

**LINEAR SEMBLANCE VELOCITY ANALYSIS IN THE T^2-X^2 DOMAIN:
CONCEPT AND APPLICATIONS TO SYNTHETIC AND REAL SEISMIC
DATA**

BY
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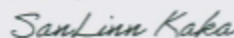
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To my mother... who taught me to share and overwhelmed me with her kindness and tenderness.

To my father... who has left our world and continues to help me with his guidance.

To my brothers and sisters... for their continuous help and assistance.

To my wife.... who has filled my life with passion and strength to overcome problems.

To my children... and my heart pounding.

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LIST OF ABBREVIATIONS

CMP	:	Common Midpoint
RMS	:	Root Mean Square
NMO	:	Normal Move Out
CVS	:	Constant Velocity Stacks
AVO	:	Amplitude versus offset
P-Wave	:	Compressional Body Wave
SV-wave	:	Shear body wave - polarized in the vertical plane
SH-wave	:	Shear body wave - polarized in the horizontal plane

ABSTRACT

Full Name : Saleh Saeed Al-Zahrani
Thesis Title : Linear Semblance Velocity Analysis in the t^2 - t^2 Domain: Concept and Applications to Synthetic and Real Seismic Data
Major Field : Geophysics
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Two types of velocities, NMO, and stacking velocities, which are considered similar in the case of a short spread, are indirectly obtained from seismic reflection data. The calculation and analysis of the stacking velocities are important for retrieving enhanced seismic data stacks. The main objective of this study is to apply the squaring technique to common midpoint (CMP) gathers and analyze this technique.

Selected synthetic and real 2D seismic datasets were squared in the offset and time domains to obtain linear events, which were used for velocity analysis. Velocity spectrum scanning for linear events was used to estimate the velocities. The results show that stacking velocities picked using the squaring technique are similar or better than those selected conventionally (i.e., using the hyperbolic technique). Furthermore, squaring techniques often provide a better vertical velocity resolution. Therefore, the squaring technique provides another method for picking stacking velocities and is comparable and compatible with conventional methods.

ملخص الرسالة

الاسم الكامل: صالح سعيد الزهراني

عنوان الرسالة: تحليل سرعة التماثل الخطي في مجال T^2-X^2 : المفهوم والتطبيقات على البيانات الزلزالية الاصطناعية والحقيقية

التخصص: الجيوفيزياء

تاريخ الدرجة العلمية: مايو ٢٠٢٠

يتم الحصول على نوعين من السرعات، بما في ذلك NMO وسرعات التراص، والتي تعتبر متشابهة في حالة الانتشار القصير، بشكل غير مباشر من بيانات الانعكاس الزلزالي. يعد حساب سرعات التراص وتحليلها مهمين في استرجاع حزم التعزيز من البيانات الزلزالية. الهدف الرئيسي من هذا البحث هو تطبيق وتحليل أسلوب التربيع على تجمع نقطة الوسط المشتركة (CMP).

تم تربيع مجموعات البيانات الزلزالية الاصطناعية والحقيقية ثنائية البعد المحددة في نطاقات الإزاحة والوقت للحصول على أحداث خطية، والتي تم استخدامها لتحليل السرعة. تم استخدام مسح طيف السرعة للأحداث الخطية لتقدير السرعات. تظهر النتائج أن سرعات التراص المنتقاة باستخدام تقنية التربيع متشابهة أو أفضل من السرعات المنتقاة تقليدياً (أي باستخدام تقنية القطع الزائد). علاوة على ذلك، غالباً ما توفر تقنيات التربيع دقة أفضل للسرعة الرأسية. لذلك، توفر تقنية التربيع طريقة أخرى لاختيار سرعات التكديس التي يمكن مقارنتها وتتوافق مع الطرق التقليدية.

CHAPTER 1

INTRODUCTION

1.1 Background

1.1.1 Seismic Reflection Method

Seismic reflection surveys are the most commonly used and popular geophysical techniques. The current state of the art is largely a result of large investments in hydrocarbon development, in addition to the development of advanced electronic and computer technologies (Kearey et al., 2002). Additionally, seismic reflection has been applied to delineate near-surface geology in recent years with increased accuracy (Yilmaz, 2015).

The concept of the seismic method is fairly simple. An energy source generates seismic waves that travel down the earth, and some are reflected at the interfaces between layers and travel back to motion detectors on land or pressure detectors at sea. The detectors convert variations in motion or pressure into electric current (Gadallah and Fisher, 2009).

A collection of seismic response traces reflected at one surface midpoint is called a common midpoint (CMP) gather. The main aim of seismic reflection processing is to collect seismic traces for each CMP and transform them into subsurface images presented as a seismic section (Kearey et al., 2002).

1.1.2 Seismic Velocities

In the case of a single horizontal layer with constant velocity, the shape of the travel-time curve is a hyperbola. Normal move out (NMO) is the time difference between the travel time at zero offset and that at any other offset. Knowing the velocity is mandatory to correct for NMO, which is called the NMO velocity. However, in practice, a hyperbolic assumption can be obtained and is valid as long as the spread is small and the dip is gentle (Yilmaz, 2015).

NMO correction and stacking velocities are usually considered equivalent, even though a different method is used to estimate each of them. The stacking velocity is dependent on the best-fit data over the spread length of the hyperbola. However, NMO velocity is dependent on flattening a hyperbolic curve (Taner and Koehler, 1969; Al-Chalabi, 1973).

1.1.3 Hyperbolic Assumption

The hyperbolic assumption is essential for analyzing velocity conventionally. In the time–offset (t – x) plane, reflections appear as hyperbolas, while in the t^2 – x^2 plane, they appear linearly. For a given reflector, the zero-offset time and stacking velocity

can be estimated from the best-fit line of arbitrary t - x picks on the t^2 - x^2 plane (see Figure 1-1).

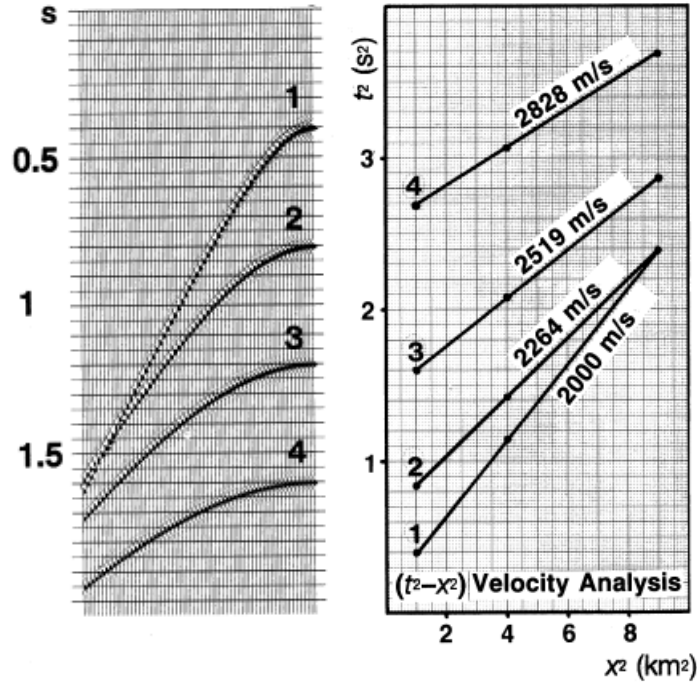


Figure 1-1: t^2 - x^2 velocity analysis applied to synthetic gathers (Yilmaz, 2015)

1.2 Research Problem

It has been confirmed that the t^2 - x^2 method is more dependable for obtaining the stacking velocity than the constant velocity stacking method (CVS) is (Semwal and Agarwal, 2015). A variety of selected hyperbolic events was picked on the CMP gather that was later plotted in the squaring (t^2 - x^2) domain (Semwal and Agarwal, 2015). Linear events were observed as a result of plotting the hyperbola picks (Semwal and Agarwal, 2015). From the best-fit line of each event, the velocities

were determined by calculating the reciprocal of the square root of the slope of each fitted line (Semwal and Agarwal, 2015). The t^2-x^2 technique in that previous study was applied by squaring the hyperbolic event picks, which might be inaccurate due to noise or human error.

1.3 Research Objectives

The objective of this research is to apply the squaring (t^2-x^2) method to the seismic data directly as opposed to applying it to arbitrarily picked $t-x$ pairs. In particular, I develop a method to square the time and offset of a CMP gather. Then, the velocity spectrum is computed to find the velocity of seismic reflections, which are linear in the squaring domain.

1.4 Study Significance

Velocity analysis methods have been developed and continue to develop to improve seismic imaging. The following is a list of benefits achieved from this study:

1. Provide another approach for calculating seismic velocity.
2. This study provides a comprehensive comparison of the squaring technique compared with the conventional velocity method on several seismic data, which can be used as a reference for further studies.
3. Improve the computed velocity semblance, which can help improve the velocity analysis step.

1.5 Structure of the Thesis

The research is carried out in the following chapters.

First chapter (Introduction): This chapter presents the subject and its background, with the problem statement, objectives, study significance, scope, and limitations as well as the methodology used.

Second chapter (Literature Review): This chapter provides an exhaustive summary of current literature, including the theory, developments, context, ideas, and methods of seismic velocity analysis and related theories.

Third chapter (Dataset): This chapter provides significant information about the selected datasets for this study and summarizes the importance of each dataset.

Fourth chapter (Methodology): This chapter presents the main steps of the squaring method, along with a discussion of each step.

Fifth chapter (Results): This chapter presents the results of applying the squaring method on the datasets and compares it with the conventional method.

Sixth chapter (Conclusion and Recommendations): This chapter offers lessons learned from this study and recommendations for possible future studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Understanding direct and indirect velocity measurements will improve seismic velocity analysis. Velocity information is an essential tool for investigating the results of seismic exploration (Gadallah, 1994). The direct measurement of the formation velocity is represented by the acoustic well logs as a function of depth. However, indirect velocity measurement is represented by seismic data. Many types of velocities, such as root mean square (RMS), interval, normal move out (NMO), stacking, and migration emerge from the differences between these two types of information (Yilmaz, 2015 & Gadallah, 1994). Two velocity types have been used to prove that the RMS velocity cannot exceed the stacking velocity over horizontally layered ground (Al-Chalabi, 1972). The difference between the RMS and stacking velocity is determined more effectively using quantitative evidence. Strong oscillations have been observed when the spread length/depth ratio was high during tests on the convergence of RMS and stacking velocities (Al-Chalabi, 1979).

2.2 Normal Moveout

In the case of a single horizontal layer with constant velocity, the shape of the travel-time curve is a hyperbola. NMO is the time difference between the travel time at zero offset and at any other offset and knowing the NMO velocity is mandatory to correct

for NMO. In practice, however, a valid hyperbolic assumption can be obtained as long as the spread is small and the dip is gentle (Yilmaz, 2015 & Castle, 1994 & Bazelaire, 1988).

2.3 Seismic Velocities

NMO correction and stacking velocities are usually considered equivalent, even with a difference property between them. The stacking velocity is dependent on the best-fit data over the spread length of the hyperbola. However, NMO velocity is dependent on small-spread hyperbola (Yilmaz, 1987; Taner and Koehler, 1969; Al-Chalabi, 1973). According to Al-Chalabi (1973), the relationship between RMS and average, interval, and stacking velocities is essential for extracting the velocities from one another.

