# Chapter 4 Seismic Hazard Assessment

## 4.1 Modeling of Ground Conditions

### 4.1.1 Outline of Shallow Ground Condition

The outline of shallow geological structure of Yerevan city is as follows:

a) The Tertiary sedimentary rocks widely distribute in Yerevan. They outcrop in the south area of Yerevan city.
b) The volcanic rocks cover the Tertiary sedimentary rocks in the north area of Yerevan city.
c) The Terrace deposits cover the Tertiary sedimentary rocks in the west area of Yerevan city.
d) Along the liver, basaltic lava from recent activity or liver deposits cover the above mentioned rocks partly.

The shallow ground of Yerevan city is composed by volcanic rocks, sedimentary rocks and terrace deposits. The surface layer is composed by cracked volcanic rock (basalt) in north area, by weathered sedimentary rock in south east area and by terrace deposits in south and west area. The properties of rocks are deeply influenced by the weathered condition. The schematic geological cross sections in Yerevan city are shown in Figure 4.1-1.

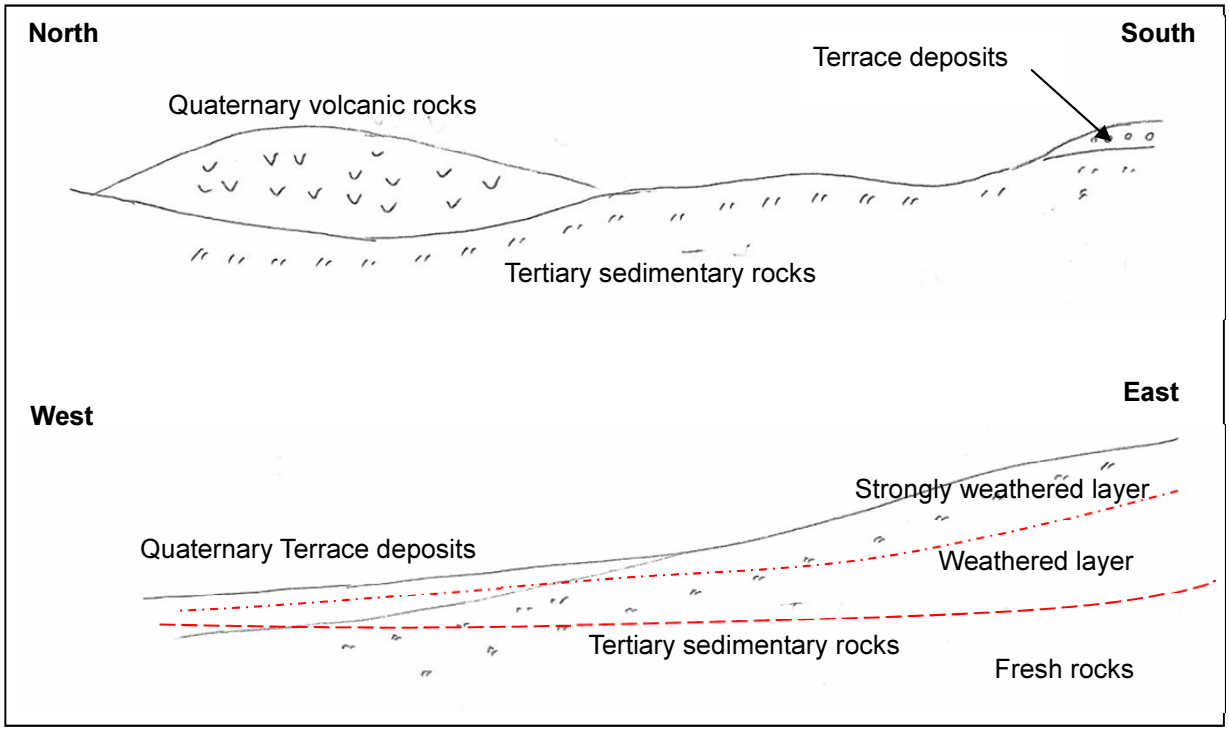


Figure 4.1-1 Schematic geological cross section in Yerevan city

### 4.1.2 Analysis of the S wave velocity structure of rocks

The S wave velocity (Vs) structure is studied based on the results of surface wave exploration, PS logging and microtremor survey. The altitude/depth of the upper end of layers, where S wave velocity is shown below, is determined at each geophysical survey points. The classification of S wave velocity is determined from the results of geophysical survey. In this study, Vs~760m/sec layer is selected as the engineering seismic baserock.

1) Vs ~ 760m/sec (Engineering Seismic Baserock)
2) Vs ~ 500m/sec
3) Vs ~ 360m/sec

The altitude of Vs~500m/sec layer detected by surface wave exploration is shown in Figure 4.1-2 as an example.

