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TIES TO HARBOUR BASES FOR DRIFT, SCALE AND DATUM DETERMINATION IN ANTARCTIC MARINE GRAVITY PROFILES

Abstract. Gravity reference stations have been established in the harbours of Buenos Aires, Ushuaia, Punta Arenas, Wellington, Singapore, Hobart, Dunedin and Christchurch to give the gravity reference values and to compute the calibration factor and the drift rate of the marine (surface) gravity meter employed during the first four polar expeditions by OGS, Trieste, in the period 1987-91 for the Italian Antarctic Project run by ENEA.

INTRODUCTION

The gravity connections at the harbours which are dealt with in the present paper were made to establish a standard for the continuous gravity profiling carried out by the research vessel "O.G.S. Explora" belonging to the Osservatorio Geofisico Sperimentale, Trieste (Italy) in the framework of the Italian Antarctic Program run by ENEA, during the first four expeditions (from the 1987-88 to the 1990-91 austral summers).

The inherent drift of the Bodenseewerk sensor (n. 14) used in the measuring system for gravity profiling is thought to be rather low and almost linear so that little residual error is expected from the closure compensation, provided the base values are self-consistent and no abrupt jumps (tares) are induced in the instrument during its operation by mechanical or electrical shocks (e.g., by blackouts).

For the scale, a refining calibration factor needs to be precisely determined to convert the instrumental readings into gravity units (milliGals). A first approximate factor of 0.8400 was applied in the instrumental options, but a further accurate correction must be determined and applied since the expected gravity values in Antarctica (in the southernmost part of the Ross Sea) are 2 to 3 Gal greater than the gravity values of the nearest gravity comparison bases in the harbours. Therefore, scale calibration uncertainties of the order of ± 0.3 parts in 1000, which are considered acceptable in ordinary operations, would lead to systematic errors of the order of about 1 mGal for operations in the Ross Sea, due to extrapolation of the gravity values.

To solve the problem it was decided to make suitable comparisons at harbours with gravity base values spread over the largest possible range, according to the routes planned for the ship when reaching Antarctica.

The International Gravity Standardization Net 1971 (IGSN71, Morelli et al., 1974) was mainly used to forward the datum. Where available, other modern gravity measurements were also considered, to improve accuracy and/or to check IGSN71.

All the gravity values were corrected to neglect the so-called Honkasalo term, according to resolution n. 15 of the IUGG General Assembly in Camberra (1979).

The new land ties were made with LaCoste & Romberg gravity meters: a G367 was employed

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during the first campaign and a G433 during the other ones. These instruments had already been calibrated on the absolute scale during previous operations.

Another point should be made about the reference stations taken by the side of the ship. Normally, it is difficult and of uncertain accuracy to get the actual mean sea level, so no reference is made to it: the measurements were made simultaneously at the pier and on board while another auxiliary site, less close to the waterline and therefore less affected by sea tides, was added for future reference.

The vertical distance (Dh) from the ship's gravimeter to the base site on the pier was taken into account and is reported here in the text. Some inaccuracies may arise from the unknown vertical gravity gradients, which were estimated by considering the actual situation, from a maximum of 0.3086 mGal/m in the cases of pole-piers to lesser values when solid rock extends up to the sea front (see Appendix 1).

The elevation differences quoted from the pier sites are referred to the level of the gravity sensor, which is normally 0.2 to 0.4 meters above the sea level.

After the first campaign, the Bodenseewerk system KSS30 was modified into version KSS31, by changing some of the electronics and adopting the new stabilized platform. However, the same sensor (n. 14) was retained.

GRAVITY TIES FOR THE FIRST CRUISE (Jan. 19 TO Mar. 12, 1988)

Bases in Buenos Aires

The gravity base station set in the harbour of Buenos Aires was not directly involved in the first OGS gravity campaign, since the period of actual profiling in Antarctica was between calls at the ports of Ushuaia and Wellington. A harbour station was established anyway to help in the calibration factor and drift rate determination for studying the behaviour of sensor n. 14 of the Bodenseewerk KSS30 gravity system.

As reference station in Buenos Aires, only the IGSN71 site 43848A (Instituto Geografico Militar, in San Martin, basement, near the old absolute station) was left, with g=979 690.03 mGal.

The IGSN71 sites at the former "Ciudad de Buenos Aires" airport (now Aeroparque "Jorge Newbery") no longer exist since the whole area has been completely rebuilt: sites 43848 L and M are therefore lost. In spite of disturbances in this area due to heavy traffic, a new site was chosen, for possible future use at the airport, and another new, very quiet and convenient place was selected near the harbour area at the monumental Custom building.

The adjusted results of the connections, performed in ABAB sequence, are as follows:

Bs.As. IGM-A		
	+5.41 mGal	
Bs.As. Customs bldng		g=979 695.44 mGal
	–7.19	
Bs.As. Aeroparque, new		g=979 688.25
	+1.78	
Bs.As. IGM-A		

The base station in the harbour was placed to the side of the moored OGS-Explora, and connected with the site at the Customs building with the following result:

Bs.As., Wharf D4S3, OGS Explora 1988	g=979 695.21 mGal
with	Dh=–4.35 m

Bases at the harbour of Ushuaia

The gravity tie to the harbour of Ushuaia (Tierra del Fuego, Argentina) was intended to give the starting gravity values for the first polar journey of the ship "O.G.S. EXPLORA".

There some IGNS71 stations already existed in the old airport but descriptions and sketches were available only for the 51148L, now in a military area and partially rebuilt. An old officer of the air base remembered that a wall had been built over the place were the bronze disc of station 51148K was fixed. The gravimeter was therefore set up within about 20 cm of the presumed position of this IGSN71 station. However, should the comparison give unsatisfactory results, the opening of the Antarctic loop can be forwarded to Buenos Aires: plans for check connection weres kept for the future and the results of this a control are shown when treating the ties made for the third cruise later in this text.

A new reference station has been located at the present airport of Ushuaia, outside the passenger arrival and departure terminal. Another station was placed at the foot of the wharf near the customs entrance, close to a stele set at the crossroads leading to the wharf.

The results of the ties, in closed loop, are as follows:

Ushuaia (51148K, actually lost!)		(g=981 468.68?)
	+0.008 mGal	
AP new site		981.468.69*
	+0.125	
Ushuaia stele		981 468.82*

The base station in the harbour was positioned beside the moored OGS Explora and connected to the stele site with the following gravity values:

Ushuaia wharf, OGS Explora 1988 g=981 468.44 mGal*
Dh=—1.8 m

The values marked with an asterisk could be modified by future connections to reference stations.

Bases in Wellington

The adopted reference station is the IGSN71 site at the Seismological Observatory of Kelburn, in the corridor, east of the seismometer room, IGC no. 48714B, with g=980 250.98 mGal.

The old IGSN71 stations in Wellington airport (sites E and K) no longer exists due to extensive rebuilding.

An auxiliary station has been set in the harbour area, close to the wharf, with the gravity value:

Michel Fowler Hotel g=980 277.72 mGal.

On the pier, at the side of the OGS Explora, the values is

Wellington, Shed 26, OGS Explora 1988 g=980 276.46 mGal
Dh=—2.9 m

GRAVITY TIES FOR THE SECOND CRUISE (Nov. 19, 1988 to Feb. 28, 1989)

Bases in Singapore

The choice of Singapore as one of the comparison harbour bases was suggested by its logistics and its very low gravity, since this city is near the equator, which allows a good calibration over a large range. Singapore harbour is unusual in that ships lie there at anchor in a roadstead, also during bulk and bunker operations. Our ship, the "OGS-Explora", got permission to moore for the time needed at the Pasir Panjang Wharves, and an auxiliary station was established outside the wharves area (outside Gate 6). Other auxiliary stations were established outside the Pan Pacific Hotel, in the Marina area, and at the Changi International Airport.

Reference gravity stations available from IGSN71 are located at the National Museum (site 02613B) and at the old University (pendulum site 02613A). The present situation is somewhat changed: the former Geography Building where site A was positioned is now building n. 3 of the Education Institute, since the University has moved outside the city; the Raffles statue close to site B has been removed, since the rotunda over it is under repair and the platform on which to statue was set has been demolished. A new more convenient auxiliary station was therefore established near the Art Gallery building, adjacent to the National Museum.

