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RESEARCHING MIGRATION METHODS, ENTROPY AND ENERGY DIAGRAM TO PROCESS GROUND PENETRATING RADAR DATA

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ABSTRACT: Electromagnetic wave velocity is the most important parameter in processing ground penetrating radar data. Migration algorithm which heavily depends on wave velocity is used to concentrate scattered signals back to their correct locations. Depending wave velocity in urban area is not easy task by using traditional methods (i.e., common midpoint). We suggest using entropy and energy diagram as standard for achieving suitable velocity estimation. The results of one numerical model and areal data indicate that migrated section using accurate velocity has minimum entropy or maximum energy. From the interpretation, size and depth of anomalies are reliably identified.

Keywords: Migration, entropy, energy, processing GPR data.

INTRODUCTION

Ground Penetrating Radar (GPR) is the wave electromagnetic reflection method with high frequency, from 10 MHz to 4 GHz, which is used to study shallow structure (i.e., identifying and mapping underground objects of construction works; forecasting subsidence and landslide...). The advantages of GPR over other methods are non-destructive structure, high resolution, accuracy, rapid data collection.

Transmitter antenna transmitting GPR wave consists of form of pulses having dominant frequency. Receiver transmitter receives reflection signals from objects or boundaries that have difference in electromagnetic parameter. Processing GPR data improves signal to noise ratio and cross-section quality, determines wave velocity and calculates depth - size of underground objects.

HEADINGS

Migration methods

In seismics, migration methods are used to move dipping reflections to their true positions and collapse diffraction [1]. Migration is done by extrapolating recorded wave field on the ground to reflecting point wave field at depth. Hence the scattered wave field recorded from reflecting points will converge. Amplitude, shape and phase of migrated image relate to the reflection coefficient of reflecting boundary. Therefore, migration shows us not only geologic information but also reflection coefficient at the boundary and physical properties of rock (fig. 1) [1].

Decisive factor of the success of migration is the accuracy of velocity model. In fact, wave velocity is very complex, changing in both vertical and horizontal directions. The more complex velocity model is, the more challenging application of migration is. Therefore, selection of suitable migration method for each geologic media plays an important role in improving the quality of migrated section.

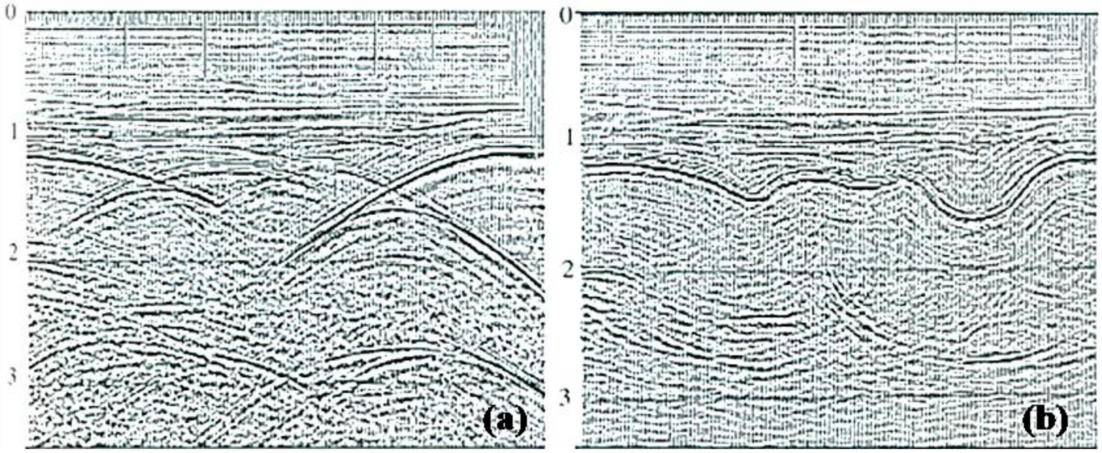

Fig. 1. (a) Seismic section before migration; (b) Seismic section after migration

GPR method and seismic method have a number of similarities: their principle based on reflection of wave and approaches of solving wave equation (ie., Szaraniec (1976, 1979), Ursin (1983), Lee and others (1987), Zhdanov (1988)). The similaritiy of the geometrical characteristics between two such wave fields can be exploited in the processing of data. Therefore, many methods in seismics can be applied directly to processing of GPR data if they have the same type of (ie., Van N.T and et al., (2014, 2015) [2-4]).

