REPEAT MEASUREMENT OF GRAVITY IN TAIWAN: ANOMALOUS GRAVITY RELATED WITH THE MAY 20, 1986 HUALIEN EARTHQUAKE

By Horng-Yuan Yen, Yih-Hsiung Yeh and Cheng-Horng Lin

ABSTRACT

Repeated microgravity measurements have been made by using a LaCoste-Romberg model D gravimeter along six profiles across active or earthquake faults in Ilan, Hualien, Yuli, Taitung areas in eastern Taiwan and in Meishan, Hsinhua areas in western Taiwan since 1980. Each profile has 6 to 10 stations. The period of repeat measurement is about half year. The measurement is also made when it is necessary. The measurement error of gravity is less than 10 μgal. Conspicuously systematic changes of gravity at certain stations along the Hualien profile had been observed since the beginning of 1985. The magnitude of changes was greater than 100 μgal in March, 1986. These changes may be interpreted as a precursor to the May 20, 1986 Hualien earthquake (M_L 6.5).

INTRODUCTION

Local changes in gravity field can be expected from changes in elevation and the redistribution of mass of earth's crust due to the tectonic stresses. Many examples of gravity changes accompanying both seismic and aseismic deformations have been reported. A gravity increase of 200 μgal was observed at Valdez after the 1964 Alaskan earthquake (Barnes, 1966). During the 1965-1967 Matsushiro, Japan earthquake swarm, gravity variations in the order of 80 μgal were reported (Kisslinger, 1975). A gravity decrease of 30 μgal was measured in conjunction with the uplifting of Izu Peninsula, Japan between 1974 and 1976 (Hagiwara, 1978). The gravity profile along the eastern coast of Izu Peninsula showed significant gravity changes preceding the Kawanazaki earthquake swarm, 1979 and the Izu-Hanto-Toho-Oki earthquake, 1980 (Hagiwara et al., 1980).

Taiwan is located at a complex juncture between the Eurasian and Philippine Sea plates where active collision and subduction are taking place. Such plate-tectonic process results in intense seismicity in Taiwan region (Tsai et al., 1977, 1981). Numerous damaging earthquakes occurred in the past. Some of them caused great losses of life and property (Hsu, 1971; Hsu, 1983; Tsai, 1985; Yeh, 1986). Therefore, high seismicity and dense population in Taiwan area make earthquake prediction a highly worthy research topic. Following one year of planning and preparation, a long-term comprehensive earthquake prediction research program has been undertaken since 1979 through a joint effort between the Institute of Earth Sciences with support of National Science Council and the University of Southern California with support of U.S. Geological Survey. The repeated microgravity survey along profile across known active fault is one of items included in this program (Tsai, et al., 1983). Six profiles across active or earthquake faults in Ilan, Hualien, Yuli, Taitung areas in eastern Taiwan and in Meishan, Hsinhua areas in western Taiwan (Fig. 1) have been chosen since 1980. Each profile has 6 to 10 stations.

In this study, we will describe briefly the survey procedure and discuss the possible gravity change associated with the Hualien earthquake (M_L 6.5) in Taiwan on May 20, 1986.