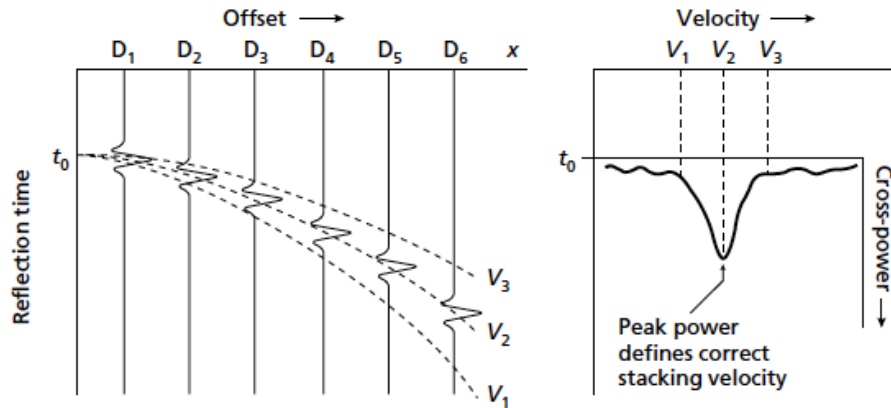


Figure 2-1: A CMP gather with corresponding cross-power (Kearey et al., 2002)

The RMS and average velocity relationship can be determined using a “heterogeneity factor,” which is a quantity obtained through velocity measurement. The spread length and “heterogeneity factor” affect the difference between the stacking velocity and RMS velocity. However, the “heterogeneity factor” is not

affected by the accuracy of the stacking velocity in the presence of random noise (Al-Chalabi, 1973). Nevertheless, Taner and Koehler (1969) proposed conventional velocity semblance (Luo and Hale, 2012). The RMS velocity can be directly determined from the common reflection point method by utilizing the multiplicity of the wave travel path information (Taner and Koehler, 1969). A display of the velocity spectra was plotted using measured semblances from a hyperbolic search (Taner and Koehler, 1969). Accurate estimations of the primary and multiple velocities can be derived from the display of velocity spectra (Taner and Koehler, 1969). Moreover, the maximum power of discrimination for semblance interpretation was approved along with the examination of common likenesses or coherence measures (Neidell and Taner, 1970). Spectrum resolution can be increased by adding weight to these terms (Luo and Hale, 2012).

Vertical velocity in inhomogeneous transverse isotropies shows that the curves derived using the three-term Taylor series are not perfectly hyperbolic (Hake, 1984). The t^2-x^2 curves are impacted by the resulting slope and curvature of inhomogeneous and transverse isotropies (Hake et al., 1984). Consequently, P-wave curves are bent upward, unlike SV-wave curves, which are bent downward, while SH-wave curves are not impacted (Hake et al., 1984). However, Shah and Levin (1972) used their model of horizontal layers to test the characteristics of time–distance curves and their velocities. The results of this examination show that V_{rms} can be calculated using the slope curve of t^2-x^2 at any offset, and that V_{rms} increases with the value of x observed in the t^2-x^2 curves. The resulting error from dropping the x^4 term is less than 2% (Shah and Levin, 1972) (see Figure 2-1).

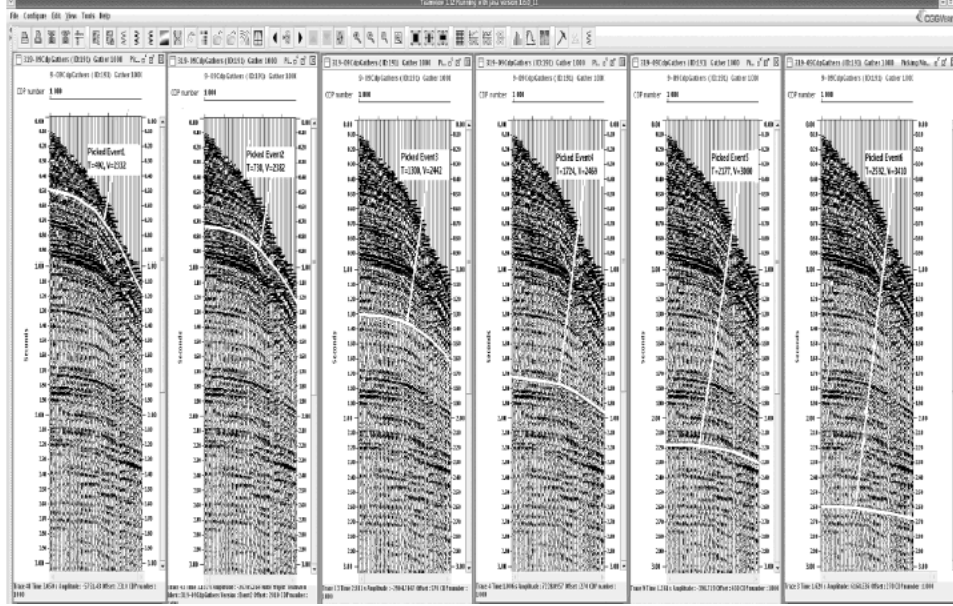


Figure 2-2: t^2-x^2 Velocity Estimation (Semwal and Agarwal, 2015)

2.4 Hyperbolic assumption

The hyperbolic assumption is essential for analyzing the conventional velocity. In the t^2-x^2 plane, the hyperbolic assumption is linear. For a given reflector, the zero-offset time and stacking velocity can be estimated from the best-fit line of the plotted picks in the t^2-x^2 plane (see Figure 2-2). Consequently, the t^2-x^2 technique is a reliable method for estimating the stacking velocity, and its accuracy depends on the pick quality, which is affected by the signal-to-noise ratio of the data (Gajewski, 2001).

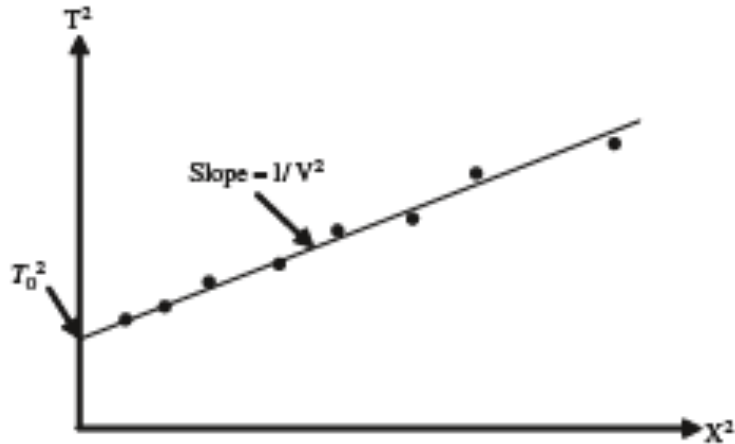


Figure 2-3: T-X analysis (Gadallah and Fisher, 2009)

Dix (1955) discussed that both the field and interpretive techniques help to determine the most accurate interval velocity from the seismic data, which could be useful to consider, especially for drilling purposes. Multiple reflections are required to determine the average velocity used to calculate interval velocity using the t^2-x^2 technique (Dix, 1955). Determining velocity using t^2-x^2 techniques is helpful not only for obtaining accurate structural interpretation, but also for obtaining better lithological information (Dix, 1955). Another technique commonly used for velocity estimation is based on the velocity spectrum by displaying measures of signal coherency on the plot of velocities against zero-offset two-way time (Yilmaz, 2015). With noisy seismic data, it is almost impossible to use automatic picking on the direct arrivals that are not considered as first arrivals (Al-Shuhail, 2011). The water table depth can be estimated by analyzing the linear move out (Al-Shuhail, 2011).

CHAPTER 3

METHODOLOGY

Studying the effects of the squaring technique t^2-x^2 on CMP gathers is the main purpose of this research.

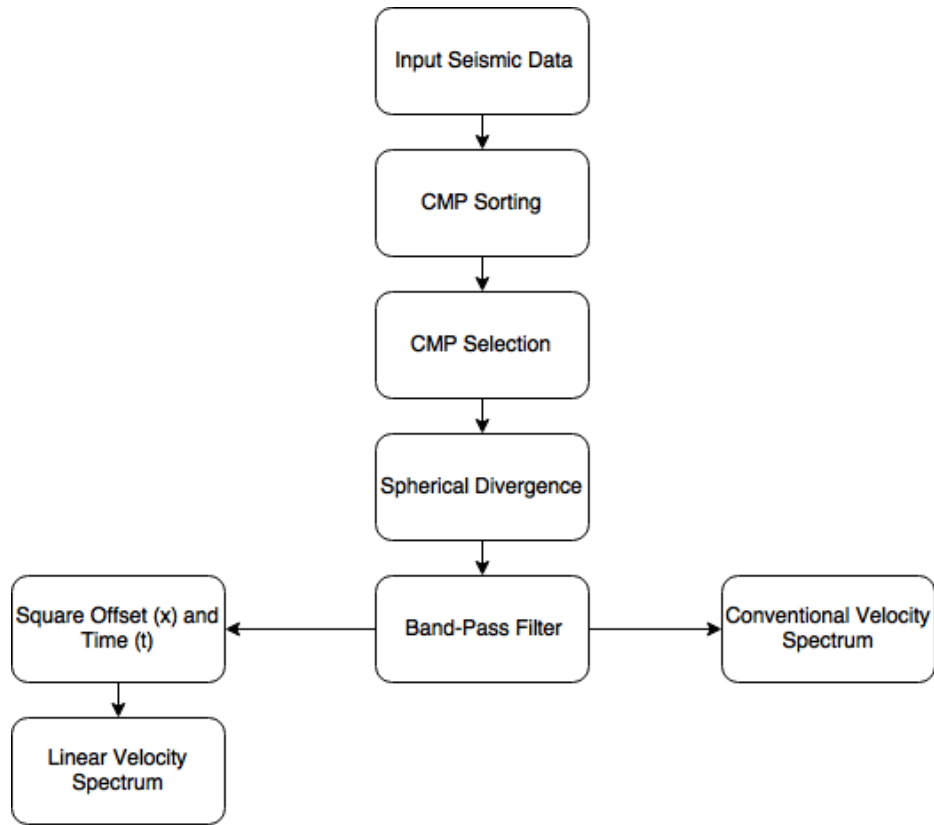


Figure 3-1: Methodology of main workflow

The following steps describe the methods that were used (Figure 3-1):

3.1 Input seismic data

The following seismic data were selected for this research:

- a- 2007 BP anisotropic velocity benchmark (2D synthetic land) (Figure 3-2)
- b- KFUPM-KAUST Red Sea model (2D synthetic land) (Figure 3-3)

c- Mobil AVO Viking Graben line 12 (2D real marine) (Figure and 3-4)

d- Poland 2D Vibroseis line 001 (2D real land) (Figure 3-5)