To apply poststack migration, we have to use zero-offset data. Normally, when surveying in the city, GPR data are recorded by common offset type by shielded antennas. The time delay caused by distance between transmitter and receiver is really small (about 10 - 20 cm). The ratio between correction time and travel time is less than 1% - 2%, so we can neglect the correction without affecting migration result. Therefore, CO section in GPR is considered zero-offset section in seismics.

Migrations in GPR and seismics have the same purpose. They all help us to know information about shallow reflecting geologic structure, define the true velocity of media, shape and size of object and put boundary into its real position. Migration is substantially solving inverse problem in GPR.

Mathematically, migration is essential to solve problem of mechanical wave propagation equation. In practical data processing, migration is conducted in computer systems and programming software, which require the use of algorithms to approximate the roots of the wave equations. Each philosophy of migration method leads to a certain type of algorithm. There are three most popular algorithm methods applied to migration: the energy summation of diffraction wave field – Kirchhoff migration, the 2D Fourier transformation - F-K migration, the wave field downward continuation - Finite Difference migration (FD) and Phase Shift Plus Interpolation migration (PSPI).

The authors (i.e., Yilmaz (2001), Forte and et al., (2014), Sham and et al., (2016) [5-7]) have mentioned several ways of determining GPR propagation velocity for common midpoint (CMP) and common offset (CO) data. Previously, normal moveout (MNO) was the most efficient method of determining velocity. However, NMO is only used for CMP data, which is usually collected by non-shielded antennas and can not be used in urban areas because of electromagnetic interference caused by human activities. Currently, migration methods are used to determine GPR veolcity based on the convergence of scattered hyperbolas for CO data, which is collected by shielded antennas to minimize interference. Migrating GPR data by approximate velocities will give similar migrated sections, which can not be distinguished by naked eye. To evaluate the best velocity, therefore we combine migration methods with entropy and energy values to process GPR data.

Entropy and energy

GPR sections displayed on computer is obtained by digital methods in GPR equipments. The most common image representation is the raster pattern, in which the image is represented as a matrix of points, with the size (m×n) [8].

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ : & : & : & : \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \qquad (1)$$

The elements in matrix X correspond to pixel images and have the value as recorded GPR amplitude (i and j are trace and sample number). Therefore, we can apply entropy standard in image processing to GPR data. To overcome the limitations in entropy formula of Shanon (1948), entropy of *X* image is approximated by formula [2]:

$$E(X) = \sum_{j=1}^{n} \left\{ \sum_{i=1}^{m} x_{ij}^{4} \Big/ \left[\sum_{i=1}^{m} x_{ij}^{2} \right]^{2} \right\} \qquad (2)$$

According to the definition, the maximum value of entropy is 1 for the single trace data set when the data contains only peak pulse with single-unit amplitude, as to the N trace sets, the value is N. In terms of an image, the greater its entropy is, the more confusing the image target point is. Vice versa, minimizing the entropy of image after migration processing can optimize the focus effect. So the effect of migration processing can be evaluated by minimum entropy technique in order to make the focus effect optimal.

On the other hand, energy of X image is defined as [3, 4]:

$$D(j) = \sum_{j=1}^{m} x_{\mathrm{ij}}^{2}, \;\; j = 1, 2, \ldots, n \qquad (3)$$

According to physical principle, a buried object will create more reflection than surrounding media, so that its signal will increase. However, the recognition of energy is easily affected by the noise. Therefore, we have to remove noise by moving average and arithmetic average method before calculating energy of signal.

The combination of entropy and energy standard to optimize migration algorithm is implemented as follows:

Step 1: processing GPR data through basic steps: time correction, noise reducing and amplification to highlight important signal.

Step 2: migrating GPR data with possible velocity range to calculate entropy and energy value.

Step 3: defining minimum entropy or maximum energy value to determine exactly electromagnetic wave velocity of media above the object.

