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DETERMINATION OF BEDROCK STRUCTURE OF TOTTORI PLAIN USING SEISMIC EXPLOSION, MICROTREMOR AND GRAVITY SURVEY

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SUMMARY

Seismic explosion survey, Microtremor observations and a gravity survey were made to determine the subsurface structures of the Tottori Plain. This area was severely damaged during the 1943 Tottori earthquake (M7.2), damage being concentrated in the plain. The microtremor data were analyzed by the spatial auto correlation (SPAC) method. The subsurface structures were determined by 1) S-wave velocity structure models obtained at the array observation sites, 2) a 2D bedrock configuration based on the residual gravity anomaly and travel time, 3) a 3D bedrock configuration based on the horizontal-to-vertical spectral ratio and the residual gravity anomaly. The bedrock suddenly deepens from the eastern mountainous area to the plain. A shallow bedrock area extends over a belt-like zone along the coast. The depth to the Vs=2500m/s layer ranges from about 100m minimum to about 400m maximum.

INTRODUCTION

The Tottori plain in the Sanin area of Japan, the target area of this study, was severely damaged by the 1943 Tottori earthquake (M7.2). The Tottori plain, the target area for this study, is an important factor for the prevention or mitigation of earthquake disasters. The severely damaged area was concentrated on the Tottori plain (Architectural Institute of Japan, 1944), whereas there was less damage in the western and southern parts of Tottori City. This concentration of damage is thought to have been caused by the characteristics of the earthquake strong motion affected by the local subsurface structure of the Tottori plain. The observations of microtremor and gravity have been carried out in this area.

The purpose of our study was to determine the subsurface and bedrock structures of the Tottori plain by the use of seismic explosion survey, microtremor and gravity observation records.

OBSERVATIONS

The observations of microtremor and gravity have been carried out in this area (Noguchi and Nishida, 2002). Overviews of the observation are explained with the study of Noguchi and Nishida (2002).

3-component single-site observations at 19 sites and array observations at 410 points were observed microtremors in the Tottori plain. A 3-component seismometer (T_0=5s) was used in the single site

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observation system. The array observation system consisted of four vertical seismometers (T_0=1s or 8s), an amplifier, and a data-recorder.

Gravity observations at about 1100 points were observed in the Tottori plain and peripheral mountains. A Racoste Lon Berg's G type gravimeter was used. The precision of the altitude measurements was kept within 1m.

Seismic explorations were carried out on 2 sections (east - west measurement lines) and 1 section (north - south measurement line). The observation points were distributed regularly with a 500m interval. And the numbers of observation points were 11on A-Line, 7 on B-Line and 19 on C-Line. We used the source of Research Group for Seismic Expedition in SW Japan as an explosion source. The sampling frequency was set to 100Hz, and the time was synchronized with a GPS clock.

Locations of the observation points are shown in Fig. 1.