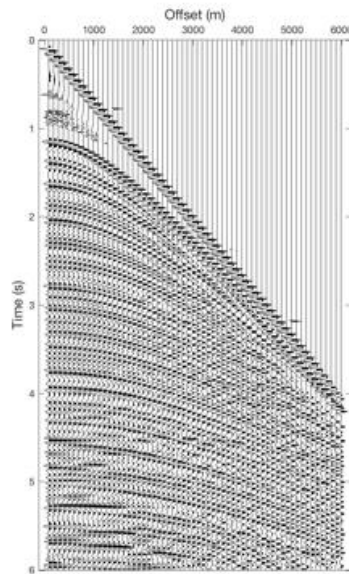


Figure 3-2: CMP # 8900 - 2007 BP Anisotropic Velocity Benchmark

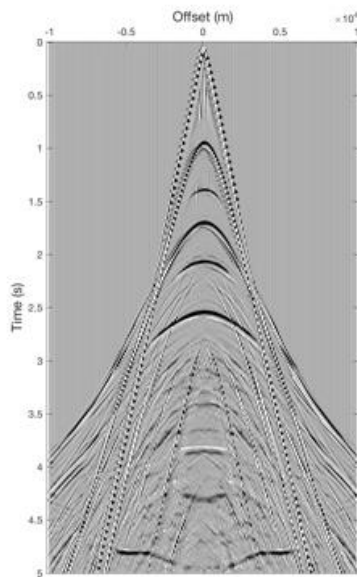


Figure 3-3: CMP # 400 - KFUPM-KAUST Red Sea model

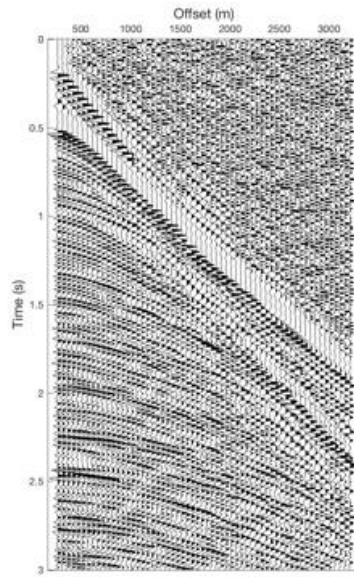


Figure 3-4: CMP 1100 - Mobil AVO Viking Graben line 12

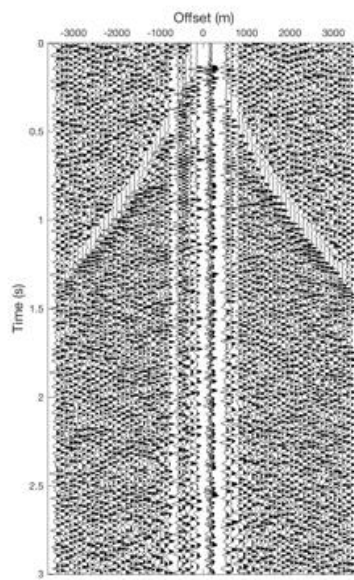


Figure 3-5: CMP # 440 - Poland 2D Vibroseis line 001

3.2 CMP sorting

The origin of each seismic trace was defined by three key geometric factors. The shot and receiver locations were two factors. The third, and perhaps most important factor, was the sub-reflection point position. This location is uncertain before seismic analysis; however, the best estimation is made at this point because the reflection point falls vertically under the mid-way location on the surface between the shot and the receiver for the selected trace. Earlier terminology labeled this location as the “depth point,” but the term “reflection point” defines what the position is, rather than what it is meant to represent and is thus preferred. Collecting traces with a particular midpoint is the CMP of that particular midpoint (Figure 3-6) (Kearey et al., 2002).

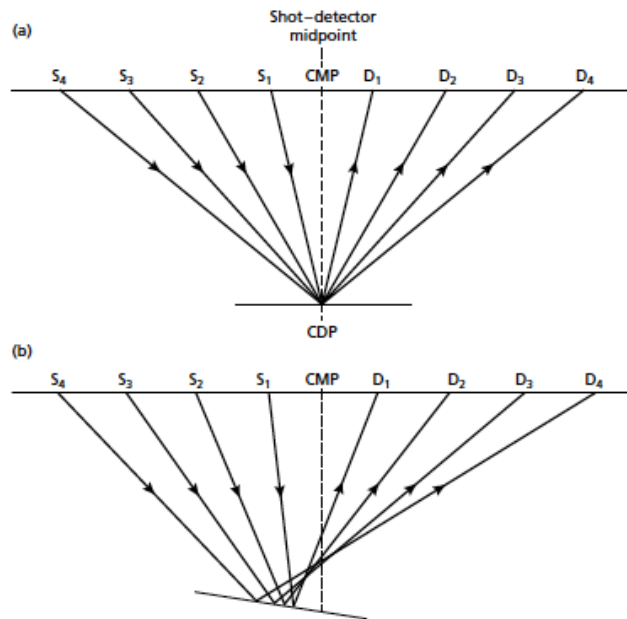


Figure 3-6: CMP reflection profiling (Kearey et al., 2002) (a) CMP reflection profiling in case of a flat horizontal layer (b) CMP reflection profiling in case of a dipping layer

Sorting the data in the common midpoint is a mandatory step before velocity analysis.

3.3 Application of spherical divergence

Because it is assumed that lateral variance in reflection amplitudes contains useful information, it is common practice to avoid interfering with recorded amplitude values. However, due to spherical spreading and absorption, correcting the amplitudes for gradual decrease with depth is important (Gadallah and Fisher, 2009). The t^a scaling function was applied to these data to enhance the event later.

3.4 Application of the band-pass filter

This is a filter designed to attenuate the frequency components deemed undesirable and protecting the most essential part of the spectrum (Rosa, 2018). Band-pass filtering is an essential method applied to remove coherent noise by avoiding any noise stretching after the squaring technique to obtain a better velocity spectrum.

3.4.1 Conventional Velocity Performance

To compute a conventional spectrum on the CMP gather before the squaring technique is computed, the following equation is fitted:

Hyperbolic Equation:

$$T = \sqrt{T_0^2 + \left(\frac{Offset}{V}\right)^2} \quad (3.1)$$

where

T = travel time at selected offset,

T₀ = travel time at zero offset.

V = stacking velocity.

3.5 Squaring of CMP gathers in the offset (x) and in time (t)

Squaring the CMP gathers entails squaring both the time and offset domains. First, the time domain is selected for squaring. The results of this method show event compression at the start time, making it shorter than the events occurring at a later time and causing stretching in the data. A lower dominant frequency is expected to be observed. Squaring the offset domain increases the spacing between traces, and the magnitude of this increment increases with the offset. Overall, the amplitude is not affected during the squaring process.

```
Squaring_Method.m  +
1  % Square & interpolate the data in the time domain
2
3  % Compute the total number of seismic traces
4  Nh = length(Da(1,:));
5
6  % Create an empty matrix which will be used to store the Squared Gather
7  Da2 = [];
8
9  % Loop trace by trace
10 for nh=1:Nh
11     % Original Time for the trace before squaring
12     t0=(StartTime:SampleInterval:EndTime);
13
14     % Original data trace before squaring
15     y0=Da(:,nh);
16
17     % Squared time with an irregular sample interval
18     t1=t0.^2;
19
20     % Squared time with regular sample interval
21     t2=(StartTime:SampleInterval:EndTime^2);
22
23     % Interpolation between samples
24     y2=spline(t1,y0,t2);
25
26     % Add the squared trace to the squared gather matrix
27     Da2(:,nh)=y2;
28 end
```

Figure 3-7: Squaring time axis (pseudocode)

3.5.1 Linear Velocity Semblance

To compute the velocity spectrum on the CMP gather after the squaring technique, the following equation is fitted to the time-offset data of a single CMP.

Linear Equation:

$$y = y_0 + m \cdot b \quad (3.2)$$

where:

b = squared offset

y = squared travel time, b

y_0 = line intercept = squared travel time at zero b

m = line slope = $1/V^2$, where V is the stacking velocity

CHAPTER 4

DATASET INFORMATION

In this thesis, I used four seismic datasets collected from the SEG Open Data website. Each dataset had its own objective; namely, either to acquire or generate, which have been used in many research projects.

4.1 BP Data

BP synthetic data were used at the 2010 EAGE meeting in Barcelona, Spain; these data were originally created by Shah in 2007 (Exploration Operation Company Limited, "BP"). Figure 3-1 shows the velocity model. The main reason for using the BP data was for the TTI velocity-analysis benchmark, and the parameters are described in Table 4-1

Table 4-1: Parameters of BP Dataset

Parameter	Value
Nominal Receiver Point Interval	25 m
Nominal Source Point Interval	12.5 m
Input Model Information	dX & dY are 6.25 m, Absorbing Surface
Generation Method	2D Elastic Finite Difference
Number of Channels	800
Record Length	9.2 s
Sample Interval	8 ms

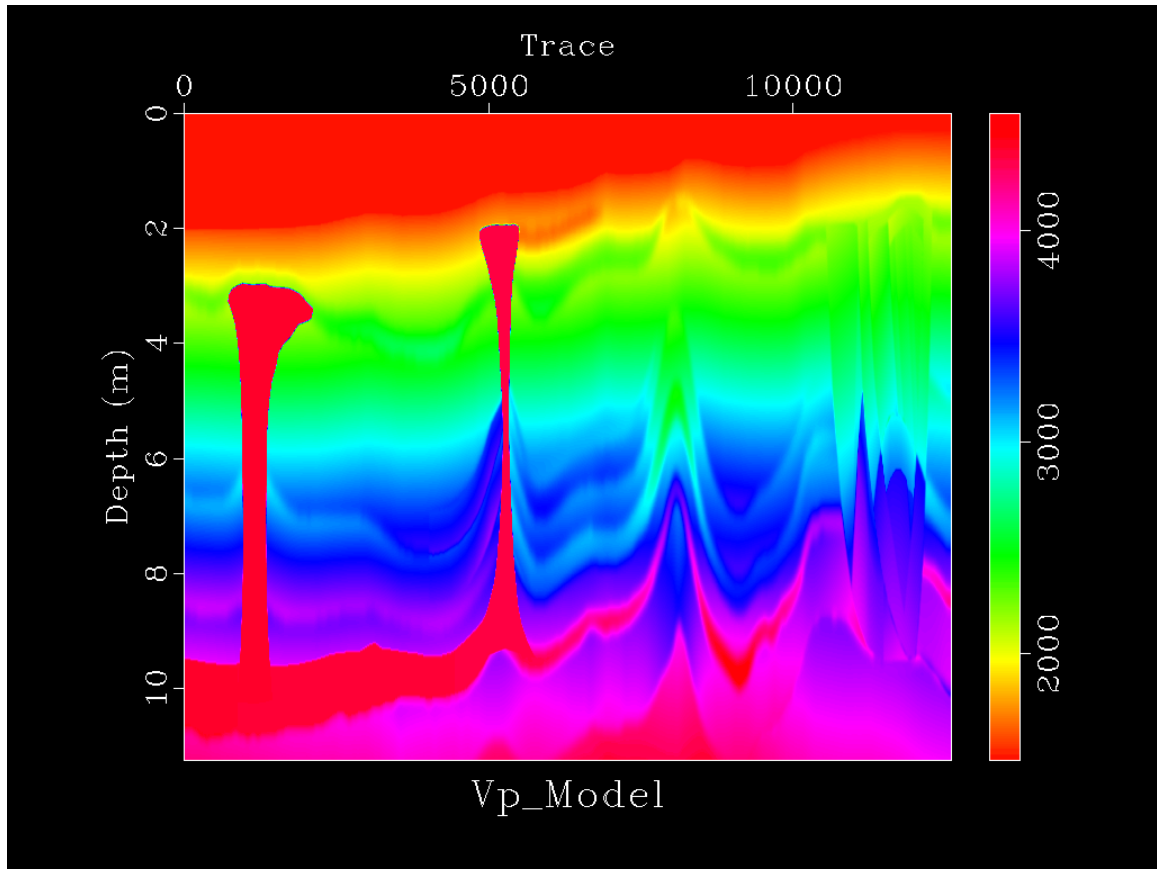


Figure 4-1: P-wave Velocity Model (Shah, 2007). Color bar units are in m/s.