RESULTS

Numerical model

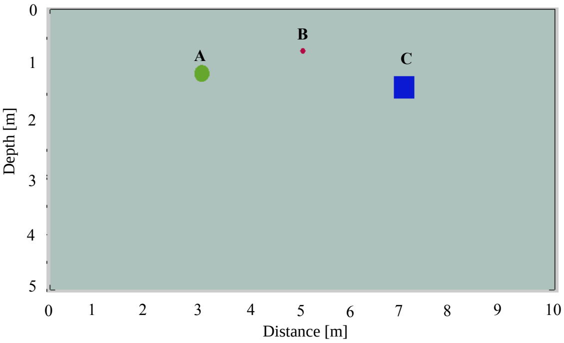

Fig. 2. Model of six anomalies in Cartesian coordinate

To illustrate, we build theoretical model with three objects, consisting of two round pipes and one square pipe. The propagation velocities are 0.113 m/ns in medium, 0.02 m/ns in two round metal pipes and 0.122 m/ns in square concrete pipe (fig. 2). We use MATGPR program to build velocity model and GPR data in CO type (fig. 3) [9].

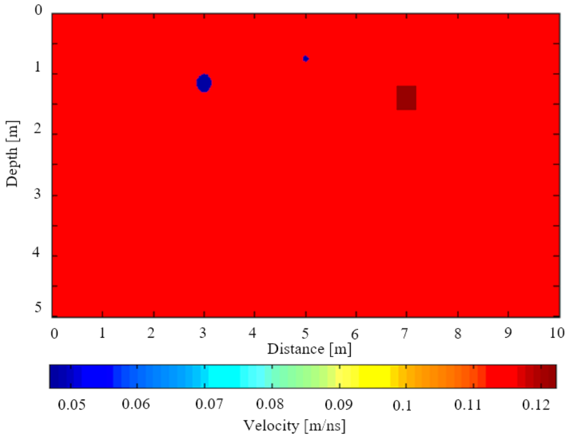

Fig. 3. Velocity model

Observing fig. 2, the locations of pipes are x = 3, 5, 7 m respectively. Two metal pipes A and B only show reflected signals at the top. Meanwhile, pipe C shows two distinctive hyperbolic signals, which are the reflected signals at the top and the bottom.

We migrate data with the velocity values of 0.110, 0.115, 0.12 m/ns (fig. 4). Fig. 4c shows that the hyperbolic signals at 5 m and 7 m are curved up. This means that migrated velocity is greater than the velocity of medium. Fig. 4a and fig. 4b both show converged hyperbolae which are quite similar, so that we can not determine the right velocity.

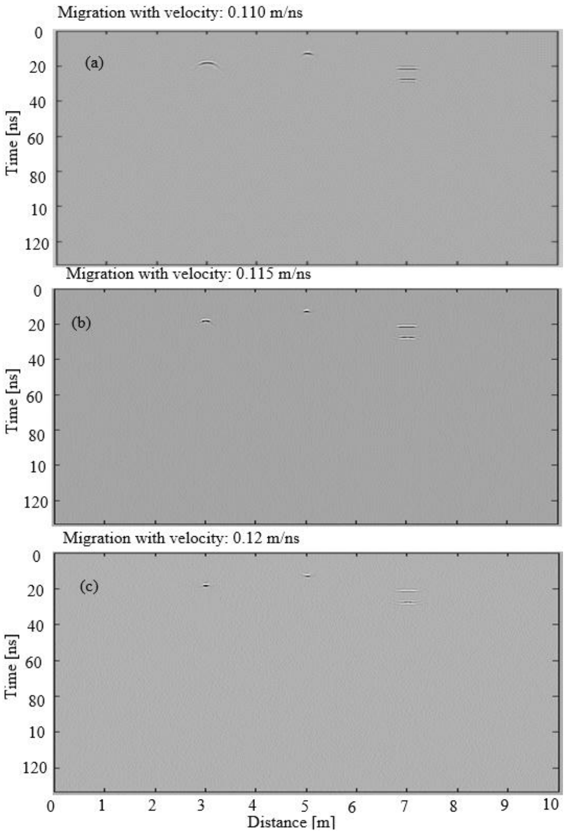

Fig. 4. Different migrated sections for synthetic data

Selecting the reflected signal of pipe B (fig. 5), we combine migration methods with entropy and energy to process data. The calculated wave velocity is 0.117 m/ns (fig. 6). This is consistent with model velocity. The error is just 3.5%.

