What Can We Gain? Optimizing Amplification Settings to Improve Seismic Resolution

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Summary

Seismic sensors are fundamental to subsurface imaging, capturing wavefield information that informs exploration and monitoring applications. However, the usefulness of recordings depends not only on the survey design but also on how gain settings are configured. Gain settings determine the amplification of recorded seismic signals, impacting the signal-to-noise ratio (*SNR*), data resolution, and dynamic range. Optimizing gain settings is particularly important in modern seismic acquisition, where single-sensor nodal systems, multi-component sensors, and multiple energy sources are utilized. This presentation will include a comprehensive discussion on seismic sensors, their operational principles, and the impact of gain settings based on controlled field experiments conducted across multiple programs.

Objective

Seismic data acquisition relies on the ability of sensors to accurately capture and preserve wavefield characteristics. Traditional geophone arrays used multiple sensors per station to improve *SNR* through stacking (Campman *et al.*, 2016; Dean *et al.*, 2018; Makama *et al.*, 2021), whereas modern nodal systems use single receivers, requiring precise gain settings to compensate for the absence of array-based noise suppression (Campman *et al.*, 2016; Dean *et al.*, 2018). Gain settings impact data quality by influencing whether weak reflections are adequately recorded or strong signals become clipped due to saturation (Campman *et al.*, 2016). Clipped traces caused by excessive gain settings can distort true amplitudes, leading to artifacts that persist through processing (as illustrated in ***Figure 1***) and compromise data usability during seismic inversion. This study aims to evaluate how different gain settings influence seismic resolution by conducting controlled tests across various acquisition environments. Specifically, we examine how gain settings interact with sensor type, acquisition geometry, and subsurface conditions, providing a detailed overview of best practices for optimizing signal fidelity in different seismic applications.

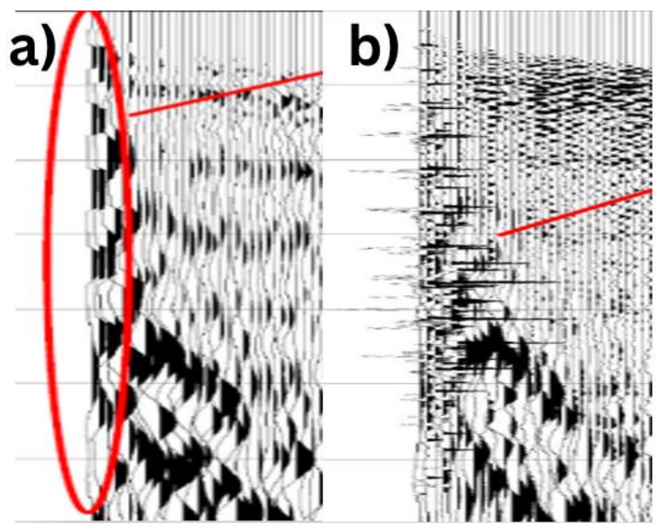

Figure 1. (a) Raw seismic record showing clipped near-offset traces (highlighted in red). (b) The same data after deconvolution, where clipped traces fail to recover amplitude information and introduce artifacts, making them unusable for inversion.

Methodology

To quantify the effects of gain settings on seismic data, field tests were conducted in multiple programs using a variety of sensors and sources under diverse ground conditions. These experiments included multiple seismic sensors, *e.g.*, single- and three-component sensors, and various source types ranging from dynamite to vibroseis and impact sources. A key component of this study involved the collocation of multiple sensors with different gain settings, allowing for direct assessment of gain effects on *SNR* and overall data fidelity (as shown in ***Figure 2***). Gain levels were systematically varied, and data were analyzed in terms of spectral content, amplitude preservation, and dynamic range.

Several key parameters were evaluated:

- Impact of gain settings on near- vs. far-offset data, assessing whether weak reflections were preserved or clipping introduced.
- Influence of sensor type on gain optimization, particularly the differences between 1C and 3C sensors and their response to different energy sources.
- Role of environmental and subsurface conditions on gain-dependent noise suppression and frequency content preservation.

Figure 2. Example of receiver station with multiple collocated sensors with tailored gain settings.

Observations & Conclusions

Results from our experiments highlight that gain settings must be carefully tailored to acquisition geometry and sensor type to achieve optimal seismic resolution. High gain settings enhance weak signal detectability but increase the risk of clipped arrivals, particularly in high-energy sources or near-offset recordings (Makama *et al.*, 2021). Low gain settings, while preventing saturation, may result in poor resolution for deeper reflectors, requiring post-processing enhancements to recover lost amplitude information.

Collocated sensor tests demonstrate that tailored gain settings, where gain is optimized based on source-receiver distance and survey objectives, provide the best balance between signal fidelity and noise suppression. In nodal systems, where a single gain setting must be applied per receiver, careful selection is critical to avoid sacrificing dynamic range (Attia *et al.*, 2020; Makama *et al.*, 2021). Our findings suggest that integrating gain selection with pre-survey modeling and field calibration techniques leads to improved data quality and seismic resolution. Future advancements in automatic gain control may further refine these processes, making adaptive gain selection more feasible for large-scale seismic surveys.

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