



King Fahd University of Petroleum & Minerals  
Earth Sciences Department

Report

----- GEOP 402

Senior Project Report  
Team Work Part

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# MODELING OF SEISMIC REFRACTION VELOCITY ALONG RUS FORMATION IN KFUPM

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## ABSTRACT

Seismic refraction is a commonly used geophysical technique in classical sense to delineate subsurface features, depth to bedrock, competence of bedrock, depth to the water table or depth to other seismic velocity boundaries. Recently, it has been used to 2D map of seismic velocity to generate a seismic tomogram for subsurface geology (Pullammanappallil and Louie 1994; Louie, Pullammanappallil et al. 1997). Due to exposed buried geology which made clear based upon the excavating works near the building 26 in KFUPM, Refraction Tomography based on the seismic refraction survey is conducted to understand spatial velocity changes through the exposed part of the Rus formation. . Based on that opportunity to have information on buried part of Rus formation which is because exposed due to excavation as noted above, we decided conducting a project in this area to compare their seismic refraction velocity model with real cross section. While making seismic refraction in working area is surrounded by difficulties and challenges it was very great informative chance for students. Five seismic refraction lines (profiles) were done in 3 different sites. Each student is responsible for one profile. In addition, each student build his profile design in which he determines the Geophone spacing, shot spacing, profile length and target depth.

In order to have a better visualizing of the 2D velocity model for each individual profile line, it is an important to choose the better software for the seismic refraction data processing. Data Processing following the data acquisition is next step before final step which is modeling. Different software is used for different steps in processing the data (i.e. Ixseg2segy, SeisOpt Picker). SeisOpt@2D is the modeling software used which is recently installed in the ESD PC Lab.

## I. INTRODUCTION

### A. Background on the Area of Study:

Dammam dome spatially lower Rus Formation in KFUPM campuse is the specific are of the study (Hariri and Abdullatif 2005).

Dammam dome has an elliptical shape with the following Formations; Rus Formation, Dammam Formation, Hadruk Formation, Dam Formation and Quaternary coastal deposits, Sabkha plains and Aeolian sands. Dammam dome has an age varies from Palaeocene to middle Miocene. See Figure.1

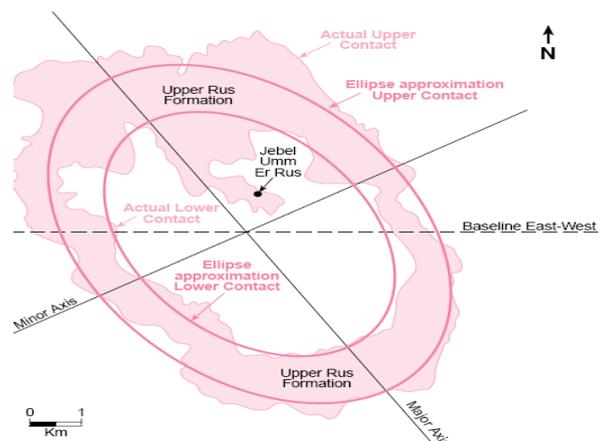
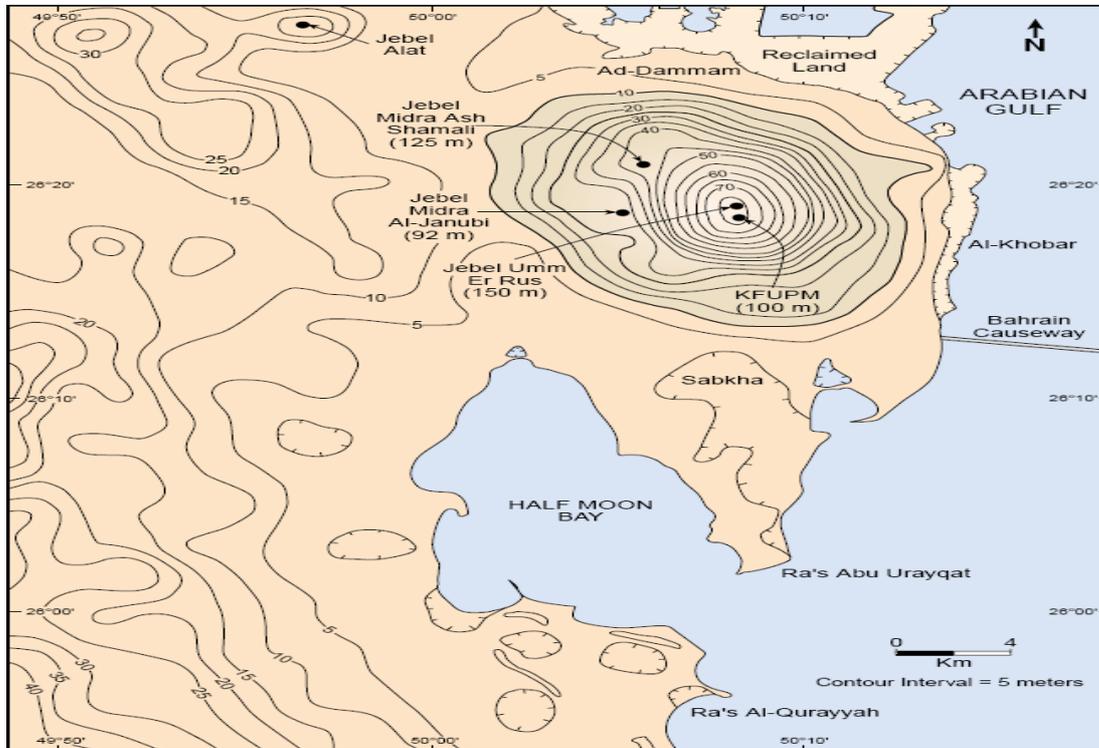


Figure.1 Elliptical shape of Dammam dome (Weijermars, R. 1999)

The Rus strata dip ( $1^{\circ} 6'$ ) almost with the same angle as the topographical slope, this causes an extensive surface exposure of it (56 m thick). The top of the Rus Formation disappears under the strata of the Dammam Formation only when the topographical slope.



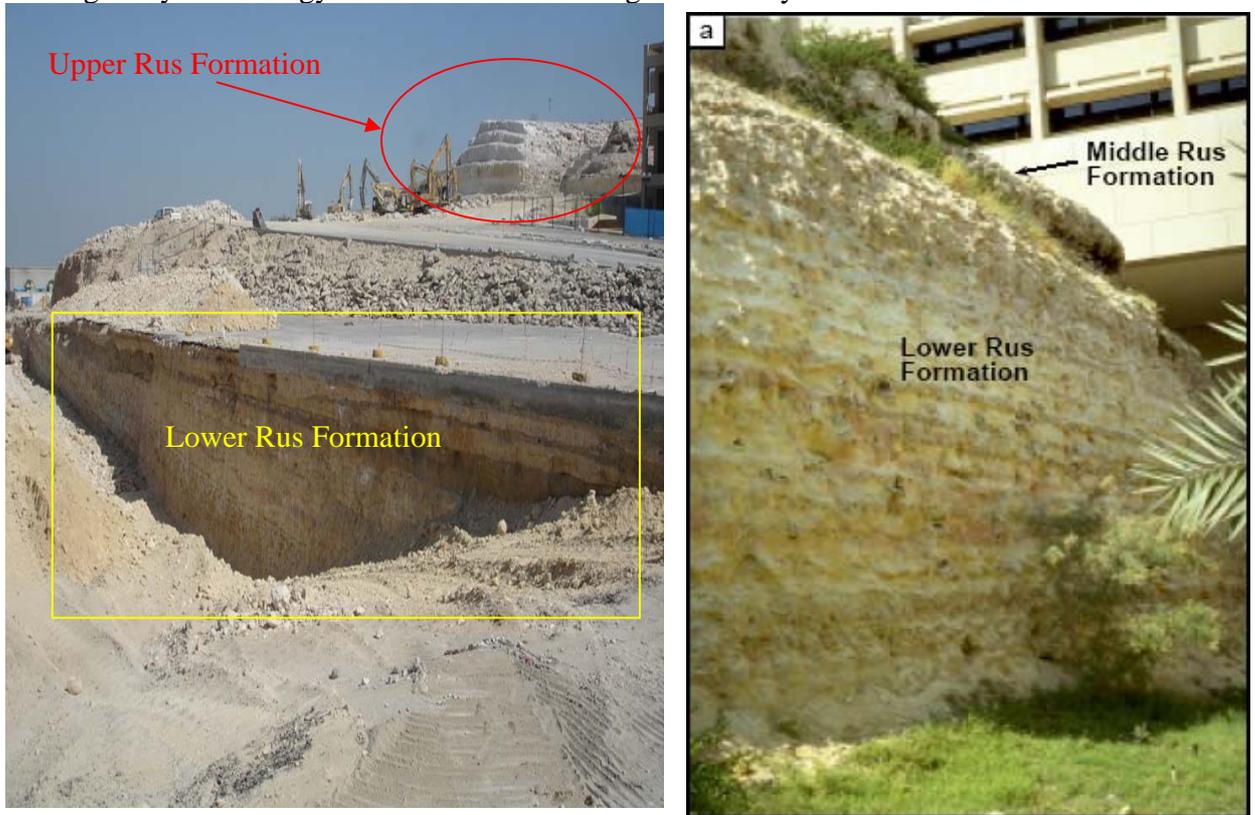
**Figure.2** Contour map showing the elevation variation with in the Dammam dome included the Rus formation, also the KFUPM position is clear on the map (Weijermars, R. 1999)