4.2 Red Sea Data

The Red Sea is considered to be young and is still evolving and capable of offering good insights into the initial phases of ocean maturity. Consequently, it is an important subject of study. It also contains significant mineral resources such as zinc, copper, silver, and gold. Furthermore, fair volumes of oil resources have been discovered in the Red Sea offshore and onshore regions and further exploration is underway. Figure 4-2 shows the horizons and faults of the Red Sea model; these horizons are listed in Table 4-2.

Table 4-2: Parameters of the Red Sea Dataset

Parameter	Value
Source Wavelet	15 Hz Zero-Phase Ricker
Receiver Spacing	25 m
Shot Spacing	50 m
Total Number of Shots	237
Total Number of Receiver	473
Offset Range	0 to 11,800 m
Record Length	4.99786 s
Sample interval	4.06 ms

These data were generated using the finite difference method (FDM) of data collection. Additionally, these data were used for conventional 2D land seismic survey geometry. Sources span the entire model from $x = 0$ m to $x = 11800$ m with a 50-m spacing. The receivers cover the entire model from $x = 0$ m to $x = 11800$ m, with a 25-m spacing. The sources and receivers were buried 15 m below the surface to combat ghost reflections. The offset ranged from 0 m to 11800 m. Table 4-2 lists the parameters used to generate these synthetic seismic data.

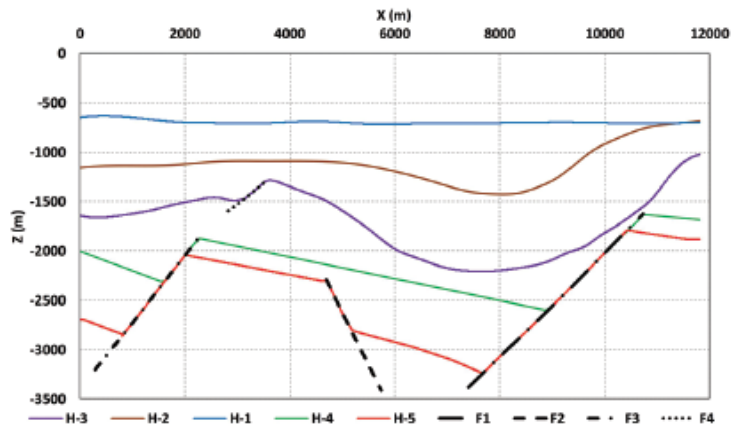


Figure 4-2: Red Sea model horizons and faults (Al-Shuhail et al., 2017)

4.3 AVO Data

The AVO dataset is from the North Sea Viking Graben, which developed due to late Permian to Triassic rifting, and trends north–northeast. Episodic extension and accompanying sedimentation continued to the early Cretaceous throughout the Jurassic period. Normal basin subsidence and filling during the late Cretaceous was the primary deposition mechanism.

Table 4-3: Parameters of AVO Dataset

Parameter	Value
Nominal Receiver Point Interval	25 m
Nominal Source Point Interval	25 m
Source	BOLT AIR GUNS
Number of Data Channels	120
Cable Length	2975 m
Record Length	6 s
Sample Interval	4 ms

The seismic AVO line consists of 1001 records oriented towards structural dip. Each shot record was recorded for 6 s on 120 channels at 4-ms sampling intervals (Table 4-3).

4.4 Mobil Data

The prestack 2D Land Vibroseis dataset was donated by Geofizyka Torun S.A., Poland to the public domain. The 2D line was originally released on the FreeUSP.org website. Table 4-4 lists the detailed Mobil 2D dataset information.

Table 4-4: Parameters of Mobil dataset

Parameter	Value
Nominal Receiver Point Interval	25 m
Nominal Source Point Interval	50 m
Source	Vibroseis
Sweep Frequency	8 Hz to 95 Hz
Geophone Frequency	10 Hz
Record Length	6 s
Sample Interval	2 ms

CHAPTER 5

RESULTS

This section summarizes the results and findings of the linear semblance on squared CMP gathers. The results of this analysis are then compared with conventional semblance on normal CMP gathers. In this section, I illustrate the experimental results using the four selected seismic datasets.

5.1 Squaring of CMP Gathers:

5.1.1 Dataset # 1: 2007 BP anisotropic velocity benchmark (synthetic):

In Figure 5-1, at approximately 4.5 s, it is observed that a flat noise appears in the normal gather (left side), which becomes more noticeable in the squared gather (right side) at approximately 20 s^2 .

Another promising observation was that the linear noise time between 5.5 and 6 s in the normal gather was the same event observed in the squared gather time between 30 and 36 s^2 while the reflections hyperbola became linear after squaring, which made linear noise detection easier.

- Gather Parameters:
 - CMP # 8900
 - Sample interval = 8 ms
 - Record Length = 6 s
 - Offset = 6000 m

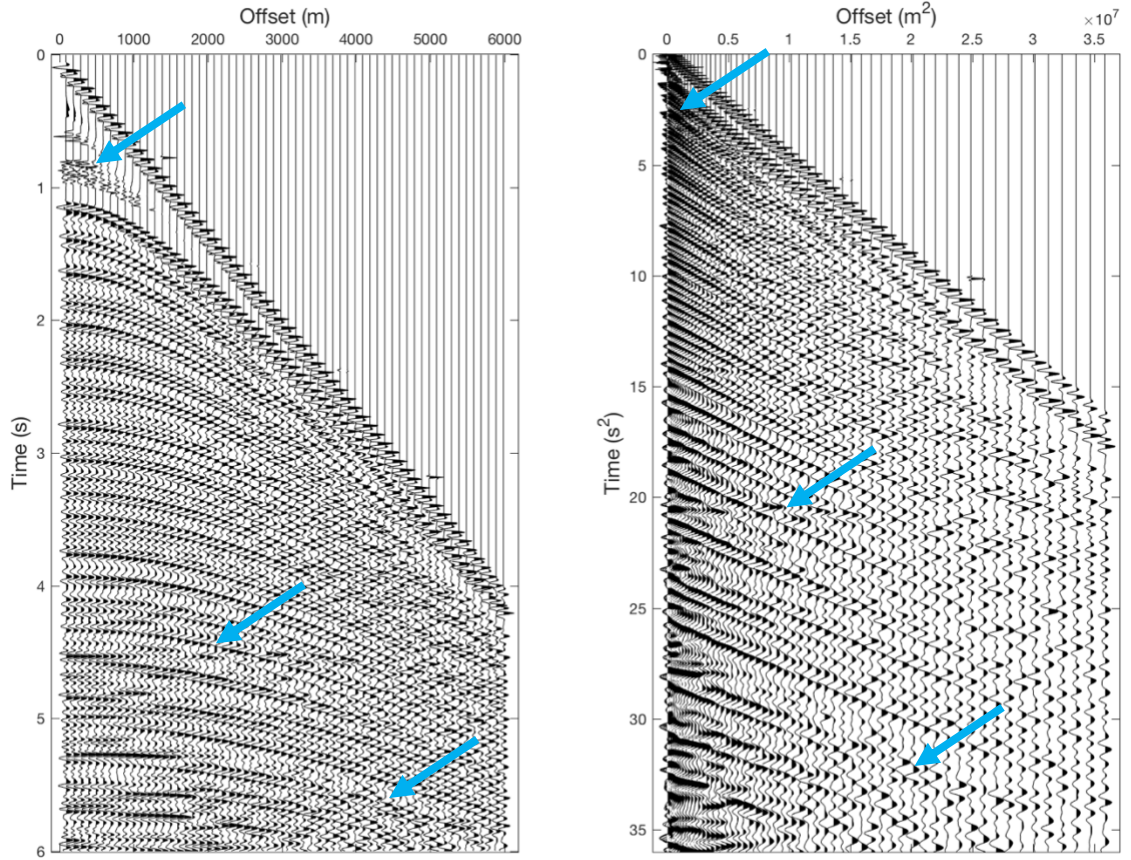


Figure 5-1: CMP # 8900 before (Left) and after (Right) squaring - (Dataset 1)

5.1.2 Dataset # 2: KFUPM-KAUST Red Sea model (synthetic)

Figure 5-2 shows the KFUPM Red Sea data results. As presented in the dataset section, the Red Sea has a complex geological structure. Nevertheless, it was observed that the hyperbolic events time between 2.6 and 2.8 s became linear at a time between 6.6 and 8.2 s² and the linear events remained linear.

Gather parameters:

- CMP # 400
- Sample interval = 4 ms
- Record Length = 3 s
- Offset = 6000 m

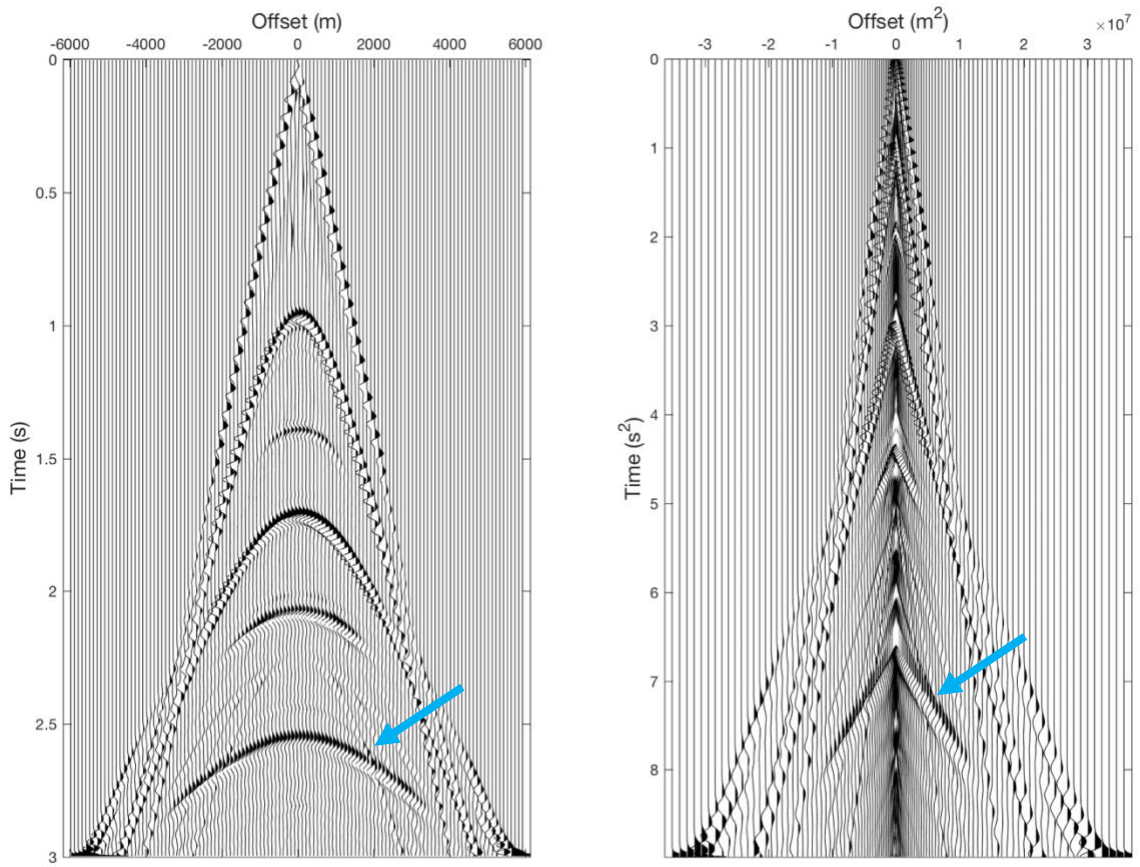


Figure 5-2: CMP # 400 Before (Left) and After (Right) squaring - (Dataset 2)

5.1.3 Dataset # 3: Mobil AVO Viking Graben Line 12 (Marine)

Figure 5-3 depicts the Mobil data before and after squaring. Mobil data were contaminated with water-bottom multiples; however, we still observed the change in the hyperbolic events to linear events after squaring.

