary features tied to the project alignment.

DATUM DESCRIPTION

THE LOCALIZED COORDINATE SYSTEM DEVELOPED FOR THIS PROJECT
IS BASED ON THE STATE PLANE COORDINATES ESTABLISHED BY
NCDOT FOR MONUMENT "B-2803 C-2"
WITH NAD 83 STATE PLANE GRID COORDINATES OF
NORTHING: 999020.219 ft. EASTING: 1378152.105 ft.
THE AVERAGE COMBINED GRID FACTOR USED ON THIS PROJECT
GROUND TO GRID IS: 0.999968993
THE N. C. LAMBERT GRID BEARING AND
LOCALIZED HORIZONTAL DISTANCE FROM
B-2803 C-2 TO -L- STA. 10+00 IS
S 73 DEG 52 MIN 47.4 SEC W 960.14 ft.
ALL LINEAR DIMENSIONS ARE LOCALIZED HORIZONTAL DISTANCES
VERTICAL DATUM USED IS NGVD 1929

FIGURE 2

Sharing Digital Data With Local Governments

Using project specific localized networks minimizes the difference between the ground measurements and grid north and east values. This allows integration of multi-source data that is based on the North Carolina State Plane.

Several local governments, across North Carolina, have developed comprehensive Geographic Information Systems (GIS) based on North Carolina's grid plane.

These systems include casdastral data that can be integrated into preliminary mapping for transportation projects. This provides a low cost method of incorporating property lines, with ownership data, into preliminary mapping, providing the designer data needed to minimize impacts to cultural properties. It also helps to reduce the number of affected properties by providing the ability to design alignments relative to property lines, particularly on large tracts.

We in the Department of Transportation share customers with local governments and cost savings for us are enjoyed by mutual users. Using a project specific localized network keeps the delta north and delta east less than one meter, well within the accuracy requirements for local GIS integration. Local governments realize a major savings in electronic merger of digital right-of-way boundaries, from transportation plans, into their casdastral database.

Integrating Mapping Grade Survey Data

Wetlands boundaries, surveyed using mapping grade GPS devices, are referenced to the planning and functional design mapping giving the designer the ability to use avoidance, the most desired method of wetland mitigation. This data is transferred to plan sheets to aid in estimating project construction cost and in preserving wetlands that may be adjacent to the project.

Selecting a project specific method for localization allows for GPS Real Time Kinematic (RTK) Staking. This is a rather new use of GPS in NCDOT, but it appears to have great potential for pre-construction staking for Geological and Hydrological evaluation.

Localizing a Project Control Network

The Localized Coordinate System involves establishing a control plane which relates all geodetic control points in proximity to the project by selecting one central control station, with NC Grid N and E values, as the Network Reference Station, (NRS), and determining a combined factor for the project. To minimize projection distortion, the NRS should be as central to the project as possible. A combined factor is the product of the scale and ellipsoid factors.

Projects Less Than 3 Miles (5 Kilometers)

Project combined factors for projects less than three miles, 5 kilometers, can be calculated by averaging the scale factor for a station near the beginning, one near the middle, and one near the end. The Scale Factor for a control station is a function of its Latitude and may be obtained from North Carolina Lambert Conformal Conic Projection Tables or taken from the control station data sheet.

Computing a project ellipsoid factor requires using a median elevation rather than averaging the elevations of control stations in the network. Using the median elevation will minimize error from control stations being placed on hills or in valleys with substantial elevation differences.

The ellipsoid factor is computed using the following equation:
NAD 83 Datum

$$EF = R / (H + \text{Geoid Height} + R)$$

R in North Carolina = 6370944 meters or 20,902,055.44 feet
H = Elevation on Mean Sea Level (meters or feet)
Geoid Height in North Carolina is approximately -33.0 meters
Advisory Note: Assure all units are the same

Control Station Combined Factor is the product of the ellipsoid and scale factor.

