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Water bottom seismic refraction survey for engineering applications

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Abstract: The accurate mapping of the basement is one of the most crucial factors in construction of harbour facilities and bridges in the coastal areas. In shallow waters, the seismic reflection method often fails to image the basement geometry beneath the sediment cover in many cases. We present the result of a shallow marine seismic refraction survey using two ships, 12-channel hydrophone arrays deployed on the bottom and a borehole sparker or percussion powder as sources. Velocity structure could be computed by tomography algorithm since more than 6 different source points had been applied for one spread. The comparison of the results of the refraction survey with drilling logs demonstrates remarkable consistency in basement geometry. It thus appears that the refraction method in this study is an efficient and cost-effective way to investigate the basement structure in coastal area, river, and lake.

1. Introduction

We've watched a drastic increase in construction of harbour facilities and bridges in the coastal areas of Korea. The mapping of the basement is a fundamental task for the construction of these structures. A seismic refraction survey is routinely employed to obtain information on subsurface geology on land. In contrast, in coastal and inshore areas, a seismic reflection survey is widely employed. However, there are many serious problems with the marine seismic reflection method; (1) it cannot give accurate velocity information of the sea-bottom, unless multichannel data acquisition is not performed. (2) The conventional wave sources such as transducer, boomer, and sonar for high-resolution surveys do not generate seismic pulses strong enough to penetrate deep into the bottom. (3) When an air gun or a sparker is used for a source to generate much stronger pulses in the shallow water, the data are poor in resolution and degraded by significant reverberation. (4) Water bottom multiples smear subsurface reflections particularly when the sea bottom is shallow. As an alternative to solve these problems, a seismic refraction method is used to investigate shallow and deep geological structure.

The simplest way of refraction field work on the sea is to use a sonobuoy, which results in a point velocity sounding data. This method can only be applicable in the flat stratified geologic structures which are hardly met in engineering scale in Korea. Another simple way of data acquisition is towing multi-channel hydrophone streamer. With this method, it can be possible to get velocity tomogram. But the sufficient survey acreage is required to perform the field work, for example, large space is needed for a ship to turn around.

We present the result of water bottom seismic refraction surveys conducted in the coastal areas of Korea. Instead of placing the sonobuoy on the sea surface, we deployed two 12-channel streamers on the bottom, following the ocean bottom seismology technique (Kim et al., 2003). Subsurface structure was computed by tomography using the first arrival times.

2. Water Bottom Seismic Refraction Survey

Though a seismic refraction survey is one of the most popular methods on land for engineering purposes, its application in the sea has been limited. The main difficulty is likely to be related to the special design of a source and a receiver that operate properly in the water. In general, a refraction method yields reliable results when the ground is flat-layered and velocities increase with depth. However, sedimentary structure on land shows a high degree of deformation. This is especially true of mountainous regions such as Korea. Indeed, it is the sea that provides favourable conditions for the refraction survey; above all, the layered structure of sediments is well preserved because the sea is essentially free of erosion; sedimentary layers are well sorted and mark clear boundaries.

In the underwater situations including sea, lake, and river, the field acquisition technology is different from that used on land. Descriptions are given below of the procedure of the underwater refraction survey, equipment, data processing and interpretation.

Field works

In principle, refraction field work in the water is the same as that on land, yet, it has many restrictions. Moving and locating source and receiver on the bottom are very difficult. Figure 1 illustrates a schematic diagram for the water bottom refraction survey in this study using two survey boats, 12 channel streamers and a water bottom explosive source.

