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Coherent Noise (Ground roll) Consideration: Local Wave-field Decomposition (*LWD*) Based Approaches to Suppression

ADIZUA, Okechukwu Frank[1*] and OKORIE, Iheanyichukwu Patrick Chikwendu[2]

[1,2]Geophysics Research Group – GRG, Department of Physics, Faculty of Science, University of Port Harcourt, Port Harcourt, Rivers State, Nigeria.

***Corresponding author**

ADIZUA, Okechukwu Frank,
University of Port Harcourt,
Port Harcourt,
Rivers State,
Nigeria.

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Abstract
There is always a signal and a noise component in seismic data. Noise can be defined as any recorded energy that tampers with the desired signal of interest. Although it might be difficult to separate signal from noise due to the variety of noise kinds, effective noise suppression is crucial for high-quality imaging. Surface waves or ground roll are a prominent source-generated coherent noise in exploration seismology. Ground roll contains little to no information about the deeper subsurface as it moves laterally through the earth's near surface. The low-frequency contents and strong amplitudes of these arrivals often mask recordings of body waves reflected by deeper subsurface targets. This discussion paper will describe ground rolls, a significant form of seismic coherent noise, as well as their unique characteristics, how they appear on acquired seismic data, the significance of suppressing them in seismic processing applications, and an examination of local wave-field decomposition (LWD) techniques and their applications.

Keywords: Seismic Data, Signals (Primary Reflections), Noise, Coherent Noise, Ground Roll, LWD Based Suppression Strategies.

Introduction

Strong coherent noise, such as ground-roll, multiples, converted waves, diffracted waves, direct waves, etc., frequently contaminate land (onshore) seismic data. According to (Linville & Meek 1995). This noise disrupts and obscures the deep subsurface signal in seismic gathers. Specifically, strong dispersive surface waves are produced by near surface lateral velocity variations, overwhelming the useful information in short gathers. In seismic data processing, band pass and f-k filters are frequently used to reduce coherent noise while trying to maintain the signal's phase and amplitude. These techniques are predicated on the ability to discriminate between signal and noise using attributes like apparent move out (f-k filtering and radon transform) or frequency content (band pass filter) (Yilmaz & Doherty, 1987; Yilmaz, 1989; Yilmaz 2001). A collection of surface waves produced by a seismic source is coherent noise, of which ground roll is a primary form. It is a specific kind of Rayleigh wave with low frequency, low velocity, and high amplitude. Because ground rolls are dispersive, the intended reflected signal is typically overwhelmed. Ground-roll conceals strong reflections at long offsets and shallow reflections at short offsets due to its dispersive nature (Claerbout, 1983; Saatcilar & Canitez, 1988; Henley, 2003). Surface waves are the most important type of waves that are connected to a material's border as opposed to waves that travel through the material's body. These are referred to as Rayleigh waves in conventional seismic practice and as Love waves in shear work. The focus of this brief discussion paper will be on ground roll, also known as Rayleigh waves, which are the main source of what field geophysicists typically identify as the primary form of onshore coherent noise.

The Problem of Coherent Noise (ground roll) in seismic data

In land seismic investigation, coherent noise, often known as ground roll, is a well-known serious issue. The reason behind ground roll is that a seismic source can send a seismic signal through the subsurface's geological strata and along the ground's surface. Because the surface wave velocity is less than the velocities of the signals that have been reflected at the boundaries of the geological layers, ground roll, which is often present on a seismic record, may contaminate these reflected signals and obscure signals of interest, lowering the quality of the survey's overall data. Therefore, coherent noise, also known as ground roll, frequently poses a significant challenge to the interpretation of land seismic data. It results in a decline in signal quality information in land (onshore) seismic data.

Seismic Signal Versus Noise Consideration

Any event on the seismic record that we want to extract and use to get useful subsurface information is called a signal. Seismic signals are primary reflections, and noise in the record is everything we do not want to record. Two categories of seismic noise exist:

1. Coherent noise that is discernible over a minimum of several traces. It consists mostly of direct waves, diffractions, refractions, surface waves (also known as ground roll), and multiples.
2. Incoherent or Random noise that is inconsistent across all traces. It encompasses noise produced by wind, rain, near-surface scatterers, footsteps from machinery, and human activities.

Coherent noise of which ground roll are a prominent type is the noise type of focus in this discussion paper and emphasis would be laid on it rather than the incoherent or random noise component (type) of seismic noise.