Station Combined Factor = Station Ellipsoid Factor x Station Scale Factor

Project Combined Factor = Project Ellipsoid Factor x Project Scale Factor

Advisory Note: This is an approximate calculation, but well within the parameters of computations needed for project development.

Projects Greater Than Three Miles

Projects greater than three miles require a weighted average to determine the project combined factor. The weighted average is calculated by selecting the combined factor for a control station near the beginning of the project (a), one near the middle (b), and one near the end of the project (c). The factors are weighted by:

$$\frac{a + 4b + c}{6}$$

This concept is typically known as the 1/6 rule and was used in determining the Northern and Southern Standard Parallels, (Figure 1) for the North Carolina projection.

Localizing Control Stations Within the Network

The Localized coordinate value for any station with known NC Grid N and E values can be determined by:

$$\text{North}_{local} = \text{North}_{NRS} + (\text{North}_{Grid} - \text{North}_{NRS}) \times (1 / \text{combined factor}) \quad \text{Eq. 1}$$

$$\text{East}_{local} = \text{East}_{NRS} + (\text{East}_{Grid} - \text{East}_{NRS}) \times (1 / \text{combined factor}) \quad \text{Eq. 2}$$

North $_{Grid}$ and East $_{Grid}$ are the published grid values for the control station to be localized
North$_{NRS}$ and East$_{NRS}$ are the published grid values for the Network Reference Station

Localizing a Project Control Network

Project: US 421 relocation from I-77 to US 601 near Yadkinville, North Carolina
The project is approximately 12.5 kilometers, on new location, beginning at the interchange of US 421 and I-77 at the west end, and tying to the existing US 421 near US 601 interchange on the east end.

The following tables is derived from GPS measurements. North and East values are in meters on the state plane, (NAD 83), Elevations are based on NGVD 1929.

Station	North	East	Elevation	Combined Factor
R-2120-1	264113.168	448635.633	330.38	0.99994017

R-2120-2	264563.339	448642.861	332.62	0.99994089
R-2120-3	263560.422	450154.859	313.51	0.99994157
R-2120-5	264220.379	450947.609	320.04	0.99994215
R-2120-6	263914.365	450935.707	315.81	0.99994208
R-2120-7	264106.013	453015.022	302.82	0.99994466
R-2120-8	263823.350	453199.446	301.82	0.99994416
R-2120-9	263742.028	453802.981	298.34	0.99994453
R-2120-10	263931.931	454055.785	300.15	0.99994471
R-2120-11	263638.813	456679.304	291.42	0.99994549
R-2120-12	263232.068	456464.528	281.67	0.99994605
R-2120-13	264839.258	456128.727	295.36	0.99994772
R-2120-14	264401.537	456121.705	301.51	0.99994570
R-2120-15	264359.370	457861.667	272.92	0.99995016
R-2120-16	264591.901	458068.828	285.89	0.99994869
R-2120-17	264186.214	458423.726	279.68	0.99994871
R-2120-18	264479.259	458333.352	290.89	0.99994765
R-2120-19	264126.458	459007.174	262.60	0.99995127

Calculating the Project Combined Factor using 1/6 Rule

R-2120-8 was selected as the NRS due to its central location to the project and it was located well outside of the construction limits.

$$\text{Project Combined Factor} = \frac{0.99994017 + 4(0.99994416) + 0.99995127}{6}$$

Project Combined Factor = 0.99994468

Localizing Control Station R-2120-1 Using Eq. 1 and Eq. 2

Selected NRS R-2120-8

$North_{local\ R\text{-}2120\text{-}1} = North_{NRS} + (North_{Grid\ R\text{-}2120\text{-}1} - North_{NRS}) * (1/\text{combined factor})$

$North_{local\ R\text{-}2120\text{-}1} = 263823.350 + (264113.168 - 263823.350) * (1/0.99994468)$