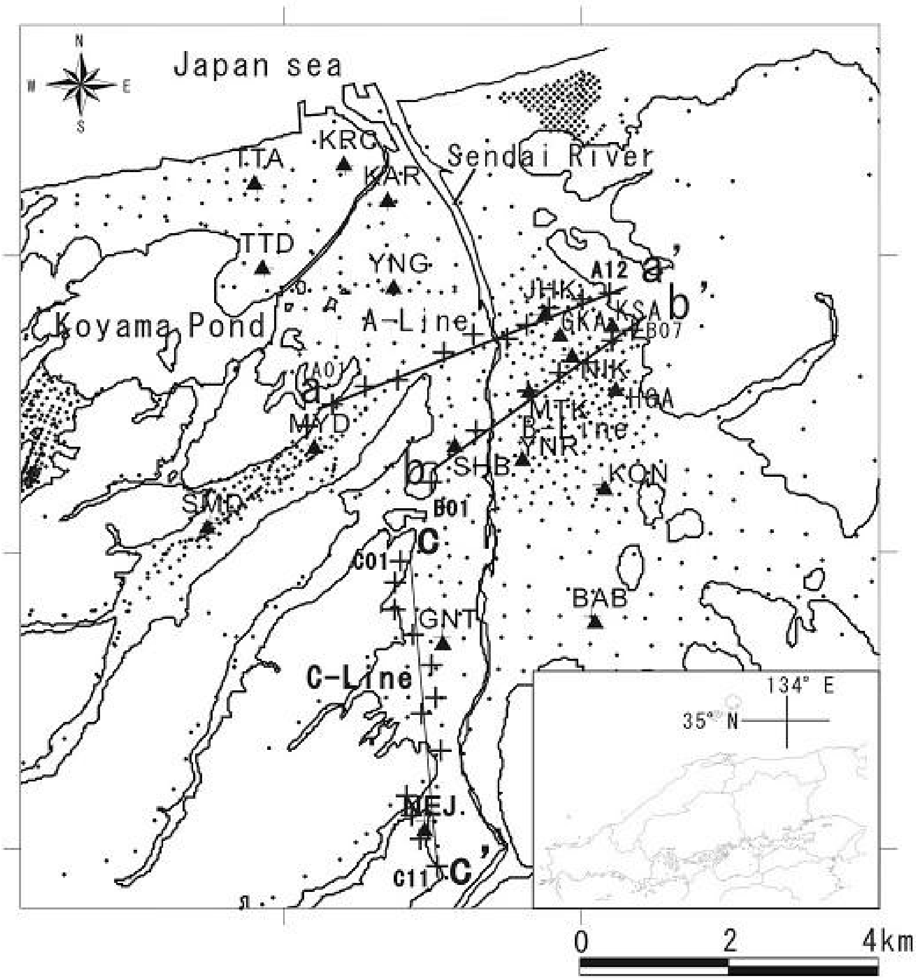

Fig.1 Locations of observation sites. Small circles: gravity observation sites, and triangles: array observation sites, (+): Artificial earthquake.

DETERMINATIONS OF UNDERGROUND STRUCTURES

Determination of Subsurface Structure Using Microtremors

Horizontal-to-vertical ratio (H/V) was calculated by use of using the averaged Fourier spectra of the selected data. A contour map of the peak periods of H/V is shown in Fig. 2.

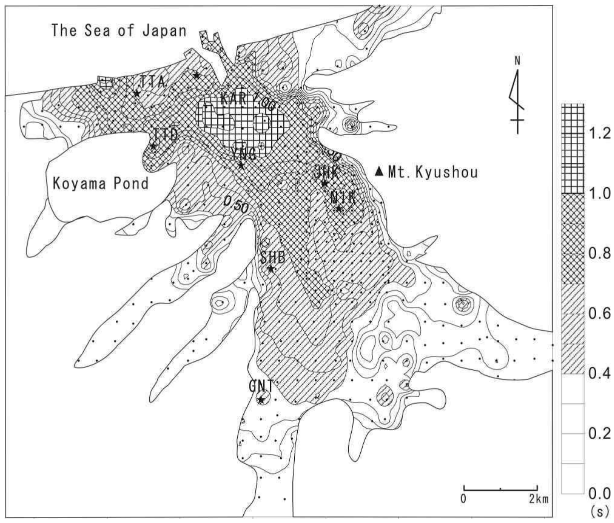

Fig.2 Contour map of the H/V peak period. The contour interval is 0.1s. Small circles; microtremor single-site observation sites, stars; array observation sites.

The dispersion curve of the phase velocity was calculated by the SPAC method (Aki, 1957). Parameters (number of layers, density, P-wave velocity; [Vp] S-wave velocity; [Vs]) of the subsurface structure models are shown in Table 1. Vp was found by the formula Vp=1.11Vs+1290(m/s) (Kitsunezaki et al., 1990). By holding Vs, Vp and densities value and changing only the layer thickness, a subsurface model could be determined by trial and error. The final subsurface structure model is shown in Table 2.

Table 1 Parameters for determination of the subsurface structural models at the microtremor array observation sites.

