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Title

Comparative study between VSP and SWD in Algerian exploration petroleum fields

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Dedication

I dedicate this thesis to the remarkable individuals who have played an invaluable role in my life and academic journey:

To my dear grandmother, whose wisdom, strength, and love have been a constant source of inspiration throughout my life. Your guidance and unwavering faith in me have shaped the person I am today. To my loving and supportive parents, whose unwavering encouragement and belief in me have been the driving force behind my success.

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Mendil Walid

Dedication

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Mana Mansour

Dedication

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الملخص

تهدف هذه الأطروحة إلى إجراء دراسة مقارنة بين تقنيتين جيوفيزيائيتين مستخدمتين في صناعة النفط والغاز؛ غير أن هذه الدراسة تقتصر على حقول الاستكشاف الجزائرية. هاتين التقنيتين هما هي التسجيل السيزمي الرأسي (VSP) والاهتزازي أثناء الحفر (SWD). للمضي قدمًا في المقارنة، من الأفضل تسليط الضوء على القيود التكنولوجية والمزايا في كل واحدة منها من خلال دراسة حالة أجريت في بئر استكشافي في الجزائر فيما يتعلق بالتسجيل السيزمي الرأسي (VSP).

اما فيما يخص SWD من خلال محاكاة في MATLAB باستخدام اهتزازات العصا كمصدر لأن هذه الطريقة لم تستخدم في الجزائر حتى الآن. أيضًا، يوصى من خلال نتائج المحاكاة بأن SWD هي طريقة عملية للتصوير تحت السطح في الوقت الفعلي لإدراك بنية الطبقة الجوفية للبئر بشكل أفضل لجعل الحفر أكثر كفاءة وأمانًا.

الكلمات المفتاحية: اهتزازات اَنزلاق انعصا، الزلزالية أثنُاء الحفر، التسجيل السيزمي الرأسي، الاستكشاف، الجزائر.

Abstract

This thesis aims to make a comparative study between two geophysical techniques used in the oil and gas industry; however, this study focus only on the Algerian exploration fields. Those techniques are vertical seismic profile (VSP) and seismic while drilling (SWD). To proceed the comparison, it is better to highlight the technological limitations and the advantages in each and every one of them through a case study done in exploration well in Algeria regarding the SWD through a simulation in MATLAB using stick slip vibrations as a source since this method has not been used in Algeria yet. Also, it’s recommended through the results of simulation that SWD is a practical method for real-time subsurface imaging for better perceiving the inside structure of the well to make drilling more efficient and safer.

Key words: stick-slip vibration, vertical seismic profile, seismic while drilling, exploration, Algeria.

Résumé

Cette thèse vise à réaliser une étude comparative entre deux techniques géophysiques utilisées dans l'industrie pétrolière et gazière, cependant, notre étude ne concerne que les champs d'exploration algériens. Ces techniques sont le profil sismique vertical (VSP) et le sismique pendant le forage (SWD). Afin de procéder à la comparaison, il est préférable de mettre en avant les limites technologiques et les avantages de chacune d'entre elles à travers une étude de cas dans un puits d'exploration en Algérie, et dans le cas du SWD, à travers une simulation en MATLAB utilisant des vibrations à frottement pour une meilleure connaissance de la structure du sous-sol. Cette méthode n'a pas encore été utilisée en Algérie. Les résultats de la simulation recommandent que le SWD est une méthode appropriée pour l'imagerie sub-surface en temps réel, pour mieux connaître la structure du sous-sol et rendre le forage plus efficace et plus sécuriser.

Mots-clés : vibration stick slip, profile seismique vertical, sismique en cours de forage, exploration, Algérie.

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List of Abbreviation

VSP: vertical seismic profile

SWD: seismic while drilling

WSP: walkaway vertical seismic profiling

OVSP: offset vertical seismic profile

CS-DHP : Core sensors downhole pressure sensors

AGC: Automatic Gain Control

AVO: Amplitude Versus Offset

CMP: common Midpoint

TAR: true amplitude recovery

RMS: root mean square

RTD’s: Resistance temperature detectors

HIS: High side indicator

NMO: Normal moveout

TWT: two-way time

TD: total depth

RVSP: reverse vertical seismic profile

VSP-WD: vertical seismic profile while drilling

BHA: borehole assembly

RPD: rotary-percussion drilling

MWD: measuring while drilling

WOB: weight on bit

ROP: rate of penetration

NOV: national oilwell Varco

TOB: torque on bit

SDOF: one degree of freedom

MDOF: multiple degree of freedom

General Introduction

General introduction

Seismic techniques are essential in the dynamic world of oil exploration since they provide crucial insights into subsurface geological formations. Throughout time, many seismic techniques have been used to improve the precision and effectiveness of data collection. Vertical seismic profile (VSP), borehole seismic, and seismic while drilling (SWD) are effective techniques for obtaining real-time data during drilling operations. However, in order to enhance the efficiency of drilling procedures, it is crucial to assess and compare various strategies, specifically within the framework of the Algerian petroleum industry.

This work seeks to examine a comparative analysis between SWD (seismic while drilling) and VSP (Vertical Seismic Profile) and their suitability in the Algerian petroleum industry. We will explore the various features of seismic approaches, aiming to reveal the advantages and constraints of each method. By conducting a comparative analysis, our objective is to underline the benefits of the suggested SWD strategy, providing insight into its capacity to transform drilling operations in this specific region.

As the industry continues to encounter issues relating to wellbore stability, drilling efficiency, and real-time reservoir characterization, the relevance of new drilling techniques cannot be understated. By integrating the stick-slip vibration model into the SWD process, we study the possibility to mitigate drilling-related difficulties while simultaneously increasing acquiring data capabilities.

Furthermore, this work aims to address the special requirements and geological peculiarities of the Algerian petroleum field. Algeria, with its diversified reservoirs and hard drilling circumstances, presents a unique setting where the efficacy of seismic techniques must be studied carefully. By focusing on this regional context, we intend to provide significant insights and recommendations for the application of SWD in Algerian oil fields.

Through a comprehensive literature study, numerical simulations, and analysis of field data, we hope to present a holistic understanding of the stick-slip vibration model and its impact on SWD in the Algerian petroleum field. By considering both technical and operational aspects, we aspire to contribute to the ongoing efforts in optimizing drilling procedures and decision-making within the sector.

Finally, this work strives to bridge the gap between theoretical understanding and practical implementation of SWD in the Algerian petroleum field and provide a comparison between the VSP and SWD methods. We strive to present a comprehensive review of seismic approaches, with a special emphasis on the stick-slip vibration model. The results and suggestions of this study will not only be advantageous for operators and drilling engineers in the Algerian petroleum field, but also enhance the overall understanding in the field of seismic while drilling.

Chapter I

Overview of VSP

I.1. Introduction

VSP as an abbreviation of vertical seismic profile is a geophysical technique used in oil and gas fields to measure seismic activity at depth.

VSPs include recording seismic reflections from a source found at the surface and sensors in a borehole, used to view ahead of the drill bit, get images with a better resolution than surface seismic images, and correlate with surface seismic data. VSP, in its purest form, describes geophone-based measurements taken in a vertical wellbore. In a broader sense, VSPs differ based on the well configuration, the quantity and placement of sources and geophones, and the method of deployment.

The subsurface geology is mapped, structures and stratigraphic sequences are identified, and velocity information is obtained using surface seismic data. However, diffraction, attenuation, and absorption effects have an impact on the information found in surface seismic data.

I.2. Background and significance of VSP in Algerian petroleum industry

Vertical seismic profiles (VSPs) in Algerian oil fields, such as Hassi R'mel and Hassi messouad fields, are commonly used to determine S-wave velocities and for sonic calibration purposes and that to enhance subsurface imaging. For example, a multi-azimuth VSP experiment was conducted in Hassi messouad field to detect natural micro-fractures, which are important in controlling hydrocarbon flow[1].

The application of VSPs in Algeria is part of a broader effort to study the Algerian basin's fundamental structural recovery, which is known for its thick sedimentary layers, with seismic velocities ranging from 1.9 to 3.8 km/s, and Messinian salt formations that can be up to 1 km thick.

The study of the eastern Algerian margin, including the Hassi R'mel field, has been a focus of research, with projects like SPIRAL acquisition data to research the nature, architecture, and deep structure of the Algerian continental margin and deep-sea basin. An active plate boundary is seen in the Algerian basin., with a convergence rate of about 2–3 mm/yr between Africa and Europe, and seismicity is active with moderate to low magnitude earthquakes, and those several application of VSP's in Algeria cause it provides a higher resolution images than seismic images and they can be used to determine in situ formation properties such as seismic-wave velocity, acoustic impedance, seismic anisotropy, and seismic attenuation. VSPs are often used in conjunction with other techniques to improve velocity analysis, differentiate S- and P wave reflections/velocities, and integrate with surface seismic surveys [2].

In summary, VSPs have been significant in Algerian oil fields for their ability to provide detailed subsurface images, identify natural fractures, and improve the understanding of reservoir properties. They have been applied to reduce future drilling risks and improve the placement of development wells.

I.3. Historical context of VSP

The vertical seismic profile shows up for the first time in the early 20th century, when the first experiments with downhole seismography were conducted.

The main reason that makes downhole seismography developed is the need to explore for oil and gas reserves and that's in the 1940s and 1950s, during this time seismic waves were generated at the surface and their arrival times were recorded at downhole receivers to determine the subsurface velocity structure.

The advent of cutting-edge technology like multi-component sensors and cross-hole seismic in the 1960s and 1970s led to an advancement in the field of borehole seismology. With the use of these methods, the subsurface could be imaged in three dimensions and more precise details on the underlying geology and geophysical characteristics could be obtained.

With the advent of high-resolution downhole seismometers and novel data processing methods in the 1980s and 1990s, borehole seismology underwent further development. During this period, borehole seismicity developed into a significant instrument for engineering and environmental applications, including the evaluation of subterranean storage reservoirs and the research of soil and rock mechanics.

These days, geothermal exploration, the oil and gas sector, and other subsurface imaging applications heavily rely on borehole seismology, a well-established field.

The improvements in technology have made it easy to have a high-quality seismic data in a variety of subsurface environments, and fresh approaches to data processing and imaging have enhanced our comprehension of the subsurface. It was initially launched in Algeria in the 1970s, at a period when SONATRACH was leading the oil and gas sector in the use of this technology [3].

- **Equipment of VSP**

A vertical seismic profile (VSP) needs a specific equipment to assure its function (Figure I.1), this equipment include:

Seismic source: a seismic source used to generate seismic waves, such as an explosive charge, a weight drop, or a vibrator.

Seismic sensors: include geophone (on the surface) and hydrophone (in the borehole), both of them are used to record the seismic waves. Geophones typically have a frequency range of 2-20 Hz and a sensitivity of 10-100 V/m/s. Hydrophones have a frequency range of 0.5-20 kHz and a sensitivity of 1-100 μV/Pa.

Data acquisition system: The seismic signals that are obtained from the sensors are recorded using a data gathering system. The system includes a cable to connect the sensors to the recording unit (seismograph), arecording unit to convert and store the signals, and a power source to supply power to the recording unit and sensors.

Down hole tools: Seismic sensors are lowered into the borehole using downhole tools. These instruments could be a coiled tubing unit, a slickline, or a wireline.

Data processing software: The captured seismic data is processed using data processing software to produce a subsurface velocity model. This software may include tools for velocity analysis, gain recovery, and filtering may be included in the software.

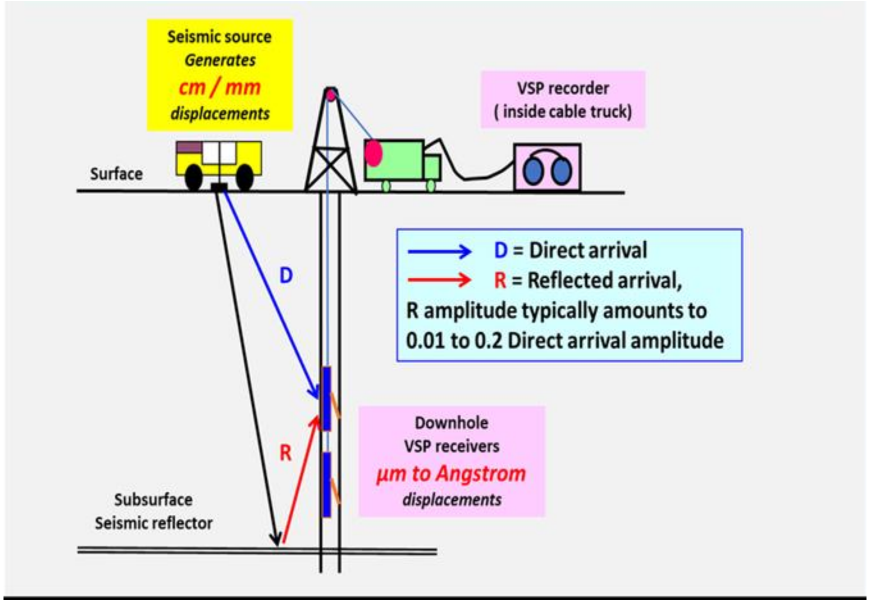


Figure I.1 vertical seismic profiling method-principle

I.4. Operating principal of VSP

The use of surface reflection seismology in the development of oil fields and oil exploration is the key method, but oil exploration involves various geophysical techniques, not just surface reflection seismics.The subsurface geology is mapped, structures and stratigraphic sequences are identified, and velocity information is obtained using surface seismic data. However, diffraction, attenuation, and absorption effects have an impact on the information found in surface seismic data. By leveraging the statistical characteristics of the signal and noise, or stacking the data, the accompanying deterioration can be largely eliminated. We have the benefit of detecting the seismic signals reflected from reflectors above and below the borehole observation site when using the VSP geometry (Figure I.2).

Because of its geometry, it is feasible to get better outcomes with regard to seismics at the surface. The downward wavefield contains the reflections from above. Conversely, reflectors below the well's observation point reflect the downward wavefield upward. Accordingly, the up-going wavefield contains the identical down-going wavefield. Because the two wavefields propagate in basically the same way (assuming acquisition is done with the source at a tiny offset), the use of the downgoing wavefields enables the deterministic deletion of the downgoing filter from the upgoing waves. There is a significant improvement in the VSP reflections after downgoing deconvolution. Surface seismic phase issues and multiple event detection are made possible by VSP surveys.

If the acquisition is carried out with a slight offset from the source. Upon downgoing deconvolution, there is a significant improvement in the VSP reflections. In addition to estimating operators for deconvolving surface seismic data, VSP surveys enable the detection of numerous events and phase issues in surface seismics. The reflectors and diffractors responsible for the reflections and diffractions seen on the surface seismic sections are in space using the VSP. To forecast the acoustic impedance differences below the well bottom, this data can be inverted. The structural and stratigraphic features of the well profile may be more closely correlated with the surface seismics using all this data in addition to synthetic seismograms. The outcome is a notable advancement in the understanding of the seismic and accurate data. Anisotropy and the fracture trend may be ascertained by analysing the arrival timings. Furthermore, because the length of the ray path is reduced, the VSP provides higher resolution than surface seismics. In fact, well seismics provides the only resolution available for observing certain formation in some wells.

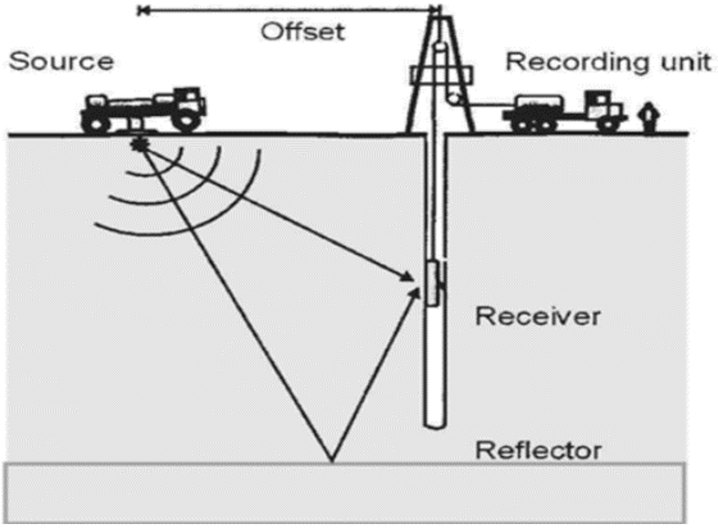


Figure I.2 Conventional wireline VSP uses the receivers in the well and surface source. The distance of the source from the well is the offset**.**

- **Types of VSP**

There are various types of VSP surveys that can be used for different purposes (Figure I.3), including time-depth correlation with surface seismic data, reservoir characterization, fault and structure identification, monitoring changes over time, and cross-well seismic imaging. Common types include zero-offset VSP, walkaway VSP, offset VSP, and deviated VSP. These surveys can calculate velocities between wells and provide high resolution imaging for applications such as velocity modeling and reservoir connectivity mapping.

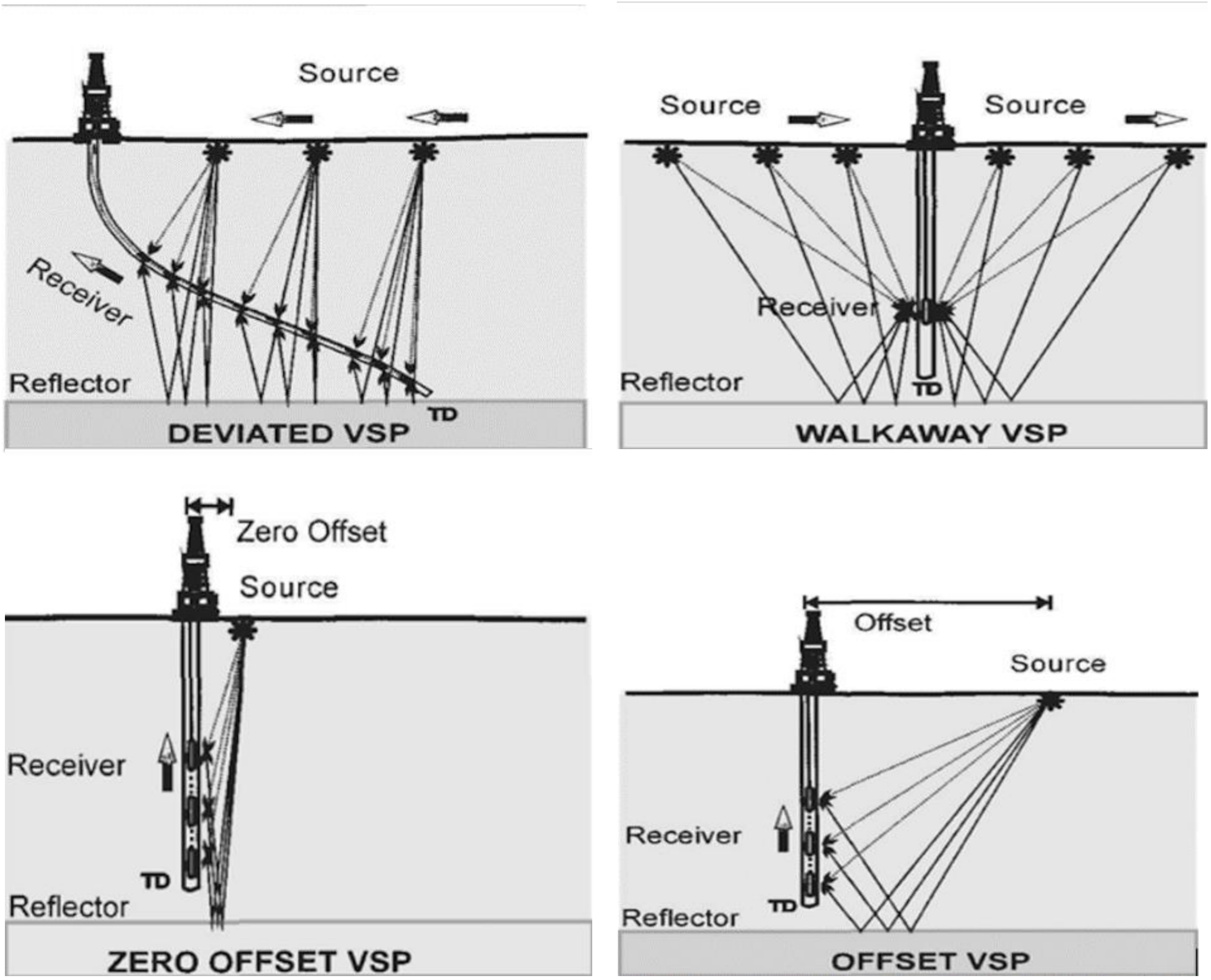


Figure I.3 Schematic representation of main types of conventional onshore VSP acquisition geometries. A similar geometry holds for offshore applications**.**

I.4.1. Fundamental principle of VSP

Basic ideas behind Vertical Seismic Profiles (VSP)

1. **Correlation**: By correlating borehole seismic measurements with surface seismic data, VSP produces pictures with better resolution than those obtained from independent surface seismic studies.

2. **Source vs Detectors Placement**: A crucial element is positioning the energy source(s) or detectors (such as geophones) within a borehole, in contrast to conventional surface seismic acquisitions in which neither element penetrates the subsurface.
3. **Types of Configurations**: There are different configurations based on whether the source remains fixed with respect to the detector array (zero-offset VSP), walks away from the wellhead gradually (walkaway VSP), uses non-collinearity between the source and detectors (offset VSP), takes into account incline well paths (walk-above VSP), targets boundaries between sediment and salt (salt proximity VSP), and uses drill bit noises instead of external sources (drill-noise / SWD VSP).
4. **Deconvolution Benefits**: After using deconvolution methods, VSP helps identify anomalous occurrences by providing information into the source wavelet through depth measurements of the seismic signal. In contrast to routine seismic recordings that document all events, deconvolve VSP concentrates only on anomalous events that may be signs of intriguing stratigraphy or lithology.

To summarise, fundamental aspects of VSP revolve around integrating borehole observations with surface seismic findings, employing unique geometric setups adapted per project needs, extracting meaningful signatures post-deconvolution, and supporting safer, smarter operation planning. Notably, although search results don't explicitly detail VSP history in Algeria outside commercial product listings, the fundamentals remain consistent regardless of regional deployment. [3]

I.4.2. VSP operation

In order to obtain highly resolved images correlated with surface seismic data there are several VSP operations, each and every operation is suitable for its own situation and needs a suitable equipment, these operations are:

- Zero-offset VSP: involves a source positioned vertically above the receiving instruments in the same hole, Zero-offset acquisition of VSP in vertical wells is referred to as standard VSP. A geophone, or geophones, are lowered to the bottom, and a seismic source is positioned close to the wellhead on the surface. Subsequently, the geophone is elevated to capture data at consistent intervals for depth collection. With a lateral resolution defined by the conventional VSP and the

Fresnel zone of the measured reflections offers the time-to-depth conversion and the identification of the principal reflected events in two-way time (TWT) on the seismic sections. Estimating the acoustic impedance contrasts below the total depth (TD) and learning about the signal attenuation as a function of encountered lithology are both made feasible by the typical VSP data.

- Offset VSP: places the source at a horizontal distance from the receivers in the wellbore, Offset VSP (OVSP): In a usually vertical well, the geophone is anchored at periodically decreasing levels, and the source is placed at a predetermined distance from the wellhead. Normal moveout (NMO) effects are introduced by recording waves because they propagate at oblique angles against the vertical; these effects are removed at the processing stage. When the outcome of an OVSP is compared to the surface seismic section, geophysicists can use the VSP data to extend the structural survey laterally from the well.

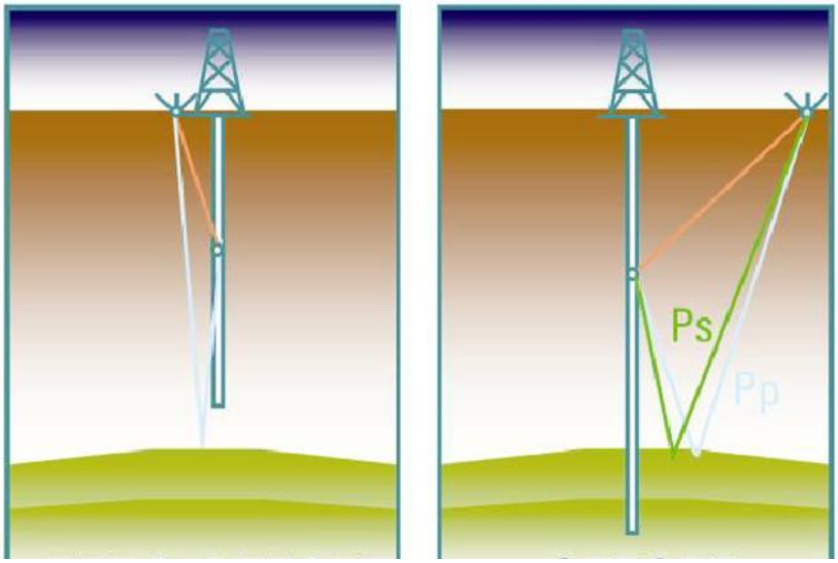


Figure I.4 Zero offset and Offset VSP

- Walk away VSP: keeps the receivers static while moving the source gradually away from the wellbore (Figure I.5), in order to record the WSP, a stationary geophone is lowered into the well, and seismic events produced by a source moving over the surface in a straight line intersecting the wellhead are recorded. The WSP lights the area beneath the sensor more precisely than the OVSP does. In this instance as well, the processed result may be placed on top of the traditional seismic section.