$North_{local\ R\text{-}2120\text{-}1} = 264113.184$

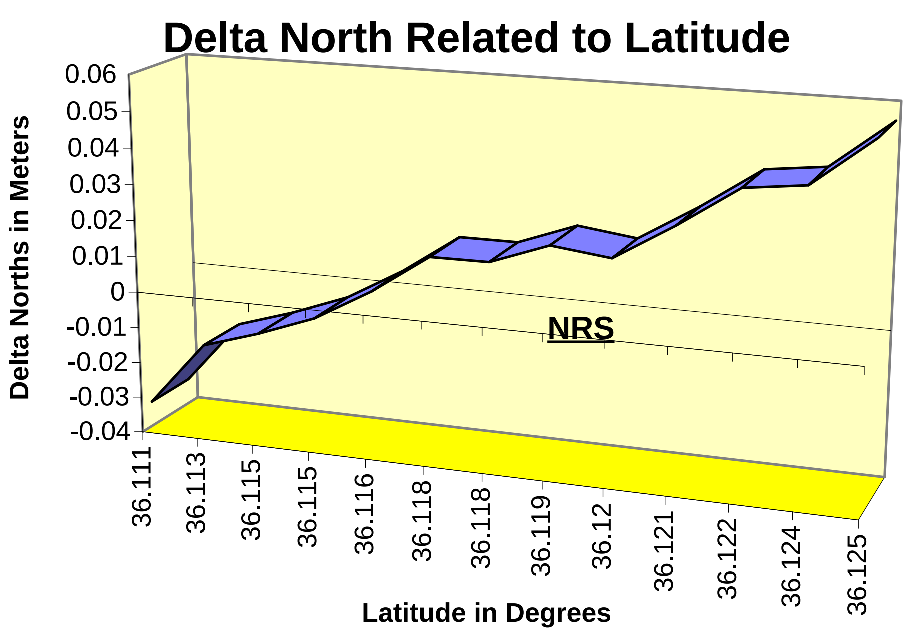
$East_{local\ R\text{-}2120\text{-}1} = East_{NRS} + (East_{Grid\ R\text{-}2120\text{-}1} - East_{NRS}) * (1/\text{combined factor})$

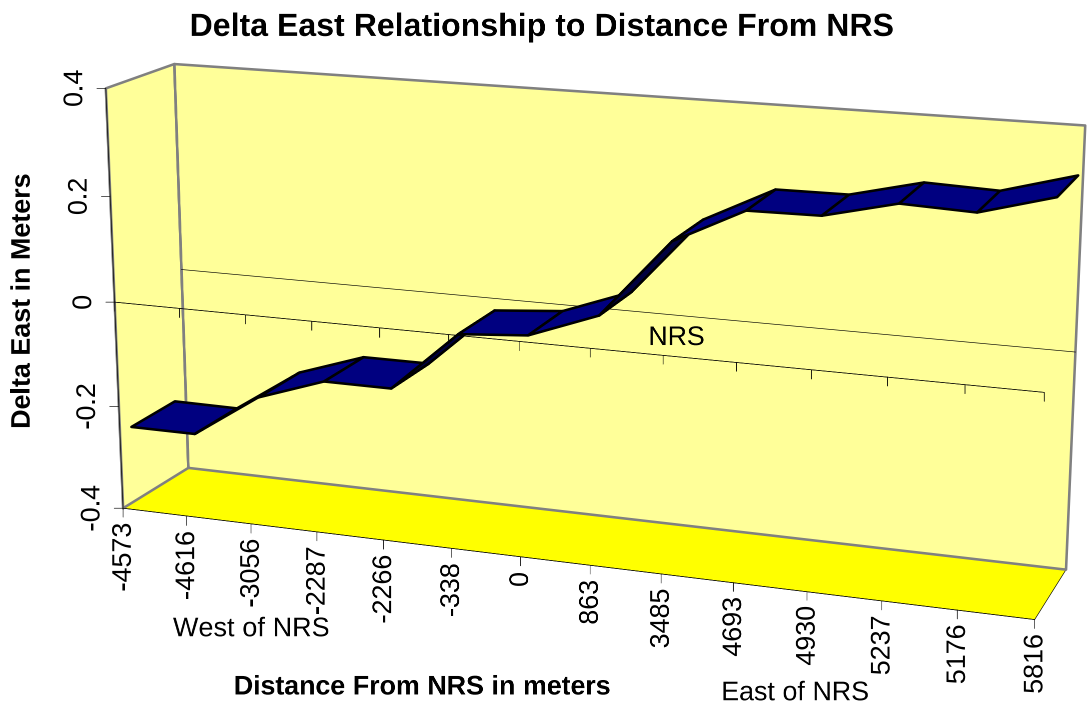
$East_{local\ R\text{-}2120\text{-}1} = 453199.446 + (448635.633 - 453199.446) * (1/0.99994468)$