Overview Of Coherent Noise Examples in Land (Onshore) Seismic Data

Direct Waves

It is the P-wave that travels directly from the source to the receiver along the ground surface. The time-distance equation of the direct wave is:

$$\mathbf{T = \mathit{X}/V_1} \quad \mathbf{(1)}$$

where T is the one-way travel time from the source to the receiver at offset X and V_1 is the velocity in the first (uppermost) layer.

The direct wave always arrives before the reflected P-wave in the first layer. The direct wave is usually the first arrival at near offsets. The head wave usually comes becomes the first arrival at far offsets after the crossover distance.

Head Waves (refractions)

Head waves are generated when the angle of incidence equals the critical angle. The critical angle is given by:

$$\mathbf{\Theta c = Sin^{-1}(V_1/V_2)} \quad \mathbf{(2)}$$

where V_1 and V_2 are the velocities in the incident and refraction media, respectively.

The velocity in the refraction media (V_2) must be higher than the velocity in the incident medium (V_1) in order for head waves to form. According to Fermat's principle, the head wave travels in the refraction medium (with V_2) along the interface, releasing seismic energy into the incident medium at an angle equal to the critical angle (Snell's law). When the offset is smaller than the critical distance, the head wave cannot be seen.

Ground Roll (Coherent noise type of emphasis)

These are Rayleigh surface waves that are moving parallel to the earth's surface. They often have strong amplitudes, low frequencies (< 15 Hz), and low velocities (100–1000 m/s). They have zero intercepts and straight lines with modest velocities on their time-distance curves. Because of their dispersive character, there may be multiple modes of ground rolls in the record (i.e., various frequency components travel with different velocities). In the field, source and receiver arrays as well as a variety of processing techniques (such as radial trace transform, f-k filtering, and frequency filtering) are used to suppress them (Henley, 1999; Henley, 2000; Henley 2003; Adizua & Ohakwere-Eze, 2014; Adizua et al., 2015; Adizua et al., 2017).

Diffraction

When the wave front comes into contact with a reflector's edge or any other obstruction whose size is equal to the wavelength, diffraction takes place. Since the incident wave disperses in all directions in diffraction, Snell's law does not apply. Diffraction amplitude is greatest at the apex and rapidly decreases as one moves away from the peak. Reflections do not alter significantly; hence this trait is helpful only when genuine amplitudes are kept in order to distinguish diffractions from reflections.

Multiples

Events that have experienced several reflections from the same interface are known as multiples. Based on their trajectories, multiples can be classified as either long-path (period) multiples or short-path (period) multiples. Near the primary, a short-path multiple is created to obstruct the primary reflection coming from the same reflector. It reduces the vertical resolution as a result. To ensure complete separation from the primary reflection from the same reflector, a long-path multiple is generated at a considerable distance from the primary. As such, it is recorded in the seismic record as a distinct event.

Short-path Multiples

Peg-leg: This is a multiple that has been reflected up and down from a deeper reflector, first from the base and then from the top of a thin layer. Over time, they successfully reduce the signal frequency.

Ghost: in land surveys, it is a multiple reflected from the weathering layer's base or surface; in marine surveys, it is the water surface.

Water Reverberation: this arises from several reflections in a layer of shallow water. Selecting candidates for the primaries is challenging because of this powerful reflection that permeates the entire record.

Long-path Multiples

Water reverberations in a deep-water layer and reflections at the base of a thick weathering layer are the strongest long-path multiples. They create significant issues, particularly when a primary arriving at the same time as the multiple has a weak amplitude and the multiple has a strong amplitude. Because of the overall rise in velocity with depth, multiples typically exhibit higher NMO (curvature) than main reflections with the same travel time. During seismic data processing, multiples are identified and eliminated based on their high NMO, low velocities, and predictive deconvolution.

Ground Roll Considerationl

Characteristics of Ground rolls

1. These are Rayleigh surface waves that are moving parallel to the earth's surface.
2. Their typical velocities range from 100 to 1000 m/s.
3. Their frequencies are low, usually less than 15 Hz.
4. Their amplitudes are large.
5. They have zero intercepts and straight lines with modest velocities on their time-distance curves.
6. Because seismic records are dispersive, meaning that various frequency components travel at different velocities, there may be several types of ground rolls.
7. They are attenuated by a variety of processing techniques (such as frequency filtering, f-k filtering, and the radial trace transform (RTT)) as well as source and receiver arrays in the field.
8. The ground roll is a surface wave of the Rayleigh type that can be seen in seismograms obtained from land (onshore) seismic surveys.
9. Because the ground-roll's amplitude is larger than that of the body waves, its overlap with the seismic events that are reflected can be hidden by body waves. But unlike body waves, the ground roll mostly consists of low frequency energy, giving it a different frequency composition. This characteristic can be used to distinguish body waves from ground-roll.
10. The most prevalent and well-known kind of coherent noise is ground roll.
11. These Rayleigh waves, also known as ground rolls, are said to be dispersive since their velocity varies with wavelength and their wave train's structure changes with distance.