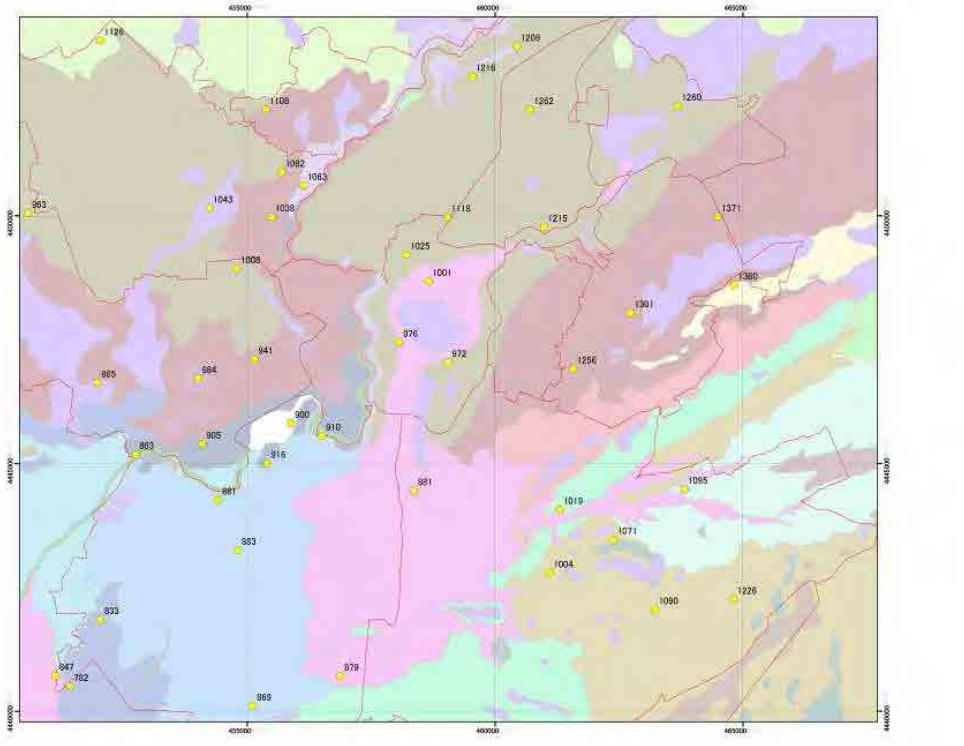


Figure 4.1-2 Altitude of the upper end of Vs~500m/sec layer by surface wave exploration

To make the ground model of all Yerevan city area, the shape of above mentioned three velocity layers should be estimated from point data by geophysical survey. For this purpose, the contour lines of three layers are drawn considering topography, geological condition and shape of fresh rocks, which is analysed by existing borehole logs. The altitudes of three velocity layers are shown in Figure 4.1-3 to Figure 4.1-5 by contour lines. The velocity structure model of rocks where Vs is larger than 360m/sec is created.