Density (g/cm^3)	Vp (m/s)	Vs (m/s)	Geological Age	Geology
1.6	1400	100	Quaternary	Alluvium & Diluvium
	1460	150		
1.7	1510	200		
1.8	1730	300		
2.0	1840	500		
2.1	2060	700	Neogene	small consolidation
2.2	2940	1500		large consolidation
2.4	4070	2500	Paleogene & Cretaceous	Granite, Mesozoic Volcanic Rocks

Table 2 Final subsurface structure models at the microtremor array observation sites.

ρ (t/m³)	Vp (m/s)	Vs (m/s)	Thickness (m)								
			JHK	NIK	MTA	YNR	KON	KSA	HGA	GKA	KRC
1.6 ~ 1.8	1400 ~ 1620	100 ~ 300	30	26	16	27	12	19	22	28	47
1.9	1850	500	50	40	40	50	55	30	80	40	15
2.1	2070	700	100	90	90	100	100	100	120	100	80
2.2	2960	1500	150	150	150	150	150	150	150	150	100
2.4	4070	2500	∞	∞	∞	∞	∞	∞	∞	∞	∞

Thickness (m)									
TTA	TTD	KAR	YNG	SHB	GNT	BAB	SMD	MYD	NEJ
29	58	60	33	37	20	10	37	20	-
20	20	50	20	20	10	30	20	10	50
50	40	80	100	80	80	80	80	70	-
100	100	150	150	100	100	100	100	100	25
∞	∞	∞	∞	∞	∞	∞	∞	∞	∞

Determination of 2D Bedrock Structure Using Gravity Anomalies

Terrain correction was made with a topographic 50m mesh and a 250m mesh digital data to obtain the Bouguer anomaly. Density measurement results for rock samples (NEDO, 1977) and CVUR method (Komazawa, 1995) were used to determine a suitable density. Program codes of a 2D or 3D analysis method by Komazawa (Komazawa, 1995) were used to determine 2D or 3D density structures.

The 2D density structure models in 3 lines are shown in Fig.3. We thought the density difference between the surface (sedimentary) and the bedrock layer is $0.4 g/cm^3$, and the assumed density for the Bouguer anomaly was set to $2.4 g/cm^3$. We inputted the data a bedrock depth is 0 m in the both edges of the sections (the border between a mountainous area and a plain) as control points.