How Ground roll appear on seismic data

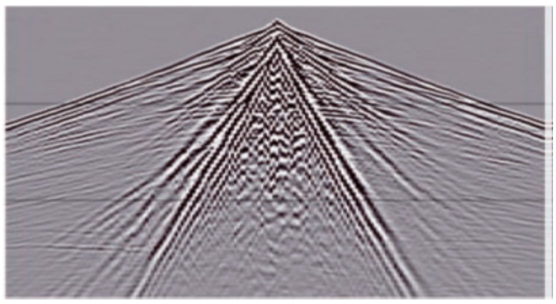

Figure 1: A raw seismic shot contaminated with severe ground roll noise with their typical fan shaped high amplitudes.

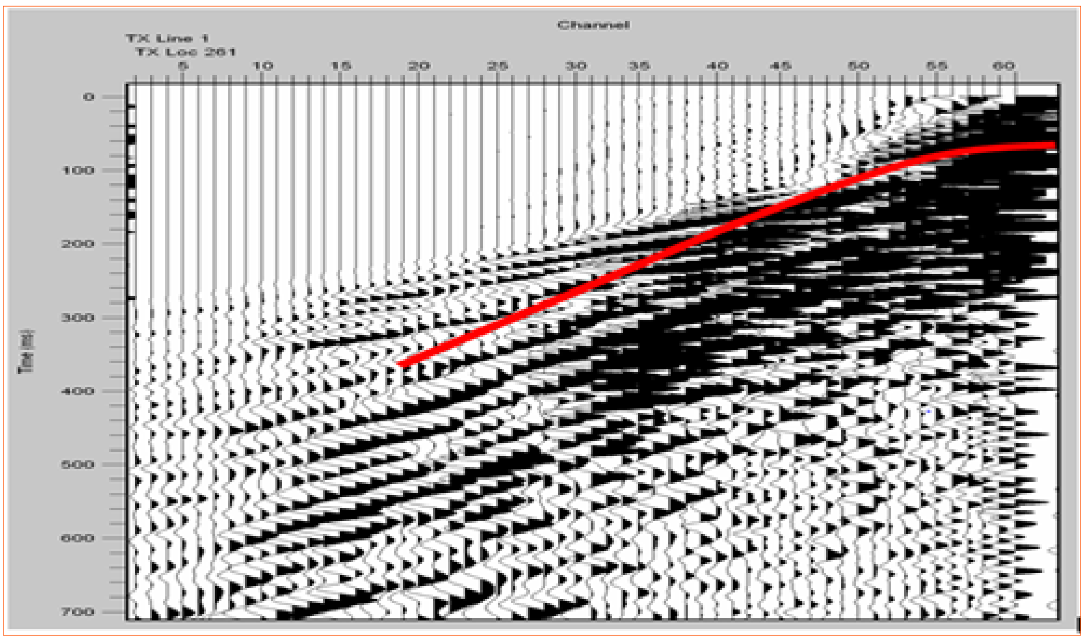

Figure 2: A seismic shot with ground roll noise (red ink areas). They are easily recognized as high amplitude events on the seismic section.

Importance of coherent noise (ground roll) suppression

1. The elimination of noise facilitates the optimal operation of all other signal processing stages. The quality of the input data is crucial for deterministic processes like deconvolution operators and surface consistent amplitude adjustments. Numerous summaries for successful summation operations pertaining specifically to dual sensor Ocean Bottom Cable (OBC) processing need to calibrate the amplitude levels of each component. The presence of significant noise precludes the accuracy of this calibration.
2. One of the most important steps in getting the data ready for prestack imaging is noise removal. While the Common Depth Point (CDP) stack is undoubtedly one of the best methods for mitigating noise, prestack imaging does not allow for its use. Taking care of the noise is necessary before imaging.
3. Properly addressing the noise provides the opportunity to track amplitude anomalies and stratigraphic objectives with confidence.
4. Good noise reduction offers the chance for advanced attribute work and inversion to gain a deeper understanding of the reservoir while maintaining the original amplitude and phase properties of the data.
5. It provides quality data for prestack imaging techniques and appropriate data for reservoir characterization techniques like rock properties, attribute analysis, and inversion, giving exploration and production companies the chance to maximize the benefit of seismic data in meeting their exploration and development targets. Ultimately, this results in a greater degree of confidence while making drilling decisions.
6. High amplitude, low frequency, and low velocity seismic records often contain Rayleigh waves, which can obfuscate signals and reduce the overall quality of the data and hence must be suppressed to increase the signal-to-noise ratio (SNR) and boost other seismic processing sequences that depends on their effective suppression like statics corrections etc.