**The Upper Rus** Unit 3, which is proposed by Powers et al. (1966), consists of 3.6 m thick, white, soft chalky, porous limestone. Calcarenite occurs at the top, which gives way to tan-colored gypsiferous and calcareous shale and interbedded marl found in the base of the Dammam Formation.

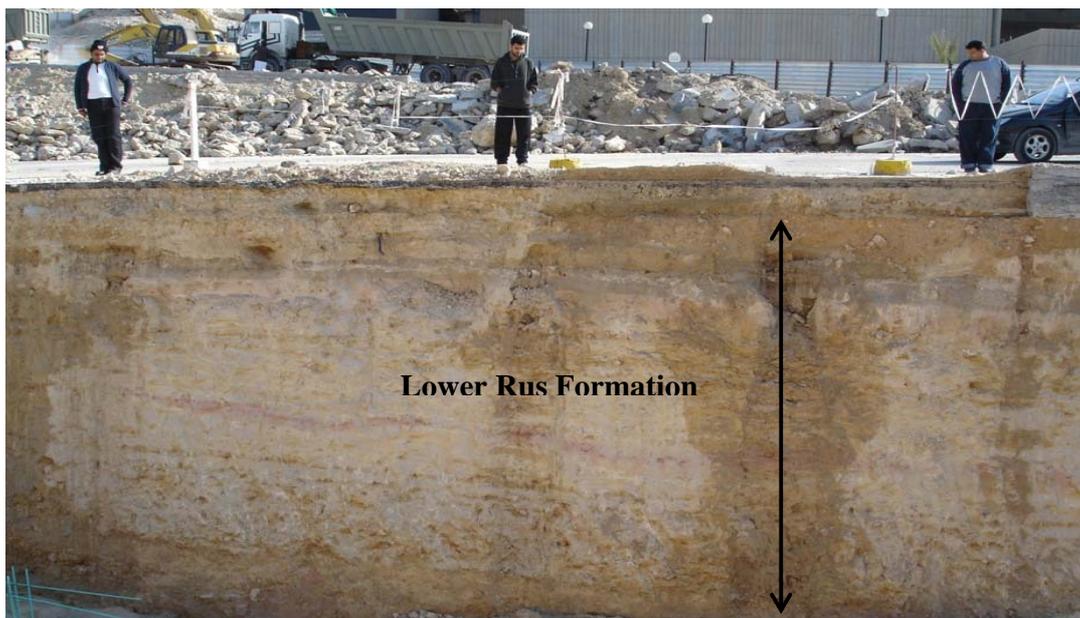
**The Middle Rus** Unit 2, which is proposed by Powers et al. (1966), consists of 31.8 m of alternating light-colored marl and limestone beds. The unit contains quartz geodes as well as masses of irregular gypsum crystals. The unit may also comprise fine crystalline anhydrite with interbedded green shale and minor amounts of dolomitic limestone, or grey marl with coarsely crystalline calcite and interbedded shale and limestone.

**The lower Rus** which is proposed by Weijermars (1999) is made up of marls and thin diplomatic limestone beds with plentiful slumps and geodes. The upper part of the lower Rus is vuggy windswept calcarenite with plentiful mud balls. Jointing is more pronounced in the upper part of the lower Rus Formation because of the nature of the rock. Our target is to understand spatial and depth velocity of the **lower Rus Formation** (See Figure.3-a, b) as: A) we will look at the range of velocity structure through the crossed lines b) then, we will look for how and where velocity is changed. C) Finally, we

will compare the exposed geology with the resolved geology to understand how surfaced heterogeneity or lithology can be a factor effecting the velocity.



**Figure 3. a.**This is taken from the KFUPM compass in front of building 26. It shows the Upper and the lower Rus Formation. **b.**Basal, marly unit of Lower Rus Formation seen overlain by ledge forming, jointed, massive limestone of the Middle Rus. Stratigraphic sections exposed are below Building 21. (Weijermars, R. 1999)



**Figure 4.** exposed corross section of lower Rus formation near B.26

Figure 4 shows clearly the features of layering of lower Rus formation along. There are red layers indicate Iron (Fe) in.

## B. Introductory To Seismic Refraction Technique

### a. Principle

The seismic refraction method utilizes seismic waves traveling through different parts of the subsurface. A seismic source is used to generate compressional waves, which is measured by a seismograph and a series of evenly spaced sensors (Reference, for example, Berger or Reynolds or Theldford, a name of book you have). The geophysical field measured property by exploration refraction seismograph is to have data on travel-time on seismic waves, which is used to determine seismic velocity. In seismic refraction surveys, two kinds of waves are of importance, namely the P-wave (a compressional, longitudinal wave) and the S-wave (a shear, transverse wave). P-waves propagate at the highest velocity of any seismic waves and are therefore commonly used to pick the first breaks of seismic waves that propagated through earth materials. Since travel time equations can be derived as a function of velocity, depth to a refractor such as bedrock can be determined in a seismic refraction survey.

Head waves involve energy that enters a high velocity medium (refractor) near the critical angle and travels in the high velocity medium nearly parallel to the refractor surface. Since seismic waves move faster in the high velocity medium than the upper, at some point, the wave refracted along that surface will overtake the direct wave. This refracted wave is then the first arrival at all subsequent geophones, at least until it is in turn overtaken by a deeper, faster refraction. The difference in travel time of this wave arrival between geophones depends on the velocity of the lower layer. If that layer is plane and level, the refraction arrivals form a straight line whose slope corresponds directly to that velocity. The point at which the refraction overtakes the direct arrival is known as the critical distance and can be used to estimate the depth to the refracting surface (see Figure 5).

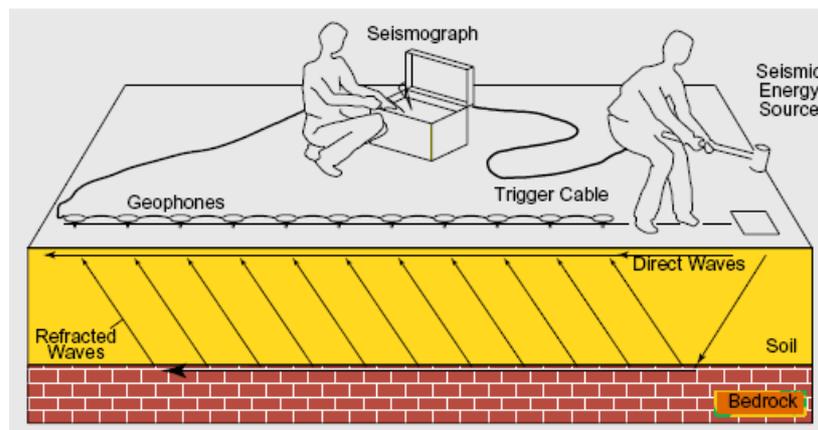


Figure.5 P-wave propagate through the first layer till reaching the second in which it propagate and then refracted to the first layer again. (NGA, 2000)

The results of a refraction survey are based on the times of arrival of the initial ground movement generated by a source recorded at a variety of distances. Later arrivals are discarded. These are then interpreted in terms of the depths to subsurface interfaces and the speeds at which motion travels through the subsurface within each layer. These speeds are controlled by a set of physical constants, called elastic parameters that describe the material.