SURVEY METHOD

The validity of interpretation of gravity data in terms of geophysical processes

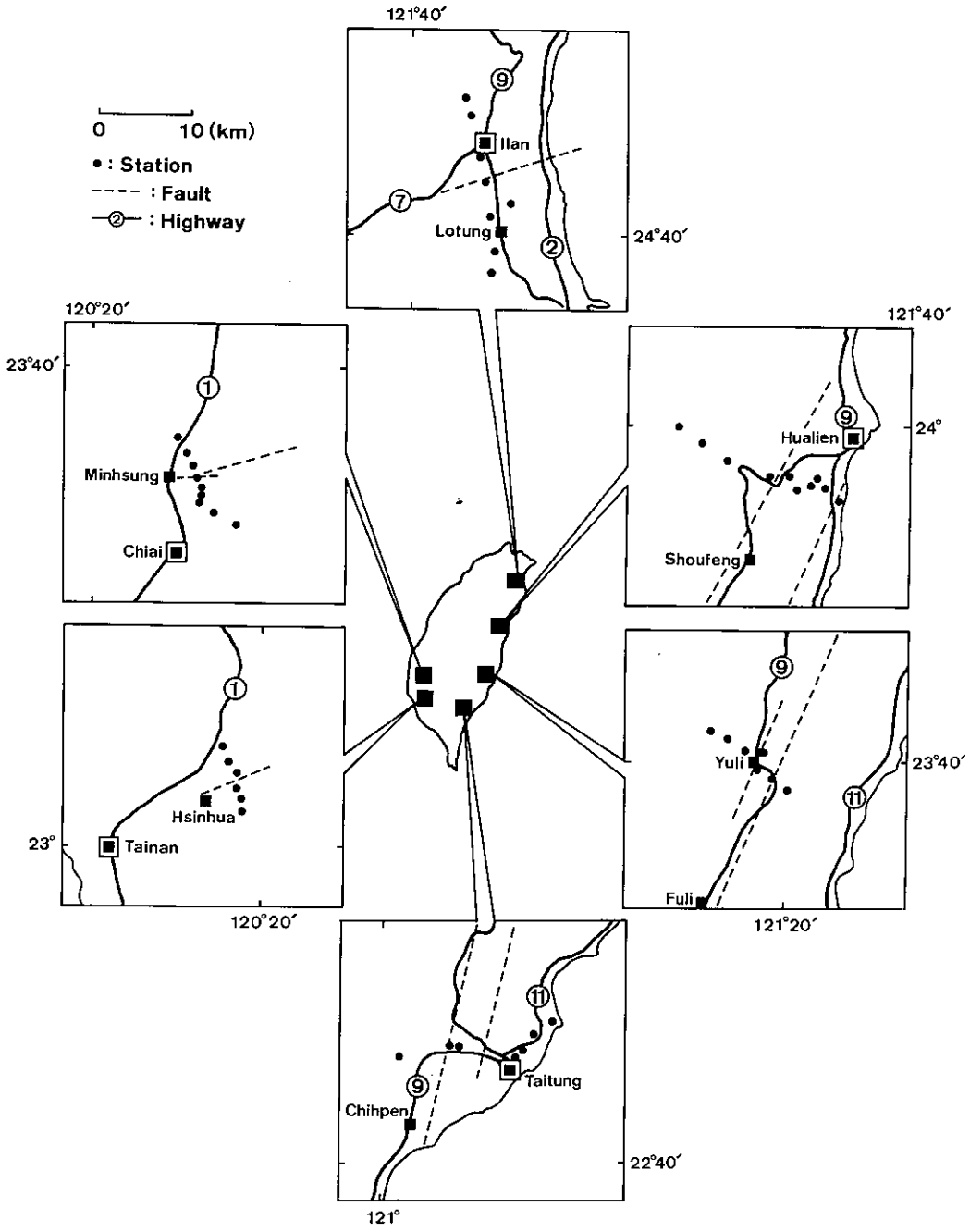


Figure 1. Locations of six repeat measurement profiles of gravity in Taiwan.

at the microgal level depends on a careful assessment of performance of the particular gravimeter used in the survey. The monitoring of gravity variations along the profiles in this study is made by using a LaCoste-Romberg model D microgal gravimeter. The meter has a reading accuracy of 5 μgal. Although the instrument is extremely reliable and trouble free, occasionally minor adjustments may need to be made before the field work. It is a good practice to run a routine level check about once a month under normal usage. Once the meter is checked, it becomes stable and is null easily.

Table 1.
List of gravity differences between two fixed stations for thirty repeated measurements.