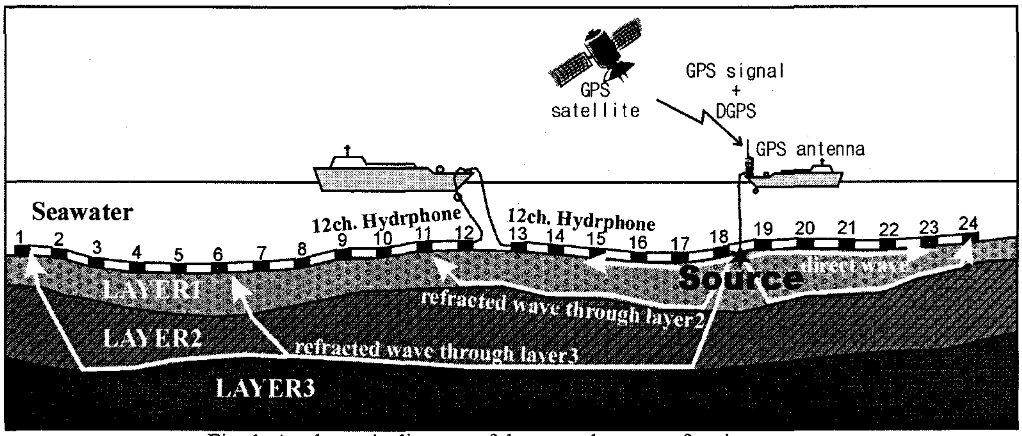


Fig. 1. A schematic diagram of the water bottom refraction survey.

The procedures of the survey were consisted of the following stages;

① to install the GPS+DGPS antennas and the navigation control unit on survey boat 1 and 2, while sources on survey boat 1 and seismograph on survey boat 2.

② to locate survey boat 2 on the centre of the survey line and fix the position by anchoring.

③ to locate hydrophone arrays on the accurate bottom positions on either side of boat 2, using survey boat 1.

④ to move the source position by survey boat 1.

⑤ to trigger the shot and record the seismic signals .

⑥ to repeat ④ and ⑤ until boat 1 reached the last source position.

Data acquisition equipments

Equipments for the refraction survey in this study included; source and receiver units; the navigation unit to locate their positions.

Source

Boomer, air-gun, dynamite, and sparker are seismic sources widely used in the sea. For a refraction survey, sources that generate stronger pulses are needed because the source to receiver distance is much longer than that for a reflection survey. Therefore, a boomer-type source like Bubble Pulser is not appropriate. An air-gun can emit very strong pulses, but additional instruments such as generator and compressor necessitate a relatively big sized survey ship that is not easy to use in the shallow sea. Dynamite can be used regardless of the size of the ship and generate the strongest source signature. Yet, it needs a permission from the law enforcement (in Korean) is dangerous to handle, thus its potential cost is not as low as expected. So the use of dynamite is confined in the geologic condition that the sedimentary layers relatively thick (in engineering sense, thicker than 20m). The borehole sparker system might be the most convenient source; it requires moderate space though its energy is not high. Since it is easy to repeat the source generation with the sparker system, we stacked the recorded signals several times to increase the S/N ratio. A sea bottom gun (Good et al., 1999) could be another choice though not employed in our tests.

Navigation and synchronising

For positioning the source and the receiver locations, a DGPS receiver was used with the positioning error of less than 1m. Because time is included in the GPS signals, the source positions can be easily incorporated in the processing stage.

Basically two ships are necessary, one for recording the signals from the deployed hydrophone arrays and another for moving the source. A synchronising unit is required for sending a trigger signal to the source and the recorder. A wireless communication system is proven to be very convenient. Long cable should be prepared as a complementary in case the wireless system fails.

Receiver and recording system

Two arrays of 12 channels with a 10 m channel interval were used. The sensitivity of the hydrophone is 24 volt/bar or higher. Heavy weights were tied to the ends of the arrays to make the position fixed. Several buoys were attached to hydrophone arrays to show their underwater positions along the survey line.

The seismograph that can acquire 24-channel data with 24-bit accuracy data was used.

Interpretation

The interpretation of refraction data obtained in the water is the same as that obtained on land except that the positions of sources and receivers are calculated from DGPS data. The positioning data from the DPGS system were recorded every second in this study from which the positions of sources and receivers were determined.

Data processing included editing, gain recovery, and band pass filtering. First arrival times were picked for every shot gather. The P-wave velocity section was obtained by 2-D tomography.