### **b. Applications**

Seismic refraction method can be used for many purposes depending on the need. But the regular application are described in brief as follows:

1. Mapping bedrock topography
2. Determining the depth of gravel, sand or clay deposits
3. Delineating perched water tables
4. Determining the depth to the water table
5. Detecting subsurface caverns
6. Estimating rippability
7. Detecting shallow faults and fracture zones
8. Detecting large boulders
9. Monitoring time-varying changes in elastic properties

### **c. Equipments**

The accessories of equipment for that we used is listed as below: (See **Figure.6**)

1. Seismograph (i.e. ES-1225)
2. Laptop
3. Sledge Hummer
4. 12 Geophones
5. Wire Connection (**connecting Geophone - Geophone & Geophones -Seismograph**)
6. Power Source (i.e. car battery)
7. Shot Plate

Unfortunately, we faced some constraint on the equipments used. We had to work with an old model of Exploration Seismograph which did not give high quality data due to constrain of sampling rate which is 0.250 milliseconds and time period which is limited to 2 milliseconds. As a result of low quality data, we faced up some problem regarding data transfer and export the data provided old-type format (SIP), which is not compatible with new software working with SEG-data. Anyway, considering our purpose to have a field experience, we have done the best we can to conduct something which might be significant from the point of scientific funding

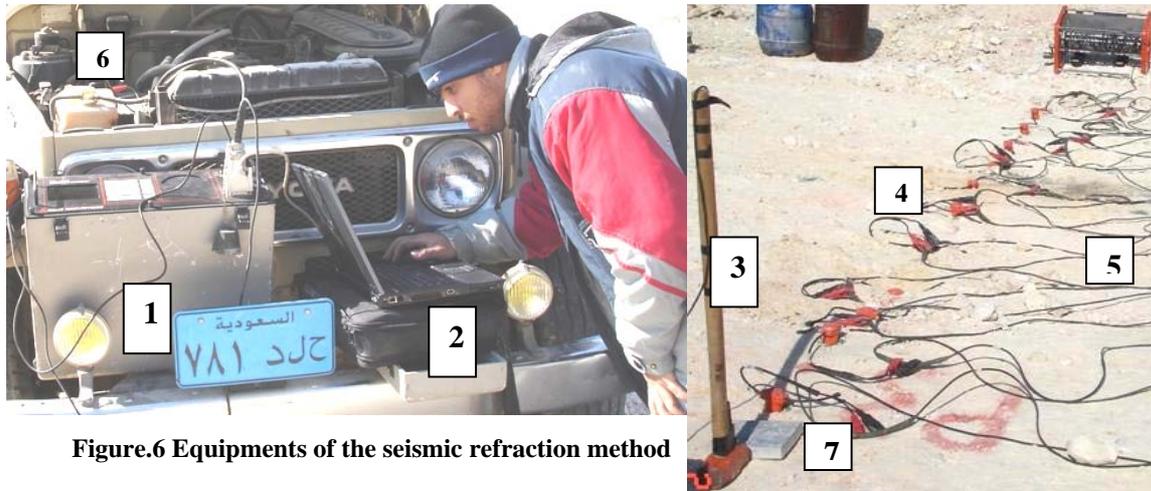


Figure.6 Equipments of the seismic refraction method

### C. Software

The strength for any kind of work is based on the popular type of software. It is an important to choose the better software for the seismic refraction data processing in order to have the better visualizing for the velocity model. Different software can be used to developed velocity model based upon seismic refraction data for different need if registered copies are valid for use of project. For example, in this project **Ixseg2seg** software is used in processing to filter the data and to convert the format. Moreover, **SeisOpt Picker** software used to pick the first time arrival and to enter the geometry of the designed profiles. The main software used is **SeiOpt@2D** for modeling and optimizing. Those above software is firstly used in KFUPM since our course design and objective of our work is proposed as a justification for purchasing some of those popular software which made us to analyze data in making some sensible results of our field work.

SeisOpt@2D is an automatic refraction interpretation package that contains modules for performing velocity optimization and visualization, virtual survey design and output report quality images. Also Seisopt@2D can be described as the Graphical User Interface to the suite of modules for performing the velocity model optimization and visualization, interactive seismic survey design and outputting postscript images of the results for printing. (Manual of SeisOpt Picker)

SeisOpt@2D uses only the first-arrival travel times and the survey geometry to derive subsurface velocity information. For this reason, accurate picks are important but it depends on the capability of used exploration seismograph. Even higher sampling rate (0.125 millisecond) is suggested for data acquisition, we could not conduct collecting such a data of high quality since the exploration seismometer we used was appeared to provide a data of lower sampling which made us difficult in picking the data. Thus, some of problem, we faced up in picking, which made impossible to see first arrival of P-waves.

It uses a nonlinear optimization technique called adaptive simulated annealing and it involves forward modeling (Pullammanappallil and Louie 1994), which does not require an geological input model. Test velocity models are created under the atomized option in the highest mode through which travel times are calculated. These calculated initial velocity model based upon travel times, are compared with the observed data, are improved with manual input for increasing the depth resolution. Testing every possible velocity model would take far too long, so SeisOpt@2D uses Optim's proprietary algorithm to search through only a small percentage of the many possible models, yet still find the best model. It is called an optimization because the discrepancy - or error - between the calculated and observed travel times is optimized. Some of those created velocity models within differences in size error with %1 are expected to resolve closely each other. In this case the optimal solution among the velocity models with the minimum travel-time error is proposed for best representative velocity model for subsurface geology