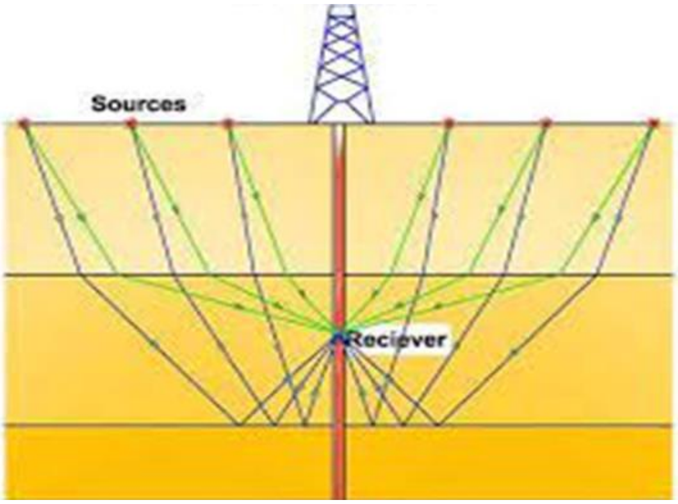


Figure I.5 Walk away VSP

- Walk-above VSP : Walk Above Vertical Seismic Profile (VSP) operations feature prominently in addressing deviated or horizontal well configurations, Unlike Zero Offset VSP, wherein the source is directly overhead the borehole containing receivers (Figure I.6), Walk Above VSP operates in tilted or curvilinear wells, maintaining a nearly straight line connecting the source and receivers despite the inclination of the wellpath itself, and also can be contributes to integrated modeling tasks and that's to determine some physical attributes like seismic wave velocity, acoustic impedance, seismic anisotropy and seismic attenuation.

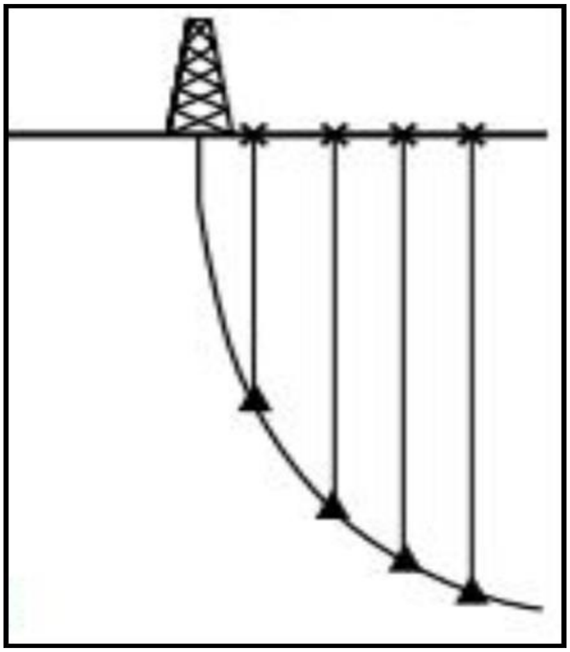


Figure I.6 Walk above VSP

- Shear-waves VSP: collects shear- waves traveling slower than compression waves, revealing elastic property differences.

- Drill-noise or seismic while drilling VSP: harnesses drill bit vibrations as the source, eliminating separate shot generation.

- Multi-offset VSP: mixes parts of previous situations, with a range of distances between the source and recipients.

Each variant addresses specific challenges faced in exploring and developing oil and gas fields. When combined with sophisticated data processing techniques, VSPs offer unprecedented clarity in depicting subsurface structures and enable effective management of well construction projects.

I.4.3 Downhole sensors configurations

Considering the downhole sensors used in vertical seismic profile (VSP) applications, here are sample configurations for some of the highlighted items:

- High side indicator (HSI) system: described as a compact unit of 3-component (3C) arranged symmetrically around a center hub, mounted radially in the casing string, it tracks x, y, z axis forces acting on the host pipe section and that’s in order to translate deflection vectors.

- Core sensors CS-DHP Downhole pressure sensors: robust sensors built to handle brutal environments characterised by high pressure and temperature. This sensor is constructed with dielectric isolated silicon Oxide Nitride (SiOn) thin film diaphragm supported by low expansion coefficient substrate, housed in stainless steel body. Equipped with optional PT1000 platinum RTD probe for concurrent temperature measurement.

- Flow meters: In general, differential pressure cells are linked with calibrated Venturi tubes that are appropriately proportioned to projected flow rates. Fluid moving through constrictions creates quantifiable pressure gradients, which are then interpreted electronically to calculate mass flux numbers.

- Resistance temperature detectors (RTDs): The PT1000 class is well-known for its nominal value of 1000 ohms at 0 °C. Made from pure metals such as copper, nickel, or noble metal complexes placed on ceramic cores and covered by glass capsule coverings. Connected serially to transmitter boards, transforming Ohmic load changes into a digitizable representation.

I.4.4. Seismic source deployment

When an interpretation project employs both compressional (P) and shear (S) data instead of relying only on one seismic mode either a P mode or a S mode more robust seismic interpretation may be produced. Unfortunately, the restricted availability of direct S sources and the high expense and complexity of deploying S wave sources throughout this essential principle of interpretation. It was provided a novel approach to seismic interpretation, which relies on the direct P and direct S modes produced by sources with vertical forces. As an example of the real data that demonstrate the physics of P and S body wave radiations generated at vertical force source stations in order to explain the possibilities of this innovative approach for obtaining direct S data. First, a vertical force source's direct S radiation is modeled in three dimensions and tested.

I.4.5. Data acquisition and recording

Seismic data acquisition and recording involve generating and recording seismic waves produced by controlled sources and detected by receivers. The fundamental principles of seismic data acquisition consist of a source, receivers, and a recording system. In VSP, either the detectors or the energy source—or occasionally both—are located in a borehole. The most typical types of VSP include zero-offset VSPs, offset VSPs, walkaway VSPs, walk-above VSPs, salt-proximity VSPs, shear-wave VSPs, and drill-noise or seismic-while-drilling VSPs. The receivers in VSP are typically geophones or accelerometers, and they recorded the reflected seismic energy that came from a surface seismic source. The VSP configuration varies in the well configuration, the number and location of sources and geophones, and how they are deployed. The recording system captures and stores the electrical signals for further analysis. The factors affecting data acquisition and recording include environmental concerns, regulatory requirements, cost optimization, and technological advances.

In vertical seismic profile data acquisition and recording needs these applications:

- Source: VSP generally uses a surface seismic source, such as a vibrator or an air gun, to create seismic waves that travel down the subsurface and are detected by receivers in the borehole.

- Receivers: VSP receivers are generally geophones or accelerometers installed at certain depths in the borehole. The number of receivers and their spacing are determined by the exact VSP setup and survey objectives. The receivers record the reflected seismic energy from the seismic source at the surface.

- Recording system: The recording mechanism of VSP catches and saves the electrical signals produced by the receivers. Signals are often digitized and saved in a digital format for further processing and analysis. Depending on the VSP arrangement, the recording system may be positioned either at the surface or downhole.

- Data processing: After the data has been collected and recorded, it is processed to derive meaningful information about the subsurface. Filtering, deconvolution, migration, and inversion are all possible data processing techniques. The processed data is then utilized to generate pictures of the subsurface and estimate attributes such as seismic wave velocity, acoustic impedance, and seismic attenuation.

- Quality control: Quality control is an important part of seismic data collecting and recording in VSP. Quality control procedures may involve monitoring the performance of the source and receivers, ensuring that the data is accurately captured, and checking that the data is of adequate quality for further processing and analysis.

I.5. Case study in Algerian field

I.5.1. Zero offset VSP acquisition parameters

a) Drilling situation: the well is located in the south of Algeria

b) Acquisition parameters

- **Well description:**

Country: Algeria

Type: exploration

Total depth drilled: 3000 m

Total depth logged: 3004 m

Maximum deviation: vertical

- **Elevation information:**

Elevation references: 356.6 (ground level)

Ground level: 356.6

Seismic datum: 356.6

Above permanent datum: 7.6 m

Drilling measured from: DF

Derrick floor: 364.2

Kelly bush: 364.2

- **Recording system:**

Type: VSI

Program version: 18C0-147

Surface sampling rate: 2.0 ms

Recording time: 18 sec

Surface recording length: 14 sec

- **Source:**

Combined tool: LEH-Q/EDTC-B/AH-199/VSIT-C

Offset: 60 m

Azimut: 50 north east

Elevation of the source: 356.6m

- **Depth corrected information:**

Water velocity: 1500 m/s

Seismic refrences datum: 356.6 m

- **Sweep:**

Sweep length: 12 sec

Sweep start/End frequency: 8-80 Hz

Sweep type: Linear

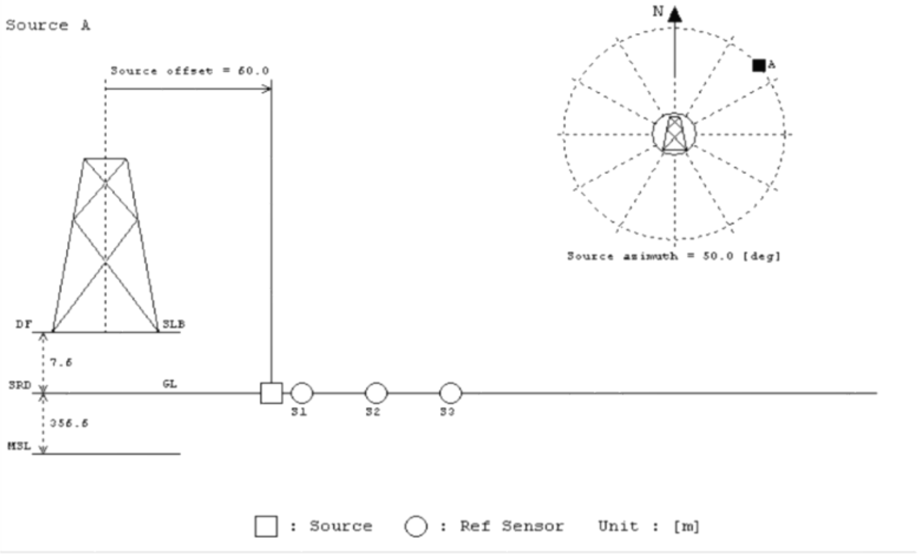


Figure I.7 Source Geometry Sketch

I.5.2. Acquisition configuration

Zero offset VSP treatment

Pre-processing: For each recording level, the VSP data is edited (noisy traces are removed) and summed to improve the S/N (sound/noise) ratio. Figure I.8 shows the raw stack data of the three components: Vertical (Vz) and Horizontals (Hx, Hy).

The amplitude spectrum of the vertical component is calculated in Figures I.9 and I.10 The arrival times of direct waves are identified and recorded to calculate the average velocities, RMS (root mean square) velocity, and interval velocities (Figure I.11). The T.A.R (true amplitude recovery) program is applied to recover true amplitudes using spherical divergence compensation (1/dist.) and a Tn gain (n=1) followed by a top mute and a band pass filter of: 8-12-60-70 Hz. The result of the pre-processing is shown in Figure I.12.[4]

Note: The processing sequence will only take into consideration the vertical component (Z).

Separation of wave fields: Each trace is shifted by the time value of the first arrival of the corresponding reference signal.

To obtain the upgoing waves, they are aligned at 200ms and then a median filter (directional filter) is applied with a window of 9 traces in reject mode, leaving us with the residual field. The upgoing waves are then aligned, and a median filter with a window of 9 traces in normal mode is applied [4].

The same procedure is applied to obtain the downgoing waves, except that the filter length is 11 traces.

- The downgoing P waves will be recorded on the radial component R.

- The upgoing P waves will be recorded on the normal component N.

Deconvolution: The purpose of the deconvolution operation is mainly to compress the emitted signal and reduce or completely attenuate the multiple reflections.

In the case of zero offset VSP The deconvolution operator is calculated based on the downgoing waves aligned at 200ms over a window of 200ms after the direct arrival and a 1000ms operator with a 1% prewhitening.

Calculation of the deconvolution operator: From the downgoing waves, a 300ms window containing different multiples is chosen. From this window, a 1000ms operator with a gain of 0.5 is calculated, and then the same operator is applied to the upgoing waves (Figure I.14 and I.15).

Corridor stack: The deconvoluted and horizontalized upgoing waves are summed in a corridor immediately following the first arrivals. The resulting summed trace may contain upgoing multiples.

To eliminate the effects of the upgoing multiples, a narrow summation corridor (150ms) must be chosen to retain only the reflected signal received immediately after the first arrival. After summing this window, a duplicated summed trace is obtained (Figure I.16) [4].

1. Without AGC (Automatic Gain Control): The deconvolved and flattened upgoing waves are summed in a corridor immediately after the first arrivals. The resulting sum trace may contain upgoing multiples. Bandpass filtering is used.

2. With AGC (Automatic Gain Control): AGC remains an effective and simple means to improve the appearance of data; however, it can modify the relative amplitudes within a CMP gather (Figure I.15).

AGC: Land data is often of low quality, making it difficult to produce attractive CMP (common Midpoint) gathers for AVO (Amplitude Versus Offse) analysis. AGC (Automatic Gain Control) remains an effective and simple way to improve data appearance, but it may alter the relative amplitudes within a CMP gather.

List of boards

Board 01: Raw recording.

Board 02: First arrival picking.

Board 03: Spectral analysis.

Board 04: Velocity analysis.

Board 05: Data preprocessing.

Board 06: Wave separation.

Board 07: Deconvolution of downgoing waves.

Board 08: Deconvolution of upgoing waves.

Board 09 : Corridor stack.

Board 10 : migration

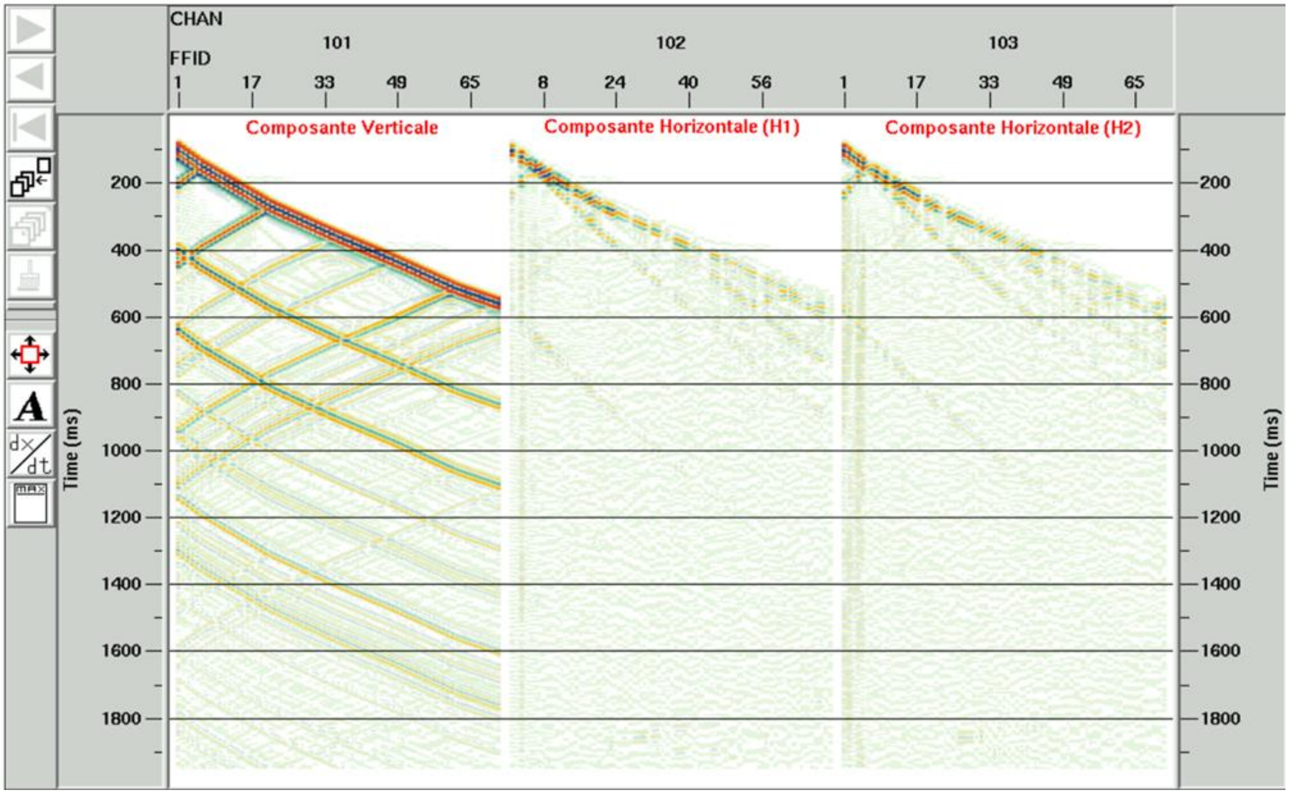


Figure I.8 Raw data

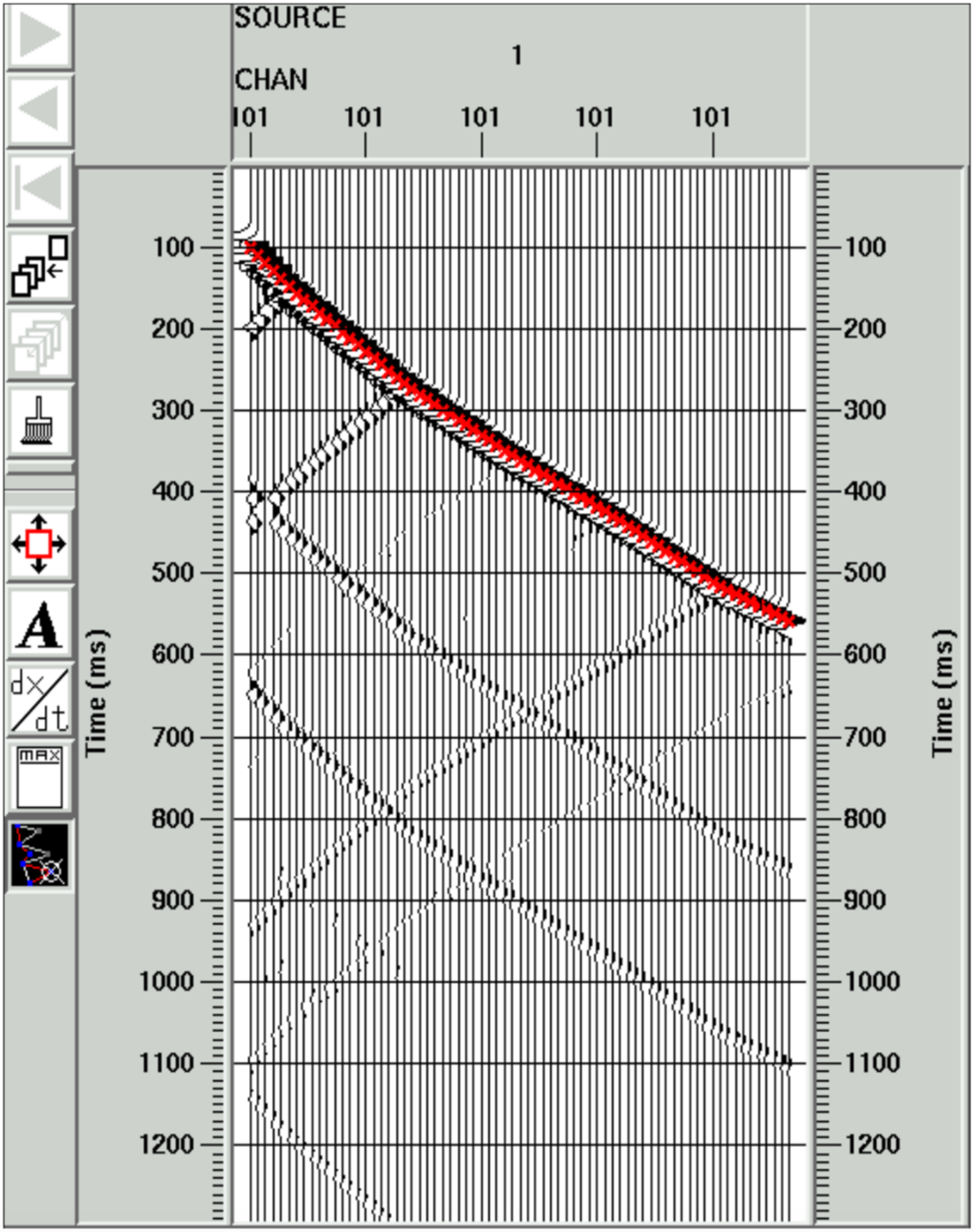
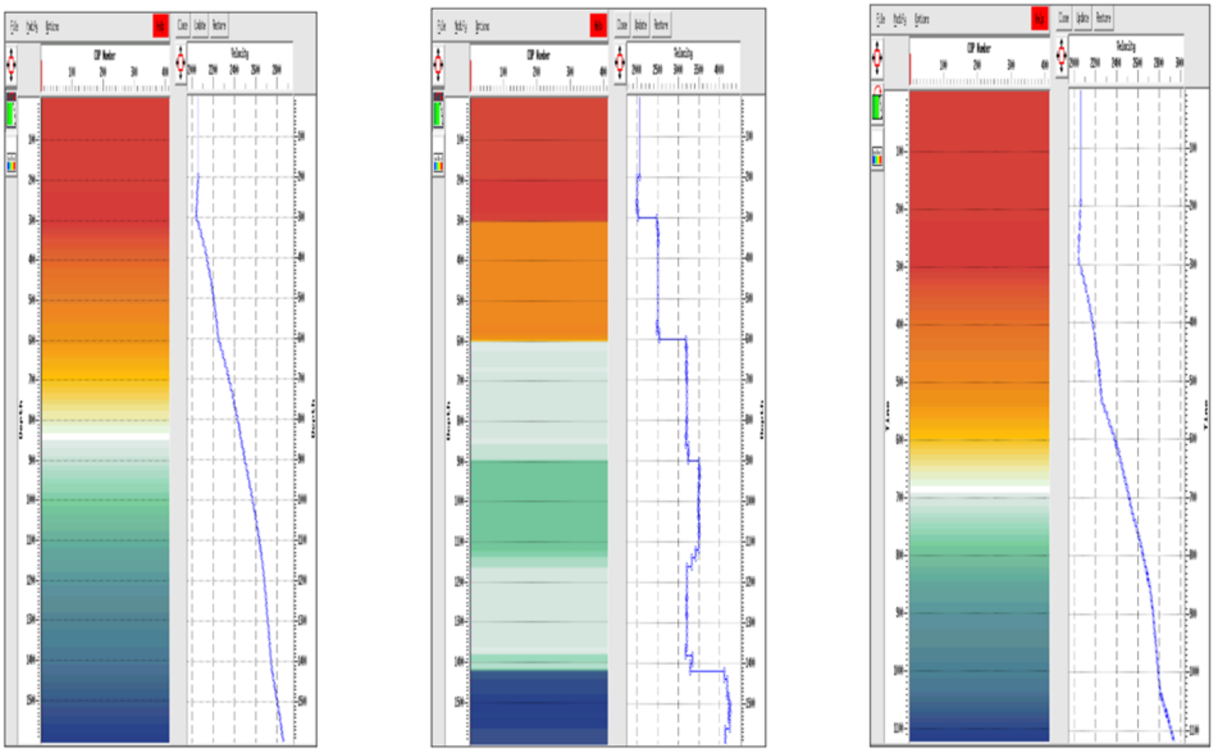


