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Gravity Terrain Corrections of Taiwan

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ABSTRACT

An island-wide gravity survey was conducted from 1980 to 1987 in Taiwan. In total, 603 gravity stations had been surveyed. Among them, 308 stations were located at elevations of 500 m or greater. Since a significant portion of our gravity stations were in mountainous areas, the terrain correction must be carefully estimated in the processing of gravity data. In this study, two methods, the Hammer method and the line mass integral method, are jointly used to compute the terrain corrections. The corrections are made to a distance of 100 km with an average density of 2.57 g/cm^3. The results show that the corrections of more than half of the areas in Taiwan are larger than 10 mgal. The corrections in the western coastal plain are less than 2 mgal. Higher corrections are in mountainous areas, mostly over 20 mgal. The maximum correction reaches 93 mgal on Yushan. We also find that topographic relief in the vicinity of the station plays an important role in the correction, and the topographic effect can be ignored in marine gravity survey around Taiwan, except off the coast along the Su-hua highway.

(Key words: Gravity terrain correction, Hammer method, Line mass integral)

1. INTRODUCTION

Gravity data are very important for understanding the subsurface structures. An island-wide gravity survey of Taiwan was started in 1980 and completed by 1987. In total, 603 gravity stations had been surveyed (Figure 1). Among them, 308 stations were located at elevations of 500 m or greater. As shown in the topographic map (Figure 2), large parts of Taiwan are occupied by mountainous areas, ranging up to nearly 4000 m in elevation. Terrain correction is an important consideration for obtaining the Bouguer gravity anomaly, especially in the areas of rugged topography. However, this correction has inherent errors due to limited topographic data. This problem was identified in other gravity surveys. For example, of the 5 mgal of total error in Bouguer values in the Central Ranges, Honshu, Japan, roughly 80% of the errors were due to the uncertainty in the terrain correction (Yamamoto,

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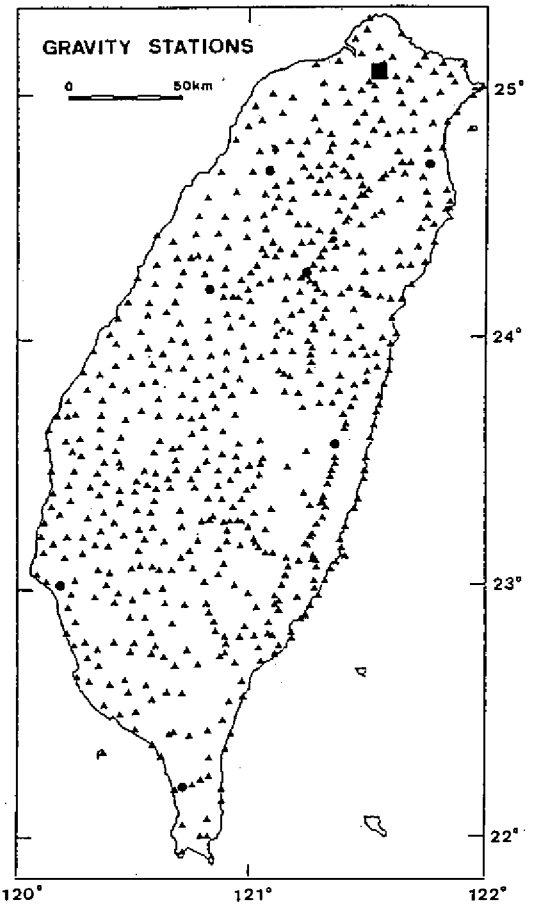

(■:TMATST base station; •:sub-base stations)

Fig. 1. Gravity stations in Taiwan.

1982). As the topography is more rugged in Taiwan (Figure 2) than in Japan, it behooves us to be more careful in calculating the topographic effects. In this study, we shall make an optimum terrain correction for the limited topographic data in the Taiwan area.