Coherent noise (Ground roll) suppression principles

Traditionally, frequency-wave number (*f-k*) or frequency-offset (*f-x*) approaches are used to reduce ground roll. These traditional methods, however, may not work in situations where near-surface heterogeneities cause ground roll to be scattered in the cross line direction because cross line scattered ground roll may occupy the same regions of *f-k* and *f-x* space as the reflected waves that we want to keep intact. When implementing any technique to suppress ground roll from obtained seismic data, appropriate caution should be used. Techniques for eliminating these dispersed surface waves, also known as ground roll, are available and fall into two categories: Prediction-removal suppression schemes estimate and subtract scattered surface waves using either modeling-based (Blonk et al., 1995; Blonk & Herman, 1996; Ernst et al., 2002) or data-driven (after Herman and Perkins, 2006) inverse-scattering series. Acquisition-based suppression schemes are based on the use of recording arrays (Regone, 1998; Özbek, 2000).

The velocity of the ground roll is usually quite low. Over the normal range of near-surface materials, ground-roll velocities are within the range of between 350 and 750 m/s (1150 to 2500 ft/s). In few exceptional cases, the ground-roll velocity may even be less than that of the compressional air wave (330 m/s, 1100 ft/s); as velocities as low as 180 m/s (600 ft/s) have been reported. The amplitude spectrum of ground roll seldom has significant content above 25 Hz. This, in combination with a low velocity of (say) 350 m/s, yields a wavelength of about 15 m (50 ft). A low ground-roll frequency of 10 Hz, in combination with a high velocity of (say) 750 m/s, yields a wavelength of 75 m (250 ft). This gives us the range 15 to 75 m (50 to 250 ft) for the wavelengths of ground roll; at the peak of the ground-roll spectrum, and for a typical velocity, a middle value might be 40 m (130 ft). We already have recognized two characteristics, then, that we may use to attenuate ground roll which could just be a simple low-cut filtering, applied below about 25 Hz (or the appropriate local frequency). Below is a graphic representation of signal and noise distribution in frequency domain (Figure 3).

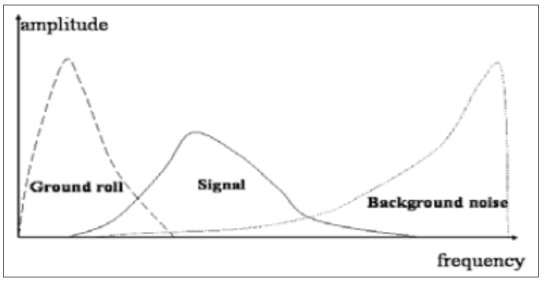

Figure 3: Signal and noise distribution in frequency domain

Seismic coherent noise (Rayleigh waves or Ground roll as they are often referred to as in the industry) can be suppressed based on certain principles. The basic principles involved include the following;

1. Acquisition Design – (Array acquisition) – which aliases the ground-roll.
2. Local Wave-field Decomposition (LWD) - which captures signal and noise in separate parts/domains such as in the F-K and RTT (which are the two major domains or techniques for brief consideration in this paper).
3. Multi-domain Noise Attenuation (MDNA) – which involves randomizing the Noise.

Coherent noise suppression based on Local Wave-field Decomposition (LWD) Approaches

The LWD principles captures signal and noise in separate parts or domains such as in the F-K and RTT domains as mentioned earlier and as would be explained briefly below.