Figure I.9 Picking of the first arrivals



Vitesses moyennes

Vitesses d'intervalles

Vitesses RMS

Figure I.10 Spectral analysis

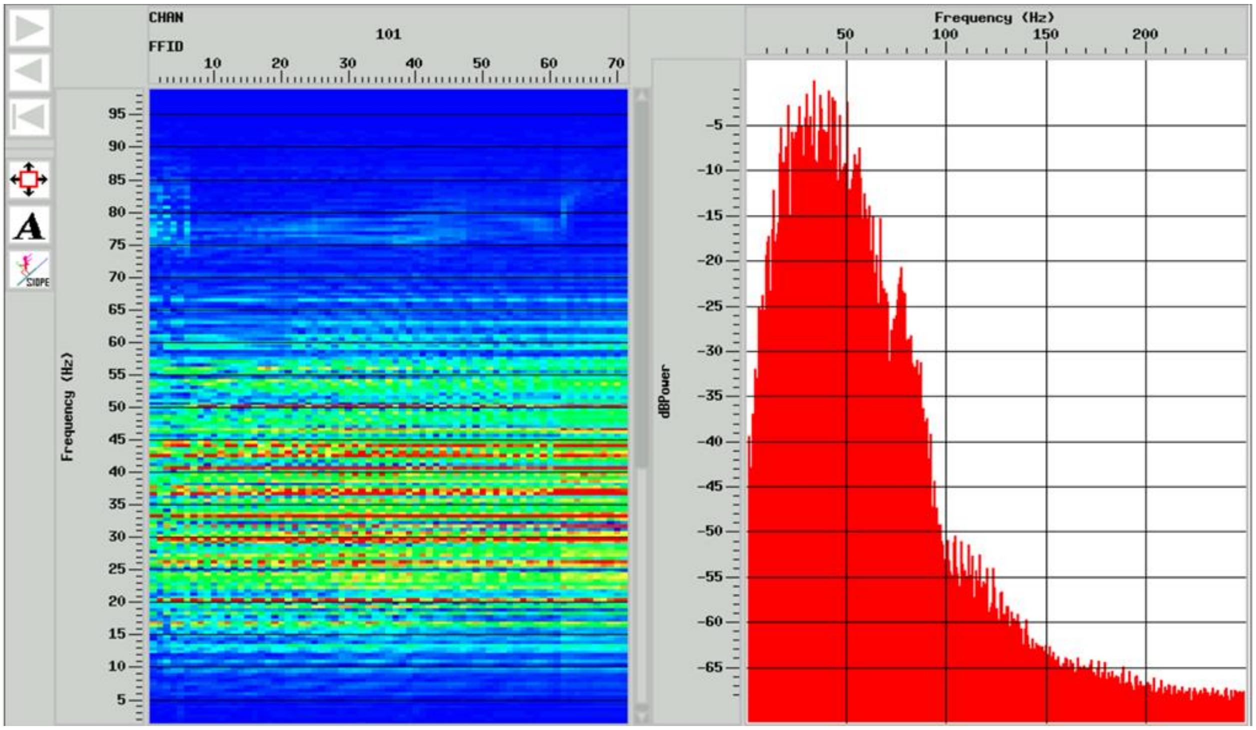


Figure I.11 Velocity laws

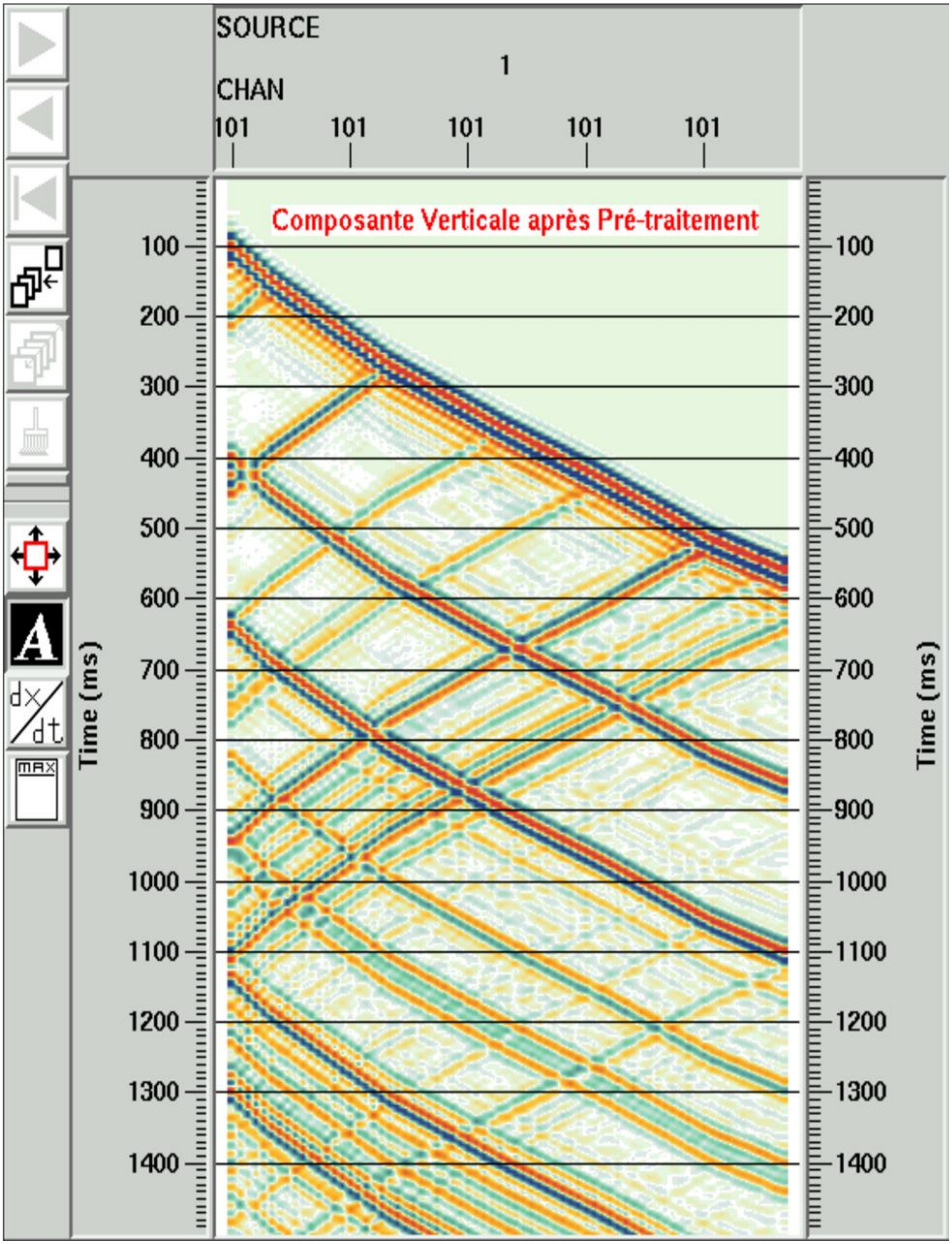
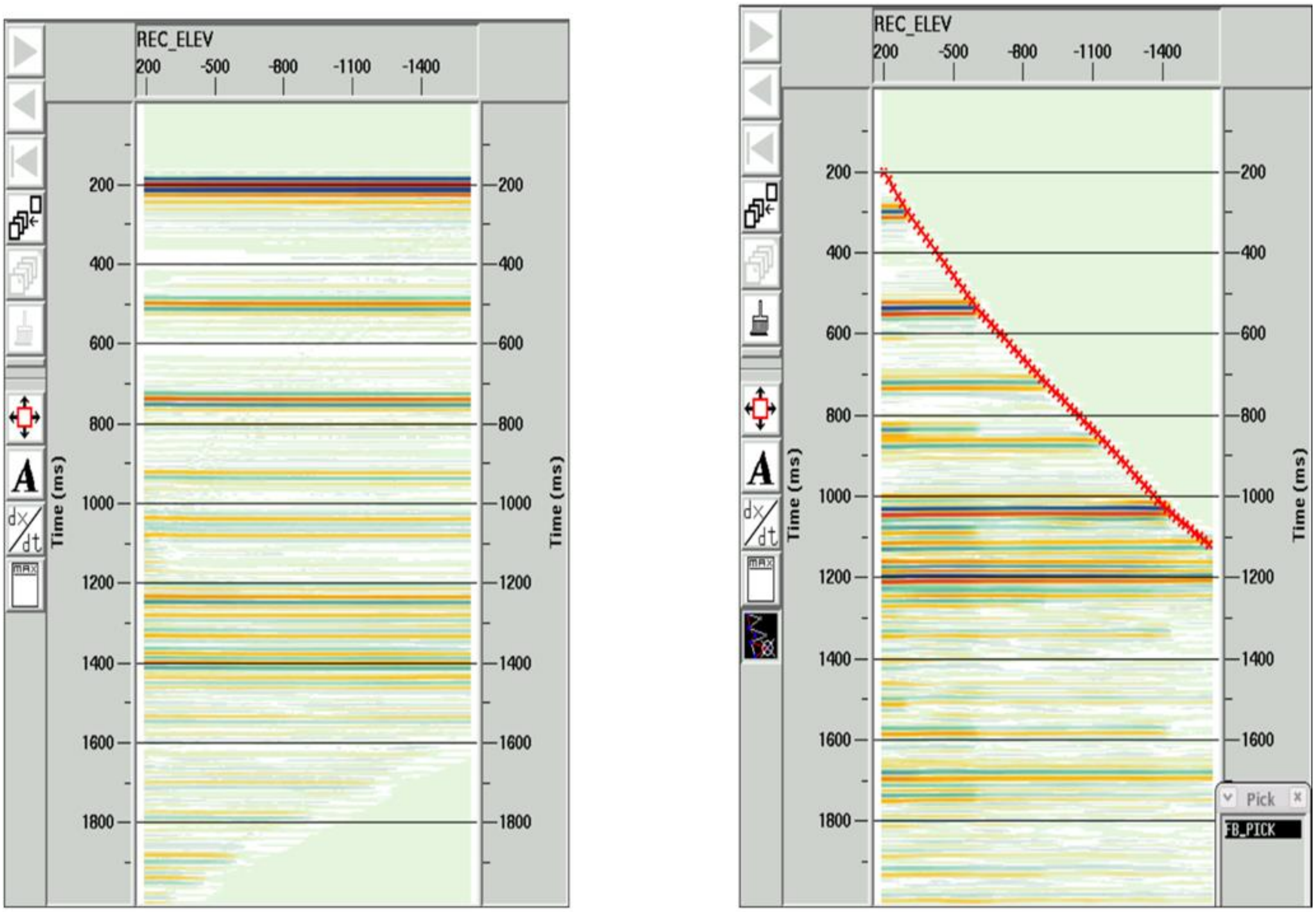


Figure I.12 Preprocessing



Ondes descendantes

Ondes montantes

Figure I.13 Waves separation

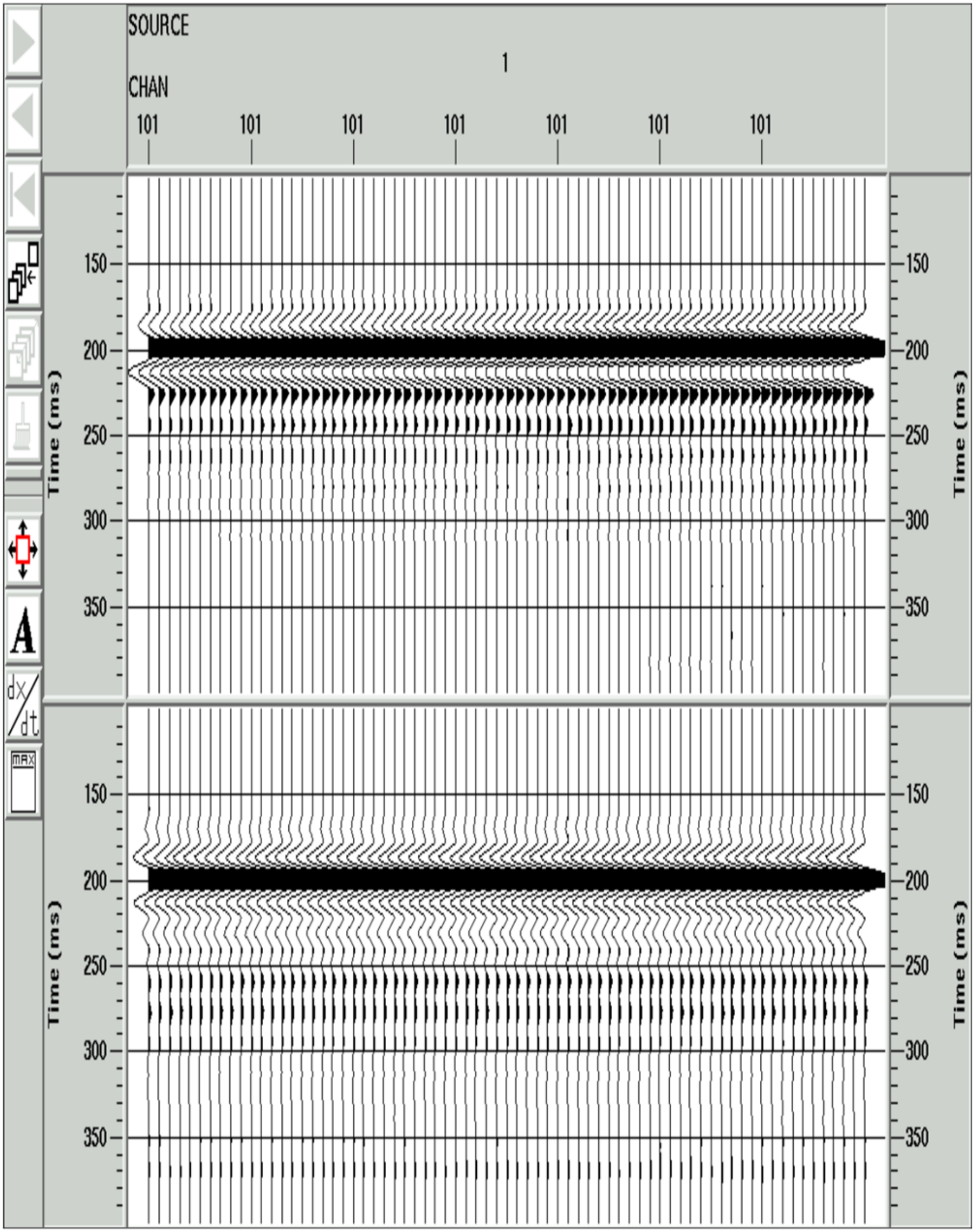
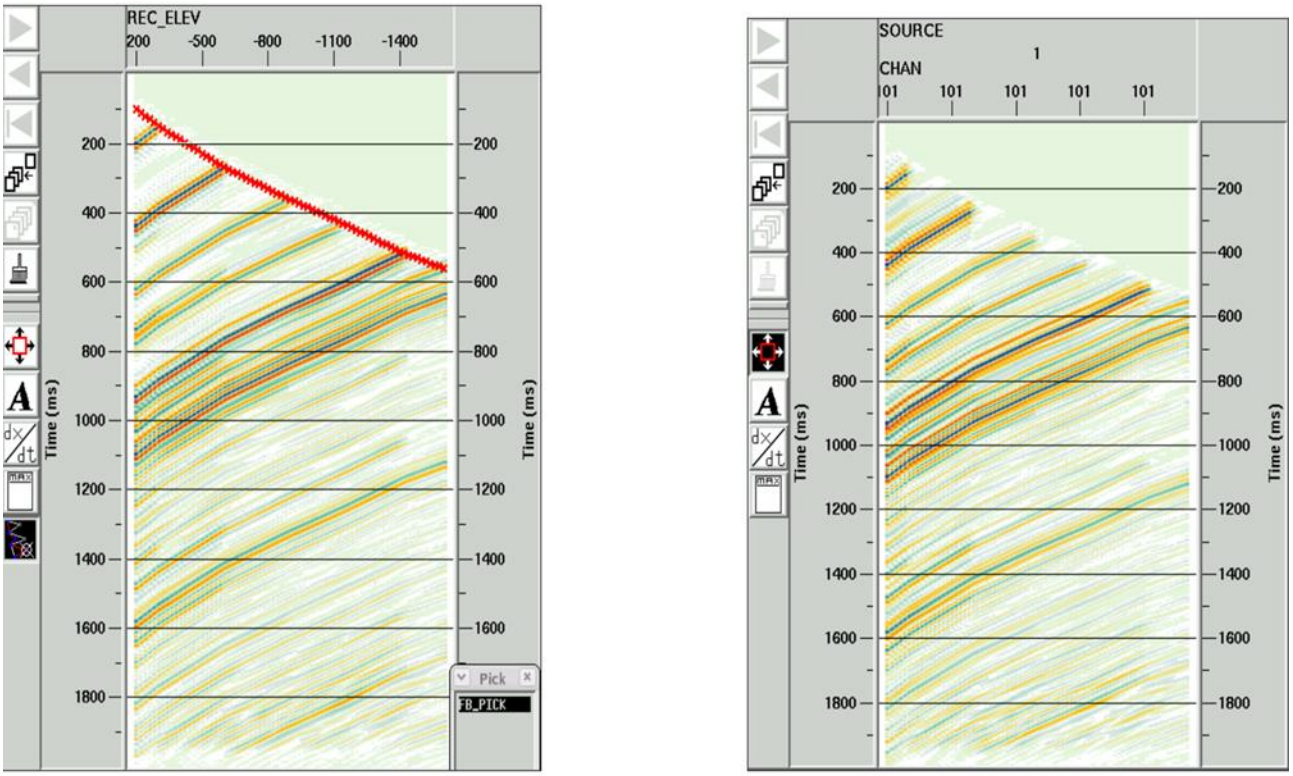


Figure I.14 Deconvolution of downward waves



Ondes montantes

Ondes montantes déconvoluées

Figure I.15 Deconvolution of upward waves

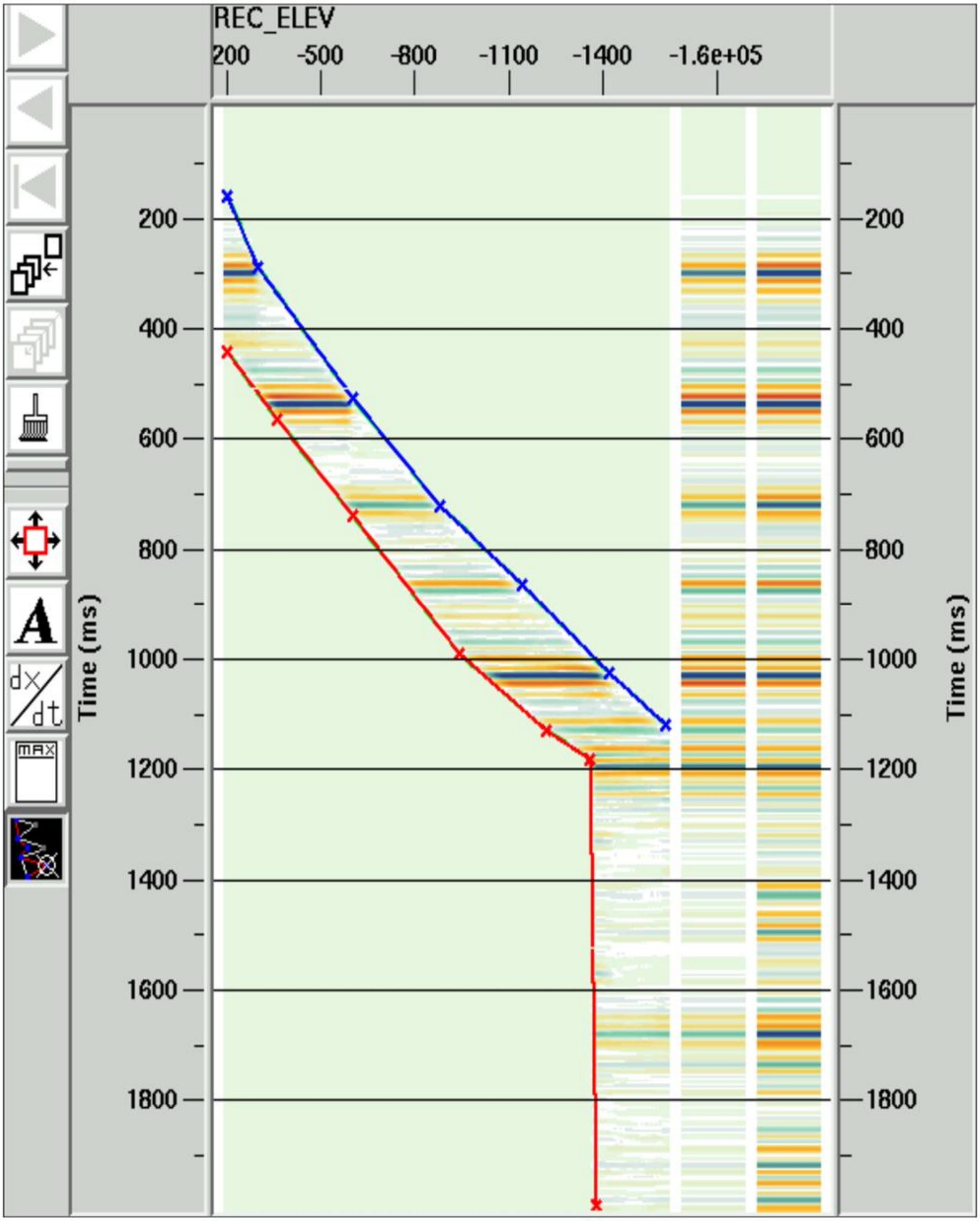


Figure I.16 Corridor

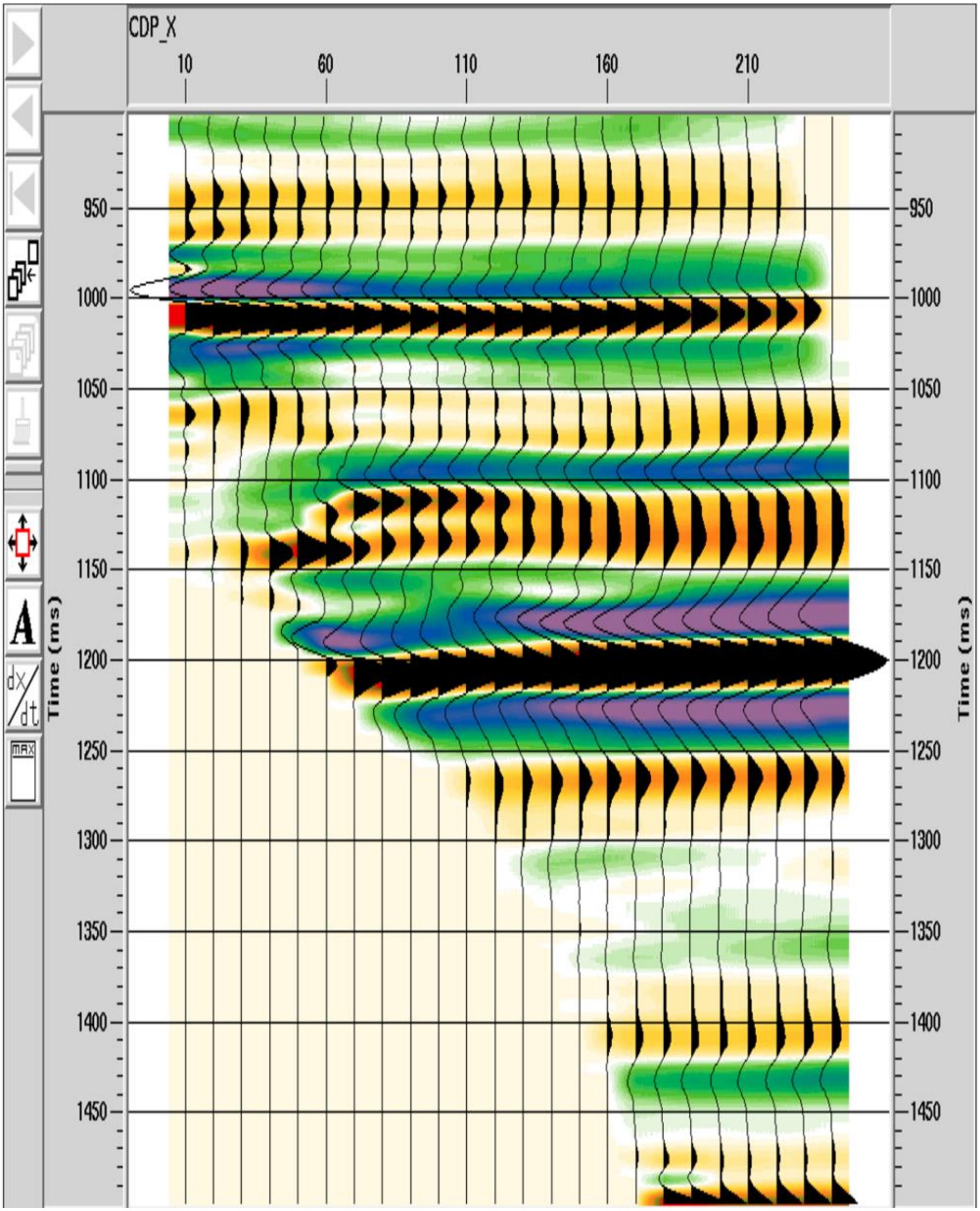


Figure I.17 Migration

I.6. Conclusion

In summary, VSP plays a vital role in improving the quality of seismic data interpretation and subsurface imaging that may lead to more successful exploration, and production activities in the oil and gas industry especially when it comes to the cost of this technique which is extremely acceptable compared to other methods.

In this chapter we have also seen the operating principal of the VSP and its historical context, beside taking a case study in Algerian field in which we discuss the use of VSP in a particular well in the south of Algeria.

Chapter II

Overview of SWD approaches

II.1. Introduction

For four decades, there has been a thorough evaluation and investigation of the use of drill-bit seismic sources for seismic while drilling (SWD) applications. The use of reverse vertical seismic profiling (RVSP) has decreased due to signal variability.

The service industry has developed a variety of seismic techniques that provide the best way to characterizing formations and comprehending the subsurface. This drilling technology is widely employed in the drilling business because it allows for safe, cost-effective, and efficient drilling. SWD is considered one of the "real-time" logging methods since seismic data is gathered utilizing vibrations created by drill-bit impact on the rock formations during drilling [5].

SWD is an innovative technique used to gather geological information about subsurface rock formations and provide real time information during the drilling process .In active SWD, an energy source, like a hydraulic vibrator or an explosive charge, is used to generate seismic waves. In passive SWD, the seismic waves are generated naturally by the drilling process itself.

II.2. SWD Methods

SWD is a valuable and interesting geophysical technique, which has undergone extensive research, testing, and improvement throughout its history.

Seismic while Drilling (SWD) refers to seismic techniques used during effective drilling, when the drillstring is lowered in the borehole, during maneuvers, or while connecting drill pipes. This method offers real-time data to enhance well placement, forecast risks, and optimize drilling efficiency [6].

There are several methods of seismic while drilling (SWD) including:

II.2.1. The drill-bit SWD technique

The drill-bit SWD method provides real-time data by using the drill-bit as a source of vibrations due to its impact on the rock formation during drilling. As seen in Figure II.1, seismic waves produced by the drill bit are picked up by surface-deployed receiver elements and a pilot sensor attached to the top of the drillstring. A seismogram can be produced by cross-correlating each receiver element's response with the pilot sensor's response, which functions as a pilot signal comparably to a vibrator sweep signal.