3. Field examples

The data and interpretation results for two cases will be described. The source for the first case (hereinafter called "Case I") was the sparker, and the second case ("Case II") the detonating powder (dynamite). Sine the main idea of "the water bottom refraction survey" lies on the fact that the source and the receiver locate as close as possible to the bottom, special efforts had been done to meet this requirement. The deploying the hydrophone cable on the bottom is a natural process, while locating the source near the sea bottom needs a little more attentions. When using the dynamite, the depth gap of 1m from the water bottom was maintained not to harm the hydrophone cable.

Survey region and Data acquisition parameters

Figure 2 shows the survey regions and the design of survey lines along with source/receiver positions. Table 1 shows the site summary of "Case I" and "Case II" in Figure 2. Attentions should be paid on the fact that there were many shot points along the spread which made it possible to perform tomographic inversion with multiple source-receiver geometries.

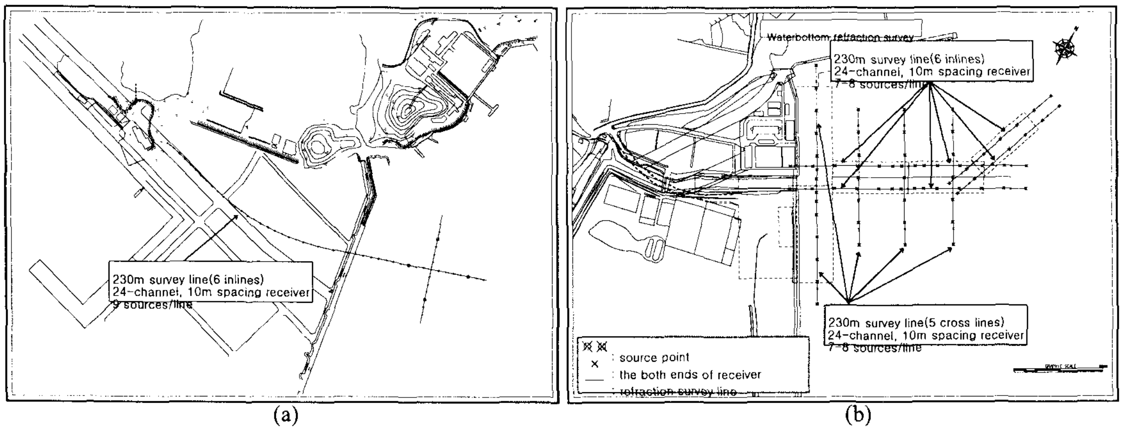


Fig. 2. The survey region and design of field examples (a) "Case I" (b) "Case II".

The data

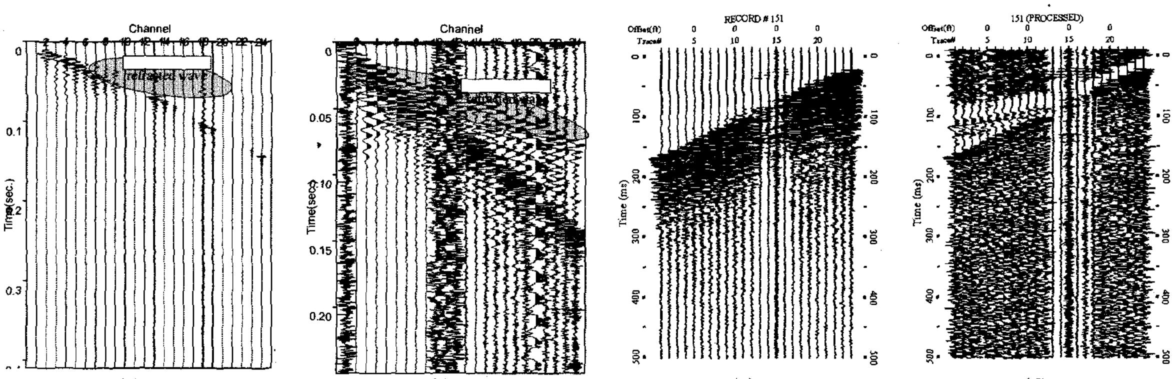
Figure 3 shows the data acquired in "Case I" and "Case II". Figures 3(a) and 3(b) are the data in "Case I" before and after processing, respectively. In Figure 3(a), refracted arrivals from the basement are not readily recognizable before processing possibly because the aggregate of direct wave and reflected wave is relatively so strong. So proper time variant gain control should be applied to pick the first arrivals. Case II example shows the same feature (Figures 3(c) and 3(d)).