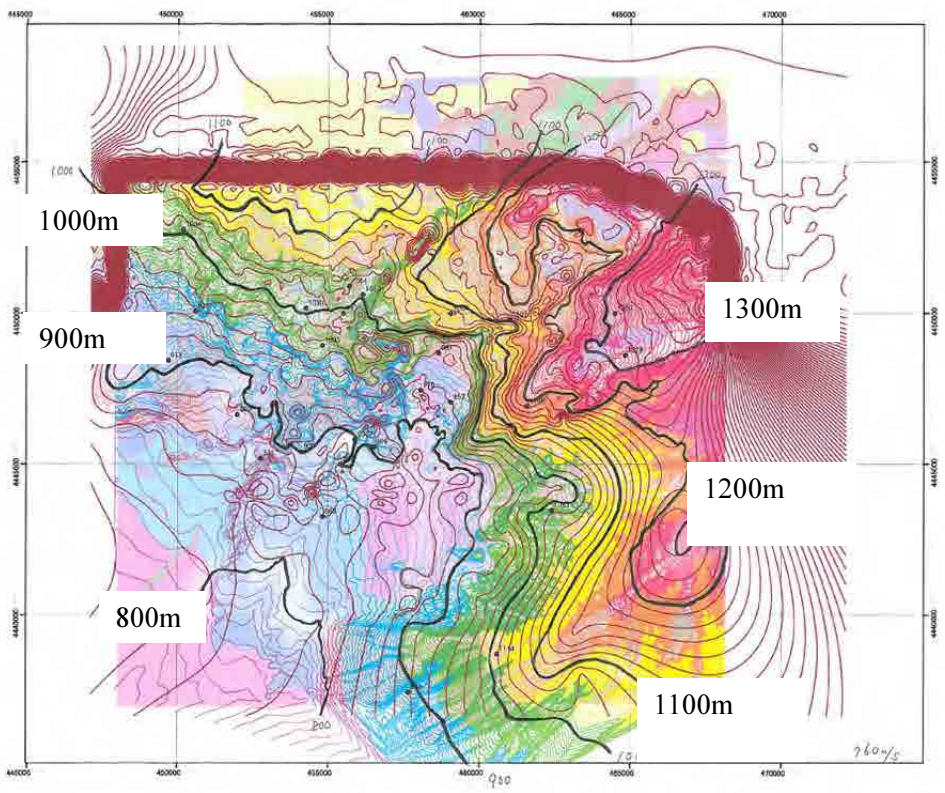


Figure 4.1-3 Altitude of the upper end of Vs~760m/sec layer

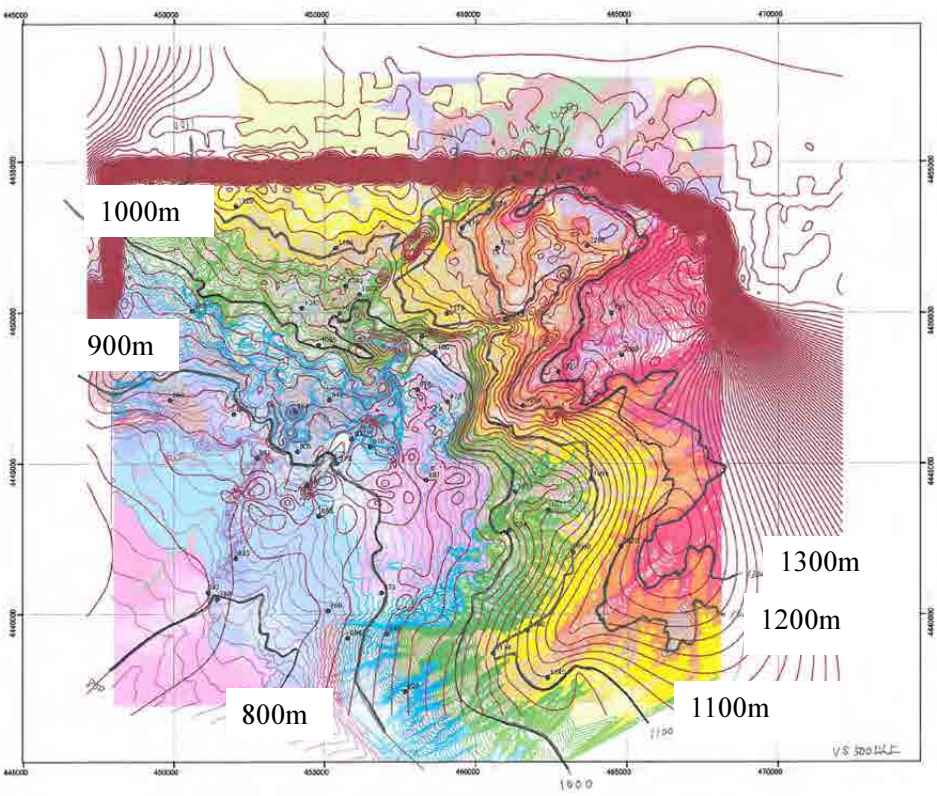


Figure 4.1-4 Altitude of the upper end of Vs~500m/sec layer

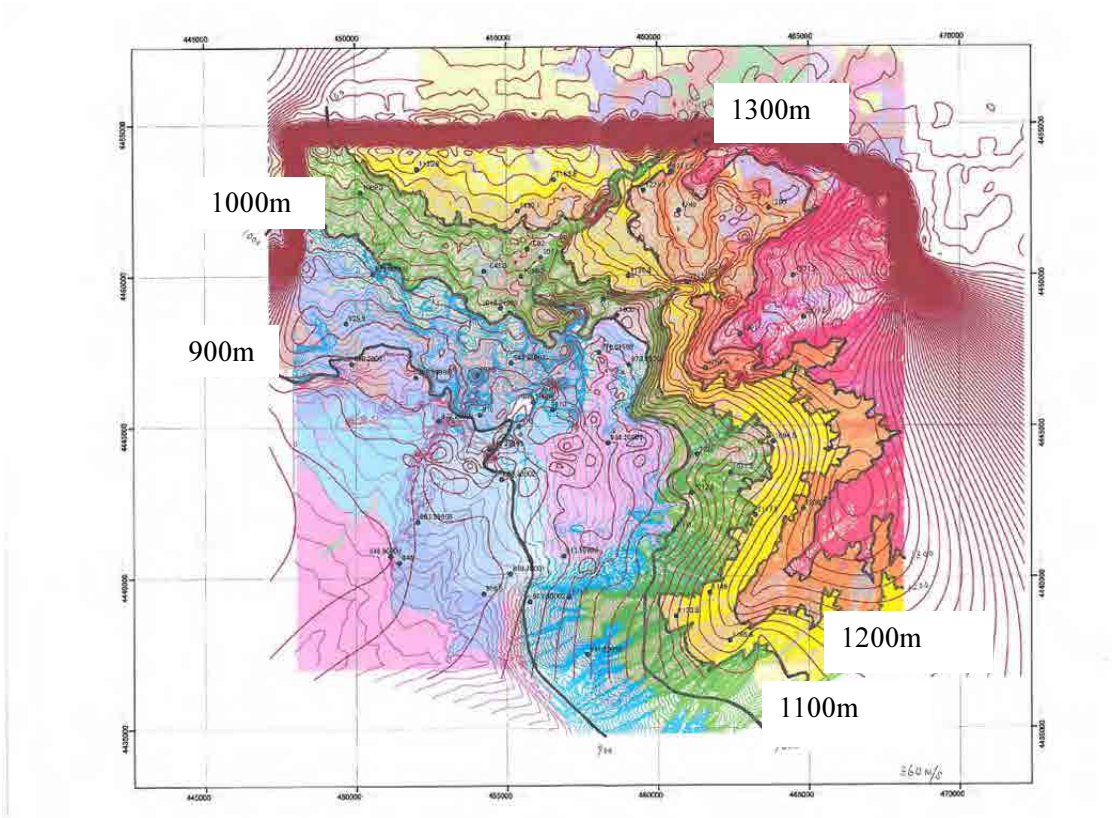


Figure 4.1-5 Altitude of the upper end of Vs~360m/sec layer

### 4.1.3 Analysis of the S wave velocity structure of shallow soils

The shallow soil layers from ground surface to Vs=360m/sec layer are studied based on the existing drilling logs, newly conducted drilling logs, PS logging results and surface wave exploration. The findings of the analysis are summarized below:

1) The S wave velocity layer from ground surface to Vs=360m/sec layer is composed by two.
2) The S wave velocity of these two layers can be estimated from surface geology. The surface geology is as follows:

    Type 1: Quaternary volcanic rocks including welded Tuff

    Type 2: Quaternary terrace deposits

    Type 3: Tertiary sedimentary rocks

The S wave velocities of two shallow layers and the ratio of thickness of two layers are determined using the results of surface wave exploration and PS logging. At first, the unsuitable data is eliminated. The data with slower second layer than first layer is removed and extremely low velocity (Vs<100m/sec) is also removed. Next, the average velocities of first and second layer are calculated for each geology type. The findings and results are shown below:

**(1) Type 1**

This type distributes in the north hill area of Yerevan city. The surface geology is shown in Table 4.1-1. Vs of first and second layers show equal or larger than 360m/sec. One data shows Vs=1,020m/sec at second layer. This may be resulted from lack of Vs=500m/sec layer. Figure 4.1-6 is the data of Vs of first layer. From this figure, the average Vs of shallow layer is decided as 360m/sec.

Table 4.1-1 Surface geology of Type 1

| Symbol | Age |
|---|---|
| abQ3 | Upper Quaternary Section (the upper part) |
| abQ2-3 | Middle-to-Upper Quaternary Sections (the upper part) |
| tQ2 | Middle Quaternary Section (the upper part) |
| bN22 | Upper Pliocene |
| babN22Q1 | Upper Pliocene-Lower Quaternary Section |