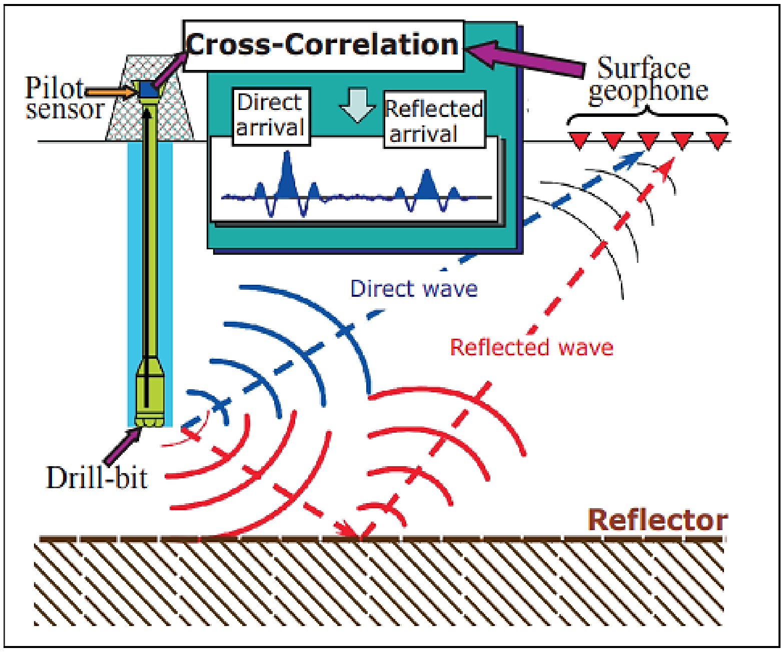


Figure II.1. The fundamental SWD configuration and the concept of cross-correlation between the Surface geophones and the pilot sensor

Data regarding on formation velocity above the drill bit and formation boundary information below the drill bit may be obtained using this method. Drilling depth can be converted to two-way travel time using the velocity information, and the drill-bit location in the seismic section can be found while drilling. The location of the drill bit and the formation boundary data are then combined to predict and prevent drilling dangers [5].

II.2.2 Vertical seismic profile while drilling (VSP-WD)

Since 2000, Schlumberger has employed this technique, which entails using hydrophone sensors incorporated into the downhole borehole assembly (BHA) to record and capture the signal released by a surface seismic source.

Using the same surface source and downhole sensors, VSP-WD transfers wireline borehole seismic to drilling operations. The primary distinction is that the tool and surface are not directly connected via a cable. Both the reflected and direct seismic signals may be captured by the device. The downhole tool has memory, processors, and sensitive receivers. A mud pulse telemetry system analyzes the signals downhole to identify the critical first breaktime, or check shot time. It then transfers this information up-hole in real-time. These waves can be recorded as one-way travel time straight from the source or as two-way travel time reflected by the formation. Figure II.3 depicts the tool's whole procedural component.

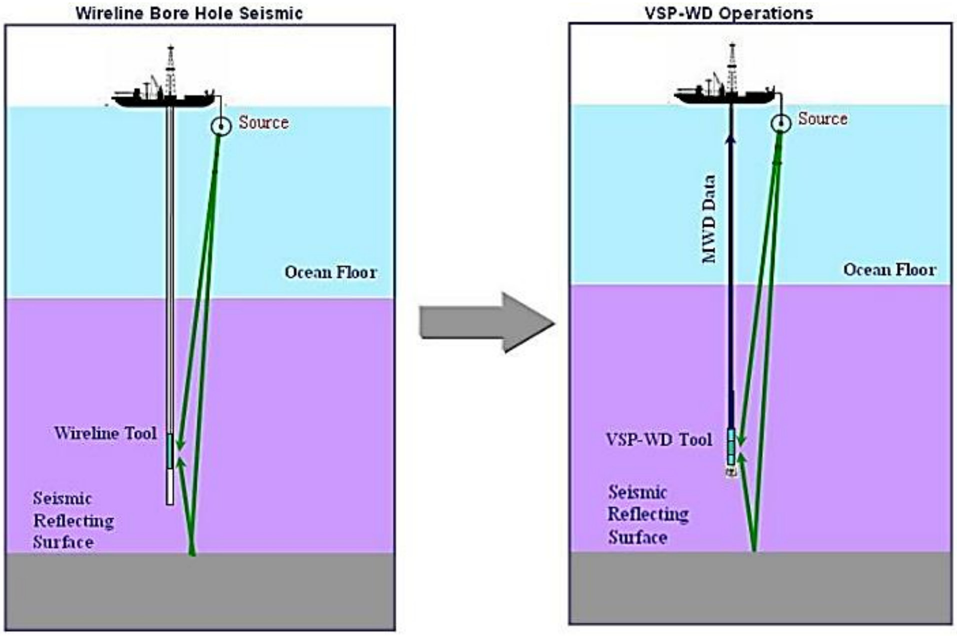


Figure II.2. Drilling operations using wireline seismic technology

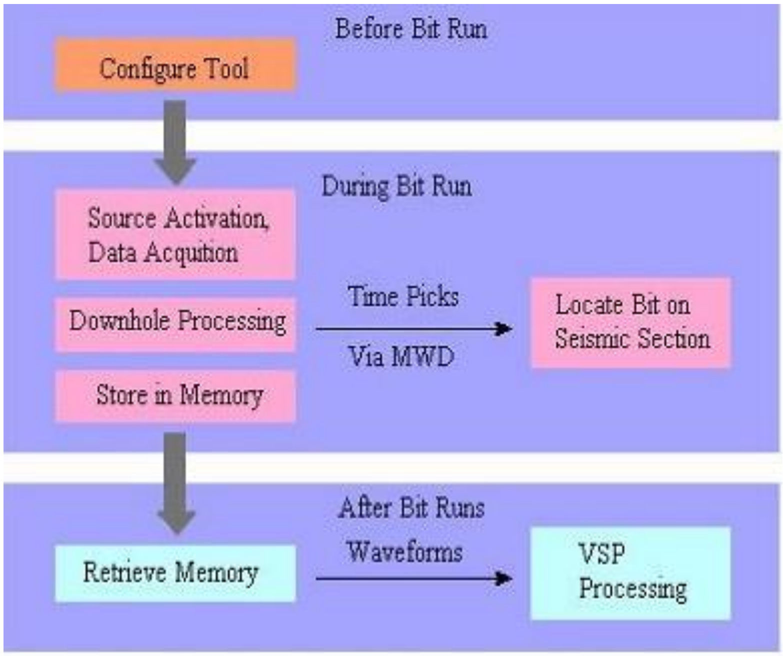


Figure II.3 Standard operating procedures for surveys using VSP-WD

II.2.3 SWD using swept impulse hydraulic tool

While drilling, the sweeping impulse hydraulic tool has the ability to produce a seismic signal at the bit site. By enabling seismic operations with PDC bit, this equipment addresses the limitations of drill-bit seismic, especially in soft formations and in inclined holes.

The hydraulic pulse valve that makes up the swept-impulse source has a mechanism that adjusts the interval between impulses. While drilling, sweeping the cycle rate allows for reflection imaging and seismic profiling of formations ahead of the bit using a method similar to swept impact-seismic profiling. The signal detected by the geophones is cross-correlated with a pressure pilot signal at the drill-string's top in order to produce a vertical seismic signal. A software correlator is used for real-time processing applications.

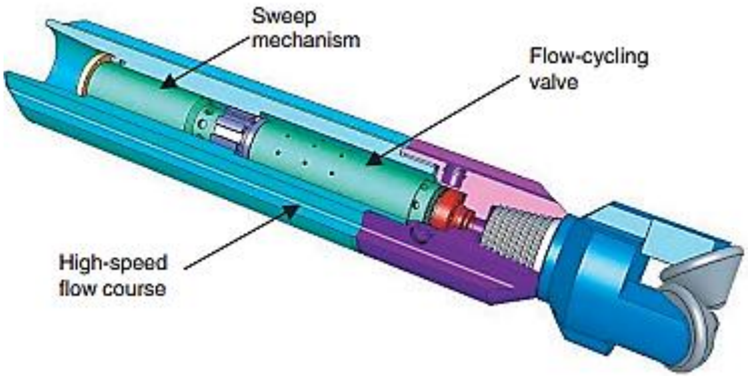


Figure II.4. Hydraulic pulse tool with a sweep mechanism and high-speed flow course housing

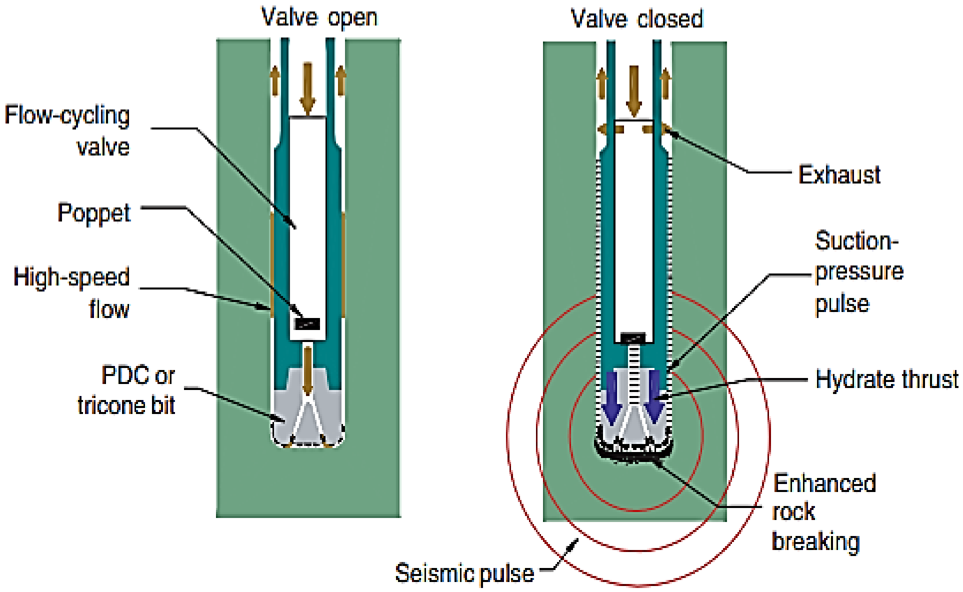


Figure II.5. Schematic of hydraulic pulse drilling tool

The tool includes a sweep modulator, offers high-resolution look-ahead imaging and real-time reverse seismic profiling while drilling, it has a separate source for compression and shear waves, and works well in both inclined and vertical holes. It also aids in providing early warning of gas kicks [7].

II.2.4 Definitions and framework of SWD

Seismic while drilling (SWD) is a geophysical technique that captures seismic signals while drilling to offer immediate insights for better well positioning, improved planning and enhanced drilling decisions without disrupting the drilling process. This approach provides real time information on time depth velocity aspects, such as checkshot and interval velocity data to minimize uncertainties before reaching the target. It aids in selecting the right mud weight steering clear of risks like pore pressure or faults and boosting safety by offering precise real time data, for well informed decision making during drilling activities.

The main goals of SWD are to:

-Assist exploration geology by utilizing data to guide drilling operations.

-Facilitate collaboration, between geophysicists, drillers and exploration geologists.

-Enhance drilling productivity minimizing risks and boosting the extraction rates of hydrocarbons

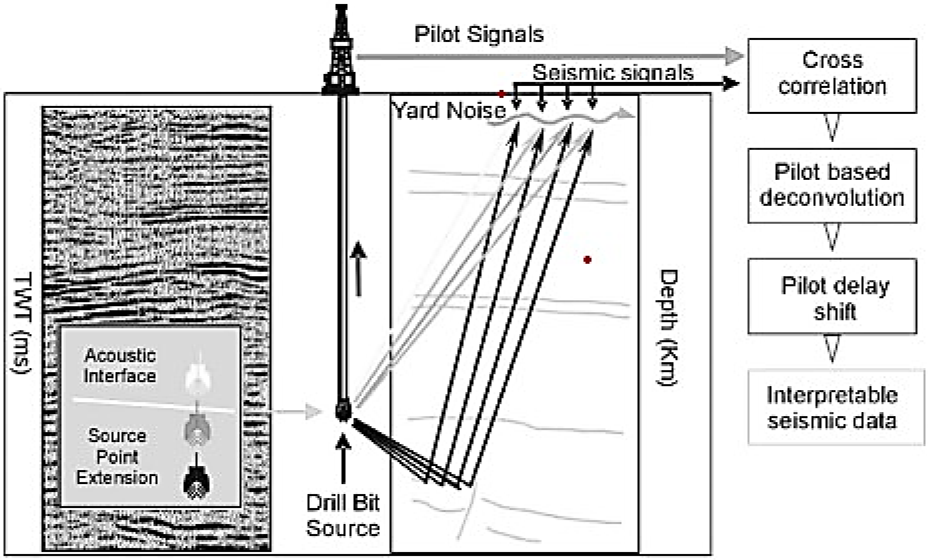


Figure II.6. SWD basic concept

II.2.5 Real-time monitoring using SWD

Using SWD services, such SLB's seismicVISION or Baker’s seismicTrack service, allows for real-time seismic monitoring while drilling. In order to optimize drilling decisions, lower costs, and increase safety during the drilling process, the service provides time, depth, and velocity information.

The use of real-time seismic checkshot data enables the precise placement of the drilling bit on the surface seismic map. This data is also helpful in selecting casing points, determining the location of the well, and predicting any dangers that may be encountered ahead of the drilling bit, such as faults or changes in pore pressure. The most modern borehole seismic software combines real-time waveforms with SWD real-time checkshot data to offer simple visualization that fosters communication and cooperation in distant offices or at the wellsite. This turns complicated information into a straightforward path for placing a wellbore [8].

This real-time seismic data helps optimize operational processes and offer the drill bit position in near real time helping to reduce well deviation risks and improve drilling accuracy

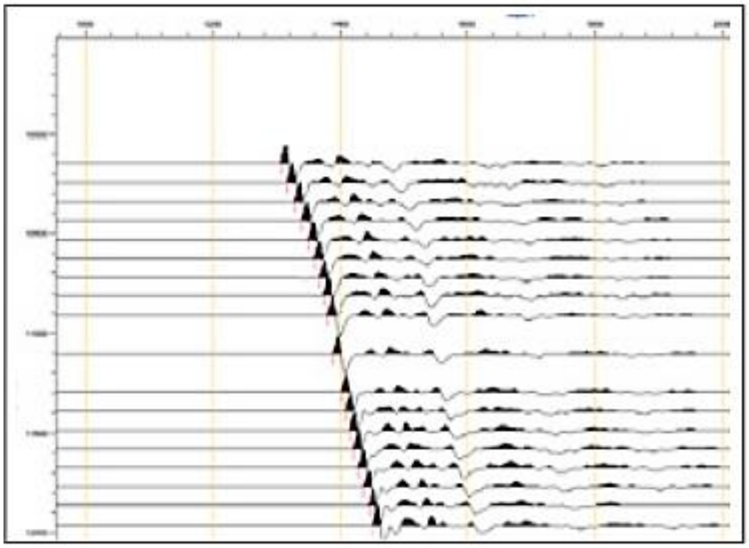


Figure II.7 Real-time waveforms from the seismicVISION service

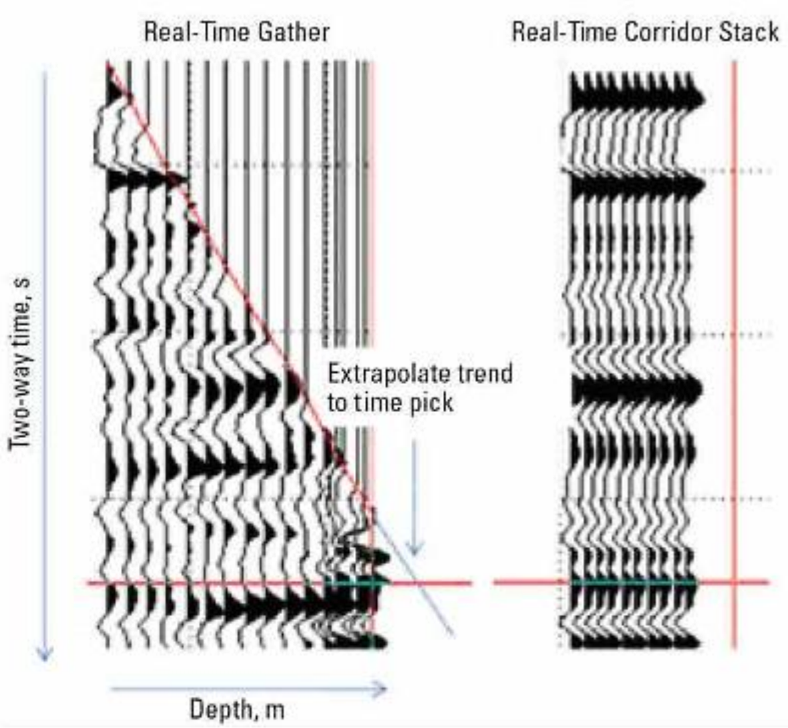


Figure II.8. Real-time gather converged on the key formation

II.2.6 Drilling-Induced Seismic Signals

Drilling-induced seismic signals refer to the seismic waves generated during drilling operations that can be detected and analyzed to provide valuable information about the subsurface geology. These signals can be used for real-time monitoring, optimizing well placement, and reducing uncertainty in drilling operations. The main sources of these vibrations:

- **The Drill-bit:** These signals are generated during the drilling process when the drill bit interacts with the rock formations. Different drilling techniques, including hammer drilling, roller-cone drilling, rotational diamond bits, and rotary-percussion drilling (RPD), produce different seismic signals. The frequency composition of these signals changes with increasing rock strength, preserving greater peak frequencies.
- **Mud flow:** The drilling mud circulating inside the wellbore isn't still. Its movement causes turbulence and pressure changes, similar to a fast-flowing river. These variations generate vibrations that travel into the surrounding rock formations.

- **Rock breakdown:** Sometimes a particularly hard rock or an unexpected geological feature is encountered by the drill bit. As the rock breaks, it releases energy in the form of vibrations, like a small explosion.

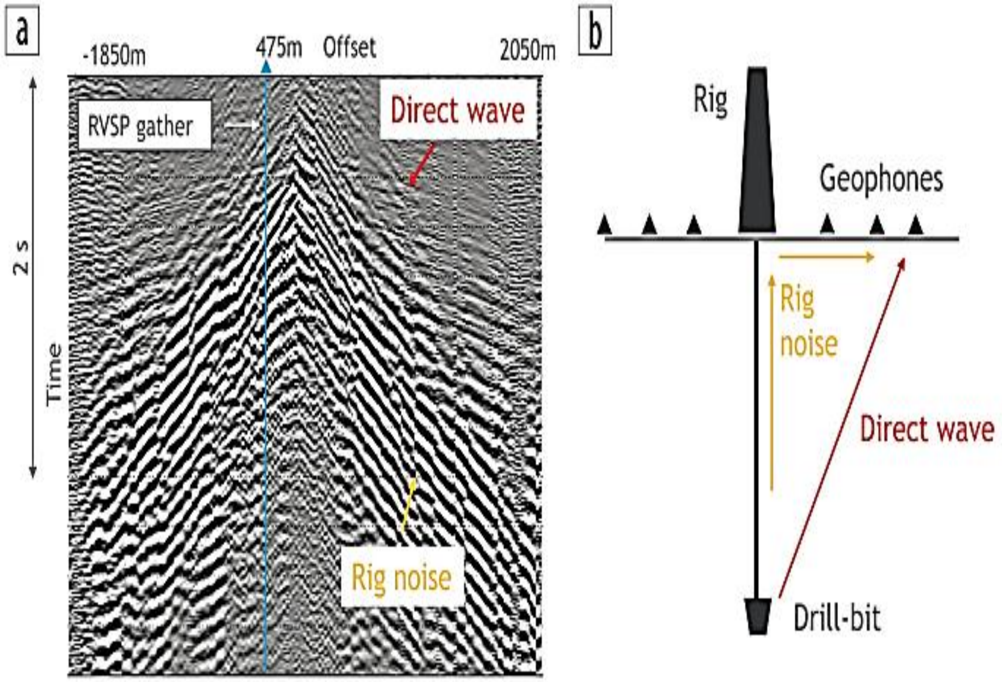


Figure II.9 (a) Common-shot gather showing direct wave and rig noise. (b) The propagation path of the rig noise component created by the bit**.**

These signals are captured using seismic while drilling technology by integrating seismic sensors into drilling tools to monitor the subsurface during drilling, which allows continuous data to be provided for decision-making without stopping the drilling operation.

II.2.7 Integration of Seismic Sensor in Drilling tools

Seismic sensors are integrated into drilling operations by positioning them in strategic locations to collect important data while the hole is being drilled. Placing the seismic sensor at the top of the drill string is one method that makes data collection effective. Redundancy of information can be obtained by increasing the number of seismic sensors, improving the accuracy of the data collected.

Seismic signals are captured for analysis during drilling operations using both downhole and surface seismic sensors, which are essential components.

- **Downhole Seismic Sensors:** are positioned within the borehole assembly to record seismic signals produced by the drill bit's contacts with the rock being drilled. These sensors offer more accurate and direct measurements compared to surface sensors, as they are closer to the source of seismic activity.
- **Surface Seismic Sensors:** They sit outside the borehole to pick up seismic waves that are sent through the earth or produced by sources on the surface. These sensors provide more data for analysis by logging seismic events connected to drilling operations. Surface sensors may be affected by attenuation and propagation effects, impacting the quality of recorded seismic signals.

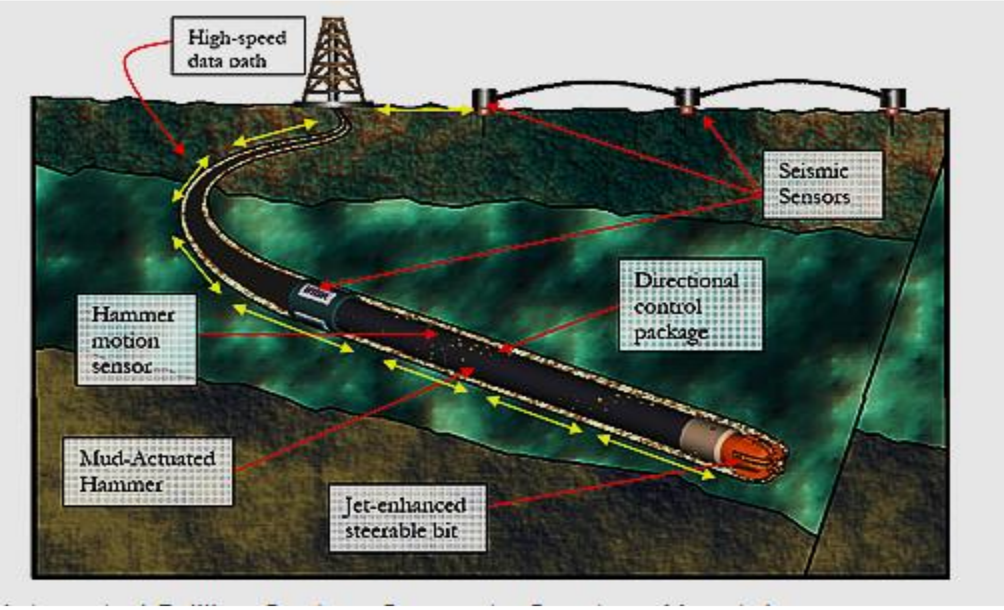


Figure II.10 Integrated Drilling System Concept

Figure II.11 Some of the advanced drillstring dynamic measurement tools

In conclusion, the use of seismic sensors in drilling operations improves productivity and safety since they offer up-to-date information on seismic velocities and rock characteristics, allowing for well-informed decision-making at every stage of the process.

II.3 Surface Seismic While Drilling

Surface seismic while drilling is used for general mapping of the subsurface, locating accumulations of gas and oil and keeping an eye on reservoir changes related to gas and oil production. When gathering surface seismic data, the z-axis (depth below the surface) is measured in the two-way travel times for the sound waves. The x- and y-axes' horizontal distances are expressed in meters. The depth (Z-axis) in drilling operations is measured in meters. The subsurface rocks' velocity needs to be known in order to convert between the two domains (such as the depth conversion). The prognosis for drilling is often uncertain because to the unreliability of velocity information.

The frequency content of the signal diminishes with burial depth, and surface seismic data has a lesser resolution. A quarter of a wavelength, or 10 meters, is the typical normal resolution for a seismic wavelength of 40 meters, a typical center frequency of 50 Hz, and a velocity of 2000 meters per second. Seismic is also used in the borehole.

II.3.1 Description of the technique

When the drill bit penetrates the subsurface formations, it's changing the subsurface formations. With high resolution seismic data, it should be possible to see this change, and hence find the true path of the well being drilled.

Before starting drilling, a reference seismic image of the subsurface is obtained. This might be the first set of seismic data acquired using the SSWD method, a simulated dataset created from an earth model, or the actual seismic data collected before the decision to drill. The seismic survey is repeated when the bit penetrates further into the ground. Installing stationary seismic sources and receivers at the surface allows for this. 2D or 3D arrays can be positioned on the ground surrounding the drill site for an onshore location. Traditional marine seismic equipment or ocean bottom seismic equipment can be employed in an offshore site.

The data from the reference seismic image is removed from the newly obtained data after another seismic data set has been collected. Therefore, only the subsurface alterations ought to be apparent. According to seismic simulations, this approach should allow for the identification of the real wellpath while the well is being dug (Johansen & Sangesland, 2013). If this technology can be utilized as anticipated, it can revolutionize several aspects within drilling technology [9].

II.3.2 Advantages of the technique

- This technique uses geophysical principles seismic, no tools or steel are required in the well.
- It does not depend upon interrupting the drilling operation.
- Favorable property of the SSWD method is that the well path is imaged directly into the seismic image. As a result, the well path's location in relation to its geological surroundings is depicted.
- Any other wells in the region are imaged using SSWD.
- The well path's mapping into the seismic image is done without big uncertainty.