During the survey of CASE I, the sparker shot did not generate a shock for us to sense on the ship, whereas the percussion powder shot with 20g was strong enough to feel the shock. Besides, the refracted signal from sparker source was not detected on the site of CASE II where the sea bottom was deep and the sediment cover was thick. It thus appears that a proper source should be employed according to the sediment thickness.

In the near offset region, it was difficult to separate refractions from the direct wave due to the fact that the velocity difference between the water and the sediments was so negligible. In this study, the velocity of the sediment cover was estimated from suspension PS logging performed in the same project area, ranging from 1500m/s to 2000m/s.

Table 1. The site summary of the field examples.

	Case I	Case II
Location	Mokpo(the Yellow Sea)	Busan(the East Sea)
Sea bottom depth	Less than 3m	3m ~15m
Tide difference	3m~4m	Less than 1m
Source Type	Electrical sparker	Percussion powder
Num. of receiver	24 channel	24channel
Num. of source per a spread	7~10 points	7~10 points



(a) (b) (c) (d)

Fig. 3. The field acquisition data. (a) before processing from "Case I", (b) after processing from "Case I", (c) before processing from "Case II", (d) after processing from "Case II".

Results

Figure 4 shows the tomogram using the data from "Case I" with drilling logs superposed. Remarkable consistency is noticeable between the basement geometry from drilling logs and that estimated from the velocity tomogram. The velocities of the topmost sedimentary layer and the underlying alluvium had been calculated as 2200m/s and 2500m/s, respectively, which seem to be a little bit higher than the normal value. Since the velocity of the sediment is almost the same as that of water, the velocity of sediment cannot be properly calculated by refraction survey. But, the velocity of the acoustic basement and the interface of the sediment and the basement can be regarded as the accurate results because we could get clear first arrivals from that interface and the layers beneath it.

Figure 5 shows the tomogram for "Case II", a 3-dimensional fence diagram, and a 3-dimensional bedrock iso-surface volume. Again, the result of the refraction method is verified by drilling logs. Furthermore, 3-dimensinal velocity fence diagram from all tomograms demonstrates that the intersecting regions agree well with the each other. A 3-dimensional iso-surface volume of bed rock estimated from the velocity contour of 2500m/sec provides detailed morphology of the bedrock.

The above two examples show that the water bottom refraction survey is very an efficient and cost-effective method to map the bedrock in the water-covered regions including coastal and inshore areas, lake, and river.