Gather parameters:

- CMP # 1100
- Sample interval = 4 ms
- Record Length = 3 s
- Offset = 3500 m

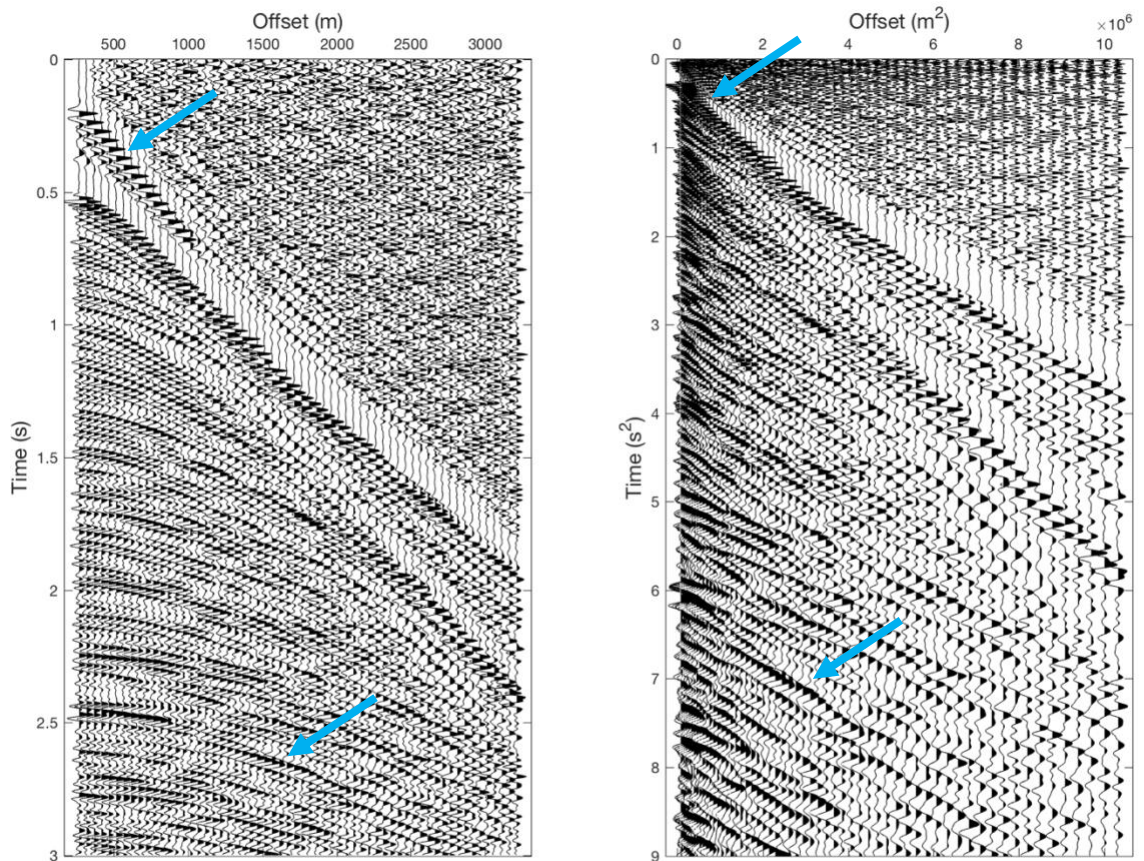


Figure 5-3: CMP # 1100 Before (Left) and After (Right) squaring - (Dataset 3)

5.1.4 Dataset # 4: Poland 2D Vibroseis line 001 (Land)

Poland 2D line had a low signal/noise ratio, but the effect could still be observed at the squaring of the selected gather (Figure 5-4). The event at ~ 2.2 s in the normal gather appeared at ~ 5 s² in the squared gather.

Gather parameters:

- CMP # 440
- Sample interval = 2 ms
- Record Length = 3 s
- Offset = 3500 m

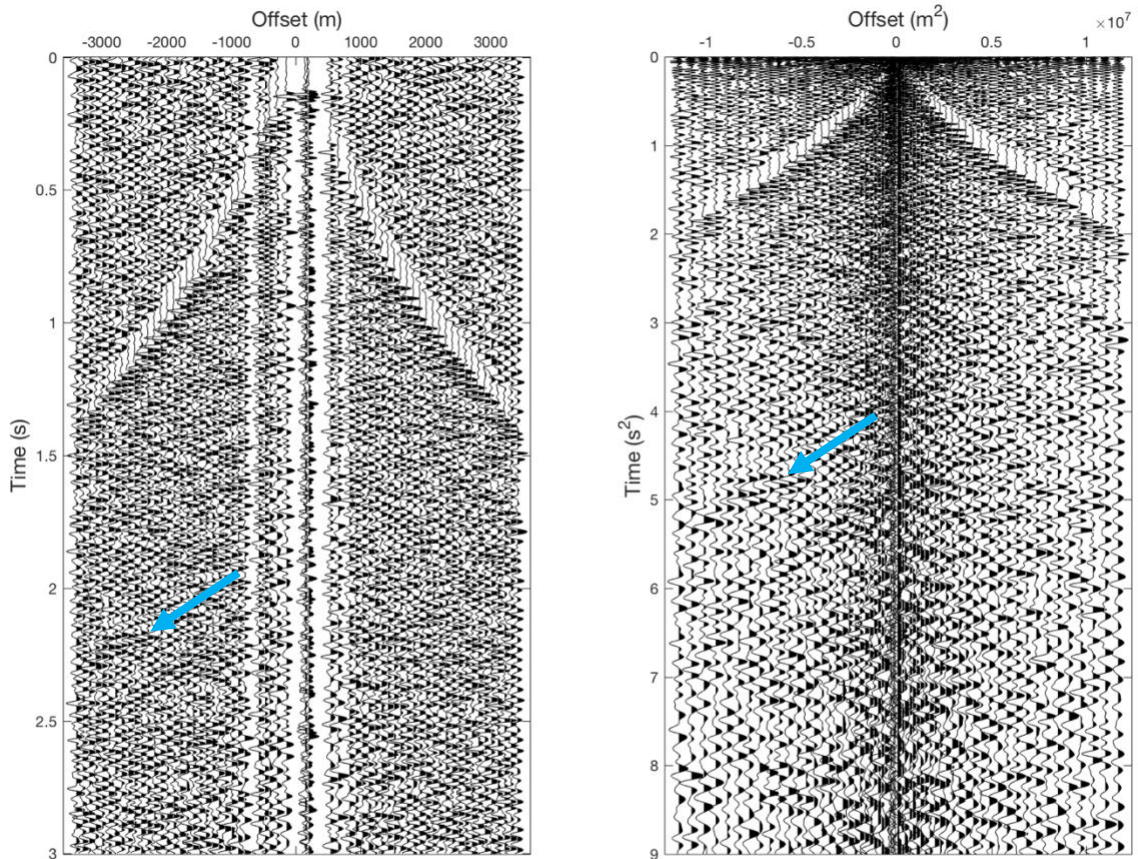


Figure 5-4: CMP # 440 Before (Left) and After (Right) squaring - (Dataset 4)

General observations made from all CMP gathers before and after the squaring results demonstrated the following:

- 1) After squaring, the time axis is compressed for shallow times and stretched for deep times.
- 2) The distance between seismic traces decreases with small offsets and increases with larger offset values.
- 3) From the results, it is clear that the reflection events appear linear after squaring the time and offset axes, while no change was observed in the linear events.

5.2 Operating Window Test for Velocity Semblance

Several operation windows were tested to obtain the optimal operating window for this study. Figure 5-5 and Figure 5-6 show different operating window selections to test and select the optimum window that should give the best velocity spectrum. A window length of 50 ms gave the best results for both types of velocity semblance, and this window was selected for further testing.

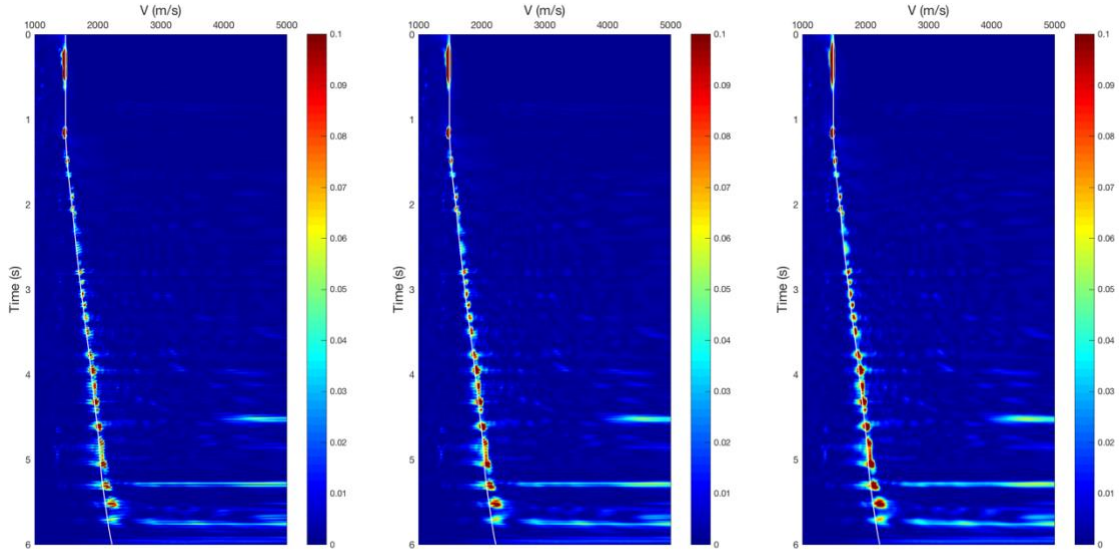


Figure 5-5: Conventional Velocity Semblance: Operating Window 25 ms (Left), Operating Window 50 ms (Middle), Operating Window 75 ms (Right)

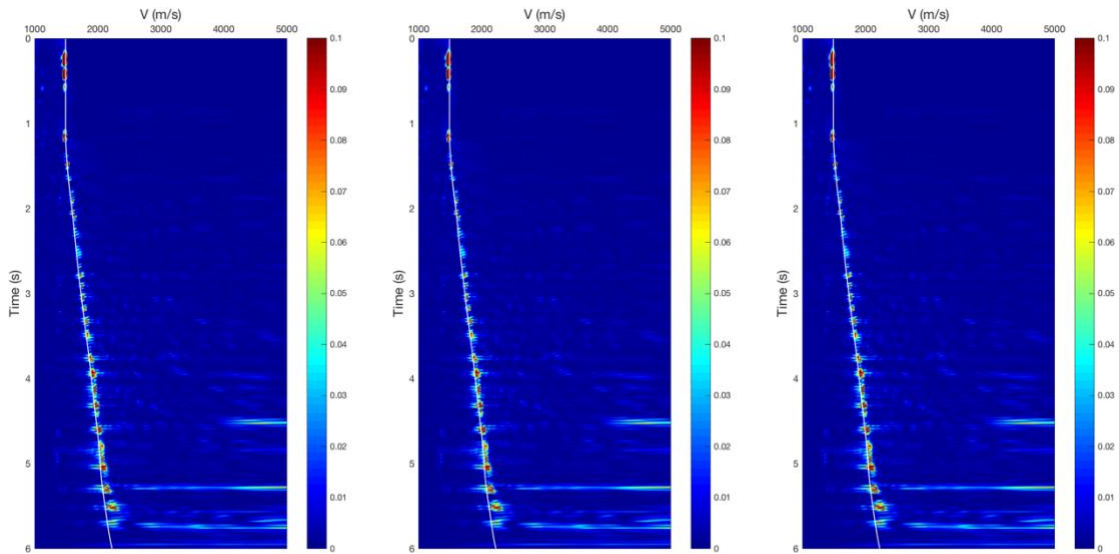


Figure 5-6: Linear Velocity Semblance: Operating Window 25 ms (Left), Operating Window 50 ms (Middle), Operating Window 75 ms (Right)

5.3 Computation of Velocity Semblance

This approach aims to determine the stacking velocity of each reflector, which maps the time–space data of a single CMP to a velocity–semblance plane. In the velocity–semblance plane, the vertical axis is t_0 , and the horizontal axis is the stacking velocity (Mousa and Al-Shuhail, 2011). In this section, we present the conventional velocity semblance versus the linear velocity semblance for each dataset.