II.3.3 Limitation of the technique

- SSWD requires specialized equipment, and the data interpretation can be challenging.
- It is more expensive compared to traditional surface seismic methods, due to the need for specialized equipment and expertise.
- It is limited in terms of the maximum depth that can be explored, which is usually a few kilometers.
- Poor quality data can result from factors such as low frequency of the seismic source, presence of borehole fluid, or poor geophone placement.

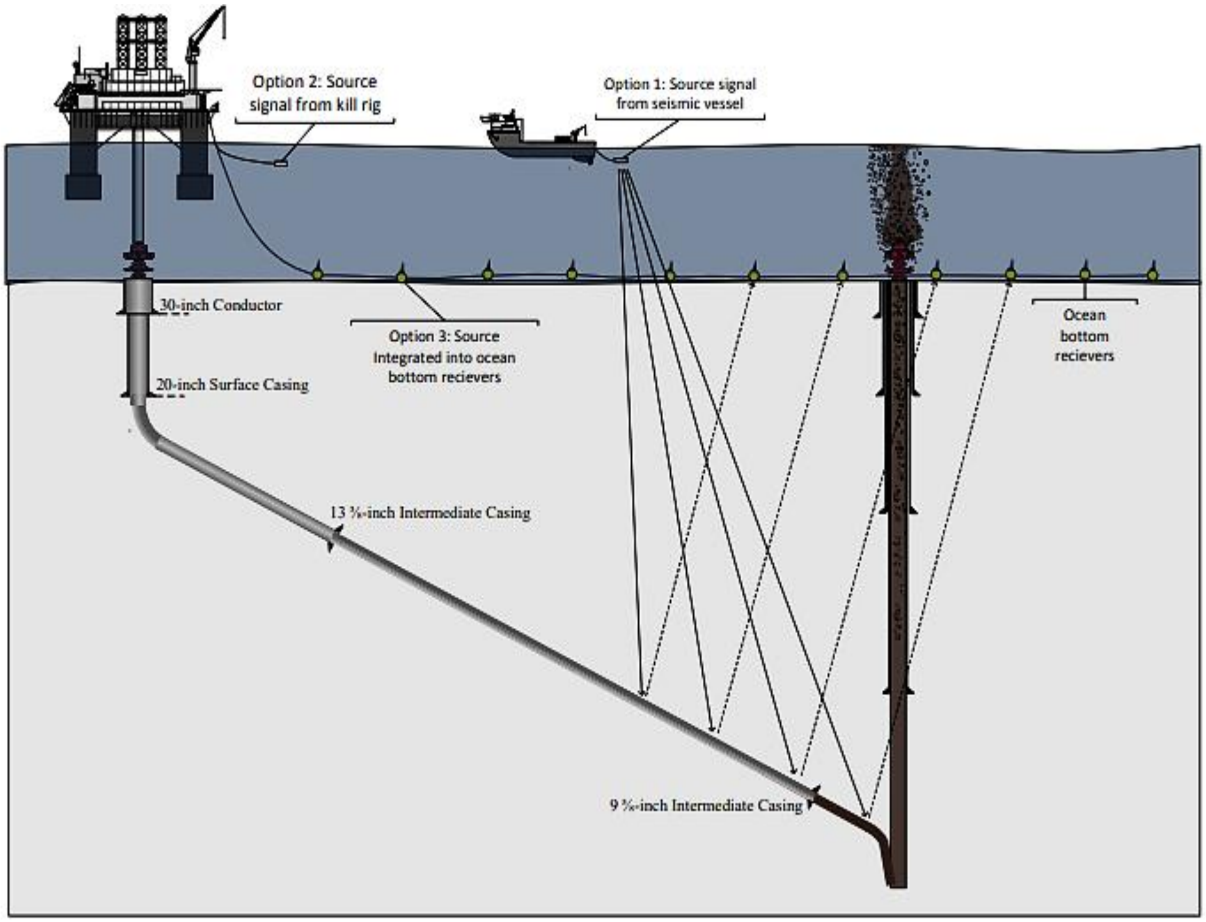


Figure II.12 Bottom intersection using SSWD

II.4 Drill bit Stick-Slip vibrations

Stick-slip is a global problem that hampers drillers, resulting in energy loss, reduced drilling efficiency, and significant damage to downhole instruments and drill strings.

Stick slip vibrations are known as the periodic alternations of stick and slip phases generated at the bottomhole assembly during drilling the well, this phenomenon occur when the bit get alternating between two situations which are sticking (stationary) and slipping (moving) phases. Consequently, the velocity experiences significant fluctuations, and the magnitude of this phenomena can result in a total cessation of the drilling operation. Rotational speed changes are regarded a major predictor of stick-slip [10].

This phenomenon can be a real problem during the drilling operation due to their adverse effects on drill bit which can cause several effects including:

- The reduction in drilling quality and efficiency.
- Reduce drilling tools life.
- Stick slip vibrations can increase the total costs and the completion time of the well.

II.5 Using Stick-Slip vibrations in SWD

In seismic while drilling (SWD) we consider the Stick-Slip as the main source and we don‘t take into account of the axial and lateral vibrations, because Stick-Slip is the origin of the vibration and the other follow from it. Stick-slip is not the only type of vibration considered in seismic while drilling (SWD). While stick-slip is the most significant type of vibration, lateral and axial vibrations can also affect the quality of seismic data obtained through SWD [2].

In seismic while drilling (SWD) stick slip can be used in several operations, which can have a positive and negative implications, in order to reduce the negative effects of stick slip vibrations we need a suitable operational parameters and technologically advanced equipment such as torsional impact hammers, and also the use of advanced strategies to reduce vibration-induced wear on drill bit. The positive and the negative implications can be defined as follows:

Positive implications

- Can be a valuable source of seismic data.
- Enhances the quality of the seismic data obtained during drilling operations.

- Provide real-time information about the drilling conditions, helping to optimize drilling parameters and avoid stuck pipe incidents.

Negative implications

- Accelerated wear: Uncontrolled stick-slip vibrations can increase wear and tear on the drill bit, shortening its life and forcing more frequent replacement.
- Increased operational costs: Stick-slip vibrations increase operating expenses owing to increased tool wear, lower efficiency, and longer completion times.
- Reduced drilling quality: Stick-slip vibrations can cause unpredictable drilling behavior, resulting in low bore hole quality and irregular borehole geometry due to uneven wear patterns on the drill bit.

II.6 Conclusion

In this chapter, we have presented an overview of SWD approaches. The SWD methods offers great value to the drilling operations by providing real-time information during drilling, it helps to enhance drilling decisions by providing exact depth of hazards prior to its penetration And we have discussed how we can use the stick-slip vibration as SWD sweep, which is a common problem in drilling operations, for reliable seismic source.

Chapter III

Stick-slip Vibrations

III.1. Introduction

In oil and gas drilling, stick-slip vibration is a frequent occurrence, especially in wells with complex trajectories like highly-deviated wells. Different rotational speeds experienced by the bit, bottom hole assembly (BHA), and/or drill string cause this vibration, which alternates between stick (where the rotation slows down or stops) and slip (where the drill string's built-up torque releases, causing the drill string to unwind and the bit's RPM to increase). Vibration caused by stick-slip can lead to expensive downtime, such as drill bit damage, twist offs, or downhole motor failures. Determining the fundamental causes of stick-slip vibrations is essential to creating mitigation plans that work and enhancing drilling efficiency. Stick-slip behavior is influenced by a number of parameters, including as the characteristics of the drilling fluid, drill bit design, and rock properties. Stick-slip vibrations have a detrimental impact on drilling safety, dependability, and efficiency. They may also raise maintenance costs and hasten the breakdown of parts like drill bits and motors [11].

III.2. Type of Vibrations: Axial, Lateral, and Torsional

Stick-slip vibrations in drilling systems can appear in different ways depending on which direction of motion they impact. Drill string wear rises excessively and rapidly when rotated at its natural resonance frequency, which can lead to fatigue failure [2]. Drilling causes three different types of vibrations: axial, torsional, and lateral (Figure III.1) . Each type's potential for destruction differs.

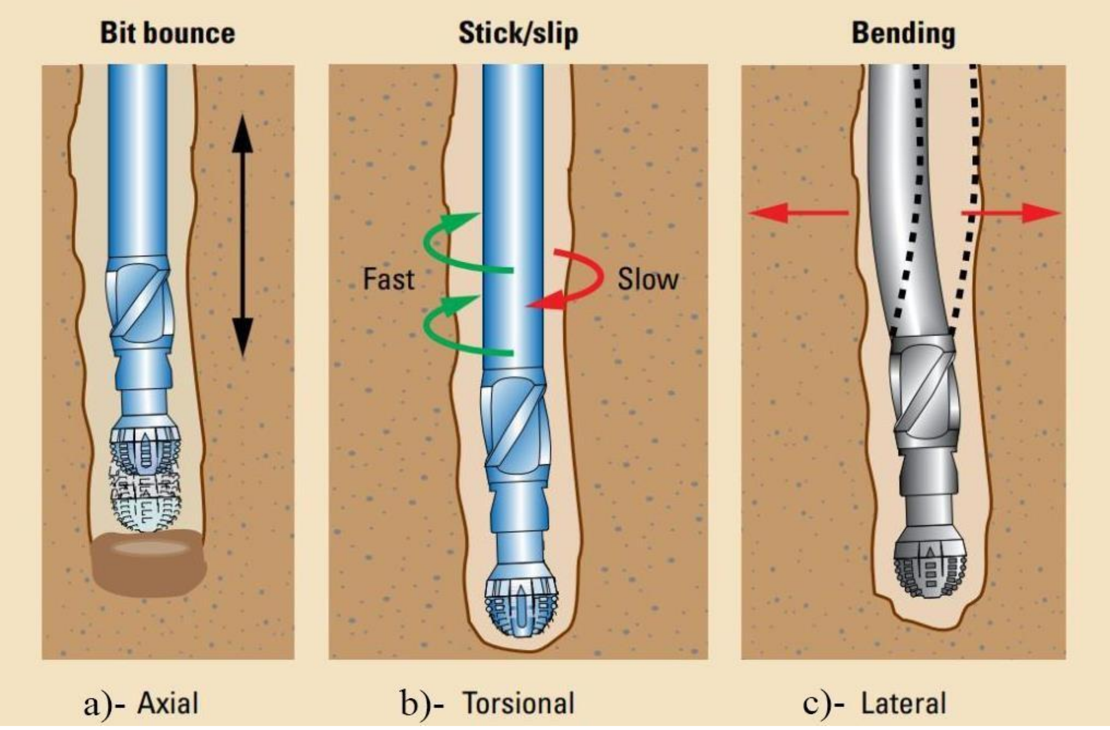


Figure III.1: Three types of drill string vibrations: a) axial, b) torsional, c) lateral

III.2.1. Axial Vibrations (Bit Bounce)

A sort of downhole vibration known as "bit bounce" happens when the drill bit slips away from the formation and bounces off the hole's bottom. Drilling with tri-cone bits frequently results in this occurrence because they create a bottom hole pattern with three ridges that cause the bit to bounce three times every revolution. The drill bit and other BHA components, such as PDM motors and MWD tools, may sustain significant damage from amplified vibrations if the frequency of these bounces matches the axial natural frequency of the drill string. Shock subs or vibration dampeners can be used to absorb vertical vibration and decrease its influence on downhole tools and surface equipment in order to reduce axial vibration. In order to eliminate the source of vibration excitation, the tri-lobed pattern must be destroyed. This can be accomplished by lifting the drill string off the bottom and beginning drilling with fewer parameters until a steady state is reached.

III.2.2. Lateral Vibrations (Bending/Whirling)

The drill string or BHA components vibrate laterally, or bending vibrationally, when they bend or flex in way that is perpendicular to the axial direction [12]. During drilling operations, these vibrations can result in serious problems such as decreased ROP, increased wear on the drill bit and other BHA components, and even equipment failure. Unbalanced vibrations, the drill string buckling, and other sources of vibration are some of the causes of lateral vibrations. There are a number of methods that can be used to reduce lateral vibrations, such as vibration dampeners or shock subs, stabilizers, and drilling parameter optimization [13].

III.2.3. Torsional Vibrations (stick/slip)

Stick-slip vibrations, also known as torsional vibrations, are a type of downhole vibration that happen when the drill string is not strong enough to move above the force of friction between the bit cutters and the formation. These vibrations consist of stick and slip phases, in which the bit RPM changes in just a couple of milliseconds from zero to several times the surface RPM. Torsional vibrations are low frequency vibrations that happen at less than 1 Hz. They can reduce the rate of penetration by more than 10% and accelerate bit wear and fatigue in downhole components as a result of cyclic torque loading. Common methods for reducing torsional vibrations involve increasing surface RPM, decreasing WOB, or doing both at once. To study the dynamic behavior of torsional vibrations, a number of drill string models have been created. Experimental testing has been done to validate these models and learn more about stick-slip behavior .

Recordings from Well-1's MWD (measuring while drilling) in an Algerian hydrocarbon field show that the bit's rotating speeds are not consistent. In particular, there are lows and highs on the curve that indicates this speed (Figure III.2). Six times the speed recorded at the surface equals the speed that corresponds to a peak. In contrast to the surface when nothing is indicated, the speed corresponding to the stuck phase might also reach zero, indicating that the bit is totally blocked. The stuck period lasts anywhere from one to five seconds. The drill string twists as the top drive system rotates at a constant rate while the bit gets stuck at the bottom of the borehole. The pipes store elastic energy because of this torsion, but after a certain point, the torque supplied to the bit exceeds the static torque that is opposing it; as a result, the bit is released, and the cycle is repeated. [10]

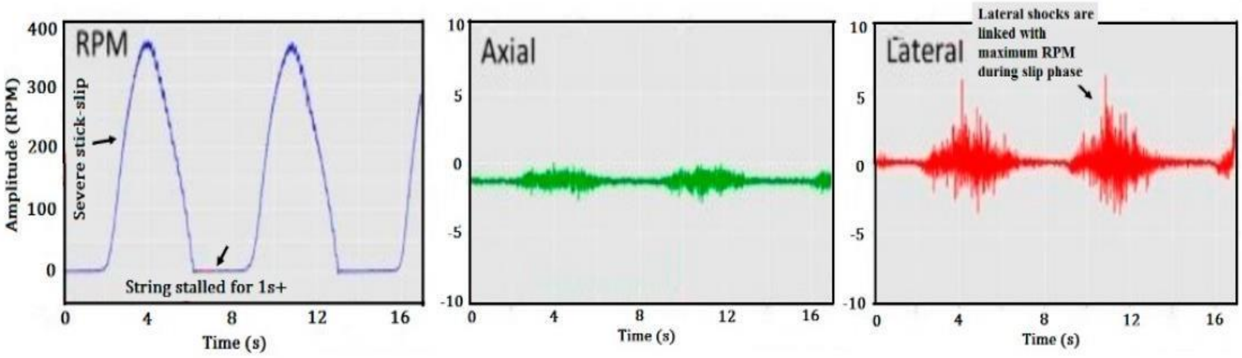


Figure III.2: Measured vibration using BlackBox in Well-1 [10].

III.3. Drill bit dynamic under Stick-Slip vibrations

Stick-slip motion is a dynamically unstable vibration that results from the change from static to kinetic frictions. Many engineering systems, including production systems, earthquakes cause, brake systems, and vehicle systems, frequently experience stick-slip vibration. Stick-slip is also frequently encountered in gas and oil drilling, where it is usually undesired. Stick-slip may significantly increase drilling costs due to downhole vibration has the potential to significantly decrease the rate of penetration (ROP) during drilling operations. Additionally, stick-slip vibration in the drill string can cause various vibrations to couple, reduce borehole quality, and increase tool failures.

In addition, the petroleum industry's development has contributed to a current trend in the area toward deep drilling methods [14].

Stick-slip vibration is likely to develop in deep wells because of the high rock strength and poor drill ability of the formation. Therefore, in the drilling sector, knowing how to control it, predicting its formation and comprehending its sources are important. A centuries-old understanding that friction-induced vibration is produced by self-excitation at the bottom has provided leading to the theory that stick-slip vibration is a major contributor to tool failures and inefficient drilling. There are currently several methods available for reducing stick-slip vibrations. To mitigate this damage, an extensive number of techniques for controlling the stick-slip vibration of drill string have been presented by numerous researchers.

Stick-slip vibrations are often experienced during oil well drilling and are thought to be self-excited. Stick-slip vibrations can cause large cycle stresses, which might cause fatigue issues. In addition, it is not anticipated that the high bit speed during the slip phase will cause additional vibrations in the bottom hole assembly (BHA). The responses from field testing or theoretical models are shown in Figures 3-6 [14].

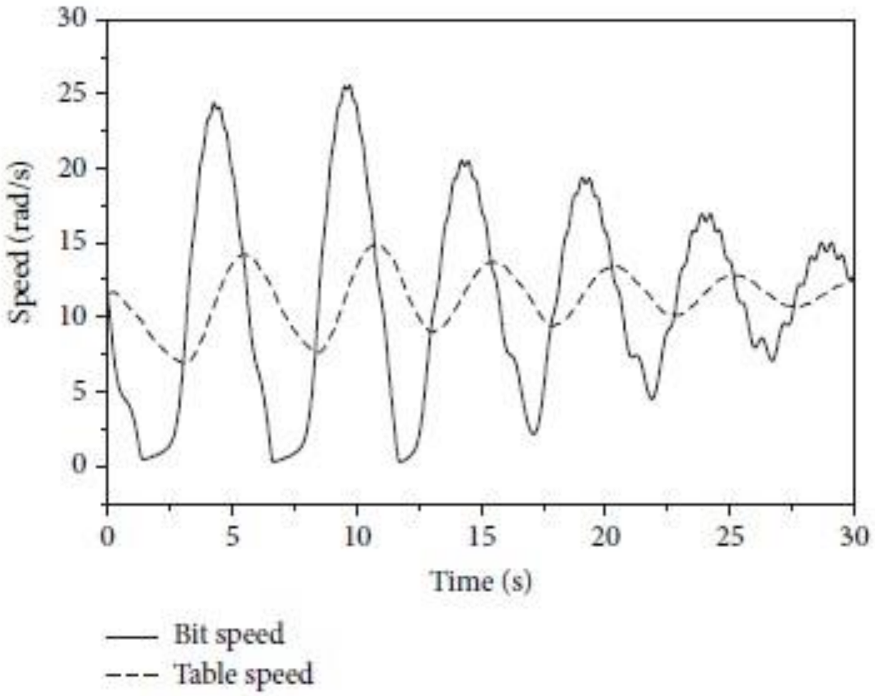


Figure III.3: Stick-slip vibrations are observed in the speeds of the bit and table [14].

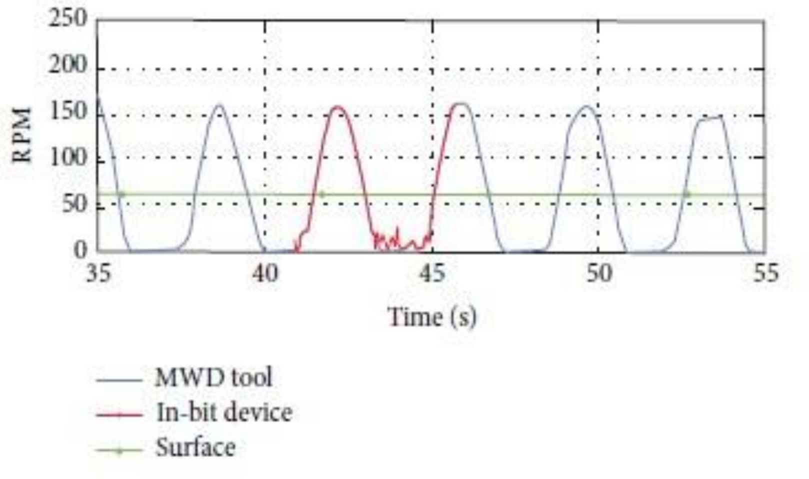


Figure III.4: Downhole measurement of rotational speed during stick-slip [14].

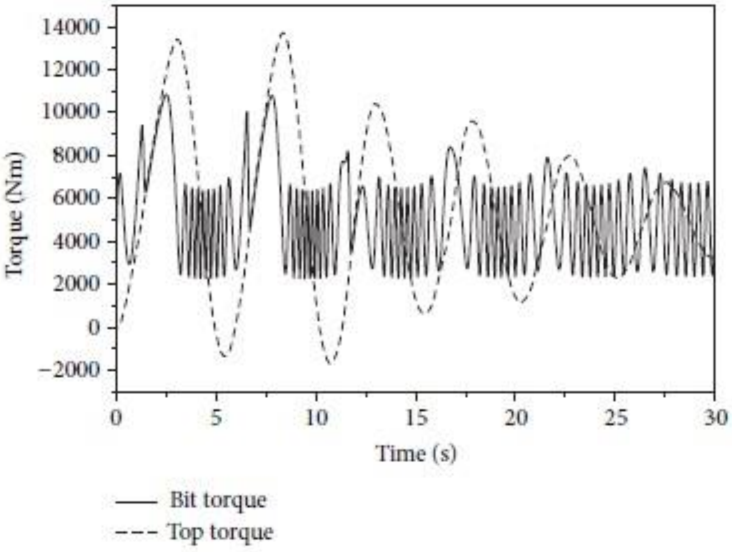


Figure III.5: Stick-slip vibrations appear in the torque applied to the bit and the top torque [14].

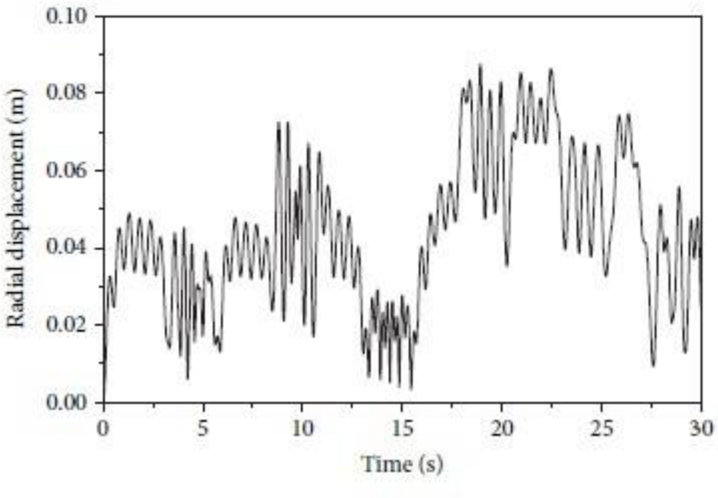
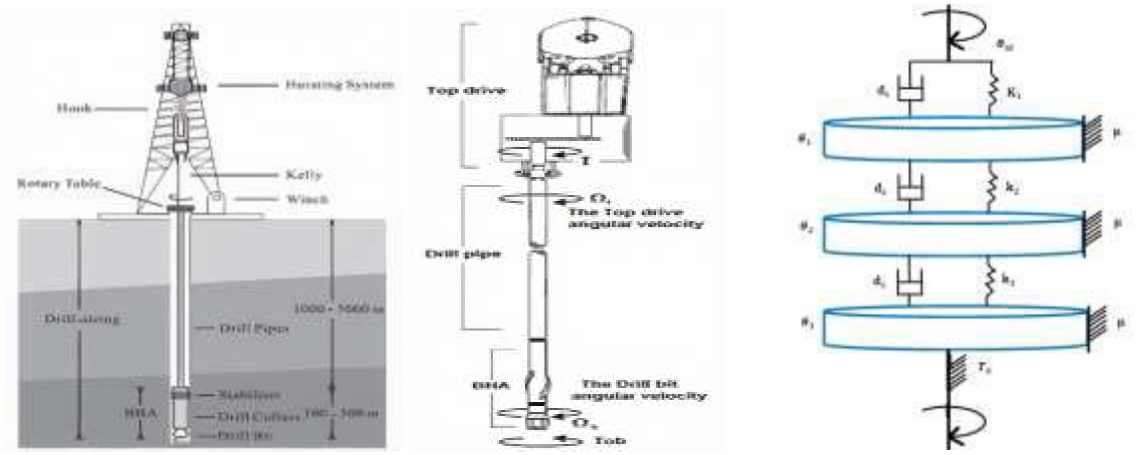


Figure III.6: Stick-slip vibrations observed in horizontal movement [14].

The figures show that sometimes during stick-slip, the BHA comes to a complete standstill. Rotation is produced when torque on the bit is released after building up. After being plugged into the formation, the bit may remain at rest for some time before being released when the drill string's stored energy reaches the threshold and allows the bit to break free from this situation. The bit rotates faster and slower than the table alternately, and its torque and rotational speed may be several times the values at the surface.

The investigation of torsional vibrations in the drillstring can be completed using a proxy model of a torsion pendulum (consisting of a mass, spring, and damper). This model is widely used for studying such effects. The proposal was initially put up by the corporation National Oilwell Varco (NOV). Figure III.7 (a,b) reveals the entire drilling rig and its schematic diagram, while Figure III.7(c) illustrates its corresponding proxy system.

The system has three degrees of freedom, with the upper disc representing the rotating table, the middle disc representing the tool string, and the lower disc representing the drill bit.