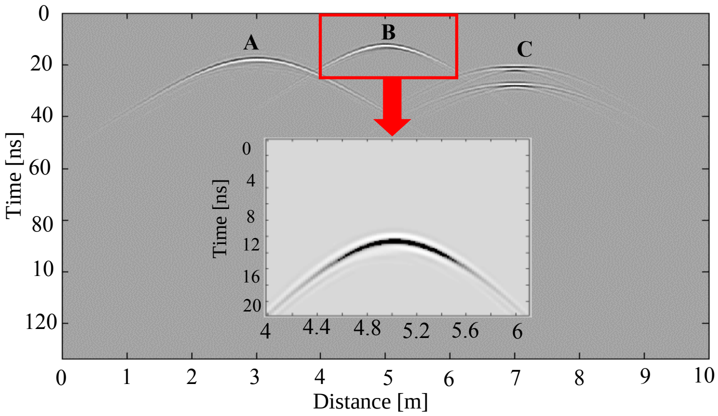

Fig. 5. Synthetic data of model

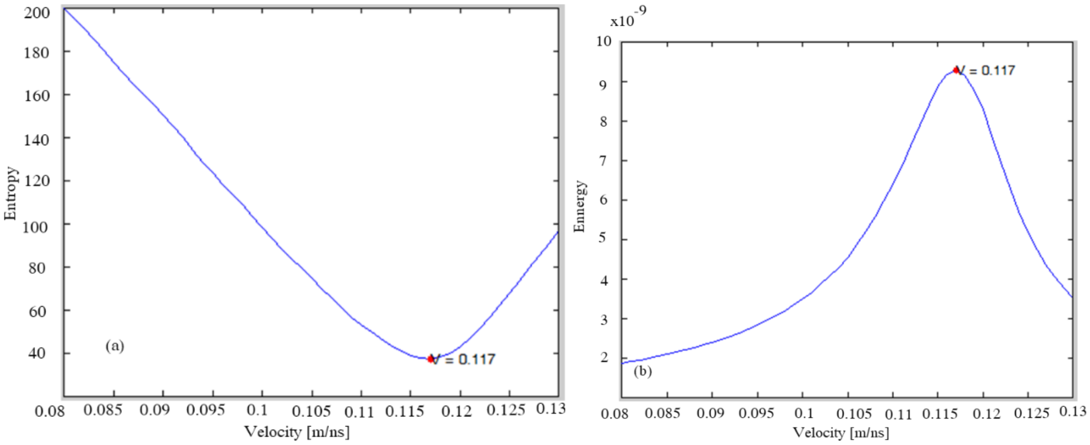

Fig.6. (a) Graph of entropy, (b) Graph of energy

Fig. 7 is the migrated section using the chosen velocity from fig. 6. The hyperbolic signals are converged into curves (objects A and B), the upper and lower reflected boundaries (object C). Consequently, the application of migration methods with entropy and energy to calculate velocity is highly reliable. With this velocity, we can obtain the best migrated section, from which the depth and size of objects can be identified.

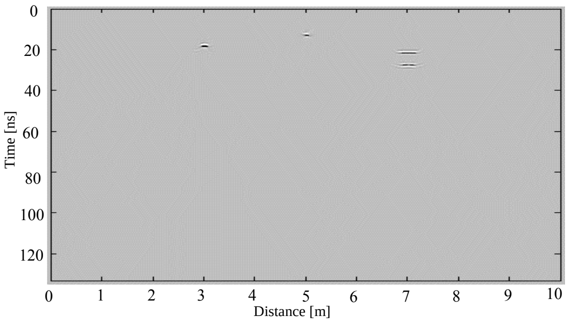

Fig. 7. Migrated section

Real data

GPR data are collected in District 4, HCMC (Vietnam) by Detector Duo with 700 MHz antenna. GPR section is 10 m long and has two water supply pipes according to the priori information provided by Urban Infrastructure MAT Company. However, the positions and depths of these two pipes were not determined. Measurement data is processed for basic steps before migrating: time correction, noise filter DC, dewow and amplification (fig. 8).