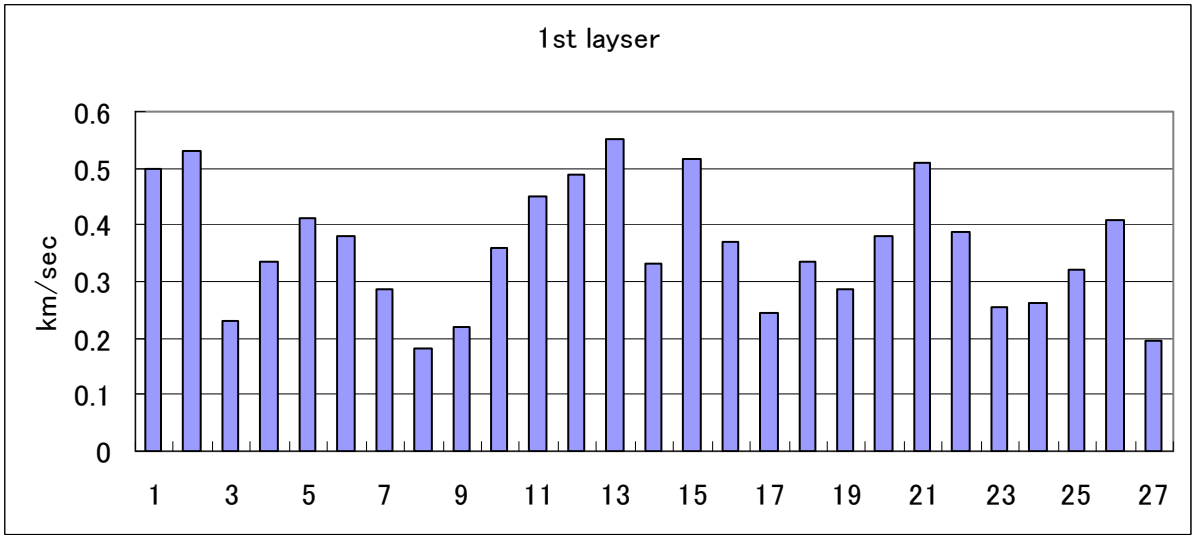


Figure 4.1-6 Vs of first layer of Type 1

**(2) Type 2**

This type distributes in the west area of Yerevan city. The surface geology is shown in Table 4.1-2. Vs of first layer is less than 360m/sec. Second layer sometimes show larger than Vs=360m/sec. This is interpreted that several velocity layers could not be separated by geophysical survey because they are thin and removed from analysis. Figure 4.1-7 is the data of Vs of first, second and third layers. The average Vs of third layer is 380m/sec and judged as rock which is modeled in section 4.1.2. The average Vs of first and second layers are 220m/sec and 290m/sec respectively. The average ratio of thickness of first layer and second layer is 0.42 : 0.58 (see Figure 4.1-8).

Table 4.1-2 Surface geology of Type 2

| Symbol | Age |
|---|---|
| apQ42 | Modern Section (the upper part) |
| apQ41 | Modern Section (the lower part) |
| apQ2-3chr | Middle-to-Upper Quaternary Sections (the lower part) |
| apQ3ar | Upper Quaternary Section (the lower part) |
| laQ1-2 | Lower-to-Middle Quaternary Sections |
| Q1nb2 | Lower Quaternary Section (the upper part) |
| Q1nb1 | Lower Quaternary Section (the lower part). |

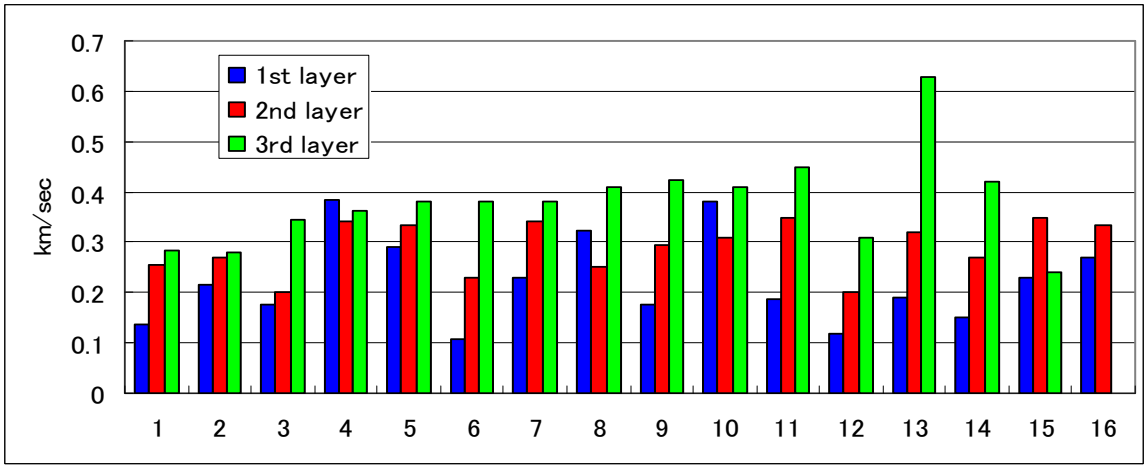


Figure 4.1-7 Vs of first, second and third layers of Type 2

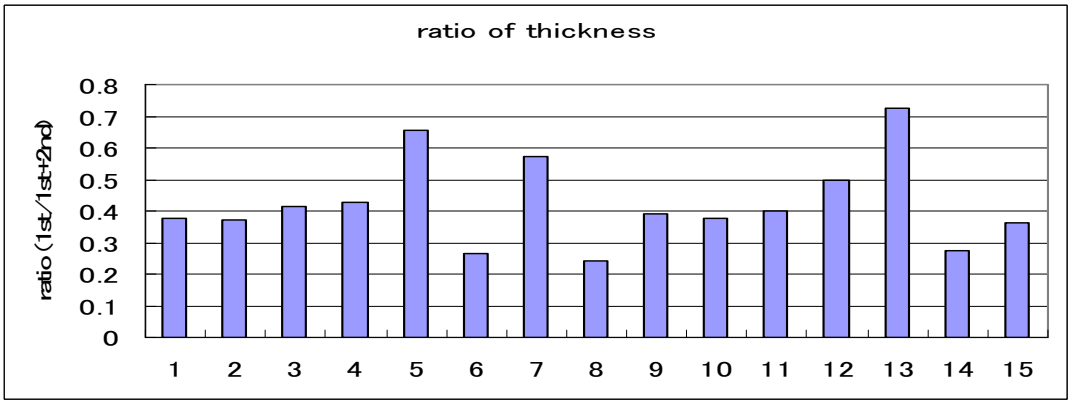


Figure 4.1-8 Ratio of the thickness of first layer to first + second layer (Type 2), No16 is not used because third layer is not detected

**(3) Type 3**

This type distributes in the south and south-east part of Yerevan city. The surface geology is shown in Table 4.1-3.Vs of first and second layer show less than 360m/sec. Second layer sometimes show larger than Vs=360m/sec. This is interpreted that several velocity layers could not separate by geophysical survey because they are thin and removed from analysis. Figure 4.1-9 is the data of Vs of first, second and third layers. The average Vs of third layer is 380m/sec and judged as rock which is modeled in section 4.1.2. The average Vs of first and second layers are 220m/sec and 290m/sec

respectively. The average ratio of thickness of first layer and second layer is 0.44 : 0.56 (see Figure 4.1-10).

