

A MODEL OF GROUND STRUCTURE TO ESTIMAGE EARTHQUAKE GROUND MOTIONS AROUND HSINCHU CITY, TAIWAN ON THE BASIS OF GRAVITY AND MICROTREMOR SURVEYS

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ABSTRACT:

To estimate the three-dimensional ground structure over a large area, the combination of gravity and microtremor surveys are useful and can provide good information without much cost. We applied these survey techniques to the area around Hsinchu, Taiwan, where is one of most important industrial area in Taiwan, to provide a basic information for earthquake disaster mitigation.

For this, the gravity and microtoremor surveys have been carried out in the target area. Observations of gravity at 393 sites was done and the structure with some different scales are found from the Bouguer anomaly. The trend of the Bouguer anomaly is independent of the topography and some localized structures are observed. Furthermore, shallow structures were estimated from microtoremor data of array observation at some sites.

As a result, the depth to bedrock is steeply variated from north-western to south-eastern area. The shape of the surface of bedrock represents the good agreement with the known geological information such as faults, anti- and syncline, and so on.

KEYWORDS: gravity survey, microtremor surbey, subsurface structure, bedrock, Hsinchu

1. INTRODUCTION

To estimate the earthquake ground motions, it is very important to know the ground structure, especially, deep and three-dimensional structure, because the ground motions excited by a large earthquake predominate components with long period which relates to the deep structure. For this purpose, we have many kinds of technique for the geological survey, though some of them may be costly. The microtremor and gravity survey are easy to conduct the survey and not so expensive techniques. Thus, for estimating the three-dimensional ground structure over a large area, these techniques are useful and provide good information without much cost. Especially, the gravity survey is suitable for the survey of very large area and can provide detailed configuration of bedrock, because of the easy operation by means of the automatic gravimeter and GPS (global positioning system).

However, since the Bouguer anomaly depends on the density structure, it is difficult sometimes to determine the velocity structure from it. To obtain the velocity structure, we can use information from the microtremor survey, because phase velocities obtained from microtremor array observation reflect the velocity structure directly.

The geological setting of Taiwan is really complicated because there is the boundary between the Eurasia and Philippine plates and we can find so many active faults in the Taiwan island. This means that the seismic activity is very high in Taiwan. Under this circumstance, we focus the target for our survey on Hsinchu city, Taiwan, where many industrial factories, especially for IT, computer, semiconductor companies are located. We, therefore, may





Hscinchu is represented in the map as "新竹."

Figure 1 Location of Hsinchu city. Figure 2 Topographical map around Hsinchu city. Horizontal and vertical coordinates show the longitude and latitude, respectively. In this map, \times stands for the observation sites of gravity, \bigcirc for the control points which are used for the calculation of the gravity basement, the rectangular frame for the area of the analysis.

say that Hsinchu area should be key for the Taiwanese economy.

From this, it is very important to know the ground structure and to estimate some strong ground motions in this area. As a first step to estimate earthquake ground motion for earthquake disaster mitigation, we will try to make a preliminary model of three-dimensional shape of the surface for the bedrock which is defined, hereafter, as hard rock.

2. GEOLOGICAL SETTINGS AROUND HSINCHU CITY, TAIWAN

Hsinchu city is located at the north-western area of Taiwan as shown in Figure 1. The altitude of north-western part is very low and the south-eastern part is very high such as more than 1000m. The topographical map is shown in Figure 2. Furthermore, we can find many faults around Hsinchu city as shown in Figure 3. In the southern part of Hsinchu city, anticline and syncline, whose directions are north-eastern to south-western, are found and the fault is recognized between them. The Hsincheng fault is considered as an active fault and it is key issue to consider mitigation of the earthquake disaster. Furthermore, we can see the similar structure in the northern part of Hsinchu city, which includes the anti- and syncline structure with Hsinchu fault.

As shown in the previous section, a part of Hsinchu city is called "science park" and there are many companies and research centers for high technology in this area. From this, Hsinchu city is called "Silicon Valley of Taiwan" and very important city of the Taiwanese economy. We hope the basic observation and research for the estimation of earthquake ground motion will help the provision against the future earthquake.

Some pioneering studies are available for the ground structure around Hsinchu from the geological points of view. These studies are summarized as "report on the ground structure of Hsinchu district" by Shu-Fan (2006), however the authors could not follow the detailed references and original sources. Thus, we introduce some important points from the report by Shu-Fan (2006).

Gravity survey in Taiwan has been carried out, and especially, dense and accurate observations are done in the last decade. Thus, the reliable Bouguer anomaly map is available as shown in Figure 4 by Yeh and Yen (1992). The details around Hsinchu city is shown in Figure 5. Furthermore, using the information of the gravity anomaly, the density structure is proposed as shown in Figure 6.