After making these new local ties, information was received that modern absolute gravity measurements had been made with the Soviet GABL apparatus (Singapore-2, at 1.274 m above the floor, mean gravity 978 064.096 mGal, Arnautov et al., 1988, mean from the 1979, 1982, 1984 and 1987 determinations). By taking into account the gravity difference of —5.827 mGal quoted from Singapore-2 (at h=1.274 m) to Singapore-1, the mean gravity observed at this last point, deriving from all the 1979-1987 soviet absolute measurements, is 978 069.917 mGal. Gravity differences to sites A and B as measured by Barlow, BMR (in Boulanger et ala., 1980) are +3.262 and +3.914. Furthermore, during the measurements of the LCR gravimeter circum-Pacific loop (Nakagawa et al., 1983), the Singapore-1 site (called 7907) was also connected to IGSN71 sites A and B, so that we can take the average values for these local differences. Gravity values in A and B were quoted in the same paper, thus the information can be summarizad as follows:

station	IGSN71	from soviet absol. app.	from Nakagawa gvm. loop
Singapore A (old)	978 066.72	066.641	066.684
Singapore B (old)	066.08	066.011	066.075

For our purposes, the scattering in the above value is very acceptable. It seems convenient to assume a reference gravity value in the auxiliary site outside the Art Gallery, using the new local ties from sites A and B. In fact, we have:

IGSN71 site A (old)
—0.42
Art Gallery out
—0.14
IGSN71 modified site B

But to go from the modified site B to the old site B it is probable that another 0.02 mGal must be subtracted to account for the demolished floor.

The other new local ties are:

Art Gallery out
—6.10
Changi AP new
+3.36
Pan Pacific Hotel

Art Gallery out
—2.74
Pan Pacific Hotel
+2.73
Pasir Panjang Gate 6

and

Pasir Panjang, Gate 6
0.00 ± 0.05 (swell)
on Wharf at OGS Explora (1989)

By taking the auxiliary site outside the Art Gallery as a new reference, with a mean value of 978 066.24 mGal, the new gravity station values may be computed as follows:

Singapore,	Changi AP new	978 060.14 mGal
	Pan Pacific hotel	978 063.50
	Pasir Panjang, Gate 6	978 066.23

and finally,

Wharf, OGS Explora 1989	g=978 066.23 mGal
	Dh=—2.3 m

Bases in Hobart

The first part of the second Antarctic cruise started from Hobart harbour. An absolute determination made with the GABL Soviet apparatus was available in the seismic vault of the University of Tasmania, BMW site 7499.0160, with the value g=980 417.834 (Arnautov et al., 1979). In addition, the circum-Pacific loop (Nakagawa et al., 1983) also placed some stations in Hobart. However, the single IGSN71 station (49027K) no longer existed, the airport having been completely remodelled.

New auxiliary stations were therefore positioned, one at the Hadley's Orient Hotel and another in the harbour area, at the Princes Wharf n. 1 Shed. They were connected with the absolute site and with a BMR station (n. 8090.0160) at the TAA terminal in the airport, with the following results:

Seism. vault, absol.		HO hotel, foyer	
	+15.515		+5.65
HO Hotel, foyer		Princes Wharf n. 1 Shed	
	+1.84		—0.52
AP, BMR 8090.0160		OGS Explora, on pier	

The following comparison can be made of the gravity values:

Hobart stations:	from soviet absol. app.	from Nakagawa gvm. loop
seismic vault, absol. site	980 417.834	417.789
AP, TAA (BMR 8090.0160)	—	435.129

By taking the mean value measured in the seismic vault, we get:

Seismic vault, absol. site	980 417.81
Hadley's Orient hotel	980 433.33
Princes Wharf n, 1 Shed	980 438.98
AP, BMR 8090.0160	980 435.17

and

on pier, OGS Explora 1989	g= 980 438.46 mGal
	Dh=—2.6 m

Although presently no longer possible, a comparison with the IGSN71 was done and it was reported that the GABL value is higher by 0.14 mGal (Arnautov et al., 1979). This figure is high but possible, since Hobart was a poorly connected station in the IGSNS71. Furthermore, this difference has the opposite sign to the 0.08 mGal found in Singapore, so that no significant datum shift should be present.

Bases in Dunedin

The gravity base in the harbour of Dunedin was used during the intermediate halt of the OGS-Explora for bunkering, after the first part of the second expedition and prior to departure for the Ross Sea.

The IGSN71 base is at the Geology Dept. of the University, site 48750A, with g=980 727.51. This site was connected with the harbour, where an auxiliary station was set up at warehouse Y, close to the oil wharf where the OGS Explora was moored for refuelling, and to a new site at the airport. The results are as follows:

Dunedin, Univ. 48750A	g=980 727.51
AP new	980 728.60
harbour, WH Y, auxil.	980 729.27

and

oil wharf, OGS Explora 1989	g=980 728.92 mGal
	Dh=—3.3 m

Bases in Lyttelton (and Christchurch)

At the end of the second campaign, the OGS-Explora arrived in Lyttelton harbour of Christchurch.

The IGSN71 main station 48732A is in a former workshop (now offices of the Rangers) near the Magnetic Observatory (no longer existing) in the Botanic Gardens of Christchurch. The site is marked by an aluminum plate with engraved indications about the station. The site is not accessible by car, so that an auxiliary site was established at the entrance of the Noahs Hotel and tied to the airport, at the site where the IGSN71 48723E station possibly existed. The results are:

Christchurch, Botanic Garden 48732A	
	+1.13
Noahs hotel	
	—13.84
AP (48723E?)	

totalling —12.71, in sufficient agreement with the difference of —12.738 mgals by (Nakagawa et al., 1983).

Further connections were made to Lyttelton, where a church in Winchester Road and an auxiliary station at the harbour were tied:

Christchurch, Noahs hotel	
	+21.70
Lyttelton, Church	
	+9.43
harbour, aux.	
	—0.32
OGS Explora, pier	

The following gravity values can be derived:

	from:		IGSN71	jap. gvm
Christchurch,	Botanic Garden 48732A	g=	980 494.27	494.298
	Noahs hotel		980 495.40	
	AP, (HBA, U,)		980 481.56	481.560
Lyttelton,	Church		980 517.10	
	Harbour, auxil. site		980 526.53	

and

OGS Explora, on pier 1989	g= 980 526.21	mGal
	Dh=—2.8	m

A direct gravity connection was also made to the new station just positioned in the airport of Dunedin, with resulting value +247.02 mGal. The difference between g values derived independently from the IGSN71 bases is +247.04: the agreement is therefore very good.

GRAVITY TIES FOR THE THIRD CRUISE (Nov. 24, 1989 to Feb. 27, 1990)

The continuation of the Italian Antarctic Program was preceded by an oceanographic campaign in the Straits of Magellan and thus a new harbour was visited by the ship, Punta Arenas (Chile), where gravity connections had to be performed, since the third Polar cruise was planned to start from that harbour.

The next planned harbour check was in Ushuaia, where the ship was to be refuelled, and some thies made there to improve the gravity value previously assumed.

Other connections were also to be made in New Zealand to give gravity base comparisons, since the harbour location was being changed.

Bases in Punta Arenas

The Polar survey began with the Scotia Arc area.

Punta Arenas in the southernmost station of the Americas in the circum-Pacific gravity loop created by Japanese scientists (Nakagawa et al., 1983) as a contribution to the reform and update of the IGSN71: Nakagawa's sites all still exist, so that it was very easy to tie the ship's mooring positions to points where gravity was well known.

A new control site was established at the Hotel Cabo de Hornos (here named HCH) in Punta Arenas, which was connected with three of Nakagawa's original sites:

- the old IGSN71 site 51230A (water filtration plant) named A;

- the station at the Presidente Ibanez Airport (benchmark in the newspaper and souvenir kiosk), Nakagawa's site P';

- on the axis of the entrance staircase to the harbour administration building where Nakagawa's site N is placed but no benchmark has been found (the staircase has probably been repaved).

The results for this new HCH site are in perfect agreement; the gravity value is there given by:

g at site A	+18.23	mGals
P'	+21.08	"
N	− 2.13	"

and is therefore 981 318.69 mGals, assuming the IGSN71 data.

Gravity at site N is hence 981 320.82 mGal, and this site has been connected to the base at the harbour:

Punta Arenas, wharf, OGS Explora 1980	g=981 320.82 mGal
	Dh= —2.25 m

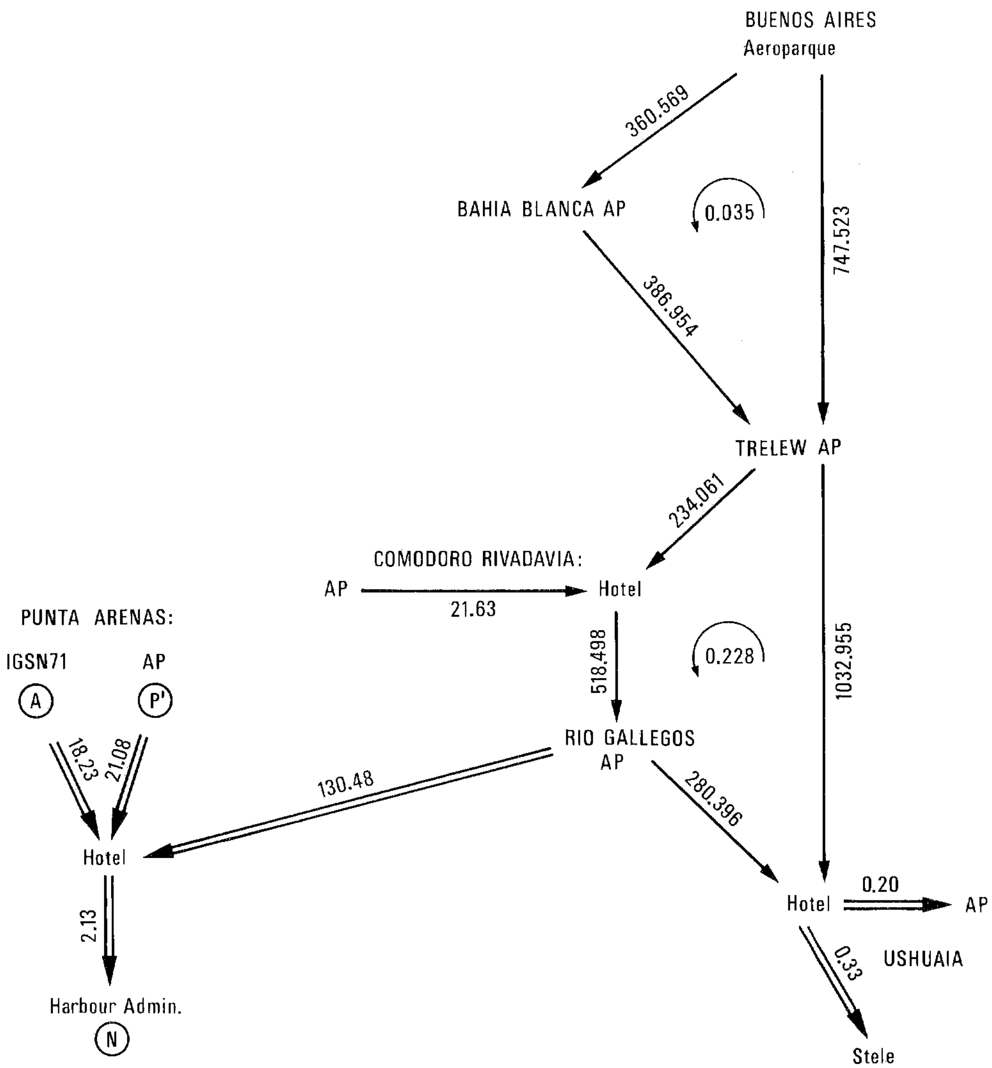


Fig. 1 — Diagram of gravity ties in South America.

Gravity connections from Chile and in Argentina

During execution of the first gravity connections in Ushuaia (Argentina) some doubts arose about the accuracy of the IGSN71 site retrieval, since the building where the site was located had undergone extensive remodelling, and about the accuracy of IGSN71 itself, since these were open leg connections.

Therefore a direct gravity connection was made from Punta Arenas to Rio Gallegos and a loop of ties by air transportation was created from Buenos Aires to Ushuaia, with intermediate measurements in the airports along the route and in Rio Gallegos.

The purpose was, as already stated, to check the gravity value in Ushuaia: the status of the IGSN sites in Southern Argentina was inspected and found very poor, since IGSN71 measurements date from 1960s and the airports in which these stations were located have been completely rebuilt.

The result of these ties is summarized in Fig. 1, where closure errors and adjusted values of the measured gravity differences are presented. Rescaling was done by recomputing the average recalibration factor to the manufacturer calibration tables of the gravity meter used (LCR G433) from the mean of the available long range comparisons of IGSN71 stations (Singapore-Hobart, in 1988-89, and Punta Arenas-Buenos Aires, in Nov. 1989).

It was found to be 1.000515, in eccellent agreement with the absolute calibration factor for that meter already assumed (1.00050).

Base stations in Ushuaia

The results of the new measurements gave the gravity at Ushuaia Airport as 981 468.81 mGal when computed from Punta Arenas through Rio Gallegos and 981 468.93 mGaals from Buenos Aires, Aeroparque, while the previously determined gravity was 981 468.69 from the local (uncertain reoccupation!) IGSN71 station.

Averaging these gravity values, we get for Ushuaia airport g=981 468.81 (±0.07), which can be accepted as good enough for our purposes, and which leads to a gravity value of 981 468.58 mGal for the new station at the Albatros Hotel. This new value for Ushuaia is 0.12 mGal greater than the previous reference value for the first Antarctic cruise.

The harbour site was different to that of the previous campaign and a connection was made with the station in the Albatros Hotel, giving:

Ushuaia, pier, OGS Explora 1990	g=981 468.71 mGal
	Dh= —2.7 m

Base stations in New Zealand

Before beginning the Ross Sea measurements, the ship stopped for bunkering in Dunedin, where a base measurement was therefore taken. The point was about 5 meters from the 1988-89 site, and reconnection with the auxiliary site gave the following results:

Dunedin, oil pier, OGS Explora 1990	g=980 728.73 mGal
	Dh= —2.8 m

At the end of the third campaign, the O.G.S. Explora moored at Lyttelton, in another area of the harbour (at Cashin Quay), and a gravity connection was made to the previously institued bases to derive gravity for this new site, with the following result:

Lyttelton Union Paris Church	
	+9.72 mGal
Cashin Quay auxiliary site	
	—0.68
pier	

The gravity reference value is therefore:

Lyttelton, Cashin Quay pier, OGS Explora 1990	g=980 526.14 mGal
	Dh= —1.5 m

GRAVITY TIES FOR THE FOURTH CRUISE (Dec. 10, 1990 to Mar. 16, 1991)

Bases in Wellington

Two new bases were observed in Wellington harbour, the first at the Queen's Wharf on arrival from Europe, through Panama Channel, and the second at the Aotea Quay, at the refuelling point before leaving for the Ross Sea. They were connected with the previous auxiliary station established at the Michel Fowler Hotel. A new station was also set in the Arcade of the James Cook Hotel.

The results are as follows:

James Cook Arcade	
	+2.62 mGal
Michel Fowler Hotel	
	—2.78
Queen's Wharf	
Michel Fowler Hotel	
	—9.57
Aotea Wharf (oil outlet)	

Gravity values at the bases near the ship's positions are therefore:

Wellington, Queen's Wharf, OGS Explora 1990	g=980 274.94 mGal Dh= —2.10 m
Wellington, Aotea Wharf, OGS Explora 1990	g=980 268.15 mGal Dh= —2.80 m

Bases in Dunedin and Ushuaia

The comparison at the harbour of Dunedin on January, 7, 1991, was made practically in the same place where it had been made in the previous cruises.

After the port call of February 15 (site 1991A), a direct comparison was made in Ushuaia harbour at the end of this cruise, in March, 1991 (site 1991B). The level of the tide was the same in both measurements and the local gravity connection gave the following results:

Ushuaia, Albatros Hotel		
	+0.12 mGal	
pier, OGS Explora 1991a		g=981 468.70 mGal Dh= —2.1 m
	—0.05 mGal	
pier, OGS Explora 1991b		g=981 468.65 mGal Dh= —2.0 m

SCALE FACTOR AND DRIFT RATE FOR THE FIRST CRUISE

A comparison can now be made among the readings (R_1 , referred to the site on the pier) taken with the KSS30 during the port calls (at time T, in Julian days) and the corresponding gravity values (G_i) at the pier "i" to determine the unknowns:

G_0=gravity value at the "zero" reading (and at time T_0),

K=calibration factor to multiply the KSS30 readings, and

D=drift rate.

In our case we adopt the simple mathematical model:

$$(K\,R_i + D\,T_i + G_o - G_i = v_i) \qquad i = 1,\ n$$

which is unfortunately not overdetermined, since we have n=3.

The numerical values are listed in Tab. 1 where the values G_z corresponding to zero readings at time T_i of the harbour base comparisons (including closure error and drift) are listed in the last column; these values were computed by assuming the weighted mean (according to gravity comparison ranges) of the scale factors computed from data of Tab.s 1, 2, 3, 5, which is K=0.95319.

Table 1 — Harbour data, 1st cruise.

PORT	days of 1988 T_i	— KSS30 — reading divis. R_i	elev. (—m)	Gravity values at ship gvmtr G_i	corresp. to "zero" reading G_z=980000+
i=1 Bs Aires	18.98	—980.56	4.35	979 696.13	630.92
2 Ushuaia	24.82	+879.00	1.8	981 469.11*	631.14
3 Wellington	66.88	—371.07	2.9	980 277.10	630.85

*) according to the last connections to Punta Arenas and Buenos Aires

The solution (for v=0) is:

K=0.953 389 mGal/division,
D=—0.002 315 mGal/day,
G_o=980 631.03 mGal.

From previous works, PRAKLA-SEISMOS, the former owner of the ship, derived K=0.953 568, which differs by 0.18/1000 from the new determination. Therefore, the next cruise was planned to include a better test of the calibration.

It should be noted that during the first Antarctic cruise, two power supply failures occurred, which caused the sensor to be automatically clamped. This could have introduced jumps (tares) in the readings: in fact, the hypothesis of a linear drift is the only one possible with the available port calls and gravity comparisons. The only guarantee comes from the smallness of the individual closure errors (maximum 0.29 mGal, if drift is not corrected for): it is very probable therefore that no relevant tare occurred during this cruise.