The Frequency Wave Number (*F-K*) Domain Filtering

Coherent noise/linear events such as ground roll in the *t-x* domain can be separated in the *f-k* domain by dip (Yilmaz & Doherty, 1987). It is thus possible to eliminate these kinds of unwanted energy, also known as "ground roll noise", from the original data by zeroing the *f-k* spectrum across a specific range of angles. The 2-D Fourier transform is used to convert seismic data from the t-x domain to the *f-k* domain. Events can be divided using the 2-D Fourier transform based on where in the f-k domain they dip (Zhou & Greenhalgh, 1994). Equation (3) can be used to describe a linear event, f (*t, x*).

$$f(t, x) = s(t) * \delta(t - \tan(\alpha)x + b) \quad (3)$$

Where the symbol "*" denotes convolution with respect to the variable *t*, time, *s (t)* is seismic wavelet, α is the angle between the simulated linear event and the space axis, and the constant b is the intercept of the event on the time axis. The 2-D Fourier transformed expression of equation (3) is given as

$$F(\omega, k) = S(\omega)\, e^{i\omega b}\, \delta(k - \omega \tan(\alpha)) \quad (4)$$

Where *S (ω)* is the Fourier transform of the time function *s (t)* in equation (3), equation (4) shows that any linear event in the *t-x* domain can be transformed into another linear event in the f-k domain (Zhou & Greenhalgh, 1994). Thus, we may create a filter in the *f-k* domain to exclude the undesired ground roll imprints (noise) from our seismic data based on a property of the 2-D Fourier transform. Good processing outcomes and outputs were obtained when (Adizua & Ohakwere-Eze 2014). Adizua *et al*. (2015), & Adizua *et al*. (2017) utilized this technique in the Niger Delta sedimentary Basin, Nigeria.

The Radial Trace Transform (RTT) Technique

Since the Tau-P transform and the radial trace transform were introduced to seismic processing at roughly the same time and for essentially the same purpose, most geophysicists frequently confuse the two. The less well-known (but very successful) radial trace transform (Adizua et al., 2015). is a straightforward point-to-point mapping, whereas the more well-known *Tau-P* transform is an integral transform with similar coordinates. Wave field amplitudes are extracted from seismic trace panels, such as shot or receiver gather then interpolated onto velocity and travel time coordinates using the R-T transform (Henley, 1999; Henley, 2000; Henley 2003). All of the amplitudes intercepted by a certain trajectory are transferred in succession to the new domain as a single radial trace in order to map seismic amplitudes from the shot gather to the radial trace domain. This operation is done for each trajectory. It is significant to remember that the X-T and radial traces have the same sample interval and time scale by definition. As a result, samples needed for a radial trace frequently lie in between discrete X-T trace samples, necessitating interpolation from values close by. Since there are numerous interpolation techniques available, this R-T transform algorithm step can be customized to fit the needs of the intended purpose. Although interpolating along the X-direction is suitable for many uses, interpolating along radial trace trajectories can also be done and may be more appropriate in some cases (Brown & Claerbout, 2000). Likewise, interpolation methods can be chosen which use only nearest neighbor values for interpolation or which involve other nearby points. The effectiveness of this technique for coherent noise suppression has been demonstrated and documented in (Henley, 1999; Henley, 2000; Henley 2003). and for the Niger Delta sedimentary Basin by (Adizua et al., 2015).

End Note

The diversity of noise types often makes separation of signal and noise a challenging process. The importance of efficient noise suppression schemes for high-quality seismic imaging application has been emphasized. In this discussion paper, we have described ground rolls which constitute a major type of seismic coherent noise, highlighted their distinguishing characteristics and outlook on seismic data, pointed out the importance of suppressing them in seismic data processing and imaging applications and a consideration of local wave-field decomposition (*LWD*) based suppression techniques, mainly the frequency-wavenumber (*F-K*) and the radial trace transform (*RTT*) for their suppression and where they have been applied in sedimentary Basins around the world including that of the Niger Delta in Nigeria.