## **II. DATA ACQUISITION**

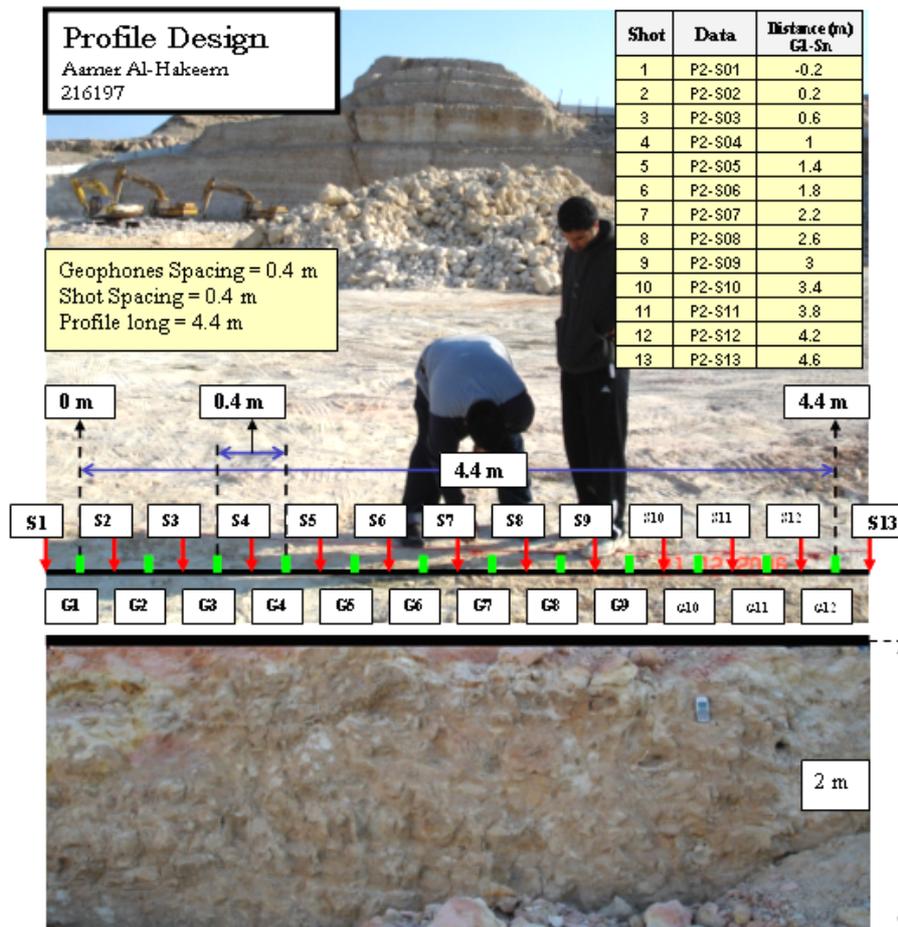
### **A. Field Work Procedure**

#### **a. Important Decision before Proceeding**

Each seismic refraction spread (profile) consists of a series of 12 or 24 geophones placed along the line at a set distance or geophone interval but we had to use 12 channels due to number of geophone constraints in seismograph. In general, the geophone interval 4 to 23 meter length depending on the desired resolution and the desired depth of exploration. In our case of study the length of the different five profiles ranged from 4 m to 9.9 m because we need to get high resolution model and the target depth. Due to the geometry of refraction (governed by Snell's Law), it is necessary for the length of the seismic spread to be approximately 3 to 5 times the depth of the overburden in order to detect the primary refractor (i.e., the bedrock). (NGA, 2000)

Several options are available for the impulsive seismic source and the number of shots. A sledge hammer, which is simply used as an energy source, may be effective if the bedrock is not deeper than 9 or 12 meter, and if the overburden is sufficiently consolidated. A higher energy source, such as 8-gauge seismic shells or small charges of a two-component explosive, may be required if the overburden is soft and poorly consolidated, or if the bedrock interface is significantly deeper. In order to get more seismic trace data, the number of shot is increased. (NGA, 2000)

Finally, a profile design (Figure.7) must be made depending on the area of survey and the rules of the seismic refraction method explained before. The profile design includes the spacing between Geophone-Geophone, shot-shot and Geophone-shot, length of the profile, the target depth and the nature of the survey area.



**Figure.7** Profile design is illustrated for profile 2. The receiver distance is 0.4 meter regarding the target depth of 2meter. The number of shots are 13, which is more than minimum required number, to resolve velocity better.

### b. Main Steps In the Field

We are giving the steps to make clear followed ways in refraction seismic tomography work in the field. The steps in the following are seven as:

**STEP1:** Lineation and labeling the geophones and shots positions depending on the profile design.

**STEP2:** Setting up the Geophones in their specified positions.

**STEP3:** Wire connection between Geophone-Geophone, Geophones-Seismograph, Seismograph-Laptop and Power source-Seismograph

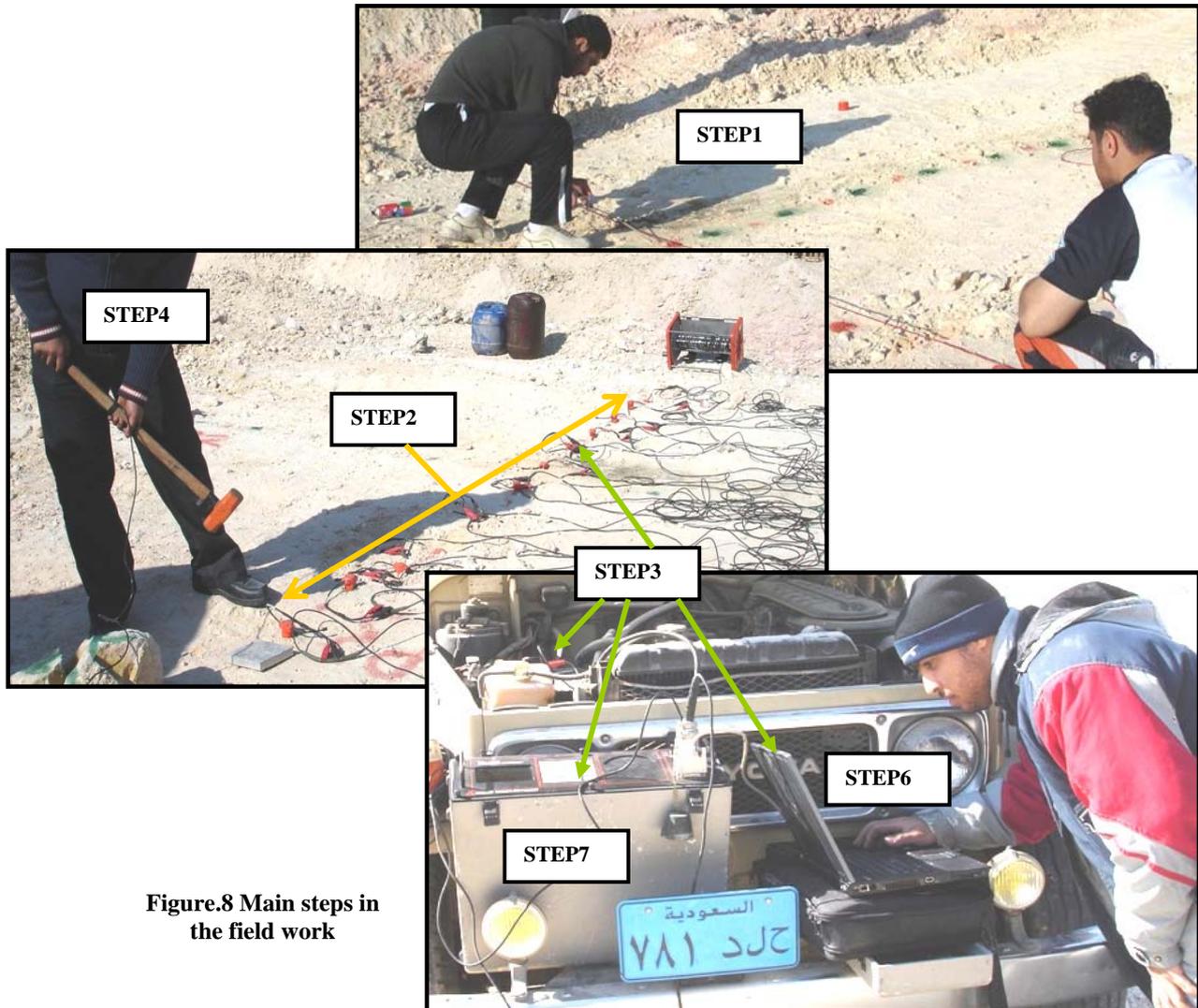
**STEP4:** Making an impulsive seismic source by hitting the shot position by a sledge hammer.

**STEP5:** Receiving the shot by the Seismograph and examining the recordings.

**STEP6:** Sending the first shot recording, as a data file, to the laptop using SIP program.

**NOTE:** the last 3 steps are repeated depending on the number of shot needed.

**Figure.8** explains the steps of the seismic refraction method in the field work.



**Figure.8** Main steps in the field work

## **B. Challenges**

On the field we faced some problems in acquiring our data. The first problem was to fix the geophones in the ground, we face this problem in almost all the geophones within the profiles, and the ground material was hard especially the first profile asphalt and the hard material as well. We solved this problem by making hole to the asphalt by a jackhammer (Figure 9b). For Profile1 we made holes 10 to 15 cm within the asphalt and for the other profiles if necessary we just tried to shake the ground in order to be easier for us to immerge the geophones (Figure 9b,c). We faced another problem which is the electric power source (Figure 9.d), we asked the KFUPM maintenance for help but there was no response then we solved that by renting electric cords from out side shop which is 150 m length.



