International
Association
of Oil & Gas
Producers

Surveying & Positioning Guidance note 13

Advisory note on derivation of geodetic datum transformations

Revision history

Version	Date	Amendments
1.0	April 2004	First release

1 The Problem:

Since the advent of satellite positioning users have been faced with the need to transform coordinates delivered by the satellite based systems to those based on the national geodetic system of the country or area concerned. Transformations between Co-ordinate Reference Systems based on different geodetic datums (sometimes colloquially referred to as "datum shifts") used within oil company operations are normally expressed as three geocentric translations (colloquially known as shifts – dX, dY, dZ) and, less frequently, as four, five, seven or ten parameter transformations additionally involving rotations and a scale change. Often, the three parameter translations that are used to change co-ordinates and heights derived by the ubiquitous GPS system to the local national geodetic and mapping system are available from the local national survey department or NGA list. (NGA is the National Geospatial Intelligence Agency of the USA, formely NIMA and DMA). But in the absence of prior knowledge through the local source or NGA list, or from a previous reliable determination, it may be necessary to determine values for the datum transformation required.

This note offers neither specification nor procedures for such work but merely suggests the methods and precision appropriate for such derived datum transformations, which may be subsequently used by different operators.

2 The EPSG recommended solution:

GPS data from many continuously recording stations thoughout the world, forming the IGS (International GPS Service) network, or ITRF (International Terrestrial Reference Frame), has become readily available via the Internet. It has thus become possible to post process locally recorded GPS data with simultaneously recorded data from a selection of the nearest IGS stations and thus achieve high accuracy for the determined coordinates of the user's observation station. Certain organisations may undertake the computations for the user if provided with the locally recorded data in RINEX format via the Internet, or the task may be readily undertaken by the user, using receiver manufacturers' or other software, after downloading appropriate IGS station data from their website. The computational processing yields a local ITRF position and ellipsoidal height to an accuracy depending on various observational and computational factors but generally to better than 0.3m.

Using this computed three dimensional WGS 84 position with the position of the observation station expressed in the local geographic coordinate reference system enables an evaluation of a three parameter dX, dY, dZ transformation between WGS 84 and the local geographic coordinate reference system. Repeating the exercise on several local observation stations allows the least squares determination of an improved mean datum shift for the area with, if desired, the evaluation of all seven translation, rotation and scale change parameters. While the derived WGS 84 co-ordinates for the stations may be of consistently high accuracy one must also have regard to the origins and basis of their local co-ordinate values, which may be of variable accuracy. If part of the same triangulation network they will all have an accuracy reflected by the order of accuracy of that network. If from other less reliable sources, e.g. a series of well positions, one must be prepared for inconsistencies and outliers in the local co-ordinate data. Obvious outliers, which will show up in the calculations, should be eliminated from the derivation of the datum transformation.

Evaluation of the transformation from the local datum to WGS 84 by this means has become commonplace, with oil company operators and their contractors regularly establishing the datum transformation to be used for a new survey in an area where no official or previously evaluated transformation exists. Repeated evaluations may result in multiple datum transformation evaluations in a territory, which, though showing only small variation, may tend to confuse future users of the data. Parameter values are generally derived using receiver manufacturers' software and often quoted very precisely, sometimes to many decimal places.

The derivation of the datum transformation parameters requires a comparison between the XYZ cartesian co-ordinates of a point or points expressed in both datums. Those for WGS 84 will be derived from the latitude, longitude and ellipsoidal height delivered by the GPS receiver and the differential processing with the IGS data. Those for the local system will be obtained from a knowledge of the latitude and longitude of the point or points and a determination of its or their height above the local ellipsoid. This height in turn must be obtained from combining its gravity related height above mean sea level and the height of the geoid above the local ellipsoid at the point. This latter quantity may not be well known in large parts of the world.

It is recommended that best practice is served if any derived or quoted datum transformation parameter values always represent the differences between the true geocentric cartesian values of the point expressed in both datums. These geocentric values will relate to the latitude, longitude and ellipsoid height of the point in both source and target coordinate reference systems and will NOT consider the local topographic or orthometric height.

3 Alternative procedure:

In an area where the relationship of the geoid and the ellipsoid used for the national survey is not known or uncertain, some operators and their contractor may evaluate a transformation derived by means of a comparison of the three dimensional cartesian co-ordinates of a point derived from (i) the WGS 84 latitude, longitude and ellipsoidal height of the point and (ii) a compound coordinate reference system consisting of (a) the latitude and longitude on the local geographic 2D co-ordinate reference system and (b) the gravity-related or Mean Sea Level height of the point. Strictly speaking this is not a true datum transformation in that it is not comparing like with like. It implicitly incorporates the unknown geoid height correction. However, for the practical purposes of oil company operations within the limited area of a typical licence, it surmounts the problem of the unknown geoid height referred to the local ellipsoid. And it enables local near orthometric heights to be derived directly from the GPS observations without involving a geoid model. Note that the transformation so derived strictly applies only to the observation point and it will change slowly with distance from that point according to the degree of slope of the geoid surface. Hence the reason for restricting its application to a limited area surrounding the point.