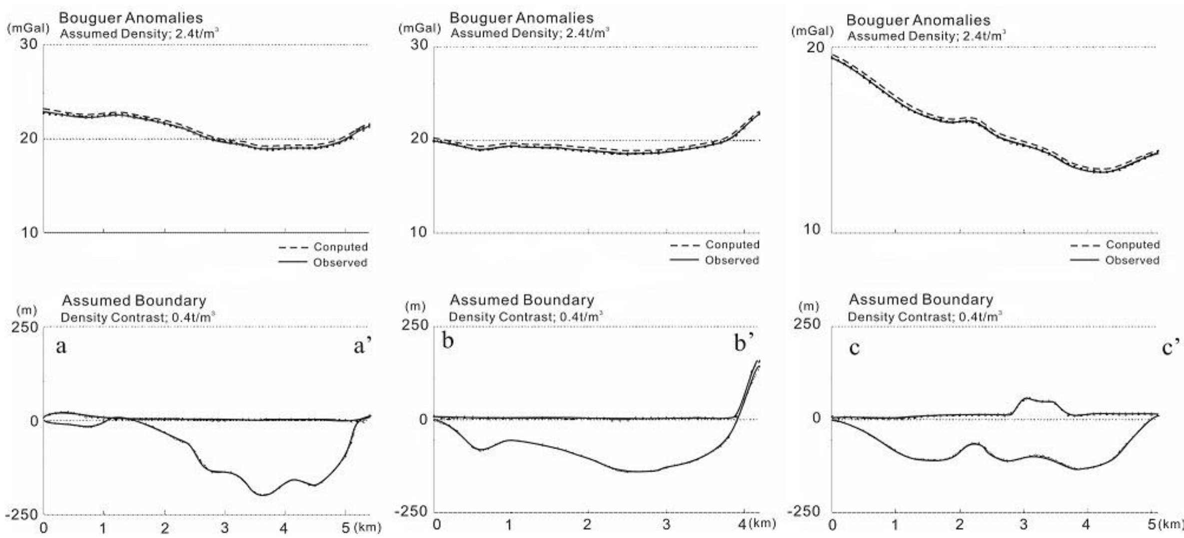

Fig.3 2D density structure models. The upper panel shows the Bouguer gravity anomaly value where the measured and calculated values overlap. The lower panel gives the calculated density structure. The locations of these sections are shown in Fig.1.

Determination of 2D Bedrock Structure Using Artificial Earthquake Data

2D P-wave structures were obtained from a travel-time analysis by reading Primary motions of P-wave from the artificial earthquake records. The waveforms in all sections' records were so clear to read. Apparent velocities were 5.6km/s on A-Line, 5.3km/s on B-Line, 5.2km/s on C-Line.

We used the SEIS83 for a ray tracing program and determined a structure models by forward modeling method. Layer velocities are given by linear interpolation between the upper layer and the lower layer of the structure models, and the structure model was 2 layers where the velocities change from P-wave velocity 1.5km/s to 3.0km/s in the sedimentary layer, from 4.4km/s - 5.15km/s to 6.0km/s in the bedrock layer. The determination results of P-wave structure are shown in Fig.4.

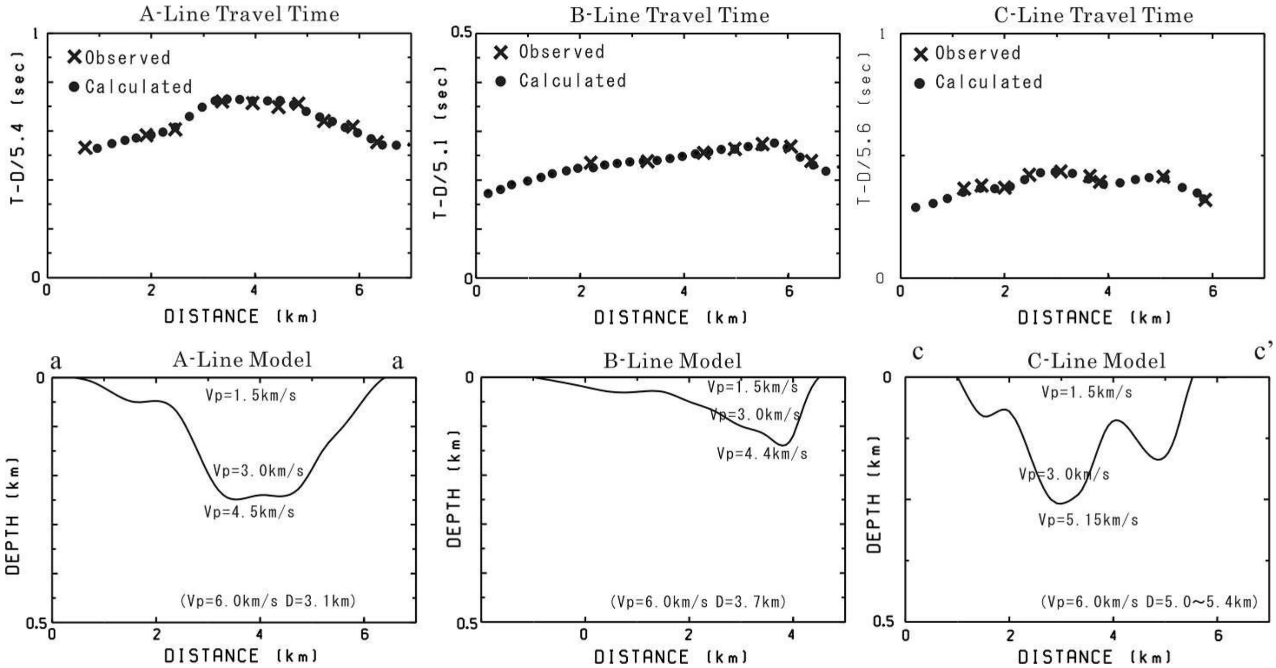

Fig.4 2D P-wave structure models by the ray tracing analysis. The upper panel shows the observed (×) and analytical (●) travel times. The lower panel shows the layered model.