**Figure 9. (a) Profile. 1 marking the position of the Geophones & Shot Point, Before digging asphalt. (b) An example in holding the Jackhammer that we (c) Geophones are Set up after digging asphalt (d) electric source found within students dorm buildings to be used in P4,5. before, for P1,2,3 electric power from Building 26. (e) Profile 2 near to it a truck from the project of the parking lots. The source of the noise (f) Dr. Oncel's Laptop used to acquire our data and transfer the data to it**

Another problem was the barking lot project workers they are starting from 8:00 am tile 5:00 pm every day except Friday, even on Friday they didn't stop from their work tile 11:00 am, after that time we started our work. (Figure 9e)

The last Problem was the data transfer from the Seismograph. None of the team (students) has a laptop, so we tried to barrow one from the ES department, they gave us one not compatible with the Seismograph. So, we used Dr. Oncel's Laptop. (Figure 9f)

### C. Data Processing

In order to model the seismic refraction data in SeisOpt@2D, the data must be prepared, but there is new model of exploration seismograph that provides filtered data (e.g. Smartseis seismograph) and useful data format for new professional software such as SeisOpt@2D. The main steps of preparation are as follows:

#### a. Filtering

The data is filtered by Band pass filter frequencies using any professional software (i.e. Ixseg2segy) (see Figure.10). the range in filtering is automatic in range for low band from 10,000 to 20,000 and high band from 160,000 to 220,000). It is difficult picking the first time arrival without filtering the data (Figure.11-a,b).

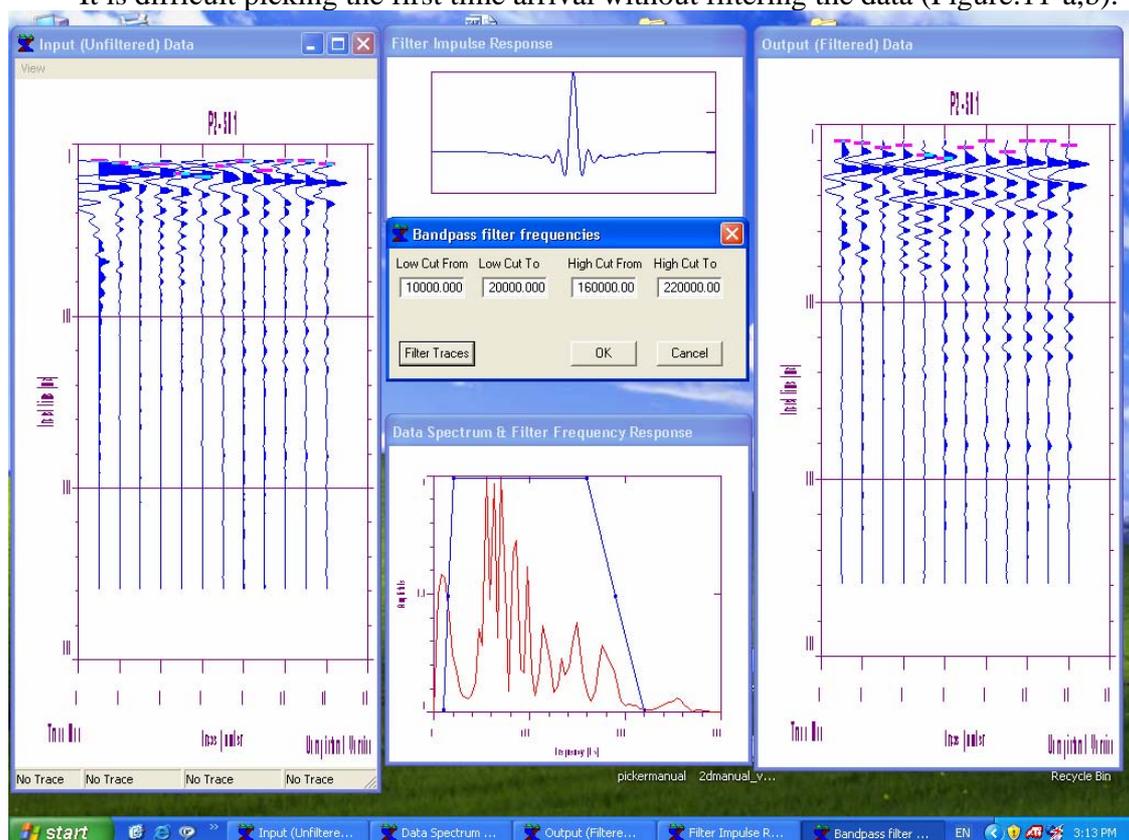
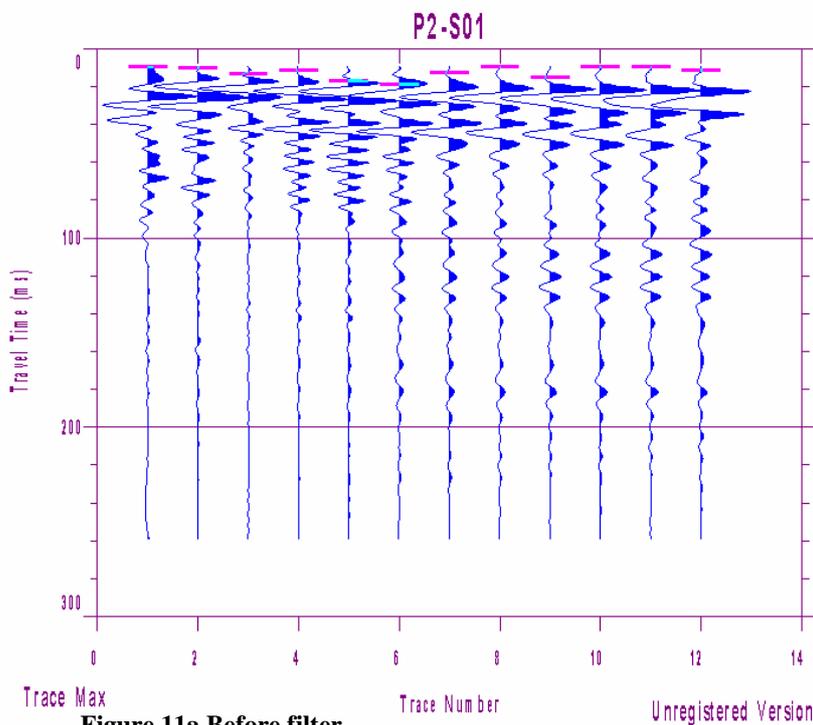
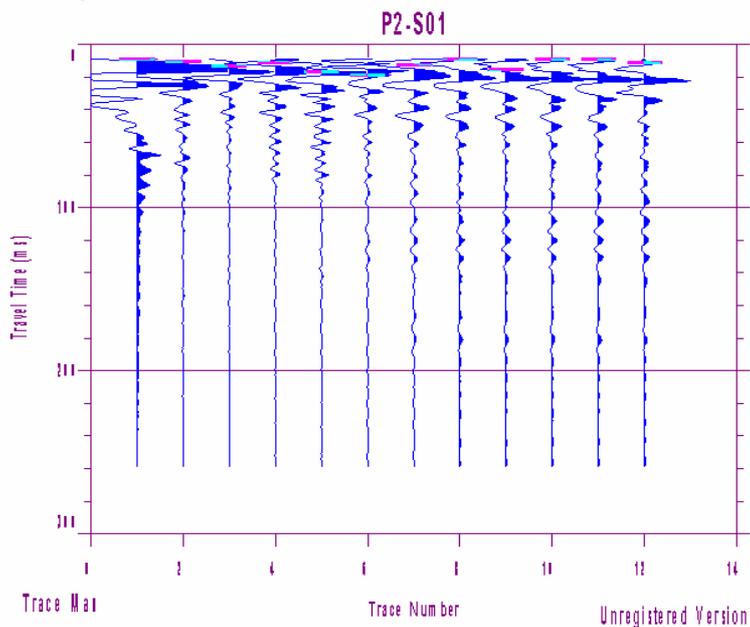


Figure.10 Bandpass filter frequencies using Ixseg2segy



**Figure.11a Before filter**



**Figure.11b Data after filter. automated picking is worked as an immediate action of this software but we made hand based filtering since some of picked is delayed by this program, which is clear in the given above example.**