2. CORRECTION METHOD

It is well-known that gravity terrain correction is the most awkward and time-consuming work. In principle, the correction is obtained by the following steps. The terrain is subdivided into small prisms; the average elevation of each prism is estimated from topographic data; the gravity field of each prism is calculated; and then the contributions of all the prisms are added up. Commonly two alternatives, the traditional chart method (Hammer, 1939; Campbell, 1980) and computer programs based on gridding topographic data (Bott, 1959; Kane, 1962; Ketelaar, 1976; Krohn, 1976; Lin, 1980; Nozaki, 1981), are applied for performing topographic reductions. In this study, the above two methods (Hammer, 1939; Nozaki, 1981)

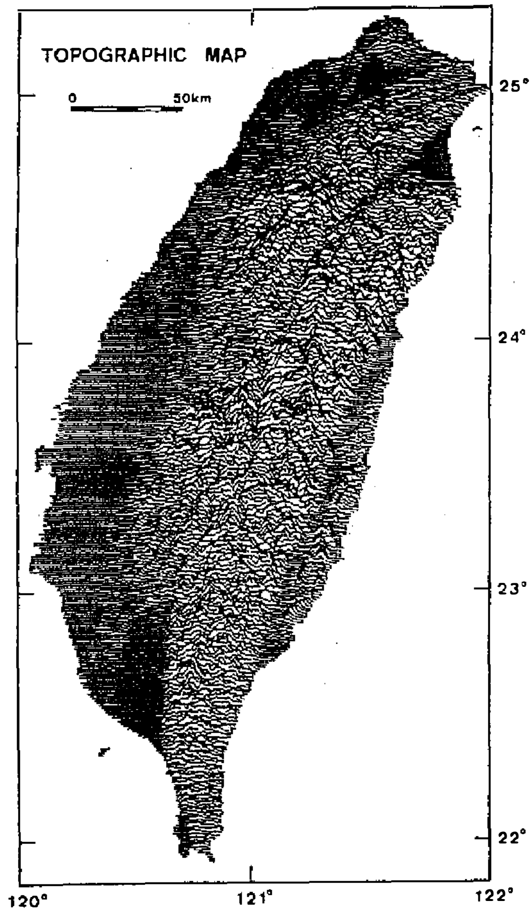

Fig. 2. Topographic map of Taiwan.

are jointly used to compute the terrain corrections for the gravity survey of Taiwan. These two methods are briefly described as follows.

In the Hammer method, a transparent template is superimposed on a topographic map of the area around a gravity station. This template consists of a series of concentric circles with radial lines dividing the zones between the circles into compartments. Sectors with areas increasing with distance from the center are also made. Practically the center of the circles is placed over the gravity station on the map. Then, the gravity effect of a single compartment on a certain sector can be calculated by the formula:

$$\Delta g_{tc} = \frac{2\pi G\rho}{N}(R_2 - R_1 + \sqrt{R_1^2 + h_d^2} - \sqrt{R_2^2 + h_d^2}\ ) \qquad (1)$$

where h_d is the difference between station elevation and average elevation in the compartment, R_2 is the outer-sector radius, R_1 is the inner-sector radius, G is the gravitational constant and ρ is the average density. The total gravity effect can be obtained by summing up the contributions of all compartments.

In the line mass integral method, topography is regarded as many collective prisms (Figure 3). The gravity effect of a terrain prism can be calculated by the formula (Nozaki, 1981) :

$$\Delta g_a = f(x_2, y_2, H) - f(x_1, y_2, H) - f(x_2, y_1, H) + f(x_1, y_1, H) \quad (2)$$

where

$$\begin{aligned} f(x,y,h) = G\rho[x \cdot log(&\frac{\sqrt{x^2+y^2}+y}{\sqrt{x^2+y^2+h^2}+y} \cdot \frac{\sqrt{x^2+h^2}}{x}) \\ &+ y \cdot log(\frac{\sqrt{x^2+y^2}+x}{\sqrt{x^2+y^2+h^2}+x} \cdot \frac{\sqrt{y^2+h^2}}{y}) \\ &- h \cdot tan^{-1}\frac{h \cdot \sqrt{x^2+y^2+h^2}}{xy} + \frac{\pi}{2}h] \end{aligned} \quad (3)$$