(a) (b) (c)

Figure III.7: Rotary drilling system: (a) Complete Drilling rig, (b) Its Schematic diagram, (c) Equivalent Proxy model with three element**s.**

The three-element proxy model of a rotary drilling system is defined by equation (1):

$$\begin{cases} \ddot{\theta}_1 = \frac{1}{j_1}\left(d_1\left(\dot{\theta}_{td} - \dot{\theta}_1\right) - k_1(\theta_{td} - \theta_1) - d_2\left(\dot{\theta}_1 - \dot{\theta}_2\right) - k_2(\theta_1 - \theta_2) - \mu\dot{\theta}_1\right) \\ \ddot{\theta}_2 = \frac{1}{j_2}\left(d_2\left(\dot{\theta}_1 - \dot{\theta}_2\right) + k_2(\theta_1 - \theta_2) - d_3\left(\dot{\theta}_2 - \dot{\theta}_3\right) - k_3(\theta_2 - \theta_3) - \mu\dot{\theta}_2\right) \\ \ddot{\theta}_3 = \frac{1}{j_3}\left(d_3\left(\dot{\theta}_2 - \dot{\theta}_3\right) + k_3(\theta_2 - \theta_3) - \mu\dot{\theta}_3 - T_b\right) \end{cases} \quad (1)$$

Table III.1 Parameters description for the designed rotary drilling model

Parameter	Description	Unit
θ_{td}	The top drive angular displacement	[rad]
$\theta_{i=1,2,3}$	The angular displacement of the rope section *i*	[rad]
$k_{i=1,2,3}$	Torsional stiffness coefficient of the rope section *i*	[N.m/rad]
$d_{i=1,2,3}$	Internal damping coefficient of the rope section *i*	[N.m.S/rad]
μ	Wall friction coefficient	[N.m]
$j_{i=1,2,3}$	The inertia of the rope section *i*	[kg.m^2]

In order to keep the standard notation for states and inputs in equation (1), the following modifications were made to the variables: $\dot{\theta}_1 = x_1$, $\dot{\theta}_2 = x_2$ $\dot{\theta}_3 = x_3$,

$\theta_{td} - \theta_1 = x_4$, $\theta_1 - \theta_2 = x_5$, $\theta_2 - \theta_3 = x_6$, θ_{td}=u .

Next, the system's state equations were rebuilt in the format provided by (2).

$$\begin{cases} \dot{x}_1 = A_1x_1 + A_2x_2 + A_3x_4 + A_4x_5 + A_5u \\ \dot{x}_2 = B_1x_1 + B_2x_2 + B_3x_3 + B_4x_5 + B_5x_6 \\ \dot{x}_3 = C_1x_2 + C_2x_3 + C_3x_6 + C_4T_b \\ \dot{x}_4 = \dot{\theta}_{td} - \dot{\theta}_1 = u - x_1 \\ \dot{x}_5 = \dot{\theta}_1 - \dot{\theta}_2 = x_1 - x_2 \\ \dot{x}_6 = \dot{\theta}_2 - \dot{\theta}_3 = x_2 - x_3 \end{cases} \qquad (2)$$

Where

$$\begin{cases} A_1 = \frac{-d_1-d_2-\mu}{j_1} \\ A_2 = \frac{d_2}{j_1} \\ A_3 = \frac{k_1}{j_1} \\ A_4 = \frac{-k_2}{j_1} \\ A_5 = \frac{d_1}{j_1} \end{cases} ; \quad \begin{cases} B_1 = \frac{d_2}{j_2} \\ B_2 = \frac{-d_2-d_3-\mu}{j_2} \\ B_3 = \frac{d_3}{j_2} \\ B_4 = \frac{k_2}{j_2} \\ B_5 = \frac{-k_3}{j_2} \end{cases} ; \quad \begin{cases} C_1 = \frac{d_3}{j_3} \\ C_2 = \frac{-d_3-\mu}{j_3} \\ C_3 = \frac{k_3}{j_3} \\ C_4 = \frac{-1}{j_3} \end{cases} \qquad (3)$$

Next, the matrix form as provided by (4) was formed.

$$\begin{cases} \dot{x}(t) = A\big(x(t)\big) + B(x)u(t) \\ Y(t) = C\big(x(t)\big) \end{cases} \qquad (4)$$

The measured output variable, the drill bit speed, is represented by Y(t), where: x(t) = [$x_1 \quad x_2 \quad x_3 \quad x_4 \quad x_5 \quad x_6$] is the state vector, with

C(x)=[0 0 1 0 0 0], A(x)= $\begin{bmatrix} A_1x_1 + A_2x_2 + A_3x_4 + A_4x_5 \\ B_1x_1 + B_2x_2 + B_3x_4 + B_4x_5 + B_5x_6 \\ C_1x_2 + C_2x_3 + C_3x_6 + C_4T_b \\ -x_1 \\ x_1 - x_2 \\ x_2 - x_3 \end{bmatrix}$, B($x$) = $\begin{bmatrix} A_5 \\ 0 \\ 0 \\ 1 \\ 0 \\ 0 \end{bmatrix}$

T_b is the torque on the bit, it is the nonlinearity term and is determined by (5).

$$T_b = X_3\left(\frac{A}{\sqrt{{x^2}_3}+{\Omega^2}_0} + \frac{B}{{x^2}_3+{\Omega^2}_0}\right) - Dx_3\left(\frac{x_3}{\Omega_1} - 1\right) \qquad (5)$$

Where A=$\mu_n Nr$, and B= A Ω_0 , the numerical values for the various constants used in the simulation are : $K_1 = K_2 = K_3 = 481.29\ N.\frac{m}{rad}, j_1 = j_2 = 1030.45\ kg.m^2, j_3 = 223.44, d_1 = d_2 = 51.38\ N.m.s/rad$, $d_3 = 39.79\ N.m.s/rad, \mu = 10\ N.m$, Wob = 120 $N.m$, the parameters in (5) are summarized in Table 2.

Table III.2 Parameters description of Torque on bit term

Parameter	Description	Value
μ_n	Nominal friction coefficient	40 Nm
N	The force vector	9.81×Wob N
R	The contact radius vector	0.1 m
Ω_0	Chain transition speed	1
Ω_1	Transition speed for the well	31.4159
P	The initial friction parameter	1.5
D	The linear damping vector	0.28

III.4. Mechanisms Leading to Stick-Slip Vibrations

The technology used in the petroleum business has advanced, and as the demand for oil and gas resources has grown, so has oil drilling, eventually reaching deep marine regions and deep depths. When drilling a deep well, the formation's hardness and flexibility increase as the well's depth does so due to confining pressure at the well's bottom. Deep well drilling simultaneously involves traversing numerous layers, varies in geography, and presents challenging geological conditions. The equivalent torsional stiffness of the drill string reduces as drill string length increases, and the transmission torque is insufficient. The stick-slip vibration of the drill string system is easily caused under the friction action of the bit, sidewall, bottom hole, and drill string. The bottom hole bit stops rotating, the peak torque rises, and the ground torque oscillation frequency falls when slippage happens on the drill string. The drill string is still rotating at this point while the rotary table rotates. The drill bit will rotate at a speed that is twice or more than the rotary table's rotational speed, and the bottom drill tool will vibrate violently, when the drill string's accumulated energy is sufficient to overcome the friction torque between the bit and the rock. The torque applied to the bit rotation varies significantly with increasing swing intensity. Intermittent movement the drill bit's passivation process can be accelerated up by the drill string's alternating tension, compression stress, and friction between the positive and negative processes and the borehole wall. The energy generated by the wellhead will be wasted when it slides away due to the frictional collision between the drill string and the borehole wall as well as the interaction with the drilling fluid. Stick-slip vibration frequently happens concurrently with other vibration types during the actual drilling process, creating a range of coupling vibration forms that have a significant impact on drilling tool damage as well as the penetration rate and completion cycle. Simultaneously, the vibration of the drill string and the irregular rotation of the drill bit might lower the quality of the wellbore. In the 1980s, research on drill string stick-slip vibration was conducted abroad. When the rotary table's torque was being measured, this occurrence was initially observed. After decades of study, the field's general research growth is slow; in contrast to other drill string vibration research areas, there are less ground-breaking findings and useful recommendations for guidance [15].

III.4.1. Mechanism of Drill-string Stick-slip Vibration

III.4.1.1. Introduction

The contact between the drill bit and the formation is causing considerable stick-slip vibration in the drill string. The drill string’s stick-slip vibration manifests as recurring shifts in the stick and slip phases. The bit remains motionless during the stick phase until the torque on bit (TOB) rises to a point where it breaks this state. The bit quickly releases during the slip phase and accelerates to an angular velocity that is many times the rotary table's velocity. Stick-slip vibration raises the amount of non-productive time, which raises the cost of development in addition to reducing tool life. Also, this vibration can result in axial and lateral vibrations, which would reduce the rate of penetration (ROP) and lead to equipment failure.

The study of stick-slip vibration in drill strings dates back to the work of Belokobyl'skii and Prokopov, who presented the idea of self-excited drill string vibration and examined friction-induced vibration. Dareing investigated the self-excited vibration caused by bit motion and suggested that drill string vibration might be eliminated by adjusting the rotational speed. The drill string vibration was described as a stick-slip phenomenon by Dawson et al.

Many articles have been made about the stick-slip phenomena in recent decades, but the majority of them focus on field observations and passive and active mitigation strategies. Stick-slip vibration is becoming more and more important as drilling technology progresses and drilling conditions vary. As the petroleum industry develops, for example, an increasing number of deep and ultra-deep wells are being evaluated for conduction.

III.4.1.2. Stick–slip vibration with different models

The mathematical techniques for simulating stick-slip vibrations are examined in the section that follows. The contributions are grouped under lumped parameter models with one degree of freedom (SDOF), vibration models with multiple degrees of freedom (MDOF), and continuous system models.

III.4.1.2.1. SDOF Lumped pendulum vibration models

The stick-slip vibration of the drill string was investigated by Halsey et al by treating the bottom-hole assembly (BHA) like a lumped flywheel. The SDOF model was unable to anticipate the formation of stick-slip motion under the specified parameters. Kyllingstad and Halsey found that mean torque increased as rotational speed increased, but they did not offer a suitable explanation. The model did not take the damping effect into account. A lot of work was done on the lumped parameter model taking the damping effect into account by Lin and Wang. In an effort to shed more light on the origin of the stick-slip phenomena, Brett provided a model that demonstrated how variations in bit properties can produce torsional drill string vibration. The drill string was viewed by the model as a lumped mass-spring system (Figure III.8), and the stick-slip motion was described by two linked differential equations. The findings suggested that stick-slip vibration may be avoided by adjusting the torque applied to the rotary table rather than increasing the velocity; however, this was not confirmed by a field test.

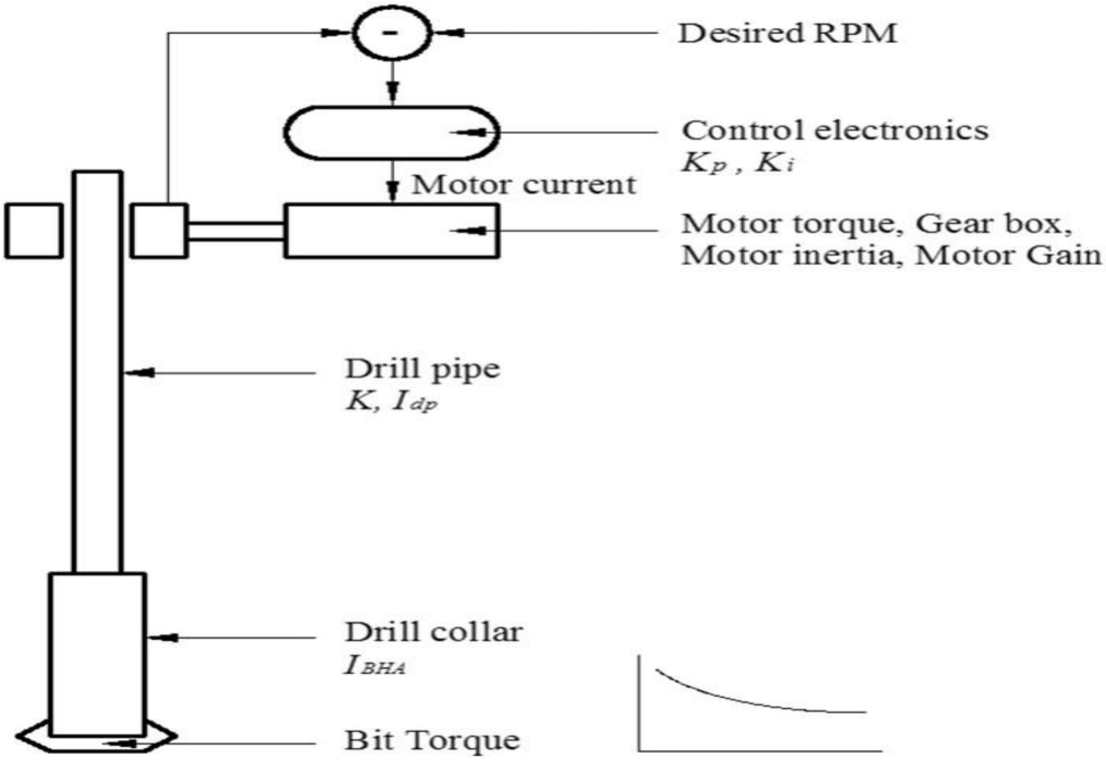


Figure III.8 Lumped mass spring model of the drill string [15].

The drill string was represented as a mechanical oscillator with rotational SDOF by Rudat and Dashevskiy (Figure III.9). The downhole stick-slip vibration intensity was predicted by the model, which allowed for the determination of ideal parameters. Only the steady state answers, however were presented. Qiu et al investigated the stick-slip vibration of drill string using an SDOF model resembling the one displayed in (Figure III.9). Stick motion and slip motion were handled independently in the model, and the bit-rock contact was represented as random friction. A Monte Carlo simulation was conducted in order to validate the model.

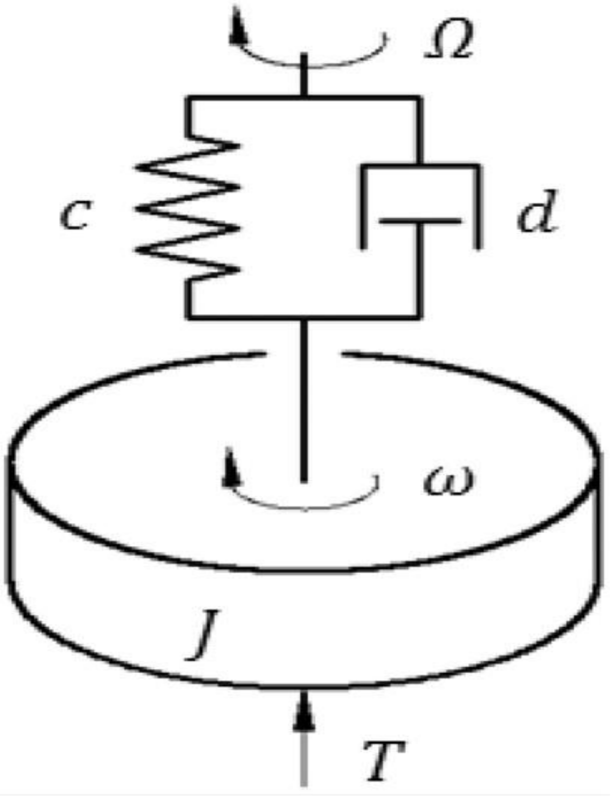


Figure III.9 Mechanical SDOF model of the drillstring [15].

Complex nonlinear drilling dynamics processes can be reproduced using a simple lumped mass model using real drilling parameters. To investigate the torsional stability of the drillstring and gain a better understanding of the origins of the stick-slip phenomena as well as strategies for mitigating it, Cunha-Lima created a simplified SDOF model. Tang created a mechanical model akin to this one in order to investigate how drilling settings affect stick–slip vibration (Figure III.10). The findings demonstrated that stick-slip vibration's occurrence and dynamics are significantly influenced through the manipulation of the rotary table velocity, friction coefficients, and viscous damping.

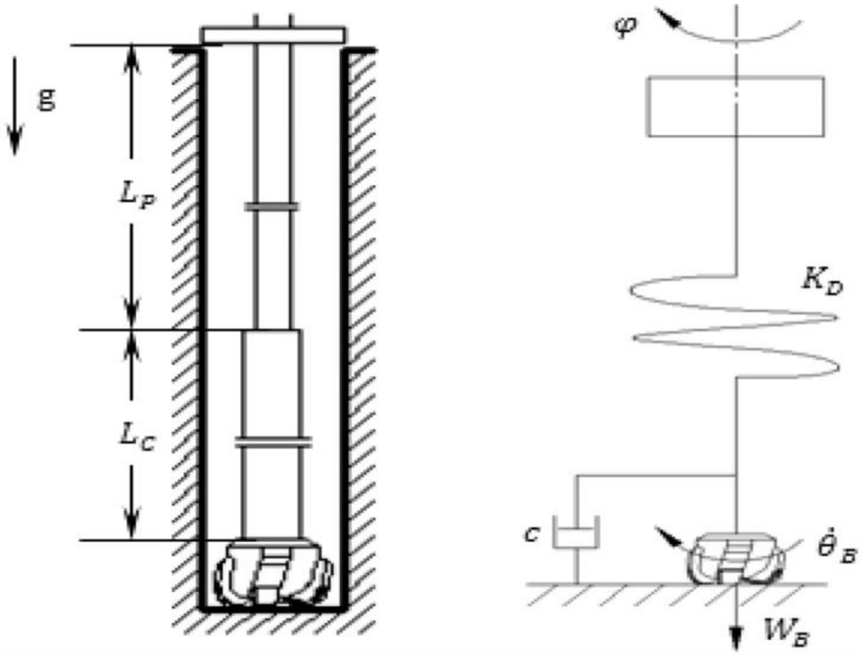


Figure III.10 Analytical model of the drill string system [15].

The block-on-belt model, seen in (Figure III.11), is another kind of SDOF model used to study the stick-slip. Van de Vrande created an SDOF block on belt model to investigate the drillstring's stick-slip action. Using an ordinary differential equation (ODE) solver, the smoothing process and basic shooting method can be used to determine periodic stick-slip vibration.

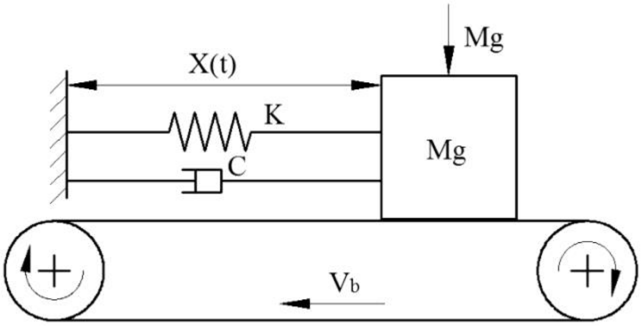


Figure III.11 The block-on-belt model [15].

III.4.1.2.2. MDOF vibration models

MDOF models have the ability to capture more drilling system detail than SDOF models. As a result, a lot of research employed MDOF vibration models to study stick-slip vibrations. Abdulgalil and Siguerdidjane viewed the drilling system as a torsional pendulum in order to create a straightforward dual DOF (DDOF) model (Figure III.12) of stick-slip vibration. The model's underlying assumption isn't always accurate since alterations in drilling conditions quickly change the friction behavior.

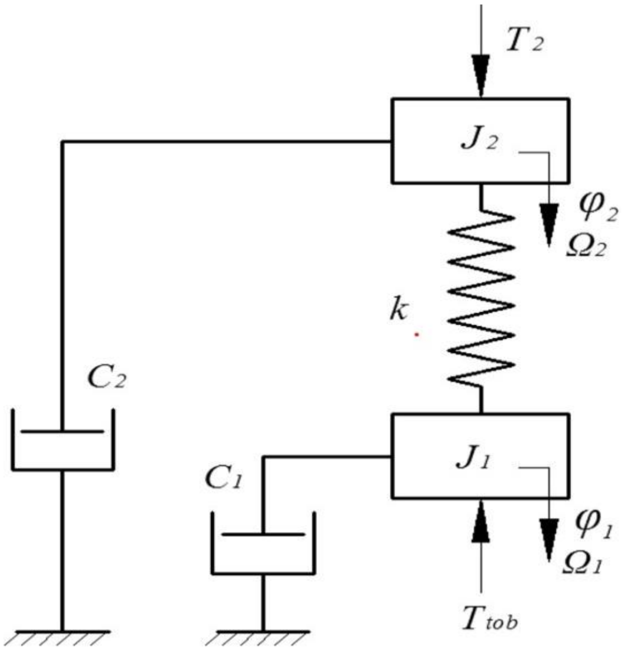


Figure III.12 Drilling rotary model [15].

Canudas-de-Wit created a comparable open-loop plant model (Figure III.13) to Rudat and Dashevskiy, but with different boundary conditions and the presumption that rotational speed is constant. The weight on bit (WOB), a control parameter, was used to put an end to friction-induced limit cycles. Navarro-López and Suárez recreated the stick-slip motion under different operating situations using this type of DDOF model. Karkoub employed genetic algorithms (GAs) to increase stick-slip responses, while Bayliss looked at the mitigation of the stick-slip phenomenon in the drilling system applying an online-identification-based adaptive design.

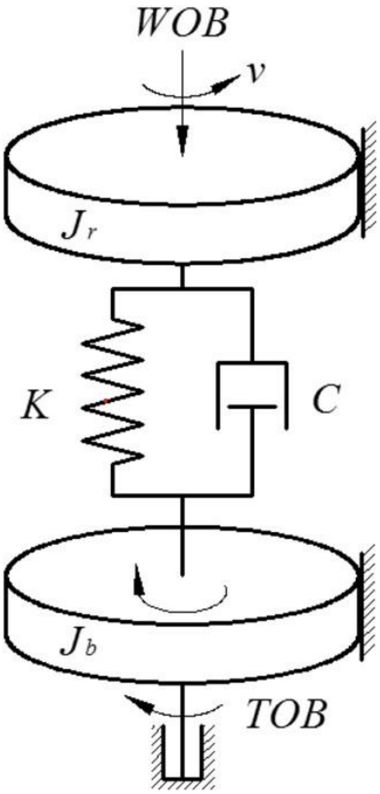


Figure III.13 The DDOF [15].

In order to study the drill string stick-slip behavior, Silveira and Wiercigroch analysed the bit-rock interaction and created a three DOF (TDOF) torsional pendulum model. Using a TDOF stick-slip model (Figure III.14) and nonlinear friction forces to simulate the bit-rock interaction, Patil and Teodoriu investigated the impact of varying parameters on stick-slip vibration.

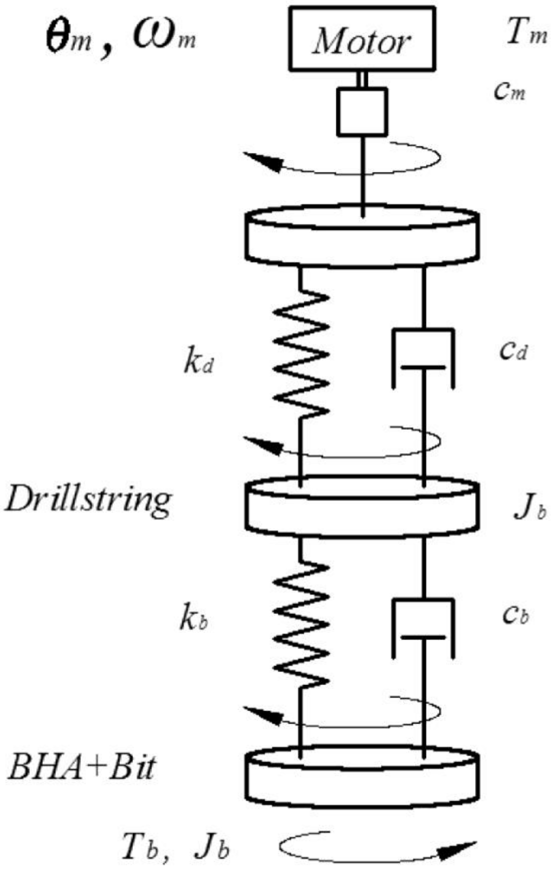


Figure III.14 The TDOF torsional pendulum model [15].

A more general discontinuous torsional model of four DOF (rotary table, drill pipes, drill collars, and drill bit) was presented by Navarro-López and is depicted in (Figure III.15). Using this model, bit stick phenomena at the BHA were examined and a sliding motion that causes self-excited vibrations was identified. Exploring Hopf bifurcations allowed for the determination of the critical drilling parameters.

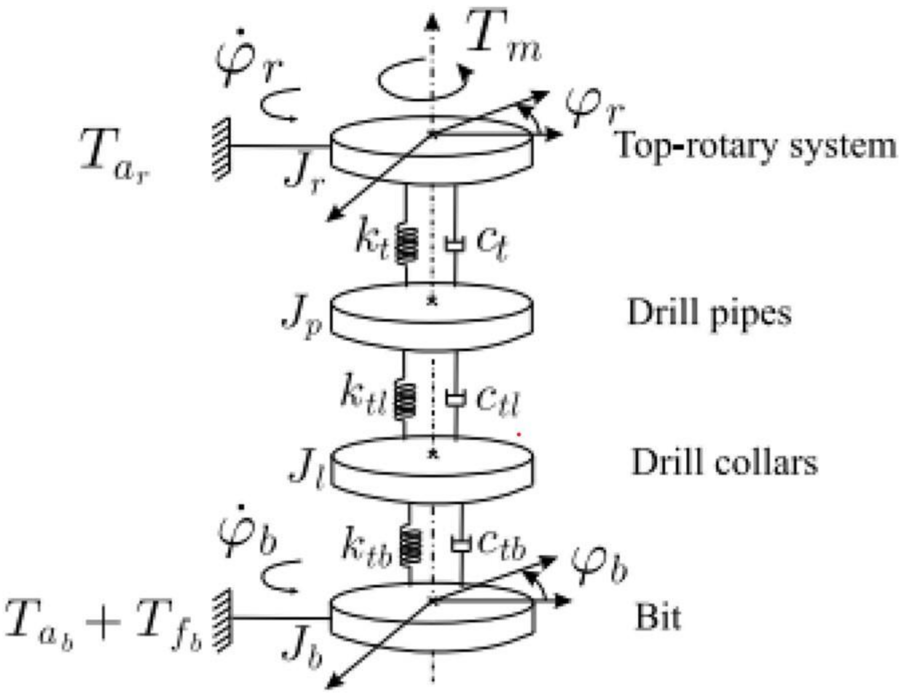


Figure III.15 The FDOF lumped pendulum model explaining the stick–slip vibration of a drillstring [15].