(Unit: mgal)

1. 28.116	7. 28.121	13. 28.127	19. 28.143	25. 28.133
2. 28.124	8. 28.134	14. 28.139	20. 28.133	26. 28.124
3. 28.134	9. 28.123	15. 28.129	21. 28.135	27. 28.129
4. 28.134	10. 28.137	16. 28.144	22. 28.137	28. 28.133
5. 28.135	11. 28.138	17. 28.134	23. 28.133	29. 28.119
6. 28.134	12. 28.125	18. 28.148	24. 28.137	30. 28.132

Mean value = 28.132 mgal. Standard deviation = 0.007 mgal.

To achieve survey precision approaching the resolution capability of the instrument and to minimize systematic errors, the following rigorous field procedures are employed in this study.

First, gravity stations along the profiles are carefully chosen to provide stable, noise-free, permanent and easily accessible for instrument disc. All stations in our study are located at benchmarks which are made of granite or concrete materials, or at bases of stable buildings.

Second, the meter is set up as follows at each station to minimize substantial errors. The legs of instrument are placed into the fitted holes which are punched on the levelling disc. This can avoid the high frequency vibration possibly caused by road traffic or the motion of trees nearby. To confirm the meter always at the same elevation above the disc, a certain leg of instrument is kept at the same length. Thus, the levelling of meter is adjusted by other two legs.

Third, the measurement is done as follows. The dial range of instrument is set as same as possible at a fixed station of each profile in every repeat survey. A measurement sequence of A-B-A-B-A, B-C-B-C-B, and so on is adopted. Each loop is completed within an hour. The gravity difference between two adjacent stations is measured twice in each survey. If the variation of these two differences is greater than 10 μgal, another measurement or more will be made until a reasonable mean difference is obtained. Before taking the readings, the springs of meter should be relaxed for about 5 minutes after unclamping. The measurements are required to have the same of three consecutive readings within a short-time at a station. It is noted that the instrument can not be struck by sunlight directly. The reason is the sunlight may affect the levelling bubbles.

In order to understand the measurement accuracy in our survey, the meter had been used to measure the gravity difference repeatedly between two stations which are selected under the criteria mentioned above. Table 1 is a list of gravity differences between the two stations for thirty repeated measurements. The mean value and standard deviation are 28.132 mgal and 7 μgal respectively. Thus, we may conclude that the measurement error is less than 10 μgal in this study.

Normally, the measurement is made repeatedly in a period of half year. The measurement is also made when it is necessary.

GRAVITY CHANGES ASSOCIATED WITH THE MAY, 1986 HUALIEN EARTHQUAKE

Figure 2 is the result of repeat measurement of gravity along the profile in Hualien area. The horizontal axis represents the distance between adjacent stations.