If a prism is far away from the measuring point, its topographic mass can be considered as condensed into a central line (i.e. line mass). In this case, equation (3) may be simply written as :

$$\Delta g_1 = 4G\rho D_1 D_2 (\frac{1}{d} - \frac{1}{\sqrt{d^2+H^2}}) \quad (4)$$

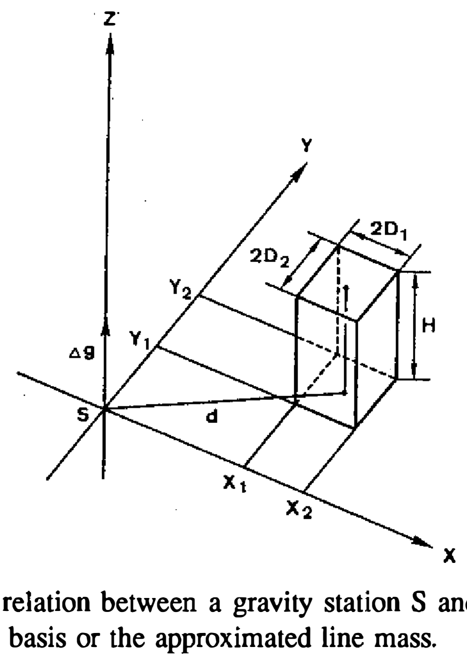

Fig. 3. Geometric relation between a gravity station S and a terrain prism with rectangular basis or the approximated line mass.

where D_1, D_2 and H are the dimensions of the prizm and d is the horizontal distance between station and prizm.

The above two methods will be jointly applied to the terrain corrections in this study. The way of how to treat the methods is based on the topographic data available. We have 1:5000 and 1:10000 scale photomaps, 1:25000 and 1:50000 scale topographic maps. For corrections to the distance of 6.5 km, the Hammer method (Eq.(1)) is used traditionally by a transparent template. Topographic maps of different scales are used for the different zones (Table 1). For the near distance within 25 m, topographic data by in-situ estimation are used since no large-scale map is available. For D zone, we use a 1:5000 or 1:10000 photomap on which the accuracy of elevation is 2.5 or 5 m respectively. The 1:25000 scale topographic map is for E and F zones, while the 1:50000 scale map is for G, H, I and J zones. Their accuracy of elevations are 5 and 10 m respectively. For distances larger than 6.5 km, corrections are calculated by the line mass integral method (Eq.(4)) using an island-wide topographic database. This database was made by the authors from 1:50000 scale topographic maps with 1 km spacing grid. Figure 2 is a plot based on the database.

Table 1. The subdivided zones within the Hammer J zone and the scale of topographic map adopted for each zone.

zones	divisions	inner radius (m)	outer radius (m)	scale
	4-8	0	25	in-situ estimation
D	6	25	170	1/5000 or 1/10000 photomap
E	8	170	390	1/25000 topographic map
F	8	390	895	
G	12	895	1529	1/50000 topographic map
H	12	1529	2615	
I	12	2615	4454	
J	16	4454	6500	

3. OPTIMUM CORRECTION DISTANCE

Theoretically, the distance for both of Bouguer and terrain corections is infinitive. In practice, a finite distance is commonly applied if the corrections beyond this distance can be neglected. However, a question is that what the finite distance is? Danes (1982) emphasized that the distance may vary from area to area, depending on the topographic relief of the area under consideration. He used a distance of 52.6 km for the corrections in the Washington Cascades. In the Central Range of Japan, a distance of 80 km was used by Yamamoto *et al.* (1982). Since about 70% areas of Taiwan are occupied by mountain ranges and more than half of our gravity stations are located in the higher relief topographic areas, this finite distance should be decided very carefully. In principle, our approach is dealt with a trade-off between accuracy and computational time for the corrections to find the distance. We selected six representative gravity stations, including two benchmarks located along the branch of the East-West Cross-Island Highway and four triangular points located in the peak nearby the highway. Their elevations are shown in Figure 4. The Bouguer and terrain corrections (Δg_B