East $_{local\ R\text{-}2120\text{-}1}$ = 448635.381

The following table is a listing of the North Carolina grid north and east values, derived from GPS observation, and their relationship to the localized north and east values for this project. Advisory Note: this project is running west to east with less than 1 minute change in latitude; therefore, the greater difference in the localized values will be in the east.

Station	North Grid	East Grid	North Local	East Local	Diff. North	Diff. East
R-2120-1	264113.168	448635.633	264113.184	448635.381	0.016	-0.252
R-2120-2	264563.339	448642.861	264563.380	448642.609	0.041	-0.252
R-2120-3	263560.422	450154.859	263560.407	450154.691	-0.015	-0.168
R-2120-5	264220.379	450947.609	264220.401	450947.484	0.022	-0.125
R-2120-6	263914.365	450935.707	263914.370	450935.582	0.005	-0.125
R-2120-7	264106.013	453015.022	264106.029	453015.012	0.016	-0.010
R-2120-8	***263823.350***	***453199.446***	***263823.350***	***453199.446***	***0.000***	***0.000***
R-2120-9	263742.028	453802.981	263742.024	453803.014	-0.004	0.033
R-2120-10	263931.931	454055.785	263931.937	454055.832	0.006	0.047
R-2120-11	263638.813	456679.304	263638.803	456679.497	-0.010	0.193
R-2120-12	263232.068	456464.528	263232.035	456464.709	-0.033	0.181
R-2120-13	264839.258	456128.727	264839.314	456128.889	0.056	0.162
R-2120-14	264401.537	456121.705	264401.569	456121.867	0.032	0.162
R-2120-15	264359.370	457861.667	264359.400	457861.925	0.030	0.258
R-2120-16	264591.901	458068.828	264591.944	458069.097	0.043	0.269
R-2120-17	264186.214	458423.726	264186.234	458424.015	0.020	0.289
R-2120-18	264479.259	458333.352	264479.295	458333.636	0.036	0.284
R-2120-19	264126.458	459007.174	264126.475	459007.495	0.017	0.321





Assigning NC Grid N and E Values to Points With Known Localized Coordinates

A key component of this procedure is to provide the local user the ability to relate boundary features to the North Carolina Grid for re-establishment and retracement. Any feature tied to the horizontal alignment can be assigned a NC Grid coordinate by calculating a localized coordinate value, then using the Project Combined Factor and the Network Reference Station to compute the NC Grid coordinates. The following equations are helpful in understanding this concept:

$North_{GRID} = North_{NRS} + (North_{LOCAL} - North_{NRS}) \times Combined\ Factor$ Eq. 3

$East_{GRID} = East_{NRS} + (East_{LOCAL} - East_{NRS}) \times Combined\ Factor$ Eq. 4

Example: Assigning NC Grid values to a control station with known Localized values