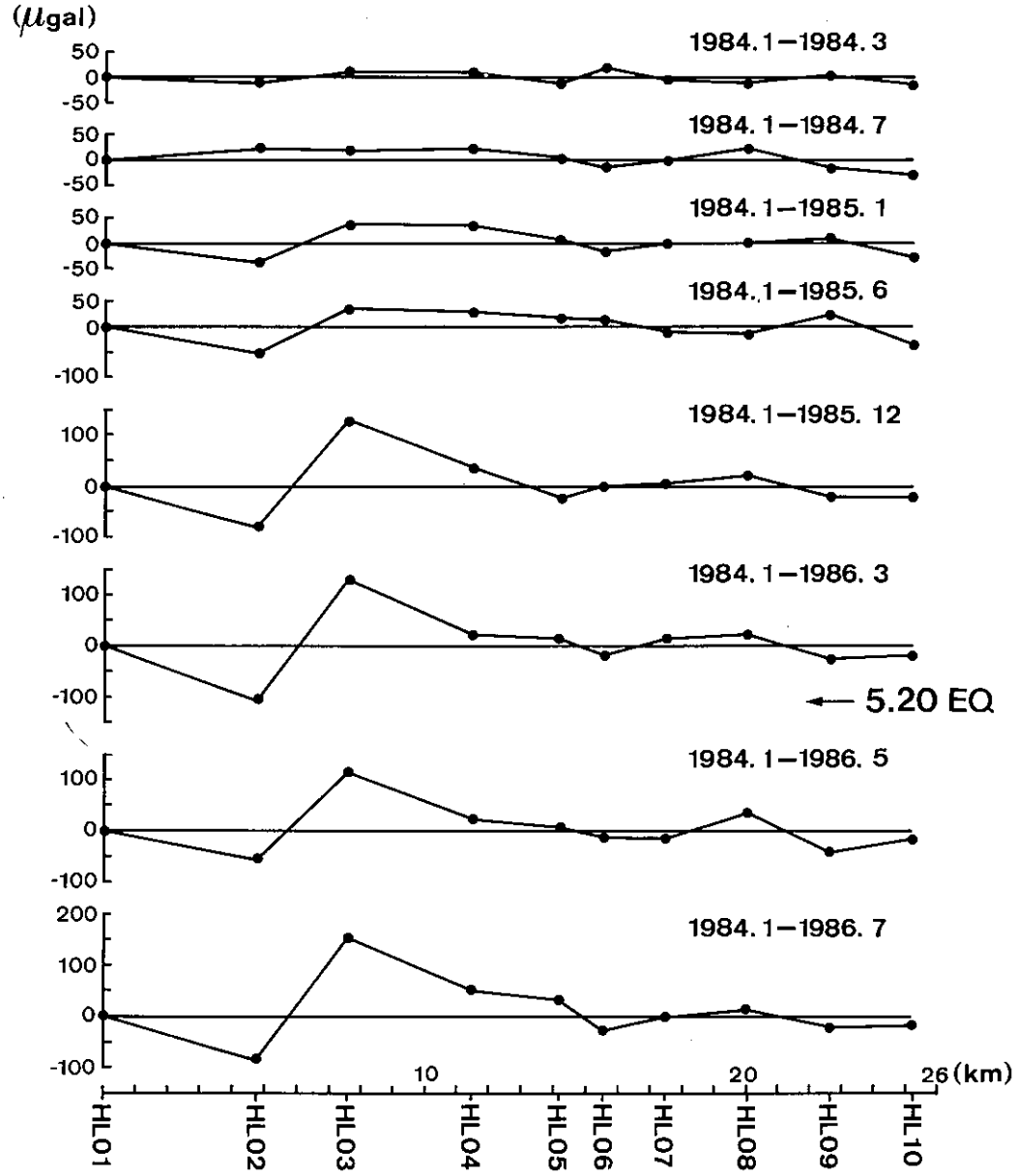


Figure 2. Result of repeat measurement of gravity along the profile in Hualien area. The horizontal axis represents the distance between adjacent stations. The vertical axis represents the observed gravity difference, with respect to the difference measured in January 1984, between two adjacent stations.

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This figure reveals that the gravity differences between stations HL01 and HL02 (hereafter referred to as G12) and between HL02 and HL03 (hereafter referred to as G23) have shown systematic decrease and increase, respectively, since the beginning of 1985. There were no significant gravity changes observed at other stations. The values of G12 and G23 are −108 μgal and +129 μgal, respectively, in March, 1986. These conspicuous variations which are more than 10 times the measurement error should be meaningful. On May 20, 1986, a moderate earthquake (M_L 6.5) occurred at about 15 km north to the profile (Fig. 3). Chen and Wang