SCALE FACTOR AND DRIFT RATE FOR THE SECOND CRUISE

It was preferred to perform the computations separately to get drift and scale for each of the first two Antarctic campaigns, considering the modifications made to the instrument on board and the large time interval between them.

The mathematical model adopted was the same, and the numerical values are:

Table 2 — Harbour data, second cruise.

PORT	days of 1988 T_i	— KSS30 — reading divis. R_i	elev. (—m)	Gravity values at ship gvmtr G_i	corresp. to "zero" reading G_z=980000+
i=1 Singapore	—42.98	—2688.05	2.3	978 066.72	629.29
2 Hobart	—25.09	— 199.40	2.6	980 439.26	629.35
3 Dunedin	10.22	+ 105.88	3.3	980 729.94	629.00
4 Lyttelton	58.77	— 107.52	2.8	980 527.05	629.55

The solution (for Σv^2 minimum) gives:

$$K= 0.953234 \text{ mGal/div.},$$
$$D=+0.003434 \text{ mGal/day},$$
$$G_o=980\ 629.24 \text{ mGal}.$$

DRIFT FOR THE THIRD CRUISE

The data collected at the harbours during this cruise were also processed separately: the gravity range being smaller, a highly reliable result for the scale factor is not expected here.

The mathematical model adopted wast he same. Numerical values are lited in Table 3:

Table 3 — Harbour data, third cruise.

PORT	days of 1988 T_i	— KSS30 — reading divis. R_i	elev. (—m)	Gravity values at ship gvmtr G_i	corresp. to "zero" reading G_z=980000+
i=1 P. Arenas	—38.32	+719.56	2.25	981 321.53	635.56
2 Ushuaia	— 5.47	+876.84	2.7	981 469.51	633.60
3 Dunedin	+22.63	+102.05	2.8	980 729.60	633.31
3 Lyttelton	+59.13	—110.43	1.5	980 526.61	631.89

The solution (for Σ v^2 minimum gives:

$$K=0.952803 \text{ mGal/div.},$$
$$D=-0.04321 \text{ mGal/day},$$
$$G_o=980\ 633.96 \text{ mGal}.$$

During this cruise the drift rate D reached a very high value, but the reason is unknown, since no alteration was made to the observational procedure and the meter gave no trouble.

DRIFT FOR THE FOURTH CRUISE

A similar comparison can be made for the fourth cruise in Antarctica, but with some particular considerations.

Initially, the same mathematical model can be applied to all the numerical values of the harbour comparisons. In this case we get the data of Table 4.

Table 4 — Harbour data, fourth cruise.

PORT	days of 1988 T_i	— KSS30 — reading divis. R_i	elev. (—m)	Gravity values at ship gvmtr G_i	corresp. to "zero" reading G_z=980000+
i=1 Well. 1990 A	—21.16	—383.85	2.1	980 257.57	633.50
2 Well. 1990 B	—14.85	—389.12	2.8	980 268.99	639.95
3 Dunedin 19 91	6.83	+ 96.67	2.7	980 729.60	637.44
4 Ushu. 1991 A	45.50	+872.25	2.0	981 469.26	637.73
5 Ushu. 1991 B	74.53	+873.32	2.1	981 469.35	636.80

We get (for Σv^2 minimum) the solution:

$$K=0.952167 \text{ mGal/div.},$$

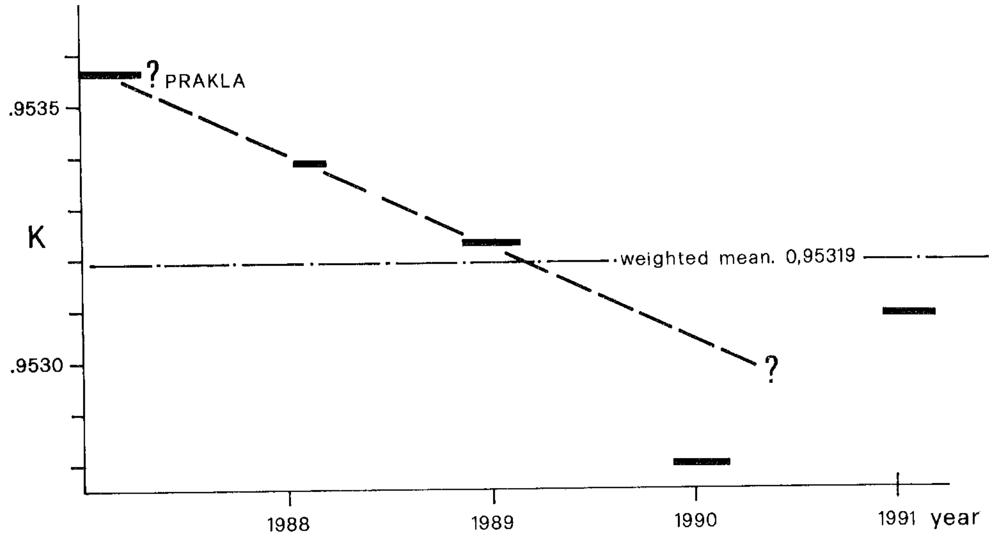


Fig. 2 — Plot of sea gravimeter scale factor (k) versus time.

$$D = +0.02328 \text{ mGal/day},$$
$$G_0 = 980\ 639.35 \text{ mGal}.$$

If we disregard the 1st and 3rd harbour comparisons of Table 4, because the corresponding land gravimeter ties were not made at the same time as the sea gravimeter dockside readings, we get the data sequence given in Table 5.

Table 5 — Harbour data, fourth cruise (SIMULTANEOUS COMPARISONS)

PORT			days of 1988 T_i	— KSS30 — reading divis. R_i	elev. (—m)	Gravity values at ship gvmtr G_i	corresp. to "zero" reading G_z=980000+
i=1	Well. 1990	B	−14.85	−389.12	2.8	980 268.99	639.95
2	Ushu. 1991	A	45.50	+872.25	2.0	981 469.26	637.73
3	Ushu. 1991	B	74.53	+873.32	2.1	981 469.35	636.80

With the solution (for $v=0$):

$$K = 0.953093 \text{ mGal/div.},$$
$$D = -0.03203 \text{ mGal/day},$$
$$G_0 = 980\ 639.38 \text{ mGal}.$$

This second set appears more consistent with the results of the previous years, and was adopted as far as scale is concerned.

As already stated, a unique mean scale factor (K=0.95319) was adopted for all the cruise computations, weighted according to the gravity range, in spite of a possible variation with time, which may possibly be evident in Fig. 2. Whether these time changes are real or not, will hopefully be resolved by future comparisons.

The Fig. 3 shows the plot of G_z values versus time: the long term tendency of the drift is rather odd, since an inversion of sign occurs after having the instrument remodelled from a KSS30 to a KSS31 version, which is not logical since these changes only involved the gyro-stabilized table and the electronics.

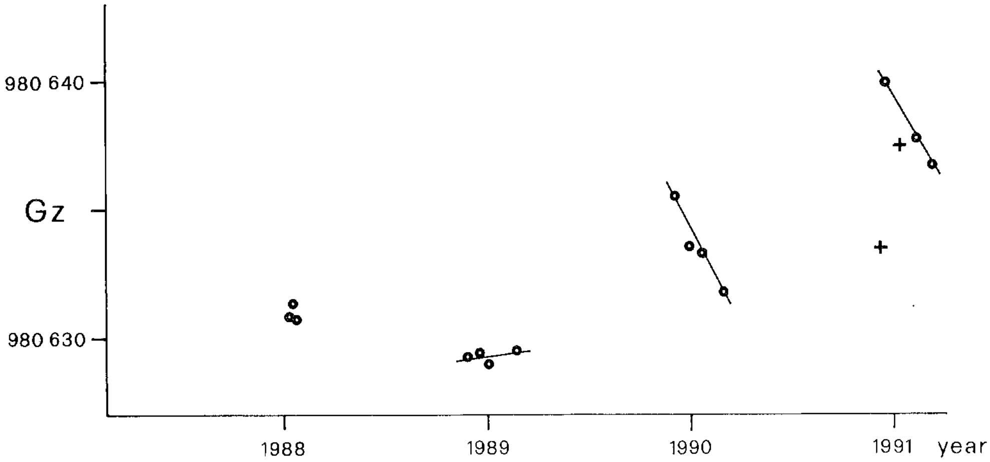


Fig. 3 — Plot of gravity at "zero" reading (G_z) versus time.

CONCLUSIONS

The results for the standardization of the marine gravity measurements are satisfactory, and the behaviour of the meter appears to be with in factory specifications and state of the art.

The simultaneous correction for drift and closure errors appears convenient and effective, and was therefore applied to the computation of the detailed gravity profiles.

A few comments should be made on the present status of the IGSN71 stations, which is unfortunately getting continuously worse, so that information is given about site modifications to help in maintenance.