Table 4.1-3 Surface geology of Type 3

| Symbol | Age |
|---|---|
| N13hr | Upper Miocene, Sarmatian (the upper part) |
| N13er | Upper Miocene, Sarmatian (the lower part) |
| N12dj (b) | Middle Miocene |
| N1hc1 | Upper Oligocene - Lower Miocene |
| Pg3sh3 | Lower-Middle Oligocene |
| Pg3sh2 | Lower-Middle Oligocene |
| Pg3sh1 | Lower-Middle Oligocene |

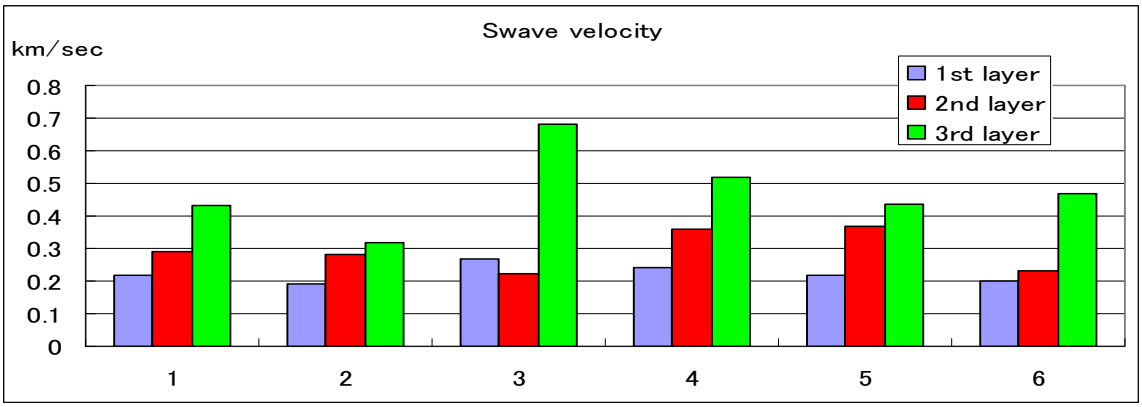


Figure 4.1-9 Vs of first, second and third layers of Type 3

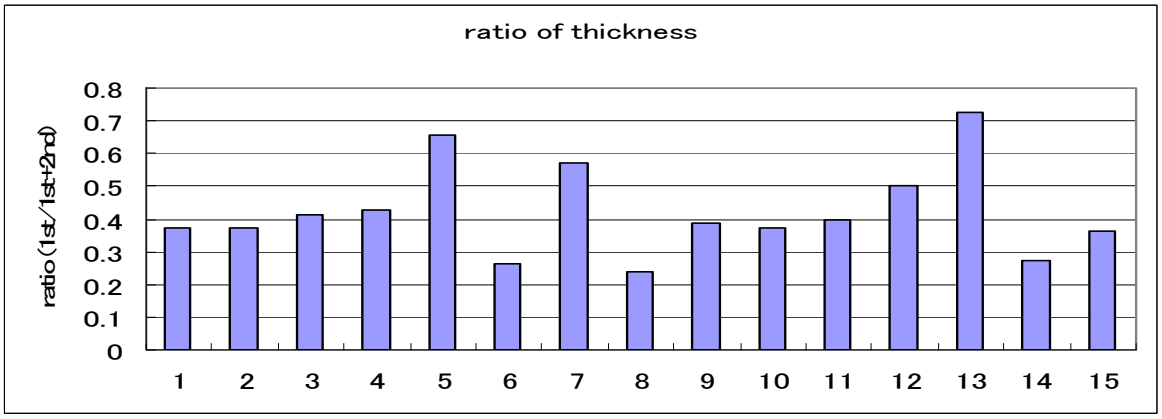


Figure 4.1-10 Ratio of the thickness of first layer to first + second layer (Type 3)

**(4) Summary**

Table 4.1-4 is the summary of analysis.