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Figure 4 Bouguer anomaly map of Taiwan (Shu-Fan, 2006)



地表密度 地下密度 潘 谢兴明 代 平 本研究 地 層 (1965 1972) 台地堆積 ____ 1.85 _____ 红土台地堆積 1.90 更新世 大南渭層 1.95 90~2.00 上 部 上新一更新世 崩料山層 2.09 2.10 下部 卓 鮪 層 2.30 2.20 上新世 錦水頁岩 2.35 2.30 桂竹林層 2.45 2.40 上福基砂岩 2.40 南莊層 2.54 河排層 2.40 2.55 南港層 中新世 石底層 2.56 大寮層 2.57 木山層 2.60

Fan, 2006)

Figure 5 Bouguer anomaly map around Hsinchu city (Shu- Figure 6 Examples of the available density structure (Shu-Fan, 2006). The right column is obtained by the results of a research in 1975.

From these figures, the peculiar low anomaly of gravity is found in the southern part of Hsinchu city. They consider existence of the oil around this low anomaly area, and carried out many kinds of survey to know the ground structure including the deep borehole and dense gravity survey. Unfortunately, in this area, there is no oil, but we can see the geological profiles along some lines. Figures 7 and 8 are examples. Although these maps might be made by considering the gravity anomaly, the authors have no information about the detailed processes to make the profiles.

Many kinds of survey have been carried out, however, the detailed information of the available geological data is not so clear. This means that they cannot provide enough information to make the model of ground structure for the estimation of earthquake ground motions. Of course, we use the available information at a maximum, but we carry out the gravity survey to be suitable for our objective.

Figure 3 Faults and geological system around Hsinchu city

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Figure 7 The SSW-NNE section of Hsinchu and loca- Figure 8 The S-N section of Hsinchu and location of tion of control point (CHL1) (adding some information control point (CHL10) (adding some information to the to the figure of Shu-Fan (2006)).



Figure 9 Observation system for the gravity. GPS receiver and its antenna on the tripod, and Burris automatic gravity meter below them.



figure of Shu-Fan (2006)).



Figure 10 Bouguer anomaly map (assumed density: 2.1 t/m^3)

3. OBSERVATIONS AND RESULTS

3.1. Gravity Survey

To obtain the three-dimensional ground structure at Hsinchu city accurately, we have carried out the measurements of gravity around the surrounding area, which includes many towns in Hsinchu County: $24^{\circ}39'N - 24^{\circ}55'N x$ 120°50'E - 121°12'E; 30 km NS x 40 km EW. We observed gravity at 393 sites during 20 days of September 7th to 28th, 2006. The averaged distances among close sites are about 1 km. The location of observation sites are shown in Figure 2.

For the observation, we used the Burris automatic gravity meter by ZLS Corporation and Type G Gravimeter by LaCoste & Romberg and applied the technique of relative observation. To determine the position of the observation site accurately, the differential survey using the GPS (Global Positioning System) is performed. As a result, the error of the position is less than 1m. The observation system are shown in Figure 9.

To apply the technique of relative observation, firstly, we set a reference site with absolute gravity value in Hsinchu city through the comparison between our reference site and the official gravity base site in Hsinchu area. Then,







Figure 12 An example of sensor layout for array observation and system.

using the reference site, we carried out the relative observations of gravity and the absolute values of the gravity were determined at each site.

3.2. Bouguer Anomaly

We analyze the data with the existent gravity data, which were obtained at more than 60 sites in this area. We apply the data at 453 sites to calculate the Bouguer anomaly except for a few inaccurate data.

After some data correction such as corrections for height of the instrument, tide, drift, terrain, free-air, and Bouguer correction, the Bouguer anomaly can be obtained. For the Bouguer correction, we have to give a value of the assumed density ρ . For this purpose, some methods are proposed such as the G-H correlation method (Komazawa, 1998), and a method to check the correlation between the Bouguer anomaly map and topography (Komazawa, 1998). We apply the latter technique and determine ρ as 2.3 t/m³.

The obtained Bouguer anomaly map is shown in Figure 10. From this figure, we can say the follows:

- The Bouguer anomaly in the target area is negative and the negative anomaly increases from north-west to south-east. This trend is independent of the topography of the hilly area. However, this trend agrees with the peculiar low anomaly as shown in Figure 5.
- Around the south-eastern area of the Hsinchu city, minimum value of the Bouguer anomaly is found. This minimum value seems to correspond to the local minimum which is shown in the Bouguer anomaly map for whole Taiwan island of Figure 4.
- For most parts of south-eastern area, steep change of Bouguer anomaly is observed. This suggests that the existence of steep slope of the bedrock in this area.

3.3. Microtremor Survey

To determine the velocity structure, we carried out array observations of microtremors at 10 sites around Hsinchu city, where are shown in Figure 11. For this observation, we used Force-balanced-type accelerometers and digital recorder with 24-bit resolution $\Delta\Sigma$ A/D converter, which include an analog gained filter and GPS clock system. The time is synchronized by this clock and data is recorded by sampling rate 800 cps after passing the low pass filter with cut off frequency of 30 Hz.