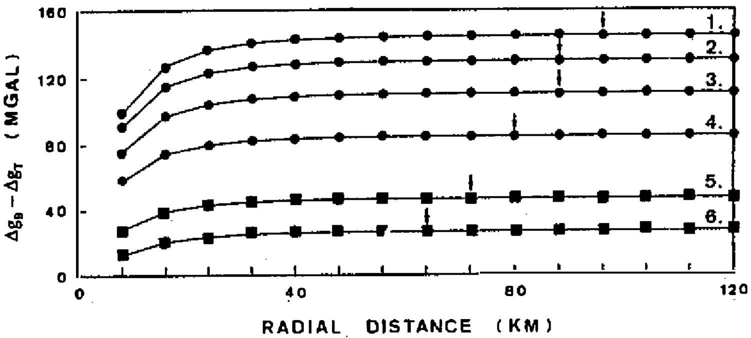

Fig. 4. Differences between Bouguer and terrain corrections(Δg_B-Δg_T) versus the radial distances for the representative stations. (■:Benchmark, •:Triangulation point; 1.Taoshan: 3315m, 2.Yuantochieshan: 2888m, 3.Tochiatunshan: 2703m, 4. Chililoushan: 2492m, 5.Suyuanyakou: 1949 m, 6.Hsiangkuchiao: 1781m)

and Δg_T) for these stations are calculated to a radial distance of 120 km with an increment of 8 km. The method used for calculating terrain correction is as that described in the last section. Since a significant portion of our gravity stations were in mountainous areas, with horizontal dimensions of topography varying from a few kilometers to tens of kilometers, it is obvious that an approach different from the technique of assuming an infinite horizontal slab for the Bouguer correction should be applied. In this study, the Bouguer correction Δg_B is taken as (Turcotte and Schubert, 1982)

$$\Delta g_B = 2\pi G\rho \int_0^h [1 - \frac{y}{\sqrt{(R^2 + h^2)}}]dy \tag{5}$$

where G is the gravitational constant, ρ is the average density, h is the elevation of the gravity station and R is the radius of integration. An average density of 2.57 g/cm^3 is used for the corrections. This density was found for near-surface rocks based on the Free-air gravity data by using the least-squares method (Yen *et al.*, 1990).

Figure 4 shows the differences between Bouguer and terrain corrections (Δg_B-Δg_T) versus the radial distances for the representative stations. In this figure, arrows indicate the distance at which the difference (Δg_B-Δg_T) takes a value less than 1 mgal beyond this distance. In general, the optimum distance depends on the elevation of the gravity station. The differences become less than 1 mgal at a distance of about 100 km in all cases we examined. This suggests that if we take the distance of 100 km, the corrections can be made with a relative accuracy of 1 mgal. Thus, for simplicity, the optimum distance for the corrections in the Taiwan area is set at 100 km.

4. TERRAIN CORRECTIONS OF TAIWAN

In this study, the terrain corrections of all gravity stations in Taiwan are done with an optimum distance of 100 km and an average density of 2.57 g/cm^3. Corrections to the distance of 6.5 km from the stations are calculated by the Hammer method, while the corrections from 6.5 to 100 km are computed by the line mass integral method.

Figure 5 is a contour map of the terrain corrections in the Taiwan area. Corrections of more than half of the areas in Taiwan are larger than 10 mgal. The corrections in the western coastal plain are less than 2 mgal. Higher corrections are in mountainous areas, mostly over 20 mgal. The maximum correction reaches 93 mgal, which is on Yushan, the highest peak (3952 m) in Taiwan. The corrections of some peaks with elevations above 3000 m in the Central Range are larger than 80 mgal. The corrections of stations near Lishan, located in the middle segment of the Central Range, are less than 20 mgal. They are due to less topographic relief in the vicinity of Lishan.

Figure 6 is a plot of the terrain corrections with respect to the station elevations. This figure shows that the terrain corrections seem to be larger when the elevations are higher but they are not in good correlation. This implies that the terrain correction does not depend only on the elevation of the station but also on the topographic relief in the vicinity of the station. The topographic relief may play an important role.