Both velocity semblance methods have the same time range and unit because while computing the linear semblance on the linear gather at squared time, the time of the linear velocity semblance was mapped to the original time (without squaring) to be able to compare both semblance and obtain the selected velocity at true timing.

5.3.1 Dataset # 1: 2007 BP anisotropic velocity benchmark (synthetic):

- Semblance parameters:
 - Semblance interval = 2 samples
 - Operating window = 7 samples.

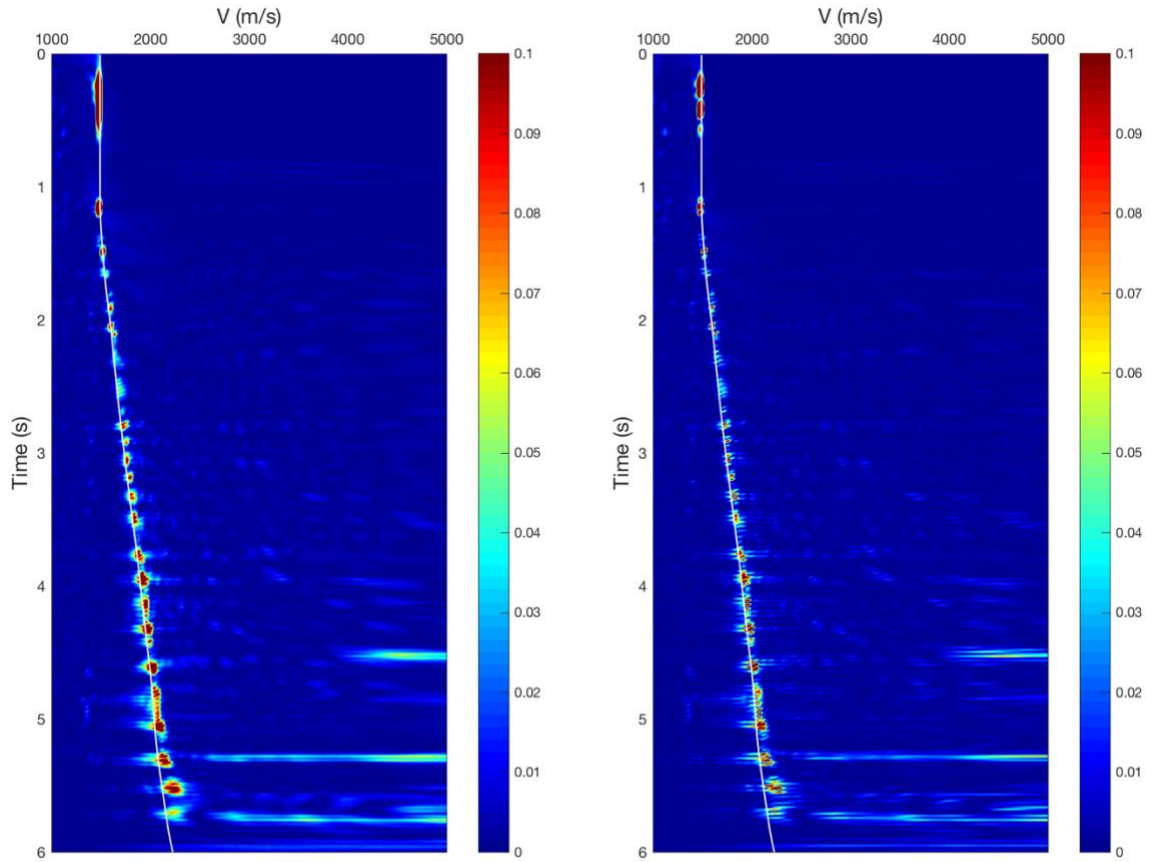


Figure 5-7: Conventional Velocity Semblance (Left), Linear Velocity Semblance (Right) – (dataset 1).

Color bar indicates semblance values. White line indicates model velocities.

As shown in Figure 5-7, the vertical resolution for the linear semblance was improved compared with that of the conventional semblance but with weaker semblance energy. Referring to the first event in both semblances at 0.2–0.6 s, in the conventional velocity semblance, the event appears as one event, while it appears as two events in the linear velocity semblance. This observation is valid for other similar events.

5.3.2 Dataset # 2: KFUPM-KAUST Red Sea model (synthetic)

- Semblance parameters:
 - Semblance interval = 2 samples
 - Operating window = 15 samples.

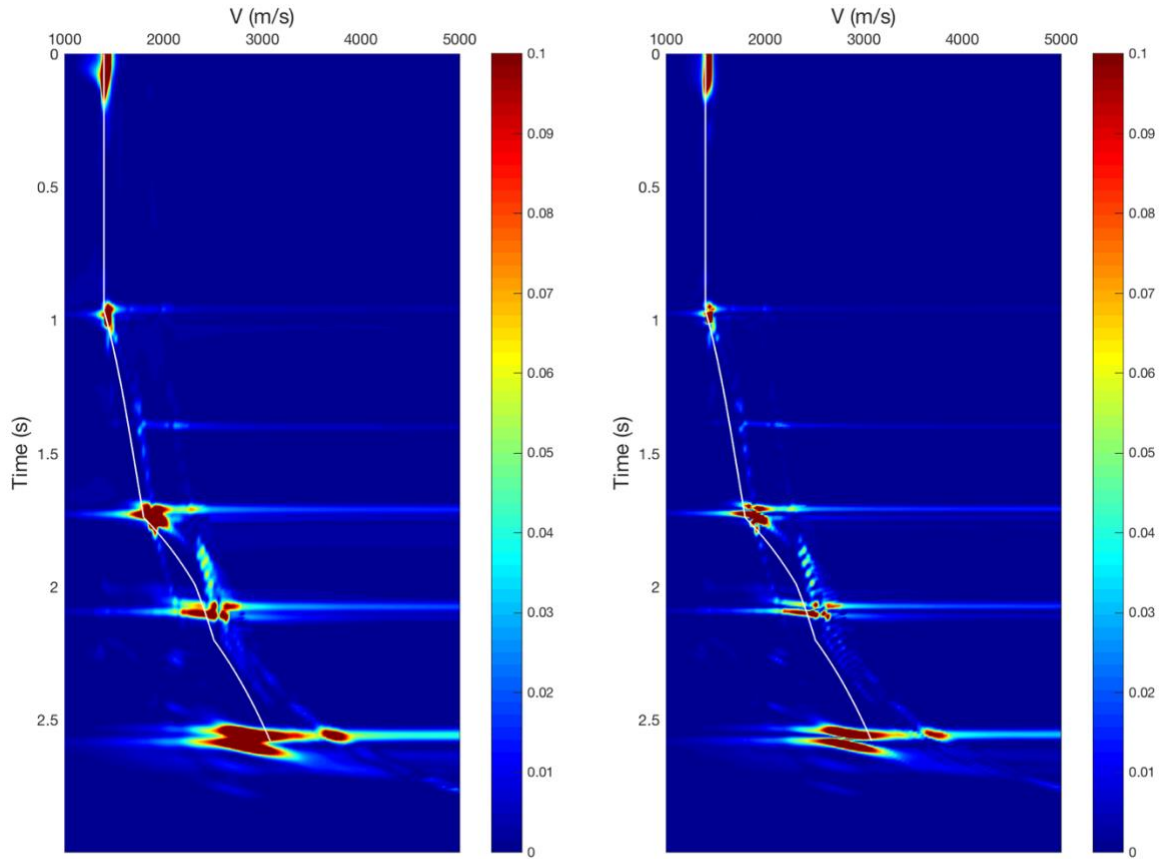


Figure 5-8: Conventional Velocity Semblance (Left), Linear Velocity Semblance (Right) – (dataset 2).

Color bar indicates semblance values. White line indicates model velocities.

Like dataset 1, it was observed in Figure 5-8 that the vertical resolution for the linear semblance was improved compared with that of the conventional semblance but with no weaker semblance energy. For example, the event at 2.6 s shows more details in the linear semblance compared with conventional semblance.

5.3.3 Dataset # 3: Mobil AVO Viking Graben Line 12 (Marine)

- Semblance parameters:
 - Semblance interval = 2 samples
 - Operating window = 15 samples.

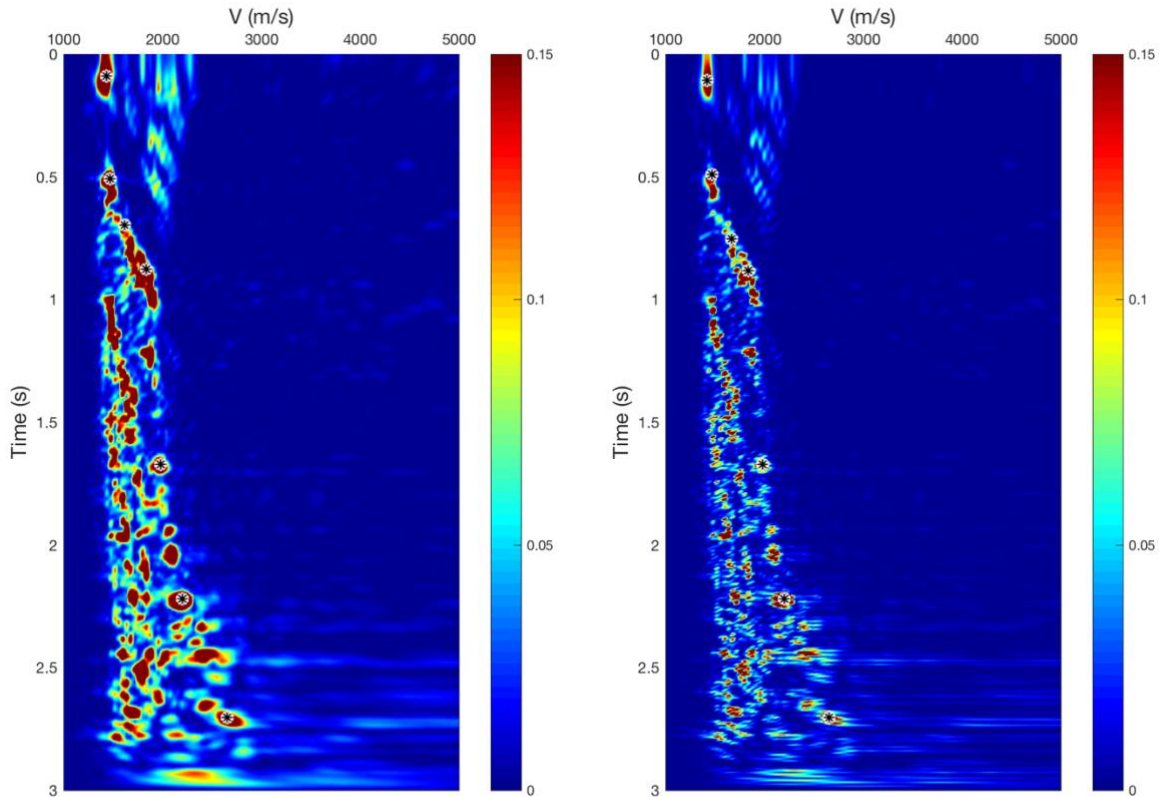


Figure 5-9: Conventional Velocity Semblance (Left), Linear Velocity Semblance (Right) – (dataset 3).