The IGSN71 is still of fundamental importance for avoiding a proliferation of individual standards. A remarkable example of repair from the ravages of time is the loop created by Nakagawa: should a similar operation be carried out in Africa and around the Atlantic - Indiana ocean, and integrated with the former URSS - China blocks, with the addition of a well planned set of absolute stations, the global gravity standard could be effectively strengthened and made available with reasonable distribution for all practical uses. The importance of having stable and permanent reference stations closer to (land and sea) operation areas should not be neglected. The danger implicit in using old reference stations not checked and/or not recently established with verifiable criteria should be absolutely avoided.

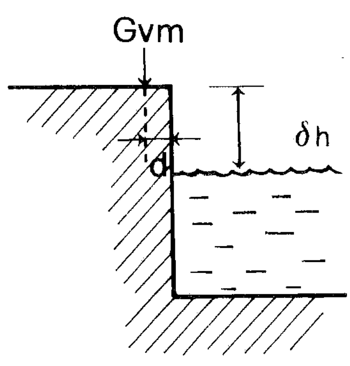


Fig. 4 — Model of gravity base at piers.

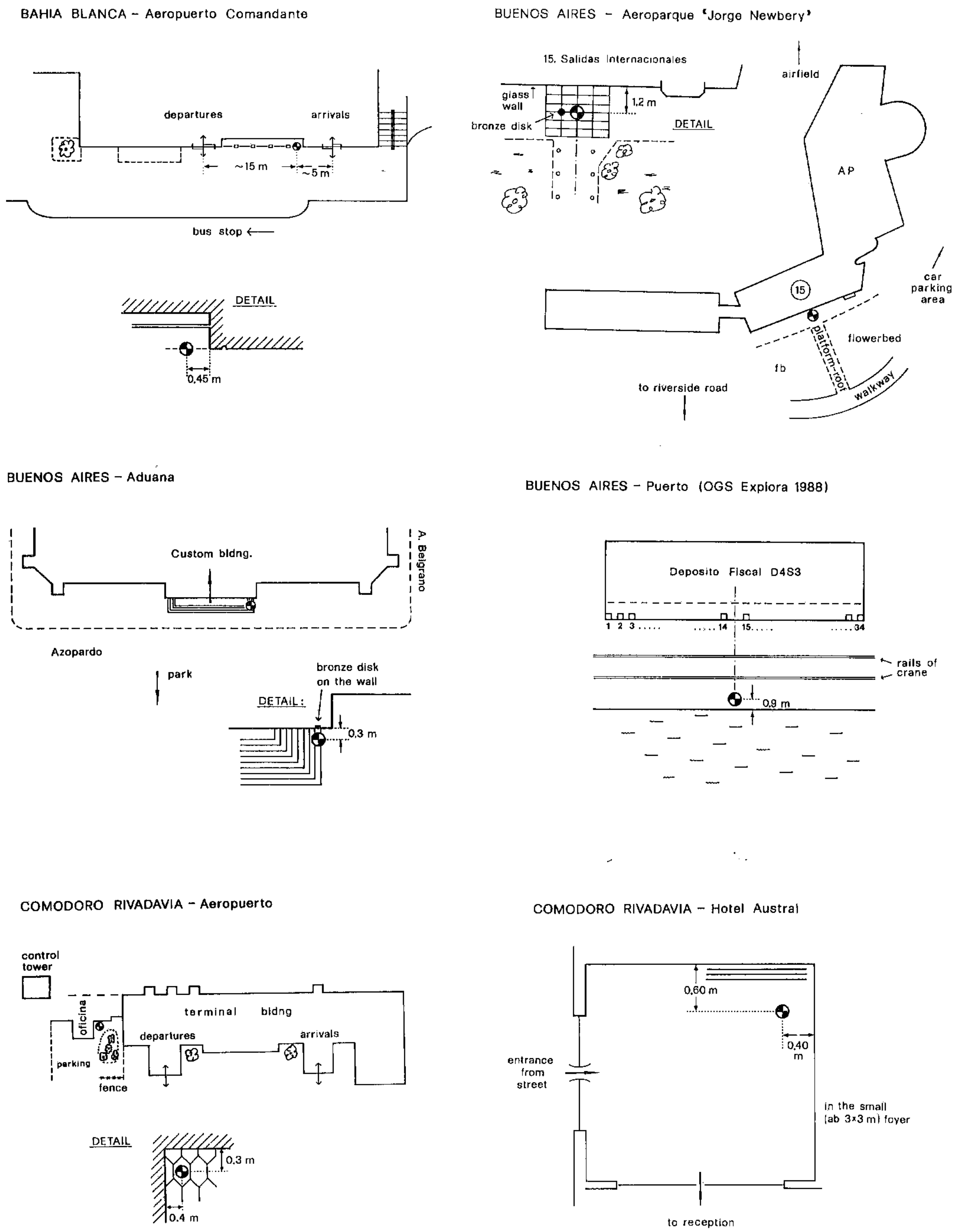


Fig. 5a — Sketches of the new gravity stations.

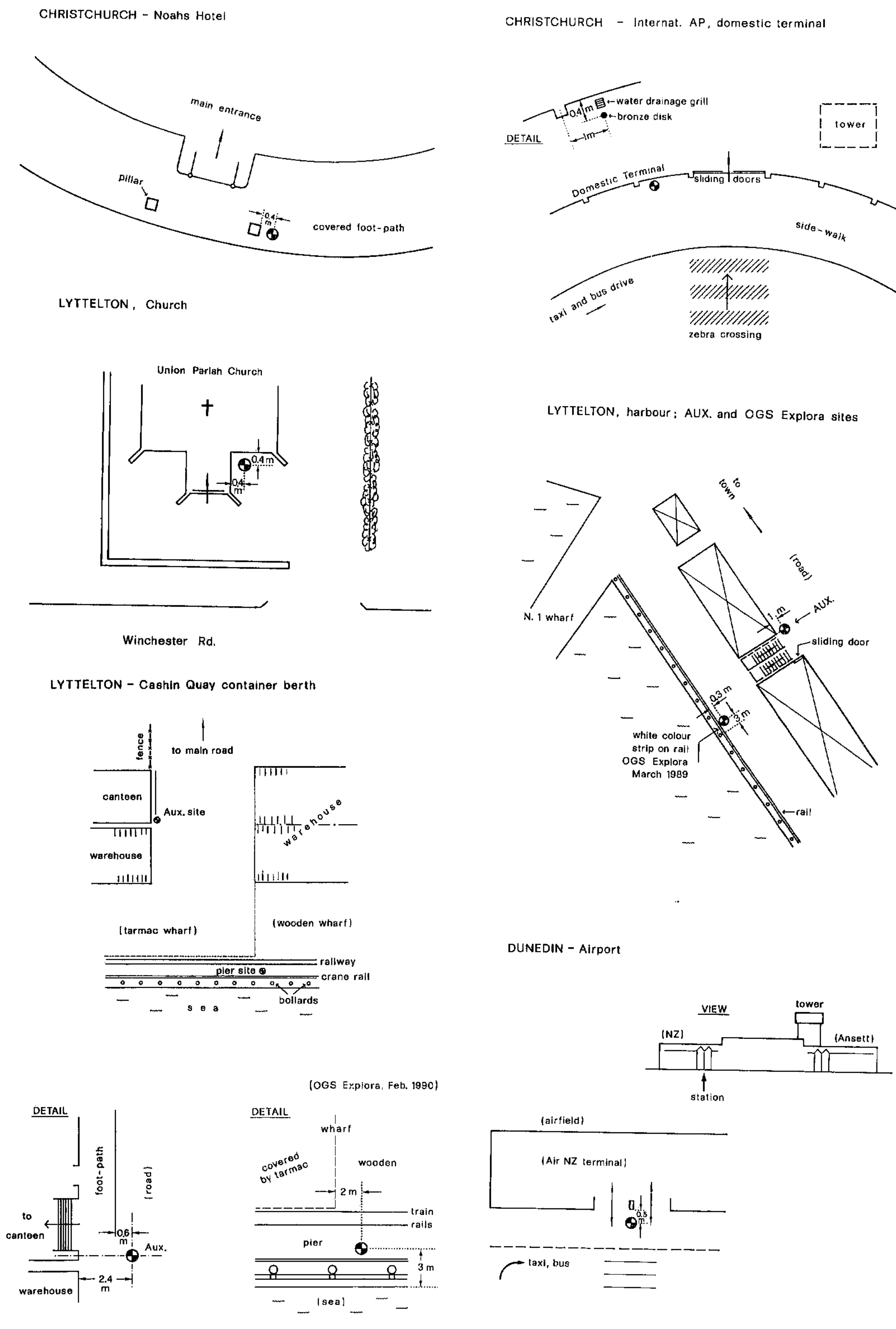
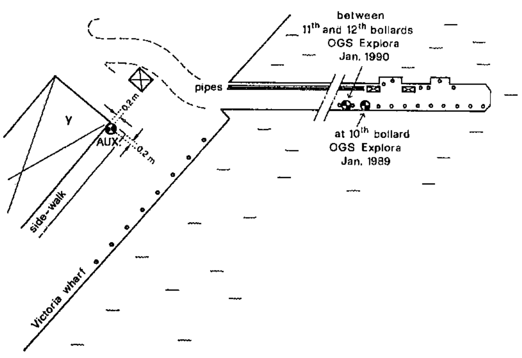
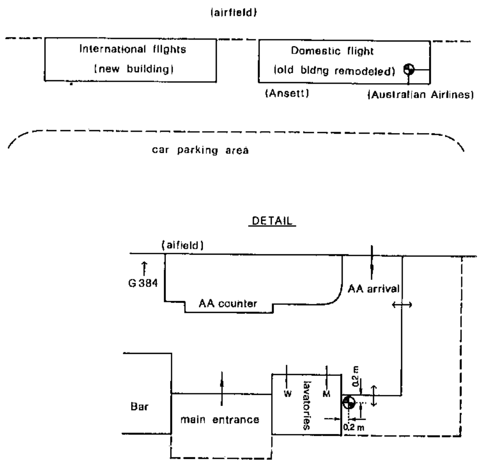


Fig. 5b —Sketches of the new gravity stations.