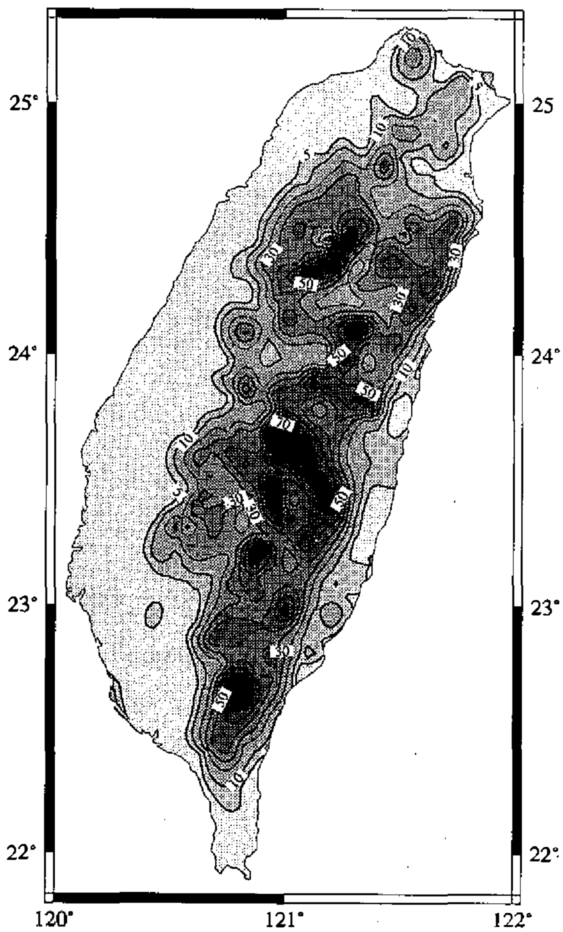

Fig. 5. Contour map of gravity terrain corrections in Taiwan. Contour interval: 5 mgal (correction$\leq$10 mgal), Contour interval: 10 mgal (correction > 10 mgal)

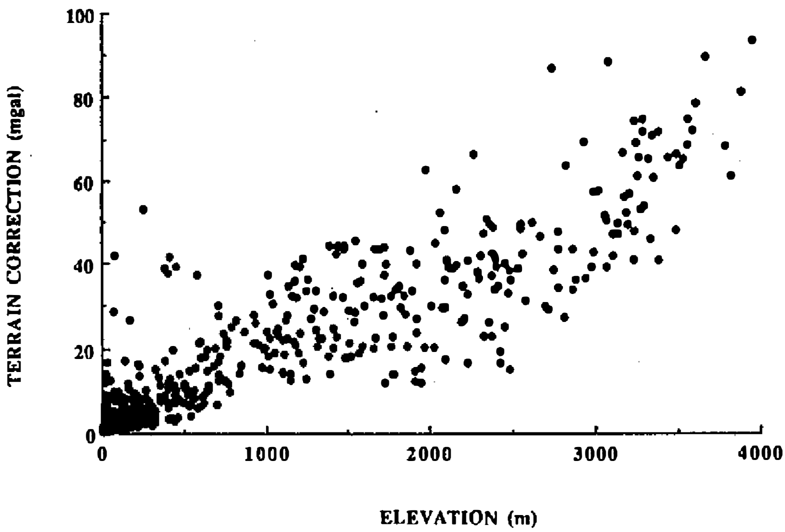

Fig. 6. Plot of terrain corrections with respect to station elevations.