A 51-element high-dimensional drillstring model with one element representing the rotary table, one element representing the BHA, and 49 elements modeling the string with self-excited stick-slip vibration was developed by Kreuzer and Steidl.

Drillstring was modeled using the finite element (FE) approach; however, the majority of documented experiments focused on studying the BHA. The rotating drilling system's motion equation was derived by Khulief using the Lagrangian and FE methods in order to comprehend the severe torsional and axial vibrations caused by stick-slip vibration. For the purpose to investigate the motion of the drilling system in the presence of stick-slip vibrations, the drillstring model includes both drill pipes and drill collars. Specifically, when stick-slip vibration occurs, Kapitaniak created a comprehensive MDOF model of a drilling system using the FE approach to verify a TDOF mathematical model.

III.5. Factors Influencing Stick-Slip Behavior

The stick-slip is one of the main reasons for decreased drilling efficiency, shorter tool lifespans, and lower drilling quality. It also has a significant impact on drilling costs and completion times.

Drilling processes with complex conditions lead to modest development in this area; breakthroughs are rare.

There are factors that influence the behavior of Stick-Slip, including them:

- Friction behavior: Variations in drilling conditions can significantly impact the friction behavior, which affects the frequency of stick-slip vibrations.
- Damping Effect: In oil and gas drilling systems, stick-slip behavior is considerably affected by the damping effect created by the friction between the drill bit and formation.
- Drill Bit and Formation Interaction: Stick-slip vibrations in oil well drill strings are influenced by the interaction between the drill bit and geologic formations.
- Material Properties: Stick-slip behavior in granular materials is influenced by various factors, including particle size, uniformity, density, and effective confining pressure. These factors may also be relevant in oil field conditions.

Understanding these factors is essential to reducing related costs, increasing drilling efficiency, and decreasing stick-slip vibrations during oil field operations.

III.6. Stick-Slip as a Source of Seismic Signals (sweep)

In oil fields, stick-slip behavior can in fact serve as a source of seismic signals in specific situations. Better understanding the stick-slip behavior in oil fields could help with better seismic activity estimates and the creation of risk management plans for flow-induced seismicity.

A technique used in the exploration and production of oil and gas resources is seismic-while-drilling, or SWD. It uses a drill bit that spins and enters the rock to produce low-frequency stick-slip vibrations. Seismic waves are produced by these vibrations, which travel through the rock and are detected by surface sensors. After that, the seismic data can be used to guide the drilling process in real time and to learn more about the subsurface geology [2].

III.7. Integration of Seismic Sensors with Stick-Slip Vibration

(Figure III.16) shows the signal pathways used to handle stick-slip vibrations for inverse VSP. The vibrations go through the earth and up the drill string. A pilot sensor is installed at the bottom of the drill string to detect upward-moving waves. Receivers are positioned on the surface or at the base of the borehole to detect seismic waves moving through the earth. A downhole receiver can be placed in a near borehole for crosswell imaging. Every receiver signal is cross-correlated with the signal detected by the pilot sensor. This stage is similar to the Vibroseis method, including the cross-correlation of a sweep signal and a geophone signal [2].

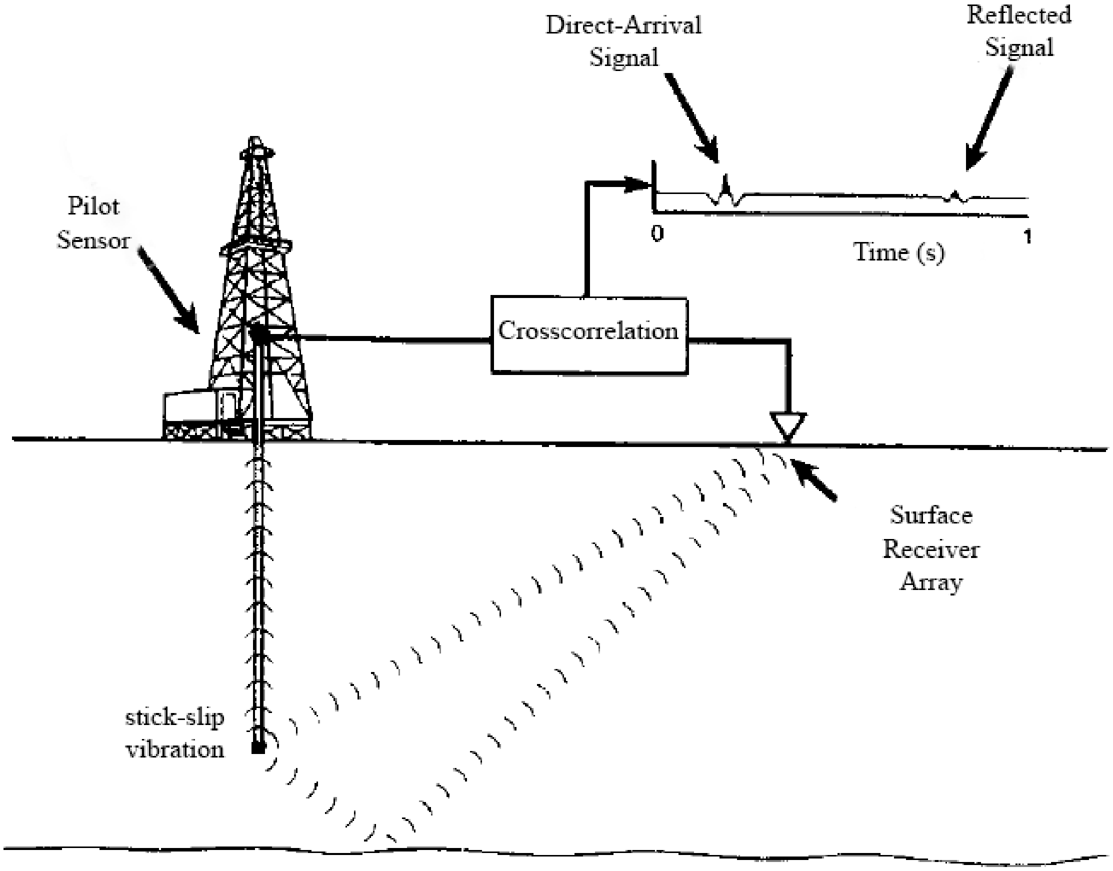


Figure III.16: Using stick-slip vibrations to acquire SWD geometry [2].

The drill-bit energy arrival times can be measured using the cross-correlation function as a reference frame. An unnormalized estimate of the cross-correlation function in discrete time is provided by: assuming that the signals recorded by the receiver and the pilot sensor at the top of the drill string are G(t) and R(t), respectively.

$$\mathrm{cc}(\tau) = \sum_{n=1}^{N} R(nt)G(nt+\tau) \qquad (6)$$

where:

τ: time shift between the signals rand G

N: total recording length (in samples)

n: number of recording samples

t: sampling interval

After that, the cross-correlation function is adjusted to produce a value between 0 and 1, which represents how similar the two signals are to one another. An estimation of the temporal lag between the two signals can be obtained from the lag at which the maximum correlation occurs. An image of the subsurface structure can be created and the distance between the drill bit and the receiver measured using this time delay [2].

III.8. Advantages of Stick-Slip Based SWD

Advantage of Stick-Slip based Seismic While Drilling (SWD) techniques come essentially from advancements in drilling safety and efficiency. Between the principal advantages we have :

- help optimize drilling parameters and prevent stuck pipe problems, stick-slip vibrations are capable of providing real-time information concerning drilling conditions.
- Drillers and geologists can make better decisions by using the stick-slip signals, which can reveal information about the subsurface formation, such as the type of rock, the degree of stress, and the fluid content.
- Before problems happen, the real-time data from SWD with stick-slip vibration can assist in identifying possible drilling hazards such overpressure zones or fractures.
- There is minimal rig time lost and no drilling pause (NPT) because the stick-slip vibration surveys are obtained without the need for any downhole equipment.

III.9. Conclusion

In this chapter, we have discussed about the Stick-Slip vibration which is a true issue in the oil fields, we have presented the types of vibrations, the drill bit dynamic under Stick-Slip vibrations, also, we have explained the mechanisms leading to Stick-Slip vibrations and the factors influencing Stick-Slip vibrations. In addition, we have detailed how we can use the Stick-Slip vibrations as a source of Seismic Signals, the Integration of Seismic Sensors with Stick-Slip vibrations and we have pointed the advantages of Stick-Slip based Seismic While Drilling (SWD).

Chapter IV

Comparative study

IV.1. Introduction

Both vertical seismic profile and seismic while drilling are geophysical tools serve the main goal of gathering information about the subsurface, however there is a difference between them in the way they operate, design objectives, approaches and applications.

As we know the SWD method has not used in Algeria yet, and to better understand its potential in reality we need to execute a MATLAB simulation imitate the use of this method in Algerian oil fields and that's based on stick slip vibrations. The purpose of this simulation is to make a comparative study between VSP and SWD and to highlight the similarities and differences between the two methods beside focusing on their advantages and limitations.

IV.2. VSP Advantages and Limitations

IV.2.1. Advantages

- Provides higher resolution images compared to surface seismic surveys because to its closer proximity to the target formations and reduced travel paths for seismic waves.
- Borehole seismic signals tend to have higher frequencies compared to surface seismic signals, which enables an increase in subsurface resolution.
- VSP offers more precise depth measurements as it uses the wellbore as a reference point, decreasing uncertainty associated with surface-based velocity models.
- The VSP create a seismogram provides a clearer reflection profile than that acquired from the sonic logs, that owing to the difference quantity of data offered by two approach because the sonic log delivers an image just near the borehole unlike VSP which gives a broader picture
- VSP encompasses several configurations (e.g., zero-offset, offset, walkaway) gathering to different exploration and monitoring purposes, such as imaging near-wellbore structures, detecting fractures, and evaluating reservoir performance.
- The direct downward wave-field can be utilized to estimate velocities which give information on rock properties.

IV.2.2. Limitations

- Have high costs due to the necessity for specialist equipment and the complexity of the acquisition procedure, and some operational risk because of having the drill string out of the well for one or more days.
- VSP data quality can be impacted by factors such as near-surface variations, ambient micro seismic noise, and the existence of numerous reflections, which can make data interpretation difficult.
- VSP surveys have low lateral resolution due to the geometry of the sources and receivers, which are generally positioned along a single vertical wellbore. This can make it challenging to resolve lateral variations in subsurface structures or properties.
- VSP data takes specialist knowledge and advanced processing techniques to understand effectively, which might be a drawback for less experienced practitioners.
- VSP data often has to be merged with other geophysical and geological data sets to offer a thorough picture of the subsurface, which can be limitation in places where data is scarce or of low quality.

IV.3. Advantages of SWD

Seismic while drilling (SWD) offers several advantages in the oil and gas industry. These advantages include:

- ✓ SWD delivers real-time seismic imaging, which enables for continuous monitoring of the subsurface during drilling operations. This allows the drilling team to adjust the well path in real-time, lowering the danger of drilling into undesirable formations or missing the target zone.
- ✓ SWD may dramatically increase safety during drilling operations by allowing the drilling team to spot possible risks like as gas pockets or unstable formations in real-time, enabling them to take remedial action before accidents occur.

- ✓ Reduce Non Productive Time (NPT) by allowing the drilling team to make adjustments to the well path in real-time.
- ✓ SWD can offer extensive information on the subsurface, allowing for better reservoir characterization and greater knowledge of the geological structure. This information may be utilized to optimize future drilling operations and increase overall recovery.
- ✓ The information obtained from SWD can be used to guide well placement, ensuring that the well is drilled in the optimal location.
- ✓ Reduce rig cost ().
- ✓ High reliability for deep-water conditions.
- ✓ Minimize uncertainty for increased safety.

IV.3.1. Real time imaging and geosteering

Real time imaging can be defined as a continuous acquisition, processing, and interpretation of subsurface data, that provides a live view of the subsurface conditions as the well is being drilled. On the other hand, geosteering (Figure IV.1) is the process of adjusting the trajectory of a wellbore in real time based on geological data, to optimize well placement and that can be crucial to accurately guide the drill bit along a specific path to reach target reservoir zones, geological formations or to ensure that it stays within the desired zone of interest.

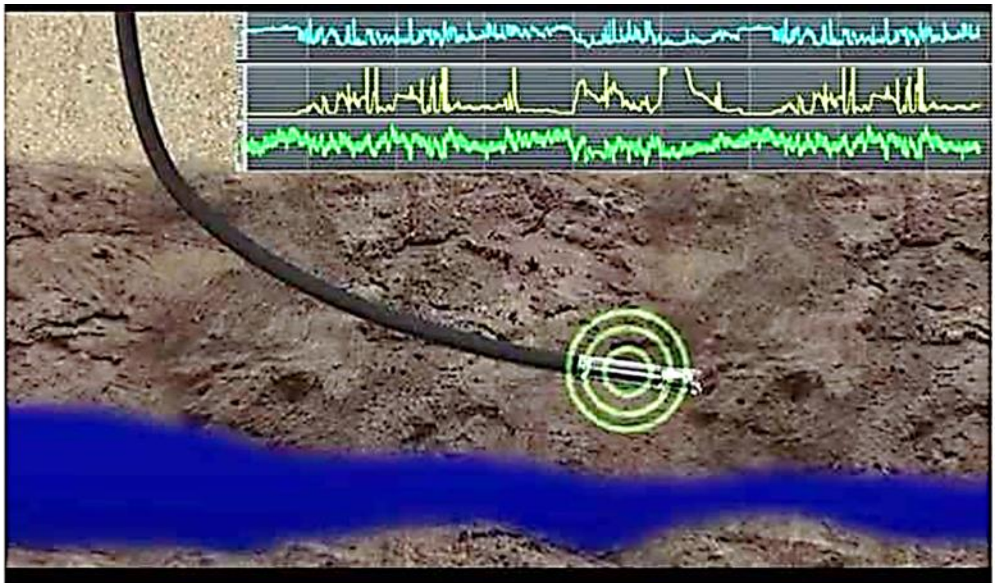


Figure IV.1 Geosteering technologies

IV.3.2. Reducing drilling risks and uncertainties

Both of real time imaging and geosteering can reduce drilling risks through recognizing drilling hazards and also possible threats as they occur, by detecting geological structures such as faults, fractures or unstable formations, and that give the time for operators to make quick decisions during drilling [16].

Real time imaging and geosteering can reduce uncertainties through:

- Accurate formation evaluation: both of the techniques enable geoscientists and drilling engineers to make quick and informed decisions during drilling operations, with continuous monitoring and analysis of geological data during drilling, providing valuable insights into subsurface geology, leading to improved reservoir modeling and development strategies.
- Improved reservoir characterization: by providing real time information about the reservoir, geoscientists can receive a huge amount of data about geological formations, fluid contrast, and other reservoir features.
- Optimized well placement: geosteering decisions are guided by real time imaging data, which provides a precise view of subsurface geology ahead of the drill bit. This information aids in steering the wellbore through the reservoir's most productive zones, increasing hydrocarbon recovery and optimizing well performance.
- Efficiency and cost savings: real time imaging and geosteering improves drilling efficiency by decreasing nonproductive time and optimizing drilling procedures. By using real time data to make informed decisions and eventually lower drilling costs.
- Maximizing production rates: geosteering helps in maximizing hydrocarbon production rates, by steering the wellbore through the most productive zones of the reservoir.

IV.4. Stick slip vibrations simulation

The Algerian formation is well-known for its high level of hardness, resulting in frequent stick-slip vibrations during drilling operations. However, instead of being an obstacle, these vibrations can be used for seismic during drilling operations. In order to complete our comparative study, we have to execute simulation of SWD through stick slip vibration since this technique is not applied yet in Algeria.

It is well recognized that modeling a concept is important for understanding its potential in the petroleum field. This is crucial when dealing with procedures like seismic data processing. To realize this simulation, we have to use MATLAB 2023a software.

IV.4.1. MATLAB

MATLAB (Matrix Laboratory) is a high-level programming language and interactive environment for numerical computing, visualization, and programming. It is frequently utilized in numerous domains like engineering, physics, and mathematics for data analysis, algorithm development, and model generation. MATLAB is especially effective for numerical computations, linear algebra, and data visualization, making it a popular option among researchers and engineers [17].

MATLAB offers a wide range of features include:

- Supports a broad collection of matrix operations, including matrix multiplication, matrix inversion, and eigenvalue decomposition.
- Provides sophisticated capabilities for data visualization, including plotting, graphing, and 3D visualization.
- MATLAB offers a large selection of toolboxes that provide additional capability for specialized applications, such as signal processing, image processing, and control systems.

IV.4.2. Simulation results

The rotary motion of the top drive and drill bit is replicated by the utilization of the well-established dynamic model of the drill string as outlined in Chapter 3. The dynamic of angular velocity of the drill bit reflects the appearance and the severity of the stick-slip vibrations.

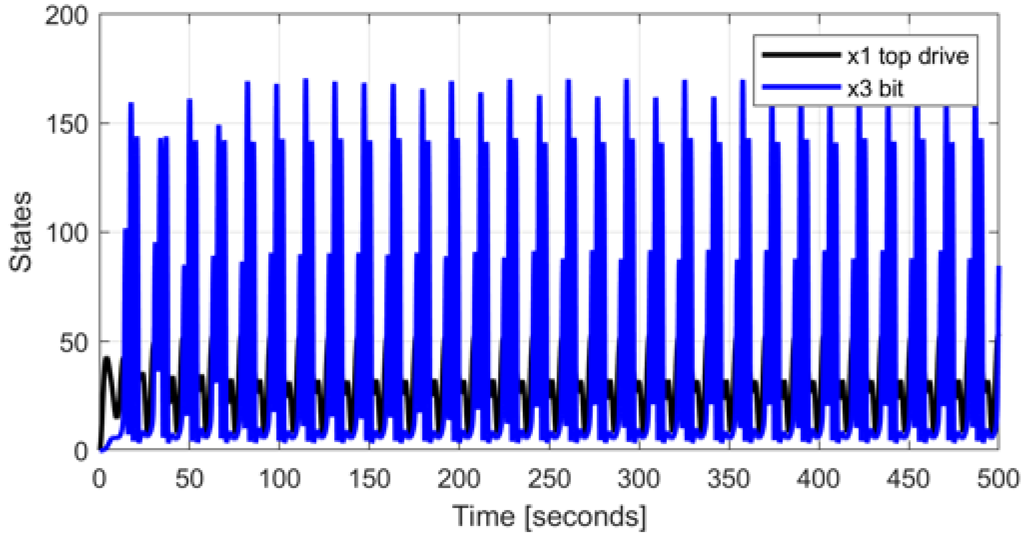


Figure IV.2 Stick-slip vibration simulation with: Input velocity of 40 rpm and Wob=120 N

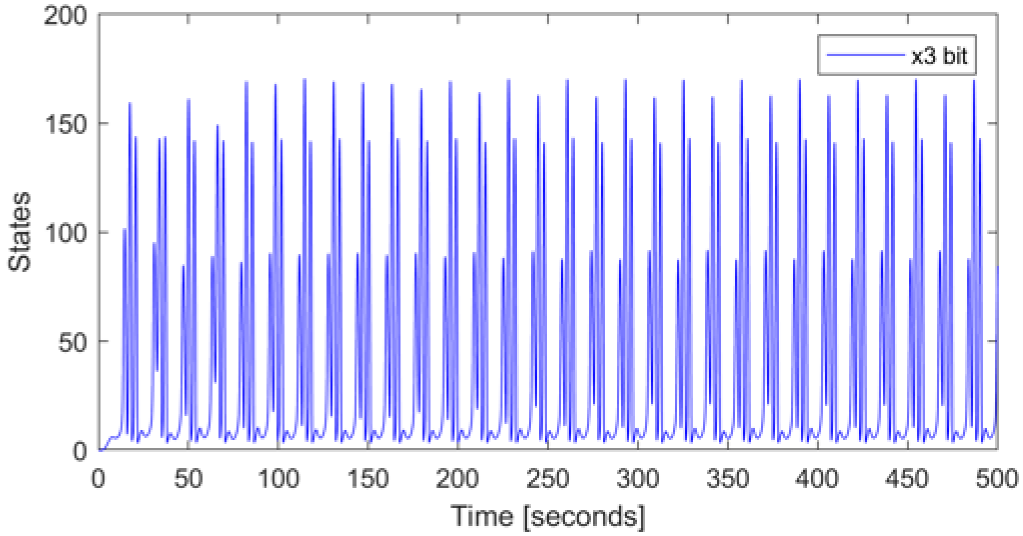


Figure IV.3 Torsional vibrations on drill bit

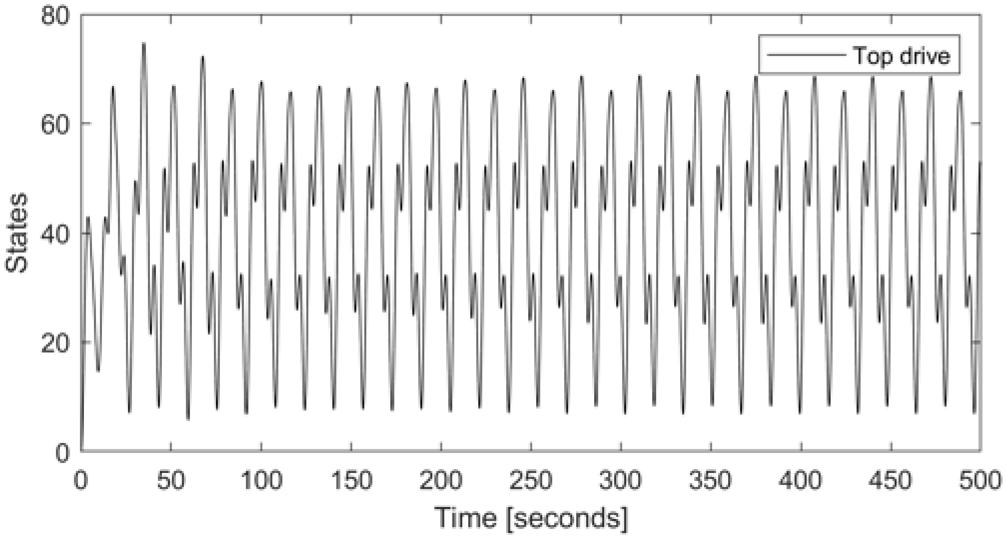


Figure IV.4 Torsional vibrations on Top drive

Figure IV.2 depicts the torsional vibration occurring in stick-slip mode, which is caused by changes in parameters due to geological formation needs and the monitoring of weight on bit (WOB). The stick-slip phenomenon refers to the occurrence of intense torsional vibrations that can cause significant damage to the drill bit, tool string, or top drive if left uncontrolled for an extended length of time.

In the optimal situation, it can cause a 50% increase in non-productive time (NPT) out of the overall drilling time. The primary reason for these vibrations is the complex and nonlinear interaction between the rock and the drill bit. This interaction causes the rotational speed of the bit to become unstable and fluctuate significantly in response to rapid changes in the mechanical characteristics of the rock. Hence, the behavior of the rotary drilling equipment during oscillations cannot be entirely deterministic. Consequently, developing the friction model design was a challenging task, as it required the inclusion of several factors to accurately capture the physics of friction processes (this simulation is based on mathematical model described in chapter 3).

In order to accurately characterize the physics of friction phenomena, it was essential to incorporate a significant quantity of factors. Among the researched friction models, the general model has showed its great representability of stick-slip phenomena in its high frequency mode and the severe torsional vibrations.