Table 4.1-4 Summary of S wave velocity structure in Yerevan

| Type | Type 1 | Type 2 | Type 3 | Deep /Shallow |
|---|---|---|---|---|
| Age, properties and conditions | Quaternary Volcanic rocks including welded Tuff | Quaternary Terrace sediments | The Tertiary sedimentary rocks including the rocks before Tertiary | |
| Area | North hill area | Western area | South and south-east area | |
| Age | Quaternary | Quaternary | Before Tertiary | |
| 1st layer | 360 m/sec | 220 m/sec | 220 m/sec | Shallow layer |
| 2nd layer | | 290 m/sec | 290 m/sec | |
| 3rd layer | 360 m/sec | | | Deep layer |
| 4th layer | 500 m/sec | | | |
| 5th layer | 760m/sec | | | |
| Thickness ration between 1st layer and 2nd layer: Type2 = 0.42 : 0.58, Type3 = 0.44 : 0.56 | | | | |

### 4.1.4 Ground modeling for hazard assessment based on the geological structure

The ground model for hazard assessment is created for each 250m x 250m square grid based on Figure 4.1-3 to Figure 4.1-5 and Table 4.1-4. The type of the ground of each 250m grid is shown in Figure 4.1-11.

The created numerical model is confirmed by comparing with the geological cross sections, which is made based on the existing drilling database. Figure 4.1-12 to Figure 4.1-14 are the example of S wave velocity section and geology cross section at same place. The geological cross sections are made based on the 555 selected drilling data from existing database. Followings are the criteria of borehole data selection;

1) The borehole should be in the study area.
2) Total depth should be more than 15m, because 15m is necessary to exam geological structure.
3) Total depth should be less than 100m, because the deep depth data sometimes includes typo.
4) When there are several data in the same grid, one typical data is selected.

The geological sections are shown in the lowest part in Figure 4.1-12 to Figure 4.1-14. In drawing the cross sections, following information are considered.

- Some of the gravels or the pebbles in the drilling log may be crackly basalt. If basalt is crashed during drilling, it looks like gravel or pebble.
- The clay layers between the tertiary sediment rocks are sometimes found in the drilling logs. The layer may be actually sediment rocks because it looks like clay when it is crashed during drilling.