### **b. Converting Data Formats**

Converting from SEG1 to SEG2 by the ixseg2segy Program and another conversion from SEG2 to SU format this is done by the SeisOpt Picker Program, the SU format is the needed format for our processing. See Figure.12, 13

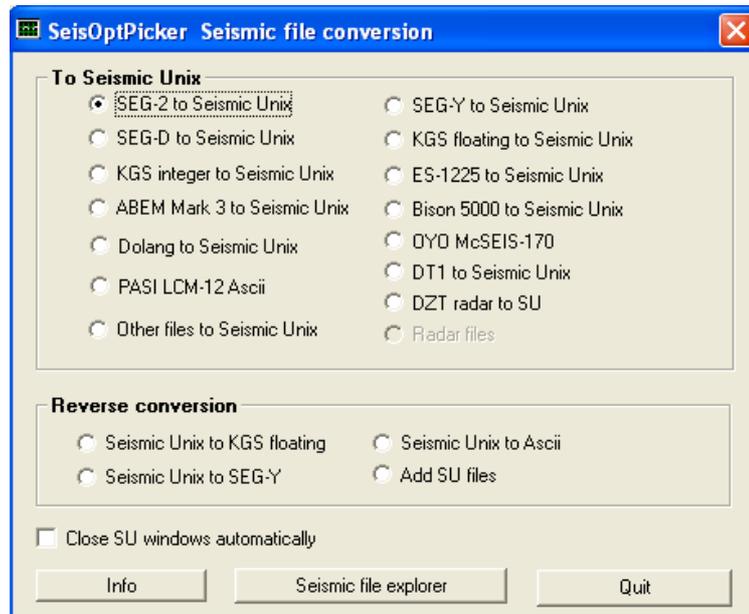


Figure.12 SeisOpt Piker can convert different formats SU and reversely

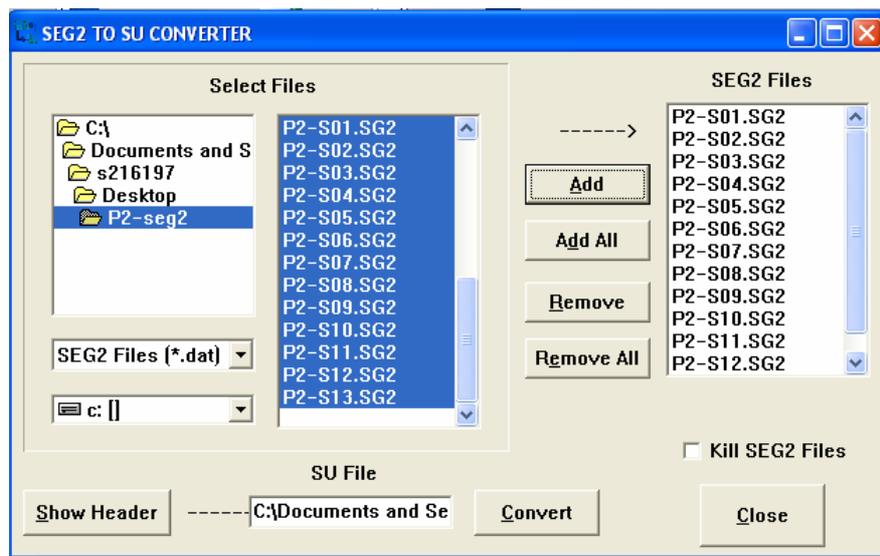


Figure.13 SeisOpt Piker window for converting from SEG2 files format to one file in SU format

### c. Picking the first time arrival

SeisOpt Picker (Figure.14) is spatial version from SeisOpt software used to pick the first time arrival for each recording. So, after filtering the data the first arrival is picked for each trace and saved.

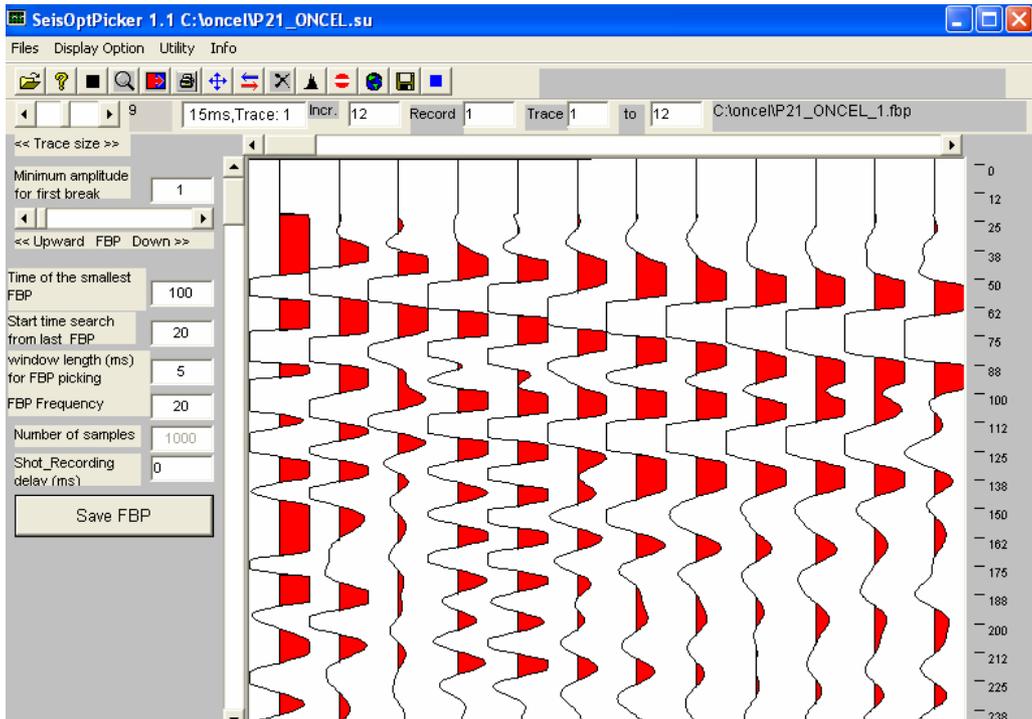


Figure.14 SeisOpt Picker- Reading SU of Profile 2

**d. Entering Geometry**

In order to make a direct relation between the seismic refraction data and the parameters of the profile design, it is important to enter this parameter such as the Geophone spacing, the shot spacing and Geophone-shot spacing. (Figure15)