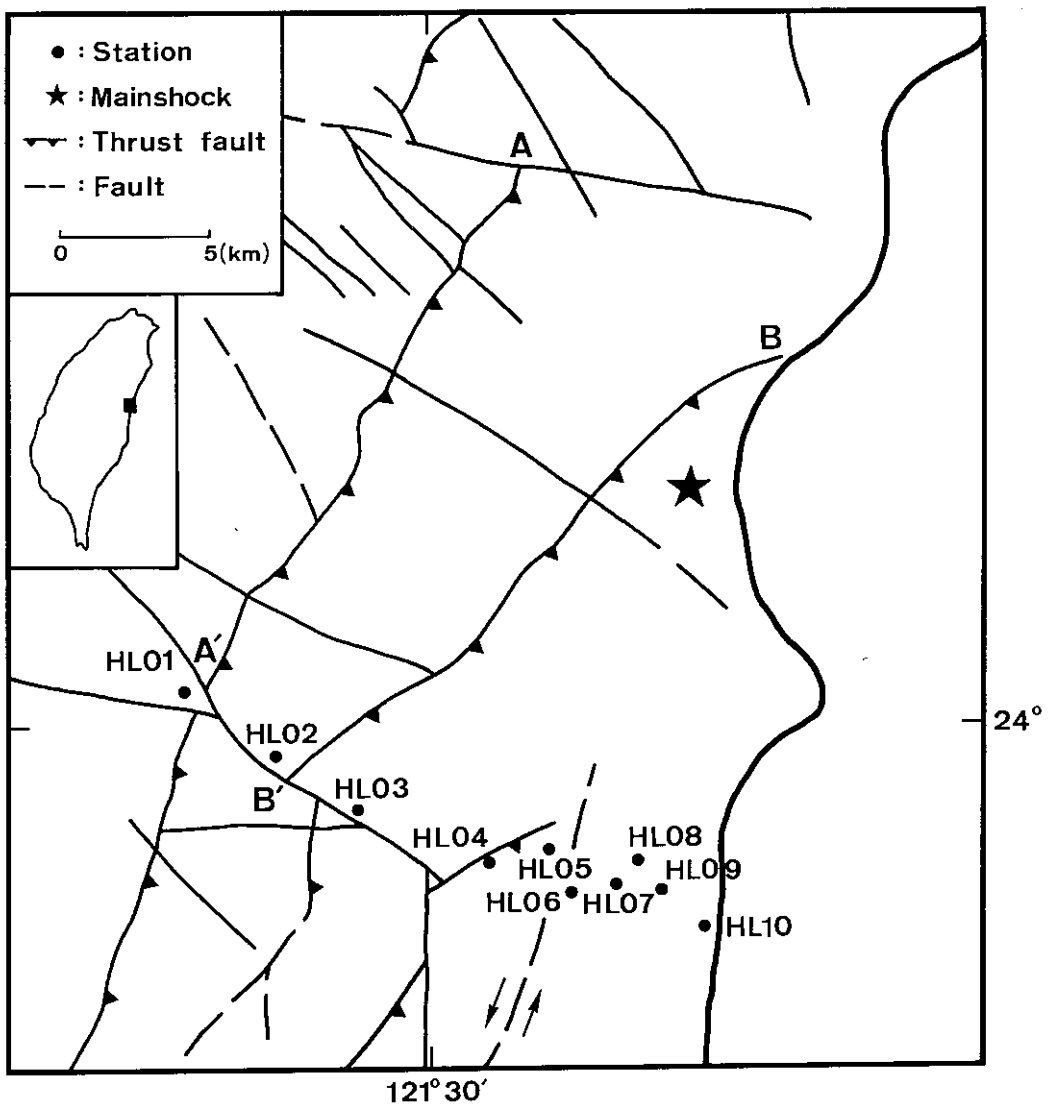


Figure 3. Locations of stations along the gravity profile in Hualien area and epicenter of the May, 1986 Hualien earthquake. And the fault traces recognized from radar imagery.