Determination of 3D Bedrock Structure

We compared the gravity analysis results with the ray tracing ones. The results were superimposed each other are shown in Fig.5. The configurations of both structure models were seemed to be almost same. Then, we inputted the bedrock depth from the ray tracing results as a control point of the 3D structure analysis by gravity, where A-Line and B-Line were used but C-Line was not used for the analysis. And the 30 points a bedrock depth is 0m were also used as a control point. We thought the density different of the 2-layer is 0.4g/cm^3. And Bouguer anomalies were filtered with the band-pass range from 50m to 1000m to reduce an effect of the deep structure. The 3D bedrock structure is shown in Fig.6.

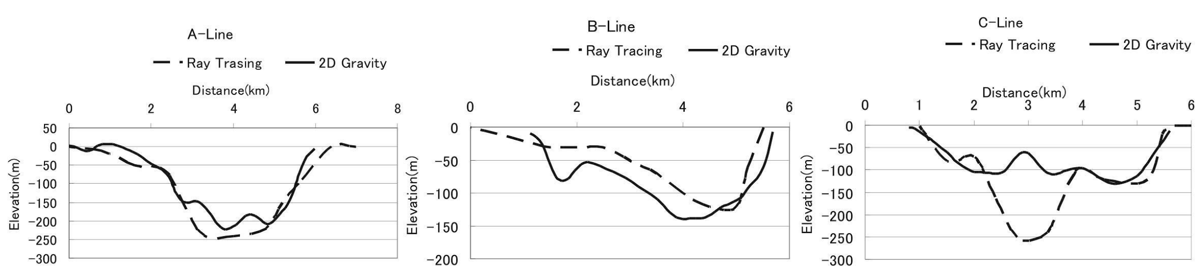

Fig.5 Comparison of the ray tracing result and the gravity analysis. The dotted lines: P-wave velocity models by ray tracing analysis, the solid lines: 2D density models by gravity analysis.

