

MACAU SPECIAL ADMINISTRATIVE REGION

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Macau S.A.R. is situated in the South China Sea, and consists of the Macau Peninsula and the two small islands of Taipa and Colôane, all 64 km west of Hong Kong. Visited by Portuguese traders in 1513, it was settled by the Portuguese in 1587. Declared a Portuguese territory in 1849, its claim was recognized by China in an 1887 treaty. In 1951, the status was changed from a colony to an overseas territory of Portugal. On 13 April 1987, Portugal agreed to return Macau to China on 20 December 1999. Ilha da Taipa is connected to the mainland by a bridge, and to Ilha de Colôane by a causeway. Ferries run between Macau and the islands as well as to Hong Kong. The total land area of Macau (SAR) is 21 sq km; the lowest point is the South China Sea, and the highest point is Colôane Alto at 174 m.

In 1907, General Castelo Branco established a triangulation network in the Macau Peninsula. The earliest baseline was set in Avenida Conselheiro Borja. The coordinates of that baseline were (0,0) for "Base A," and (-673.73 m, 84.84 m) for "Base B;" and the total length was 679.056 m. The original astronomical Datum was observed in 1912 at the Hospital Conde de S. Januario on the "colina" (mountain), Colina de Visconde de S. Januario, and was observed again by the Portuguese military in 1965. The coordinates appear to have been lost, but the Datum was transferred to Guia Farol (lighthouse) ($\phi_0 = 22^\circ 11' 51.557''$ North and $\lambda_0 = 113^\circ 32' 48.063''$ East of Green-

wich). The Macau Datum origin was later again transferred to Monte da Barra where $\phi_0 = 22^\circ 11' 03.139''$ North and $\lambda_0 = 113^\circ 31' 43.625''$ East. This was a plane system and did not use an ellipsoid. The grid was based on an Azimuthal Equidistant projection.

In 1919-1920, Capitão de Artilharia (Capitan of Artillery) José Soares Zilhão and Capitão-Tenente de Marinha (Naval Full Lieutenant) Justino Henrique Herz established a triangulation network in Macau, Taipa, and Colôane. The azimuth of the initial Branco line was found to be in error by $001^\circ 42' 06''$ eastwards. This network initially served as control for the large-scale hydrographic survey of the Port of Macau. The network was expanded and later included more stations. The above information was provided by "Direcção das Obras Dos Portos de Macau." The Zilhão/Herz hydrographic survey obviously included work on heighting. Only one tide gauge was in existence on the peninsula at that time so additional gauges were established on Taipa and Colôane. The vertical datum was defined as the "hydrographic zero plane at 0.7 m below the level of the maximum tide low point of spring tides." This level was marked on all three gauges, and heights with respect to the zero plane were transferred by leveling to the trig stations Passagem (1920) and Monte de Artilharia (1920) on Taipa and Colôane, respectively.

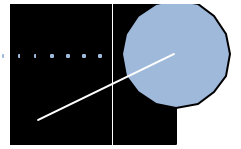
According to the "Repartição Técnica das Obras de Macau-1943," the baseline was updated such that the coordinates of "Base A" were (20,000 m North, 20,000 m East) and the coordinates of "Base B" were (19,915.18 m, 20,673.54 m). The length was 678.8545 m. The work was supervised by Engineer Chau of

the Sanitation Brigade of the Macau Public Works Department.