IV.4.3. Different rotation rotational speed and WOB results

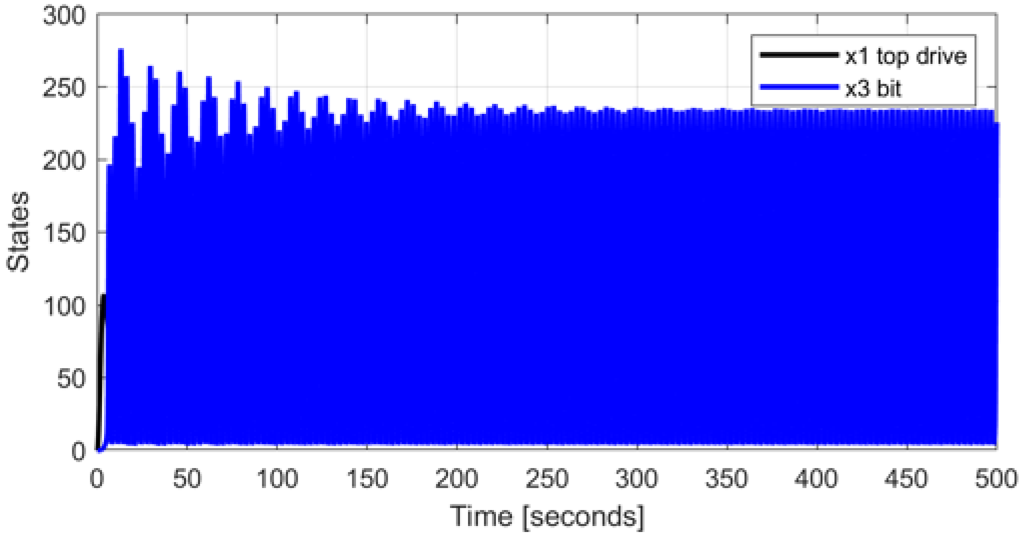


Figure IV.5 Stick-slip vibration simulation with: Input velocity of 100 rpm and Wob=180 N

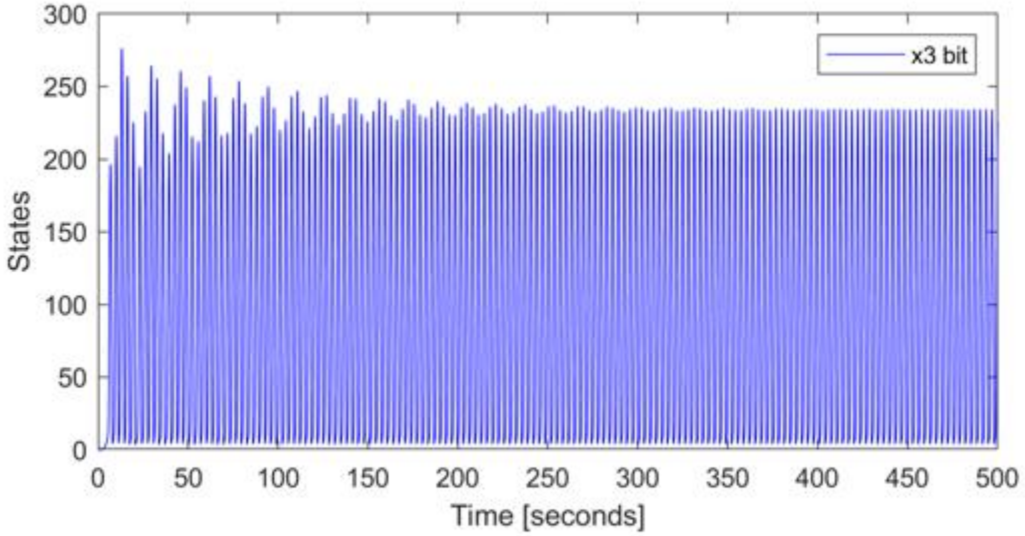


Figure IV.6 Angular velocity of the drill bit for the same parameters in Fig IV.5

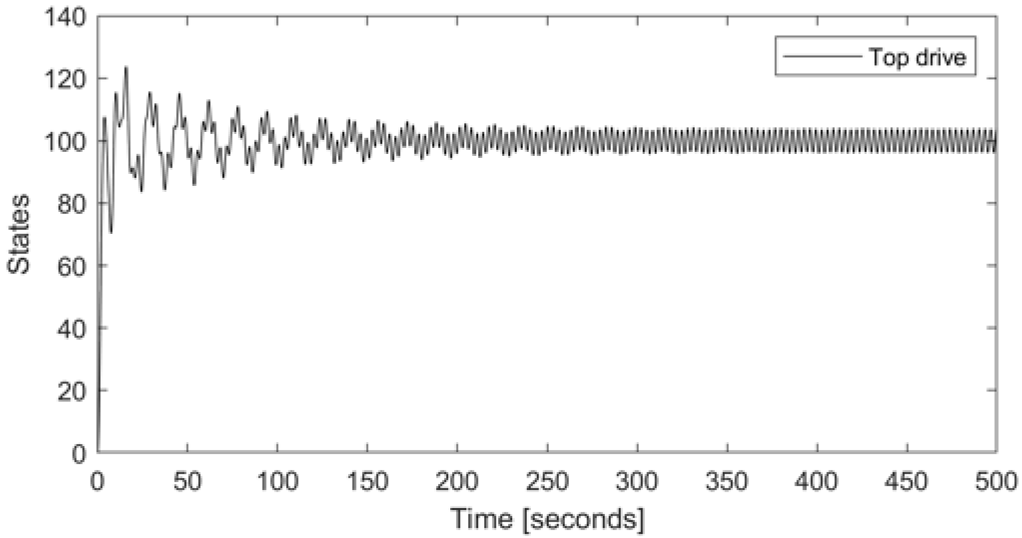


Figure IV.7 Angular velocity of top drive for the same parameters in Fig IV.5

Figure IV.6.7 displays the angular velocity of the top drive in black and the angular velocity of the bit in blue, representing the open loop response of the system. The broad rock-bit interaction term has been employed in order to accurately capture the stick-slip dynamic. By setting the weight on bit (WOB) to 180 Nm and the input velocity to 100 rpm, the speed of the drill bit fluctuates. However, the oscillations of the top drive are smaller than those of the drill bit because the vibrations are absorbed from the bottom hole up to the surface. Furthermore, it is worth noting that during the slip phase, the highest bit velocity surpassed twice the top drive velocity, and then plummeted to nearly zero during the stick phase, repeating this pattern.

IV.5. Contrasting SWD with conventional seismic techniques

Contrasting seismic while drilling (SWD) with conventional seismic techniques based on comparing the main characteristic, advantages, and limitations. As follows:

- **Data collection:**

a) SWD: collects seismic data in real time during drilling, and that's to provide immediate input on subsurface formations along the borehole path [18].

b) Conventional seismic: acquiring seismic data before drilling operations requires time for processing and interpretation.

- **Depth coverage:**

a) SWD: provides coverage at a shallow to moderate depth, focused on the immediate area surrounding the borehole [19].

b) Conventional seismic: offers in higher depth a coverage of subsurface structures and with that offering a more comprehensive view of the entire area.

- **Resolution:**

a) SWD: usually offers a higher resolution in immediate area surrounding the borehole, providing by that a precise information.

b) Conventional seismic: provides a reduce level of detail in image quality, but broader coverage, allowing for a more generalized understanding of the subsurface geology.

- **Cost and Efficiency:**

a) SWD: it can be helpful in reducing costs by optimizing well placement in real time, and also reducing the need for additional seismic surveys.

b) Conventional seismic: requires a considerable initial expense for data collecting, processing and interpretation, this method offers a full understanding of the subsurface.

- **Risk mitigation:**

a) SWD: help in the real time detection of drilling dangers, such as faults or unstable formations, allowing for immediate adjustments to mitigate risks during drilling.

b) Conventional seismic: provides a preliminary evaluation of potential subsurface hazards, but it cannot offer a real time insight to address drilling difficulties as they arise.

- **Application:**

a) SWD: this technology is well suited for enhancing the positioning of wells, guiding drilling operations, and analyzing reservoir properties.

b) Conventional seismic: appropriate for regional exploration, reservoir mapping and through subsurface imaging prior to drilling.

In summary, SWD provides real time data acquisition and immediate feedback for optimizing drilling operations, whereas conventional seismic techniques provide a broader and deeper understanding of subsurface structures but require more time and resources. The choice between SWD and conventional seismic methods depends on the specific objectives, budget constraints, and depth coverage requirements of the exploration or production project [20].

IV.6. Advantages of SWD over Traditional Seismic Methods

There are many benefits to Seismic-While-Drilling (SWD) over conventional seismic techniques. SWD offers distinct advantages over traditional methods as it uses seismic techniques while the drillstring is in the borehole.

Furthermore, SWD enables real-time data collecting, which improves decision-making during drilling operations by providing quick insights into subsurface geological information ahead of the drill bit.

SWD techniques also have the potential to provide high-resolution seismic interpretation, which might enhance imaging and provide a better knowledge of the geology for use in the mining and oil and gas sectors.

These benefits demonstrate the importance of SWD in modern geophysical exploration and its capacity to completely change the methods used to obtain seismic data.

IV.7. SWD in offshore and onshore

IV.7.1. SWD in offshore

For offshore drilling operations, seismic while drilling (SWD) equipment is essential because it provides real-time seismic data that lowers formation uncertainty and enhances wellbore placement. This method is especially useful in offshore wells when there are adjacent salt bodies, difficult trajectories, pressure changes, and velocity uncertainty.

SWD services provide quick access to high-quality reservoir data that may be used to improve production and recovery by taking measurements during drilling's natural pauses without negatively impacting operations.

Furthermore, SWD can access boreholes that wireline may find difficult, reducing the necessity for extra open hole time or unsafe deployment techniques in wells that are severely deviated, horizontal, or have extended reach.

For safer and more effective drilling operations, operators could modify the well trajectory, mud weight, or casing setting depth by detecting changes in pressure, possible reservoir exits, and other uncertainties.

In addition, improvements in SWD technology, such Technology International's Seismic Pulser, aim to fix problems like the absence of a real downhole source at the drill bit. With the help of this innovative technique, low frequencies may be produced from high-frequency impulse sources, allowing seismic data to be sent from very deep depths to the surface with no interference to drilling operations [21].

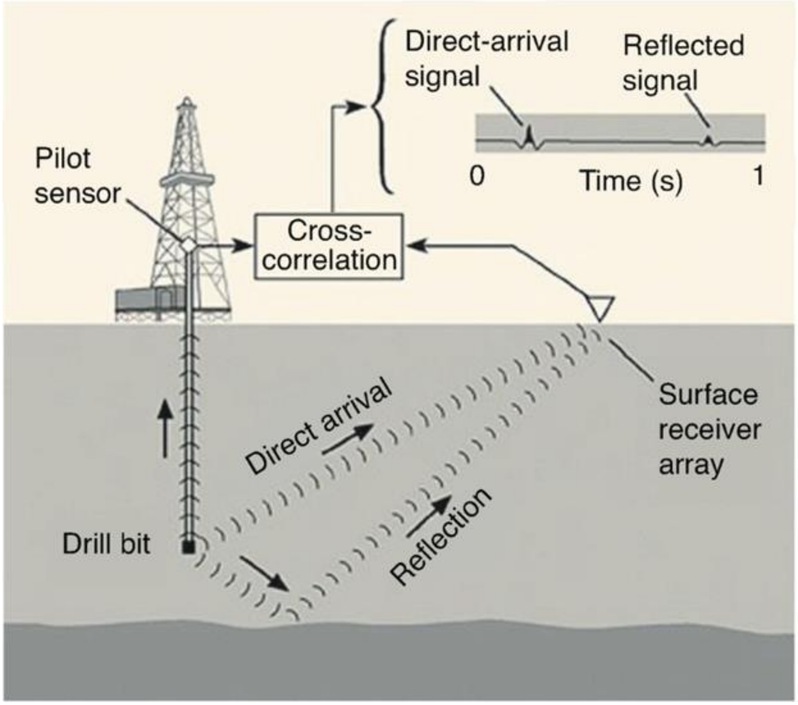


Figure IV.8 SWD in offshore

IV.7.2. SWD in onshore

In onshore settings, seismic while drilling (SWD) methods have been effectively used, offering significant real-time data to enhance drilling operations and reservoir characterization.

The drill bit may be used as the seismic source in a reverse walkaway SWD survey carried out in onshore regions where unfavorable field conditions make it challenging to operate seismic sources.

To capture the seismic waves produced by the drill bit, this technique involves positioning geophones at the surface and inside the borehole [22].

Only the changes in the subsurface are visible when the recently received seismic data is subtracted from the reference seismic data obtained before drilling.

This makes it possible to monitor the drilling process in real-time and identify any potential risks or geological characteristics that can affect the well's direction.

Drill bit seismic profiling in onshore locations has also been conducted using the TRAFOR MWD system.

In conclusion, SWD techniques have shown to be successful in onshore settings, including reverse walkaway surveys and drill bit seismic profiling. These techniques provide vital real-time data to optimize drilling operations and improve reservoir characterization, especially in difficult field circumstances.

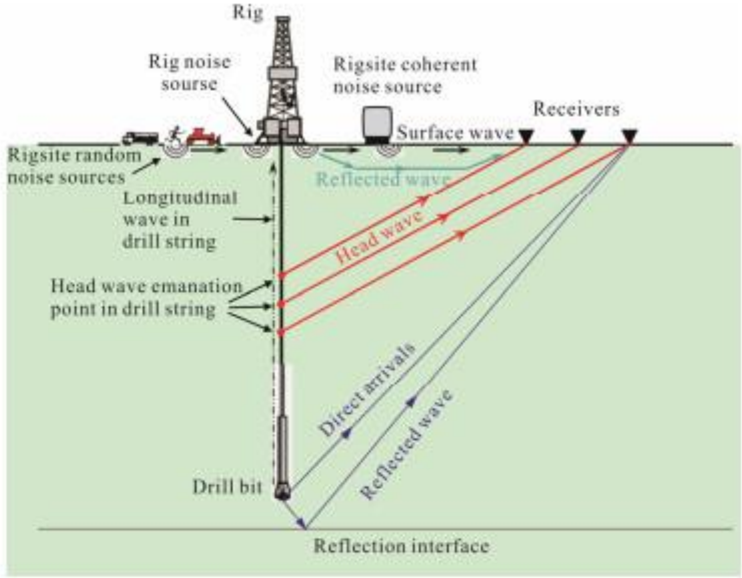


Figure IV.9 SWD in onshore

IV.8 Conclusion and recommendation

Starting from the simulation and analysis of seismic while drilling using drill bit stick slip vibrations as a source, we can easily assume that the SWD has shown the ability to provide high resolution subsurface images in real time during drilling the well if used in Algerian oil fields. This privilege can lead to better identification of hydrocarbon reservoir and reduce drilling risk especially for unconventional reservoirs that will explored in the next few years.

In the other hand there are some limitations and failures must be considered like the limited depth of investigation offered by the SWD, the data quality and the most important of them the high cost of operating this technique, which is under development for lowering its cost.

Despite these limitations, it is recommended that further research and experimentation can be conducted to fully understand that the seismic while drilling method offers the advantage of real time data acquisition that can lead to better identification of hydrocarbon reservoir and reducing drilling risks.

At the end, SWD using stick-slip vibration from the drill bit as a source shows potential as a real-time subsurface imaging tool for drilling in the Algerian oil field. It is necessary to carefully evaluate specific drilling conditions and geological formations in order to assure the technique's efficacy and applicability.

General conclusion

In this work, our research focused on a comparative study between VSP and SWD in Algerian exploration petroleum fields. The study aimed to investigate SWD's capabilities based on stick slip vibration compared to VSP as a technique for capturing subsurface in real time during drilling operations.

The initial chapters highlighted an overview of borehole seismic survey techniques and their benefits, including their ability to provide detailed information and cost efficiency. The idea of SWD emerged as a feasible alternative in response to the need for developments in reservoir monitoring techniques.

Throughout our research, the VSP technique was examined. This technique's advantages, such as higher-resolution images and more precise depth measurements, were highlighted. However, there are limitations, including high costs and data quality can be impacted by factors such as near-surface variations, ambient micro-seismic noise, and the existence of numerous reflections, which were also acknowledged.

During our research, we particularly focused on the stick-slip vibration model as a source of SWD technique. The benefits of this method, such as its capacity to deliver a precise seismic signal for precise reservoir identification and decreased drilling risks, were emphasized.

The simulations done in our work provide useful insights into the feasibility and efficacy of stick-slip vibration for SWD in the Algerian oil field. The results suggested that this technology has the potential to significantly improve subsurface imaging accuracy and resolution during drilling operations. To fully leverage the possibilities of SWD employing drill bit stick-slip vibration as a source in the Algerian oil field, more research and experimentation are recommended.

Finally, based on the study and the data provided in this work, we highly recommend using this approach in Algerian petroleum fields. The various pros connected with this technology definitely exceed its downsides, making it a potential solution for real-time subsurface imaging during drilling operations. By integrating SWD, the Algerian petroleum industry may benefit from increased subsurface imaging during drilling operations, leading to more informed decision-making, optimal reservoir characterization, and eventually improved exploration and production performance.

Bibliography

[1] A. R. Rezaee, A. Kadkhodaie-Ilkhchi, and M. Zoveidavianpoor, Seismic While Drilling: A Review, Published in: Journal of Petroleum Science and Engineering; Year: 2017.

[2] Anchliya, A. "A Review of Seismic-While-Drilling (SWD) Techniques: A Journey From 1986 to 2005." Paper presented at the SPE Europec/EAGE Annual Conference and Exhibition, Vienna, Austria, June 2006. doi: https://doi.org/10.2118/100352-MS

[3] Baker Hughes website: https://www.bakerhughes.com/sites/bakerhughes/files/2020-09/seismictrak-seismic-while-drilling-slsh_0.pdf.

[4] Ch. Naville, S. Serbutoviez, A. Throo, O. Vincké and F. Cecconi, Seismic While Drilling (SWD) Techniques with Downhole Measurements, Introduced by IFP and its Partners in 1990- 2000.

[5] Chafiaa Mendil , Madjid Kidouche , Mohamed Zinelabidine Doghmane, Hybrid sliding PID controller for torsional vibrations mitigation in rotary drilling systems, Indonesian Journal of Electrical Engineering and Computer Science, Vol. 22, No. 1, April 2021, pp. 146~158, DOI: 10.11591/ijeecs.v22.i1.pp146-158

[6] Doghmane, M. Z., Kidouche, M., & Ahriche, A. (2023). Decentralized Overlapping Control Design with Application to Rotary Drilling System. IETE Journal of Research, 69(4), 2070–2079. https://doi.org/10.1080/03772063.2021.1886602

[7] Doghmane, M.Z., Bacetti, A., Kidouche, M. (2021). Stick-Slip Vibrations Control Strategy Design for Smart Rotary Drilling Systems. In: Hatti, M. (eds) Artificial Intelligence and Renewables Towards an Energy Transition. ICAIRES 2020. Lecture Notes in Networks and Systems, vol 174. Springer, Cham. https://doi.org/10.1007/978-3-030-63846-7_20

[8] F. Poletto and F. Miranda, Seismic while drilling, fundamentals of Drill-bit seismic for exaplorations, handbook of Geophysical explorations, Elsevier 2004. http://dlibrary.univ-boumerdes.dz:8080/handle/123456789/5432

[9] Idir Kessai, Samir Benammar, M.Z. Doghmane, Dynamic failure analysis and lifetime estimation of Tool-string in rotary drilling system under Torsional-Axial coupled vibrations, Engineering Failure Analysis, Volume 134, 2022, 106037, https://doi.org/10.1016/j.engfailanal.2022.106037

[10] Idir Kessai, Samir Benammar, Mohamed Zinelabidine Doghmane and Kong Fah Tee- Drill Bit Deformations in Rotary Drilling Systems under Large-Amplitude Stick-Slip Vibrations 18 September 2020.

[11] Kessai I, Benammar S, Doghmane MZ, Tee KF. Drill Bit Deformations in Rotary Drilling Systems under Large-Amplitude Stick-Slip Vibrations. Applied Sciences. 2020; 10(18):6523. https://doi.org/10.3390/app10186523

[12] Kessai, I., Doghmane, M.Z., Benammar, S. (2022). Weight-On-Bit Variations Analyses in the Drillstring of Rotary Drilling Systems Under Stick-Slip Vibrations. In: Hatti, M. (eds) Artificial Intelligence and Heuristics for Smart Energy Efficiency in Smart Cities. IC-AIRES 2021. Lecture Notes in Networks and Systems, vol 361. Springer, Cham. https://doi.org/10.1007/978-3-030-92038-8_72

[13] Khelfani Slimane, Kadi Med Tahar. M'Hamed BOUGARA University – Boumerdes- Etude d'un profil sismique vertuical zéro offset, avec offset & walk away. 2006.

[14] Kristoffer Evensen, Norwegian University of Science and Technology (NTNU), Surface Seismic While Drilling A new method for relief well drilling, June 2013.

[15] Kristoffer Evensen, Sigbjørn Sangesland, Ståle Emil Johansen, Espen Birger Raknes, Børge Arntsen, Norwegian University of Science and Technology (NTNU), Relief Well Drilling Using Surface Seismic While Drilling (SSWD), 4–6 March 2014.

[16] Liping Tang , Baolin Guo , Xiaohua Zhu, Changshuai Shi and Yunlai Zhou, Stick–slip vibrations in oil well drillstring: A review,2020.

[17] Liu Shuguang, Chen Wuyang, Wu Kecheng and Jiang Jia, Review on Stick-slip Vibration's Mechanism Analysis and Its Control Strategy in Deep Drilling with Drag Bits ,September 2020.

[18] M. Zoveidavianpoor, A. R. Rezaee, and A. Kadkhodaie-Ilkhchi, Seismic While Drilling: A Review of the Technology and Applications, Published in Geophysics Year: 2018.

[19] MathWorks. MATLAB. https://www.mathworks.com/.

[20] Meddah, Sabrina; Idir, Abdelhakim; Tadjer, Sid Ahmed et al., PID Control Design of Strongly Coupled Axial-Torsional Vibrations in Rotary Drilling Systems, Przeglad Elektrotechniczny, 2024, Vol 2024, Issue 3, p196, DOI: 10.15199/48.2024.03.35

[21] Mendil, C., Kidouche, M., & Doghmane, M. Z. (2023). Hybrid Backstepping Sliding Mode Controller for Stick–slip Vibrations Mitigation in Rotary Drilling Systems. IETE Journal of Research, 69(6), 3477–3487. https://doi.org/10.1080/03772063.2021.1919217

[22] Mendil, C., Kidouche, M., Doghmane, M.Z. (2021). Modeling of Hydrocarbons Rotary Drilling Systems Under Torsional Vibrations: A Survey. In: Hatti, M. (eds) Artificial Intelligence and Renewables Towards an Energy Transition. ICAIRES 2020. Lecture Notes in Networks and Systems, vol 174. Springer, Cham. https://doi.org/10.1007/978-3-030-63846-7_24

[23] Mendil, C., Kidouche, M., Doghmane, M.Z. (2022). Sliding Mode Controller Design for Torsional Vibrations Minimization Under Rock-Bit Interaction Effects. In: Hatti, M. (eds) Artificial Intelligence and Heuristics for Smart Energy Efficiency in Smart Cities. IC-AIRES 2021. Lecture Notes in Networks and Systems, vol 361. Springer, Cham. https://doi.org/10.1007/978-3-030-92038-8_61

[24] Mendil, C., Kidouche, M., Doghmane, M.Z., Benammar, S. and Tee, K.F. (2021), "Rock–bit interaction effects on high-frequency stick-slip vibration severity in rotary drilling systems", Multidiscipline Modeling in Materials and Structures, Vol. 17 No. 5, pp. 1007-1023. https://doi.org/10.1108/MMMS-10-2020-0256

[25] Mohamed Zinelabidine Doghmane, Conception de commande décentralisée des systèmes complexes en utilisant les stratégies de décomposition et optimisation par BMI, PhD thesis, university m'hamed bougara de boumerdes, 2019.

[26] Mohamed Zinelabidine Doghmane, Optimal decentralized control design with overlapping structure, magister thesis, university m'hamed bougara de boumerdes, 2011.

[27] N. Benmir, H. Akroum, M. Z. Doghman and M. Kidouche, "A Survey Study of Modeling, Analysis, and Control Drill String under Torsional, Axial, and Lateral Vibrations," 2023 Second International Conference on Energy Transition and Security (ICETS), Adrar, Algeria, 2023, pp. 1-11, doi: 10.1109/ICETS60996.2023.10410728

[28] Riane R, Doghmane MZ, Kidouche M, Djezzar S. Observer-Based H∞ Controller Design for High Frequency Stick-Slip Vibrations Mitigation in Drill-String of Rotary Drilling Systems. Vibration. 2022; 5(2):264-289. https://doi.org/10.3390/vibration5020016

[29] Riane R, Doghmane MZ, Kidouche M, Tee KF, Djezzar S. Stick-Slip Vibration Suppression in Drill String Using Observer-Based LQG Controller. Sensors. 2022; 22(16):5979. https://doi.org/10.3390/s22165979

[30] Riane, R., Kidouche, M., Doghmane, M.Z., Illoul, R. (2021). Modeling of Torsional Vibrations Dynamic in Drill-String by Using PI-Observer. In: Bououden, S., Chadli, M., Ziani, S., Zelinka, I. (eds) Proceedings of the 4th International Conference on Electrical Engineering and Control Applications. ICEECA 2019. Lecture Notes in Electrical Engineering, vol 682. Springer, Singapore. https://doi.org/10.1007/978-981-15-6403-1_12

[31] S. M. Hosseini, M. Zoveidavianpoor, S. M. Mousavi, and M. Torabi."Seismic While Drilling (SWD) Technology: A Comprehensive Review", Published in: Journal of Petroleum Science and Engineering; Year: 2016.

[32] Salah Said Med AMEUR, Mohammed Abd El illah ABBOU, Amine DERGAOU, Kasdi Merbah University - Ouargla -, Seismic While Drilling (SWD) Process Simulation Based on Stick-Slip Vibration Model in Algerian Petroleum Field, 18/06 /2023.

[33] Schlumberger site: https://www.slb.com/vision .

[34] SLB, glossary energy. vertical seismic profile. 2024.

[35] Society of Petroleum Engineers (SPE): https://www.spe.org/.

[36] Toshiyuki Yokota, Kyosuke Onishi, Tetsuji Ohno, Akinori Ota, Tsutomu Kaneko, Hirokazu Ksawa, Seismic while drilling: Basic experiments using a percussion drill as an energy source Exploration Geophysics (2004) 35, 255-259.

[37] Treitel, Klaus Helbig and Sven. Seismic While Drilling Fundamentals OF Drill-Bit Seismic for Exploration. 2004.

[38] Xiaohua Zhu,zm Liping Tang, Qiming Yang, A Literature Review of Approaches for Stick-Slip Vibration Suppression in Oilwell Drillstring, January 2014.

[39] Yuriy Batrak, LATERAL VIBRATION PREDICTION ISSUES, ShaftDesigner.