Height Systems for LCLS Construction

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Brief Summary: This document describes the two height systems currently in use on the SLAC site and defines the formula to convert between these systems.

Change History Log

<table>
<thead>
<tr>
<th>Rev Number</th>
<th>Revision Date</th>
<th>Sections Affected</th>
<th>Description of Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>000</td>
<td>9/15/05</td>
<td>All</td>
<td>Initial Version</td>
</tr>
</tbody>
</table>
Introduction

For planning and construction purposes on the SLAC site, GPS/RTK measurements are now the preferred way to generate coordinates for points. These measurements are based on a permanent GPS base station operated by the Alignment Engineering Group. They allow in particular the production of ellipsoid height and derived orthometric height through an existing geoid model. This process ensures that the height derived refers to NAVD88, the datum currently maintained by the National Geodetic Survey (NGS).

In the machine tunnels, the height of monuments and components is derived through precise level methods. During the SLC construction, a value was assigned to Station-100 and this height of 77.643680 m serves as a reference for all the current work related to machine development. This value is in accordance with NGVD29, the datum previously supported by NGS.

To avoid confusion, it is necessary to know which datum is used in the production of a height value as well as how to transform from one to another.

NGS conversion between the NAVD88 and NGVD29 vertical datums

NGS offers on its web site an interactive transformation routine allowing the computation of the datum shift given the latitude and longitude of the point of interest:

http://www.ngs.noaa.gov/cgi-bin/VERTCON/vert_con.prl

When entering the coordinates for our GPS base station it produces a computed shift (NAVD88 minus NGVD29) of 0.853 m. This computation is based on the VERTCON 2.0 model derived by the analysis of 381833 datum difference values all over the continental US. It is considered to be accurate at the 2 cm (one sigma) level. More details can be found at:

http://www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html

SLAC observed vertical datum shifts

Most benchmarks at SLAC were installed during the construction of the three following machines: Linac, PEP and SLC. A lot of them have disappeared due to various construction efforts. The best set still usable is the one implemented for SLC. The heights for these benchmarks are dated March 1986 which clearly placed them before the introduction of NAVD88. At that time, precise leveling loops were carried outside the SLAC site to some local NGS points. Today, it is not easy to reproduce this effort as the current NGS database for benchmarks does not show obvious close-by points to tie to and the SLC documentation requires time to sort. But in any case, this set of heights can been taken as is: it represents the SLAC realization of the NGS height system at this epoch. It is also in accordance with all the heights inside the tunnels and in particular the height of Station-100 used in the definition of the LCLS undulator coordinate system (LCLS TN-03-08).

A total of 25 SLC benchmarks were observed. All but 2 could be occupied directly with a GPS/RTK antenna on a pole. The other 2 were observed from a direct level shot from a temporary point observed by GPS/RTK technique. The observations were carried out twice with a one month interval. The two sets agreed and they make the “Series1” in the histogram below.
Seven 3D monuments in the research yard make “Series2”. These points were installed in February 2003 for the construction of the SPPS experiment and they were determined by a special survey based on existing points in the FFTB tunnel and the ESA building. They are another source of points with height linked to the SLAC machines and they showed a very good agreement with the SLC benchmarks. For this study, these points were observed by GPS/RTK technique. With this new campaign of observations, both series now have two sets of heights: the published height $H_{\text{SLAC}}$ and a GPS/RTK derived height $H_{\text{RTK}}$ obtained through a 2 step process:

- NAD83 ellipsoid height based on M40, the SLAC GPS base station
- Geoid undulation using the NGS GEOID99 model

The computed height datum shift is then simply: $H_{\text{RTK}} - H_{\text{SLAC}}$
The value of 0.753 meters has been chosen, an even 10 centimeters shorter than the NGS predicted value. Its accuracy is also about 2 cm. Explanations for the difference between the predicted shift obtained from the VERTCON model and the computed shift obtained from direct observations can be found in the fact that both sets of heights are only one particular realization of an existing global height system. For example the height derived from the GPS/RTK measurements depend on the following issues:
- The quality of the coordinates of the SLAC GPS base station
- The quality of the geoid model
- The quality of the GPS/RTK measurement itself.

The SLAC GPS base station was originally determined in the datum: ITRF2000. A conversion to NAD83 was then applied (based on NGS publication). Finally it is worth noting that the latest NGS geoid model is GEOID03. At the base station, the geoid undulation is -32.503 meters using GEOID03 and -32.512 meters using GEOID99.

**Conclusion**

To avoid having to modify all existing drawings and to maintain continuity with past write-ups, it was decided to keep the published height of Station-100 at 77.643680 m and use this as the height reference for all LCLS related work. This means that the SLAC height datum is close to NGVD29 and not NAVD88.

When performing GPS/RTK observations, a height will be derived following these steps:
- Produce the observed ellipsoid height: $h_{RTK}$
- Interpolate the geoid undulation using the NGS GEOID99 model: $N_{99}
- Apply the SLAC specific datum shift between NAVD88 and NGVD29

Using meters as units, this can also be written as: $H_{SLAC} = H_{RTK} - 0.753 = h_{RTK} - N_{99} - 0.753$