A topographic survey of Macau was carried out by Lt. Numes of the Macau Military Command of the Portuguese Army in 1955-1956. The task was to produce 1:2,000-scale mapping of Taipa and Colôane. According to Miss S. Fletcher of the U.K. Geodesy Division of Her Majesty's Defence Geographic and Imagery Intelligence Agency, "An assessment of the earlier survey work (1907, 1920, 1940s) was carried out to establish the best control on which to base the new survey network required. As already mentioned, it was found that there was conflict between measurement and orientation of the baseline used. The coordinates differenced could not be resolved by shifts or rotations of the coordinate axes. It was decided that as Chau's results did not actually include a check on baseline orientation, and that the change to orientation made in 1920 still maintained the original baseline length, coordinates for control points based on Macau would be taken from the 1920 results. Height control was taken from the trig stations D.Maria (Macau), Monte da Barra (Macau), Passagem (Taipa), and Monte de Artilharia (Colôane), since all had previously been geodetically leveled with respect to the vertical datum (the Hydrographic Zero Plane of 1920). The network contained two control stations on Macau (Monte da Barra and Guia Terraco), 35 stations on Taipa and 43 on Colôane. The average length of side on the islands was about 500 m. Trig stations were marked with concrete pillars. The two islands are joined together by an observed braced quadrilateral figure, as is

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the connection between Taipa and the Macau peninsula. The latter was observed using a Universal Wild T4 theodolite; most of the other observations were made using Wild T3 theodolites. Leveling was carried out to height a number of trig points using an NK2 precise level; the remaining points were measured by Trig Heighting (vertical and horizontal angles). Plane tabling was also undertaken. Two baselines were measured: Base A (NW) – Base B (SE) on Taipa and Base C (Sul) – Base D (Norte) on Colôane. These were used to provide control for scale within the observed network and also to check the relative positions of the two control points on the Macau Peninsula as determined by the 1920 survey. This corresponded to an average of 0.023 m which was within the accuracy required for the purpose of this survey. The Taipa baseline is recorded as being measured by nine sets of observations (forward and reverse) with a 100-meter invar tape. The accuracy is quoted to ± 0.0021 m (1.48 sigma). In 1965-1966, a Hydrographic Survey was carried out by Captain Fernandes. The first part of this hydrographic survey was to carry out triangulation observations in Macau for the planning of major dredging works in the port. Although the 1920 and 1940s work provided coordinates for various trig stations on the Macau Peninsula, they were found not to have a high enough order of accuracy for what was required and discrepancies between the two data sets were in the order of tens of centimeters. The results of the 1955-1956 topographic survey were assessed as providing a suitable base for this re-observation work as it included a well-measured baseline, adequate observation procedures and adjustment of results by least squares. The source coordinates for Monte da Barra and

Guia (Terraco) were taken as fixed (originally dating back to 1920 results), and stated as: Monte da Barra (X = 19207.44 m, Y = 16878.29 m), Guia (Terraco) (X = 21026.58 m, Y = 18367.08 m). The same coordinate system as for the 1955-1956 survey was used. Observations were carried out using a Wild T2 theodolite with tripod. Only one trig station (Observatorio) made use of forced-centering. Third order observation procedures were employed (four sets) with mean misclosures of sets in the order of 1" (of arc). Confusion over the definition of the vertical datum had arisen over the years and so another task of this survey was to try to rectify this. The heights of trig stations in this survey are quoted in terms of a newly determined Mean Sea Level. Two sets of heights are quoted: "pont. Mira" – height to the top of the pillar/reference mark, and "terreno" – height of ground level."

In May 1981 the No. 512 Specialist Team, Royal Engineers (512 STRE) of the U.K. Military Survey observed and computed the coordinates of two Doppler TRANSIT stations in the (then) Province. (This was the same era as when they re-surveyed Hong Kong – see *PE&RS*, January, 1998, pp. 15-16). They were based on existing trig points at Monte da Barra and Colôane Alto. These stations were observed before the Macau Survey Department carried out the network re-adjustment such that the 512 STRE position of Monte da Barra was held to $\phi_0 = 22^\circ 11' 03.14''$ N, $\lambda_0 = 113^\circ 31' 43.63''$ E, and $H_0 = 74.45$ m. This marked the beginning of Macau's use of an ellipsoid for its network and plane coordinate system. The ellipsoid of reference was once thought to be the Clarke 1858 and cast on the Cassini-Soldner Grid (same as Hong Kong). Not so! The ellipsoid of reference is the International 1924 where the semi-major axis $a = 6,378,188$ m and the reciprocal of flattening $1/f = 297$.