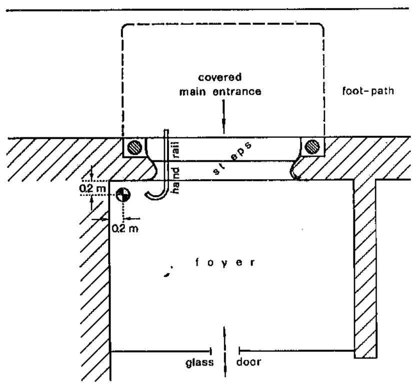
DUNEDIN, harbour; AUX. site and OGS Explora 1989 and 1990 sites



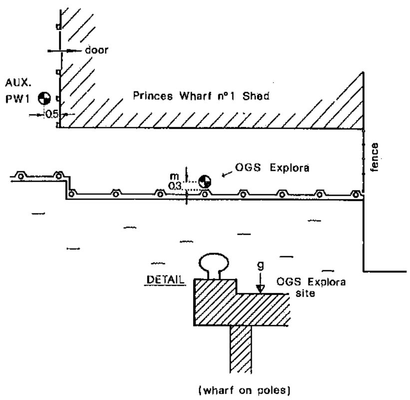
HOBART (Llanherne) Airport, BMR site (n. 8090.0160)



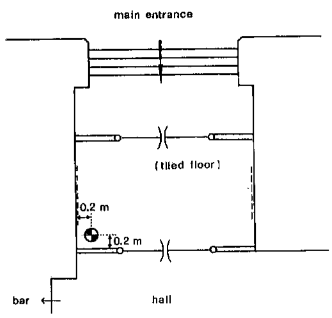
HOBART - Hadley's Orient Hotel



HOBART, harbour : AUX. (PW1) and OGS Explora sites



PUNTA ARENAS - Hotel Cabo de Hornos



PUNTA ARENAS - Puerto (OGS Explora; 1989)

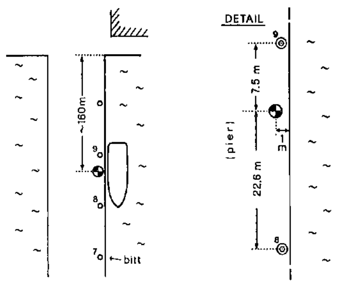


Fig. 5c — Sketches of the new gravity stations.

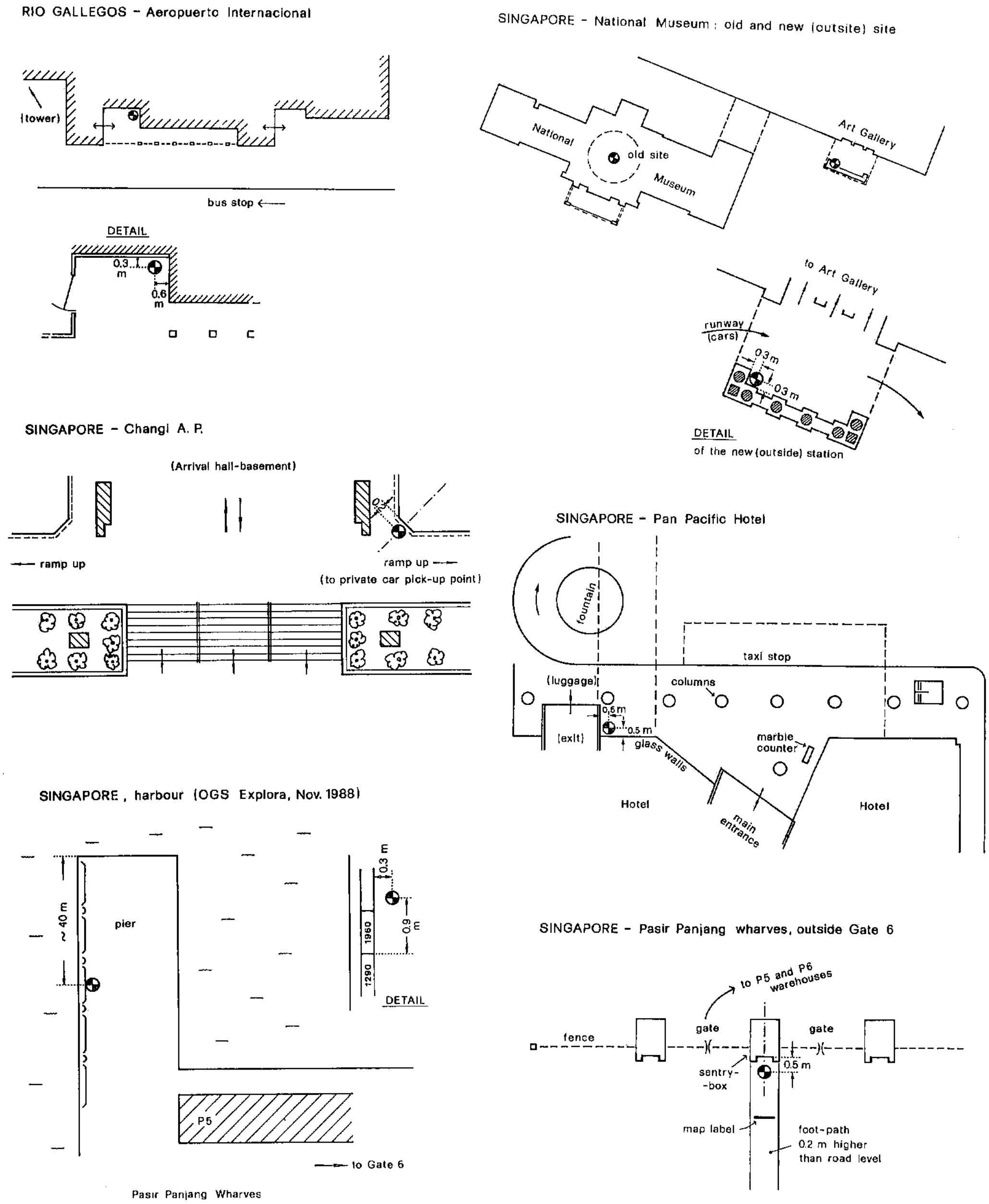


Fig. 5d —Sketches of the new gravity stations.