(1986) studied the earthquake and its aftershocks. They concluded that the seismicity was closely related to the two faults, namely AA′ and BB′ in Fig. 3, recognized from the radar imagery (MRSO, 1982). The mainshock and the largest aftershock were associated with the fault AA′ which is a thrust type with a dipping angle of 60° to southeast. The aftershocks associated with the fault BB′ were triggered essentially by the mainshock. Fault BB′ is also a thrust type with a dipping angle of 65° to southeast. Three of gravity stations, namely HL01, HL02 and HL03, are close to these two faults. And the conspicuous gravity changes were only found among these three stations. There had no obvious gravity changes at other stations. It may be suggested that the gravity changes are associated with the earthquake. However, the senses of decrease and increase in gravity were not corresponding to those of elevation changes which may be caused by the fault motion. We believed that these gravity changes were mainly from the redistribution of mass of earth's crust in this area

due to the tectonic stresses. In other words, they were related to the distribution of stress field in the area.

Right after the occurrence of mainshock, we went to Hualien with instrument. We made the gravity measurement along the profile next day. An increase of 52 μgal in G12 and a decrease of 16 μgal in G23 were observed. These changes may be due to elevation changes after the fault motion. The southeast side of the fault was uplifted, while the northwest side was subsided. We did not find significant gravity changes at other stations.

After two months of the earthquake, we made another measurement. G12 decreased about 30 μgal and G23 increased about 38 μgal. The other stations still had no significant changes. It may be explained that the faults began to accumulate the strain energy again. We will continue to make the gravity measurement repeatedly. The survey route will be extended westwardly. Thus, more conclusive relationship between gravity change and earthquake activity may be obtained in the future.

SUMMARY AND CONCLUSIONS

The repeated microgravity measurement along profile across known active fault is one of the items included in the earthquake prediction research program in Taiwan. Six profiles in Ilan, Hualien, Yuli, Taitung areas in eastern Taiwan and in Meishan, Hsinhua areas in western Taiwan have been chosen since 1980. Each profile has six to ten stations. The measurement is made repeatedly in a period of half year. The measurement is also made when it is necessary. A rigorous field procedure of measurement is employed in this study. It includes selection of stations, calibration and setting up of the instrument, and measurement of gravity. The measurement error of gravity is less than 10 μgal.

In the Hualien profile, conspicuously systematic decrease and increase of relative gravity between certain stations have been observed since the beginning of 1985. The values of G12 and G23 were −108 μgal and +129 μgal, respectively, in March, 1986. These gravity changes were more than 10 times the measurement error. We believed that these changes were related to the May 20, 1986 Hualien earthquake (M_L 6.5). The changes were mainly from the redistribution of mass of earth's crust in this area due to the tectonic stresses. After the earthquake, an increase of 52 μgal in G12 and a decrease of 16 μgal in G23 were observed. These changes may be due to elevation changes after the earthquake. The gravity data of two months after the earthquake revealed that the faults began to accumulate the strain energy again. More conclusive relationship between gravity change and earthquake activity may be obtained in the future by means of repeated measurement.

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Institute of Earth Sciences
Academia Sinica
P.O. Box 23-59
Taipei, Taiwan
Republic of China

台灣重力重複觀測：與民國七十五年五月二十日花蓮地震相關之重力變化

顏宏元　葉義雄　林正洪

摘　要

自1980年起，中央研究院地球科學研究所於台灣東部的宜蘭、花蓮、玉里和台東及台灣西部的梅山、新化等六個地區，各別選定一條橫跨斷層之重力測線，利用 La Coste-Romberg D 型微重力儀進行重複性的精密重力觀測。每一條測線分別有 6 至10個不等之測站。原則上大約每半年重複觀測一次，在實際情況需要時，亦實施額外觀測。觀測誤差小於10毫伽。目前的結果顯示花蓮測線西邊三個測站之相對重力值，自民國七十四年起呈現顯著而規則性的變化，至七十五年三月，其改變量超過 100 毫伽。這些重力變化可能是五月二十日花蓮地震（M_L6.5）的一項前兆。