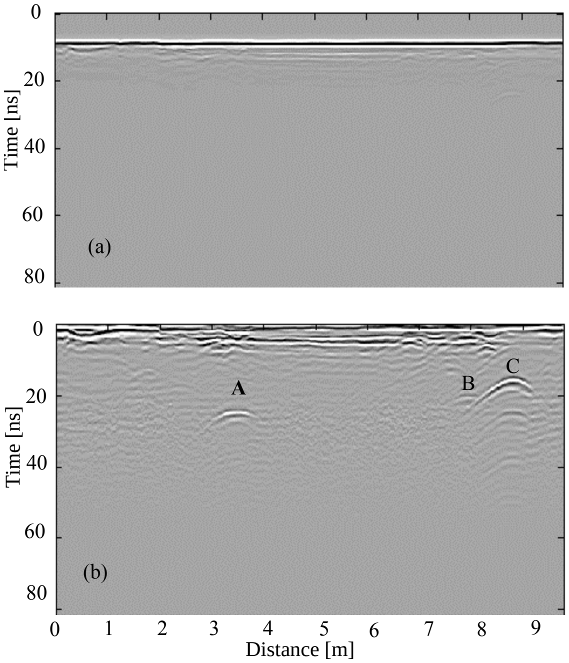

Fig. 8. GPR sections: (a) Raw data, (b) Processed section

Section 8b shows three reflected hyperbolic signals (A, B and C) at x = 3.5, 8.0, 8.8 m. Two signals A and C correspond to two supply water pipes provided by MAT company. The hyperbolic signal at B is a newly formed object that has not been updated in the priori information.

Combining migration methods with entropy and energy diagrams for each reflected signal, we determine that wave velocities corresponding to each position x = 3.5, 8.0, 8.8 m are $v_1 = 0.0785$ m/ns, $v_2 = 0.075$ m/ns, $v_3 = 0.0875$ m/ns (fig. 9). The error of velocity calculated by using entropy or energy is negligible.