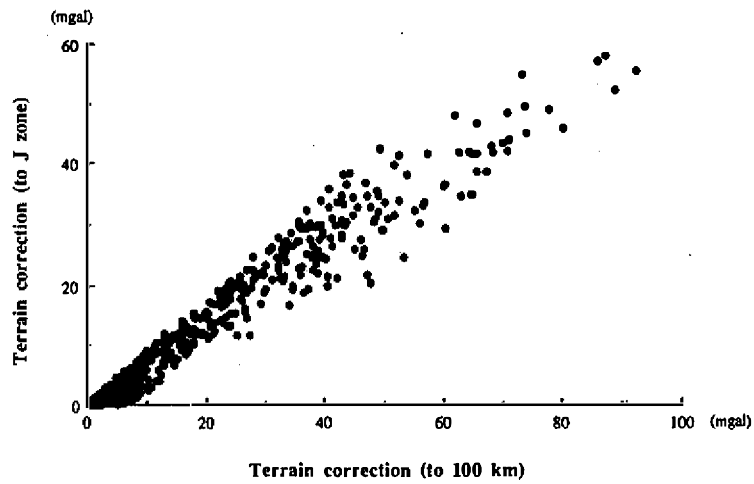

Fig. 7. Relationship between the corrections done to the distance of 6.5 km (to the Hammer J zone) and to the distance of 100 km.

Figure 7 shows the relationship between the corrections done to a distance of 6.5 km (to the Hammer J zone) and to a distance of 100 km. It clearly shows that the contribution to terrain correction comes not only from within the Hammer J zone but also from larger distance. In other words, terrain correction in the Taiwan area for a distance larger than that of the Hammer J zone cannot be neglected.

Terrain corrections of gravity stations which are located along the coast and on the offshore islands of Taiwan are plotted in Figure 8. Correction values along the western coast

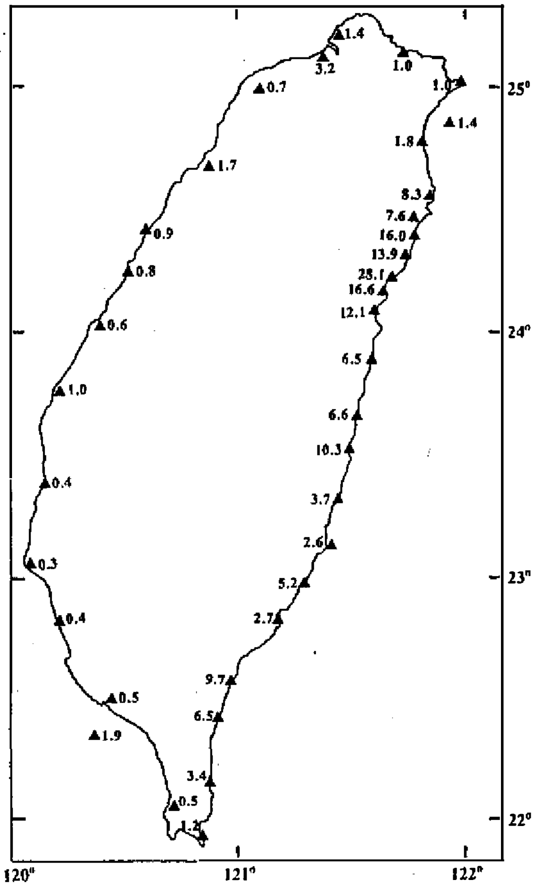

Fig. 8. Terrain corrections at stations along the coasts and offshore islands of Taiwan.

are mostly below 1 mgal. Corrections along the eastern coast are more or less 5 mgal except at few stations along the Su-hua highway. At these stations the corrections are higher than 10 mgal with a maximum value up to 28 mgal at Chingshui, in the southern section of the Su-hua highway. In general, most of terrain corrections along the coast are small. This suggests that the topographic effect may be ignored in marine gravity measurement around Taiwan, except off the coast along the Su-hua highway.

5. CONCLUSIONS

Two methods, the Hammer method and the line mass integral method, are jointly used to compute the terrain corrections for all gravity stations in Taiwan. The corrections are made to a distance of 100 km with an average density of 2.57 g/cm^3. The results show that the corrections of more than half of the areas in Taiwan are larger than 10 mgal. The corrections in the western coastal plain are less than 2 mgal. Higher corrections are in mountainous areas, mostly over 20 mgal. The maximum correction reaches 93 mgal on Yushan. We also conclude that the topographic relief in the vicinity of the station plays an important role for the terrain correction and the topographic effect can be ignored in marine gravity measurement around Taiwan, except off the coast along the Su-hua highway.

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