References

1. Yilmaz, Ö. (1989). Velocity Stack Processing, *Geophysical Prospecting*. 37, 357–382. DOI: https://doi.org/10.1190/1.1892186
2. Yilmaz, Ö., & Doherty, S. M. (1987). Seismic Data Processing. SEG Reference Book series. Retrieved from: https://www.abebooks.com/servlet/BookDetailsPL?bi=30800194410&cm_sp=snippet-_-srp1-_-tile6&searchurl=an%3Dyilmaz%2Bdoherty%26ds%3D10%26sortby%3D17
3. Yilmaz, Ö. (2001). Seismic Data Analysis: Processing, Inversion, and Interpretation of Seismic *Data, Investigation in Geophysics. 1*(10), DOI: https://doi.org/10.1190/1.9781560801580
4. Claerbout, J. F. (1983). Ground roll and radial traces, Stanford Exploration Project Report, SEP-35, 43-53. Retrieved from https://sep.stanford.edu/data/media/public/oldreports/sep35/35_03.pdf
5. Henley, D. C. (2003). Coherent noise attenuation in the radial trace domain, *GEOPHYSICS, 68*(4), 1408-1416. DOI: https://doi.org/10.1190/1.1598134
6. Henley, D. C. (1999). The radial trace transform: An efficient domain for coherent noise attenuation and wave-field separation. Proceedings of the 69th Annual International Society of Exploration Geophysicists Meeting and Exposition. October 31-November 5, 1999. Houston, TX, USA. 1204-1207. DOI: https://doi.org/10.1190/1.1820721
7. Henley, D. C. (2000). Wave field separation and other useful applications in the radial trace domain. Proceedings of the 70th Annual International Society of Exploration Geophysicists Meeting and Exposition. August 6-11, 2000, Calgary, Alberta, Canada .2111-2114.
8. 8. Adizua, O. F., Ebeniro, J. O., & Ehirim C. N. (2015). Application of the frequency-wave number (F-K) and the Radial Trace Transform (RTT) in the attenuation of coherent noise in onshore seismic data, *Asian Journal of Earth Sciences (AJES), 8*(1), 15-23. DOI: http://dx.doi.org/10.3923/ajes.2015.15.23

9. Adizua, O. F., Inichinbia, S., & Ekine, A. S. (2017). Design of an optimal high pass filter in frequency-wave number (F-K) space for suppressing dispersive ground roll noise from onshore seismic data; *Universal Journal of Physics and Application UJPA, 11*(5), 144-149. DOI: http://dx.doi.org/10.13189/ujpa.2017.110502
10. Blonk, B., Herman, G. C., & Drijkoningen, G. G. (1995). An elastodynamic inverse scattering method for removing scattered surface waves from field data, *GEOPHYSICS, 60*(6), 1897–1905. DOI: https://doi.org/10.1190/1.1443921
11. Blonk, B., & Herman, G. C. (1996). Removal of scattered surface waves using multi-component seismic data: *GEOPHYSICS, 61*(5), 1483–1488. DOI: https://doi.org/10.1190/1.1444073
12. Ernst, F., Herman, G., & Ditzel, A. (2002). Removal of scattered waves from seismic data, *GEOPHYSICS, 67*(4), 1240-1248. DOI: https://doi.org/10.1190/1.1500386
13. Herman, G. C., & Perkins, C. (2006). Predictive removal of scattered noise, *GEOPHYSICS, 71*(2), 41–49. DOI:10.1190/1.2187808
14. Herman, G. C., and Perkins, C. (2003). Predictive removal of scattered noise, *GEOPHYSICS*, 71, 41–49. DOI: https://doi.org/10.1190/1.2187808
15. Regone, C. J., (1998). Suppression of coherent noise in 3D seismology, *The Leading Edge, 17*(11), 1584–1589. DOI: https://doi.org/10.1190/1.1437900
16. Özbek, A. (2000). Adaptive beam-forming with generalized linear constraints, 70th Annual International Meeting, SEG, Expanded Abstracts, 2081– 2084. DOI: https://doi.org/10.1190/1.1815855
17. Zhou, B. & Greenhalgh, S. A. (1994). Wave-equation extrapolation-based multiple attenuation: 2D filtering in the f-k domain, *GEOPHYSICS, 59*(9), 1377–1391. DOI: https://doi.org/10.1190/1.1443696
18. Adizua, O. F., Ebeniro, J. O., & Ehirim, C. N. (2015). Comparative study of Radial trace transform and the Frequency- Wave number techniques for suppressing dispersive ground roll energy from onshore seismic data (Amplitude spectrum approach), *International Journal of Research and Innovations in Earth Science (IJRIES). 3*(1) 2394-1375. DOI: http://dx.doi.org/10.3923/ajes.2015.15.23
19. Brown, M. & Claerbout, J. (2000). A pseudo-unitary implementation of the radial trace transform, Society of Exploration Geophysicists (SEG) Technical Program Expanded Abstracts, Retrieved via SEG digital library, DOI: https://doi.org/10.1190/1.1815865
20. Linville, A., & Meek, R. (1995). A Procedure for Optimally Removing Localized Coherent Noise, *GEOPHYSICS, 60*(1), 191–203. DOI: https://doi.org/10.1190/1.1443746
21. Saatilar, R., & Canitez, N. (1988). A Method of Ground-Roll Elimination, *GEOPHYSICS, 53*(7), 894- 902. DOI: https://doi.org/10.1190/1.1442526.