Black stars are manual velocity picks. Color bar indicates semblance values.

Figure 5-9 shows that some noise energy was reduced/removed from the linear semblance at time 0.1 s to 0.5 s (at $V = 2000$ m/s). Moreover, most of the event energy was separated and the imaging was improved. For example, the event at ~ 0.8 s and ~ 2000 m/s was well defined in the linear semblance, which helped to select the right pick location.

5.3.4 Dataset # 4: Poland 2D Vibroseis line 001 (Land)

- Semblance parameters:
 - Semblance interval = 2 samples
 - Operating window = 29 samples

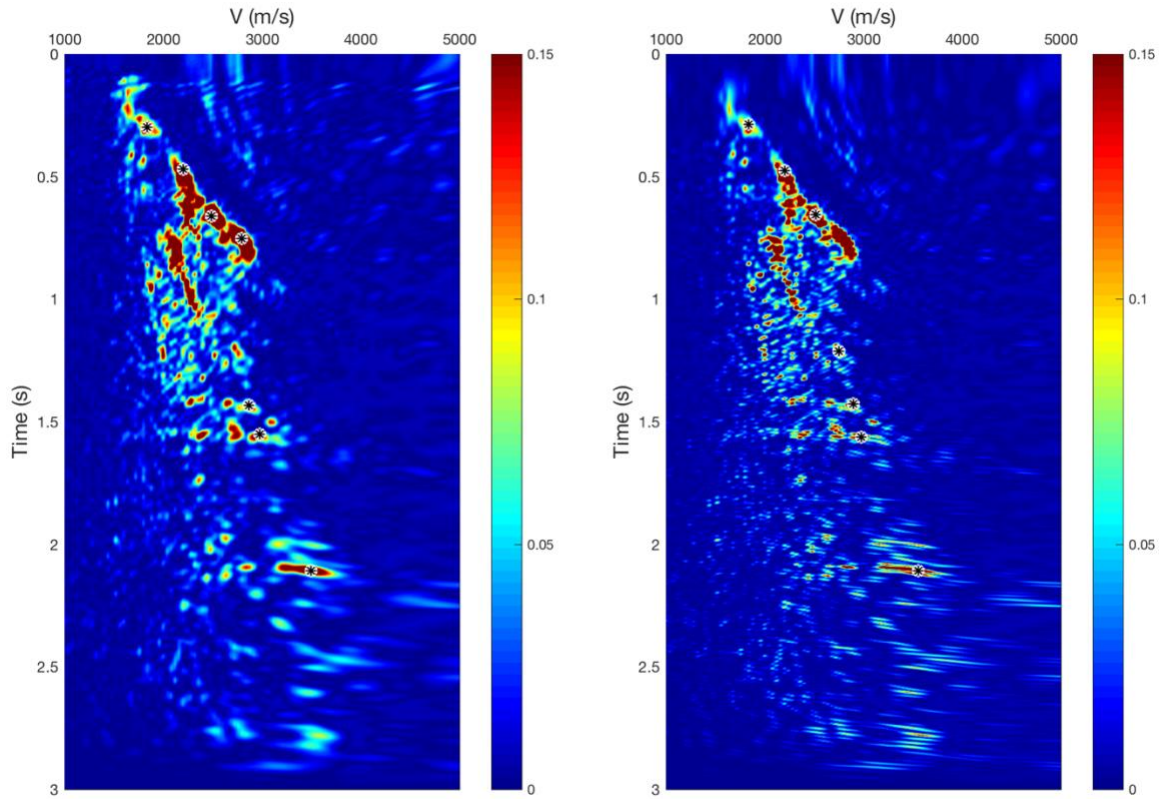


Figure 5-10: Conventional Velocity Semblance (Left), Linear Velocity Semblance (Right) – (dataset 4).

Black stars are manual velocity picks. Color bar indicates semblance values.

Like dataset 3, Figure 5-10 shows that some noise energy was reduced/removed from the linear semblance at shallow times and most event energy was resolved, which improved the imaging.

General observations made from the conventional versus linear semblance are as follows:

- 1) The vertical velocity resolution was improved in the linear semblance.
- 2) Linear semblance has a weaker energy than conventional semblance.
- 3) Linear semblance has less noise energy.

5.4 Manual Velocity Picking on Both Semblance

Manual velocity picking was performed on both linear and squared velocity semblances. This section illustrates the manual picking results and the NMO correction on selected CMP gather from both velocity semblances.

5.4.1 Dataset # 1: 2007 BP anisotropic velocity benchmark (synthetic):

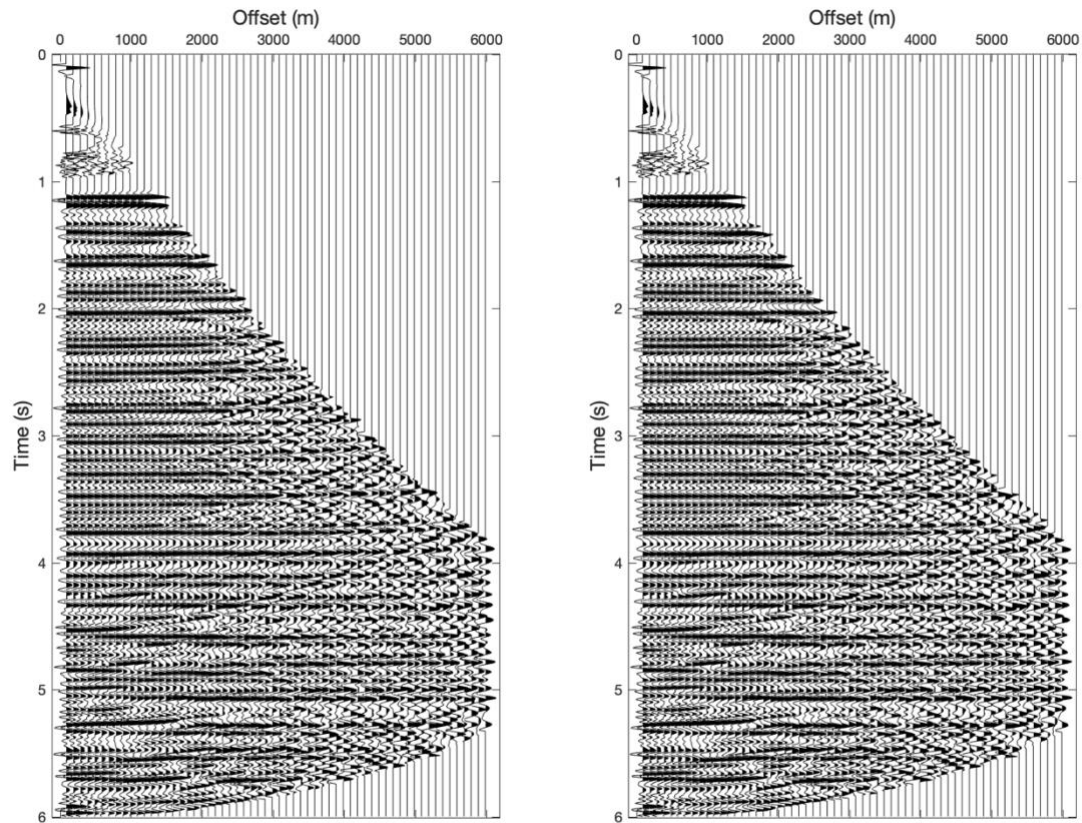


Figure 5-11: NMO Gather # 8900 of BP data using Manual Velocity Picking on - Conventional Velocity Semblance (Left), Linear Velocity Semblance (Right)

Figure 5-11 shows the NMO corrected gather using manual velocity picks performed on conventional and linear velocity semblances. The two gathers were almost identical.

5.4.2 Dataset # 2: KFUPM-KAUST Red Sea model (synthetic)

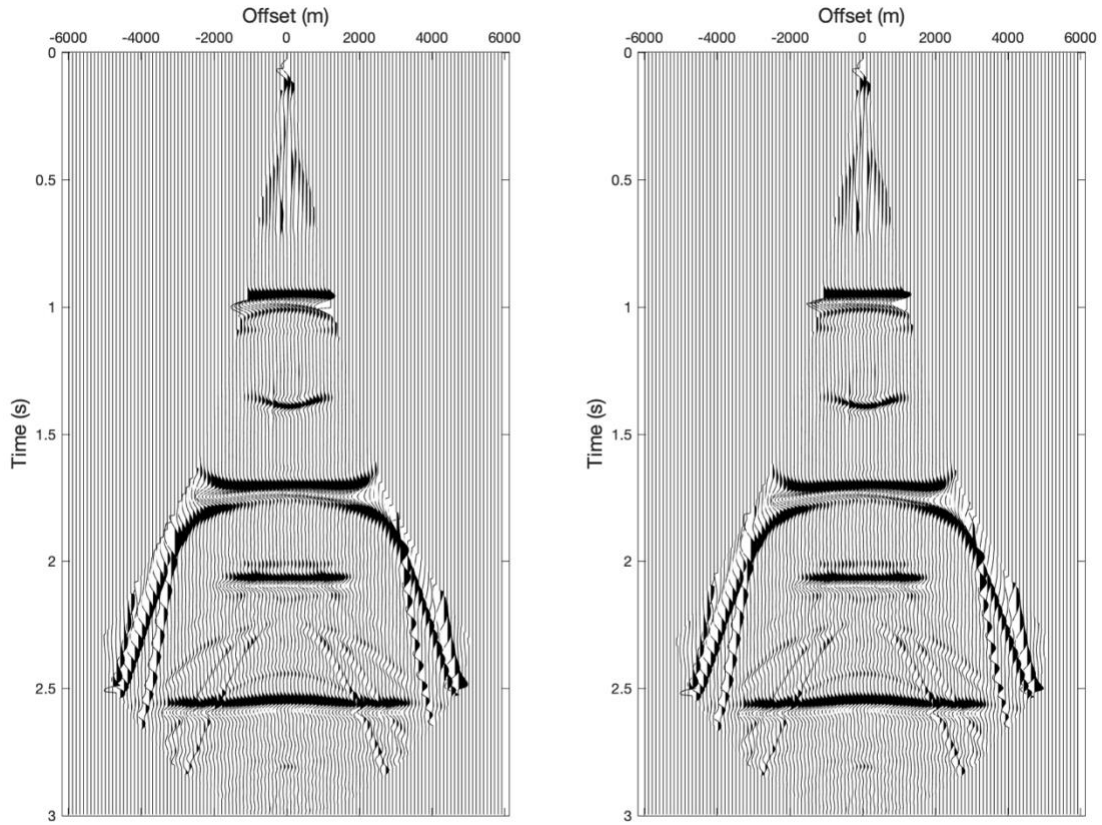


Figure 5-12: NMO Gather # 400 of Red Sea data using manual velocity picking on - Conventional Velocity Semblance (Left), Linear Velocity Semblance (Right)

Figure 5-12 shows the two NMO gathers using manual velocity picking performed on conventional and linear semblances. Manual picking was similar for both gathers.