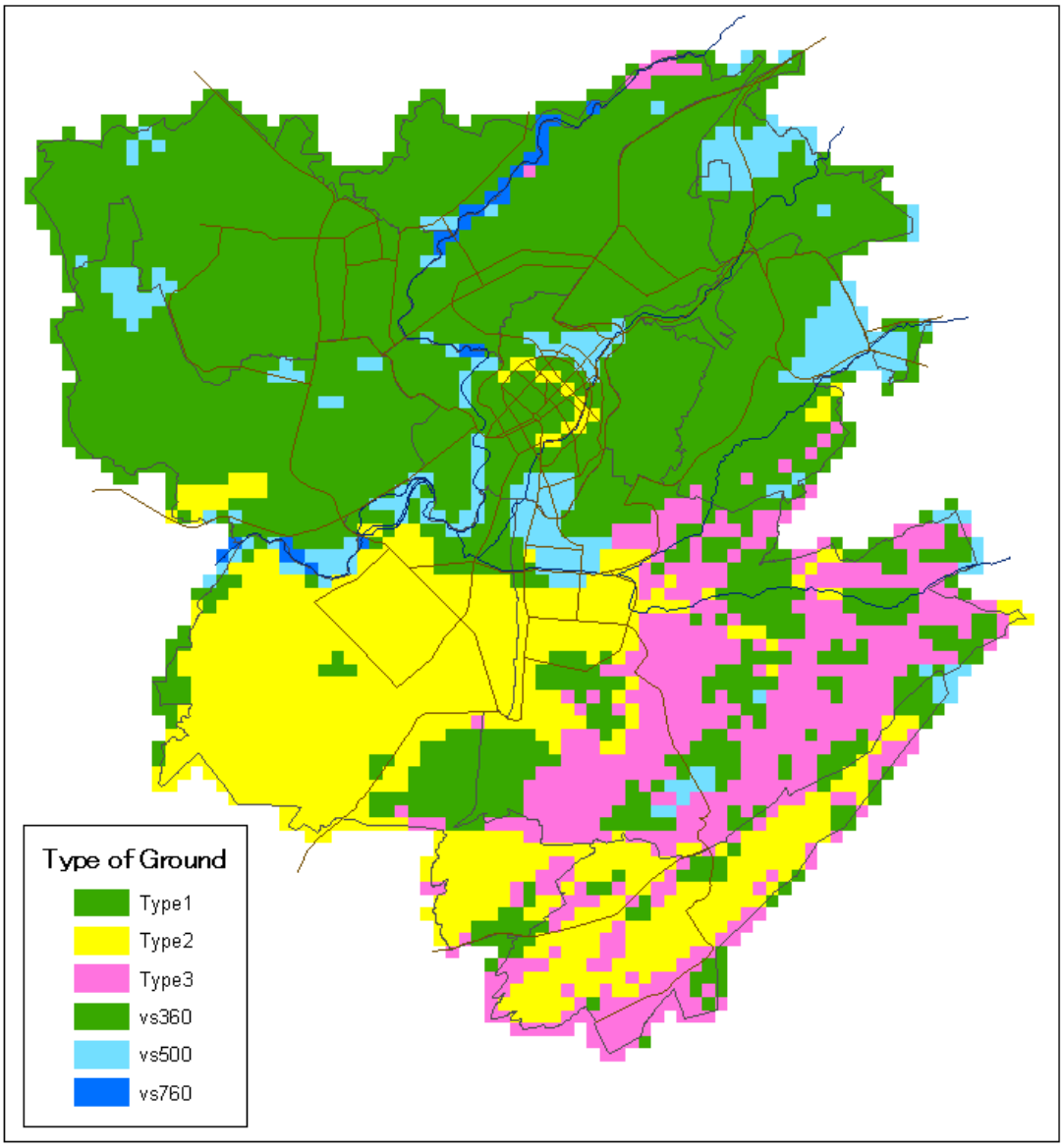


Figure 4.1-11 Type of ground; Vs360, Vs500, Vs760 means outcrop of corresponding rock layer

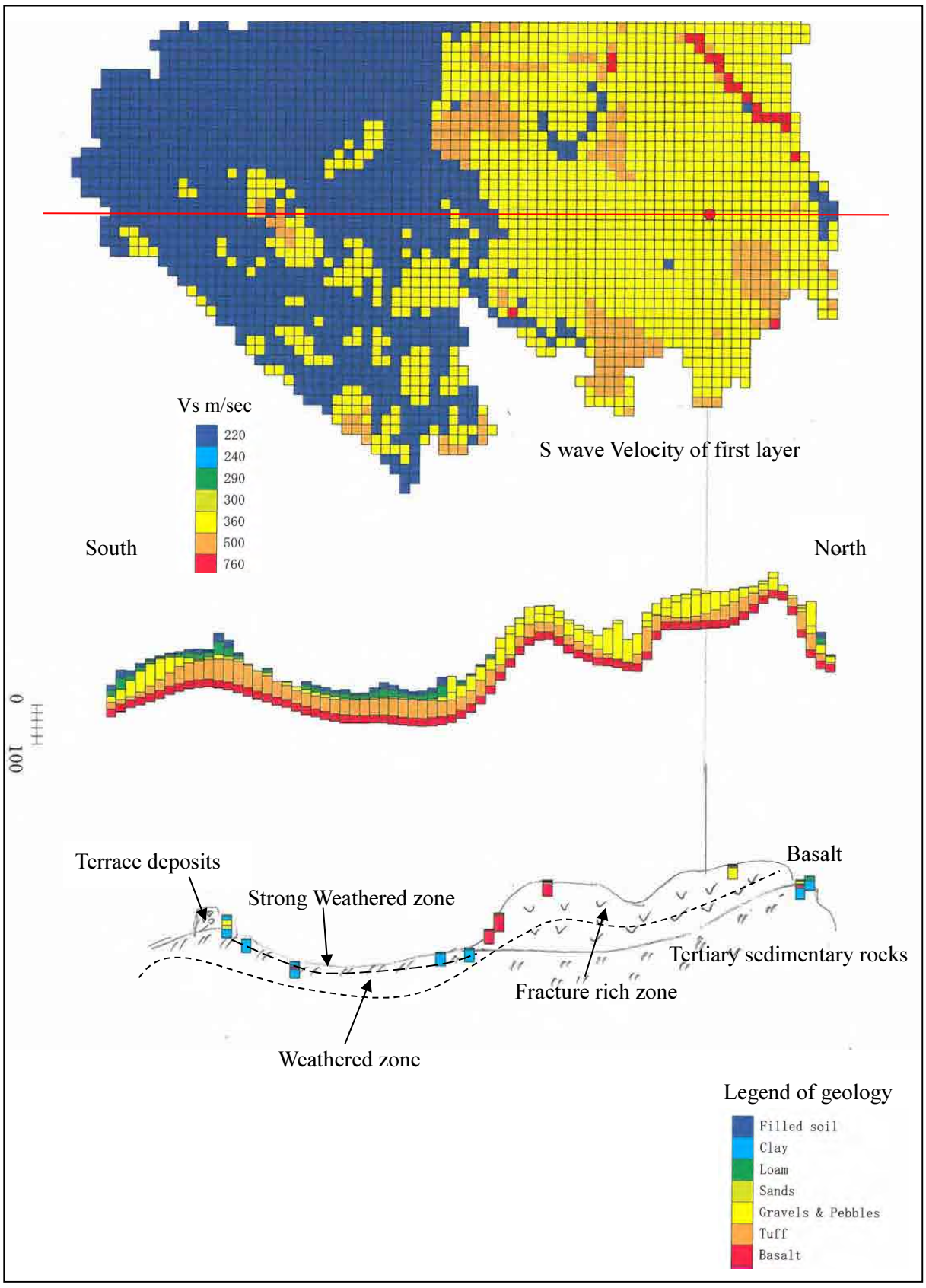


Figure 4.1-12 Comparison of S wave velocity section with the geology section
- N-S direction -