NRS = R2120-8 Grid coordinates N 263823.350 E 453199.446

Localized coordinates for R-2120 baseline point BL-83

BL-83 Localized coordinates N 264080.390 E 460004.294

$North_{GRID}$ = 263823.350 + (264080.390 - 263823.350) x 0.99994468
$North_{GRID}$ = 264080.376

$East_{GRID}$ = 453199.446 + (460004.294 - 453199.446) x 0.99994468
$East_{GRID}$ = 460003.918

Baseline Traverses

Pairs of GPS control stations are placed along the project corridor at approximately 1.5 kilometers intervals. These control stations are a part of the project control network and are assigned localized N and E values.

Control traverses are located along the preliminary alignments to develop a baseline network for gathering project data and staking out the final alignment and right-of-way boundary. The baseline traverses are tied to the GPS control stations, providing intermediate position and azimuth checks.

The baseline traverses are adjusted to the localized control stations using least squares adjustments. This is a network adjustment using all traverses and restricting the GPS control stations. This network adjustment eliminates intermediate errors that would occur if independent adjustments were made at each GPS control station.

The integrity of measurements along the baseline is maintained by comparing observed ground distances with ground distances computed from localized and grid N and E coordinate values of the GPS control stations

To minimize differences in actual ground distances measured along the surface of the earth, calculations are made to insure the 1:X ratio of measured ground distances to computed ground distance exceeds 1:40,000. This calculation is made by computing a combined factor for the line between a pair of GPS control stations and calculating the ground distance, from grid values. Compare this calculated distance with the localized distance between the two control stations to obtain the ratio. If the difference does not exceeds 1:40,000 an analysis should be made to determine if selecting another NRS would meet this criterion. Using the farthest control stations from the NRS the following calculations demonstrates this process:

The combined factor for R-2120-18 = 0.99994765
The combined factor for R-2120-19 = 0.99995127

The average combined factor for this line = 0.99994946

The Grid bearing and distance from R-2120-18 to R-2120-19 is
N 62 degrees 21 minutes 51.3 seconds W 760.595 meters

The localized bearing and distance from R-2120-18 to R-2120-19 is
N 62 degrees 21 minutes 51.3 seconds W 760.637 meters

The ground distance, computed from grid values, from R-2120-18 to R-2120-19 using the line combined factor is :

$$760.595/0.99994946 = 760.633 \text{ meters}$$

All things perfect, an observer on R-2120-18 should detect a 0.004 meter difference between the measured distance and the localized distance to R-2120-19. This error yields a 1:X ratio of 1:190,000.

Field Checks

To confirm the procedure, Baseline Point Number 83 was selected to convert the localized coordinate values to grid. Localized values were assigned by a least squares adjustment of the project control traverse. Point Number 83 is 6.8 KM east of the NRS for this network.

Localized values for Point 83 BL - 83 N 264080.390 E 460004.294

GPS observations were made on Point BL-83 with following results:

NC Grid values from GPS tie BL - 83 N 264080.372 E 460003.879

Grid coordinates were calculated using Eq. 3:

$North_{Grid} = 263823.350 + (264080.390 - 263823.350) \times 0.99994468$

$Ease_{Grid} = 453199.446 + (460004.294 - 453199.446) \times 0.99994468$

NC Grid values from localized BL - 83 N 264080.376 E 460003.918

Differences delta N 0.004 delta E 0.039

These results are consistent with similar field tests made on other localized networks.

Conclusion

The procedures discussed in this paper have been presented to potential users and have received overwhelming acceptance. The Location and Surveys Units has presented this in seminars offered through the North Carolina Society of Surveyors and continues to offer presentations to local professional organizations. Making this data available to the private sector has strengthened the professional relationship with NCDOT and has shown our willingness to be private/government partners.

References

Development and Application of the State Coordinate System, North Carolina Geodetic Survey Section

Plane Coordinate Utilization, A Workshop Course by the North Carolina Department of Transportation.