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Unification of Vertical Datum In Sabah and Sarawak

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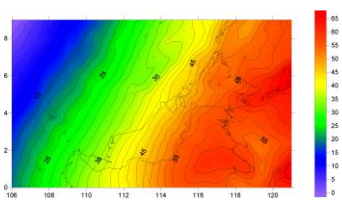
Graphical abstract



Abstract

The present vertical datums in Sabah and Sarawak (East Malaysia) are based upon various tide gauge measurements of mean sea level over certain period defined locally, are manifested by a physical framework of vertical reference point i.e benchmarks. An effort to establish a unified vertical network in Sabah and Sarawak has undergone very tedious survey operation, lack of access routes to connect levelling network due to geographical setting constraint, and it is too costly to be fully implemented. This paper discussed the current status of vertical datum in East Malaysia as well as the concept of realizing new vertical datum based on gravimetric geoid model.

Keywords: Vertical datum, unification of vertical datum, GNSS levelling

Abstrak

Datum tegak di Sabah dan Sarawak (Malaysia Timur) adalah berdasarkan pengukuran pasang surut tempatan ataupun aras laut purata pada masa-masa tertentu mana diwakili oleh rangkaian titik-titik rujukan tegak iaitu tanda-tanda aras. Usaha menubuhkan satu jaringan tegak yang seragam di Sabah dan Sarawak melalui proses ukur yang sangat sukar , kekurangan jalan yang baik untuk menghubungkan jaringan ukur aras disebabkan kekangan struktur geografi , dan terlalu mahal untuk dilaksanakan sepenuhnya. Kertas ini membincangkan status semasa datum tegak di Malaysia Timur dan juga konsep merealisasikan datum tegak baru berdasarkan model geoid gravimetrik.

Kata kunci: Datum tegak ; Penyeragaman datum tegak, ukur aras GNSS

1.0 INTRODUCTION

Vertical geodetic datum provides the reference surface or zero level from which heights on land or elevation are measured. Over recent years, height determination within a unified and consistent vertical datum is the basis for a large number of economic activities and many applications such as engineering, cartography, survey and mapping and other scientific applications.[1]

Over long time ago, vertical datum is theoretically geoid surface which is defined associated with some average of local mean sea level. The Mean Sea Level (MSL) value representing zero level assume to be coincided with geoid then is extended to other places using spirit levelling via precise vertical network. The vertical network consisted of bench marks linked to tide gauges. The precise vertical network then is unified by adopting a vertical datum value defined at a tide gauge as been practice in Peninsular Malaysia. [2] The height of benchmarks are known by professionals as level height or orthometric height system to start the survey and engineering project.

The vertical network establishment in Peninsular Malaysia, Sabah and Sarawak were constructed separately. The unification of vertical datum has been completed in 1998 with the adoption of Peninsular Malaysia Geodetic Vertical Datum.[3] A consistent and accurate adjusted heights of bench mark has been achieved in adjustment of Precise Levelling Network of Peninsular Malaysia on a datum defined by MSL height at Port Klang.[4] Meanwhile, levelling networks in Sabah and Sarawak are still not unified and always referred to various vertical datums.[5]

It is useful to note that it is uncommon to have multiple vertical datums that propagated from separate tide gauges.[6] In East Malaysia, it can be found that there exist six vertical datums currently in use.[7] The main reasons is lack of good access route to connect levelling network between the tide gauges stations. In addition, the geographical constraint such as the wide river and mountainous area may limit the precise levelling technique.[8] Therefore, unification of vertical datum by using vertical network is too rigorous and tedious, costly and time consuming to be implemented in Sabah and Sarawak.

The alternative approach to spirit levelling for creation of vertical datum is through geoid modelling.[8] Geoid is a fundamental surface which orthometric height is refered. Nowadays, Global Navigation Satellite System (GNSS) has been accepted by people in practical height determination. GNSS measurement give ellipsoidal height which is geometrical height and in practice, people need physical height or orthometric height. Therefore, in order to transform ellipsoidal height from Global Positioning System (GPS) measurement into orthometric height, precise geoid need to be used to obtain orthometric height easily, faster, and at lower cost.

Malaysia has invested millions of dollars to develop MyRTKNET station and precise geoid model in Peninsular Malaysia, Sabah and Sarawak. MyRTKNET is use for improving GPS position to sub-cm accuracy. The geoid model is for strengthen vertical network infrastructure in Malaysia. The accuracy of geoid model is better than a few centimeters.[10] Since problems of having a unified vertical network is obvious, geoid model infrastructure has a potential value as a tool to unify vertical datums in Sabah and Sarawak.