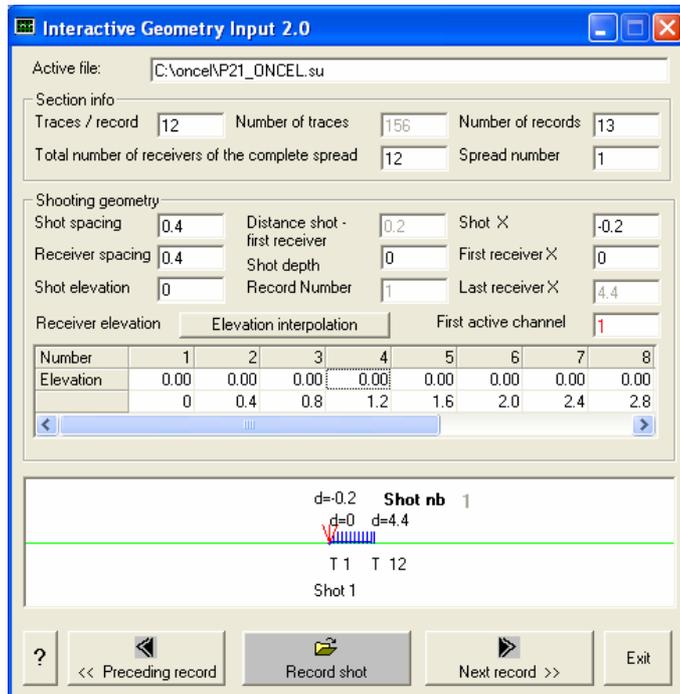
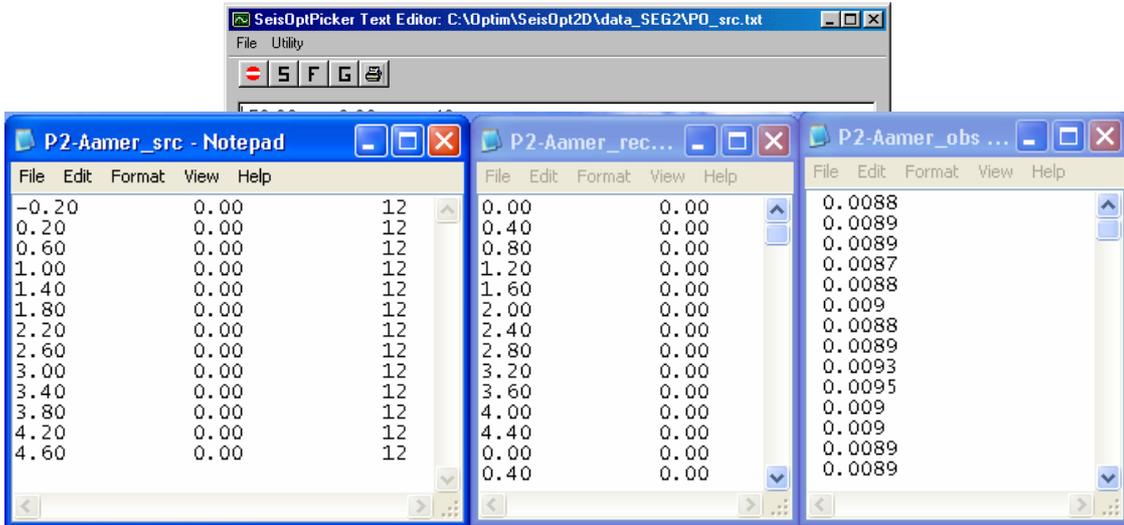


Figure.15 Entering Geometry, checking the survey line

**e. Save The Seismic Data**

Seisopt@2D can read only spatial type of data “\*.txt” also in 3 different files (\_src, rec, \_obs) these files is prepared by the SeisOpt Piker.(Figure.16)

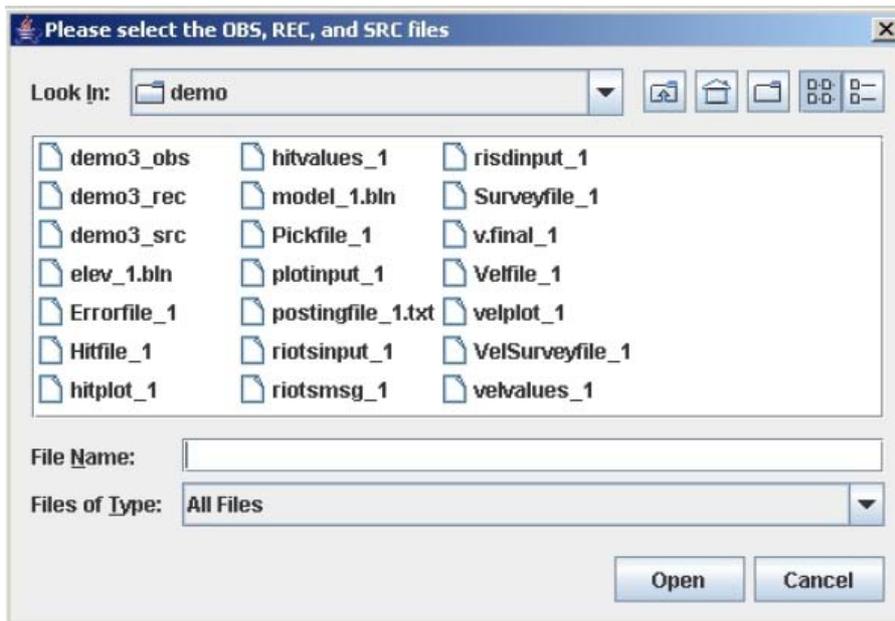


**Figure16. shacking the three (\*.txt) files to be saved**

**f. Modeling**

**Step.1**

After input the three files (\_src, rec, \_obs) in the SeisOpt@2D (Figure.17) the window of the software is opened with no data.(Fig.18).



**Figure.17 input the three files**

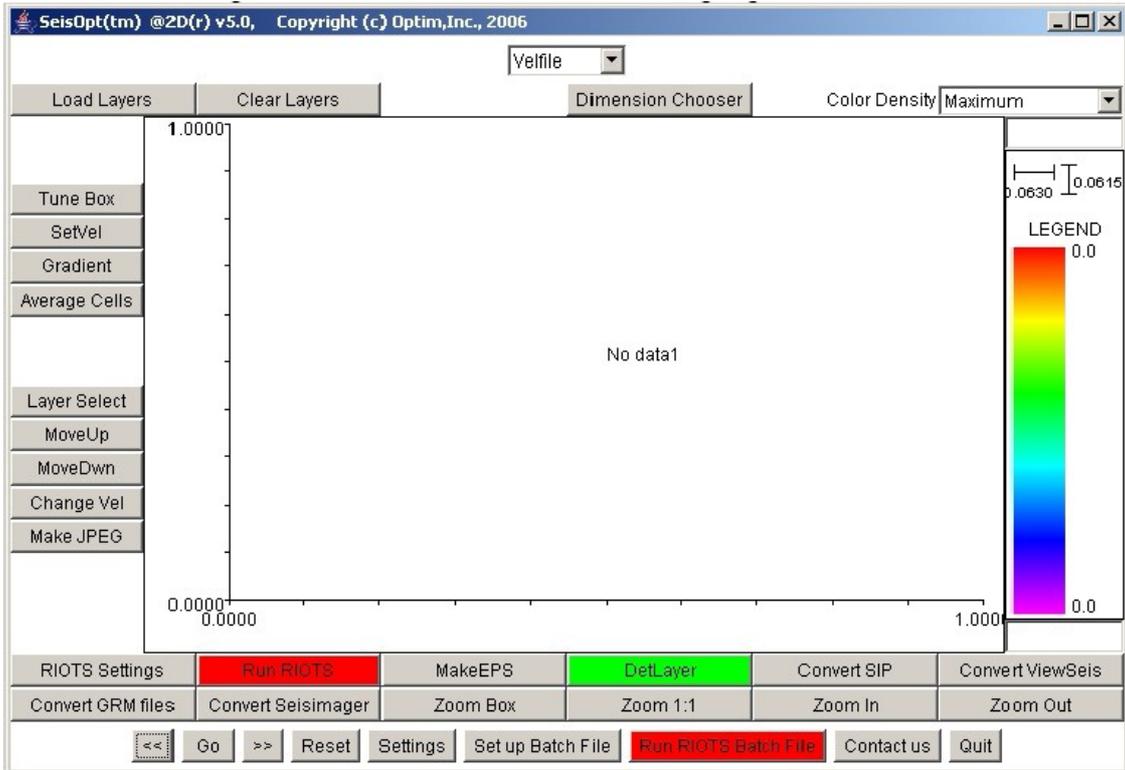


Fig.18 SeisOpt@2D window with no data

## Step 2

Filling the parameter in RIOTS setting (Figure.19).