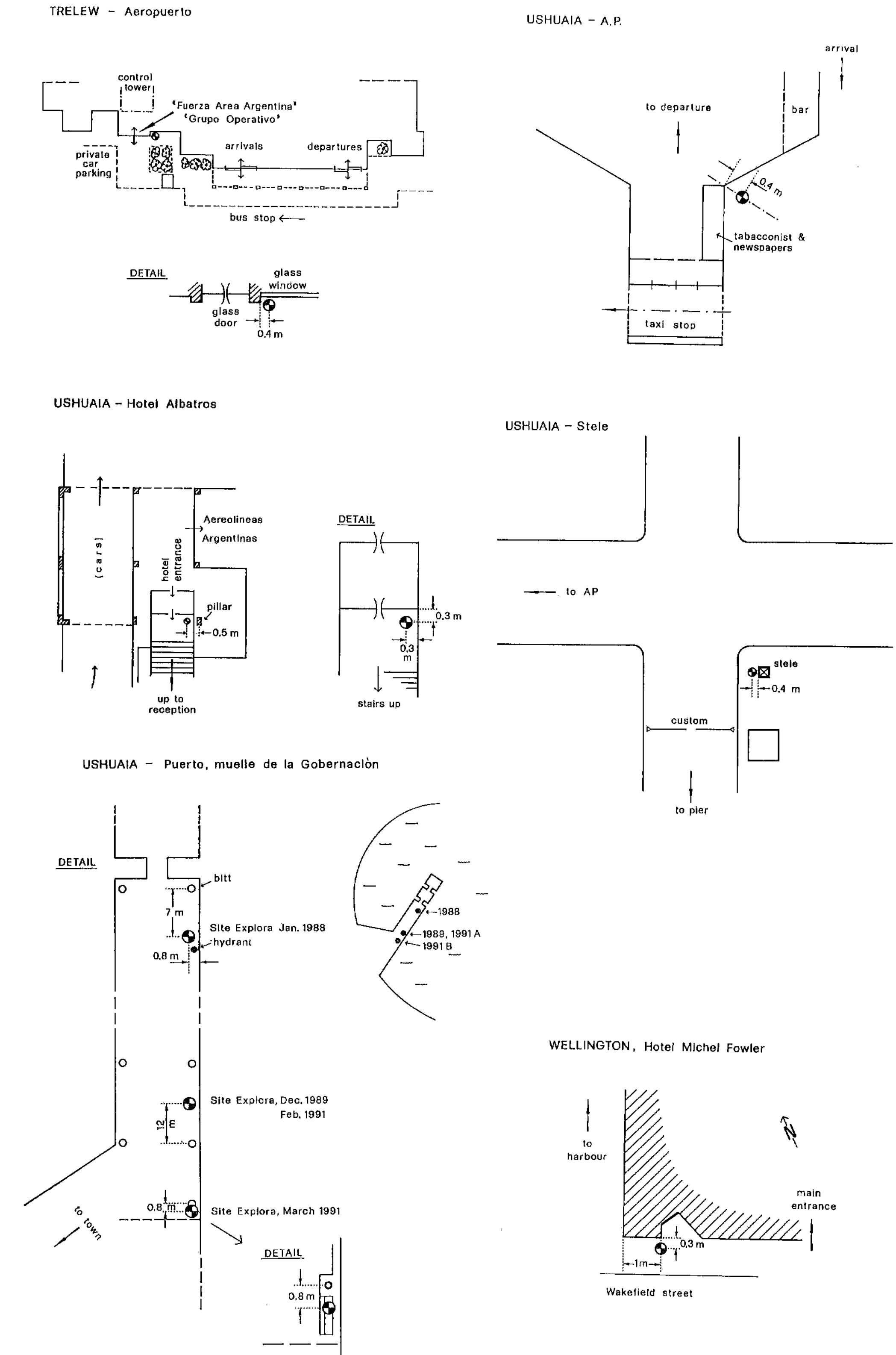
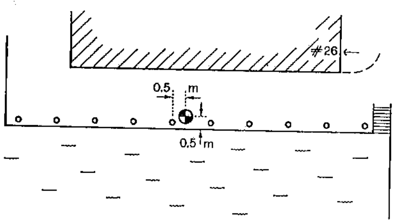
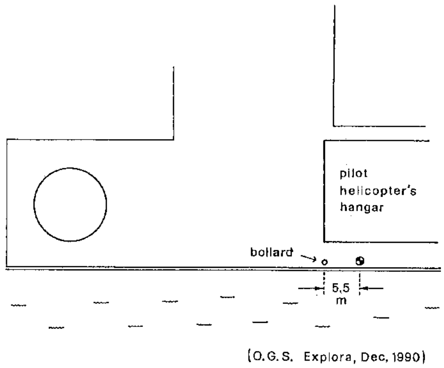


Fig. 5e — Sketches of the new gravity stations.

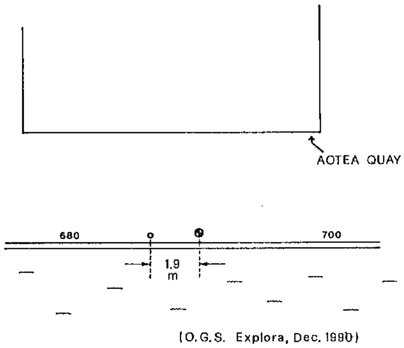
WELLINGTON, harbour (OGS Explora 1988)



WELLINGTON – Queen's Wharf



WELLINGTON – Aotea Quay



WELLINGTON – James Cook Hotel, Arcade

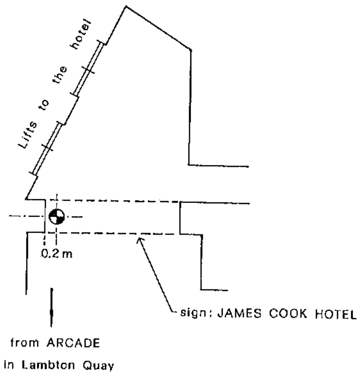


Fig. 5f — Sketches of the new gravity stations.

The following Table 6 summarizes the principal facts ascertained for the visited IGSN stations.

Table 6 — Results of inspection at IGSN71 sites.

IGSN71 station	02613 Sing.	43848 Bs. As.	48714 Well.	48732 Xcrch	48750 Duned.	49027 Hobart	51148 Ushu.
n. of avail. sites	14	7	6	5	3	1	4*
OK or minor changes	A	A	B	A	A		
not visites	CDEFFJL MOQ	CDJK	CD	K	D		A*
uncertain				E			K
destroyed	BKS	LM	AEK	FL	C	K	L
corrctn. to cancel Honk. term (mGal)	+0.037	+0.001	–0.011	–0.016	–0.020	–0.014	–0.037

*) Descriptions of sites A, B did not exist!

Descriptions of the new gravity stations are enclosed in Appendix 2, with reference to the sketches in Figures 5a-5f.

Due to the lack of time in the intermediate halts in the air connections from Ushuaia to Buenos Aires, the old IGSN71 sites could not be sought for thoroughly: it seems that they are all lost, since airports in Bahia Blanca, Trelew, Comodoro Rivadavia and Rio Gallegos have been completely rebuilt in recent years.

It has been confirmed that the status of the IGSN71, at least in some parts of the world, is now very poor: the airports (where a large number of the IGSN71 stations were located) are subject to frequent and extensive changes, and therefore are not suitable for permanent sites but only to accomodate intermediate sites. Permanent reference stations, sited at scientific institutions, churches, museums and other historical buildings should always be established and connected to the airport sites.

Very little maintenance to IGSN71 has been done in those nations where geophysics and geodesy are little applied, or where no central reference agency exists. After the establishment of the IGSN71, which however gained an accuracy higher than that expected or claimed, the greatest effort for a worldwide practical, affordable and useful improvement in the gravity reference was that made by the Nakagawa group, but this was unfortunately limited to about one third of the planet. It is advisable that other similar campaigns be carried out around the Atlantic and Indian oceans, with the African continent as backbone, after which the planned series of absolute stations might provide the framework for a new world absolute system.

The degree of detail needed for gravity-meter employment should be coordinated at an international level, taking into account the actual requirements to satisfy. From the practical point of view, now seems the right time to prevent a new proliferation of local standards, and to meet the needs of a datum unification over the world gravity coverage.

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Thanks are due to Mayor Josè Luis Royo and miss M.G. Borozuki of IGM for the precious assistance received at Buenos Aires, to Dr. Leonie Jones for her kind help in Hobart. Assistance from Dr. Reilly in Wellington and Prof. Koons in Dunedin is gratefully acknowledged. Thanks go to Prof. Boulanger who communicated the absolute value for the station of Singapore, and to Dr. Frederick Davis who gave the data for previous stations in New Zealand. The cost of the research was supported by the Progetto Antartide, ENEA, Roma (Italy).

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APPENDIX 1

GRAVITY GRADIENTS AT THE HARBOUR BASE STATIONS

Comparisons in the harbours occur between stations on the edge of piers and readings from the on-board sea gravity-meter: they require that a correction of one of these values be made to transfer it to the location of the other. We preferred to transfer the sea gravimeter reading to the base station location.

To do this, an estimate of the vertical gravity gradient is required, which depends mainly on the type of pier: in the case of a pole-pier, the normal value in free-air may be assumed (=0.3086 mGal/m). If the pier is filled with rock or concrete, a partial Bouguer slab must be computed and subtracted from the free-air effect.

Within the small range of elevation differences encountered (less than 6 meters), we verified that a single mean factor can be applied to obtain this correction, and that this factor is a function of the distance from the base point to the edge of the pier, since the distance (=2 m) from the pier to the gravimeter in the ship is constant, and neglecting horizontal gradient.

With reference to Fig. 4 we have

$d=$	$\delta g/\delta h$
0.2 m	0.225 mGal/m
0.4	0.220
0.6	0.218
1.0	0.212
1.5	0.207
ϕ	0.2038

for a terrain density of 2.5 g/cm3.

It is likely that the maximum error introduced by this simplification is not greater than 0.01 mGal, apart from the effect of local anomalous vertical gradients.

APPENDIX 2

DESCRIPTION OF GRAVITY STATIONS

1. BAHIA BLANCA, Aeropuerto Comandante.

Between the arrival and departure doors, in the front of the airport building, there is a recessed colonnade of concrete pillars. The station is 0.45 m from the edge next to the arrival door (right side of the building) in line with the front wall.