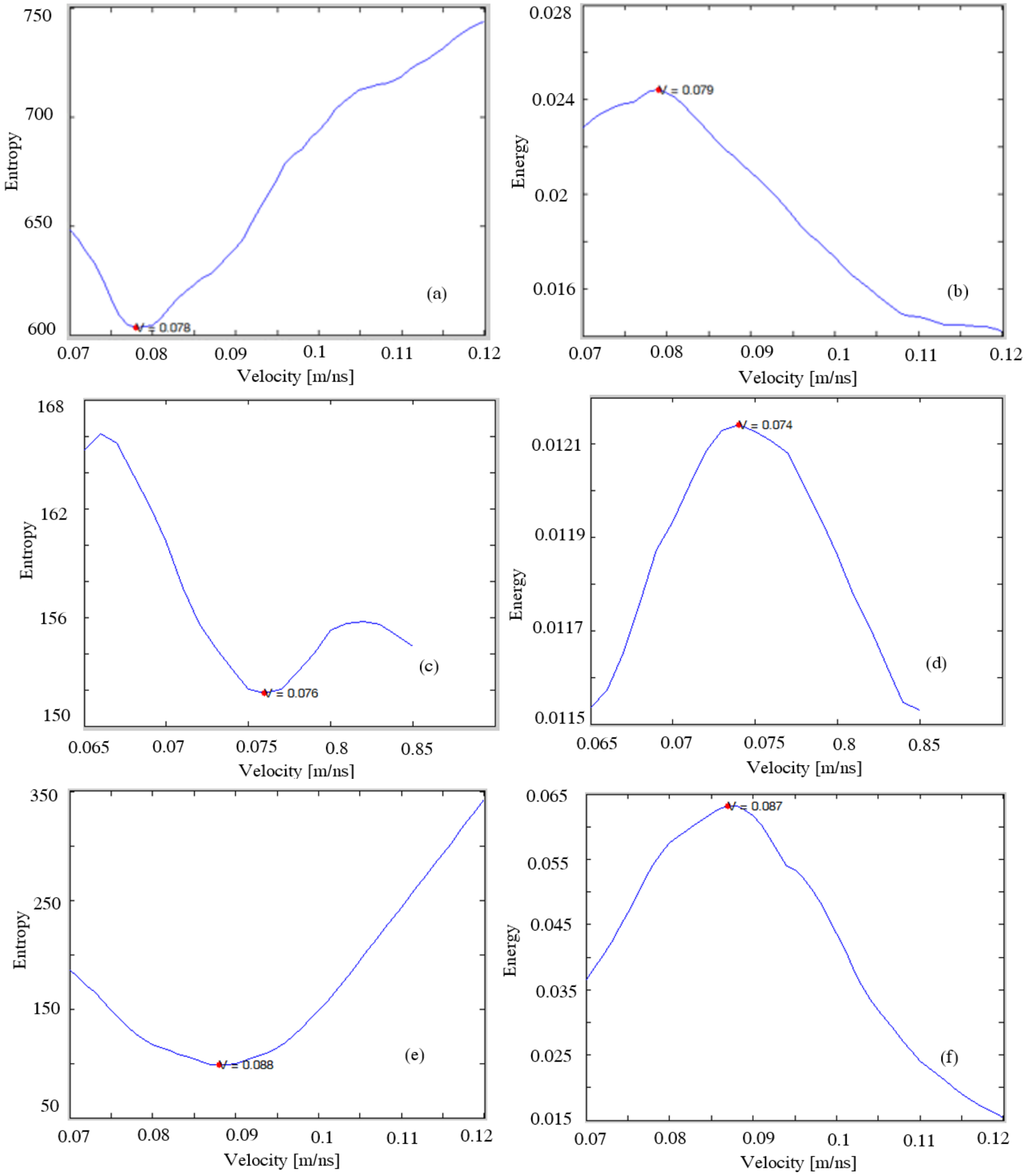

Fig. 9. Graph of entropy and energy: (a, b) Subject A, (c, d) Subject B, (e, f) Subject C

For each velocity, hyperbolic signal of the corresponding object converged (fig. 10). Based on this, the calculated depth and size of pipes are (1.0 m, 0.49 m), (0.75 m, 0.11 m) and (0.66 m, 0.14 m) respectively. These results are perfectly consistent with the priori information. The error is just 2% for pipe A, 6.6% for pipe C, and B is a new object added to MAT Company data.

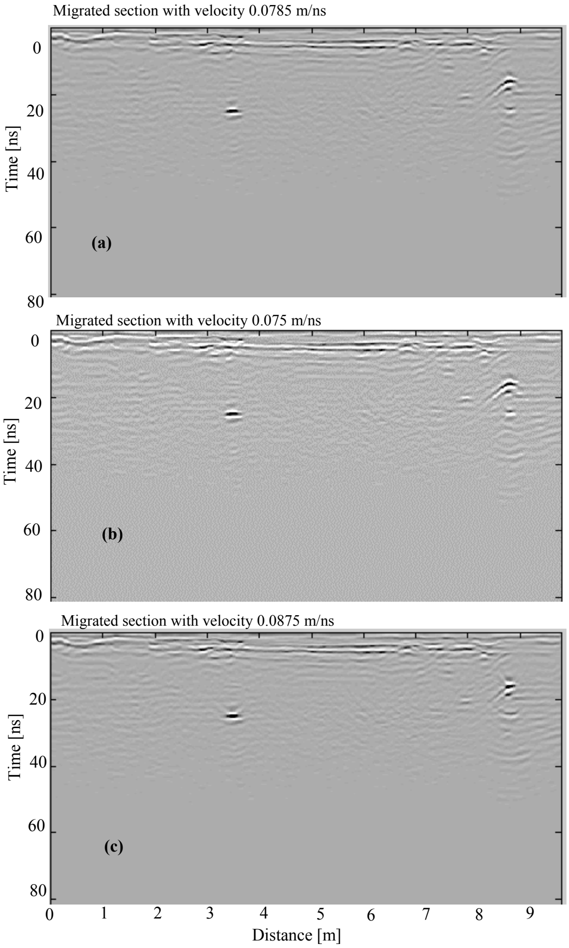

Fig. 10. Migrated sections

CONCLUSION

Migration techniques are not only effective methods in identifying reflected surfaces but also practical tools for determining electromagnetic velocity. Combining migration with entropy and energy standard can give more accurate velocity estimation, so that the problem of the depth and size of object is solved completely. We have tested this approach on theoretical and filed data, both of them show good results. We believe that this approach can support practically in processing GPR data, reduce processing time and serve the rebuilding of under-structure map in urban areas.

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