The setting of the sensors and the observation system are shown in Figure 12. Radii of the arrays are 3 m to 800 m and the radii depend on the sites. Unfortunately, the response sensitivities of the sensors are not enough to observe







Figure 13 Examples of estimated phase veloci-17 and 35 m at TKS.

ties. Array radii are 6, 19, and 38 m at RKS and Figure 14 Residual gravity map (blued contour line represents positive and red negative anomaly).

the microtremors in long period range. We applied the spatial auto-correlation (SPAC) method (Matsushima, 1990) and estimated the phase velocities. Figure 13 shows a part of the results.

4. DISCUSSION

4.1. Comparison with the Known Structure

We can discuss the shallow structure with the residual gravity map. Thus, we show the residual gravity with the anti- and syncline in the target area as shown in Figure 14. From this figure it can be recognized the good correspondence of the geological structure and the residual anomaly. This means that the obtained gravity anomaly can explain the geological sytem.

4.2. Gravity Basement

Using the technique by Komazawa (1995), we estimate a 3-D gravity basement under the assumption that the ground consists of two layers, which are homogeneous sediment and basement with density of 2.1 and 2.4 t/m^3 , respectively.

To obtain a realistic model of gravity basement, we consider the follows: to remove the contribution for the Bouguer anomaly from the deep structure such as upper mantle and to constrain the depth to the basement using some other information. For the former, a band-pass filter (50 to 5000 m) is applied to the Bouguer anomaly. For the latter, we give some control points in Figure 2: that is, deep borehole sites CHL-1, STP-1, CTH-10, FP-3, and R-1 of Figure 3, which reach to the basement. The basement appear on the surface at the south control point in Figure 2. The boundary of sediments and basement is set at the surface of Kueichulin Form on the basis of Figure 6.

The 3-D shape of the gravity basement is shown in Figure 15. From Figure 15, depth of the gravity basement reaches to about 3000 m in the south-eastern area and about 1500m around the downtown of Hsinchu City. Steep slopes of the gravity basement are observed around the southern area of Hsinchu City, whose location corresponds to the known fault; Hsinchu and Hsincheng faults. However, the depth to basement around downtown of Hsinchu City is too deep compareing some available shallow borehole data.

Thus, we consider another layer with slightly lower density than basement. The density of this added layer is set as 2.25 t/m^3 and it corresponds to Chinshui and Cholan Form. To obtain three-layered model, we apply the technique by Takahashi (2008) and give the control points which are same as the two-layerd case. In this case, the boundaries of the layer are assumed as the surfaces of Cholan and Kueichulin Form.

Obtained density model is shown in Figure 16, where the upper panel shows the upper boundary of Cholan Form





Figure 16 Altitude of the upper surface of middle layer with density of 2.25 t/m³ and basement with 2.4 t/m³.

with density of 2.25 t/m^3 and lower panel is the upper boundary of basement (Kueichunlin Form with 2.4 t/m^3). From this figure, depth to the middle layer is very shallow around western coast and downtown of Hsinchu city. On the other hand, the depth to the basement is very deeper than two-layerd model around the low anomaly area of south-eastern part.

4.3. Velocity Structure

In this time, it is very difficult to discuss the deep velocity structure because of less information of phase velocity in long period range. However, it is observed that the phase velocities around lower gravity anomaly are slower than ones around heigher gravity anomaly. In the future development, we will discuss the relationships between the velocity and density structure in this area.



5. CONCLUSIONS

We have carried out the gravity observation at 393 sites and array observation of microtremor at 10 sites around Hsinchu area, Taiwan. Using this data, we estimated the Bouguer anomaly and phase velocities. Furthermore we estimate the gravity basement around this area. From this, we can say that the three-dimensional structure is very complicated: some different scales of structure are found. The results from this research is listed as follows:

- The density around Hsinchu area is estimated as 2.4 t/m^3 for basement and 2.1 t/m^3 and 2.25 t/m^3 for sediment.
- Negative Bouguer anomaly is found and the absolute value of anomaly increases from north-west to southeast. This trend can be seen in the shape of the gravity basement.
- To explain the very low Bouguer anomaly around south-eastern area, we introduce three-layerd density model. As a result, the depth to the middle layer is very shallow around the downtown of Hsinchu city.
- The depth to the middle layer is 200 m around Hsinchu city and 1200 m in the south-eastern area. The shape of the gravity basement is very complicated but it corresponds to the geological information such as antiand syncline and some known faults.

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REFERENCES

- Komazawa, M. (1995). Gravimetric Analysis of Aso Volcano and its Interpretation, J. Geod. Soc. Japan, 41, 17–45.
- Komazawa, M. (1998). Gravity survey, *Handbook of Exploration Geophysics*, **4**, Society of Exploration Geophysicists of Japan, 433–468.
- Matsushima, T. and Okada, H. (1990). Determination of Deep Geological Structures under Urban Areas using Long-Period Microtremors, *Butsuri-Tansa*, **43**, 21–33.
- Shu-Fan (2006). Report on the ground structure around Hsinchu district, through the personal communication with Prof. Yen of *Central University (NCU)*, *Chinese Taiwan*.
- Takahashi, C. (2008). Takahashi, C., A Method to Detect a Vertical Boundary of Density Structure using Gravity and Magnetic Data, *Master Thesis*, Department of Built Environment, Tokyo Institute of Technology.