In 1986, a team of Portuguese geodetic surveyors carried out as-

tronomical observations for the baseline Monte da Barra - Colôane Alto, but results were not received in Macau until late 1991. The results showed that the latest local survey network (1981) still contained a swing of approximately $1' 19.73''$ of arc. That fact stands out like a sore thumb in a later paragraph here where the seven-parameter transformation values are listed.

The subsequent WGS 72 coordinates of Monte da Barra are $\phi_0 = 22^\circ 10' 58.696''$ N, $\lambda_0 = 113^\circ 31' 53.827''$ E, and $h_0 = 70.29$ m. The line between the two TRANSIT points checked with the new adjustment results to within 0.036 m, or 4.7746 parts per million. The WGS 72 ellipsoid semi-major axis $a = 6,378,135$ m and the reciprocal of flattening $1/f = 298.26$.

Geographic Engineer and Director Adelino M. L. Frias dos Santos of the Direção dos Serviços de Cartografia e Cadastro wrote to me in 1997 regarding the systems of Macau. Thanks also to Geographic Engineers Law Sio Peng and Lou Kuan Hou, who cleared up some of the long-standing mysteries of Macau. As mentioned previously, the original astronomical Datum at the Hospital Conde de S. Januario on the "colina" (mountain), Colina de Visconde de S. Januario, was observed again by the Portuguese military in 1965 such that, at station Observatório, $\phi_0 = 22^\circ 11' 45.46''$ N and $\lambda_0 = 113^\circ 32' 39.00''$ E. The old references to Guia Lighthouse have been confused by others because there are two OTHER stations: Guia II (Chapa da Guia) where X = 21,052.91 m E and Y = 18,366.28 m N, and Guia Terraço (Guia Marco) where X = 21,026.88 m E and Y = 18,367.24 m N. Thanks to Mr. John W. Hager, the projection used for Observatório Meteorológico Datum of 1965 is the Azimuthal Equidistant with origin at Point "Base W" where $\phi_0 = 22^\circ 12' 44.63''$ N, $\lambda_0 = 113^\circ 32' 11.29''$ E, and False Easting = False Northing = 20 km.

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According to the Instituto Hidrográfico Portugal, the transformation vector used for the conversion from the WGS 72 Datum to the Observatório Metereológico Datum 1965 is $\Delta X = +187.77$ m, $\Delta Y = +297.54$ m, and $\Delta Z = +160.35$ m. According to Engineers Peng and Hou, the 512 STRE returned in 1991 and established a strong geodetic link with the Hong Kong and Macau networks based on the WGS 84 Datum and ellipsoid. "Six primary geodetic stations were occupied in Macau (including Monte da Barra, Hotel Oriental, Taipa Grande Taipa Pequena, Colôane Alto, and Monte Ká Hó). Three years later, we observed the coordinates of 14 stations (including the six primary stations) with the Global Positioning System

and transformed the WGS 84 coordinate system into the local coordinate system. The Molodensky-Badekas transformation system (seven-parameter transformation) was adopted to transform the WGS 84 coordinate system into the local coordinate system." Those parameters are Rotation Origin at $X_o = -2,362,038.81$ m, $Y_o = 5,417,496.26$ m, $Z_o = 2,390,633.71$ m, and $\Delta X = +203.010$ m, $\Delta Y = +302.491$ m, $\Delta Z = +155.296$ m, $R_x = +32.876850''$, $R_y = -76.963371''$, $R_z = -32.622853''$, Scale = -8.204889 ppm. Thanks to Paul Gosling of the Geodetic Branch of the Defence Geographic Centre and to Giles André of the Defence Geographic and Imagery Intelligence Agency for their substantial contributions.