■2.0 CURRENT STATUS OF VERTICAL NETWORK

Levelling networks in Sabah and Sarawak are still not unified and always being referred to various vertical datum. There are many problems in defining a unified vertical datum for Sabah and Sarawak where the main reason is no access road to connect between the tide gauges.[11] Currently, Sabah has unify vertical network by adopting datum at Kota Kinabalu.[12] In Sarawak, there are three datum in use such as Pulau Lakei Datum, Original Datum and Bintulu Datum.[13] The various vertical datum in East Malaysia will implicate many development and planning of Infrastructure .

Nowadays, geoid modelling and GPS become popular in height determination and this approach is one of the viable options in this contemporary era.[14] In MyGEOID 2003, two geoid models have been computed; Gravimetric geoid model and Fitted geoid model.[15] The gravimetric geoid has been computed with relative accuracy of 5cm. Due to inconsistency between gravimetric geoid and local datums in practices, the gravimetric geoid model will be fitted into the local levelling network. To carried out this , the definition of National geodetic vertical datum (NGVD) is adopted at Kota Kinabalu to represent unify datum in East Malaysia.[16] Then , the gravimetric geoid fits the NGVD by introducing corrector surface. [17] Then, the user will obtain the height with respect to MSL straight away by using GPS using fitted geoid in equation **(1)**:

$$\mathbf{H_{msl}=h^{GPS} - N^{fittedgeoid}} \qquad \mathbf{(1)}$$

$\mathbf{H_{msl}}$: Height with respect to mean sea level
$\mathbf{H^{gps}}$: Height measured by GPS
$\mathbf{N^{fittedgeoid}}$: geoid height from fitted geoid

The accuracy of fitted geoid in East Malaysia is 10cm.[5] Thus, indicating fitting process may not be at the expected accuracy level which is probably due to errors in levelling or various vertical datum and GPS data related to antenna height. In addition, the crustal movement also play a role if the subsidence has occurred between epoch of levelling and GPS observation.[18]
Since the making, maintenance of benchmarks and upgrading of levelling network become obsolete and costly, the GPS combine with geoid alone will be able to define a vertical datum. Therefore, it is questionable whether to define the vertical datum with respect to gravimetric geoid model which has a better accuracy than fitted geoid or to unify the existing vertical datums in Sabah and Sarawak using a new definition of vertical datum.

■3.0 REALIZATION OF A UNIFIED VERTICAL DATUM

The vertical datum and height system adoption is crucial in development of national geodetic reference. Since GNSS technology has many advantages including height determination, the need for geoid has become crucial. Nowadays, many countries are reviewing their current vertical datum and revisit it definition due to many obstacles with current definition and realization. Few options to define and realize vertical datums has been discussed in Australia.[19] One of the approaches is based on the geoid model-based vertical datum. There are a few example of country which has adopted geoid as vertical datum such as New Zealand and Canada.[20] USA is planning to redefine its vertical datum to geoid-based vertical datum. This shows that the geoid model can be a universal choice to be adopted as current or future vertical datum.

3.1 Vertical Datum

Datum is a coordinate surface in a well defined coordinate system and vertical datum is coordinate surface to which heights, taken as vertical coordinates of points, are referred.[20]

There are three kinds of vertical datum used in Geodesy;

1) Geoid - a reference surface for orthometric and dynamic height
2) Quasi geoid – a reference surface for normal height
3) The reference ellipsoid (horizontal datum) – a reference surface for geodetic (geometric) height.

Height system using geoid or quasi-geoid are referred to physical (or natural height), as they better indicate the direction of fluid flow. The choice of height system is depend on the vertical datum used.[21] In practice in Malaysia, the orthometric height is more familiar.In the modern sense, good vertical datum have attributes for example a single reference system across country and its offshore land, consistent with geocentric datum, compatible with GNSS technology, consistent with gravity and sea level and easily adopted by users.

3.2 Gravimetric Geoid as Vertical Datum

With present geodetic infrastructure, it is possible for East Malaysia to adopt gravimetric geoid as vertical datum. East Malaysia Gravimetric Geoid is defined as continuous surface which has been defined with respect to GDM2000. The user only need a GPS coordinates in GDM2000 to access this datum. The orthometric height system is been referred to this gravimetric geoid surface.

The accuracy of orthometric height, H from the GPS levelling will mostly depend on GPS observation and gravimetric geoid accuracy in relative way as follows:

$$\boldsymbol{\sigma^2 \Delta H = \sigma^2 \Delta h + \sigma^2 \Delta N} \qquad \mathbf{(2)}$$

Whereas,
$\sigma^2\Delta H$: total accuracy of error propagation for orthometric height.
$\sigma^2\Delta h$: accuracy for GPS observation.

$\sigma^2 \Delta N$: accuracy for geoid determination.