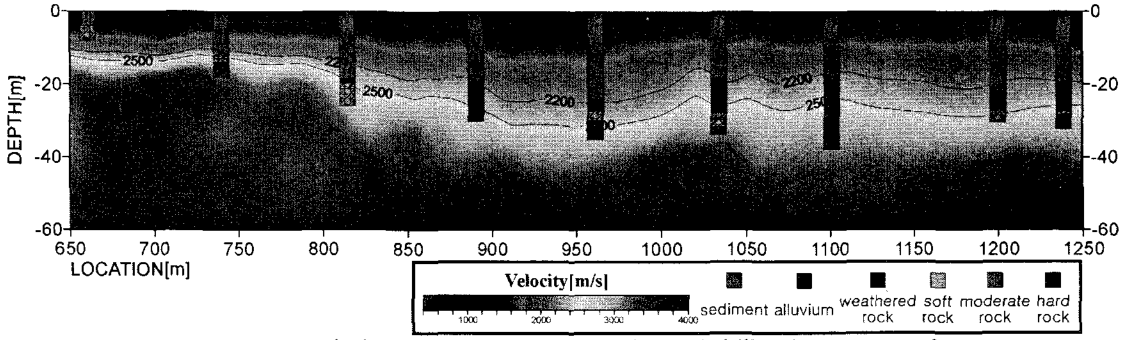
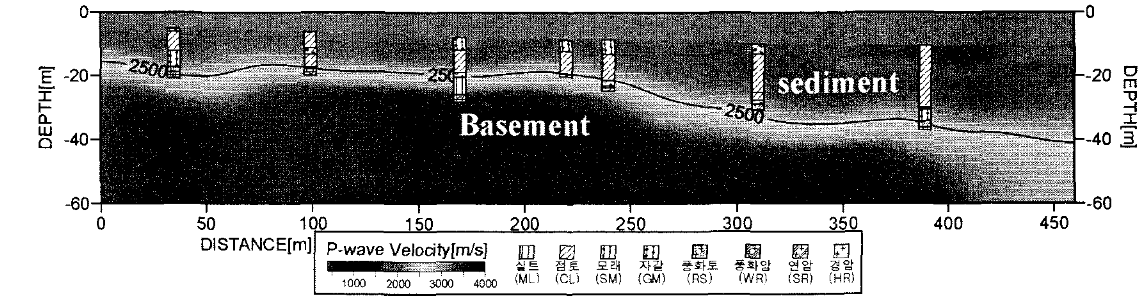
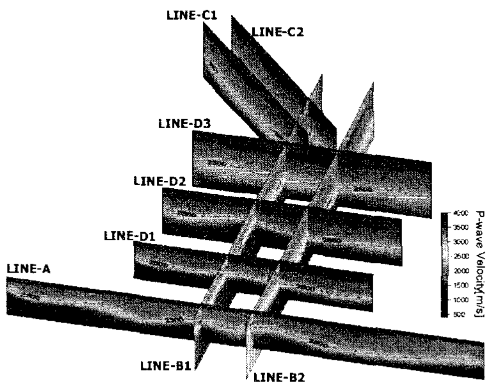


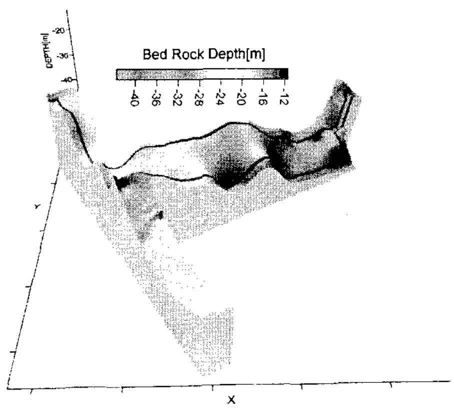
Fig. 4. A velocity tomogram from "Case I" data with drilling logs superposed.



(a)



(b)



(c)

Fig. 5. The results from water bottom refraction survey in "Case II" (a) velocity tomogram (b) 3-dimensional velocity fence diagram (c) 3-dimensional iso-surface volume of bed rock.

4. Conclusions

Water bottom seismic refraction surveys had been performed for the civil engineering purposes in the coastal areas of Korea. To carry out the field work, two survey ships had been used, one for data recording in a fixed point, the other for source generating while moving along the spread. Two 12-channel hydrophone arrays were deployed on the water bottom on either side of a ship along the survey line. A borehole sparker and percussion powder (dynamite) used as wave sources. The basement geometry estimated by tomography shows remarkable consistency with that determined from densely acquired drilling logs. We speculate that the high accuracy result could be obtained by deploying the hydrophone sensors on the bottom, since it avoids the unnecessary ray path through the water layer causing the noticeable amplitude attenuation on the interface.

The positioning of the source and receiver points is the crucial factor to get the accurate interpretation. DGPS system of horizontal positioning error less than 1m would be required for this object. The explosive source generates the strongest energy so that the clearest signals may be achieved and the penetration depth can be deeper than any other sources. The sparker source is more convenient and easier to handle but its relatively low energy makes it difficult to get signals from deep refractors. So it is recommended to check the maximum depth of the acoustic basement in the project area before the field work.

Because the velocity contrast across the sediment-bedrock boundary is usually high in coastal area, the refraction method can be very efficient and cost-effective in mapping the basement. To get the better quality data and to get the accurate result, the seismic refraction survey by deploying the hydrophone cable on the water bottom which can make it possible to get the clear first arrivals with different source-receiver geometries.

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