Note that datum transformations may be applied to GPS-derived WGS 84 latitude and longitude positions only to yield local datum latitude and longitude. Gravity related heights may be derived directly from the WGS 84 ellipsoidal height by correcting it by a value of the geoid height relative to the WGS 84 ellipsoid determined from a world geoid model. Several of these have been derived over the period of use of satellite positioning each incorporating more data than its predecessor and purporting to be more accurate. At the present time it is recommended that the EGM96 (Earth Geodetic Model) is used for this purpose.

4 Nature of Datum Transformation methods:

The three geocentric translations transformation method assumes that the minor axes of the two ellipsoids are parallel. This is rarely true, but is a quite satisfactory assumption for many oil industry applications for small areas, such as within specific licences. However there is an attraction in reducing the size of the residuals by deriving a transformation with more parameters, typically three geocentric rotations and a scale change in addition to the three geocentric translations. Readers are warned that when derived over limited areas of the earth (less than a continent), these seven parameters are highly correlated: whilst the least-squares solution might give smaller residuals, it may be mathematically unstable. Application of the resulting transformation at positions other than those used for its derivation may give inappropriate results, with optimistic indications of accuracy. To eliminate the high correlation between the parameter values, instead of being derived about the geocentric coordinate reference system origin the rotations may be derived at a location within the points used in the determination. Three additional parameters, the coordinates of the evaluation point, are then required. This is the so-called

Molodenski-Badekas 10-parameter transformation method. For local application, where accuracy requirements cannot be met by the 3-parameter geocentric translation method the Molodenski-Badekas 10-parameter method is preferable to a 7-parameter transformation method. Formulae for transformation methods are discussed in more detail in Guidance Note 7.

5 Precision of Datum Transformation parameter values:

Since the local system co-ordinates of the observation stations will seldom be accurate to better than 0.1m and few exploration and production applications will require higher accuracies there is little virtue in deriving or expressing the translation elements of derived datum transformations to better than this. Further, as this is equivalent to a rotation of the position about the earth axes of 0.03 seconds it is appropriate to express any derived rotational elements to no more than three places of decimals of a second. And finally, the appropriate equivalent precision of the scale change parameter will be 0.016 parts per million, rounded to 0.01ppm. The examples which follow this note use geographical positions expressed to 0.001 second (about 3cm) and derive the translations to 0.01m.

In any derivation of datum transformations the finally quoted parameters must be accompanied by a statement of how the heights have been treated and whether the results of applying the derived transformation will be to produce ellipsoidal or gravity related heights. In the case of the latter its applicability should be limited to an area within a few tens of kilometres of the derivation point.

There follow two examples of datum transformation derivations, one for when the height

of the geoid above the local ellipsoid is known, the second where it is not and the derived datum transformation includes the geoid height correction.

Example 1 – where the geoid height above the local ellipsoid is known:

GPS derived WGS 84 latitude and longitude and ellipsoid height for a point in Italy:

WGS 84 latitude	44°33′24.683″N
WGS 84 longitude	10°58′29.281″E
WGS 84 ellipsoid height	133.68m

whence –
X = 4469114.59m, Y = 866668.19m, Z = 4452486.12m

Monte Mario datum (International 1924 ellipsoid) latitude and longitude, mean sea level height and height of geoid for the point:

Monte Mario latitude	44°33′22.313″N
Monte Mario longitude	10°58′30.229″E
Mean Sea Level height	94.90m

Geoid height above International 1924 ellipsoid at point = 45.00m (from geoid contour map)

whence height above International 1924 ellipsoid is 94.90 + 45.00 = 139.90m

Then X = 4469372.44m, Y = 866739.50m, Z = 4452517.86m

and the true derived datum transformation from ellipsoidal co-ordinates of the local datum to WGS 84 is then the difference between the two sets of XYZ cartesian co-ordinates:

dX = -257.85m, dY = -71.31m, dZ = +31.74m†

Example 2 – where the height above the local ellipsoid is unknown:

GPS derived latitude and longitude and ellipsoid height for a point in Bolivia:

WGS 84 latitude	21°49′41.887″S
WGS 84 longitude	63°44′36.652″W
WGS 84 ellipsoid height	847.00m

whence –
X = 2620882.04m, Y = -5313106.82m, Z = -2357089.59m

Geoid height above the WGS 84 ellipsoid at this point, from EGM96 geoid model, = 26.28m whence the height of the point above the geoid = 847.00 – 26.28 = 820.72m

Using this with the Provisional South American 1956 Datum (International 1924 ellipsoid) values of Latitude 21°49′28.442″S, Longitude 63°44′31.131″W gives

X = 2621189.75m, Y = -5313372.15m, Z = -2356726.11m

The datum transformation PSAD56 to WGS 84 **implicitly incorporating the geoid correction** is then the difference between the two sets of XYZ cartesian co-ordinates:

dX = -307.71m, dY = +265.33m, dZ = -363.48m†

† For illustration only. Values not to be used for geodetic purposes.

OGP

International Association of Oil & Gas Producers

209-215 Blackfriars Road
London SE1 8NL
United Kingdom
Telephone: +44 (0)20 7633 0272
Fax: +44 (0)20 7633 2350

165 Bd du Souverain
4th Floor
B-1160 Brussels, Belgium
Telephone: +32 (0)2 566 9150
Fax: +32 (0)2 566 9159

Internet site: www.ogp.org.uk
e-mail: reception@ogp.org.uk