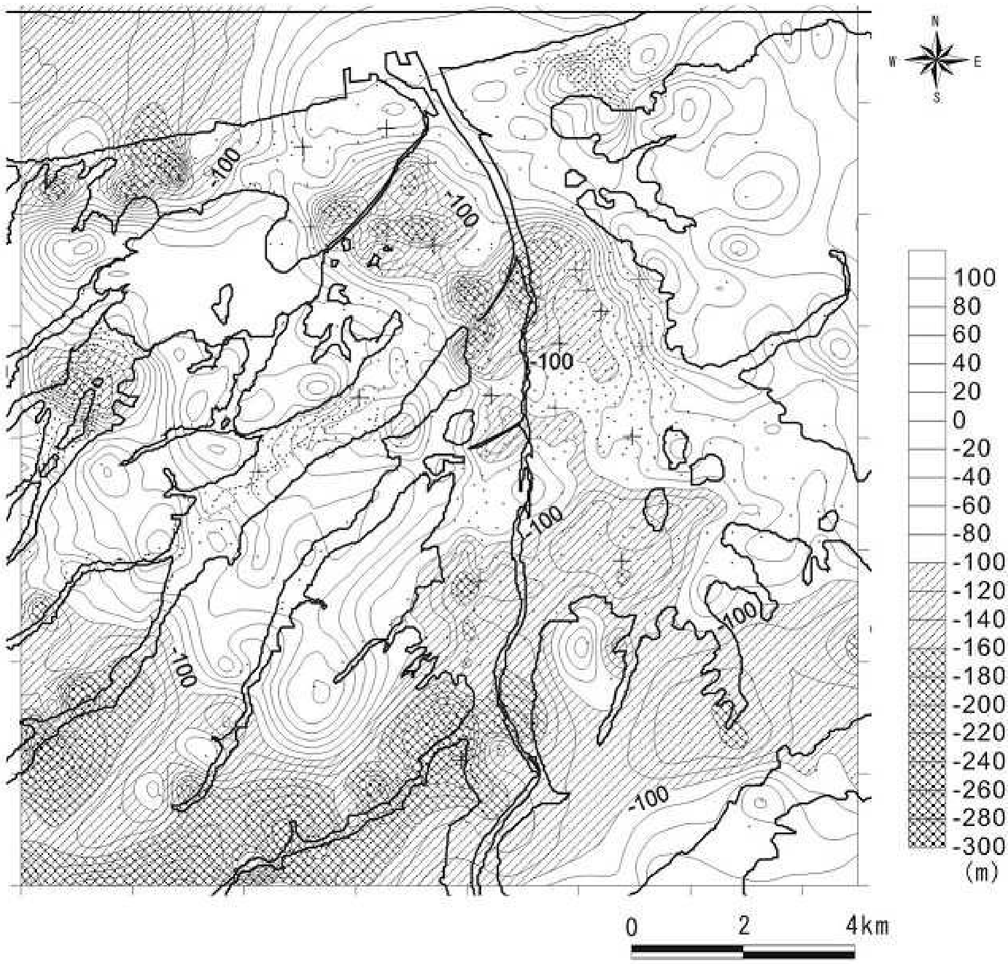

Fig.6 Contour map of the 3D density structure model. The interval of the contour lines is 20m.

CONCLUSIONS

Seismic exploration surveys, microtremor observations and gravity surveys were carried out in Tottori Plain to determine the subsurface structure. The result is as follows.

(1) The S wave velocity structure models were obtained on 19 points from the data of microtremor array observation (Table 2). The depth to the layer of S wave velocity 2.5km/s was found to be approx. 100-300 m.
(2) The H/V peak period data were obtained from the microtremor single site 3-component observations (Fig. 2).
(3) The 2D-density structures (Fig.3) were determined from the gravity data by using a 2D gravity analysis.
(4) The bedrock structures of P wave velocity structure on 3 measurement lines were obtained from the artificial earthquake record by using a ray tracing method (Fig.4).
(5) From the comparison of the artificial earthquake analysis and the gravity analysis results, bedrock depth and configuration were found to be almost same (Fig.5).
(6) The 3D bedrock model was obtained by a 3D gravity analysis using the results of artificial earthquake analysis for the bedrock depth as control points. The bedrock depth was found to be approx.250m at most (Fig.6).

REFERENCES

1. Architectural Institute of Japan. The Tottori prefecture earthquake disaster investigation report, Jour. of Architecture and Building Science (in Japanese), 1944.
2. Noguchi T and Nishida R. Determination of subsurface structure of Tottori plain using microtremors and gravity anomaly, J. Natural Disaster Science, Vol. 24, No.1, pp1-13, 2002.
3. Aki K. Space and time spectra of stationary stochastic waves with special reference to microtremors, Bull. Earthq. Res. Inst., 35; 415－456, 1957.
4. Research Group for Seismic Expedition in SW Japan. Deep seismic refraction / wide-angle reflection profiling across SW Japan (in Japanese), 2002.
5. Kitsunezaki C et.al. Estimation of P- and S- wave velocities in deep soil deposits for evaluating ground vibrations in earthquake, Jour. Natural Disaster Science, 1-17 (in Japanese), 1990.
6. Komazawa M. Gravimetric analysis of volcano and its interpretation, Jour. Geod. Soc. Japan, 41; 1; 17-45, 1995.
7. NEDO. Fundamental Research Report of Terrestrial Heat Development: No. 10, Shikano, Matsuzaki Ⅱ, 7-21 (in Japanese), 1977.