5.4.3 Dataset # 3: Mobil AVO Viking Graben Line 12 (Marine)

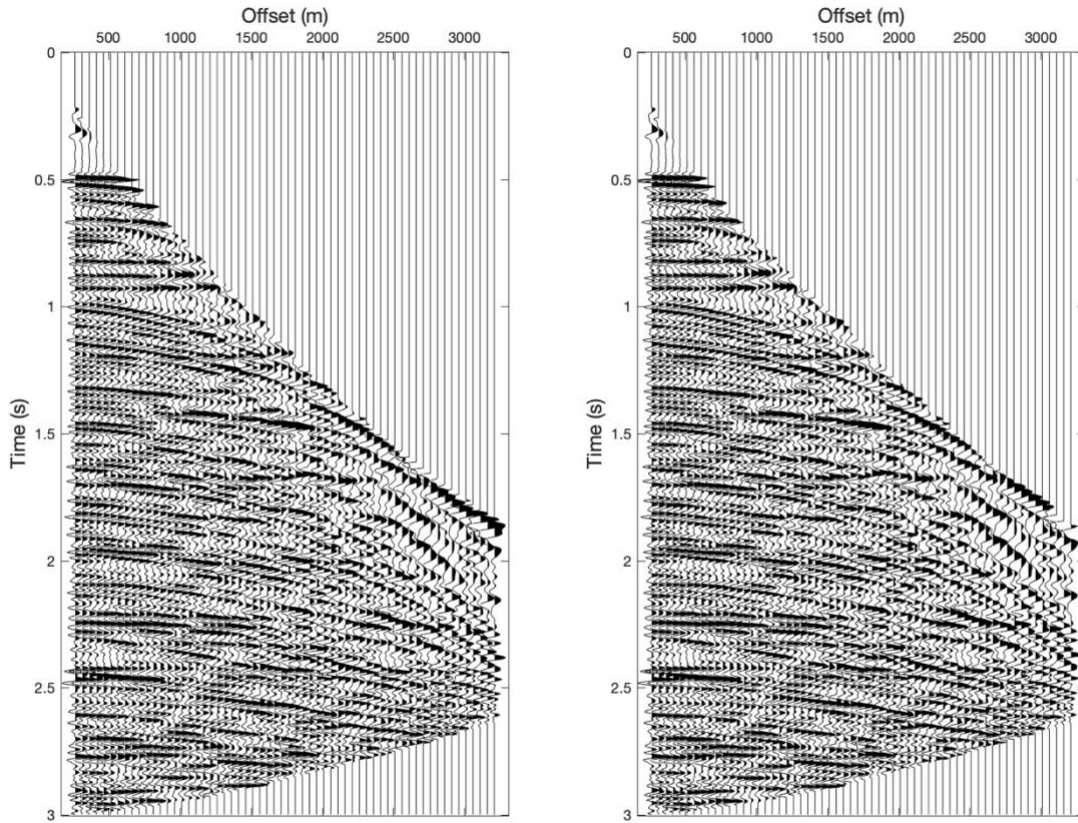


Figure 5-13: NMO Gather # 1100 of Mobil data using manual velocity picking on - Conventional Velocity Semblance (Left), Linear Velocity Semblance (Right)

The Mobil gather was contaminated with multiples, as shown in Figure 5-13. The results are similar for both methods.

5.4.4 Dataset # 4: Poland 2D Vibroseis line 001 (Land)

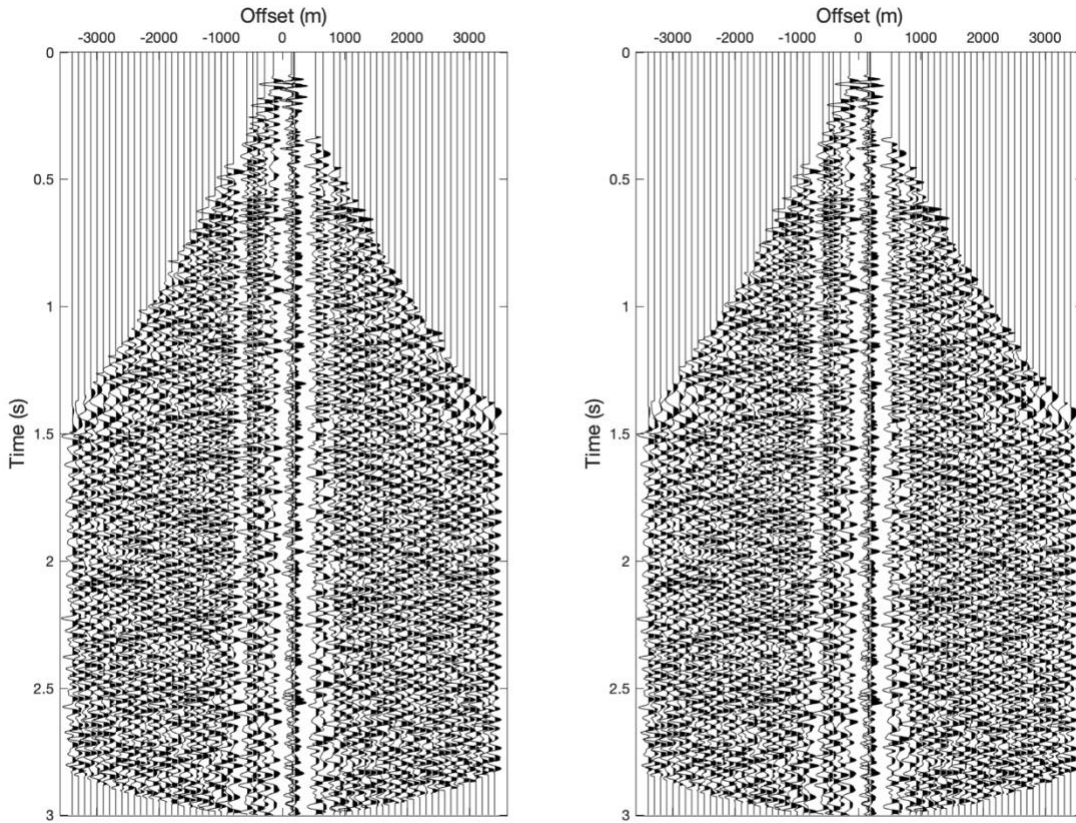


Figure 5-14: NMO Gather # 440 of Poland data using manual velocity picking on - Conventional Velocity Semblance (Left), Linear Velocity Semblance (Right)

The Poland gathers have a low signal-to-noise ratio, as shown in Figure 5-14, and both gathers look similar. Therefore, linear semblance can be considered equivalent to conventional semblance for this type of data.

Finally, by comparing the results of the NMO correction across all datasets, we can see that the result of linear semblance is equal to or better than the result of conventional semblance that is currently used.

5.5 Computational cost:

The running time of both conventional and linear semblance was estimated by rerunning the computation of conventional/linear semblance several times and recording the running time for each iteration. Figure 5-15 shows the running time for the conventional/linear semblance by iteration.

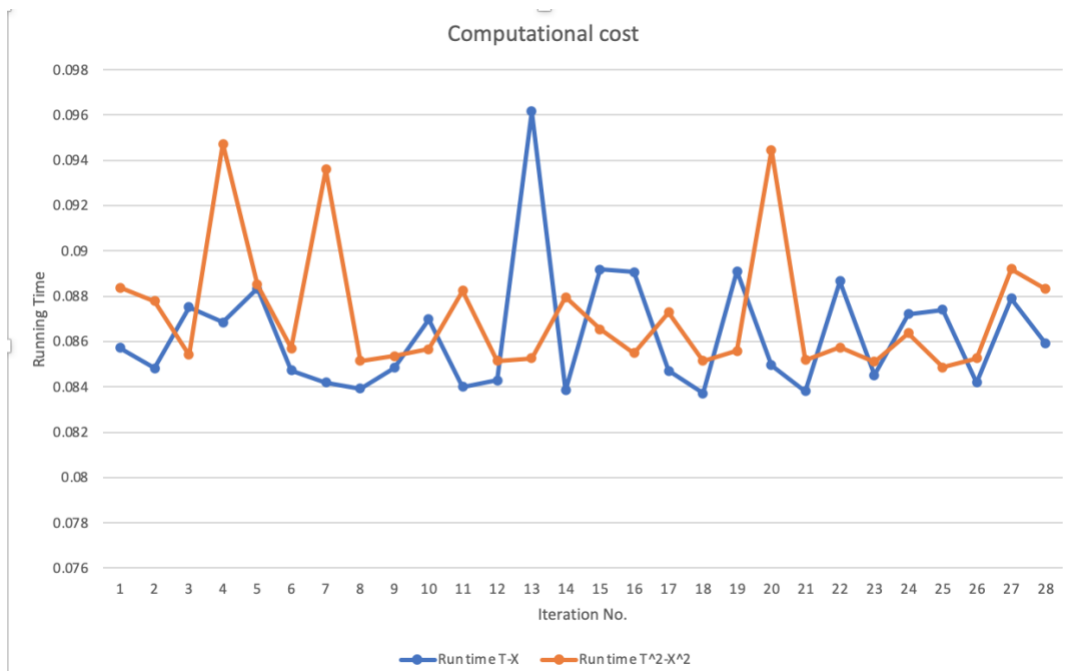


Figure 5-15: Computational cost for $t-x$ vs. t^2-x^2

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The seismic reflection data indirectly generate two main types of velocities, NMO and stacking velocities, which are considered the same in terms of shot spread. Using and applying the t^2-x^2 technique leads to a better understanding of the stacking velocity used for velocity analysis. The time axis was compressed at shallow times and stretched further at deeper times after applying the squaring technique. Likewise, the offset axis was compressed at near offsets and elongated at larger offsets.

The results of applying the t^2-x^2 technique to the datasets show that linear noise is observed at the same locations in both the normal and squared gathers. The reflection hyperbola became linear after applying the squaring technique, which allowed for more accurate detection. In particular, linear events were clearly observed after applying the t^2-x^2 technique to the Mobil data, which were contaminated by water-bottom multiples. The Poland dataset with a low signal-to-noise ratio showed that slight effects of the squared technique were observed on the selected gather. Moreover, the application of the t^2-x^2 technique to the computation of velocity semblance for a variety of datasets created a linear velocity semblance map that was comparable to the conventional velocity semblance. Enhancement in the linear semblance was observed in the vertical resolution, while the semblance energy decreased. Velocity estimation was extracted by scanning the spectrum for linear events.

Because the events became linear after applying the squaring technique, it is recommended to test and apply linear filters (e.g., Frequency–Wavenumber, F–K) on the squared gather. Results after applying the squaring method and the F–K filter should be compared to test the squaring technique. Based on the improvement in the linear semblance, the squaring technique would be a better selection for obtaining the velocity. Nevertheless, a noisy dataset will always be challenging to pick. Applying and testing the squaring technique is recommended to remove linear noise.

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Vitae

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