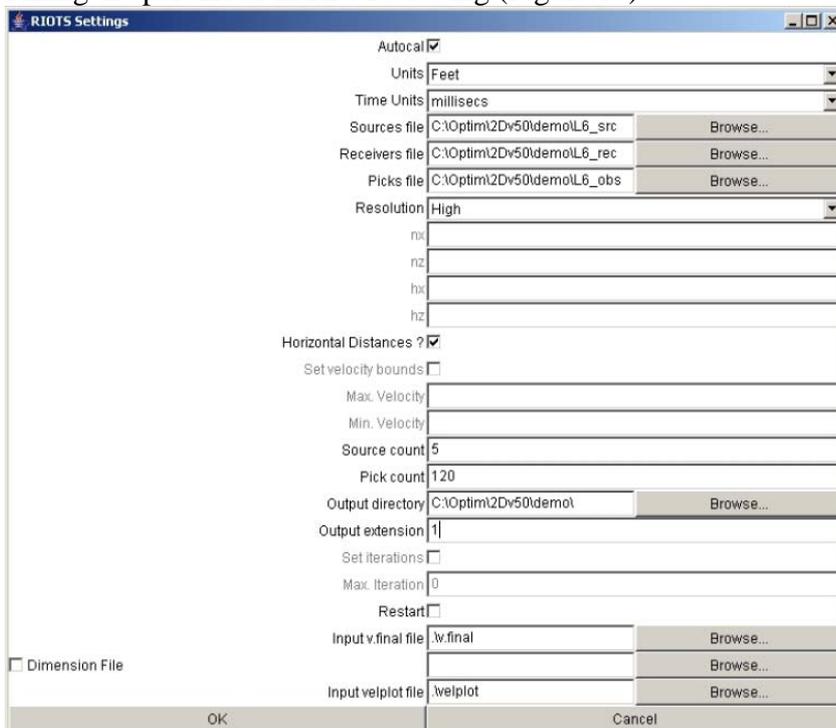


Fig.19 RIOTS setting

### Step 3

Running RIOTS to get the estimated parameter with the error of the model, after, high number of iteration done by the software. (Figure.20)

```
*****
RIOTS - Refraction Inversion and OpTimization Software
Part of SeisOpt @2D Version 5.0
Copyright (c) Optim, Inc., 1998-2006

Visit us at http://www.optimsoftware.com/

For Support Contact support@optimsoftware.com
*****

***** Auto Calculation of nx, nz and h *****
Nearing completion..., iterations = 38841
hitgen: good = 64, total = 156, ratio 0.410

Maximum velocity in model= 7523.056 m/s
Minimum velocity in model= 17.380 m/s

Parameters used for this run were
nx=35 nz=22 hx=1.500000e-001 hz=7.500000e-002 m and Highest resolution
(res=5)

Least-square error between picks and calculated times
through the final model = 3.207554e-006 s^2

Your picks and fits are in seconds

Output files WITHOUT extension written to the directory from
which SeisOpt @2D was launched AND
Output files WITH extension _report written to the directory C:\Documents and
Settings\s216197\Desktop\final-P2\velocity model\

This run of RIOTS took 4 minutes

Done
```

Figure .20 Progress, Auto calculation of nx,nz,hx, hz

### Step 4

By pressing bottom “GO” the seismic refraction velocity model well be in the SeisOPT@2D window(Figure15). Also, different features of the model can be visualized. (see Figure.21)

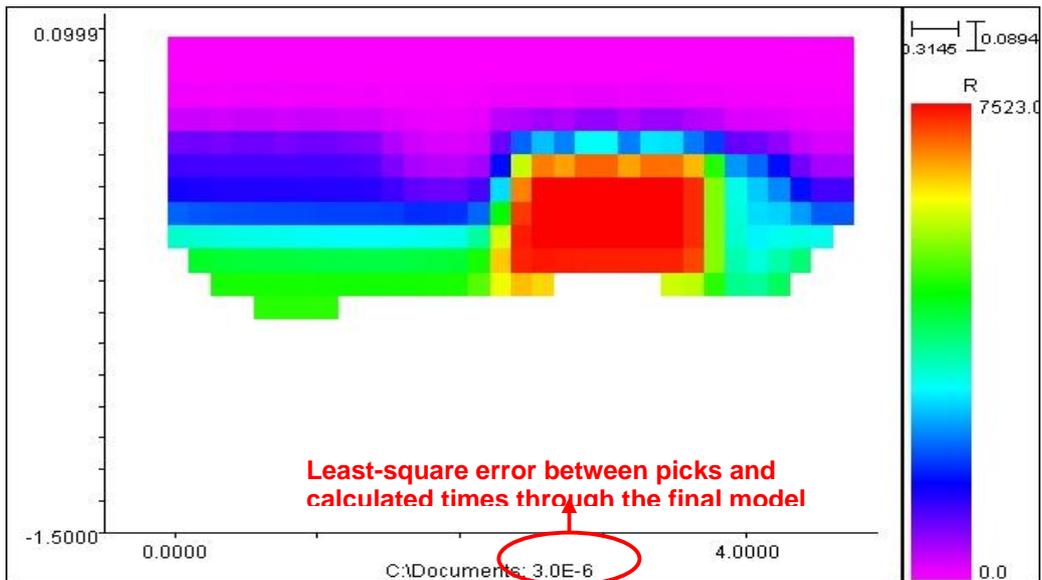
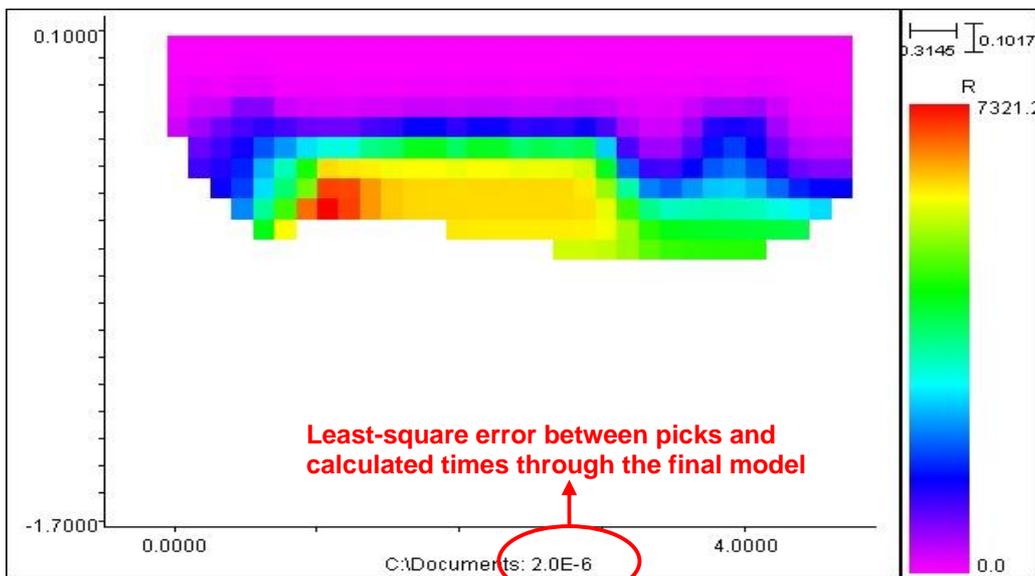


Figure 21. The seismic refraction velocity model of the profile data with Auto calculation of nx,nz,hx, hz

### **Step5**

Entering parameter manually in the RIOTS setting for (nx, nz, hx, hz). These parameters can be taken from the progress of the first model. Different estimated values of nz are interred to get the best model with the lower error. The model in Figure.22 is the least error of many different models that are run manually by entering different nz values.



**Figure 22. the seismic refraction velocity model of the profile data with manually entry of nx,nz,hx, hz**

## **CONCLUSION**

It was a good chance in using seismic refraction technique in order to understand the geophysical field. Obviously, Geophysical processing are very complicated, because, different Geophysical technique needs different professional software for different purposes. In fact, there are lots other applications of SeisOpt@2D that are not used because that is the first seismic refraction velocity modeling we do.

This report is the team work part of the final term report of the senior project course (GEOP 402). There is also individual part of each student. The individual part includes the final results of processing and modeling for each one of the five profiles.

## Acknowledgment

This project is done by the students Group of Senior Project (GEOP 402) under the support of ESD, supervision of their course instructor Dr. Ali Oncel and cooperation of the ESD Geophysical technician Abu-Jehad Muhammad Ahmad.

Thanks to the Senior Project Instructor Dr. Ali Oncel for his continues support. It is great that he brought this new software (SeisOpt) to the ESD PC Lab. Also, we are grateful to (Abu-Jehad) Mohammad Ahmad, ESD Geophysical technician, for his cooperatively.

We acknowledge the company of *INTERPREX* whom provided a free-copy of *Ixseg2segy* software for us to use our filtering.

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