East Malaysia has a gravimetric geoid model called EMG03C (see figure 1) .[13] This is pure geoid which is not fitted to any tide gauge or Bench marks. If this model is fitted to bench marks, it will diminish its accuracy due to fitting errors.[22] Therefore, to maintain the accuracy of the model, the fitting process should be avoided because of some reasons such as bench mark error due to land subsidence and uplift, damaged by widened road construction and so on. [23]

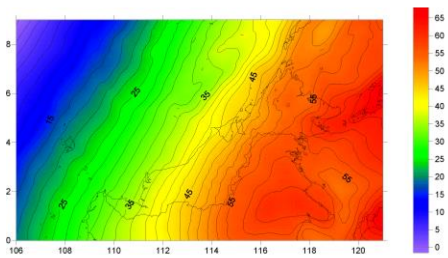


Figure 1 East Malaysia Gravimetric Geoid (EMG03C) [10]

There are few examples based on many Australian and South East Asian practices [22] and some considerations before implementing and adopting geoid-based vertical datum.[24]

3.2 Monumention of New Height System

Monumentation is one of the task to realize the new height system based on the adopted vertical datum. This become a framework of new height datum.[1] The height system in Sabah and Sarawak will be based on geoid model and the origin of the geoid model is physically monumented realized by observing GPS on local levelling origin. Therefore, GPS campaign will be executed to define origin of the new height system. In addition, this GPS campaign will be done in order to find relationship between new datum with the old datum. This offset represents the datum shift from local datum and regional vertical datum (regional gravimetric geoid). This offset is useful when user want to convert the orthometric height system with respect to regional datum to local vertical datum.

GNSS levelling will be a tool to replace the sprit levelling. It is important to determine a height of points with this new approach. There are two ways to determine orthometric height; in absolute and relative.[25]

The formula for absolute GNSS heighting is given in equation **(3)**,

$$\mathbf{H^{orthometric} = h_{GPS} - N_{gravimetric\ geoid}} \qquad \textbf{(3)}$$

$H^{orthometric}$: Height orthometric with respect to new height system.
h_{GPS} : Ellipsoidal height with respect to GDM 2000 datum
$N_{gravimetric\ geoid}$: Geoid height interpolated from East Malaysia Gravimetric Geoid.

To obtain better accuracy, we use relative or differential , GPS observations that provide ellipsoidal height differences with respect to a fixed monument station with known orthometric height. The change in orthometric height over the GPS baseline *AB* is determined by using a corresponding change in ellipsoid **ΔH** and geoid separation **ΔN** as in equation 4 :

$$\mathbf{H_A - H_B = h_A - h_B - (N_A - N_B)\ @ \qquad \Delta H = \Delta h - \Delta N} \qquad \textbf{(4)}$$

There are few guidelines,[9] several error sources that affect the accuracy of orthometric, ellipsoidal, and geoid height values are generally common to points near each other. Because these error sources are in common, the uncertainty of height differences between nearby points is significantly smaller than the uncertainty of the absolute heights of each point. Adhering to NGS' earlier guidelines, ellipsoid height differences (Δh) over short base lines, i.e., not more than 10 km, can now be determined to better than ± 2cm from GPS phase measurements. Adding in small error for uncertainty of geoid height difference and controlling remaining systematic differences between the three height systems will typically produce a GPS-derived orthometric height with 2-sigma uncertainties, with ± 2 cm local accuracy. Geoid height differences, ΔN can be determined (in selected areas nationally) with uncertainties that are typically better than 1 cm for distances up to 20 km, and less than 2-3 cm for distances between 20 and 50 km. When high-accuracy field procedures for precise geodetic levelling are used, orthometric height differences can be computed with an uncertainty of less than 1 cm, over a 50-kilometer distance. Depending on the accuracy requirements, GPS surveys and current high-resolution geoid models can be used instead of classical levelling methods.[9]

The development of geodetic infrastructure such as MyRTKnet and MyGeoid has given great opportunity in GNSS heighting.[15] However, many of this study has been conducted in Peninsular Malaysia area. it is therefore, necessary to extend this study to Sabah and Sarawak since it has a potential to replace the current traditional method in practical height determination. The study suggests that it is sufficient to replace the conventional tedious, time consuming ordinary levelling technique for rapid height transfer for engineering applications. It is also very much cost-effective to use GPS for validating bench marks in view of providing the current status of vertical datum network in Malaysia.[26]

■4.0 CONCLUSION

Gravimetric geoid-based vertical datum is a new approach for a vertical datum definition for Sabah and Sarawak. The adoption of gravimetric geoid means that the vertical datum is unified with the height system in orthometric height. The connection of local vertical datum with this new reference datum is done by GNSS observation on origin of the local vertical network . Therefore, this lead to monuments in new height system established with respect to each different datum zones.

In summary, instead of establishing vertical network using precise levelling technique over whole Sabah and Sarawak, the new realization concept of a unified vertical datum is proposed. By taking this approach, the vertical datum unification process becomes faster, easy and not too costly to be implemented. Hence, it will modernize the height system in conjunction with GNSS technology.

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