2. BUENOS AIRES, Aereoparque "Jorge Newbery".

On the left when entering the car parking lot of the Aeroparque, there is a platform roof leading to the sidewalk around the building of the "Salidas Internacionales". The station is on the axis with this platform roof, 1.3 m (=3 large tiles) from the glass wall of the building. A bronze bench mark has been installed.

3. BUENOS AIRES, Aduana.

On the lower granite step, 0.3 m from the wall to the right when entering the Customs (Aduana) building in Azopardo Square.

4. BUENOS AIRES, Puerto (OGS Explora, 1988)

Customs warehouse (Deposito Fiscal) Dique 4, Seccion 3, in the harbour. Entering from Cangallo gateway, it is the third red brick building to the left. The station is 0.9 m from the edge of the pier on the axis midway between the 14th and 15th pillar of the arcade on the sea side of the building.

5. COMODORO RIVADAVIA, Aeropuerto.

On the left, facing the departure entrance, there is an office building nearly behind the control tower, next to the military area. The station is on the right corner of the protruding entrance to this building, 0.35 m from the walls. A military permit should be obtained to measure in this area.

6. COMODORO RIVADAVIA, Hotel Austral.

In the small foyer at the entrance of the hotel, on the tiled floor, 0.6 meters from the left wall and 0.4 m from the front wall. The reception is after another door to the right.

7. CHRISTCHURCH, Noahs Hotel.

The site is 0.4 m from the right side pillar when looking towards the main entrance of the hotel, on the covered porch.

8. CHRISTCHURCH, Airport.

At the left side of the entrance to the Air New Zealand departure lounge, 1 m in front of the concrete frame there is a water drainage hole, covered with a grill, and a small bronze disk. The station site is on the disk which has no inscription.

9. (Christchurch) LYTTELTON, Church.

In the right side corner at the entrance to the Union Parish (Presbiterian - Methodist) Church in Winchester Road, 0.4 m from both walls.

10. (Christchurch) LYTTELTON, harbour.

At Breastwork N. 1, there are in the line a small cottage and two long warehouses. The station is placed behind (further from the seaside) the green painted warehouse set in the middle, 1 m from its corner, nearly under the wooden stairs, on the tarmac edge of the road running behind these buildings, almost in line with the axis of the sliding door leading to the last warehouse.

11. (Christchurch) LYTTELTON, pier (OGS Explora, 1989).

The site is 3 m in front of the 10th bollard on the waterfront of Breastwork N. 1, on the pile-wharf 0.3 m from the protecting rail.

12. (Christchurch) LYTTELTON, Cashin Quay (OGS Explora, 1990).

When arriving at Cashin Quay from the main road, the tarmaced portion of the quay ends on the left: the site is aligned 2 m beyond the border of the tarmac, 3 m in front of the edge (wood beam) of the quay.

13. DUNEDIN, Airport.

The Air New Zealand terminal is in the left wing of the AP building. The site is 0.5 m from the centre concrete frame of the double sliding door leading to the departure lounge.

14. DUNEDIN, harbour warehouse Y.

On the concrete side-walk at the sea side of the warehouse Y, Victoria Wharf, 0.2 m from the building and 0.2 m from the edge where the building ends, toward the oil wharf access.

15. DUNEDIN, oil wharf (OGS Explora, 1989)

At the 10th bollard from the end of the pole-pier called "oil wharf". The site is very disturbed by swell.

16. DUNEDIN, oil wharf (OGS Explora, 1990).

Between the 10th and the 11th bollards from the end of the pole-pier called "oil wharf". The site is very disturbed by swell.

17. HOBART, Airport. BMR n. 8090.0160.

At the Llanherne airport, outside the domestic flight building and on its rigth end, there is the Australian Airlines arrival section: in a roof covered corner formed by the brick section with the glass walls, a bronze disk is fitted, which monuments the BMR gravity station site n. 8090.0160.

18. HOBART, Hadley's Orient Hotel.

In the foyer of the hotel, to the right of the entrance in the corner where the handrail bends, 0.2 m from the walls, on a tiled floor, three steps higher than the outside foot-path.

19. HOBART, Harbour, Princes Wharf n. 1 Shed.

The site is on the front of the Princes Wharf N. 1 Shed where the entrance door is placed, in axis and 0.5 m from the concrete frame in the middle between the door and the corner nearest to the sea.

20. HOBART, Harbour (OGS Explora, 1988).

The site is 0.3 m from the 5th bollard of the pier along which the Princes Wharf n. 1 Shed is built.

21. PUNTA ARENAS, Hotel Cabo de Hornos.

Entering the hotel, there is a foyer between the two entrance doors. The station is in the right corner, 0.2 m from the second door and from the right wall, on the tiled floor.

22. PUNTA ARENAS, pier (OGS Explora, 1989).

On the left side of the pier, 1 m from its edge and 22.6 m from the 8th bollard counting from the end of the pier (ab. 160 m from the coastline).

23. RIO GALLEGOS, Aeropuerto Internacional.

Under the colonnade, in the left side of the building, there is a covered porch with an entrance door. The site is 0.3 m from the glass wall and 0.6 m from the brick wall, in the corner opposite to that door.

24. SINGAPORE, Art Gallery (new site, outside).

Under the pronaos at the entrance of the Art Gallery, in the corner formed by the columns to the right when going out of the building, on the tarmac, 0.3 m from the base walls.

25. SINGAPORE, Changi International Airport.

Outside the Changi AP, under the crescent with the taxi stand, there is the exit of the basement (lower) level, labelled also as "Emergency (Fire) Exit", which can be used also as entrance to the passenger terminal coming from the Car Park A. The site is on the tiled floor, 0.2 m from the wall at an angle, to the right of the entrance. Its level is lower than the surrounding ground.

26. SINGAPORE, Pan Pacific Hotel.

Outside the Pan Pacific Hotel, Marina, in the corner of the exit door protruding into the passageway, behind the concrete pillar of the front side of the building where the taxi stand is located. The site is 0.5 m from both corner walls, on marble tiled floor.

27. SINGAPORE, Pasir Panjang, Gate 6.

At gate 6 to the Pasir Panjang wharves, outside the harbour area. On the axis and 0.5 m from the central sentry-box, on the traffic island in the middle of the road. A "blue-pass" is required to enter the harbour and may be obtained from the police office at gate 5.

28. SINGAPORE, Pasir Panjang Wharves (OGS Explora, 1988)

About 40 m from the head of the pier after the P5 warehourse, in the area accessed through gate 6.

29. TRELEW, Aeropuerto.

On the left facing the airport, behind the control tower, there is a door leading to the "Fuerza Aerea Argentina-Grupo Operativo". The site is at the right door jamb.

30. USHUAIA, Airport.

At the AP, 0.4 m from the corner to the right of the entrance doors with the arcade.

31. USHUAIA, Hotel Albatros.

At the entrance, before climbing the stairs leading to the reception, in the left corner immediately after the second door, 0.3 m from the walls.

32. USHUAIA, stele.

The station is 0.4 m from the stele with the inscription "USHUAIA 1884-1934 Armada Nacional", on the sidewalk of the road leading to the customs entrance of the harbour.

33. USHUAIA, Puerto, muelle de la Gobernacion (OGS Explora, 1988).

Near the end of the first protruding section of the wharf, 7 m before its last bollard and 0.8 m from the southern edge.

34. USHUAIA, muelle de la Gobernacion (OGS Explora, 1989).

Nearly in the same place as in Feb. 1991, OGS Explora (=1991A). Near the base of the first protruding section of the wharf, alaong the southern edge of the pier, 12 m from the second bollard in the pole supported section (this bollard is opposite the first bollard fitted on the northern edge).

35. USHUAIA, muelle de la Gobernacion (OGS Explora, March, 1991).

This site is called 1991B. At the base of the first protruding section of the wharf, 0.5 m from its southern edge, 1 m from the first bollard located in the pole supported section.

36. WELLINGTON, Michel Fowler Hotel.

At a secondary door near the westernmost corner of the hotel, in Wakefield Street, on the foot-path, 0.3 m from the building, 1 m from the corner.

37. WELLINGTON, Harbour (OGS Explora, 1988).

In Tanaki Street, 0.5 m from the 5th bollard along the pier where warehouse n. 26 is sited.

38. WELLINGTON, Queens Wharf (OGS Explora, 1990A).

Aligned with the front of the harbour pilot helicopter hangar, there is a bollard on the outer side of the Queen's wharf: the station is 0.2 m from the kerb, 5.5 m North of this bollard.

39. WELLINGTON, Container Terminal, Aotea wharf (Explora 1990B).

There are numbers on the kerb at the Aotea wharf, where oil and water outlets are present. The station is sited 1.9 m North of the bollard set between the numbers 690 and 700.

40. WELLINGTON, James Cook Hotel, Arcade.

In the end of the corridor leading to the lifts to enter the James Cook Hotel from the arcade in Lambton Quay, there are two pillars supporting the lintel with the sign of the hotel: the station is 0.2 m from the wall of the left side pillar.